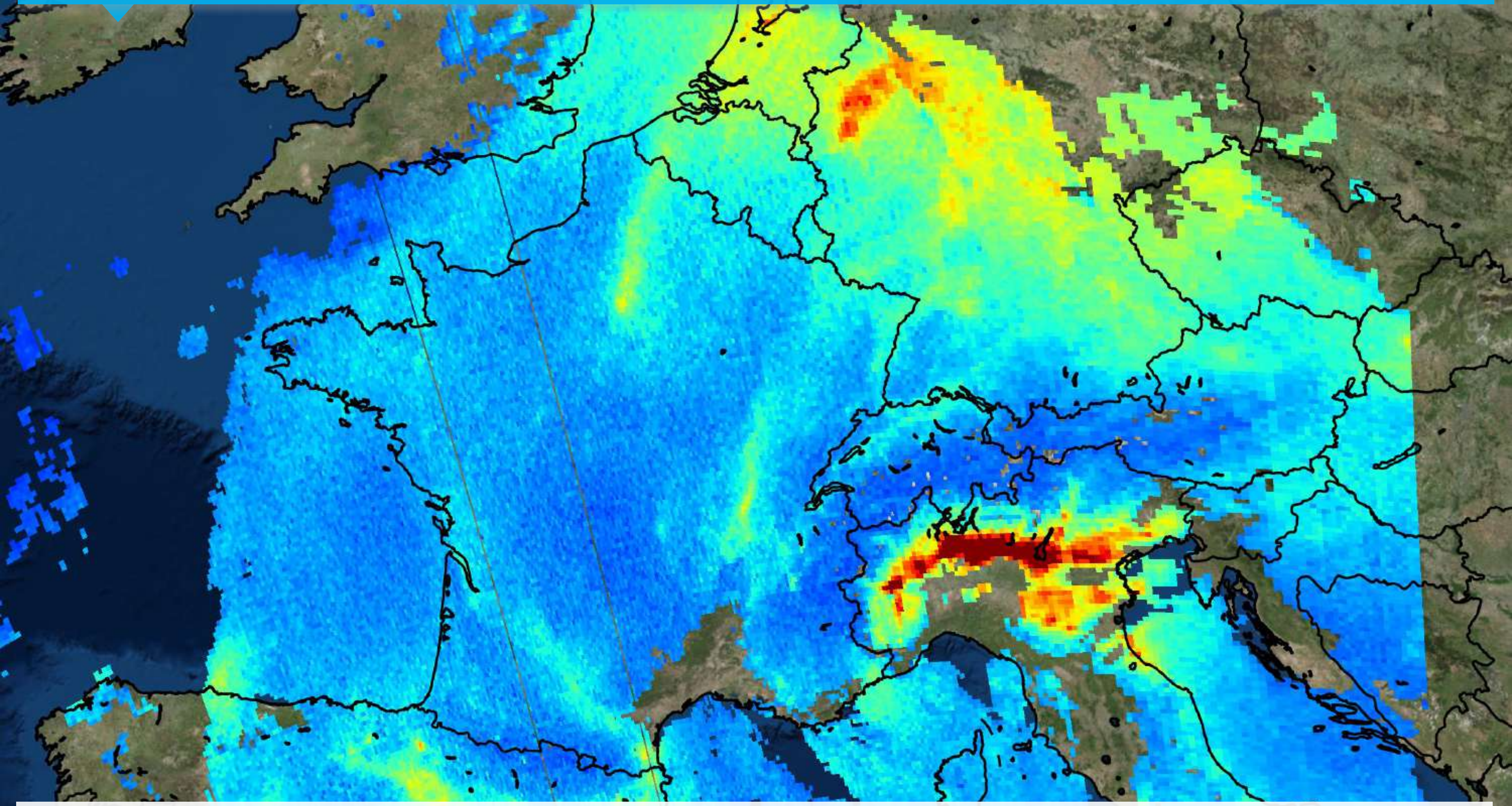
OPPORTUNITIES OF SATELLITE OBSERVATIONS FOR IMPROVING NITROGEN DEPOSITION ESTIMATES



Shelley van der Graaf
Jan Willem Erisman

VU UNIVERSITY AMSTERDAM

TNO innovation for life

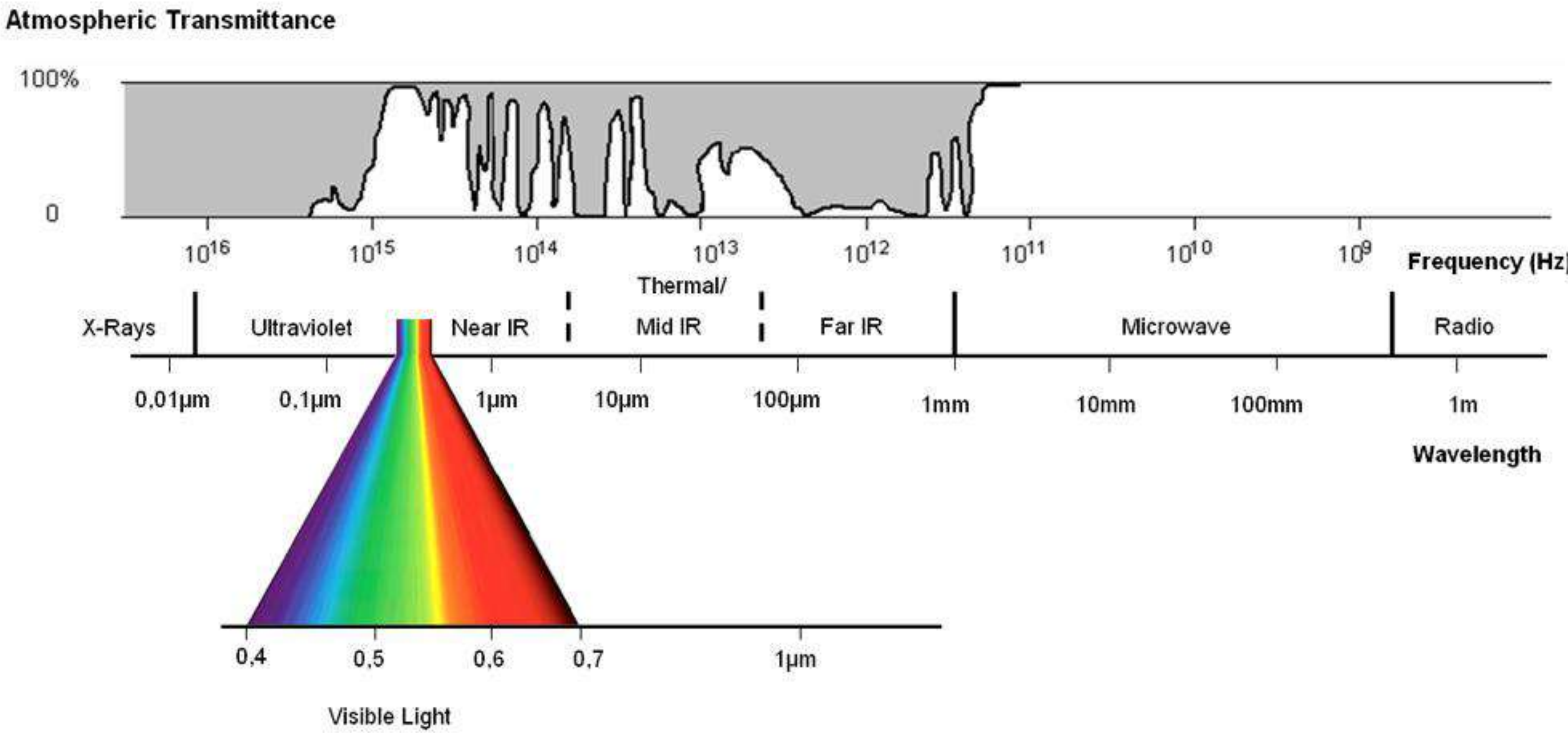
OUTLINE

- Introduction
- Satellite products relevant for N (-deposition)
- Combining models and satellite: Recent developments
- VU and TNO activities
- Potential products expected the coming years

