Progetto MIMESI: assimilazione di dati satellitari di NO2 nella catena kAIROS

Model
Integration
Mission
s**E**ntinel with data
a**S**s**I**milation

XIII giornata della modellistica
in Arianet
24 e 25 marzo 2026

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Agenda

- Progetto MIMESI
- Osservazioni satellitari
- catena modellistica kAIROS – Arpae
- DART tool
- conclusioni

ARIANET

Model Integration Mission sEntinel with data aSsImilation

Funded by ESA – European Space Agency
ESA Kick-Start Programme

esa

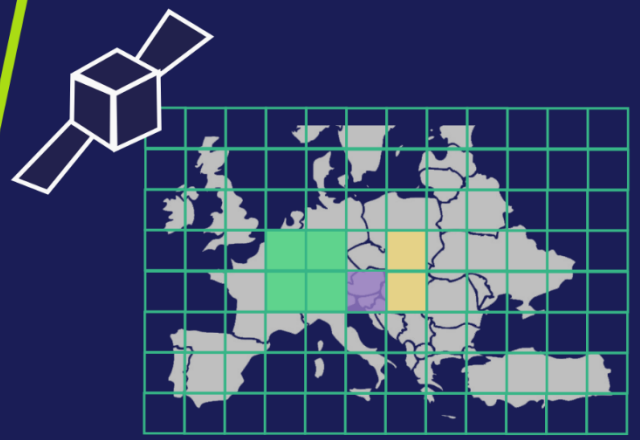
Earth observation inputs

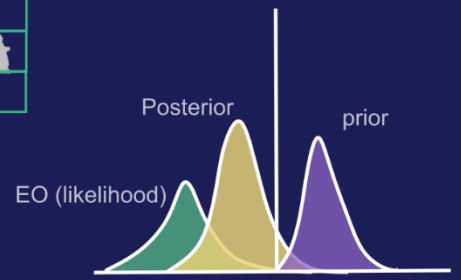
Sentinel 5P
Low-Earth Orbit • Global coverage
NO_2 • O_3 • SO_2 • CO • HCHO
Daily observations

Sentinel-4 (upcoming)
Geostationary • Europe
NO_2 • O_3 • SO_2 • CO • HCHO
Hourly observations

Satellite observations strenghtens air quality climate monitoring & forecasting

Chemical Transport Models assimilate EO to improve accuracy





Data Assimilation

Model state updated with observations
Bias and uncertainty reduction

An air-quality system where data assimilation runs independently, and is owned by the agency

MIMESI: implementazione

End User

Arpae Emilia-Romagna: fornisce catena CTM, infrastruttura

Data assimilation

DART: The Data Assimilation Research Testbed
Metodo: Ensemble Adjustment Kalman Filter

Inquinante: NO_2

Infrastruttura

Accesso a HPC: CINECA, Galileo
Risorse di calcolo:

