



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

# **TROPOMI on Sentinel 5P**

*Global Urban-Scale Monitoring of  
Air Quality and Climate*

J.P. Veefkind\*, P.F. Levelt,  
& TROPOMI team

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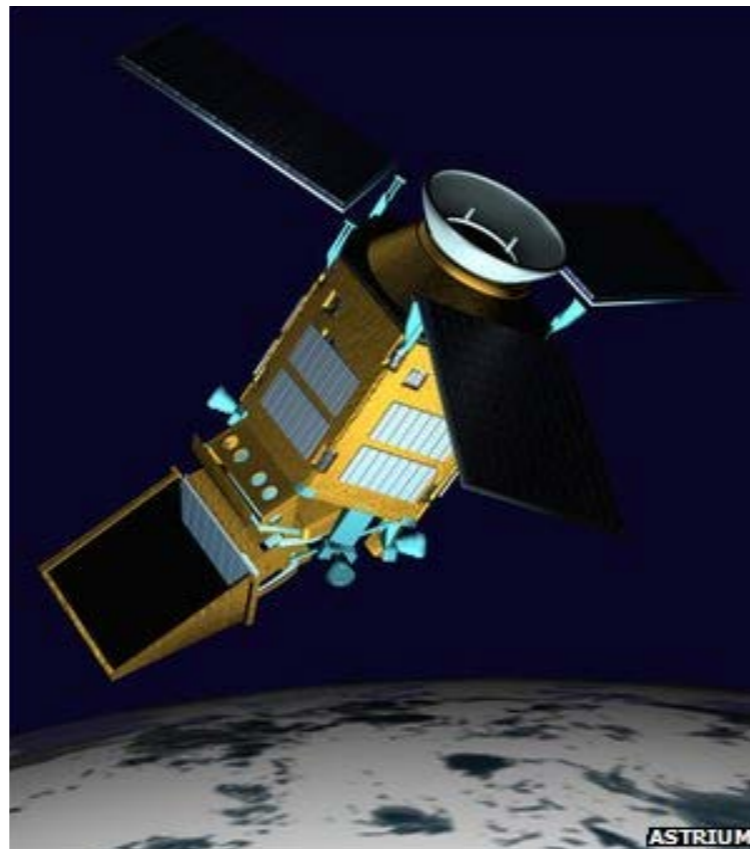
# sentinel-5 precursor

GMES ATMOSPHERE MISSION IN POLAR ORBIT

- The ESA Sentinel-5 Precursor (S-5P) is a pre-operational mission focussing on global observations of the atmospheric composition for air quality and climate.
- The TROPospheric Monitoring Instrument (**TROPOMI**) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.
- The planned launch date for S-5P is 2015 with a 7 year design lifetime.

## TROPOMI

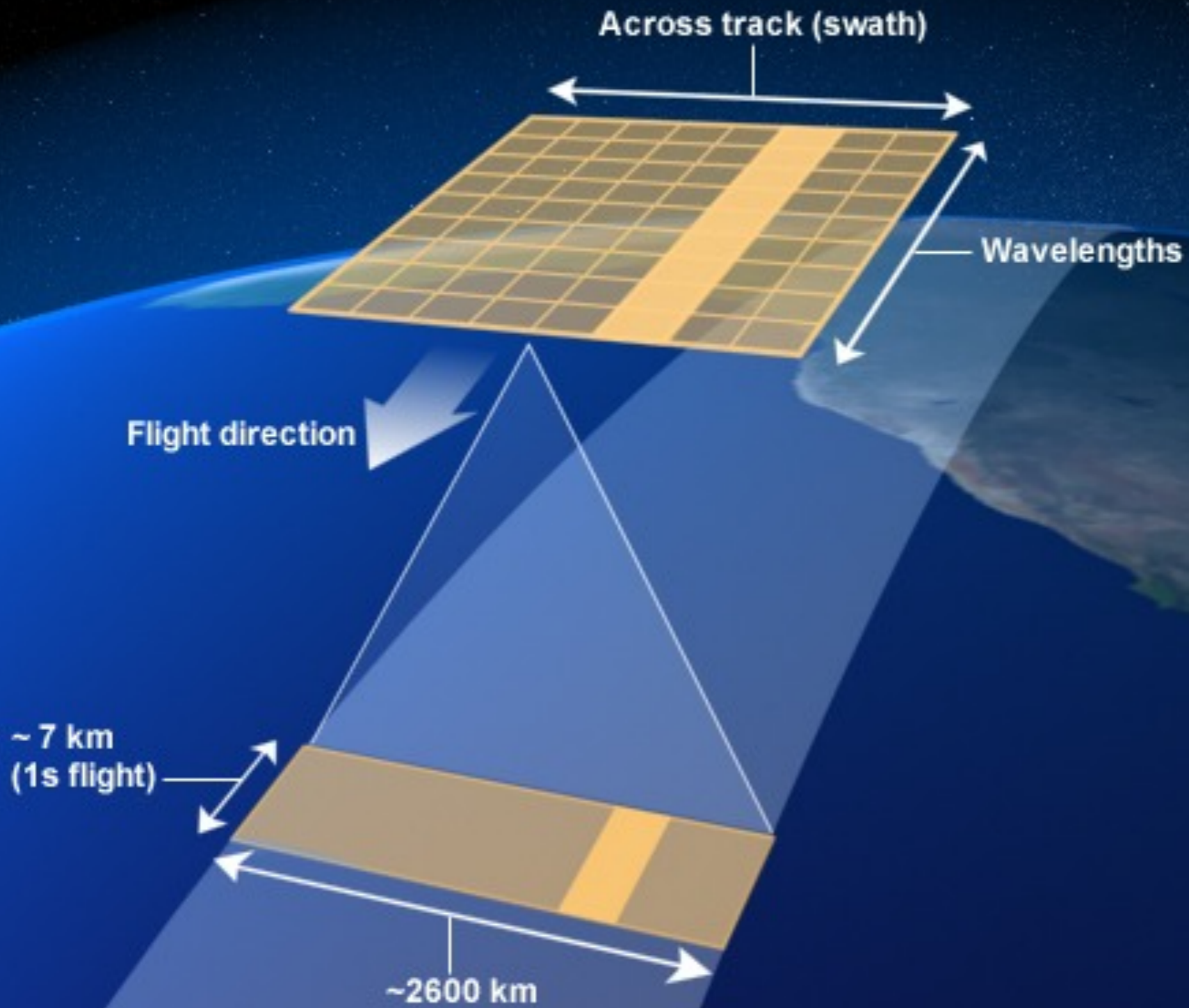
- ▶ UV-VIS-NIR-SWIR nadir view grating spectrometer.
- ▶ Spectral range: 270-500, 675-775, 2305-2385 nm
- ▶ Spectral Resolution: 0.25-1.1 nm
- ▶ Spatial Resolution: 7x7km<sup>2</sup>
- ▶ Global daily coverage at 13:30 local solar time.



## CONTRIBUTION TO GMES

- ▶ Total column  
O<sub>3</sub>, NO<sub>2</sub>, CO, SO<sub>2</sub>, CH<sub>4</sub>,  
CH<sub>2</sub>O, H<sub>2</sub>O, BrO
- ▶ Tropospheric column  
O<sub>3</sub>, NO<sub>2</sub>
- ▶ O<sub>3</sub> profile
- ▶ Aerosol absorbing index,  
type, optical depth

# The TROPOMI Measurement Principle



Courtesy of Pepijn Veeffkind, KNMI, The Netherlands

Radiant Cooler

Nadir FOV

Telescope Support Structure

SUN Calibration FOV

**TNO** innovation  
for life

  
**Dutch Space**  
an EADS Astrium company

# TROPOMI Spectral Bands

Spectrometer	UV		UVIS		NIR		SWIR	
Band ID	1	2	3	4	5	6	7	8
Full Range [nm]	270 - 320		310 - 495		675 - 775		2305 - 2385	
Performance range [nm]	270-300	300-320	320-405	405-495	675-725	725-775	2305-2345	2345-2385
Spectral Resolution [nm]	0.48	0.49	0.54	0.54	0.38	0.38	0.25	0.25
Spectral Sampling Ratio	6.8	6.7	2.5	2.5	2.8	2.8	2.5	2.5
Signal-to-noise	100	100-1000	1000-1500	1500	500	100-500	100-120	100-120
Spatial Sampling [km <sup>2</sup> ]	21x28	7x7	7x7	7x7	7x7	7x7	7x7	7x7



Tropospheric Monitoring Instrument

# TROPOMI Data Products

Product	Accuracy :: Precision
<b>Ozone</b> total column profile (incl. troposphere) trop. column	3% :: 1% 10% :: 5% 25% :: 10%
<b>NO<sub>2</sub></b> total column trop. column	$1 \cdot 10^{15}$ mol/cm <sup>2</sup> 10% :: $1 \cdot 10^{15}$ mol/cm <sup>2</sup>
<b>CO</b> total column	15% :: 10%
<b>CH<sub>4</sub></b> total column	2% :: 1%
<b>SO<sub>2</sub></b> volcanic plume top. column	2 DU :: 1 DU 1 DU :: 0.5 DU
<b>Aerosol</b> AAI aerosol layer height* aerosol optical thickness single scattering albedo	n/a :: 0.25 1 km :: 0.5 km 0.1 (20%) :: 0.05 (10%) 0.05 :: 0.01
<b>Cloud</b> radiance fraction pressure mask Regridded VIIRS	0.05 :: 0.02 50 hPa :: 20 hPa

Product	Accuracy :: Precision
<b>CH<sub>2</sub>O</b> total column	TBD
<b>CHO-CHO</b> total column	TBD
<b>BrO</b> total column	TBD
<b>HDO</b> total column	TBD
<b>H<sub>2</sub>O</b> total column	20% :: 10%
<b>OCIO</b> total column	TBD
<b>UV</b> surface flux	10% :: 5%
<b>Surface Reflectance</b> monthly climatology	3% :: 1%

**The operational data products will be developed by a collaboration of European institutes.  
 KNMI/DLR-IMF/IUP/BIRA-IASB/SRON/MPIC/RAL/FMI**



# sentinel-5 precursor

→ GMES LOW EARTH ORBIT ATMOSPHERE MISSION

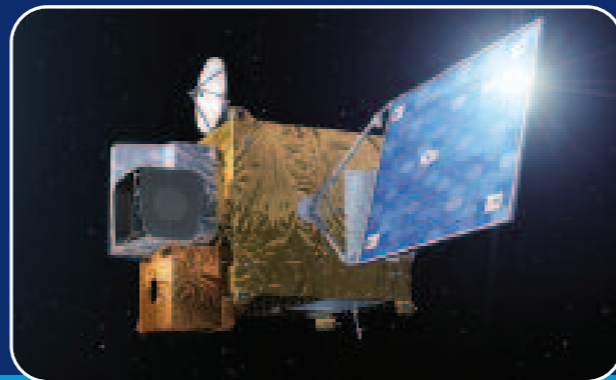
→ GMES LOW EARTH ORBIT ATMOSPHERE MISSION

