DLR

esa

living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

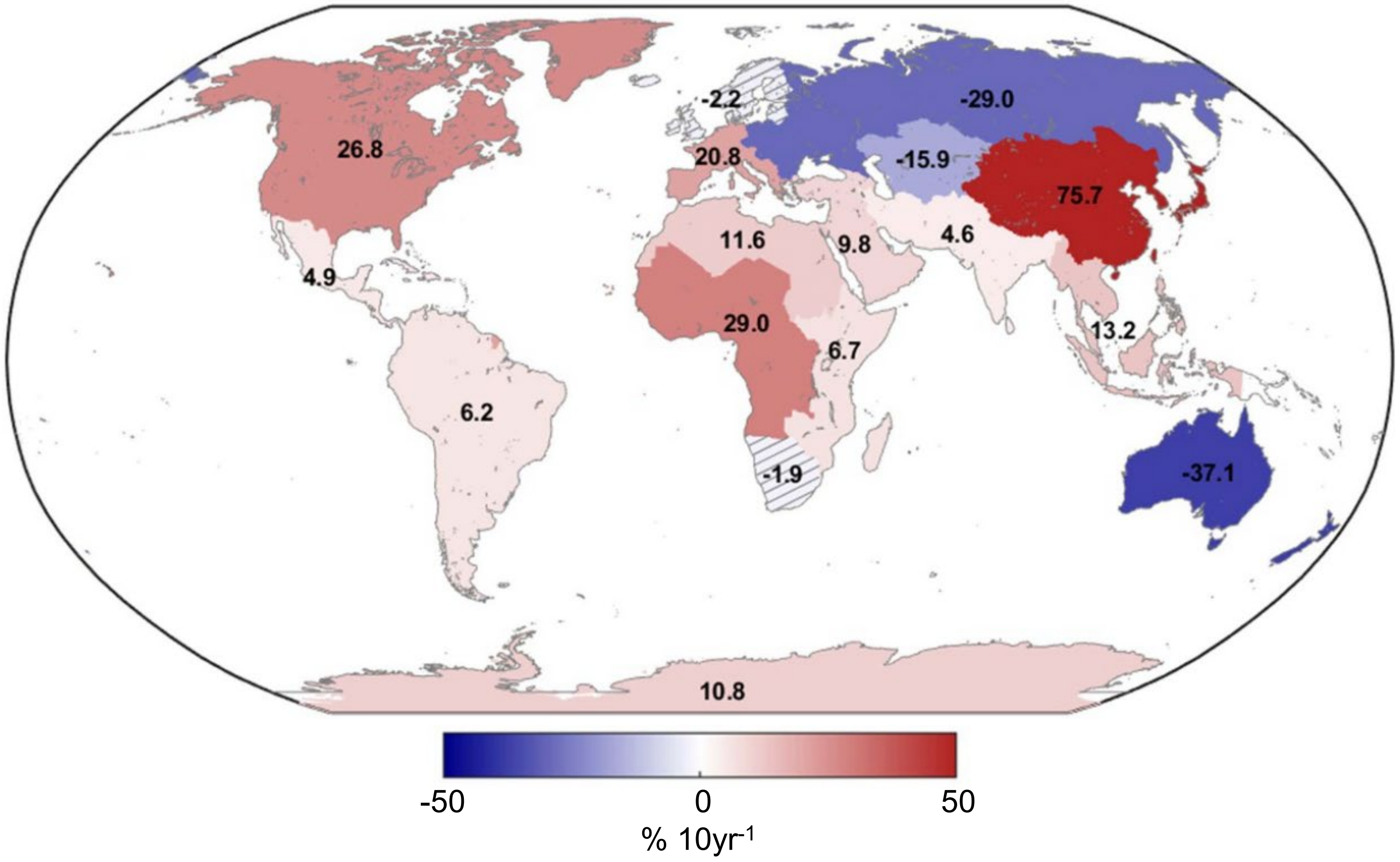
Aircraft observations of ammonia from industrial sources and derivation of emission fluxes

L. Noppen[1], L. Clarisse[1], F. Tack[2], T. Ruhtz[3], A. Merlaud[2], M. Van Damme[1,2], D. Schuettemeyer[4], S. Chabrillat[5], C. Hohmann[5], L. Jacobs[2], M. Van Roozendael[2] and P. Coheur[1]

(1) Université libre de Bruxelles (ULB), SQUARES, Brussels, Belgium
(2) Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium
3) Institute for Space Sciences, Freie Universität Berlin, Berlin, Germany
(4) European Space Agency (ESA-ESTEC), Noordwijk, the Netherlands
(5) German Research Center for Geosciences (GFZ), Potsdam, Germany

Ammonia (NH_3)

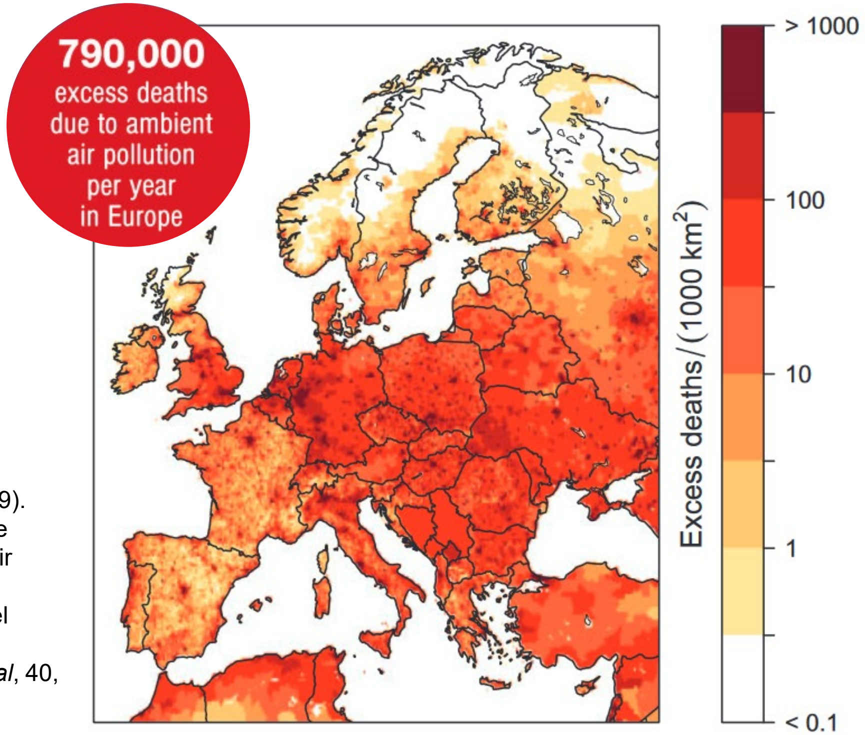
- NH_3 is massively emitted in the atmosphere by anthropogenic activities
- Levels of NH_3 on the rise in Europe and in most other developed countries



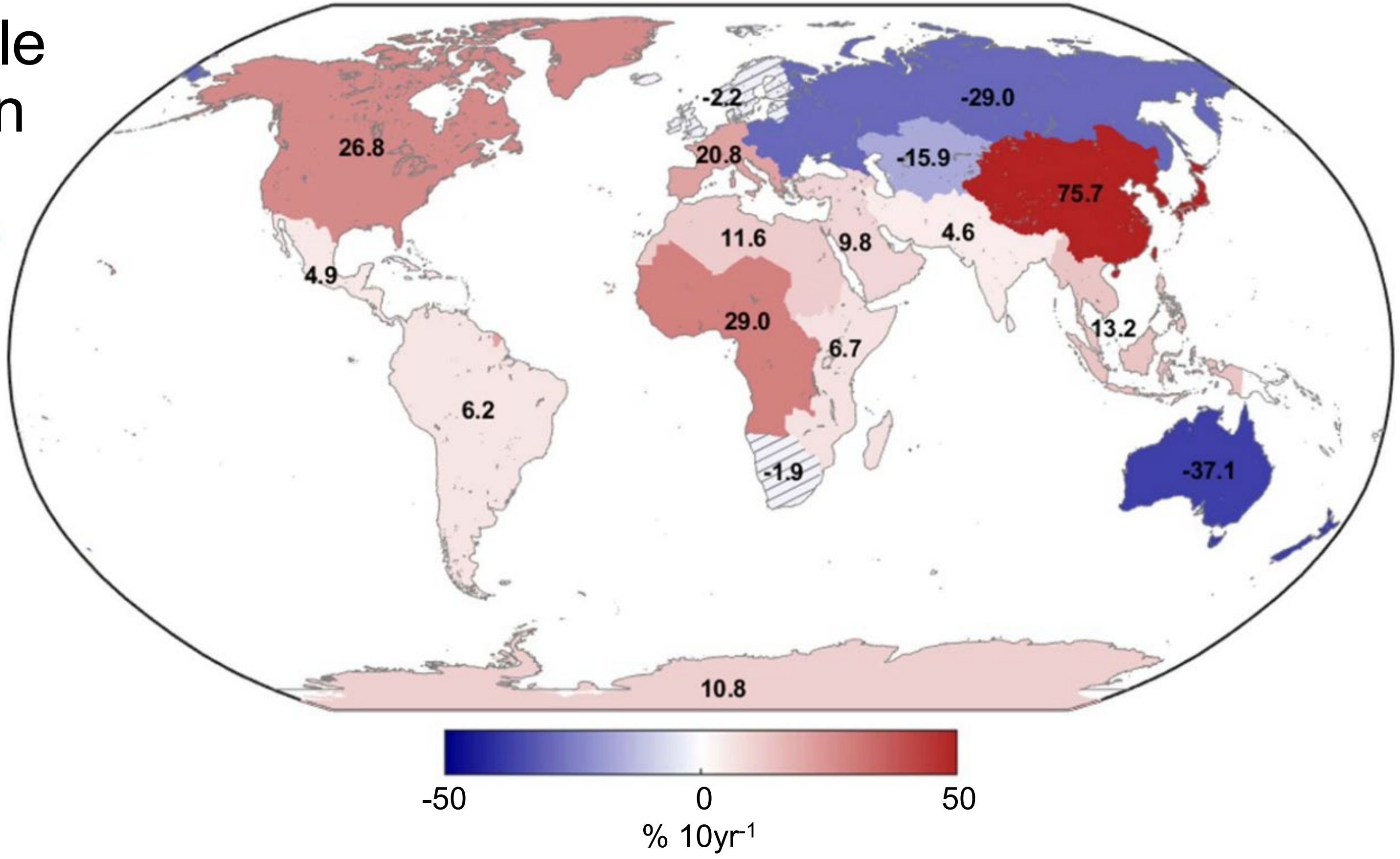
Van Damme, M. et al. (2021). Global, regional and national trends of atmospheric ammonia derived from a decadal (2008–2018) satellite record. Environ. Res. Lett., 16(5), 055017.