SATELLITE REMOTE SENSING

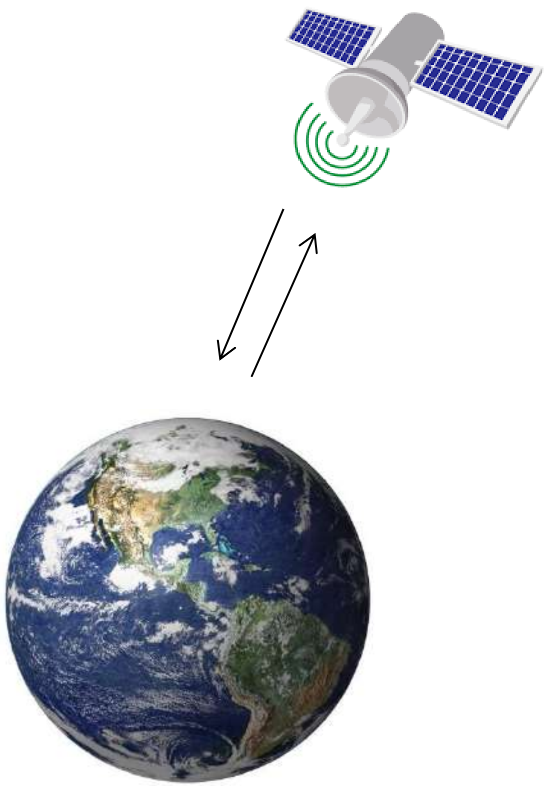
SATELLITE REMOTE SENSING

Electromagnetic spectrum & atmospheric transmittance



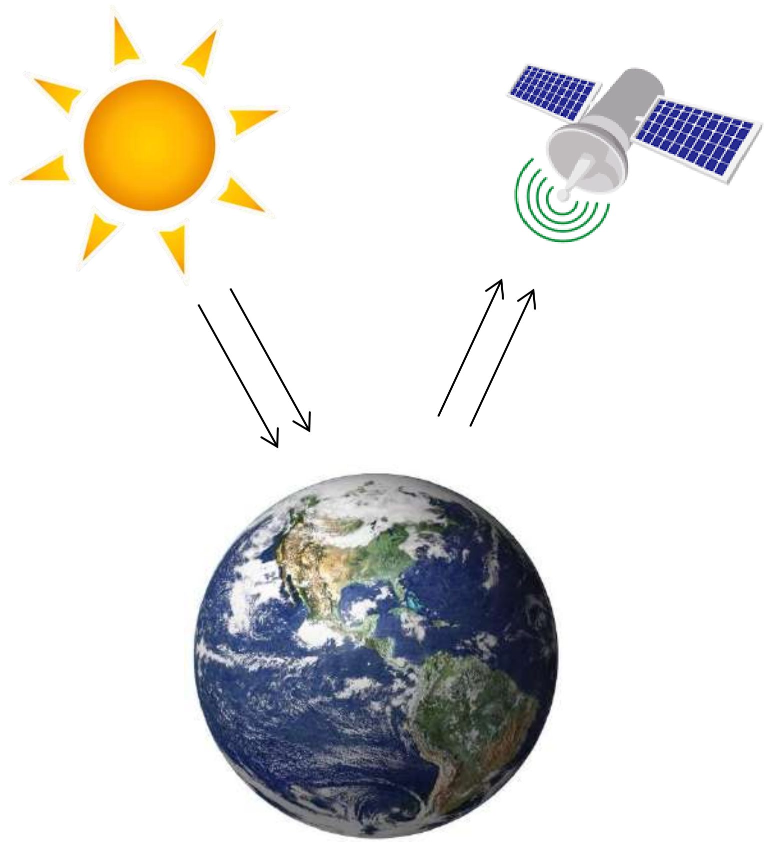
Source: Albertz et al., 2007

SATELLITE REMOTE SENSING



Active sensors

Emit their own energy source



Passive sensors

Use the sun and earth as energy source

ACTIVE REMOTE SENSING

RADAR

RAdio Detection And Ranging

- MetOp, Envisat, Sentinel-1, …
- SAR, scatterometers, altimeters

LIDAR

LIght Detection And Ranging

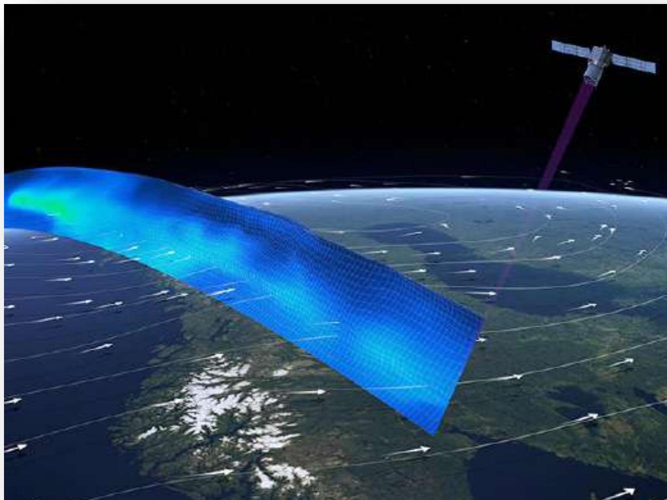
- ICESat, CALIPSO, …
- Discrete return or full waveform

Figure 1: CALIPSO’s laser probing Earth’s atmosphere.

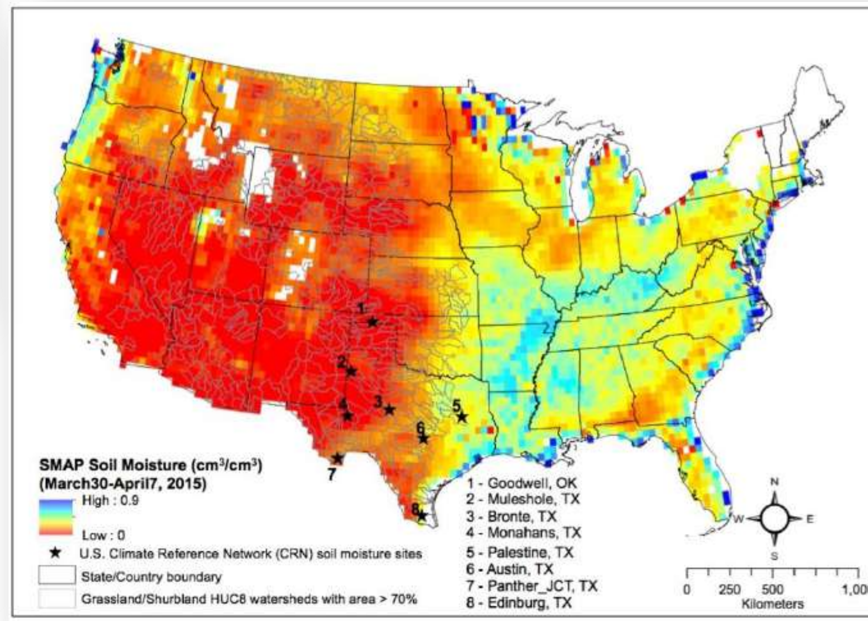
Credits: P. Carril / CNES

ACTIVE REMOTE SENSING

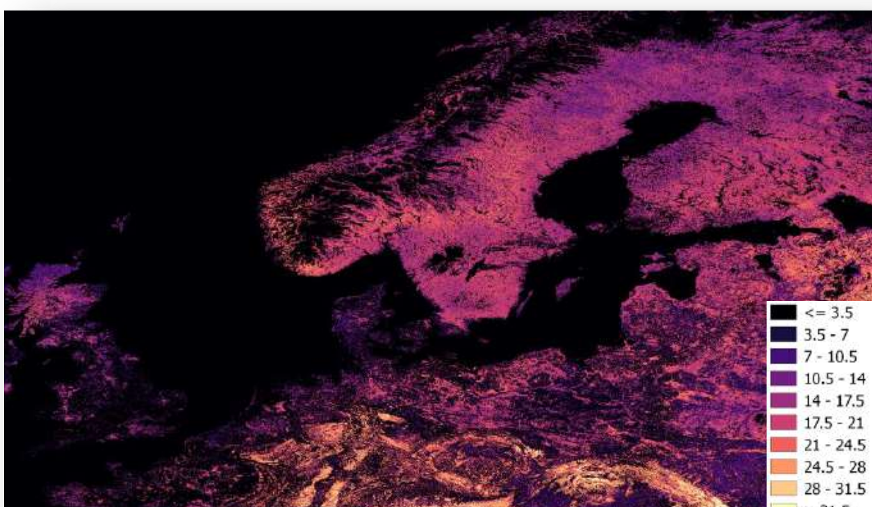
Wind speed



Soil moisture



Tree canopy height



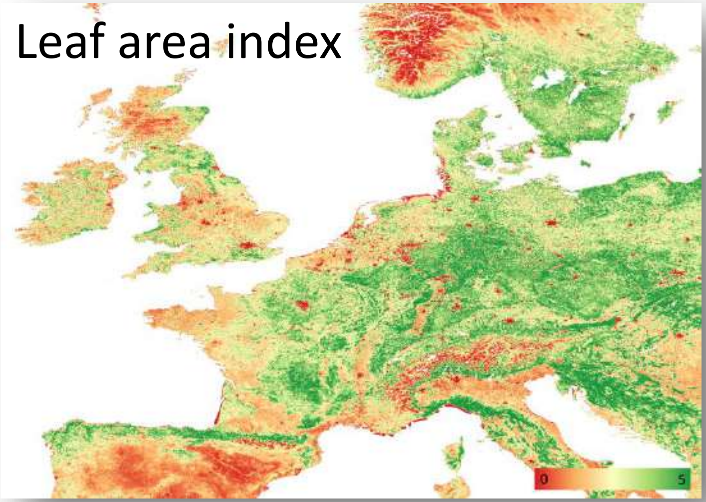
PASSIVE REMOTE SENSING

Mission (Instrument)	Spectral bands	Resolution	Coverage
Terra/Aqua (MODIS)	36 bands	250 – 500 m	Global, daily
Landsat (OLI-TIRS)	11 bands	30 m	Global, 16 days
RapidEye (5 satellites)	5 bands	5 m	Global, 5 days
SPOT	5 bands	5 – 1.5 m	Global, 26 days

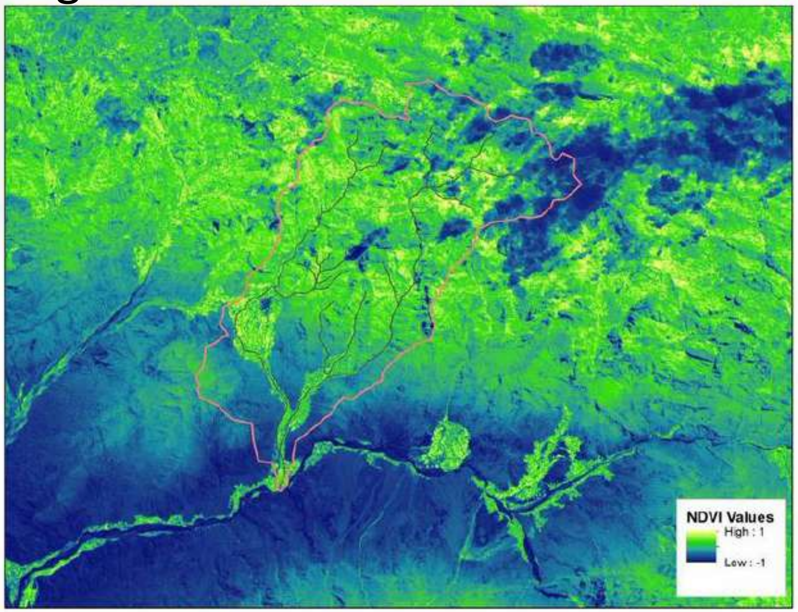
Table 1: Examples of multi-spectral satellite missions with different horizontal resolutions.

