SEEDS

Sentinel EO-based Emission and Deposition Service

Funded by the European Union

Deriving emissions from satellites

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NILU

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Waters

BIRA-IASB

CERFACS
CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE

METEO FRANCE

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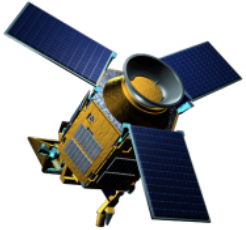
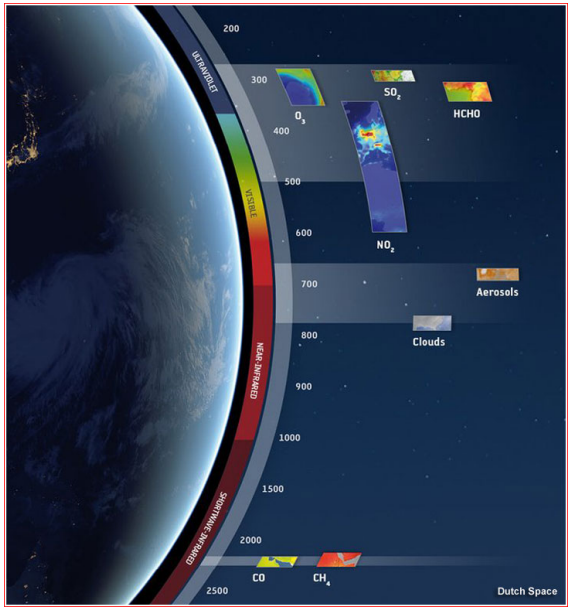
What makes TROPOMI unique?

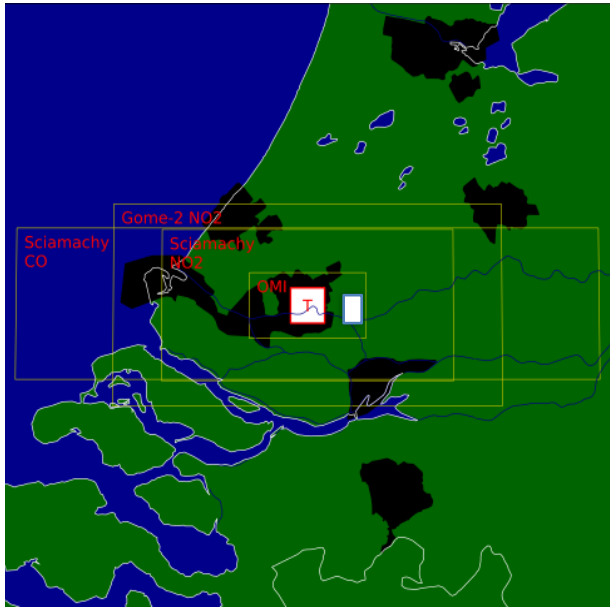


TROPOMI combines 4 unique features:

Large spectra range
(large # of trace gas species)
High signal-to-noise

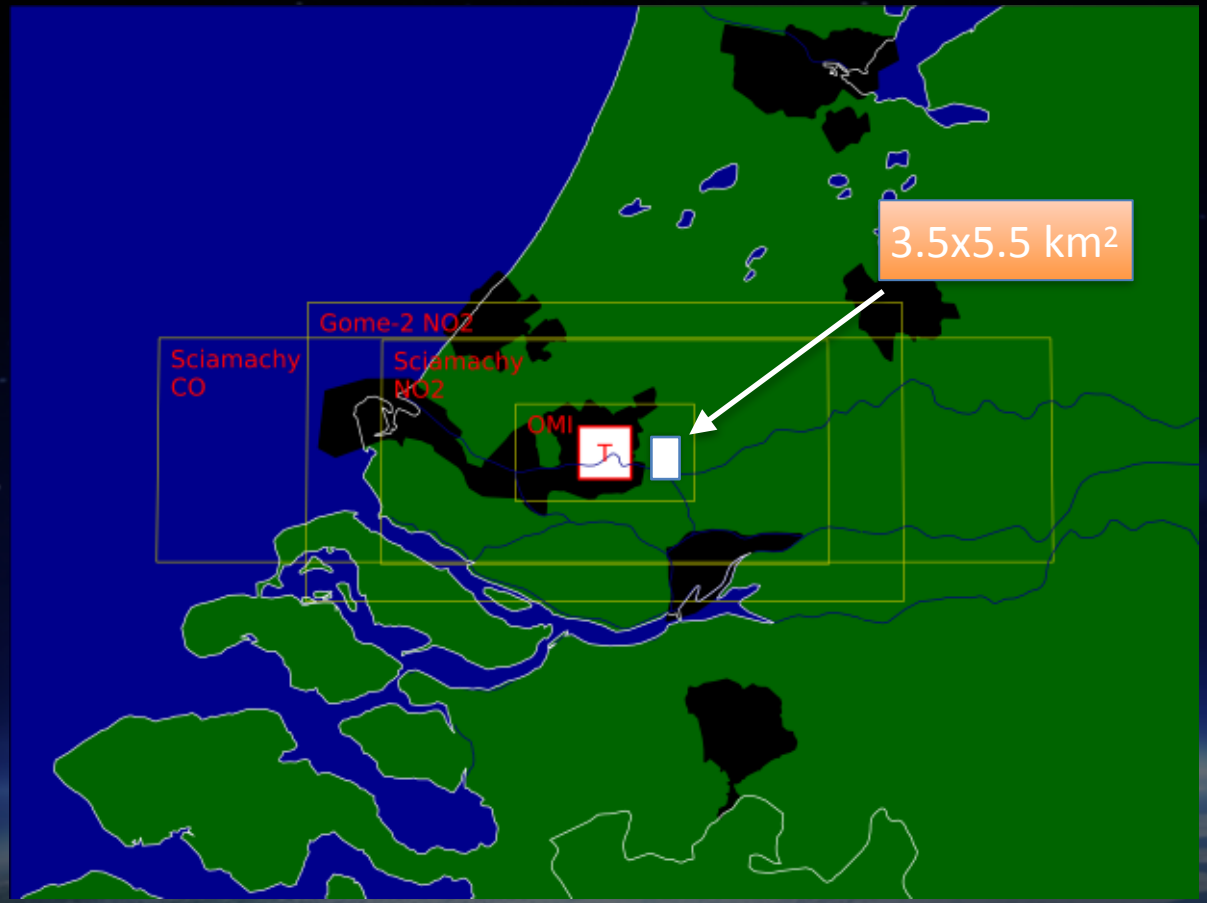


High spatial resolution
(3.5 x 5.5 km)



Daily global coverage

TROPOMI Spatial Resolution



TROPOMI Operational Data products

Product	Application
Ozone	Ozone layer monitoring, UV-index forecast, Climate monitoring
NO_2	Air quality forecast and monitoring
CO	Air quality forecast and monitoring
CH_2O	Air quality forecast and monitoring
CH_4	Climate monitoring
SO_2	Air quality forecast and monitoring, Climate monitoring, Volcanic plume detection
Aerosol	Air quality forecast and monitoring, Climate monitoring, Volcanic plume detection
Clouds	Climate monitoring
UV-Index	UV index forecast

KNMI | DLR | BIRA-IASB | SRON | RAL |IUP-Bremen | MPIC | FMI | ESA

Development of supplementary products: SIF, AOD, CHOCHO, HONO, ALH

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Full mission reprocessing TROPOMI

All operational TROPOMI products have been re-processed using processor version 2.4.0, based on the **latest L-1B v2 product with degradation correction**.