2015-2022  
**daily global coverage**



EUMETSAT Polar System

2019 - ~2030  
**hourly over Europe**



# sentinel-4

→ GMES GEOSTATIONARY ATMOSPHERIC MISSION

→ GMES GEOSTATIONARY ATMOSPHERIC MISSION

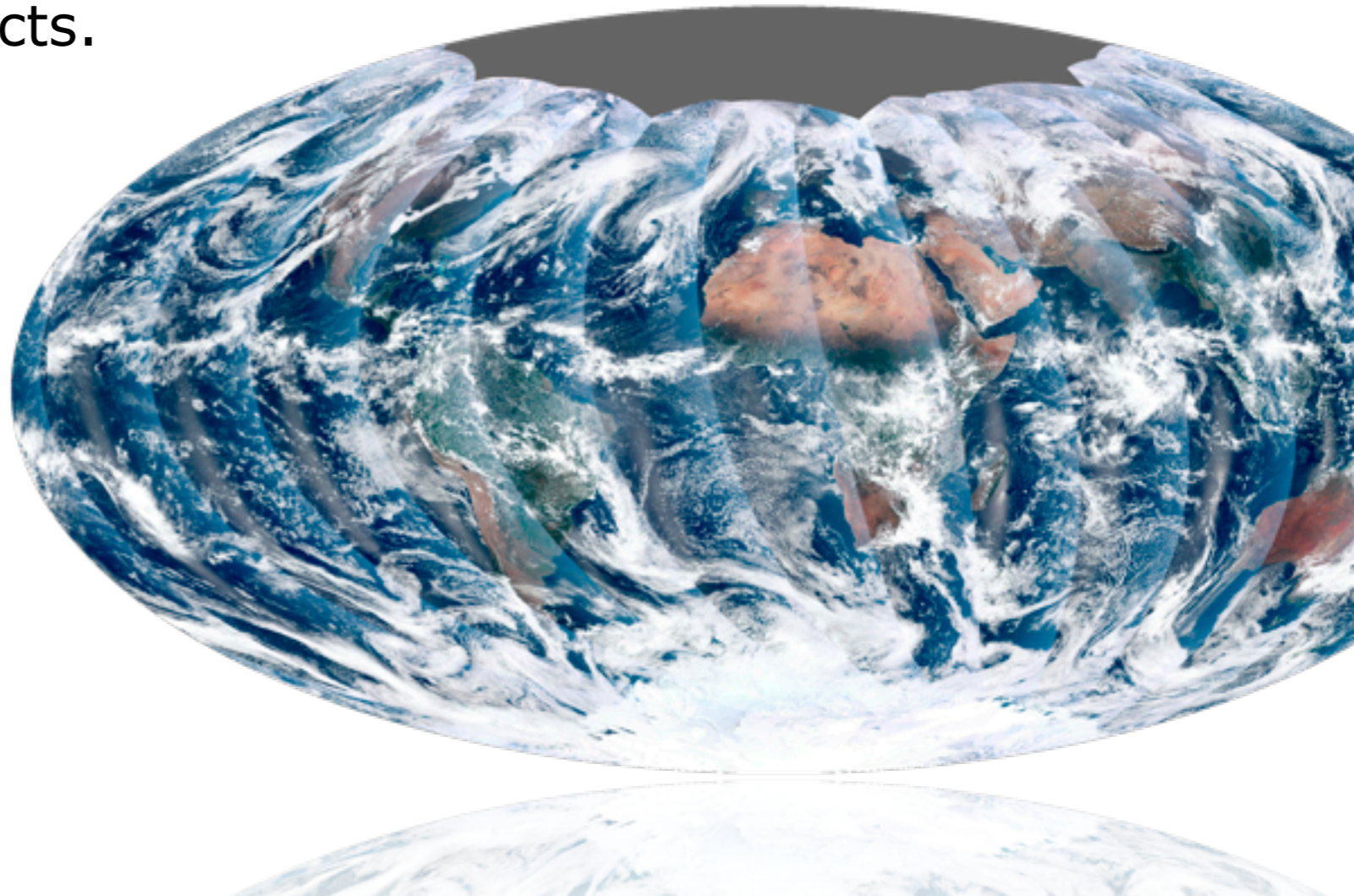
2017 - ...  
**hourly over SE - ASIA**

**gems | tempo**  
KARI | NASA

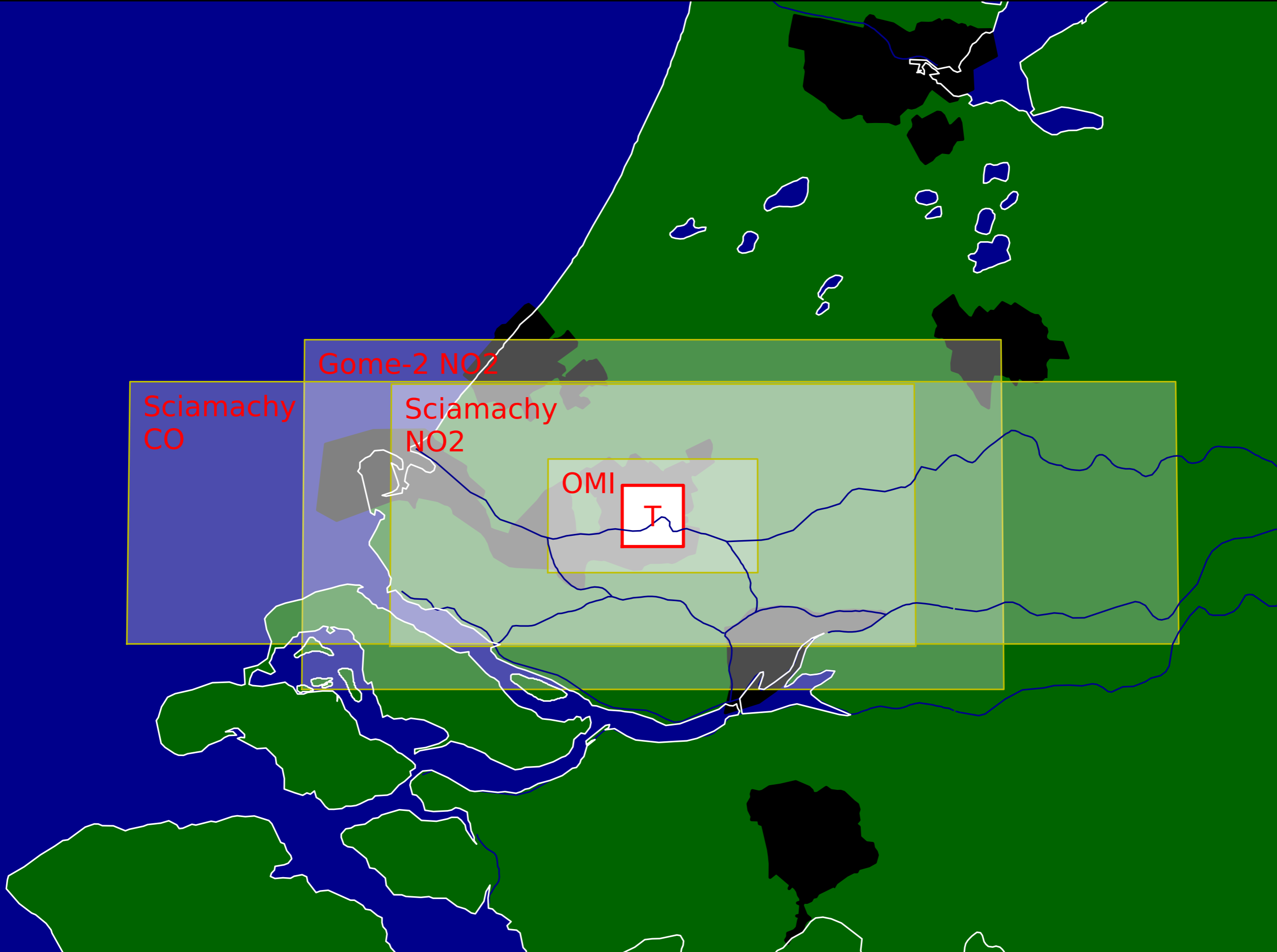
2017 - ...  
**hourly over N-America**

# Suomi-NPP - S5P formation Flying

- S-5P is planned to observe within 5 min. of Suomi-NPP.
- Primary goal is to use VIIRS cloud mask for S-5P methane observations.
- Other opportunities:
  - ▶ TROPOMI-VIIRS cloud and aerosol combined products.
  - ▶ TROPOMI-OMPS-CRIS ozone profiles.
  - ▶ TROPOMI-OMPS inter-calibration.