PASSIVE REMOTE SENSING

Leaf area index

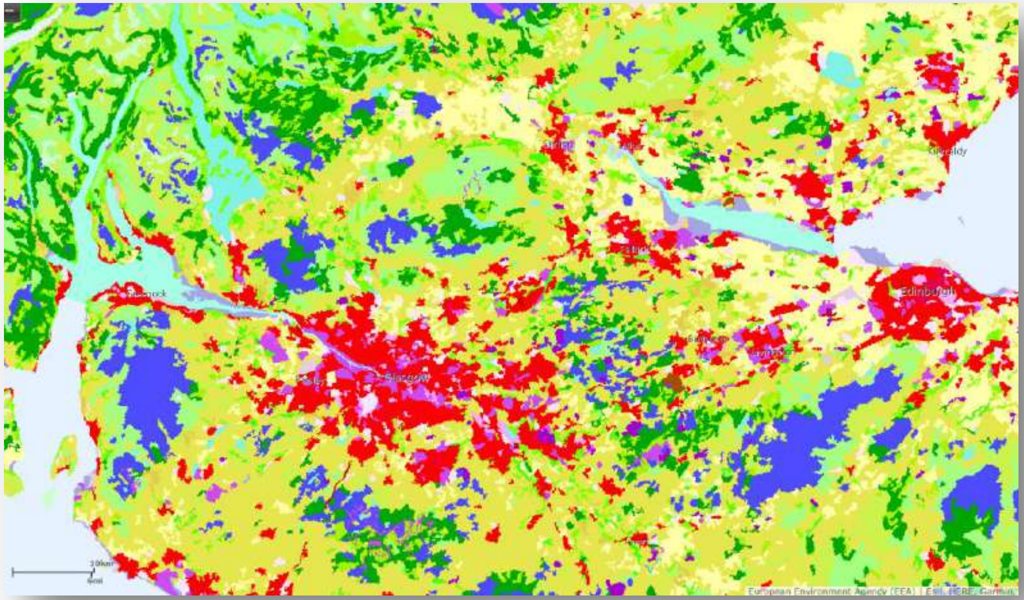


Vegetation indices



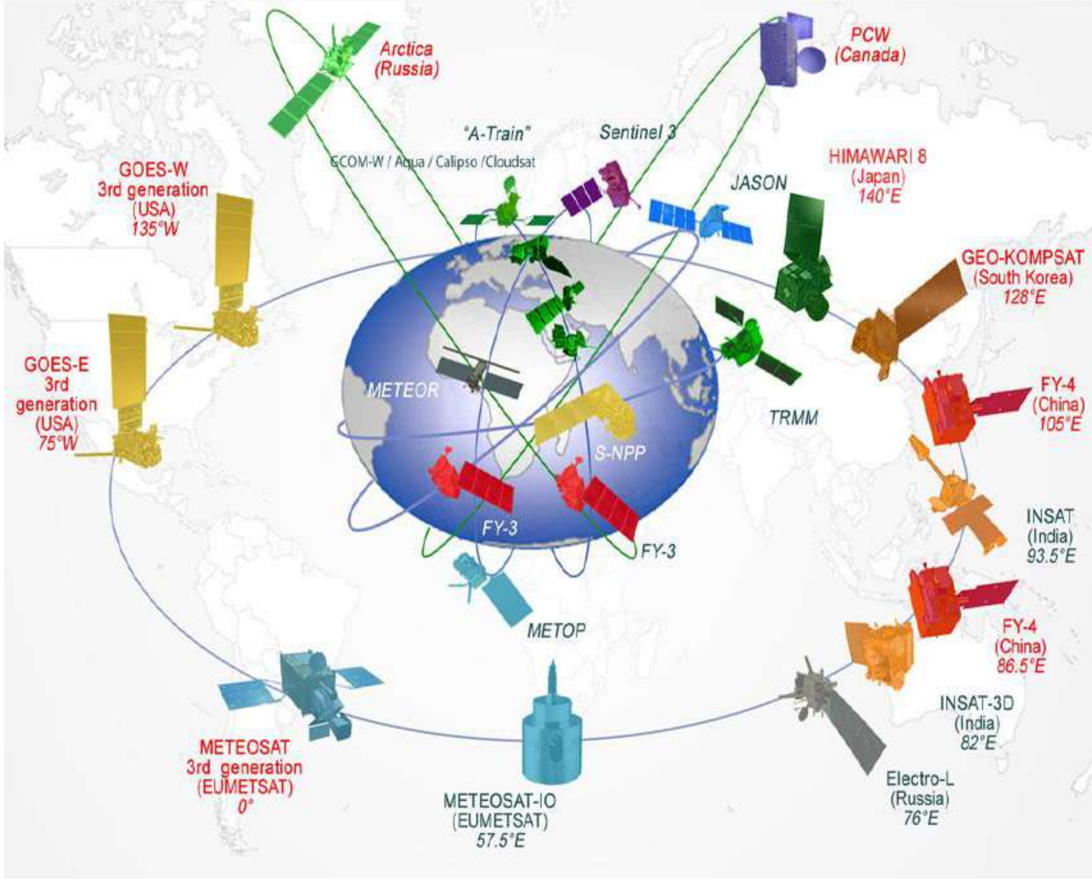
(Padgett-Vasquez, S., 2014)

High resolution land use maps



METEOROLOGICAL SATELLITES

- Passive remote sensing (most)
- Geostationary & polar-orbiting
- Examples of products:
  - Temperature
  - Humidity
  - Wind fields
  - Cloud fields



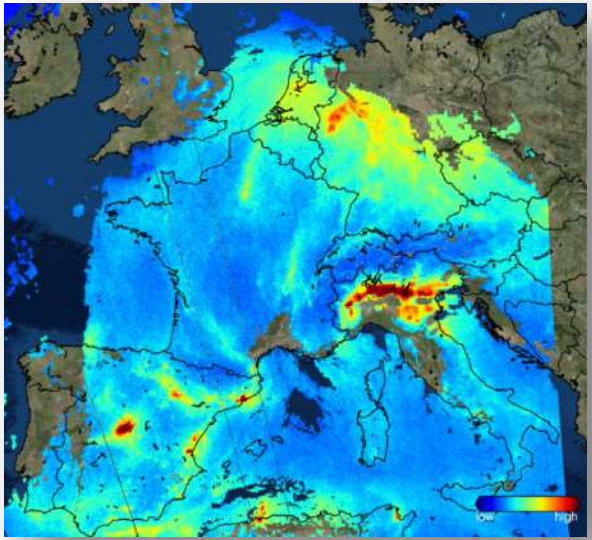
Source: Deutsche Wetterdienst, www.dwd.de

- Foundation of Numerical Weather Prediction Models
- Used in Atmospheric Transport Models

ATMOSPHERIC COMPOSITION

- Passive sensors
- Main absorption lines
  - NO_2 in UV region
  - NH_3 in IR region

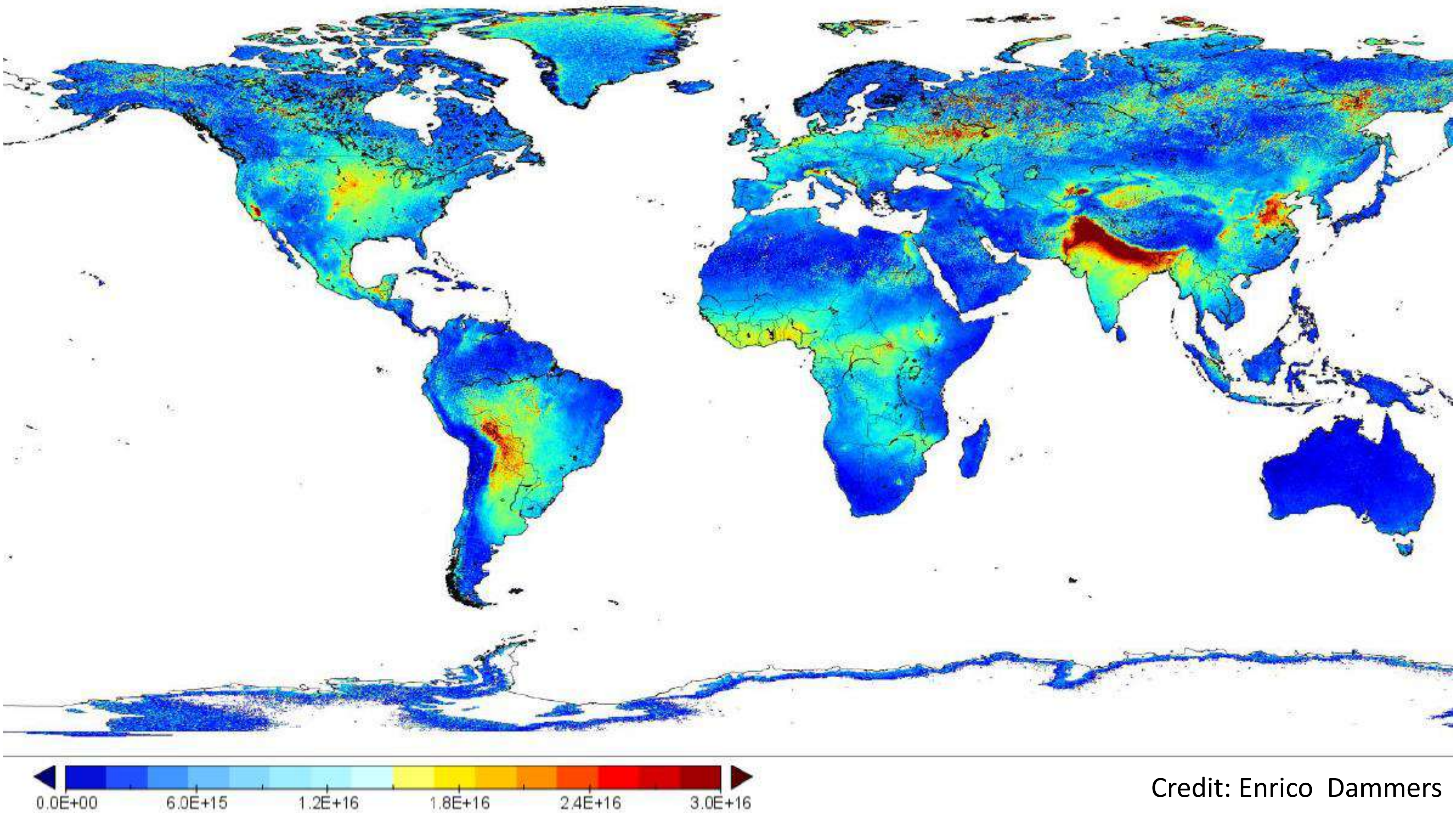
Figure 1: TROPOMI measurements of atmospheric NO_2 over Europe.