- All products will be released before EGU (23 April)

(see ESA Sentinel Online news items)

Consistent datasets for period 30 April 2018 - now (approaching 5 years).

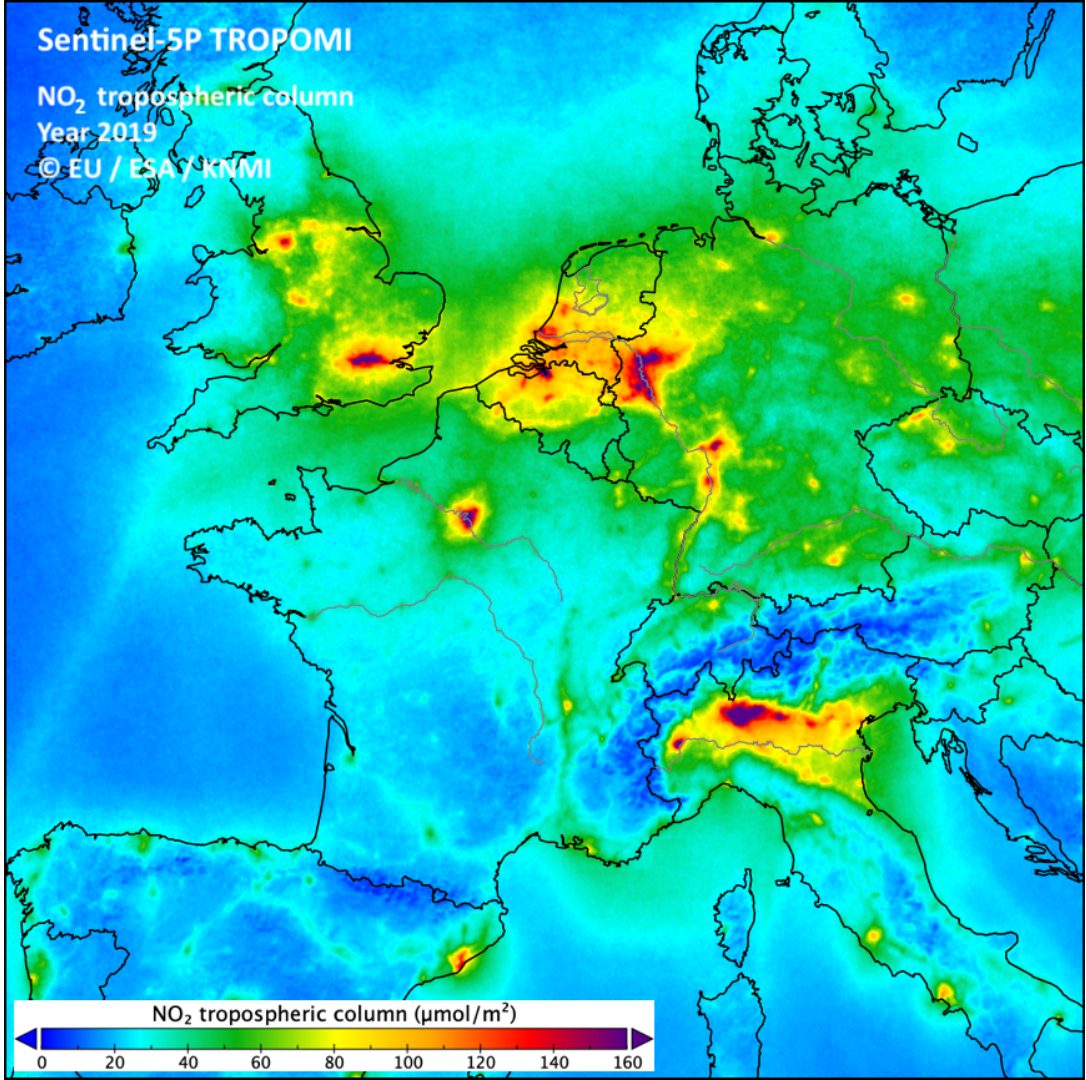
For some products a substantial upgrade, others more minor.
E.g. the **NO_2 now uses TROPOMI DLER surface albedo**
in UV-Vis (NO2) and NIR (cloud retrieval)

The NOx emissions of SEEDS will be reprocessed in 2023
with this latest product release and latest version of the DECSO inversion system

TROPOMI NO2 over Europe

Average for the year 2019

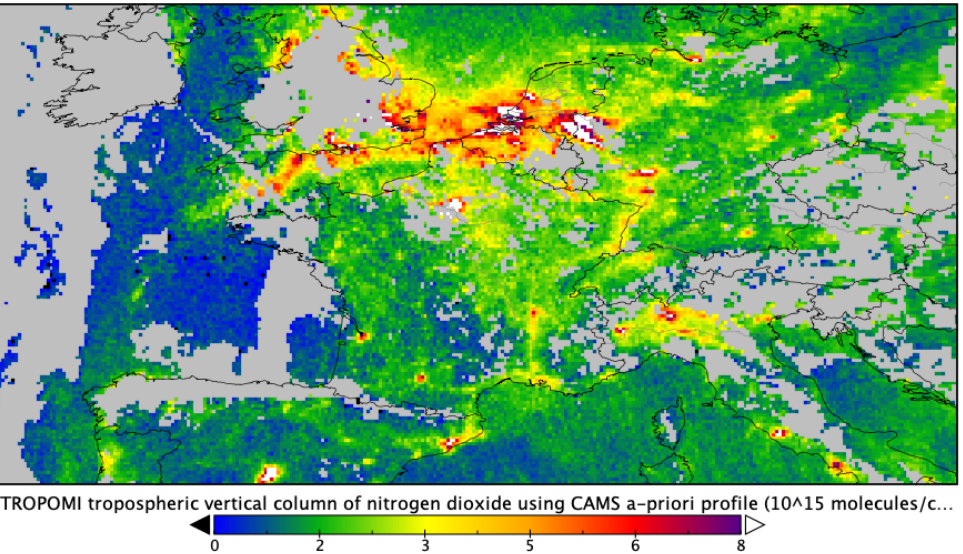
- cities
- highways
- ships
- airports
- industries

