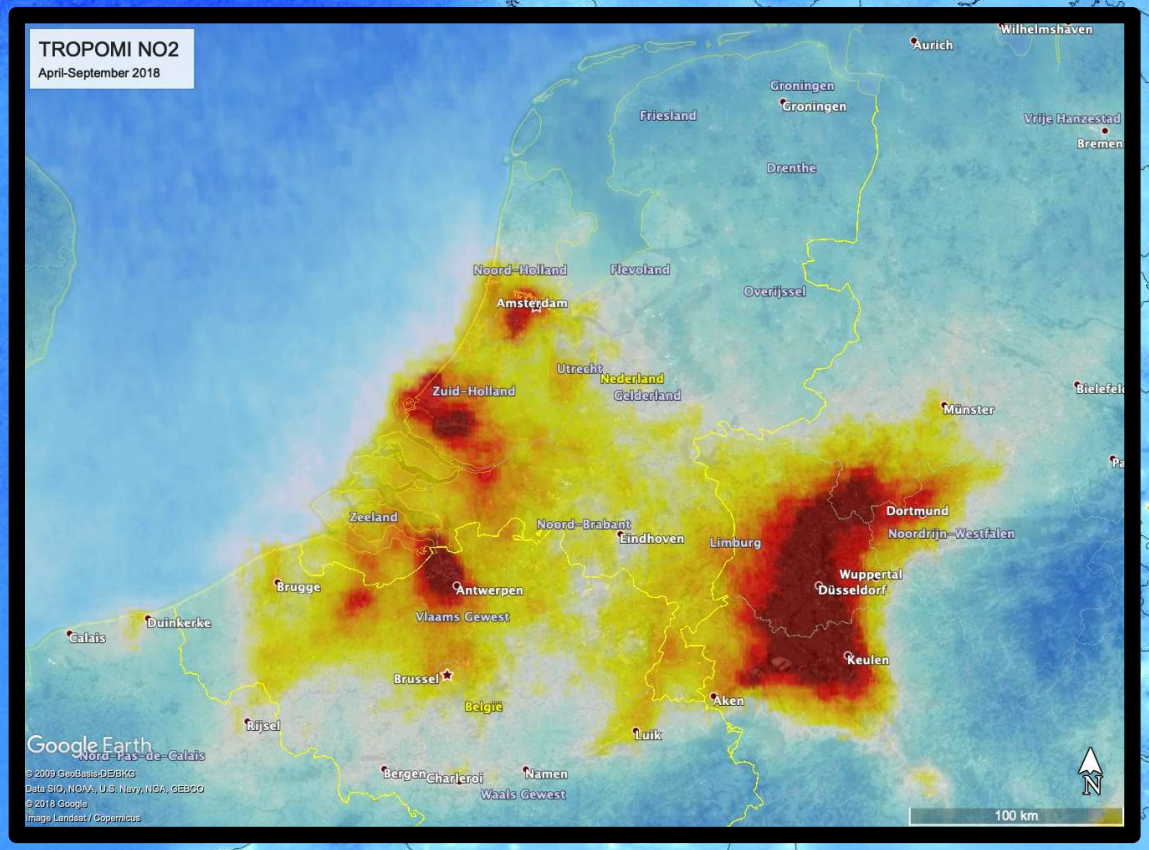



# Monitoring emissions from space from space: indicator of human activity.


**Prof. dr. Pieternel Levelt**

**KNMI & University of Technology Delft**

**levelt@knmi.nl; p.f.levelt@tudelft.nl**


**Masterclass IenW**

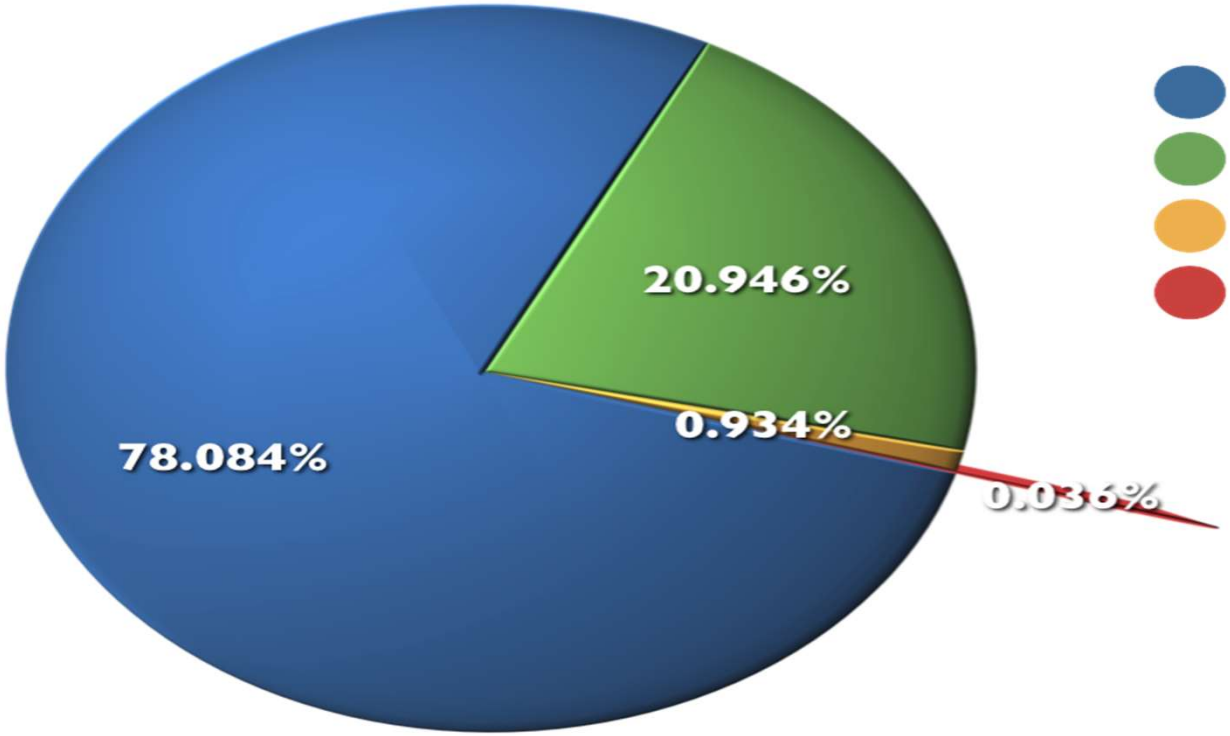
**3 December 2019**

**TROPOMI $NO_2$ Tropospheric Column over Europe**
**April-September 2018**

# The “Antropocene” Nobelprice winner Paul Crutzen


- Ozone Layer
- Air Quality
- Climate


# Atmospheric composition: gases




Nitrogen
Oxygen
Argon
Trace gases:

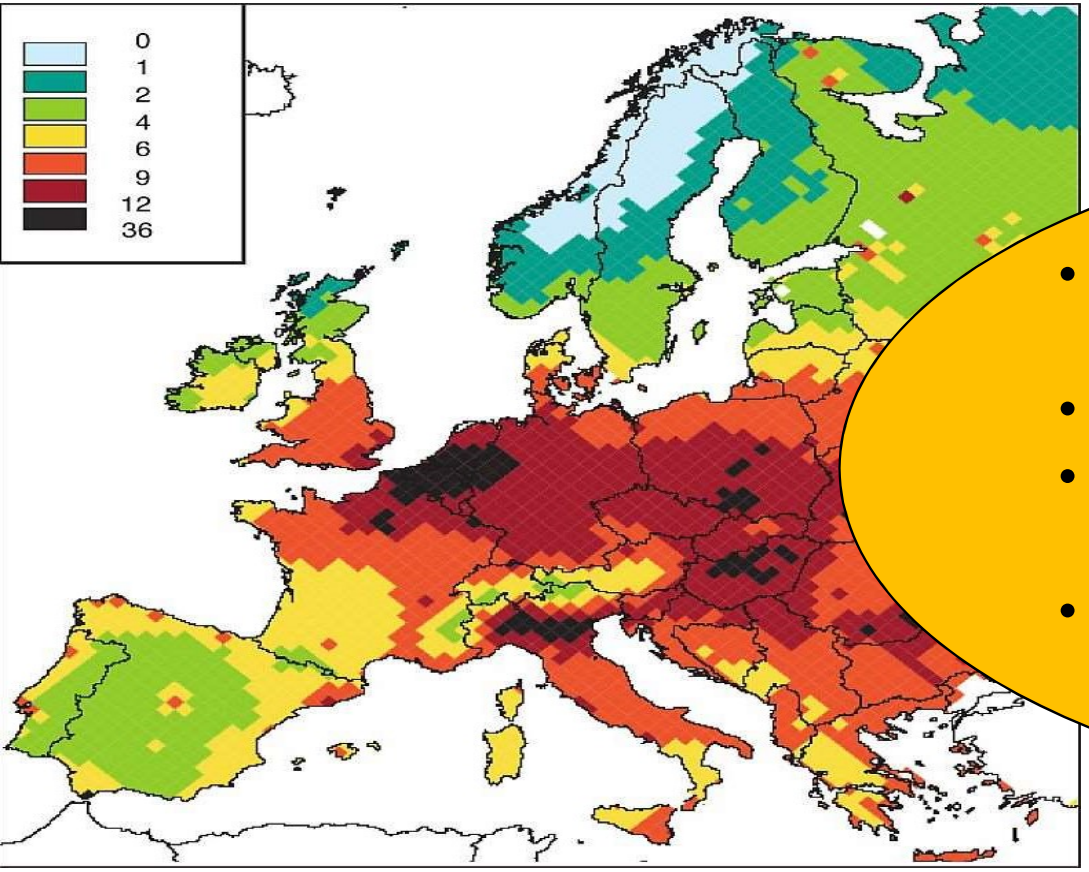
- Carbon dioxide ($CO_2$)
- **Methane ($CH_4$)**
- Ozone ($O_3$)
- **Nitrogen dioxide ($NO_2$)**
- Sulfur dioxide ($SO_2$)
-…….

# Air Pollution

Chinese city on a clean and polluted day

*Courtesy David G. Streets, Atm. Env. 41 (2007) 480-492*

# Air Quality and its effect on human health



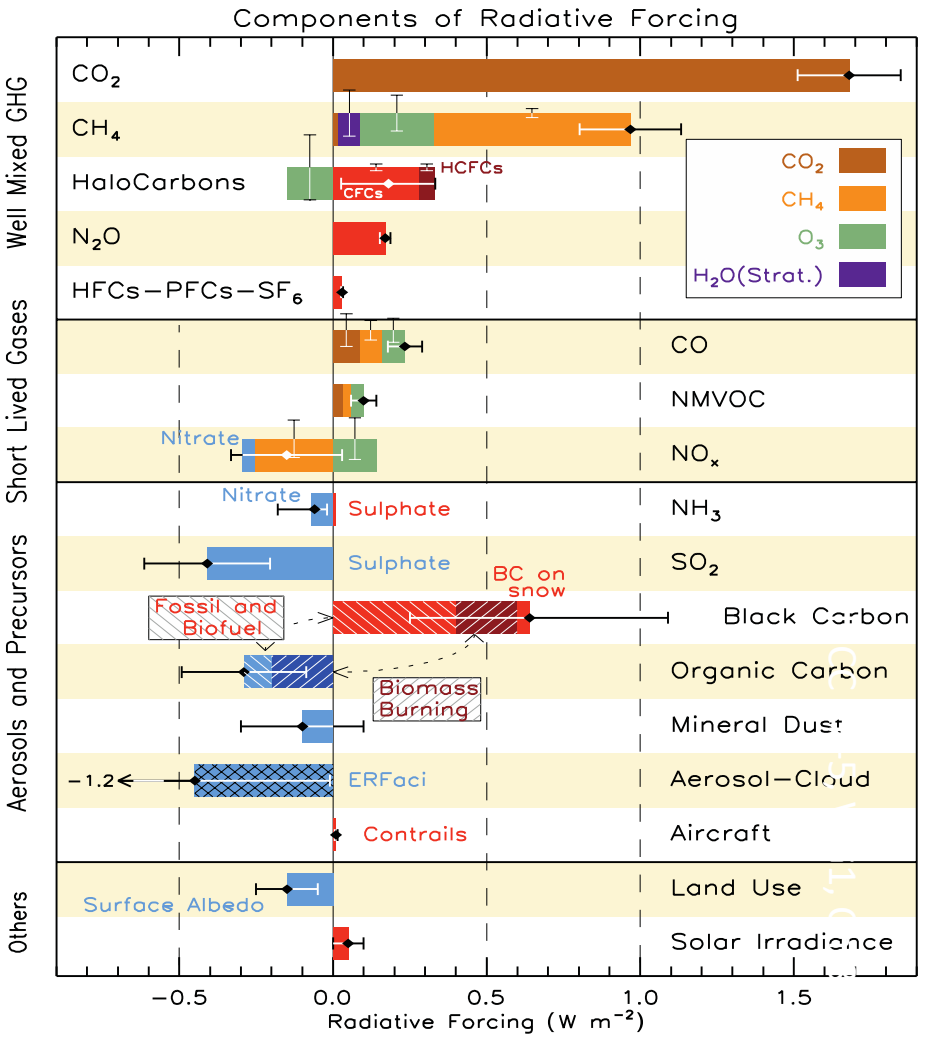

- Europe is [illegible] affected regions

- 4.2 million death a year due to PM2.5 outdoor pollution (WHO 2017)
- 4000 death a year in The Netherlands
- Children are more vulnerable to air pollution
- NO2 is more toxic than previously thought