Gome-2 NO2

SciAmachy  
CO

SciAmachy  
NO2

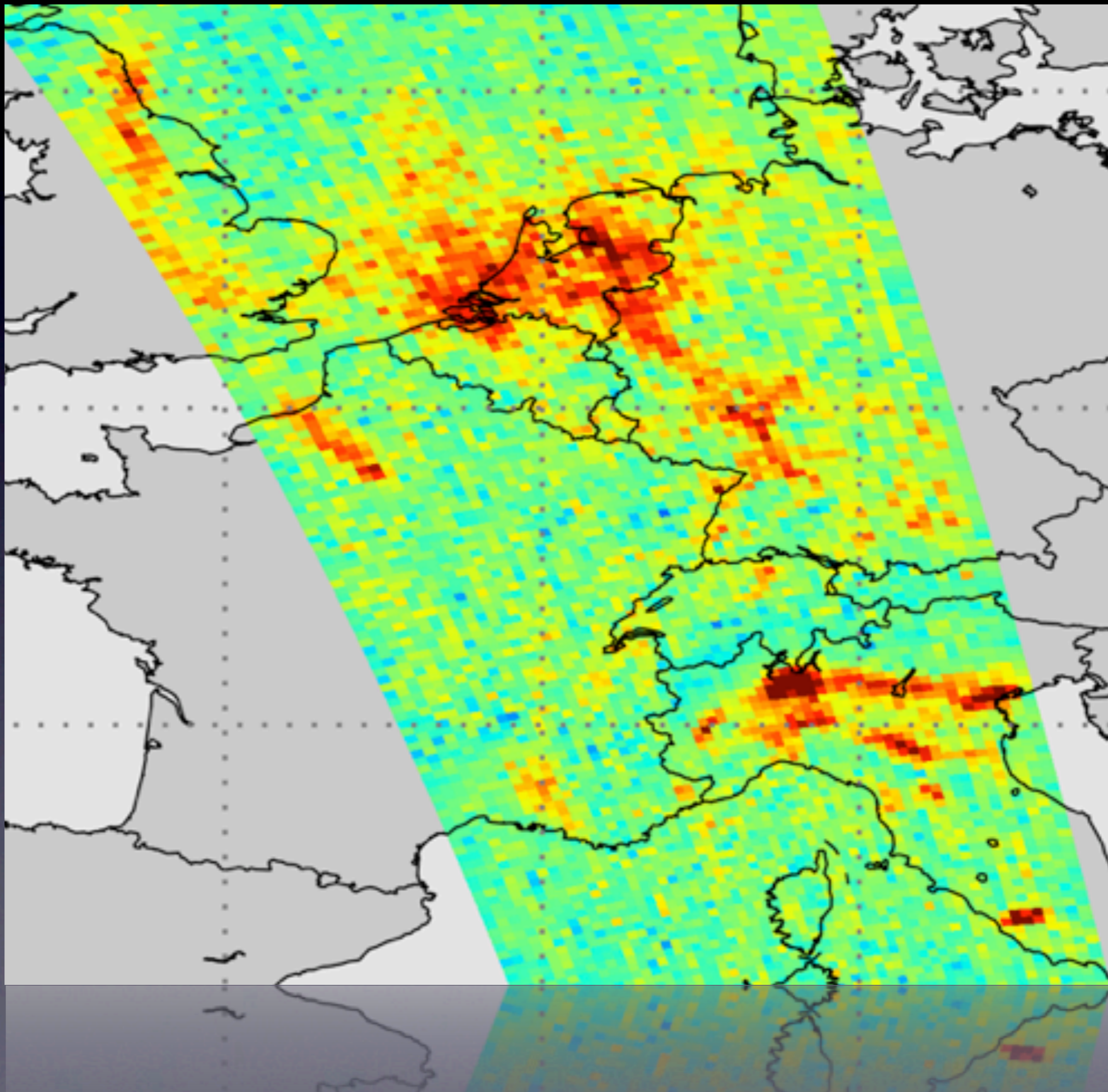
OMI

T

# OMI Zoom

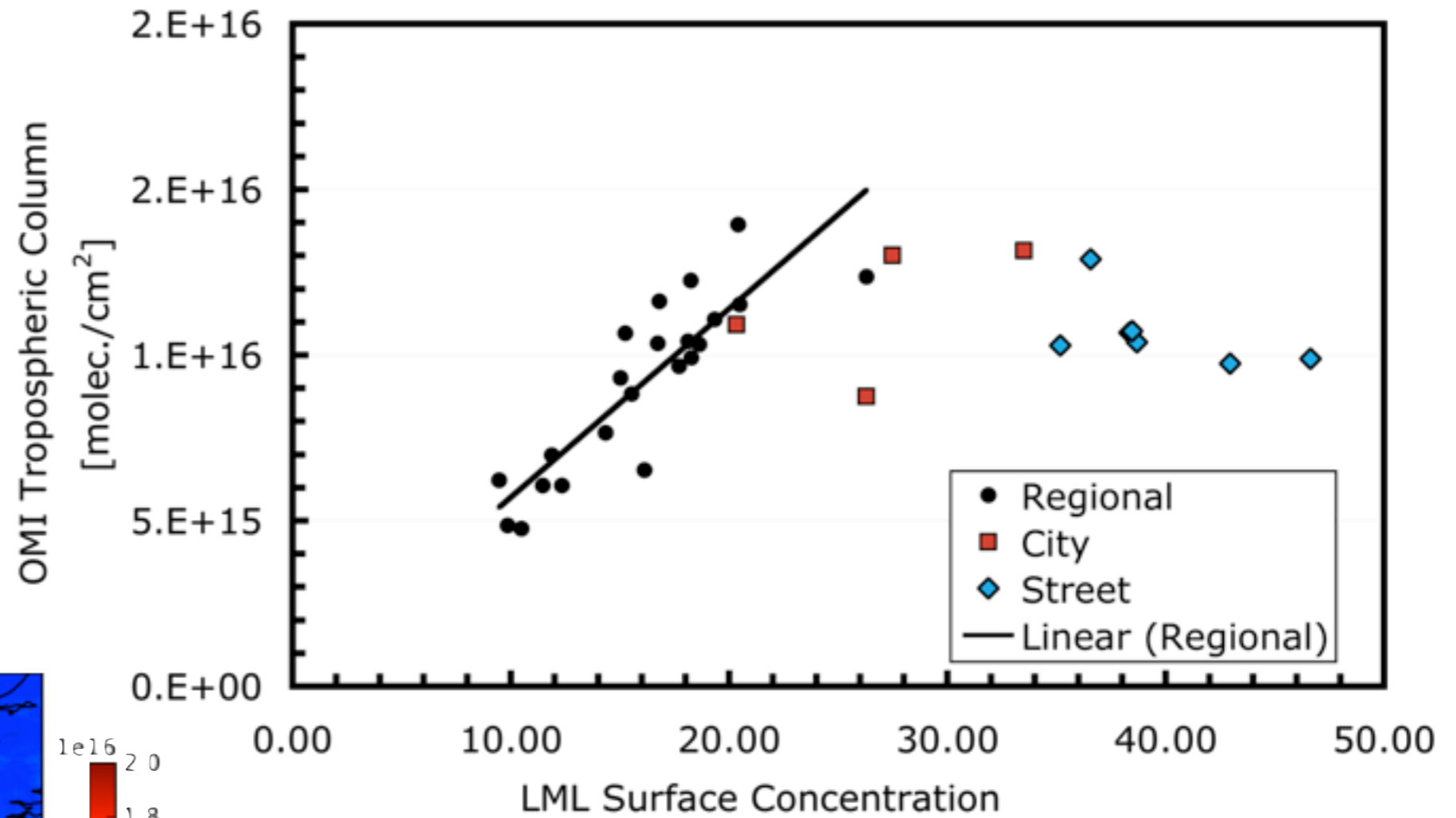
~13x12 km<sup>2</sup> Sampling

12 September 2006

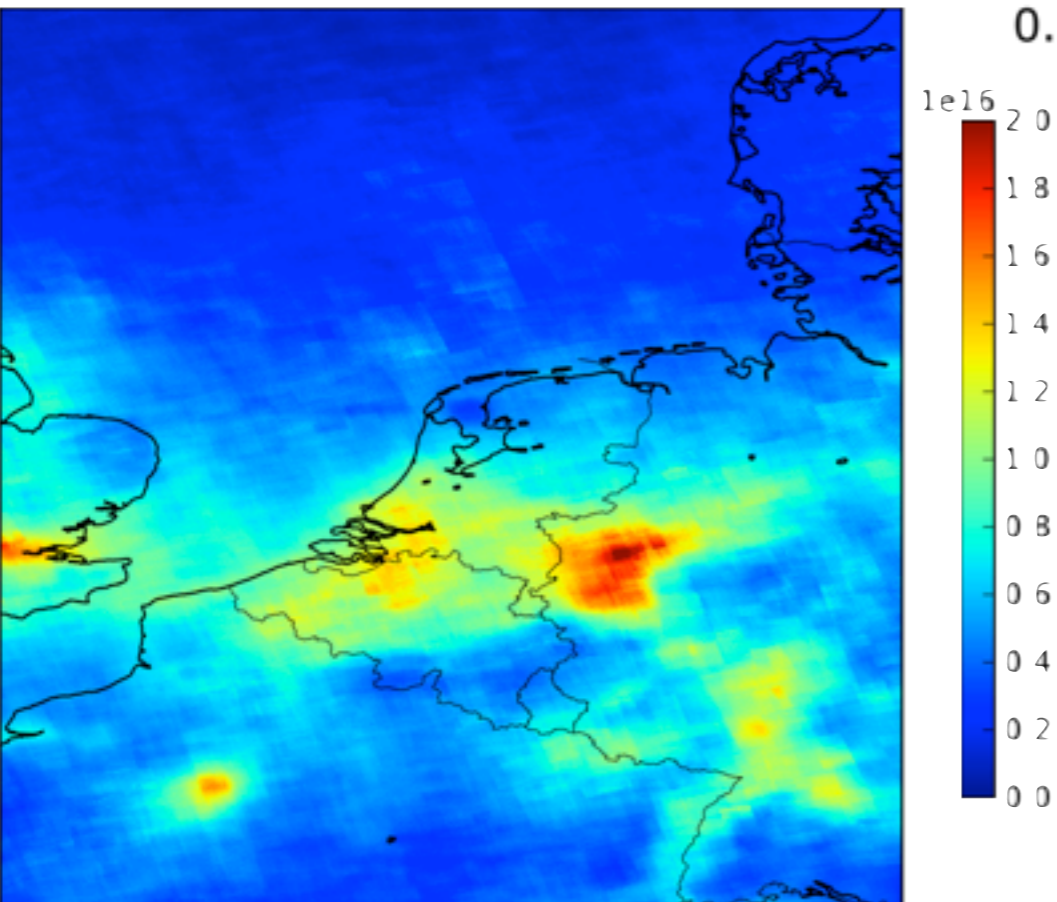


# Comparison with In-situ Measurements

## Comparison OMI - LML NO<sub>2</sub>, 2007



NL2007, NO<sub>2</sub>

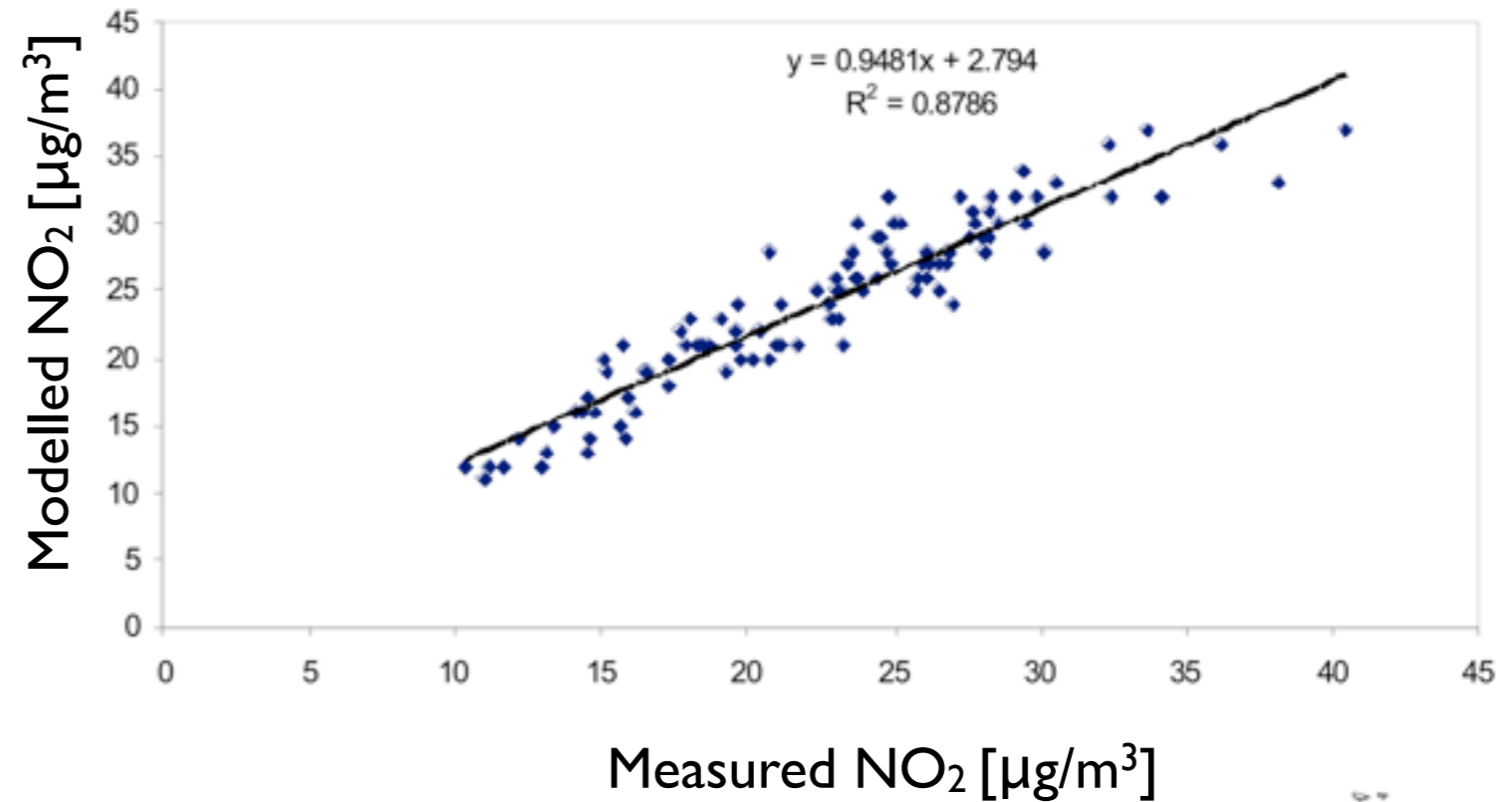


# Statistical Modeling of NO<sub>2</sub> at Street Level

Gerard Hoek, UU

- Statistical models use predictor variables.
- Using OMI data to describe the urban background 84% of the spatial variability was explained by the model.

