Self-Assessment Report 2015-2020

Geoscience and Engineering Geoscience and Remote Sensing

TU Delft

Content

General introduction

Scope of this self-assessment

This self-assessment report discusses the strategy and accomplishments of the geoscience research at the Faculty of Civil Engineering and Geosciences (CEG) over the period 2015-2020 and presents the strategy of geoscience research for the period 2021-2026.

The units that will be assessed are:

- The Department of Geoscience and Engineering (GSE), led by Prof. Jan Dirk Jansen until April 2018, Prof. Michael Hicks from May 2018 until December 2018 (interim), and Prof. Timo Heimovaara since January 2019.
- The Department of Geoscience and Remote Sensing (GRS), led by Prof. Herman Russchenberg since 2015.

The assessment committee is requested to evaluate the departments GSE and GRS independently, according to the criteria explained in the Strategy Evaluation Protocol 2021-2027.

TU Delft

Impact for a Better Society

TU Delft was founded in 1842 as the Royal Academy for the education of civil engineers and has grown into a university with eight faculties, more than 26,400 students and 3,600 scientific staff members. The TU Delft strategic framework for 2018-2024 is entitled "Impact for a Better Society". The vision, mission and values are:

Vision:
Delft University of Technology contributes to solving global challenges by educating new generations of socially responsible engineers and expanding the frontiers of the engineering sciences.

Mission:

- We perform world-class research by combining science, engineering and design in a socially responsible manner. Thus, we advance and share the benefits of technology.
- We develop and enhance the expertise of tomorrow's engineering leaders and educate professional, high-level and responsible engineers throughout their careers.
- We help to develop and deliver technology-driven, innovative solutions to societal problems through collaborations with leading national and international partners whilst being firmly rooted in Delft.
- We continuously improve our collective effectiveness, performance and organisational resilience through the principles and practice of professionalism, collaboration and openness.

Our values:
Diversity, Integrity, Respect, Engagement, Courage, Trust.

Application-inspired, fundamental research

To explain the nature of research carried out at TU Delft, we use a classification in two dimensions as shown in Figure I. The first dimension concerns the motivation of the research activities which may range from curiosity-driven to application-inspired, as indicated on the horizontal axis. The second dimension concerns the nature of the research activities which may range from fundamental to pragmatic as indicated on the vertical axis.

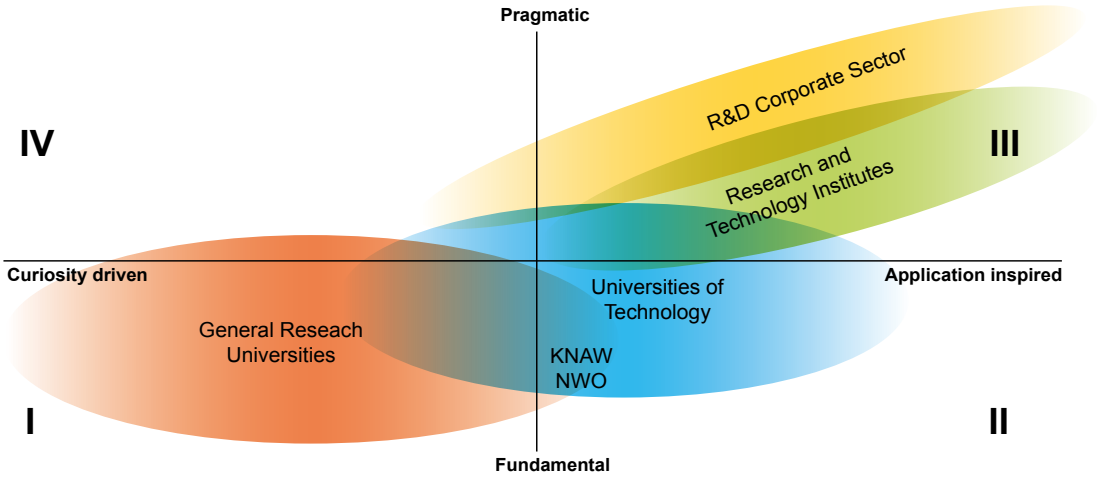


Figure I. Two-dimensional field describing the nature of research.

Both general research universities and universities of technology are primarily concerned with fundamental research. The difference between these two types of university lies in the motivation for their research, namely curiosity-driven or application-inspired. Universities of technology share the application-inspired motivation with large research and technology institutes (GTIs; like TNO, Deltares or KNMI) or R&D departments of the corporate sector. Their research differs, however, in the nature of the respective research activities. Whereas universities of technology carry out (application-inspired) fundamental research, technological institutes and industry mainly are engaged in more pragmatic research. The common motivation, inspired by application, forms the basis for our cooperation with industry and the difference in the nature of research is reflected in the structure of many of our collaborative research contracts: Fundamental research questions are addressed in PhD and post-doc research projects, whereas the more pragmatic research questions and the implementation aspects are addressed by research staff from our partners at GTIs or the industry.

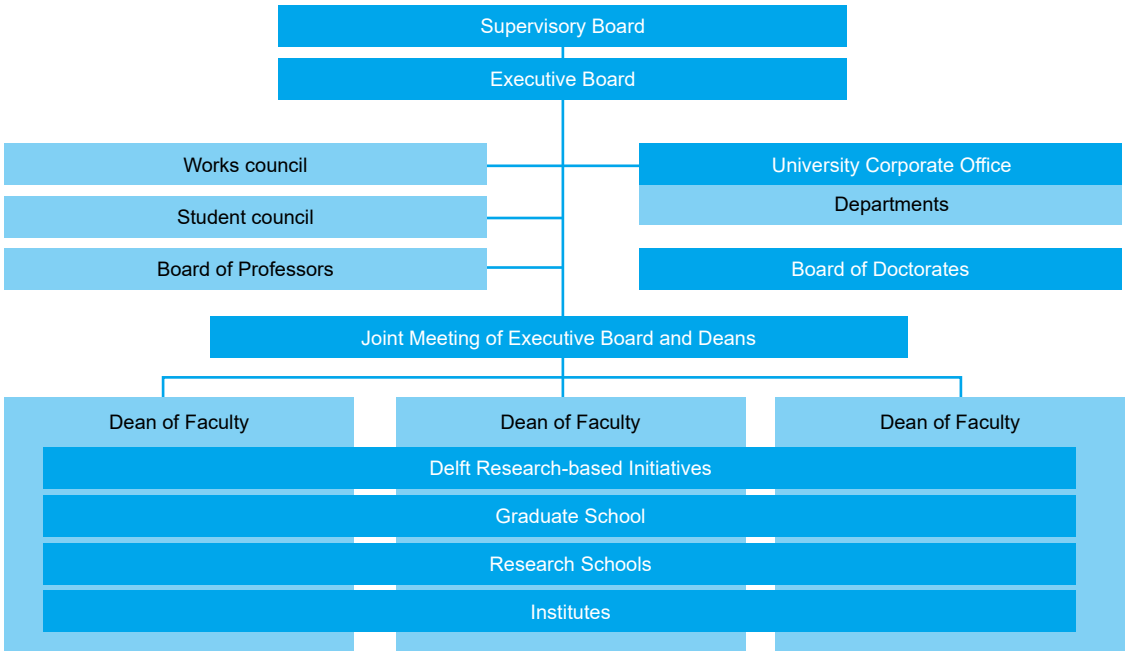
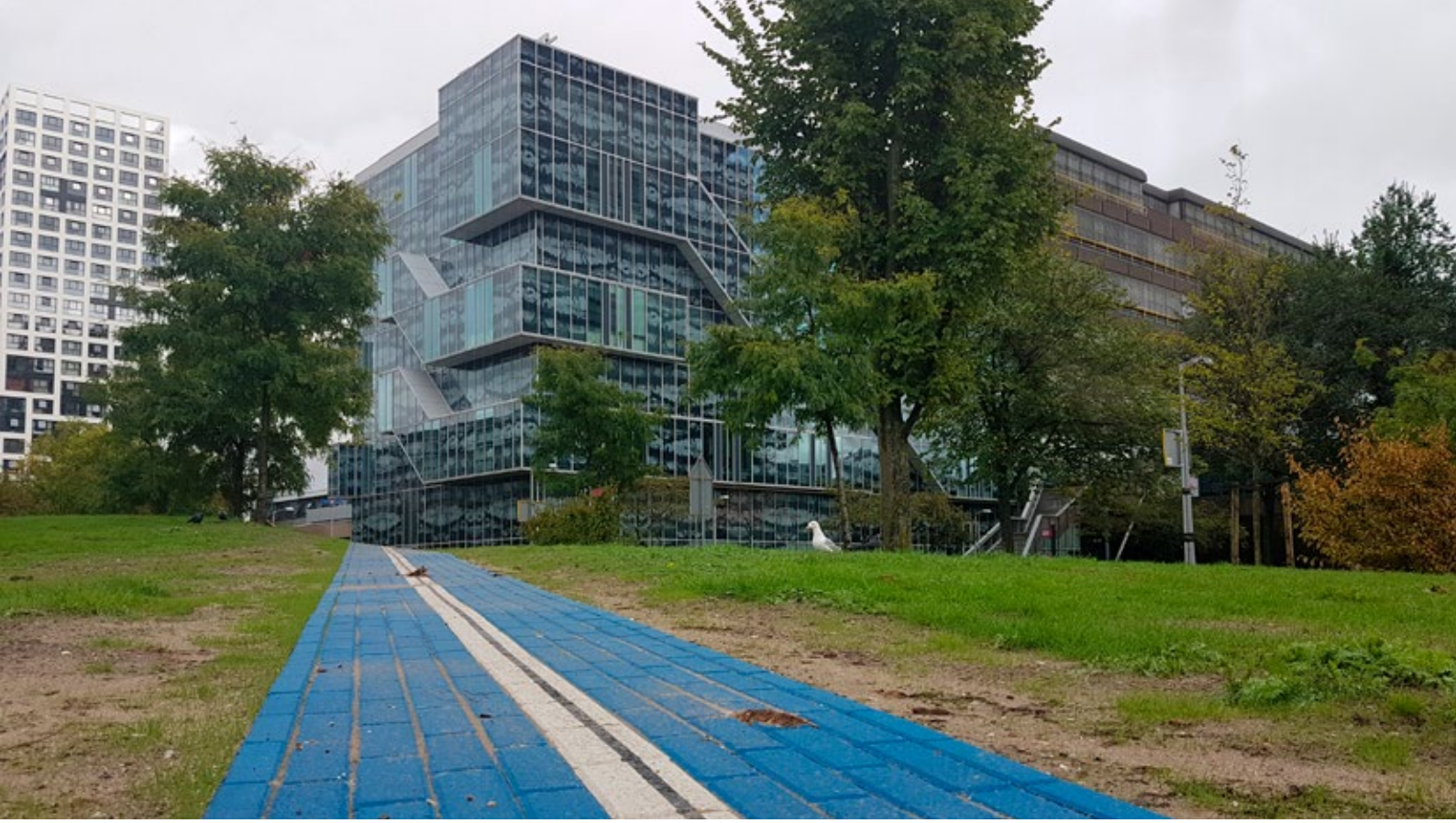


Figure II: Main organisation of Delft University of Technology

TU Delft consists of eight discipline-oriented faculties, while interdisciplinary activities can be developed on a broader scale either in interfaculty research institutes, in university-wide research-based initiatives (DRIs) or in (inter)national programmes (Figure II).



Delft Research Initiatives and Delft Research Institutes

An important approach to support research within TU Delft are the Delft Research Initiatives and Delft Research Institutes. Other important developments are related to the Convergence Alliance: ecosystem in South Holland. Research schools are in general all disciplinary collaborations, which are co-organized with departments from other universities. In 2012, the TU Delft Graduate School was launched, organised in a central University Graduate School with staff in each faculty.

The faculty CEG, including the departments GSE and GRS, is a strong partner in all university-wide initiatives.

Faculty

Faculty structure

The faculty consists of seven departments: two in geoscience (for this assessment) and five in civil engineering, being:

- Geoscience and Engineering (GSE);
- Geoscience and Remote Sensing (GRS);
- Materials, Mechanics, Management and Design (3MD);
- Engineering Structures (ES);
- Transport and Planning (T&P);
- Hydraulic Engineering (HE);
- Water Management (WM).

Prof.dr.ir. Jan Dirk Jansen is since May 1st, 2018, the dean of the Faculty of Civil Engineering and Geosciences. He is overall responsible for research, education, valorisation, and management.
The dean, the seven department chairs and the director of education form the management team (MT), responsible for the strategic decisions about research directions and major developments in educational and valorisation processes. The Faculty Secretary and the managers of HR and Finance also participate in the MT meetings, to guarantee a direct link to the execution of the decisions. The faculty regulations describe the governance and operations of the faculty. A schematic overview of the structure of the faculty CEG is given in Figure III.

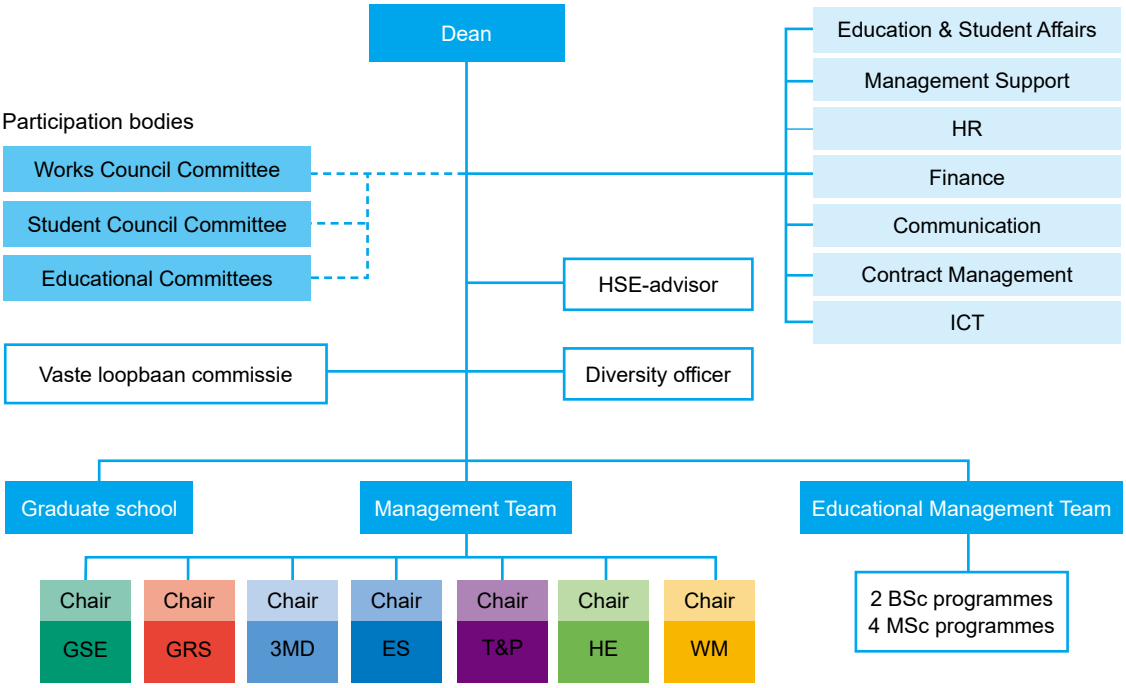


Figure III. Schematic overview of the structure of the Faculty of CEG.

The director of Education and the four directors of study form the educational management team and are responsible for all educational matters for the studies Civil Engineering (CE), Transport, Infrastructure & Logistics (TIL), Construction Management & Engineering (CME) and Applied Earth Sciences (AES). From September 2022, the programmes CE and AES will have undergone a complete revision and Environmental Engineering (EnvEng) will be introduced as a new programme.

The support staff consists of seven departments: Education & Student Affairs, Management Support, Human Resources, Finance, Communication, Contract Management, and Information Communication & Technologies.

Participation of employees and students is organised through a chosen Work council (employees) and the Faculty Student Council. Periodically the councils separately meet with the dean on policy matters.

The faculty also has a Graduate School director and a Diversity officer. The diversity officer has a broad role to serve as an ambassador for Diversity & Inclusion (D&I), initiate faculty activities to increase the awareness of students and staff on diversity and inclusion topics, assist in implementing the policy and promote D&I competency training for faculty staff and students.

The faculty is supported by an HSE-advisor (Health-Safety-Environment).

Faculty Strategy

In 2018 and 2019 a faculty-wide strategy discussion led to a new faculty strategy, summarized in Figure IV. In short, the mission is to create a better living environment for society.

The departments of the faculty all have proven to be successful at education and research in their own disciplines, resulting in the faculty's strong position. However, to make impact in a world that is highly subject to change, the faculty must find a balance between responding to current and future developments in society and maintaining the strengths of its core disciplines.

The purpose of the new strategy is to enable and guide all departments and their personnel in necessary decisions regarding research priorities, educational programmes, and budget within the overall TU Delft Strategic Framework. It should provide shared boundary conditions for the organization and provide a basis for next Civil Engineering and Geosciences research evaluation cycles.

Figure IV. Summary of the faculty strategy for 2019-2024.

We emphasized that the process towards the faculty strategy should be as important as the result itself and therefore be designed as a bottom-up process. To make sure that the defined strategy truly reflects the shared vision and goals of (especially younger) academic staff, we ensured their participation in the project team, which consisted, by design, mostly of (tenure track) assistant and recently promoted associate professors. The project team delivered and communicated the strategy document, liaised with the departments, and managed dependencies. Senior research staff was involved on a voluntary basis in the strategy development process by participating in so-called walk-in sessions. Furthermore, junior research staff (including post-docs and PhD candidates), support staff and student councils have participated through a review process. Decisions were made by the faculty's management team. Taken together, the approach towards the strategy was a real combination of bottom-up and top-down.

The strategy development process started with collecting the most important societal challenges, the most relevant emerging technologies and the most needed core disciplines per department. After intensive assessment and dialogue, the project team formulated the faculty's why, how, and what, as a proposal to their colleagues. In the following iterative process, this intermediate result was sharpened and adopted by the majority. In the same manner, strategic ambitions were formulated by the project team on the key activities 'student and education', 'research and innovation', 'people and community' and 'campus and services'. Next, change themes and strategic choices were defined considering the faculty's ambitions and its current position. All (intermediate) results were broadly communicated within the faculty.

To keep it practical for everyone the faculty's strategy came as a (double-sided) one pager which can be found in Appendix 1.

Organizational Structure

Over the past period we have experimented with various forms of organisational structure within the departments, with the aim to create more departmental coherence, a less hierarchical structure and room for increased participation of “younger” staff, in particular (tenure-track) assistant and associate professors. The role of sections as independent sub-units has been strongly reduced and, as a matter of policy, decisions about finance, strategy, and staff (new hires) are taken primarily at department level. We aim to develop a set of shared starting points and boundary conditions within which the departments can choose their organisational model, somewhere in between the traditional “pyramid” and a totally flat “PI model”, such that we increase the freedom of individual researchers to excel while maintaining a considerable degree of cooperation and teamwork. Another step to increase the empowerment of our “younger” scientific staff has been the conscious decision to invite them to take the lead in the educational revision of our MSc programmes. The initial project team, which designed the overall structure and main content (tracks and cross program modules) consisted mainly of (tenure track) assistant and associate professors. Thanks to their fresh view on the current and desired future contents of our educational program we have ended up with a significantly renewed curriculum.

Faculty Human Resources policy

Tenure track

Over the past decade we have gradually adopted a version of tenure track system where assistant professors are hired on a temporary contract. During a five-year period, they are expected to demonstrate their suitability for an academic career through developing an independent research line, acquiring funding to build their own group of PhDs and Postdocs, demonstrating, and developing their teaching skills, publishing in high-quality journals, performing as a team member, and growing organisational and leadership skills. If successful they obtain a permanent position as assistant professor with the expectation to be promoted to associate professor within a maximum of five years (but often much faster). An important recent change has been the introduction of the perspective of a subsequent internal performance-based promotion to full professor (governed at university level) which has replaced the traditional system of a limited fixed number of full professor “chairs”.

This entire academic career development track is a very demanding and high-intensity process. Over the past years it has resulted in an influx of high-quality staff with often rapid career development, but also in a high stress level and sometimes frustration amongst tenure trackers. Over the past two years we have therefore performed an extensive review of our tenure track system, including input from a larger representation of younger staff. This review resulted in several changes, notably more credit for team-based

performance, more room for education as a primary focus rather than research, and a stronger coupling of the regular yearly results and development cycle to the agreements, as documented in individual tenure track plans. Moreover, we have increased the level of financial support for starting tenure trackers who now all receive a start-up fund to directly hire a PhD student. Another change, pending agreement at university level, is a decoupling of permanent contract provision and assessing the suitability for an academic career. In addition, the national and international attention for the way success is reviewed in academia is also an important aspect of the TU Delft strategy. The ideas formulated in the TU Delft perspective on recognition and rewards of academics are being implemented in the faculty and department strategies.

Leadership, diversity, and further elements of academic culture
Increasingly we pay attention to leadership development of our academic staff. In addition to initiatives at university level, we developed an in-house leadership course for (mainly) associate professors and provided many staff with opportunities to attend external leadership programmes or obtain coaching-on-the-job. The yearly results and development cycle includes preview and review meetings for each department attended by the departmental MT, the HR manager and departmental HR advisor, the director of education and the dean, during which individual staff development is discussed in terms of research, education, valorisation, organisation, and leadership.

Another critical point of attention has been the attraction of female staff. We participated in the university-wide Delft Technology Fellowship, via which we hired several female assistant and associate professors over the past three years. Moreover, we decided at Faculty MT level to aim for at least 50% female candidates for all Sector Plan and van Rijn positions (see below). We therefore actively stimulated vacancy holders to scout for female talent and employed the services of a dedicated agency (Web Shark), resulting in 11 female and 11 male new-hired (tenure-track) assistant and associate professors. Nevertheless, we realize that we still have a long way to go before the gender balance in our staff is at least on par with the gender ratio in our student population (about 30% female), especially in senior (full professor) and faculty MT positions.

Another aspect of diversity concerns the ratio of “home grown” versus “external” staff. Out of the 22 newly hired Sector Plan and Van Rijn professors, six were formerly associated with TU Delft (as MSc student, PhD or PostDoc) while the other 16 originated from universities world-wide. We much value the benefits of a diverse academic community, and we welcome an international staff influx. Unavoidably, such an increasing diversity in cultures and nationalities also leads to an increasing variety in expectations, values, and beliefs, sometimes resulting in disappointments, conflicts, or undesirable behaviour. No doubt, the Covid measures of the past 2 years, which virtually ended all face-to-face personal contacts, have worsened some of these problems. As one of the measures to develop and reap the benefits of a diverse community, and overcome the negative side effects, we recently appointed a Faculty Diversity Officer, who will work closely with the TU Delft Diversity Officer. Furthermore, two years ago our PhD community organised themselves in a representative PhD council, which now also has a formal representation in the OdC (works council). However, a better representation of our PostDoc community is still outstanding. Also, we requested an ad-hoc Academic Culture committee, chaired by an Assistant Professor, to reflect on how they experienced the academic culture in our faculty. An overview of their findings has been included as Appendix 2. It clearly shows that, although we addressed many aspects of academic culture over the past period, there is still considerable room for improvement, at a policy level as well as in communication and implementation at all levels of the organisation.

Sectorplan Beta en Techniek and Van Rijn funds

Sector Plan
In 2019 the Dutch government made 60 million euros available annually for strengthening academic university research in technical and natural sciences. With these Sector Plans, the Ministry of Education, Culture and Sciences strives to reinforce the foundation of the natural and technical sciences, by attracting new research talent to expand research capacity. The Sector Plan also contributes to overarching goals such as more strategic cooperation between universities, increasing diversity and strengthening education, research, and valorisation.

One of the technical sciences is Civil Engineering and a yearly budget of 1.75 Meuro is granted to finance 12 tenure track positions in 7 focal areas:

- Fluid dynamics and sediment transport in human-influenced marine, inland and urban water systems
- Fluid structure interactions for infrastructure and for nature-based solutions
- Materials and environment
- Computational mechanics of materials
- Dynamics and monitoring of structures and infrastructural components
- Interface and multi-scale mechanics of structures
- Soil mechanics

Please note that the Geoscience disciplines in the different departments in the faculty were not included in this sector plan.

Van Rijn – report

On request of the ministry of Education, Culture and Sciences, the committee van Rijn reviewed the funding of education and concluded that higher education should become less dependent on student growth for funding and a larger part of the budget should be directed to science and technology education. TU Delft developed a program to distribute the funds within the University. The CEG Faculty is allocated annually 1.2 Meuro to raise the number of teaching staff and to strengthen educational support. Six of these positions are Tenure track assistant professors who also have a research profile.

PhD policy

Much of the research in the departments GSE and GRS is carried out by PhD candidates. The aim of the TU Delft Graduate School and the Faculty Graduate School (FGS) is that PhD projects are completed within 5 years (the present TU-wide average is 7 years). To achieve this, the departments have fully implemented the policies of the graduate school. The most important policies are:

- Increasing attention for the PhD selection process;
- New GO-NOGO structure, aimed at strengthening the PhD candidate and identifying ways to improve the quality of the project and of the supervising team;
- Yearly progress meetings and monitoring by the graduate school.

The performance of the supervisors and the criticalities in PhD supervision and progress are discussed in closed-door meetings (twice a year) with the Director of the FGS and with HR. The FGS encourages PhD candidates to take responsibility and play an active role in ensuring the success of their PhD. Since a few years, these efforts are supported by an active and stimulating Faculty PhD Council. Appendix 3 gives a more detailed overview of the policies of the faculty graduate school.

Funding schemes

In the Netherlands, research funding schemes are divided into three pillars. Note that in spoken Dutch, these types of funding are often referred to as ‘first’, ‘second’ and ‘third’ ‘money stream’.

1. Direct funding: Internal funding received by the faculties/departments from the Executive Board of the university, originating from the Dutch Government.
2. Research grants: Following the Strategy Evaluation Protocol (SEP), this stands for external funding received in competition, from the Netherlands Organisation for Scientific Research (NWO).
3. Contract research: Following the SEP, this not only stands for external funding from industry, but also for governmental funds and EU projects, including personal ERC Grants and Marie Curie Fellowships.

In general, salaries of post-docs and PhD candidates are not paid by university funds. Our research depends on national governmental funding and industrial/EU funding. National governmental funds are valued because they contribute to the international academic reputation. This is especially true for personal research grants, e.g., the NWO Veni-Vidi-Vici-scheme. Unfortunately, these grants do not cover the integral costs. EU funding normally covers more, but still not fully the integral costs. Therefore, there is an overall need for matching of these funds. Consequently, industrial funding, which mostly covers all integral costs, is important for a healthy budget. Within this domain, we aim to concentrate on projects that are scientifically attractive and offer potential for publication in refereed journals.

Over the years the total funding of the faculty remained stable. The positive effects on the Direct funding due to the Sector plan and Van Rijn report are not yet visible in the numbers. From 2021 we will see a rise of the Direct funding with approximately 15%. We expect that research grants and contract research will equally rise over time. New personnel will also apply for funding from these sources. A considerable part of our PhD-research is executed by bursary PhD candidates and is not visible as such in the funding table.

Until recently no Direct funding was available for PhD or PostDoc research. However, the recent hiring of 22 new research staff members in 2020 (most of which are in tenure track positions) with another expected 20 staff in 2021, and the availability of additional funds from the Sector Plan and van Rijn schemes allowed us to review this policy and we now provide all new assistant professors with a directly funded PhD student and new associate professors with a 200 k€ start-up package.

The faculty is in a healthy financial state. Additional investments in personnel and infrastructure are being discussed.

Table I. Overview of the financial situation of the faculty CEG from 2015 to 2020.

*K EUR	2015		2016		2017		2018		2019		2020	
All CEG departments												
Direct funding[1]	24.864	44%	26.606	47%	27.730	47%	25.126	43%	26.612	39%	28.518	44%
Research grants[2]	6.839	12%	7.581	14%	8.359	14%	9.504	16%	11.597	17%	11.971	19%
Contract research[3]	23.795	42%	20.812	37%	20.888	36%	21.259	37%	27.885	41%	21.570	34%
Other[4]	1.571	3%	1.141	2%	1.499	3%	1.920	3%	1.520	2%	2.185	3%
Total funding	**57.069**	**100%**	**56.139**	**100%**	**58.477**	**100%**	**57.809**	**100%**	**67.614**	**100%**	**64.244**	**100%**
Personnel costs	-42.966	76%	-44.392	80%	-46.190	80%	-49.543	86%	-53.891	83%	-53.545	86%
Other costs	-13.671	24%	-11.108	20%	-11.844	20%	-8.098	14%	-10.994	17%	-8.371	14%
Total Expenditure	**-56.637**	**100%**	**-55.500**	**100%**	**-58.034**	**100%**	**-57.641**	**100%**	**-64.885**	**100%**	**-61.916**	**100%**

[1] Direct funding (Internal funding received by the faculties/departments from the Executive Board of the university).
[2] Research grants obtained in national scientific competition (mainly grants from NWO).
[3] Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, European organisations and charitable organisations.
[4] Funds that do not fit into the other categories.

Geosciences in the Departments of CEG

The faculty CEG has two Geoscience Departments which will be assessed in this review.

Other departments also do research within the geosciences. The department of Water Management focuses on research in observation & modelling of water resources and monitoring & control of water processes.

The department of Hydraulic Engineering has also a strong interface with the geosciences with respect to the research they do in the field of Physical Oceanography, Coastal Morphology and Morphodynamics of Lagoons and Estuaries.

There are strong collaborations between researchers across all departments in the field of geosciences. The faculty strategy intends to further strengthen these collaborations for the future.

Part 1
Department of Geoscience and Engineering

1. Introduction

1.1 Brief presentation of the research unit

The department of Geoscience & Engineering (GSE) at the faculty of Civil Engineering and Geosciences (CEG) focuses on surface and sub-surface science and engineering technology for energy, mineral geo-resources, fluvial and shallow marine sediment dynamics, underground construction, soil structure interaction and geotechnical aspects of surface infrastructure. This research is inspired by the societal challenges posed by climate change, energy transition, resource security, and a sustainable society in an urbanized delta. Research addressing these societal issues requires an interdisciplinary approach.

The research at our department can be characterized as “application-inspired, fundamental research.” The fundamental research ranges from understanding and predicting the properties of (fractured) sedimentary reservoirs, modeling of flow- and heat transfer in reservoirs and reactive transport in rocks and soils, imaging and monitoring of subsurface processes, developing sensor technology for zero-waste mining, to modeling and measuring the behaviour of complex, coupled, non-linear geomaterials and geotechnical constructions.

The department is organized in five sections, which are executing high-level fundamental research in the different geoscience and engineering disciplines, and which jointly define, organize and execute interdisciplinary societal research themes.

Staff within GSE teach in the BSc programmes of Civil Engineering (CE) and Applied Earth Sciences (AES), and in the MSc tracks of Geo-Energy Engineering, Geo-Resources Engineering, Geo-Engineering, Environmental Engineering and Applied Geophysics.

1.2 Changes over the last years

In the previous research evaluation (2008-2014), GSE was assessed as four independent research units, with thirteen research themes (see Appendix 4). Motivated by the current societal challenges, we defined two overarching societal themes, each of them supported by the fundamental research in the sections. We changed our department accordingly and for the current research evaluation (2015-2020) we present ourselves to be assessed as a single research unit.

During the review period we organized several occasions where colleagues from outside the department were invited to critically assess different aspects of our policy and strategy. This included a discussion on the ethical aspects related to working with the hydrocarbon industry and a mid-term assessment of our internal policies. These assessments led to a wide range of recommendations on the following aspects:

- PhD supervision and planning.
- Gender balance and cultural diversity.
- Academic culture and sharing of information across the department.
- Workload balancing and relieving the stress perceived by staff in a tenure track.

We have taken these aspects into account in our strategic choices for the next six years.

2. Mission and strategic aims of the past six years

2.1 Mission

The mission of our department GSE is that our research contributes to:

Responsible Use of the Geosphere considering the Impact on the Earth System and Society.

The geosphere is the Earth itself, inclusive of rocks, minerals, soils and landforms; it interacts with the hydrosphere, the biosphere and the atmosphere. Responsible use includes the activities related to exploration and exploitation of natural resources and undergound space, and the mitigation of natural and human-induced geo-hazards.

2.2 Strategic Aims

During the review period 2015-2020 we focused on the following strategic aims:

1. The department as a single research unit: The aim to be assessed as a single research unit instead of four separate units implied significant changes to the organization of the department (section 3.1).
2. Strengthening the academic culture: Integration into one unit gave us the opportunity to address the department culture, namely: Focus and mission, ethical dilemmas in working with the hydrocarbon industry, the department SWOT-analysis, cultural beliefs and department structure and organization(section 3.2).
3. Human Resources: The foundation of success lies in our staff. Embracing the opportunities offered to us by the TU Delft tenure-track system implemented at the faculty level allowed us to hire excellent new staff and support their career development. We have put special emphasis on attracting more female staff (section 3.3).
4. Department-wide project portfolio management: Alternative funding sources needed to be found to compensate for the expected decline in one-to-one industry funding in hydrocarbon research. An approach to do this was the introduction of portfolio management (section 3.4) and the introduction of cross-sectional integrated themes in the department (section 3.1).
5. PhD strategy: The department has fully embraced the policy and support of the TU Delft Graduate School aimed at improving the quality of the PhD experience and substantially reducing the duration of the PhD trajectory, bringing it below 5 years (sections 3.5 and 5.4).

The department aims to play a leading role in energy research that is moving toward sustainable energy forms with the aim to reduce carbon emissions, while, at the same time, minimizing the ecological footprint. Geothermal energy and sub-surface storage of energy carriers such as green hydrogen are two of the most important societal application fields for the department. To reduce the carbon emissions to the atmosphere, sub-surface storage of CO_2 is a focal point as well. In addition, solving societal challenges requires a large effort in developing the required fundamental knowledge on cause–effect relationships and how these should be extrapolated to the future.

Our fundamental application-inspired knowledge on geotechnical engineering is essential to maintain and extend the lifespan of the ageing infrastructure in the Netherlands, where sea-level rise induced by climate change increases the challenge.

The transition to sustainable energy in society will lead to a huge increase in demand for mineral resources such as lithium, copper, cobalt and rare earths. All these minerals are mined. Reduction of the carbon emissions and minimization of the ecological impact of such mining operations is one of the biggest challenges society currently faces. Our research on waste management and mitigation of environmental emissions is essential.

The department of GSE has traditionally had very strong ties with industry. We can pride ourselves on being the champion of industry projects within the faculty of CEG. This has been a very lucrative position in the past. Consequently, we depend quite strongly on income from industry projects. From 2015 on, we gradually moved from one-to-one industry projects to more consortia-based projects, which, although still lucrative, have a higher risk profile than the one-to-one industry projects.

3. Strategy 2015-2020

3.1 The department as a single research unit

During the review period the department transitioned from four research units to a single unit with a single mission, common goals and common strategy. This required integration across the sections. To realize a cohesive integrated department, the following organizational changes have been made:

- The budget is no longer split into section budgets. This change makes it possible to make more significant investment choices at the department level. Such decisions are made collectively within the department Management Team (dMT).
- Decisions about hiring new staff are made by the dMT as well. This has resulted in defining new academic staff profiles based on requirements which go beyond the sections and are related to the interdisciplinary themes. Clear examples for this are the positions filled by Dr. Anne-Catherine Dieudonné (engineering geology), Dr. Anne Pluymakers (experimental fluid-rock interaction), Dr. Guillaume Rongier (numerical geology and artificial intelligence), Dr. Maren Brehme and her successor Dr. Alexandros Daniilidis (geothermal energy).
- Also acquisition of projects is coordinated at the department level. This applies particularly to the acquisition of interdisciplinary projects within the themes. Our research support officer, Dr. Anke Dählmann, closely works together with staff from the Innovation & Impact Centre of the TU Delft (I&IC) and the contract manager of CEG. She advises primarily on alignment of research ideas with call requirements, proposal structure and textual requirements. For calls within the field of Geothermal Energy, Dr. Susanne Laumann serves as research support officer.

In the review period 2015-2020 we have developed more and more integrated, multi-disciplinary, research programmes. This process was stimulated by the following developments / reasoning:

- The demand for carbon-neutral technology within the energy transition calls for solutions to be developed across disciplines.
- An integrated approach allows our department to engage increasingly within comprehensive large-scale programmes such as DeepNL, WarmingUP and EPOS-NL and to achieve optimal synergy in these programmes.
- An integrated approach is also appreciated by our students who want to become engineers who can develop solutions for the grand challenges faced by humanity. This led us to develop the new MSc-programmes in Applied Earth Sciences and Environmental Engineering.

Integration of our subsurface expertise from 0 to 10 km depth is crucial for many research challenges and puts us internationally at the forefront of geoscience and engineering.

The multi-disciplinary themes we developed are:

(1) Energy Transition, in which we run:
   a. Geothermal Science and Engineering,
   b. Subsurface Storage,
   c. Geo-research for Offshore Renewables (this is the odd one out as it is not a cross-departmental theme but cross-faculty as it is run within a single section in close collaboration with the department of Hydraulic Engineering).

(2) Consequences of Underground Engineering (still under construction).

These themes match with the strategic themes Energy Transition, Resource Availability, Climate Change and Urbanisation of the CEG Faculty Strategy 2019-2024 (Figure IV of the General Introduction) and cover the CEG domains Earth System and Natural Resources.

Each of these themes builds, in a specific way, on the different geoscience and engineering disciplines that are present in our department. These disciplines are developed within the five sections of the department, namely (i) Reservoir Engineering, (ii) Geo-Engineering, (iii) Applied Geology, (iv) Applied Geophysics & Petrophysics and (v) Resource Engineering. This naturally leads to a department organized as a matrix, in which the columns represent the disciplines and the rows the interdisciplinary programs. Figure 1 shows this 'matrix structure', represented here in the form of an ancient Greek temple. The superstructure (entablature) represents the interdisciplinary themes, which rest on the columns (the disciplines). This representation reflects the department's conviction that excellent, societally relevant, interdisciplinary research is only possible when it is supported by strong geoscience and engineering disciplines. These disciplines, in turn, can only excel when supported by dedicated experimentation. Hence, the columns rest on a platform (crepidoma), representing the Geoscience and Engineering Laboratory, including the Fieldwork Infrastructure. More detailed information about the interdisciplinary themes and the disciplines is given in chapter 5.

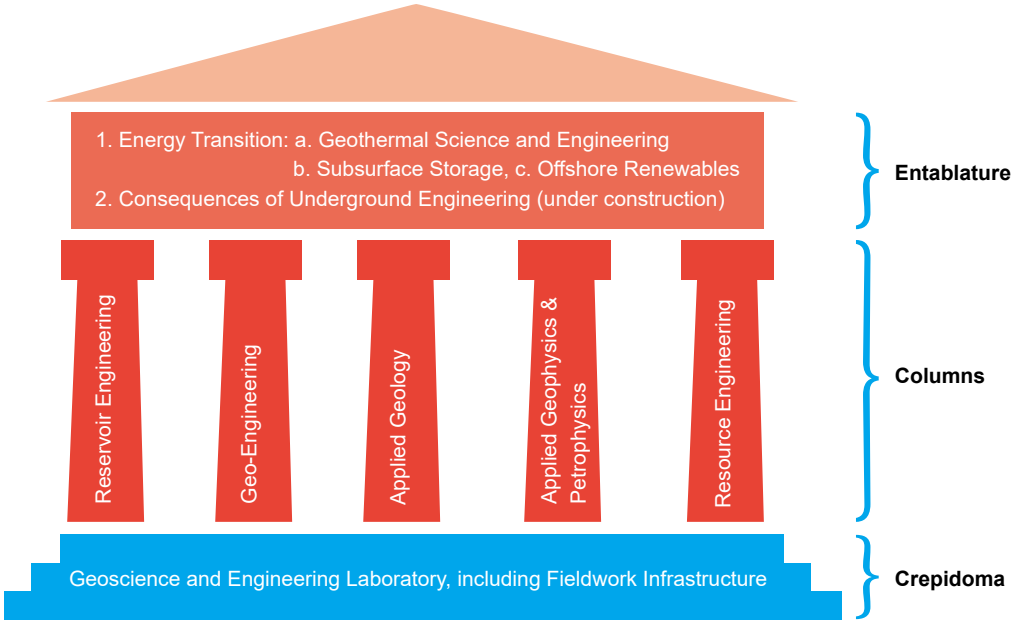


Figure 1: Integrated 'matrix structure' of the Department of Geoscience and Engineering

The sections are organized along the core disciplines and each section has regular staff meetings. There are monthly (a) Department Management Team Meetings among section heads, laboratory director, department manager and department chair, to discuss ongoing HR and financial matters, (b) Research Meetings between theme leaders, research support officer, section representatives and department chair, where research- and strategy-related issues are discussed and (c) Department Meetings with all staff. To better share the teaching load among staff, monthly meetings are held with the BSc and MSc-track coordinators, department chairs of GSE and GRS and the director of the AES programmes.

3.2 Strengthening of the Academic Culture

From 2015 to 2020, a series of department-wide discussions has been held. Staff could sign-up for discussions in groups with a maximum of 15 people. Each group would discuss the same topic and the results from each group session were shared with the department and, based on the outcome of these discussions, decisions were made by the Department Chair and the dMT on how to move forward. The following topics were addressed in these discussions:

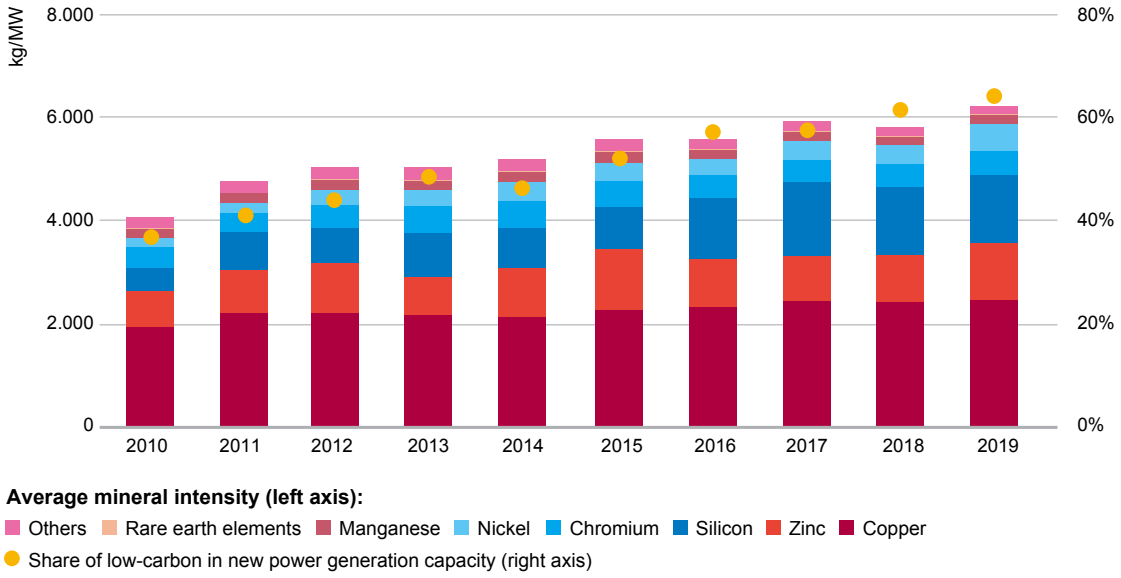
1. Department focus and mission (section 3.2.1)
2. Ethical dilemmas in working with the hydrocarbon industry (section 3.2.2)
3. Department-wide SWOT analysis, cultural beliefs and department structure (section 3.2.3).

3.2.1 Department focus and mission

A series of department-wide discussions led to the definition of a new mission for the department GSE. Our research contributes to:

Responsible Use of the Geosphere considering the Impact on the Earth System and Society.

The transition to carbon-free renewable energy sources does not imply that the rate of extraction of sub-surface resources will become lower in the future; on the contrary, we may expect an increase in extraction rates. This is because the energy transition necessarily will lead to an increase in extraction rates of an increasingly diverse set of elements, minerals, and raw materials. The amounts of lithium, copper, cobalt, and other minerals required in the next decades are 2 to 9 times what we have used until now. These minerals are going to be mined. We aim to develop the knowledge that leads to technology that allows this mining with minimal impact.



Note: Low-carbon technologies include renewables and nuclear.

Figure 2. Increase in demand for minerals related to increase in low-carbon electrical power generation
Source: International Energy Agency, webpage: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions).

A similar story holds for hydrocarbons. As the world's economy continues to expand, so will its energy demand. Renewable energy sources will become more important, but currently the growth in renewables is not yet able to keep up with the growth in energy demand on a global scale. Hydrocarbons remain necessary until at least 2050; however, the carbon footprint needs to become negative to achieve the carbon emission goals we have set. Sub-surface storage of CO_2 is one of the feasible ways to move toward negative or at least reduced carbon emissions.

As green energy resources increase, so will the need to buffer energy increase. Renewable energy will be converted into green gas (e.g. hydrogen) or compressed and hot fluids. We aim to play a major role in this sector.

Geothermal energy is becoming more and more important in providing heat to society. Tools for reservoir-scale subsurface characterization, knowledge of reservoir engineering and technology developed in the hydrocarbon industry are essential for developing geothermal energy. A major challenge we face is the fact that the profitability of geothermal energy for industry is currently much lower than the profitability of exploitation of hydrocarbon reservoirs. Bringing geothermal energy to fruition therefore requires collaboration with a wide range of disciplines in much broader consortia than we have been working with in the past.

The Earth's population grows and people on all continents strive to increase their living standards. More people live in urban areas than ever before, and most of these fast-urbanizing regions are in low-lying deltas. Soil conditions in such areas are not the best for building and infrastructure. Climate change, sea-level rise, groundwater extraction, and other environmental threats are all challenges that require significant innovations in the field of subsurface engineering and the understanding of soil-structure interaction.

To protect the environment in the above-described situation of growing techno-sphere and increasing human population, it is important that the technology and approaches we develop, are developed considering a minimal ecological footprint. To ensure that the generation of waste should be kept to a minimum, technology needs to be developed where cyclic use of all materials is an important starting point while considering that the final waste stream needs to be stored safely.

Data science and modelling have become important drivers in the above fields. Consequently, we require technologies which allow smooth integration of large amounts of data in our research and engineering. To not fall behind it is important that we integrate data science as a basic tool in our department. Topics where we already excel are in the fields of inverse analysis, data-assimilation, and computational modelling.

3.2.2 Ethical dilemmas in working with hydrocarbon industry

The quest for energy transition got strong momentum from the Paris Climate Agreement in 2015, at the beginning of the review period, and from the related Dutch policies (National Climate Agreement – the Netherlands). Having a long tradition in developing methods for exploration and exploitation of hydrocarbon resources, often in cooperation with the hydrocarbon industry, the most logical way forward within the new framework was to use our knowledge and expertise in geoscience and engineering to develop a research programme dedicated to meet the challenges of the energy transition. As the hydrocarbon industry has also become convinced of the need to invest in this transition, we continued collaboration with this industry, which can be of great value in our transition towards a more sustainable use of the subsurface. In 2018 we organised several internal workshops to discuss how to ensure that this cooperation is in line with the Netherlands code of conduct for research integrity. These discussions were joined by Prof. Sabine Roeser, professor of Ethics and chair of TU Delft's Integrity committee, Prof. Behnam Taebi, professor of Energy and Climate Ethics at TU Delft, and Dr. Lucia van Geuns (strategic advisor energy at The Hague Centre for Strategic Studies, HCSS). The main outcomes of these workshops have been integrated in our strategy for the coming 6 years.

3.2.3 SWOT, Cultural-beliefs and department structure

The department-wide discussions led to a detailed SWOT analysis, and a set of shared cultural beliefs. From these discussions changes to the department structure and organization were felt to be necessary. The outcome of these discussions is discussed in chapter 6 (Strategy for the next six years).
As part of our culture we adhere to the Open Science policy of TU Delft (see Appendix 5). We stimulate staff and PhD candidates to publish their research in peer-reviewed journals and to adhere to the FAIR data policy (Findable, Accessible, Interoperable and Reusable).
As part of the preparation for this review, we benchmarked against ETH Zürich, visiting the department of Earth Sciences (D-ERDW) and the department of Civil, Environmental and Geomatic Engineering (D-BAUG), to learn about their organization and academic culture. This benchmark and the conclusions for our department are discussed in Appendix B.

3.3 Human Resources strategy

3.3.1 Department specific policy

The department GSE has decided to add some aspects to the faculty HR-strategy. The first is that PhD candidates, Post-docs and the staff in the tenure-track (TT) and staff who have recently received tenure (Assistant Professors) have organized themselves in a PhD-council, Postdoc-council and Young Staff Council, respectively. The second is that the TU Delft tenure track process has been evaluated and recommendations are now being implemented. In the department we aim to more-closely align the TT process with the regular R&O (performance and development) cycle.

The R&O preview and review have been lifted to the level of the department. Decisions about promotions are made in the dMT. Coaching and training of staff in a tenure track have high priority. Starting staff in a tenure track get a small start-up package which has increased to 1 fully funded PhD candidate from 2019 onward. We are aware that this is only a small step when compared with the generous start-up packages at for example ETH (see benchmark, Appendix B).

3.3.2 Newly appointed staff from 2015 to 2020

In the review period, 8.1 fte academic staff left the department, whereas we were able to hire 13.5 fte (Figure 3). The growth of 5.4 fte academic staff was possible through additional funds from the governmental "Sectorplan Techniek", the "Wet Studie Voorschot" and "Commissie Van Rijn fondsen" (see the General Introduction for explanation).

In hiring new staff, we strive to hire women, which we achieved in 37 % of the new hires. As a result, the percentage of female academic staff increased from 5% in 2015 to 21% in 2020, see Figure 3(c), which shows that our strategy to hire more female staff bore fruit (faculty-wide the percentage female academic staff was 16.9% in 2020, see Appendix 2). Due to the hiring of new staff, the percentage

of academic staff younger than 50 years increased from 42% in 2015 to 56% in 2020, and the international staff slightly increased from 39% in 2015 to 42% in 2020, see Appendix C for details.

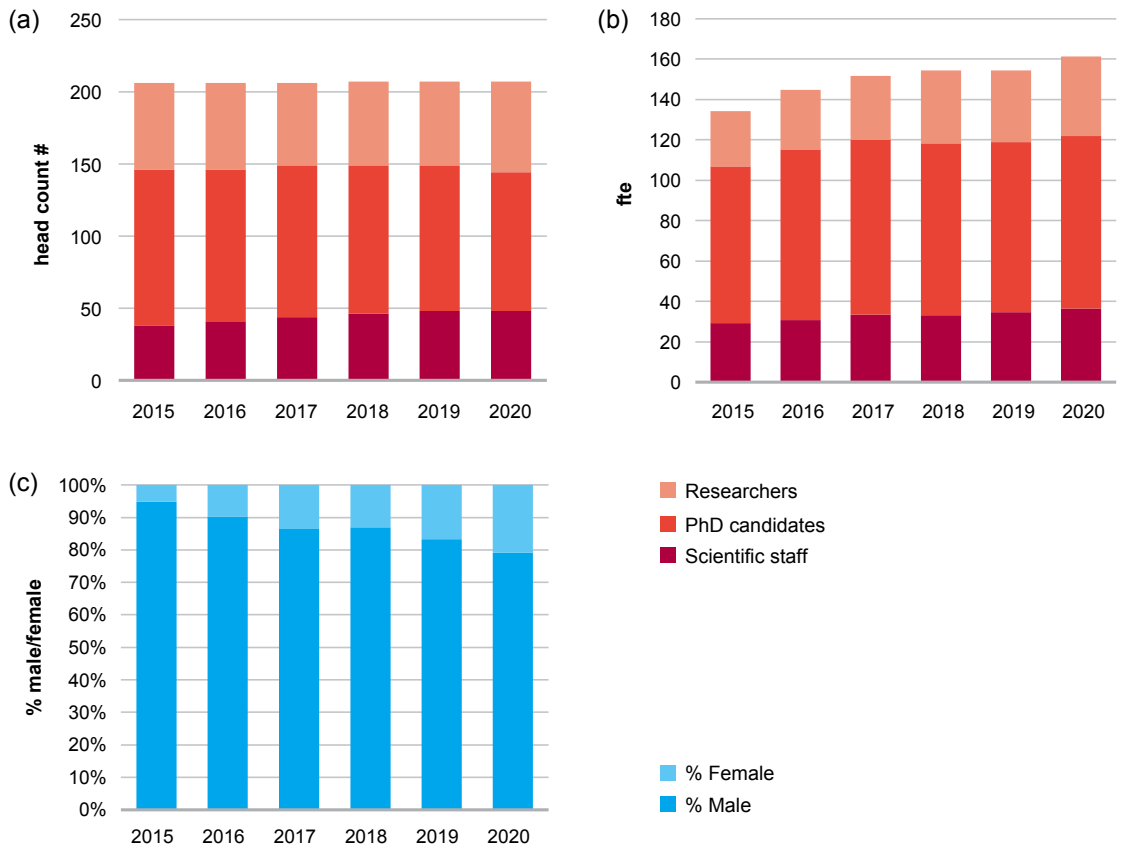


Figure 3: Composition of staff during the review period (for names and numbers, see Appendix C). (a) Head count. (b) Full-time equivalents. (c) Gender distribution of scientific staff.

The “Sectorplan techniek” aimed to significantly strengthen the Civil Engineering disciplines, of which Soil Mechanics was of special importance. Together with the other departments in the faculty, funding for 3 new positions in the Geo-Engineering Section was secured and we were able to appoint Dr. Bram van den Eijnden in a tenure track in Geotechnical Uncertainty, Dr. Giorgia Giardina in a tenure track in Geo-monitoring and Data Analytics and Dr. Stefano Muraro in a tenure track in Experimental Soil Mechanics.

The aim of the “Wet Studie Voorschot” is to strengthen the teaching capacity. In the department we appointed Dr. Anne-Catherine Dieudonné in a tenure track in Engineering Geology. Because of the particularly high teaching load in Engineering Geology and Environmental Geo-Engineering Ir. Richard de Nijs was appointed in a 0.4 fte lecturer position in Underground Space Technology. The department was able to use part of the additional funds from the “Commissie Van Rijn fondsen” allocated to the faculty to appoint Dr. Anne Pluymakers in a tenure track in Experimental Fluid-Rock Interaction.

The Delft Technology Fellowship is a TU Delft fund to support departments in appointing highly talented women in the tenure track programme of TU Delft. The fellowship pays up to 50 % of the costs, including a start-up package for a period of 5 years. The department was able to appoint Dr. Femke Vossepoel as associate professor of Data Assimilation and Dr. Julia Gebert as associate professor of Environmental Soil Engineering.

Other new hires in the review period are Dr. Denis Voskov (associate professor of Modelling of Complex Subsurface Systems), Dr. Hemmo Abels (assistant professor of Sedimentology and Stratigraphy), Prof. Ken Gavin (professor of Subsurface Engineering), Dr. Kees Weemstra (assistant professor of Seismo-Acoustics), and Dr. Maren Brehme (assistant professor of Geothermal Engineering).

Furthermore, we expanded the chair of Prof. David Bruhn (professor of Geothermal Engineering) from 0.3 fte to 0.6 fte and we appointed seven new part-time staff members (between 0.2 and 0.3 fte).

In 2021 we hired Dr. Guillaume Rongier (assistant professor of Numerical Geology) as part of a “roof-tile construction” (a position which partly overlaps with that of a retiring staff member) funded by the Delft-AI-Lab initiative and Dr. Pierre-Olivier Bruna (assistant professor of Structural Geology).

3.4 Department-wide project acquisition and portfolio management

As the department depends quite heavily on the additional funds brought in through projects it is becoming increasingly important to ensure continuity in this project income. Two aspects are important in this respect: 1) project acquisition, and 2) project control.
In 2020, the department implemented a process of streamlining the project acquisition process.
Dr. Anke Dählmann supports researchers in writing proposals. In addition, we make use of the services of the CEG contract manager and the TU Delft Innovation and Impact Centre (I&IC).
Together with the financial support department we have been working on improving project management and project control in order to increase awareness of the magnitude of department investment in each project and to ensure that projects are run within budget. Improving insight into the current state of projects across the department is complex and improving this will be a priority issue for the next review period.

3.5 PhD strategy

As has been discussed in the general introduction, the department adheres to the faculty PhD policies which are managed via the faculty graduate school. In addition to the faculty policy the department has initiated a department PhD council and we actively invite the PhD candidates to join the departmental themes in order to integrate the PhD candidates in larger research teams. These efforts have led to a significant improvement of the PhD performance and, at present, the GSE Department is one of the best performing units of the faculty, in terms of average duration of PhD projects (section 5.4).

4. Evidence: Key Performance Indicators

The SEP defines three categories of evidence for research quality and three for relevance to society. Here we discuss per category which indicators are relevant for the aims and strategy of our department. A summary is given in Table 1.

Table 1: Selected key performance indicators

Research Quality	Relevance to Society
Research Products for Peers	**Research products for societal target groups**
• Peer-reviewed journal articles	• MSc and PhD Graduates
• PhD dissertations	• Products for professionals
• Software products, data-bases and e-lectures	• Courses and MOOCS for professionals
Use of research products by peers	**Use of research products by societal target groups**
• Use of developed methodologies by peers	• Use of developed methodologies by societal parties
• Access to research facilities	• Use of open software platforms
Marks of recognition from peers	**Marks of recognition from societal target groups**
• Individual research grants	• Significant financial support
• Collaborative research grants	• Secondary appointments
• Prizes/awards	• Membership of civil-society organisations

4.1 Research quality

4.1.1 Research products for peers

The foremost indicator for this category is the research output in terms of publications in international peer-reviewed journals. We publish our research in the top journals in our field, which is an excellent way to reach our peers. The output in the form of PhD dissertations and the reduction of the average duration of PhD projects are other important indicators for this category. These indicators are discussed and substantiated in chapter 5 and Appendix E.

We also present our work at international conferences, which often goes along with publication of peer-reviewed conference proceedings (>3 pages). This is very good for direct communication with scientific peers, particularly for PhD candidates, but we don't consider conference proceedings as important as journal papers.

Another relevant indicator for this category is formed by software products for peers, data bases, e-lectures etc. (for details see Appendix E), which contributes to making our research results visible to the scientific community and which stimulates collaboration and knowledge transfer.

4.1.2 Use of research products by peers

Our research published in journal papers is used by many peers world-wide (such as new methods to calculate the stability of dykes, a new approach for dealing with multiple reflections in seismic imaging and monitoring, etc.). This is discussed in chapter 5 and in the research highlights listed in Appendix E.

We provide access to our research facilities (primarily those from our large research infrastructure projects) and software to researchers from other institutes (national and international), see Appendix E for further details.

4.1.3 Marks of recognition from peers

Eleven of our staff members, at different stages in their career, have received prestigious personal research grants from NWO, EU (including ERC) and the Delft Technology Fellowship programme, see chapter 5 for details.

GSE staff members (with an emphasis on early- and mid-career staff members) have acquired significant research funding from NWO and the EU (on top of the personal grants mentioned above). The department is involved in several major collaborative research projects that have been acquired during the review period (DeepNL, EPOS-NL etc.). Last, but not least, many staff members have received prestigious prizes from international professional organisations and seven staff members are in the Stanford list of the world's top 2% scientists. See Appendix E for details.

4.2 Relevance to society

4.2.1 Research products for societal target groups

One of our main 'products' consists of trained scientists (at MSc and PhD level), who find employment in a wide range of companies, research institutes and governmental bodies.

Our societal themes are dedicated to the energy transition and to the effects of underground engineering. To this end, in many of our projects we cooperate closely with industrial and governmental parties. The results of these projects range from the development of new knowledge, methodology and software products to the development of infrastructure (such as the geothermal well on the TU-Delft campus), see Appendix E for an overview.

Other products are courses and MOOCS for professionals, and popular articles, lectures, documentaries, blogs and forums for a general audience. See Appendix E for details.

4.2.2 Use of research products by societal target groups

Our published research products are used by many societal groups (such as a pile testing method used by the Port of Rotterdam, a seismic survey design method used by the sponsors of the Delphi consortium, etc.). This is discussed in chapter 5 and in the research highlights listed in Appendix E.

Moreover, our software products reach societal users via open platforms such as GitHub, see Appendix E for details.

4.2.3 Marks of recognition from societal target groups

The foremost indicator for this category is the funding we receive from societal target groups. In the review period we acquired 21,727 kEuro for contract research (EU funding excluded), which is 42% of our externally acquired funding (see Appendix D). Other marks of recognition are secondary appointments and memberships of civil-society organisations (see Appendix E for details).

5. Accomplishments during the past six years – research quality and societal relevance

5.1 Formation of interdisciplinary societal themes

To address the societal challenges posed by the energy transition and by underground engineering, we established a number of interdisciplinary societal themes. The formation of these themes, and further developing the underlying disciplines, formed a major part of achieving our strategic aims of the review period. In line with our strategy to let young and promising staff members grow, the themes are led by the rising stars of our mid-career staff, who get the responsibility and freedom to run these themes. In the following, we discuss the status of the formation of the interdisciplinary themes.

5.1.1 Energy Transition

5.1.1.1 Geothermal Science and Engineering (established in 2017; theme leader Phil Vardon). Worldwide, governments, industry and policy makers are looking for solutions for sustainable energy supplies in order to reach their sustainability goals and mitigate climate change. It is generally expected that geothermal energy, as a sustainable georesource, has an important role to play in this process. In order to increase the use of geothermal energy and to fulfill the high ambitions in the Netherlands, as well as worldwide, it is necessary to better understand the processes involved over the full lifetime of a geothermal project. In 2017 we set up the theme of Geothermal Science and Engineering. Research questions that we address are how much energy can be delivered, what is the long-term fluid and heat flow behaviour, how can we best monitor geothermal projects (for energy, for surface impacts), how do materials (geothermal fluids, reservoir material, casing material) perform? This requires knowledge from a number of disciplines and an integrated approach. At our department we have the relevant subsurface expertise in-house, ranging from geology, hydrogeology and geo-engineering to geophysics and reservoir modelling and are therefore able to tackle these challenges and advance the field. Moreover, TU Delft is working together with industry partners to implement a geothermal research well on campus, which will form a living laboratory for this theme. Equipped with a broad range of advanced technologies for monitoring and data acquisition, this well will deliver essential information on processes affecting deep geothermal energy provision. Many projects have been acquired within this theme, the most notable large projects are the NWO-large scale infrastructure project EPOS-NL, the EU ITN EasyGo, and the RVO project Warming-UP. Currently, the theme hosts 9 PhD candidates and postdocs. A more detailed discussion of this theme and how it deals with open science, PhD policy and training, academic culture and human resources policy, can be found in the case study in Appendix A.

