BAQ
BETTER AIR QUALITY
CONFERENCE

CLEAN AIR ASIA
ADB
CLIMATE & CLEAN AIR COALITION
a UNEP convened initiative

SATELLITE BASED AQ ANALYSIS AND MODELLING

Leonor Tarrasón, NILU

Europe’s eye on Earth: Copernicus

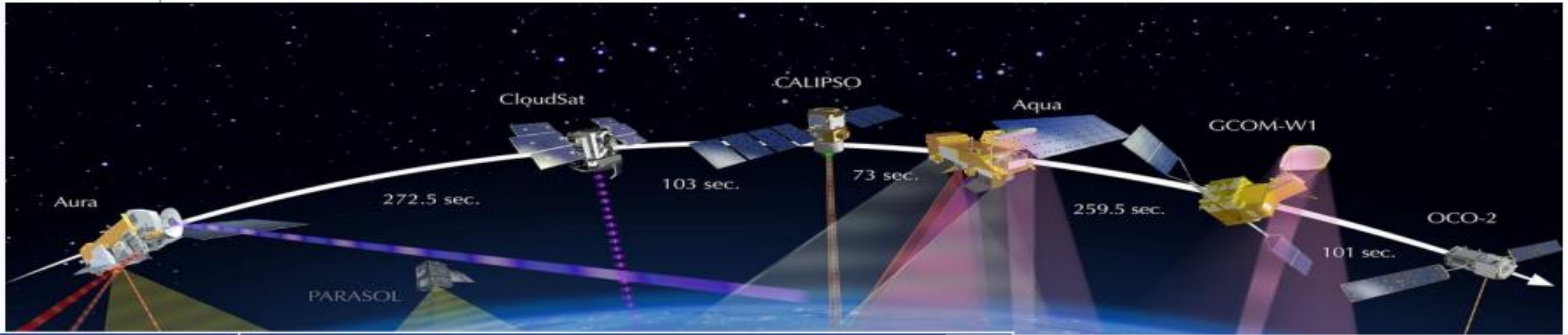
Copernicus is the Earth Observation Programme of the European Union.

- ✓ Six services
- ✓ User driven with free data and unrestricted access
- ✓ EUs EO service infrastructure streamlined with EU research funding

The Copernicus Atmosphere Monitoring Service: CAMS

Atmosphere Monitoring

Earth Observation satellites in CAMS



Species	Instruments
Global system	
O_3	OMI, SBUV, GOME-2, MLS, OMPS S5p
CO	IASI, MOPITT, S5p
NO_2	OMI, GOME-2, S5p
SO_2	OMI, GOME-2, S5p
Aerosol	MODIS, PMAp, VIIRS, S3
CO_2	GOSAT, OCO-2
CH_4	GOSAT, IASI, S5p
GFAS fire emissions	MODIS, SEVIRI*, VIIRS, Sentinel-3, GOES-E/W*, HIMAWARI-8*

Assimilated **Monitored** Under development *Geostationary platform

Atmosphere Monitoring

Exciting times ahead

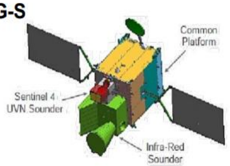
MetOp-SG-A

- IASI-NG
- 3MI
- Sentinel-5

Preparation activities using S5p data, gradually introduced in operational global forecasting system. Feedback from CAMS testing has led to significant improvements in data quality.

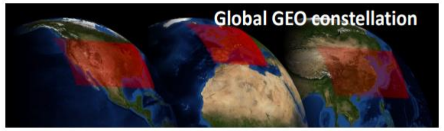
EUMETSAT
esa

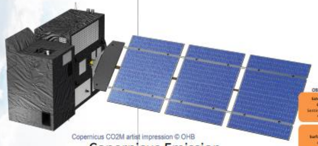
MTG-S



- IRS
- Sentinel-4

Initial studies for the use of Sentinel-4 observations in the regional forecasting models