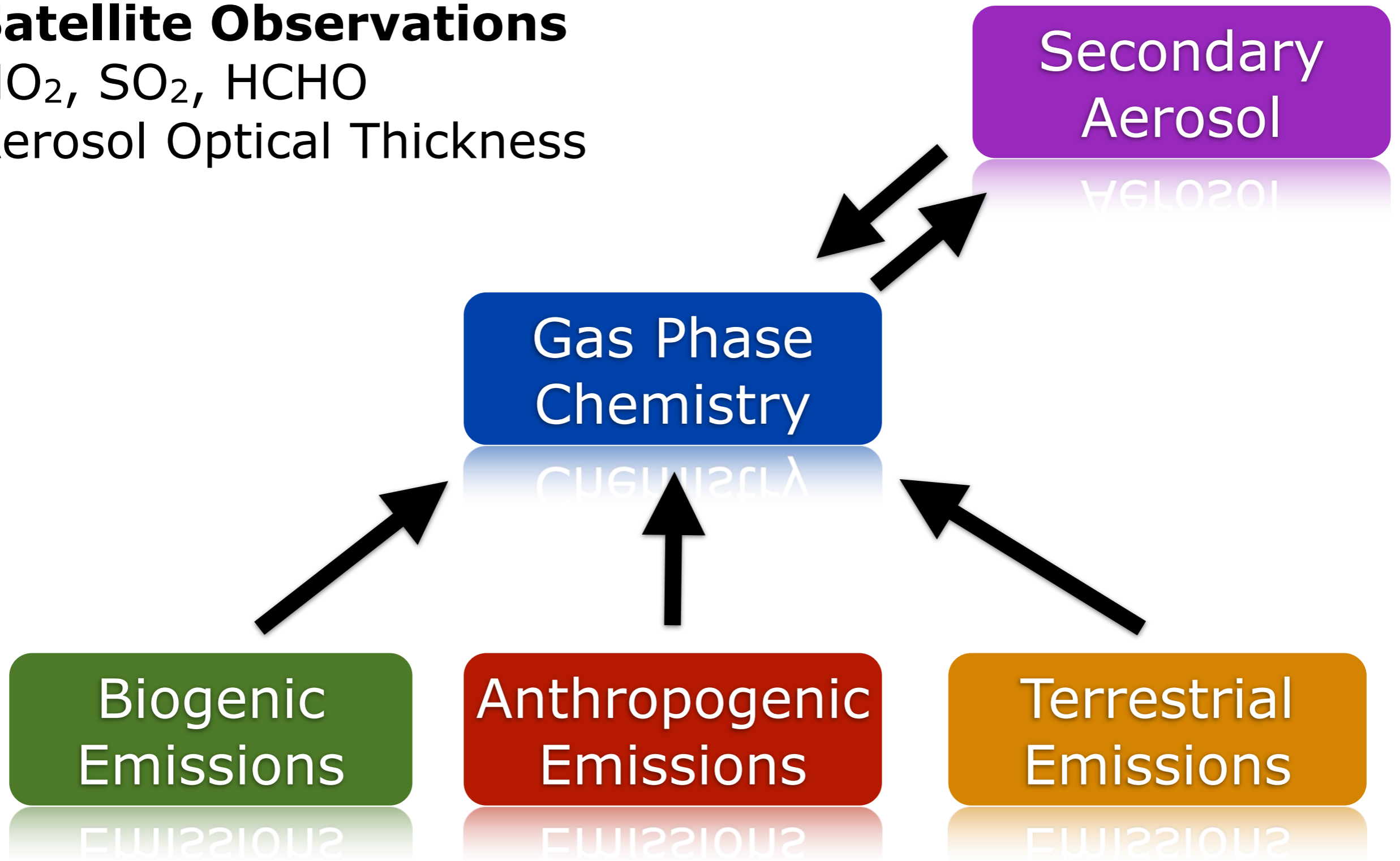
All Background Stations (n=104)



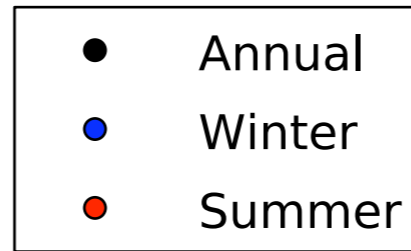
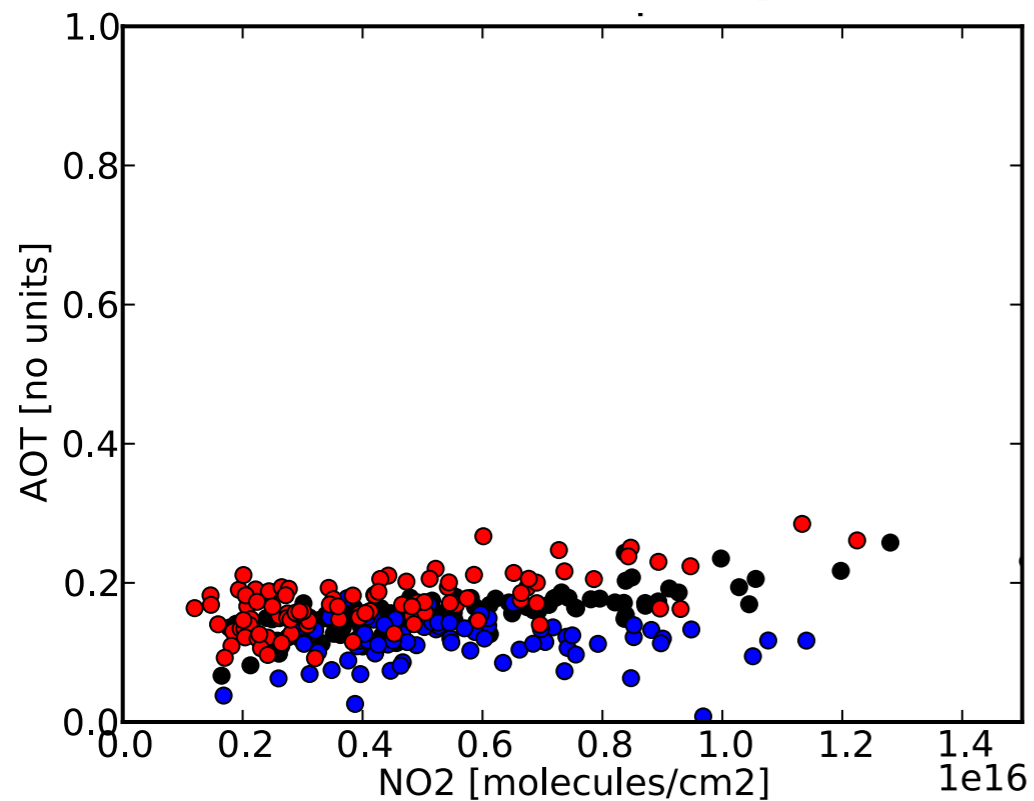
# Satellite Observations