5.1.1.2 Subsurface Storage (established in 2019, theme leader Hadi Hajibeygi). The growing share of renewable energy produced from sun and wind has introduced new technological challenges. Their natural temporal fluctuations make it difficult to match the energy demands instantaneously. Hence, the development of storage systems is necessary to accumulate energy in periods of high production and release it when the demand is higher. Geological formations have a huge storage capacity and can serve as energy buffers in the form of e.g. green fuels (hydrogen, green

methane, etc.), hot fluids, and compressed air. Formations can also be used for safe large-scale storage of industrial by-products, e.g. CO_2. Finally, subsurface formations are a major resource of fresh water. In 2019 we started the theme Subsurface Storage. In this theme, we develop knowledge required for subsurface storage systems, building on the scientific expertise present in our department, such as (pore-scale) modeling and optimization, geomechanics, hydrodynamics, geological site characterisation and geophysical monitoring. The theme received funding from NWO (Vidi grant ADMIRE of the theme leader, 2019) and industrial sponsoring (SafeInCave, 2021). More funding sources will be applied for in the coming period.

5.1.1.3 Geo-research for offshore renewables (project leader: Federico Pisanò)

The share of offshore renewables in the global energy mix, and particularly in the Netherlands, has been constantly growing in the last two decades – especially owing to the development of new-generation offshore wind farms. The GSE Department substantially contributes to the offshore energy sector by liaising with prominent industry partners for the development of new geo-solutions, such as innovative foundation and anchoring systems for bottom-fixed and floating structures. Geo-research for offshore renewables is strongly supported by combined public-private funds, and is carried out through multi-disciplinary synergies across the CEG Faculty and with other TUD Faculties. The relevance of the subject is currently fostering a strong collaboration in the faculty with the Hydraulic Engineering Department, which is attracting growing interest and recognition both nationally and internationally. Two notable industry consortia projects are MIDAS and BLUE-Piling. This subject fits very well in the Energy Transition theme, which is why it is listed here. At the same time it is different from the other themes in the sense that it is focused to collaboration with another department.

5.1.2 Consequences of Underground Engineering

(under construction, theme leader Auke Barnhoorn)

Fifty years of gas production in Groningen has largely contributed to the prosperity of the Netherlands, but it has also led to undesired effects such as induced earthquakes and subsidence. In 2018 the DeepNL programme was established by NWO, with the aim to improve the fundamental understanding of the dynamics of the deep subsurface under the influence of human interventions. Our department

acquired significant funding from this programme to address the problems related to gas-extraction in Groningen. In an integrated approach we investigate how to estimate fault slip occurrence, develop multiscale geophysical imaging, monitoring and forecasting of induced seismicity and subsidence, we investigate heterogeneous soft top soils for wave propagation, cyclic degradation and liquefaction potential and we are developing a scientific basis for production and reinjection strategies to minimise induced seismicity in gas fields. This research leans on the department's expertise in geomechanics, geophysical monitoring, soil mechanics and rock-fluid processes. This research forms a solid basis for setting up an interdisciplinary theme Consequences of Underground Engineering (which will start in 2022). With this theme we aim to address the challenges posed by underground engineering in a broader sense.

5.2 Geoscience and engineering disciplines

Geoscience and engineering disciplines are being developed in the five sections of the department. The research in the sections addresses the scientific and societal challenges related to their specific discipline (mono-disciplinary research) and contributes to the societal challenges posed by the energy transition and underground engineering (multi-disciplinary research, supporting the societal themes of the department).

5.2.1 Reservoir Engineering

The Reservoir Engineering section has a long history in studying flow through porous media with laboratory research. The section has a strong international reputation in the field of research for Enhanced Oil Recovery (EOR) and CO_2 storage. This expertise is essential for the geo-thermal energy and sub-surface storage themes. While EOR research is now focusing on minimizing the carbon footprint, current projects like DRAGLOW and SafeInCave underpin the research in the storage theme.

The department themes involve coupled flow-geomechanical, thermal and chemical processes. To simulate these processes, the Reservoir Engineering section is developing state-of-the-art simulators with efficient multi-scale schemes and use of GPU computing. Developments of multiscale simulators as part of the Vidi project ADMIRE ensure realistic simulation at acceptable computational costs. The section actively contributes to studies that address the effects of injection and production of fluids on induced seismicity and subsidence. The section contributes to three of the DeepNL projects (Science4Steer, Subsidence and InFocus), with two section members acting as PIs. The quantification of uncertainties critical to interpretation of the simulation results is ensured through the development of data-assimilation methods. Application of data assimilation in areas outside of the GSE research domain ensure cross-fertilization between various disciplines, including remote sensing and water management. Combined with research in the field of optimization and control theory the data-assimilation research contributes to the optimization of the use of the subsurface.

5.2.2 Geo-Engineering

The Geo-Engineering section is a world leader in the stochastic characterization and modelling of soil heterogeneity and the reliability-based propagation of uncertainty from the material level to the structure response level. The section contributes with this expertise to the department themes. Techniques developed as part of the NWO-TTW Reliable Dykes project (2015-2021) are now being used in one DeepNL project (SOFTTOP), to assess the influence of heterogeneities and soft soils in the shallow subsurface on-site response due to induced seismicity. A second DeepNL project (3DSOIL), a joint venture between the sections of Geo-Engineering and Geophysics & Petrophysics, is seeking to establish a more detailed visualization of heterogeneities in the shallow subsurface by linking geophysical measurements with CPT data. The techniques will be further developed and applied in RESET, a new joint venture with the department of Engineering Structures, investigating reliable embankments for the safe expansion in rail traffic.

The section also has strong collaborations with other departments in the faculty. In 2017, the academic platform MUDNET was founded as a multidisciplinary network of TU Delft researchers. It aims to: promote interdisciplinary and multi-methodological collaborative research on fine-grained sediments

(MUD); unite researchers in geosciences, physics, chemistry and biology; facilitate contacts and exchange between scientific, private and public stakeholders; identify research needs; and provide new solutions for optimizing sediment management, as well as developing new port and waterways maintenance strategies. MUDNET research is reflected in 20+ recent journal publications and in successful NWO grants such as Sediment-to-Soil (S2S). To promote research and education, the foundation MUDNET was formed in 2020, and the first MUDNET conference was held in 2021.

Research on Sustainable Aftercare of Landfills continued throughout the review period leading to three PhD theses. In 2017 a research grant from RVO allowed us to run a unique 2 year project which allowed us to install a large amount of research infrastructure in three full-scale landfill stabilization pilots in the Netherlands. This laid the basis for our successful application of the NWO-Groot program CURE.

Bio-based environmental geo-technology research into using Podzol inspired Aluminium-organic carbon flocs as a means to the reduce the in-situ permeability of soils led to the development of the SoSEAL concept. This concept has been applied at pilot scale in a STW-Water (now NWO-TTW) programme.

5.2.3 Applied Geology

Responsible use of the subsurface for the energy transition critically hinges on our ability to predict the multiscale spatial distribution of geological and physical properties of reservoir-scale underground bodies and, eventually, the dynamic behavior of reservoirs. Predicting the equally multiscale sedimentological and structural processes controlling physical properties is the overarching aim of the activities of the Applied Geology section. This is achieved with a strong emphasis on outcrop studies integrated with process-based numerical models. Close collaboration within the departmental themes is systematically pursued.

In the sedimentological domain we have acquired extensive field data (e.g. Bighorn and Williston Basins) and numerical models to improve the understanding of fluvial systems which are comparable/applicable for hydrocarbon, geothermal, as well as Hydrogen and CO_2 storage applications. We have further developed Forward Stratigraphic Modelling (FSM) tools (Delft3D-GeoTool) and, within the DELPHI consortium, worked on the integration of Artificial Intelligence in FSMs to extract sub-seismic scale information of subsurface reservoirs. To investigate in a holistic manner the effects of climate (sea-level change) on the future of deltaic regions such as the Netherlands, a TU-broad initiative has been coordinated.

In the domain of structural geology, we would like to mention three main achievements: 1) development of new Multi Point Statistic methods to populate subsurface models with fracture networks, 2) innovative studies of dissolution features with caves built on 3D images of cave systems and reactive transport models, 3) expansion of the digital models of outcrops and caves; these are accessible to the wider community. To preserve and strengthen the link with fundamental geology research, we have continued our collaboration in the NARG consortium with widespread activities in North Africa.

5.2.4 Applied Geophysics and Petrophysics

The mission of the section Applied Geophysics and Petrophysics is to execute fundamental geophysical (seismic & EM) and petrophysical research, directed towards developing cutting-edge acquisition, imaging, characterization and monitoring methodologies for resource exploration, environmental and engineering applications. This expertise forms an essential foundation for all departmental themes. We discuss some highlights.

Geophysical imaging is hampered by multiple reflections. The section pioneered the Marchenko method (51 journal papers in the review period) for suppressing internal multiples during seismic imaging of the subsurface and for internal multiple elimination from seismic reflection data at the surface. This approach is recognised by the international geophysics community as one of the preferred methods for dealing with internal multiple reflections in seismic data. It is developed in an ERC-AdG project, an NWO-TTW project and a DeepNL project. This methodology implies a significant step forward for monitoring of processes in the subsurface and as such contributes to the societal themes of the department.

The section has a strong tradition in research on seismic interferometry (45 journal papers in the review

period). This research is used by many research groups around the globe to image structures and monitor processes in the subsurface of the Earth (and Mars) with ambient seismic noise.

Laboratory research of the section has focused since 2015 on developing and validating monitoring concepts for the forecasting of failure in materials. We have shown that, with active acoustic monitoring (by continuously sending ultrasonic waves through deforming materials), the subtle changes of the waveforms already show very early that failure and seismicity is imminent (e.g. Barnhoorn et al., 2018, Zotz-Wilson, 2019; 2020). In the DeepNL project we show that precursors to failure in active acoustic wave form analyses are omnipresent (in fracturing of intact rocks, during reactivation of pre-exiting faults and failure due to fluid injection). This approach is valued by the geophysics community and companies and is currently extended in new collaborative research programmes (SUCCEED and SHARP).

5.2.5 Resource Engineering

The scope of the section Resource Engineering covers primary raw material to mining wastes. The goal of the section is to enable mining for zero waste through the application and development of sensor technology for geochemistry and mineralogy, combined with data analytics and chemometrics for raw material characterization. The multi-format and multi-scale sensor-derived spectral data are used to give a holistic overview of material attributes. The outcomes are used to generate applied knowledge for decision making.

The section has been very successful in participating in numerous highly competitive European project grants. A key project included the H2020 Real Time Mining Project where the section acted as initiator, coordinator and WP leader for 3 work packages. This successfully demonstrated the ability to fuse multiple spectral datasets and machine performance datasets to distinguish ore, waste, deleterious material and the resulting knowledge was used to update the mineral resource model in real time.

Collaboration with major industry partners has resulted in successful automated discrimination of ore and waste and real time material tracking through the mining process for specific gold-mine applications. The European FP7 project, STOICISM, was successfully completed during the review period and demonstrated the benefits of real-time automated material property characterisation from mine to calciner for a variety of industrial materials.

The tools developed during the past six years for geoscience material characterization and modelling have been increasingly refined and adapted to multiple different applications. Subsequent projects focussed on automated drill-core logging (SOLSA), sensor applications in harsh operational environments (InSITE), the use of sensor derived data for mine waste characterization in order to recover critical raw materials (Inco Piles) and revalorization of abandoned mine workings (VAMOS). Since 2017 the focus has been on the implementation of Machine Learning applied to large multi-parameter datasets to generate material fingerprints that capture physical and chemical properties.

For as yet, the section Resource Engineering has a limited integration in the departmental themes.

5.3 Scientific Output and Open Science

In the previous review period 2008-2014 (seven years), the four units that made up the GSE department published 671 journal papers. In the current review period 2015-2020 (six years), GSE published 871 journal papers. Corrected for the different lengths of the review periods, this is an increase of 51%. This shows that our continuous effort to stimulate staff and PhD candidates to publish their research in peer-reviewed journals has been very effective. Many of the journal papers are very well cited.

Figure 4(a) shows the details of the publication output for the review period. Note that the number of refereed journal articles has been gradually increasing over the years. Due to Covid, the number of conference papers (and ‘other research output’) decreased significantly in 2020. We expect that this is a temporary effect.

In the review period there has been an increasing awareness and prioritization of Open Science in the department, evidenced by increasing amounts of FAIR data publications and open access journal articles and by the hiring of a department data manager (Dr. Lora Armstrong). Large projects like EPOS-NL and GEOLAB provide access to data, software and facilities. Figure 4(b) shows a clearly increasing trend in open access journal papers, from 49% in 2017 to 77% in 2020. We aim to continue this trend in the years to come, with the ultimate aim to reach 100% open access in a few years time.

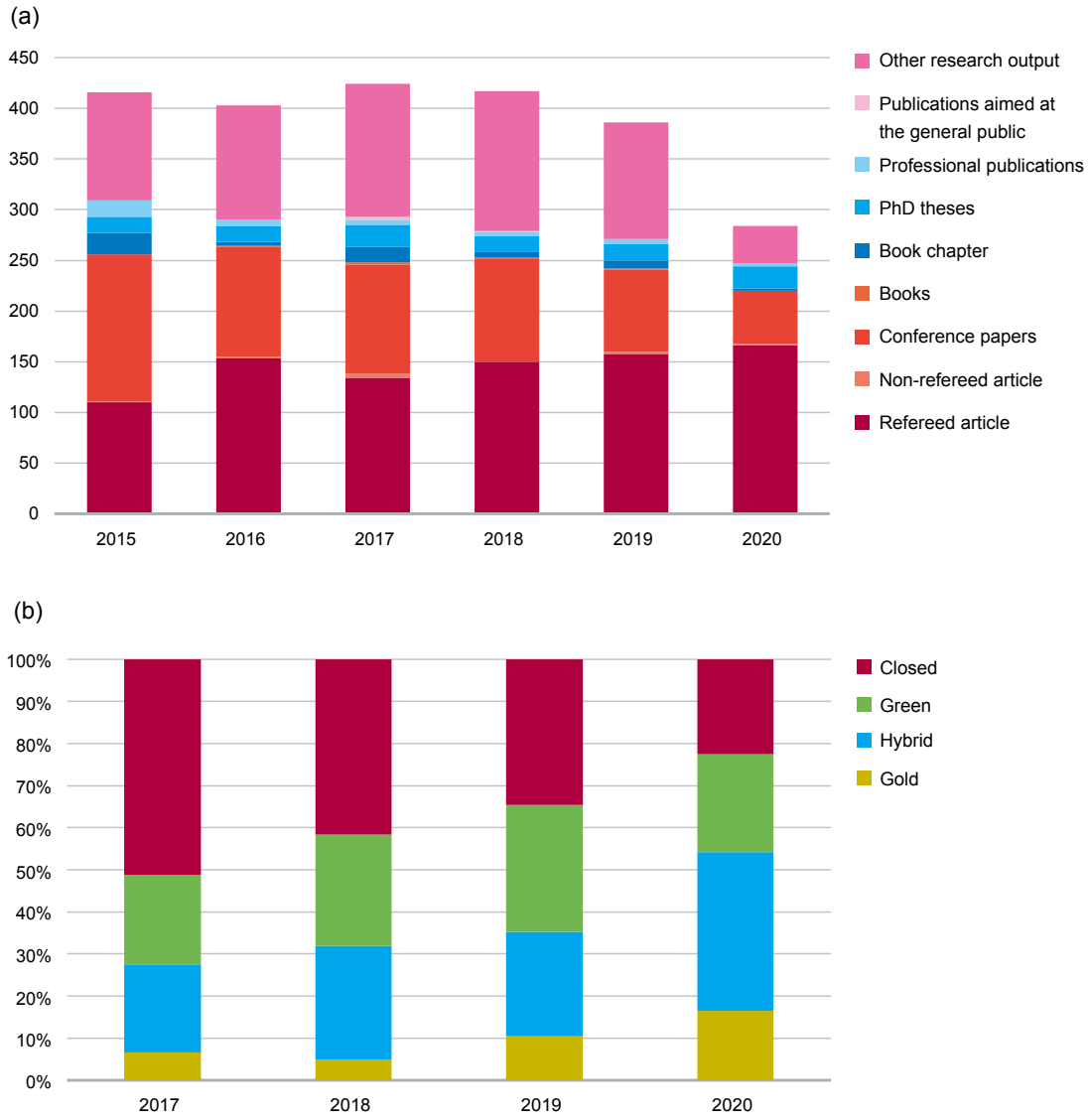


Figure 4: (a) Research output during the review period (for numbers see Appendix E). (b) Open access journal articles (for numbers and more information, see Appendix E).

5.4 PhD graduations

One of the aims of the establishment of the Faculty Graduate School in 2012 was to reduce the duration of PhD projects, ideally to the Dutch (target) standard of four years. Figure 5 shows the PhD graduations during the review period. Figure 5(b) shows a clear trend of the increasing percentage of PhD graduations in less than 5 years. Averaged over the review period, 61% of the PhD candidates finished their thesis in less than 5 years (column 'GSE'). This is significantly higher than the averages of approximately 40% for Delft University (column 'TUD') and 39% for the Netherlands (column 'NL'). The establishment of the Faculty Graduate School played an important role in this. The number of dissertations increased from 81 in the previous review period to 108 in the current period, representing an increase of 56% (after correction for the different lengths of the review periods).

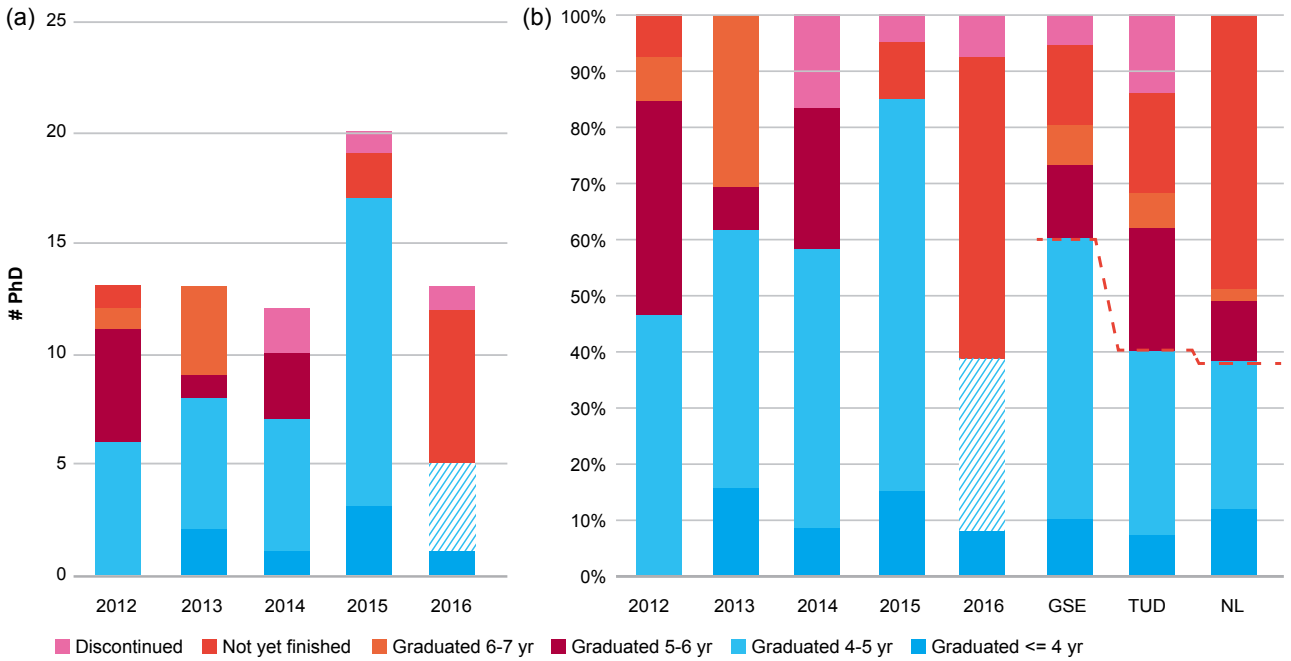


Figure 5: PhD graduations during the review period (for numbers see Appendix E; years are starting years). This overview only includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0.8-1.0 FTE contract. Figure (b) includes columns GSE (average 2012-2016), TUD (average 2012-2016), NL (average 2012-2014). The numbers for the NL average are based on VSNU data for cohorts 2012-2014 only, as no further data is available from VSNU. There is no differentiation between the categories 'discontinued' or 'not yet finished' for the VSNU data.

5.5 Funding

To realize our aim to establish a number of interdisciplinary societal themes, we have put much effort in acquiring funding from NWO, the EU and industry for interdisciplinary research:

- In 2018, NWO granted the EPOS-NL proposal of Utrecht University, Delft University and the Royal Meteorological Institute. EPOS-NL is the national infrastructure for Solid Earth Science and forms the Dutch contribution to EPOS (the European Plate Observing System). The total funding for EPOS-NL is more than 12 M€ by NWO, of which nearly 6 M€ is assigned to our department. This finances new infrastructure, a data manager and a research manager, primarily to support the interdisciplinary societal themes of the department. EPOS-NL provides facility access and data access to researchers from other national and international institutes.
- In late 2018, we acquired funding from NWO in the DeepNL programme. In this programme we cooperate with the Department of Geoscience and Remote Sensing and with the Faculty of Geosciences at Utrecht University. Our department currently hosts 10 DeepNL PhD candidates and 3 postdocs. This programme contributes largely to the establishment (in 2022) of the theme Consequences of Underground Engineering
- In 2019, the WarmingUP programme was granted (9M€, of which 351 kEuro for GSE, Co-PI Phil Vardon). The WarmingUP collective brings together 38 participants including many industry partners to make collective heating systems reliable, sustainable and affordable for the heat transition. Within the Geothermal Science and Engineering theme, we have two PhD candidates working in the consortium and focusing on (i) groundwater monitoring using seismic and electromagnetic methods and (ii) the exploration and efficiency of high-temperature aquifer thermal energy storage (HT-ATES).
- In 2020, the EU granted an ITN proposal, named EasyGo (Efficiency and Safety in Geothermal Operations, PI Maren Brehme), and assigned 1479 k€ to our department. This programme is a big stimulus for the theme Geothermal Science and Engineering.
- In 2020, the EU H2020 (Research and Innovation Programme) project of GEOLAB was granted (5 M€, of which 0.5 M€ for our department). The GEOLAB Research Infrastructure consists of 11 unique installations in Europe aimed to study subsurface behaviour and the interaction with structural

critical infrastructure elements (e.g. a bridge) and the environment. The overarching aim of GEOLAB is to integrate and advance these key national research infrastructures towards a one-stop-shop of excellent physical research infrastructure for performing ground-breaking research and innovation to address challenges faced by the Critical Infrastructure of Europe.

Next to our efforts to acquire funding for the themes, we have continued (and will continue) to support our staff to apply for the excellence programmes from NWO and the EU, and consider the potential to be successful in such schemes in the selection of new staff. In the review period, this resulted in the awarding of:

- an ERC-Advanced Grant to Wapenaar, 2017;
- an NWO-Vidi grant to Evers, 2015;
- an NWO-Vidi grant to Hajibeygi, 2019;
- an NWO-Veni grant to Pluymakers, 2017;
- an NWO-Veni grant to Dieudonné, 2019;
- a Delft Technology Fellowship to Vossepoel, 2016;
- a Delft Technology Fellowship to Gebert, 2016.

The following projects were granted in 2021, but the proposals were prepared/submitted in 2020:

- an NWO-Vidi grant to Giardina, 2021 (proposal submitted in 2020);
- a Marie Curie Fellowship to Liaudat in 2021 (proposal submitted in 2020).

More research grants acquired in the review period are listed in Appendix E.

Figure 6 gives an overview of the total funding, split up in direct funding, research grants (such as NWO), contract research (EU and industry) and other.

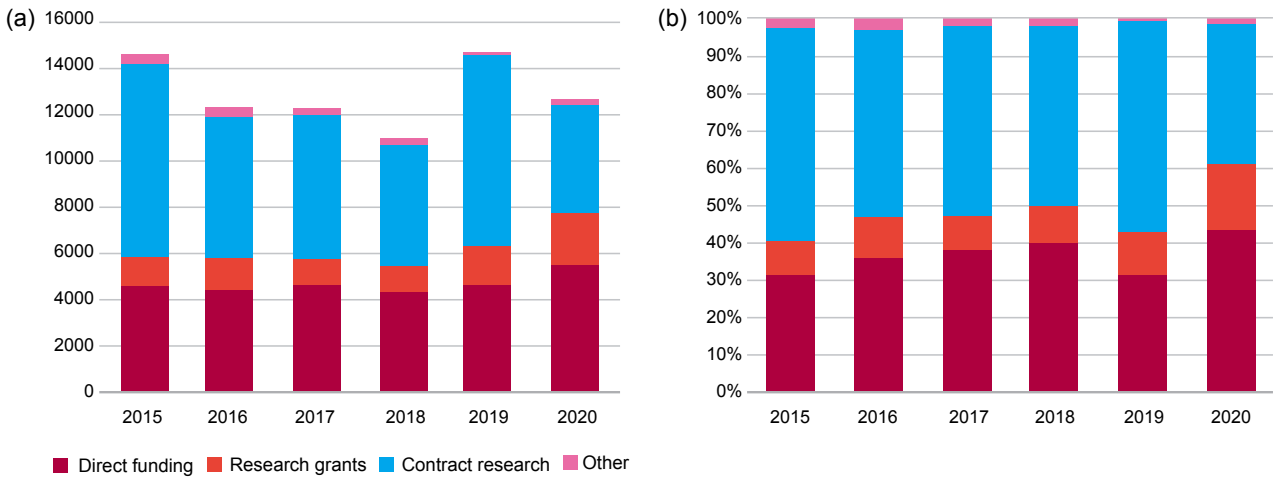


Figure 6: (a) Research funding in kEuro's (a) and percentages (b). For numbers, see Appendix D.

6. Strategy for the next six years

6.1 SWOT Analysis

The discussions on how to integrate the department into a single research unit in 2019 and 2020 included a detailed SWOT analysis, which is summarized in Table 2.

Table 2. Summary of the SWOT Analysis from 2019 and 2020

Strengths	Opportunities
Research/Teaching • people are strong in their disciplines • high quality research • both engineers and scientists **Organization** • cooperative people • theme approach • opportunities for continuous development • regular self-reflection • able to attract high quality young staff **Societal challenges** • research and teaching focuses on essential "grand" challenges of society • diversity in disciplines provides us with a unique profile • strong groups at the frontier of their discipline • integration of geo-science & engineering, environmental engineering and civil engineering • research highly relevant to society (as proven by industrial funding) • strong links with other departments in the faculty	**Research/Teaching** • "groeifonds" participation • "Sector plan Earth and Environmental Sciences" • key player in all 3 of the new MSc programs **Organization** • tenure track system of the TU Delft • graduate school • autonomy as a department • integration within the faculty **Societal challenges** • energy transition • increasing demand for mineral resources • need to reduce climate and environmental emissions • urbanization in low lying deltaic areas • young generation is interested in "protecting" the earth
Weaknesses	**Threats**
Research • external profile of department still too much linked with historical image of "Mining & Petroleum Engineering" **Teaching** • high volume of teaching leads to excessive workload **Organization** • science requires focus • department is quite large • staff experiences a lack of transparency • tenure track is felt to be stressful (but not as stressful as a few years back: young staff see their peers successfully obtain tenure) • PhD and Postdocs are sometimes poorly connected (but there are examples of very good connection) • workload is aggravated by large amount of internal committee work **Societal Challenges** • strong national focus, which can lead to limited awareness of international opportunities	**Research** • drive in funding toward larger and larger thematic and mission driven programs • large dependence on 3rd money stream implies focus on short-term questions • we have unlimited ambitions and find it difficult to make choices • appreciation in TT system is based on individual achievements, competition may be counter productive **Teaching** • relatively small number of students in AES BSc and MSc tracks **Organization** • internal support systems provide limited insight in projects • internal administration is overly complicated and opaque **Societal challenges** • clinging to our past reputation

This SWOT analysis formed the basis of reformulating the goals and ambitions for 2021 to 2026.
The take home messages from this analysis are that:

- The department must develop an external profile that reflects our ambition to help solve the grand challenges faced by society.
- Research collaboration in themes is a way to develop a strong external focus.
- We need to develop a diverse portfolio of projects funded from a range of different funding sources.
- We need to continue improving the way we work together in the department in order to:
  - reduce the work pressure experienced by the staff,
  - be prepared to participate in large research programmes,
  - optimally contribute to the society's grand challenges.
- Staff numbers need to increase to sustainably reduce workload.
- The two-way communication between department management and staff needs to be improved significantly, especially considering the expected growth in staff numbers.
- On-boarding of new staff needs to be improved.

This SWOT analysis led to the formulation of four strategic topics for 2021-2026:

1. Goals and Ambitions
2. Organization of the department
3. Information and data management
4. Project and financial management

6.2 Goals and ambitions 2021 - 2026

6.2.1 Research

The aim of our research is to develop knowledge that leads to the employment of engineering, construction, and exploration activities at the surface and in the shallow and deep underground, in a way that leads to minimal environmental impact. We will strengthen our research in the following thematic areas and, if necessary, develop new themes:

1. The Energy Transition, where we currently have the following three sub-themes: Geothermal Science and Engineering, Subsurface Storage (of H_2 and CO_2), and a collaboration with the Hydraulic Engineering Department: Geo-research for Offshore Renewables,
2. Consequences of Underground Engineering.

These themes provide us with a framework which enhances our capability to participate in, and lead large (> 2.5M euro) national and international research initiatives.

A concrete example is our participation in a proposal for the NWO Large-scale infra-structure call of 2022: EPOS eNLarge (UU, TU Delft, KNMI and TNO). The research topic of eNLarge is centered around understanding the effects of human use of the subsurface, as well as natural processes active there, with a focus on new facilities to bridge lab to field/system scales. The requested budget of eNLarge will be in the order of 20 M€. At TU Delft, we aim to develop a deep monitoring well and heat storage facility for the DAPwell (Delft Aardwarmte Project well) and (together with TNO Rijswijk center) a long-range fluid flow testing well. In addition, various lab equipment will be installed at TU Delft and UU for imaging of multi-scale dynamic processes. This proposal is a follow-up to the current EPOS-NL programme.

Another example is the RESET research programme with ProRail and TU Delft (departments of GSE and Engineering Structures) with a total budget of 15 M€ for 5 years. In RESET we will focus on the consequences of increased and heavier rail traffic and climate change on our railway embankments.

Discipline focused research is coordinated within the sections of the department. Staff will be stimulated and supported to apply for prestigious personal grants from NWO and the ERC of the EU.

As we are a research university, a significant part of our research effort is done in BSc and MSc graduation projects. The redesign of the MSc programmes in the faculty brings new opportunities for

cross-departmental and cross-faculty research collaboration. We will continue to integrate BSc and MSc thesis work in ongoing PhD and Postdoc research projects.

6.2.2 Partnerships

Moving in the direction of large theme-oriented research programmes, necessarily involves development and management of strategic relationships with societal partners, from research, industry, and government. We aim to manage such partnerships more strategically at the level of the department, within the different themes. We actively stimulate staff to visit international strategic partner institutes and highly visible researchers from partners to visit Delft.

The department of GSE currently hosts a diversity of disciplines which gives us a unique position in the field of sub-surface and geotechnical engineering. This position becomes even stronger if we integrate these with departments like Hydraulic Engineering, Engineering Structures, Geoscience & Remote Sensing and Water Management in projects where the research focus lies on the interface between the subsurface, atmosphere and society. We aim to carefully adapt our disciplinary profile to optimally fit the changing requirements of society and, if possible, expand our disciplinary profile. However, we need to realize that our resources are limited and that focus in the department is essential to allow multiple disciplines to collaborate in a fruitful manner.

6.2.3 Academic independence

We value academic freedom. In research projects where we closely collaborate with industry or other societal partners, we always ensure that it is us determining the scientific questions, how to address these and which methods we use. We aim to primarily operate at low technology-readiness-levels. We are transparent about our results and use open science approaches to disseminate our knowledge and data.

To make sure that industry related projects are functional to solving the grand societal challenges, we require the PI at the proposal stage to develop a scheme on how the developed knowledge can be used. To be open and transparent, we aim to publish our projects, specifying the funding body, on our website where we also indicate the expected societal impact.

6.3 Organization of the Department

6.3.1 Management

To achieve the goals and ambitions, the department will strengthen the involvement of staff in important strategic decisions, which is essential to ensure wide support. This is comparable with policies at ETH-Zürich (see Appendix B). To strengthen the two-way communication between department management and staff, a department council (DC) will be installed with the aim to represent the department staff in the discussions and advise the department management team (dMT). The DC will consist of 10 members which are nominated by functional groups. To facilitate the communication between DC and the department, we have initiated several councils for PhDs, Postdocs, and young staff (assistant professors), associate professors and full professors.

Sections remain an important part of the structure of the department as discipline groups. However, as finance, staff recruitment, external communication, external stakeholder management, and project portfolio management have been lifted to the department level, the role of the section heads in the department will change as well. The dMT consists of the heads of the different sections, the laboratory director and the department manager. The dMT, as a team, supports the department chair (DCH) in managing the department and, as such, also carry department-wide responsibility. Each member in the dMT has a supervisor role for the members in their sections. The DCH is the formal supervisor of all section heads (SH) and the full professors in the department. The organizational structure of the department needs to comply with the Departmental Organizational Principles defined by the Dean and the faculty MT.

6.3.2 HR strategy

An important aspect of HR strategy is the hiring of new staff. Hiring policy is managed at the department level. In 2021, with the redesign of the three MSc programs in the faculty, the department and faculty have decided to invest heavily in the fields of Geo-resource Engineering and Geo-Environmental Engineering by creating three new positions.

Given the age distribution in the department, a significant number of staff will retire between 2026 and 2032. We will prepare for these retirements by looking for opportunities to use so-called “roof-tile” constructions such as the Delft Technology Fellowship and the DAI-labs, to replace retiring staff.

Successful examples of such “roof-tile” constructions are the hiring of Prof. Sebastian Geiger on temporary funds provided by the faculty until the retirement of Prof. Giovanni Bertotti and the hiring of Dr. Guillaume Rongier in a tenure track temporarily funded by the Delft “DAI-LAB” programme until the retirement of Dr. Karl-Heinz Wolf.

In 2022, the dMT will initiate a discussion in the department on how the disciplinary profile of the department needs to evolve to meet the future challenges in society. The “Sectorplan Earth and Environmental Sciences” which will be submitted in 2022, is going to be an important opportunity to invest in staff. We hope to be able to expand our staff strategically with this sectorplan initiative. The discussion in the department will outline a position and replacement strategy for the coming decade.

In order to improve an easy start of new staff, special procedures will be developed together with the HR department of the faculty to improve the on-boarding.

6.3.3 Academic culture and social cohesion and integrity

An open work environment requires a sufficiently inclusive culture where people feel safe to speak about problems, trust that their problems are taken seriously and be dealt with. Establishing and maintaining this environment is at the core of the TU Delft code of conduct, which was established in 2019. It presents the core values of the university as DIRECT: diversity, integrity, respect, engagement, courage and trust. At institutional level, the university has set up a set of regulations for complaints concerning undesired behaviour, an integrity office, a confidential advisor, such that everyone can experience an environment where they feel welcome and treated with respect. In addition, the university has an ombuds officer for employees. The outcomes of the yearly Employee Monitor carried out by the university will be used to develop actions to strengthen de departmental culture. The training in “Non-violent-communication” organized in 2021 is an example how we aim to do this in the future.

Anyone affiliated with our department, faculty, and university, be it as a student, employee or visitor, contributes to a mutually respectful treatment, regardless of origin, gender, sexual preference, handicap, religious belief, position or job. Cultural diversity is strong in the GSE department, which gives room for implicit biases. This leads to situations of misunderstanding and friction and can result in feelings of unsafety. To help reduce the vulnerability of PhD candidates, the department has embraced the policy of having two supervisors, in line with the university policy.

For the coming years, the department plans to work on creating situational awareness in all its employees and guest PhD candidates. This will be done by organizing implicit bias training, active bystander training, and the department has already started with a nonviolent communication training. The department is planning to take part in the university social safety programme.

In the review period, the department has firmly incorporated the concept of responsible research and responsible innovation as a base to contribute to the key values, sustainability, safety, security, wellbeing, and respect for persons, as well as to the UN Sustainable Development Goals. As an overall guiding principle, research integrity plays a role in the choice of research topics we spend our energy on.

6.3.4 PhD and Postdoc strategy

The dMT and PhD supervisors actively work together with the graduate school officers to ensure that average time for finishing a PhD thesis will continue to decrease until the Dutch standard of 4 years. In order to embed the PhD candidates in the fabric of the department, a PhD council has been initiated which will have a representative in the DC. The department will continue to integrate PhD projects in the department themes in order to bring PhD candidates in larger research teams.

Postdocs form an important category of researchers with which GSE achieves its research ambition. Currently Postdocs are not very well embedded in the fabric of the department. In recent years, a department Postdoc council has been installed, which will have a representative in the DC. The ambition of the department is to strengthen the position of the Postdocs by structurally developing options for them to develop toward their future career, for example by including them in teaching in the new MSc-programmes.

6.4 Information and data management

In the review period, we have seen an increasing awareness and prioritization of Open Science in the department. For the coming six years we aim to prioritize Open Science by explicitly including it in our department strategy. Goals have been defined which state that:

- We adhere to the TU Delft information and data management policies.
- We publish open science, open data and open source by default.
- We adopt FAIR data principles (Findable, Accessible, Interoperable, Reusable).
- Data management is coordinated at the level of the Department.

The department has hired a data manager in 2020, making the department the first and only one at TU Delft to have a dedicated research data management support beyond what is offered by the university, i.e. the faculty data-steward. Additionally, several members of the department have signed up to be 'Data Champions', one of the initiatives of the "Open Science Community Delft". Data champions are researchers with a self-identified interest in advocating for research data management, informing policy and participating in training relating to data management.

Research code and software is generated and maintained by many members of the department, but there is a general lack of awareness of the best practices for publishing and sharing the software in a FAIR manner. Over the coming six years, we will increase awareness and compliance with best practices for publishing FAIR code and software, as addressed in the new departmental strategy and in the newly released Research Software Policy and Guidelines from the university (released late March, 2021). Education related to research software management was already begun in the research data management training offered for department PhD candidates in 2020. Feedback from the course indicated that there was great interest in learning more about how to maintain and share research code.

6.5 Project and financial management

The research of the department depends on a steady project income from 2nd and 3rd funding sources. Besides focusing on acquiring projects, it is just as important to ensure that projects are run within their budget. The increased diversity of funding sources makes this more complicated. Together with faculty contract managers and financial administration we will develop procedures to safeguard our projects from going over budget.

An important aspect is administrating the cost accountability of our laboratory and field work activities. This is especially demanding, because the accounting rules we need to adhere to for the different funding organizations are varying widely. With our large-scale infrastructure projects such as the EU GeoLab we need to develop ways of accounting costs so that external partners can use our facilities as well and still declare costs with the EU.

Many funding organizations allow for budgeting investments which are strategic to the laboratory. In these cases, the department has to provide significant co-funding. A lab-user committee works closely together to identify investment priorities across the whole laboratory so we can optimize our co-funding related to the different funding schemes.

The administrative system in a university is complex because of the necessity to comply with many different rules. We will work on developing a hybrid (live and online) training for academic staff on how the administrative system works and what requirements need to be met for the different types of projects. The aim is to increase the autonomy of academic staff to make investment choices for their own research ambitions. Another important goal of this training is to ensure that projects are managed on time and within budget to prevent project overruns.

Summary

The department GSE focuses on surface and sub-surface science and engineering technology for energy, mineral geo-resources, fluvial and shallow marine sediment dynamics, underground construction, soil structure interaction and geotechnical aspects of surface infrastructure. Societal challenges are posed by the energy transition, the urbanization of low-lying deltas, etc. We address these in interdisciplinary research themes: (1) Energy Transition, with sub-themes Geothermal Science and Engineering, Subsurface Storage, and Geo-research for Offshore Renewables, and (2) Consequences of Underground Engineering (theme under construction). These themes build on the different geoscience and engineering disciplines, which are developed in the five research sections Reservoir Engineering, Geo-Engineering, Applied Geology, Applied Geophysics & Petrophysics, and Resource Engineering. The research is supported by experimentation in the Geoscience and Engineering Laboratory (including fieldwork infrastructure).

The interdisciplinary themes have been set up during the review period and are at different stages of development. The most matured theme (Geothermal Science and Engineering) is discussed as a case study in Appendix A.

During the review period, the research of GSE has led to a significant scientific output of 871 journal papers (a growth of 51% w.r.t. the previous period) and 108 PhD dissertations (a growth of 56%). Many staff members and PhD candidates have received international prizes for their research. Successful research worked as a seed for acquiring prestigious grants (one ERC-AdG, three NWO-Vidi grants, two NWO-Veni grants, two Delft Technology Fellowships, one Marie Curie Fellowship).

Open science. The department has made a serious effort to make its research results accessible to the scientific community and the general public. The percentage of journal papers with open access increased from 49% in 2017 to 77% in 2020. Over the whole period, 588 of the 871 papers (68%) were published open access. The facilities and data of EPOS-NL and GEOLAB are made available for other researchers.

PhD policy and training. PhD candidates take part in the Faculty Graduate School. They get assigned two supervisors and their research is monitored in yearly progress meetings. Averaged over the review period, 61% of the PhD candidates finished their thesis in less than 5 years, which is significantly higher than the averages of approximately 40% for Delft University and 39% for the Netherlands.

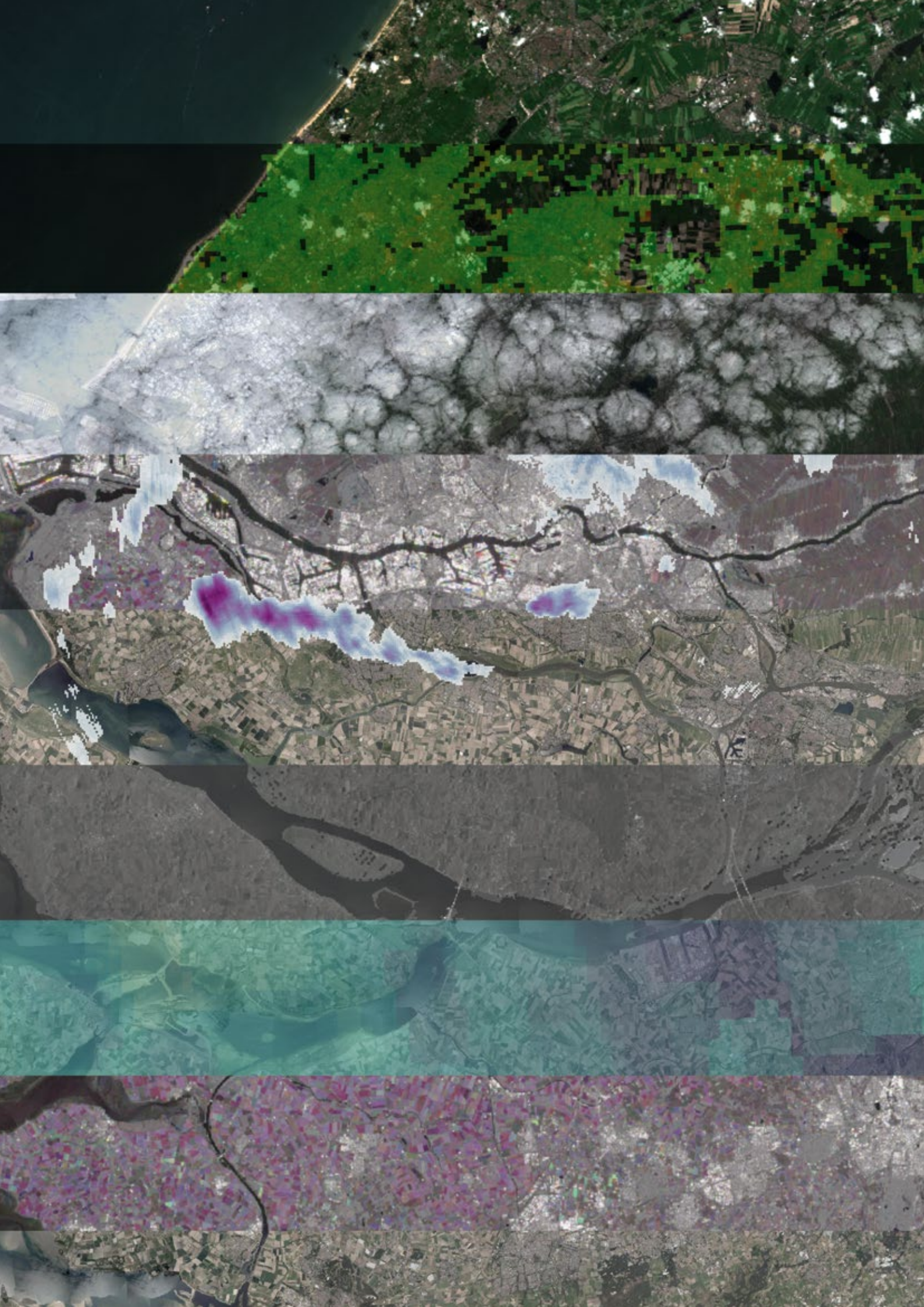
Academic culture. Department-wide discussions have been held on a range of aspects related to academic culture. In particular, ethical dilemmas related to working with the hydrocarbon industry have been discussed in the light of the Netherlands code of conduct for research integrity. The main outcomes of these discussions have been integrated into our strategy for the coming 6 years.

Human resources policy. The department is moving towards implementing the ideas formulated in the TU Delft perspective on the recognition and rewards of academics. The interdisciplinary themes are led by the rising stars of our mid-career staff, who get the responsibility and freedom to run these themes. Our efforts for attracting more female staff led to an increase from 5% female staff in 2015 to 21% in 2020.

Strategic goals for next six years

- Further development of the interdisciplinary themes.
- Installation of a department council.
- Improving of academic culture, social cohesion and integrity.
- Continue on improving our PhD-strategy.
- Prioritizing Open Science.
- Improving project and financial management.

Part 2
Department of Geoscience and Remote Sensing



1. Introduction

The Department of Geoscience and Remote Sensing (GRS) was established in January 2013, with the aim of merging research groups studying the Earth system. A part of the Department of Earth Observation and Space Systems (Faculty of Aerospace Engineering), the Remote Sensing of the Environment section (Faculty of Electrical Engineering, Mathematics and Computer Science) and the Clouds, Climate and Air Quality group from (Faculty of Applied Sciences) were united to form the new GRS Department within the Faculty of Civil Engineering and Geosciences.

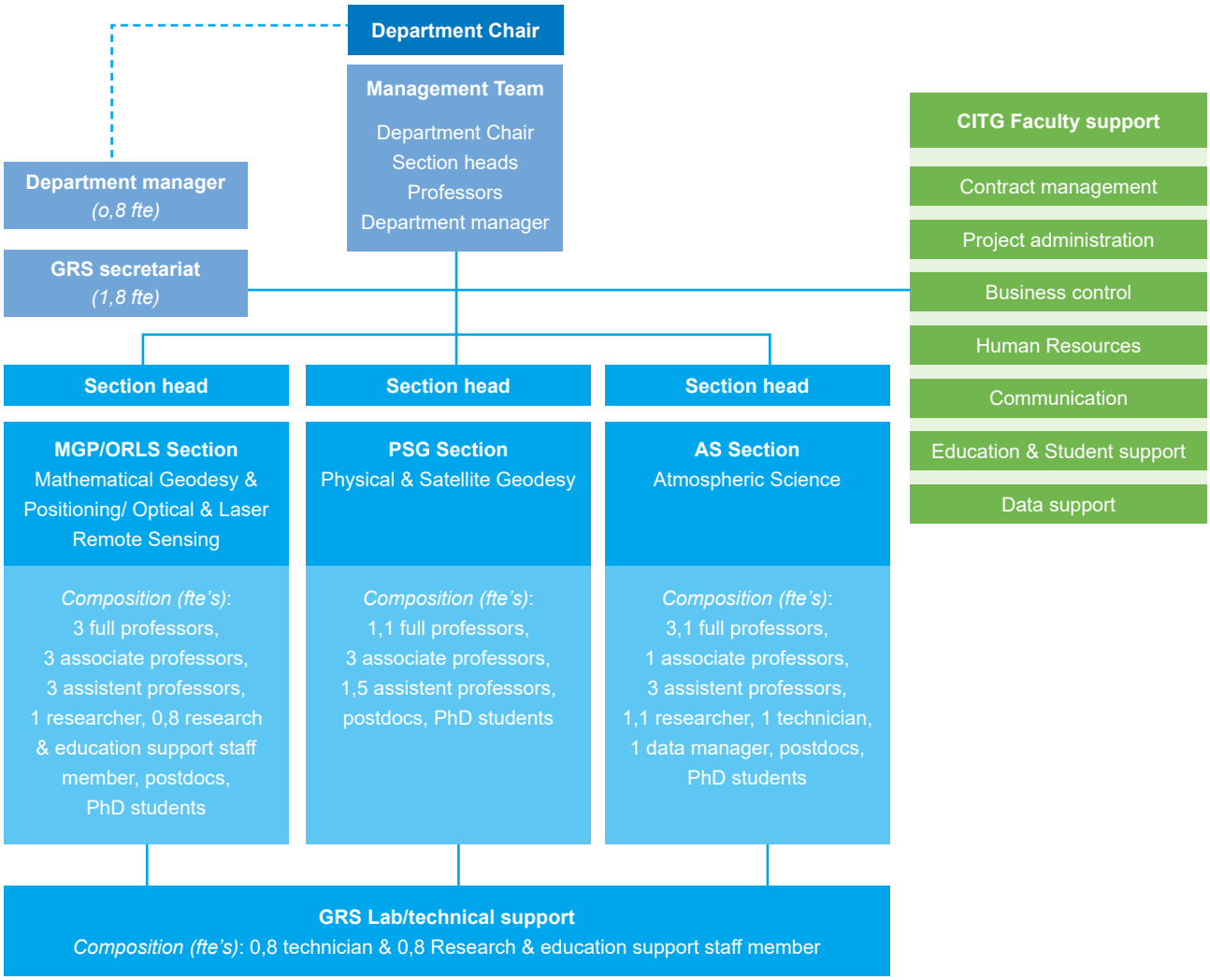


Figure 1: Department of Geoscience and Remote Sensing organization

This young Department has evolved considerably between 2015 and 2020, growing in terms of staff numbers, solidifying its financial foundation, and integrating a diverse range of research interests and priorities to form a cohesive Department. The current composition of the Department, and their research interests are listed in Table F1a. The scientific staff on 31st December 2020 comprised 6.4fte full professors, 5.2fte Associate professors and 11.4fte Assistant professors. This represents an increase from 16.5fte to 23.0fte from 1-1-2015 to 31-12-2020 (Table I1). From 2015 to 2020, the recruitment of several new tenure track assistant and associate professors has achieved a mix of experienced tenured and non-tenured staff with excellent academic records, and filled vacancies in geophysical geodesy, remote sensing of the environment, and atmospheric sciences. This has also created a more diverse Department in terms of gender, background and career stage (Appendix F & Table I4).

The influx of new academic staff has played a key part in shaping the identity and key research themes of the Department. Research is now organized around four core themes, namely Atmosphere, Earth System Science, Geodesy and Remote Sensing. Staff generally contribute to more than one research theme, creating a highly connected Department and a stimulating academic environment.

As GRS is part of a university of technology, our research tends to be motivated by applications, but fundamental in nature. It provides the basis for our collaboration with a wide range of external partners. In our collaborative projects, the more fundamental research is performed at GRS by staff, PhD students and post-doctoral scientists, while the pragmatic embedding of this research in real applications is performed in collaboration with external partners. Several members have part-time appointments at other institutes including KNMI, IMAU, NIOZ.

Comparable research themes are also pursued at Utrecht University, VU Amsterdam, Wageningen University, University of Groningen and Twente University. However, GRS' strong emphasis on observation methodology, parameter estimation, and data science combined with its application-oriented character ensures that our perspective is highly complementary to that of our neighbors. Our unique expertise allows us to lead and participate in large-scale, national projects such as Ruisdael Observatory for Atmospheric Sciences.

2. GRS Mission & Strategic Aims for 2015 –2020

2.1 Mission

In the period 2015-2020 the *Geoscience and Remote Sensing* program was given its current shape by integrating the two originally constituting sub-programs *Geodesy* and *Atmosphere.* Its mission is *'to understand the interaction between human activities, the Earth system and our living environment through the combination of observational data science and physical modelling'.* The GRS program provides fundamental knowledge for improving our society, as is also reflected in the motto of the CEG Faculty: *understand, intervene and improve*.

This mission implies crucial elements of the original mission statements of the individual programs:

1. to advance technology and knowledge for monitoring and modelling the Earth and the living environment in space and time,
2. to perform cutting edge research and development aiming at local and regional scales.
3. to develop associated applications in science and society using opportunities offered by new observational platforms and sensors
4. to contribute to top-level MSc and PhD education.

To make the sum more than its parts we have defined four themes: Atmosphere, Earth System Science, Remote Sensing and Geodesy. These themes serve to structure and foster collaboration, and to enhance our visibility, thereby addressing a recommendation of the 2008-2014 assessment committee to improve our communication strategy. The thematic representation makes clear that we are both working on new observation and data science methodologies and physical modelling. Our activities in these research themes are concentrated on:

Atmosphere: Modelling and simulation with the focus on high-resolution simulation of thermodynamic processes, wind, turbulence, clouds, rainfall and radiation. New methodologies to measure atmospheric parameters, from space or ground.

Earth System Science: Understanding and modelling of past, ongoing and future sea level changes, the contribution from ice sheets, and the impacts of ice sheet change on the climate system through advanced analysis of in-situ and remote sensing data and Earth System Modelling.

Remote Sensing: The development and exploitation of remote sensing techniques to detect and understand changes in the Earth's system. The focus lies on the development of tailored methods for changes in the solid earth, cryosphere, hydrosphere, biosphere, and the built environment.

Geodesy: The development and exploitation of geodetic techniques for society. The activities range from pure theory and methodology to the development of data retrieval algorithms, real data processing, quality control and interpretation.

Both Geodesy and Remote Sensing contribute to and are inspired by the development of new satellite missions, which provide new data with higher accuracy and space-time resolution. Activities common to all themes are direct numerical simulations, regional modelling, and developing conceptual models, signal processing, the development of retrieval algorithms, sensor synergy and data fusion, calibration and validation. We cover the complete chain from model and sensor development to information products. In addition to the Earth System, GRS research spans the CEG domains of Natural Resources, Water and Infrastructure. With our research, we aim to contribute to solutions for the societal challenges highlighted in the CEG strategy particularly Climate Change, the Energy Transition, Urbanization and Mobility.

2.2 Strategic aims for 2015-2020

Our strategic aims are defined at a department, rather than section level to pursue our mission, meeting our collective ambition to deliver high-quality research and education, and benefit society. This requires excellent people (HR policy, PhD Policy and Training), sufficient resources (financial viability) and an effective organization (Connectivity and Cohesion, Governance and Organization). Ensuring that research results translate to societal impact requires increasing awareness of our expertise and research (visibility). Our strategic aims fully reflect the policy and ambitions of the Faculty CEG.

2.2.1 Connectivity & Cohesion

The Department was formed by merging several research groups from three different faculties. While all of these groups studied the Earth system, the range of research interest and expertise was wide, and the natural interface was often limited. GRS identified the need to have a clear and balanced research portfolio and a clear profile for prospective students, employees and stakeholders. Therefore, a core aim has been to increase connectivity and cohesion to ensure that GRS could grow from being the sum of its constituent groups to a single department with a strong identity and mission, with national and international visibility.

2.2.2 Personnel strategy

The goal of the personnel strategy for 2015 – 2020 was to consolidate the research program by filling vacancies with highly-qualified and ambitious researchers. The specific aims were to:

- Attract and appoint new faculty members with excellent academic records, and a balance of scientific quality, teaching, valorization and organization.
- Address gender diversity by using existing programs like Delft Technology Fellowship and structural funding to attract highly qualified female faculty.
- Establish strong connections with external partners (e.g., KNMI) via part-time positions.
- Consolidate the research program by filling vacancies in existing research domains and expand complementary expertise in emerging fields such as big data analytics.
- Strengthen our research program by making GRS attractive to excellent PhD candidates and post-doctoral candidates.

2.2.3 Financial viability

GRS aimed to establish a healthy financial basis for the recruitment of high-quality scientific staff and to support the operation and maintenance of research infrastructure. GRS aimed to secure its financial foundation by diversifying its funding portfolio to include a balance of direct university funding, competitive research grants and contract research.

2.2.4 PhD policy & training

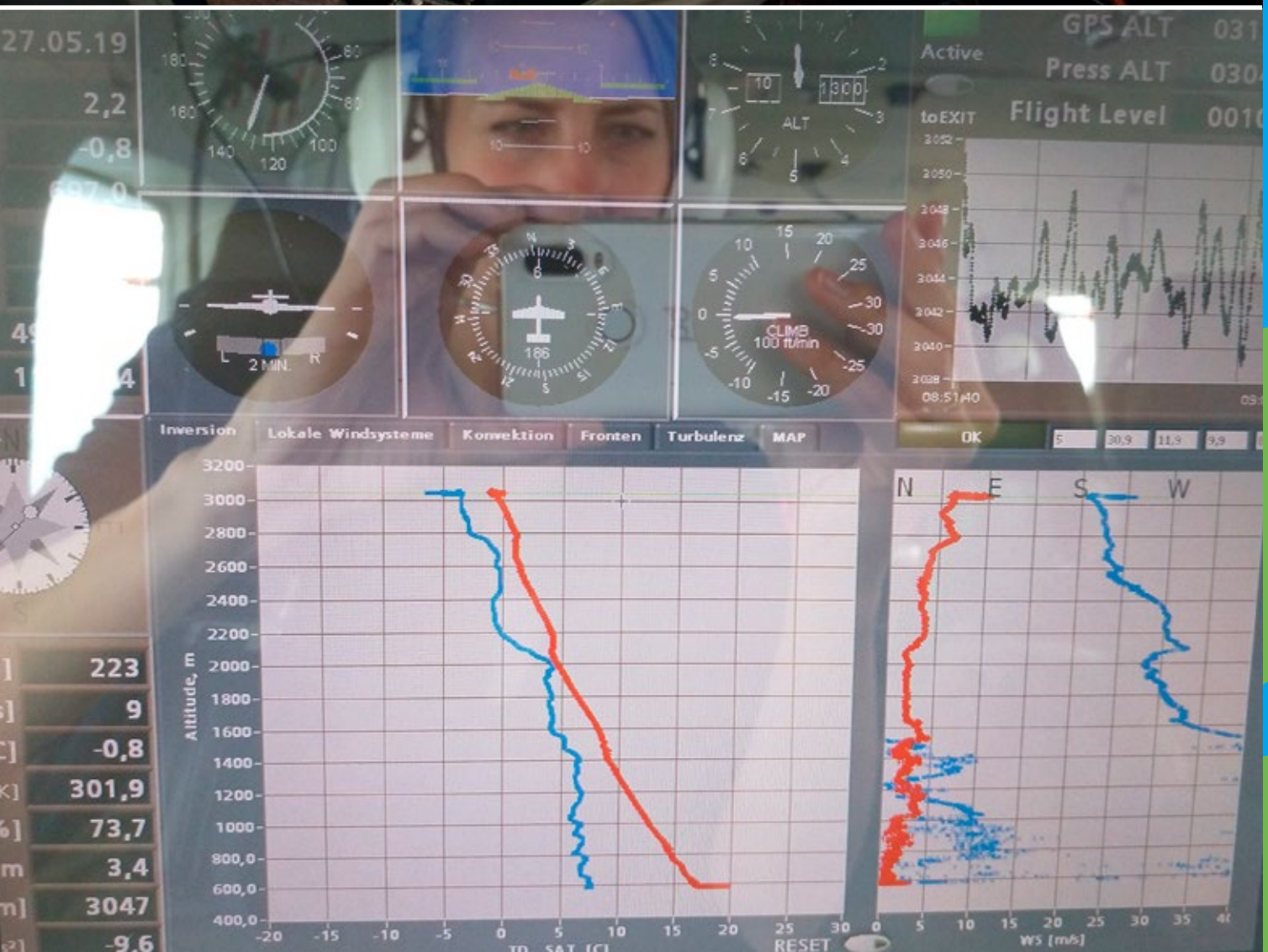
Our research quality is closely related to our ability to attract capable PhD students, and to provide them with the training and support needed to conduct high-level research. During the last assessment, it was noted that the number of PhD students per staff member was relatively low, and that the duration of PhD studies often exceeded the nominal four years. We aimed to identify and create the pre-conditions necessary to ensure that all PhD students can complete the doctoral education program within four years.

2.2.5 Visibility

GRS aimed to raise the visibility of our research results and staff expertise to research and industry stakeholders as well as the general public. We aimed to develop a more systematic approach to outreach. We lead the TU Delft Climate Institute, and participate in the university's Space Institute and Institute for AgroTechnology, opening up structural pathways to knowledge dissemination.

2.2.6 Governance & Organization

GRS aims to ensure that the organizational structure and decision-making process adapts to the changing composition, the growth and diversification of the department, and to the rise of a new generation of mid-career faculty which will gradually have increased organizational responsibilities, as was also recommended by the mid-term evaluation committee. These renewed structure and processes should facilitate the community, communication, shared goals and trust within GRS.


27.05.19
2,2
-0,8
223
9
-0,8
301,9
73,7
3,4
3047
-9,6
Active
GPS ALT
Press ALT
Flight Level
toEXIT
08:51:40
OK
Inversion
Lokale Windsysteme
Konvektion
Fronten
Turbulenz
MAP
Altitude, m
RESET
WS [m/s]
N
E
S
W

3. The GRS Strategy for 2015 – 2020

3.1 About the process

The GRS strategy 2015-2020 was not cast in stone in 2015 but evolved in response to the Research Assessment (2008-2014), the mid-term assessment in 2018, the outcomes of the university employee monitor, faculty strategy meetings and discussions within the Department at our regular plenary staff meeting and MT meeting. Working groups are set up to address the strategic aims, and to make recommendations that are discussed in the plenary staff meeting and acted on by the Management Team and Department Chair. The case study on PhD Policy includes details on how this process works in practice.