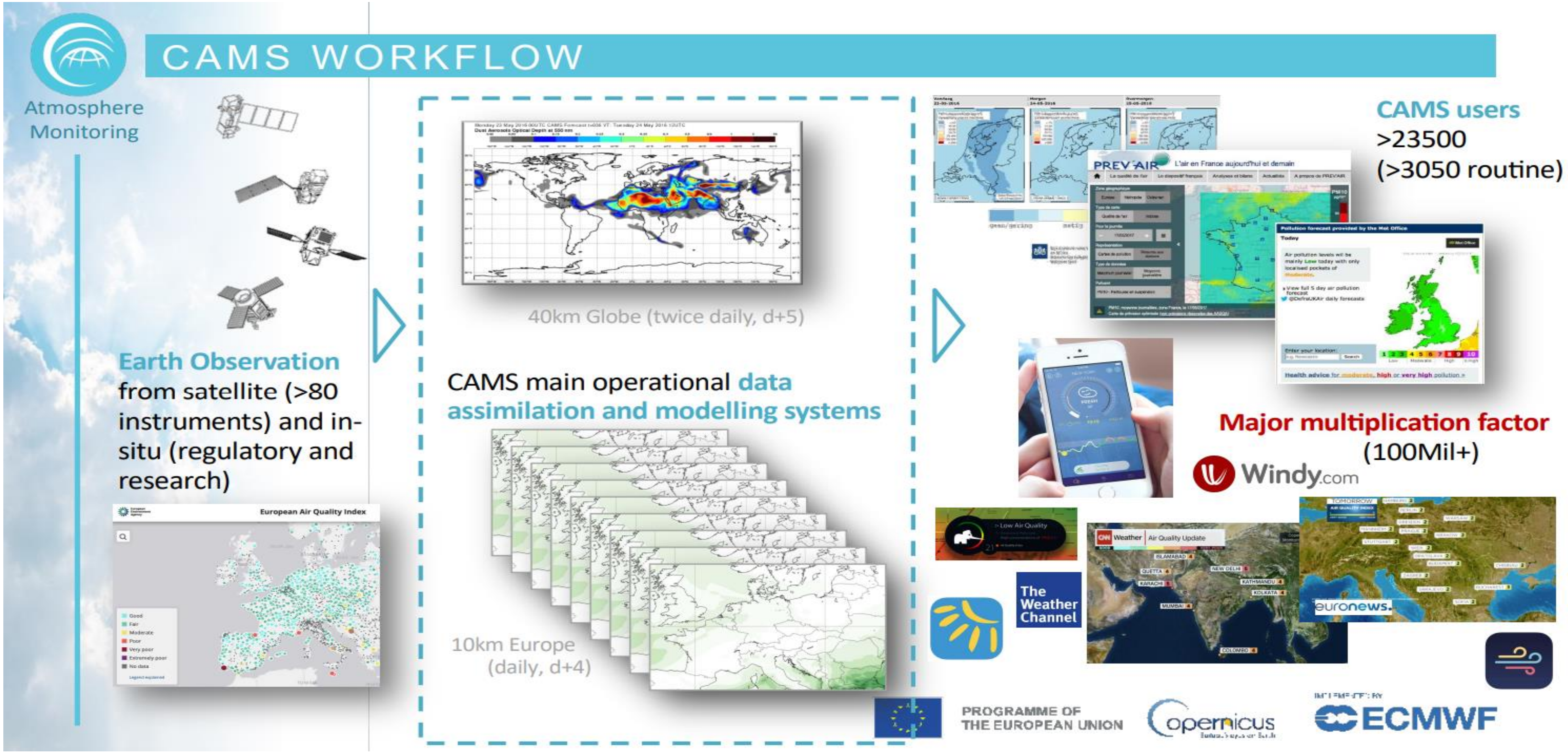




CO2M

Copernicus Emission Monitoring & Verification Support Service

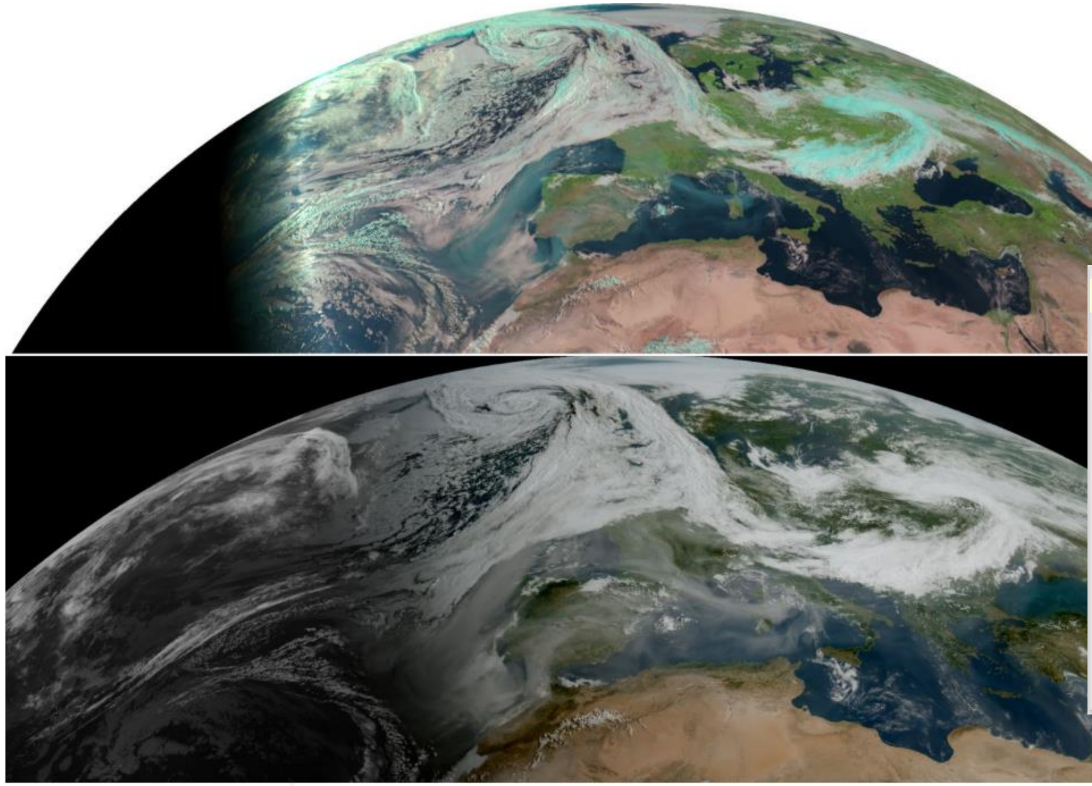
ECMWF Copernicus European Commission

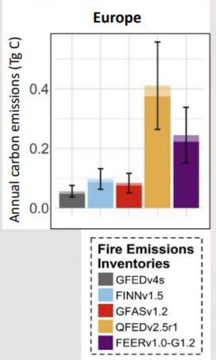


https://atmosphere.copernicus.eu **Global Daily AQ forecasts**

BAQ 2023 BETTER AIR QUALITY CONFERENCE 15–17 NOV• MANILA
CLEAN AIR ASIA
ADB
CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS
a UNEP convened initiative

Improved forecasts of natural dust and forest fires with the use of satellite data





Large differences between inventories

BB datasets	Relies on
GFED4s	MODIS burnt area + MODIS active fires (for small fires)
FINN	MODIS active fire counts + MODIS active fires
GFAS	Assimilated MODIS FRP
FEER	As in GFAS, constrained by MODIS AOD
QFED	FRP fire products, constrained by MODIS AOD
SEEDS	Top-down, uses chemical observations of HCHO

- Uncertainties due to detection of area burnt, FRP, emission factors, biome types, fuel consumption, difficult to account for understory fires
- Factor of ~4 between the global emission estimates
- QFED and FEER much higher than other datasets