NO<sub>2</sub>, SO<sub>2</sub>, HCHO

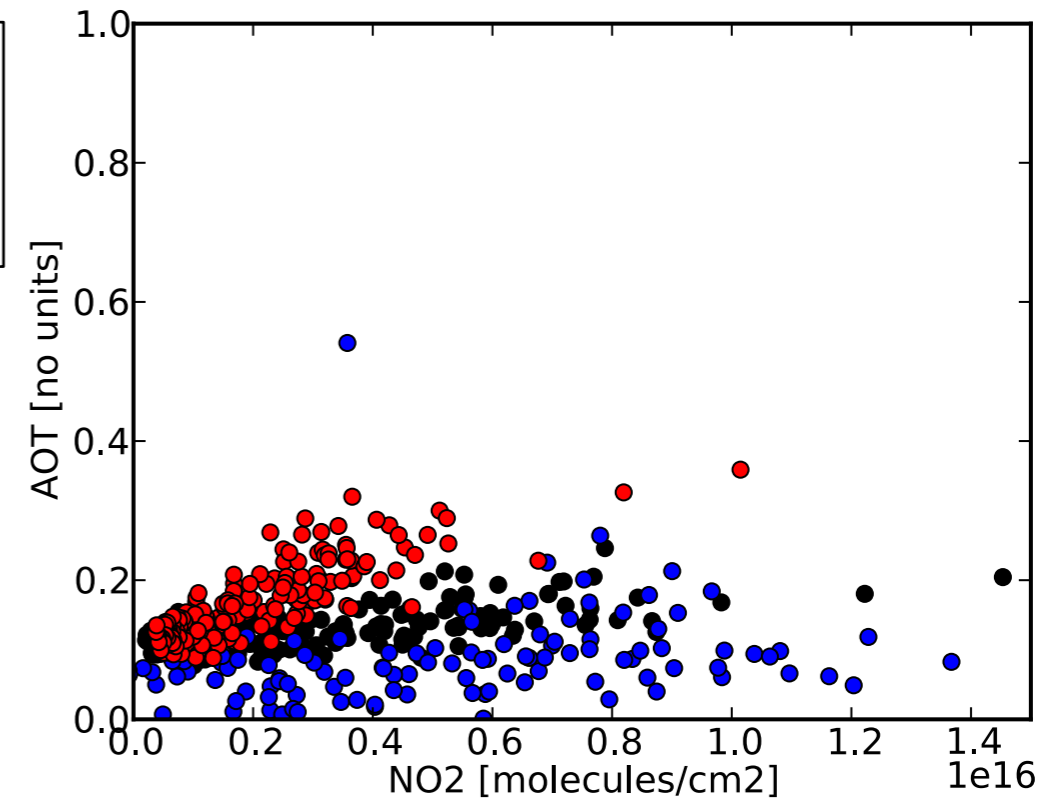
Aerosol Optical Thickness



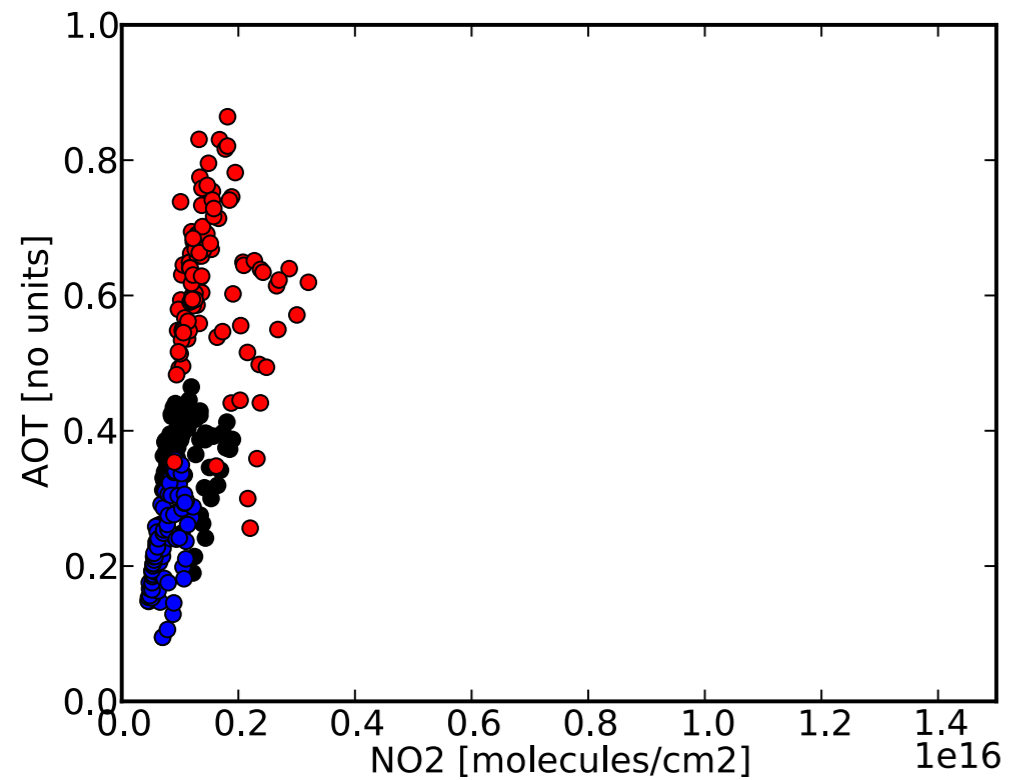
# West-Europe



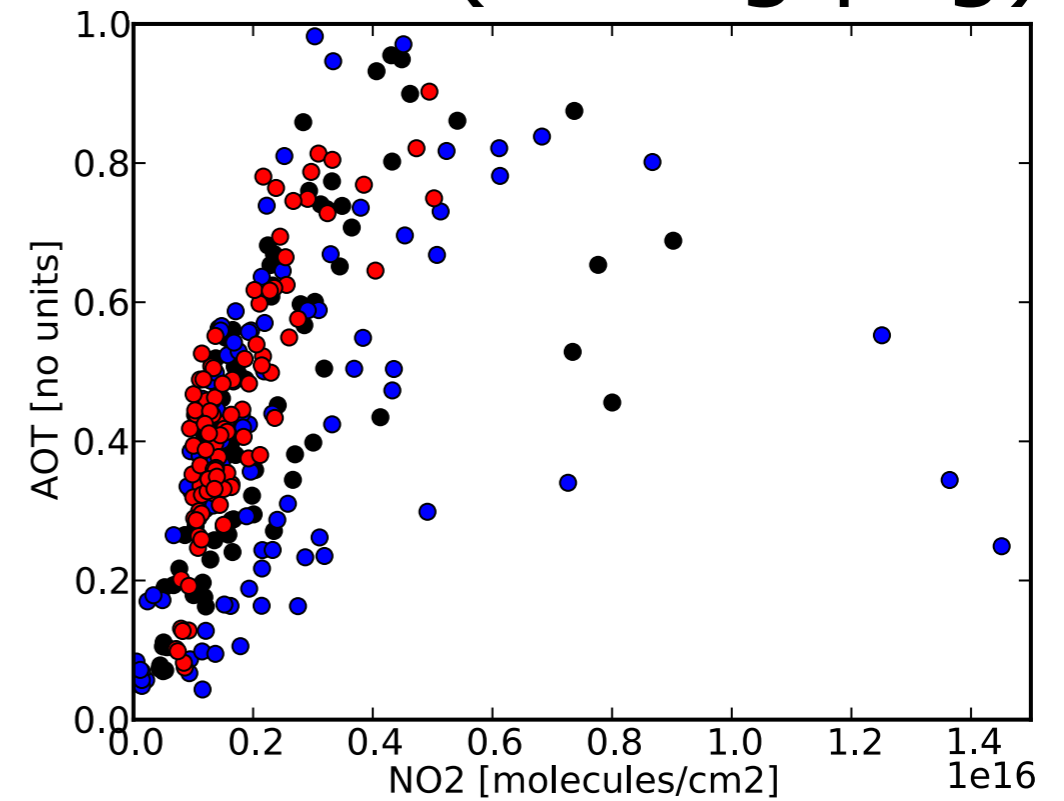
# East USA



# West Africa

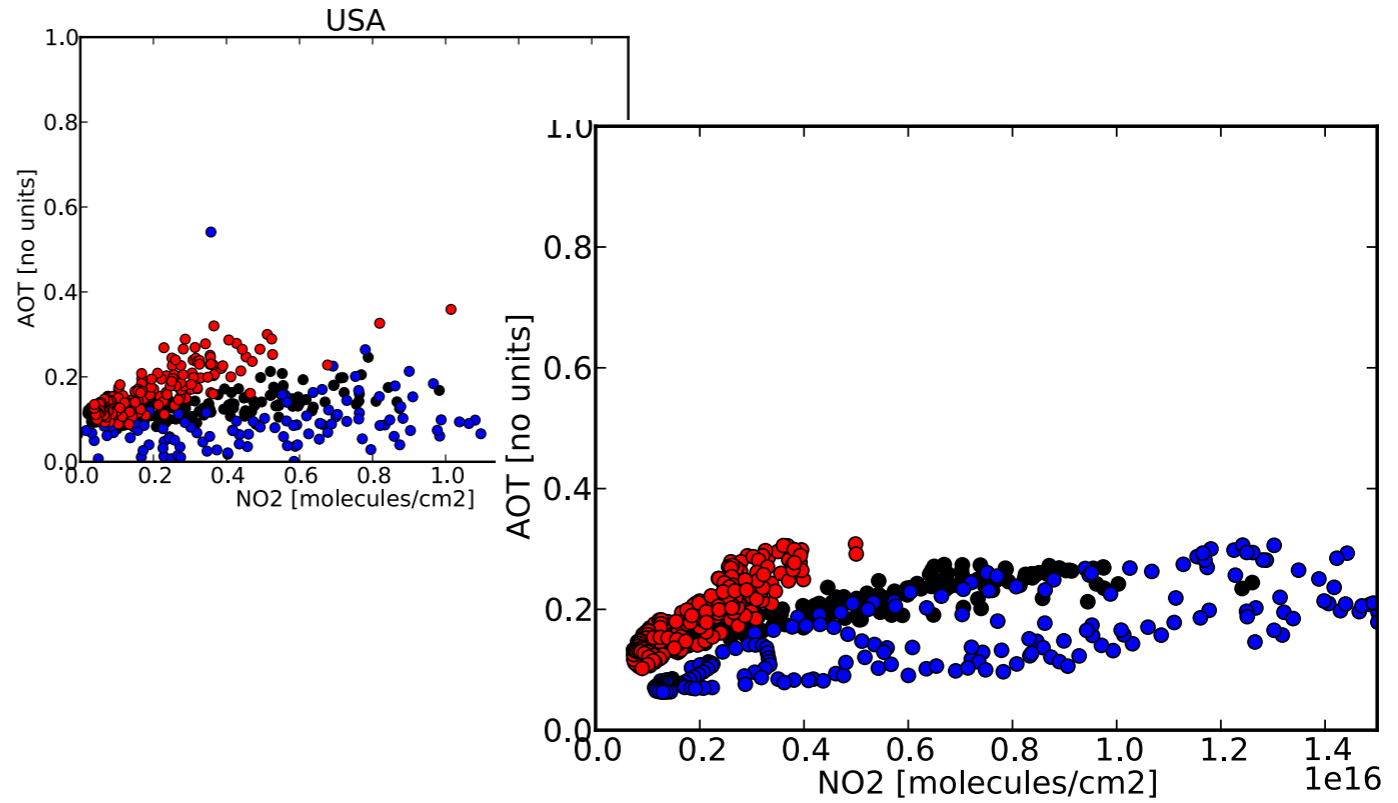
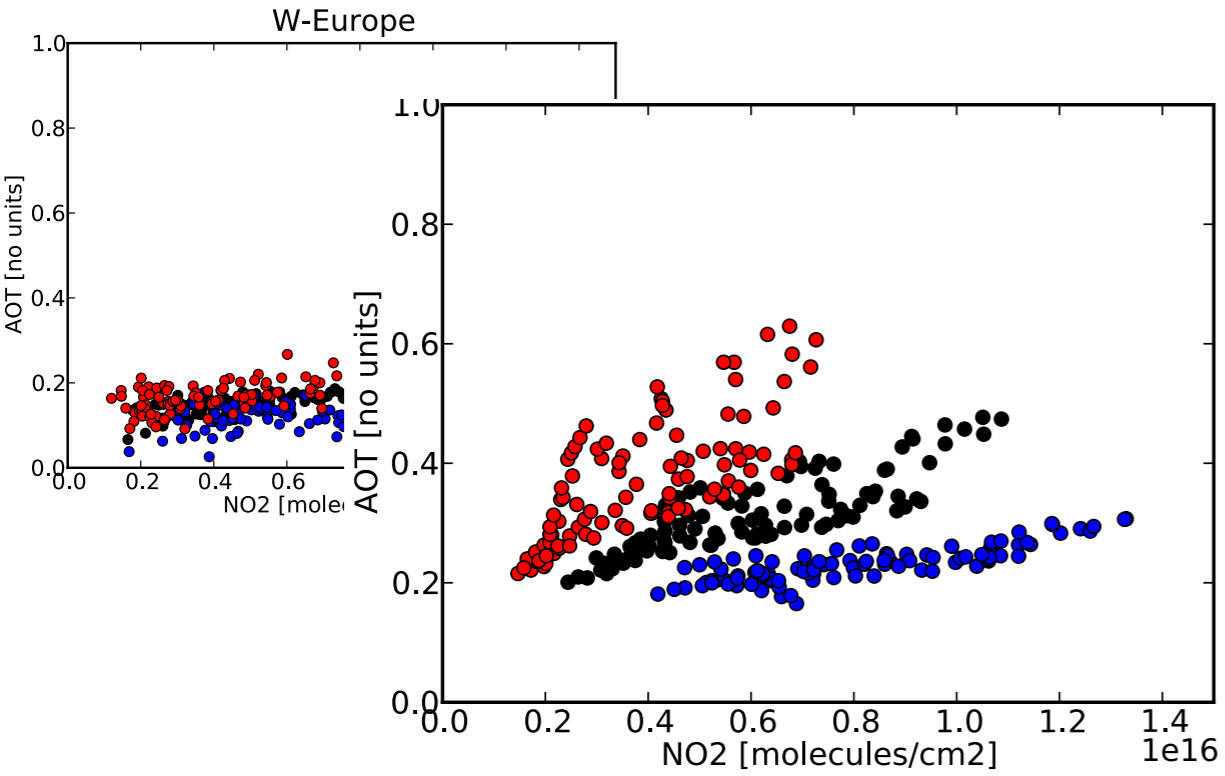


