PEGASOS Project Overview: Summary of Activities for the Evaluation of the Operational GEMS L2 Products

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ATMOS, 1-5 July, Bologna, Italy

PEGASOS: Consortium

Product **E**valuation of **G**EMS L2 via **A**ssessment with **S**5P and **O**ther **S**ensors

DLR: German Aerospace Center

AUTH: Aristotle University of Thessaloniki

BIRA: Royal Belgian Institute for Space Aeronomy

IUP-UB: University of Bremen

ESA - ESRIN

GEO Ring for Air Quality

GEMS:

- South-Korean geo mission launched 2020 on GK-2B
- **G**eostationary **E**nvironmental **M**onitoring **S**pectrometer
- UV-VIS from 300-500nm
- spectral res: 0.6 nm
- 6-10 scans per day
- spatial res: 7 km x 8 km

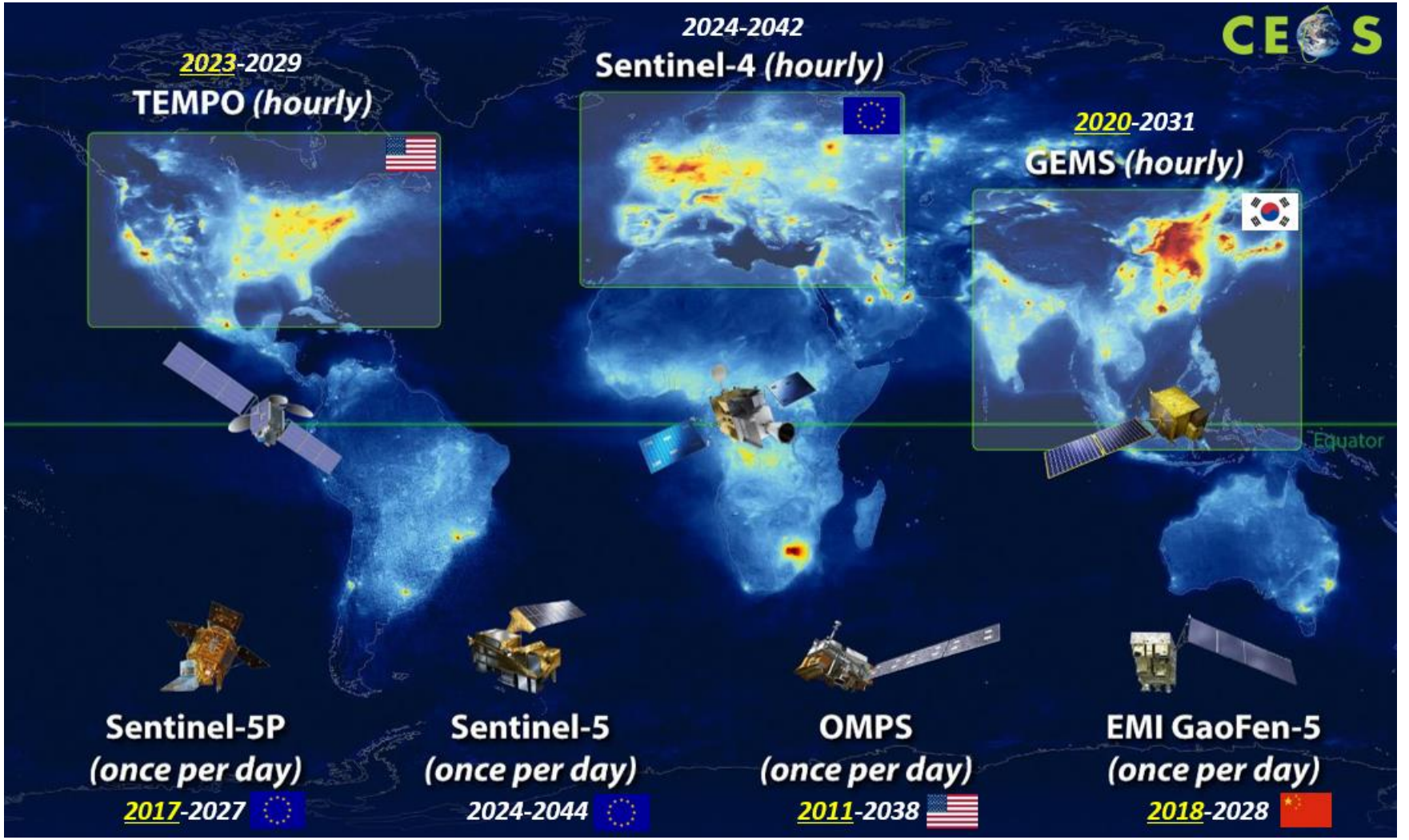
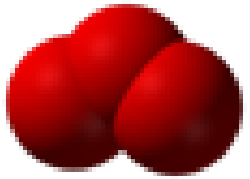
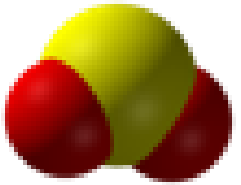