	Instrument	Footprint	Coverage	
NO_2	**OMI** (Ozone Monitoring Instrument)	24 x 13 km^2	Global, daily	2004 -
	GOME-2 (Global Ozone Monitoring Experiment)	80 x 40 km^2	Global, near-daily	2006-
	TROPOMI (TROPOspheric Monitoring Instrument)	7 x 7 km^2	Global, daily	2018 -
NH_3	**AIRS** (Atmospheric InfraRed Sounder)	50 x 50 km^2	Global, twice daily	2002 -
	TES (Tropospheric Emission Spectrometer)	5 x 8 km^2	Global, 16 days	2004-2018
	IASI (Infrared Atmospheric Sounding Interferometer)	12 x 12 km^2	Global, twice daily	2006 -
	CrIS (Cross-track Infrared Scanner)	14 x 14 km^2	Global, twice daily	2011 -

Table 1: Overview of satellite instruments that measure atmospheric N_r components.

ATMOSPHERIC COMPOSITION

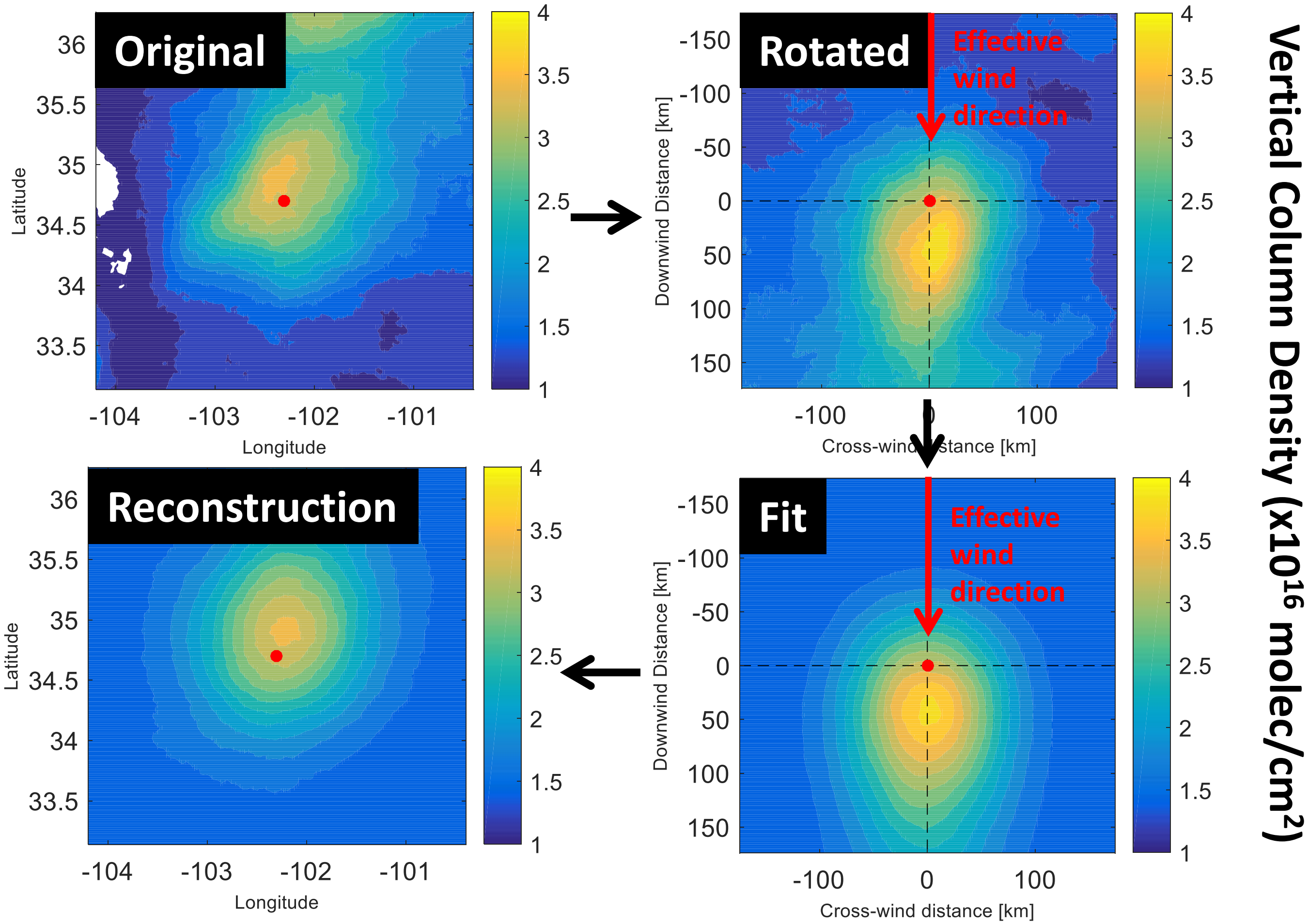


Credit: Enrico Dammers

Figure 1: NH_3 total column (molecules/cm2) measured by IASI, weighted mean 2008-2013.

POINT SOURCE EMISSIONS

Point source emissions and atmospheric lifetime estimation



Credit: Enrico Dammers & Chris Mclinden

COMBINE MODEL AND SATELLITE

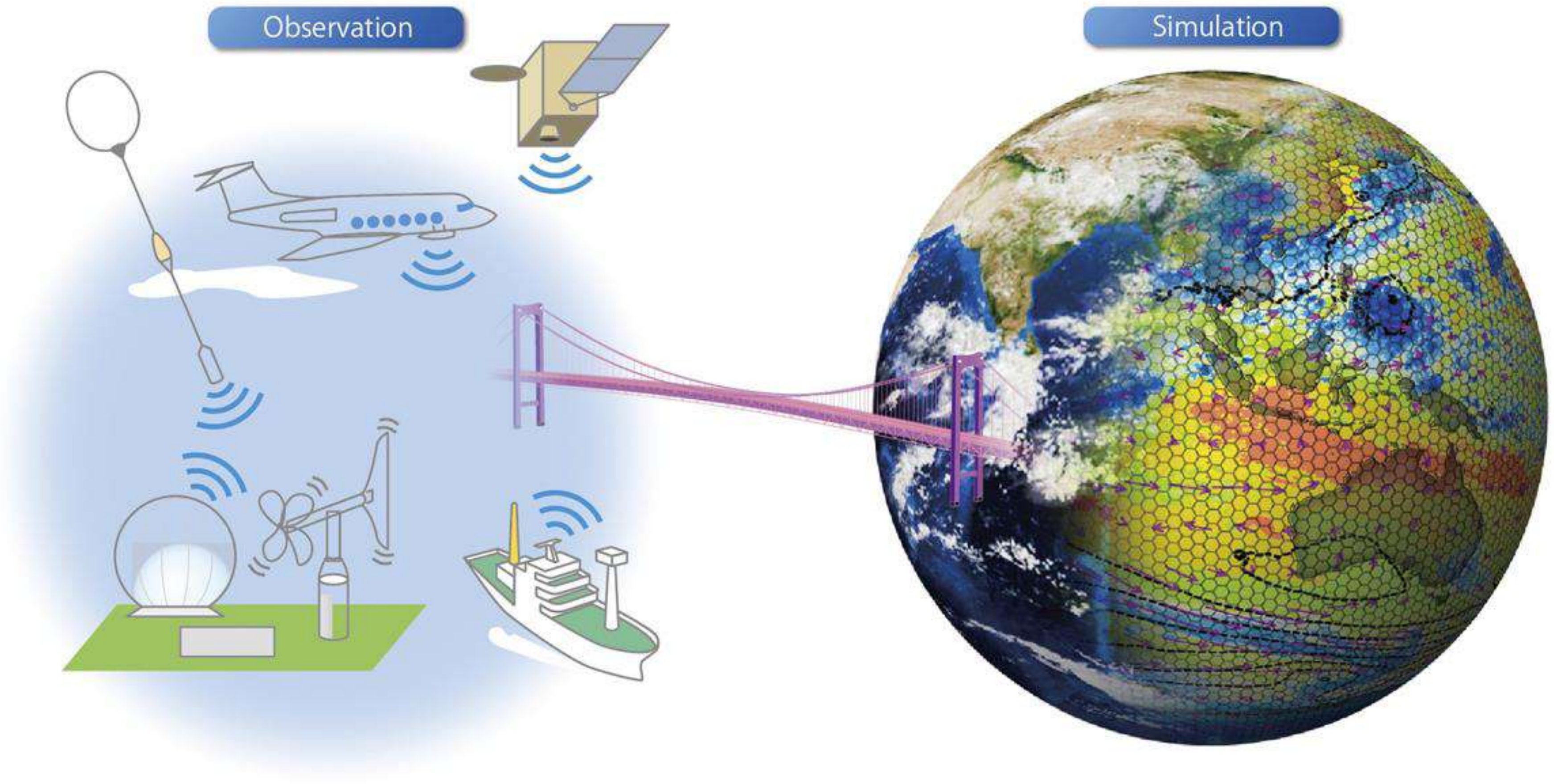
Advantages of satellite observations:

- Many different products available
- Large-scale coverage at high spatial resolution

But…

- Only observe state of a system at the satellite overpass
- Missing data (e.g. clouds, instrument errors,…)
- Limited validation

COMBINE MODEL AND SATELLITE



Create a link between observations and model simulations

COMBINE MODEL AND SATELLITE

Possible ways to combine model & satellite:

- Satellite observations as input for models
- Models for translating satellite information into products
- Data-assimilation
  - Observations incorporated into the model state itself
  - Considers uncertainty of both the model and observations

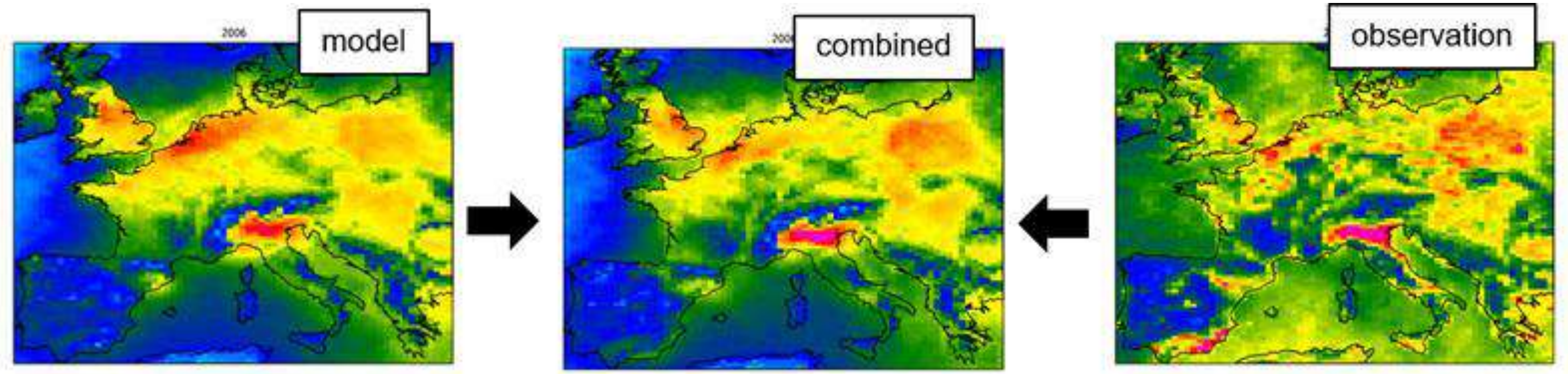


Figure 1: Data-assimilation of the OMI-NO_2 product in the LOTOS-EUROS atmospheric transport model.

RECENT DEVELOPMENTS (N_R DEPOSITION)

Global dry deposition of nitrogen dioxide and sulfur dioxide inferred from space-based measurements

C. R. Nowlan[1,2], R. V. Martin[1,2], S. Philip[1], L. N. Lamsal[3], N. A. Krotkov[3], E. A. Marais[4], S. Wang[5], and Q. Zhang[6]

2014

Global inorganic nitrogen dry deposition inferred from ground- and space-based measurements

Yanlong Jia[1,2], Guirui Yu[1], Yanni Gao[3], Nianpeng He[1], Qiufeng Wang[1], Cuicui Jiao[1,2] & Yao Zuo[1,2]

2016

Dry deposition of NO_2 over China inferred from OMI columnar NO_2 and atmospheric chemistry transport model

X.Y. Zhang[a], X.H. Lu[a,*], L. Liu[a], D.M. Chen[b,c], X.M. Zhang[a,d], X.J. Liu[e], Y. Zhang[f]

2017

Estimation of monthly bulk nitrate deposition in China based on satellite NO_2 measurement by the Ozone Monitoring Instrument

Lei Liu[a], Xiuying Zhang[a,*], Wen Xu[b], Xuejun Liu[b], Xuehe Lu[a], Dongmei Chen[c], Xiaomin Zhang[a], Shanqian Wang[a,d], Wuting Zhang[a]

2017

Global deposition of total reactive nitrogen oxides from 1996 to 2014 constrained with satellite observations of NO_2 columns

Jeffrey A. Geddes[1,a] and Randall V. Martin[1,2]

2017

Dry Deposition of Reactive Nitrogen From Satellite Observations of Ammonia and Nitrogen Dioxide Over North America

S. K. Kharol[1], M. W. Shephard[1], C. A. McLinden[1], L. Zhang[1], C. E. Sioris[1], J. M. O'Brien[1], R. Vet[1], K. E. Cady-Pereira[2], E. Hare[1], J. Siemons[1,3], and N. A. Krotkov[4]

2018

RECENT DEVELOPMENTS

Global dry deposition of nitrogen dioxide and sulfur dioxide inferred from space-based measurements

C. R. Nowlan[1,2], R. V. Martin[1,2], S. Philip[1], L. N. Lamsal[3], N. A. Krotkov[3], E. A. Marais[4], S. Wang[5], and Q. Zhang[6]

Dry deposition of NO_2 and SO_2

- Combination of OMI-NO_2 and the GEOS-Chem model
- Vertical profiles from GEOS-Chem used to compute surface concentrations

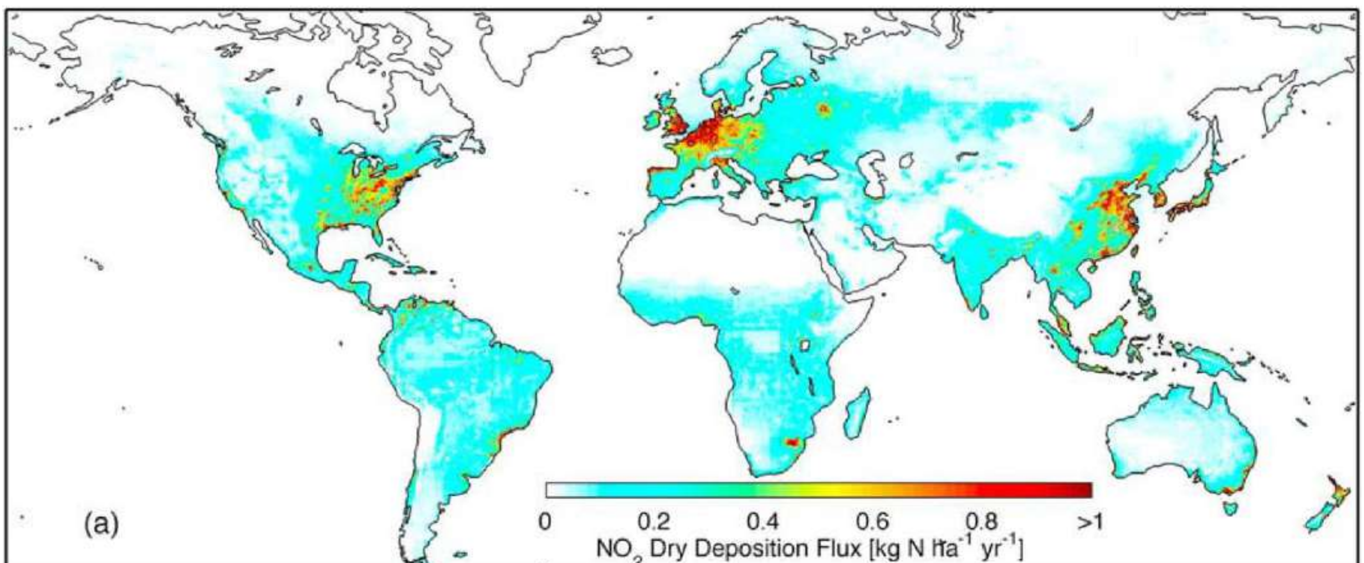


Figure 1: Total 2005-2007 annual mean nitrogen deposition from NO_2 dry deposition [Nowlan et al., 2014].