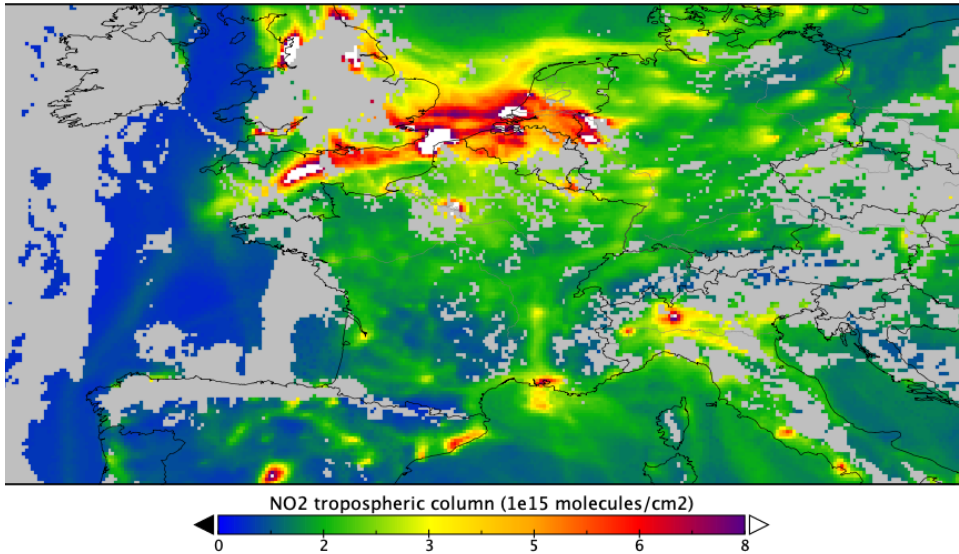


Comparing TROPOMI NO2 concentrations with models on daily basis

TROPOMI NO2 based on CAMS-regional a-priori

CAMS-regional vertical column NO2





Single overpass, 26 July 2018

John Douros, KNMI

==> Emission time series

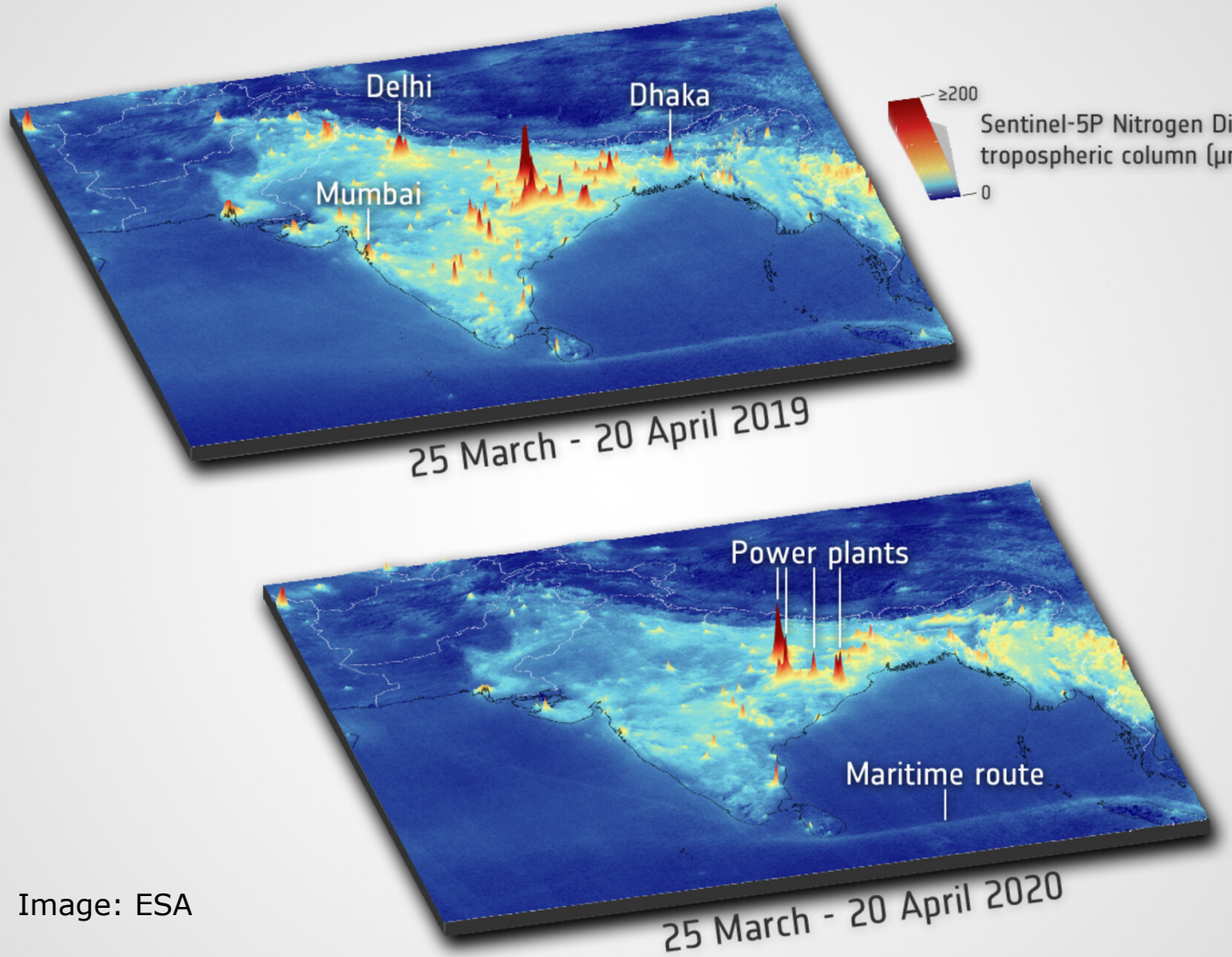


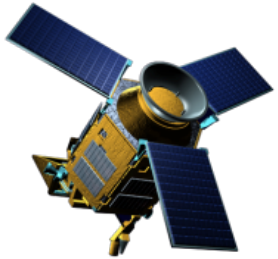
Image: ESA

COVID-19

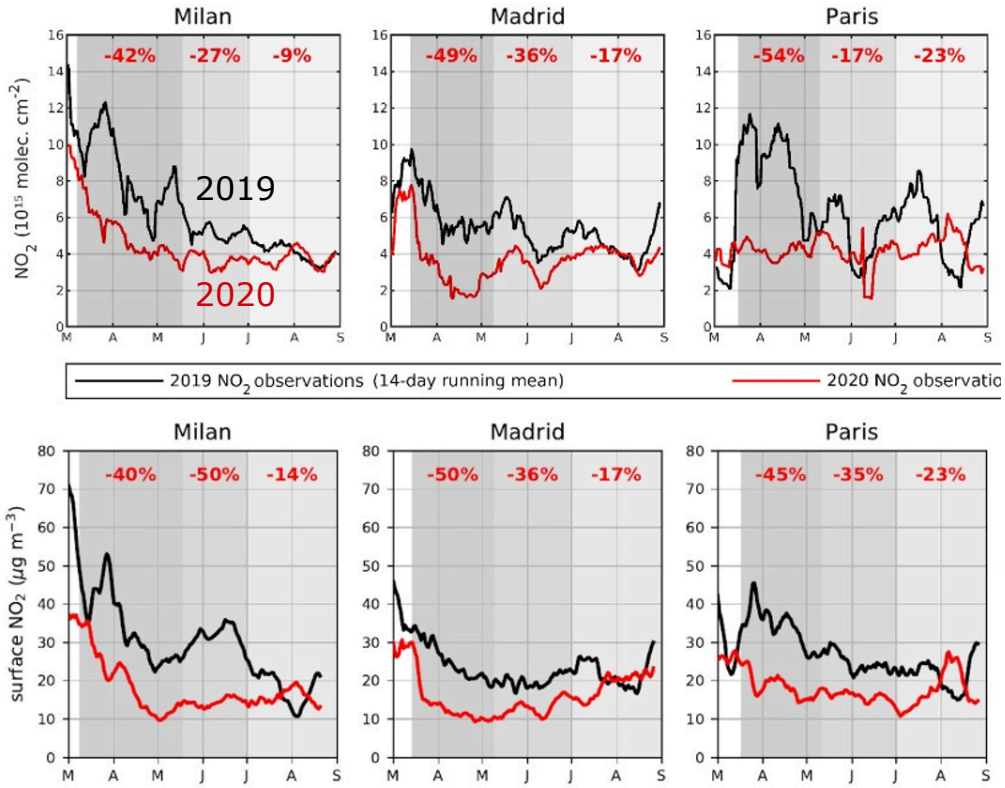
Strong reductions in NO_2 during lockdown in India