→ Satellite formaldehyde offers an alternative way to constrain fire emissions

BAQ 2023 BETTER AIR QUALITY CONFERENCE 15–17 NOV• MANILA

CLEAN AIR ASIA

ADB

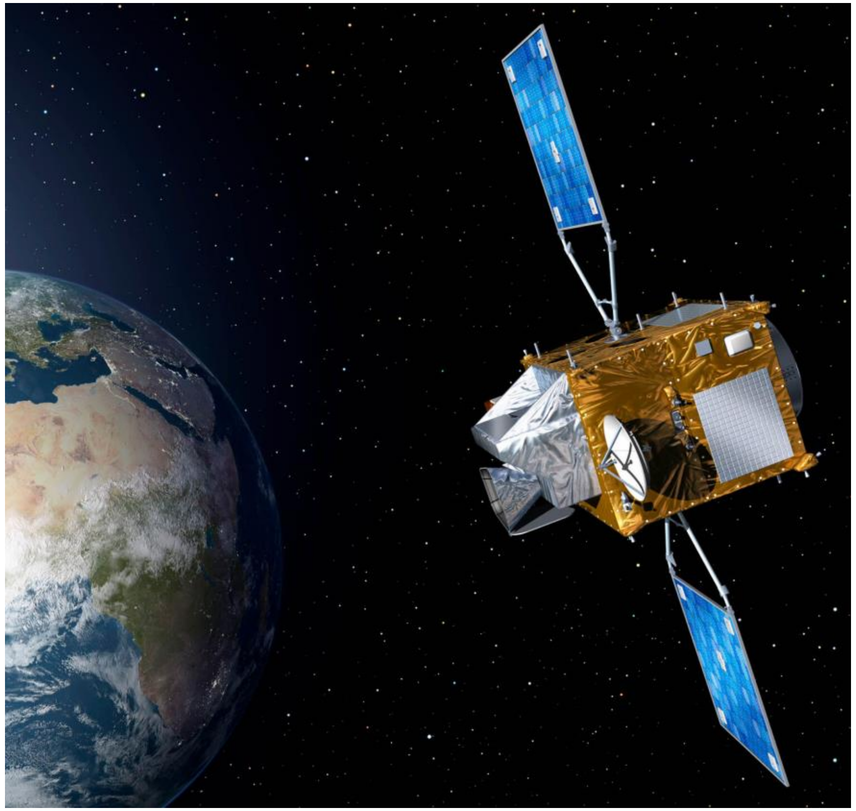
CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

a UNEP convened initiative

SEEDS – H2020 project

Sentinel EO-based Emission and Deposition Service

SEEDS
Sentinel EO-based Emission and Deposition Service



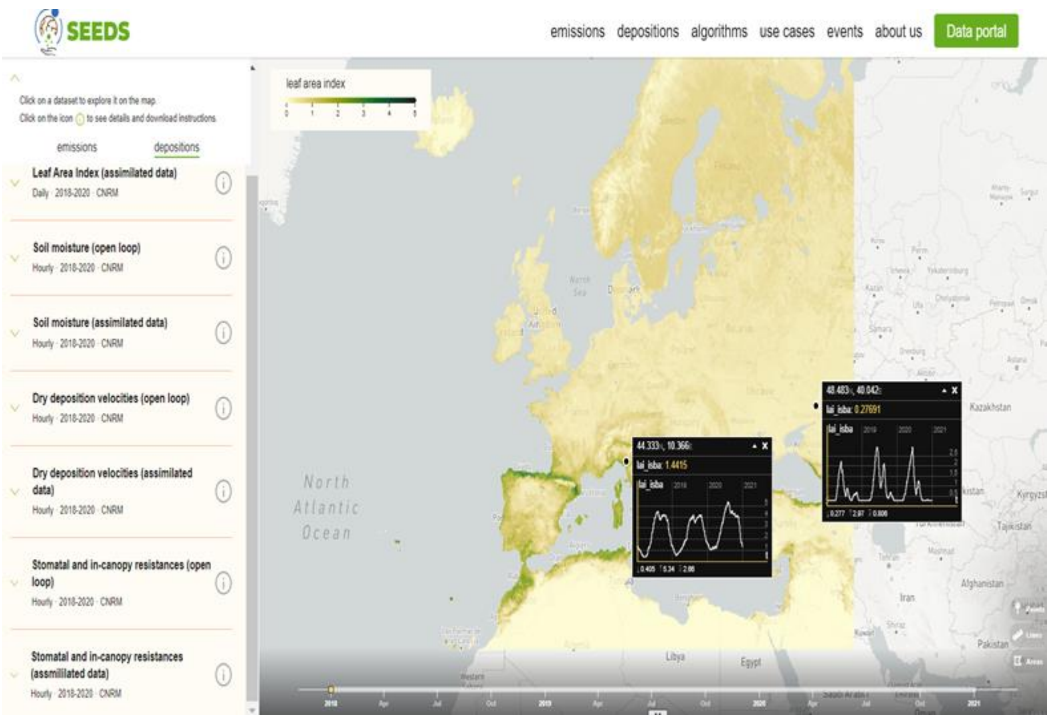
Sentinel 5P & Preparation for Sentinel 4

- The SEEDS project goal is to develop several top-down (satellite) inversion techniques to estimate European emissions of NOx, NH3, VOC, improve deposition flux modelling and develop advanced data assimilation techniques.
- The project is developing techniques that may eventually become part of the Copernicus Atmosphere Service (CAMS).
- SEEDS is now on its third and final year and we have compiled a significant number of datasets in our portal for further evaluation.

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
cnrs
isardSAT
lobelia.

SEEDS
Sentinel EO-based Emission and Deposition Service

SEEDS – New Products



https://www.seedsproject.eu/data

SEEDS uses inverse modelling to produce up-to-date high-resolution estimates of NOx, NH_3 and biomass burning emissions.