*Loss in statistical life expectancy in months*
*EU Programme CAFE, (CAFE Scenario Analysis Report Nr. 2., Amann et al., 2004)*

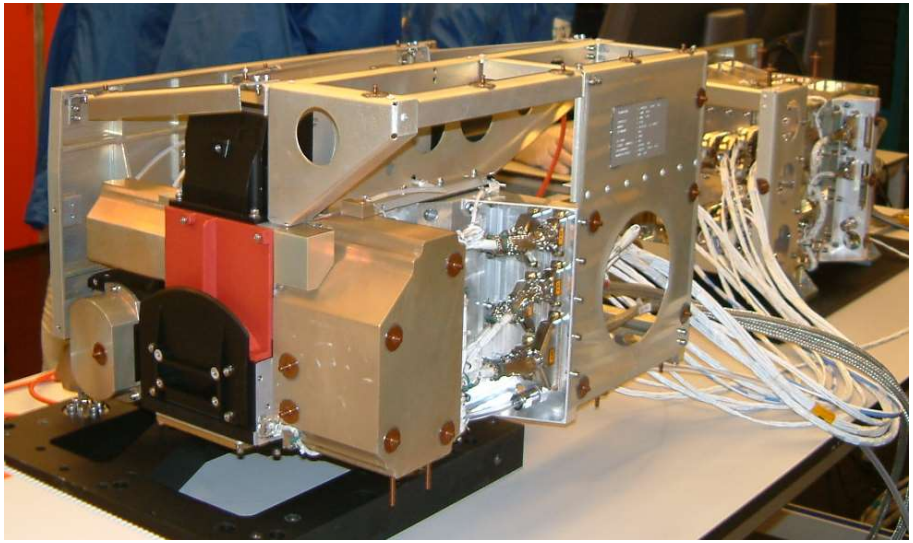
# Climate – Emission based view

- Climate change is driven by changes in the atmospheric composition
- COP 21 addresses the emission control of long-lived greenhouse gases
- For the sort and medium term, also the short lived components - air pollutants - are important



# Netherlands Leading role in OMI & TROPOMI

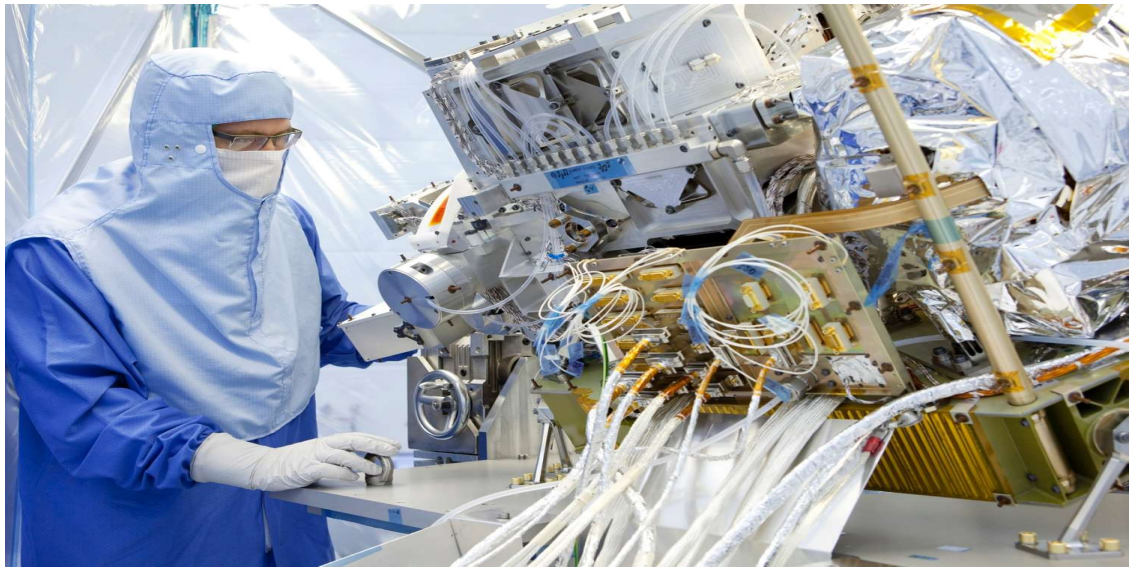
Royal Netherlands Meteorological Institute
*Ministry of Infrastructure and the Environment*



**OMI launched at July 15, 2004 at NASA's Eos-Aura satellite**

**13 x 24 km2 & daily global coverage**

**OMI received the NASA/USGS Pecora Award 2018!**



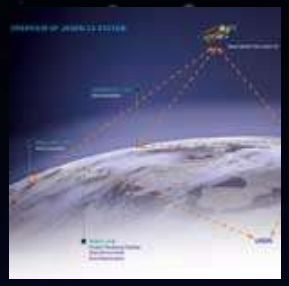
**TROPOMI launched at October 13, 2017 at ESA's sentinel-5 precursor satellite**

**3,5 x 5 km2 & daily global coverage**

***KNMI: PI institute for OMI and TROPOMI***

# EU Copernicus Sentinels

Sentinel 5



Sentinel 6

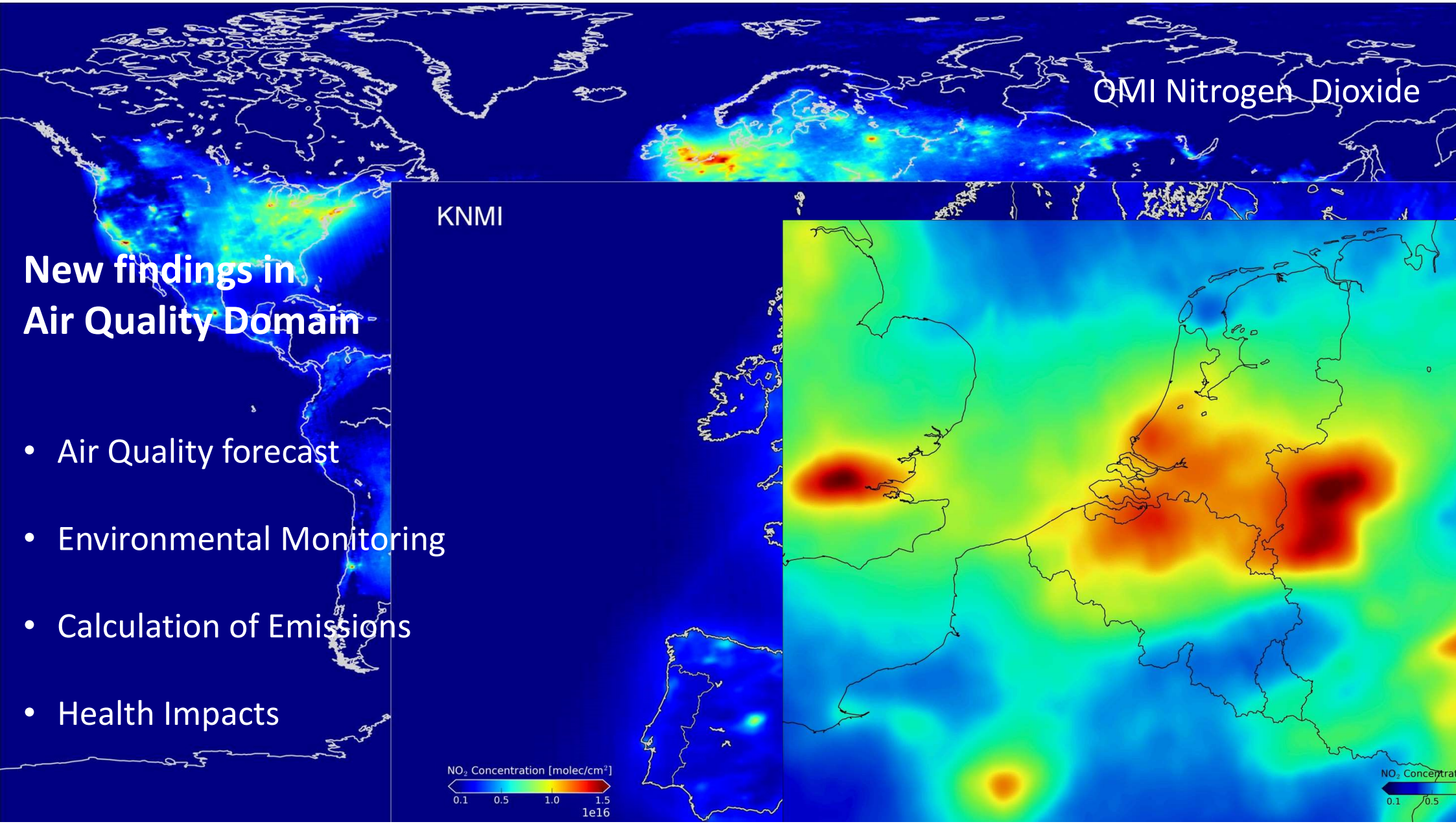
Sentinel 1

Sentinel 2

Sentinel 4

Sentinel 5P

Sentinel 3




## New findings in Air Quality Domain

- Air Quality forecast
- Environmental Monitoring
- Calculation of Emissions
- Health Impacts

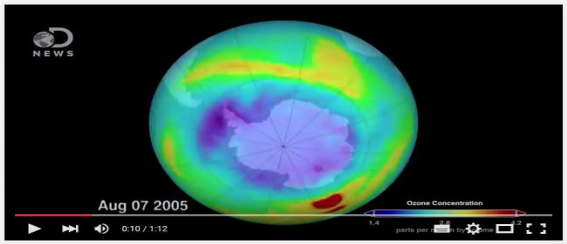
# President Barack Obama about OMI $NO_2$ and emission control

## Science Channel, April 12, 2016

Royal Netherlands Meteorological Institute
*Ministry of Infrastructure and the Environment*