RECENT DEVELOPMENTS

Dry deposition of NO_2, HNO_3, NO_3^-, NH_4^+, NH_3

- Empirical model that relates OMI-NO_2 total columns to ground measurements from 555 monitoring sites for NO_2, HNO_3, NO_3^-, NH_4^+
- NH_3 surface concentrations directly interpolated from 267 monitoring sites

Global inorganic nitrogen dry deposition inferred from ground- and space-based measurements

Yanlong Jia[1,2], Guirui Yu[1], Yanni Gao[3], Nianpeng He[1], Qiufeng Wang[1], Cuicui Jiao[1,2] & Yao Zuo[1,2]

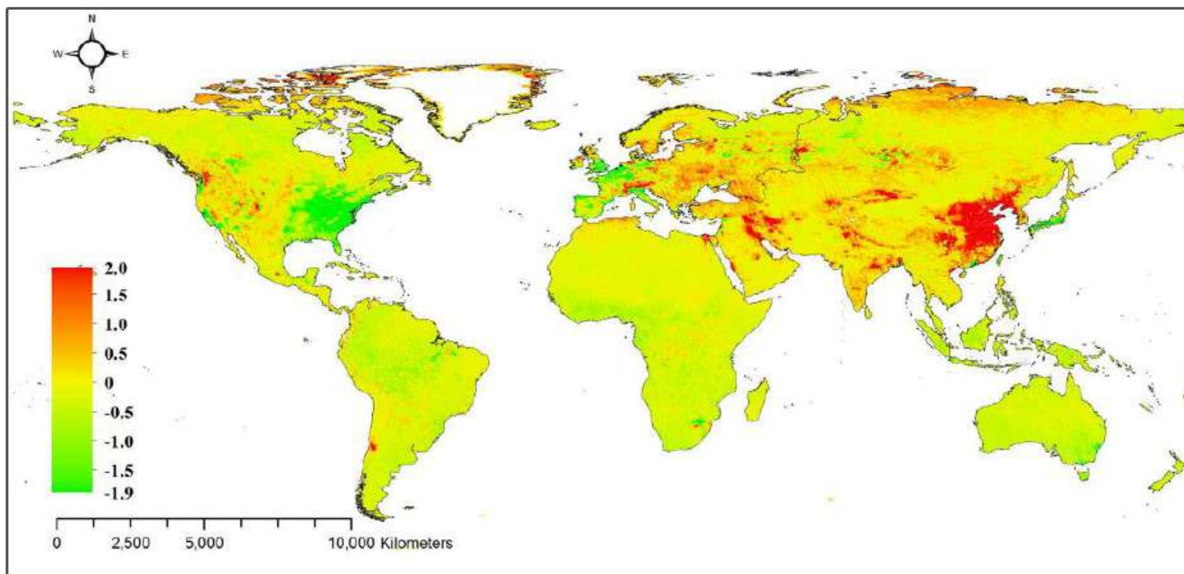
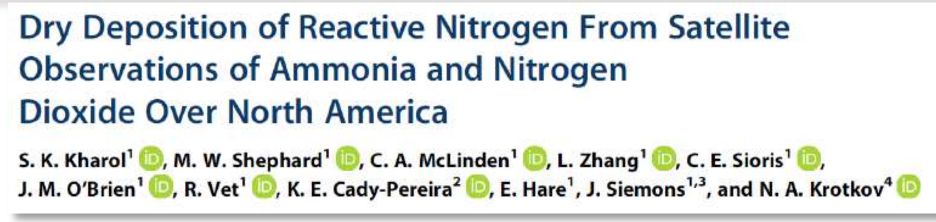


Figure 1: Average annual changes in dry N deposition fluxes (kg N ha-1 a-1) from 2005-2014 [Jia et al., 2016].

RECENT DEVELOPMENTS


Dry Deposition of Reactive Nitrogen From Satellite Observations of Ammonia and Nitrogen Dioxide Over North America

S. K. Kharol[1], M. W. Shephard[1], C. A. McLinden[1], L. Zhang[1], C. E. Sioris[1], J. M. O'Brien[1], R. Vet[1], K. E. Cady-Pereira[2], E. Hare[1], J. Siemons[1,3], and N. A. Krotkov[4]

Dry deposition of NO_2 and NH_3

- OMI-NO_2 and CrIS-NH_3 satellite observations
- NO_2 vertical profile and V_d from GEM-MACH model
- NH_3 vertical profile from CrIS retrieval

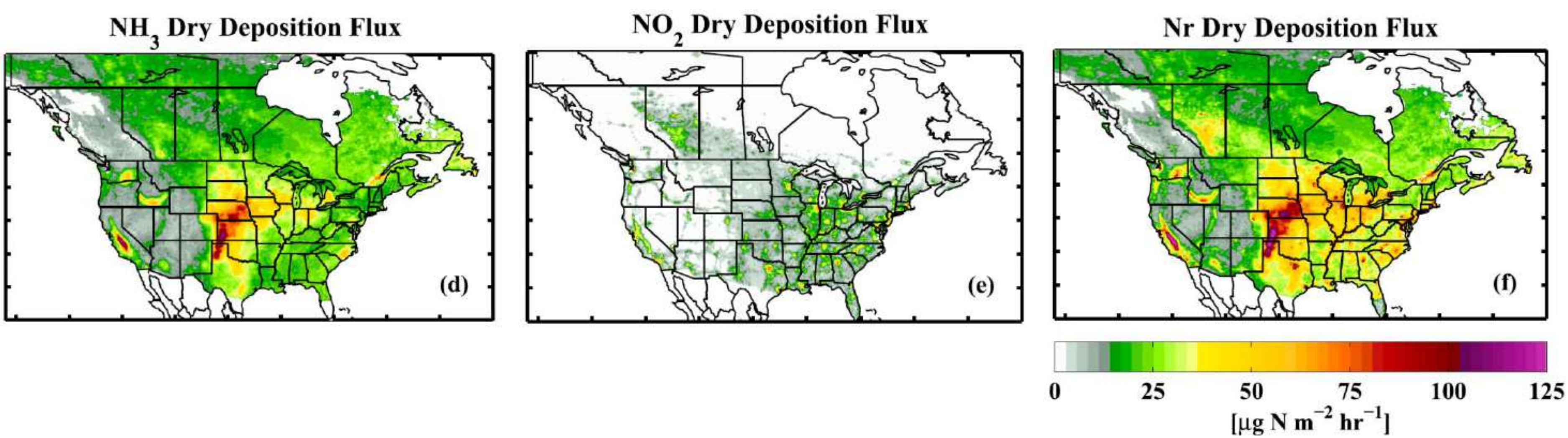
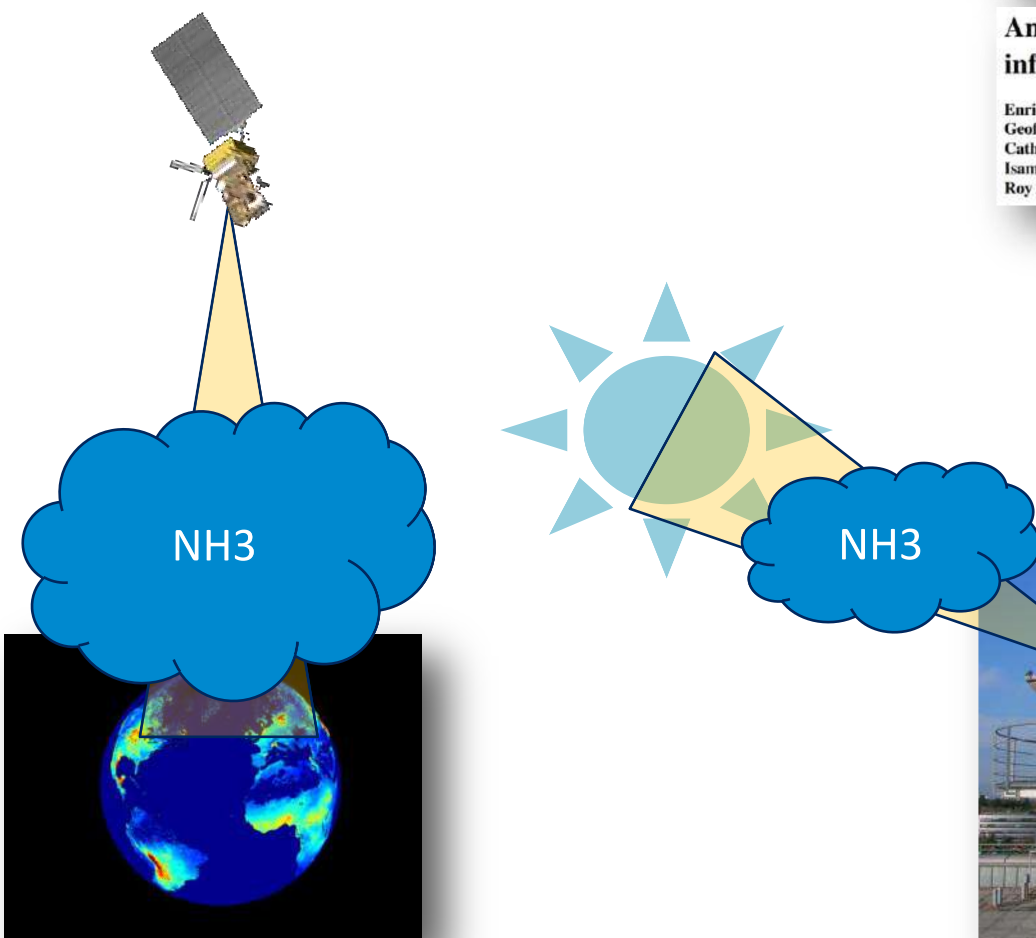


Figure 1: Dry nitrogen deposition from NH_3 and NO_2 during the warm season of 2013 [Kharol et al., 2018].