# China (Chongqing)

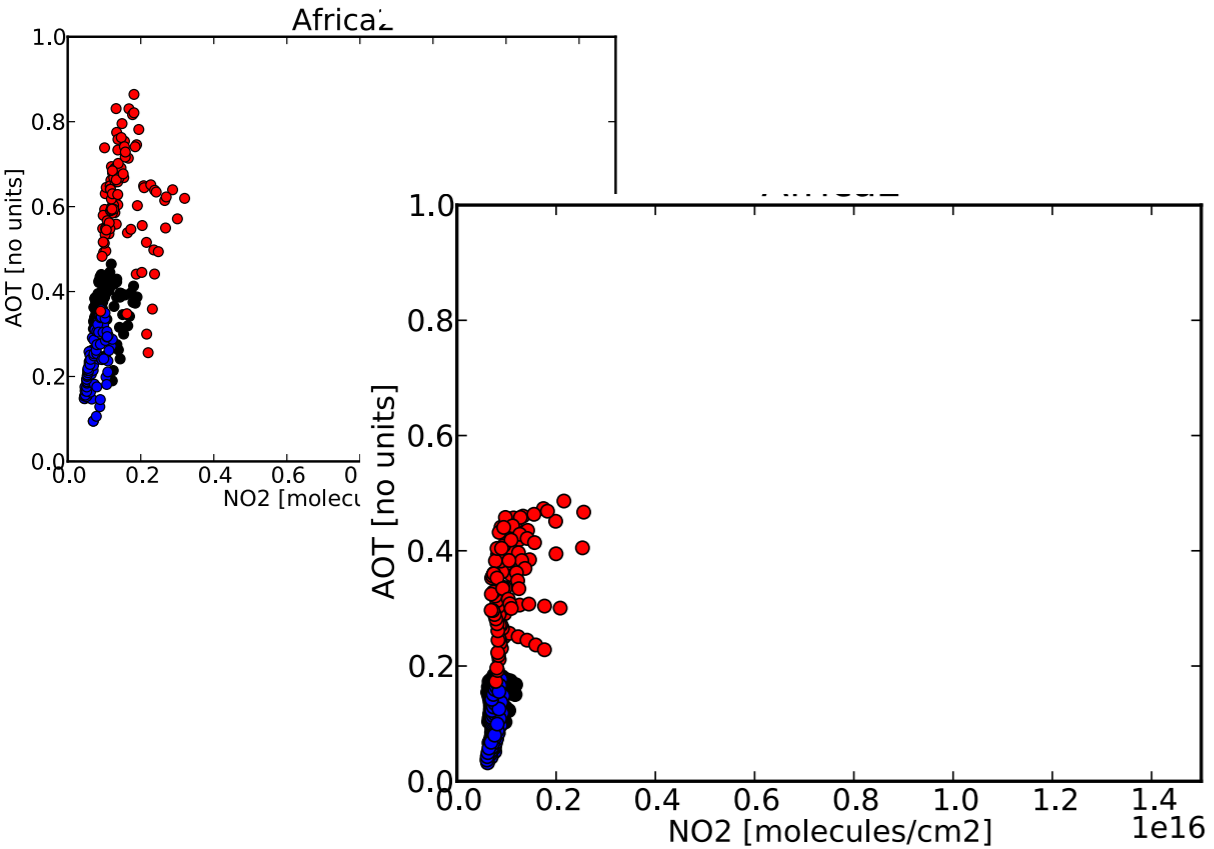


Veefkind, J. P., K. F. Boersma, J. Wang, T. P. Kurosu, N. Krotkov, K. Chance, and P. F. Levelt (2011), *Atmos. Chem. Phys.*, 11(3), 1255–1267.

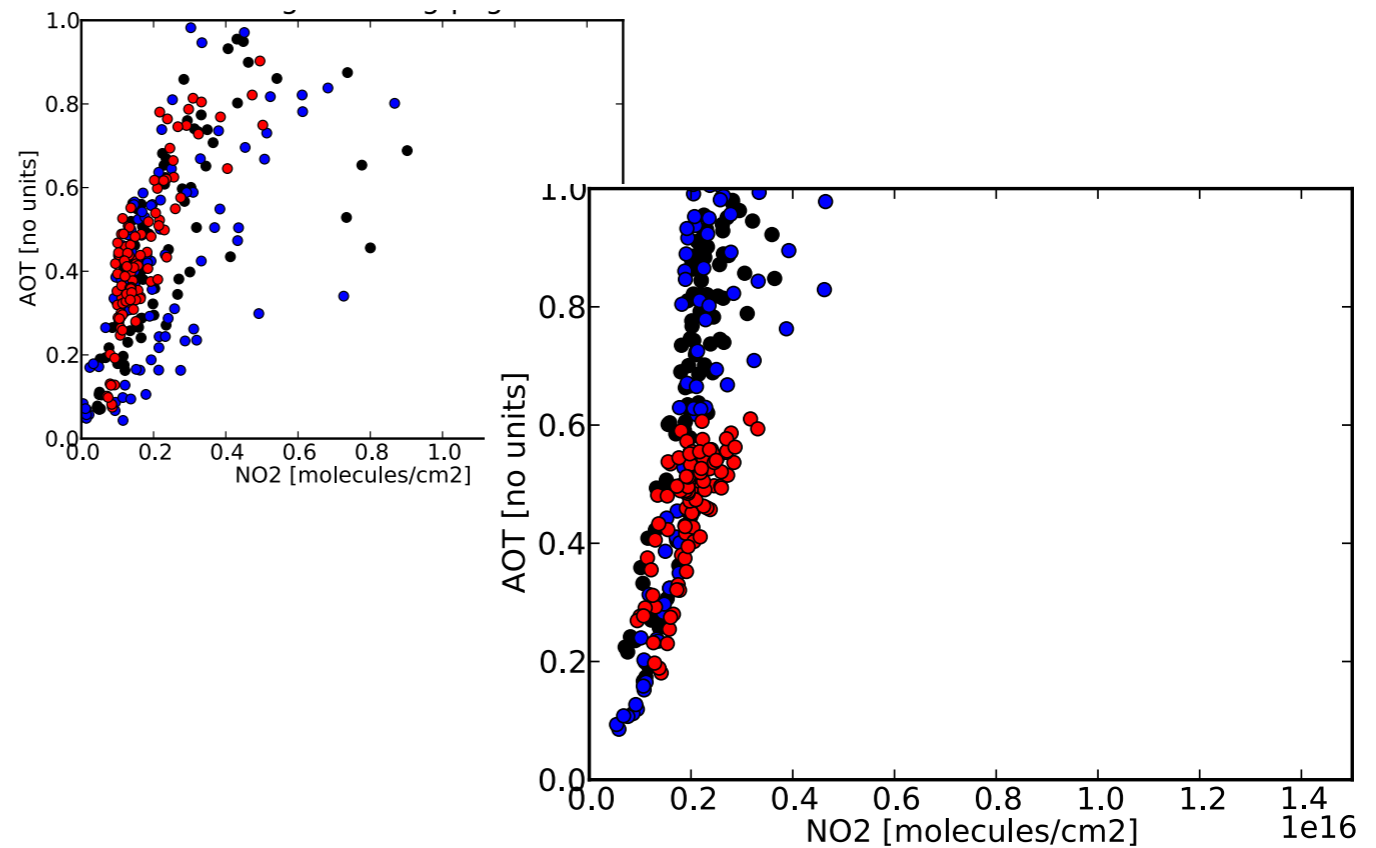
# West-Europe **GEOS-CHEM** East USA



## West Africa



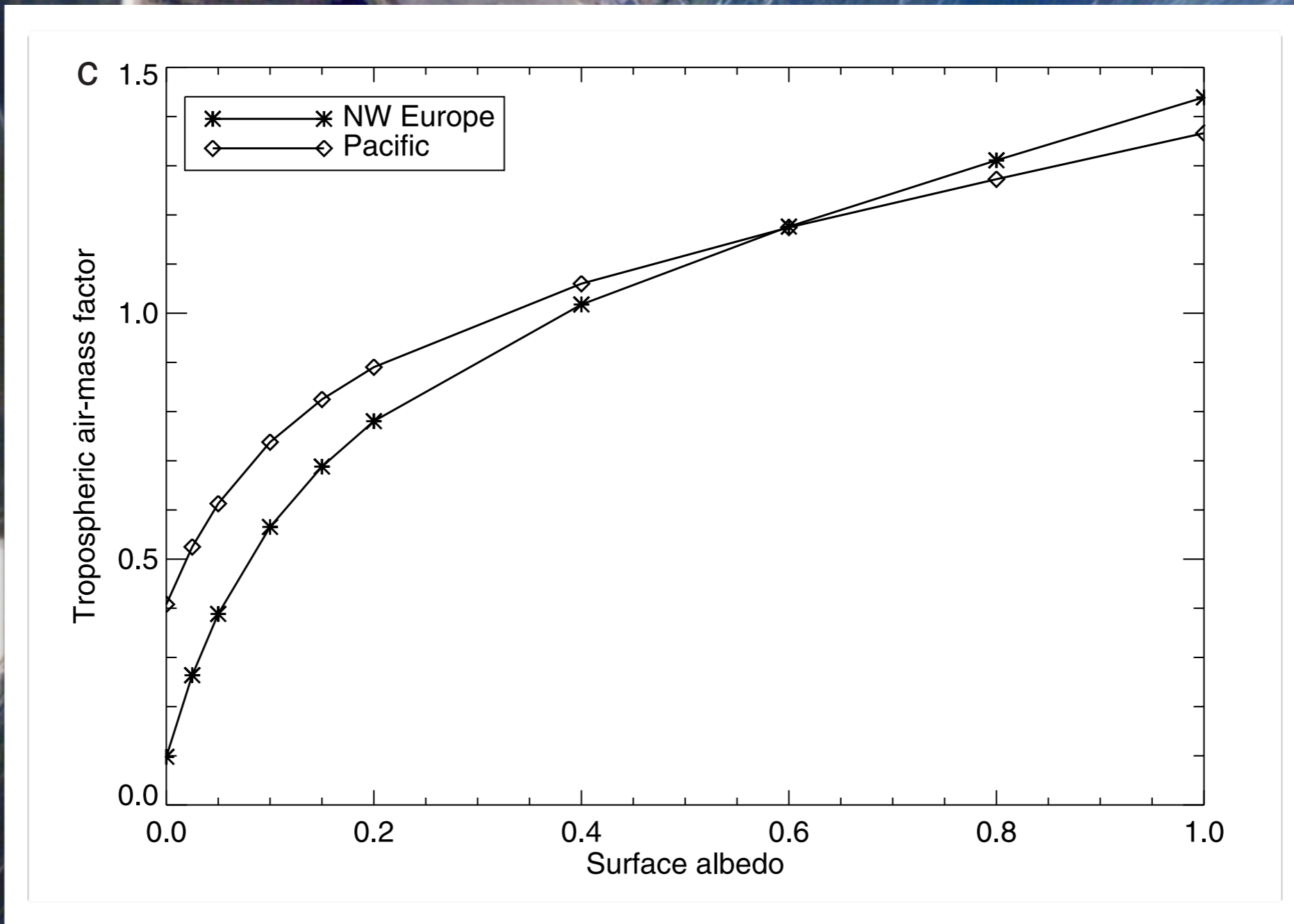
## China (Chongqing)