- CTM: 128 cores * N membri ensemble

Demonstrator: caso studio

Galileo IBM NeXtScale

Galileo (supercomputer) - Wikipedia

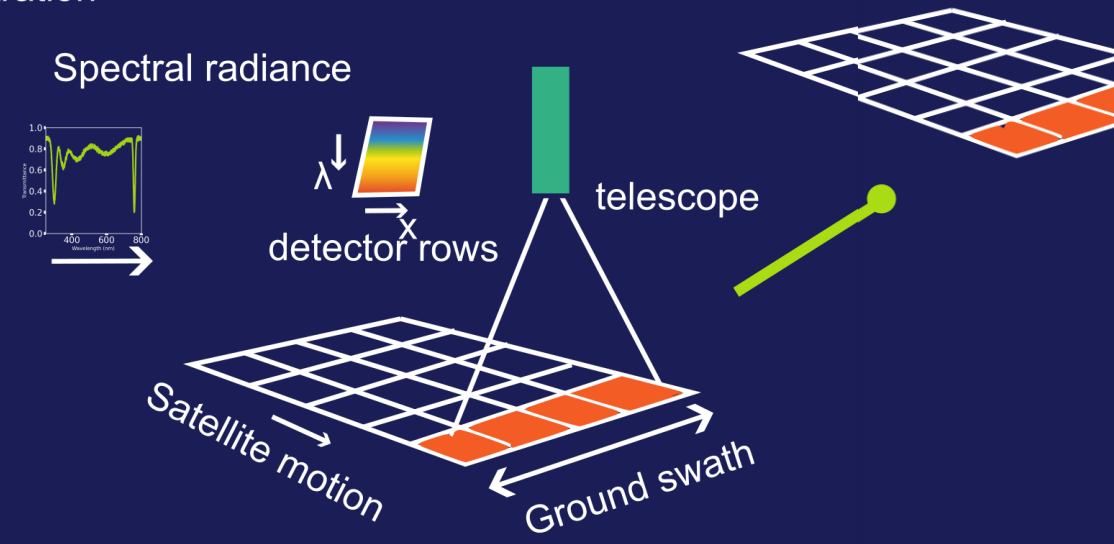
MIMESI

Chapter 1

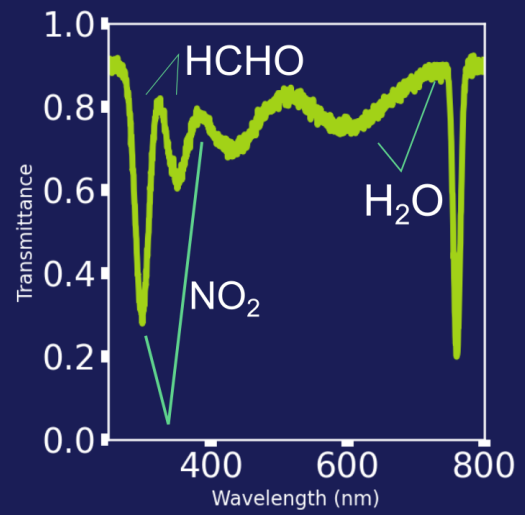
Earth observation inputs

Measurement principle

Sunlight reflected by Earth is measured from space. Atmospheric gases leave spectral fingerprints that allow retrieval of their concentration



Sentinel 5P - TROPOMI instrument



Vertic… averag…

Satellite m… sensitive t… Averaging… each atmo… retrieved c…

Clouds can redu…

Funded by ESA – European Space Agency
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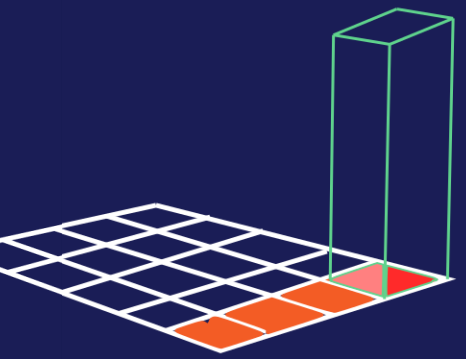
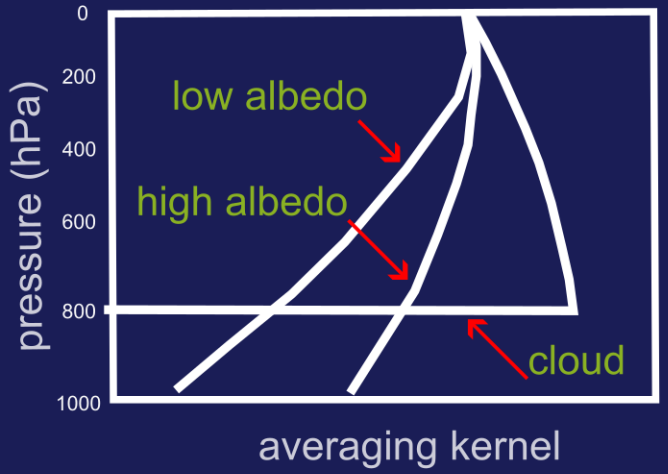
Vertical column density



Satellite observations provide vertical column densities:
the total amount of gas contained in an atmospheric column

Integrated concentration from surface to upper troposhere



Vertical sensitivity: averaging kernels

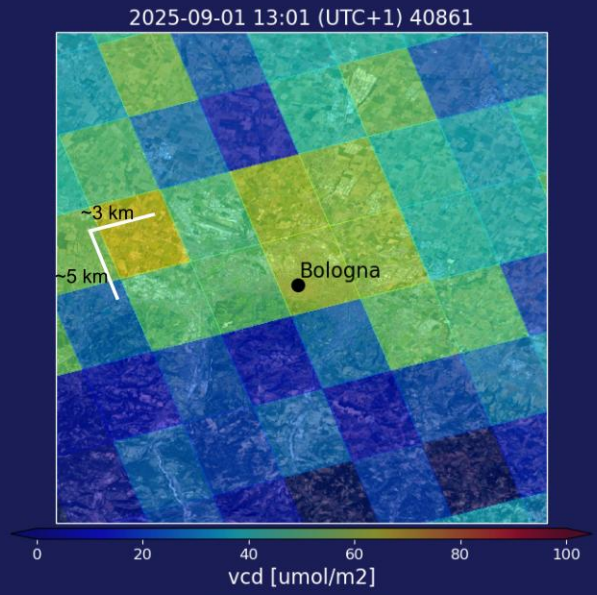
Satellite mesaurements are not equally sensitive to all heights.
Averaging kernels describe how strongly each atmospheric layer contributes to the retrieved column