Differences megacities vs. coal powerplants

Real-time monitoring rapid changes



TROPOMI observed reductions compared to surface observations



TROPOMI NO2

Good consistency between reductions observed by TROPOMI versus surface (EEA European air-quality monitoring stations)

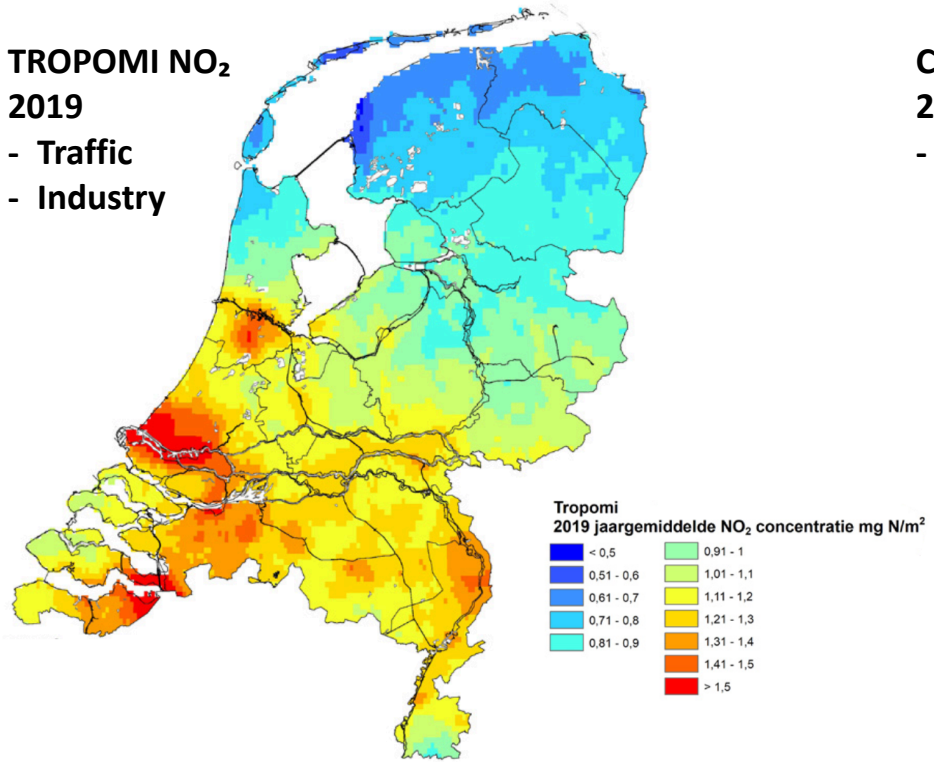
Influence of weather

Surface NO2

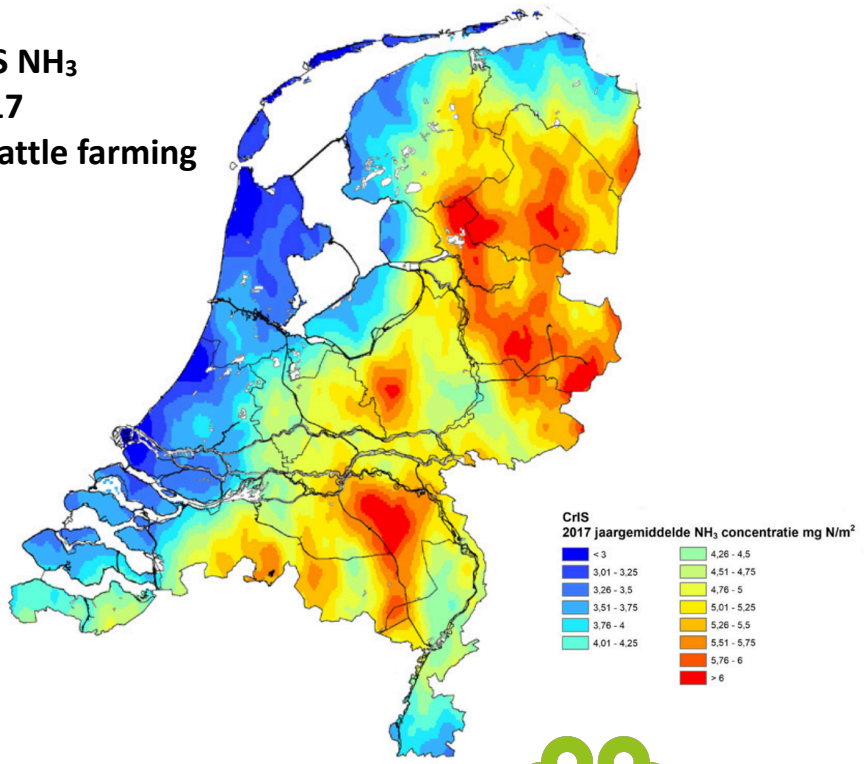
Bas Mijling, KNMI; Maite Bauwens BIRA

The Dutch reactive nitrogen (deposition) problem: loss of biodiversity

TROPOMI NO_2
2019
- **Traffic**
- **Industry**



CrIS NH_3
2017
- **Cattle farming**



Supreme court ruling limiting N emissions to protect nature (N2000)

Why use satellite data?