President Obama Explains How Pollution Affects Our Planet

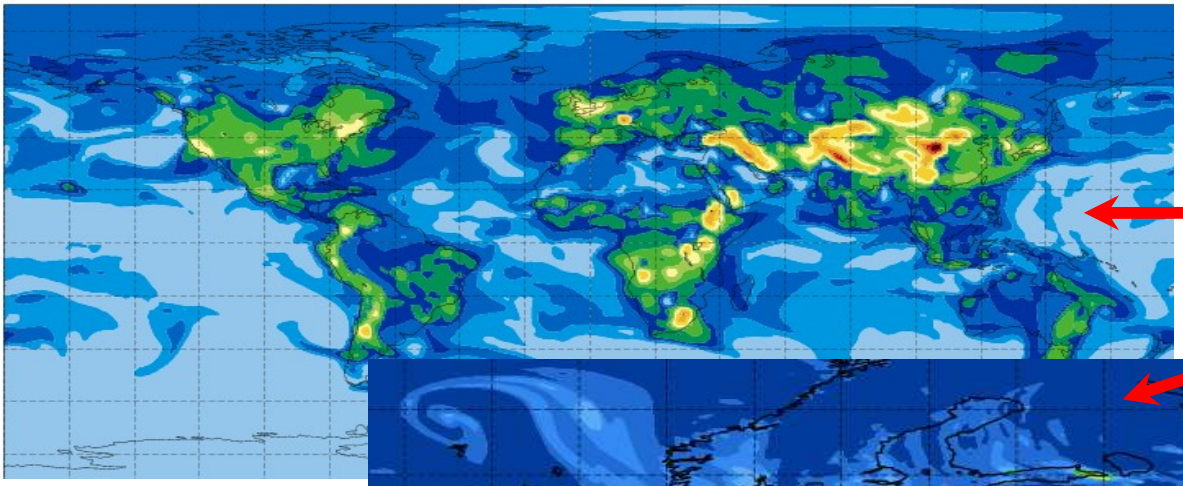



President Obama Explains How Pollution Affects Our

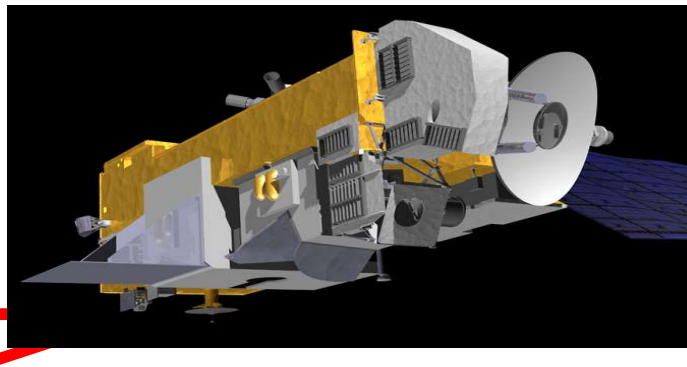

President Obama Explains How Pollution Affects Our

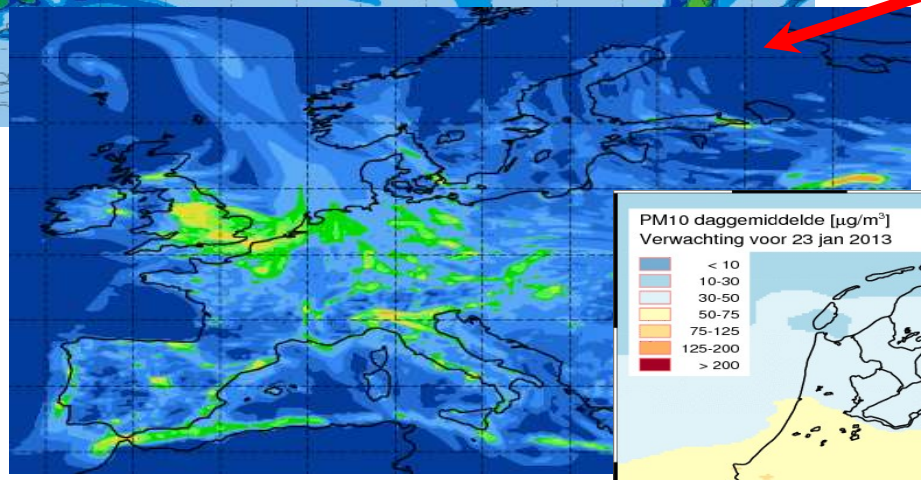

President Obama Explains How Pollution Affects Our

# EU Copernicus Atmosphere: Air Quality product chain

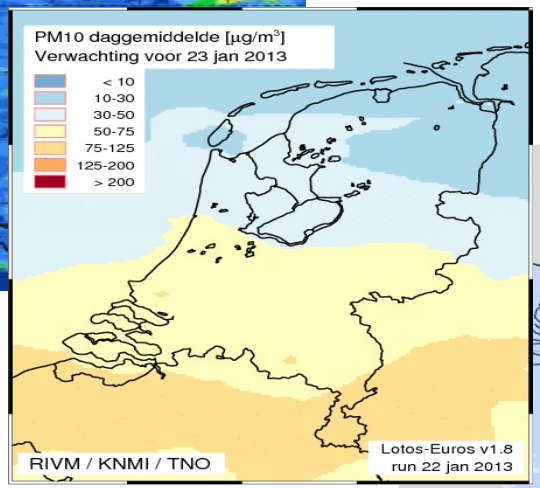


OMI NRT contributions

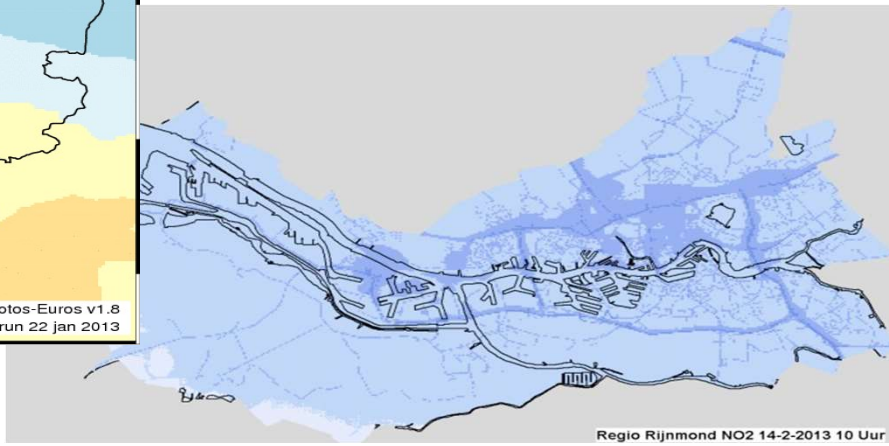




National forecasts:
Nesting in MACC regional



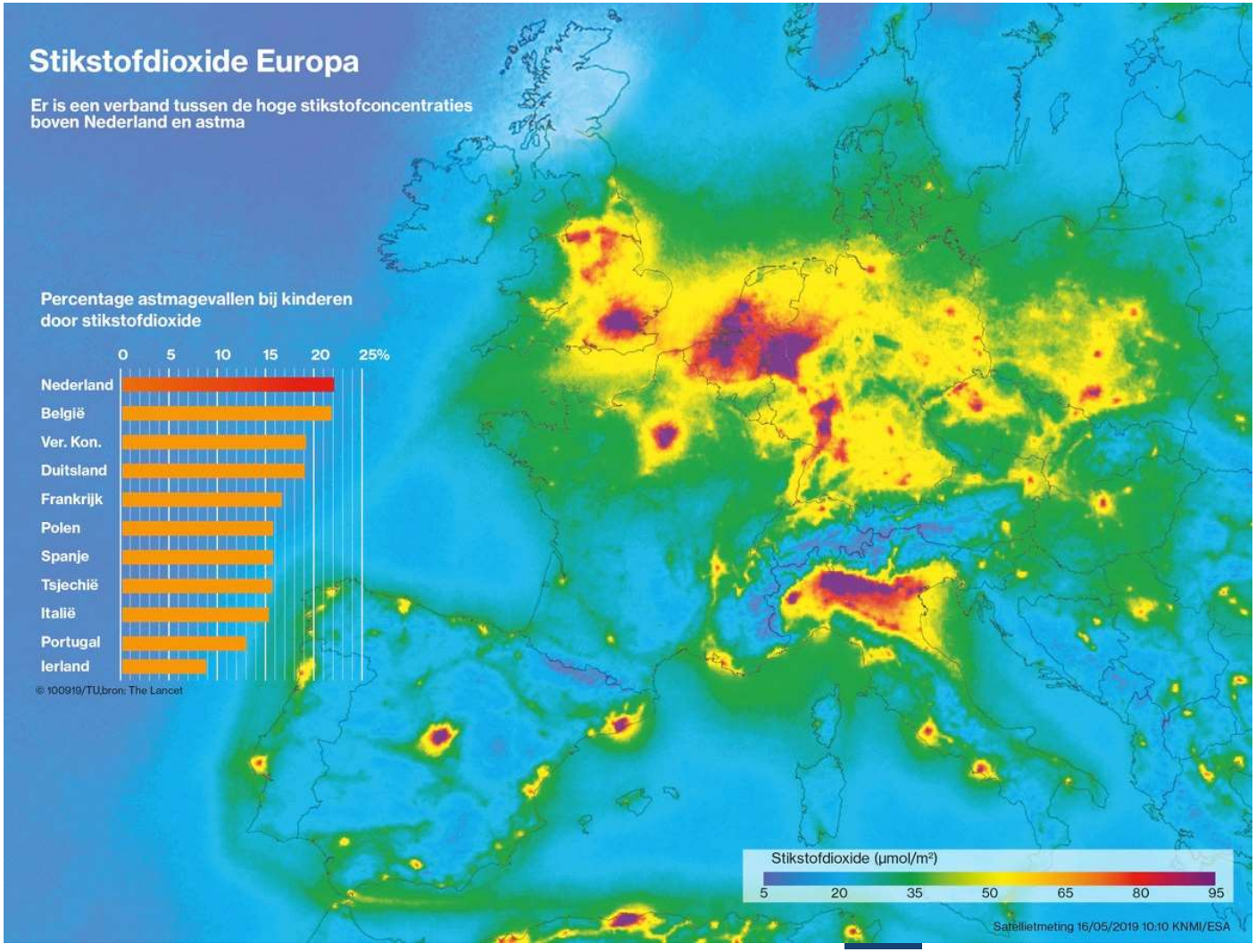

Couple to
city-scale models




Use of
CAMS-global analyses as
boundary conditions for
CAMS-Europe

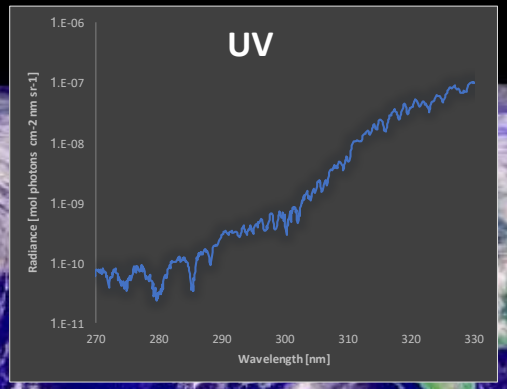
# Air quality and the impact on health (based on The Lancet)

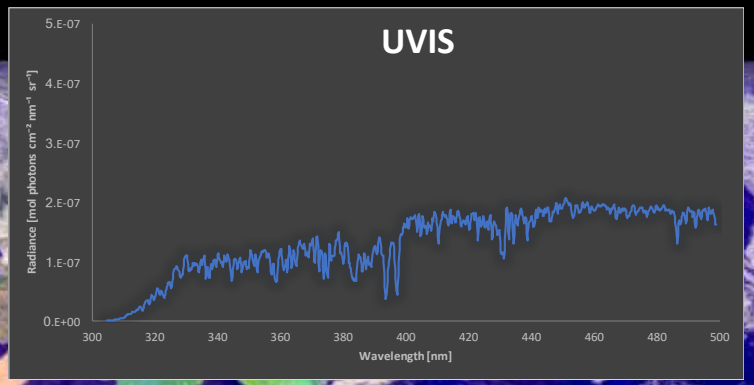
Royal Netherlands Meteorological Institute
*Ministry of Infrastructure and the Environment*



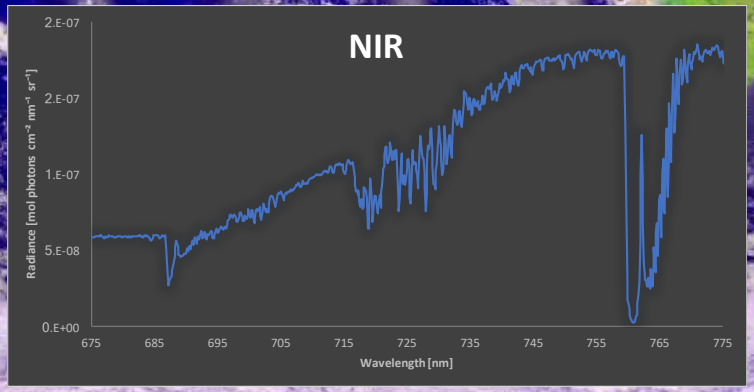

Algemeen Dagblad,
10 September 2019

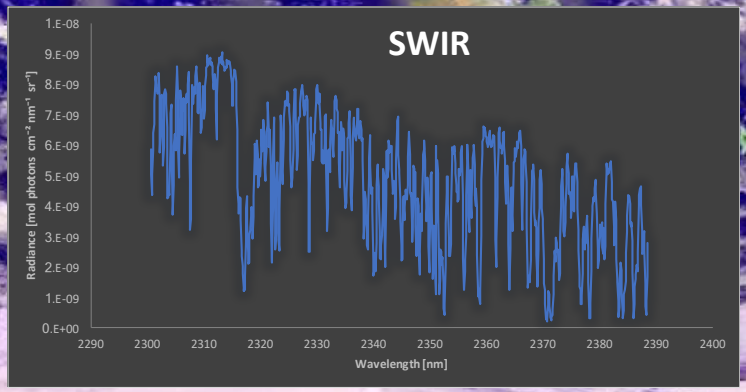

sentinel-5p
→ GLOBAL AIR MONITORING FOR COPERNICUS
TROPOMI Launch Successful!
See further updates at
www.esa.int/sentinel5p
#sentinel5p
sentinel-5p
→ GLOBAL AIR MONITORING FOR COPERNICUS
October 13, 2017




- 1 scanline per second
- 440 spectra per scanline
- 3000 scanlines per orbit
- 15 orbits per day
- 20 million groundpixels per day
- 225 Gbyte raw data per day
- 1 Tbyte L1b data per day