3.2 Addressing our strategic aims

3.2.1 Connectivity & Cohesion

GRS has engaged in a process to increase connectivity and cohesion to ensure that the department could evolve from being the sum of its constituent groups to a single department with a strong identity and mission, with national and international visibility. A key part of this process has been the recruitment and appointment of **new academic staff**. In particular, the choice to hire several staff in a relatively open call in 2016 provided a chance to address gaps in geodesy and atmospheric science, but also an opportunity to strengthen connections within the Department and expand expertise in emerging research directions. In total, ten new academic staff joined GRS between 2015 and 2018, contributing to a more even balance of observation methods, modelling, and applications and increased connectivity. This has allowed GRS to evolve from a combination of Atmospheric Science and Geodesy to a department that is increasingly interconnected by shared methodologies (e.g., machine learning, observation techniques) and physical processes (e.g., clouds and precipitation) or systems of interest (e.g., ice sheets).

This influx of new staff and their impact on the research portfolio stimulated a series of department-wide discussions about the mission, identity, and research profile of the Department. These discussions resulted in the definition of the four research themes: Atmospheric Science, Geodesy, Remote Sensing and Earth System Science. Staff generally contribute to more than one research theme, creating a highly inter-connected Department and a stimulating academic environment. This thematic organization brings modelers and observation experts together, facilitates organic collaboration and has resulted in the formation of informal clusters where staff meet to share knowledge on specific topics (e.g., Cryosphere, AI and (In)SAR, Mesoscale Organization). In addition, it also facilitates stronger cooperation with other departments in the Faculty.

3.2.2 Personnel Strategy

Following the lessons learned from the benchmark at MIT in the previous assessment, GRS adopted a strategy to search primarily for excellent candidates in key fields, irrespective of niche or level (assistant/associate/full professor). Appendix F provides a list of the scientists who joined GRS in the last six years. The recruitment of these new staff has achieved the desired mix of tenured and tenure-track staff with excellent academic records and high scientific potential. The diversity of expertise allowed for the consolidation of both the geodesy and atmospheric science research programmes and introduced complementary expertise in AI and remote sensing.

GRS has been successful in attracting high-qualified and ambitious female academic staff. Louise Nuijens from the Max-Planck Institute for Meteorology joined GRS as an assistant professor in 2016.

Her position was created using additional strategic funding in the TUD-KNMI collaboration program with a view to developing fundamental understanding of cloud and wind processes for improving weather and climate models. In 2020, Franziska Glassmeier joined GRS as an assistant professor. She was appointed using additional structural (Van Rijn) funding to strengthen our education capacity in atmospheric sciences.

GRS made several part-time appointments to strengthen ties with key partners. Bert Vermeersen, Bert Wouters, Pier Siebesma and Wouter van der Wal are also affiliated with key partners such NIOZ, IMAU, KNMI, and the Faculty of Aerospace Engineering. George Biskos has a joint affiliation with GRS and the Cyprus Institute. These appointments have allowed us to establish long-term close ties to leading research institutes, creating excellent opportunities for MSc. and PhD research, and a clear route to ensure that our scientific research translates to societal impact.

3.2.3 Financial viability

Our aim was to establish a healthy financial basis by diversifying our funding portfolio, and in particular to reduce our dependence on direct university funding (first money stream). Table I.3 shows that direct funding stayed relatively stable during the period 2015-2020. However, GRS achieved an increase in total funding from around €5M to €8M through increased income from research grants, contract research and other sources. This has been achieved by strengthening and extending our network, setting the research agenda, increasing our visibility and seeking out funding opportunities that closely align with our mission.

We **strengthened our collaborations with existing partners and extended our network** to include new partners, particularly those with the potential to transfer our research products to applications. Table J.21 provides an overview of our key national and international partners from industry, governmental agencies and research institutes. Working closely with these partners has been central to our success in securing funding through a wide and well-balanced range of sources.

We have taken an active role in **setting the research agenda** of national and international funding agencies by initiating ideas for new programs (e.g Ruisdael Observatory for atmospheric sciences (See Case Study H5: Ruisdael Observatory in Appendix H), participating in relevant committees (e.g. the national infrastructure roadmap committee for Geosciences, the strategic advisory panel for Earth Observation, the Earth Science Round Table and actively engaging with the relevant ministries and agencies. Examples are the Regio Deal and Deep-NL program and the gravity monitoring program for Rijkswaterstaat. We have initiated the discussion for setting up a national program for climate engineering, which will materialize in 2022.

We have actively pursued a wide range of funding including contract research, and competitive funding from national (NWO) and EU (ERC and H2020) programmes. At NWO, we have targeted programmes aligned with our mission and research themes, particularly the Satellite User Support program, the NWO ENW program, opportunities within the National Science Agenda (NWA), and the NWO TTW Open Technology Program.

3.2.4 PhD Policy and Training

To reach our aim of identifying and creating the pre-conditions necessary to ensure all PhD students can complete the doctoral education program within 4 years GRS has made strides in (1) making GRS attractive to prospective PhD students (2) improving our recruitment process to select talented PhD candidates and (3) PhD training and supervision.

Ad-1) One of the drivers to improve our outreach, online presence and visibility was to attract highly qualified PhD candidates. We use social media and other channels (e.g. Stories of Science) to promote the research activities and successes of our PhD students. In addition, we have invested in scouting among our own talented MSc. students, and soliciting applications via our collaborative networks. This has increased the number of applications for PhD positions, and the number of excellent candidates from TU Delft and other leading universities.

Ad-2) The introduction of the TU Delft Graduate School, and the support provided by the Faculty Graduate school has ensured a more systematic recruitment process. It has ensured that external candidates (with secondary appointments, or scholarships) are subject to the same admission criteria as those hired as TU Delft employees. Clearer and more stringent guidelines have been set regarding English language scores. Validation and evaluation of transcripts and qualifications from international candidates has also been improved. This more systematic and rigorous process has made it easier to identify suitably qualified applicants for PhD positions. At GRS, the selection process has also been improved through the inclusion of additional staff in the recruitment process and interview stage.

Ad-3) During the previous assessment, one of the main concerns was that the duration of PhD studies often exceeded the nominal four years. This has been one of our main priorities in the past six years, and a working group was established to address PhD training and supervision. The process and the outcomes are described in Case Study H1 in Appendix H, and the recommendations have already been implemented in the Department.

3.2.5 Visibility

GRS has a strong reputation and is highly visible in the scientific community. Many staff are editors or members of the editorial boards of leading journals (Table J.8), active in professional organizations and involved in the organization of international conferences (Table J.9a). GRS staff are actively involved in leading community bodies and fora (a.o., Earth Observation Strategic Plan Netherlands Space Office, International Association of Cryospheric Sciences, IUGG, International Association of Geodesy) and assessment activities (a.o., IPCC, AMAP, IMBIE, BAMS State of the Climate), both as regular members and in leadership roles (Table J.9). Our aim in the last six years has been to extend this visibility to industry stakeholders, policy makers and the public through systematic outreach and communication.

The GRS website was redesigned following the formulation of our department mission and the definition of our four research themes. It provides an accessible and coherent overview of the research activities and staff expertise at GRS. We use “Stories of Science” to promote our research within CiTG and the wider TU Delft community (Table J.16). These narratives are highlighted on our website to promote the expertise within our department to new stakeholders, and to provide insight for non-expert users on the value of our research to address societal challenges.

To extend this visibility to industry stakeholders, policy makers and the public, we have established close ties to TU Delft Communication and the TU Delft Institutes for Climate, Space and AgroTech. This allowed us to increase our presence in both traditional and social media as staff are called on to participate in public debate and provide insights on topics of national and international interest (e.g., sustainability or climate change) (Table J.12, Table J.13). GRS staff have appeared on Dutch and international news, talk shows, children’s television, and documentaries (Table J.14). GRS increasingly uses twitter to disseminate research results and engage with mainstream media and the public. Case Study H4 on Antarctica (Appendix H) highlights the value of outreach and communication in achieving impact, stimulating new collaboration, and facilitating excellent research. The extent of media coverage also highlights the increasing public interest in GRS research topics.

3.2.6 Governance & Organization

The university has implemented a new policy for internal promotion to full professor. It is expected that in the coming period mid-career GRS staff members will be promoted to full professor, and that the total number of full professors in the department will increase. Furthermore, in the period 2021-2026 several full professors, who are now in a leading position, will retire. Against this backdrop, a working group was created to review the current governance and the department structure. Interviews with faculty of other departments were carried out to explore organizational models ranging from our current hybrid ‘section-with-PI’s’ model to a flat PI-model. In addition, a dialogue within the department was initiated on how to identify and improve the GRS governance and organizational model and to discuss the way forward. In this transitional period with mid-career staff accepting more organizational responsibilites, one finding is a desire for a stronger involvement in the decision making process. Suggestions include redefining the role of the staff and the MT in the decision making process, and improving communication. Potential changes in the department structure are under discussion and decisions will be made during the next period.

4. Performance Indicators

An overview of the selected performance indicators is provided in Appendix G including details on where the evidence can be located in the Appendices. Here, we explain our choice of performance indicators in terms of how they relate to the GRS mission and strategic aims and how they will be used as evidence of our accomplishments in Chapter 5.

4.1 Research Quality

4.1.1 Research products for peers

(Open Access) Peer-reviewed journal articles are our most valued research product for peers. Chapter 5 provides a narrative description of our research accomplishments, including references to selected key publications listed in Appendix L. These key publications are highlighted to demonstrate that we have been achieving our mission to deliver cutting edge science, and that we have been successful in targeting the top, reputable journals in our fields of expertise, and major interdisciplinary journals (e.g., Nature, Science). Peer-reviewed conference papers and PhD dissertations (Figure J.1) reflect our productivity. Publication of seminal books (Table J.1) highlights the value of GRS expertise within our research fields. Open access publication of datasets (Table J.3) and software (Table J.4) increases visibility, collaboration, and facilitates societal impact. We make substantial contributions to the design and development of widely used models, and satellite missions (Table J.5). These research products highlight the direct contribution of GRS expertise in observational science and physical modeling to our mission of advancing our ability to monitor and model the Earth and the living environment.

4.1.2 Use of our research products by peers

One of the most important indicators of the impact of our research in the scientific community is the number of citations of our peer-reviewed publications. This is illustrated by the number of citations of the key publications included in Appendix L. In addition, where available, the download/usage statistics of datasets (Table J.4), software and infrastructure (Table J.5) are provided. Finally, Chapter 5 includes examples of how we contribute our models and datasets to the scientific community in large-scale and inter-comparison projects like the Ice sheet Mass Balance Inter-comparison Exercise (IMBIE).

4.1.3 Marks of recognition from peers

GRS scientific staff have been successful in acquiring prestigious personal grants from national (NWO Talent Programme) and European programmes (ERC) (Table J.6). Research quality and reputation are demonstrated by our participation in, and leadership of, large national and international collaborative research projects (Table J.7). Success in terms of funding acquisition is central to our strategic aim to establish a healthy financial basis. GRS staff have editorial roles in leading journals (Table J.8), and are active in key national and international scientific organizations, often in leadership roles (Table J.9). GRS staff are members of Mission Advisory Groups and Science Teams of several ESA satellite missions (Table J.9b). We contribute to, and chair, several working groups, study groups and committees of leading scientific organizations and have contributed to the IPCC reports (Table J.9). In addition to demonstrating our strong reputation, these activities are central to our strategic aim to improve our visibility. GRS staff have been awarded several individual and team scientific awards (Table J.10). Several GRS staff have secondary appointments at leading research institutes (Table J.11).

4.2 Societal Relevance

As discussed in Chapter 2, we aim to contribute to solutions for the challenges posed to our society: the consequences of climate change and urbanization, the energy transition, water safety, reliable and sustainable transport and safe infrastructures. These are topics of considerable interest to the general public. Inkeeping with the CEG philosophy, our expertise is also essential for companies, government agencies and institutions who aim to *understand, intervene and improve* in the context of these challenges.

4.2.1 Research products for societal target groups

Our greatest societal impact comes through educating future engineers. Graduates from our GRS MSc Track are employed across the public (e.g., Rijkswaterstaat, ministries, local authorities, water boards, ESA, KNMI, Deltares, NLR, TNO, NSO, GFZ) and private sectors (e.g., Fugro, Arcadis, Sweco, Vandersat, CGI, Terradrone, Shell, SkyGeo, Boskalis, van Oord, McKinsey).

As well as performing research related to the societal challenges listed above, we have a responsibility to participate in public debate, inform the public and provide scientific knowledge to stakeholders. At GRS, this is achieved by providing public lectures for a general audience (Table J.12), contributing to films and documentaries for a wide audience (Table J.13) and by disseminating our research outcomes to the wider public through traditional and social media (Table J.14 & J.15). Case Study H4: Antarctica (Appendix H) demonstrates the power of effective communication to enhance research quality and societal impact. Finally, our research has generated several patents (Table J.17).

4.2.2 Use of research products by societal target groups

To improve financial viability, we strengthened our collaborations with existing partners and extended our network. In Chapter 5, it will be shown that we work closely with many companies, government agencies and other societal target groups to ensure the direct use of research products by societal target groups in the form of collaborative research projects (Table J.6, J.7) and contract research (Table J.7B5). Case study H2: New on- and off-shore vertical reference surfaces for The Netherlands illustrates how these close ties translate to high scientific quality, substantial societal impact and benefit financial viability.

4.2.3 Marks of recognition by societal target groups

The strength of our connection to industry is reflected in the degree of financial and material support provided by companies in research projects (Table J.6, J.7). This forms an important part of our diverse funding base and highlights the value of our research to societal partners. GRS staff provide expert advice in matters of national importance (Table J.19).

5. Accomplishments 2015-2020

Here we describe the results we have achieved in the past six years per research theme, emphasizing research quality and societal relevance. This is followed by a reflection on how effective our department strategy has been in terms of achieving scientific quality and societal impact and the influence our PhD policy and training, HR policy, and approach to academic culture and open science have had on our ability to achieve our goals. The selected key publications (KP) can be found in Appendix L.

5.1 Geodesy

Very precise and reliable Positioning, Navigation, Timing and Atmospheric Sensing (PNTA) applications rely on the use of **Global Navigation Satellite Systems** (GNSS) – GPS (USA), Glonass (Russia), Galileo (EU) and BeiDou (China). We have developed a **unifying framework for all existing PPP-RTK** (Precise Point Positioning – Real Time Kinematic) methods, together with the introduction of a novel PPP-RTK transformation rule, to deliver the interoperability of correction products (orbits, clocks, code and phase biases) from different service providers. Using S-system theory, the estimability-deficiencies of multi-GNSS PPP-RTK models were analytically described, allowing us to identify pitfalls in some of the current operations (KP1, KP2).

We are founder and global leader of the geodetic **theory of mixed-integer estimation**, a unified theory that underpins ultraprecise GNSS parameter estimation and validation (KP3). The utility of the theory is evidenced by its widespread uptake (GNSS, InSAR, RIPS, VLBI, X-ray Pulsar), while several of its methods have become a household name (e.g., LAMBDA, Z-decorrelation, ADOP). Until now, seamless integer ambiguity-resolved GLONASS parameter estimation was not possible due to the Frequency Division Multiple Access (FDMA) method used. We developed a **new GLONASS FDMA model** using a canonical integer matrix decomposition, allowing the identification of easy-to-compute unbiased integer-estimable functions in rank-defect mixed-integer models (KP4, KP5).

GNSS is increasingly used for integrity-critical applications (i.e., where fault tolerances are very low) such as in autonomous systems. A new integrity estimator, with distributional theory, was developed for the **Detection, Identification and Adaptation** of multivariate GNSS threats. It rigorously combines the intrinsic uncertainties of parameter estimation and hypothesis testing (KP6, KP7).

Our work on **PNTA systems** focused on modelling and integrating upcoming satellite systems, enabling low-cost sensory inference and developing an innovative terrestrial PNT system. Crucial for integrating different GNSSs is the proper modelling of their inter-system biases. We developed such models for the different systems, and introduced an innovative **multi-GNSS** network calibration method (KP8). We discovered the mixed-receiver BeiDou Inter Satellite Bias, a critical insight that prompted awareness from the global receiver industry and adoption of our solution.

We developed **high precision interferometric GNSS** with low-cost receivers by means of advanced signal modelling combined with targeted algorithmic design and antenna calibration. We demonstrated its feasibility for a range of different PNT and amospheric sensing applications (KP9). We conceived and developed a terrestrial PNT prototype system, **SuperGPS**, with atomic time reference distributed to base stations through a fibre-optic network. It was experimentally demonstrated that the anticipated 1-dm positioning accuracy by a receiver in a multipath urban environment can be achieved using wireless wideband signals transmitted by the base stations. The scalability and compatibility with existing mobile communication technology pave the way for GNSS-independent back-up systems for timing and positioning, as well as complements to GNSS with improved coverage and performance (KP10) (See Figure 2).

The GNSS group at GRS is world-renowned. The research magazine of "The Australian" named Prof. Teunissen as a top researcher in the fields of geophysics and radar positioning and navigation. He is also included in the Stanford University list of world's top 2% scientists.

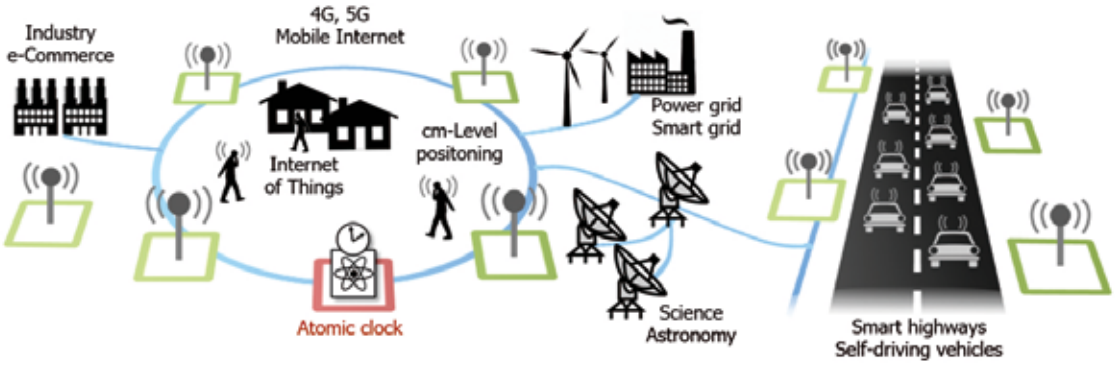


Figure 2: SuperGPS concept. The red square houses an atomic clock (national UTC traceable time scale in this case), blue lines represent fibre optic connections, and the green squares contain terrestrial wideband radio base stations.

Research on ***Vertical Reference Frames*** refers to the realization of surfaces to which heights and depths refer. Our activities focused on the operationalization of a previously-developed conceptual framework previously developed by Cornelis Slobbe to realize a set of vertical reference surfaces (land and sea). We developed a novel method to combine a satellite-only global geopotential model (GGM) with full noise covariance matrix with terrestrial and airborne datasets and provides a full noise covariance matrix of the computed quasi-geoid model. We showed that centimeter errors may be introduced by ignoring the random nature of the GGM (KP11-KP13) or ignoring colored noise in terrestrial datasets (KP14). More information about the scientific and societal impact of the research is provided in the Case Study H2: "New vertical reference surfaces for the Netherlands, the Netherlands Continental Shelf and the Wadden islands." We developed a model-based hydrodynamic levelling approach (KP15), and successfully established centimeter accurate connections of the Dutch Wadden islands with the Amsterdam Ordnance Datum (NAP). This paves the way for a new approach of regional to global height system unification by exploiting the fastly improving accuracy and skills of hydrodynamic models.

Research on ***Water Levels*** refers to the development of observation- and model-based retrievals of water levels of sea, lakes, rivers, and leads, and the study of processes which cause water level variations. We applied the Fully-Focused Synhetic Aperture Radar (FF-SAR) algorithm to Cryosat-2 full-bit-rate data to measure, for the first time ever, water level heights of lakes, canals, and ditches in the Netherlands (KP16). This paves the way to a broad range of new applications of satellite radar altimetry. Our activities related to the processing of Low-Resolution Mode (LRM) and SAR/FF-SAR altimeter data led to the development of the Delft Altimetry Retracking Toolbox (DART), which allows level 1A to level 2 processing for all types of radar altimeter data. DART is being used across several themes of the GRS research program.

GRS is a global leader in ***InSAR Geodesy,*** at the forefront of the scientific and methodological developments required to advance the geodetic applications of satellite radar interferometry (e.g. KP17). This enables InSAR to provide crucial information on critical infrastructure, such as levees, geodynamics, natural hazards, and the impact of human interaction with the Earth system (e.g. KP18). Research in InSAR geodesy at GRS includes fundamental research on InSAR estimation theory, structural health monitoring, early-warning detection of High-Impact/Low-Probability (HILP) events (e.g. KP19) and the development of methodologies to estimate land subsidence from peat soils and gas production (e.g. KP20). These results led to 50 scientific journal papers with 850 citations, and are discussed in detail in the Case study H3: InSAR Geodesy (Appendix H). There, details are provided on the societal challenges, the fundamental research conducted, the key innovations to which we have contributed, and the emerging challenges to be tackled in the coming years.

5.2 Earth System science

Our research on ***Sea Level Change*** is dedicated to the quantification and interpretation of regional variations in space and time, with a focus on the 20th and 21st centuries (see also Riva's Story of Science, Table J.16). Large efforts were devoted to understanding the causes of recent sea level change by studying sea level budgets, i.e., by separating observed sea level signals into the contributions of the main driving processes (continental freshwater fluxes, ocean volume changes, ocean dynamics, vertical land motion). As a result, we have demonstrated that it is possible to close the decadal budget over most of the North Atlantic as well as the secular budget over most of the global ocean (KP21,KP22). Particular attention has been devoted to producing improved estimates of the contribution of solid earth deformation to sea level change (KP23,KP24) and to mass changes of the Greenland and Antarctic ice sheets (KP25,KP26).

Efforts on sea level research have led to about 50 scientific journal papers including two papers in Nature (KP25, KP26) and two papers in PNAS (KP27,KP28). Those papers received more than ten citations in both the 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) and the 2021 IPCC Sixth Assessment Report (AR6). Highlights are the contribution to an analysis of the global sea level budget by the World Climate Research Programme (KP29), the co-organization of a benchmark about GIA modelling (KP30), the fact that our GIA models of Greenland and Antarctica were the only models including lateral variations in earth structures used in the Ice Sheet Mass Balance Inter-comparison Exercise (IMBIE) (KP25,KP26), and the use by NASA-JPL of our improved approach to determine geocentre motion as the new standard for GRACE products (KP31). We have also collaborated with the EU ERC project GlobalMass (PI: Bamber, U. Bristol).

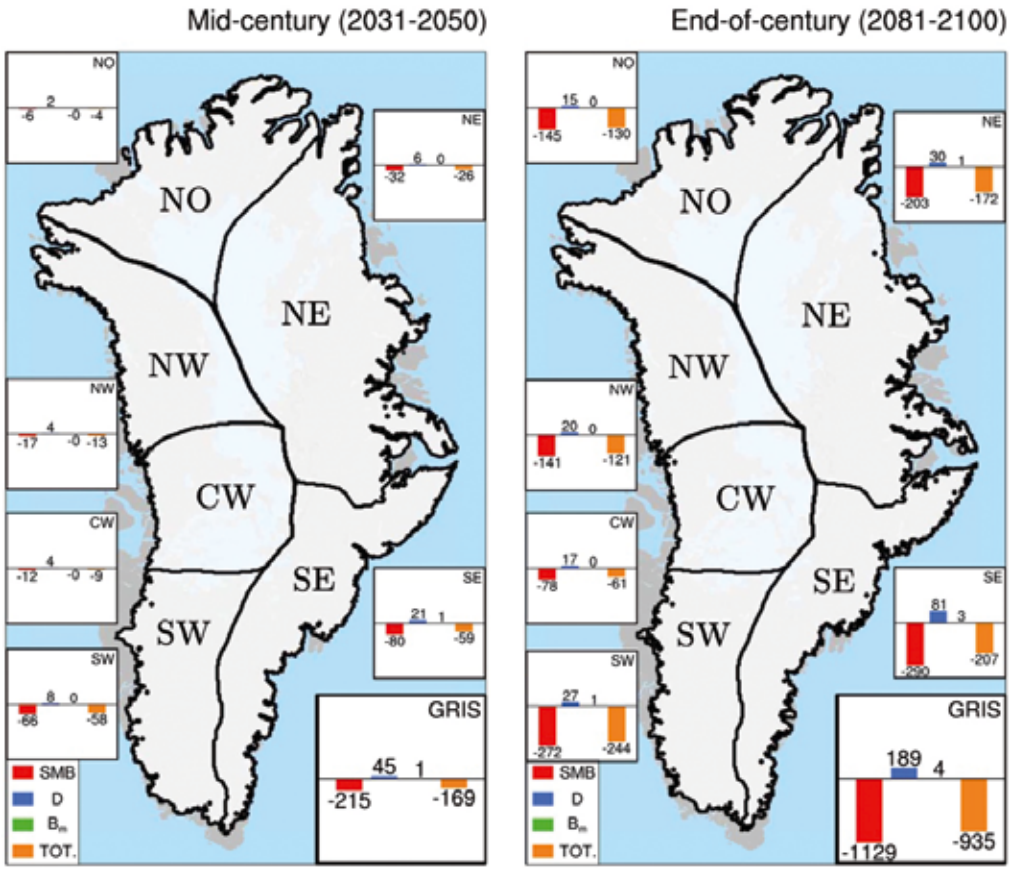


Figure 3: Projections of contribution of Greenland ice sheet (GRIS) basins to mid- and end-of-century sea level rise (TOT), in Gt/yr and contribution from surface mass balance (SMB), ice discharge (D, positive indicates projected decreases) and basal melt (Bm) change. 360 Gt are equivalent to 1 mm of sea level rise. Note the rising relative contribution of northern basins to the total mass loss. Figure from KP36.

Our research on ***Ice Sheet and Earth System Modelling*** contributed to the development, testing and evaluation of an interactive ice sheet component in CESM2 and is supported by the ERC Starting Grant and NWO grant of Miren Vizcaino. This interactive ice sheet component has been presented by the NCAR leadership as a major highlight of CESM2 e.g., see preface to the AGU Special Collection. We have published several studies with his model, in the areas of model description (KP32), evaluation (KP33) and scientific applications (e.g. KP34). These include the most advanced coupled ice-climate simulation of future multi-century Greenland Ice Sheet (GrIS) evolution (KP35). Five studies with CESM-CISM have been cited in IPCC AR6 WGI. One of those (KP36) has provided the only estimates in AR6 on 21st century GrIS contribution to sea level rise with a coupled ice sheet and Earth System Model of full complexity (WG1, Table 9.2). Besides our research on the GrIS, we have performed the first simulations of the Last Glacial Maximum including an advanced, high resolution melt calculation. Besides the publication impact of our work, we have exchanged expertise with several European modelling centers engaged in the emerging field of coupling of ice sheet and climate models, namely EC-Earth-PISM (PI: Mottram), UKESM-BICICLES and FAMOUS-Glimmer (PI: Smith, Gregory), MPI-PISM (PI: Mikolajewicz) and NorESM-CISM (PI: Goelzer).

In addition to studies with CESM2-CISM2 we published two studies with its predecessor CESM1 on the effect of GrIS melt on the ocean circulation and on the surface mass balance of Antarctica (KP37, KP38). We have also contributed to the ISMASS review paper on the mass balance of ice sheets and glaciers (KP39). Our simulations with the MPI-model (KP40) have been cited both in SROCC and AR6. In total, we have published 17 papers related to the sub-theme.

5.3 Remote Sensing

Our work on **future Earth System Observation radar missions** includes the development of novel observation concepts and retrieval approaches, and detailed mission performance analyses. Many of these activities are supported by the European Space Agency (Table J.7B2) and Dutch Space Office (Table J.7B3). The group has been deeply involved in ESA Earth Explorer programme, participating in the Phase-A of SKIM, and the Phase-0 of Hydroterra. A recent GRS highlight has been the selection of Harmony (with Paco Lopez-Dekker as PI) as the only mission to proceed to Phase A in the Earth Explorer 10 programme. Harmony (e.g. KP41) is envisaged as a mission comprising two companion radar-satellites flying in formation with one of the Copernicus Sentinel-1 satellites. The resulting geometric viewing diversity will be exploited to retrieve small scale surface motions and stress over solid-Earth, oceans and the cryosphere.

We have a strong focus on the use of **remote sensing for assessing land- atmosphere interactions** in order to determine the effect of climate (change) on the cryosphere, the hydrological cycle and, sea level rise (KP42,KP43) or ecosystem dynamics (KP44) etc. and their feedbacks on (future) climate. We employ opportunities at the intersection of remote sensing, land-surface models and land-atmosphere interactions to identify albedo feedbacks over ice sheets and ice shelves, to assess snow/firn properties, to assess key processes over ice shelves, to assess snow/cloud interactions, to determine vegetation response to climate anomalies.

Our research also addresses the technological and methodological challenges that come with the use and analysis of the rapidly expanding satellite data archives. Research focused on **the integration of big data and e-science approaches to analyze remote sensing**. Projects focused on the development of new data science approaches for the expanding satellite data archives including i) advanced image processing and machine learning, ii) optimized data handling and big data approaches (e.g., HiRise GeoForGood funded by Google) and iii) data assimilation.

Our research on **laser scanning** is focused on efficient extraction of geometric information from spatial point clouds (KP45), e.g., for the IQmulus project, from different platforms including satellite (ICESat-1 & 2, GEDI), airborne and ground-based sensors, including our own laser scanner. Research was focused on the information quality including the role of novel processing approaches including machine/deep learning

approaches, automated big data methods, novel geometric methods, time series analysis and change detection, like in the CoastScan project, (KP46) and the combination/fusion with other data sets like photogrammetry (KP47) for the NWO Maps4Society project U&Me4WaterMAps.

Our research on ***satellite gravimetry*** focused on methodological improvements of GRACE level 1B to 2 data retrieval algorithms to estimate parameters of the Earth's time-varying gravity field. Highlights are demonstrating the significance of modelling coloured noise in GRACE level-1B data on the quality of the monthly GRACE solutions (KP48). Since then, all GRACE analysis centers use similar schemes to model coloured noise in GRACE data. In our research into future satellite gravity missions the PhD research of Inacio (2020) showed that a specific combination of satellite formations provides a substantially higher performance if a properly chosen set of orbital planes is used. We also showed that the commonly used assumption of a spherical Earth when converting gravity field parameters into mass changes may introduce noticeable distortions of short-scale signals, and developed a new scheme which is free of these distortions (KP49). This scheme is now used by the GRACE analysis centers. Finally, we developed a methodology which for the first time ever allows to accurately assess the quality of monthly GRACE solutions provided by the various GRACE analysis centers at any geographic location. This scheme helps users of GRACE data products to choose the product which best fits their requirements depending on the geographic location.

Regarding ***Mass Change in the Hydrosphere*****,** we developed a method to assimilate GRACE-based mass anomaly estimates into hydrological models using an ensemble Kalman filter approach. The results highlighted the added value of GRACE data, particularly in data-sparse regions. Moreover, we have shown the importance of using full error variance–covariance matrices in GRACE data assimilation (KP50). The developed assimilation scheme was applied to assess the status of water resources over the Hexi Corridor region (China), including an estimation of the contribution of individual water storage compartments (groundwater, soil moisture, etc.) to the total water storage variations. Finally, we demonstrated that an analysis of mass anomalies even in a small hydrological basin, such as the Tonlé Sap basin (Southeast Asia), may substantially benefit from GRACE data, provided that the mass change signal is sufficiently large (KP51).

Our research on ***Mass Change in the Cryosphere*** encompasses all glaciated regions on our planet and relies on both satellite gravimetry and altimetry. In the PhD research of Ran (2017), we developed an approach to maximize the spatial resolution of the gravimetry data for mass change of the Greenland Ice Sheet (GrIS). We demonstrated that combination of the full error variance-covariance matrices of GRACE level-2 data and a proper spatial parameterization of mass changes may substantially improve the accuracy of the mass change estimates (e.g. KP52). For the Antarctic Ice Sheet (AIS), we developed a dynamic patch approach that combines climate model output with satellite gravity and altimetry data to simultaneously estimate Antarctic mass balance and present-day GIA (KP53). We also developed an approach to estimate time-variable rates from geodetic time series, using the state space model framework (e.g. KP54). Olga Didova received the IAG Young Author Award 2016 for this article in which she analyzed vertical deformations in GRACE and GPS time series, demonstrating that the methodology provides more reliable trend estimates compared to traditional methods, because it accounts for any long-term evolution in the time series and avoids any contamination from seasonal variability. Moreover, Didova's PhD research demonstrated the potential of GRACE for correcting GPS data for non-linear variations in elastic uplift and a better understanding of the limitations of GPS data as an explicit constraint to Antarctic GIA.

Our satellite gravity and altimetry data of the polar regions are frequently used by the community as validation of regional climate and Earth System models. Amongst other things, these studies showed that climate forcing from an Earth system model (CESM2) is able to reconstruct the historical GrIS surface mass balance (KP55). It provided essential validation data to GrSMBMIP, a community intercomparison effort of SMB models for Greenland, and revealed that individual models are affected by non-systematic regional biases. Besides validation, the resulting time series were combined with climate model output and other remote sensing data to gain process understanding of the physical drivers of the observed changes in joint analyses. This resulted in several publications in high-impact journals (Nature, PNAS, Review of Geophysics). Amongst others, our work quantified for the first time the evolution of meltwater

storage within the GrIS (KP56); it revealed that the current dynamic ice loss of the GrIS is driven by inland migration of the glaciers' calving fronts (KP57) we found that the increased ice discharge into the ocean makes mass gain of the ice sheet highly unlikely in the coming decades, even in years with high snowfall (KP58). We also participated in community efforts with international scientific and societal impact, such as the Ice Sheet Mass Balance Inter-comparison Exercise (KP25, KP26) and the Arctic Monitoring and Assessment Programme report (KP59). A study on global glacier mass loss led by TUD (KP60) used a new method to combine different GRACE products and presented the first estimates of global annual glacier mass balance. With more than 30 mentions, this work provided key input to the recent IPCC AR6 and SROCC reports and was also presented at the recent COP26 meeting.

5.4 Atmosphere

Over the last six years the atmosphere section has expanded in its observational and simulation capability as well as in the range of atmospheric processes that are explored. The focus remains on process understanding and tool development in relation to the societal challenges.

Stable atmospheric boundary layers frequently occur under nocturnal or cold conditions. Yet, our current understanding of the underlying physics is still poor. By combining system dynamics techniques (conceptual modeling) with observational and numerical analysis and high resolution modeling (LES as well as DNS) breakthroughs have been obtained in understanding why atmospheric turbulence in the evening can collapse under weak wind conditions and newly theories have been able to predict sharp regime changes in accordance with observations (KP61). By combining high-resolution Large-Eddy Simulations and linear perturbation theory with analysis of local observations, we were able to reveal the mechanism that generates intermittent turbulence in uniform conditions (KP62). A new improved **parameterization formulation** with a more physically realistic length scale formulation in Deardorff's sub-grid scale model has significantly improved the overall quality of the LES of stable boundary layers (KP63). Equally important improvements are made in improvements of the formulation of the Monin-Obukhov similarity-based boundary conditions in very high-resolution large eddy simulations (KP64).

More applied research has been done with respect to **fog forecasting** and research on **fruit frost** mitigation measures in agriculture. Various aspects of fog formation where investigated using a combination of field experimental, numerical and conceptual methods (KP65). In order to fight fruit frost in agriculture, a combination of field experiments and numerical simulation studies have been conducted.

An emerging applied branch of boundary layer science lies in the field of **renewable energy**. DALES and its commercial spin-off GRASP (GPU Resident Atmospheric Simulation Program) are capable of explicitly incorporating wind farms by using immersed boundary conditions and used to assess wake effects of wind farms (see Fig): combined with the operational mesoscale model HARMONIE a high resolution reanalysis has been made showing the effects of wind farms in present and future scenario's. For the first time an analysis and climatology was made of so-called *Dunkelflaute events* which lead to low wind and solar energy production.

The interaction between shallow cumulus clouds and wind is the theme of the ERC Starting Grant CloudBrake and the NWO Vidi CMTRACE led by Louise Nuijens. The approach combines (1) high resolution turbulence resolving simulations, (2) wind profiling observations from ground and aircraft and (3) conceptualization of mechanisms at play. This work is done in close collaboration with the European Centre of Medium Range Weather Forecasts (ECMWF). Main results are that momentum transport by the shallow cumulus convection (the so called cumulus friction) is not as evident as in the more deeper convection cases (KP66, KP67). Coherent convective cells in the sub-cloud layer that are associated with moist convection and (mesoscale) horizontal circulations are found important for maintaining a wind maximum near cloud base. This mechanism is important for maintaining strong surface winds and enhancing ambient wind shear. A comparison of observed and IFS wind tendencies during EUREC4A suggests that long-standing wind turning biases in the IFS are linked to the inadequate representation of sub-cloud convective overturning, mesoscale flows and cumulus friction.

Analyses of high-resolution simulations of boundary layer clouds have directly contributed to the strong reduction of the estimated uncertainty in equilibrium climate sensitivity (ECS) (KP68) as was reported in the recent AR6 of the IPCC in 2021.

More recent research is now concentrated on the role of spatial cloud organization on **cloud climate feedback** (KP69,KP70) (see Figure 4). As first crucial steps in this directions, new ways of characterizing **cloud organization** have been defined (KP71).

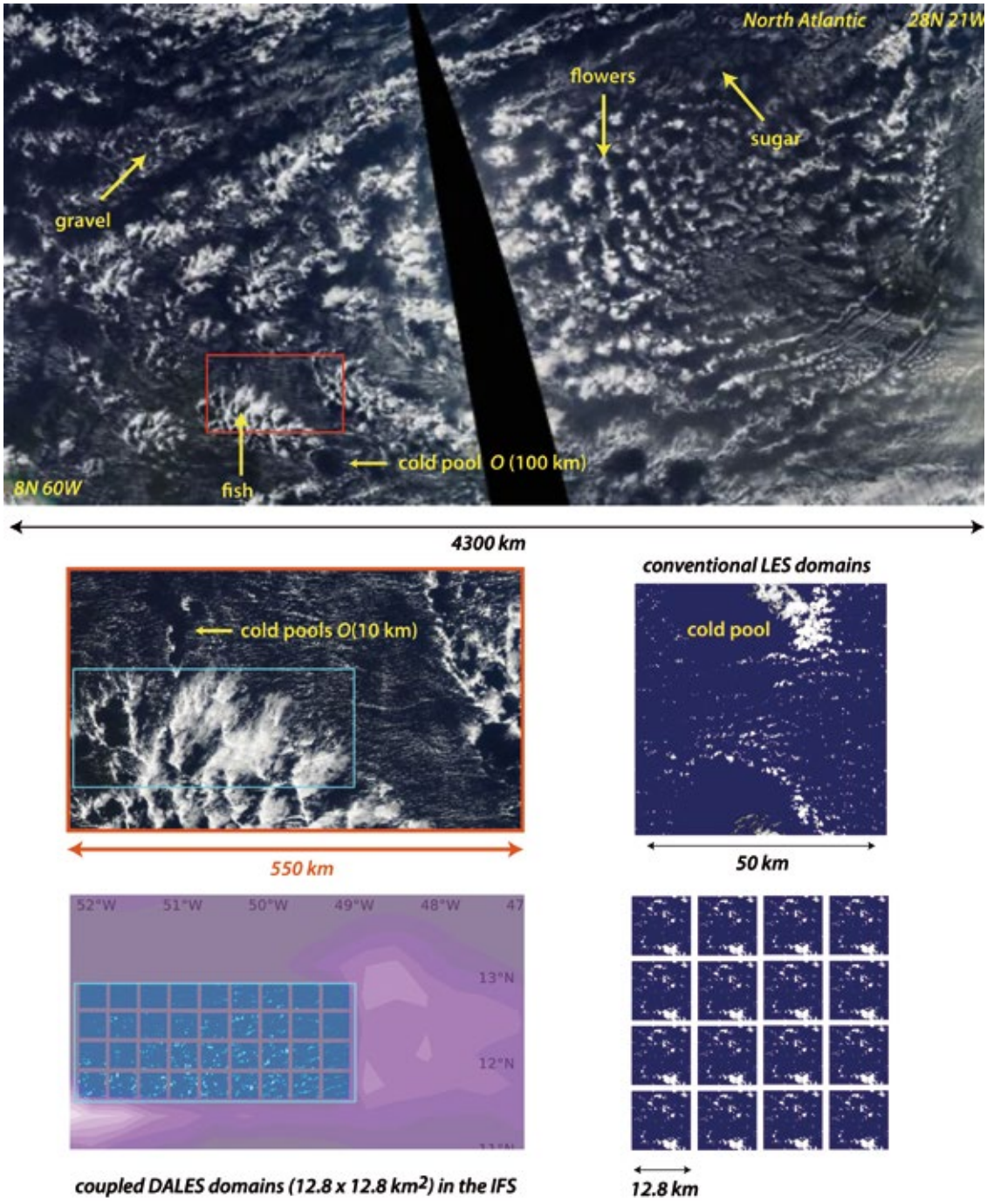


Figure 4. Shallow convection over the Northern Atlantic ocean as viewed by MODIS Aqua at 13:30 local time on December 12, 2013 (top); zoom in on a subarea (middle, left), which is simulated by a superparameterized version of the ECMWF-IFS (T152), using several coupled Dutch atmospheric LES domains, each 12.8 × 12.8 × 5 km3, with a 200-m horizontal grid spacing (bottom, left); conventional idealized LES simulations using domains of 50 km and 12.8 km in both dimensions (Figure from Nuijens & Siebesma).

Another key theme in cloud research is on their relation with aerosols: how do aerosols modify the cloud micro and macro structure, the cloud-radiation interaction and its influence on precipitation formation? To this end, retrieval techniques for cloud microphysics were developed (KP72). Research results range from local monitoring methods of aerosol concentration (KP73) cloud-aerosol interactions (KP74) to the impact of clouds and aerosols on decadal trends in solar radiation for the Netherlands over the last 50 years. More recently, Franziska Glasmeier has been applying a more dynamical systems type of approach to quantifying aerosol-cloud interactions in stratocumulus clouds (See Figure 5).

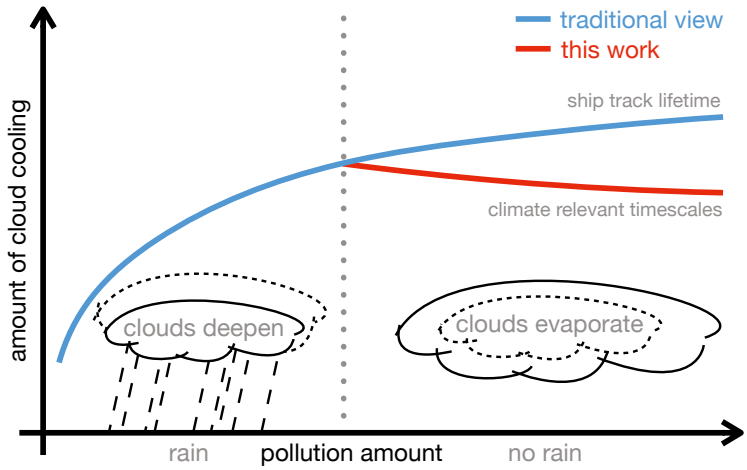


Figure 5: The climate-cooling effect of aerosol pollution on non-raining stratocumulus can be negative when considering climate-relevant timescales rather than easily observable ship tracks. (Figure courtesy F. Hoffmann).

The measurement, modeling and forecasting of **precipitation** is another key area of interest and the Ruisdael observatory plays a central role in this theme. High resolution simulations and rain radar data have shown univocally that higher temperatures (as can be expected in a warming climate) and a coinciding increase in moisture availability favor the formation of extreme convective storms, and that the number of the most extreme and largest rain events increase at the cost of smaller and weaker events (KP75) (see Fig. 6), an also affect the intermittency of rain events (KP76). A large effort was dedicated to the **design of radar remote sensing techniques** for rainfall estimation (KP77), ice particle growth in mixed-phased clouds (KP78) and turbulence estimation within precipitation. For the study of rainfall microphysics instruments like the micro-rain radars and disdrometers are placed in different locations (urban and polder) in The Netherlands. A new rain dropsize distribution retrieval technique was proposed and one of its assumptions (RDSD model) examined in. In the European MUFFIN project comparative studies were performed on the accuracy of weather radar at urban scales. We have also developed new radar drone-based **calibration** and clutter mitigation techniques. As a result, GRS is heading one of the European centres for cloud radar calibration.

Much of our atmospheric chemistry research is done in close collaboration with R&D Satellite Observations department of Royal Netherlands Meteorological Institute. It has a focus on algorithm development and data exploitation of the OMI and TROPOMI satellite instrument which provide global observations of several trace gases, for air quality, ozone layer and climate applications (KP79). The researched performed included using quantification of NO2 and CH4 data from oil and gas exploitation, the generation of long-term global data sets of absorbing aerosols using machine learning techniques and speeding-up the radiative transfers using neural-networks to enable operational retrieval of the aerosol layer height (KP90). Comparisons between global stratospheric ozone observations and models have shown inconsistencies in the trends over mid-latitudes. Will Ball received the “Dobson Award for Young Scientists” for being the first one to have discovered this disparity. Furthermore, through collaboration with the Cyprus Institute we have access to the development of small and economic sensors for aerosol measurements for deployment in the Ruisdael Observatory.

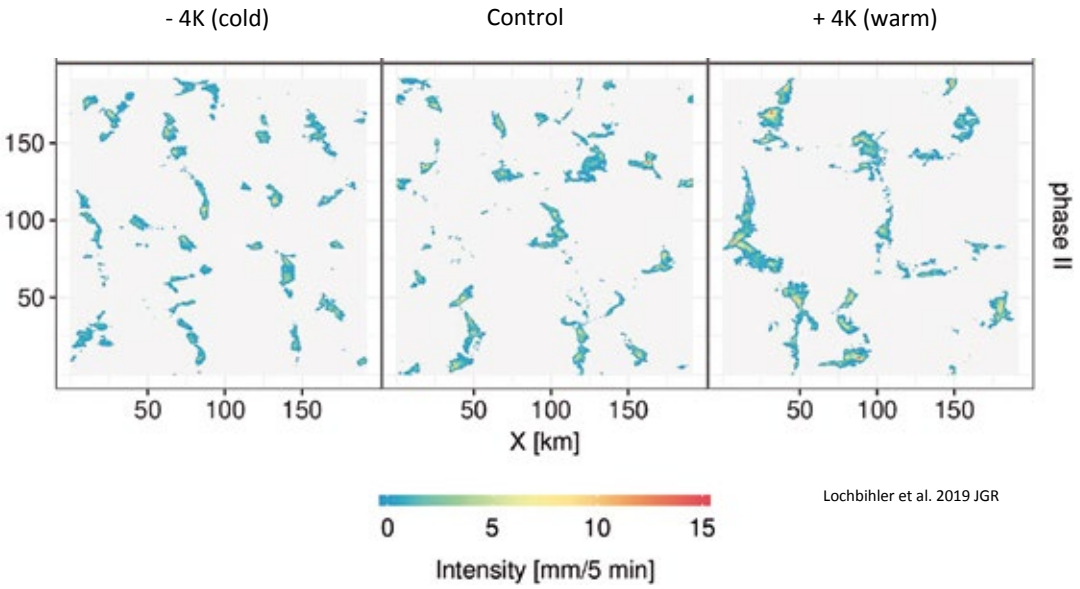


Figure 6. Top view of an extreme precipitation event under different atmospheric conditions: Centre: Control experiment; Left: Same experiment but 4 Kelvin colder; Right Same experiment but 4 Kelvin warmer. Note that the precipitation clusters becoming larger and more intense under warming conditions (Further info: Lochbihler et al. 2019)

5.5 Reflection

One could say that the overarching strategic aim of the GRS department for the period 2015-2020 was to create an attractive, social, and financially healthy department with an open atmosphere to which all members would truly feel connected. Did we succeed in this?

At a national level, GRS has been successful in securing funding from numerous **Netherlands Organization for Scientific Research (NWO)** programmes. Several GRS staff have been successful in obtaining prestigious **personal grants** (Table J.6) from the NWO Talent Program. GRS experts have been successfully awarded twelve grants from the Satellite User Support program in the past six years (Table J.7B4). GRS was among the first groups to get a project awarded within the National Science Agenda (NWA), Living on Soft Soils. Several collaborative projects have been funded through dedicated NWO calls focused on topics of considerable societal interest and importance where GRS expertise is indispensable (Table J.7A). Many GRS projects, in co-operation with industry partners, have also been funded through the NWO TTW Open Technology Program, and the NWO ENW program (Table J.7B4).

At a European level, GRS staff have been awarded highly competitive European Research Council (ERC) starter and consolidator grants. Several large-scale collaborative projects have been supported through the EU H2020 programme and the Marie-Curie International Training Networks (Table J.7B1). GRS was one of the founding partners of the European infrastructure ACTRIS (Aerosols, Trace Gas and Cloud Infrastructure), which has secured participation in a succession of EU programs (ACTRIS, ACTRIS-2, ACTRIS-IMP, RI-URBAN).

GRS experts conduct contract research for a wide range of partners (Table J.7B5 & J.21). This includes some **long-term contracts** with governmental agencies. One example is a contract with the Ministry of Infrastructure and the Environment (Rijkswaterstaat) on research and analysis of the vertical stability of the Amsterdam Ordnance Datum (NAP) using absolute gravimetry which was originally signed in 2007 and has been extended every four years since.

The ‘open’ recruitment of new staff in 2016 and 2017 has given a strong impetus to the quality of the department – to its research program as well as to the academic culture. The research interests the new staff brought in stimulated discussions about the scientific identity of the department, and eventually

lead to the themes we now use now for profiling ourselves, cross-bordering between the organizational sections the department set off with when it started. The quality impetus through our collaboration with KNMI also increased our attractiveness to academics: it led to the recruitment of an ERC laureate and Veni grant holder.

A good example of our social media strategy is the generated attention for our Antartica research (Case Study H4 in Appendix H). Not only did it serve the purpose of informing the general public, but it also contributed to upscaling the research activities. In general, our media visibility has increased significantly. Our open science effort has mainly focused on creating open access. We have made good progress here: most papers and data sets are now 'open'. In the wider context of open science there is room for improvement, for instance by incorporating citizen science more explicitly in our research program.

At first, individual staff members had to focus on building their academic career, but over time organizational involvement grew: the growth of the department necessitates a rebalancing of responsibilities. While we did start the process towards an adapted governance structure and described its contour, but we have not yet reached the final operational stage. This is still work in progress.

It is too early to evaluate if the impact of the new measures regarding PhD training and supervision is already reducing the time to graduation. However, it is expected that the combination of the new rules and guidelines will help PhD candidates to take ownership of their PhD program planning and help their supervisors to stay fully involved and adaptive to the needs of individual PhD candidates, thereby ensuring that PhD students can complete their studies in the nominal 4 years. The first signs are positive: progress seems to be faster. In addition, the PhD Council of the department is instrumental in identifying potential issues of concern – either for individual students, or for the collective. Especially during the COVID pandemic this has proven to be very valuable.

In conclusion, we have been successful in achieving many of our strategic aims – although for some it's still work in progress. We believe that the department is attractive, socially healthy, and financially in good shape.

6. GRS Strategy 2021-2026

Our research and strategic aims for 2021-2026 have been identified and articulated through a series of online staff meetings and in-person “strategy days”, as well as discussions with other CEG departments in view of the Faculty strategy. As part of the preparation for this assessment, we benchmarked against the Technical University of Denmark (DTU), visiting DTU Space and DTU Environment. DTU has an excellent reputation, is highly visible in Geoscience and Remote Sensing and is very successful in acquiring funding to perform high-quality research. We were particularly keen to learn about academic culture and organization and learned a great deal in terms of their PhD policy and approach to funding.

6.1 Research Plans 2021-2026

Most of the following plans are already financially grounded in granted research programs.

6.1.1 Geodesy

In **GNSS theory and modelling**, a further extension of our mixed-integer integrity theory for the integration of estimation and multivariate threat-testing is needed, as data increase and densification of geodetic sensory networks call for cooperative inference realized through distributed computing. As the challenges of new multi-satellite constellations and new GNSS-designs (e.g. Kepler) offer great opportunities for **improved PNTA**, our aim is to extend our models and methods to hybrid GNSS-LEO (Low Earth Orbiter) constellations with corresponding signals of opportunity. Furthermore, we will extend our interferometric methods to local and regional GNSS-reflectometry, for low-cost soil-moisture and geodetic water-level monitoring, and in co-location with tide gauges offering an improved link to vertical reference. We will establish a **Delft GNSS FieldLab**, consisting of a dense reference network of continuously operating low-cost multi-GNSS receivers.

We will investigate the potential of model-based hydrodynamic levelling for the realization of continental-wide and world-wide **vertical reference surfaces,** based on a combination of spirit levelling/gravimetry and model based hydrodynamic levelling and contribute to the realization of a new European Vertical Reference System (EVRS). To account for time-variations in the quasi-geoid and the absolute vertical position of NAP markers, we will do research into a methodological framework for dynamic connection between GNSS-ellipsoidal heights and NAP heights.

We will continue our work on the **assimilation of total water levels** from radar altimeter data and tide gauge data in 3D hydrodynamic models. We will develop an FF-SAR coastal water level processor that will be applicable to Cryosat-2, Sentinel-3 and Sentinel-6/Jason CS data. Moreover, we will develop a new hybrid sea state bias model for the Dutch North Sea to quantify the water level variability due to freshwater discharge in the Rhine region of freshwater influence (RoFI) and its significance for safe navigation and better salt-water-intrusion predictions.

For **InSAR Geodesy**, the main aim is to build CAROLINE (Contextual and Autonomous processing of satellite Radar Observations for Learning and Interpreting the Natural and built Environment), a continuously and autonomously operating computer system that uses SAR and contextual data as main input and provides as output (i) a queriable database of points with attribute values, and (ii) push-notifications on objects or situations that are potentially hazardous and require further investigation. The related scientific objectives are to realize context-supported model selection in mixed integer-real valued parameter estimation problems, which refers to tailor-made parametric models per-point and/or per-epoch for data which involve integer phase ambiguities.

6.1.2 Earth System science

For **Sea Level Change**, we will continue to analyze observations of coastal sea level with state-space model and machine learning techniques, aiming at the advanced assessment of adaptation measures. We will develop new numerical tools to separate the contribution of tectonics from GIA, and for a more accurate interpretation of the geological sea level record, which provides some of the best available evidence of past climate changes. We will research the insufficiently quantified, negative feedback between solid earth motion and ice melt. We aim to improve process understanding of **Antarctic ice shelves** and implications of ice shelf instability for present and future sea level and extremes through a multidisciplinary approach (ocean, atmosphere, regional sea level modelling, remote sensing, in-situ measurements). Finally, we aim to produce a solid earth model to be integrated in next-generation Earth System Models.

Regarding our research on **Ice Sheet and Earth System Modelling**, we will advance CESM-CISM with inclusion of ocean forcing to ice sheets and improved initial ice sheet state. We aim at unprecedentedly detailed, coupled simulation of the last deglaciation (21-9 ky BP) to advance understanding of ice, climate and sea level change and test/improve current models.

We aim to provide the first descriptive models of **shallow and deep subsurface dynamics**, that both cover the impact of climate change on irreversible land subsidence, as well as data-assimilation based models to disentangle deep and shallow surface dynamics.

6.1.3 Remote Sensing

We will focus on strengthening our involvement in i) the development of the **new satellite missions,** particularly Harmony, (ii) the development and exploitation of **Big Data archives** and (iii) the development of **novel techniques (e.g., machine learning and data assimilation)** to analyze large remote sensing data archives. We will build on our experience in both to assess ocean-land-atmosphere interactions and to assess the state and changes in the Earth and its infrastructure. We will focus on large scale applications and on the development of methodologies for information extraction from remote sensing data that that are easily accessible or adaptable by other research teams (e.g., via open access software packages).

We will improve our algorithms to track **mass changes in the cryosphere and hydrosphere,** concentrating on specific data products tailored to selected geographical regions and specific mass change processes, where the envisioned added value of new data types, such as high precision Laser Ranging Interferometry data, is maximal (e.g., melting of small glaciers in high-latitude areas or the accumulation of meltwater within the Greenland Ice sheet). Apart from working on established satellite concepts, we continuously strive to provide novel approaches exploiting the latest available data resources, such as the recently the launched ICESat-2 laser altimeter, for which we developed a new method to derive ice sheet topography at a resolution superior to that provided in the official NASA product. Furthermore, we will focus on the combination/assimilation of altimetry, gravimetry, GNSS, and other data with/in models to improve the resolution and quality of mass change estimates. This will facilitate a decomposition of total mass change estimates into contributions of individual compartments. In addition, we aim to tackle the penetration of radar waves in the upper snowpack, a major source of uncertainty in radar altimetry measurements. We will set up a **portal for data dissemination** to the scientific and general public to boost the scientific and societal impact of this research.

6.1.4 Atmosphere

The research in the atmospheric program will remain curiosity driven and processed based, but with a strenghtened emphasis on the societal challenges that we are facing as a result of climate change. The program will be embedded in the TU Delft Climate Action program and expand into these directions:

- High resolution forecasting of weather and air quality at regional and local scales, such as the Rotterdam delta, as well for forecasting of wind and solar energy yields;
- Ocean-atmosphere processes to understand and model the interaction between the mesoscale spatial variability of sea surface temperture, clouds and precipitation;
- Cloud microphysical processes to improve our modelling and observational capability of thermodynamic phase change, particle growth processes and interaction of clouds with atmospheric radiation, with the latter also aiming at building up the knowledge base for assessing climate engineering methods.

Methodologically, it fits well in the Ruisdael observatory that aims to measure and simulate and understand the atmospheric processes over the Netherlands at a 100 meter resolution. The ultimate aim is to transition the Ruisdael observatory into a digital twin for the Dutch Delta, so that it can be an urban scale version of the European Digital Earth Program. Research will incorporate new machine learning techniques to take full advantage of the high resolution observational and simulation data for down-scaling purposes. The atmosphere program will be embedded in the future ATMO-NL research infrastructure: and extension of Ruisdael Observatory covering parts of the North Sea and the Randstad area.

6.2 Strategic aims (2021 – 2026):

6.2.1 SWOT Analysis

Strengths:
- Our research field is curiosity-driven and application-inspired. It contributes to important societal challenges.
- We have a diverse and stable scientific and societal network.
- We have a good reputation, deliver work of high quality and impact.

Weaknesses:
- Strongly competitive funding schemes can hamper a long-term continuation of research programs.
- Due to their nature, some of our research activities are less visible and tangible for non-expert users.

Opportunities
1. National and international programs such as the EU Green Deal, Destination Earth, and the national sectorplan for Earth and Enviromental Sciences offer funding schemes and networking opportunities to secure and intensity our activities.
2. The TU Delft Climate Action program can strengthen our research portfolio and collaboration across different departments in the university.
3. The new Rewards and Recognition scheme creates a diverse range of stimulating working conditions and increases the attractiveness of working in academia.
4. Pressing and urgent/short term societal issues offer the opportunity to enhance our visibility, for instance via student-driven *rapid response teams.*
5. The new MSc programs aims at educating the next generation of academics to approach scientific and societal challenges with a data-driven attitude, giving us the possibility for increasing visibility and attractiveness.

Threats
1. An increasing workload and decreasing level of control over one's time lowers the productivity.
2. Systematic lack of national research funds lowers the success rate of proposals.
3. Funding agencies increasingly favor large multi-disciplinary programs, which require long preparation times for capacity building. This can be counter-productive for early career scientists.

6.2.2 Financial viability

Since direct university funding is not sufficient to fulfil our scientific ambitions, we must diversify our money streams.

More specifically:
- *First money stream.* Since this depends on the number of graduated BSc, MSc, and PhD students, we can only strengthen this by increasing student numbers. Our revised PhD policy is aiming at just this, while the new MSc programs will offer us good opportunities to increase our share.
- *Second money stream.* We strive for a wide portfolio of NWO projects and programs, ranging from personal grants to one-PhD projects, NWO Groot and other large programs, such as NWA of infrastructure programs.
- *Third money stream.* We aim at increasing our role in European programs, and at strengthening our collaboration with societal partners.

These ambitions require continued investment in networking and agenda setting committees. We already do this, but we will increase our efforts. To increase the success rate of proposals, we will strengthen our internal review system: while currently only used for personal grants, we will increase the scope to other proposals as well. Many projects require good infrastructure and computational facilities, and corresponding technical support. We will invest in this to make us more competitive.
There are many opportunities for us to participate in the EU initiative Destination Earth. Already we have taken, together with GSE, the initiative to organize ourselves on a national level in Destination NL. In addition, the European Green Deal and Horizon Europe offer ample opportunities. Sukanta Basu's participation in the recently funded European Scalable Complementary Offshore Renewable Energy Sources (EU-SCORES) project (total budget €46m) is indicative of the opportunities on the horizon under the Green Deal.
We will use the organizational structure of the TU Delft Climate Action program and the Innovation & Impact Centre of the university to give input to the definition of future calls of these programs. We participate in the national platform for Earth and Environmental Sciences. In this platform we co-create the national investment plan for additional, structural funding in this domain, offering good opportunities for strengthening and securing our research program.

6.2.3 Future-proof organization

As described earlier, the changes in staff composition and related responsibilities call for an adaptation of the governance structure. In addition, the dean of the CEG Faculty has recently (Autumn 2021) issued the CEG Departmental Organisation Principles to substantiate 'the conditions set by the dean' as stated in Article 13.6.3 of the Faculty Rules: "The department chair is authorized, with due observance of the conditions set by the dean, to further design the management structure within his department." In the review period, decisions were made by the Department chair after consultation with all academic staff at weekly meetings and additional monthly meetings with the full professors, the latter focussing more on long-term strategic matters. In view of an expected increase of the number of full professors, this needs to be reconsidered: one of the goals for the coming period is to establish a balanced governance process.

The specific implementation is currently under discussion within the department. Under consideration are:

- An adaptation of the management team such that next to the section heads, representatives of all ranks of academic staff participate to broaden the base for operational decision making. The management team supports and advises the department chair and liaisons with the different units within the department.
- A non-permanent duration of the terms of section heads, in order to create an opportunity for leadership development.
- Strengthening the role of the staff in strategic processes.

Another goal is to update the structure and definition of roles in the department to improve the alignment with the current nature of academic work and its associated culture, which puts the individual researcher at the centrum of the process. This can be achieved by transferring responsibilities and control (mainly financial, but also personnel related issues) to individual project leaders, within boundaries set by the department. A reconfirming but still important insight resulting from the visit to DTU is the importance of putting the focus on communication and community building rather than on complex formal processes. A goal of the revised governance structure is, therefore, that the different sections, or cross-links between them, maintain to be effective scientific and strategic discussion forums.