Strong points:

- Daily measurements (about 1 per 2 days due to clouds):
  detect sudden changes in emissions within a few days (e.g. COVID-19 lockdown related)
- Measurements everywhere.
- Changes in total column are direct measure of emissions
  Detected plumes can be analysed to provide emission estimates.
- Very little noise in NO2. For HCHO / NH3 noise is larger - averaging in space / time

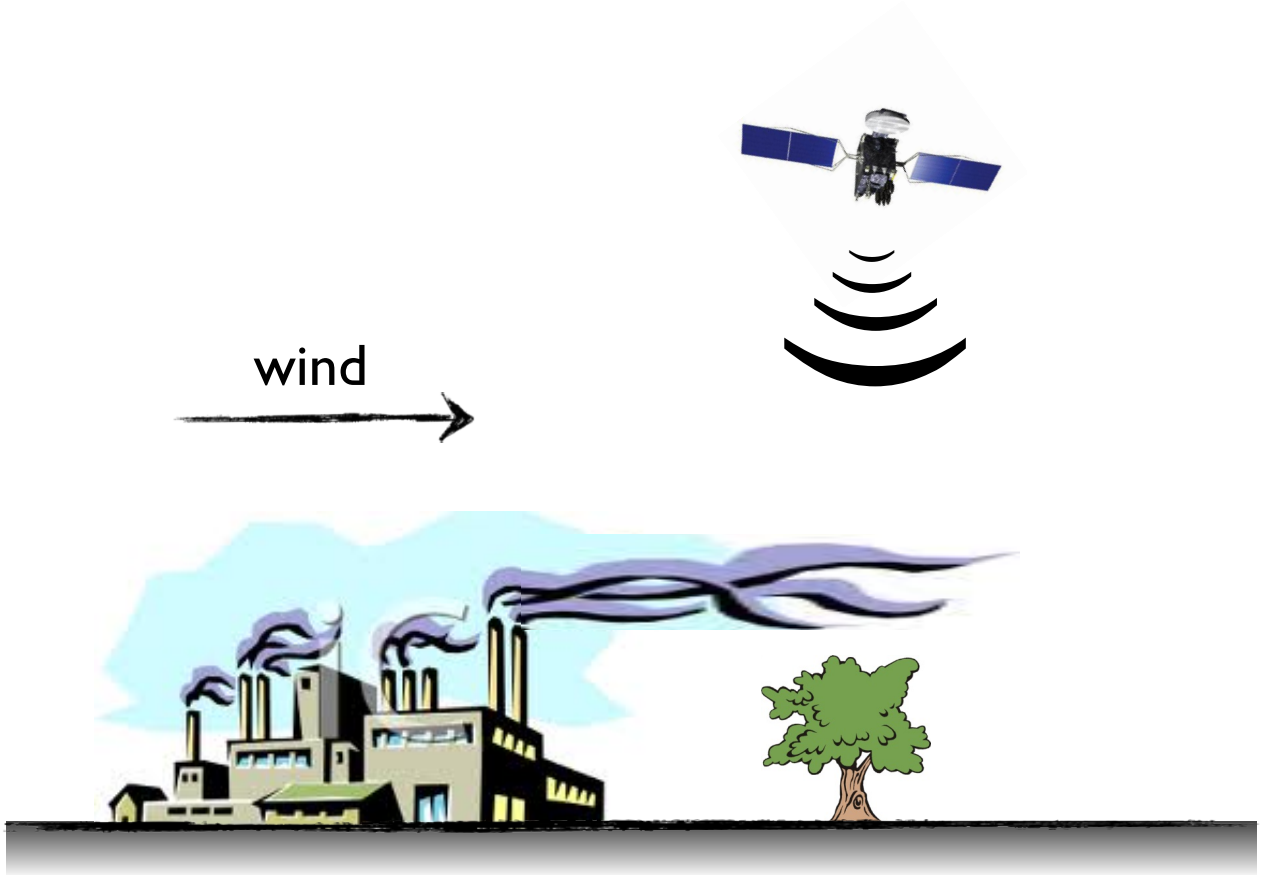
Note:

- Only one overpass per day, close to noon time.
  TROPOMI observations reflect emissions in the morning. Diurnal profiles needed.
- No direct emission sector information, but can be derived indirectly from spatial distribution

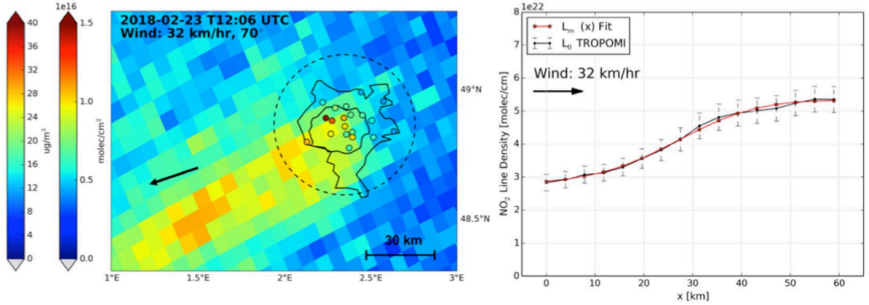
Future: Geostationary satellite observations over Europe with **Sentinel-4** (launce 2024)

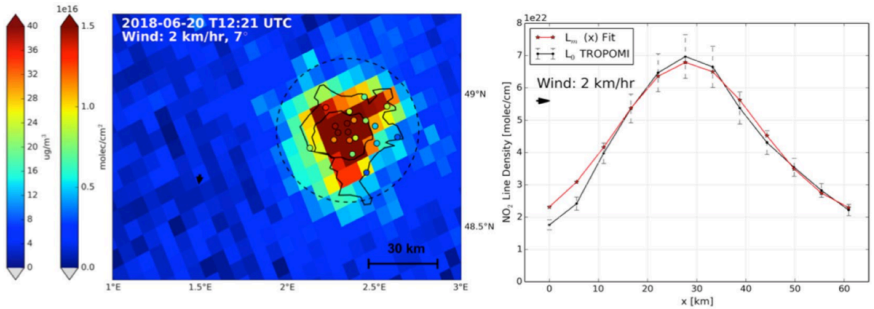
SEEDS will perform a case study for Sentinel-4 potential using TROPOMI data at high latitudes

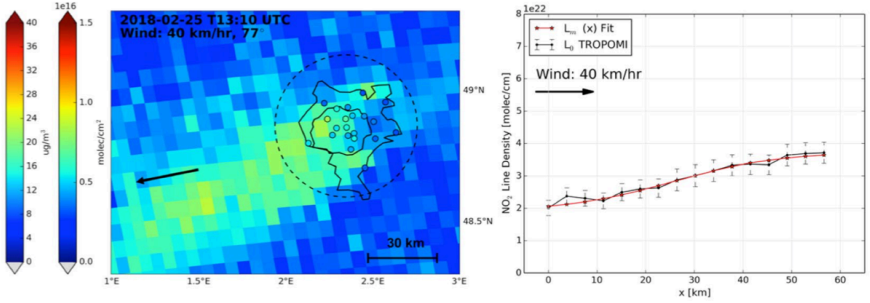
Using satellite data to derive emissions: principle



Emission estimates #1: plume analysis







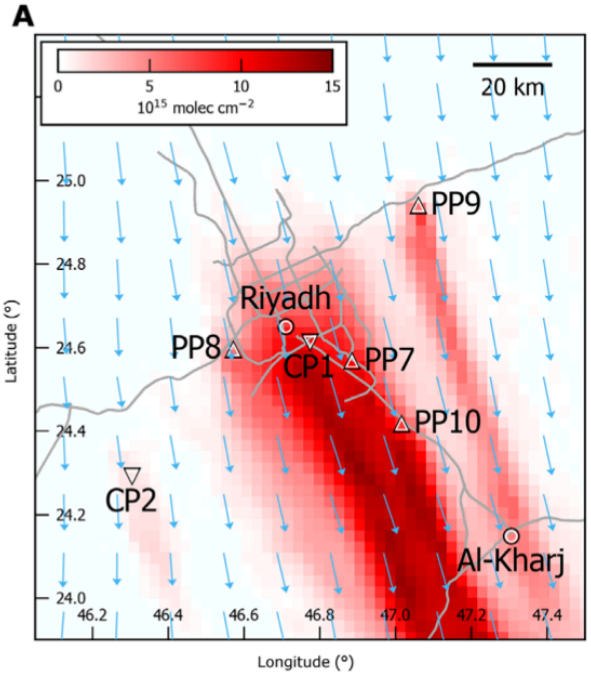
Plume fit depending on
- emission strength,
- plume width,
- NO2 lifetime