- **NOx** – 2019 -**2022** Monthly anthropogenic NOx emissions at up to 5 km resolution
- **NH_3** – 2019 -2022 Monthly NH_3 emissions with 20 km resolution
- **Fires** – 2018-2020-2022 Daily top-down biomass burning emissions at 10 km resolution
- **Soil NOx** – 2019 -2022 Agricultural soil NOx emissions at up to 5 km resolution
- **BVOC** – 2018-2022 Top-down and bottom-up estimates of Biogenic Organic Compounds with 10 km resolution
- **LAI** - 2018-2022 Leaf area index data sets at 10 km spatial resolution
- **Soil Moisture** – 2018-2022 Soil moisture datasets at 10 km spatial resolution
- **Deposition** - 2018-2022 Deposition fluxes and diagnostics (e.g., stomatal resistance) for ozone and nitrogen at 10 km spatial resolution

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
cnrs
isardSAT
lobelia.

SEEDS – H2020 project

Sentinel EO-based Emission and Deposition Service

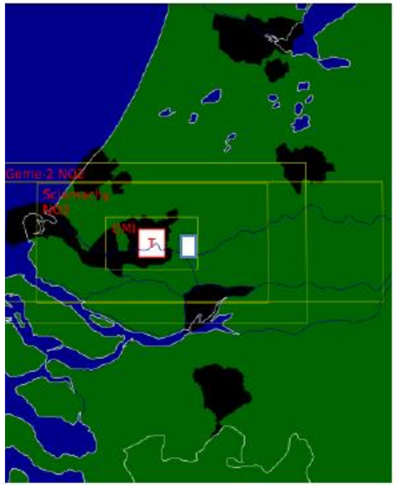
SEEDS
Sentinel EO-based Emission and Deposition Service

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 Operational Data products

Product	Application	
Ozone	Ozone layer monitoring, UV-index forecast, Climate monitoring	
NO_2	Air quality forecast and monitoring	← SEEDS
CO	Air quality forecast and monitoring	
CH_2O	Air quality forecast and monitoring	← SEEDS
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

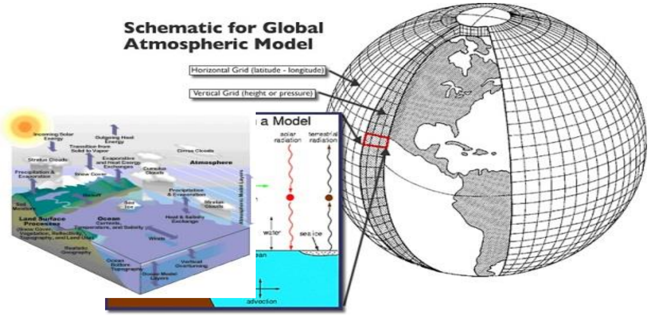
Development of supplementary products: SIF, AOD, CHOCHO, HONO, ALH

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
cnrs
isardSAT
lobelia.

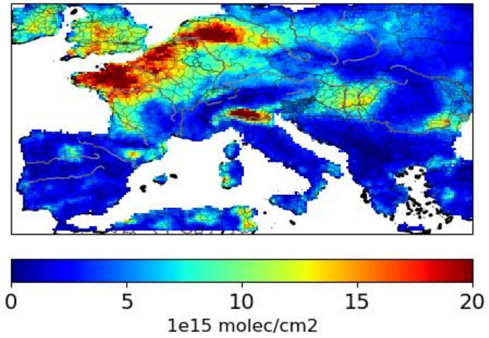
DECSO (Daily Emission estimates Constrained by Satellite Observation)

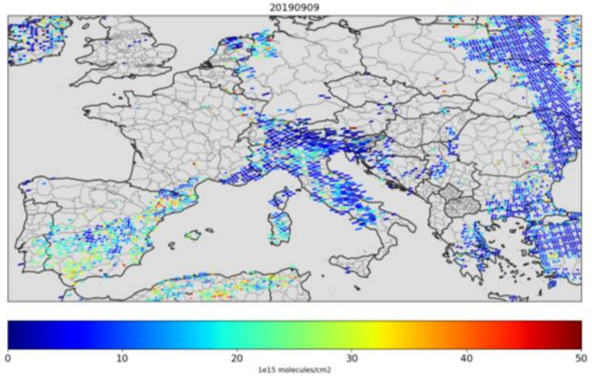
SEEDS inversion of satellite observations for NOX and NH3 based on DECSO (KMNI)

Chemistry Transport Model - Chimere

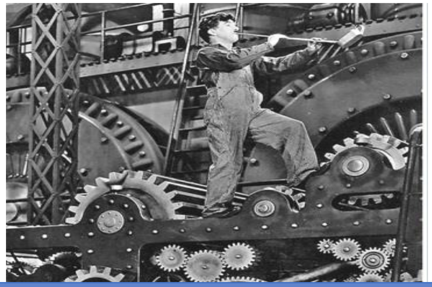


Concentrations



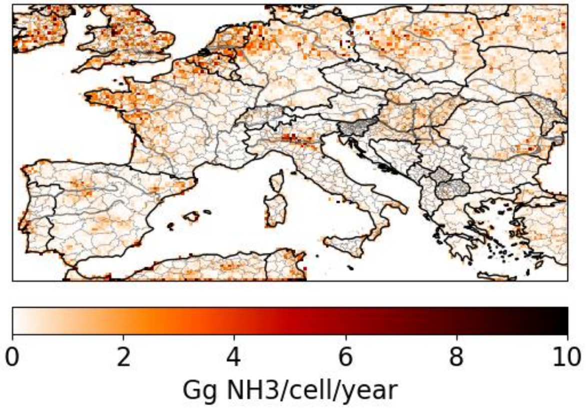


Satellite observations



State vector forecast	$\mathbf{x}^f(t_{i+1}) = M_i\,[\mathbf{x}^a(t_i)]$
Error covariance forecast	$\mathbf{P}^f(t_{i+1}) = \mathbf{M}_i\mathbf{P}^a(t_i)\mathbf{M}_i^T + \mathbf{Q}(t_i)$
Kalman gain matrix	$\mathbf{K}_i = \mathbf{P}^f(t_i)\mathbf{H}_i^T[\mathbf{H}_i\mathbf{P}^f(t_i)\mathbf{H}_i^T + \mathbf{R}_i]^{-1}$
State vector analysis	$\mathbf{x}^a(t_i) = \mathbf{x}^f(t_i) + \mathbf{K}_i(\mathbf{y}_i^o - H_i\,[\mathbf{x}^f(t_i)])$
Error covariance analysis	$\mathbf{P}^a(t_i) = (\mathbf{I} - \mathbf{K}_i\mathbf{H}_i)\,\mathbf{P}^f(t_i)$