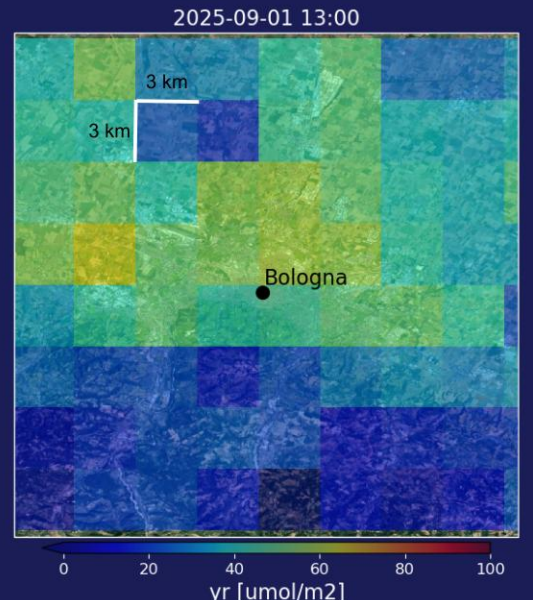
Clouds can reduce sensitivity to near-surface pollution

From pixels to maps

Individual satellite pixels are combined and mapped onto the target modelling domain

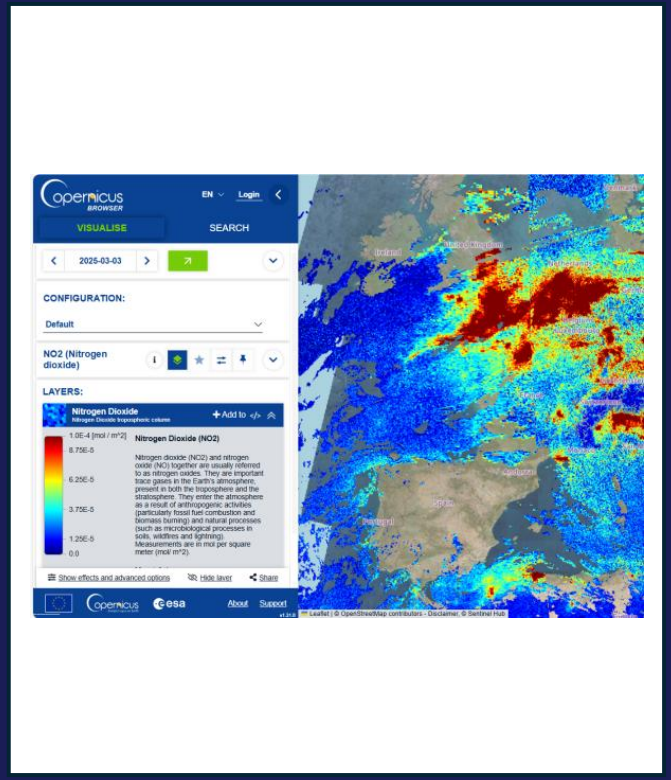
footprints vary in size depending on viewing angle of instrument