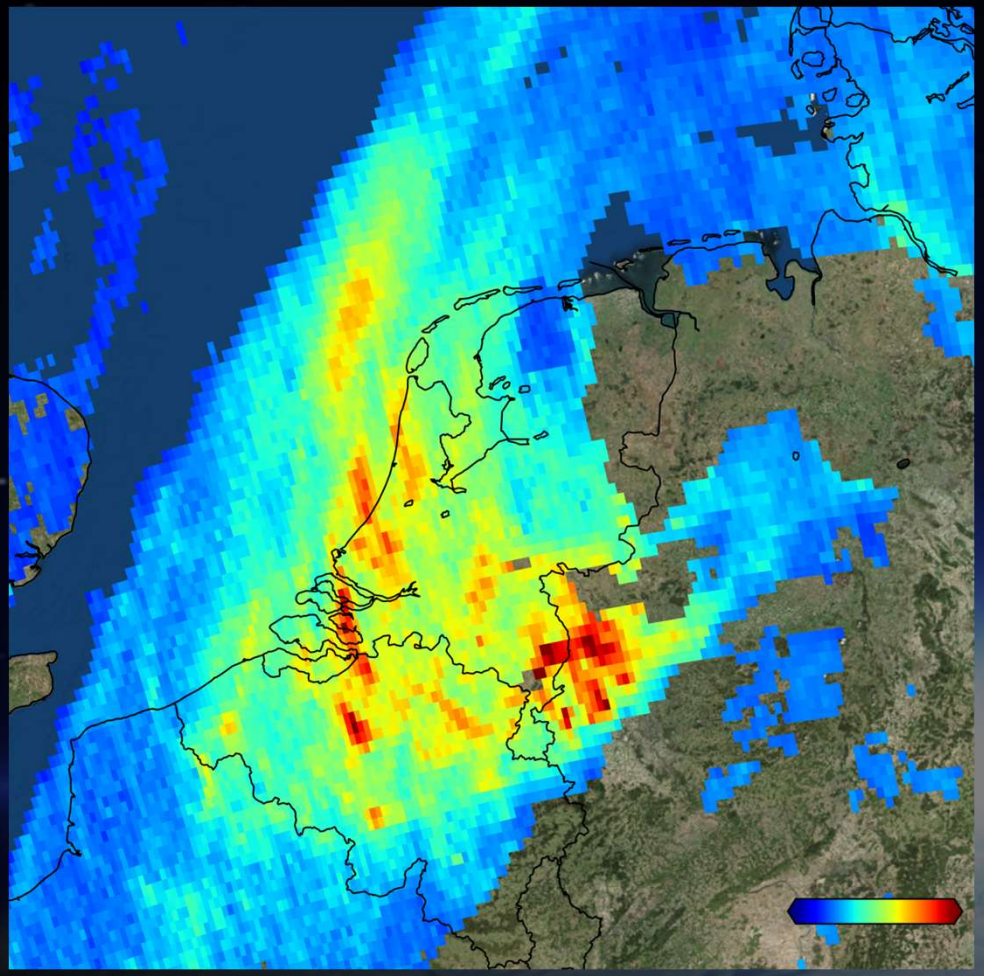


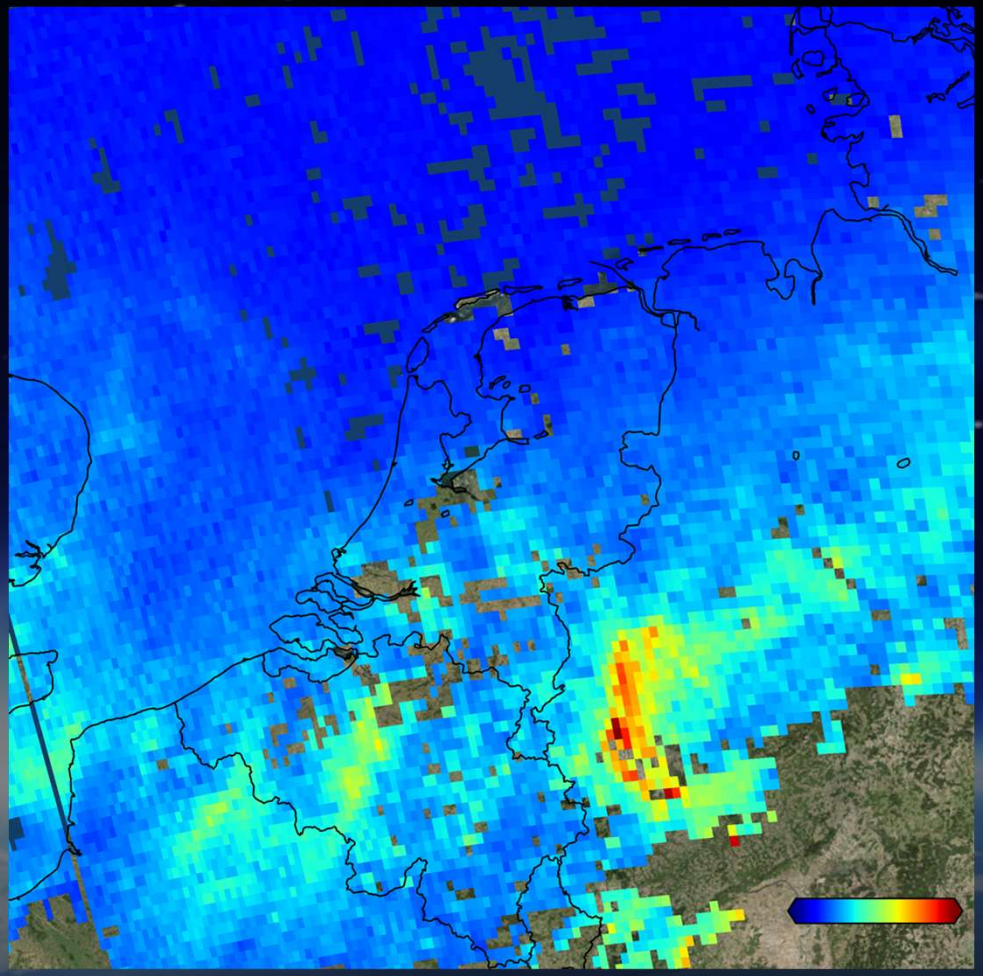
S5p/TROPOMI KNMI/NSO/ESA

TROPOMI

## $NO_2$ 07-11-2017

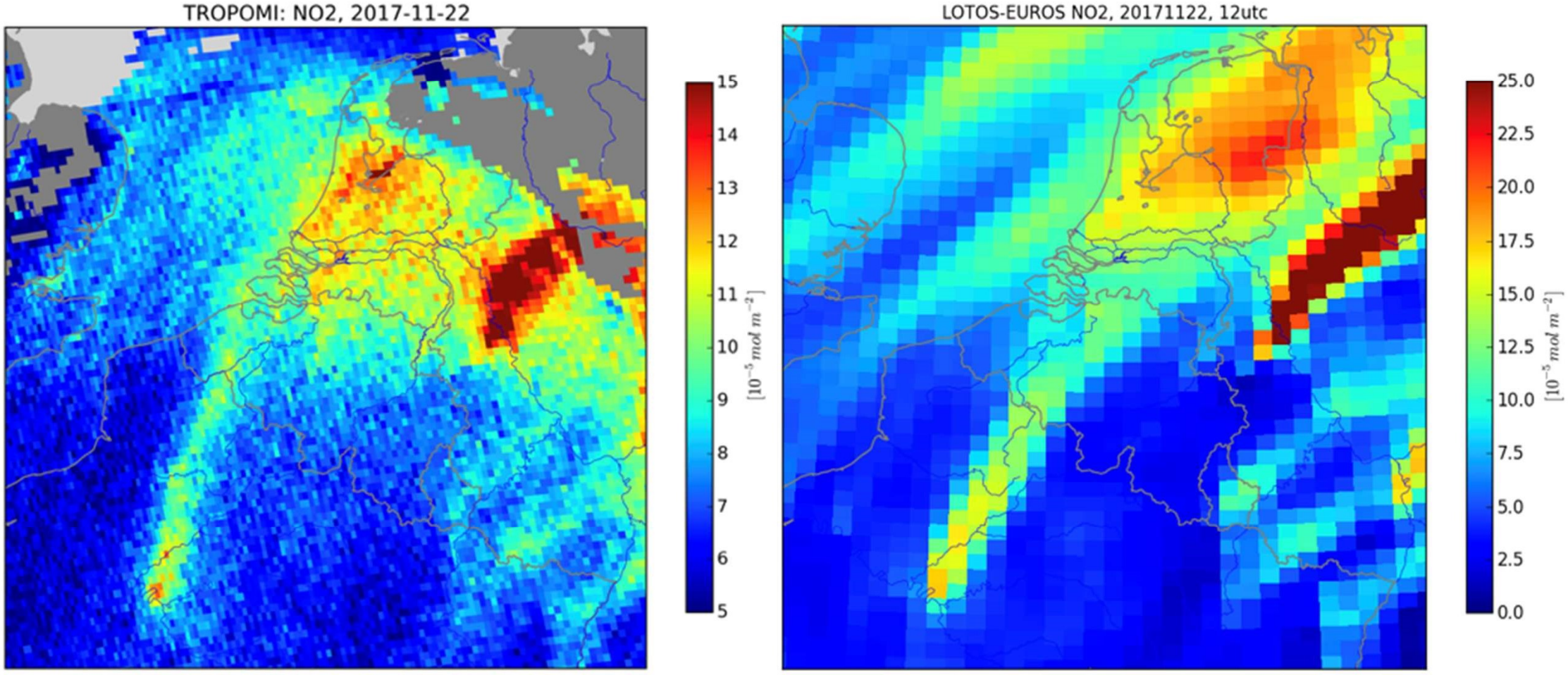


## $NO_2$ 17-11-2017



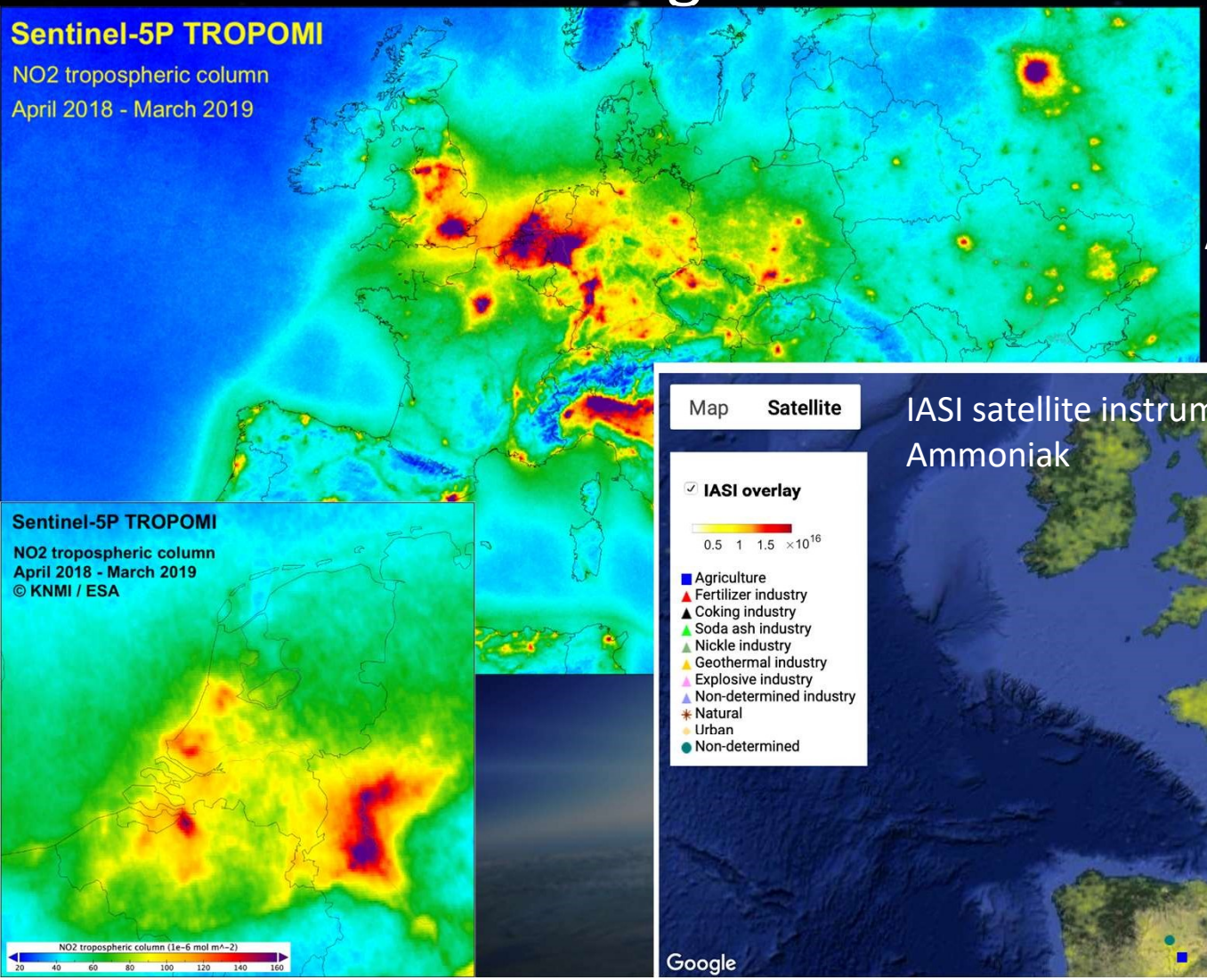
## TROPOMI

## EUROS-LOTOS MODEL



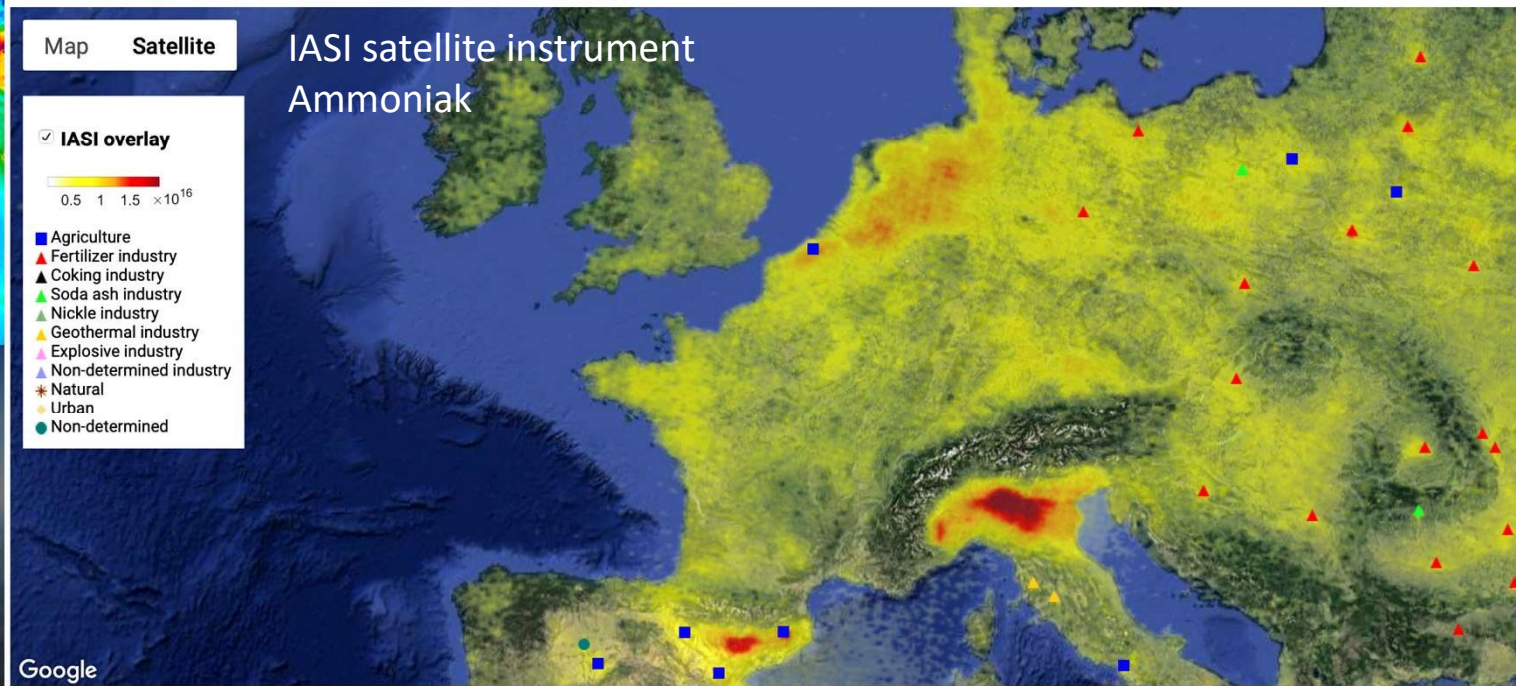

Henk Eskes, KNMI

# Nitrogen crises The Netherlands

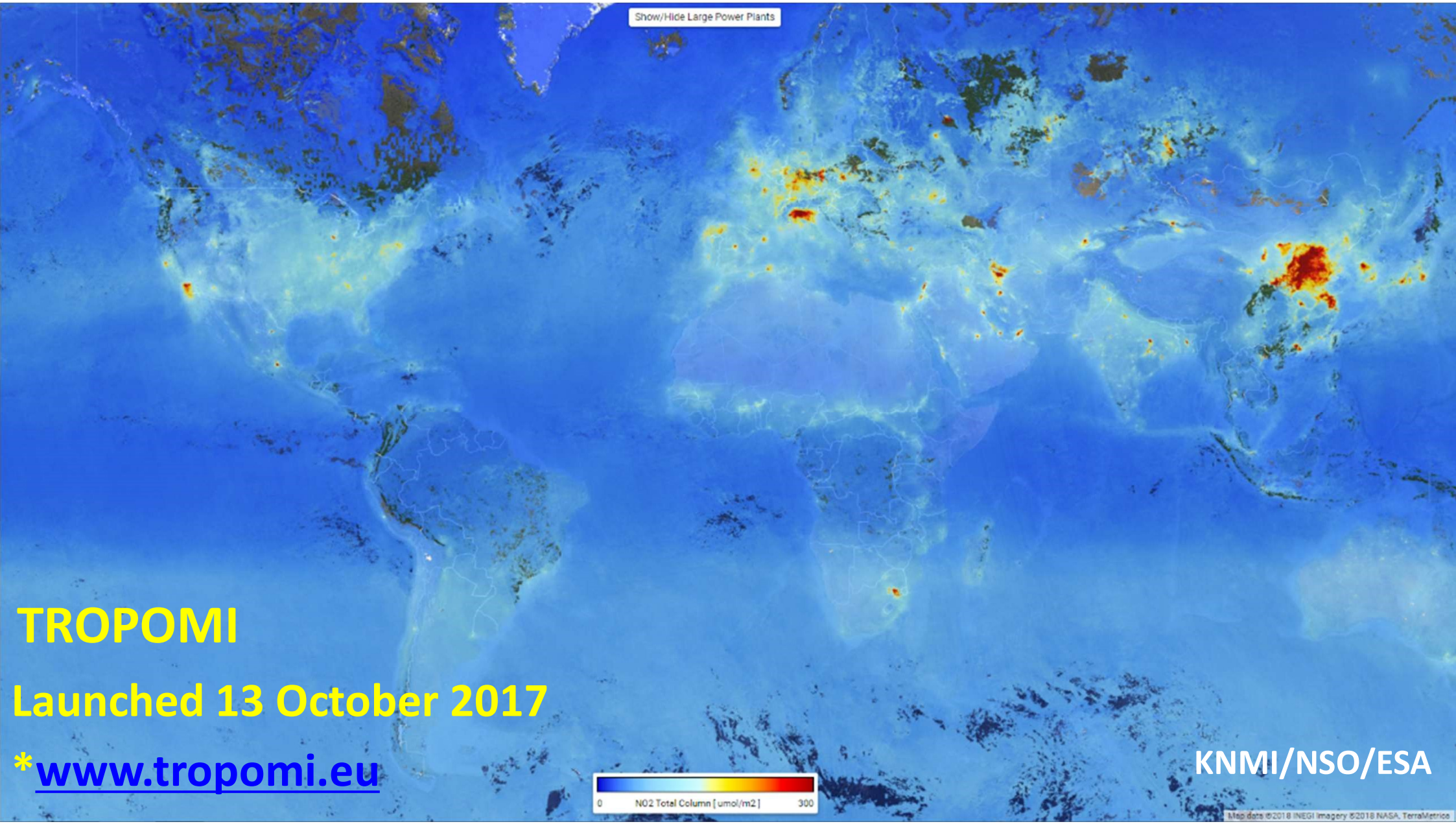