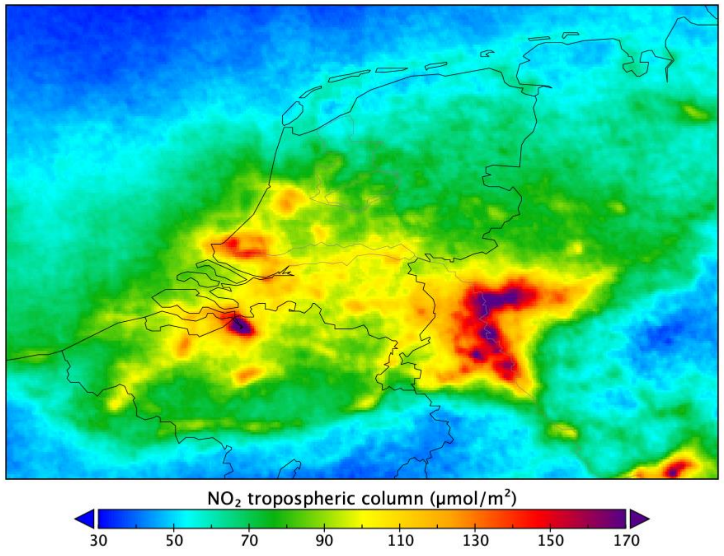
Inversion algorithm



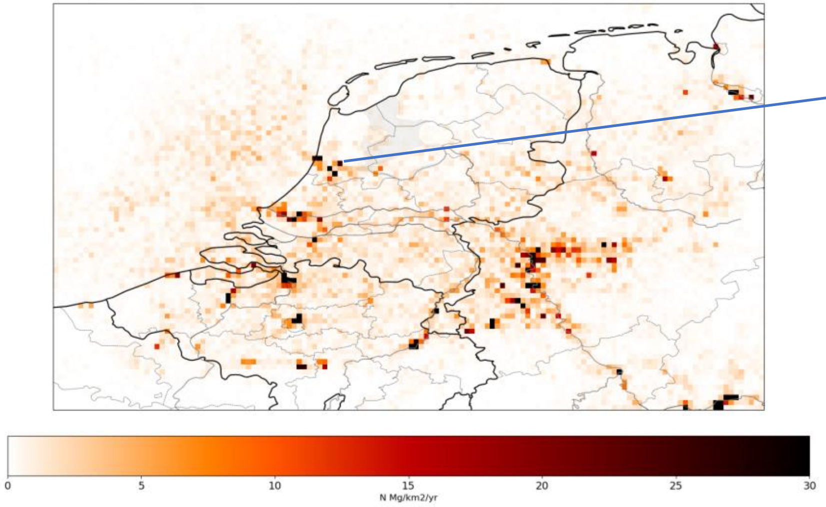
Emissions

Timeseries checks with use of satellite data

Sentinel-5P NO_2 tropospheric column, 2019 yearly mean

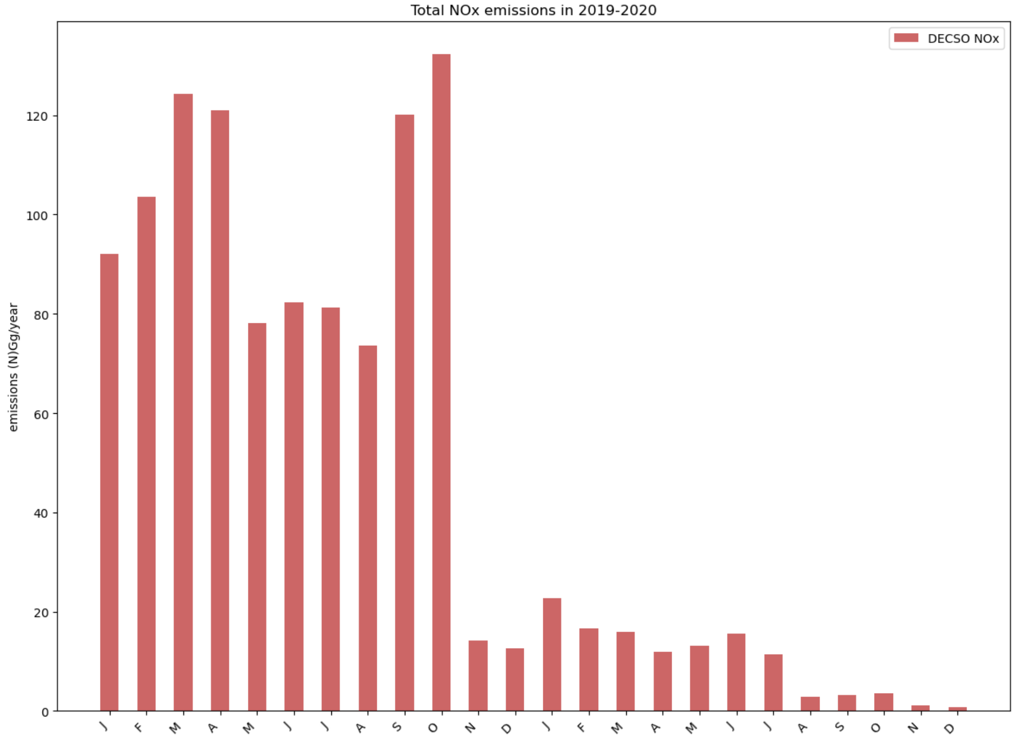


DECSO 2019

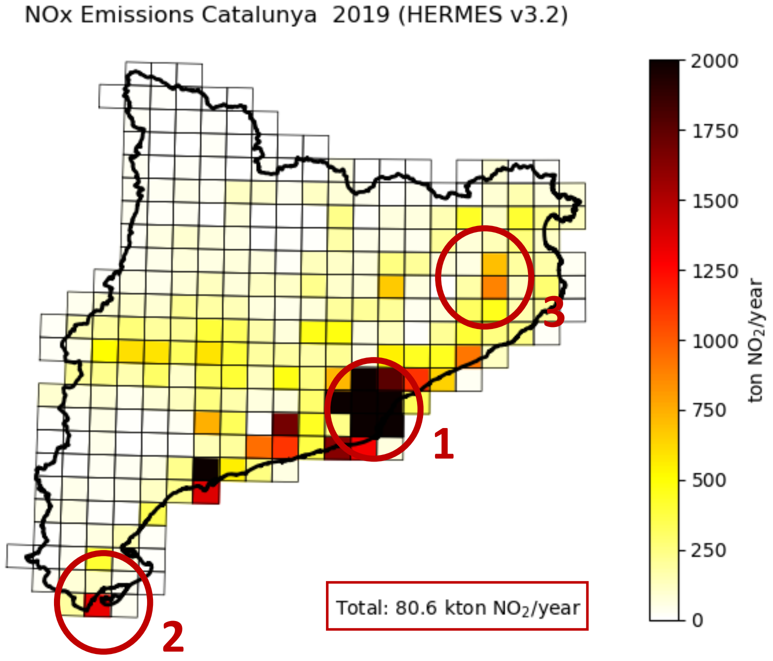