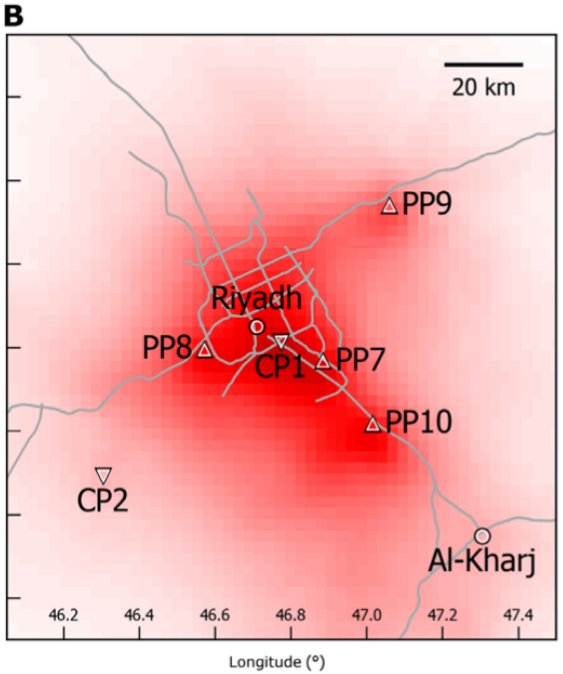
Emission distribution within megacity

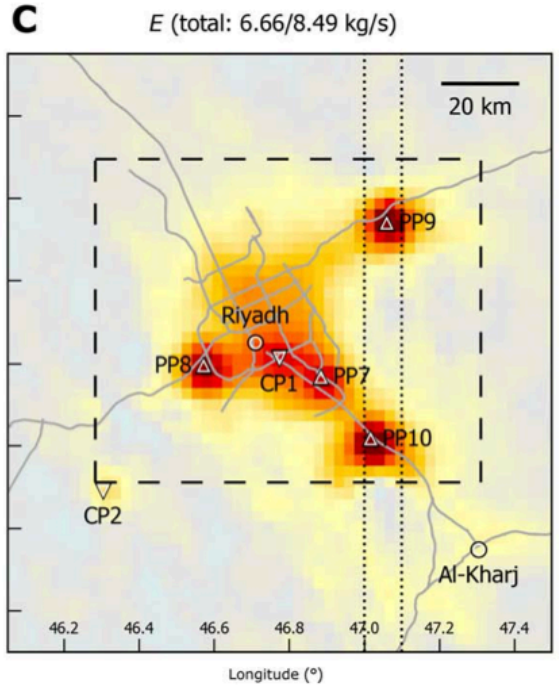
Estimating emissions of Parijs
Combining daily plume observations with wind information
Lorente et al., Nature Sci. Rep. 2019

Fioletov et al.,
https://doi.org/10.5194/acp-22-4201-2022
Distinguishing background/urban/industry

Emission estimates #2: flux divergence approach







Flux divergence method
Beirle et al., Science Adv. 2019

Emission estimates: Pros and Cons

Plume fitting:

- Pro: Analyse individual plumes on daily basis
- Con: Overlapping plumes more messy, retrieval a-priori dependent

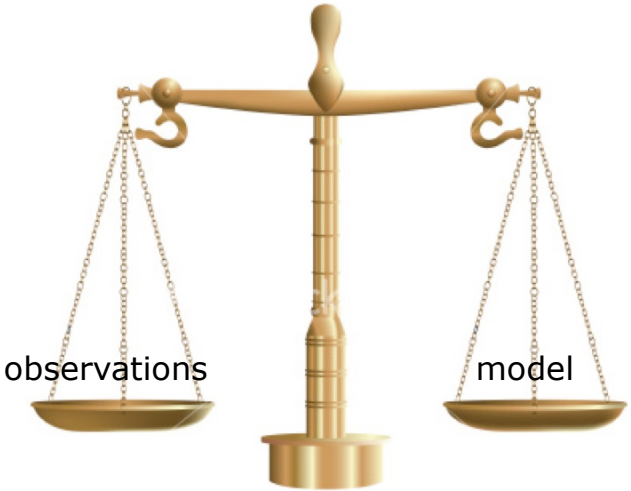
Flux divergence method:

- Pro: Easy to implement, fast
- Cons:
  - Retrieval a-priori dependent
  - Lifetime difficult part
  - Noisy: not for individual days

Emission estimate #3: Inverse modelling and data assimilation

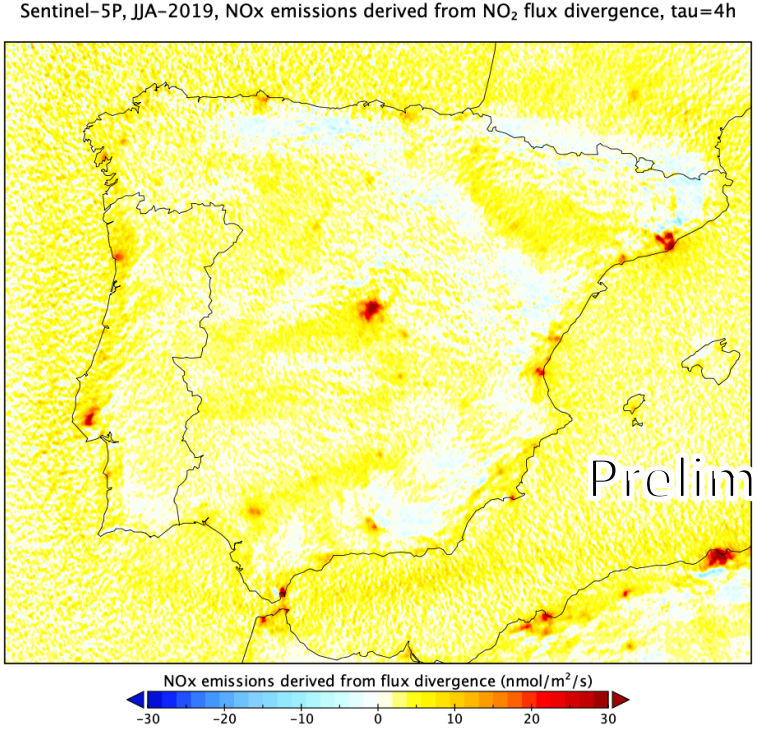
Match of **satellite observations** and **chemical-transport model** via **data assimilation**:

- 4D-var and/or Ensemble Kalman Filter (computationally expensive)
- Kalman Filter (**DECSO** algorithm of KNMI) — **Used in SEEDS**
  - Based on French CHIMERE model
  - Fast, only one model run needed
  - No a-priori needed, unknown sources
  - Error estimates