Ammonia (NH_3)

- NH_3 is massively emitted in the atmosphere by anthropogenic activities
- Levels of NH_3 on the rise in Europe and in most other developed countries
- Alteration of the global nitrogen cycle
  → Cascade of deleterious effects on health, environment and climate



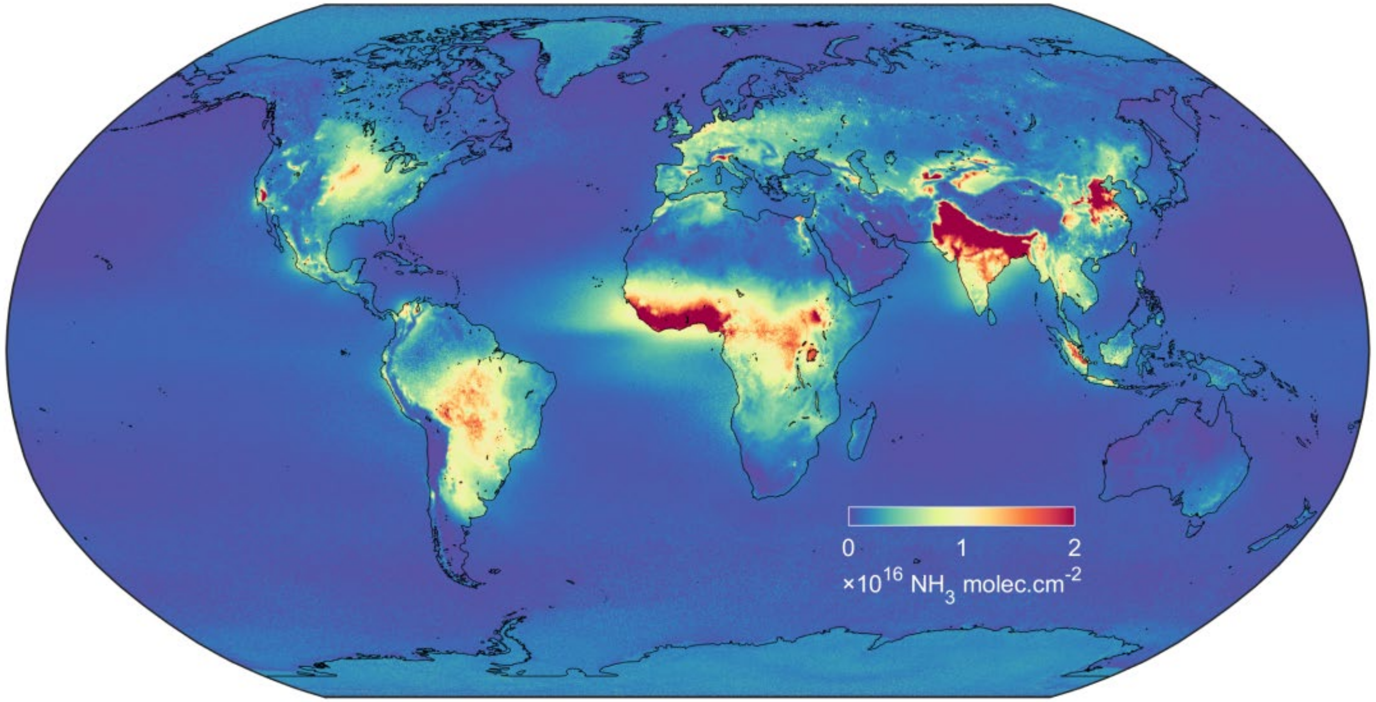
Lelieveld, J. et al. (2019). Cardiovascular disease burden from ambient air pollution in Europe reassessed using novel hazard ratio functions. *European Heart Journal*, 40, 1590–1596.



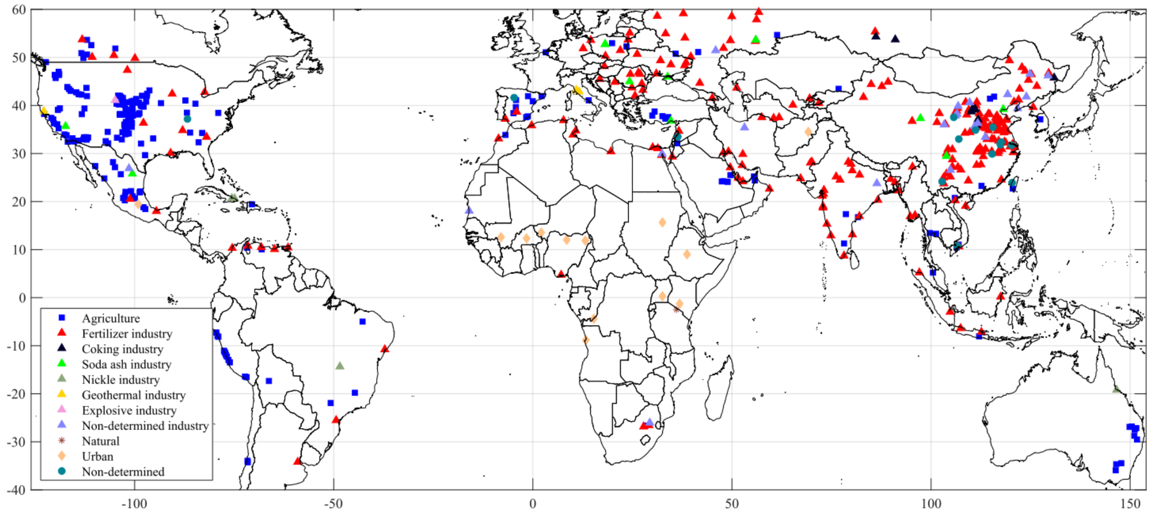
Van Damme, M. et al. (2021). Global, regional and national trends of atmospheric ammonia derived from a decadal (2008–2018) satellite record. Environ. Res. Lett., 16(5), 055017.

Current satellite measurements

- Global distribution of NH_3 columns from satellite measurements obtained from 11 years of IASI data (2008-2018)
- Importance of point sources (already +/- 500 pinpointed)



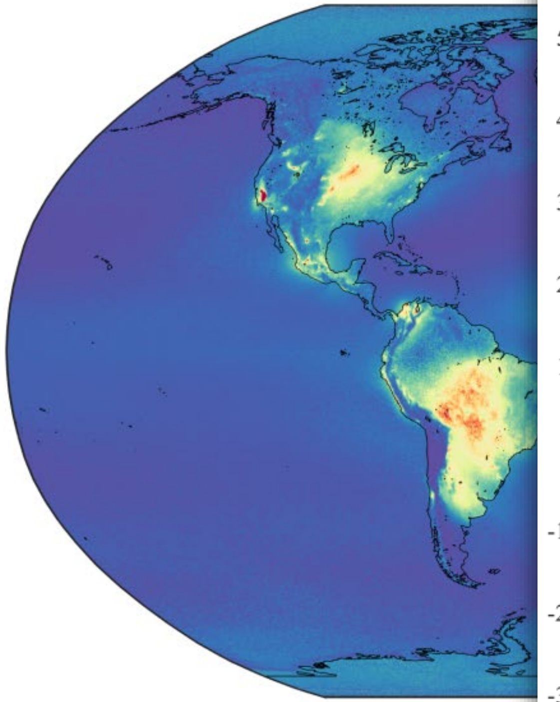
Van Damme, M. et al. (2018). Industrial and agricultural ammonia point sources exposed. *Nature*, 564(7734): 99–103.