RECENT DEVELOPMENTS

Validation of IASI and CrIS NH_3 products



Retrieval of ammonia from ground-based FTIR solar spectra

E. Dammers[1], C. Vigouroux[2], M. Palm[3], E. Mahieu[4], T. Warneke[3], D. Smale[5], B. Langerock[2], B. Franco[4], M. Van Damme[1,6], M. Schaap[7], J. Notholt[3], and J. W. Erisman[1,8]

An evaluation of IASI-NH_3 with ground-based Fourier transform infrared spectroscopy measurements

Enrico Dammers[1], Mathias Palm[2], Martin Van Damme[1,3], Corinne Vigouroux[4], Dan Smale[5], Stephanie Conway[6], Geoffrey C. Toon[7], Nicholas Jones[8], Eric Nussbaumer[9], Thorsten Warneke[2], Christof Petri[2], Lieven Clarisse[3], Cathy Clerbaux[3], Christian Hermans[4], Erik Lutsch[6], Kim Strong[6], James W. Hannigan[9], Hideaki Nakajima[10], Isamu Morino[11], Beatriz Herrera[12], Wolfgang Stremme[12], Michel Grutter[12], Martijn Schaap[13], Roy J. Wichink Kruit[14], Justus Notholt[2], Pierre-F. Coheur[3], and Jan Willem Erisman[1,15]

Validation of the CrIS Fast Physical NH_3 Retrieval with ground-based FTIR

Enrico Dammers[1], Mark W. Shephard[2], Mathias Palm[3], Karen Cady-Pereira[4], Shannon Capps[5*], Erik Lutsch[6], Kim Strong[6], James W. Hannigan[7], Ivan Ortega[7], Geoffrey C. Toon[8], Wolfgang Stremme[9], Michel Grutter[9], Nicholas Jones[10], Dan Smale[11], Jacob Siemons[2], Kevin Hrpcek[12], Denis Tremblay[13], Martijn Schaap[14], Justus Notholt[3], Jan Willem Erisman[1,15]

Credit: Enrico Dammers

RECENT DEVELOPMENTS

Both IASI and CrIS satellite products are consistent with FTIR measurements

IASI:

- Underestimates the retrieved columns (~30%)
- Not enough sensitivity near surface for good comparison with in situ-data

CrIS:

- Underestimates high concentration levels
- Overestimates low concentration levels
- Good correlations with in-situ data

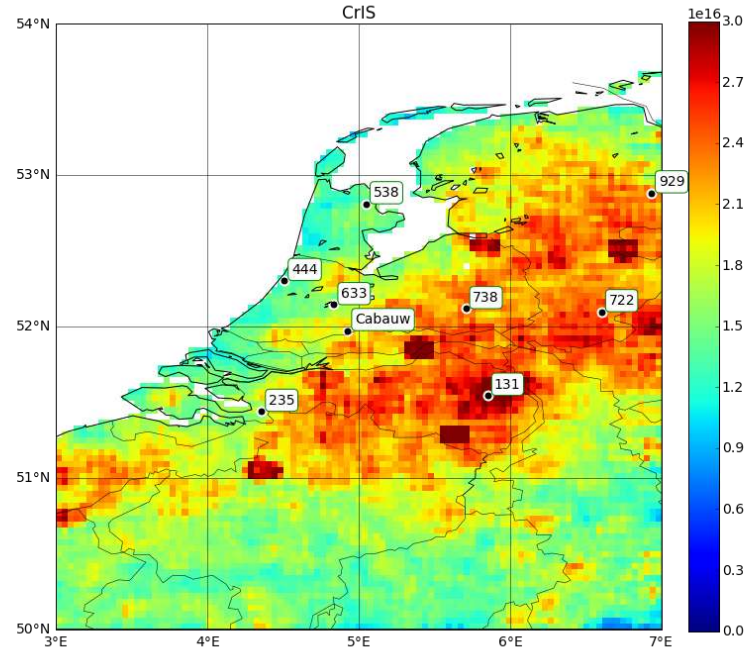


Figure 1: CrIS mean NH_3 total column [Dammers et al., 2017].

Science and mission objectives

Mission objectives

mapping near-surface atmospheric NH_3 and NO_2 at spatial scales of 1 km or below

1. To *quantify the* **emissions** of the main contributors to reactive nitrogen –NO_x and NH_3– on the landscape scale, and to *attribute the relative contributions of natural, industrial, agricultural, fire and urban sources*.
2. To *quantify the atmospheric* **dispersion and deposition** of reactive nitrogen and its impacts on ecosystems.
3. To *quantify the contribution of reactive nitrogen to* **air pollution**.
4. To *reduce uncertainties in the contribution of reactive nitrogen to* **climate forcing** through a better understanding of atmospheric chemical reactions, secondary aerosol formation and biogeochemical cycles.

Nitrosat would will fill observational gaps needed to address several ESA's living planet scientific challenges

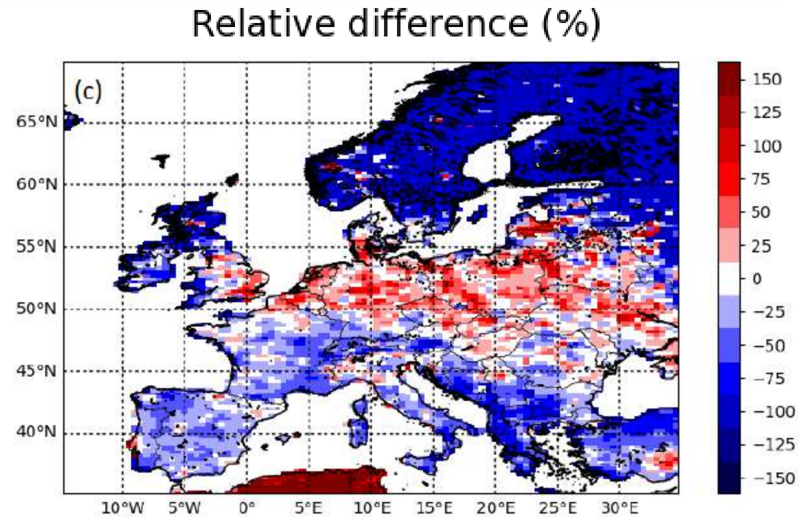
Atmosphere (A1, A2, A3) - Land surface (L1, L2, L3, L5) - Ocean (O1, O3)

Credit: Martin van Damme, Pierre Coheur, UVB

VU AND TNO ACTIVITIES

NH_3 surface concentrations & dry deposition fluxes over Europe

- Combination of LOTOS-EUROS model and IASI-NH_3 satellite observations
- Comparison with in-situ measurements



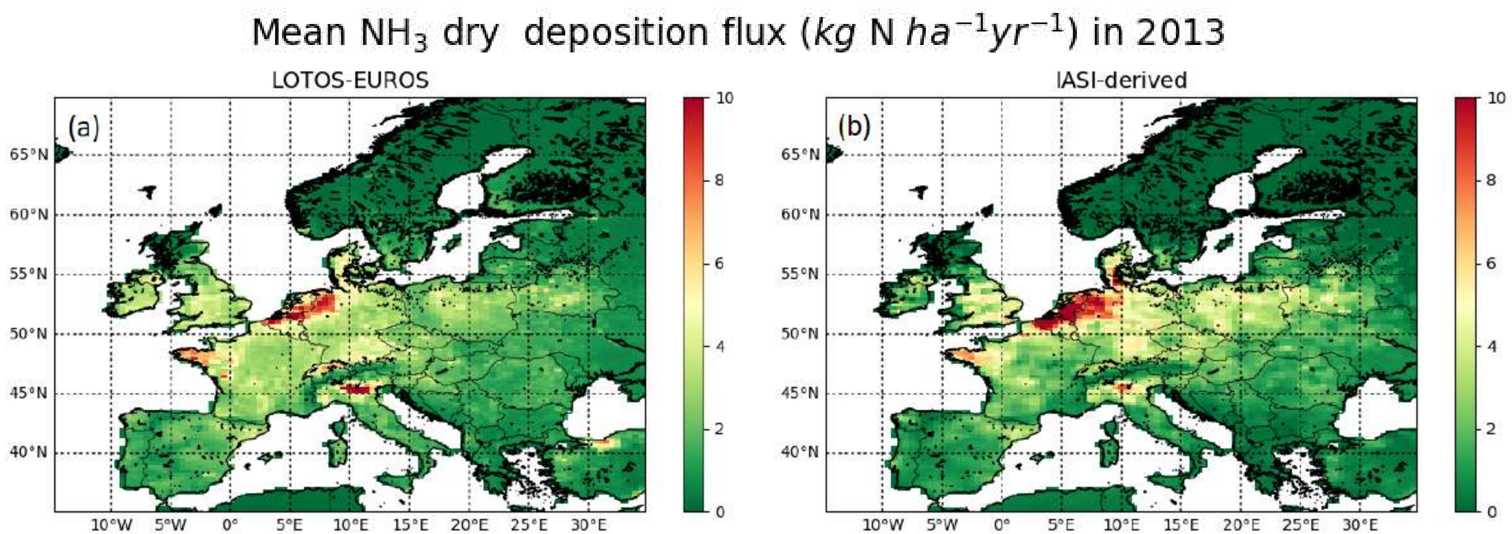
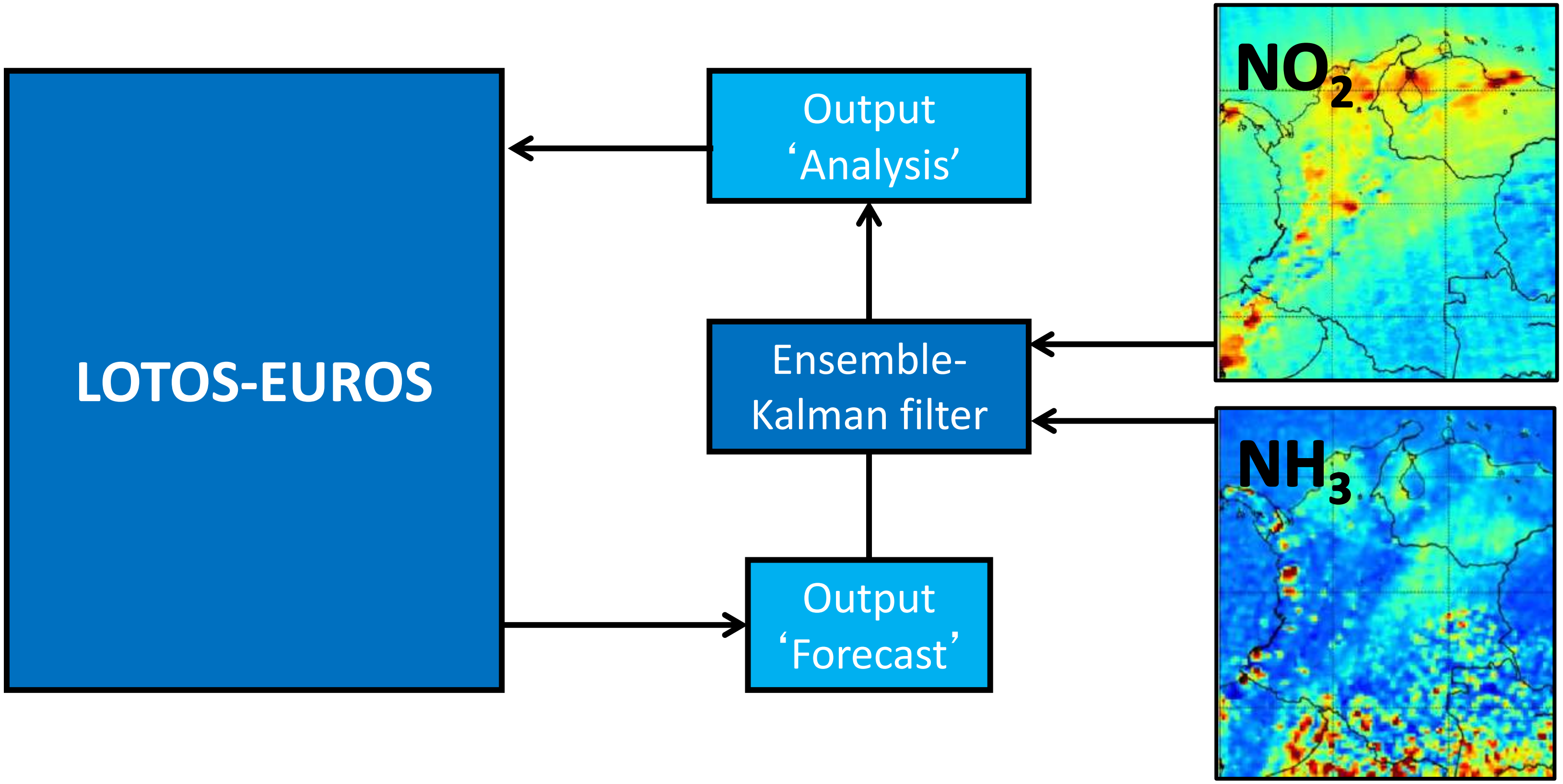