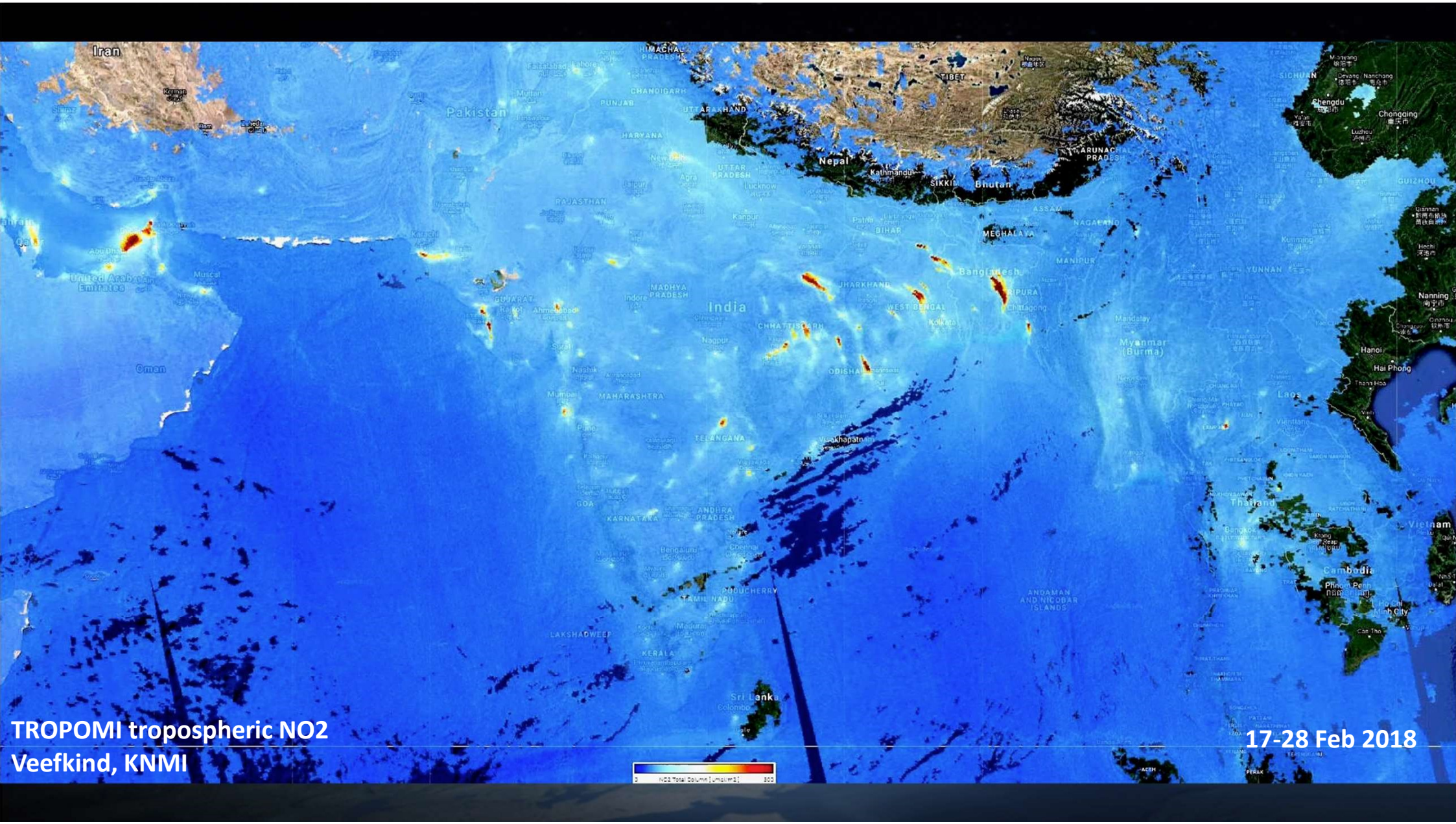

Nitrogen : ~ 80 % of the dry atmosphere
Nitrogen Dioxide: traffic, industry and powerplants
Ammonia: amongst others Agriculture



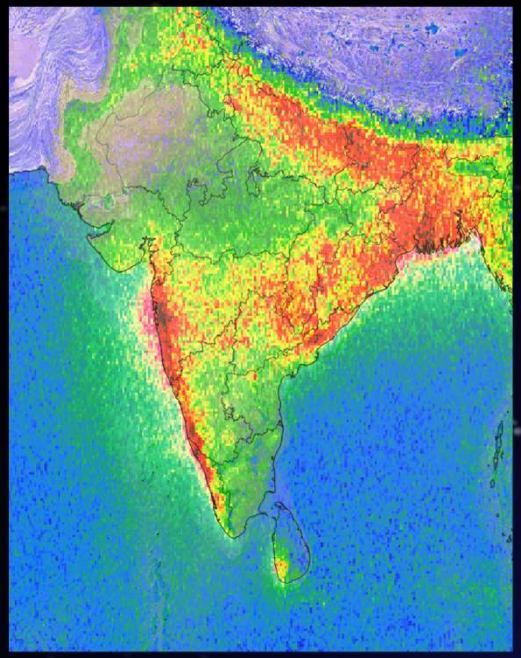




IASI satellite instrument
Ammoniak


Show/Hide Large Power Plants
TROPOMI
Launched 13 October 2017
*www.tropomi.eu
KNMI/NSO/ESA
0
NO2 Total Column [ umol/m2 ]
300
Map data ©2018 INEGI Imagery ©2018 NASA, TerraMetrics