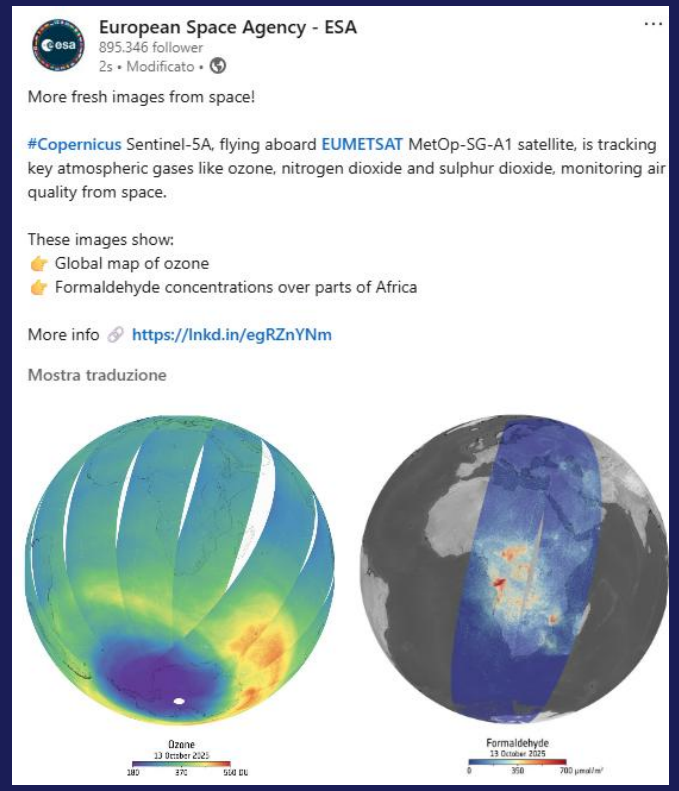
Osservazioni satellitari per l'NO2

Sentinel 5P



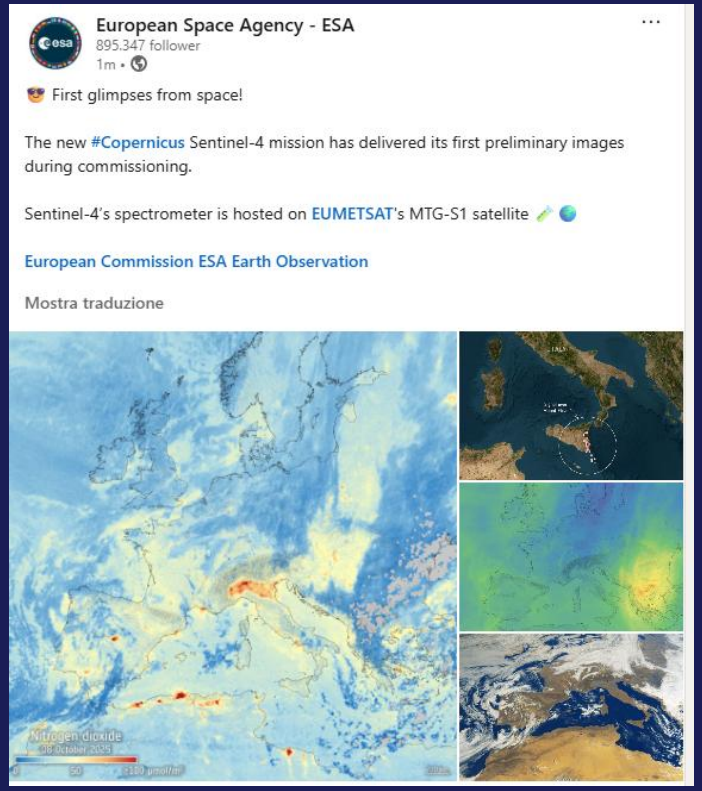
LEO (Sun-Synchronous)
Coverage : Global
Temporal res: daily global
Spatial res: 3.5 km x 5.5 km
Instrument TROPOMI
Operational since 2018

Sentinel 5A



LEO (Sun-Synchronous)
Coverage : Global
Temporal res: daily global
Spatial res: ~ 7km
Instrument UVNS spectrometer
Launched in 2025

Sentinel 4



GEO (geostationary)
Coverage: Europe & N. Africa
Temporal res: hourly observations
Spatial res: 8 km x 8 km
Flown on Meteosat Third Generation

KAIROS

Sistema operativo previsionale di Arpae-ER di qualità dell'aria

https://www.snpambiente.it/prodotti/previsioni-qualita-dellaria-in-italia

kAIROS AIR Operational System

Sistema operativo di previsione e valutazione della qualità dell'aria

- CTM: CHIMERE
- una corsa quotidiana 0:00
  - Analisi (-24h, 0)
  - Forecast +72h
- domains
  - ITA7 --> *SNPA*

OUTPUT

- Campi completi orari per nesting regionale
- Sito SNPA: previsioni orarie di PM10, PM2.5, O3, NO2, dust

KAIROS

Sistema operativo previsionale di Arpae-ER di qualità dell'aria

https://www.snpambiente.it/prodotti/previsioni-qualita-dellaria-in-italia

INPUT

- Condizioni al contorno: CAMS regional Air Quality Forecast, ensemble model
- **Forzante atmosferica**: ICON-2I
- Emissioni antropiche: INEMAR ER, ISPRA IT, CAMS EU --> NO_2, NO
- **restart**

DART tool: Data Assimilation Research Testbed

The Data Assimilation Research Testbed (Version 11.19.1) [Software]. (2025). Boulder, Colorado: UCAR/NSF NCAR/CISL/DAReS. https://doi.org/10.5065/D6WQ0202