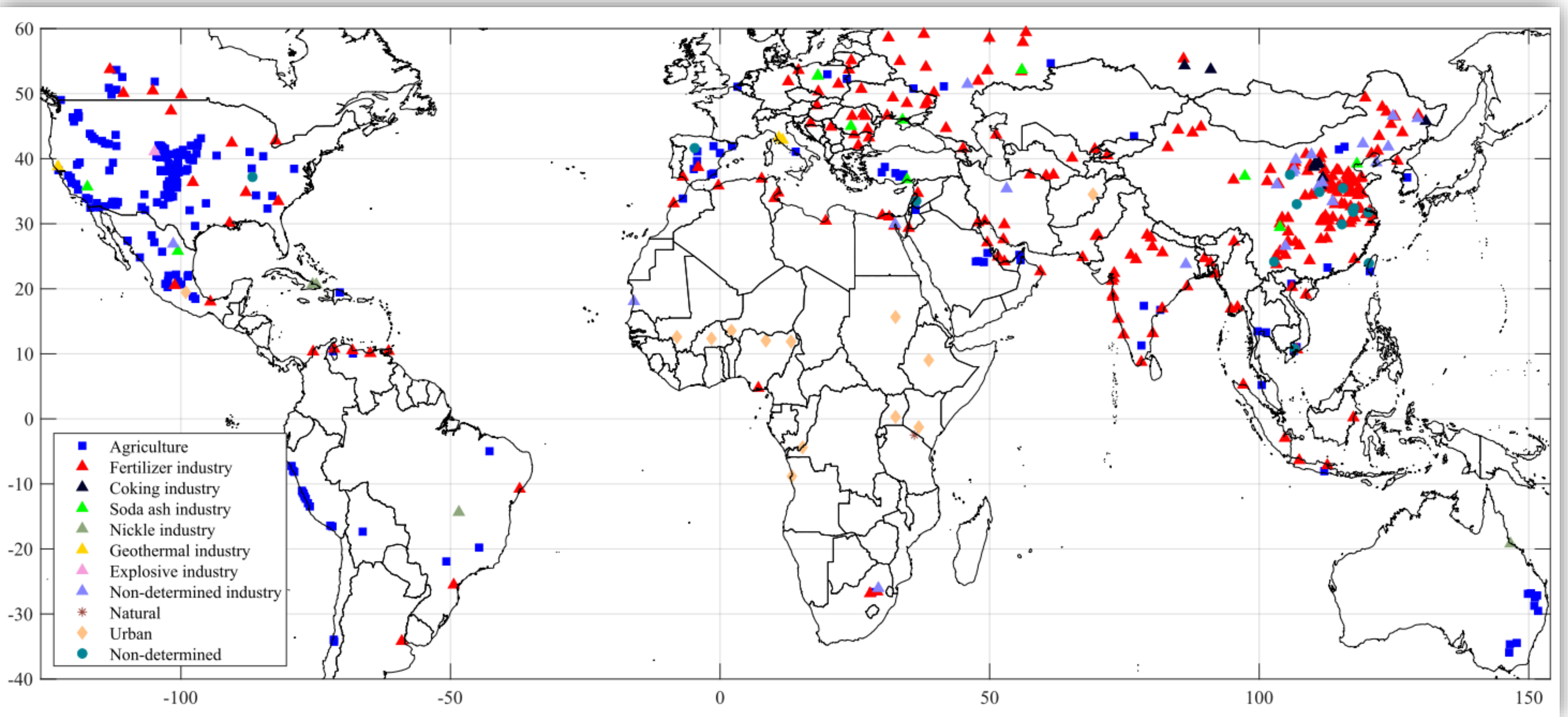


Clarisse, L. et al. (2019). Tracking down global NH_3 point sources with wind-adjusted superresolution. *Atmos. Meas. Tech.*, 12, 5457–5473.

Current satellite measurements

- Global distribution of NH_3 columns from satellite measurements obtained from 11 years of IASI data (2008-2018)
- Importance of point sources (already +/- 500 pinpointed)

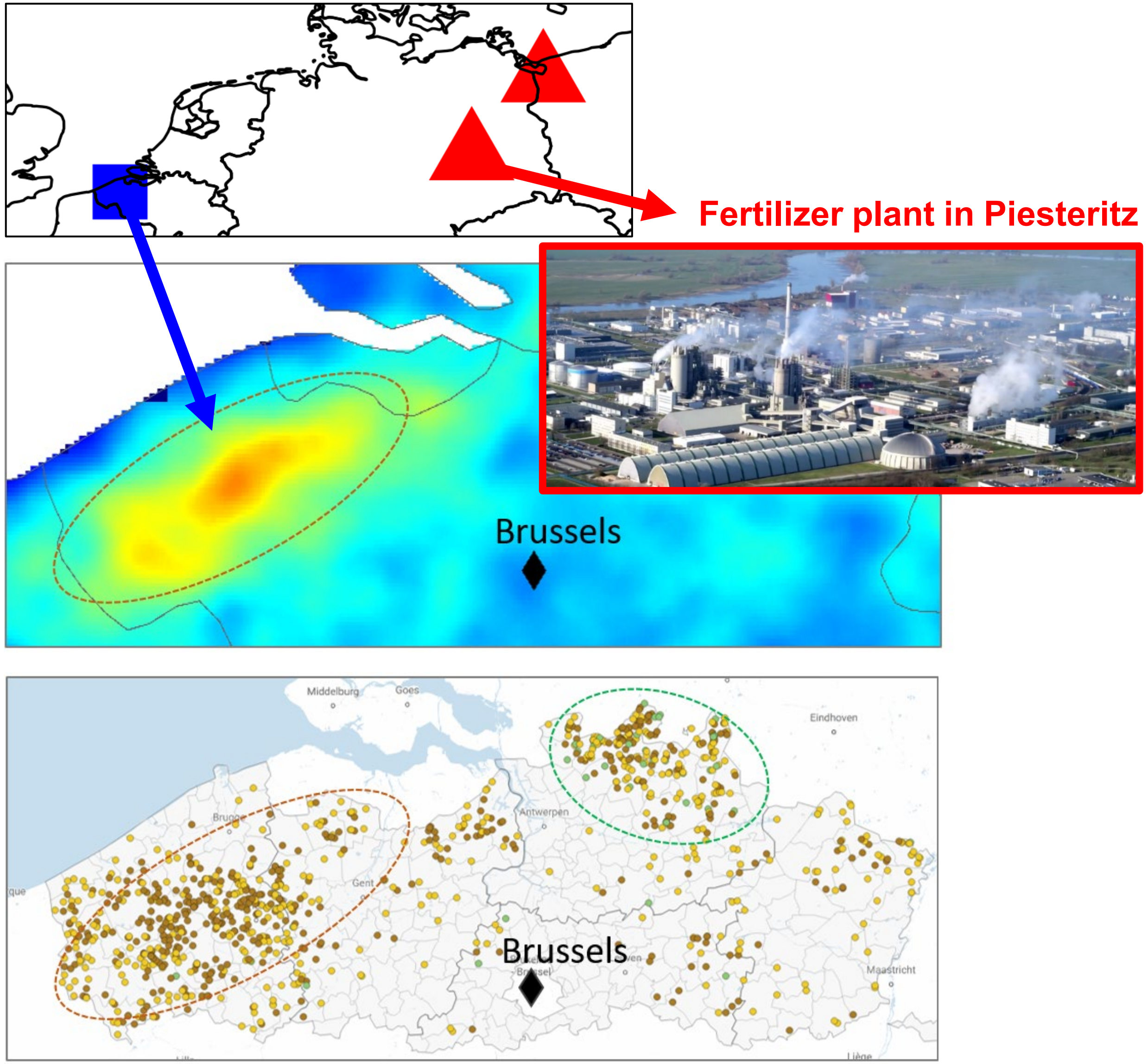




Van Damme, M
ammonia point s

Limitations of satellite measurements

- Limitations of current satellite measurements to quantify emissions:
  - Spatial resolution
  - Lifetime of NH_3
  - Background
- Nitrosat
  - Satellite mission proposed in answer to the 11th ESA's Earth Explorer call (currently in phase 0)
  - Simultaneous observations of NO_2 and NH_3 globally at a spatial resolution of at least 500 m
- NITROCAM
  - Aircraft measurements of NO_2 and NH_3 at a very high spatial resolution



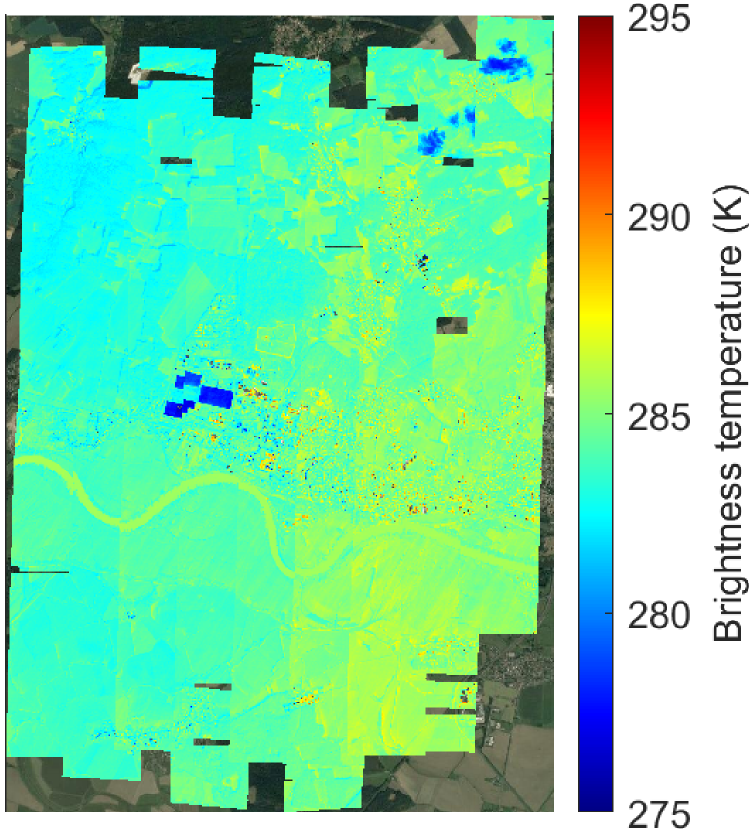
Coheur, P. et al. (2020). NITROSAT : Mapping reactive nitrogen at the landscape scale. Technical report.