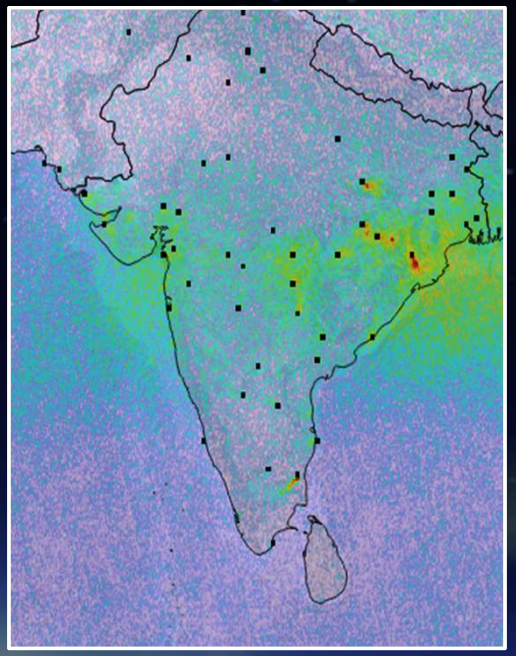

TROPOMI tropospheric NO2
Veefkind, KNMI
17-28 Feb 2018

# India

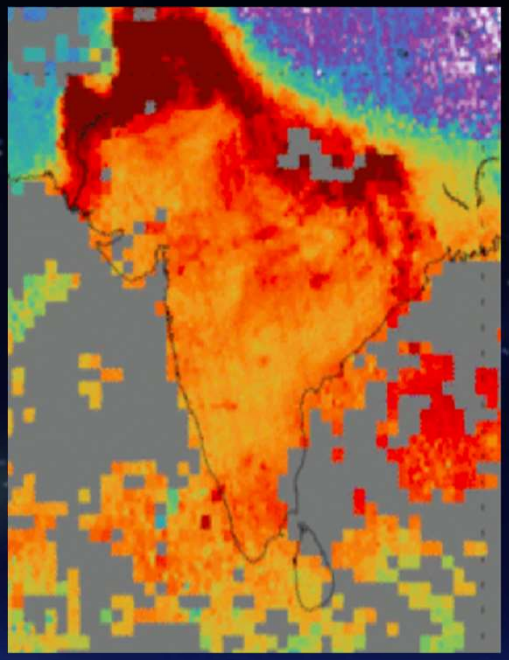


HCHO


$NO_2$



$SO_2$

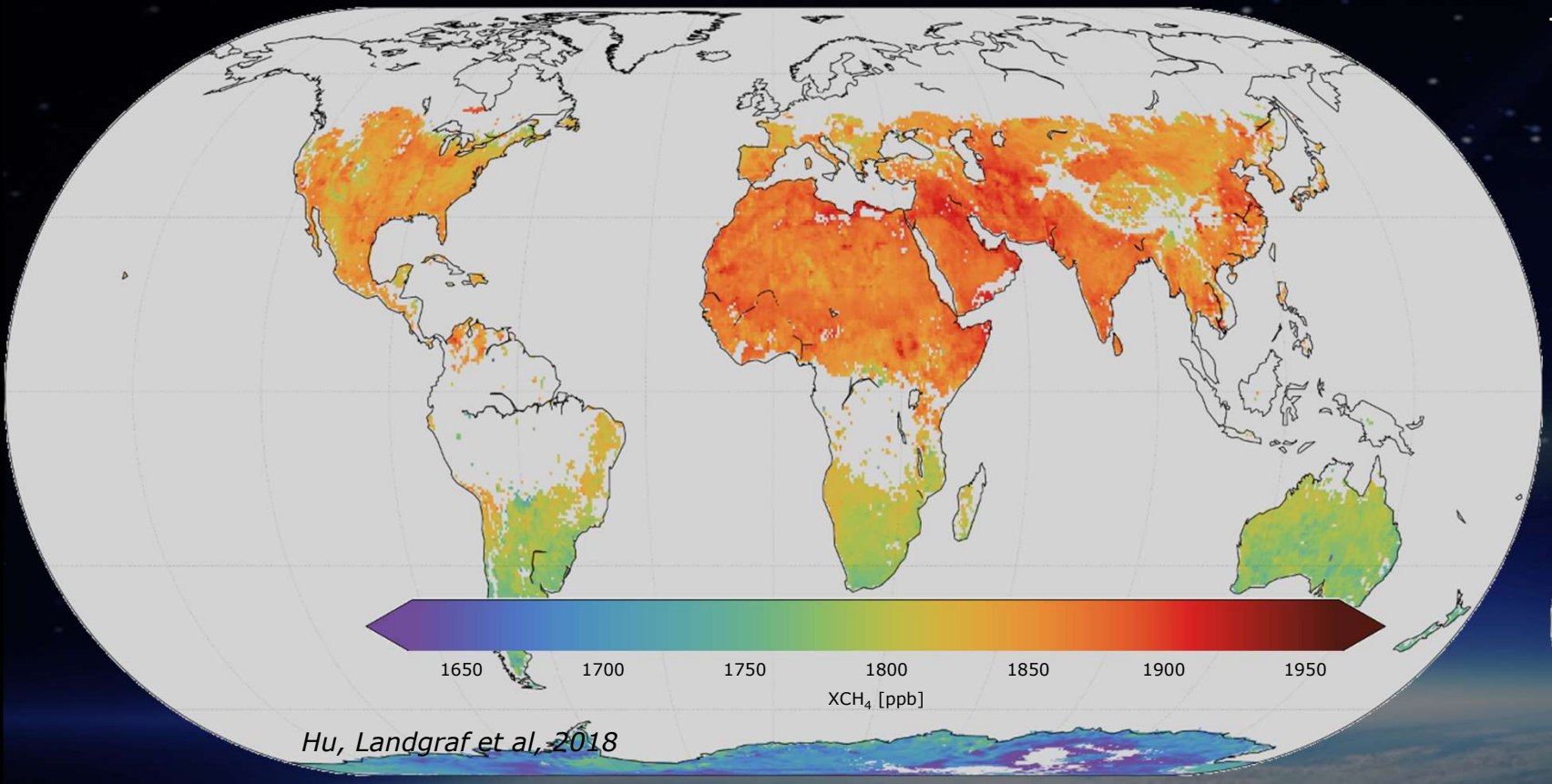


CO

Figure credits: Pepijn Veefkind, KNMI

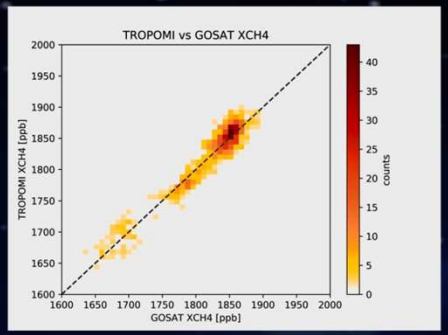
# Methane XCH4

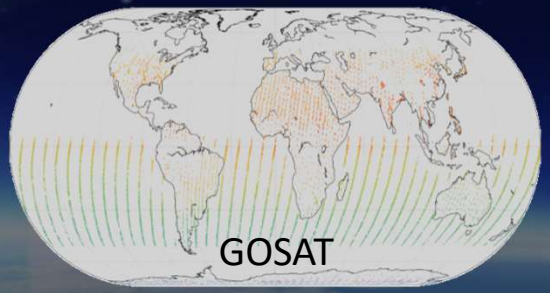
12 Nov – 30 dec 2017




*Hu, Landgraf et al, 2018*

TROPOMI-GOSAT comparison



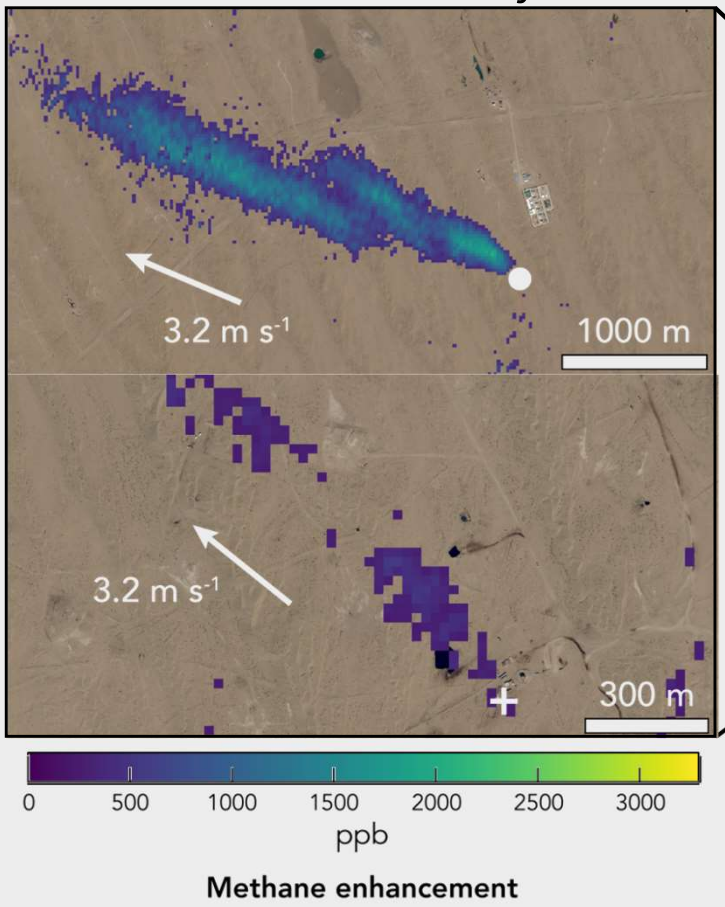

TROPOMI **1000 x** more measurements than GOSAT!!

Credits: SRON

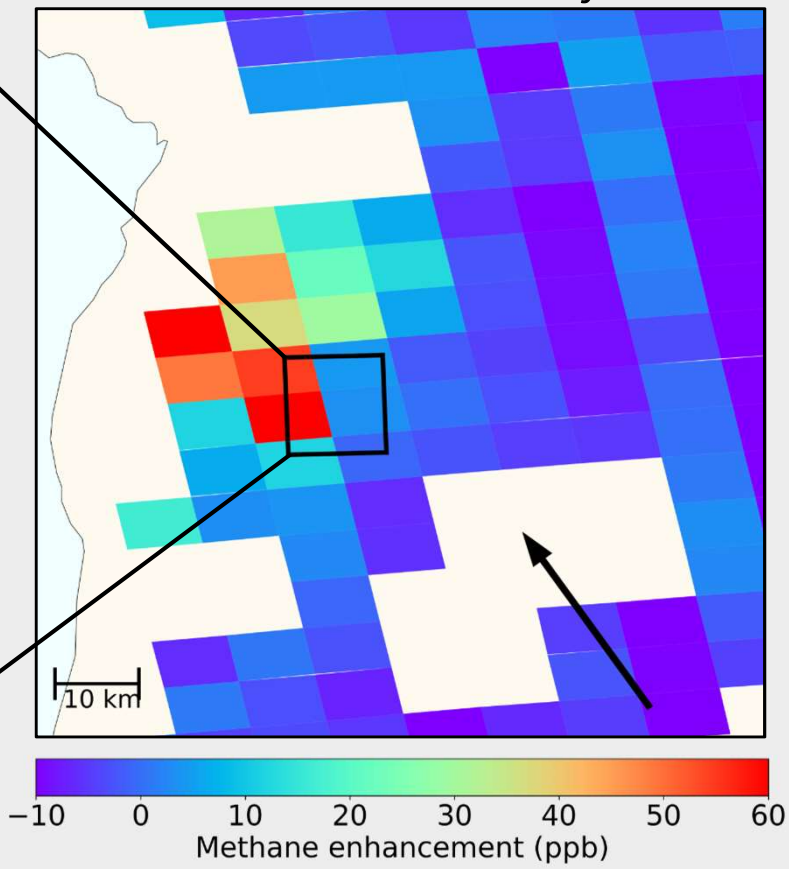
# Satellite discovery of large gas leaks