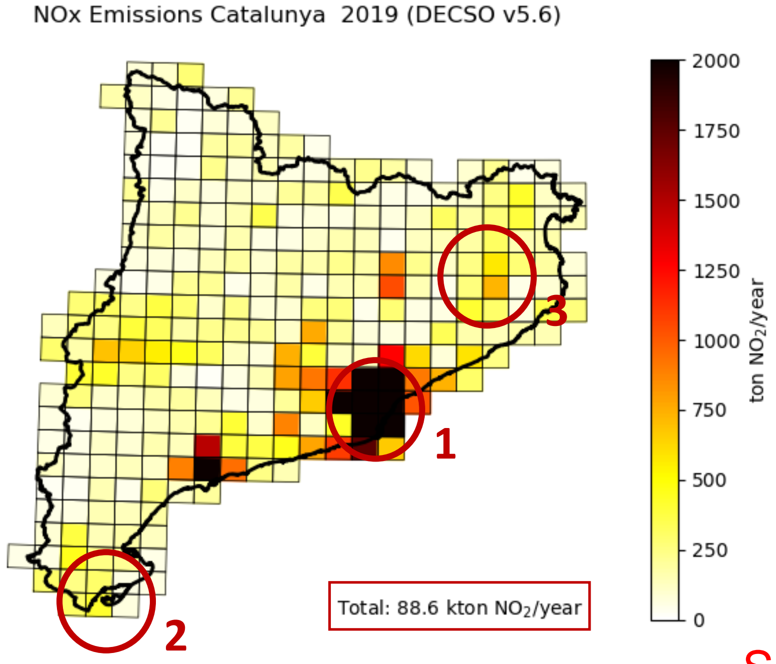
Going to a higher grid resolution: 3x5 km in the Netherlands

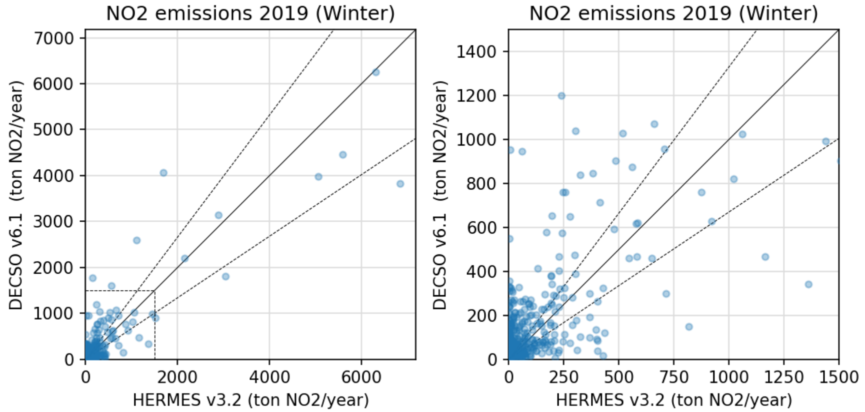
Powerplant “Hemweg centrale” decommissioned end of 2019



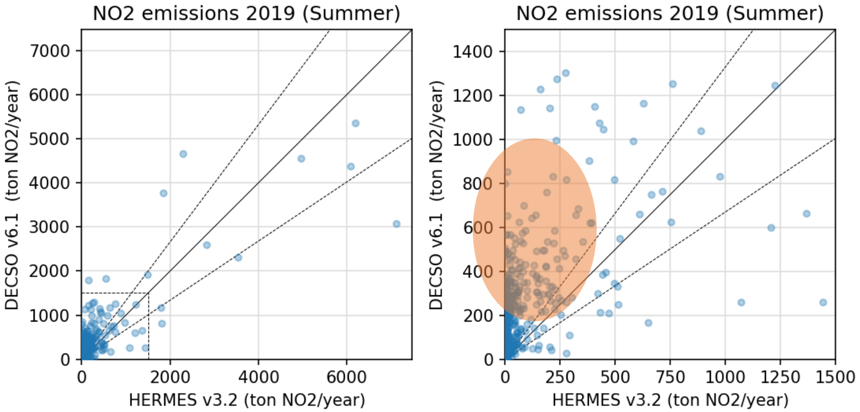
BU emission HERMESv3 vs TD inverse DECSO