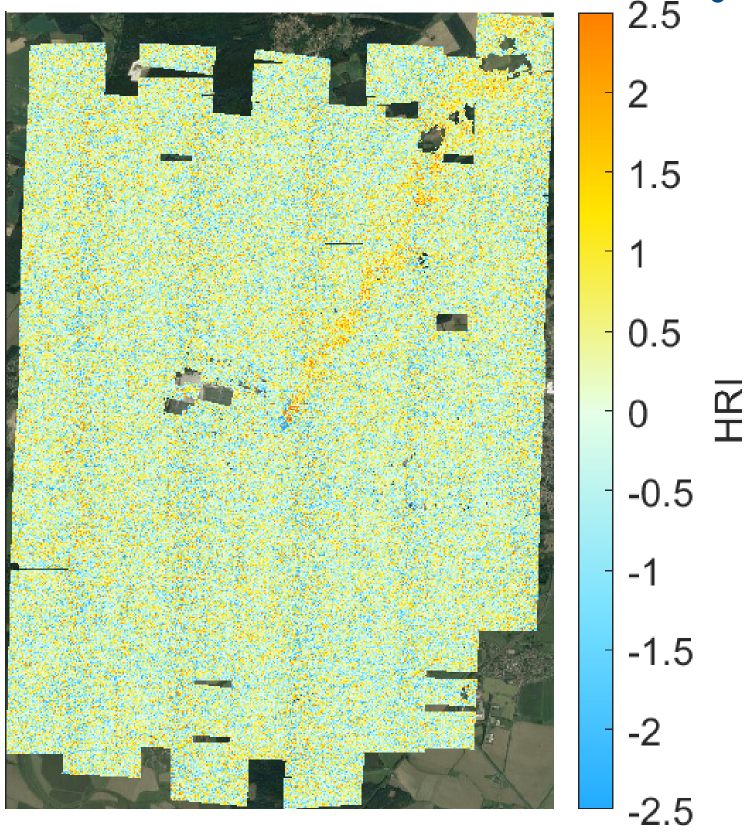
Flight over a fertilizer plant in Piesteritz

esa

Fertilizer plant in Piesteritz

- Flight over the industrial site of Piesteritz in autumn 2020
- Measurements by the Hyper-Cam instrument in the infrared (800-1350 cm^{-1}) at a spatial resolution of 4 m

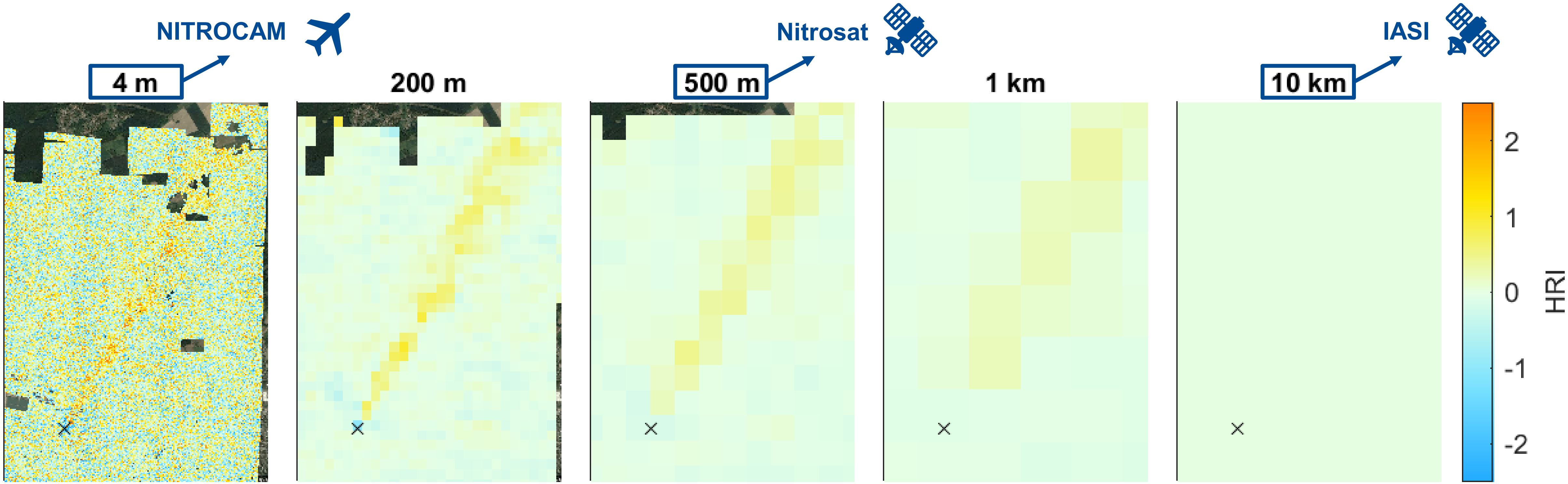




- Detection of NH_3 with the HRI → plume

Various satellite footprints

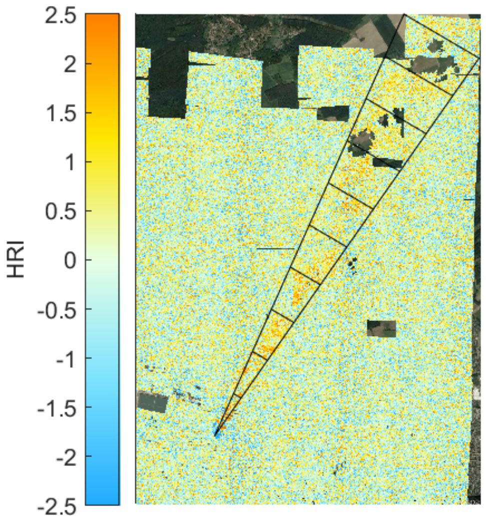
- Progressive degradation of the spatial resolution of HRI distributions
- Sub-km spatial resolution required to identify the point source

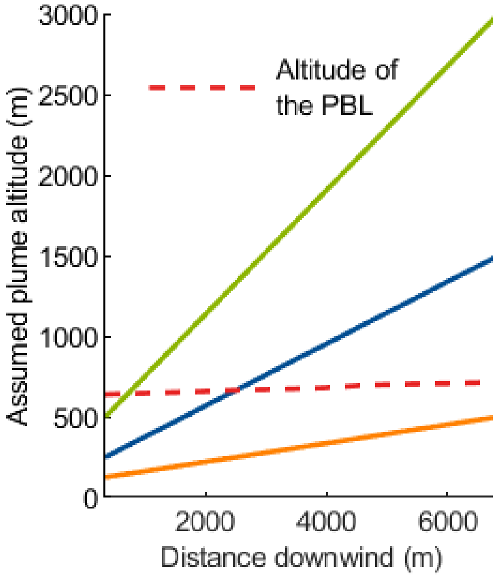


- Limitations of current satellite measurements to quantify emissions:
  - ~~Spatial resolution~~
  - ~~Lifetime of NH_3~~
  - ~~Background~~

Emission rate retrieval

- General behaviour of the plume → it rises with the distance downwind the source (Gaussian model)