***NOS News on television at 20:00, Friday November 22, 2019***

GHGSat, 27 January 2019




TROPOMI, 27 January 2019

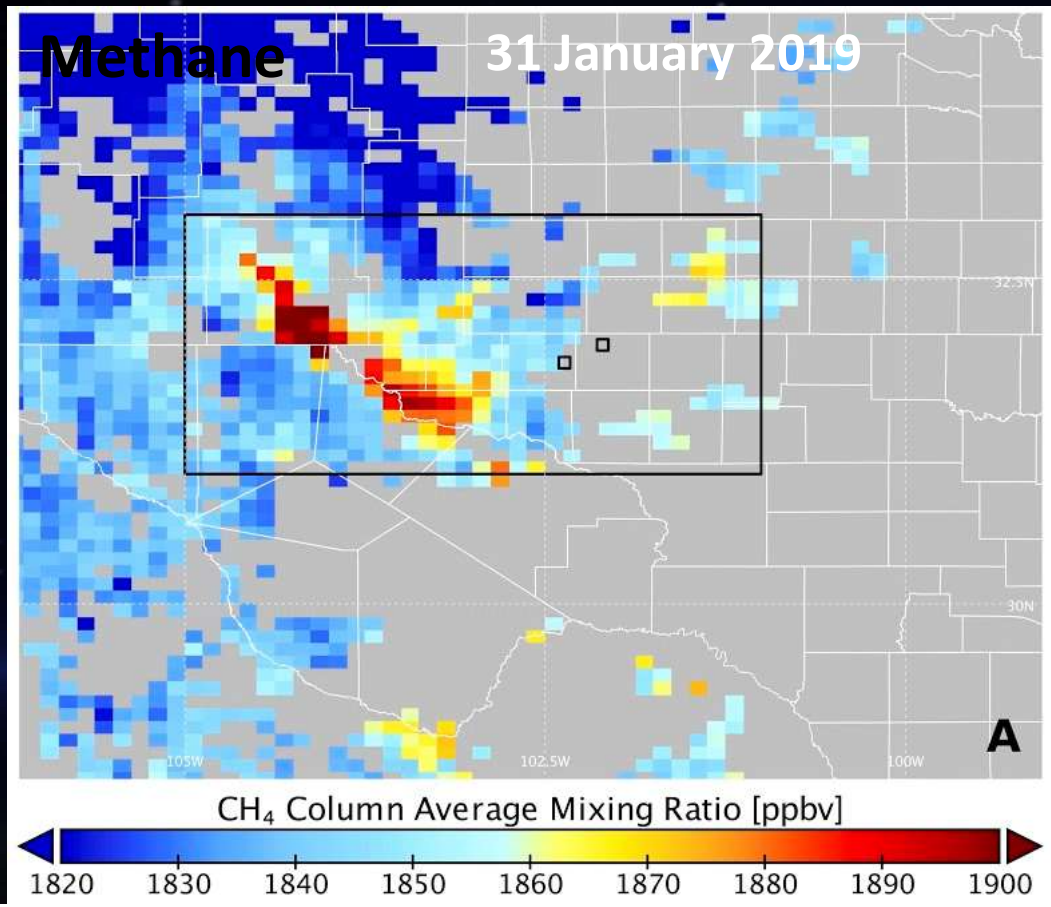


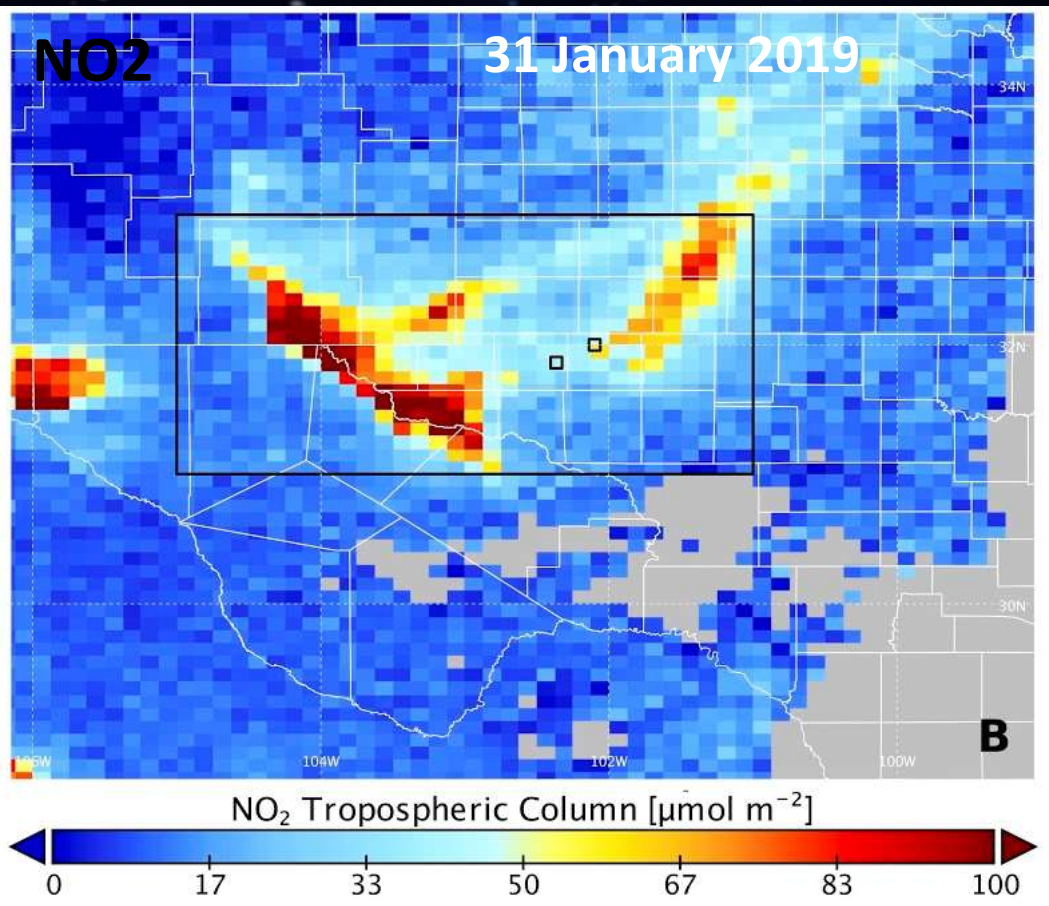

Pitch by J.D. Maasakkers this afternoon (Climate/Air Quality Workshop)

Paper out now in GRL: Varon et al. (2019)

# Oil and Gas : TROPOMI NO2/Methane in the Permian basin

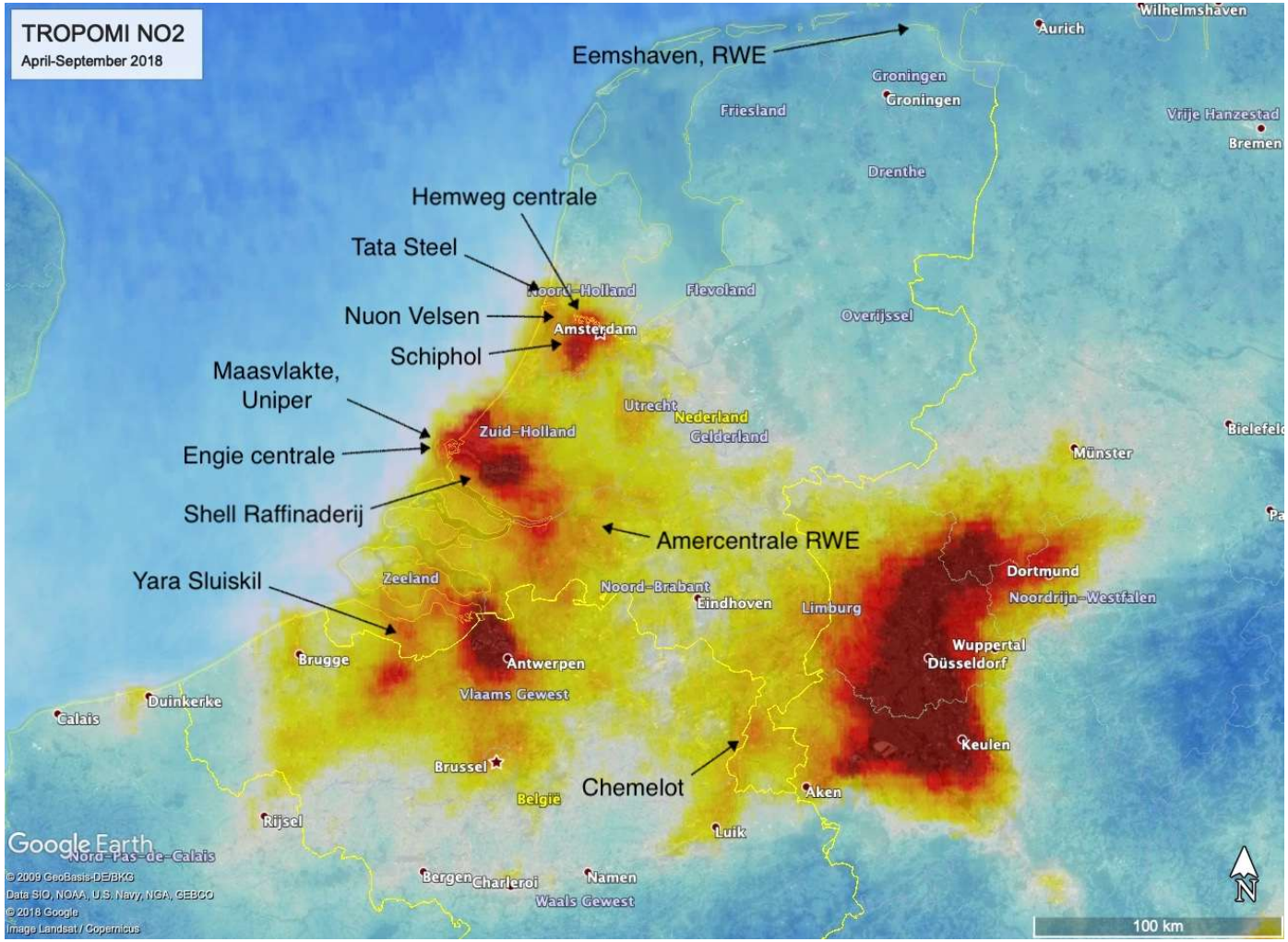
Joost de Gouw, Pieternel Levelt, Pepijn Veefkind et al., submitted to Scientific Reports



# Relation NO2 and CO2 – anthropogenic contribution
# 10 largest CO2 emitters in The Netherlands

Royal Netherlands Meteorological Institute
*Ministry of Infrastructure and the Environment*

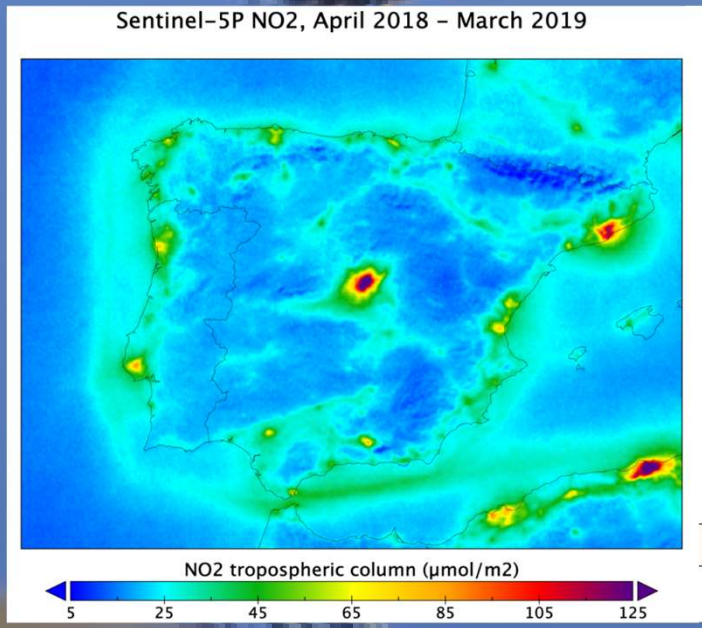



Henk Eskes, KNMI

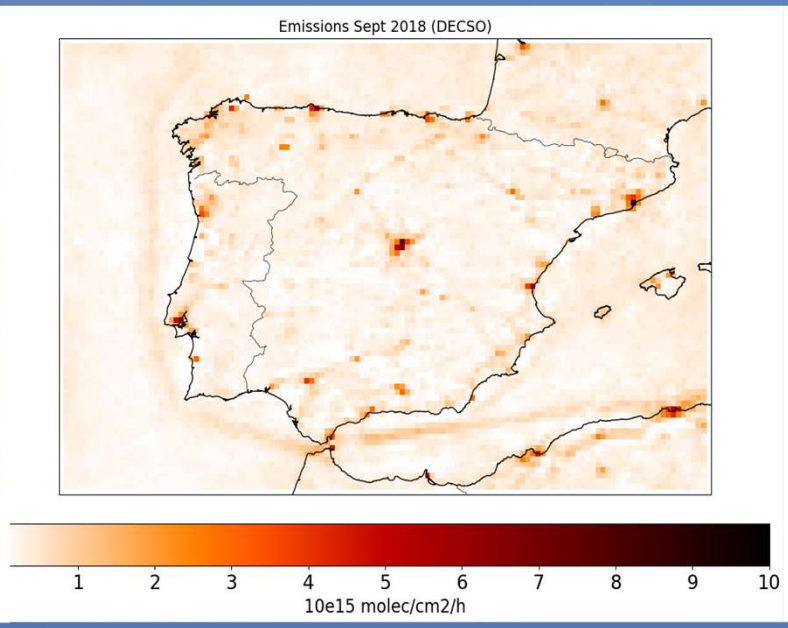
# The Iberian peninsula:

Ronald van der A, KNMI
H2020 CHE and AirQast project

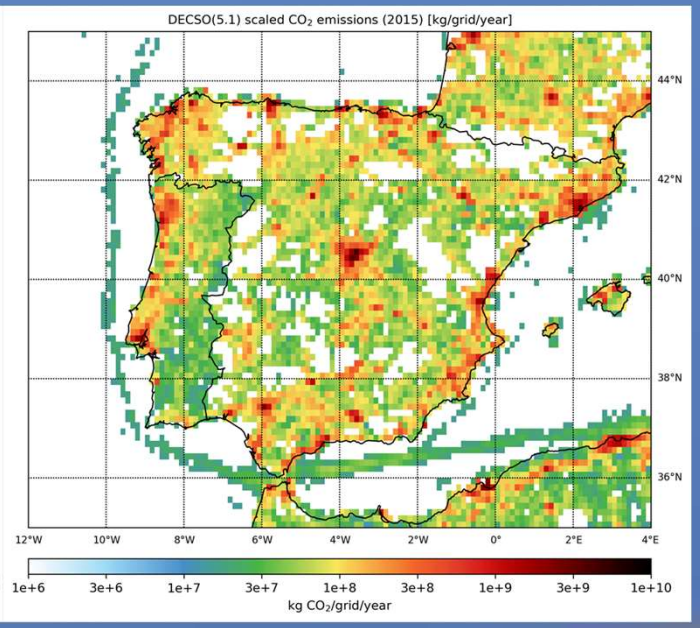
## Derived NOx and CO2 emissions from TROPOMI obs. for Sept. 2018




**Tropospheric NO2 columns**

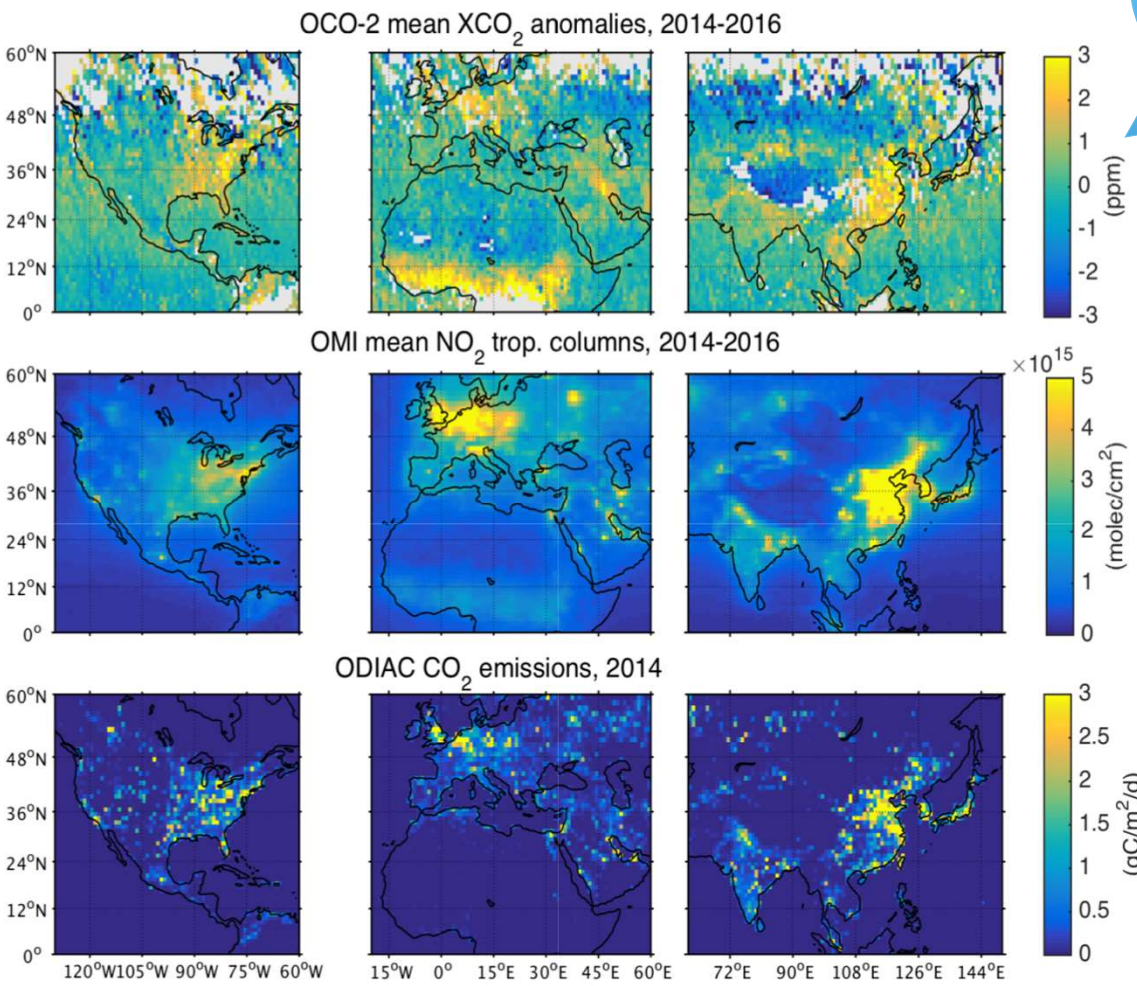



**NO2 emissions**




**CO2 emissions**

# OCO-2 $CO_2$ and OMI $NO_2$




The $CO_2$ anomalies are obtained deseasonalising and detrending the OCO-2 data

- First direct observation of anthropogenic $CO_2$ from OCO-2
- Synergy between OCO-2 $CO_2$ and OMI $NO_2$ data is used as a first step towards anthropogenic $CO_2$ identification

**REFERENCE:** Hakkarainen, J., et al.: Direct space-based observations of anthropogenic $CO_2$ emission areas from OCO-2, Geophys. Res. Lett., in review, 2016.

# Candidate Copernicus Expansion Mission
## End-to-end System requirements to monitor $CO_2$

1. **Detection of emitting hot spots** such as megacities or power plants.

2. **Monitoring the hot spot emissions** to assess emission reductions/increase of the activities.

3. **Assessing emission changes against local reduction targets** to monitor impacts of the NDCs.

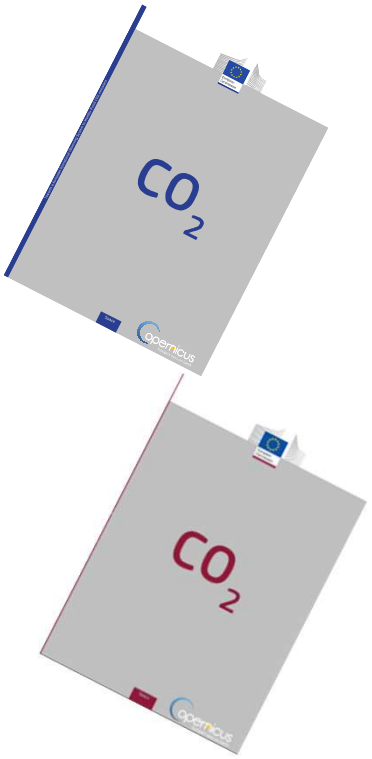
4. **Assessing the national emissions and changes** in 5-year time steps to estimate the global stock take.

Accuracy

200-400 t/year

km & daily scales

Space & Time

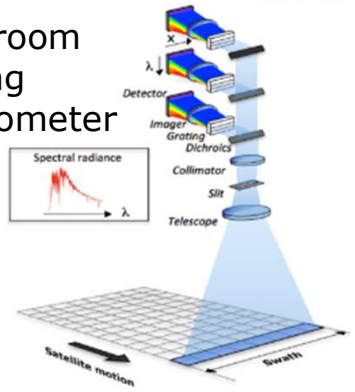


# $CO_2$ Monitoring – Space Segment Requirements 1/2

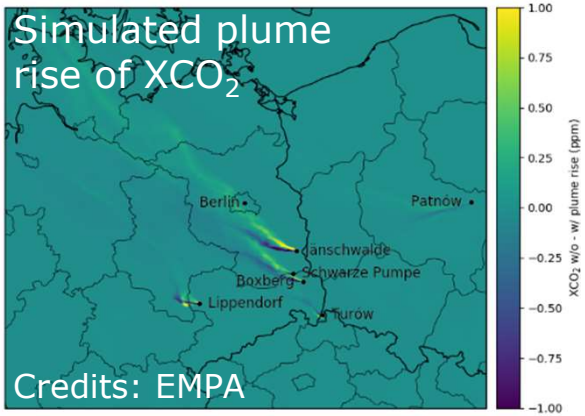
## Mission requirements for $XCO_2$ & $NO_2$:

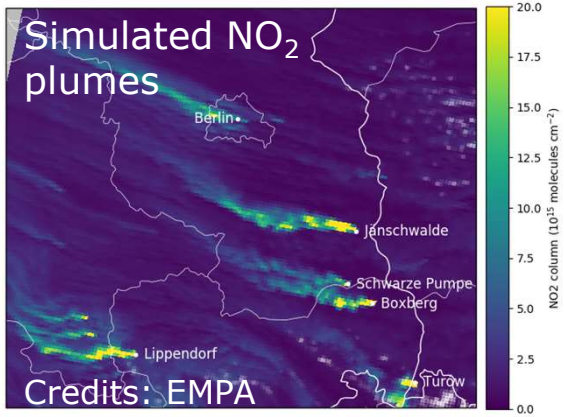
- Spatial resolution **4 km²**
- Revisit around **3 days** (poleward of 40 deg)
- $XCO_2$ precision: **0.5 – 0.7 ppm**
- $XCO_2$ systematic bias: **< 0.5 ppm**
- $NO_2$ precision: **1.5·10¹⁵ molec/cm²**
- Imaging swath **> 250 km**
- Equator crossing: **11:30 hrs**


Pushbroom imaging spectrometer




Credits: IUP, Bremen

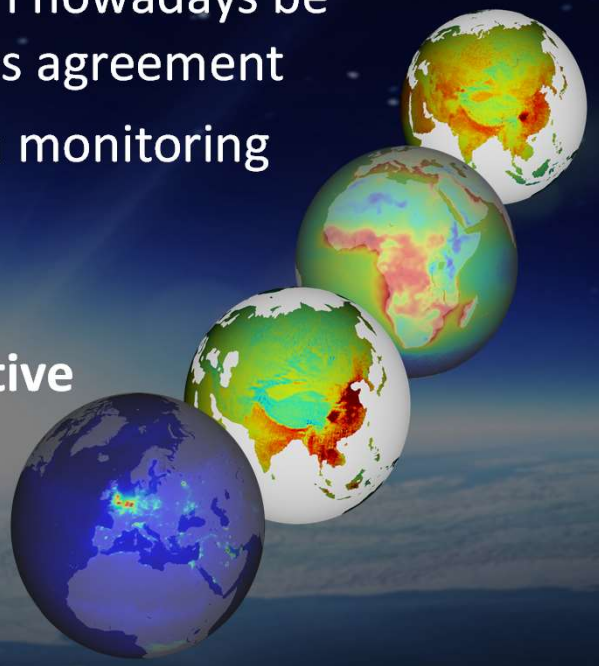



# Summary

- The Netherlands has an international leading position in measuring the atmospheric composition from space
- OMI and TROPOMI led to new findings in the air quality & health domain
- Air Quality and Greenhouse gas emissions can nowadays be monitored from space, important for the Paris agreement
- The Netherlands is working towards emission monitoring from space on a 1 x1 km2 spatial resolution.

- **Emission regulation have been proven effective**




levelt@knmi.nl

veefkind@knmi.nl


www.tropomi.eu

www.temis.nl

www.knmi.nl/omi

sentinels.copernicus.eu

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