6.2.4 Recruitment and development of academic staff

GRS expects to recruit several new academic staff in the period 2021-2026: in the first half of 2022 we will recruit two assistant-professors in urban air quality, and one for earth radiation modification, while more may be expected, would the national sector plan for Earth and Environmental Science materialize into more funding. In line with Faculty policy, decisions around the recruitment of new permanent staff will be taken at department level. The strategy of hiring with a relatively open profile has proven successful and is preferred where possible. However, where positions become available through, e.g., DAI Lab, Delft Climate Action program, or in response to teaching requirements, the profile will be more specifically defined. The Department will continue to engage in talent scouting to identify top talent in our respective domains and find opportunities to attract them to TU Delft. In recent years, start-up packages were introduced for new academic staff which has made TU Delft more attractive.

While the number of female academic staff is increasing, we continue to pay attention to bias in the recruitment process, particularly in the selection and interview stage. We aim to ensure the timely promotion, and satisfactory **career development** of our academic staff. To address this, we will comply with the guidelines proposed by the TU Delft Rewards & Recognition Perspective (2021 – 2024) to increase transparency, clarity and consistency regarding the tenure and promotion processes. We aim to provide an environment in which staff develop academic leadership as outlined in the TU Delft Leadership Profile (Shared Appendix), not only through leadership courses, but also through 'training on the job' in the department.

6.2.5 Academic Culture

Our aim is to maintain GRS as a social and scientific community in which staff and students have a sense of belonging, based upon shared values and engagement, and driven by our common goal of performing societally meaningful education and cutting-edge science. We aim to provide a workplace where all employees and students feel safe and respected. Therefore, GRS has committed to participating in a pilot scheme in which staff and new PhD candidates receive training on communication in a diverse workplace. We will also follow the recommendations of the Faculty Academic Culture Committee, with respect to diversity, openness, inclusivity, research integrity and social safety, as presented in the Midterm report 2017-2020 of Civil Engineering. The planned transition to an organization with more participatory and transparent decision-making will lead to a department with less (in)formal hierarchy and softer internal boundaries, both of which facilitate more open communication. Given the COVID-related uncertainty of the coming years, the connectivity and interactions arising from shared responsibility will be important for sustaining a sense of community and reducing the isolation of working at home.

6.2.6 Workload

Our goal is to ensure that academic staff have the space needed to conduct high quality research. It is essential that academic staff have time, and sufficient control over their own time to focus on their research priorities, investigate new ideas, engage discussion, and develop new research plans. GRS aims for a fair distribution of educational and organizational tasks across the Department. GRS aims to protect academic staff from excessive process/administrative overhead via increased, and dedicated staff to provide support with acquisition, project administration etc. We aim to provide additional support to staff in educational activities by increasing the involvement of PhD students and teaching assistants in the preparation, grading, and logistics tasks that accompany teaching responsibilities.

6.2.7 Successful PhD completion

In the coming six years, our priority is to monitor whether the new guidelines of the memorandum are followed by both PhD and advisors. The Graduate School has an important role in progress monitoring via the personal "Educational and Development Plan", and the annual progress meetings. The progress of all PhD candidates will be discussed twice per year at the staff meeting to create peer accountability. The annual (individual) R&O meetings will also be used to monitor whether the new guidelines are being followed by both PhD candidates and advisors.

We also learned during our benchmark visit to DTU. Students there emphasized the value of feeling part of a team, contributing to something bigger than their individual project, and the opportunity that provided to gain independence gradually. At DTU they have a so-called PhD-mum who acts as a pro-active confidant. She welcomes the PhDs at day one, helps them orient themselves within the organization, visits them regularly during the project and provides support when they need it.

6.2.8 Systematic outreach

Outreach is important for several reasons: to inform the general public, to engage into public debates, and to communicate with peers. We will continue to publicize our work via different channels to target specific audiences. While all staff will be requested to contribute, we recognize that there is not a one-size-fits-all approach. While social media suits one, other media may fit other staff members better: we will diversify, making the most of the resources and support provided at CiTG and TU Delft.

Summary

The department Geoscience and Remote Sensing aims to understand the interaction between human activities, the Earth system and our living environment through the combination of observational data science and physical modelling. The GRS program provides fundamental knowledge for improving our society, as is also reflected in the motto of the CEG Faculty: understand, intervene, and improve. It is organized around the themes Atmosphere, Earth System Science, Remote Sensing and Geodesy. Both Geodesy and Remote Sensing contribute to and are inspired by the development of new satellite missions, which provide new data with higher accuracy and space-time resolution. Activities common to all themes are direct numerical simulations, regional modelling, and developing conceptual models, signal processing, the development of retrieval algorithms, sensor synergy and data fusion, calibration and validation. We cover the complete chain from model and sensor development to information products.

GRS has produced a significant scientific output of 655 journal papers and 47 PhD dissertations. Many staff members and PhD candidates have received international prizes for their research. Successful research worked as a seed for acquiring prestigious grants (two ERC Starting Grants, one ERC Consolidator Grant, two NWO-Vidi grants, one NWO-Veni grants, one Branco Weiss Fellowship).
Open science. The department has made a serious effort to make its research results accessible to the scientific community and the general public. The percentage of journal papers with open access increased from 64% in 2017 to 86% in 2020. Over the period 2017 to 2020, 372 of the 466 papers (80%) were published open access. The facilities and data of Ruisdael Observatory and others, are made available for other researchers. In addition, public outreach via social and other media has increased significantly.
PhD policy and training. The PhD candidates are part in the Faculty Graduate School. In addition, the GRS department has developed a dedicated PhD policy based on the input of the PhD students. At the time of writing the report, it was still too early to report on the impact of this policy, but the first signs are positive: progress seems to be faster.
Academic culture. The influx of new staff members, the expected retirement of professors and the opportunities offered by the new internal careering policy of the university necessitated a revisit of departmental governance, organization, and responsibilities. Department-wide discussions have been held on these aspects. The main outcomes of these discussions have been integrated into our strategy for the coming 6 years.

Human resources policy. The department is moving towards implementing the ideas formulated in the TU Delft perspective on the recognition and rewards of academics. Special attention is given to attracting more female staff via scouting and networking.

Strategic goals for next six years.
- A future proof organization.
- Improving the gender balance.
- An open academic culture.
- Timely successful PhD completion.
- Prioritizing Open Science and strategic public outreach
- Reduce workload by increasing support

Appendices
General introduction

Appendix 1:
CEG strategy 2019-2024*

Student and Education

Ambitions 2024

To educate students to become and remain world class civil, environmental and geoscience engineers who:

- have in-depth knowledge in and understanding of core disciplines
- are competent to work in data rich yet uncertain environments
- come up with innovative and integrated engineering solutions
- can convince stakeholders for evidence-based decision making
- can work and collaborate in an interdisciplinary and multi-cultural environment
- act in society as responsible engineers

To be the institute of choice for students and teachers. CEG has:

- best courses: inspiring teachers and methods, synergy between fundamental and application-driven, lab and field teaching, high face-to-face contact between teacher and student and excellent online self study possibilities
- an excellent reputation on education
- up-to-date and coherent tracks based on broad civil, environmental and geoscience engineering knowledge
- up-to-date laboratories
- healthy student - staff ratio
- balanced teaching load

People and Community

Ambitions 2024

To be the employer of choice for all staff. CEG:

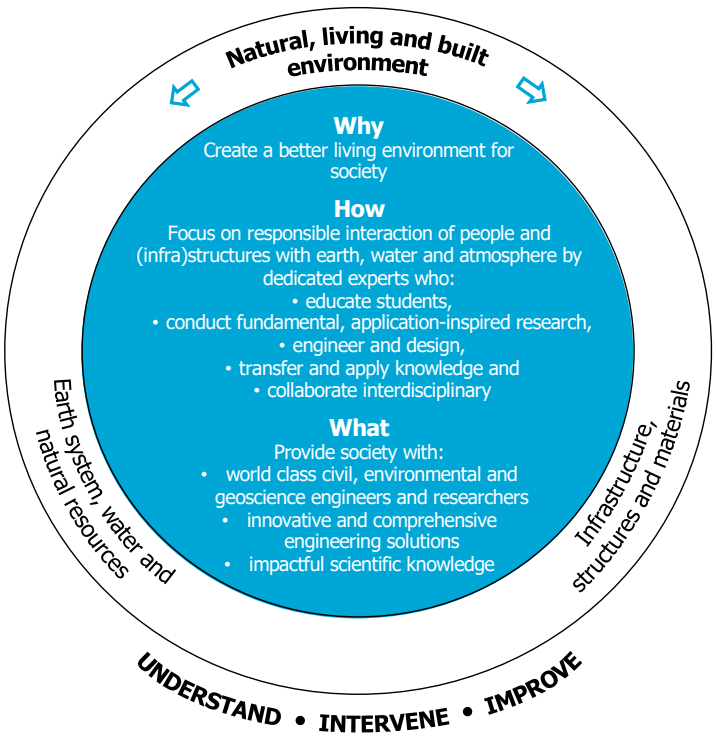
- has a stimulating intellectual environment
- provides opportunities comparable to other renowned universities
- promotes and practices diversity
- develops leadership capabilities in its scientific staff
- offers transparent and flexible career paths
- assesses and rewards both individual and team performance
- feels responsible for a healthy work-life balance
- focuses on a good team spirit
- ensures a fair distribution of workload

To have an active and connected science, staff and alumni community based on:

- common interests
- shared values

TU Delft

Faculty of Civil Engineering and Geosciences



Research and Innovation

Ambitions 2024

To conduct world class fundamental application-inspired research that supports the responsible interaction of people and (infra)structures with earth, water and atmosphere. CEG has:

- a strong link between education, science, engineering and design
- strong mono-disciplines and coherent interdisciplinary research themes
- researchers who are able to work and collaborate in an interdisciplinary and multi-cultural environment
- a strong focus on new research techniques
- flexibility to adopt new research topics
- an open science approach

To be the institute of choice for researchers. CEG:

- is a recognized research authority by society and scientific peers
- has a proven track record on transferred and applied knowledge to society
- is proactive in identifying and responding to societal needs
- has highest standards for scientific integrity
- values individual and collective output
- aims for outstanding research facilities, funding and support
- works in excellent teams that cover research, acquisition of funding, valorization and support
- involves stakeholders from public and private domains
- has high visibility at industry, government and funding agencies

Campus and Services

Ambitions 2024

Our building is the place to be for students, academic and support staff. CEG's faculty building:

- meets high health, safety and environment (HSE) standards
- fulfills diverse workspace needs
- has appropriate computing, teaching and lab facilities
- is a showcase of our world-class expertise and ambitions
- stimulates co-operation, personal growth, creativity and productivity

To have excellent and efficient support services that are fully aligned with academic and educational staff's needs

* This Appendix is taken from the Midterm report Civil Engineering 2017-2020

Student and Education

Change themes 2019-2024	Strategic choices 2019-2024
Curriculum structure and content	1. Give core disciplines a structural place throughout broad BSc programs as a basis for advanced specialization in the various master programs 2. Challenge the status quo of existing BSc and MSc programs and tracks and decide on and implement necessary improvements in line with CEG mission statement 3. Give emerging technologies and societal challenges a recognizable role in both BSc and MSc programs 4. Oblige interdisciplinary education in MSc linked to the key societal challenges for CEG
Environment for education to grow	1. Enhance skill-based knowledge like academic writing, presentation and programming 2. Improve educational facilities (i.e. instruction rooms, e-learning facilities, computing) and educator support 3. Create extra-curricular showcase projects for students to participate in (CEG dream teams)
Distribution of teaching load	1. Distribute teaching load more evenly over departments and individuals 2. Increase the number of lecturers per BSc course with specific in-depth knowledge on course aspects involved 3. Distribute student influx more evenly over the MSc-tracks
Education and promotion culture and efficiency	1. 80% of students who have passed their BSA finish their BSc within 4 years 2. 90% of PhD candidates who have passed their go/no-go obtain their degree within 5 years.

People and Community

Change themes 2019-2024	Strategic choices 2019-2024
Appreciation of group and individual	1. Appreciate in R&O and VLC also individual contributions to: a. the group output and responsibilities b. establishment and maintenance of external relations for education, research and valorisation c. societal impact and outreach 2. Change VLC norms to be tailored to individual talents: Faculty members should be excellent on at least one criterion and competitive on other criteria 3. Align R&O with VLC expectations and recommendations
Environment for individuals to grow	1. Develop staff actively and based on transparent HR policy on recruitment, guidance, training, promotion and outplacement 2. Reward initiatives and responsibilities taken by individuals to get the best out of themselves and out of others 3. Integrate every Faculty members' actual personal mission statement and personal development plan in R&O cycle 4. Initiate a VLC track for the career development of lecturers
Inclusiveness	1. Increase the number of female Faculty members (UD, UHD, HL) and lecturers to be a representation of the PhD population 2. Represent at least 1 junior staff i.e. 'young' U(H)D in each department MT 3. Apply zero tolerance on prejudices, gossiping and intimidation

Research and Innovation

Change themes 2019-2024	Strategic choices 2019-2024
Societal challenges and faculty research themes	1. Align, focus and strengthen all research activities (including moonshots) concerning the key societal challenges for CEG: a. Availability of clean water b. Climate change c. Transition to renewable energy systems d. Resource depletion e. Urbanization 2. Set the societal agenda through mapping and involving of stakeholders aimed on the key societal challenges for CEG
Environment for research to grow	1. Maintain strengths in following disciplines: a. Fluid and sediment dynamics b. Physics of materials c. Earth sciences d. Mechanics of solids and structures e. Transport network and system sciences 2. Develop cross-department methods and technologies: a. Monitoring, sensing and data b. Numerical modelling, simulation and design c. Risk analysis, uncertainty quantification, probablistic design d. Smart materials and structures 3. Realize integrated use of experimental lab facilities of the faculty

Campus and Services

Change themes 2019-2024	Strategic choices 2019-2024
Health, safety and environment (HSE)	1. Create an environment to have zero incidents: a. Staff at all levels take own responsibility in behaviour b. Clear organization, policy and procedures c. Implement structural HSE measures d. Have 100% coverage of safety reports for experiments e. Use dedicated HSE software routinely for registration and monitoring f. Publish safety performance
Co-ownership	1. Ensure sufficient (quantity and quality) project and financial support staff to departments 2. Make distribution of responsibilities between academic staff and support staff fully clear and complied with 3. Make the degree of academic and educational staff's satisfaction a criterion in support staff's R&O and vice-versa
Building and workspace	1. Aim for mid-term renovation with attention for: a. Improved spatial lay-out including more small meeting rooms b. Up-to-date interior design c. Improved climate control 2. Practice sustainability throughout the building including the restaurant

Appendix 2:
Academic Culture at the Faculty of Civil Engineering and Geosciences*

Background & Process

During the kick-off meeting for the CE 2021 midterm assessment, a decision was made to form a committee tasked with assessing the daily practice of the research unit with respect to academic culture, as well as how the culture fosters or hinders the attainment of the Faculty's strategic aims. To properly assess how the culture is perceived by the majority of scientific employees, it was decided not to include any individuals in higher-ranking management roles in the committee. The following criteria were defined for its composition:

- Members are > 50% PhD-candidates or Postdocs
- Members are < 25% in a management role
- Workplace diversity is balanced with attention to identity, male/female, country/continent

This led to the Academic Culture Committee (ACC) as presented in the table below, where its members should be viewed as selected individuals as opposed to departmental representatives.

Eliz-Mari Lourens (Chair)	Assistant Professor	South African/Dutch; female
Florentia Kavoura (Secretary)	Postdoc	Greek; female
Florencia Balestrini	PhD candidate	Argentinian; female
Leon Hombergen	Assistant Professor	Dutch; male
Alexandra Rocio Urgilez Vinueza	PhD candidate	Ecuadorian; female
Riccardo Riva	Associate Professor	Italian/Dutch; male
Ali Vahidi	PhD candidate	Iranian; male
Meng Wang	Assistant Professor	Chinese; male

The committee was split into groups addressing, respectively, diversity, openness and inclusivity, research integrity, and social safety. During a period of just over 2 months, the groups gathered information on these topics through interviews, surveys, and qualitative and quantitative research. Although the focus was on the Faculty of Civil Engineering and Geosciences, comparisons were also sought with other universities, both nationally and internationally.

The findings of the committee were presented to the Management Team of the Faculty on May 7th, 2021. In what follows, these findings will first be summarized. A brief discussion of the meeting with the Management Team will subsequently be given, focusing on the conclusions made based on the discussions that took place during that meeting.

* This Appendix is taken from the Midterm report Civil Engineering 2017-2020. Hence, in this Appendix, terms like 'review' refer to 'Civil Engineering review', etc.

Diversity, Openness & Inclusivity

Policies and regulations at the TU Delft

At the university level, the senior leaders, staff, and students are encouraged to embody and embrace the power of differences through the Strategic Framework 2018-2024 and the diversity policy. The Diversity and Inclusion (D&I) Office of the TU Delft aims at making a sustainable impact on improving the campus culture, the demographic composition, and in elevating educational standards. The D&I office mainly focuses on seven thematic areas:

- Gender equality
- Gendered Research and Innovation (GRI)
- Study and work success and representation
- Institutional support & wellbeing for students and staff
- Further professionalize recruitment practices vis-à-vis diversity and inclusion
- Religion and spirituality
- Disability support services for staff and students with disabilities

In the understanding of the ACC, the policies and activities supported by the D&I office at TU Delft are still being developed/adjusted and advanced, so it is not yet clear which specific actions will be taken in order to address the aforementioned thematic areas. The D&I Office is, however, planning a diversity week in October, when also a campus-wide diversity survey will be conducted.

In terms of gender diversity specifically, The *Delft Technology Fellowship* aims to improve the recruitment, selection, career development and retention of female senior staff. It offers faculty positions to internationally recognized female scientists and engineers and provides additional resources to female assistant professors in order to accelerate their promotion to associate professor. Our Faculty supports the Fellowship, and recruits female scientists through the Fellowship. Specifically, over the past 6 years, the CEG Faculty participated in all 6 rounds of the DTF, and recruited 6 female scientists via this route, three of which are Associate Professors.

Experiences within the Faculty

Diversity

Diversity is a broad term referring to people from a range of different social, ethnic, religious, and cultural backgrounds, of different genders and sexual orientations, to people that are physically or mentally handicapped, etc. The focus here will be on gender diversity, which was identified as a point of concern for the CEG Faculty specifically, already in the previous research review.

The concern resulted in the bold initiative of only starting selection procedures for vacancies if 50% of the candidates on the shortlist were serious female candidates. As a result, 50% of the 22 Sectorplan/van Rijn vacancies were filled with female scientists last year. The percentage of female staff increased, but the ambitious goal of 23% female senior staff overall by 2020 was not met. As shown in the table below, female senior staff is now at 16,9%.

Percentage women per staff category (based on headcount)		2017	2018	2019	2020
Scientific staff	Assistent professor	21,9%	21,9%	24,4%	27,5%
	Associate professor	16,5%	14,7%	12,3%	16,9%
	Full professor	6,4%	8,2%	8,2%	8,6%
	Total	**13,9%**	**14,1%**	**14,3%**	**16,9%**
Other Research staff	Researchers	30,7%	29,9%	30,5%	26,0%
	Total	**30,7%**	**29,9%**	**30,5%**	**26,0%**
Other	Support staff (research)	13,9%	13,6%	12,9%	13,8%
	Total	**13,9%**	**13,6%**	**12,9%**	**13,8%**

Source: HR system, reference date: 01-02-2021. Faculty: CEG / Department: 3MD, ES, HE and 4 more

The ACC was of the opinion that the Faculty still suffers from a lack of awareness of implicit biases, and their consequences for recruitment and promotion processes especially. This pertains not only to gender diversity, but to diversity in general. On the basis of interviews with employees previously employed at other universities, the committee concluded that the discussions (and implemented procedures) in our faculty is still relatively immature when compared to many other universities, both nationally and internationally. Examples of recruitment procedures designed to eliminate/minimize such bias at other universities were presented as examples.

Networks and organizations
At TU Delft awareness of diversity is growing. Most certainly in our students, but also in our staff. The staff has already organized themselves in professional networks like DEWIS for female scientific staff and TrueU for all LGBTI-staff. The ACC expects that in the future more networks – some formal and some informal – will be organized including more minority groups (e.g. staff with special needs). Similar initiatives are expected in the student populations. The importance of recognizing these organizations were raised, and empowering them to be in touch, as they can generate important signals to the Faculty, and improve awareness in staff.

Hierarchy
The ACC reported that, when talking to faculty members that joined the TU Delft after having worked in other universities outside the Netherlands (especially the UK), a recurring comment was that the faculty is much more hierarchical than what they were used to. In some cases, a feeling of involvement was lacking because of this. An example here is the inclusiveness and transparency of the Faculty Management Team, which was also commented on in the previous research review.

Chinese and Russian colleagues
Recent reports from Dutch media speculated on the espionage of Chinese and Russian researchers in Dutch Universities. The increasing media attention can influence the perceived safety and well-being of colleagues with Chinese and Russian origins working at the Faculty. TU Delft has initiated a Greater China Team focusing on the university-wide strategy when collaborating with China. There were cases when Asian colleagues and their family experienced racial discrimination outside the university since COVID-19. The ACC suggested that the Faculty follows these developments closely.

Suggestions for the future
To give more structural attention to diversity, openness, and inclusivity, the ACC proposes the establishment of a CEG Diversity and Inclusion Team. Representation from the faculty members, HR, and the Student, PhD, and Works councils is suggested. A few initial points of attention for this committee are listed in their report, including (further) professionalization of recruitment processes in view of implicit biases, exploring ways to make diversity more visible and recognizable (especially in decision-making bodies), and ways to make the faculty hierarchy more transparent. The latter is not meant in terms of reducing the perceived hierarchy, but in terms of making the decision-making processes more transparent, in order to open the door for an increased influence of young/diverse staff members on faculty, department, or even section policy.

Research integrity

Policies and regulations at the TU Delft

The TU Delft Strategic Framework 2018-2024 is addressing research integrity as one of its core values and sets the goal of setting up an integrity policy that protects scientific data and personal data in line with EU and Dutch directives. Details can be found in the TU Delft Vision on Integrity 2018-2024 and in the TU Delft Code of Conduct, which in turn is based on the Netherlands Code of Conduct for Research Integrity, adopted by the Association of Universities of the Netherlands (VSNU). Here we reproduce the key concepts from the Code:

- *Honesty:* it means, among other things, reporting the research process accurately, taking alternative

opinions and counterarguments seriously, being open about margins of uncertainty, refraining from making unfounded claims, refraining from fabricating or falsifying data or sources and refraining from presenting results more favorably or unfavorably than they actually are.
- *Scrupulousness:* it means, among other things, using methods that are scientific or scholarly and exercising the best possible care in designing, undertaking, reporting and disseminating research.
- *Transparency:* it means, among other things, ensuring that it is clear to others what data the research was based on, how the data were obtained, what and how results were achieved and what role was played by external stakeholders.
- *Independence:* it means, among other things, not allowing the choice of method, the assessment of data, the weight attributed to alternative statements or the assessment of others' research or research proposals to be guided by non-scientific or non-scholarly considerations.
- *Responsibility:* it means, among other things, acknowledging the fact that a researcher does not operate in isolation and hence taking into consideration – within reasonable limits – the legitimate interests of human and animal test subjects, as well as those of commissioning parties, funding bodies and the environment.

On ancillary activities the CEG Management Team approved on October 5th 2018 a policy which is approved as per the Sectoral Scheme Ancillary Activities and the additional conditions:
1) the ancillary activities are reported every two years via the online registration form: TU Delft: Ancillary activities
2) the Department Chair and the Dean approve;
3) the ancillary activities are reported yearly within the Department during a Department meeting;
4) if the ancillary activities are performed during regular working hours, any income will be transferred to the Department, while agreements about spending of the income can be made with the Department Chair.

Experiences within the Faculty

Research Integrity is a key principle for all academics. It is hence assumed that all researchers, from PhD candidates to full professors, know its meaning and uphold it at all times. As a result, the ACC had the impression that it is not often explicitly discussed. A similar comment was raised by the assessment committee in the previous research review. In response to this, a short questionnaire was distributed to the members of the Faculty Management Team and to some section heads on March 26th, 2021. The purpose of this questionnaire was to verify, next to the personal experience of the members of the ACC, whether research integrity is explicitly discussed within the Faculty, and to collect the viewpoints of the highest level in the faculty hierarchy. The questionnaire can be found in Appendix 2A.

From the responses obtained, the principle of responsibility stood out, for different reasons: on the one side because responsible behaviour leads to upholding the other principles, but also as a point of attention, because it might not always be clear with whom the responsibility lies. It was also commented that data privacy rules and handling of potential conflicts of interest should receive more attention, because disregarding them could damage both the organization and individual researchers. Besides, it was commented that part of the problem with conflicts of interest could be due to conflicting university policies (e.g. when dealing with intellectual property and patent policies). It has also been suggested to clearly explain what is meant by scrupulousness, since it is a term that could have different meanings.

No mention of a specific training was received, apart from a Graduate School course compulsory for PhD candidates. Research integrity does occasionally arise in discussions, at the individual level. It is sometimes discussed during R&D meetings, when the occasion arises and especially in relation to writing and publishing, but not on a regular basis. It was also noted that the Data Management Plan is a good tool to address research integrity.

It is expected that the staff is aware of the Code and Roadmap, but mostly through faculty channels. There do not seem to be specific actions regarding awareness at department level.

The topic of research integrity was by some acknowledged as in need of more specific attention.

Apart from the questionnaire, the ACC also collected feedback on research integrity from colleagues. One of the issues raised was transparency/openness towards the wider academic community. While a data management plan is required for PhD students by TU Delft and for research projects financed by some funding agencies such as NWO, the execution of the plan and the quality of the data is not always checked. The reproducibility of the work from the data may not be guaranteed.

Suggestions for the future

The ACC encourages the Faculty to make discussions about research integrity a regular point of attention and discussion. More specifically, it is suggested that a dedicated training about Research Integrity could be offered to all new employees, and repeated every few years through their transition in all career levels from junior researchers to mentors and leaders, with possible embedment in the tenure track. Research Integrity could also be explicitly mentioned in the R&D meetings, by requesting employees to write a short reflection on it.

Concerning potential conflicts of interest, it is suggested to consider explicitly addressing the issue at the beginning of every department and strategic meeting, by asking the people present whether they have any conflict with respect to individual agenda items. If that is the case, they could temporarily leave the room.

Execution of the data management plan and quality of data could be impartially checked by the faculty data steward to ensure reproducibility of the research work.

Finally, the various screens around the faculty (at the coffee machines, in the corridors) could be used to remind students, staff and visitors about the TU Delft Code of Conduct.

Social safety

Policies and regulations at the TU Delft

The coordination of the TU Delft policies and activities on integrity lies with the Integrity Office. Here, the focus is on social integrity. As part of the Association of Dutch Universities (VSNU), TU Delft designed a statement on social safety in which they speak out against undesirable behaviour. Additionally, this statement mentions the commitment of Dutch universities to provide students, employees and visitors with a safe and respectful environment, where any type of undesirable conducts, such as harassment, aggression, bullying or discrimination are not tolerated.

Social integrity is further addressed in the TU Delft Code of Conduct and its ‘Vision on Integrity 2018-2024’, mentioned earlier. The vision elaborates on the wish to ‘offer employees, students and guests an environment where everyone feels welcome and where everyone treats each other with respect.’ It is stated that all members of the TU Delft community must treat each other with respect, irrespective of their culture, religion, ethnicity, socio-economic background, gender or sexual orientation. The Vision on Integrity also proposes an infrastructure regarding information, regulation, reflection, consultation, investigation and coordination. It is stated that it is of utmost importance that all members of the TU Delft community are aware of the TU Delft’s integrity policy. But also that awareness of existing policies is not enough: rather, students and staff should be encouraged and feel safe to discuss integrity dilemmas. This requires continuous attention for the topic within all levels of the organization and for all dimensions of integrity.

Situations involving inappropriate behaviour, such as intimidation (sexual or otherwise), bullying, aggression or conflicts (personal or work-related) are covered by the TU Delft Regulations for complaints about undesirable behaviour. An employee, student or third party who claims to have been subjected to inappropriate behaviour should file a complaint. The complaint is passed to a complaints committee, which then makes a recommendation to the Executive Board. If necessary, the Executive Board can impose disciplinary measures on the perpetrator. For assistance, advice or support in this area, a confidential advisor is available at the TU Delft. This confidential advisor for undesirable behaviour is an external, impartial person, who ensures adequate help for people that encounter undesirable behaviour.

Additionally, TU Delft has an Ombuds officer for staff who can help individuals or groups of staff to resolve their work-related questions, dilemmas or conflicts. The Ombuds officer acts as an intermediary and is independent and impartial.

Experiences within the Faculty

Although adequate policies and regulations are in place at the university level, the ACC concluded that for social safety – just as for diversity – there is still some discrepancy between what is arranged at national or TU level, and what is operational at the Faculty. Based on their interviews, 85% of reported cases regarding social safety are related to international employees, which means that cultural differences play a significant role. The advisors at the university level indicated that most of the problematic cases at the CEG Faculty are related to intimidation, harassment, and bullying.

Concerns regarding social safety come back in the faculty-specific Medmon statistics, where for the CEG Faculty 25% of the employees indicated that they have experienced one or more instances of undesirable personal treatment by colleagues, supervisors, students and/or strangers. More specifically, the ACC received signals of authoritarian professors not accepting deviations from the general direction they set out for their group. Also more serious cases including patterns of misconduct not being recognized and acted upon by superiors, were reported. Escalation routes are often not used because they are unknown or untrusted. According to the Medmon statistics, only 56% of the employees that experienced undesirable personal treatment reported the incident(s) to their superiors, HR advisor, confidential advisor, or another person.

The confidential counsellor believes that more awareness of the TU Delft Code of Conduct and the importance of third party counsellors must be created. Many people still have no knowledge about the code and under such circumstances, a space is permitted for people to repeat their bad behaviour.

The ACC consequently concluded that there is not enough communication, which negatively affects implementation and the creation of awareness. Additionally, the perception of some of the available information related to social safety is indeed subjective. As an example, the meaning of bullying is not explained, while it could have different meanings to different people. Most people do not intend to make fun of someone and create an uncomfortable environment, but they sometimes do not realize their behaviour is inappropriate within the international community they find themselves in. This lack of information comes from a lack of education and communication. Through PhD candidates, it was brought to the attention of the ACC that due to religious beliefs, functional disabilities, English fluency (accent) and dietary restrictions/ choices, some people feel bullied by colleagues and senior researchers.

Suggestions for the future

A problem that seems common in engineering schools is the lack of communication and interaction. The route to discuss undesired behaviour should be much clearer, something the Integrity Office is working on as well. The ACC stresses that it is important to ensure that especially the people with different nationalities/ religions/beliefs are heard, and feel included.

It is recommended to consider appointing a confidential advisor for the Faculty specifically, and to communicate his/her existence more broadly. Whether faculties should have their own confidential advisor and how to ensure that he/she is well trained and equipped to do the job have been points of debate, however, of which the ACC was unaware. Also the importance of monitoring the situation is raised, where systematic recording by the confidential advisor and/or Ombudsman, action plans, and plans for periodic attention from management is suggested. It is suggested that the listed advices with regard to social safety should also fall under the responsibility of the future CEG Diversity and Inclusion Team.

Presentation to the Management Team

The ACC was invited to present their findings to the Faculty Management Team on May 7th, 2021. During the meeting it became apparent that there are indeed points on which the perception of management versus lower-level scientific employees diverge. The differences were discussed, and the value of the ACC in identifying these differences, was underlined. It also became clear that for some points of attention raised by the ACC, processes were already initiated (e.g. implicit bias trainings). Due to its composition, the committee was not aware of some of the actions already undertaken at the management level.

In the same meeting Prof. Giovanni Bertotti was appointed as the new Diversity Officer of the Faculty. In the months to come, the ACC will be recruiting members for the Faculty Diversity & Inclusion Team, and defining the role and mandate of the team as well as its interaction with the Faculty Diversity Officer.

Summary

The academic culture at our faculty needs to adapt to the transition of our university to a larger, more international, and more diverse organization. This is a positive process, but not one with only positive (side-)effects, and requires supervision and monitoring. Some values are essential and non-negotiable; others will be changed in time. The process needs leadership and professional guidance.

Assembling the ACC was a valuable first step in giving this process the attention it deserves. The mandate and time given to the ACC to do their assessments were (consciously) ill-defined and limited, however. For this reason the ACC explicitly refrained from prioritising their recommendations, and rather limited it to one main suggestion: the establishment of a CEG Diversity and Inclusion Team. All information gathered by the ACC and their suggestions will serve as a starting point for the new team.

Appendix 2A: Short questionnaire about Research Integrity

The upcoming CEG Mid-term Research Evaluation needs to include a discussion about Research Integrity, including suggestions for improvement.
In the 2018 Review, the assessment committee wrote that *"all systems and procedures are in place, but we noticed in the interviews that this topic is not seen as very important in daily practice. No signs of problems were observed at this stage, but we encourage the Faculty to make this a regular point of attention and discussion"*.

In order to form a better picture of current practices across the faculty, we would appreciate whether the members of the MT could answer a few questions.

From the Netherlands Code of Conduct (Netherlands Code of Conduct for Research Integrity), adopted by TU Delft, Research Integrity is explained by the following principles:
1. Honesty
2. Scrupulousness
3. Transparency
4. Independence
5. Responsibility

In addition, the following issues are relevant for research integrity:
6. Data privacy rules
7. How to handle potential conflicts of interest

Questions:
1. In your opinion, which principle/topic of the above requires more attention and why

2. Would you suggest additional points of attention?

3. Is there in your department any training on research integrity for different career stages, and if so what type of training is it?

4. Is research integrity discussed in R&D meetings for scientific staff (post-doc and senior staff)?

5. Do you know whether all scientific staffs are informed about the TUD Code of Ethics and Integrity Roadmap (http://integrity.tudelft.nl)? If yes, how does it happen?

6. Any additional comment:

Appendix 3:
PhD candidates, the (Faculty) Graduate School and related issues*

Background

For more than 10 years, TU Delft has explicitly acknowledged the key role played by PhD candidates for research performance and, in general, for the entire life of the University community. The realisation has grown that the success of a PhD is a **shared responsibility** of the entire University rather than being only dependent on the promotor/co-promotor. Consequently, a holistic effort was needed to unlock the full potential of PhD candidates and to reduce the exceedingly long duration of PhD theses. In 2012, the Graduate School was launched, organised in a central University Graduate School and Faculty Graduate Schools. Key components of the Graduate School are as follows:

1. A series of formalised steps to monitor the progress of the PhD, align expectations and to make sure that the PhD candidate can develop his/her full potential reaching the goal of producing exciting science and thereby becoming an *independent researcher* within four years. These steps include the GO-NOGO meeting typically held 9-12 months after the beginning of the PhD and the 2nd year and 3rd year Progress Meetings (YPM). After some initial resistance and difficulties, most supervisors are now well-acquainted with the new reality and, more importantly, PhD candidates increasingly recognise these meetings as a key opportunity they have to (re)define their project (see below) and realise their ambitions.
2. The **Doctoral Education** (DE) **program** was launched with the goal of strengthening the PhD candidates. In the DE, PhD candidates are required to acquire a number of credits in discipline-related research and transferrable skills. Credits are obtained in a variety of ways, from courses to summer schools, from paper-writing to conference presentation and from MSc thesis supervision to Teaching Assistant activities.

All these activities are supported by a dedicated software package DMA, which allows PhD candidates and other involved members of the University community to access relevant data. Being able to monitor in detail the progress of PhDs has been a key step in the strengthening of the Graduate School and also plays a key role in identifying possible bottlenecks (see below).

Having reached an acceptable level of efficiency, the University and Faculty Graduate Schools have in the last few years stepped up their activities. We acknowledge the full support of the University as a whole and of the Civil Engineering and Geoscience Faculty.

General challenges

The triangle to PhD success

Possibly one of the most important “cultural” changes being pursued is the knowledge that the success of a PhD depends not only on the quality of the PhD candidate her/himself but also on that of the supervising team and of the project structure (Figure 1). PhD development and all related activities are geared to the constant improvement of all three components.

* This Appendix is taken from the Midterm report Civil Engineering 2017-2020. Hence, in this Appendix, terms like ‘visitation’ refer to ‘Civil Engineering visitation’, etc.

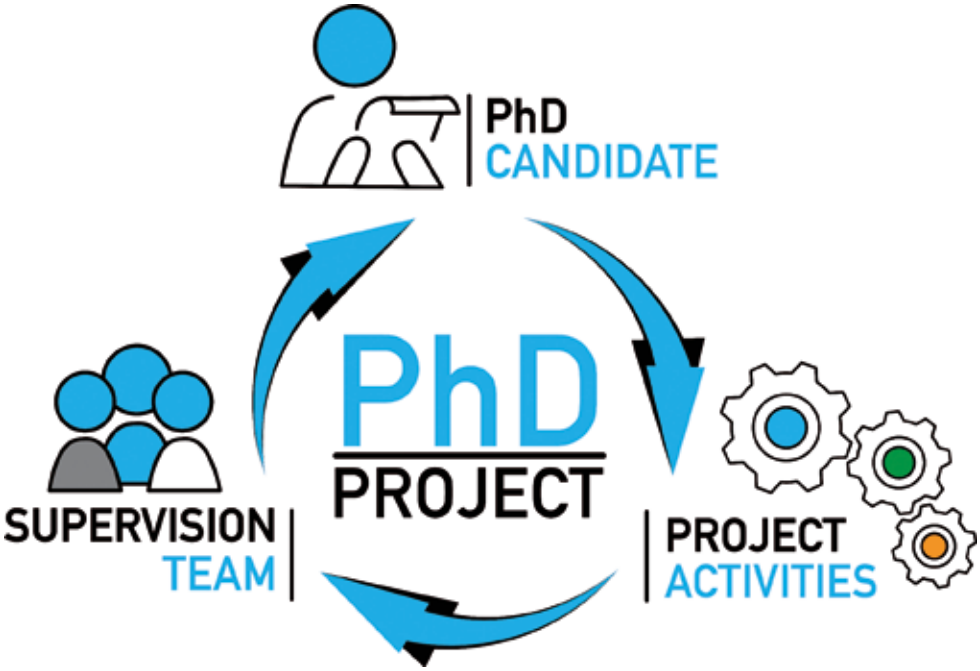


Figure 1 - The triangle of PhD success

Empowering PhD candidates

As a Faculty Graduate School, we believe that empowering PhD candidates and encouraging them to play a proactive role in all meetings and throughout the entire PhD path, is a long-term engagement and a fundamental step in improving PhD success. The Faculty Graduate School is investing a substantial amount of energy in communicating to PhD candidates the notion that they are “captains of their boats” and should prepare meetings and make sure that they have all the information needed. In the view of the Graduate School, empowering PhD candidates is a fundamental component of ensuring the success of PhD projects.

To facilitate this process and to give PhDs an even stronger voice, a PhD council was founded in 2017, composed of PhD representatives of all departments of the Faculty. The PhD council meets on a monthly basis with the Director of the Faculty Graduate School, has organised a number of highly successful PhD days and represents a key bridge between the PhD community on the one side and the Faculty Graduate School and the Faculty staff on the other. As of mid 2020, one of the PhD Council members represents the PhD Council in the CEG Employee Council (CiTG OdC) as an elected member of that Employee Council. Moreover the dean has monthly meetings with representatives of the PhD council.

As a further support for PhD candidates, a system of mentors is in place by which a mentor (a member of staff of the Faculty) is assigned to a group of 10-15 PhD candidates. The FGS has also opened a MS Teams channel dedicated to the best practices developed by the various departments.

Improving supervision

The notion that the success of PhDs is a shared responsibility bears the consequence that the Faculty should take an active role in improving the quality of the supervisors, promotors and co-promotors alike. In the Civil Engineering and Geosciences Faculty, this is implemented in the HYPPR (Half-Year PhD Progress Review) meetings. Twice a year, the Director of the Faculty Graduate School, together with the FGS coordinator, HR representative and the Department manager, meets the Department Chair to discuss the specifics of the progress of PhD candidates. Behind closed doors and in a fully confidential manner, the performance of single promotors is discussed, criticalities are identified and improvement strategies defined. On a yearly basis, the Director of the Faculty Graduate School reports his findings to the Dean of the Faculty, who is the formal “supervisor” of Professors. HYPPR meetings have proven extremely useful tools to identify criticalities and, more in general, in spreading the notion that the Faculty and its Graduate School consider the quality of supervision a first-order challenge.

PhD candidate well-being

The well-being of PhD candidates is obviously key for their success and, thereby, for the success of the University as a whole. Aware of the major investment these individuals make in choosing to perform a PhD in Delft, the (F)GS is fully engaged in ensuring that the PhD path is scientifically and humanly exciting and productive. Major efforts are deployed to make sure that PhD candidates are welcomed in the respective departments and research groups and that they can develop their work as smoothly as possible.

The (F)GS also provides a number of support programmes inclusive of psychological coaching when needed.

These efforts have been further strengthened since the outbreak of the CORONA pandemic with initiatives such as buddy systems and coaching.

The path from PhD selection to successful completion

Selection

Building on the recognition that delays in PhD projects are often associated with an insufficient level of PhD candidates, the selection process has been made stricter and more transparent. A four-eye principle is presently implemented by which selection interviews are conducted by at least two staff members; these rules are now followed by all departments. Members of the Committee are also asked to produce a short description of how the selection took place and what possible points require further attention. Criteria and workflow of PhD selection are extensively addressed in booklets shared with all staff members. To tackle shortcomings and delays associated with insufficient knowledge of the English language, an English proficiency test (at least TOEFL 100 or IELTS 7.0 overall) has been required since the beginning of 2021. PhD candidates are also strongly encouraged to take English proficiency courses during the first year of their PhD.

GO-NOGO and yearly progress meetings

From its beginning, the Graduate School has defined a number of formal milestones in the PhD path to monitor the progress of the project, to identify challenges and, most importantly, to create new opportunities. The FGS has invested significant energy and time in raising the awareness of staff members and PhD candidates alike of the importance of these meetings and encouraging the various stakeholders to use them at their full potential. The message is conveyed that, rather than being a bureaucratic nuisance, these meetings are key opportunities to assess the progress of the project and, at least as important, identify new exciting and challenging goals. For the PhD candidates in particular, these meetings are a key step to align expectations with those of the supervising team and identify weaknesses and opportunities in the project.

The first formal step, typically after four months, is the formulation of a **PhD agreement** between the PhD candidate and supervisors in which the nature of the project and a course time plan is defined.

The **GO-NOGO** meeting is a key step in the PhD path and, more or less, the last moment when a PhD contract can be terminated. Expanding on the more traditional approach, we see the GO-NOGO as an occasion to judge and identify improvements not only for the PhD candidate herself or himself, but also of the other two key components, namely the quality of the supervising team and the structure of the project itself (Figure 1). To facilitate this process, the GO-NOGO meeting is led by a committee composed of at least three members, including the co-promotors and supervisor and an independent member. The promotor is present but is not a member of the committee. The goal of the committee is to judge the potential of the PhD candidate in order to successfully complete the PhD within four years, as well as to identify ways to strengthen his or her development, to identify weaknesses in the project planning, to identify other opportunities which might be taken and to check that all knowledge is available in the supervising team.

It is during the GO-NOGO meeting that agreements are made on, for instance, the number of papers to be published, teaching duties and all other relevant topics.

The **2nd and the 3rd year YPMs** are the next formal steps in the PhD path. They are designed to identify weaknesses and bottlenecks and, even more importantly, to define new and exciting opportunities. Strong emphasis is put on the 3rd year meeting, in which all contents of the thesis should be defined making sure that the thesis is completed within the anticipated four years.
As a Faculty Graduate School, we regularly monitor the quantitative performance of the different promotors in having the GO-NOGO and YPM meetings. As PhD candidates with problems typically have a history of no/few/poor milestone meetings, we also look regularly at the quality of the resulting reports.

Specifics from previous visitation

Dropout rates

High dropout rates have been mentioned as a point of attention in the previous visitation. The data at the moment of writing are shown in Figure 2. The number of PhDs interrupting their path before or immediately after the GO-NOGO is generally <5% and generally stems from the realisation of the candidate that the PhD life is quite different from what was expected, as well as from not-strict-enough selection; in our view, these numbers are physiologic.

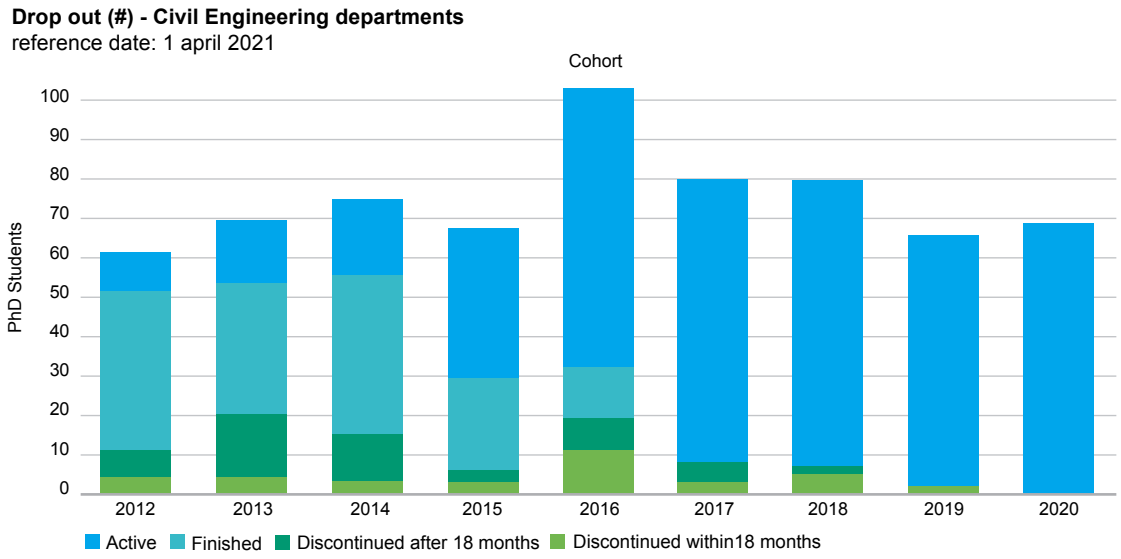


Figure 2 - Status of PhD candidates. Numbers of discontinuations after 18 months of cohorts 2017 and younger have limited value as a substantial portion of candidates has not ended yet the PhD.

The number of discontinuations after 18 months is significant and oscillating. As the University has basically no way of terminating ongoing contracts after the GO-NOGO, these discontinuations reflect decisions of the candidates themselves.[1] To understand more of the underlying reasons, we have conducted some interviews and believe this decision reflects the recognition of candidates that the PhD life is not what they wanted (see box).

Student M decided to interrupt her PhD at the end of the 2nd year. We were somewhat surprised because we, as Graduate School, had no signal that the candidate was experiencing any negative situation. M. has always been a brilliant student, all the way back in high school; she had performed well in an excellent MSc program and, not surprisingly, she was offered various PhD projects within TU Delft. Without thinking too much and without being challenged too much, she simply walked through this wide open door, only to discover that the she did not fully appreciate the somewhat isolated research conducted by a PhD. Having also spoken with the promotor, the lesson we drew is that there needs to be more alignment between expectations of the candidate and of the supervisors.

[1] To increase flexibility, the University has recently decided to split the contracts of PhDs in two parts of 1.5 and 2.5 years.

GO-NOGO Compliance

As mentioned above, the GO-NOGO meeting plays an important role in the development of a PhD candidate and his/her project, indeed far beyond the initial goal of deciding if the PhD candidate is fit to bring his/her project to successful completion. The GO-NOGO plays an important role in empowering PhDs and is key in making aware the supervision team of the shared responsibility of the project. As shown in Figure 3, we observe a significant increase in the number of GO-NOGO meetings taking place and submitted reports. We believe this is a significant achievement of the GS which suggests an important shift in the attitude of the University towards PhD candidates.

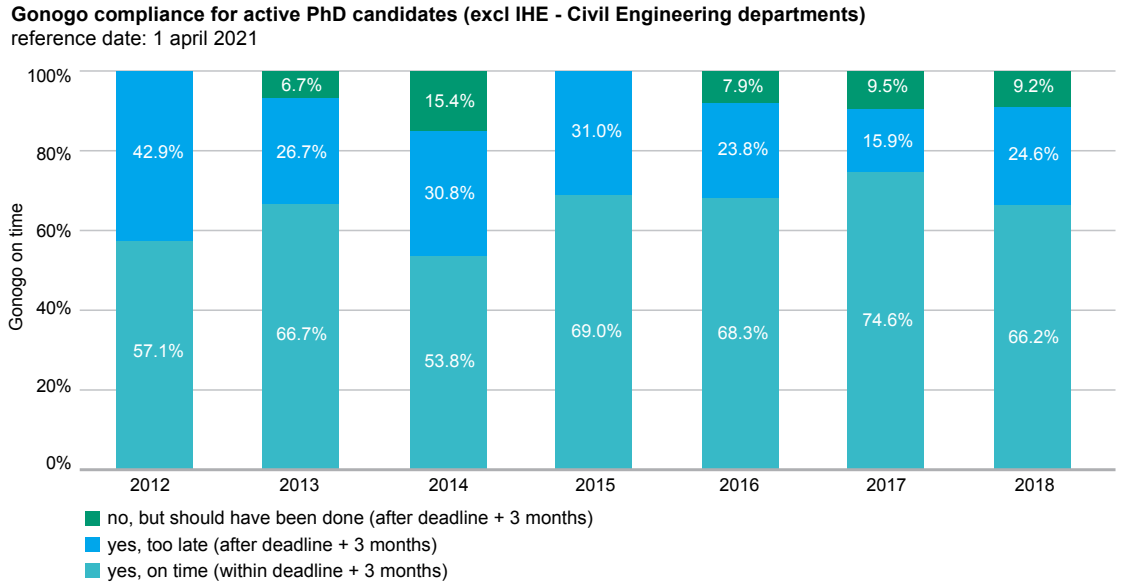


Figure 3 - GONOGO compliance

Homegrown vs PhDs from outside

A remark was made on the “too large percentage of homegrown PhDs”. Our data suggest that this percentage varied in the last eight years between 25% and 35% (Figure 4). In our view, this percentage is far from deserving the attribute of “too large”. We believe that TU Delft MSc students are provided with high-level education and are well-known to staff.

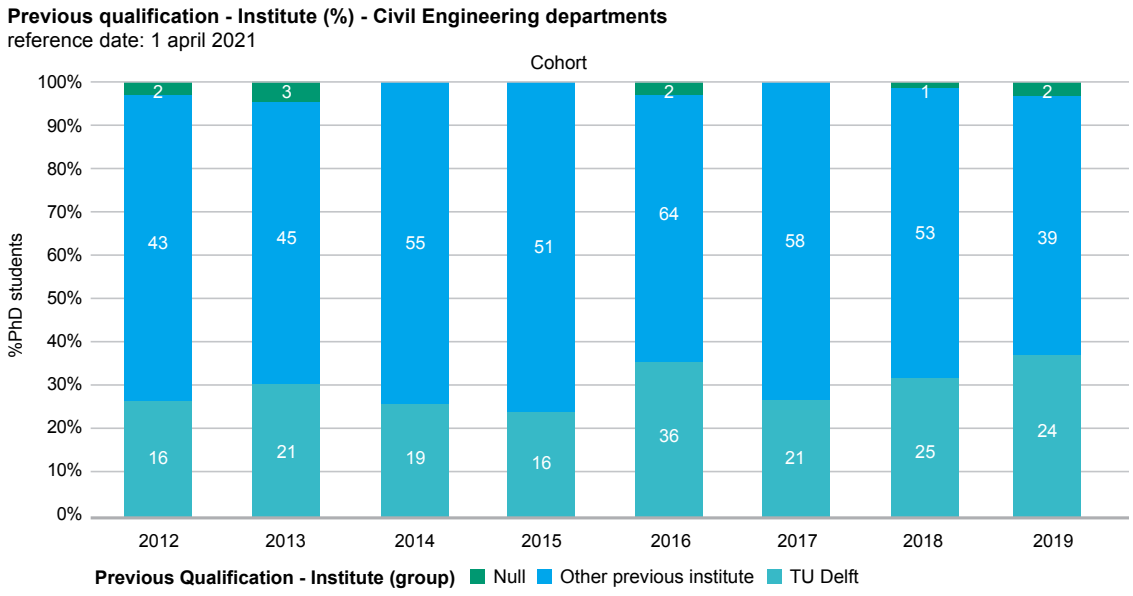


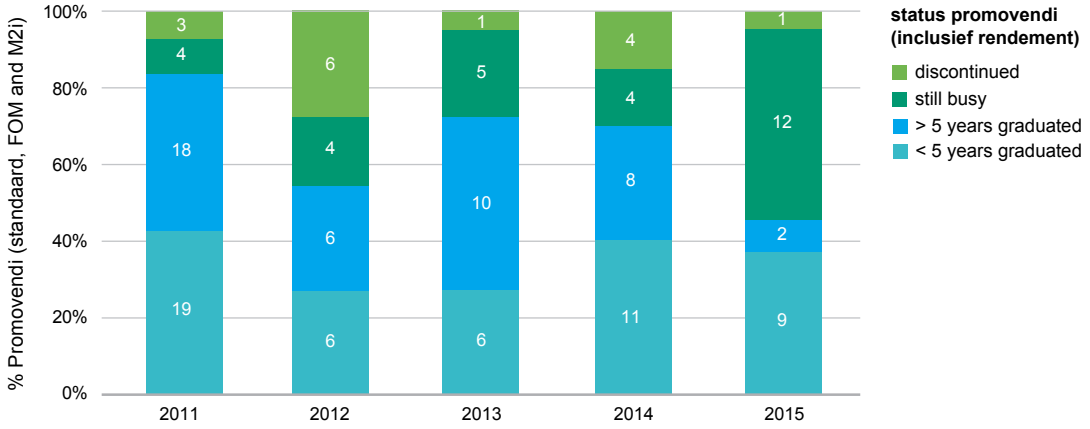
Figure 4 - homegrown vs "external" PhD candidates

PhD duration

The exceedingly long duration of PhD projects is one of the main challenges facing the University and the Faculty. With the partial exception of PhD candidates who pursue their project while working, typically full-time, in industry, we see no justification for an overlong PhD duration. The general approach and the specific actions undertaken have been discussed in the previous parts of this document.

The results shown in Figure 5 can be obviously interpreted in different ways but, admittedly, they do not convey the message we would like to see, namely that the duration time is substantially decreasing. A number of proxies have been presented above which indicates that we are on the right track, but the positive results are still to come. As the first years of the Graduate School (basically until 2015-16) were essentially dedicated to bringing the "machine" to a good level of operation and that limited energy was invested in the issues underlying long PhD duration, we are confident the results will be visible over the next few years.

Status VSNU category Standaard, FOM, M2i - Civil Engineering departments - PhD candidates who discontinued within 18 months excluded
reference date: 1 april 2021



Status VSNU category Standaard, FOM, M2i & Bursaal - Civil Engineering departments - PhD candidates who discontinued within 18 months excluded
reference date: 1 april 2021

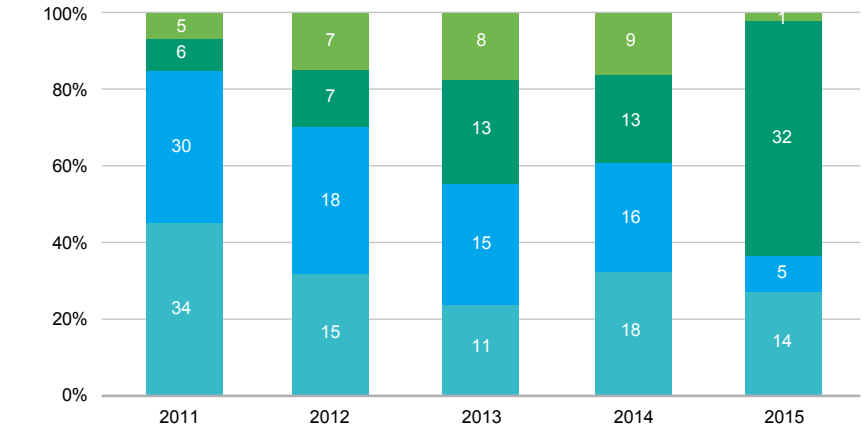


Figure 5 - Data on PhD duration

Specific action has been taken to decrease the impact of delays associated with the COVID-19 pandemics on PhD completion. While we consistently communicated the message that it is the responsibility of the supervising team to identify activities alternative to those made impossible by the pandemics, a scheme has been implemented allowing a three-months extension for PhDs in specific and grave need.

Evaluation, perspectives and future challenges: the big picture

The various initiatives taken by the (F)GS to uplift the PhD performance have been mentioned in the previous parts of this document and will not be further elaborated. Looking at larger trends inside the University and the surrounding society, we believe a number of developments can be defined which will require some reflection on our perception of PhDs. We believe that these challenges are opportunities for us to improve our mission.

- Improving the PhD experience requires a major cultural shift towards the knowledge that PhD success is a *shared responsibility* of all stakeholders, namely University staff and PhD candidates. Solving some of the problematic issues identified in these years requires a significant improvement of our Academic Culture, which includes topics such as diversity, integrity and human resources. In this respect, improving PhD performance is organically linked to the work of the Academic Culture Committee and related initiatives.
- At TU Delft as in other universities, the goals of a PhD as well as the path to reach them are only vaguely defined. A graphic illustration of this is the large variety of guidelines as to the number of papers PhD candidates are required to publish and how strict these requirements should be. In doing this, the University “outsources” the judgement to the quality of a thesis to journals and respective editors. Is this a welcome development or should the University develop new, more informative forms of judgement of the PhD thesis?
- The Academic community agrees that the fundamental goal of a PhD trajectory is to form an independent researcher within the prescribed four years. Obviously, this can happen at different levels and requirements of the promotor to “achieve the highest standard” should not translate in substantial delays in PhD completion.
- TU Delft, like other technical universities, has a substantial number of PhD candidates who write their thesis while working in companies. While these candidates fulfil a necessary bridge function between university and industry, the question should be raised as to how far this model adheres to the generally accepted idea that a PhD candidate should obtain his/her own data and, for instance, not simply use data generated by the candidate and his/her company.
- In a large number of occasions, PhDs have expressed their frustration about the insufficient transparency of the University and on the rights they have. A similar concern is regularly manifested by postdocs and assistant professors. In the view of the FGS, there is a lot of mileage to be gained in this domain. Widespread and real transparency can have a major impact on the motivation of PhD candidates and, thereby, improve their overall experience.

Appendix 4:
Observations and Recommendations of the Review Committee 2008-2014

In 2015, an international review committee conducted an assessment of the research of the geo-departments Geoscience and Engineering (GSE) and Geoscience and Remote Sensing (GRS) of the faculty Civil Engineering and Geosciences (CEG). The committee made a number of observations and recommendations, which we summarize here, and we indicate the actions taken in the review period 2015-2020.

It should be noted that in the previous evaluation, GSE was assessed as four independent research units (Geology, Geophysics, Geo-Engineering and Geo-Resources) and GRS as two units (Geodesy and Atmosphere). The six units together formed the 'Geo-cluster'.

In the following, page numbers refer to the report of the review committee.

Societal Relevance

Observations and recommendations (pages 12, 26, 33):
…. compared to the scientific part of the mission of the departments and research units, there seems to be much less coordination of, and reward for, the work that staff members do in the broader societal domain. While many staff members are indeed enthusiastically and successfully disseminating their research results (e.g. developing teaching material for high schools, obtaining visibility through media appearances), the initiative for such activities seems to be left primarily to the individual researcher. The committee suggests that the departments and units undertake more structural efforts in developing and monitoring strategy plans, in order to ensure that there is a more systematic and rational approach to the demonstration and realisation of public outreach... include certain metrics to assess the unit's performance ..., as well as incentives for its research staff … be more alert to media opportunities.

Response and actions taken:
GSE: The theme approach of the department has led to significantly more focus on societal relevance and public outreach (GSE Section 3.1 and Appendix A).
GRS: Increasing our visibility was a strategic aim in 2015-2020 (GRS Section 2.2.5, and GRS 3.2.5). The realization of outreach is demonstrated by our collaborative research projects (Table J.6, Table J.7) and contract research (J.7B5). The feedback between visibility, societal relevance, scientific quality and financial viability is outlined in Case Studies H2, H3 and H4.

Societal applications are reported via Stories of Science (for GSE and GRS).

PhD programme

Observations and recommendations (page 13):
... this scheme for cooperation in Earth Sciences research and training of PhD candidates of the joint Netherlands universities is disassembling gradually to be (partly) replaced by new graduate schools for each individual university. The review committee urges that the positive aspects of the old system (e.g. easy interaction of PhD candidates of different universities, joint scientific and educational activities, access to international scientific networks as well as to public and private stakeholders) are sustained in the newly evolving system.

Response and actions taken:
We don't recognise the problem. Arguments: Interaction is more and more international than national; international network is accessed otherwise; as we do have the GS, this would also mean keeping two systems running.
GSE: Supervisors stimulate PhD students to participate in international summer schools such as the Alert-Geomaterials and Cargèse Passive Imaging.
GRS: PhD students regularly participate in courses and summer schools offered at other universities or international conferences/workshops. Supervisors stimulate access to their international scientific networks through research collaboration and participation in multi-institute, often international experimental campaigns.

Observations and recommendations (pages 18, 19):
Finishing within four years is – as yet – very rare, below ten per cent. The time required for a student to complete a PhD in any of the six research units is of concern to the committee. Apart from the low graduation rates within four years, only about half of the PhD students finish within six years. ... The committee was pleased to learn that the two departments have ... made serious efforts to substantially improve completion times. It is too early to comment on actual results, but the committee believes it is important to facilitate and incentivize PhD completion within a four-year time frame. This might be accomplished by making earlier Go/NoGo decisions, requiring the development of clear research plans, and/or considering PhD student graduation statistics in faculty assessments.

Response and actions taken:
Major steps have been taken within the faculty and the departments GSE and GRS (such as improving the selection process, a new GO-NOGO structure, yearly progress meetings, see section on PhD policy in the General introduction). The percentage of graduations in less than 5 years during the review period is 61% (GSE) and 33% (GRS). We aim to continue this improvement during the next review period. PhD policy and training was a strategic aim at GRS (GRS Section 2.2.4, Section 3.2.4 and Case Study H1).

Female staff

Observations and recommendations (page 20):
The lack of female faculty members in all units has drawn the attention of the committee. It believes that more effort should be placed on female hires. One approach for this, ... compatible with the PI system, is to expand the definition of 'research fit', while not compromising on quality. ... Alternatively, the units might consider taking full advantage of existing programs for recruiting female faculty, such as the Delft Technology Fellowship.