Ensemble Adjustment Kalman Filter

EnAKF provides a deterministic update of the forecast ensemble (ensemble square root filters)

N membri ensemble: 15 -100

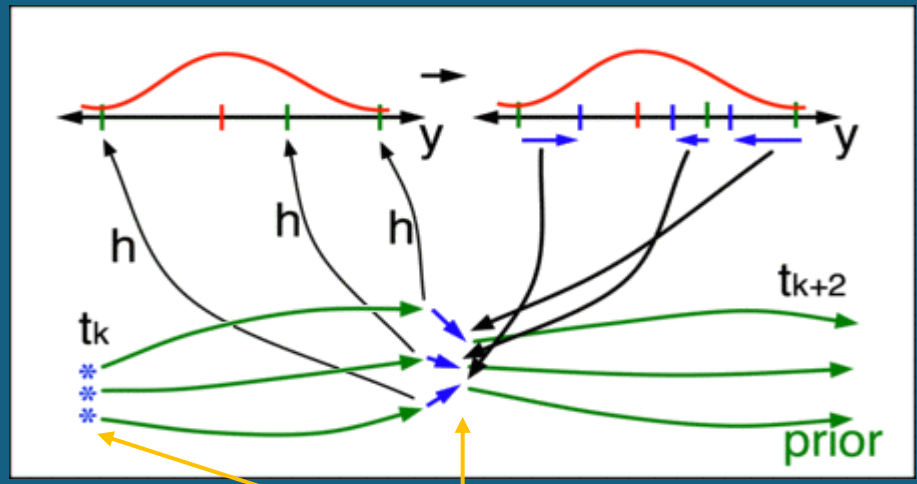
Low members' number:
- **covariance localization function**
- **inflation** techniques