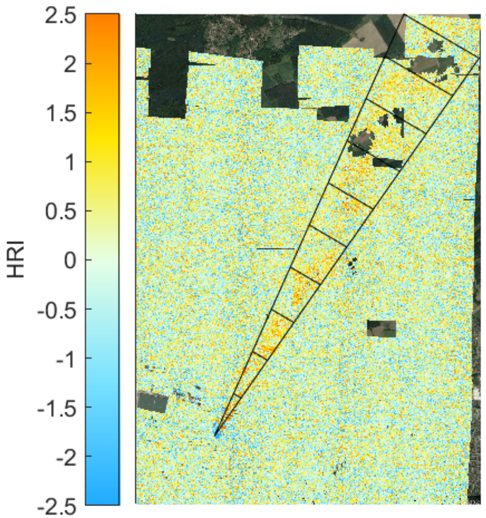


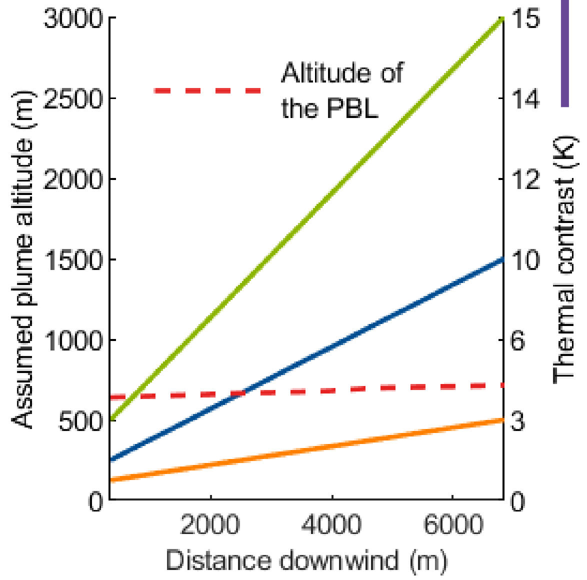


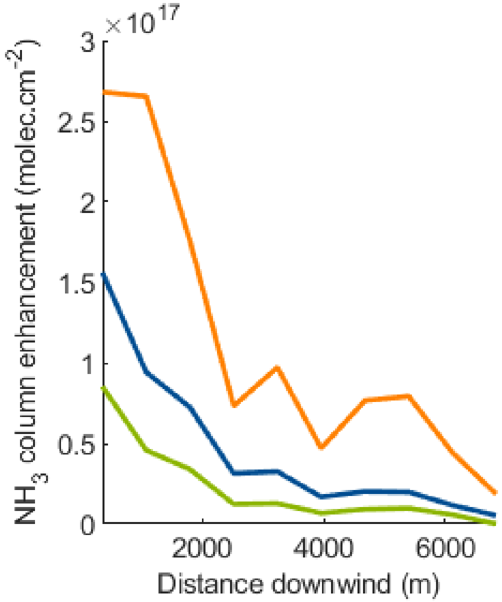
Emission rate retrieval

$$TC = T_{surf} - T_{air}$$

- General behaviour of the plume → it rises with the distance downwind the source (Gaussian model)
- Columns retrieval by inversion of the spectra → they decrease with distance







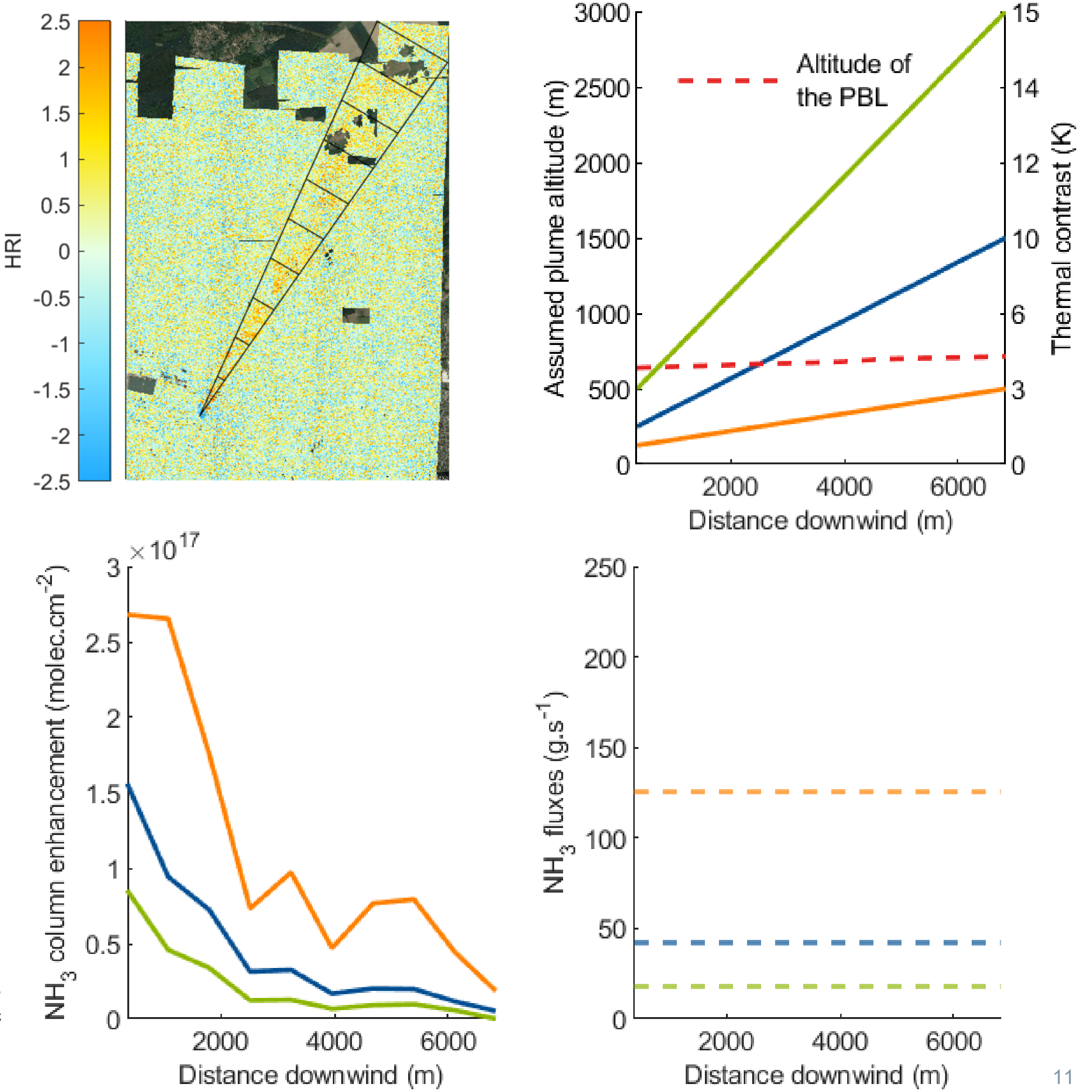
Emission rate retrieval

- General behaviour of the plume → it rises with the distance downwind the source (Gaussian model)
- Columns retrieval by inversion of the spectra → they decrease with distance
- Emission rate retrieval with the **integrated mass enhancement** (IME) method → one single flux