Response and actions taken:
We have implemented concrete activities to increase the number of female hires (such as participating in the Delft Technology Fellowship programme, aiming for at least 50% female candidates for Sector Plan and van Rijn positions, see section on Human Resources policy in the General introduction). The percentage of female scientific staff in 2020 is 21% (GSE) and 18% (GRS). We aim to continue this improvement during the next review period.

Funding

Observations and recommendations (page 10):
... a further decrease of direct university funding could compromise the research infrastructure itself, the continuity and quality of which are difficult to secure with 'soft money'. ... a situation in which the running of laboratory and computational facilities is solely dependent on project funding is a liability. [The committee] would therefore advise the Faculty to earmark solid funding for the maintenance of core facilities.

Response and actions taken:
GSE: Research facilities (equipment and technical staf) are taken into account in project acquisition as much as possible, and when managing project and research portfolio. Since 2019, there is a positive result on budget used for investments in research facilities. Large infrastructure investments were acquired within the EPOS-NL and the GeoLab projects (e.g. DAPwell, geotechnical centrifuge, GSE Section 5.5).
GRS: Large infrastructure investments were acquired for the Ruisdael observatory (GRS Section 3.2.3). The university's own contribution in these large infrastructure investment calls is up to 25%, of which half is covered by the faculty. The faculty has done a one-time investment in infrastructure from faculty reserves in 2021.

Observations and recommendations (page 10, 19, 20):
... the committee is particularly worried about the lack of start-up funding available for newly hired staff. The fact that the departments do not have the means to provide new staff with competitive start-up packages puts the reviewed units at an international disadvantage. Having the ability to provide promising candidates with start-up funds could prove vital to recruitment efforts and therefore for maintaining research quality.
… the committee did not feel that sufficient resources are provided to enable young faculty to thrive as they develop their own research areas. ... In US universities, ... award startup funds ... might cover the expenses of two PhD students and/or post-docs for a period of 2-3 years. Such funding, or something similar, is important to facilitate success in the PI system... The committee recommends the units to consider introducing this, or a similar funding mechanism, as they transition to the PI system.

Response and actions taken:
Since 2020, starting faculty get a start-up package which allows the appointment of 1 PhD candidate (for Assistant Professors) and entails 200 k€ (for Associate Professors), respectively.

Observations and recommendations (page 11):
The extent to which the participating research units are, effectively, still dependent on direct funding, varies. This could signal that some research units have more successfully adapted to the new funding reality than others.

Response and actions taken:
GSE: GSE did not depend much on direct funding. This observation does not apply to GSE.
GRS: Financial viability was a strategic aim for GRS (GRS Section 2.2.3, Section 3.2.3). We have succeeded in increasing our total funding, and reducing our dependence on direct funding by increasing our income from research grants, contract research and other sources.

Observations and recommendations (page 11):
… connect with the so-called topsectoren, … which attract an increasingly large part of the available governmental funds.

Response and actions taken:
GSE: Geothermal theme has been very successful in attracting funds (e.g. RVO Warming-UP). Water safety has been an important topic in the Geo-Engineering section. The theme approach has demonstrated that we can significantly strengthen our position in this field.
GRS: While not being involved much in the topsectors as such, we have attracted funds from large national programs, such as the National Science Agenda NWA and DeepNL.

Observations and recommendations (pages 23, 27):
Risk for GSE of decreasing external funding from petroleum industry if the oil price remains as low as it is today

Response and actions taken:
GSE: This issue has been a major driver for our strategic changes in the review period (GSE report, sections 3.2 and 5.5). The financial figures show that we are doing very well.

Organisation of the Geo-cluster

Observations and recommendations (page 17):
... the committee is inclined to identify the two departments or even the Geo-Cluster as a whole as research units in the sense that they are equipped to pursue a strategy of their own in terms of size and resources. During the site visit, the committee learned that the Faculty will discuss and implement a new Strategic Plan.

Response and actions taken:
Indeed the two departments GSE and GRS are now the research units.

Observations and recommendations (page 17):
It is difficult to assess the strategy that units have in place in order to achieve their goals in the years ahead, or the relation of each unit's strategy to the faculty-broad Strategic Plan document in development. It is recommended that each unit with enough mandate and resources to pursue a strategy of its own develops one as soon as possible for the next 5 to 10 years.

Response and actions taken:
This observation is rooted in the set-up of the evaluation in 2015. With the departments GSE and GRS now being the research units, we have been able to define clear strategic plans for these units. These plans are aligned closely with the faculty strategy, both in research as well as education.

Integrity / Data management

Observations and recommendations (page 19):
new employees of the Geo-Cluster are made aware of the Code [of Ethics] during an introduction meeting.

Response and actions taken:
With the increase in staff numbers because of the additional funding, much effort was invested in introducing new staff to the systems and culture of the university. This process however needs to be improved as it is currently rather ad-hoc. Currently actions to improve this are being undertaken in the faculty by HR. A pilot is running in the departments of Hydraulic Engineering and Water Management.

Observations and recommendations (page 19):
the Geo-Cluster started a pilot with regard to data management

Response and actions taken:
GSE hired a dedicated data manager (GSE Section 5.3), in order to support data management activities from the proposal stage onwards. This function is closely linked to the university's data stewards, in order to ensure embedding in university services and policies.

Observations and recommendations (page 19):
awareness of and commitment to research integrity should start at the earliest stages of any academic career: in class

Response and actions taken:
The Graduate School provides in-class instruction on topics including research integrity. However, PhD students' awareness of, and commitment to research integrity increases during their PhD study as they are faced with real dilemmas. Supervisors share their experience and expertise to guide PhD students through these aspects of academic research.

Detailed recommendations per unit

The committee made several detailed observations and recommendations for the original units Geology, Geophysics, Geo-Engineering, Geo-Resources, Geodesy and Atmosphere. Most of them have been addressed in the review period, and recommendations such as ‘increasing the size of this unit would help to reach its ambitious vision’, ‘cooperation with the other units needs to be reinforced’ have been addressed by integrating the original units into the new units GSE and GRS.

Appendix 5:
TU Delft Policy

TU Delft Open Science Programme

Open Science is creating new forms of scientific interaction that were impossible or undreamed of in an earlier age. This has a strong impact on core academic processes like research, education and innovation. It is, for instance, easier to replicate an experiment if the relevant data sets are digitally available to any scientist who wishes to corroborate her colleague's findings. Delft has a long history of engagement with Open Science. Yet, with its Open Science Programme 2020-2024, Research and Education in the Open Era, TU Delft wishes to take Open Science to the next level: a situation in which Open Science has become the default way of practising research and education, and the "information era" has become the "open era". It is TU Delft's ambition to be frontrunner in this revolutionary process. This is reflected in the TU Delft Strategic Framework 2018-2024, with "openness" as one of its major principles.

The TU Delft Open Science Programme 2020-2024 tackles all areas of scholarly engagement where restrictions limit the flow of academic knowledge. It proposes new approaches to the processes of research, education and innovation, with a strong focus on transparency, integrity and efficiency.
The programme, updated in 2021, consists of seven interrelated projects:

- Open Education;
- Open Access;
- Open Publishing Platform;
- FAIR Data;
- FAIR Software;
- Citizen Science; and
- Open Hardware.

Figure 1 - TU Delft Open Science Programme 2020-2024

The projects are aimed at creating and disseminating various types of resources for the benefit of TU Delft researchers, teachers and students, as well as the general public. They will range from educational materials and software to a publishing platform. All outputs of the programme will be as 'FAIR' as possible: findable, accessible, interoperable and reusable. Key policies, guidelines and services in this domain include:

- TU Delft Policy on Open Access Publishing
- TU Delft Research Data Policy Framework
- TU Delft Research Software Policy
- Support by the team of TU Delft faculty data stewards.

PhD Policy and Training at TU Delft

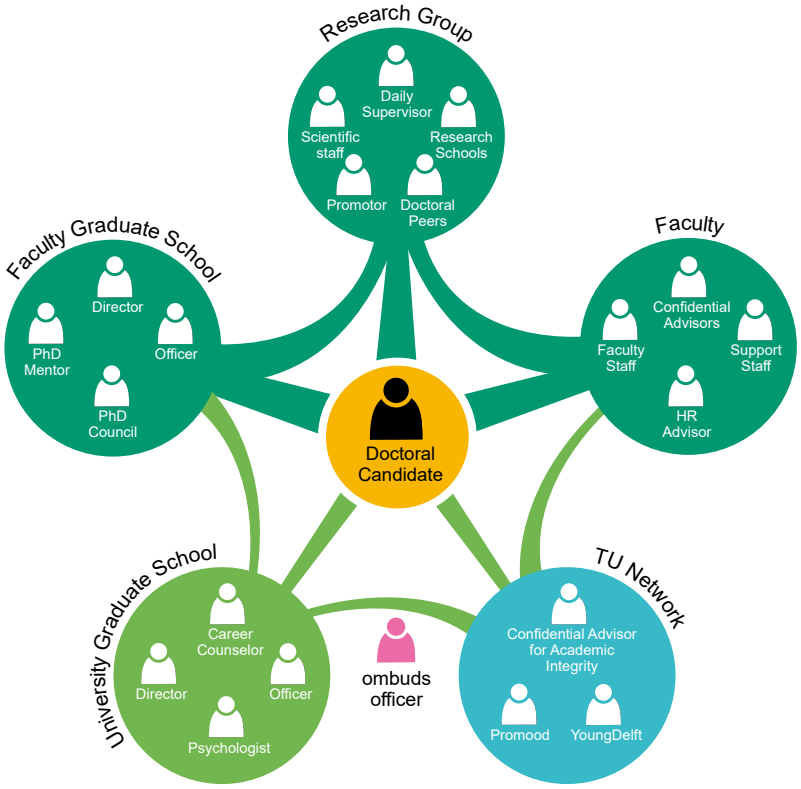
The TU Delft Graduate School prepares and trains doctoral candidates to become highly qualified, autonomous and leading researchers and skilled professionals. The Graduate School is composed of the TU Delft Graduate School and the Faculty Graduate Schools. The support organisation comprises a single university-wide Graduate Office and one Graduate Office per faculty.

The Graduate School coordinates, on behalf of the Board for Doctorates, the appointment of promotors and the evaluation and defence of doctoral dissertations. It also provides an overview of the framework and regulations that are related to obtaining the degree of Doctor at TU Delft. In this process a number of terms and conditions need to be considered[1]:

- Situation "I am a PhD Candidate"
- Recruitment & selection PhD candidates
- General onboarding information (doctoral candidate & support staff)
- Registering a new PhD candidate (support staff)
- Doctoral Education Programme (doctoral candidate & supervisor)
- Research Data Mangement (doctoral candidate)
- Doctoral Monitoring Application (DMA) (doctoral candidate & supervisor)
- PhD Develoment Cycle (doctoral candidate & supervisor)
- Support & Supervision (doctoral candidate & supervisor)
- Doctoral Regulations & Defence timeline (doctoral candidate & supervisor)
- Copyright & plagiarism scan procedure PhD (supervisors)
- After your PhD (doctoral candidate)
- PDEng programmes
- Board for Doctorates

The TU Delft Graduate School Board consists of the Graduate School Director (chairman, vice-rector), the Rector Magnificus (vice-chairman), and the directors of the faculty Graduate Schools. The faculty Graduate Schools coordinate the faculty PhD policy, which consists among other things of guidelines for the selection and interim evaluation of PhD candidates, support for promotors and the objectives and guidelines for research and discipline-specific courses. The below figure 'Doctoral candidate in the centre' illustrates the position of a PhD candidate and the people that play a part in research group, at faculty, at TU Delft and in the TU network.

[1] Many of the following are links to documents on the TU-Delft intranet. The documents are available to the committee members upon request via the secretary of the committee.



Academic Culture

Openness, (social) safety and inclusivity at TU Delft

TU Delft strives to be both a leading university and a great place to work. At the heart of this lie our core values: Diversity, Integrity, Respect, Engagement, Courage, and Trust (DIRECT), as described in the 2020 Code of Conduct. The core values are embedded across the TU Delft community and manifest in how we work, study and socialise together.

The coordination of the TU Delft policies and activities on integrity happens at the Integrity Office, established to help the TU community with their questions on integrity, and what to do in the case of a specific query or complaint. The portfolio Social Integrity has a dedicated policy advisor whose remit includes topics such as social safety, (un)desirable behaviour, well-being and health. The topics diversity and inclusion are shared with the Diversity & Inclusion Office, with whom the policy advisor on social integrity is to work closely together. Key policies, guidelines and services in this domain include:

- The TU Delft Code of Conduct
- The TU Delft Regulations for Complaints Concerning Undesirable Behaviour and Complaints committee for undesirable behaviour
- The confidential counsellors on undesirable behaviour
- Ombuds office for staff
- Faculties, departments, research institutes & chairs can approach the Integrity Office and D&I Office for advice and collaboration on reinforcing social integrity
- HR offers the Social Safety @TU Delft programme, an integrated programme on tackling undesirable behaviour by focusing on working together to achieve a positive and safe working environment for everyone.
- HR and the Health Coach Programme (HCP) are offering individual coaching on workload and vitality.

Research integrity at TU Delft

One of the three portfolios of the TU Delft Integrity Office is Academic Integrity. As with Social and Organisational Integrity, the portfolio has a dedicated Policy Advisor whose remit includes issues around Research Integrity, Research Ethics and Educational Integrity. The Integrity Office works closely with research units on research ethics and integrity. Key policies, guidelines and services in this domain include:

- The TU Delft Code of Conduct
- The TU Delft Regulation on Complaints about Research Integrity
- The TU Delft Regulation on Human Trials
- The confidential counsellors in Research Integrity, who can be approached for confidential advice on research integrity issues
- Formal complaints can be made to the University's Research Integrity Committee
- Advice on Human Research Ethics is provided via the dedicated HREC committee
- Faculties, Departments, Research Institutes & Chairs can approach the Integrity Office for advice and collaboration on developing training, guidance and practical tools for embedding Academic Integrity into good research practice
- The Integrity Office also provides specific expertise in the European and Netherlands Codes of Conduct for Research Integrity – the first of which will be essential to Horizon Europe funding and the latter of which is regarded as critical to the Netherlands Research funding body NWO

Human Resources Policy

Diversity & Inclusion at TU Delft

At TU Delft we embrace diversity and aim to be as inclusive as possible. We follow The Universal Declaration of Human Rights, believing that "All human beings are born free and equal in dignity and rights." Hence, the differences between humans ought not diminish our respect for each and every individual as equally worthy of our consideration. This concerns differences in socio-economic, cultural or religious background, nationality, gender, sexual orientation, age, physical appearance and ability as well as roles and positions. Put positively, the joining of diverse perspectives is an aspect we want to promote with our activities. These differences add value - not only to our daily lives but also to the work we do together. We should therefore protect and embrace the diversity within our community.

The TU Delft has founded a Diversity & Inclusion Office in 2021 with dedicated policy advisors on these topics. They are to work closely together with the policy advisor on social integrity at the Integrity Office. The first focus of the D&I Office is on the implementation of the "Terms of Reference Diversity & Inclusion TU Delft, 2018-2024".

Talent management at TU Delft

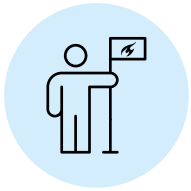
TU Delft aims to attract and recruit talented people, create excellent teams and give employees the room to discover and develop their talents. TU Delft endorses the principles of the European Charter for researchers and European Code of Conduct for the recruitment of researchers and has been awarded the HR Excellence in Research logo.

Researchers are encouraged to develop themselves in the areas of research, education, valorisation and leadership. Working in (multidisciplinary) teams with talented colleagues, good supervision and an open learning climate are important to this. TU Delft sets high standards for the English competency of the teaching staff and offers training to improve English and learn the Dutch language. TU Delft expects that everyone displays personal leadership in performing their role. Most staff also have a role as a leader – leading a team or a project, supervising or helping students or colleagues, or implementing change. This requires good leadership skills, built on professionalism, collaboration and openness. We build a stimulating and motivating work environment in which everyone can perform at their very best. Leadership skills training is offered at different career stages. To get a good insight in future needs in resources and training the HR departments offers departments the possibility to make a strategic personnel plan. The strategy of the department is matched with current personnel and future needs.

Appendix 6:
Leadership profile

4 leadership roles

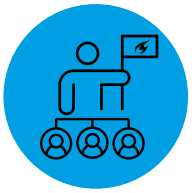
1. PERSONAL LEADERSHIP



2. LEADING A PROJECT OR TEAM

3. LEADING A PROGRAMME OR MULTIPLE TEAMS

4. LEADING AN ORGANISATION



Personal leadership by all

As a staff member of TU Delft, in your own role and on the strength of your expertise, you contribute to science, education, innovation and service provision. As such, you display personal leadership in performing your role as best you can. You possibly also have a role as a leader – leading a team or a project, supervising or helping students or colleagues, or implementing change. This requires good leadership skills, built on professionalism, collaboration and openness. This is the way we build a stimulating and motivating work environment in which everyone can perform at their very best.

This makes life pleasant for you and for those around you. In addition, we need this to be able to contribute to TU Delft's vision: Making a contribution to solving global challenges by educating new generations of socially responsible engineers and by pushing the boundaries of the engineering sciences.
The way in which you can develop your leadership skills is something you discuss with your manager during your development meetings. Read here about the components that form part of the leadership profile, the various leadership roles, and how you can develop your personal leadership skills. See the back of this leaflet for the behaviour that TU Delft expects of you personally and of you as a leader.

The development of your personal leadership skills is built on our core values: **Diversity, Integrity, Respect, Engagement, Courage and Trust (DIRECT).**

The six components of the leadership profile

OWNERSHIP AND COLLABORATION

1

You take responsibility and collaborate with colleagues towards achieving good results.

VISION AND STRATEGY

2

You have vision and are able to get others on board, you set goals and implement them.

SELF-AWARENESS AND SITUATIONAL AWARENESS

3

You consider your actions and are open to the ideas of others. You are aware of developments in your field and in the organisation, and know how decisions are made.

TRUST AND INTEGRITY

4

You have integrity. You behave in a committed and transparent manner. You create an inclusive and diverse work environment which allows everyone to function optimally.

ATTRACTING AND ENCOURAGING TALENT

5

You focus on spotting, attracting and developing talent.

INITIATIVE AND COURAGE

6

You make decisions, show initiative and instigate change.

How can you develop your leadership skills?

The back of this leaflet lists a description of the behaviour required in each leadership role and for each component.

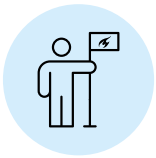
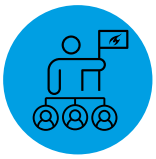
Self-reflection
Read through the leadership profile and consider where you do and do not (yet) exhibit this kind of behaviour.

Feedback
Engage in dialogue with other people, for example your supervisor, a colleague, someone who is receiving your guidance or supervision. Ask these people to provide feedback based on the leadership profile. You could also conduct a team discussion or ask for 360-degree feedback.

Development
Consider what aspects you would like to develop and what you would need for this.
- What experience would you like to gain? Examples might include participating in a project, committee, conference or think tank.
- What training would you like to take in order to develop your competences and increase your effectiveness? It is important for the training to be interactive and to focus on your own situation and learning objectives.
- Who would you like to learn from? Consider an exchange with colleagues and peers in your field and meetings with a mentor or on-the-job coach.

Discuss your leadership profile and your development needs with your manager. You could also ask your HR advisor for advice.

TU Delft

The six components of Leadership	4 Leadership roles			
	1. PERSONAL LEADERSHIP 	2. LEADING A PROJECT OR TEAM 	3. LEADING A PROGRAMME OR MULTIPLE TEAMS 	4. LEADING AN ORGANISATION 
	Focus on personal leadership in own role and position. Applies to every single staff member.	**Focus on leadership in relation to managing others, projects or changes.**	**Focus on personal leadership when directing groups, programmes, movements and partnerships, within and beyond TU Delft.**	**Focus on administrative leadership. Represents TU Delft in the national and international context.**
1  OWNERSHIP AND COLLABORATION Taking full responsibility, achieving results, working together.	• Where necessary, ensures others are aware of his/her own activities. • Assists colleagues when requested to do so. • Takes an active interest in the specialisation, motivations and interests of others he/she is collaborating with. • Shows respect towards others and their work. • Takes responsibility for the work and achieves results. • Shares successes and involves and acknowledges colleagues who have made a contribution.	• Exchanges information, knowledge and ideas with staff members/colleagues at his/her own initiative. • Identifies problems within the team and applies him/herself to solving these together with others and achieve results. • Is aware of, respects and understands mutual interests.	• Helps colleagues in determining objectives that are not necessarily in their own interest. • Initiates collaboration between different groups in order to achieve results together. • Creates a context in which mutual understanding and respect can be taken for granted.	• Focuses on actions and projects involving productive and constructive collaboration with other divisions or organisations. • Brings together the interests, actions and activities of different parties in order to achieve joint results and create a win-win situation.
2  VISION AND STRATEGY Having vision, implementing it, influencing others and having an impact by taking risks.	• Understands and highlights the broad outlines of his/her own group/team's objectives, within the wider context. • Is able to recognise other people's interests.	• Converts project/department strategy and goals into a course for his/her own research and education and/or own project team. Encourages others to contribute ideas to this. • Sets long-term objectives and develops scenarios to enable the team to achieve them. • Thinks several steps ahead and acts accordingly.	• Has a clear picture of the strategy of the department/faculty/service department, formulates appropriate objectives, works towards them and sets the chosen course in a way that inspires others. • Encourages others to do the same.	• Provides the organisation with direction by translating (societal) developments into new directions in the faculty. • Initiates large-scale movements within and outside the organisation and gets others on board. • Promotes synergy.
3  SELF-AWARENESS AND SITUATIONAL AWARENESS Reflecting on one's own actions and being open to ideas and comments from others, from an independent perspective. Awareness of the specialisation, organisation and the influencing and decision-making processes, and responding to these.	• Reflects on his/her own role and own personal development. • Is aware of his/her own behaviour and how it affects those around them. • Shows that he/she can critically assess and modify his/her own behaviour where necessary. Is open to feedback. • Is aware of his/her immediate surroundings, has insight into how the department is organised, an understanding of other people's interests and points of view and the ability to act accordingly. • Organises feedback on his/her own actions.	• Is aware of his/her own intrinsic motivation and the direct/indirect impact this has on their surroundings. • Shows exemplary behaviour, courage and resilience. • Is aware of decision-making processes and how they are influenced. • Is visible within the organisation to the departmental director, dean, director and colleagues from other (service) departments. • Knows and respects other disciplines and recognises	• Reflects on the development of others and his/her own role in their development. • Shows an understanding of group dynamics, including the impact of his/her own behaviour, and acts accordingly. • Encourages others to reflect on their own behaviour and be aware of their own motivation. • Is a discussion partner on strategic subjects and can generate leverage in this respect.	• Uses forces from within and outside the organisation to achieve strategic goals and create broad support. • Provides administrative support and backing for ideas developed and implemented in the faculty/service department. • Creates team spirit within TU Delft.
4  TRUST AND INTEGRITY Acting with integrity, expertise, commitment and transparency. Creating an inclusive and diverse working environment in which everyone can perform at their best.	• Speaks respectfully to others, also when disagreeing. • Provides accurate information to others, even if it is to his/her disadvantage. • Respects the values, standards, knowledge and skills of others. • Recognises and utilises what others have to offer. • Shares relevant information so that trust can grow. • Acts reliably (do what you say and say what you do).	• Safeguards the integrity, expertise, commitment and transparency of his/her own actions in research, teaching and in the group. • Is transparent about what is and is not part of his/her own area of expertise; encourages others to act in the same way. • Facilitates and creates a diverse group, and encourages everyone to perform to the best of their abilities. Provides a safe social environment. • Makes sure that agreements about duties and powers of authority are clear. • Gives feedback to people from the group and is willing to accept feedback; encourages and motivates others to do the same.	• Raises matters of integrity. • Shows others how to be committed and transparent, as well as being trustworthy and knowledgeable, and how to discuss these issues. • Gives staff members room to question authority and content, and shows that disputes are not settled by power and position. • Communicates the intended goals and results with stakeholders and encourages team members to achieve them together.	• Ensures an environment in which questions of integrity can be discussed. • Acts on violations of integrity. • Is a visible example of acting with integrity to people from both within and outside the university. • Widely promotes the virtues of a diverse organisation, stimulates an inclusive work environment and explicitly raises this subject at various levels.
5  ATTRACTING AND ENCOURAGING TALENT Focusing on spotting, attracting and developing talent.	• Creates a good atmosphere (space, trust and attention), in which others are encouraged to make use of and develop their talents. • Takes care of rapid induction of new colleagues and ensures they feel at home within the team. • Celebrates successes with others and ensures that everyone's contributions are recognised.	• Creates opportunities and encourages colleagues to take full advantage of them. • Puts others in the spotlight. • Focuses on identifying and attracting talent and creating diverse teams.	• Gives talented staff members the chance to grow to a level that may even exceed his/her own level within or outside the organisation. • Encourages colleagues to be visible in the organisation as well as beyond. • Is always actively scouting for talent.	• Always plays an active role in developing and attracting talent for the organisation and creates the right conditions and context for talent recruitment and development.
6  INITIATIVE AND COURAGE Taking responsibility, making decisions and instigating changes.	• Flags up issues and comes up with ideas and proposes strategies at his/her own initiative. • Initiates activities and takes the lead. • Takes responsibility and dares to take risks, understands his/her own impact on decisions.	• Recognises opportunities for improvement, innovates within his/her own specialisation, challenges the status quo. • Organises conferences and network meetings. • invites speakers and is impactful. • Dares to stand out, shows determination and gets things done. • Is visible and active within relevant networks.	• Is visible in the international academic or professional field, brings about changes in the department/faculty/service department. • Takes responsibility in order to increase his/her own impact in a broader context and enable others to do so.	• Explores and utilises new partnership opportunities and applications in teaching, research and valorisation for faculties (and similarly for service departments), both within and beyond TU Delft, beyond the boundaries of faculties and universities. Boosts these opportunities by applying focus and prioritisation. • Takes an active part in improving the university.

Appendices
Department of Geoscience and Engineering

Appendix A:
Case study – Geothermal Science and Engineering Theme

Introduction

The Geothermal Science and Engineering theme (hereafter Geothermal theme) was formed in 2017 within the Department of Geoscience and Engineering and is one of the focal points for current and future research and education. As TU Delft is a multi-disciplinary research environment, where strong fundamental science meets societal challenges, a dedicated theme is a focal point where knowledge can be developed and can be recognised as a global player in geothermal research and education.

Why a Geothermal theme?

Worldwide governments, industry and policy makers are looking for solutions for sustainable energy supplies in order to reach their sustainability goals and mitigate climate change. It is generally expected that geothermal energy, as a sustainable georesource, has an important role to play in this process. Geothermal energy has the potential to deliver low-cost thermal energy (for direct use or conversion), and is increasingly considered as a key contributor for urban heat supply, even in areas outside the classical hotspots with high thermal gradients. Sedimentary aquifers provide a large global resource for direct low-enthalpy (<150 °C) geothermal heat. In the Netherlands, for example, the ambition of the geothermal industry is to drill 700 well doublets for low-enthalpy heat production by 2050 (Master Plan Geothermal Energy in the Netherlands, 2018). Currently there are 20 running geothermal projects, and to further and more rapidly upscale is hampered by large uncertainties in subsurface properties and a lack of monitoring tools, along with large required initial capital investments.

In order to increase the use of geothermal energy and to fulfil the high ambitions in the Netherlands and worldwide, it is necessary to better understand the processes involved over the full lifetime of a geothermal project. The processes we target mostly relate to two societal drivers (i) safe use of the subsurface and (ii) sustainable, reliable and affordable energy. The specific scientific questions are related to long term fluid and heat flow behaviour across a range of scales (from the microstructure to field scale), detailed geophysical monitoring in a noisy (i.e., urban) environment, a better understanding of geochemical processes and material testing. At the Department of Geoscience and Engineering we have the relevant subsurface expertise in-house to tackle these challenges and advance the field. This requires knowledge from a number of disciplines and an integrated approach, for example with Geology taking the lead in investigating the sedimentary processes and microstructure influencing fluid and heat flow, Geophysics leading the monitoring, Petrophysics contributing to analysis of properties (at well and sample scale), Reservoir Engineering leading the numerical simulation aspects including upscaling and Geo-Engineering focusing on shallow geothermal technologies. This expertise and knowledge is combined in the Geothermal theme.

TU Delft is working together with industry partners Hydreco Geomec, EBN and Shell Geothermal as Geothermie Delft to implement a geothermal research well on campus, called the DAPwell (Delft Aardwarmte Project well). This fits within the TU Delft ambition to develop a sustainable campus, where electricity is already provided by solar panels on TU buildings and an off-shore wind park. Heating campus buildings with geothermal energy would bring TU Delft a big step towards being CO_2-neutral. The idea for a geothermal research well on campus was first imagined by a group of TU Delft students in 2008. Once implemented, it will add a critical component to the current engagement of TU Delft within the energy transition. We have the vision to further expand this infrastructure to form an Urban Energy

Laboratory including heat storage, cascading heat networks, a smart thermal network and a series of monitoring and exploration wells at different depths (from 100 to 4 500 m depth). The multi-disciplinary research and the development of this large-scale infrastructure requires a central coordination point which is the Geothermal theme.

Strategy

The Geothermal theme aims to become an expertise centre and a global player for geothermal research and development. We want to solve fundamental and applied research questions to contribute to safe and efficient geothermal energy production. Impact is achieved through solid scientific investigation, close connection with industry and full-scale test cases operating in real-world conditions.

Leadership: The theme has a leader with a small leadership team, made up from colleagues with key expertise, a focus on geothermal technology and range of skills. The team provides academic leadership and project management support and communicates activities and outcomes within the theme.

Scientific questions: Form both grand challenges which require large teams to tackle, and focused questions which can be tackled by individual scientists.

HR: Grow the leadership team to approximately 4 FTE to achieve sufficient momentum, and integrate with other academics within the department. There is a gap in skills in geochemistry, which is partly being filled via new recruitment in 2022.

Funding: Acquire funds in collaboration with internal and external collaborators within the Topsector Energy programmes, the NWO Applied and Engineering Sciences domain, the Dutch National Research Agenda programme and the EU framework programmes. Work with a network of industry partners (many current sponsors) to ensure industrial impact.

Education: Continue providing education in the Applied Earth Science BSc programme to ensure students learn about geothermal energy, expand education primarily within the Geo-Energy MSc track, and expand within a newly proposed Heat track in the Sustainable Energy Technology programme of the Dutch 4TU federation.

Atmosphere/culture: Create an open atmosphere where students, researchers and scientific staff are able to openly communicate, propose ideas and discuss challenges.

Theme organisation

The Geothermal theme was conceived and is operated as a knowledge and cooperation group, and it contributes to department policies/implementation. The leadership team of the theme comprises the staff in the department who focus on geothermal energy. The theme is led by Phil Vardon (Associate Professor), who was just promoted to Associate Professor when he started this position. This way full trust and leadership opportunity is given to mid-career staff in the department. The leadership team furthermore includes David Bruhn (Professor of Geothermal Engineering, who expanded his position to 0.6 FTE in 2021), Alexandros Daniilidis (Assistant Professor who joined in December 2021, replacing Maren Brehme who left in July 2021), and Martin Bloemendal (Assistant Professor in the Water Management department of CEG, joined in 2021). David Bruhn focuses on internationalisation and has recently become the coordinator of the Joint Programme on Geothermal Energy in the European Energy Research Alliance (EERA). In 2020, the department deliberately chose to invest in the position of a research/programme manager to support the management and coordination activities in the theme (Susanne Laumann).

Currently the theme comprises about 20 academic staff from various disciplines, ranging from geophysics, petroleum engineering, rock mechanics, geology, hydrology and reservoir modelling, to policy making e.g. in regulation. The group is changing dynamically as projects and interests evolve. It

should be noted that while the theme is hosted in the Department of Geoscience and Engineering, it also includes academics from other departments such as Water Management and Computational Mechanics. The theme therefore stimulates collaboration within the department and across departments.

Achievements

Education

Over the last years we expanded the amount of educational content related to geothermal energy. We did this not only in our own BSc and MSc programmes of Applied Earth Sciences, but also in the context of 4TU (TU Delft, TU Eindhoven, University of Twente, Wageningen University) and LDE (TU Delft, Leiden University, Erasmus University Rotterdam). The MSc track Petroleum Engineering and Geosciences has been replaced by a newly designed MSc track Geo-Energy Engineering with a major geothermal component, and with geothermics playing an increasing role in the BSc programme. Within most MSc programmes, there is the possibility to take part in a Joint Industry Project (JIP), where geothermal energy has played a prominent role. In addition, we contribute to a comprehensive programme on renewable energy (4TU SET MSc course) and a broader view on geo-resources, including societal, environmental and geo-political aspects (LDE Minor). Together, the course work makes TU Delft more attractive and enhances its visibility for (the growing numbers of) students interested in this topic. At PhD level, the Innovative Training Network (ITN)/IDEA league programme EASYGO is the first standardised doctoral education programme focusing on geothermal energy in Europe (see textbox page 116 on *PhD Policy and Training for details).* All of these developments will help to attract students and train future generations of engineers that are able to work in the geo-energy sector.

Internal TU Delft collaboration

- Founding member of the university-wide Urban Energy Initiative, and founding member of Thermo-X (the Thermal energy platform, a sub-group of the Urban Energy Initiative).
- Pioneer in the development of the campus as a living laboratory concept – which has now been adopted as a broad TU Delft ambition.
- Geothermal energy and high-temperature aquifer thermal energy storage (HT-ATES) embedded in the sustainability concept for the university.
- Regular collaborations in teaching cross-programme/faculty and in MSc thesis supervision.

National and International embedding of the theme

National and international embedding is organised through various activities. The Geothermal Get-Together (GGT), for example, is an initiative to bridge the emerging geothermal industry, policy and university research, by the combination of a short seminar followed by informal networking and discussions and therefore reaches the whole knowledge chain. The GGT contributions range from state-of-the-art research to new policy to industry best practices. Since 2018, we held nine GGTs of which the last four were organised as webinars due to the corona pandemic. During these webinars we regularly had more than 70 participants.

We also extensively engage with industry via the Stichting DAP. This organisation, via a network of industry partners, co-funded 5 years of David Bruhn's position and is currently funding a tenure tracker assistant professor (initially Maren Brehme, replaced by Alexandros Daniilidis in December 2021), with a generous start-up fund. Every 2 years, a geothermal symposium co-hosted by TU Delft and Stichting DAP is held at the university, attracting more than 100 attendees.

On an international level, we are closely involved in the EERA Joint Programme on Geothermal Energy (EERA JP Geothemal). David Bruhn has been elected as the new coordinator of the joint programme in July 2021, and with this appointment, also the Programme Office moved to Delft, which is led by Susanne Laumann. Being closely involved in EERA and the joint programme assures our strong position in the European geothermal research and it allows us to be connected to the major EU players and to provide input into agenda-setting procedures, e.g. the roadmap of the EU Strategic Energy Technologies Plan.

In addition, in 2020 the Geothermal theme took over the leadership of the geo-energy community within EPOS from the British Geological Survey. We are currently working on the re-establishment of the community and its embedding in one of the EPOS Thematic Core Services.

The IDEA league is a strategic alliance between five leading European universities of science and technology. Our department has been one of the leaders of the joint Applied Geophysics MSc programme. We proposed to make geothermal a new theme within the IDEA league, with a focus on doctoral education and research collaboration. The first success of this new initiative was the writing and award of the EASYGO ITN, which links large-scale infrastructure available at each of the partner universities and ten industrial partners into a doctoral education programme and funds 13 PhD candidates.

Project highlights

Built on our network and strong track record, we were able to attract research funds from various sources. An overview of our research projects is presented on the theme website. Here we highlight a few:

Geothermal research well on campus, DAPwell

The geothermal well (planned to be drilled in 2022) will offer a unique full scale research infrastructure of international significance, as it provides access to an operating geothermal system. Equipped with a broad range of advanced technologies for monitoring and data acquisition, the geothermal well will deliver essential information on processes affecting deep geothermal energy provision. The DAPwell will additionally provide heat to the TU Delft campus and at a later stage to other buildings within the Municipality of Delft.

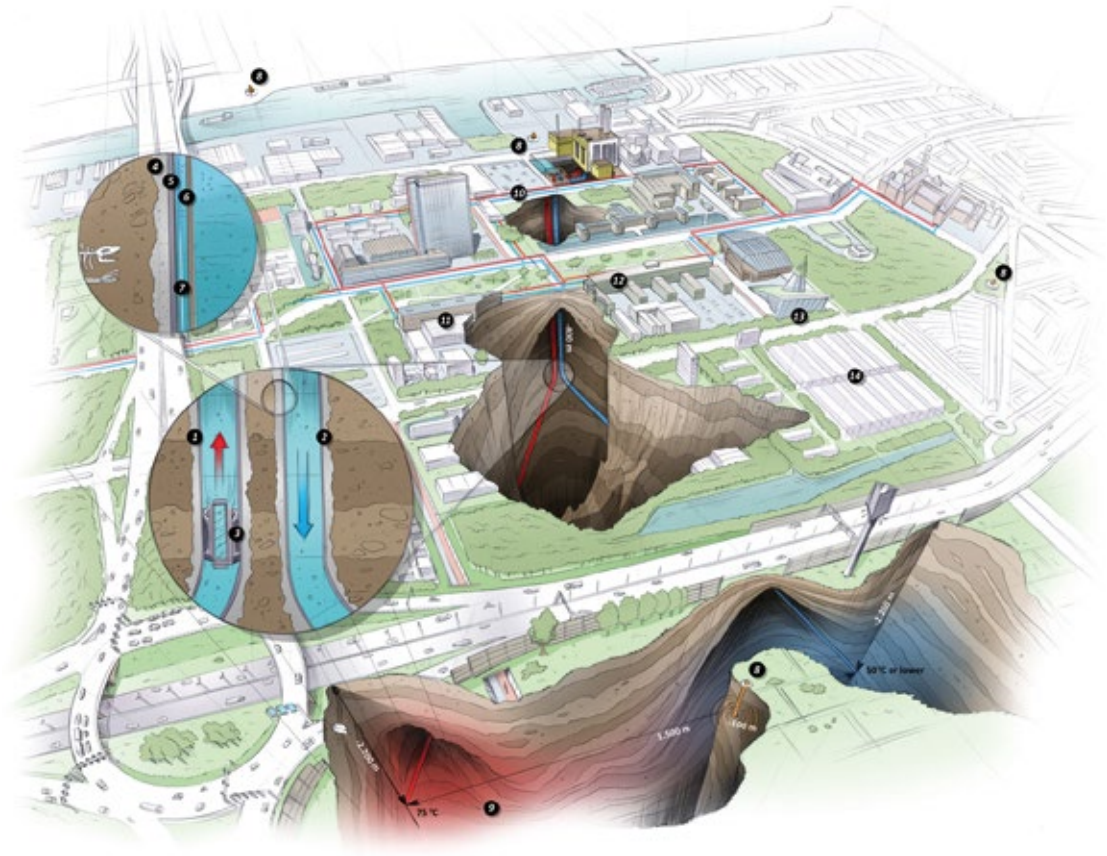


Figure A-1. Graphic illustration of the geothermal doublet and the surrounding infrastructure on campus. (1) producer (app. 82 °C), (2) injector (app. 50 °C), (3) submersible pump, (6) fiber optic installation in producer and injector, (8) geophysical monitoring stations, (10) campus heating grid (illustration Stephan Timmers, Total Shot Productions)

The combined aim of heat delivery and research requires collaboration and negotiation internally (with TU Delft Campus Real Estate and the Executive board) as well as with the industry partners of Geothermie Delft. The development of the project was an extensive process, which involved comprehensive decision making processes to ensure the project could address the dual aims, be financially viable and be technically feasible.

Ultimately, this unique infrastructure will make TU Delft a key partner for national and international research cooperation, as access to operating, well-characterised geothermal wells is scarce and thus presents a decisive stepping stone for a major advance in the development and understanding of geothermal systems in sedimentary basins. DAPwell will be complemented by high quality field tests, laboratory and numerical facilities and serve as a reference case for geothermal developments elsewhere.

EPOS-NL

The geothermal research well is part of the Dutch Large Scale Research Infrastructure EPOS-NL that was awarded more than €12 million by NWO. It is a partnership between TU Delft, the Royal Netherlands Meteorological Institute (KNMI) and Utrecht University. The Geothermal theme members contributed significantly in the proposal phase to make this project application successful. EPOS-NL is the Dutch contribution to the European Plate Observing System (EPOS), the Europe-wide infrastructure of geological sciences, geo-hazards and resources (see also text box on open science). EPOS-NL is a cluster of large-scale geophysical facilities for research on georesources which address key geo-societal challenges such as exploration of geo-energy resources, subsurface storage of fluids and CO_2 and hazards such as induced and natural earthquakes. Next to DAPwell, the infrastructure consists of the Earth Simulation Lab in Utrecht, a Multi-scale Imaging and Tomography Facility in Utrecht and Delft, the petrophysics laboratory in Delft and the Orfeus Seismological data centre at KNMI.

Energy Piles in the Netherlands

Energy efficiency of buildings is desirable to reduce costs, greenhouse gas emissions and meet legislative targets. This project aims to tackle a number of outstanding questions for the widespread use of energy piles, an existing technology that has the potential to reduce energy consumption in the heating and cooling of buildings. Energy piles provide both foundation (structural) support to the building and the heating/cooling required. The project aims to address the thermo-hydro-mechanical interaction between the pile and the ground under realistic and extreme conditions, addressing both the short- and long-term behaviours. To achieve these realistic conditions, a 10 meter deep stand-alone experimental pile has been installed in TU Delft's Green Village (~0.7kW), containing detailed instrumentation in the energy pile foundations in order to test and speed up their use on the market. This will help to further standardise the pile technology and help the construction industry move to more sustainable solutions. Following the initial findings and industry collaborations in the project, a novel building on the Green Village has been fitted with 9 energy piles, that are currently being linked to a novel climate control system (~10kW).
A development in Zeeland, the Netherlands has been constructed with 500 energy piles (~1MW).
See Figure A-2 for an impression of the different projects.

Figure A-2. Graphic illustration of the different energy pile installations: left – the standalone single pile test, middle – the Co-Creation Centre in the Green Village with 9 energy piles, right – the installation of 500 energy piles in Breskens for a new apartment complex.

WARMINGUP

The WarmingUP collective brings together almost 40 participants from research, industry and government to make collective heating systems reliable, sustainable and affordable for the heat transition. System and process innovations are necessary for improved designs, construction and management. WarmingUP wants to develop these innovations at an increased pace. Acceleration, upscaling and cooperation from the entire heat chain is necessary to realise the heat transition. The Geothermal theme members were closely involved in setting up the consortium and writing the proposal and two PhD candidates have been appointed to work on (i) groundwater monitoring using seismic and electromagnetic methods and (ii) the exploration and efficiency of HT-ATES. In both areas, we are developing techniques and intend to test on real projects during the lifetime of the PhD projects to accelerate adoption into industry. For example, additional measurements for exploration for HT-ATES are being carried out during test borings and drillings for geothermal projects and investigated to gain knowledge on more effective exploration and the impact of heterogeneities.

Highlights of the four Specific Aspects of the Strategy Evaluation Protocol

Open Science: Engagement, outreach and dissemination are a core part of open science, in particular in a societally important topic as geothermal energy. Alongside more traditional methods, the theme stimulates this, for example, through the Geothermal Get-Together where a group of academics (staff and students), industry and government meet in an informal but regular format at TU Delft or online. The research well on campus as a key facility for demonstration of technology as well as an infrastructure for research will further boost these activities.

The ability to offer and maintain open access to data and research facilities/infrastructure are facilitated by the facilities of the European Plate Observing System (EPOS) and EPOS Netherlands (EPOS-NL). EPOS-NL gives national and international researchers the possibility to access its research infrastructures free of charge (which includes laboratory equipment as well as the geothermal research well on campus). Financial support for facility access is provided through the research infrastructure EPOS-NL, which is financed by the Dutch Research Council (NWO). So far, two facility access calls have been launched in 2021 (call 1: access to microscopy infrastructure; call 2: access to petrophysics laboratory equipment) with about 30 applicants. More calls will follow in the upcoming years.

PhD Policy and Training: PhD students are closely involved in the Geothermal theme, with a bi-weekly informal meeting to share news, give informal presentations and stimulate involvement in activities. The group gathering forms an additional support group for early stage researchers outside of their direct supervisors in the section. One major achievement within the theme was the funding of the Innovative Training Network (ITN) EASYGO 'Efficiency & Safety in Geothermal Operations' in 2020 which created 13 PhD positions within the IDEA League universities TU Delft, ETH Zurich, RWTH Aachen University, Politecnico di Milano (PoliMi) and 10 industry partners. The EASYGO ITN is the first standardised doctoral education programme in Europe and it builds on experience and collaboration among the IDEA League universities in various research projects and (since 2006) the joint MSc programme of Applied Geophysics. Within the EASYGO ITN, the PhD students work on a pre-defined project and learn aspects of the entire geothermal operation chain in a specifically designed training programme. The programme includes training weeks on geothermal research related topics as well as on transferable skills, such as team work and communication. In addition, secondments are scheduled at a minimum of one partner university and one industry partner. This way the EASYGO graduates will form a new generation of multidisciplinary experts in geothermal operations trained to achieve standardised efficient and safe operations of geothermal systems to enable the ambitious international expansion plans.

Academic Culture: The theme aims to stimulate academic interactions in an informal and low hierarchy environment. This is complimentary to the formal supervision. There are two main methods to stimulate these interactions: (i) Firstly, we meet and have lunch (pre/post pandemic) on a bi-weekly basis. Usually, 10 to 15 people participate (mostly PhD students and postdoctoral researchers, often with MSc and BSc thesis students, and with professors and industry partners more irregularly). The main parts of the meeting are sharing news/developments/opportunities, an informal presentation and (during non-corona times) the social lunch. Presentations range from BSc project pitches, MSc or PhD thesis plans, updates or final presentation to proposal ideas, granted projects or project updates. The topics include the various disciplines that are represented in the theme and all members broaden their knowledge in the geothermal research field and gain experience of academic presentation/discussion. (ii) Secondly, we meet less regularly (approx. every 2 months) to discuss ongoing projects, project proposals/opportunities, human resources and external communication. This meeting is designed to be focused on permanent academic staff, but all theme participants are invited to also highlight academic activities to more junior members.

Human Resources Policy: Formal human resource management is undertaken via the sections. The leadership team frequently mentors staff within the theme and feeds into the HR process for these staffmembers. This allows clarity of line responsibility for the staff members, while taking advantage of the thematic expertise available.

Future outlook

We will continue developing and contributing research and education in the direction of geothermal energy. In education, geothermal content will be required to be maintained or grown in the Applied Earth Science BSc and MSc programmes and added into the new Environmental Engineering MSc programme. In addition, we foresee that a 'Heat' track can be added into the Sustainable Energy Technology programme (SET), which currently focuses on electricity. A proposal has been made via the Thermo-X platform and is currently being discussed at Dean level of the faculties involved in the SET programme.

In research, there are several key challenges. Upscaling from a niche industry to a mainstream industry in low-enthalpy heat is the first; this requires innovations which reduce costs, decrease uncertainties, increase reliability and increase safety. As part of this, it is essential that heat storage and novel subsurface/surface installations are developed and investigated. Secondly, additional resources are needed: (i) hotter resources (which are deeper in most parts of the world) are needed to be exploited for industrial heat; inevitably enhancing systems will be needed, as well as novel exploration and monitoring techniques; (ii) lower temperature (medium depth) resources are more widespread and can be explored, which may reduce financial risks, but have challenges in well stability and required high flowrates; (iii) further integration of shallow geothermal systems into building components and 5th generation heating and cooling networks requires developments in technology, monitoring and smart control. Finally, the majority of geothermal based heating and cooling is low-emission, rather than emission free. Innovations to reduce or eliminate emissions is required.

One of the major infrastructures we are developing is the DAPwell. We intend to develop this infrastructure into a Delft Urban Energy Laboratory on the TU Delft campus. We target (and have undertaken a feasibility study on) a HT-ATES system, and are aiming to develop further projects on heat network control and building integration. As buildings are refurbished and the heat network is extended, different operation modes can take place, which will also affect the subsurface operation. We are also aiming for a deep exploration / monitoring well with a depth of 4.5 km, which will enable testing of novel electromagnetic geophysical monitoring on a real geothermal system, and exploration of both deeper and hotter resources and shallower cooler resources. This infrastructure will be a major asset for the TU Delft research community as a whole and not just for the Geosciences. Scientists from for example Architecture, Process & Energy, and Systems & Control are keen on using such a facility as a living lab which can thus serve as a linking project for campus-wide thermal research.

Appendix B:
Benchmark with ETH Zürich

ETH Departments D-ERDW and D-BAUG

In September 2021, several professors from the department visited our colleagues at the ETH in Zürich, Switzerland, to carry out a benchmark on the organization and academic culture. We chose ETH to do this benchmark because of their high ranking in the world. We visited two departments of ETH, with research disciplines overlapping with ours: at the department of Earth Sciences (D-ERDW), we visited several groups constituting the research theme Georesources and Geohazards (including the Geothermal Energy and Geofluids and Rock Physics and Mechanics laboratories). At the department of Civil, Environmental and Geomatic Engineering (D-BAUG) we visited the Institute for Geotechnical Engineering and the Clay Laboratory.

We are very grateful to our hosts that they were willing to engage with us in very open discussions on academic culture and how this ties into the way the departments at ETH are organized.

During the benchmark visit we focused on:
- The structure of the departments,
- The different sources of funding available in the department,
- Department organization, roles, responsibilities and mandates,
- Formulation of department strategy,
- The staff development strategy within a department,
- Organization of the PhD process within the department.

Structure of the departments

At ETH they do not have the layer of faculties. All 16 departments of the university fall directly under the Executive Board. Each department is subdivided in institutes, which are a cooperation of several research groups. Each research group is led by an elected chair (elected refers to the fact that the ETH-rat – the ETH governing body – has formally elected the chair at her/his (permanent) appointment), also referred to as an “ordinary professor”, sometimes supported by a non-elected adjunct professor (“Titular professor”). The difference is that the non-elected adjunct professors do not have the same full administrative rights as elected chairs, but are allowed leading independent research groups and enjoy research independence (including the role of PhD advisor). In short, they are senior scientists with a permanent appointment, whose reputation and academic stand have earned them the right to be a professor.

D-ERDW has 20 elected chairs, of which at the time of the visit, 16 were full-professors, 2 (tenured) associate professors and 2 assistant professors (tenure track). At the time of the visit, the department hosted 9 adjunct professors. The chairs lead 20 research groups, distributed over 3 institutes. Further to these 3 institutes, the department also hosts associated groups such as the BedrettoLab, the Georesources Switzerland Group and the Swiss Seismological Service. The department hosts about 150 doctoral students.

D-BAUG has 30 elected chairs, 10 assistant professors – both tenure track (TT) and no TT – and 5 adjunct professors, distributed over 10 institutes. Each institute has between 2 to 7 chairs / research groups. The department hosts about 300 doctoral students. During the visit we went on a tour through the Geotechnical Engineering institute and the Clay Lab.

Department funding

Departments receive from the ETH Executive Board an annual budget. A very minor part of it is retained to cover the costs of central staff and the related running costs. The majority of the budget is allocated to the elected chairs. The amount of funding is decided during the negotiations with the chair during the hiring process. Each chair starts with a (very) significant start-up package, after which each chair receives a yearly budget, which, over years converges to the standard allocation for each chair.

When a chair retires, 50% of the budget stays with the department for a transition period. When a professor retires, the department (sitting chairs) are allowed to develop a profile on new research topics with which they can try to convince the president of the university to re-instate a new chair in the department. Decision on the new profile is made by the professor council of the department.

The chair is free to decide how to use the budget. The direct funding can be used to hire/build-up senior research staff and enable them to lead their own research groups within the research group. The number of senior staff in a research group with a permanent position is very limited. We understand that ETH aims to limit the age difference between the chair and the permanent staff in the research group to maximally 5 years. This is so that any new chair in the future can start to build their own group. A new professor can theoretically be “strong-armed” in to accepting a staff member on a permanent position. Non-permanent staff can have a contract with a maximum duration of 6 years (as “Oberassistant”), after which they must leave the university. This policy is felt to be harsh, but it is as it is.

Chairs are expected to attract external funding and the large majority is also very successful in attracting research funds from other sources as well. External funds are used to expand the research group with senior scientists and doctoral students. All doctoral students get a salary for a maximum of six years. In addition, PhD salaries vary between departments, based on market conditions.

Department organization

A department is led by a department head. The term for the head of the department is 2 to 4 years, after which, generally, the deputy head will take over. ETH has a strong culture of participation of different groups (from students to professors) to ensure broadly supported decision making. This is organized through delegates in various department-level conferences. The different committees are defined in the ETH Zürich organisation ordinance and department bylaws, which are available on the department and university websites.

The department conference is the supreme body of the department. It elects the head of the department, the deputy head, the director of studies and the members of the different committees in the department. The conference is responsible for approving the curricula of the study programmes and is in charge of approving doctoral co-referees and doctoral theses after a doctoral defence. And it decides on all other academic business matters such as planning of new chairs.

All elected and adjunct professors are members of the department conference; other staff groups and students can send delegates to the department conference. The elected professors and adjunct professors are also members of the professor conference which is responsible for all personnel matters at the professorial level (promotions, award of a professorship) and it examines “Habilitation” applications.

Department strategy formulation

Due to the funding strategy, research groups have a very large autonomy in deciding on their own strategy. Department strategy is formulated in the first instance by an elected strategy commission. The draft strategy is then discussed, consolidated and approved by vote in a professorial retreat. However, before a proposal is put forward, discussions have taken place to ensure that consensus is found before the proposal is put to the vote. This ensures broad support before voting takes place.

Available funding at the department level is very small compared to the funding available at research group level, as the latter can count on third party money acquisition. Therefore, the power of the head of the department to make strategic choices by selecting investments is limited.

Examples of department-wide strategic initiatives with D-ERDW were the Bedretto Underground Laboratory for Geoenergies (which received an ERC synergy grant and funds from the Werner Siemens Foundation and Swiss National Science Foundation), and the development of three department-wide research themes where collaboration is sought with other departments within ETH: Earth and Planetary dynamics, Earth surface systems, and Georesources and Geohazards.

D-ERDW has no formal department policy related to the ethics related to industry funding from oil & gas. In general, such issues are handled by the ETH transfer office. The department does recognize an increasing amount of student protests, however, ETH follows a more reactive than pro-active strategy. On the other hand, there are no large oil and gas projects now.

With respect to gender and hiring strategy, each shortlist should have at least one female candidate. However, at D-ERDW the gender balance at the chair level is felt to be good, also for the PhDs. A gender unbalance is perceived at the post-doc level as this group is male dominated. The reason for this is thought to lie in the social structure of the Swiss society related to topics such as maternity leave.

Staff development strategy

ETH has no structural staff development strategy in the sense that young people are attracted in a tenure track as assistant professor, with the aim to develop into associate and eventually full professors. Instead, retired elected chairs are replaced by new elected chairs in the same domain or in a new one, depending on the departmental strategy. Each chair can build their own group, with a limited number of permanent staff. The sizeable amount of direct funding, together with the start-up package, makes the new positions attractive and what we found is that this model gives the chair a large amount of freedom to pursue curiosity-driven research.

The chairs have a large autonomy in building their research group. Staff is in general employed on a temporary contract. All academic staff can be involved in teaching. On average, faculty teach up to two courses a year. The balance between teaching and research was felt to be healthy.

Organization of the PhD process

The ETH has no university-wide graduate school. Procedures how to organize the PhD process are up to the departments, but as of January 1, 2022, there will be a stronger regulation in place to make the organization of the PhD process more uniform across departments. Each PhD candidate must defend her/his research proposal in front of a panel from the department. This is in principle the only department regulation for the PhD process until the defence. PhD candidates in principle have one supervisor.

At D-ERDW some changes will be implemented: There will be annual conversations and an appraisal, and the go/no-go meeting will be planned after 1.5 years instead of 1 year. There is also a “help desk” for all non-permanent staff to facilitate in conflicts between a professor and staff. Of course, the head of the department can mitigate in such cases as well.

D-ERDW has an unwritten rule that a PhD thesis should (most often) be based on 3 publishable pieces of work. At the 1st year proposal defence, these three projects already need to be defined. D-BAUG allows both the option of a monograph and that of a paper-based dissertation. The PhD project must be completed within 6 years. The average duration of a PhD project is 4.3 years.

Elected associate professors as well as adjunct professors can be promotor. On average each promotor has about 10 doctoral students. There are rules at the ETH which allow to remove the supervisor. If this is the case, a new project is funded for the student, or the supervisor accepts that the student continues with the project under a new supervisor. On the other hand, a PhD student can be dismissed by his/her supervisor if there are traceable and good reasons for this step.

Conclusions for GSE

The base funding of GSE goes to the department and covers part (not-all!) of the fixed costs in the department. The department needs a significant amount of external funding to be able to cover all fixed costs. At ETH, each professor receives a fixed budget (variable from department to department). The professor may appoint one permanent staff member in his or her chair; however, getting a permanent position, without being an elected professor is difficult at ETH. The maximum duration of a temporary appointment at ETH is 6 years. At ETH we understand, there is an agreement in the department that the age difference between the professor and permanent staff employed in a chair should be less than 5 years.

Another major difference is the strategy to develop staff in a tenure track. At TU Delft, we aim to recruit young people with a PhD and some experience as a postdoc to develop their career within a tenure track towards full professor. In principle, ETH chooses to hire full professors who are usually in their early forties, however, there is more and more a push for appointing new chairs at assistant professor (tenure track) level. They cannot be over 35 years old at their appointment.

In 2020, the CEG faculty has agreed to fund the salary of 1 PhD candidate per starting TT as a start-up package, however this funding is not guaranteed for the long term. At ETH, the start-up package for a starting professor is significant (multiple M€). Base funding of the research group is negotiated at the start and is then fixed.

Our research within GSE is driven by questions from industry and society (but we decide which questions we work on). There is limited opportunity for purely curiosity-driven research. At ETH, we experienced a culture where there was more room for curiosity-driven research.

Despite the much tighter funding situation in Delft, we feel that we are quite efficient, thereby increasing the value of our base funding.

Discussion on the ethical aspects of research, especially in Oil & Gas, was not really an issue in ETH. Perhaps because the volume of this research in the department of ERDW was quite small. In addition, ETH has a central office for such ethical issues. Within GSE, discussions on the ethical aspect are felt to be a core aspect of our academic culture, which we aim to integrate in our research.

Another major difference is the TU Delft graduate school, which is developing strong procedures to guide the PhD development process and ensures strong monitoring of progress. D-ERDW plans to have the go/no-go meeting after 1.5 years instead of after 1 year. Similarly, TU Delft has decided that, as of 2022, PhD contracts will consist of a 1.5 years contract, followed by a 2.5 years contract after an approved go.

The approach of ETH in representation of staff in the department conference was very appealing. We aim to adopt aspects of this representation approach in our department council structure.

Appendix C: Composition

GSE academic staff members per 31-12-2020

1. Abels, Hemmo, Assistant Professor, Sedimentology and Stratigraphy
2. Askarinejad, Amin, Associate Professor, Experimental Soil Mechanics
3. Barnhoorn, Auke, Associate Professor, Rock Mechanics and Rock Structures
4. Bertotti, Giovanni, Professor, Structural Geology (Director Faculty Graduate School)
5. Blacquière, Gerrit, Associate Professor (part-time), Seismic Acquisition
6. Blom, Jan Kees, Director of Studies / Lecturer, Geology
7. Brehme, Maren, Assistant Professor, Geothermal Engineering
8. Brinkgreve, Ronald, Associate Professor (part-time), Numerical Methods for Geo-engineering
9. Broere, Wout, Assistant Professor, Underground Space Technology
10. Bruhn, David, Professor (part-time), Geothermal Engineering
11. Bruna, Pierre-Olivier, Assistant Professor, Structural Geology
12. Buxton, Mike, Associate Professor, Resource Engineering
13. Dieudonné, Anne-Catherine, Assistant Professor, Engineering Geology
14. Draganov, Deyan, Associate Professor, Seismic Interferometry
15. Drijkoningen, Guy, Associate Professor, Seismic Experiments and Modelling
16. van den Eijnden, Bram, Assistant Professor, Geotechnical Uncertainty
17. Evers, Läslo, Professor (part-time), Seismo-acoustics
18. Farajzadeh, Rouhi, Assistant Professor (part-time), Transport Phenomena in Porous Media
19. Gavin, Kenneth, Professor, Subsurface Engineering
20. Gebert, Julia, Associate Professor, Environmental Soil Engineering
21. Ghose, Ranajit, Associate Professor, Near-surface Geophysics
22. Giardina, Giorgia, Assistant Professor, Geo-monitoring and Data Analytics
23. Hajibeygi, Hadi, Associate Professor, Reservoir Simulation
24. Heimovaara, Timo, Professor, Geo-environmental Engineering (Department Chair)
25. Hicks, Michael, Professor, Soil Mechanics
26. Jansen, Jan Dirk, Professor, Reservoir Systems and Control (Dean of Faculty)
27. Jommi, Christina, Professor, Dikes and Embankments
28. Keersemaker, Marco, Lecturer, Geology
29. Korff, Mandy, Associate Professor (part-time), Geoengineering
30. Leeuwenburgh, Olwijn, Assistant Professor (part-time), Data Assimilation
31. Martinius, Allard, Professor (part-time), Petroleum Geology
32. Mulder, Wim, Professor (Part-time), Geophysical Imaging
33. Muntendam-Bos, Annemarie, Associate Professor (part-time), Induced Seismicity
34. Ngan-Tillard, Dominique, Assistant Professor, Engineering Geology and Rock Mechanics
35. de Nijs, Richard, Lecturer, Underground Space Technology
36. Pisanò, Federico, Associate Professor, Offshore Soil Mechanics
37. Pluymakers, Anne, Assistant Professor, Experimental Fluid-Rock Interaction
38. Slob, Evert, Professor, Geophysical Electromagnetic Methods
39. Soleymani Shishvan, Masoud, Assistant Professor, Resource Engineering
40. Storms, Joep, Associate Professor, Sedimentary Geology
41. Stuijfzand, Pieter, Professor (part-time), Chemical Hydrogeology
42. Thorbecke, Jan Willem, Senior Researcher, Geophysics and High-performance Computing
43. Vardon, Phil, Associate Professor, Geothemal Science and Engineering
44. Voskov, Denis, Associate Professor, Modelling of Complex Subsurface Systems
45. Vossepoel, Femke, Associate Professor, Data Assimilation

46. Wapenaar, Kees, Professor, Geophysics
47. Weemstra, Kees, Assistant Professor, Seismo-acoustics
48. Wolf, Karl-Heinz, Associate Professor, Petrophysics
49. Zitha, Pacelli, Professor, Oil and Gas Production Engineering (Head of GSE Laboratory)
50. Zwanenburg, Cor, Assistant Professor, Soil Mechanics

GSE academic staff members who left or retired during the review period

1. Benndorf, Jörg, Assistant Professor, Resource Engineering (now at TU Bergakademie Freiberg)
2. Bosch, Johan, Professor (part-time), Subsurface Engineering (retired)
3. Donselaar, Rick, Associate Professor, Sedimentology (retired)
4. Luthi, Stefan, Professor, Production Geology (retired)
5. van Paassen, Leon, Assistant Professor, Geoengineering (now at Arizona State University)
6. Rossen, William, Professor, Reservoir Engineering (retired)
7. Voncken, Jack, Assistant Professor, Resource Engineering (retired)
8. Wambeke, Tom, Assistant Professor, Resource Engineering (now data-scientist at Pfizer)

Table C-1. Composition of staff during the review period. (a) Head count. (b) Full-time equivalents.