DART

distribuzione dell'errore

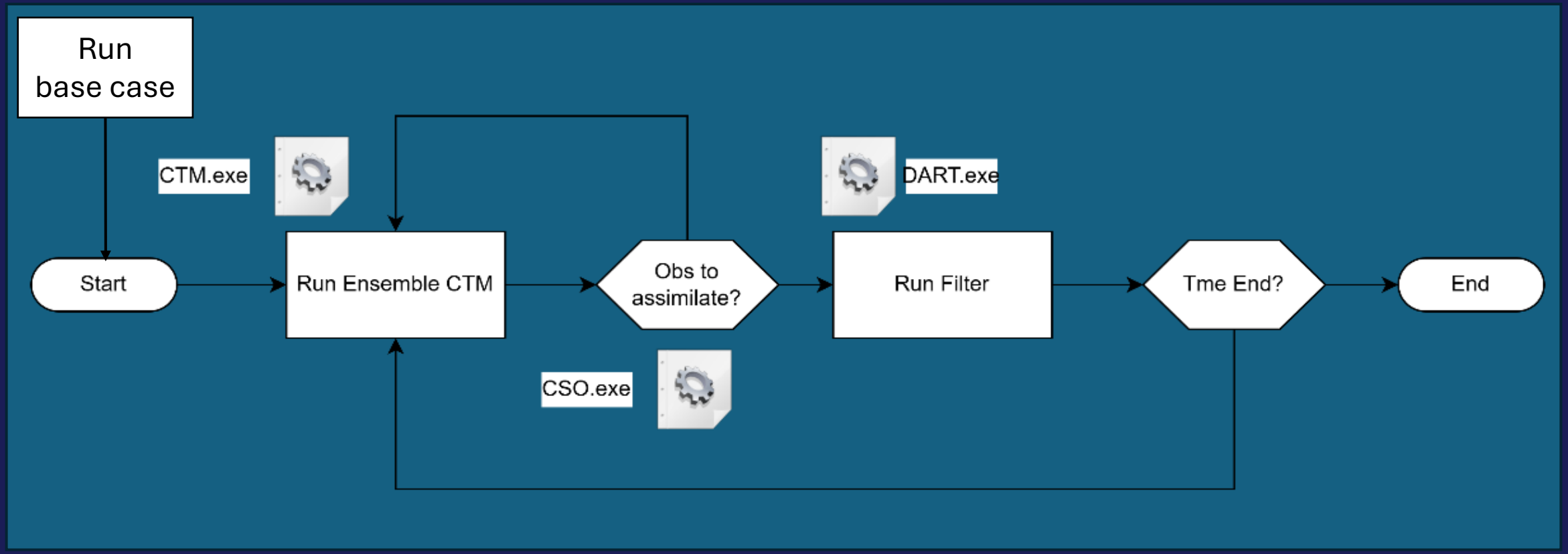
h: osservazione attesa

incrementi



MIMESI

workflow della catena di assimilazione MIMESI



Modello perturbazione emissioni

$E = E_0 \exp(\epsilon)$

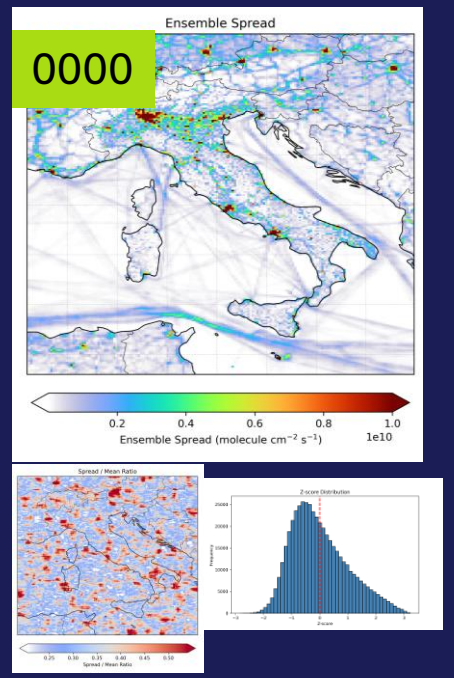
Le emissioni seguono un campo log-normale spazialmente correlato:

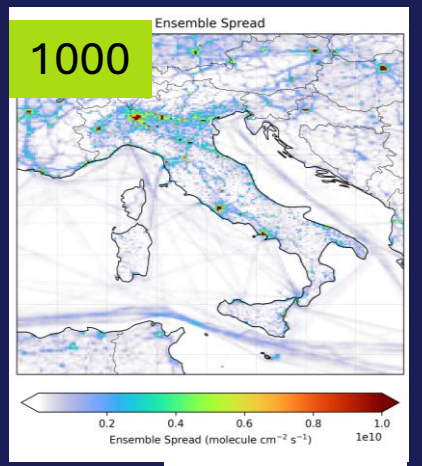
$\epsilon(x, y, z, t) \sim N(0, \Sigma)$

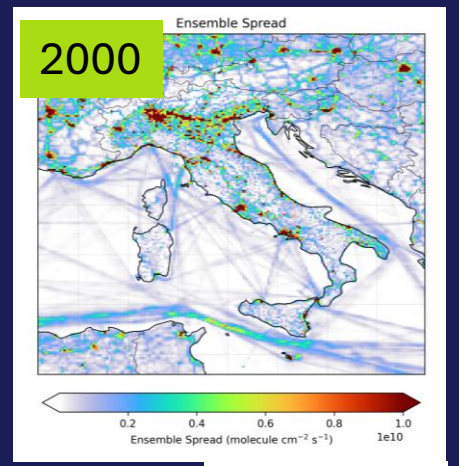
Parametri

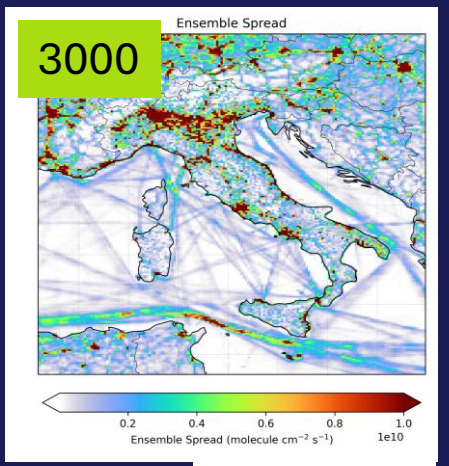
- Spread (0.3, 0.5, 0.8)
- Corr orizzontale (10, 50, 100 km)
- Corr verticale (4 levels)
- Corr temporale (6h)
- N membri (12)
- Emissioni NO2

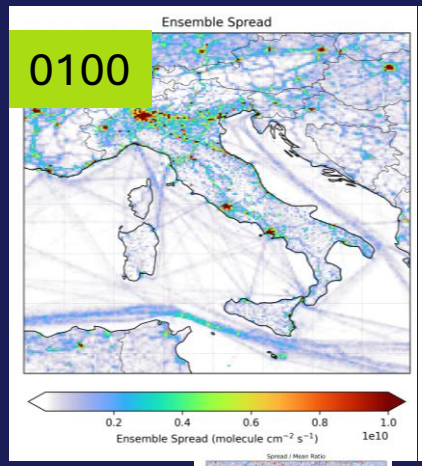
Caso	Spread	Hz (km)
0000	0.5	50
1000	0.3	50
2000	0.8	50
3000	1.5	50
0100	0.5	20
0200	0.5	100
3300	1.5	200