Figure 1: Modelled (a) and IASI-derived (b) mean dry NH_3 deposition flux in 2013.

VU AND TNO ACTIVITIES

Simultaneous data-assimilation of NO_2 and NH_3 satellite observations to obtain:

- Top-down emission adjustments
- Total N_r deposition maps



VU AND TNO ACTIVITIES

Towards a more realistic surface characterization in LOTOS-EUROS…

Implementation of a higher resolution land-use map with coupled remote sensing derived parameters, such as:

- Leaf-area index
- Vegetation height, roughness length z_0
- …

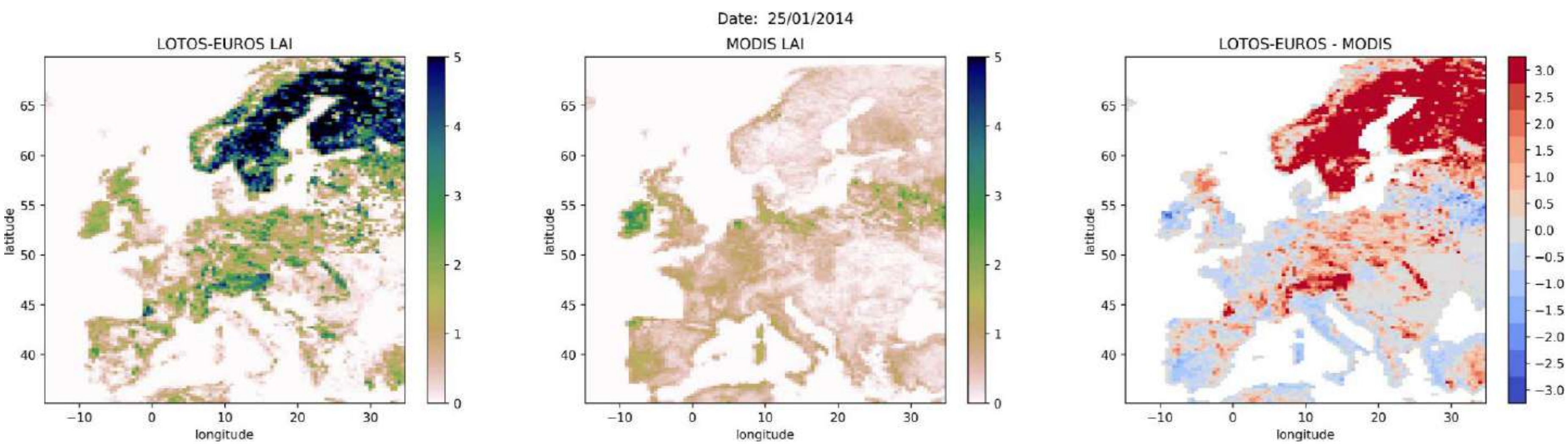


Figure 1: Comparison of the leaf-area index in the LOTOS-EUROS model and from MODIS.

VU AND TNO ACTIVITIES

Link between nitrogen deposition and carbon exchange/drought stress

Compare newly-derived nitrogen deposition maps to:

- Local-scale measurements of C-exchanges
- Satellite-derived drought indicators
- Satellite-derived vegetation parameters

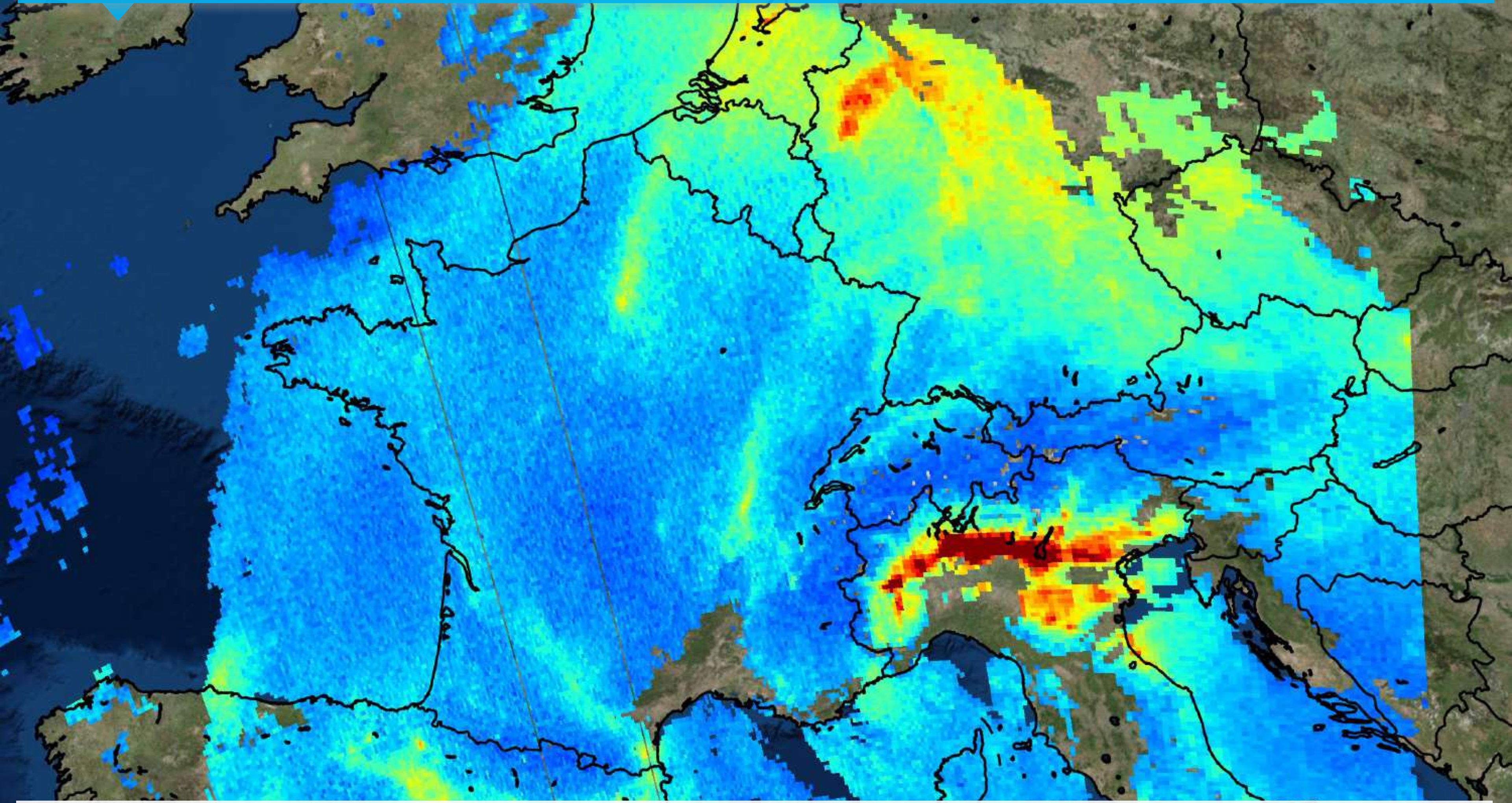
POTENTIAL PRODUCTS EXPECTED THE COMING YEARS

Methodology for improved quantification of N_r deposition at different scales (local-global)

- N_r deposition/emissions
- N_r concentration distributions
- Trend analyses
- N_r in relation to greenhouse gases
- N_r in relation to future emission scenarios
- Assessment of N_r critical load exceedances
- Assessment of effect of N_r in relation to biodiversity loss
- …

INMS

OPPORTUNITIES OF SATELLITE OBSERVATIONS FOR IMPROVING NITROGEN DEPOSITION ESTIMATES



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