(a) Geoscience & Engineering	2015 #	2016 #	2017 #	2018 #	2019 #	2020 #
Scientific staff						
- Assistant professors	13	13	15	16	16	16
- Associate professors	10	12	13	14	17	17
- Full professors	15	16	16	16	15	15
Researchers	60	60	57	58	58	63
PhD candidates	108	105	105	103	101	96
Total Research staff	**206**	**206**	**206**	**207**	**207**	**207**
Technical support staff	9	7	6	6	5	7
Total staff	**215**	**213**	**212**	**213**	**212**	**214**

(b) Geoscience & Engineering	2015 FTE	2016 FTE	2017 FTE	2018 FTE	2019 FTE	2020 FTE
Scientific staff						
- Assistant professors	11,4	11,2	12,1	12,1	11,2	13,1
- Associate professors	7,1	8,9	10,5	10,8	13,6	13,4
- Full professors	10,8	10,6	10,9	10,1	10	9,8
Researchers	27,3	29,4	31,8	36,3	35,4	39,4
PhD candidates	77,6	84,8	86,6	85,2	84,2	85,3
Total Research staff	**134,2**	**144,8**	**151,9**	**154,6**	**154,3**	**161,2**
Technical support staff	7,3	6,1	5,2	4,8	3,4	5,2
Total staff	**141,5**	**150,9**	**157,1**	**159,3**	**157,7**	**166,4**

Table C-2. Gender distribution of staff during the review period.

Geoscience & Engineering	2015				2016				2017			
	Male	Female	%Male	%Female	Male	Female	%Male	%Female	Male	Female	%Male	%Female
Scientific staff	36	2	95%	5%	37	4	90%	10%	38	6	86%	14%
Researchers	46	14	77%	23%	47	13	78%	22%	45	12	79%	21%
PhD candidates	84	24	78%	22%	83	22	79%	21%	85	20	81%	19%
Total Research staff	**166**	**40**	**81%**	**19%**	**167**	**39**	**81%**	**19%**	**168**	**38**	**82%**	**18%**
Technical support staff	7	2	78%	22%	7	0	100%	0%	6	0	100%	0%
Total staff	**173**	**42**	**80%**	**20%**	**174**	**39**	**82%**	**18%**	**174**	**38**	**82%**	**18%**
Geoscience & Engineering	**2018**				**2019**				**2020**			
	Male	Female	%Male	%Female	Male	Female	%Male	%Female	Male	Female	%Male	%Female
Scientific staff	40	6	87%	13%	40	8	83%	17%	38	10	79%	21%
Researchers	44	14	76%	24%	42	16	72%	28%	49	14	78%	22%
PhD candidates	83	20	81%	19%	82	19	81%	19%	79	17	82%	18%
Total Research staff	**167**	**40**	**81%**	**19%**	**164**	**43**	**79%**	**21%**	**166**	**41**	**80%**	**20%**
Technical support staff	6	0	100%	0%	5	0	100%	0%	7	0	100%	0%
Total staff	**173**	**40**	**81%**	**19%**	**169**	**43**	**80%**	**20%**	**173**	**41**	**81%**	**19%**

Table C-3. Age distribution of staff during the review period.

Geoscience & Engineering		2015		2016		2017		2018		2019		2020	
Scientific staff	- 20 yr		0%		0%		0%		0%		0%		0%
	21 - 30 yr		0%		0%	1	2%	2	4%		0%		0%
	31 - 40 yr	9	24%	8	20%	8	18%	7	15%	11	23%	13	27%
	41 - 50 yr	7	18%	10	24%	12	27%	14	30%	15	31%	14	29%
	51 - 60 yr	18	47%	18	44%	17	39%	16	35%	13	27%	12	25%
	> 60 yr	4	11%	5	12%	6	14%	7	15%	9	19%	9	19%
Researchers	- 20 yr		0%		0%		0%		0%		0%		0%
	21 - 30 yr	15	25%	11	18%	8	14%	6	10%	7	12%	9	14%
	31 - 40 yr	34	57%	37	62%	37	65%	40	69%	36	62%	38	60%
	41 - 50 yr	7	12%	7	12%	6	11%	6	10%	9	16%	11	17%
	51 - 60 yr	3	5%	3	5%	2	4%	1	2%	1	2%	1	2%
	> 60 yr	1	2%	2	3%	4	7%	5	9%	5	9%	4	6%
PhD candidates	- 20 yr		0%		0%		0%		0%		0%		0%
	21 - 30 yr	63	58%	57	54%	56	53%	54	52%	56	55%	53	55%
	31 - 40 yr	39	36%	44	42%	45	43%	44	43%	40	40%	36	38%
	41 - 50 yr	5	5%	2	2%	2	2%	3	3%	3	3%	5	5%
	51 - 60 yr	1	1%	2	2%	2	2%	2	2%	2	2%	2	2%
	> 60 yr		0%		0%		0%		0%		0%		0%
Technical support staff	- 20 yr		0%		0%		0%		0%		0%		0%
	21 - 30 yr	1	11%	1	14%	1	17%	1	17%	1	20%	1	14%
	31 - 40 yr	4	44%	2	29%	2	33%	2	33%	2	40%	2	29%
	41 - 50 yr		0%		0%		0%		0%		0%	2	29%
	51 - 60 yr		0%		0%		0%		0%		0%		0%
	> 60 yr	4	44%	4	57%	3	50%	3	50%	2	40%	2	29%

Table C-4. Nationality distribution of staff during the review period.

Geoscience & Engineering		2015		2016		2017		2018		2019		2020	
Scientific staff	**NL**	23	61%	25	61%	26	59%	27	59%	27	56%	28	58%
	Rest of EU (excl NL)	8	21%	9	22%	11	25%	12	26%	13	27%	12	25%
	Rest of Europe (non EU)	4	11%	4	10%	4	9%	4	9%	4	8%	4	8%
	Asia	2	5%	2	5%	2	5%	2	4%	3	6%	3	6%
	Africa		0%		0%		0%		0%		0%		0%
	North America	1	3%	1	2%	1	2%	1	2%	1	2%	1	2%
	South America		0%		0%		0%		0%		0%		0%
	Oceania		0%		0%		0%		0%		0%		0%
Researchers	**NL**	18	30%	21	35%	20	35%	20	34%	19	33%	18	29%
	Rest of EU (excl NL)	19	32%	20	33%	17	30%	19	33%	14	24%	12	19%
	Rest of Europe (non EU)	4	7%	2	3%	1	2%	3	5%	3	5%	5	8%
	Asia	16	27%	14	23%	15	26%	14	24%	16	28%	21	33%
	Africa	1	2%	1	2%		0%	1	2%	2	3%	2	3%
	North America		0%		0%	1	2%	1	2%	2	3%	2	3%
	South America	1	2%	2	3%	3	5%		0%	2	3%	3	5%
	Oceania	1	2%		0%		0%		0%		0%		0%
PhD candidates	**NL**	32	30%	29	28%	26	25%	26	25%	21	21%	24	25%
	Rest of EU (excl NL)	19	18%	19	18%	19	18%	16	16%	15	15%	15	16%
	Rest of Europe (non EU)	3	3%	3	3%	3	3%	2	2%	2	2%	3	3%
	Asia	42	39%	45	43%	47	45%	48	47%	55	54%	46	48%
	Africa	2	2%	2	2%	3	3%	2	2%	1	1%	1	1%
	North America	3	3%	2	2%	2	2%	2	2%	2	2%	1	1%
	South America	7	6%	5	5%	5	5%	7	7%	5	5%	6	6%
	Oceania		0%		0%		0%		0%		0%		0%
Support staff	**NL**	8	89%	7	100%	6	100%	6	100%	5	100%	7	100%
	Rest of EU (excl NL)	1	11%		0%		0%		0%		0%		0%

Appendix D:
Funding

Table D-1. Distribution of funding sources during the review period.

Geoscience & Engineering *K EUR	2015		2016		2017		2018		2019		2020	
Funding:												
Direct funding[1]	4487	31%	4352	35%	4564	37%	4289	39%	4539	31%	5373	43%
Research grants[2]	1328	9%	1379	11%	1129	9%	1082	10%	1662	11%	2265	18%
Contract research[3]	8281	57%	6127	50%	6202	51%	5239	48%	8264	57%	4685	37%
Other[4]	426	3%	434	4%	299	2%	274	3%	152	1%	241	2%
Total funding	**14523**	**100%**	**12292**	**100%**	**12195**	**100%**	**10884**	**100%**	**14616**	**100%**	**12564**	**100%**
Expenditure:												
Personnel costs	9471	65%	9531	78%	9359	77%	9143	84%	10014	81%	10288	86%
Other costs	5052	35%	2677	22%	2786	23%	1699	16%	2368	19%	1618	14%
Total Expenditure	**14523**	**100%**	**12208**	**100%**	**12144**	**100%**	**10842**	**100%**	**12382**	**100%**	**11905**	**100%**

[1] Direct funding (Internal funding received by the faculties/departments from the Executive Board of the university).
[2] Research grants obtained in national scientific competition (mainly grants from NWO).
[3] Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, European organisations and charitable organisations.
[4] Funds that do not fit into the other categories. All numbers are invoiced amounts per year.

Table D-2. Specification of EU funded and non-EU funded contract research during the review period.

Total Research Funding obtained during 2015-2020 Geoscience & Engineering		
Research grants[2]	18461	35%
EU funded[5]	9759	19%
Other Contract research[6]	21727	42%
Other & Faculty[7]	2198	4%
Total Funding	**52145**	
Projects > 1M€	15378	29%
Projects < 1M€	36766	71%

[5] Contract research funded by EU (including ERC).
[6] Other contract research, not directly funded EU.
[7] Other and faculty (internal) funded research.
All numbers are granted funds for the review period.

Table D-3: Funding success rate of H2020 projects during the review period, specified for Delft University of Technology (TUD), the Faculy of Civil Engineering and Geosciences (CEG) and the Department of Geoscience and Engineering (GSE). Fluctuations over the years are large.

		2015	2016	2017	2018	2019	2020
TUD	**Projects**	69	81	67	67	99	82
	Submissions	456	422	469	390	498	575
	Success Rate	15%	19%	14%	17%	20%	14%
	Funding	50,082	45,959	38,995	36,788	57,867	48,438
	Avg. Funding per Project	726	567	582	549	585	591
CEG	**Projects**	9	10	9	11	12	15
	Submissions	69	49	85	69	74	94
	Success Rate	13%	20%	11%	16%	16%	16%
	Funding	5,117	9,637	3,585	5,664	5,086	9,355
	Avg. Funding per Project	569	964	398	515	424	624
GSE	**Projects**	3	2	1	1	1	4
	Submissions	9	8	14	13	14	13
	Success Rate	33%	25%	7%	8%	7%	31%
	Funding	1,221	2,900	289	531	464	2,337
	Avg. Funding per Project	407	1450	289	531	464	584

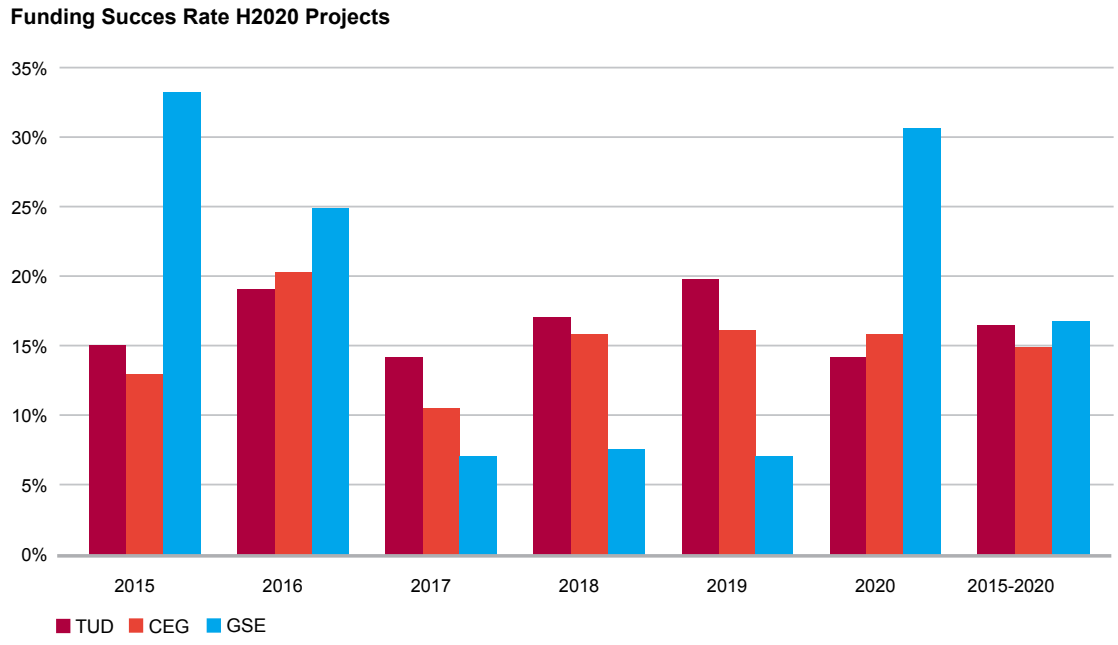


Figure D-1: Graphical representation of Table D-3. The right-most set of bars shows that on average GSE performed comparable to TUD and CEG.

Appendix E:
Supporting information for indicators

This Appendix supports chapters 4 (Evidence) and 5 (Accomplishments during the past six years – research quality and societal relevance) in the main GSE report. Ordered according to the six categories of indicators, it provides additional information in the form of tables and listings.

Research products for peers

Publications

Table E-1: Research output during the review period, including 871 refereed journal articles.

Geoscience & Engineering	2015	2016	2017	2018	2019	2020
Refereed article	110	153	134	150	158	166
Non-refereed article	1	2	4	0	2	2
Conference papers	145	108	108	102	81	52
Books	0	2	2	1	1	0
Book chapter	21	3	15	5	8	2
PhD theses	16	16	22	16	16	22
Professional publications	16	6	5	4	5	3
Publications aimed at the general public	0	0	3	1	0	0
Other research output	107	113	131	138	115	37
Total	**416**	**403**	**424**	**417**	**386**	**284**

Table E-2: Open Access (OA) refereed journal articles during last four years of the review period

Journal Articles		Gold: OA publication in an OA journal		Hybrid: OA in a subscription based journal		Green: OA available through a trusted repository		No OA	
		#	%	#	%	#	%	#	%
GSE	2017	9	7%	28	21%	29	21%	69	51%
	2018	7	5%	39	27%	38	26%	60	42%
	2019	16	10%	38	25%	46	30%	53	35%
	2020	27	16%	62	38%	38	23%	37	23%

PhD dissertations

Table E-3: There were 108 PhD dissertations produced during the review period. This overview of PhD graduations only includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0.8-1.0 FTE contract. Please note that the data in the grey cells are incomplete. There are still PhD candidates active from those starting years that are able to graduate within the time-frame of the given years. Reference date: 31 December 2020.

Geoscience & Engineering					Graduated <= 4 yr		Graduated <= 5 yr		Graduated <= 6 yr		Graduated <= 7 yr		Not yet finished		Discontinued	
Starting year	Female	Male	Total	Graduated	#	%	#	%	#	%	#	%	#	%	#	%
2012	2	11	13	12		0%	6	46%	11	85%	12	92%	1	8%		0%
2013	5	8	13	13	2	15%	8	62%	9	69%	13	100%	0	0%		0%
2014	2	10	12	10	1	8%	7	58%	10	83%	10	83%	0	0%	2	17%
2015	4	16	20	17	3	15%	17	85%	17	85%	17	85%	2	10%	1	5%
2016	2	11	13	5	1	8%	5	38%	5	38%	5	38%	7	54%	1	8%
GSE	15	56	71	57	7	10%	43	61%	52	73%	57	80%	10	14%	4	6%
TUD						7%		40%		62%		68%		18%		14%
NL						12%		39%		48%		50%		N/A		N/A

Software and databases developed by GSE in review period

- Overview of datasets.
- Open-source seismic Marchenko imaging software;
- Open-source electromagnetic modelling software: https://emsig.xyz
- Software to reproduce all figures in Ziolkowski and Slob, 2019, Introduction to Controlled Source Electromagnetic Methods: https://github.com/emsig/csem-ziolkowski-and-slob
- Open-source DARSim simulator: https://gitlab.com/darsim
- Open-Source ADMIRE simulator: https://gitlab.tudelft.nl/ADMIRE_Public/mechanics
- Delft Advanced Research Terra Simulator (DARTS): https://darts.citg.tudelft.nl/
- DARTS benchmark study on buoyancy and capillarity: https://doi.org/10.4121/16553901.v1
- Contribution to LAGAMINE multiphysics finite-element code

E-lectures

- Data-driven Green's function retrieval from reflection data (EAGE 2015)
- Virtual seismology: monitoring the subsurface with virtual sources and receivers (EAGE 2019)
- Theory of Marchenko imaging of marine seismic data with free-surface multiple elimination (EAGE 2019)
- Exploration applications of seismic interferometry with active and passive sources (SEG 2020)

Use of research products by peers

Research highlights (other than those mentioned in the main GSE report, sections 5.1 and 5.2)

- In collaboration with Fugro, Vardon developed a new method of determining thermal properties of in-situ soils (Vardon et al., 2019, Géotechnique). This solved a key problem of the construction sector, mainly for offshore windfarms, as reliable thermal properties at shallow depths were not available previously. Several hundreds of tests have been applied worldwide so far.
- A large strain evaporative consolidation model able to simulate ripening of very liquid soils (e.g. dredged material/mine waste) was developed by Vardon et al. (2015, Proc. Tailings and Mine Waste Management; 2016, Proc. IOSTC2016). It is now being used by Deltares to predict the behaviour of dredged sediments in the Kleirijperij project.
- The NWO-STW Reliable Dykes project (2015-2021) resulted in new methods to calculate the stability of dykes taking into account soil heterogeneity, which are now beginning to be applied in industry. The controlled failure of a regional dyke on peat was used to validate an advanced probabilistic approach for slope stability assessments, which has since been used by Dutch water boards in reducing over-conservatism in assessments of, and mitigation measures for, other dykes (Hicks et al., 2019, Georisk; Varkey et al., 2020, Géotechnique Letters).
- In collaboration with Royal IHC, Askarinejad (2021) and his team developed a novel electro-mechanical actuator for the geotechnical centrifuge. This device physically simulates the impact driving of monopiles for offshore wind turbines. Together with innovative instrumentation this provides a unique environment to closely study the hydro-mechanical processes during offshore monopile installation. This actuator is further used and developed in the H2020 project of GEOLAB and the RVO funded project of BLUE piling.
- Research by Ghose and his team led to the development of a new model and a focusing analysis technique for imaging, characterizing and monitoring in-situ hydraulic properties of dipping fractures using scattered tube waves observed in a borehole (Minato and Ghose, 2017; Minato et al., 2017). It also allows measurement of in-situ permeability, with potential applications in geological CO_2 storage and geothermal field developments.
- Automatic tracking of fracture networks from large (10 m^2*10 m^2) digital outcrop models has always been a major challenge preventing the full use of outcrops. Prabhakaran et al. (2020) have eventually developed an efficient solution which has then been applied to extract data sets of millions of fractures.
- De Hoop (GRS) and Voskov (GSE) have developed the first reactive transport model aimed at the understanding of hypogenic karst (caves) development.
- Prabhakaran (GSE) and de Hoop (GRS) have developed the first workflow to acquire, process and interpret 3D images of caves (using portable LiDAR tools).

Access provided to facilities and software

- EPOS-NL provides facility access packages to researchers from other institutes (national and international): https://epos-nl.nl/facilities/
- GEOLAB (Horizon 2020 project) provides access to our geotechnical research facilities: https://project-geolab.eu/facilities-in-project-geolab/
- DARTS software is used in SPE Energy GeoHackathon: https://www.spehackathon-eu.com/
- Open-source seismic imaging software: access information (2017 - 2021).

Review books

- Schweckendieck, T., van Tol, F., Pereboom, D., van Staveren, M., and Cools, P., 2015, Geotechnical Safety and Risk V. IOS Press (1006 p).
- Craig, W., and Gavin, K., Eds., 2018, ICE Themes Geothermal Energy, Heat Exchange Systems and Energy Piles. ICE Publishing (304 p).
- Gavin, K., and Craig, W., 2018, ICE Themes Wind Turbine Foundations. ICE Publishing (278 p).
- Grobbe, N., Revil, A., Zhu, Z., and Slob, E.C., Eds., 2020, Seismoelectric Exploration: Theory, Experiments, and Applications, Wiley (496 p).

Marks of recognition from peers

Selection of research projects with significant NWO or EU funding

- Seismo-Acoustics (NWO-VIDI, 2015, Evers as PI, 800 kEuro for GSE)
- Reliable Dykes (NWO, 2015, Hicks as PI, 1012 kEuro for GSE)
- Marchenko Imaging (NWO-STW, 2015, Wapenaar as PI, 452 kEuro for GSE)
- WAVES (EU-ITN, 2015, Wapenaar as Co-PI, 3480 kEuro in total, 496 kEuro for GSE)
- Real Time Mining (EU-H2020, 2015, Buxton as co-PI, 5.6 MEuro in total, 1.1 MEuro for GSE)
- SOLSA (EU-H2020, 2016, 9.7 MEuro in total, Buxton as Co-PI, 221 kEuro for GSE)
- RTRO Coal (EU-RFCS, 2017, Benndorf as PI, Buxton as Co-PI, 560 kEuro for GSE)
- SAFE-10-T (H2020, 2017, Gavin as Co-PI, 2997 kEuro in total, 780 kEuro for GSE)
- VirtualSeis (ERC, 2017, Wapenaar as PI, 2499 kEuro for GSE)
- Smart Exploration (EU-H2020, 2017, Draganov and Ghose as Co-PIs, 250 kEuro for GSE)
- Fluid-Rock Interactions (NWO-VENI, 2017, Pluymakers as PI, 250 kEuro for GSE)
- I2Mon (EU-RFCS, 2018, Vossepoel, Vardon and Buxton as Co-PIs, 270 kEuro for GSE)
- EPOS-NL (NWO, 2018, Wapenaar as Co-PI, 12272 kEuro in total, 5668 kEuro for GSE)
- SOFTTOP (NWO-DeepNL, 2018, Hicks as PI, 1042 kEuro for GSE)
- Science4Steer (NWO-DeepNL, 2018, Jansen as PI, 1451 kEuro in total, ~ 1000 kEuro for GSE)
- InFocus (NWO-DeepNL, 2018, Vossepoel as PI, 766 kEuro in total, 275 kEuro for GSE)
- Subsidence (NWO-DeepNL, 2018, Hanssen as PI, Vossepoel as Co-PI, 230 kEuro for GSE)
- DeepImage (NWO-DeepNL, 2018, Wapenaar as PI, 1053 kEuro for GSE)
- Sustainable Dykes (NWO, 2019, Dieudonné as Co-PI, 620 kEuro for GSE)
- Self-healing mechanics for clays (NWO-VENI, 2019, Dieudonné as PI, 250 kEuro for GSE)
- Admire (NWO-VIDI, 2019, Hajibeygi as PI, 800 kEuro for GSE)
- SUCCEED (EU-ERAMet, 2019, Wolf as Co-PI, ~3900 kEuro in total, 720 kEuro for GSE)
- LOSS (NWO, 2019, Department GSE as Co-PI, 1069 kEuro in total, 400 kEuro for GSE)
- InSITE (EIT-KAVA, 2019, Buxton as WP leader, 1.8 MEuro in total, 256 kEuro for GSE)
- EASYGO (EU-ITN, 2020, Brehme as PI, 3416 kEuro in total, 1479 kEuro for GSE)
- CURE (NWO-Groot, 2020, Gebert as PI, 2670 kEuro in total, 1649 kEuro for GSE)
- EXCITE (EU-INFRAIA, 2020, Barnhoorn and Armstrong as Co-PIs, 329 kEuro for GSE)
- REFLECT (EU-H2020, 2020, Pluymakers as Co-PI, 465 kEuro for GSE)
- ATES Triplet (NWO-TTW, 2020, Vardon as PI, 343 kEuro for GSE)
- GEOLAB (EU-H2020, 2020, Askarinejad as Co-PI, 5 MEuro in total, 500 kEuro for GSE)
- Trim4Post Mining (EU-RFCS, 2020, Buxton as WP leader, 1.43 MEuro, 338 kEuro for GSE)

The following projects were granted in 2021, but the proposals were prepared/submitted in 2020:

- Minimizing Risk of Induced Seismicity (NWO-TTW, 2021, Pluymakers as PI, 594 kEuro for GSE)
- CEMENTEGRITY (EU-ERANet, 2021, Pluymakers as Co-PI, 510 kEuro for GSE)
- Assess bridge safety from space (NWO-VIDI, 2021, Giardina as PI, 800 kEuro for GSE)
- SHARP Storage (EU-ERANet, 2021, Barnhoorn as Co-PI, 940 kEuro for GSE)
- Sediment to Soil (NWO-TTW, 2021, Gebert as PI, 1368 kEuro in total, 700 kEuro for GSE)
- Satellite subsidence….in the Bangkok area (NWO, 2021, Vossepoel as PI, 250 kEuro for GSE)
- 3DSoil (NWO-DeepNL, 2021, Hicks as PI, Ghose as Co-PI, 358 kEuro for GSE)
- GASCLAY (EU-Marie-Curie, 2021, Liaudat as PI, 187 kEuro for GSE)

Prizes awarded to individuals or collaborative research projects

- van der Neut (J. Clarence Karcher Award, SEG 2015)
- van der Neut and Wapenaar (Best paper in Geophysical Prospecting, EAGE 2016)
- Noorlandt and Drijkoningen (Best paper in Geophysics, SEG 2016)
- Ruigrok (Division Outstanding Early Career Scientist Award, EGU 2016)
- Hicks and Vardon (Best paper in Géotechnique Letters, 2016–Quarter 2)
- Shah (Europe Region Student Paper Contest, SPE 2016)
- Gavin (Fleming Award, British Geotechnical Association 2017)
- Dieudonné (Ioannis Vardoukalis PhD prize, ALERT Geomaterials 2017)
- Hicks (Georisk Most Cited Paper Award, 2017)

- Gavin (TRA VISIONS Senior Research Competition, 2018)
- Askarinejad (Bright Spark lecture award, ISSMGE 2018)
- Farajzadeh (North Sea Regional Reservoir Dynamics and description Award, SPE 2018)
- Jansen (Distinguished Achievement Award, SPE 2018)
- Jansen (Distinguished Membership, SPE 2018)
- Pisanò (Bright Spark lecture award, ISSMGE 2019)
- Vardon (Environmental Geotechnics Prize, ICE 2019)
- Gavin (British Geotechnical Association Medal, 2020)
- Slob (Reginal Fessenden Award, SEG 2020)
- Muraro (Ioannis Vardoukalis PhD prize, ALERT Geomaterials 2020)
- Boersma, Bertotti et al. (Best paper in Petroleum Geoscience, EAGE 2020)
- Ghose and Draganov (Smart Exploration project, Distinguished Achievement Award, SEG 2020)

The following are prizes awarded in 2021, for achievements in the review period:
- Hajibeygi (InterPore Award, Interpore 2021)
- Grobbe (J. Clarence Karcher Award, SEG 2021)
- Draganov (Outstanding Educator Award, SEG 2021)
- Zitha (Distinguished membership, SPE 2021)
- Bruining (Distinguished membership, SPE 2021)
- Voskov (Regional Reservoir Dynamics Award, SPE 2021)
- Gebert and Draganov (Team Science Award, NWO 2021)

Seven members of the department are in the Stanford list of the world's top 2% scientists (Wapenaar, Rossen, Mulder, Jansen, Verruijt (emeritus), Zitha and Farajzadeh).

Membership of scientific councils or committees
- Draganov, Technical Programme Officer for the Near Surface Geoscience Division of EAGE
- Draganov, member of the jury for the Escherprijs
- Ghose served as Editor-in-Chief for Near Surface Geophysics
- Ghose, member of Research and Publication Committees of EAGE
- Storms, Delta Futures Lab
- Storms, Transitional Territories Studio (Faculty of Architecture, Urbanism)
- Vossepoel, Stichting Netherlands Geoscience Journal

Research products for societal target groups

Products for professionals
- The DAPwell project cooperates closely with Hydreco, Shell, EBN and Geothermie Delft on the implementation of a geothermal well on the TU-Delft campus.
- In an NWO-OTP project, Pluymakers, Muntendam-Bos and Voskov cooperate with GeothermieNL and KNMI on the development of methodology for the minimization of induced seismicity in fractured carbonate reservoirs.
- In an NWO-TTW project, Wapenaar and Slob cooperated with Shell, TNO, CGG, Aramco Overseas, Fugro and Deltares on the development of novel seismic imaging and monitoring methodology.
- In an ERA-NET CoFUND project, Slob cooperated with Terrasys, TEEC, GFZ Potsdam and GEOMAR, with contributions from the University of Southampton and Equinor, on the development of joint inversion modules for improved geophysical interpretation.
- In the NeTTUN project, Drijkoningen closely cooperated with civil engineers across Europe to develop a seismic monitoring system for looking in front of large Tunnelboring machines (TBM's). This has resulted in a seismic source that has successfully been marketed by the company Seismic Mechatronics.
- In the SmartExploration project, Draganov and Ghose cooperated closely with Seismic Mechatronics, Delphi-Distomon, Yara, and Nordic Iron Ore on the development of active- and passive source seismic-interferometry tools for cheaper and environmentally friendly seismic imaging.
- EPOS-NL provides data sharing and access to peers and societal groups.

Courses for professionals

- Foundations for offshore windturbines (Pisanò et al, 2019), PAOTM
- Geoscience and Geoenergy webinars (Hajibeygi), public YouTubeChannel, >2600 subscribers
- ADMIRE, Physics of GeoSystems and Simulation (Hajibeygi), public YouTubeChannel
- Implicit Bias, workshop for GAIA/EAGE women's network (Vossepoel), also held at Nederlands Aardwetenschappelijk Congres.

MOOCS

- The Earth and its resources (Bertotti, 2017, 2018 and 2020, >10000 participants)
- Induced seismicity (Barnhoorn, Korff, 2017)

Popular articles for general audience

- Stories of Science (many members of Department GSE), Website Faculty CEG
- Bergen Bouwen voor meer Regen? (Askarinejad, 2016), Delta
- Towards the truth on peatlands subsidence (Dieudonné, 2017), Delta (June 2017)
- What happens beneath the sinking surface (Vossepoel, 2017), DeltaLinks (June 2017)
- Static Liquefaction Tank (Askarinejad, 2018), Delft Outlook
- Carbonated water for steam and power (Wolf, 2019), DelftOutlook
- The holy trinity of geothermal energy (Pluymakers, 2020), Geo-brief (2020-1, pp. 15-17)
- Panorama new Netherlands (Storms, co-editor, 2020), Delta (February 2020)
- Lichtkogel Zandtekort (Storms, co-guest editor, 2020), Rijkswaterstaat (June 2020)
- Predictive models for COVID-19, an Earth Science response (Vossepoel, Leeuwenburgh, 2020), Geo-Brief (2020-5, pp. 5-7)
- Verspreiding van corona volgen met datatechnieken uit de geowetenschappen (Vossepoel, 2020), Civiele Techniek (2020-7, pp. 14-16)
- Veldwerk in tijden van corona – deel 2 (Pluymakers, 2021), Geo-brief (2021-3, pp. 17-20)
- Transform by design (Storms, co-author, 2021), Delta (June 2021)
- Lessen Grimburgwal (Korff, 2021), Cobouw

Lectures and documentaries for general audience

- Modern techniques to produce 3D replicas of missing artefacts (Ngan-Tillard, 2017), BBC
- Looking inside: Micro-CT scanning, Lecture at National Museum of Antiquity (Ngan-Tillard)
- Geothermal Get-togethers (Vardon, Daniilidis and Laumann, from 2018 onwards), DAP
- Leidse winterlezing (Storms, 2019)
- Reliable Dykes (Brinkgreve, Vardon, Hicks, 2019), public YouTubeChannel
- Symposium Urban Heating (Vardon ,2019), DAP
- Lecture for the Independent School for the City, Rotterdam (Storms, 2020)
- Energiekademuur (Vardon, co-presenter, 2020), public YouTubeChannel
- Gentle Driving of Piles (Pisanò, co-presenter, 2021), public YouTubeChannel
- Energy Geostructures (Vardon, 2021), KIVI

Blogs, forums and podcasts for general audience

- Tectonics and Structural Geology, EGU (Anne Pluymakers)
- Twitter Rock Deformation TUDelft (Anne Pluymakers and Auke Barnhoorn; >500 followers)
- Hoe?Zo! Show (Jon Kortram)
- How safe are dykes? (Yajun Li)
- Computational power for reliable dykes (Divya Varkey)
- Applying Data Assimilation Tools to COVID Forecasting Models, (Vossepoel, >3400 followers)

Use of research products by societal target groups

Research highlights (other than those mentioned in the main GSE report, sections 5.1 and 5.2)

- The Pisa design method developed in the PISA project (Gavin as PI) is now implemented in the design of new offshore wind turbines supported on monopiles. The estimated cost savings achieved are 300 kEuro per offshore wind turbine.
- Gavin and colleagues completed a pile test programme on behalf of the Port of Rotterdam for the InPAD project. The design methods allowed savings of 20 mEuro for a project in the Maasvlakte and an estimated reduction of 30 kton of CO2 was achieved.
- Research on quay walls is used by the City of Amsterdam.
- Ghose performed seismic studies for assessment of affected building foundation in Amsterdam.
- Research of Sustainable Landfill aftercare of Heimovaara and Gebert is closely integrated in the Dutch national programme in introducing Sustainable Landfill Aftercare in the Netherlands (iDS, introductie Duurzaam Stortbeheer).
- Research on seismic acquisition by Drijkoningen and others led to the development of a seismic vibrator based on a Linear Synchronous Motor (Noorlandt, Drijkoningen et al., 2016, Best paper in Geophysics), which is further developed by Seismic Mechatronics in cooperation with Drijkoningen.
- Research by Drijkoningen and Wapenaar on the use of optical fibers for seismic monitoring resulted in special fibers in special configurations, which have successfully been used for active and passive monitoring in the south of Groningen, where induced earthquakes take place.
- Research by Ghose, Draganov and Ngan-Tillard led to successful application of new geophysical imaging techniques involving shear waves and seismic interferometry in the ancient archeological sites in Ostia (Rome) and in the Netherlands, for archaeologists from Leiden University.
- Research on seismic survey design by Blacquière and others, and on near-surface geophysics by Slob, Draganov and Weemstra, is used by the companies supporting the Delphi consortium.
- Research on the use of machine learning for lithofacies characterization by Vossepoel is used by the companies supporting the Delphi consortium.
- Research on near-surface geophysics by Draganov, Slob, Ngan-Tillard and others is used by Rotterdam and Hamburg Harbors, SmartPort, the Dutch Forensics Institute, The Foundation for the Preservation of the Jewish Cemetery in The Hague and The Foundation Jewish Westland and Museum Timmerwerf in De Lier.
- Research conducted by Rouhi Farajzadeh, Hans Bruining, Paul van den Hoek on controlling water cut or improving utilization factor of the injectants has gained attention in the literature and is being used by oil companies for cleaner production of their assets.

Use of software and databases

- Empymod (http://emsig.xyz) has been incorporated in SimPEG (http://simpeg.xyz), geobipy (United States Geological Survey: https://github.com/usgs/geobipy) and geoscixyz (for teaching purposes) and pyGIMLi (https://github.com/LIAG-S2/SAEM). General indication of dependencies to empymod on Github can be found here: https://github.com/emsig/empymod/network/dependents?dependent_type=PACKAGE.
- Use of DARTS in Deep Learning project at Chevron: https://doi.org/10.3389/fams.2021.689934.

Exhibitions to outside parties

- Scanning for Syria exhibition at the Dutch National Museum of Antiquities.
- Wierdeland museum, exhibition “Syria, tells: the terps of the Middle East”.

Marks of recognition from societal target groups

Selection of research projects with significant industrial funding

- Role of scour protection on the prevention of static liquefaction-induced flow slides (Rijkswaterstaat, 2015, Hicks as PI, 470 kEuro for GSE)
- OYO-TUD cooperation (OYO, 2016, extended in 2020, Ghose as PI, 950 kEuro for GSE)

- EURAD (EU and COVRA, 2018, 38000 kEuro in total, 175 kEuro for GSE)
- MIDAS (RVO + Industry, 2019, Pisanò as PI, 1000 kEuro in total, 784 kEuro for GSE)
- WarmingUP (RVO+industry, 2019, Vardon as Co-PI, 9370 kEuro total, 351 kEuro for GSE)
- InPAD (TKI, 2019, Gavin as Co-PI, 2162 kEuro in total, 220 kEuro for GSE)
- BLUE Piling project (RVO + industry, 2020, Askarinejad as Co-PI, 1000 kEuro for GSE)
- Sensor Based Ore Waste Discrimination for Hydrothermal Gold Deposits (250 kEuro for GSE)
- The Delphi consortium finances 0.4 fte of the position of Blacquière, 5 PhD candidates and 2 postdocs

The following projects were granted in 2021, but the proposals were prepared/submitted in 2020:
- SafeInCave (Shell, 2021, Hajibeygi as PI, 468 kEuro for GSE)
- GPU4CO2THERMO and GPU4CCS (Total, 2021, Voskov as PI, 497 kEuro for GSE)
- ProperBase (RVO, 2021, Abels as PI, 356 kEuro for GSE)
- RESET (ProRail, 2021, Gavin, Hicks and Jommi as Co-PI's, 4800 kEuro in total, 1400 kEuro for GSE)

Secondary appointments

- Blacquière, TNO.
- Brinkgreve, Plaxis BV.
- Evers, KNMI.
- Farajzadeh, Shell.
- Korff, Deltares.
- Leeuwenburg, TNO.
- Martinius, Equinor.
- Mulder, Shell.
- Muntendam-Bos, SodM.

Governmental consultancy and memberships of scientific councils for society

- Heimovaara has served as the chairman of the Scientific Core Team for the Dutch national programme on introducing Sustainable Landfill Aftercare in the Netherlands (iDS) since 2007.
- Korff, Ambassador of the Dutch Platform for Geotechnics "Platform Geotechniek".
- Vossepoel, "KEM subpanel" for the evaluation of the Groningen public domain seismic hazard and risk modelling instrument, commissioned by Ministry of Economic Affairs and Climate Policy.
- Vossepoel, Technische commissie bodembeweging, a committee that advises the Ministry of Economic Affairs and Climate Policy on the risks of ground motion due to use of the subsurface.
- Vossepoel, Steering committee of the seismic campaign geothermal energy Netherlands.

Membership of civil-society organisations

- ACSG: Advisory committee on damage related to groundwater (Korff)
- ALERT Geomaterials: The Alliance of Laboratories in Europe for Education, Research and Technology (TU Delft is a founding member of ALERT; Hicks, board of directors until 2017; Dieudonné, board of directors from 2021)
- Centrum Ondergronds Bouwen (Broere, Korff, Gavin)
- Comprehensive Nuclear-Test-Ban Treaty Organization, CTBTO (Evers)
- European Energy Research Alliance – EERA, Geothermal Team (Bruhn)
- International Society for Trenchless Technologies (Broere, trustee)
- International Tunnelling Association (Broere, WG20 chair)
- Ingeokring (Dieudonné and Ngan-Tillard, board members)
- KNGMG Royal Geological and Mining Society of the Netherlands (members of the board: Abels, 2015-2018, Vossepoel, 2018-2020, Pluymakers, 2020)
- Kivi (Hoffmann in Board of Kivi International Engineers)
- Mijnraad (Jansen)
- Software Underground (Swung) (Werthmüller founding board member)
- Technical Committees of Int. Soc. of Soil Mechanics and Geotechnical Engineering (Askarinejad)

Appendices
Department of Geoscience and Remote Sensing

Appendix F: GRS Staff

New GRS staff members

The following scientists joined GRS in the last six years:

- Prof. Dr. Bert Vermeersen joined the GRS Department as 0.1 Full Professor in 2015, specializing in solid earth geophysics and sea-level change. He is Full Professor in Planetary Exploration at the Faculty of Aerospace Engineering (0.7 fte) and also has a 0.2 fte position as Senior Researcher at the Royal NIOZ NWO-Institute.
- Prof. Dr. Ir. Bas van de Wiel joined GRS as an Antoni van Leeuwenhoek (full) professor in Atmospheric Physics in 2015, bringing his expertise in environmental fluid mechanics and atmospheric physics, with a specific interest in nocturnal boundary layers and atmosphere-surface interactions.
- Dr. Sukanta Basu joined GRS in 2016 as Associate Professor, with a broad range of research interests ranging from atmospheric boundary layer processes, atmospheric optics, machine learning, numerical weather prediction to renewable energy and turbulence modeling
- Dr. Louise Nuijens joined GRS in 2016 from a position as a group leader at the Max-Planck Institute for Meteorology and a post-doctoral fellow at MIT. She is an Assistant Professor and focusses on convective clouds and their coupling to wind and circulation patterns.
- Dr. Paco Lopez Dekker joined GRS in 2016 from the German Aerospace Center (DLR) where he led the SAR Missions Group. He is an Associate Professor whose current research focuses on future SAR missions and novel mission concepts.
- Dr. Stef Lhermitte joined GRS in 2016 as an Assistant professor, after obtaining a PhD in bioscience engineering at KULeuven, Belgium, and several international post-docs positions (CEAZA, KNMI, KULeuven). He works on broad range of remote sensing technologies in a variety of applications ranging from cryospheric and atmospheric sciences to ecology and hydrology.
- Pier Siebesma's appointment as a Full Professor in Atmospheric Science was increased from 0.2 to 0.8 fte. in 2017.
- Dr. Marc Schleiss joined GRS in 2017 as an Assistant Professor after graduating from EPFL, Switzerland. His research aims to improve the measurement, modeling and forecasting of rain, with an emphasis on heavy, localized events responsible for urban pluvial flooding.
- Bert Wouters joined GRS in 2018 (0.3fte in 2018 to 0.5fte in 2020) as an Assistant Professor, with a dual appointment at TU Delft and Utrecht University. He combines satellite observations and regional climate models to study the response of the Earth's glaciated regions to climate change and their impact on sea level.
- Wouter van der Wal joined GRS part-time (0.2 fte) in 2017. He is an Associate Professor working on the modelling of glacial isostatic adjustment (GIA) with 3D variation in mantle properties and the analysis of the GIA signature in gravity and deformation measurements with focus on polar areas.
- Ihor Small joined as Assistant Professor with expertise in machine learning and computer vision.
- Dr. Will Ball joined GRS in 2020 as an Assistant Professor, following positions at ETH Zurich and PMOD World Radiation Center (Davos) and Imperial College London. Dr. Ball focuses on air quality and air pollution within a climate change context, using satellite observations and chemistry climate models.
- Dr. Franziska Glassmeier joined GRS in 2020 as an Assistant Professor, following positions at Wageningen University and the National Oceanic and Atmospheric Administration (NOAA). Dr. Glassmeier combines traditional process-based approaches and data science with concepts from dynamical and complex systems theory to study cloud complexity.
- Dr. Alireza Amiri-Simkooei joined GRS in 2020 as an Assistant Professor working on geo-statistical machine learning with applications to seafloor bathymetry and classification, sea surface monitoring and sea-surface safe ship navigation.

List of all Academic staff on 31-12-2020

Table F1a. Permament Staff at 31-12-2020, GRS, including position and research themes

Name	Position	Geodesy	Earth System Science	Remote Sensing	Atmospheric Science
Amiri-Simkooei, Alireza	Assistant Professor	x	-	x	-
Ball, William	Assistant Professor	-	o	x	x
Basu, Sukanta	Associate Professor	-	-	-	x
Biskos, George	Permanent Researcher	-	-	x	x
Ditmar, Pavel	Associate Professor	o	-	x	-
Glassmeier, Franziska	Assistant Professor	-	o	o	x
Hanssen, Ramon	Professor	x	x	x	o
Jonker, Harm	Professor	-	-	-	x
Klees, Roland	Professor	x	o	x	-
Leijen van, Freek	Permanent Researcher	x	-	x	o
Levelt, Pieternel	Professor	-	-	x	o
Lhermitte, Stef	Assistant Professor	o	x	x	o
Lindenbergh, Roderik	Associate Professor	x	-	x	-
Lopez-Dekker, Paco	Associate Professor	x	x	x	o
Marel van der, Hans	Permanent Researcher	x	o	x	o
Nuijens, Louise	Assistant Professor	-	o	x	x
Riva, Riccardo	Associate Professor	x	x	-	-
Roode de, Stephan	Assistant Professor	-	o	-	x
Russchenberg, Herman	Professor	-	o	x	x
Schleiss, Marc	Assistant Professor	-	-	x	x
Siebesma, Pier	Professor	-	x	o	x
Slobbe, Cornelis	Assistant Professor	x	o	x	-
Teunissen, Peter	Professor	x	o	x	o
Tiberius, Christian	Associate Professor	x	o	x	o
Unal, Christine	Permanent Researcher	-	-	x	x
Veefkind, Pepijn	Associate Professor	-	-	x	o
Verhagen, Sandra	Assistant Professor	x	o	x	o
Vermeersen, Bert	Professor	o	x	-	-
Vizcaino, Miren	Assistant Professor	-	x	-	x
van der Wal, Wouter	Associate Professor	x	x	-	-
van de Wiel, Bas	Professor	-	o	-	x
Wouters, Bert	Assistant Professor	x	x	x	-

Table F1b. Staff that left during the assessment period

Name	Last position	Geodesy	Earth System Science	Remote Sensing	Atmospheric Science	Next:
Dufournet, Yann	Assistant Professor				x	Co-founder Start-up SkyEcho
Gorte, Ben	Assistant Professor	x		x		Research Associate, Fact. Of Built Environment, UNSW Sydney
Hooper, Andy	Associate Professor	x	x			Professor, School of Earth and Environment, Univ. Leeds
Small, Ihor	Assistant Professor			x		PI, Dept. Of Cell Biology & Molecular Genetics, Erasmus MC
Vlemmix, Tim	Assistant Professor			x	x	Researcher, Koninklijk Nederlands Meteorologisch Instituut (KNMI)

Appendix G:
Selected Performance Indicators

Research Quality

Research Products for Peers	
(Open Access) Peer-reviewed publications, conference proceedings and PhD dissertations	Appendix L (Key publications) Table I.7
Books and Book Chapters	Table J.1
Scientific Reports	Table J.2
Open Access datasets, including download statistics	Table J.3
Open Access software	Table J.4
Designs – Models and Missions	Table J.5
Use of research products by peers	
Citations of publications	Appendix L (Key publications) Table J.3, J.4
Marks of recognition by peers	
Individual research grants	Table J.6
Collaborative research grants	Table J.7
Editorships	Table J.8
Membership of scientific organizations and advisory committees	Table J.9
Prizes/awards	Table J.10
Secondary appointments	Table J.11

Marks of recognition by peers

Societal Relevance

Research products for societal target groups	
PhD students	Table I.6
MSc students	Table I.8
Public lectures for a general audience	Table I.5, I.6
Films/documentaries for a wide audience	Table J.13
Media coverage of research	Table J.14
Website for societal target groups	Table J.15
Stories of Science	Table J.16
Patents and licenses	Table J.17
Use of research products by societal target groups	
Research projects with educational components	Table J.18
Research grants with contributions from societal parties	Table J.6
Marks of recognition by societal target groups	
Financial and material support	Table J.7
Solicited expert advice	Table J.19
Public awards	Table J.20

Appendix H:
Case Studies

Case study H1: Addressing PhD supervision and completion times

During the previous assessment, one of the main concerns was that the duration of PhD studies often exceeded the nominal four years. GRS installed a working group with both a PhD-representative and 4 staff members to understand why this happens, and to make optimal use of past experience on "best practices" from the full population of PhD students and staff. A questionnaire was distributed to the PhD students asking them to share their experiences and to provide (anonymous) suggestions for improvement. Likewise, academic staff were invited to share 'best practices'. The outcomes of this survey were distilled into two documents, which are provided below:

The "PhD Memorandum" comprises a list of internal agreements within GRS that add to existing TU Delft policies and facilities offered by the Graduate School. The full memorandum is provided on the next page, but some key points include:

- Before hiring a PhD student, GRS requires that the candidate is tested (IELTS) on English language skills to ensure that they are sufficient to conduct research, publish, and write a thesis. This rule has recently been formalized at the CiTG faculty level.
- It is strongly recommended that the project lead is advised by at least one colleague (e.g. the 2nd (co-)promotor) during the recruitment process to avoid "tunnel vision".
- It is recommended that the Go/no-go decision is made earlier, at 9 months rather than 12.
- An independent committee member must be present for the 3-month "PhD agreement meeting" where the personal Educational and Developmental Plan is discussed, and the 6-month "PhD progress meeting" where plan adjustments are discussed. The mandate of this independent committee member is to advise.

A list of "Best practices" was also composed by PhD students, with suggestions for advisors.
It is provided overleaf. Key points include:

- Regular, weekly contact is important, even if it is informal.
- Feedback should be constructive and provided promptly (e.g. after 2 weeks)
- Make expectations clear to the PhD candidate. What do you expect and when? When is a thesis complete?
- Step in early when there is a road block.
- In addition to content, focus on the development of soft skills including writing and being a researcher.

These internal GRS agreements complement existing TU Delft policies and facilities offered by the Graduate School. Finally, a list of "tips and tricks" has also been produced by GRS PhD students for GRS PhD students. General recommendations include being proactive, discussing mutual expectations, and seeking help early. Specific suggestions are also made, e.g. guidelines and templates to help prepare efficiently for the 3-, 6- and 9-month meetings. Finally, it includes a list of recommended courses from the TU Delft Graduate School or external providers (e.g. via Coursera).

A representative of the PhD student community attends our weekly staff meeting to keep the PhD students informed on developments within the Department, and to ensure that PhD student voices are heard during decision-making. In addition, PhD students are represented by the GRS student association (Snellius). These connections proved invaluable during the Covid lockdowns as they provided insight into the evolving challenges facing our PhD students and a means to ensure that PhD students stayed connected with each other, and with the Department.

Best practices for advisors/promotors

This is a suggested list of "best practices" to employ throughout your PhD. It is acknowledged that each PhD is unique, with the below intended as a guide based on PhD feedback, and advisor experience.

Guidance:

1. Provide a lot of guidance at the start of the project, gradually reducing oversight during four years
2. Be actively engaged in the research
3. Meet weekly, even if just a "coffee meeting" (short, informal)
4. Provide prompt, constructive feedback; e.g., return drafts within two weeks
5. Provide clear, constructive guidance: i.e. as a constructive coach/mentor and develop ideas together
6. Step in early if there is a roadblock
7. Assist in the planning of the research and in the scheduling of the project
8. Make expectations known

Progress Meetings

1. Schedule all first-year meetings upon entry
2. Go/no go evaluation should be held during the 9th month
3. Guidelines surrounding meetings/expectations should be clear
4. Next to discussing the results, also discuss future research planning

Thesis and Research Planning

1. Discuss ideas and expectations for the "complete" thesis early in the process
1. Aim for peer-reviewed articles as chapters
2. Draft one chapter/article every 1-1.5 years and aim to have 3 by end of 3rd year.
3. It is recommended to draft list of intended topics for each thesis chapter.

Graduate School

1. Encourage PhD student to finish the full 45 credits within the first three years
2. Request a full list of the planned courses (what and when) already at 3-month meeting. New insights later may cause this list to change off course.
3. Graduate School experience should be improved to begin with trough the use of:
    - the list of recommended Graduate School courses [*Appendix B*]. Graduate School representatives of GRS are responsible for updating this list in consultations with the PhDs.
    - courses offered by external organizations (e.g. university, training institutes, research schools etc.

Best Practices for PhD candidates

This is a suggested list of "best practices" to employ throughout your PhD. It is acknowledged that each PhD is unique, with the below intended as a guide based on PhD feedback, and advisor experience

General guidance

1. Enjoy it! This is a great time to develop and explore different interests
2. Be proactive. You are ultimately responsible for any planning and issues
3. Seek help early. Make use of the knowledge and experience around you
4. Have a plan, and check it frequently. Update and revise as necessary

Guidance on interactions with your Advisor (incl. Promotor)

1. Aim to meet with your (daily) advisor at least once per week, and your promotor (if different) at least once per month to discuss progress and any current challenges
2. Your advisor should assist in both guiding and planning research
3. Your advisor should not tell you what to work on, but work with you ('advise you').
4. If you have any problems in your advisory relationship, contact your CITG-mentor.
5. Be sure to discuss mutual expectations

Progress Meetings

The current practice is to have `official' progress meetings at 3 and 6 months, the *go/no go* in the 9th month, and annual meetings thereafter.

1. Ensure your meetings are held on time
2. Consult with your advisor(s) on what to prepare
3. Focus on planning, and be sure to discuss advising and other aspects of your PhD.
4. Prepare a short report including research plans, output, and scheduling as appropriate.
5. Send your report to your advisors at least one week in advance so they can prepare.
6. Prepare a short presentation highlighting the key points of the report.
7. Agree with your advisor if it is helpful to define the discussion points beforehand (I.e. agenda) and to follow-up with the key points and agreements.

Thesis and Research Planning

1. Determine with your advisor what is expected and constitutes a "finished" thesis for your specific research.
2. Aim for at least three "research" chapters (excluding introduction and conclusions)
3. Aim to write a (draft) chapter/articles every 1–1.5 years (completed by 3rd year)
4. Decide on the approximate content of your thesis chapters at the 3 month meeting
5. Use the first year meetings to form your thesis introduction or first chapter
6. Start a list of "propositions" early so that you are able to compile a strong list by the end of your thesis

Graduate School

1. By the 3-month meeting: Plan the courses you would like to take
2. Aim to complete at least 15 credits per year such that you are done by the end of year 3 at the latest
3. Seek courses that will truly be of benefit, not just ones to "get points"
4. Look for external course opportunities, not just those at TU Delft

Case study H2: New on- and off-shore vertical reference surfaces for The Netherlands

Summary

The Netherlands lacked accurate realizations of the on- and offshore vertical reference surfaces. Moreover, the relation between both was only established at the onshore tide gauges. Departmental research led to the realisation of the two vertical reference surfaces including the transformations required for the conversion between them. The conceptual framework and part of the methodology were developed before 2015. Between 2015 and 2020 the methodological research was finalized, and the two vertical reference surfaces were computed in collaboration with Deltares, governmental agencies responsible for vertical referencing in the Netherlands, and representatives from the user community. The two vertical reference surfaces, referred to as NLGEO2018 (land) and NLLAT2018 (sea) were provided to the governmental agencies in charge of vertical referencing in the Netherlands in 2018. After a thorough validation, they have been made available to the user community in 2020.

Underpinning research

Novel research on the realization of a mutually consistent set of vertical reference surfaces was undertaken between 2009 and 2020 by Roland Klees (Professor of Physical Geodesy, at TUD since 1994) and his team, primarily Cornelis Slobbe (PhD student at TUD from 2009-2013 and Assistant Professor at TUD since 2013). The conceptual framework and methodology broke new grounds and were well received by the engineering and user community because of their novelty, the improvements over existing methodologies, and the quality of the vertical reference surfaces. The research was communicated in 8 peer-reviewed scientific journal papers and 22 presentations at international conferences. Specific innovations developed over that time period include: the conceptual framework which foresees the combination of gravimetric and altimetric data and water levels at tide gauges with water levels from a hydrodynamic model in a feedback loop [1]; a new functional and stochastic model for satellite radar altimeter data for quasi-geoid modelling [2,3]; a Kalman filter approach to realize a Lowest Astronomical Tide (LAT) based marine vertical reference surface which assimilates tidal water levels at tide gauges into a hydrodynamic model [4]; a methodology for the statistical combination of various terrestrial datasets with a global geopotential model using full noise covariance matrices [5,7,8]; and a methodology to connect the Wadden islands with the Amsterdam ordnance datum (NAP) with cm accuracy [6].

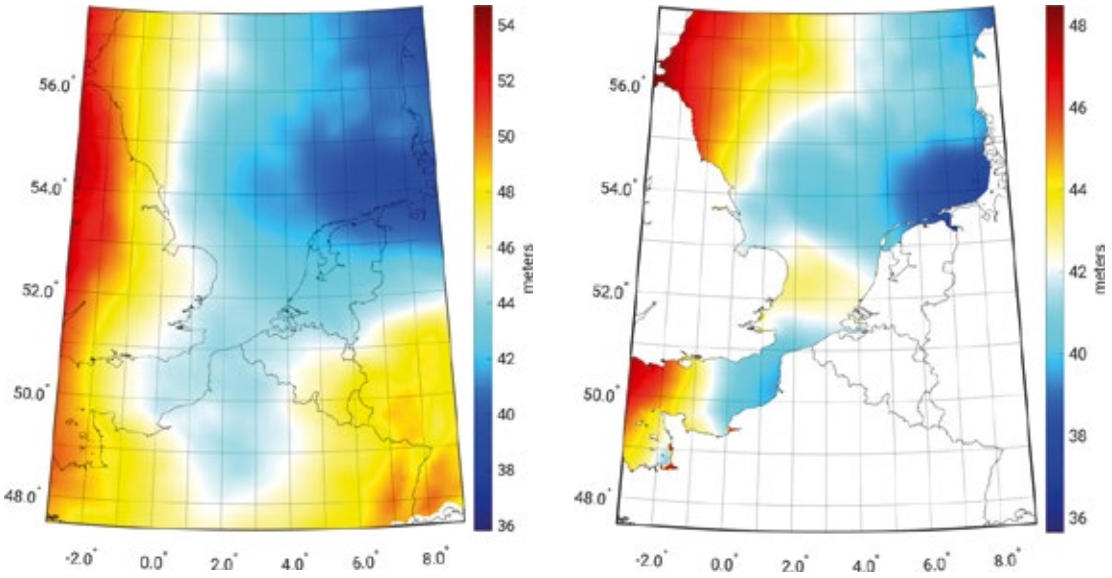


Figure H-1. New height (NLGEO2018, left) and depth (NLLAT2018, right) reference surfaces relative to the surface of the GRS80 reference ellipsoid.

Societal impact

The research activities and project deliverables addressed a broad range of problems related to vertical referencing with significant social and economic consequences for the marine and energy sector, including charting and dredging companies and companies offering navigation solutions. The benefits are numerous: faster, cheaper and more accurate hydrographic survey data for nautical charts; more precise navigation in shallow waters; better coastal zone protection by merging of marine and land datasets; more accurate planning of depth maintenance in port approach areas; sea level rise studies, eco-system studies; integrated coastal zone management, and pro-active disaster-mitigation planning; better prevention of vessel grounding. The socio-economic spin-off is substantial: improved charts, which allow for faster transits of ships with deeper draughts which in turn implies a greater amount of goods moving through the shallow Dutch waters such as the ports of Rotterdam and Antwerp; reduced number of groundings by providing more accurate charts, which will reduce insurance rates; improved quality of bathymetric data, which is critical for the selection of routes for pipelines and cables; shorter and more accurate execution of offshore dredging projects and minimized sediment removal with positive impacts on the natural environment; cost benefits for the government due to larger measurement errors in charted depths without effecting the overall error budget; cost savings for the connection of the Wadden islands and off-shore platforms to the height system on land (NAP); reduced uncertainties for hydrographic surveys in the North Sea where GNSS is not available; aiding of offshore dredging projects including large reclamations, pipeline route pre-sweeping, and insulation and stabilization of pipelines in the oil and gas industry.

To maximize societal impact, key users of the project deliverables were involved during project preparation and execution. In fact, a user committee was established with representatives from governmental agencies in charge of vertical referencing (Hydrographic Service of the Royal Netherlands Navy; Ministry of Infrastructure and Environment/Rijkswaterstaat), offshore and dredging industry (e.g., van Oord and Boskalis), surveying companies (Fugro), engineering companies (Allseas Engineering), navigation companies (e.g., QPS), and others (Netherlands Kadaster, oil and gas exploration and production company NAM). In regular meetings, the user committee was informed about the progress and provided feedback, which in turn led to adaptations of the overall plan whenever necessary. Several meetings with the Hydrographic Service of the Royal Netherlands Navy and the Ministry of Infrastructure and Environment/Rijkswaterstaat were organized to guarantee knowledge transfer. Moreover, after finalizing the project a workshop was organized to inform an even broader range of potential users of the new vertical reference surfaces and other related services. About 75 representatives from government and industry participated in the workshop.

The application of the developed conceptual framework and methodology is not confined to the Netherlands. In fact, all coastal countries suffer from similar problems. Collaborations (visits, joint workshops, and knowledge transfer) with institutions in Belgium, Brazil, and Chile, and recently, the Baltic states are on-going. We expect that in the years to come the interest in our approach will steadily increase.

Grants

Some preparatory studies were financially supported in the framework of the EU Interreg IVB North Sea Region Program project “Bringing Land and Sea Together (BLAST)”. The development of the conceptual framework and part of the methodology received financial support from the Netherlands Commission of Geodesy (NCG). Additional methodological research and the computation of the vertical reference surfaces were financially supported by the STW project “Vertical Reference Surfaces for the Netherlands Mainland, Continental Shelf and Wadden Islands (NEVREF)” and a group of governmental and industrial users. The overall financial support was about kE 1,000.