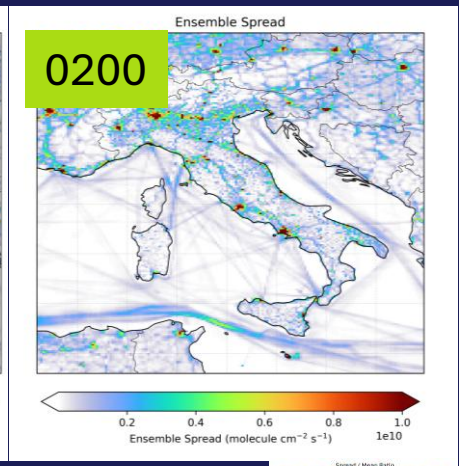


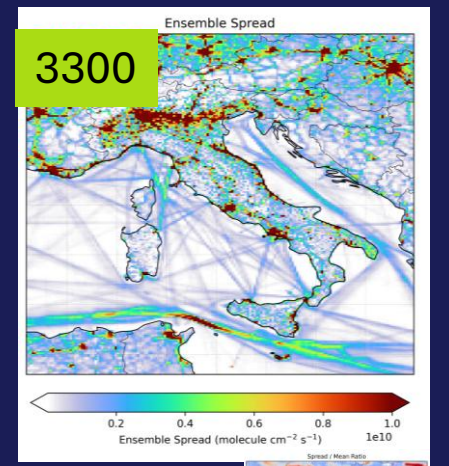




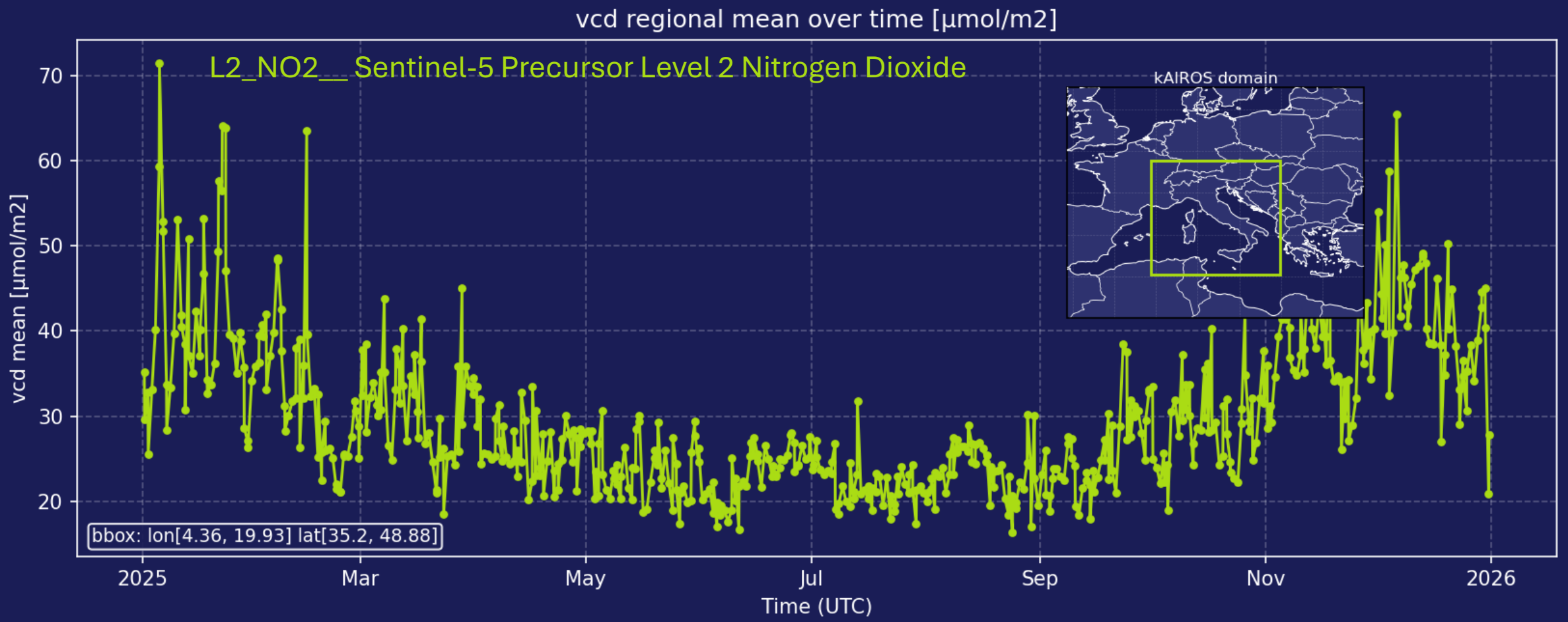




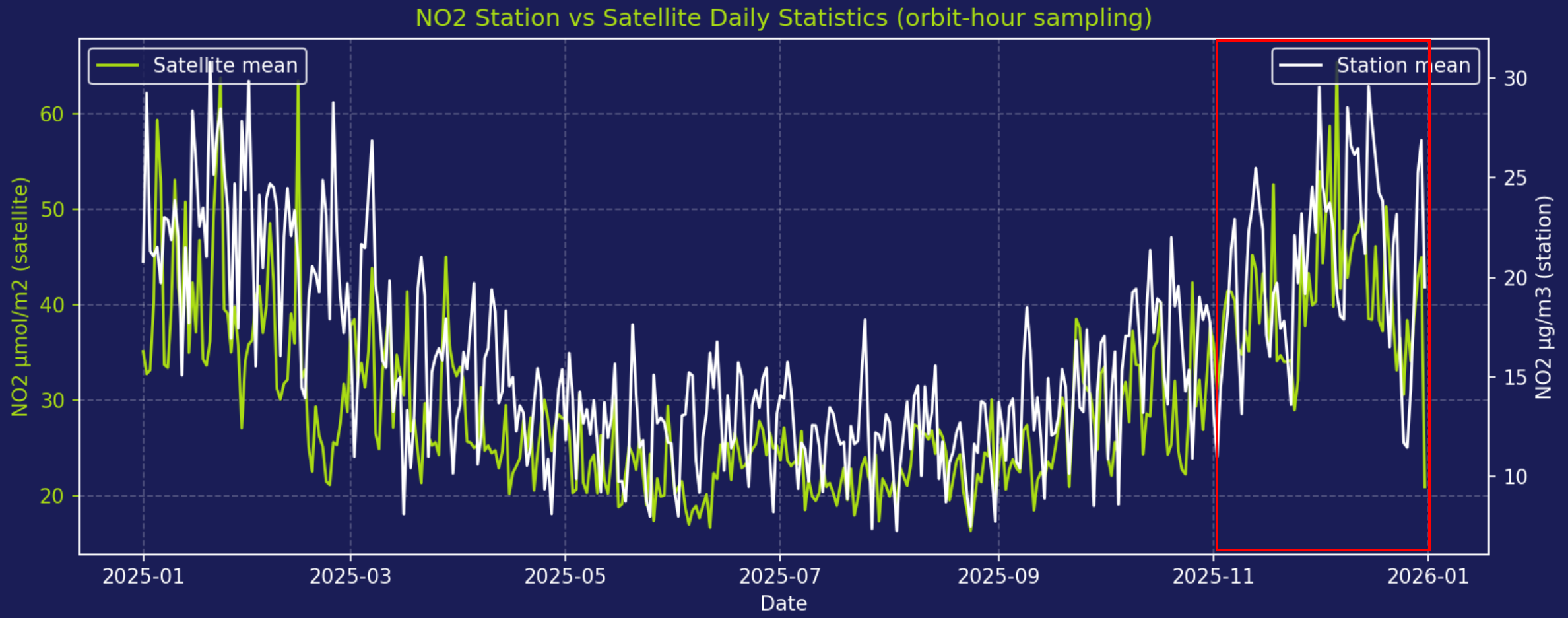




caso studio


vcd regional mean over time [µmol/m2]
L2_NO2__ Sentinel-5 Precursor Level 2 Nitrogen Dioxide
kAIROS domain
vcd mean [µmol/m2]
70
60
50
40
30
20
bbox: lon[4.36, 19.93] lat[35.2, 48.88]
2025
Mar
May
Jul
Sep
Nov
2026
Time (UTC)

caso studio


NO2 Station vs Satellite Daily Statistics (orbit-hour sampling)
Satellite mean
Station mean
NO2 µmol/m2 (satellite)
NO2 µg/m3 (station)
60
50
40
30
20
30
25
20
15
10
2025-01
2025-03
2025-05
2025-07
2025-09
2025-11
2026-01
Date

Grazie per l'attenzione