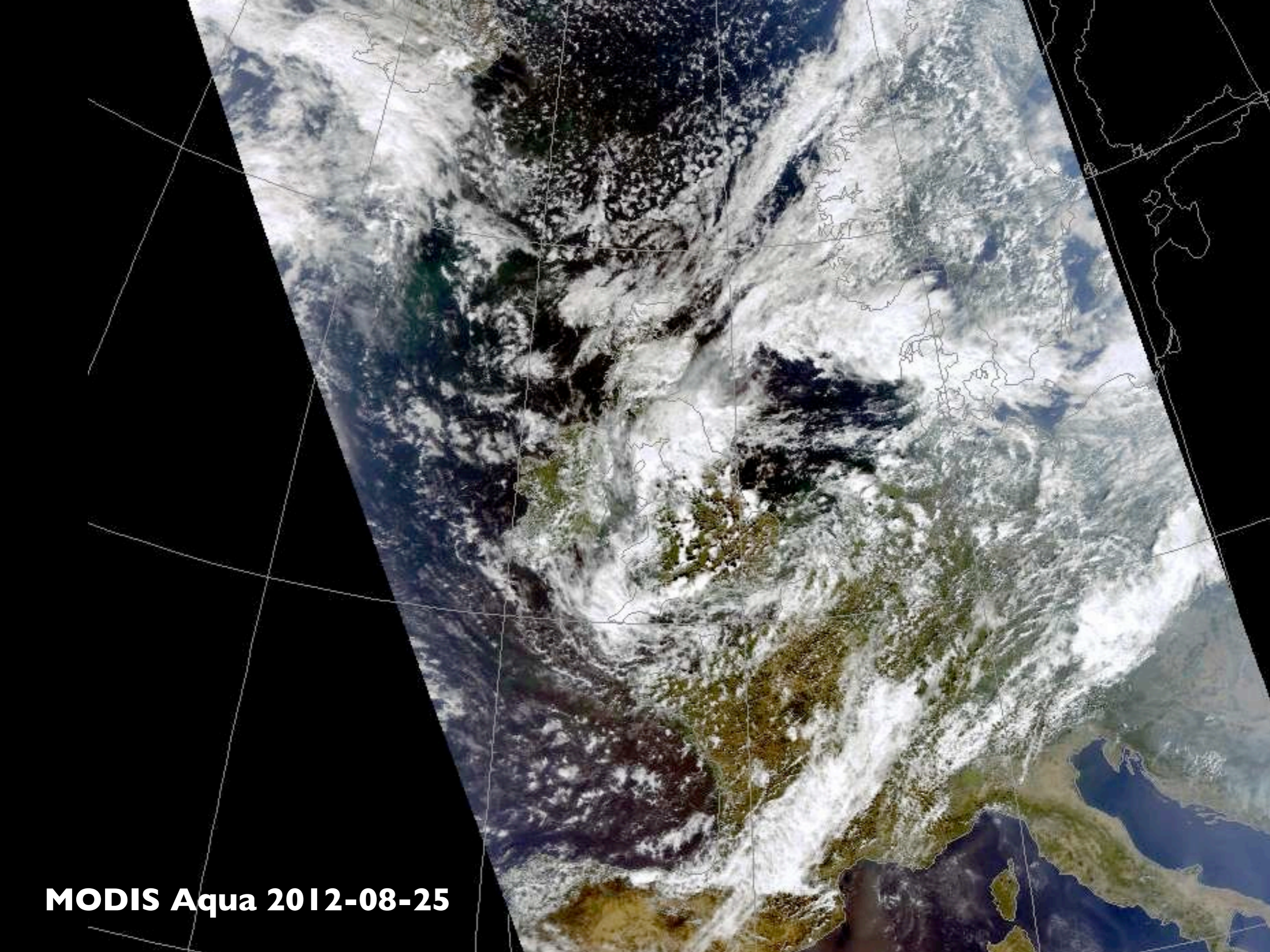


**ISS Photo, May 1, 2007**






**ISS Photo, May 1, 2007**



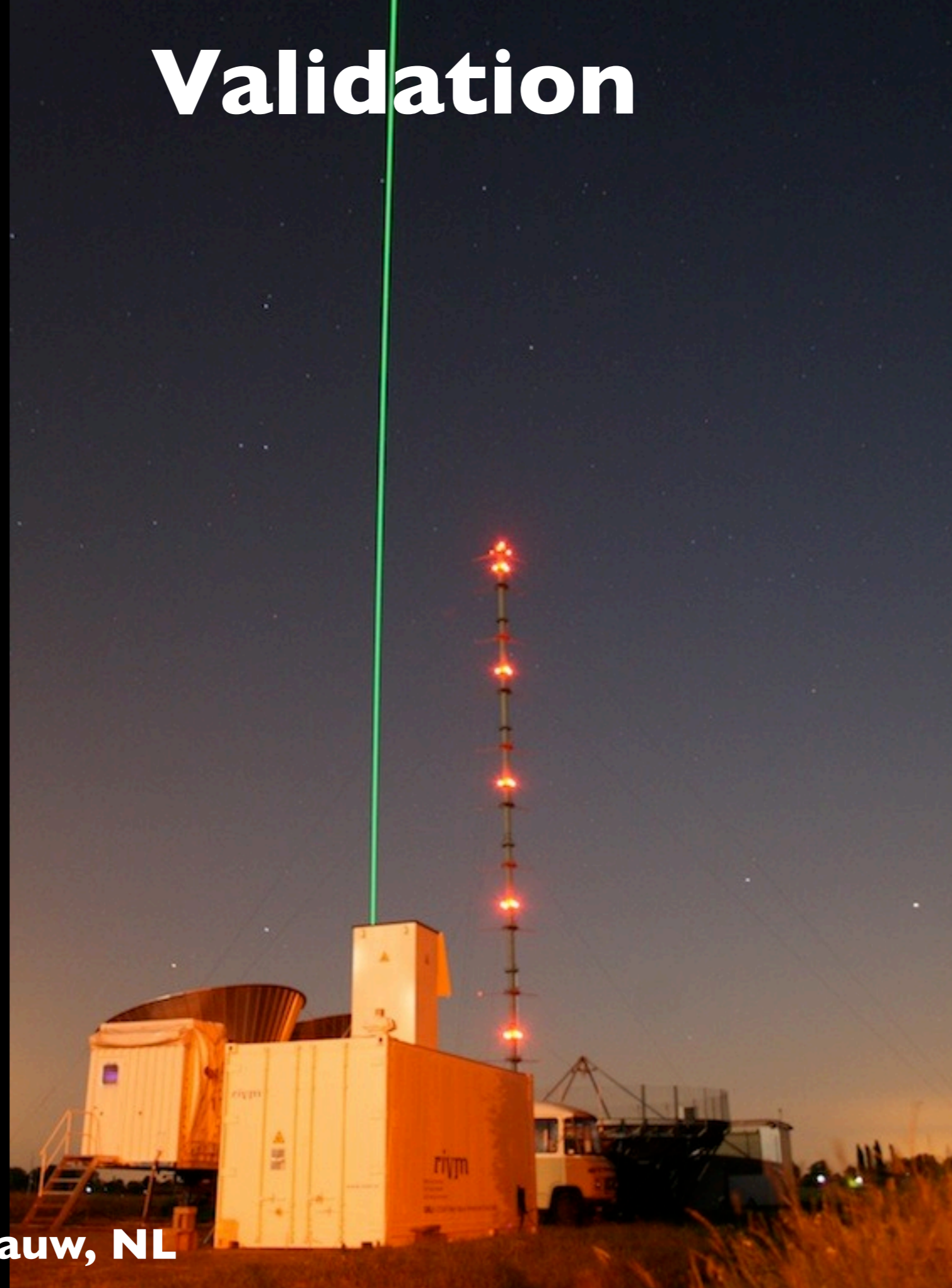
**MODIS Aqua 2012-08-25**

Wednesday, 15 May 2013

- 
- Aerosol-cloud-albedo are linked
  - Exploit all information available in the spectra
  - Combine with external information
  - Provide realistic diagnostic information

**MODIS Aqua 2012-08-25**

# Validation



**Caeli LIDAR, Cabauw, NL**

# Validation

- Shift the focus to more challenging conditions:
  - ▶ partly cloudy
  - ▶ spatial gradients
  - ▶ inhomogeneous terrain
  - ▶ high aerosol loadings
- Super sites are essential (cloud, aerosol, trace gas observations)



**Caeli LIDAR, Cabauw, NL**

# TROPOLite Initiatives

- Develop smaller and more affordable instruments for space and UAV platforms.
- Targeted spatial resolution is 1-3 km with SNR comparable to TROPOMI.



Tropospheric Monitoring Instrument

# Summary & Outlook



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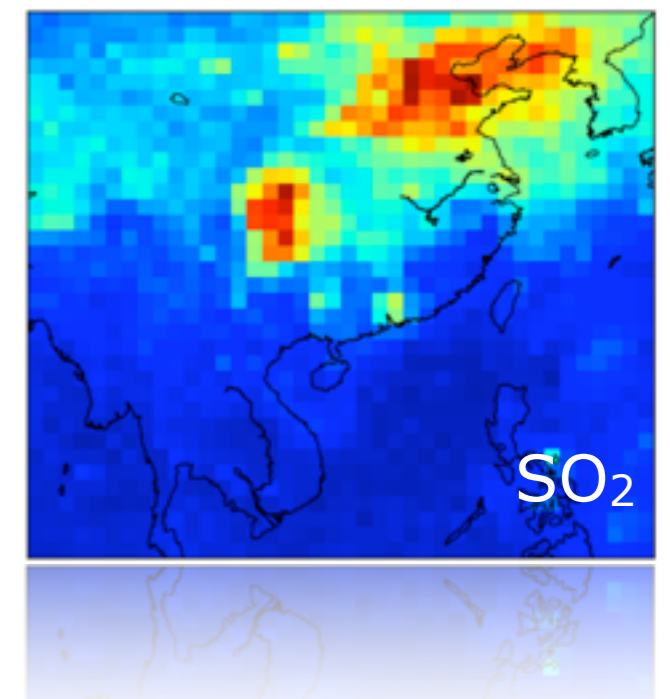
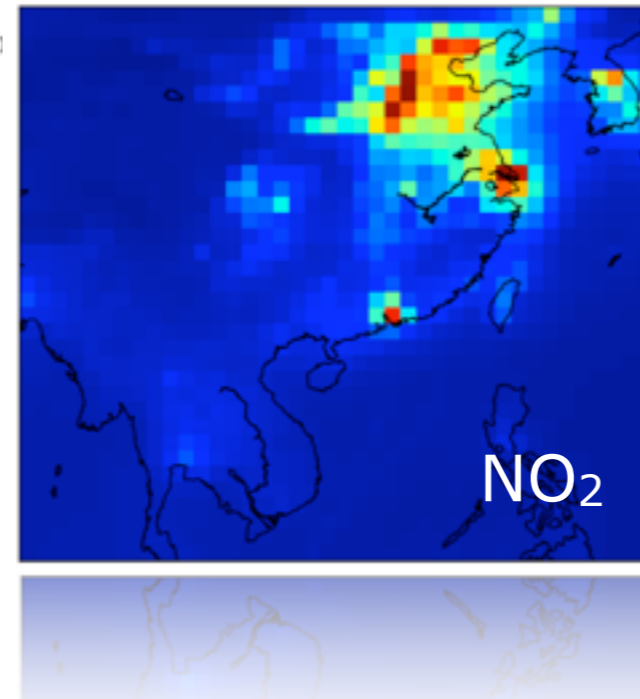
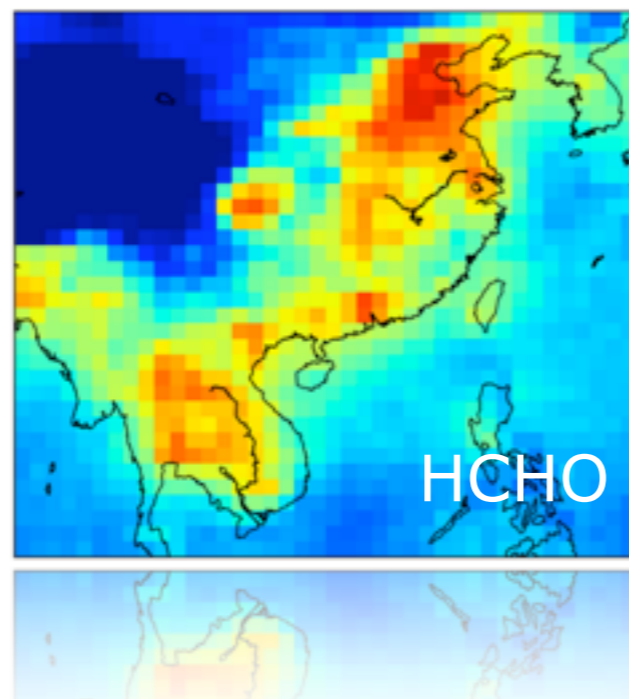
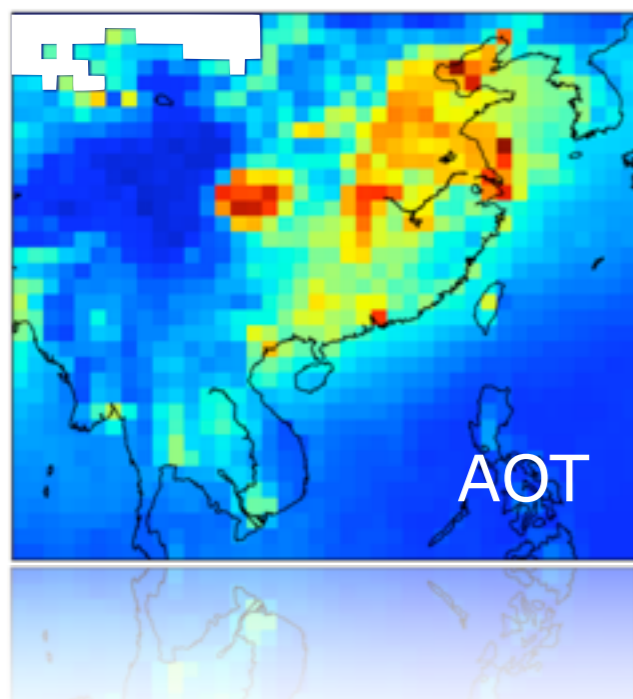
[www.tropomi.eu](http://www.tropomi.eu)