IME	570 – 3970 t.yr^{-1}

$$Q = \frac{U_{eff}}{L}\left(\sum_{j=1}^{N} \Delta\Omega_j S_j\right)$$

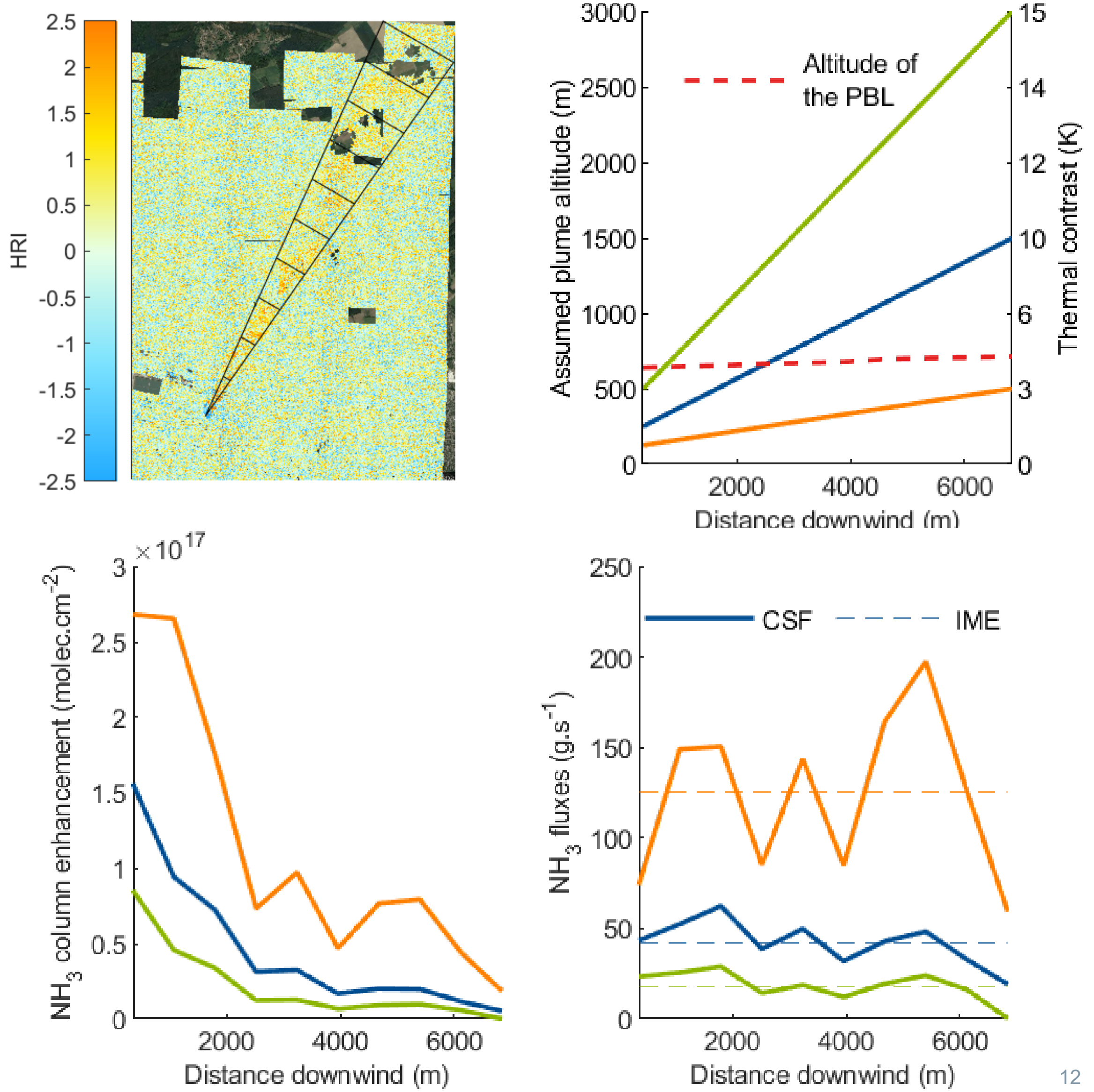
$$U_{eff} = 1.1 \log U + 0.6$$



D. J. Varon et al. (2018). Quantifying methane point sources from fine-scale satellite observations of atmospheric methane plumes. *Atmos. Meas. Tech.*, 11, 5673–5686.

Emission rate retrieval

- General behaviour of the plume → it rises with the distance downwind the source (Gaussian model)
- Columns retrieval by inversion of the spectra → they decrease with distance
- Emission rate retrieval with the **cross-sectional flux** (CSF) method → they are quite constant



IME	570 – 3970 t.yr^{-1}
CSF	580 – 3890 t.yr^{-1}

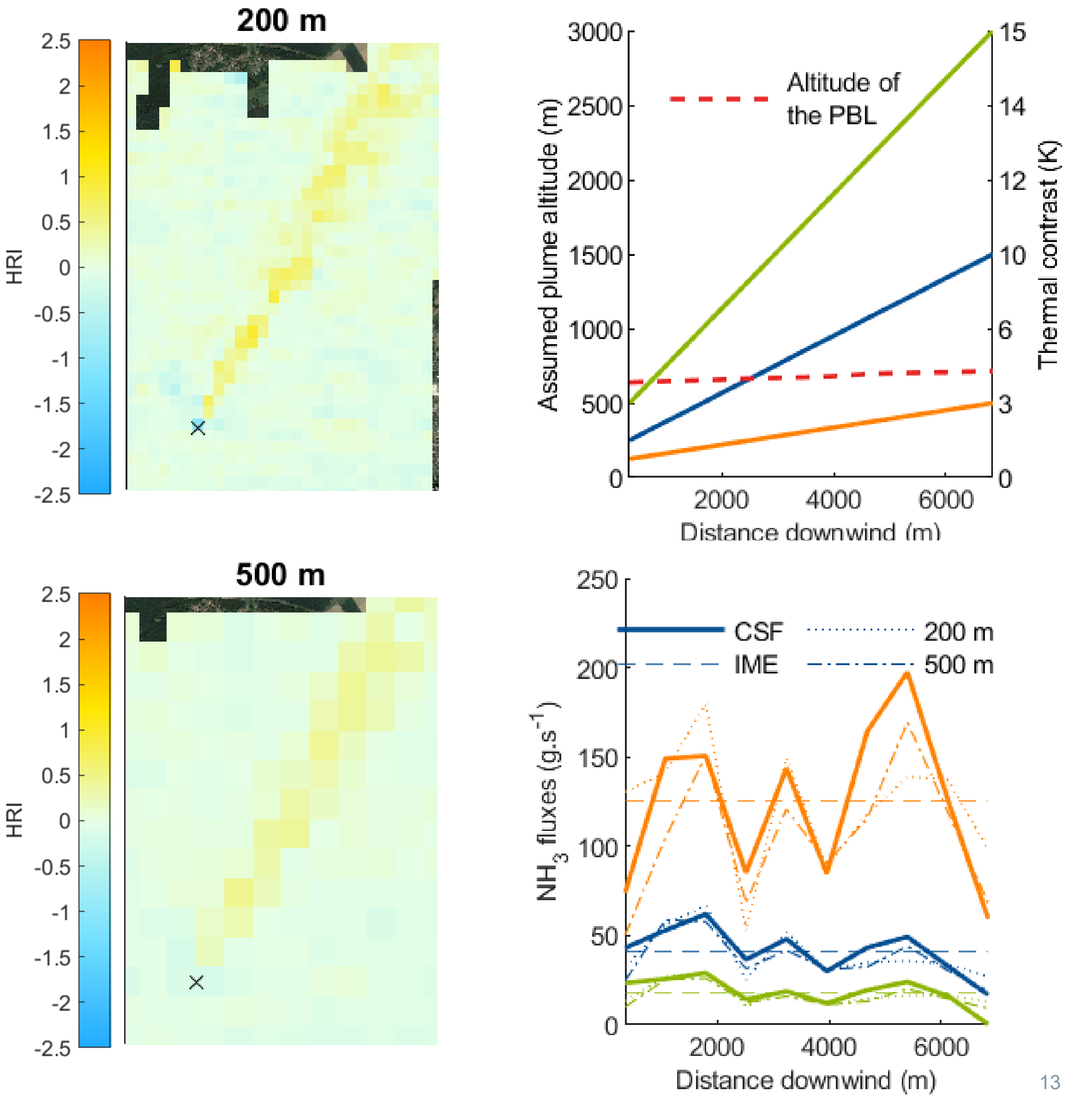
$$Q(x) = \left(\sum_i \Delta\Omega_i l_i\right) U\, e^{\frac{x}{U\tau}}$$

Emission rate retrieval

- General behaviour of the plume → it rises with the distance downwind the source (Gaussian model)
- Columns retrieval by inversion of the spectra → they decrease with distance
- Emission rate retrieval from data down sampled at 200 m and 500 m horizontal resolutions → demonstration of the interest of Nitrosat

IME	570 – 3970 $t.yr^{-1}$
CSF	580 – 3890 $t.yr^{-1}$

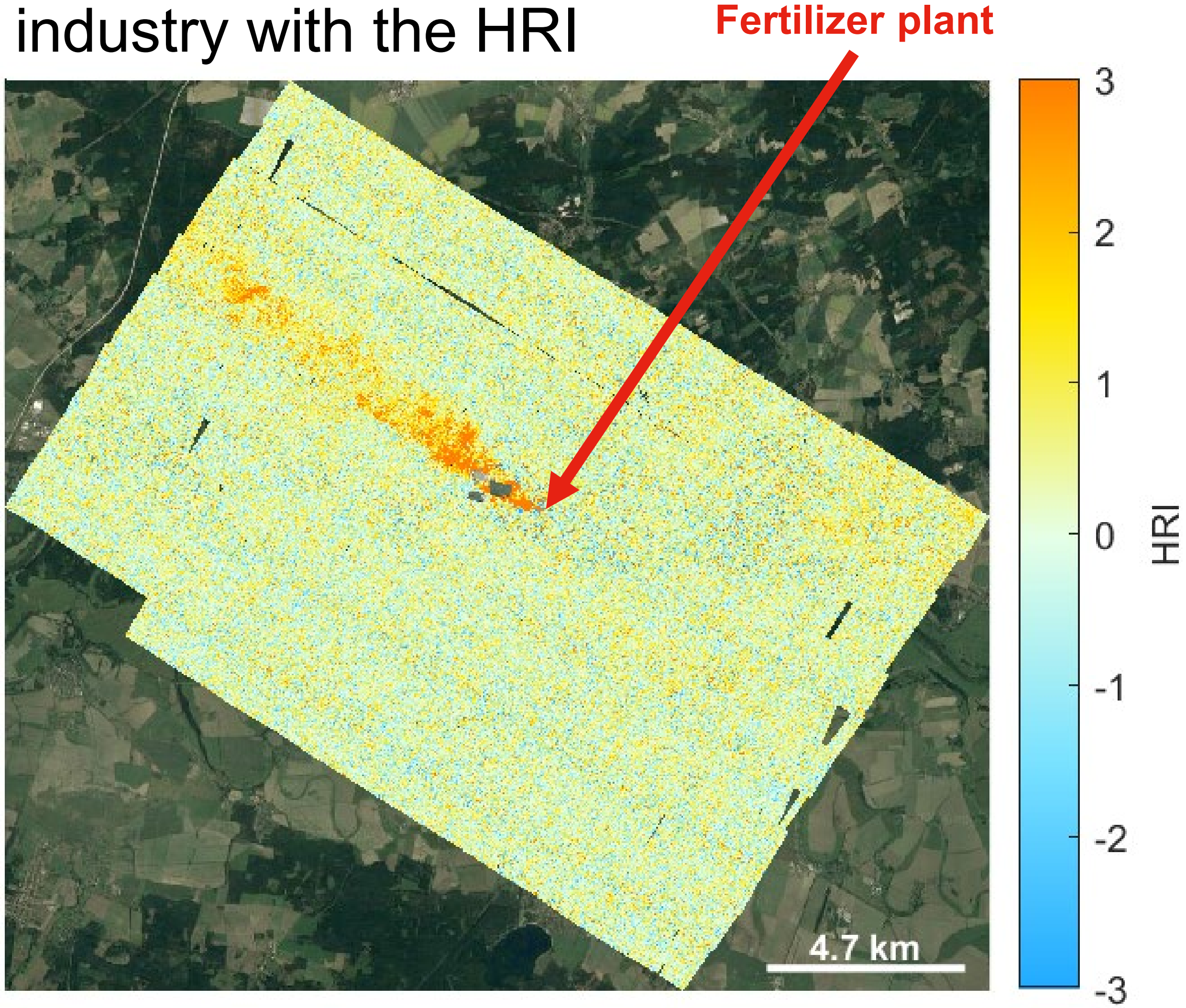
200 m	540 – 3900 $t.yr^{-1}$
500 m	500 – 3340 $t.yr^{-1}$
E-PRTR	350 $t.yr^{-1}$