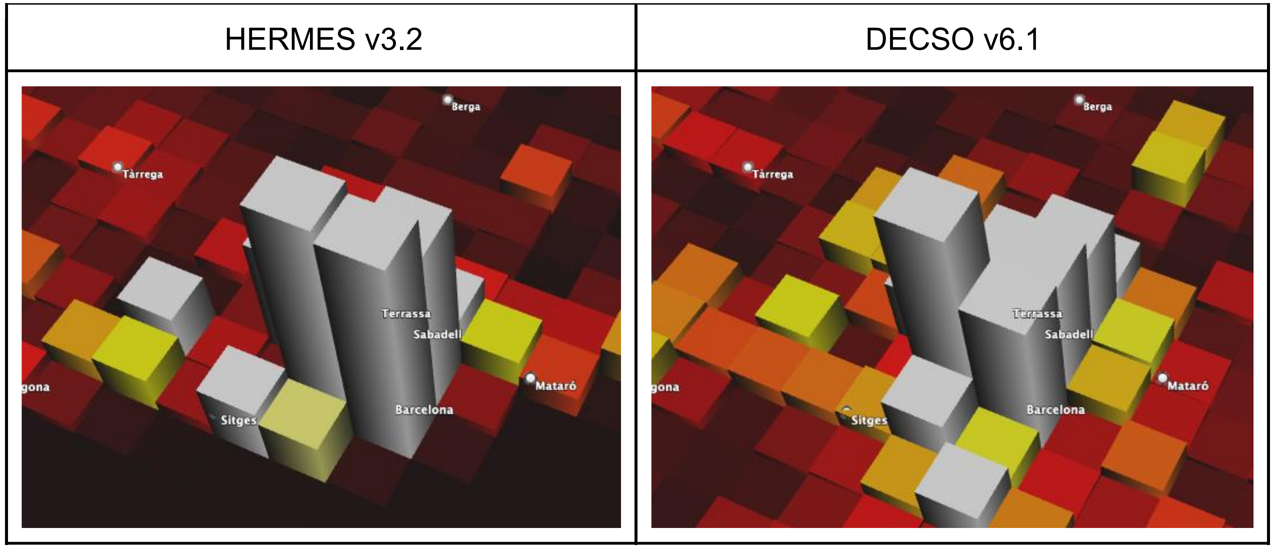
Soil NOx emissions

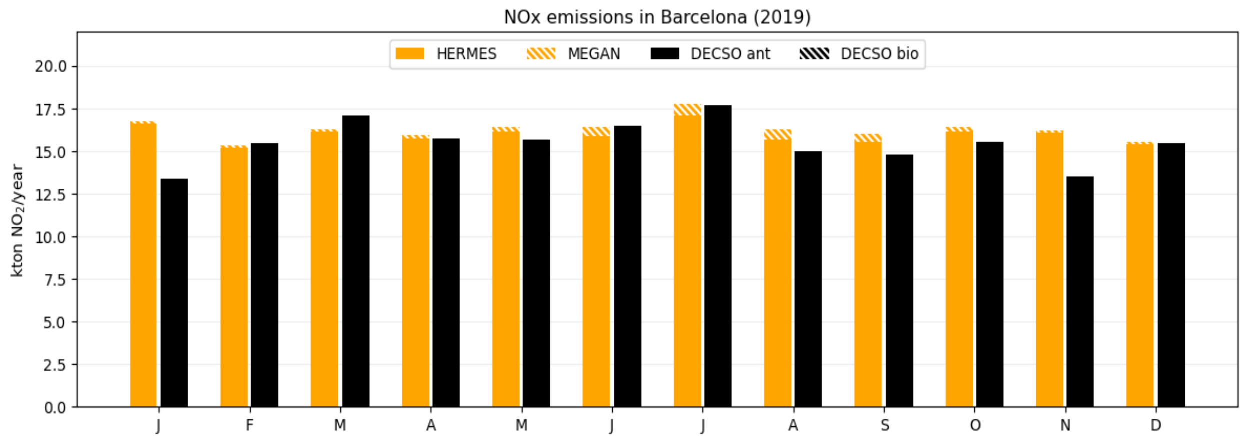


Barcelon
Supercor
Center
Centro Naci

Courtesy: Marc Guevara, BSC

Comparisons for NOx emissions in Barcelona area



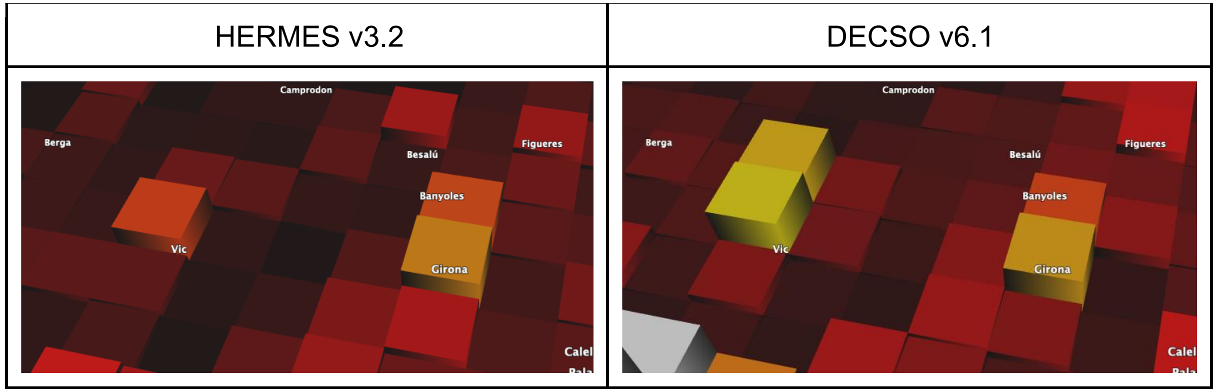


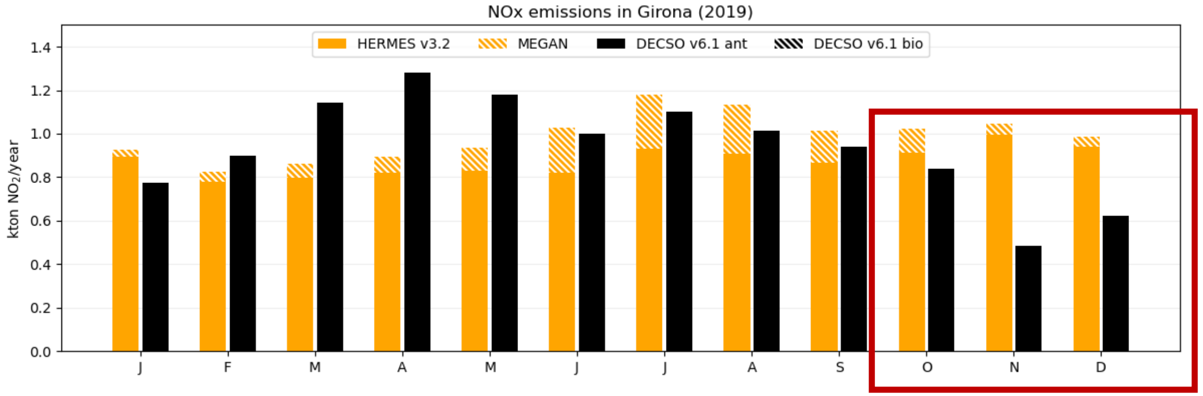
- 27.3 kton NO_2/year according to HERMES, which is about 34% of the total emissions found in Catalunya.
- DECSO estimates slightly less NOx emissions for this area: 26.1 kton NO_2/year.
- Although differently distributed over the grid cells, the aggregated emissions are well in line.
- No strong seasonalities identified neither in HERMES nor DECSO

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Courtesy: Marc Guevara, BSC

Comparison for NOx emissions in Girona area





- Results in total annual emissions agree very well, with HERMES having slightly stronger emissions.
- Important differences in the seasonal cycle: DECSO shows a continuous decrease during OND, while HERMES mantains almost constant emissions
- Influence of emissions from agricultural machinery and associated crop calendar re-considered in HERMES

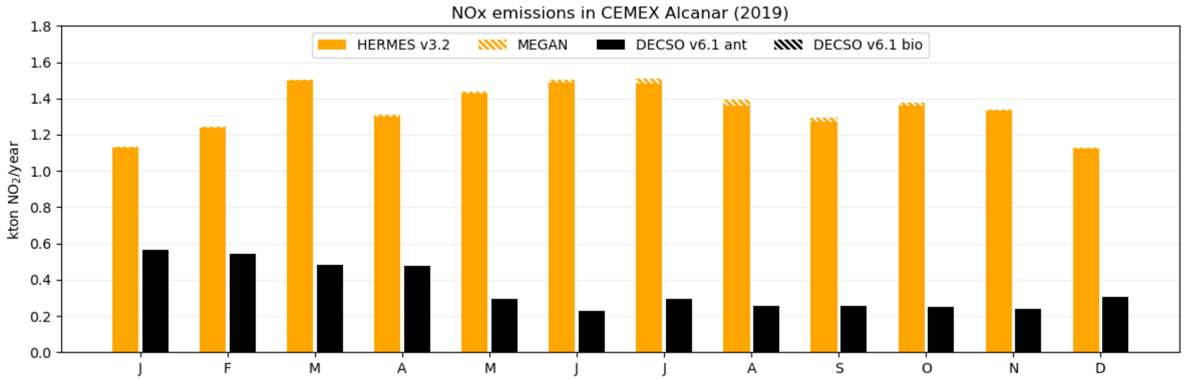
Crop type	Soil cultivation	
	Start_date	End_date
Wheat	1st November	31st December
Rye	1st September	31st October
Barley	1st November	31st December
Oat	1st October	31st November

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Courtesy: Marc Guevara, BSC

Industrial hotspot in Alcanar, Spain

HERMES v3.2	DECSO v6.1



- A strong registered point source in HERMES (**1.33 kton NO_2/year**) → emissions derived from the Large Point Source Database provided by the Spanish Ministry of Environment
- The DECSO estimation, however, is 74% lower: **0.35 kton NO_2/year**