Publications

1. Slobbe, D.C., R. Klees, B.C. Gunter (2014). “Realization of a consistent set of vertical reference surfaces in coastal areas.” *Journal of Geodesy* 88(6), 601-615.
2. Slobbe, D.C., R. Klees (2014). “The impact of the dynamic sea surface topography on the quasi-geoid in shallow coastal waters.” *Journal of Geodesy* 88(3), 241-261.
3. Farahani H.H., D.C. Slobbe, R. Klees, K. Seitz (2017) “Added value of a proper dealing with coloured noise in radar altimetry data in regional quasi-geoid modelling”, *Journal of Geodesy* 91(1), 97-112.
4. Slobbe, D. C., J. Sumihar, T. Frederikse, M. Verlaan, R. Klees, F. Zijl, H.H. Farahani, R. Broekman (2017), “A Kalman filter approach to realize the lowest astronomical tide surface.” *Marine Geodesy*, *41(1), 44-67.*
5. Klees R., D.C. Slobbe, H.H. Farahani (2017), “A methodology for least-squares local quasi-geoid modelling using a noisy satellite-only gravity field model.” *Journal of Geodesy*, 92(4), 431-442.
6. Slobbe, D. C., R. Klees, M. Verlaan, F. Zijl, H.H. Farahani (2018), “Height system connection between island and mainland using a hydrodynamic model: a case study connecting the Dutch Wadden islands to the Amsterdam ordnance datum (NAP).” *Journal of Geodesy*, 92, 1439-1456.
7. Klees R., D.C. Slobbe, H.H. Farahani (2018), “How to deal with an ill-conditioned noise covariance matrix of a satellite-only global gravity field model in local gravity field modelling?” *Journal of Geodesy, 93, 29-44.*
8. Slobbe, D. C., R. Klees, H.H. Farahani, L. Huisman, B. Alberts, P. Voet, F. De Doncker (2018), “The impact of noise in a GRACE/GOCE global gravity model on a local quasi-geoid”. J Geophys Res – Solid Earth, 124 (3), 3219-3237.

Knowledge transfer and impact

- Data products: i) Lowest Astronomical Tide reference surface with respect to the GRS80 reference ellipsoid provided to the Hydrographic Service of the Royal Netherlands Navy; ii) quasi-geoid model referenced to the GRS80 reference ellipsoid provided to the Ministry of Infrastructure and the Environment/Rijkswaterstaat.
- Description of the project and deliverables on the website of the NWO-domain TTW (http://www.ttw.nwo.nl/Projecten/).
- Spin-off NWO-TTW project “Versatile Hydrodynamics” (kE 1,100) supported by a broad user community, most of them already involved in the NEVREF project. In this project we intend to develop the water level component of a seamless forecasting system for total water depths in the Dutch North Sea.
- Formalisation of the collaboration with the Hydrographic Service of the Royal Netherlands Navy, the Ministry of Infrastructure and the Environment/Rijkswaterstaat, and the Netherlands Kadaster in the Commission of Geodesy of the Netherlands Center for Geodesy and Geo-Informatics (NCG).
- Invited talks at professional conferences and workshops:
  - Slobbe, D.C., R. Klees, H.H. Farahani, M. Verlaan, F. Zijl, and J. Sumihar (2019). “Roadmap to a Mutually Consistent Set of On- and Offshore Vertical Reference Frames - the Dutch Approach.” Oral presentation, IUGG meeting, 8-18 Jul 2019, Montreal, Canada.
  - Slobbe, D.C. (2019). “LAT as chart datum – why actually?” HSB workshop “Hydrografische referentiesystemen en hun toepassingen”, September 3, 2019, Aalst, Belgium.
  - Klees, R, DC Slobbe, HH Farahani, M Verlaan, F Zijl, J Sumihar, Developing the geospatial infrastructure to a sustainable management of the coastal zone in a changing climate. II Simposio Brasileiro sobre Praias Arenosas (II SBPA) & XI Cncontro Nacional de Gerenciamento Costeiro (XI ENCOGERCO), Florianopolis (SC), 15 a 20 de Outubro de 2018.
  - Slobbe, D. C. (2018). “Het Normaal Amsterdams Peil anno 2018” interne Expertisenetwerk Waterveiligheid (ENW) dag, May 23, 2018, Den Haag.
  - Klees, R. and Slobbe, D. C. (2018). “Results NEVREF + outlook” 3rd IHO HSSC Tides, Water Level and Currents Working Group Meeting 16-20 April 2018, April 18, 2018, Viña del Mar, Chile.
  - Slobbe, D. C. (2018). “Roadmap to a mutually consistent set of on- and offshore vertical reference frames - the Dutch approach.” Norwegian Mapping Authority, March 15, 2018, Stavanger, Norway.
  - Slobbe, D. C. (2017). “Roadmap to a mutually consistent set of on- and offshore vertical reference frames - the Dutch approach.” COLACMAR 2017, November 16, 2017, Balneario Camboriu, Brazil.
  - Slobbe, D. C. (2017). “Onshore and offshore vertical reference frames.” NCK Theme Day 2017, September 28, 2017, Leiden.
  - Slobbe, D. C. (2015). “Vertical Reference Frame for the Netherlands Mainland, Wadden Islands and Continental Shelf (NEVREF).” 20th NSHC TWG, January 27, 2015, Scheveningen.
  - Slobbe, D. C. (2014). “Satellite radar altimetry and the quasi-geoid.” NCG workshop ‘Meten en modelleren van zeespiegelvariatie’, February 6, 2014, Delft.
  - Slobbe, D. C. (2014). “On the realization of offshore vertical reference surfaces.” Hydrografische jaarvergadering, January 20, 2014, Den Helder.
  - Slobbe, D. C. (2013). “Roadmap to a mutually consistent set of offshore vertical reference frames.” 38th hydrodynamics & sediment transport & morphology lunch lecture Deltares, October 17, 2013, Delft.
  - Slobbe, D. C. (2013). “A future-proof maritime vertical infrastructure.” HSB workshop “Referentievlakken en geodesie in de Noordzee”, February 6, 2013, Antwerp, Belgium.

Case study H3: InSAR Geodesy

Research on ***InSAR Geodesy*** addresses the retrieval of reliable estimates of kinematic parameters over areas or objects with time-varying scattering characteristics. Such areas include pastures on drained peat soils, where subsidence and uplift are not reliably measurable. Exacerbated by the effects of climate change, these areas form one of the most demanding challenges for Dutch society, as their continuous drainage causes irreversible land subsidence and significant greenhouse gas emission, forcing choices between agricultural and urban societal interests. In combination with the rising sea levels and elevations already far below sea level, the lack of reliable estimates of irreversible subsidence poses an urgent challenge for the Netherlands and comparable deltaic regions. We addressed this problem in several ways.

***Fundamental research* on InSAR estimation theory** focused on a redefinition of the functional and stochastic models, integer ambiguity estimation, and quality assessment and control. Moreover, we worked on the design, development, and deployment of *new reference stations*, termed integrated geodetic reference stations (IGRS), which can be used to obtain collocated observations from seven different geodetic techniques. The design was patented, tested, manufactured, and deployed. Currently, 35 stations are operational, representing an investment of over 1.5 ME, and the design is currently in production in other countries. Apart from the IGRS, we pioneered the use of *active transponders*, connected to the Dutch tide gauges, to provide a direct reference between sea level variation and unveiling billions of new measurement locations.

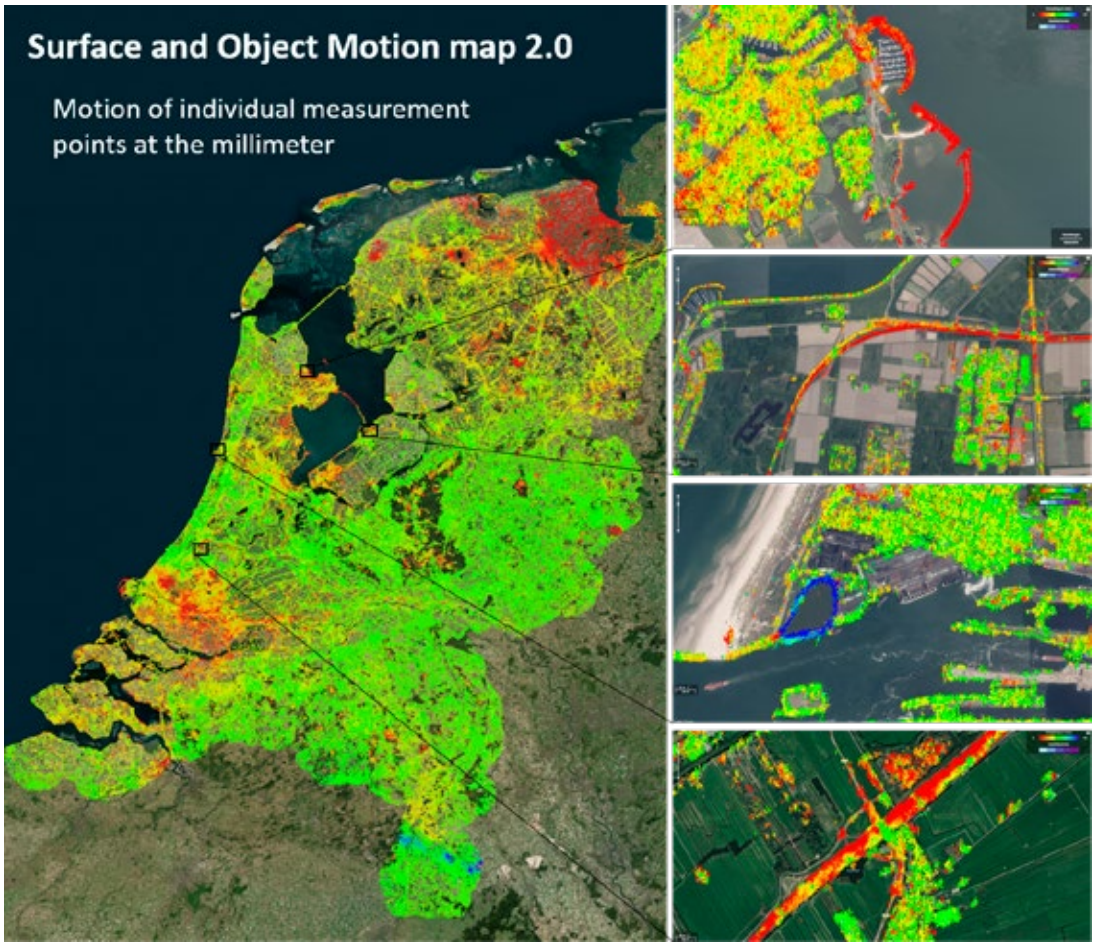


Figure H-2. Surface and object motion (SOM) map 2.0. This interactive map allows the user to zoom down to individual measurement sites, and shows the movement of these sites over time. The SOM 2.0 is mostly based on Interferometric Synthetic Aperture Radar (InSAR) data satellites reflections. These reflections are combined to estimate the motion of the earth and objects on it. GPS and gravity data are used to provide references for the data set.

Contextual data processing is a key development initiated by us. The realization that the SAR measurements are as heterogeneous as the earth's surface itself, forced the development of a different philosophy in data processing and kinematic parameter estimation. Contextual information related to the signal of interest, types of land use, disturbance signals such as the atmosphere, the deep and shallow composition of the earth, environmental conditions, and the properties of structures form intelligence that should be included in the estimation algorithms. Additionally, we developed methods for the *integrated processing* of several types of geodetic data.

Aging infrastructure is a societal driver for developing methods for ***structural health monitoring***. General concepts are developed and tuned for railways, highways, tunnels, dikes, dams, embankments, quays, sewer systems, gas, and water utility pipes. Many of these concepts have been quickly adopted by asset managers in industry and are currently operationally deployed.

A special branch of our research activities concerns the ***early-warning detection*** of HILP (High-Impact/Low-Probability) events. Using methods ranging from advanced artificial intelligence to conventional hypothesis testing, methods were developed and deployed to detect impending sinkholes, collapsing quay walls. It is our ambition to build an ***autonomous analysis algorithm*** (CAROLINE) that can demonstrate the philosophy of contextual processing for areas prone to HILP events.

One of the most important societal changes in the Netherlands during the period of evaluation is the increase in *induced seismicity*, the societal and political turmoil, and the successive cessation of the gas production in the Groningen region with its dramatic consequences on the national budget and safety. We were one of the key contributors to the survey schemes and estimation of *methodologies for land subsidence due to gas production*. The current survey philosophy, characterized by a "satellite-unless" approach, is considered optimal from an EHS (environment, health, safety) perspective and follows from direct recommendations given by us. In this philosophy, traditional monitoring using leveling is ceased indefinitely, while required reference benchmarks are maintained. Yet, we are still heavily involved in the disentanglement of the various primary and secondary drivers of vertical and horizontal land motion.

A main challenge during the elapsed and current research period is formed by the extreme numerical and computational demands associated with time series of satellite radar systems, related to data I/O and core processing time. The current data volume reaches 200 TB, and particularly the cumulative inclusion of daily updates in combination with the ambition to develop autonomous near real-time data processing poses strain on the hardware infrastructure needed and possible for a university environment. On the software side, the development is continuous, and algorithms are made available to the public.

During the period of evaluation, we produced two publicly available interactive websites showing the land motion (subsidence and uplift) of the Netherlands, in 2018 and 2020 (https://bodemdalingskaart.nl/en-us/). The Dutch Ground Motion Service, better known as the Bodemdalingskaart in Dutch, is a co-operation between universities, knowledge institutes and companies. Partners include the Netherlands Center for Geodesy and Geo-information (NCG), TU Delft, Hogeschool Utrecht, University of Twente, KNMI, SkyGeo and 06-GPS. The release of both versions of the Bodemdalingskaart triggered front-page coverage in national newspapers and key topics in major television news channels (See Table J.14). On an average day, these resources are viewed by approximately 200 users. The datasets have been made available for download (included in Table J.3).

Case study H4: Antarctica

Our research on Antarctica is a successful example of the feedback between research, funding and communication. Two GRS researchers, Stef Lhermitte & Bert Wouters, are strongly involved in research on Antarctic mass loss and understanding the processes that contribute to it. This has resulted in many publications (including Nature/Science) on ice shelf processes (e.g. KP42, KP43), atmospheric feedbacks over ice sheets and ice sheet mass loss (e.g. KP25, KP26).

At the same time, Lhermitte & Wouters actively share their knowledge with the wider public. By active involvement in open science on Twitter (with > 4900 and >1100 followers respectively), development of interactive websites (Table J.15 e.g. https://tudelft.pageflow.io/benemelt, https://tudelft.pageflow.io/pig-damage & https://tudelft.pageflow.io/gics) and a range of lectures for the wider public (Table J.12), they have been able to directly address an extremely wide audience with our scientific results. Likewise, they used their expertise and social media channels to document real-time changes in Antarctica (e.g., calving of icebergs, trajectory of iceberg A68), and to write press releases/reach out to journalists in their network, resulting in emerging news items that were covered by press globally (e.g., calving of Larsen C, Brunt, Amery, Pine Island ice shelves). These tweets have gathered more than 3 Million impressions/ viewers since 2017 and have resulted in an extended press coverage with >150 media appearances on radio, tv, written and online press. This coverage, on a variety of topics (e.g. Antarctica, climate change, remote sensing) includes major news outlets such as BBC, The Washington Post, etc. (See Table J.14)

The combination of high-quality research and strong visibility based on expertise has culminated in a hub of scientific research on ice shelves that was funded by a large investment program of NWO (~2.3M €), GeoForGood by Google, and several other NWO and H2020 initiatives.

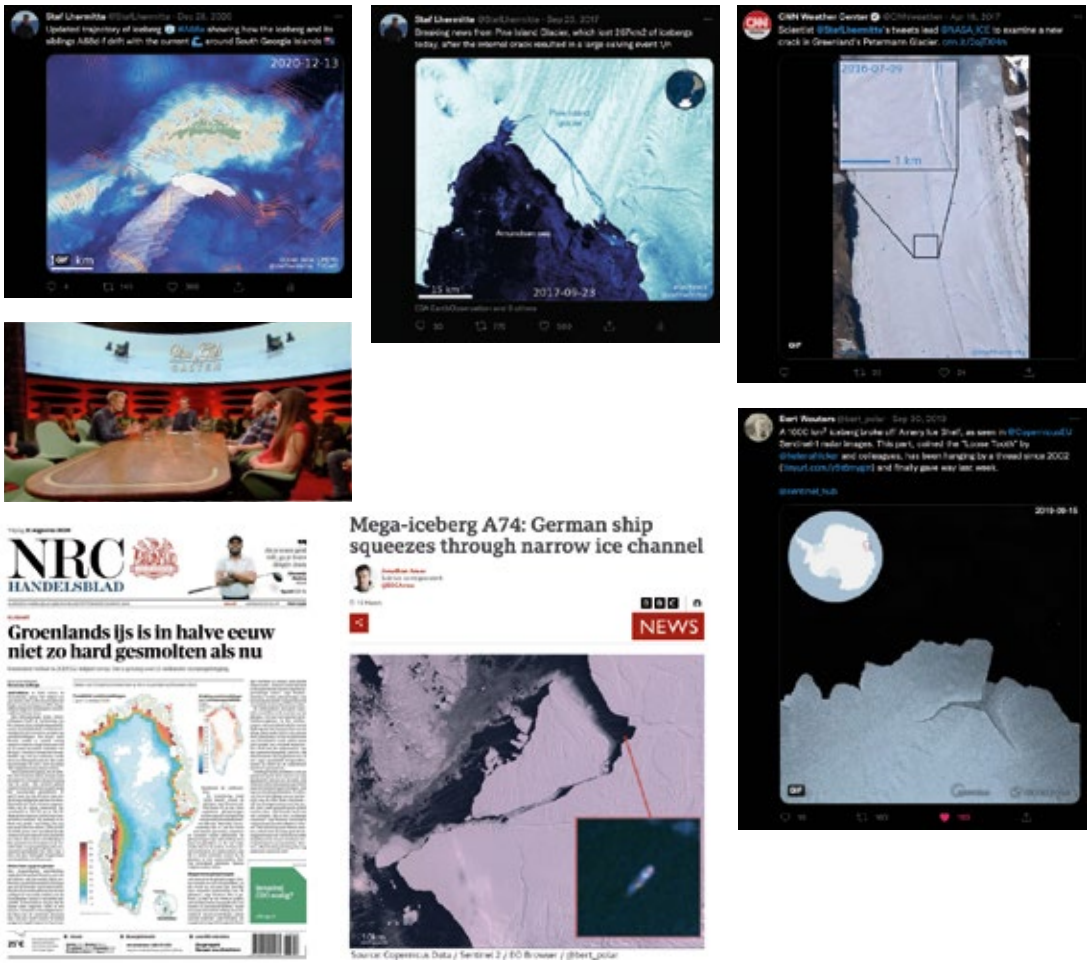


Figure H-3. Research on Antarctic mass loss as performed at Dept. GRS, triggers significant media response.

Case study H5: Ruisdael Observatory

GRS took the initiative and is leading the national research infrastructure for atmospheric sciences *Ruisdael Observatory*, a joint enterprise of the universities of Delft, Wageningen, Utrecht, Amsterdam and Groningen, as well as the national institutes KNMI, RIVM and TNO. It was granted with a NWO subsidy of 18 MEuro, and has a total budget of 85 MEuro. It is the Dutch contribution to the European ESFRI research infrastructures ICOS and ACTRIS. The Ruisdael Observatory is good example of how outreach and networking can lead to community and capacity building, and to agenda setting of future national programs: the scientific director of Ruisdael Observatory, Herman Russchenberg, is now chairing the national roadmap committee for infrastructures in the Geosciences.

Scientific background of the Ruisdael Observatory

Since the Industrial Revolution humans have increasingly altered the composition of the atmosphere by emitting carbon dioxide, aerosol particles and trace gases. This has fundamentally changed atmospheric processes on many levels, but we do not yet sufficiently understand how these emissions modify weather patterns, climate and air quality. We have at present no adequate understanding of how the atmosphere might evolve in the future. The weather forecast is limited to days – partly due to the chaotic nature of weather itself – but also because we lack sufficient insight into the physics and chemistry of small-scale processes and how they are coupled to larger scale phenomena in the atmosphere. Apart from the daily weather forecast, we also need to know the long-term trends of the weather, its variability and its extremes. How is the changing atmosphere affecting our climate, and consequently: our living environment? The science to address these issues requires data at different spatial and temporal scales in different environments, ranging from urban centres to forests or grass lands.
With the increasing availability of computational power and observational tools the atmospheric community is now at the brink of a new revolution. With the coupling of large flows of detailed observations to high resolution atmospheric model simulations, we are getting close to the realm of first principles: characterizing and predicting the state of the atmosphere based on the laws of nature with a minimized need for approximations of small-scale phenomena.
Atmospheric science encompasses many different disciplines from weather prediction to climatology, from air quality and greenhouse gas budgets to water cycle research and large-scale circulation. However, important breakthroughs in the most pressing scientific questions in many of these diverse disciplines require similar methodological advances:

- long-term detailed atmospheric and land-surface observations.
- integrating micro- and macroscopic scales using observations (from microphysical observations to large scale measurements) and models (from cloud resolving to global models).

The **Ruisdael Observatory** provides the facilities to meet this goal. It is operational in rural and urban areas to investigate the interaction between the heterogeneous mosaic landscape and the atmosphere. Observations and models will be merged in real time, integrating a wide range of spatial and temporal scales, to form a virtual laboratory for understanding multi-scale processes in atmospheric chemistry and physics, and by doing so improve the accuracy of climate, weather and air quality models on the regional scale.

The concept of the Ruisdael Observatory

The backbone of the observatory is formed by four advanced stations: the urban area of Rotterdam, Cabauw in flat grass land, Loobos in a forest and Lutjewad at the Wadden Sea coast to cover different backgrounds. These stations are embedded in national networks for the observation of meteorological parameters, radiation and air quality. Included in the observatory are also a suit of mobile stations for turbulence, atmospheric chemistry and clouds, as well as computational and data facilities for running LES models. The location of Ruisdael Observatory – in a coastal climate and amidst major European industrial areas and cities – makes that a large variety of air masses and weather types can be observed and studied. The Dutch landscape and human activities in it are well documented and also intensively monitored. This unique combination makes the Ruisdael Observatory particularly attractive to international researchers working on improvement of both observational capabilities and modelling tools for climate change predictions for regions around the world. Figure 1 and 2 show the layout of the observatory.

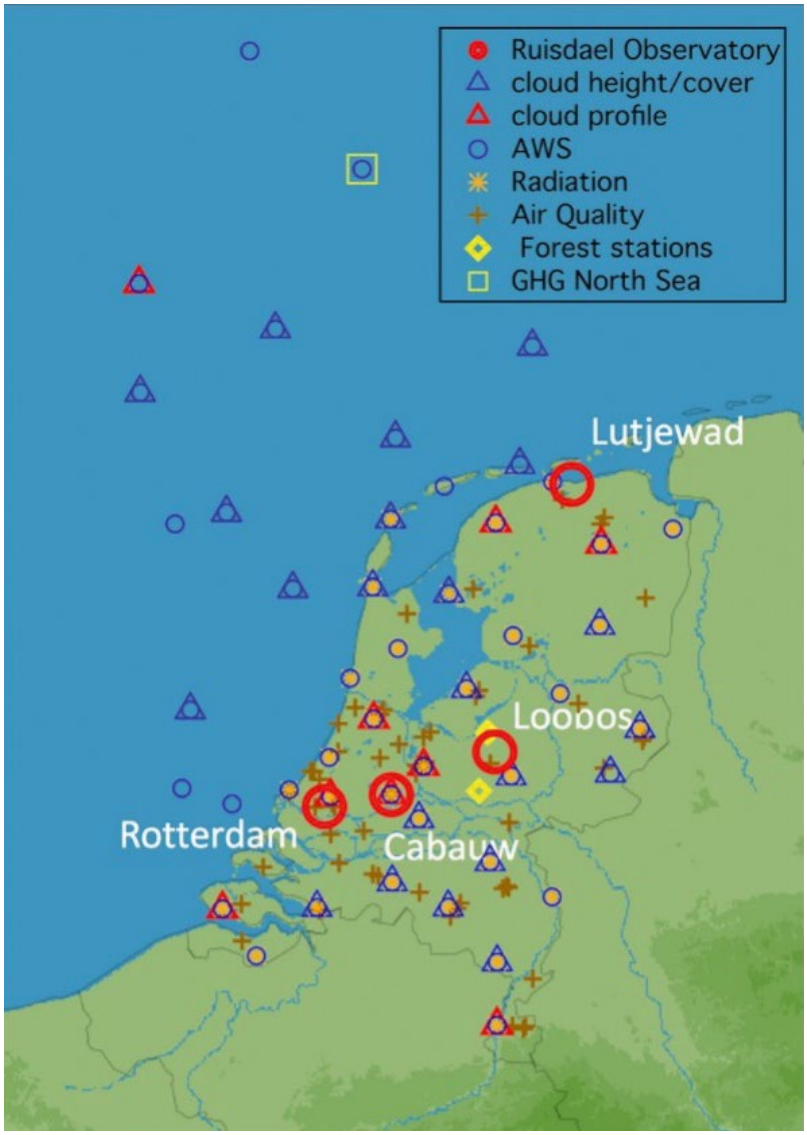


Figure H-4. Layout of the stations of Ruisdael Observatory. Also shown are the locations of the KNMI and RIVM operational networks of automatic weather stations AWS, radiation, air quality, cloud cover and height. Not shown are the mobile facilities.

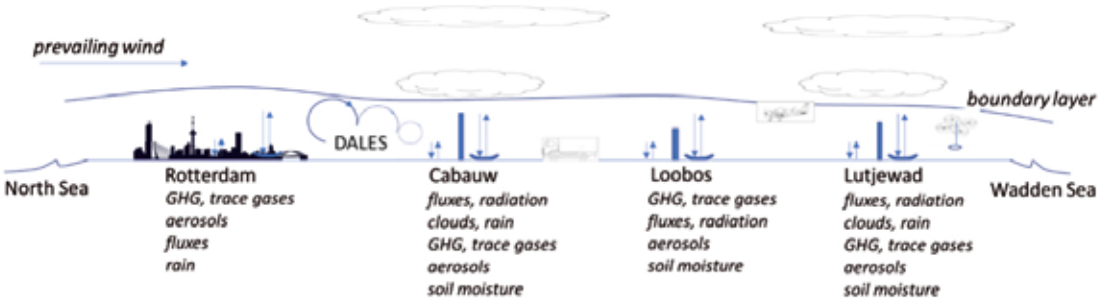


Figure H-5. Transect from Rotterdam to Lutjewad: 220 km, from the urban dome across agriculture land and forests to the sea

Appendix I:
GRS Facts and Figures

Table I1: Head count of research staff at GRS, where the number indicates the average headcount over a year. One month counts as 1/12=0.083, and entries are rounded to whole numbers. Note that the staff numbers in the Introduction compare 1-1-2015 to 31-12-2020 and therefore deviate from the average yearly headcounts in the table. A notable deviation is caused by the new appointment of Amiri-Simkooei in November 2020.

Geoscience & Remote Sensing	2015 #	2016 #	2017 #	2018 #	2019 #	2020 #
Scientific staff						
Assistant professors	10	10	11	10	12	13
Associate professors	4	6	5	6	6	6
Full professors	8	8	9	9	9	9
Researchers	36	39	39	42	48	43
PhD candidates	57	57	59	55	51	52
Total Research staff	**115**	**120**	**123**	**122**	**126**	**123**
Technical support staff	-	-	-	-	-	-
Total staff	115	120	123	122	126	123

Table I2: Research staff at GRS in terms of fte

Geoscience & Remote Sensing	2015 # FTE	2016 # FTE	2017 # FTE	2018 # FTE	2019 # FTE	2020 # FTE
Scientific staff						
Assistant professors	9.4	8.4	10.4	8.2	9.3	10.4
Associate professors	2.6	3.9	4.2	5.2	5.2	5.2
Full professors	4.5	4	5.6	5.6	5.6	6.4
Researchers	21.0	20.7	18.2	15.0	21.6	26.6
PhD candidates	37.4	33.7	33.0	31.5	31.0	32.5
Total Research staff	**74.9**	**70.7**	**71.4**	**65.5**	**72.7**	**81.1**
Technical support staff	-	-	-	-	-	-
Total staff	78.0	74.1	74.8	68.9	75.9	84.4

Table I3: GRS Funding and expenditure.

Geoscience & Remote Sensing *K EUR	2015		2016		2017		2018		2019		2020	
Funding:												
Direct funding[1]	2721	55%	2590	53%	2859	54%	2675	48%	2762	32%	3210	40%
Research grants[2]	660	13%	772	16%	469	9%	661	12%	1920	22%	2444	31%
Contract research[3]	1557	31%	1500	31%	1978	37%	2121	38%	3825	45%	2254	28%
Other[4]	35	1%	49	1%	-19	0%	88	2%	69	1%	87	1%
Total funding	**4973**	**100%**	**4911**	**100%**	**5287**	**100%**	**5545**	**100%**	**8576**	**100%**	**7995**	**100%**
Expenditure:												
Personnel costs	3871	86%	4234	88%	4527	87%	4620	88%	5901	82%	6381	80%
Other costs	640	14%	590	12%	675	13%	641	12%	1306	18%	1604	20%
Total Expenditure	**4512**	**100%**	**4824**	**100%**	**5203**	**100%**	**5261**	**100%**	**7208**	**100%**	**7985**	**100%**

[1] Direct funding (basisfinanciering / lump-sum budget)
[2] Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
[3] Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, European organisations and charitable organisations
[4] Funds that do not fit into the other categories

Table I4: GRS research staff by rank and gender for each year during the evaluation period

Geoscience & Remote Sensing	2015				2016				2017			
	Male	Female	%Male	%Female	Male	Female	%Male	%Female	Male	Female	%Male	%Female
Scientific staff	22	4	85%	15%	26	5	84%	16%	25	5	83%	17%
Researchers	24	12	67%	33%	23	16	59%	41%	23	16	59%	41%
PhD candidates	43	14	75%	25%	45	12	79%	21%	44	15	75%	25%
Total Research staff	**89**	**30**	**75%**	**25%**	**94**	**33**	**74%**	**26%**	**92**	**36**	**72%**	**28%**
Total staff	89	30	75%	25%	94	33	74%	26%	92	36	72%	28%
Geoscience & Remote Sensing	**2018**				**2019**				**2020**			
	Male	Female	%Male	%Female	Male	Female	%Male	%Female	Male	Female	%Male	%Female
Scientific staff	25	5	83%	17%	27	5	84%	16%	27	6	82%	18%
Researchers	25	17	60%	40%	32	15	68%	32%	27	15	64%	36%
PhD candidates	39	16	71%	29%	31	20	61%	39%	33	19	63%	37%
Total Research staff	**89**	**38**	**70%**	**30%**	**90**	**40**	**69%**	**31%**	**87**	**40**	**69%**	**31%**
Total staff	89	38	70%	30%	90	40	69%	31%	87	40	69%	31%

Table I5: GRS PhD candidates (conform Table J4 of the SEP)

Geoscience & Remote Sensing					Graduated <= 4 yr		Graduated <= 5 yr		Graduated <= 6 yr		Graduated <= 7 yr		Not yet finished		Discontinued	
Starting year	Female	Male	Total	Graduated	#	%	#	%	#	%	#	%	#	%	#	%
2012	2	8	**10**	8	1	10%	3	30%	7	70%	8	80%	1	10%	1	10%
2013	1	6	**7**	4		0%	3	43%	3	43%	4	57%	1	14%	2	29%
2014	2	2	**4**	4		0%	2	50%	4	100%	4	100%	0	0%		0%
2015	1	6	**7**	2		0%	2	29%	2	29%	2	29%	4	57%	1	14%
2016	2	3	**5**	1	1	20%	1	20%	1	20%	1	20%	3	60%	1	20%
	8	25	**33**	19	2	6%	11	33%	17	52%	19	58%	9	27%	5	15%

Note: This table only includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. Please note that the data in the grey cells are incomplete. There are still PhD candidates active from those starting years that are able to graduate within the time-frame of the given years. These data are indicated with a pattern in the graphs.
Reference date: 31 December 2020

Table I6: New GRS PhD candidates per year during the evaluation period. This table shows the number of new PhD students who started their PhD at GRS during each year of the evaluation period. This includes scholarship and external PhD students. The second row shows the number of students who discontinued their PhD study due to a negative Go/No-Go evaluation. The third row shows the number of students who discontinued their PhD study for other reasons.

	2015	2016	2017	2018	2019	2020
New PhDs*	8	8	10	12	4	9
Stop at Go/NoGo	1	-	1	-	-	2
Stop else	1	1	2	2	-	-

Table I7: Open Access Publications

Journal Articles		Gold: OA publication in an OA journal		Hybrid: OA in a subscription based journal		Green: OA available through a trusted repository		No OA	
		#	%	#	%	#	%	#	%
GRS	2017	32	29%	20	18%	19	17%	40	36%
	2018	41	36%	33	29%	19	17%	20	18%
	2019	44	44%	25	25%	18	18%	14	14%
	2020	58	41%	38	27%	25	18%	20	14%

Table I8) Starting and finishing GRS and EE MSc students

	Starting	Graduating	Starting	Graduating
2015	23	4	na	na
2016	24	15	na	na
2017	19	17	na	na
2018	27	19	46	12
2019	23	28	25	34
2020	29	24	38	37
	MSc Geoscience & Remote Sensing		**MSc Environmental Engineering***	

* MSc track shared with Dept. Water Management

Appendix J:
Evidence 2015 – 2020

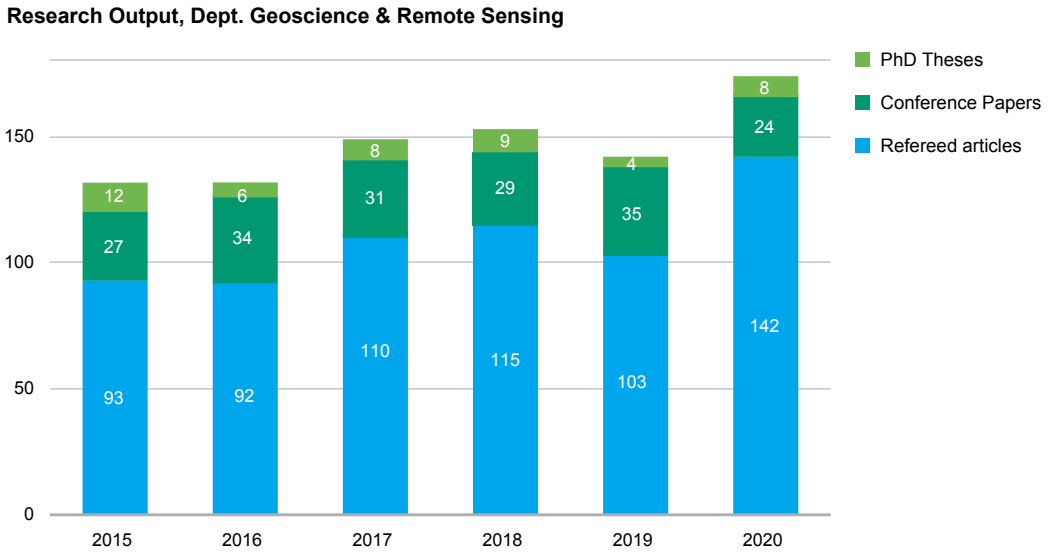


Figure J1: Total number of peer-reviewed publications, conference papers and PhD theses per year during the evaluation period 2015-2020.

Table J.1 Books and book chapters

Books partially edited by GRS staff				
Springer Handbook of Global Navigation Satellite Systems	Teunissen, P., & Montenbruck, O. (Eds.)	2017	Springer	557 citations
Laser Scanning: An emerging technology in structural engineering	Riveiro, B., & Lindenbergh, R. (Eds.)	2019	CRC Press	10 citations
Clouds and Climate: Climate Science's Greatest Challenge.	Siebesma, A. P., Bony, S., Jakob, C., & Stevens, B. (Eds.)	2020	Cambridge University Press.	7 citations
Individual chapters fully or partially written by GRS Staff:				
The importance of sediment in sea-level change	Ferrier, K. L., van der Wal, W., Ruetenik, G. A., & Stocchi, P.	2019	In: Past Global Changes Magazine, 24	
Chapters in: Clouds and Climate, Cambridge University Press (2020):				
Chapter 1: Cloudy Perspectives	Louise Nuijens and Christian Jakob			
Chapter 2: Cloud Thermodynamics	Bjorn Stevens and Pier Siebesma			
Chapter 5: Conceptualizing Clouds	Stephan de Roode and Roel Neggers			
Chapter 6: Parameterizing Clouds	Pier Siebesma and Axel Seifert			
Chapters in: Laser Scanning: An emerging technology in structural engineering, CRC Press (2019)				
Chapter 8: Laser scanning for operational multiscale structural monitoring	Roderik Lindenbergh, Sylvie Soudarissanane, Jinhu Wang, Abdul Nurunnabi, Adriaan van Natijne and Cserep Mate			
Chapter 12: Laser scanning for bridge inspection	Linh ruong Hong and Dera F. Laefer			

Table J.2 Scientific reports

Report name	Organization	Staff member	Specification
State of the Climate	American Meteorological Society	Bert Wouters	
Arctic Monitoring and Assessment Programme (AMAP) report		Bert Wouters	
IPCC SROCC		Bert Wouters	
Sixth Assessment Report (AR6) of the IPCC		Miren Vizcaino	Expert Reviewer Second Order Draft (SOD) of the Working Group (WGI) contribution

Table J.3 Open access datasets

Name	URL	Year	Explanation	Staff member	Views	Downloads
The Dutch Ground Motion Service (De Bodemdalingskaart van Nederland)	https://bodemdalingskaart.nl/en-us/	2018 (v1.0), 2020 (v2.0)		Ramon Hanssen		
Repository of the Dutch Atmospheric Large-Eddy Simulation model	https://github.com/dalesteam/dales			Pier Siebesma		
CoastScan: Data of daily scans at low tide Kijkduin January 2017	https://doi.org/10.4121/uuid:409d3634-0f52-49ea-8047-aeb0fefe78af	2020	4TU.ResearchData	Mieke Kuschnerus, Roderik Lindenbergh	421	198
Data supplements for PNAS publication	https://doi.org/10.1073/pnas.1912890117			Stef Lhermitte		
Data global glacier mass loss	https://data.4tu.nl/articles/dataset/Data_underlying_the_publication_Global_Glacier_Mass_Loss_During_the_GRACE_Satellite_Mission_2002-2016_/13663433			Bert Wouters	187	135
Atmospheric Observations Cabauw	https://doi.org/10.4121/collection:cabauw			Herman Russchenberg	347	
Ruisdael database	https://dataplatform.knmi.nl/dataset/?tags=Ruisdael&organization=tudelft			Herman Russchenberg		
Actris Data Centre node for Cloud Profiling	https://cloudnet.fmi.fi			Christine Unal		
X-band weather radar at Cabauw	https://data.4tu.nl/articles/dataset/IDRA_weather_radar_measurements_-_all_data/12696887			Christine Unal		
First interactive simulations of the Greenland ice sheet in the Earth System Model CESM2	https://agupubs-onlinelibrary-wiley-com.tudelft.idm.oclc.org/doi/toc/10.1002/(ISSN)1942-2466.CESM2			Miren Vizcaino		
	http://www.climate-cryosphere.org/wiki/index.php?title=ISMIP6_Publication_List					
	https://doi-org.tudelft.idm.oclc.org/10.1029/2020MS002356					
	https://doi-org.tudelft.idm.oclc.org/10.1029/2019GL086836					
A new time-series of GRACE monthly gravity field solutions obtained by accounting for the colored noise in the K-Band range-rate measurements	https://dataservices.gfz-potsdam.de/icgem/showshort.php?id=escidoc:2361889	2017	GFZ Data Services	Guo X, Zhao Q, Ditmar P, Liu J.		
Global elastic deformation mode	https://doi.org/10.4121/uuid:fb667e7a-52f3-4876-8cab-ae7a2ddaf0db	2017	Data supplement Riva et al. (2017)	Riccardo Riva	414	66
Sea level fingerprints	https://doi.org/10.4121/uuid:3106fb06-9723-49d1-b829-94778fa5aa6d		Data supplement Frederikse et al. (2017)	Riccardo Riva	276	118
North America GIA model	https://doi.org/10.4121/uuid:4a495bbc-0478-483a-baef-19ff34103dd2		Data supplement Simon et al. (2017)	Riccardo Riva	397	138
Global GIA model	https://doi.org/10.4121/uuid:4ecc3333-a25b-477a-a373-0503423ec9b1		Sun&Riva (2020)	Riccardo Riva	388	83
Program/code workflow of River ice classification	https://github.com/SdeRodaHusman/remotesensing-of-river-ice			Stef Lhermitte		

Table J.4 Open access software

Name	URL	Explanation	Staff member
Doris-Ripple	Versions:	DORIS: Delft Object-oriented Radar Interferometric Software	Ramon Hanssen
	https://github.com/TUDelftGeodesy/Doris/releases	Doris5	
	https://bitbucket.org/grsradartudelft/rippl	Doris-Rippl	
	https://bitbucket.org/grsradartudelft/depsi	DePSI	
DALES	https://github.com/omuse-geoscience/omuse/tree/master/src/omuse/community/dales	Python Interface to the Dutch Atmospheric Large Eddy Simulation model	Pier Siebesma
CUPiDO	https://github.com/TUDelftGeodesy/CUPiDO	Analyzes and prepares geodetic data for the use in geophysical modeling.	Freek van Leijen, Ramon Hanssen, Hans van der Marel

Table J.5 Designs – Models and Missions

Name	Description	Staff Member	URL
Harmony	Satellite mission design selected for Phase-0 and Phase-A study in Europe's Earth Exploration 10 program	Paco Lopez-Dekker	https://www.esa.int/Applications/Observing_the_Earth/ESA_moves_forward_with_Harmony
HydroTerra	Satellite mission design selected for Phase-0 study in Europe's Earth Exploration 10 program	Ramon Hanssen	
	Bi-directional coupling of ice sheet and global climate model Community Earth System Model (CESM2)	Miren Vizcaino	https://doi-org.tudelft.idm.oclc.org/10.1029/2020MS002356
	Spinning up a highly complex, coupled Earth system model Community Earth System Model (CESM2)	Miren Vizcaino	https://agupubs-onlinelibrary-wiley-com.tudelft.idm.oclc.org/doi/10.1029/2019MS001984
DALES	Dutch Atmospheric Large-Eddy Simulation Model	Pier Siebesma	https://agupubs.onlinelibrary.wiley.com/journal/19422466

Table J.6 Individual research grants

Research grants awarded to faculty staff			
NWO Veni	2018	Franziska Glassmeier	Clouds as complex systems
Branco Weiss Fellowship	2018	Franziska Glassmeier	Clouds from the perspective of complex systems theory
NWO Vidi	2016	Bert Wouters	IJsverlies van gletsjers en kleine ijskappen ontsluierd
NWO Vidi	2019	Louise Nuijens	CMTRACE - Tracing convective momentum transport in complex cloudy atmospheres
ERC Starting Grant	2015	Miren Vizcaino	COUPLEDICECLIM, The Greenland ice sheet in the year 3000
ERC Starting Grant	2017	Louise Nuijens	CloudBrake - How nature's smallest clouds slow down large-scale circulations critical for climate
ERC-Consolidator Grant	2016	Bas van de Wiel	COAT - Collapse Of Atmospheric Turbulence
Research grants awarded to temporary research staff			
Marie Curie Ind. Fellowships	2017	Host: Lindenbergh; Fellow: Truong-Hong	BridgeScan - Laser Scanning for Automatic Bridge Assessment
Marie Curie Ind. Fellowships	2017	Hosts: Stef Lhermitte, Bert Wouters; Fellow: Harry Zekollari	CAPSizing ICE caps - identifying tipping points through global modelling

Table J.7 Collaborative research grants

Funding agency	Project name	Project start	Grant size	PI
A) Grants awarded to major collaborative research projects (Projects over E 500.000,-)				
NWO	Roadmap Ruisdael	2018	E 4.396.000,00	Russchenberg
H2020	Operandum	2018	E 662.850,00	Lindenbergh
NWO	I-GNSS positioning	2020	E 616.392,00	Tiberius
NWO	DEEP NL Monitoring & Modeling	2020	E 522.694,00	Hanssen
NWO	HiRise	2020	E 2.284.939,00	Bert Wouters
STW	SuperGPS	2016	E 610.442,00	Tiberius
B) Grants until E 500.000,- awarded to individuals or collaborative research project				
B1) EU Projects:				
European Commission	TREASURE	2017	E 246.374,00	Verhagen
European Commission	CAPSICE	2019	E 165.599,00	Lhermitte
European Commission	MOSES	2018	E 485.000,00	Menenti
European Commission	ACTRIS-2	2015	E 70.905,60	Russchenberg
European Commission	Actris PPP	2017	E 52.500,00	Russchenberg
University of Leeds	CONSTRAIN (H2020)	2019	E 302.083,75	Siebesma
B2) Projects by ESA/ESTEC:				
Estec / Cir Unit	KaBandSAR	2018	249.840,00	Lopez Dekker
Centre Ifremer De Bretagne - Lops	SKIM ESA	2018	70.000,00	Lopez Dekker
Estec / Cir Unit	STEREOID-Ocean and Sea Ice	2019	259.979,00	Lopez Dekker
European Space Agency	ALCANTRA 2015	2015	107.620,00	Menenti
European Space Agency	ALCANTRA 2016	2015	107.620,00	Menenti
Space Applications Services Nv	Snow Mapping ESA	2017	29.998,00	Lhermitte
Esa Estec - Cir	Study into the Potential of a,	2019	49.161,00	Lopez Dekker
Esa Estec - Cir	ESA Prodex	2016	25.000,00	Menenti
Esa/Esrin	Dragon 4 Musycadharb	2017	20.000,00	Menenti
B3) Netherlands Space Office Projects:				
Netherlands Space Office	Dutch network on small spaceborne radar instruments and applications	2018	468.219,00	Lopez Dekker
Netherlands Space Office	SAR interferometric triplets	2018	240.563,00	Lopez Dekker
Netherlands Space Office	Harmony Support NSO	2019	200.000,00	Lopez Dekker
Netherlands Space Office	MINERVA	2020	327.672,00	Steele-Dunne
Netherlands Space Office	Harmony Support	2019	200.000,00	Hanssen
Netherlands Space Office	Effect of rainfall variability	2016	239.474,00	Russchenberg
B4) NWO/STW/TTW Projects:				
NWO	Towards an operational water vapor mapping service based on satellite radar interferometr	2015	241.960,00	Hanssen

Funding agency	Project name	Project start	Grant size	PI
NWO	Mass2Ant - East Antarctic surface mass Balance in the Anthropocene	2018	249.474,00	Lhermitte
NWO	Assessing firn processes from multi-source satellite data	2018	252.563,00	Lhermitte
NWO	Monitoring integrated crop-livestock systems through satellites and precision agriculture for more sustainable production	2018	275.095,00	Lopez Dekker
NWO	Remote sensing of damage feedbacks and ice shelf instability in Antarctica	2019	287.038,00	Lhermitte
NWO	Sim Waterworks	2016	227.000,00	Menenti
NWO	Future coupled evolution of Greenland ice sheet and climate change	2016	226.663,00	Vizcaino
NWO	MUST2SEA	2016	142.042,00	Riva
NWO	Versatile Hydrodynamics	2018	303.116,00	Slobbe
NWO	FAST4NL	2018	222.563,00	Slobbe
NWO	Clarity on Fruit Frost	2020	338.235,33	Van de Wiel
NWO	Clarity on Fruit Frost	2020	33.822,33	Van de Wiel
NWO	MUFFIN	2017	249.000,00	Russchenberg
STW	SmartSea	2015	197.392,00	Verhagen
STW	Guideline for Geodetic Deformation Monitoring	2015	50.000,00	Hanssen
STW	Up-to-date 3D City Models	2016	202.744,00	Lindenbergh
TTW	Coastscan	2019	263.460,00	Lindenbergh
NWO	KIP: Attribute-enrichment of satellite InSAR deformation measurements based on Dutch ‘basisregistratie’ information	2020	49.980,00	Hanssen
TTW	ValidDefo	2019	10.102,00	Hanssen
STW	Meteorological Finecasting	2016	39.620,00	Jonker
B5) Projects funded by others:				
Ned. Aardolie Maatschappij B.v	Offerte LTS-2 studie deel 1&2	2016	55.000,00	Hanssen
Total E&P Recherche Et Developpemen	Vibesense P3	2016	200.000,00	Hanssen
Hoogheemraadschap Van Delfland	Maaivelddaling HHR Delfland	2017	99.172,00	Hanssen
DEIMOS Space UK LTD	HD-GNSS	2018	75.133,00	Verhagen
NORCE Norwegian Research Centre AS	SATTROS	2017	124.000,00	Lopez Dekker
Ned. Aardolie Maatschappij B.v	GNSS en InSAR	2018	295.195,00	Hanssen
Prorail B.V.	Railradar	2018	50.000,00	Leijen
Mitsubishi Electric Corporation	Melco	2019	128.500,00	Hanssen
Uniwersytet Przyrodniczy we Wrocław	GATHERS	2019	96.125,00	Hanssen
Provincie Limburg	Pilot Bodembeweging Zuid-Limbu	2019	50.000,00	Hanssen
Cnrs - Service Financier Et Suivi	PROTECT	2020	150.068,00	Lhermitte

Funding agency	Project name	Project start	Grant size	PI
Universiteit Utrecht	LOSS deelproject	2020	396.103,00	Hanssen
Isard Sat S.l.	TEP HYDROLOGY	2015	143.000,00	Menenti
Rws Corporate Dienst	NAP EVRS	2015	77.747,60	Klees
Rijkswaterstaat Corporate Dienst	Stabiliteit NAP	2015	278.140,00	Klees
Rws Centrale Informatievoorziening	Zwaartekracht NAP 19-22	2019	308.671,00	Klees
KNMI	SHADOW	2020	237.038,00	Siebesma
Gemeentewerken Rotterdam	Regenradar Rotterdam	2017	136.220,00	Russchenberg
Carbon Trust	OWA Boundary Layer	2017	50.039,20	Basu
CITG	PLANTENNA	2018	225.000,00	Van de Wiel
Shell Global Solutions International	Measuring Emissions	2019	272.547,00	Levelt
Rijksdienst Voor Ondernemend	Winds of the North Sea in 2050	2020	462.869,00	Siebesma
KNMI	ACTRIS IMP	2020	59.325,00	Russchenberg
La Sapienza University Of Rome	SAOCOM	2015	43.000,00	Hanssen
N.V. Nederlandse Gasunie	DVOI grondradar	2015	21.060,00	Hanssen
Space Engineering SPA	Mute	2016	25.000,00	Marel
NVVL	NLR Bas van de Kerkhof	2017	14.000,00	Hanssen
Ned. Aardolie Maatschappij B.V	NAM DBF Reflectoren	2017	49.223,00	Hanssen
ENVEO IT GMBH	STEROID - Land Ice	2019	24.000,00	Lopez Dekker
Cranfield University	Hydroterra	2019	19.939,00	Hanssen
Deimos Space S.L.	AHD-GNSS: Absolute navigation	2020	44.700,00	Verhagen
Centre IFREMER de Bretagne - Lops	IASCO	2020	15.000,00	Lopez Dekker
Technische Universiteit Twente	Tiger bridge	2016	29.000,00	Menenti
Indonesia Endowment Funds for	Tuition Fee PhD Widyaningrum	2016	20.000,00	Lindenbergh
Cosine Research BV	Hyperscout	2017	40.000,00	Menenti
RWS Corporate Dienst	Kalibratie grondvochtsensor	2017	10.570,00	Reudink
Satellite Oceanographic	HYDROCOASTAL	2020	40.753,00	Slobbe
RWS Centrale Informatievoorziening	Hydrodynamisch waterpassen	2020	45.254,46	Klees
The Cyprus Institute	Collaboration Cyprus institute	2015	25.000,00	Russchenberg
Max-Planck-Institut fur Meteorologi	Detachering Stephanie Rusli	2016	37.000,00	Russchenberg
SkyECHO	ATTRACT	2019	20.000,00	Russchenberg
Monash University	Cumulus Workshop	2017	25.000,00	Siebesma

Table J.8 Editorial roles, including editorship of volumes and special issues.

Journal	Staff member	Name of Special Issue/Pubication
Editorships of Journals		
IEEE Transactions on Geoscience and Remote Sensing	Lopez Dekker	
ISPRS Journal of Photogrammetry and Remote Sensing	Lindenbergh	
Atmospheric Chemistry and Physics	Glassmeier	
Journal of Geodesy	Riva	
PLOS ONE	Riva	
Nature Scientific Reports	Riva	
Remote Sensing	Hanssen	
The Cryosphere	Lhermitte	
The Cryosphere	Wouters	
Guest editorships for special issues and other publications		
ACP/GMD/MT	Glassmeier	Fusion of radar polarimetry and numerical atmospheric modelling towards an improved understanding of cloud and precipitation processes
MDPI Remote Sensing	Lhermitte, Wouters	Remote Sensing of Glaciers at Global and Regional Scales
Atmospheric Chemistry and Physics	Russchenberg	Special Issue Volume 18
	Van de Wal	Geological Society, London, Memoir, Volume 56, The Geochemistry and Geophysics of the Antarctic Mantle
Sensors	Verhagen	Special Issue
	Teunissen	Encyclopedia of Geodesy
Editorial boards including GRS staff		
GPS Solutions	Teunissen, Verhagen, Tiberius	
Optimization & Engineering	Teunissen	
Studia Geophysica et Geodaetica	Teunissen	
J of Navigation	Teunissen	
Sensors	Teunissen, Verhagen	
J of Applied Geodesy	Teunissen	
Photogrammetric Record	Lindenbergh	
Wind Energy	Basu	
Environmental Fluid Mechanics	Basu	
Energies	Basu	
Atmosphere	Basu	
Journal of Geodetic Science	Amiri-Simkooei	
Geodesy and Cartography	Amiri-Simkooei	
Journal of Geomatics Science and Technology	Amiri-Simkooei	
Earth Observation and Geomatics Engineering	Amiri-Simkooei	
Journal of Surveying Engineering	Amiri-Simkooei	
Journal of Geodesy	Verhagen	

Table J.9 Membership of scientific organizations and advisory committees

Staff Member	Description
Table J.9a) Membership of Scientific Organizations	
Teunissen	Fellow of International Association of Geodesy
Teunissen	Fellow of Royal Netherlands Academy of Arts and Sciences (KNAW)
Teunissen	Fellow of UK Royal Institute of Navigation (RIN)
Teunissen	Fellow of US Institute of Navigation (ION))
Unal	Member International expert group on Raindrop Size Distributions
Wouters	Member, Science Team WCRP initiative Global Sea Level Budget assessment
Wouters	Member, IAG SC 2.6 Gravity and Mass Transport in the Earth System
Wouters	Member, Climate Change and Southern Ocean Resilience Expert Working Group
Wouters	Chair, IACS WG 'Glacier mass changes based on altimetry and gravimetry'
Wouters	Chair, IAG ICCC Joint Working Group 'Geodesy for the Cryosphere: advancing the use of geodetic data in polar climate modelling'
Wouters	Chair, IAG Sub-Commission 3.4: Cryospheric Deformation (joint with IACS)
Wouters	Chair, Regional Assessments of Glacier Mass Change (RAGMAC) - WP2 Gravimetry and Altimetry
Basu	Member, NATO SET-304 group, Modelling, measuring, and mitigating optical turbulence, 2021–Present
Basu	Member, NATO SET-ET-118 group, Modelling, measuring, and mitigating optical turbulence, 2019–2020
Basu	Member, Atmospheric Sciences Review Panel, Academy of Finland, Helsinki, 2019, 2020
Basu	Program Chair, Propagation Through and Characterization of Atmospheric and Oceanic Phenomena, OSA, 2019–2021
Basu	Coordinator, Met-ocean program line, GROW (https://www.grow-offshorewind.nl/), 2018–Present
Basu	Chair, Atmospheric Sciences Review Panel, Academy of Finland, Helsinki, 2021
Vizcaino	Co-Chair, Land Ice Working Group of the Community Earth System Model. 2016-2018 https://www.cesm.ucar.edu/working_groups/Land+Ice/
Vizcaino	Member, ISMASS 2018 Assessment of the mass balance of ice sheets and glaciers (linkages between data and models)
Vizcaino	Member, Access Committee Barcelona Supercomputing Center 2018-2019
Hanssen	President, National Committee of IUGG, International Union of Geodesy and Geophysics
Hanssen	General Chair, International Geoscience and Remote Sensing Symposium (IGARSS), Brussels, 2021
Hanssen	Chair LOC, Fringe, ESA, 2020
Hanssen	Invited lecturer, ESA's international land remote sensing training course
Hanssen	Member, LOC, IAH TiSOLS, 2020
Hanssen	Member, Council for Earth and Life Sciences, Netherlands Royal Academy of Sciences KNAW-RAL (until 2017)
Riva	Co-chair, IAG Inter-Commission Committee on "Geodesy for Climate Research," Joint Working Group "Regional sea level and vertical land motion"
Riva	Member, IAG Sub-Commission 3.4 "Cryospheric Deformation"
Riva	Member, IAG Joint Working Group 2.6 "Ice melting & ocean circulation from gravimetry"
Amiri-Simkooei	Member, IAG Joint Study Group 0.21 "Geophysical Modelling of Time Variations in Deformation and Gravity"
Amiri-Simkooei	Member, IAG-ICCT Joint Study Group: Multi-GNSS theory and algorithms
Schleiss	Member, AGU Horton grant committee
Schleiss	Member and co-founder international expert group on Raindrop Size Distributions
Verhagen	Fellow, International Association of Geodesy
Schleiss	Board Member, Nederlands Instituut voor Navigatie

Staff Member	Description
Van de Wiel	Member, International Eurasian Academy of Sciences
Lindenbergh	Member, organizing committee, ISPRS Summer School - Close Range Sensing Techniques in Alpine Terrain, Editions 2015, 2017 and 2019
Lindenbergh	Chair, Laser Scanning Workshop, Wuhan, China, 2017
Lindenbergh	Chair, ISPRS WG II/10, 3D Mapping for Environmental & Infrastructure Monitoring
Levelt	Member, International Global Atmospheric Chemistry Program Scientific Steering Committee (IGAC SSC) –January 2019 – present
Siebesma	Coordinator, Modeling Intercomparison EUREC4A

Table J.9b) Membership of Advisory Committees

Levelt	Scientific Initiator, TROPOMI (TROPOspheric Monitoring Instrument) on ESA/EU Copernicus Sentinel-5 precursor satellite, 2003-present
Levelt	Principal Investigator, OMI (Ozone Monitoring Instrument) on NASA's EOS-Aura satellite, 1998–present
Levelt	Initiator KNMI-NUIST Centre for Atmospheric Research, NUIST University, Nanjing, China (2016-present)
Levelt	Member, Management Team KNMI directly responding to the Directorate of KNMI (2009-present)
Levelt	Advisor, KNMI Director, Ministry of Infrastructure and Water Management, the Netherlands Space Office (Ministry of Economic Affairs) on Earth Observation
Levelt	Member, International Ozone Commission, 2016-present
Levelt	Member, ESA's Quality Working Group for the Sentinel 5 Precursor, 2018-present
Levelt	Member, Strategic Advice Board for TNO Industry - 2018-present
Levelt	Member, Advice Board Measuring and Calculating Nitrogen, assessing the policy tools to calculate nitrogen deposition, appointed by the Minister of Agriculture, Nature and Food Quality on December 2, 2019
Vermeersen	Member, Dutch Ministery of Economic Affairs & Climate Advisory Board on Hand of the Tap policy for gas and salt mining activities in the Dutch Wadden Sea (2020)
Vermeersen	Member, NWO Round Table Earth Sciences ("Tafel Aardwetenschappen") since 2018
Veefkind	Member, European Space Science Committee (2015-2021)
Veefkind	Member, Sentinel 5 Precursor Mission Advisory Group (2018-present)
Veefkind	Member, ESA Mission Advisory Group for CO2M (2018-present)
Jonker	Member, Industrial and Academic Advisory and Steering Committee (IAASC), Centre for Doctoral Training in Fluid Dynamics across Scales at Imperial College London
Siebesma	Member, Ruisdael Scientific Steering Committee 2017-present
Siebesma	Member, Scientific Advisory Board ECMWF (2016-Present)
Lopez Dekker	Chair, Mission Advisory Group of Harmony, ESA Earth Explorer 10 mission candidate
Lopez Dekker	Member, Mission Advisory Group of SKIM, ESA Earth Explorer 9 mission candidate
Wouters	Member, ESA Mission Advisory Group CRISTAL mission
Wouters	Member, NASA/ESA Phase A - Joint Mass Change Mission Expert Group
Wouters	Member, Sentinel-3 Altimetry Quality Working Group
Wouters	Member, Science Experts Group ESA NGGM/MAGIC science support study
Wouters	Member, ESA/NASA Ad hoc Joint Science Study Team (AJSST) for a joint mass change mission (2019-2020
Wouters	Member, CryoSat Scientific Expert Group
Wouters	Chair, Cryosphere – Earth Observation Strategic Plan Netherlands Space Office
Basu	Contributing author, "The Netherlands' Long-Term Offshore Wind R&D Agenda" (https://www.topsectorenergie.nl/nieuws/netherlands-long-term-offshore-wind-rd-agenda), 2019

Table J.10 Prizes/Awards

Individual awards		
Staff Member	**Description**	**URL**
Bert Wouters	EGU Arne Richter Award for Outstanding Young Scientists 2016	
Cornelis Slobbe	Prof. J.M. Tienstra Onderzoeksprijs 2018	
Peter Teunissen	Johannes Kepler Award (2019) For 'influential and ground-breaking contributions to the algorithmic foundations of satellite navigation'; 'sustained dedication to global education of next generation of navigation engineers'	https://www.ion.org/awards/2019-Kepler.cfm
Peter Teunissen	Included in the Stanford University list of world's top 2% scientists	
Peter Teunissen	Research magazine 'The Australian' named Prof Teunissen world-best in 'Radar, Positioning and Navigation'	
Harm Jonker	Lustrum award NVBM (Dutch Meteorological Society), category research	https://www.nvbm.nl/nieuws/aarnout-van-delden-en-harm-jonker-winnen-nvbm-awards
Jinhu Wang	2019 E.H. Thompson Award of the British Remote Sensing and Photogrammetry Society	
Roderik Lindenbergh	Best Lecturer 2016-2017, Faculty of Civil Engineering and Geosciences	
Elyta Widyaningrum	Shunji Murai award, at ACRS 2019	
Team awards		
Team description	**Description**	
Team of Levelt & Veefkind	USGS-NASA William T. Pecora Award, Group Award for the Ozone Monitoring Instrument (2019)	
Team of Levelt & Veefkind	USGS Pecora Team Award 2018 OMI International Science Team, for 15+ years of sustained team innovation and international collaboration to produce daily global satellite data that revolutionized urban air quality and health research.	