Second flight over the fertilizer plant

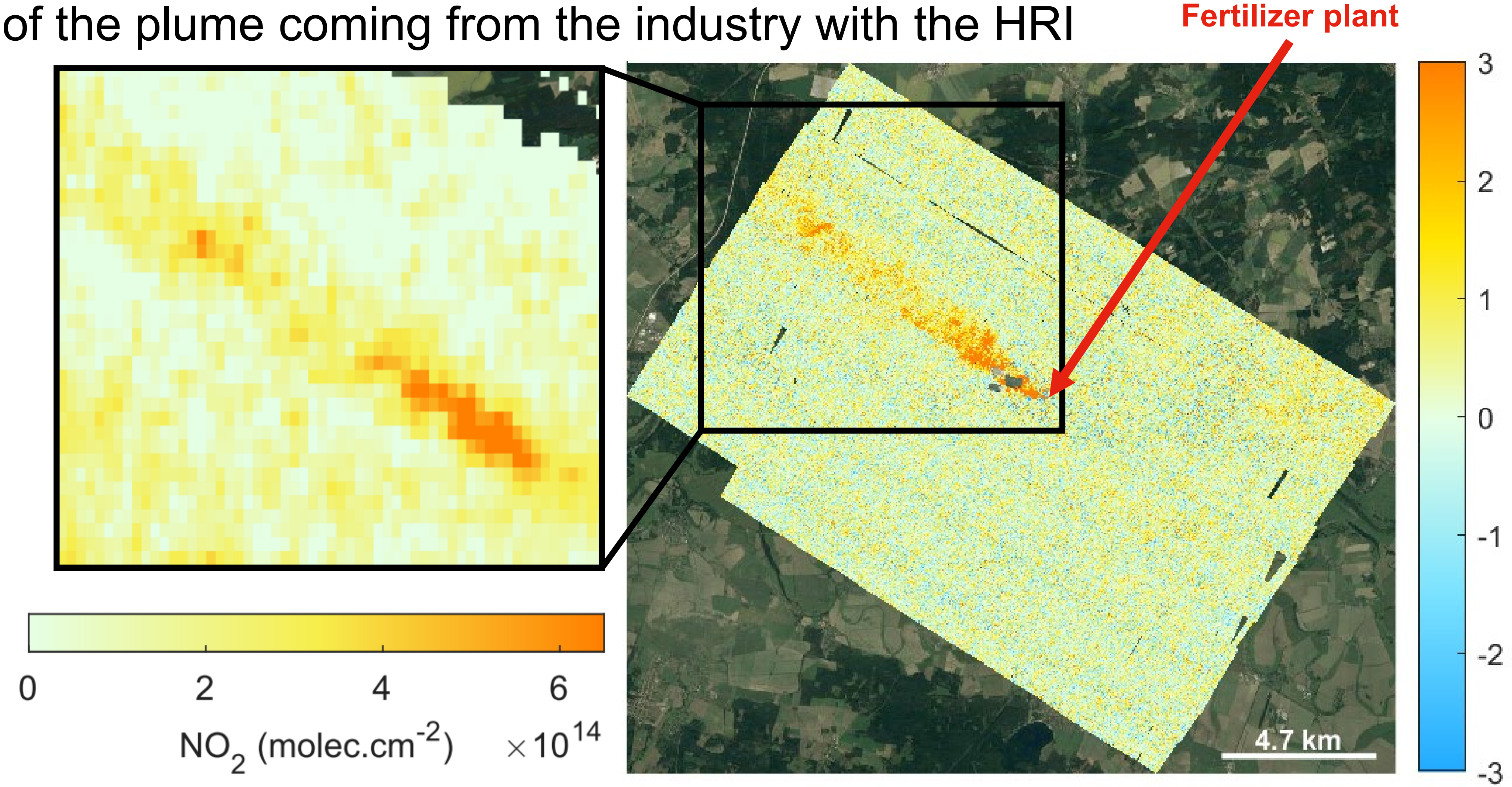
- Second flight over the fertilizer plant in Piesteritz in spring 2021
- Detection of the plume coming from the industry with the HRI
- The same quantification methods lead to higher results
  - Higher emissions
  - Higher thermal contrast
  - Lower wind speed

	1st flight ($t.yr^{-1}$)	2nd flight ($t.yr^{-1}$)
IME	570 – 3970	1330 – 4480
CSF	580 – 3890	1220 – 4060
200 m	540 – 3900	1300 – 3890
500 m	500 – 3340	1300 – 3810



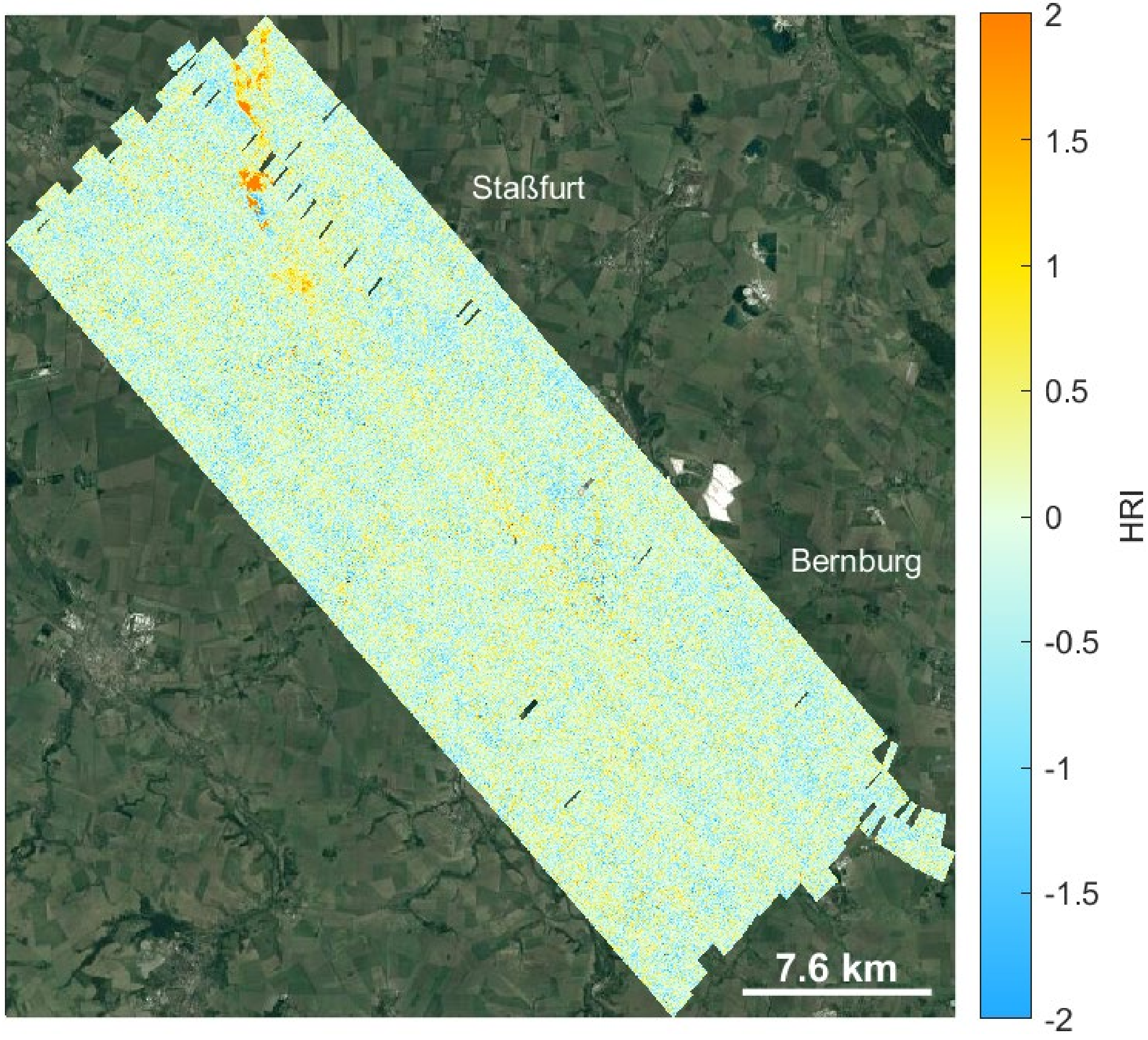
Second flight over the fertilizer plant

- Second flight over the fertilizer plant in Piesteritz in spring 2021
- Detection of the plume coming from the industry with the HRI