- Results from the Continuos Emission Monitoring System provided by the Government of Catalonia indicate emissions of **1.1kton NO_2/year**
- The large disagreement is not well understood, and subject of further investigation (factory hotspot hardly visible in the level-2 TROPOMI satellite product, errors in the assumed surface albedo?)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Courtesy: Marc Guevara, BSC

Key messages

- Air quality forecasting capabilities significantly advanced under the Copernicus Atmosphere Monitoring Service
  - relying on the combination of satellite and in-situ data, ensemble modelling and data assimilation approaches

- Satellite AQ information through inverse modelling can be used to support the review and verification of emission data
  - Location/Resolution
    - Spatial resolution of EO-based emissions still a challenge
    - Locating sites - of very limited value in most European countries - Possibly applications in other parts of the world
  - Timeseries checks
    - Verifying year to year variations -
    - Checking emissions from sources that drop below thresholds… and gap filling datasets
    - Estimating monthly/weekly emissions.
  - Emission outlier checks
    - Reported vs EO-based emissions – even if EO-based data is not specific to a point source, is still of value in identifying issues.
    - Possible additional analysis with pollutant ratio checks for instance with CO can be informative for QA/QC purposes.

Thank you !

Contributors: Chris Dore (Aether)

Jieying Ding, Ronald van der A and Henk Eskes (KNMI),

Jenny Stavrakou, Jean-François Müller and Glenn-Michael Oomen (BIRA-IASB)

Mark Guevara (BSC) and Paul Hamer (NILU)