Table J.11 Secondary Appointments

Staff Member	Description
Hanssen	Founder and Chief Science Officer of SkyGeo International, Inc.
Teunissen	Honorary Doctorate Chinese Academy of Sciences (CAS)
Teunissen	Honorary Professor of Wuhan University, China
Teunissen	Honorary Professor of Beihang University, China
Teunissen	Honorary Professor of Tongji University, China
Teunissen	Honorary Professor of University of Melbourne, Australia
Teunissen	Honorary Professor of CAS Institutes NTSC and IGG
Teunissen	Adjunct Professor Curtin University, Australia
Siebesma	Affiliation Senior Scientist KNMI
Jonker	Affiliate Scientist National Center for Atmospheric Research, 2009-2021.
Vermeersen	0.7 fte Full Professor in Planetary Exploration at the TU Delft Faculty of Aerospace Engineering
Vermeersen	0.2 fte Senior Researcher at the Royal Netherlands Institute for Sea Research (NIOZ)
Levelt	Department Head, KNMI of the R&D Satellite Observations - 2009–present (70 employees)
Levelt	Affiliated scientist, National Centre of Academic Research – Atmospheric Chemistry and Dynamics Division (NCAR-ACOM), Boulder, CO, USA, since 2020
Levelt	Guest-professor, Nanjing University of Information, Science and Technology (NUIST), China, 2016-present
Levelt	Visiting scientist, National Centre of Atmospheric Research (NCAR) – Atmospheric Chemistry Observations & Modelling (ACOM), Boulder, CO, USA – March-June 2018
Wouters	Assistant Professor Utrecht University – Institute for Marine and Atmospheric research Utrecht (IMAU)

Table J.12 Public lectures for a general audience

Staff Member	Venue	Date	Title
Stef Lhermitte: at least 15 presentations for a general audience, including:			
	Ondernemershuis Mechelen	18-12-2016	Ice shelves on Antarctica
	For geography teachers	31-1-2017	Ijsplaten van Antarctica in een veranderend klimaat
	Evening conference on Antarctic research	21-3-2018	La Belgique et l'Antarctique, Impressions de Chercheurs
	TUDelft Jeugd Universiteit	13-5-2018	Hoe koud is het echt op Antarctica?
	Natuurkunde symposium: physics of Nature	16-10-2018	De fysica van Antarctica
	EU Copernicus & Polar regions industry workshop	7-11-2018	Assessing ice sheet changes from Copernicus satellites
	Mercatorkring: Keynote for port of Antwerp representatives	8-10-2019	Antarctica voor de zeespiegel: een onzeker zwaargewicht
	NSO Earth Observation, Science & Society Symposium	10-10-2019	Remote sensing of damage feedbacks and ice shelf instability in Antarctica
Wouters	European Polar Science Week	2020	
Vizcaino	Pint of Science, Den Haag	2019	Melting ice
Verhagen	Workshop "GNSS voor nieuwe precisie toepassingen	Jun-2019	
Riva	Studium Generale, Delft	Oct-2015	Beta-balie debat "De zee stijgt!?
Siebesma	Klimaatsymposium: Nederlandse Vereniging voor Natuurkunde (NVN)	2015	Uncertainties in our knowledge of Climate Sensitivity
Siebesma	Colloqium IMAU, University of Utrecht	2015	What have we learned about cloud feedbacks
Tiberius	KennisCafe, De Balie, Amsterdam	17-8-2018	De weg kwijt
Pieternel Levelt: about 15 presentations for a general audience, including:			
	Masterclass I&M ter ere van afscheid Toine Kappelhof, The Hague	14-1-2016	Oog voor Luchtkwaliteit en Klimaat
	EU Space Conference, The Hague	2-6-2016	Monitoring of Emissions for Air Quality and Climate
	Presentatie voor Veiligheid en Justitie, KNMI, De Bilt	Oct-2016	Capabilities in Monitoring from Space,
	World Resource Institute, Capitol Hill, Washington DC	Sep-2017	The power of satellites: tackling air quality and climate issues
	KNMI seminar, De Bilt	23-3-2017	OMI, TROPOMI, TROPOLITE: towards 1 x 1 km2 Air Quality and Emission monitoring from space
	Public Lecture, Theater Diligentia, The Hague	1-4-2019	Luchtkwaliteit vanuit de ruimte; indicator van menselijk handelen
	Keynote, Tech4Climate Symposium, TNO, Eindhoven	25-6-2019	Climate Picture: Monitoring Emissions from Space: indicator of human activity
	Public Lecture with Dutch astronaut Andre Kuipers, at Planetarium Artis Zoo, Amsterdam	11-11-2019	Air Quality from Space: indicator of human activity
	Masterclass, for politicians Ministry Infrastructure and Water Management, The Hague	3-12-2019	Monitoring Emissions from Space: indicator of human activity
	Workshop organized by the Netherlands permanent representation in the EU, the European Environment Bureau and FIPRA	16-6-2020	Impact of COVID measures on Air Quality in Europe

Table J.13 Films/Documentaries for a wide audience

Staff Member	Program	Title	URL	Description
Lhermitte	BBC Earth From Space	Episode 3	https://www.bbc.co.uk/programmes/p072n2zr	
Siebesma	NOS- Klokhuis	Special over Wolken	https://www.hetklokhuis.nl/tv-uitzending/4677/wolken	
Hanssen	VPRO, Nederland van Onderen	Nederland van Onderen	https://www.youtube.com/watch?v=m55ZjmtO6X0&t=326s	On low-probability/ high-impact events for dikes, bridges and sinkholes
Hanssen	NOS- Klokhuis	Zinkgaten	https://hetklokhuis.nl/tv-uitzending/4661/zinkgaten	
Russchenberg	NPO-Sleutelen aan het klimaat	Special about climate engineering	https://www.npostart.nl/sleutelen-aan-het-klimaat/01-09-2021/VPWON_1330214	
Russchenberg	Universiteit van Nederland	Hoe weten we zo zeker dat de mens zorgt voor klimaatverandering?	https://www.universiteitvannederland.nl/college/hoe-weten-we-zo-zeker-dat-de-mens-zorgt-voor-klimaatverandering	
Russchenberg	Universiteit van Nederland	Hoe kunnen we voorspellen hoe warm het gaat worden op aarde?	https://www.universiteitvannederland.nl/college/hoe-kunnen-we-voorspellen-hoe-warm-het-gaat-worden-op-aarde	
Russchenberg	Universiteit van Nederland	Hoe zorgen wolken ervoor dat je langer leeft	https://www.universiteitvannederland.nl/college/hoe-zorgen-wolken-ervoor-dat-je-langer-leeft	
Russchenberg	Universiteit van Nederland	Waarom krijgen we straks in Nederland meer extreme buien?	https://www.universiteitvannederland.nl/college/waarom-krijgen-we-in-nederland-straks-meer-extreme-buien	
Russchenberg	Universiteit van Nederland	Kun je opwarming van de aarde ook tegengaan door zonlicht te weerkaatsen?	https://www.universiteitvannederland.nl/college/kun-je-de-opwarming-van-de-aarde-ook-tegengaan-door-zonlicht-te-weerkaatsen	
Russchenberg	Universiteit van Nederland	Waarom klopt het weerbericht niet altijd?	https://www.universiteitvannederland.nl/college/waarom-klopt-het-weerbericht-niet-altijd	
Russchenberg		Atmospheric feedback loops	https://photomonth.com/en/portfolio/susan-schuppli-atmospheric-feedback-loops/	

Table J.14 (Selected) Media coverage of research

Staff member	Medium	Date	Author	Title	URL	Description
Ricardo Riva	De Volkskrant (NL)	22/03/2019	Cor Speksnijder	Zijn alle voorspellingen over de stijging van de zeespiegel overdreven?		On impact sea level rise on The Netherlands
Ricardo Riva	NRC (NL)	6/12/2019	Marcel aan de Brugh	De zee stijgt, Nederland ligt gunstig – nog wel		Expert opinion
Bas van de Wiel	De Volkskrant (NL)	Apr-15		Helder: het hoe en waarom van Mist		On fog
Bas van de Wiel		8/12/2014		Helderheid rond grondmist		
Stef Lhermitte						Trajectory & demise of iceberg A68
	Het Nieuwsblad (B)				https://www.nieuwsblad.be/cnt/dmf20201220_97686363	
	BBC (UK)				https://www.bbc.com/news/science-environment-55305576	
	BBC (UK)				https://www.bbc.com/news/science-environment-55355381	
Stef Lhermitte						Damage on Pine Island and Thwaites Glaciers
	Washington Post, (US)				https://www.washingtonpost.com/climate-environment/2020/09/14/glaciers-breaking-antarctica-pine-island-thwaites/	
	CNN (US)				https://edition.cnn.com/2020/09/15/weather/antarctica-pine-island-thwaites-glacier-climate-intl-hnk/index.html	
	Spiegel (De)				https://www.spiegel.de/wissenschaft/natur/klimawandel-riesiger-eisbrocken-vom-groessten-gletscher-groenlands-abgebrochen-a-5c38e09d-6ea3-4fbf-bf1c-fa85ae942805	
Stef Lhermitte						Calving event Pine Island
	Daily Mail (UK):				https://www.dailymail.co.uk/sciencetech/article-7522465/Iceberg-FIVE-times-size-Malta-breaks-glacier-Antarctica.html	
	Stuttgarter Nachrichten (D)				https://www.stuttgarter-nachrichten.de/inhalt.unter-antarktis-gletscher-forscher-entdecken-riesigen-hohlraum.cd9d14f7-13d8-4b28-a76c-64b25d2b798d.html	
Stef Lhermitte						Iceberg A68
	VRT (B):				https://www.vrt.be/vrtnws/nl/2018/10/24/nasa-filmt-perfect-rechthoekige-ijsberg-op-antarctica-geniet-me/	
Stef Lhermitte						Rifting Pine Island
	Daily Mail (UK),				https://www.dailymail.co.uk/news/article-6272617/New-19-mile-long-crack-discovered-Antarctic-glacier-form-115-square-mile-iceberg.html	
Stef Lhermitte						15 years of change in the Arctic
	Washington Post (US)				https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/04/24/watch-15-years-of-arctic-change-captured-in-just-a-few-minutes/	
Stef Lhermitte						Pine Island calving
	NASA (US):				https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30914&button=recent	
	New York Times (US):				https://www.nytimes.com/interactive/2017/10/26/climate/antarctica-glaciers-melt.html	
	USA Today (US)				https://www.usatoday.com/story/news/nation-now/2017/09/26/iceberg-4-times-size-manhattan-breaks-off-antarctica/703578001	
Stef Lhermitte						Wildfire Greenland
	Guardian (UK):				https://www.theguardian.com/world/2017/aug/20/ice-and-fire-large-blaze-burns-in-greenland-for-two-weeks	
	Forbes (US):				https://www.forbes.com/sites/ericmack/2017/08/10/greenland-wildfire-ice-sheet-climate	
	Sueddeutsche Zeitung (D):				http://www.sueddeutsche.de/wissen/oekologie-feuer-und-eis-1.3623499	

Staff member	Medium	Date	Author	Title	URL	Description
Stef Lhermitte						Calving Larsen C
	AD (NL):				https://www.ad.nl/wetenschap/zuidpool-heeft-er-een-enorme-ijsberg-bij-als-larsen-c-breekt~a35b250a/	
	The Independent (UK):				https://www.independent.co.uk/news/science/antarctic-iceberg-peninsula-larsen-c-ice-shelf-a-68-water-sea-a7966456.html	
Stef Lhermitte						Peterman rift:
	@TV: Van Gils & gasten (B)	21-Apr-17			https://www.een.be/van-gils-gasten/nieuwe-scheur-in-de-petermann-gletsjer	
	@TV: NOS OP3 (NL)	6-May-17			https://nos.nl/op3/artikel/2171728-hoe-de-scheur-van-stef-wereldnieuws-werd.html	
	Washington Post (US):				https://www.washingtonpost.com/news/energy-environment/wp/2017/04/15/nasa-just-snapped-the-first-photos-of-a-new-crack-in-one-of-greenlands-largest-glaciers/?utm_term=.32dac2e45804	
	CNN (US):				https://edition.cnn.com/2017/04/17/world/greenland-glacier-new-crack/index.html	
Stef Lhermitte						Surface melt on Antarctica:
	Radio 1 (B):				https://radio1.be/als-we-zo-blijven-doorgaan-stijgt-de-zeespiegel-heel-snel-met-een-meter	
	New Scientist (US):				https://www.newscientist.com/article/2114844-mystery-antarctic-circle-means-ice-is-melting-from-surface-down	
	Volkskrant (NL):				http://www.volkskrant.nl/wetenschap/niet-inslag-maar-smeltwater-lijkt-oorzaak-reusachtige-antarctische-krater~a4432685/	
	El Mundo (E):				http://www.elmundo.es/ciencia/2016/12/15/584f-de62e2704eb91e8b4679.html	
Stef Lhermitte	Nature (UK):				http://www.nature.com/articles/nclimate3189.epdf?author_access_token=rigg3EjSKmoWnq13XGvVAtRgN0jAjWel9jnR3ZoTv0MAHvpel81bXLDc8-KdgNcekoylHW8YY7gh2ExcGhHuc0FV0N11ICqydypyGrYNQQsqq8io6udKZ14eGJbdBoNl	
	Huffington Post (US):				http://www.huffingtonpost.ca/2016/12/20/antarctica-crater_n_13748356.html?ncid=tweetlnkcahpmg00000002	
Herman Russchenberg	@TV Willem Wever (NL),				https://www.npostart.nl/willem-wever/23-02-2015/KN_1667115	Cabauw measurements
Herman Russchenberg	Radio 1 (NL): niet meer beschikbaar				https://www.nporadio1.nl/nieuwsshow/onderwerpen/402433-nieuwe-oplossing-tegen-klimaatverandering-geo-engineering	Climate Change
Herman Russchenberg	De Groene (NL):				https://www.groene.nl/artikel/verf-de-wereld-wit-en-zet-de-zon-uit	Climate Engineers:
Herman Russchenberg	@TV Tros (NL				https://eenvandaag.avrotros.nl/item/geo-engineering-maakt-wolken-witter-en-stopt-de-regen	Climate Engineers:
Herman Russchenberg	NRC (NL):				https://www.nrc.nl/nieuws/2019/09/06/waarom-kan-het-op-de-buienradar-soms-spookregenen-a3972470	Rain radar:
Herman Russchenberg	AD (NL):				https://www.ad.nl/wetenschap/climate-engineering-om-de-aarde-te-redden-dit-is-hoe-het-werkt~a9546c2b/?tm_source=email&utm_medium=sendafriend&utm_campaign=socialsharing_web	Rain radar:
Herman Russchenberg	Radio 1 (NL): niet meer beschikbaar				https://www.nporadio1.nl/spraakmakers/onderwerpen/521143-dwarsdenkers-in-de-klimaatdiscussie-deel-4	Climate discussion:
Herman Russchenberg	Volkskrant (NL):				https://www.volkskrant.nl/cultuur-media/een-college-over-hoe-we-de-aarde-kunnen-afkoelen~baa0ac05/	Cooling the Earth:
Herman Russchenberg	NRC (NL):				https://www.nrc.nl/nieuws/2021/03/18/rook-van-australische-natuurbranden-kwam-extreem-hoog-a4036314	Effect of forest fires:
Christian Tiberius	Volkskrant (NL):				https://www.volkskrant.nl/wetenschap/navigatiesystemen-moeten-steeds-betrouwbaarder-zijn-maar-wanneer-werkt-zo-n-systeem-perfect~b1dac870/	Navigation
Pieternel Levelt						Tropomi launch
	@TV, SBS (NL)	13-Oct-17		TROPOMI lancering,Hart van Nederland, 18:00	http://www.hartvannederland.nl/aanbevolen/2017/satelliet-met-nederlands-instrument-gelanceerd	
	BNR radio (NL)	13-Oct-17			https://www.bnr.nl/player/audio/10069446/10331518	
	ESA (EU):	23-Oct-17		Interview about TROPOMI and the ozone layer, Euronews,	http://www.esa.int/ger/ESA_in_your_country/Germany/ESA_Euronews_Wie_weit_erholt_sich_die_Ozonschicht	

Staff member	Medium	Date	Author	Title	URL	Description
Pieternel Levelt						Tropomi first light event
	Volkskrant (NL):	1-Dec-17			https://www.volkskrant.nl/wetenschap/wetenschappers-enthousiast-over-nederlands-ruimte-instrument-dat-luchtvervuiling-in-ongekend-detail-meet~a4542599/	
	@TV (NL): Jinek,	7-Dec-17			https://www.youtube.com/watch?v=pYgNjbFmk7s	
	@TV (NL): NOS journaal, 1	Dec-17		broadcasted at 20:00 and 22:00 hours (between 10:30-14 minutes in the program)	https://nos.nl/uitzending/29486-nos-journaal.html;	
Pieternel Levelt						First time Regular Oil and Gas exploration is measured from space by TROPOMI
	New York Times (US):				https://www.nytimes.com/2019/12/16/climate/methane-leak-satellite.html	
	Washington Post (US)				https://www.washingtonpost.com/climate-environment/a-blowout-turned-an-ohio-gas-well-into-a-methane-super-emitter/2019/12/16/fcbdf622-1f9e-11ea-bed5-880264cc91a9_story.html	
	@TV: NOS Journaal (NL)	29-Jan-20			https://nos.nl/artikel/2320765-lekkages-in-vs-van-sterk-broeikasgas-methaan-vanuit-de-ruimte-opgespoord.html	
Pieternel Levelt						Reduction in air polution due to COVID
	Nature (UK)				https://www.nature.com/articles/d41586-020-01049-6	
	New Yok Times (US):				https://www.nytimes.com/interactive/2020/climate/coronavirus-pollution.html	
	@TV NOS news (NL):			at 25 minutes	https://nos.nl/uitzending/48625-nos-journaal.html	
Pieternel Levelt		16-Apr-16			https://www.youtube.com/watch?v=LKe5FdKInJs	President Obama on OMI satellite data for Air Quality and Emissions Control, Science Channel,

Table J.15 Websites for societal target groups

Staff member	Description	URL
Russchenberg	Ruisdael Observatory	www.ruisdael-observatory.nl
Russchenberg	Cabauw data at 4TU Data centre	https://data.4tu.nl/collections/Atmospheric_observations_IDRA_Cabauw/5065367
HRRusschenberg	Cloudnet data portal	https://cloudnet.fmi.fi/search/visualizations
Schleiss	Rainfall nowcaster RainGuRu	https://rainguru.hkvservices.nl/
Schleiss	Precipitation - 10 seconds measurements by Ruisdael Micro Rain Radar (Metek) at Green Village (TU Delft) - Dataset - KNMI Data Platform	https://dataplatform.knmi.nl/dataset/ruisdael-mrr-greenvillage-1
Lhermitte	Mass loss in Antarctica	https://tudelft.pageflow.io/pig-damage
Lhermitte	Antractica and Sea Level Rise	https://tudelft.pageflow.io/benemelt#74887
Lhermitte	Greenland Mass Loss	https://tudelft.pageflow.io/north-gris
Lhermitte	Greenland and its Ice Caps	https://tudelft.pageflow.io/gics
Lindenbergh	CoastScan, continuously scanning the coast	https://coastscan.citg.tudelft.nl/
Lindenbergh	OLRS Laser Scan Archive	https://olrs.weblog.tudelft.nl/
Hanssen	Bodemdalingskaart.nl, v1 , (2018) version 1.0	https://bodemdalingskaart.nl/portal/index
Hanssen	Bodemdalingskaart.nl, v2 (2020) version 2.0	https://bodemdalingskaart.nl/en-us/
Hanssen	Interactive Land Use Map for the state of Sao Paulo, Brazil	http://be-basic.grs.tudelft.nl/maps/316/view
Lopez Dekker	NL-RIA, Dutch Knowledge Network on Radar Instruments and Applications	https://nl-ria.nl
Klees, Slobbe	NLGEO2018 quasi-geoid model	https://www.isgeoid.polimi.it/Geoid/Europe/Netherlands/netherland18_g.html
Slobbe	NLLAT2018 Chart Datum model for the Netherlands (published by Hydrographic Service of the Netherlands)	https://english.defensie.nl/downloads/applications/2020/06/12/nllat2018

Table J .16 Stories of Science

Staff member	Title	URL
Adriaan van Natijne	The landslide forecast coming to you from space	https://www.tudelft.nl/en/ceg/research/stories-of-science/the-landslide-forecast-coming-to-you-from-space
Herman Russchenberg	Climate technology you hope you'll never need	https://www.tudelft.nl/en/ceg/research/stories-of-science/climate-technology-you-hope-youll-never-need
Sukanta Basu	The wind app which puts the wind in your sails	https://www.tudelft.nl/en/ceg/research/stories-of-science/the-wind-app-which-puts-the-wind-in-your-sails
Frans Liqui Lung	Creating order in the chaos of sand and wind	https://www.tudelft.nl/en/ceg/research/stories-of-science/creating-order-in-the-chaos-of-sand-and-wind
Harry Zekollari	A super model for all the glaciers on Earth	https://www.tudelft.nl/en/ceg/research/stories-of-science/a-super-model-for-all-the-glaciers-on-earth
Riccardo Riva	Moved by moving water	https://www.tudelft.nl/en/ceg/research/stories-of-science/moved-by-moving-water
Pieternel Levelt	Globally mapping air pollution	https://www.tudelft.nl/en/ceg/research/stories-of-science/globally-mapping-air-pollution
Stef Lhermitte	A golden age for earth observation	https://www.tudelft.nl/en/ceg/research/stories-of-science/a-golden-age-for-earth-observation
Louise Nuijens	Up in the clouds	https://www.tudelft.nl/en/ceg/research/stories-of-science/up-in-the-clouds
Ece Özer	The breathing of dikes	https://www.tudelft.nl/en/ceg/research/stories-of-science/the-breathing-of-dikes
Ramon Hanssen	52° North: a tangible timeline	https://www.tudelft.nl/en/ceg/research/stories-of-science/52-north-a-tangible-timeline
Elske de Zeeuw-van Dalfsen	The Dutch volcanoes	https://www.tudelft.nl/en/ceg/research/stories-of-science/the-dutch-volcanoes
Ramses Molijn	Searching for sugarcane	https://www.tudelft.nl/en/ceg/research/stories-of-science/searching-for-sugarcane
Christiaan Tiberius/ Peter de Bakker	Navigating the motorways with pinpoint accuracy	https://www.tudelft.nl/en/ceg/research/stories-of-science/navigating-the-motorways-with-pinpoint-accuracy
Bas van de Wiel	Weather alarm: chance of sudden death	https://www.tudelft.nl/en/ceg/research/stories-of-science/weather-alarm-chance-of-sudden-death
Tim Vlemmix	Measuring air pollution street by street	https://www.tudelft.nl/en/ceg/research/stories-of-science/measuring-air-pollution-street-by-street
Herman Russchenberg	Clouds and climate	https://www.tudelft.nl/en/ceg/research/stories-of-science/clouds-and-climate
Miren Vizcaino	The evolution of the Greenland ice sheet	https://www.tudelft.nl/en/ceg/research/stories-of-science/the-evolution-of-the-greenland-ice-sheet
Harry Zekollari	A supermodel for all the glaciers on Earth	https://www.tudelft.nl/en/stories/articles/a-supermodel-for-all-the-glaciers-on-earth

Table J.17 Patents and licences

Staff Member	Description	Date
Hanssen, R. F.	Method for connecting measured interferometric synthetic aperture radar (insar) data to a geodetic reference system. The Netherlands patent.	2015
Hanssen, R. F.	Device with integrated double sar corner-reflectors, gnss, leveling. Triangulation and photogrammetric benchmarks. International patent WO 2018/236215	2017
Levelt P.	Correction of curved projection of a spectrometer slit line, Eddy van Brug et al.	8/2/2017
Levelt P.	KNMI patent NO-2 sonde, patent number NL 2 011 932	2017

Table J.18 Research projects with educational components

Staff Member	Description	Date	URL
Stef Lhermitte	Open access publication of teaching jupyter notebooks		https://github.com/steflhermitte/EO-Notebooks
Herman Russchenberg	MOOC on Water and Climate		https://www.edx.org/course/introduction-to-water-and-climate-1
Roderik Lindenbergh	Comenius Teaching Fellows 2018, 'Offering students world-class education in geoscience fieldwork through optimally using analogue skills and digital tools'	2018	
Sandra Verhagen, Ramon Hanssen	MOOC Observation Theory: Estimating the Unknown		https://online-learning.tudelft.nl/courses/observation-theory-estimating-the-unknown/
Louise Nuijens	"I Am A Scientist," classroom tools to make STE(A)M careers technically and psychologically accessible to all students by The Plenary & Co.		https://www.iamascientist.info/louise-nuijens

Table J.19 Solicited Expert Advice

Staff member	Description	Date	Specification	URL
Russchenberg, Jonker	Deventer Moordzaak (voor de Hoge Raad), Dutch court case			
Hanssen	BRIEF VAN DE MINISTER VAN ECONOMISCHE ZAKEN aan de Voorzitter van de Tweede Kamer der Staten-Generaal Den Haag (Dutch government)		Onderzoeksresultaten en maatregelenpakket inzake na-ijlende effecten van de steenkolenwinning in Limburg – Mijnbouw	https://www.parlementaire-monitor.nl/9353000/1/j9v-vij5epmj1ey0/vkarg85c3yw3

Table J.20 Public Awards

Staff member	Description	Date
Pieternel Levelt	Ridder in de Orde van de Nederlandse Leeuw. (Dutch Royal decoration)	2021

Table J.21 Collaboration Partners

Table J.21.a) Institutional Partners
510 (Red Cross)
Deltares
Hydrographic Service of the Royal Netherlands Navy
Instituut voor Marien en Atmosferisch onderzoek Utrecht (IMAU), Utrecht University
Kadaster
Koninklijk Nederlands Meteorologisch Instituut (KNMI)
Ministry of Infrastructure and the Environment (Rijkswaterstaat)
Municipalities (e.g. Rotterdam)
Nederlandse Aardolie Maatschappij (NAM)
Netherlands eScience Center.
Nederlands Loodswezen
Netherlands Organization for Applied Scientific Research (TNO)
Royal Netherlands Aerospace Centre (NLR)
Royal Netherlands Institute for Sea Research (NIOZ)
University of Twente
Wageningen University
Waterboards (e.g. Rijnland, Noord-Hollands Noorderkwartier)

Table J21.b) Industrial Partners
06-GPS
Allseas Engineering
CGI
Cosine
Cyclomedia
Fugro BV
Geodan
Geodelta
Greenchoice
KPN
Neo BV
QPS Maritime Software Solutions
SkyEcho
SkyGeo
Sobolt
TomTom
Van Oord Dredging and Marine Contractors
VSL
Whiffle

Table E.21.c) International Partners
Airbus
Belgium National Geographic Institute
CRC-SI
Danish Meteorological Institute
Deimos Imaging
European Space Agency (ESA)
German Aerospace Center (DLR)
German Federal Agency for Cartography and Geodesy
Google
Mitsubishi
National Center for Atmospheric Research (US)
Septentrio
U-blox

Appendix K:
GRS Lab Equipment and Computational Facilities

The main laboratory infrastructure of GRS can be divided in several facilities:
- Observatories
- Measurement equipment
- Computer equipment with data storage facilities

Observatories

GRS manages several observatories that include specialized equipment.

- The **Ruisdael observatory for atmospheric sciences** includes a horizontally scanning X-band weather radar, a S-band radar profiler with 3 beams capability for wind measurements, two W-band and one dual-frequency (Ka- and W-band) scanning cloud radars, microwave radiometers, a cloud profiling mobile station, seven vertically pointing FMCW radars (24 GHz), also known as “micro rain radar” and ten Parsivel optical disdrometers. See also https://ruisdael-observatory.nl/.
- The **Fundamental station Westerbork** with a bunker specifically designed for gravity measurements. Westerbork is also one of the longest serving stations in the International GNSS Network (IGS) and is maintained by TU Delft.
- The **Dutch Permanent GNSS Array** (DPGA) is a network of continuously operating receivers from different organizations, including TU Delft and a data centre for the retrieval, dissemination and archiving of the data. It acts as a local data centre for the International GNSS Service, EUREF Permanent GNSS Network (EPN) and European Plate Observatory (EPOS). The DPGA also archives data from commercial RTK network for science and education. See also http://gnss1.tudelft.nl/dpga.
- The **TU Delft Geodetic Observatory** currently contains 34 integrated geodetic reference stations (IGRS), enabling datum connection between GNSS, InSAR, leveling, photogrammetry, airborne laser scanning, tachymetry and gravity. It acts as a reference networkto estimate surface motion due to gas production as well as organic soils. Moreover, active radar transponders are deployed in a fixed and floating setup.
- Our share in the **Cabauw** Experimental Site for Atmospheric Research (**CESAR**). The world-class CESAR Observatory in Cabauw (PI: Prof. Russchenberg) is widely recognized as one of the most advanced sites for atmospheric studies. TU Delft owns and operates the high-resolution atmospheric radar systems IDRA and TARA. CESAR consists of a large set of instruments to study the atmosphere and its interaction with the land surface. It serves as a permanent bridge between the participating universities (TU Delft, WUR, TU/e) and research institutes (KNMI, RIVM, TNO, ESA, ECN). Many of the available atmospheric remote sensing instruments located at Cabauw offer unique possibilities for sensor synergy. We also operate, together with NGSI, an Integrated Geodetic Reference Station (IGRS) at Cabauw.
- The **OMI** satellite instrument (PI: Prof. Levelt) and the **TROPOMI** instrument (PI: Veefkind) give detailed information on global trends in regional and global air quality and climate related issues.
- The **Rotterdam testbed**, including a network of weather stations, high-resolution rainfall radar and in situ sensors, and remote sensing sensors for air quality is under development.
- The **KNMI Parameterization Test Bed**. Results of a variety of numerical models, ranging from GPU-accelerated large-eddy simulations, limited area models and single-column model versions are compared continuously with in-situ data as obtained from the CESAR Observatory.

Additional measurement equipment

Measurement equipment is either permanently located at an observatory site for continuous monitoring or used for long-lasting campaigns (several months or years), or shorter campaigns (days to weeks). The equipment includes 7 Davis vantage pro weather stations, LaCoste Romberg and Scintrex CG-5 and CG-6 relative gravimeters, an FG-5 absolute gravimeter, L-, C- and X-band radars, a Flow32 Sap Flow system, 2 T4 Tensiometers, 15 soil moisture sensors, 1 Rohde & Schwarz Handheld VNA (1-8GHz), 10 radar reflectors, 8 radar transponders, 4 so-called IGRS receivers/reflectors, state-of-the-art GPS equipment including 14 geodetic grade GNSS receivers and 2 GPS RTK receivers, theodolites, total stations, 3 precise levelling instrument, and laser distance measurement devices. Terrestrial acquisition is also carried out using digital cameras and a Leica P40 3D Laser Scanner.

In 2021 it was decided to further extend the monitoring capacity by updating existing equipment, or by acquiring new equipment, like an UAV-LIDAR system. Full details on the equipment to be acquired for this extension were not yet available at the time of this writing.

Computer equipment with data storage facilities

The GRS laboratory possesses some powerful high-performance clusters (HPC), and additional specialised computer equipment with data storage facilities:

1. HPC03: cluster consisting of 17 nodes, with in total 266 CPUs and 1383 Gb memory.
2. HPC/INSY: cluster consisting of 52 nodes, with in total 3264 CPUs, 96 GPUs, and 20308 Gb memory.
3. VRLab: low-latency grid-network for special GPU and visualization applications consisting of 8 nodes, 408 CPUs in total, 15940G Memory in total and 8 GPUs in total.

In 2022, the TU Delft wide DHPC will become available. It will be fast and flexible, with a peak performance of 2 petaflop/s, 20.000 CPU cores, over 400 compute nodes, 10 GPU nodes based on Nvidia Tesla V100 and 2 special nodes for interactive work, a high-speed Interconnect based on Mellanox InfiniBand and a 700TB high-speed parallel storage subsystem.

Dept. GRS staff is also using the Dutch national Sara super-computing facilities and Oak Ridge Leadership Computing Facility (OLCF).

Appendix L:
Key Publications

Table L.1 Key Publications from the research theme Geodesy

Publication	#citations
Odijk, D., Zhang, B., Khodabandeh, A., Odolinski, R. & Teunissen, P. J. G. 2016, 'On the estimability of parameters in undifferenced, uncombined GNSS network and PPP-RTK user models by means of S-system theory', Journal of Geodesy, vol. 90, no. 1, pp. 15- 44, doi:10.1007/s00190-015-0854-9	139
Knoop, V.L., de Bakker, P.F., Tiberius, C.C.J.M. & van Arem, B., 2017 'Lane determination with GPS Precise Point Positioning'. IEEE Transactions on Intelligent Transportation Systems (ITS). Vol. 18, No. 9, 2503-2513.	57
Teunissen, Peter JG, and Oliver Montenbruck, eds. *Springer handbook of global navigation satellite systems*. Vol. 1. New York, NY, USA:: Springer International Publishing, 2017.	562
Teunissen, P. J. G. 2019, 'A new GLONASS FDMA model', GPS Solutions, 23:100, 19p	14
Khodabandeh, A. & Teunissen, P. J. G. 2019, 'Integer estimability in GNSS networks', Journal of Geodesy, vol. 93, no. 9, pp. 1805– 1819, doi:https://doi.org/10.1007/s00190-019-01282-6	137
Teunissen, P. J. G. 2018, 'Distributional theory for the DIA method', Journal of Geodesy, vol. 92, no. 1, pp. 59-80, doi:10.1007/s00190- 017-1045-7	76
Zaminpardaz, S.,Teunissen P.J.G. 2019 'DIA-datasnooping and identifiability' Journal of Geodesy, 93, 85-101.	30
Odijk, D., Nadarajah, N., Zaminpardaz, S. & Teunissen, P. J. G. 2017, 'GPS, Galileo, QZSS and IRNSS differential ISBs: estimation and application', GPS Solutions, vol. 21, no. 2, pp. 439-450, doi:10.1007/s10291-016-0536-y	100
Odolinski, R. & Teunissen, P. J. G. 2016, 'Single-frequency, dual-GNSS versus dual-frequency, single-GNSS: a low-cost and high- grade receivers GPS-BDS RTK analysis', Journal of Geodesy, vol. 90, no. 11, 1255-1278.	93
Dun, H., Tiberius, C.C. and Janssen, G.J., 2020. Positioning in a multipath channel using OFDM signals with carrier phase tracking. *IEEE Access*, 8, pp.13011-13028.	9
Klees, R., Slobbe, D.C. and Farahani, H.H., 2018. A methodology for least-squares local quasi-geoid modelling using a noisy satellite-only gravity field model. *Journal of Geodesy*, 92(4), pp.431-442.	8
Klees, R., Slobbe, D.C. and Farahani, H.H., 2019. How to deal with the high condition number of the noise covariance matrix of gravity field functionals synthesised from a satellite-only global gravity field model? *Journal of geodesy*, 93(1), pp.29-44.	4
Slobbe, C., Klees, R., Farahani, H.H., Huisman, L., Alberts, B., Voet, P. and Doncker, F.D., 2019. The Impact of Noise in a GRACE/GOCE Global Gravity Model on a Local Quasi-Geoid. *Journal of Geophysical Research: Solid Earth,* 124(3), pp.3219-3237.	6
Farahani, H.H., Klees, R. and Slobbe, C., 2017. Data requirements for a 5-mm quasi-geoid in the Netherlands. *Studia geophysica et geodaetica,* 61(4), pp.675-702.	19
D.C. Slobbe, R. Klees, M. Verlaan, F. Zijl, B. Alberts, H.H. Farahani (2018), Height system connection between island and mainland using a hydrodynamic model: a case study connecting the Dutch Wadden Islands to the Amsterdam ordnance datum (NAP). Journal of Geodesy 92: 1439-1456.	6
Kleinherenbrink, M., Naeije, M., Slobbe, C., Egido, A. and Smith, W., 2020. The performance of CryoSat-2 fully-focussed SAR for inland water-level estimation. *Remote Sensing of Environment,* 237, p.111589.	9
Jiang, M., Ding, X., Hanssen, R.F., Malhotra, R., Chang, L. 2015, Fast statistically homogeneous pixel selection for covariance matrix estimation for multitemporal InSAR, *IEEE Transactions on Geoscience and Remote Sensing*, 53 (3), art. no. 6866873, pp. 1213-1224.	112
Morishita, Y. and Hanssen, R.F., 2015. Deformation parameter estimation in low coherence areas using a multisatellite InSAR approach. *IEEE Transactions on geoscience and remote sensing,* 53(8), pp.4275-4283.	27
Özer, I.E., Rikkert, S.J., van Leijen, F.J., Jonkman, S.N. and Hanssen, R.F., 2019. sub-seasonal Levee Deformation observed Using satellite Radar Interferometry to enhance Flood protection. *Scientific reports*, 9(1), pp.1-10.	10
van der Horst, T., Rutten, M.M., van de Giesen, N.C. and Hanssen, R.F., 2018. Monitoring land subsidence in Yangon, Myanmar using Sentinel-1 persistent scatterer interferometry and assessment of driving mechanisms. *Remote sensing of environment,* 217, pp.101-110.	25

Table L.2 Key Publications from the research theme Earth System Science

Publication	#citations
Frederikse, T., Riva, R., Kleinherenbrink, M., Wada, Y., van den Broeke, M., & Marzeion, B. (2016). Closing the sea level budget on a regional scale: Trends and variability on the Northwestern European continental shelf. *Geophysical Research Letters*, 43(20), 10-864.	46
Frederikse, T., Jevrejeva, S., Riva, R. E., & Dangendorf, S. (2018). A consistent sea-level reconstruction and its budget on basin and global scales over 1958–2014. Journal of Climate, 31(3), 1267-1280.	41
Riva, R. E., Frederikse, T., King, M. A., Marzeion, B., & van den Broeke, M. R. (2017). Brief communication: The global signature of post-1900 land ice wastage on vertical land motion. The Cryosphere, 11(3), 1327-1332.	35
Simon, K. M., Riva, R. E., Kleinherenbrink, M., & Frederikse, T. (2018). The glacial isostatic adjustment signal at present day in northern Europe and the British Isles estimated from geodetic observations and geophysical models. Solid Earth, 9(3), 777-795.	26
The IMBIE Team (incl. W. van der Wal & B. Wouters) - Shepherd et al. (2018). Mass balance of the Antarctic Ice Sheet from 1992 to 2017. Nature, 558, 219-222.	378
The IMBIE Team (incl. W. van der Wal & B. Wouters) - Shepherd et al. (2020). Mass balance of the Greenland Ice Sheet from 1992 to 2018. Nature, 579(7798), 233-239.	216
Jevrejeva, S., Jackson, L. P., Riva, R. E., Grinsted, A., & Moore, J. C. (2016). Coastal sea level rise with warming above 2 C. *Proceedings of the National Academy of Sciences*, 113(47), 13342-13347.	148
Dangendorf, S., Marcos, M., Wöppelmann, G., Conrad, C. P., Frederikse, T., & Riva, R. (2017). Reassessment of 20th century global mean sea level rise. Proceedings of the National Academy of Sciences, 114(23), 5946-5951.	240
Cazenave, A., et al. (2018) - The WCRP Global Sea Level Budget Group (incl. R.E.M. Riva and B. Wouters). Global sea-level budget 1993-present. *Earth System Science Data*, 10(3), 1551-1590.	129
Martinec, Z., Klemann, V., van der Wal, W., Riva, R. E. M., Spada, G., Sun, Y., Melini, D., Kachuck, S. B., Barletta, V., Simon, K., A, G., & James, T. S. (2018). A benchmark study of numerical implementations of the sea level equation in GIA modelling. *Geophysical Journal International,* 215(1), 389-414.	21
Sun, Y., Riva, R., & Ditmar, P. (2016). Optimizing estimates of annual variations and trends in geocenter motion and J2 from a combination of GRACE data and geophysical models. *Journal of Geophysical Research: Solid Earth,* 121(11), 8352-8370.	108
Sellevold, R., van Kampenhout, L., Lenaerts, J. T., NoÃ, B., Lipscomb, W. H., & Vizcaino, M. (2019). Surface mass balance downscaling through elevation classes in an Earth system model: application to the Greenland ice sheet. The Cryosphere, 13(12), 3193-3193.	10
van Kampenhout, L., Lenaerts, J. T. M., Lipscomb, W. H., Lhermitte, S., Noel, B., Vizcaino, M., . . . van den Broeke, M. R. (2020). Present-Day Greenland Ice Sheet Climate and Surface Mass Balance in CESM2. *Journal of Geophysical Research-Earth Surface,* 125(2). doi:10.1029/2019jf005318	16
Sellevold, R. and Vizcaíno, M., 2020. Global warming threshold and mechanisms for accelerated Greenland ice sheet surface mass loss. Journal of advances in modeling earth systems, 12(9), p.e2019MS002029	5
Muntjewerf, L., Petrini, M., Vizcaino, M., da Silva, C. E., Sellevold, R., Scherrenberg, M. D. W., . . . Lofverstrom, M. (2020). Greenland Ice Sheet Contribution to 21st Century Sea Level Rise as Simulated by the Coupled CESM2.1-CISM2.1. *Geophysical Research Letters,* 47(9). doi:10.1029/2019gl086836	16
Muntjewerf, L., Sellevold, R., Vizcaino, M., da Silva, C. E., Petrini, M., Thayer-Calder, K., . . . Sacks, W. J. (2020). Accelerated Greenland Ice Sheet Mass Loss Under High Greenhouse Gas Forcing as Simulated by the Coupled CESM2.1-CISM2.1. *Journal of Advances in Modeling Earth Systems,* 12(10). doi:10.1029/2019ms002031	5
Lenaerts, J. T. M., Le Bars, D., van Kampenhout, L., Vizcaino, M., Enderlin, E. M., & van den Broeke, M. R. (2015). Representing Greenland ice sheet freshwater fluxes in climate models. *Geophysical Research Letters,* 42(15), 6373-6381. doi:10.1002/2015GL064738	126
Lenaerts, J. T. M., Vizcaino, M., Fyke, J., Kampenhout, L., & Broeke, M. R. (2016). Present-day and future Antarctic ice sheet climate and surface mass balance in the Community Earth System Model. *Climate Dynamics,* 1-15. doi:10.1007/s00382-015-2907-4 %U http://dx.doi.org/10.1007/s00382-015-2907-4	107
Hanna, E., Pattyn, F., Navarro, F., Favier, V., Goelzer, H., van den Broeke, M.R., Vizcaino, M., Whitehouse, P.L., Ritz, C., Bulthuis, K. and Smith, B., 2020. Mass balance of the ice sheets and glaciers–progress since AR5 and challenges. *Earth-Science Reviews,* 201, p.102976.	34
Vizcaino, M., Mikolajewicz, U., Ziemen, F., Rodehacke, C. B., Greve, R., & van den Broeke, M. R. (2015). Coupled simulations of Greenland Ice Sheet and climate change up to A.D. 2300. *Geophysical Research Letters,* 42(10), 3927-3935. doi:10.1002/2014gl061142	65

Table L.3 Key Publications from the research theme Remote Sensing

Publication	#citations
P. López-Dekker, H. Rott, P. Prats-Iraola, B. Chapron, K. Scipal and E. D. Witte, "Harmony: an Earth Explorer 10 Mission Candidate to Observe Land, Ice, and Ocean Surface Dynamics," IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, 2019, pp. 8381-83843.	18
Lenaerts, J.T.M.*, Lhermitte, S.*, Drews, R., Ligtenberg, S.R.M., Berger, S., Helm, V., Smeets, C.J.P.P., Broeke, M.R. van den, van de Berg, W.J., van Meijgaard, E., Eijkelboom, M., Eisen, O., Pattyn, F., 2017. Meltwater produced by wind–albedo interaction stored in an East Antarctic ice shelf. Nat. Clim. Chang. 7, 58–62. https://doi.org/10.1038/nclimate3180	122
Lhermitte, S., Sun, S., Shuman, C., Wouters, B., Pattyn, F., Wuite, J., Berthier, E., Nagler, T., 2020. Damage accelerates ice shelf instability and mass loss in Amundsen Sea Embayment. PNAS 117, 24735–24741. https://doi.org/10.1073/pnas.1912890117	26
Hawinkel, P., Thiery, W., Lhermitte, S., Swinnen, E., Verbist, B., Van Orshoven, J., Muys, B., 2016. Vegetation response to precipitation variability in East Africa controlled by biogeographical factors. J. Geophys. Res. Biogeosciences 1–23. https://doi.org/10.1002/2016JG003436	45
Herrero-Huerta, M., Lindenbergh, R., & Rodríguez-Gonzálvez, P. (2018). Automatic tree parameter extraction by a Mobile LiDAR System in an urban context. PLoS One, 13(4), e0196004.	26
Vos, S., Lindenbergh, R., de Vries, S., Aagaard, T., Deigaard, R., & Fuhrman, D. (2017, June). Coastscan: Continuous monitoring of coastal change using terrestrial laser scanning. In Coastal Dynamics (Vol. 233)	26
Zhou, K., Lindenbergh, R., Gorte, B., & Zlatanova, S. (2020). LiDAR-guided dense matching for detecting changes and updating of buildings in Airborne LiDAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 162, 200-213.	11
H.H. Farahani, P. Ditmar, P. Inácio, O. Didova, B. Gunter, R. Klees, X. Guo, J. Guo, Y. Sun, X. Liu, Q. Zhao, and R. Riva, 2017. A high resolution model of linear trend in mass variations from DMT-2: Added value of accounting for coloured noise in GRACE data. Journal of Geodynamics, 103, pp. 12-25.	12
P. Ditmar, (2018). Conversion of time-varying Stokes coefficients into mass anomalies at the Earth's surface considering the Earth's oblateness. Journal of Geodesy, 92, pp. 1401–1412.	16
N. Tangdamrongsub, S.C. Steele-Dunne, B.C. Gunter, P.G. Ditmar, E.H. Sutanudjaja, Y.Sun, T. Xia, and Z. Wang, 2017. Improving estimates of water resources in a semi-arid region by assimilating GRACE data into the PCR-GLOBWB hydrological model. Hydrology and Earth System Sciences, 21 (4), pp. 2053-2074.	36
N. Tangdamrongsub, P.G. Ditmar, S.C. Steele-Dunne, B.C. Gunter, and E.H. Sutanudjaja, 2016. Assessing total water storage and identifying flood events over Tonlé Sap basin in Cambodia using GRACE and MODIS satellite observations combined with hydrological models. Remote Sensing of Environment, 181, pp. 162-173.	42
J. Ran, P. Ditmar, R. Klees, and H. Hashemi Farahani, 2018a. Statistically optimal estimation of Greenland Ice Sheet mass variations from GRACE monthly solutions using an improved mascon approach. Journal of Geodesy, 92, pp. 299–319, doi: 10.1007/s00190-017-1063-5.	21
O. Engels, B. Gunter, R. Riva, R. Klees (2018), Separating geophysical signals using GRACE and high-resolution data: A case study in Antarctica. GRL 45: 12340-12349.	7
O. Didova, B. Gunter, R. Riva, R. Klees, L. Roese-Koerner (2016), An approach for estimating time-variable rates from geodetic time series. J Geod 90: 1207-1221.	35
B. Noël, L. van Kampenhout, W.J. van den Berg, J.T.M Lenaerts, B. Wouters and M.R. van den Broeke.: Brief communication: CESM2 climate forcing (1950–2014) yields realistic Greenland ice sheet surface mass balance, The Cryosphere, 14, 1425–1435, https://doi.org/10.5194/tc-14-1425-2020, 2020	11
J. Ran, M. Vizcaino, P. Ditmar, M.R. van den Broeke, T. Moon, Ch.R. Steger, E.M. Enderlin, B. Wouters, B. Noël, C.H. Reijmer, R. Klees, M. Zhong, L. Liu, and X. Fettweis, 2018c. Seasonal mass variations show timing and magnitude of meltwater storage in the Greenland Ice Sheet. The Cryosphere, 12, pp. 2981–2999.	13
M.D. King, I.M. Howat, S.G. Candela et al. (incl. B. Wouters), Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. Commun Earth Environ 1, 1 (2020). https://doi.org/10.1038/s43247-020-0001-2	72
I. Sasgen., B. Wouters, A.S. Gardner et al. Return to rapid ice loss in Greenland and record loss in 2019 detected by the GRACE-FO satellites. Commun Earth Environ 1, 8 (2020).	38
J.E. Box, W.T. Colgan, T.R. Christensen, N.M. Schmidt, M. Lund, F.-J.W. Parmentier, R. Brown, U.S. Bhatt, E.S. Euskirchen, V.E. Romanovsky, J.E. Walsh, J.E. Overland, M. Wang, R.W. Corell, W.N. Meier, B. Wouters, S. Mernild, J. Mård, J. Pawlak, M.S. Olsen, 2019. Key indicators of Arctic climate change: 1971–2017. Environmental Research Letters 14, 045010. https://doi.org/10.1088/1748-9326/aafc1b	256
Wouters B, Gardner AS and Moholdt G (2019) Global Glacier Mass Loss During the GRACE Satellite Mission (2002-2016). Front. Earth Sci. 7:96. doi: 10.3389/feart.2019.00096	101

Table L.4 Key Publications from the research theme Atmosphere

Publication	#citations
Van de Wiel B.J.H., Vignon E., Baas P., Van Hooijdonk, I.G.S , Van der Linden, S.J.A, Van Hooft, J.A., Bosveld, F.C., de Roode, S.R., Moene, A.F., Genthon C., (2017). Regime transition in near-surface temperature inversions: a conceptual model. J. Atm. Sci.,74, 1057-1073	48
Van der Linden, S.J.A, Van de Wiel, B.J.H., Petenko, I., Van Heerwaarden, C.C., Baas, P., Jonker, H.J.J. (2020) A Businger mechanism for intermittent bursting in the stable boundary layer., J. Atm. Sci., 77, 3343-3360.	2
Yi, D., Basu, S., Maronga, B, and de Roode, S. R. (2020). "Addressing the grid-size sensitivity issue in large-eddy simulations of stable boundary layers", Boundary-Layer Meteorology, doi: 10.1007/s10546-020-00558-1.	10
Basu, S; and Lacser, A (2017) : "A Cautionary Note on the Use of Monin-Obukhov Similarity Theory in Very High-Resolution Large-Eddy Simulations" Boundary-Layer Meteorology, 10.1007/s10546-016-0225-y. (35 citations)	35
Izett, G.Z., Schilperoort B., Coenders-Gerrits, M., Baas, P., Bosveld, F.C., van de Wiel, B.,J.,H. (2019) Missed Fog? On the potential of obtaining observations at increased resolution during shallow fog events. Boundary-Layer Meteorol doi:10.1007/s10546-019-00462-3	13
Saggiorato, B., Nuijens, L., Siebesma, A. P., de Roode, S., Sandu, I. and Papritz, L. (2020). The influence of convective momentum transport and vertical wind shear on the evolution of a cold air outbreak. *Journal of Advances in Modeling Earth Systems*, 12	5
Helfer, K.C., Nuijens, L. E, de Roode, S.R. and Siebesma, A.P. :(2020) How wind shear affects trade-wind cumulus convection, Journal of Advances in Modeling Earth Systems, 12 e2020MS002183. https://doi.org/10.1029/2020MS002183.	3
van der Dussen, J. J.; de Roode, S. R.; Dal Gesso, S.; Siebesma, A. P. (2015). An LES model study of the influence of the free tropospheric thermodynamic conditions on the stratocumulus response to a climate perturbation *Journal of Advances in Modeling Earth Systems*, 7.	44
Bony, S, Stevens, B, Frierson D.M.W, Jakob, C., Kageyama, M., Pincus, R., Shepherd, T.G., Sherwood, S.C., Siebesma, A.P, Sobel, A.H., Watanabe, M., Webb, M.J., Clouds, circulation and Climate Sensitivity. Nature Geoscience 8, 261-268 (2015).	568
Nuijens, L, Siebesma, AP (2019) Boundary Layer Clouds and Convection over Subtropical Oceans in our Current and in a Warmer Climate. *Current Climate Change Reports* 5 80-94.	25
Stevens, B., Bony, S., Brogniez, H., Hentgen, L., Hohenegger, C., Kiemle, C., L'Ecuyer, T.S., Naumann, A.K., Schulz, H., Siebesma, P.A. and Vial, J., 2020. Sugar, gravel, fish and flowers: Mesoscale cloud patterns in the trade winds. *Quarterly Journal of the Royal Meteorological Society*, 146(726), pp.141-152.	51
Rusli, S. P., Donovan, D. P., and Russchenberg, H. W. J.: (2017) Simultaneous and synergistic profiling of cloud and drizzle properties using ground-based observations, Atmos. Meas. Tech., 10, 4777–4803, https://doi.org/10.5194/amt-10-4777-2017, 2017.	25
D. Mamali, J. Mikkilä, B. Henzing, R. Spoor, M. Ehn, T. Petäjä, H. Russchenberg, G. Biskos, (2018) Long-term observations of the background aerosol at Cabauw, The Netherlands, Science of The Total Environment, Volume 625, Pages 752-761,ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2017.12.136.,	4
Sarna, K. and Russchenberg, H. W. J.: Monitoring aerosol–cloud interactions at the CESAR Observatory in the Netherlands, (2017) Atmos. Meas. Tech., 10, 1987–1997, https://doi.org/10.5194/amt-10-1987-2017.	5
Lochbihler, K; Lenderink, G; Siebesma, AP (2019) Response of Extreme Precipitating Cell Structures to Atmospheric Warming Journal of Geophysical Research. 124 6904-6918.	18
Schleiss, M.: How intermittency affects the rate at which rainfall extremes respond to changes in temperature, Earth Syst. Dynam., 9, 955–968, https://doi.org/10.5194/esd-9-955-2018, 2018.	14
Reinoso-Rondinel, R., Unal, C. & Russchenberg, H.W.J.: Adaptive and high-resolution estimation of specific differential phase for polarimetric X-band weather radars, 1 Mar 2018, In: Journal of Atmospheric and Oceanic Technology. 35, 3, p. 555-573 19 p.	7
Pfitzenmaier, L., Unal, C. M. H., Dufournet, Y., and Russchenberg, H. W. J.: Observing ice particle growth along fall streaks in mixed-phase clouds using spectral polarimetric radar data, Atmos. Chem. Phys., 18, 7843–7862, https://doi.org/10.5194/acp-18-7843-2018, 2018.	14
Chimot, J., Veefkind, J. P., Vlemmix, T., and Levelt, P. F.: Spatial distribution analysis of the OMI aerosol layer height: a pixel-by-pixel comparison to CALIOP observations, Atmos. Meas. Tech., 11, 2257–2277, https://doi.org/10.5194/amt-11-2257-2018, 2018.	13
Nanda, S., Graaf, M.D., Veefkind, J.P., Linden, M.T., Sneep, M., Haan, J.D. and Levelt, P.F., 2019. A neural network radiative transfer model approach applied to the Tropospheric Monitoring Instrument aerosol height algorithm. *Atmospheric Measurement Techniques*, 12(12), pp.6619-6634.	8

List of frequently used abbreviations

ACTRIS	The *Aerosol*, Clouds and Trace Gases Research Infrastructure
ADOP	Ambiguity Dilution of Precision
AES	Applied Earth Science
AGU	American Geophysical Union
AMAP	Arctic Monitoring and Assessment Programme
AR6	Sixth Assessment Report - IPCC
ATMO-NL	Atmospheric Observatory over the Netherlands
BAMS	Bulletin of the American Meteorological Society
BSc	Bachelor of Science
CAROLINE	Contextual and Autonomous processing of Satellite Radar Observations
CEAZA	Chilean Centre for Advanced Studies in Arid Zones
CEG	Faculty of Civil Engineering and Geosciences
CESAR	Cabauw Experimental Site for Atmospheric Research
CESM2	Community Earth Systems Model version 2
CISM	Certified Information Security Manager
COP26	26th United Nations Climate Change conference
CPT	Cone Penetration Testing
DAI-Lab	Delft Artificial Intelligence Laboratory
DALES	Dutch Atmospheric Large Eddy Simulation
DAPwell	Geothermal Research Well on Campus (Delft Aardwarmte Project)
DC	Department Council
DCH	Department Chair
DeepNL	Research Programme for the Deep Subsurace (NWO-funded programme)
DLR	German Aerospace Centre
dMT	Department Management Team
DNS	Direct numerical simulation
DRI	Delft Research-based Initiative
DTU	Technical University of Denmark
EAGE	European Association of Geoscientists and Engineers
EERA	European Energy Research Alliance
EGU	European Geosciences Union
EM	Electromagnetic
EnvEng	Environmental Engineering
ENW	Flood risk management expertise network (Expertise Netwerk Waterveiligheid)
EOR	Enhanced Oil Recovery
EPFL	École polytechnique fédérale de Lausanne
EPOS	European Plate Observing System
EPOS-NL	Dutch contribution to EPOS (NWO-funded Research Infrastructure)
ERC	European Research Council
ERC-AdG	ERC Advanced Grant
ESA	European Space agency
ESFRI	European Strategy Forum on Research Infrastructures
ETH	Public University in Zürich
EU	European Union
EUREC4A	Int. field experiment ElUcidating the RolE of Cloud-Circulation Coupling in ClimAte
EU-RFCS	Research Fund for Coal and Steel (EU funding programme)
EVRS	European Vertical Reference System

FAIR	Findable, Accessible, Interoperable and Reusable
FF-SAR	Fully Focused Synthetic Aperture Radar
FGS	Faculty Graduate School
FMCW	Frequency-Modulated Continuous Wave radar
FP7	Seventh Framework Programme (EU funding programme)
FSM	Forward Stratigraphic Modelling
FTE	Full-time equivalent
GEDI	Global Ecosystem Dynamics Investigation
GEOLAB	Geotechnical Research Facilities (H2020 project)
GFZ	German Research Centre for Geosciences
GIA	Glacial Isostatic Adjustments
GLONASS	Global Navigation Satellite System (Russian)
GNSS	Global Navigation Satellite Systems
GPU	Graphic Processing Unit
GRACE	Gravity Recovery and Climate Experiment Mission
GRASP	GPU resident atmospheric simulation program
GrIS	Greenland Ice Sheet
GRS	Department of Geoscience and Remote Sensing
GS	Graduate School
GSE	Department of Geoscience and Engineering
GTI	Large Technology Institute (Groot Technologisch Instituut)
H2020	Horizon 2020 (EU funding programme)
HR	Human Resources
HSE	Health-Safety-Environment
HT-ATES	High-temperature Aquifer thermal energy storage
ICESat	Ice, Cloud, and land Elevation Satellite
ICOS	Integrated Carbon Observation System
IDEA League	Strategic alliance between TU Delft, ETH Zürich, RWTH Aachen, Chalmers University, Politecnico di Milano
IDRA	IRCTR Drizzle Radar
IELTS	International English Language Testing System
IFS	Integrated Forecast System (ECMWF)
IMAU	Institute for Marine and Atmospheric Research Utrecht
IMBIE	Ice sheet Mass Balance Inter-comparison Exercise
InSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
ISMASS	Expert Group on Ice Sheet Mass Balance and Sea Level
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
ITN	Innovative Training Network (EU funding programme)
IUGG	International Union of Geodesy and Geophysics
I&IC	Innovation and Impact Centre of TU Delft
JIP	Joint Industry Project
KEM	Kennisprogramma Effecten Mijnbouw (NWO funding programme)
KNMI	Royal Netherlands Meteorological Institute
KP	Key Publication
LAMBDA	Least-squares Ambiguity Decorrelation Adjustment
LDE	TU Delft, Leiden University, Erasmus University Rotterdam partnership
LES	Large Eddy Simulation
MDB	Minimal Detectable Bias
MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Course
MSc	Master of Science
MT	Faculty Management Team
MUFFIN	Multiple scale Urban Flood Forecasting
NAP	Normaal Amsterdams Peil (Amsterdam Ordnance Datum)

NCAR	National Center for Atmospheric Research - US
NIOZ	Royal Netherlands Institute for Sea Research
NLR	Netherlands Aerospace Centre
NSO	National Space Office (Dutch)
NWA	Dutch Research Agenda (NWO funding programme)
NWO	Netherlands Organisation for Scientific Research
OA	Open Access
OMI	Ozone Monitoring Instrument
PhD	Doctor of Philosophy
PI	Principal Investigator
PMOD	Physikalisch-Meteorologisches Observatorium /World Radiation Centre, Davos
PNAS	Proceedings of the National Academy of Sciences
PNTA	Positioning, Navigation, Timing and Atmospheric Sensing
PPP-RTK	Precise Point Positioning – Real Time Kinematics
RDSD	Rain Drop Size Distribution
RIPS	Radio Interferometric Position System
RoFI	Rhine region of Freshwater Influence
RVO	Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland)
R&D	Research and Development
R&O	Performance and Development (Resultaat en Ontwikkeling)
SAR	Synthetic Aperture Radar
SEG	Society of Exploration Geophysicists
SEP	Strategy Evaluation Protocol
SH	Section Head
SKIM	One of the 2 ESA satellite missions pre-selected to become Earth Explorer 9.
SMB	Surface Mass Balance
SPE	Society of Petroleum Engineers
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate
SWOT	Strengths-Weaknesses-Opportunities-Threats
TARA	Transportable Atmospheric RAdar
TNO	Netherlands Organisation for Applied Scientific Research
TROMPOMI	TROPOspheric Monitoring Instrument
TT	Tenure-Track
TTW	Open Technology Programme (NWO funding programme)
TUD	Delft University of Technology
UU	Utrecht University
Veni-Vidi-Vici	Personal Grant System of NWO for three career stages
VLBI	Very Long Baseline Interferometry
VSNU	Association of Universities in The Netherlands
WP	Workpackage
4TU	TU Delft, TU Eindhoven, University of Twente, Wageningen University alliance

Colophon

Published by
Department of Geoscience and Engineering
(www.GSE.citg.tudelft.nl)
Department of Geoscience and Remote Sensing
(www.GRS.citg.tudelft.nl)

Faculty of Civil Engineering and Geosciences
Delft University of Technology
Stevinweg 1
2628 CN Delft
The Netherlands

Coordinators
GSE: Timo Heimovaara (Department chair),
Kees Wapenaar, Regina Hoffmann
GRS: Herman Russchenberg (Department chair),
Susan Steele-Dunne, Josine Kelling

Text
Contributions from all GSE and GRS staff

Data collection, preparation and visualization
Els Swaen (CiTG), Roderik Lindenbergh (GRS),
Wout Broere (GSE)

Photos and illustrations
Employees and PhD candidates of the departments and
Stories of Science (Communication department CiTG)

Layout
Haagsblauw
(www.haagsblauw.nl)