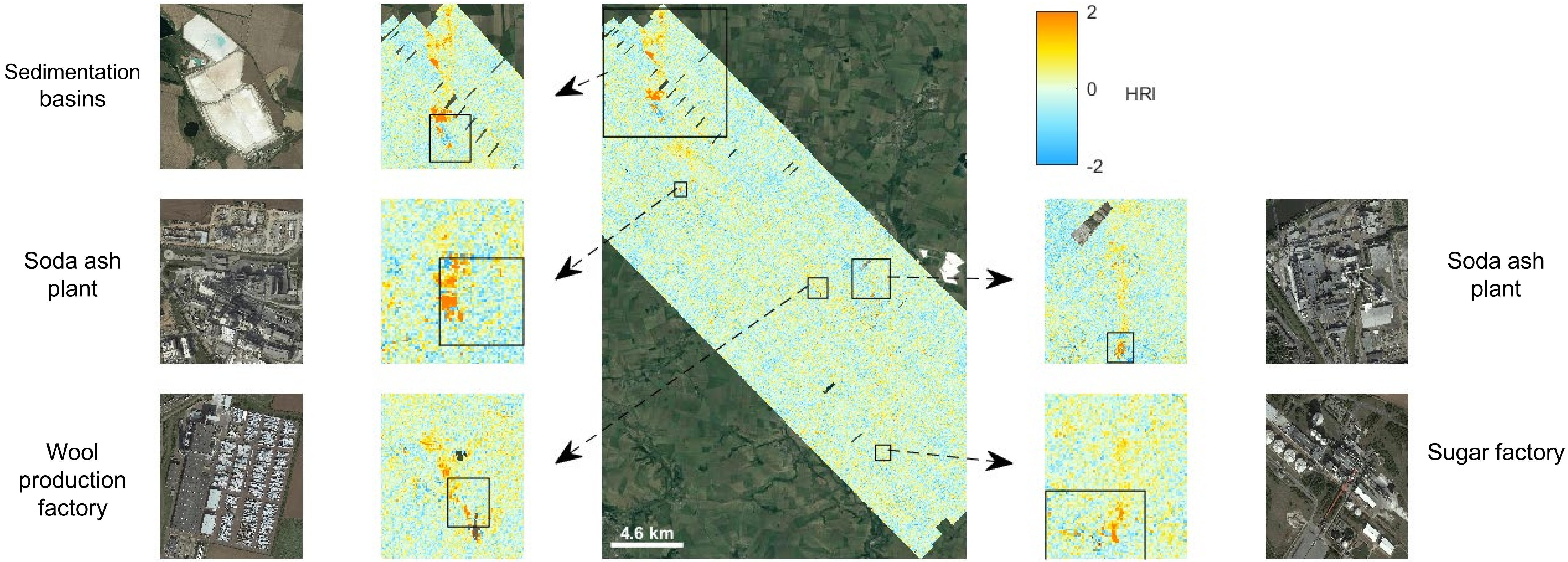
Flight over Staßfurt and Bernburg

- Flight over a large area of Staßfurt and Bernburg in spring 2021



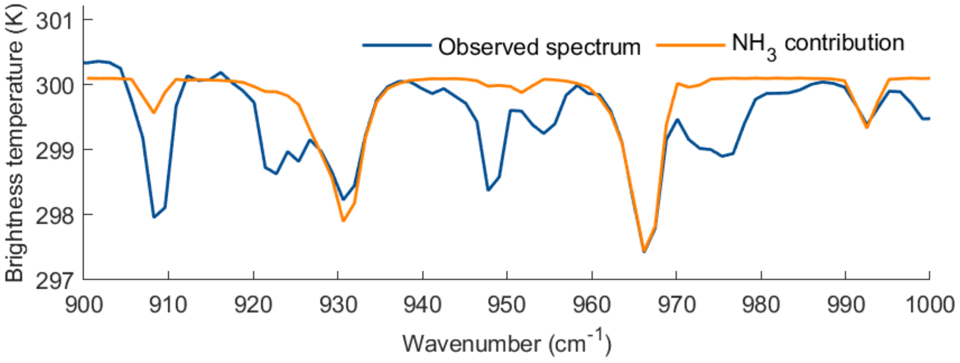
Flight over Staßfurt and Bernburg

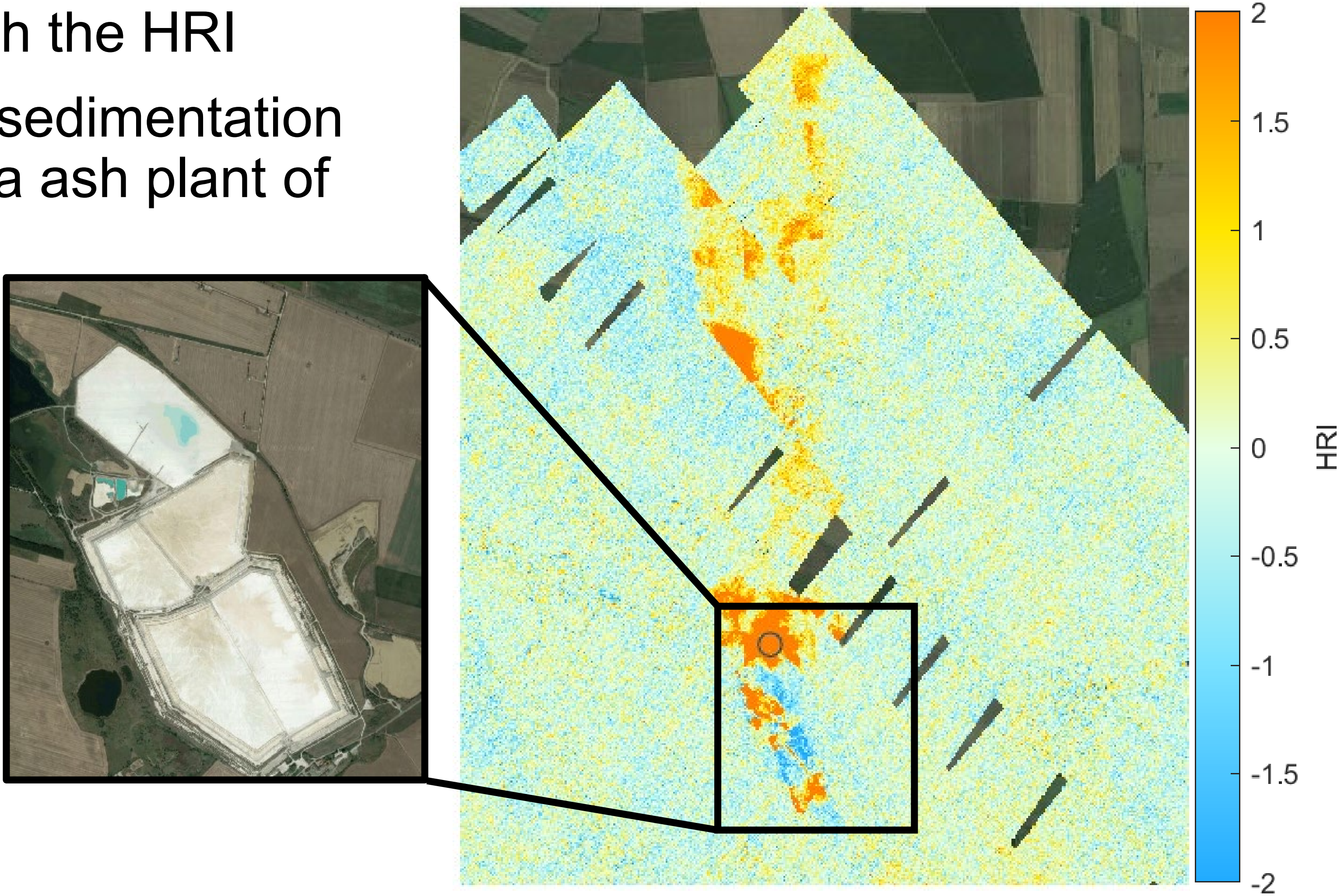
- Flight over a large area of Staßfurt and Bernburg in spring 2021
- Detection of various signals with the HRI



Flight over Staßfurt and Bernburg

- Flight over a large area of Staßfurt and Bernburg in spring 2021
- Detection of various signals with the HRI
- The large one comes from the sedimentation basins associated with the soda ash plant of Staßfurt
- Not included in the E-PRTR
- NH_3 signature in spectra





Conclusion

- Analysis of measurements at high spatial resolution over a wide variety of emission sources
- 500 m spatial resolution required to detect and isolate point sources
- More accurate flux quantification

→ Nitrosat

Po Valley
Highest hotspot region in Europe

Fertilizer experiment