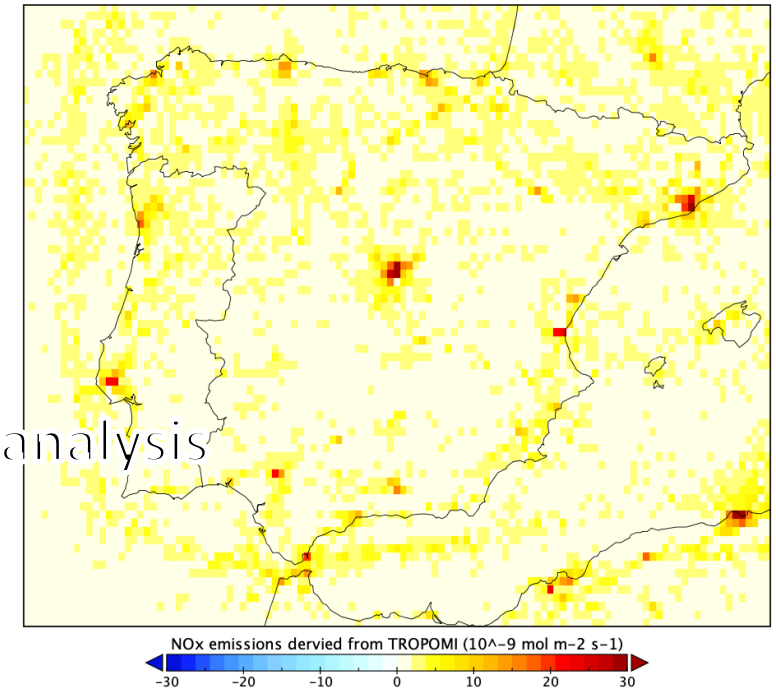


Verification of NOx emissions: DECSO versus Flux-divergence

Flux-divergence



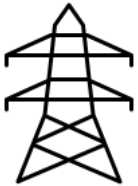
DECSO



Preliminary analysis

SEEDS
Sentinel EO-based Emission and Deposition Service

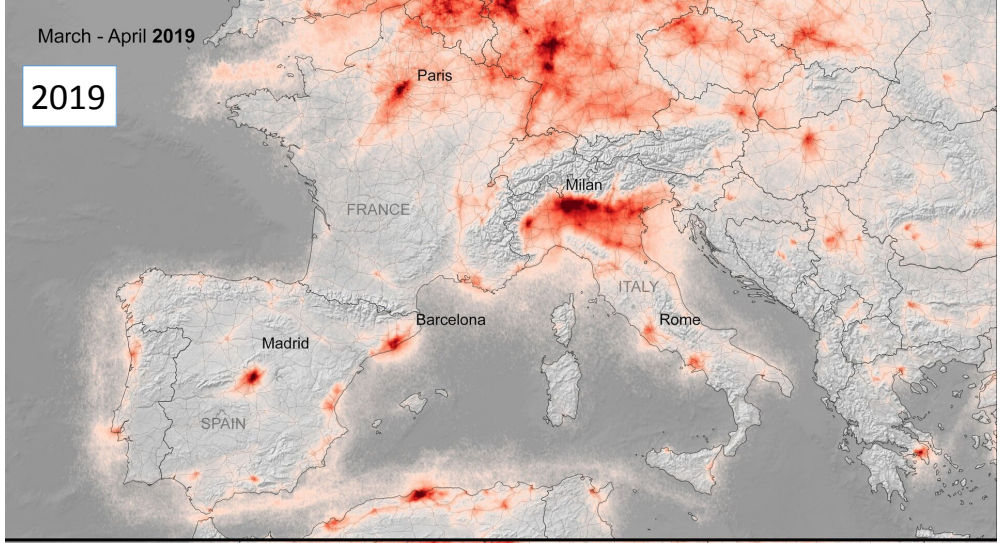


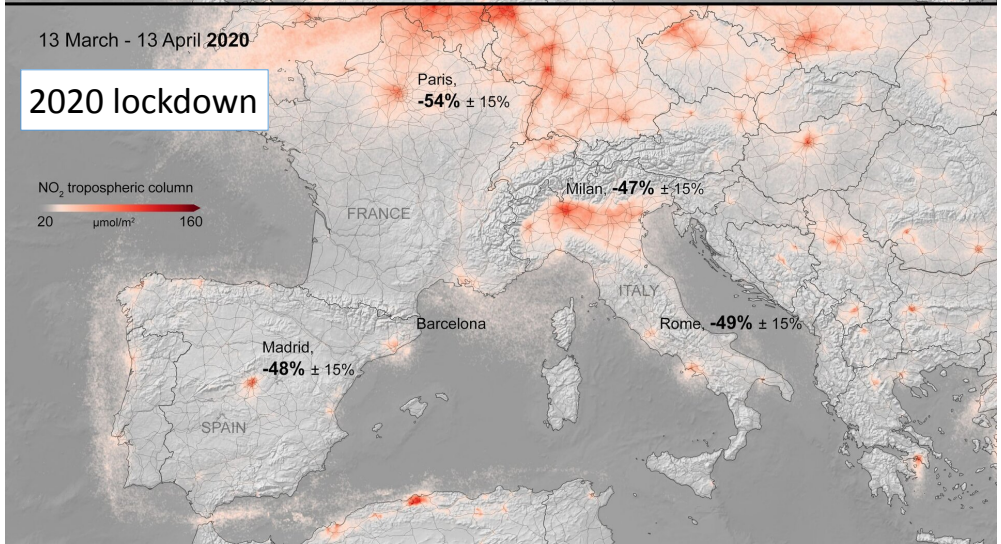


Using satellites to derive emissions

- TROPOMI:
  - 3.5x5.5 km footprint, sector information from spatial distribution
  - daily overpass, 13:30 LT, no diurnal information
  - Prospect of real-time emissions
- Column observations plus wind information —> Emission
- Different emission inversion approaches highly independent
  - used for verification, emission uncertainty estimates