[www.temis.nl](http://www.temis.nl)

[www.knmi.nl/omi](http://www.knmi.nl/omi)

<http://www.esa.int/esaLP>

- TROPOMI will be a major step forward for atmospheric composition observations due to improved spatial resolution & sensitivity.
- The high spatial resolution provides new opportunities, while at the same time being challenging for the Level 2 product development.
- In urban areas trace gas retrievals will need to better characterize albedo and aerosol effects.
- For the validation of the L2 products campaigns are needed that focus on challenging conditions.
- New instrument for smaller and simpler instruments.





Contents lists available at [SciVerse ScienceDirect](http://SciVerse.Sciencedirect.com)

## Remote Sensing of Environment

journal homepage: [www.elsevier.com/locate/rse](http://www.elsevier.com/locate/rse)



### TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications

J.P. Veefkind<sup>a,g,\*</sup>, I. Aben<sup>b</sup>, K. McMullan<sup>c</sup>, H. Förster<sup>d</sup>, J. de Vries<sup>e</sup>, G. Otter<sup>f</sup>, J. Claas<sup>a</sup>, H.J. Eskes<sup>a</sup>, J.F. de Haan<sup>a</sup>, Q. Kleipool<sup>a</sup>, M. van Weele<sup>a</sup>, O. Hasekamp<sup>b</sup>, R. Hoogeveen<sup>b</sup>, J. Landgraf<sup>b</sup>, R. Snel<sup>b</sup>, P. Tol<sup>b</sup>, P. Ingmann<sup>c</sup>, R. Voors<sup>e</sup>, B. Kruizinga<sup>f</sup>, R. Vink<sup>f</sup>, H. Visser<sup>f</sup>, P.F. Levelt<sup>a,g</sup>

<http://dx.doi.org/10.1016/j.rse.2011.09.027>

# TROPOMI

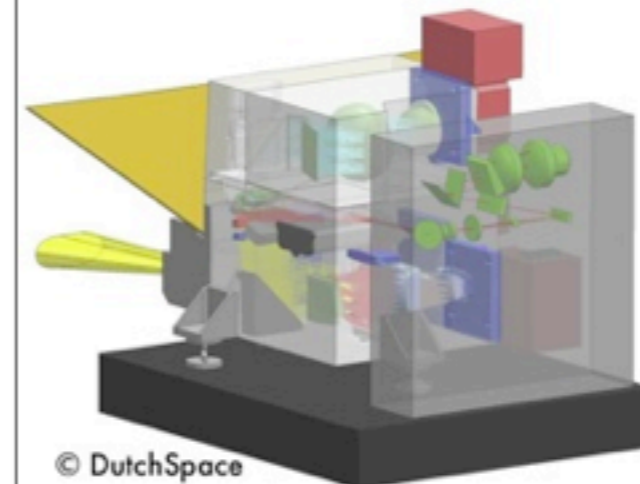
*TROPOspheric Monitoring Instrument*

[www.tropomi.eu](http://www.tropomi.eu)

[Home](#) [Instrument](#) [Data](#) [Doc](#) [Contact](#)

The TROPOspheric Monitoring Instrument (TROPOMI) is a spaceborne nadir viewing spectrometer with bands in the ultraviolet, the visible, the near infrared and the shortwave infrared. TROPOMI is the payload for the ESA/GMES Sentinel 5 Precursor mission, planned for launch in 2014 with 7 years design lifetime. The objective of the mission is to provide high-quality and timely information on the global atmospheric composition for climate and air quality applications. TROPOMI will make daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, methane, formaldehyde and aerosol properties. The Sentinel-5 Precursor mission will extend the current data records from OMI (Ozone Monitoring Instrument) on NASA EOS Aura and SCIAMACHY (SCanning Imaging Absorption spectrometer for Atmospheric Cartography) on ESA Envisat and is the link between the current scientific missions and the operational Sentinel-4/-5 missions.

TROPOMI is an initiative from the Netherlands and is developed in cooperation







# TROPOMI L2 PRODUCTS

L2 Working Group

PROTOTYPE

VERIFICATION

OPERATIONAL SW

GOME-SCIAMACHY-OMI

KNMI | DLR | IUP-Bremen | BIRA | SRON | MPIC | RAL

# Challenges and Opportunities

- High data rate ( $\sim 300$  spectra per second)
- Stringent near-real-time requirements
- Increased spatial resolution
- Enhanced retrieval approaches:
  - ▶ surface albedo variations
  - ▶ cloud and aerosol corrections
  - ▶ averaging kernels
  - ▶ ...



# TROPOMI Science Objectives

- To better **constrain** the strength, evolution, and spatiotemporal variability of **the sources of trace gases and aerosols** impacting air quality and climate.
- To **improve upon the attribution of climate forcing** by a better understanding of the processes controlling the lifetime and distribution of methane, tropospheric ozone, and aerosols.
- To better estimate **long-term trends** in the troposphere related to air quality and climate from the regional to the global scale.
- To **develop and improve air quality model processes and data assimilation** in support of operational services including air quality forecasting and protocol monitoring.



# TROPOMI Data Use

## Analysis based on multiple species

*Need for consistency in retrieval methods.*

## Data assimilation

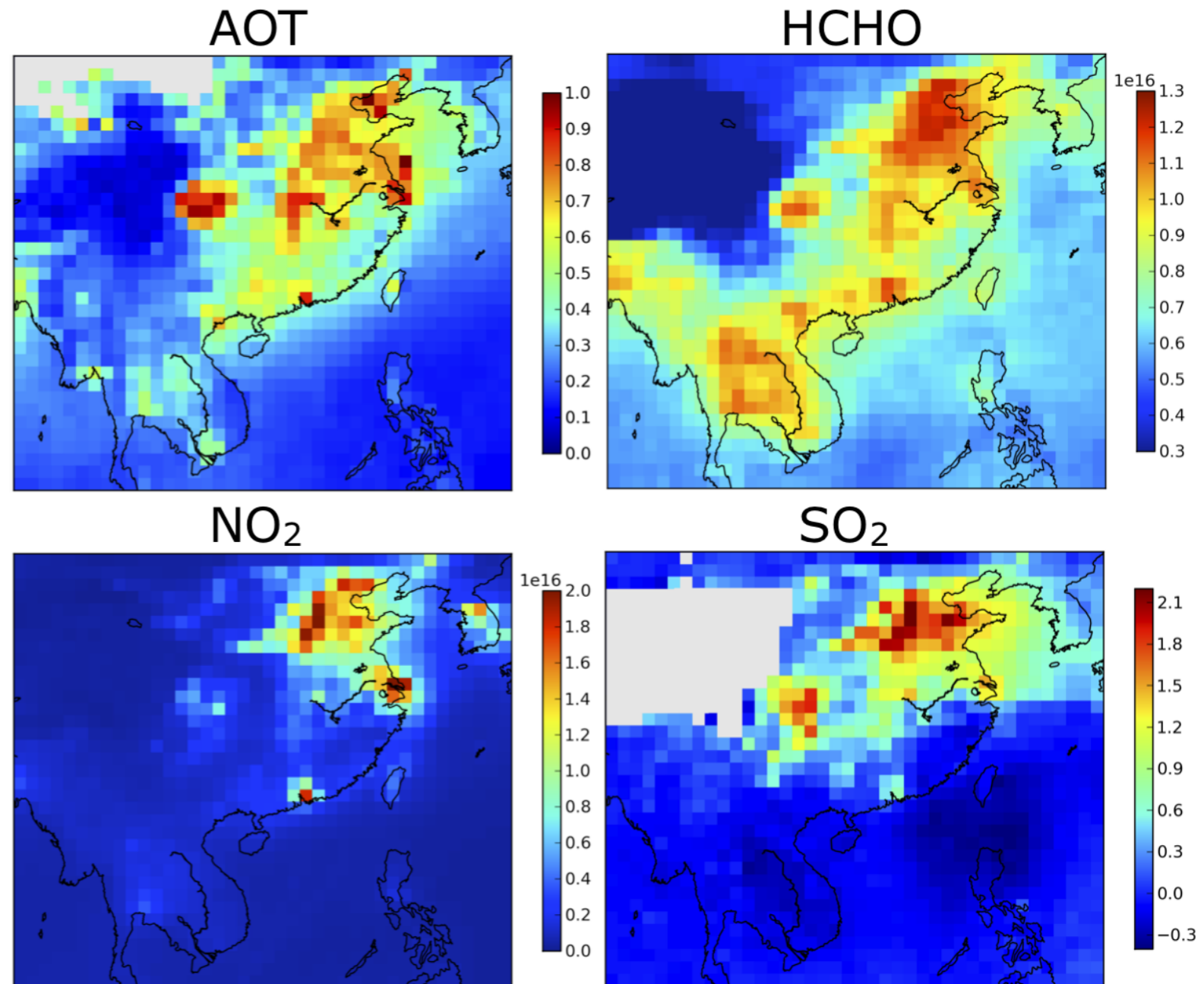
*Sophisticated error analysis are needed.*

## Focus on the troposphere

*Sensitivity varies with altitude, aerosols and clouds.*

## Operational data usage

*near-real-time data*



Veefkind, J. P., et. al.: Atmos. Chem. Phys. Discuss., 10, 18919-18951

# TROPOMI Data Product Development

*Goal: To develop operational TROPOMI data products that*

- ▶ meet the user requirements
- ▶ are state-of-science
- ▶ have reliable and well-described quality
- ▶ have open access and are easy to use
- ▶ contribute to long-term data records
- ▶ are continuously evaluated and improved
- ▶ are of reasonable quality within 3 (tbc) months after commissioning