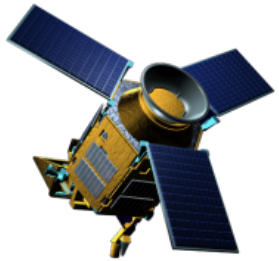
Funded by the European Union



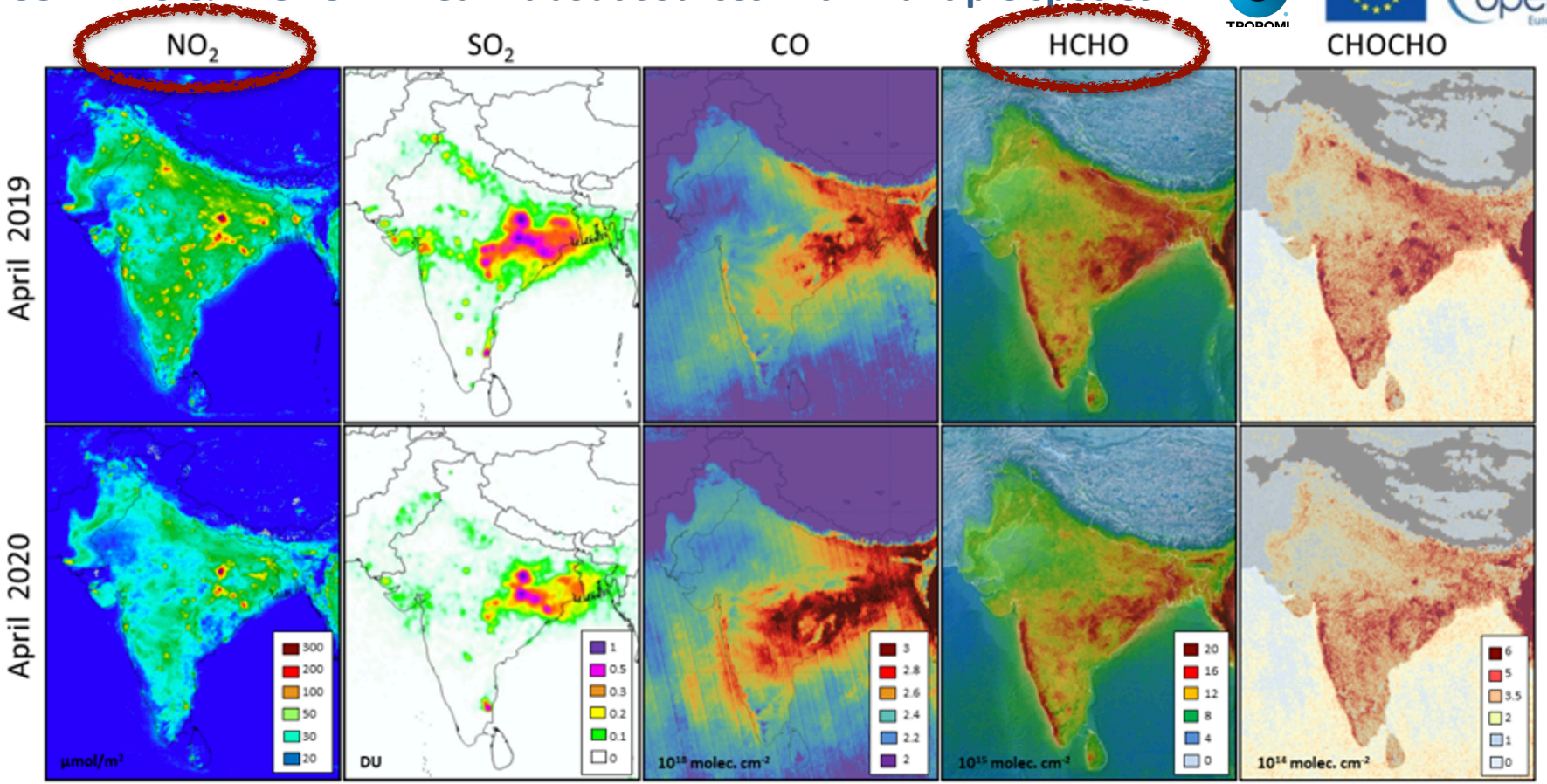


Strong reductions in NO_2 during lockdown in Italy, France, Spain

About 50% less NO2 in the major cities compared to 2019

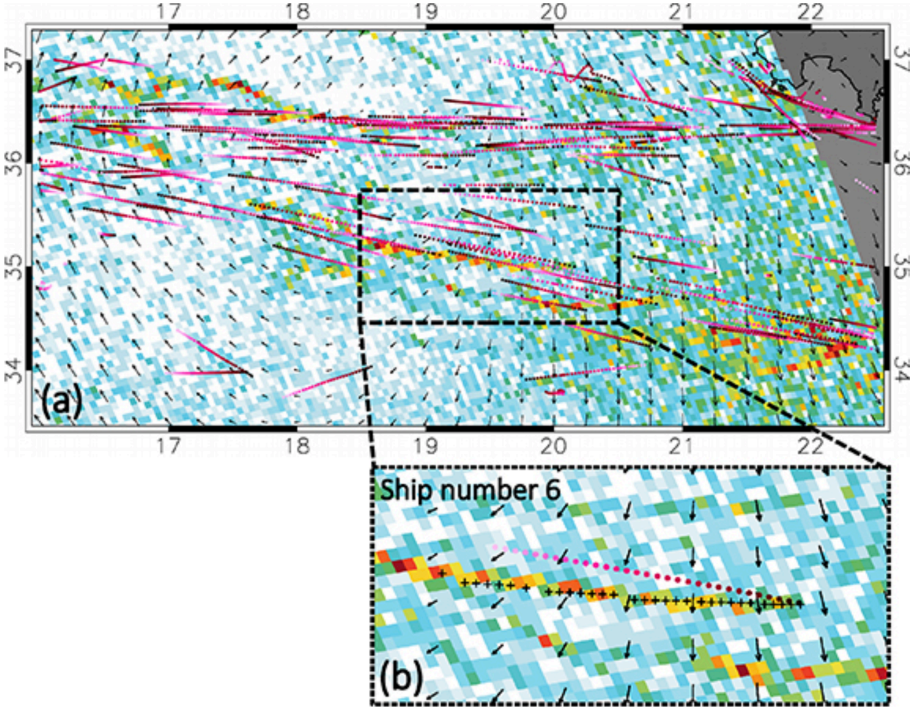


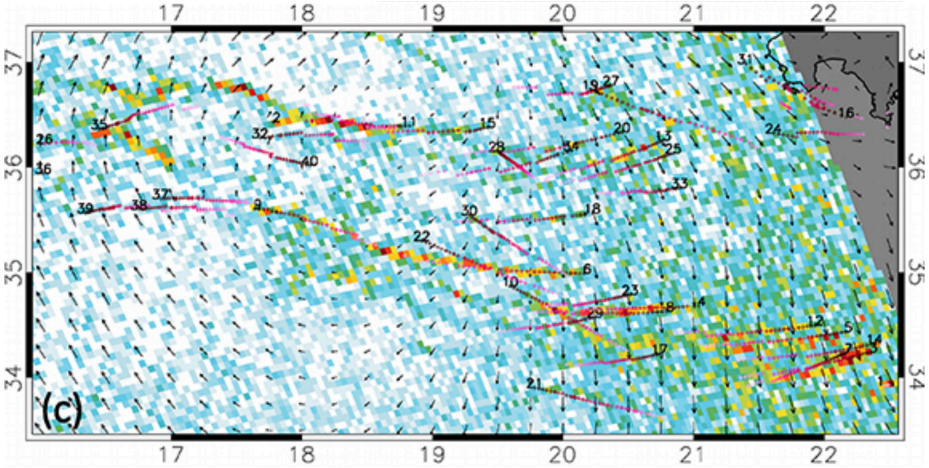
COVID-19 & TROPOMI: Learn about sources with mulitiple species



Levelt, Stein et al., 2022 (ACP)

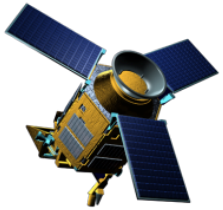
Highlight: Monitoring emissions of individual ships





Georgoulias et al., ERL, 2020

Validation of satellite-derived emissions



mass balance / flux divergence approach to estimate emissions

- Uses satellite columns + wind
- Flux divergence: emission estimate independent to DECSO
- **Estimate of uncertainties**