image courtesy: CEOS

GEMS L2 products to be evaluated



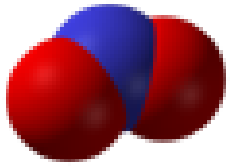
Ozone
total
tropospheric
profile



Sulfur dioxide
total

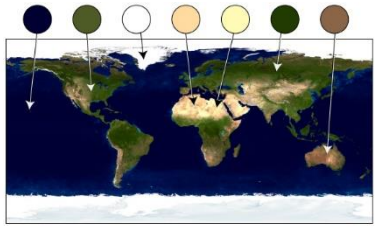
Aerosols
index
layer height

Clouds
fraction
height



Nitrogen dioxide
total

Formaldehyde
total



Surface properties
BRF

used for the evaluation:

space-borne: TROPOMI, OMI, GOME-2, IASI, VIIRS, CALIOP, AMI

ground-based: Dobson, Brewer, Ozonesondes, FTIR, MAX-DOAS, PGN, NDACC

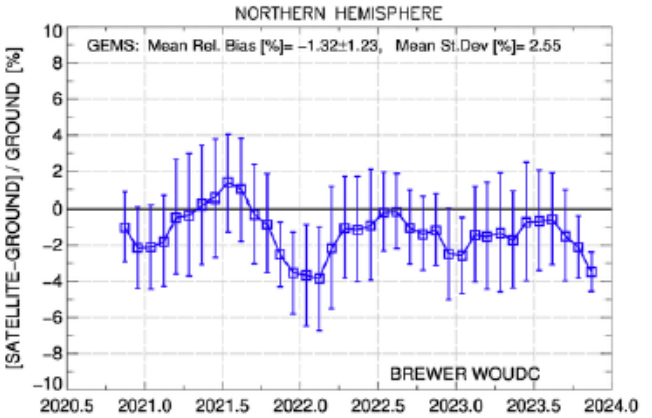
Ozone (total)

Team: K. Garane, T. Verhoelst, K.-P. Heue, S. Compernolle

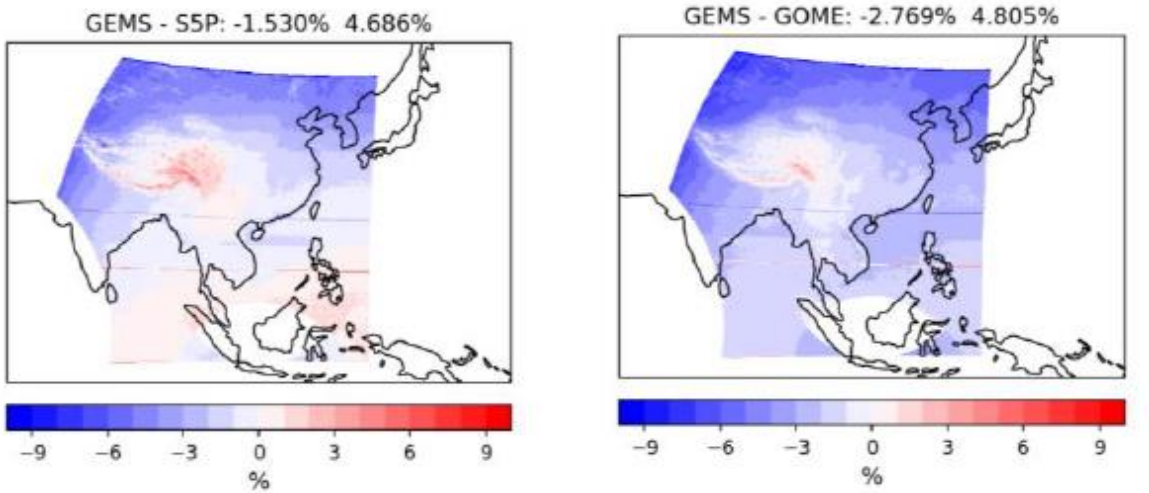
Results:

3 years of GEMS O3T v2.0 data showed:

- Mean relative bias w.r.t. gr-based stations and other satellite missions: -2 %
- Pearson correlation coefficient ≥ 0.85 (0.97 – 0.99 for the PGN co-locations), showing a very good agreement between GEMS and the reference measurements
- North – South gradient with an annual cycle:
  - Very good agreement during spring, summer and autumn months (± 1%).
  - During winter months and for higher latitudes GEMS underestimates total ozone by up to -4%.



Hemispherical time-series of the mean relative bias (%) of the GEMS O3T observations w.r.t. ground-based reference measurements from Brewer stations within the GEMS FOV.



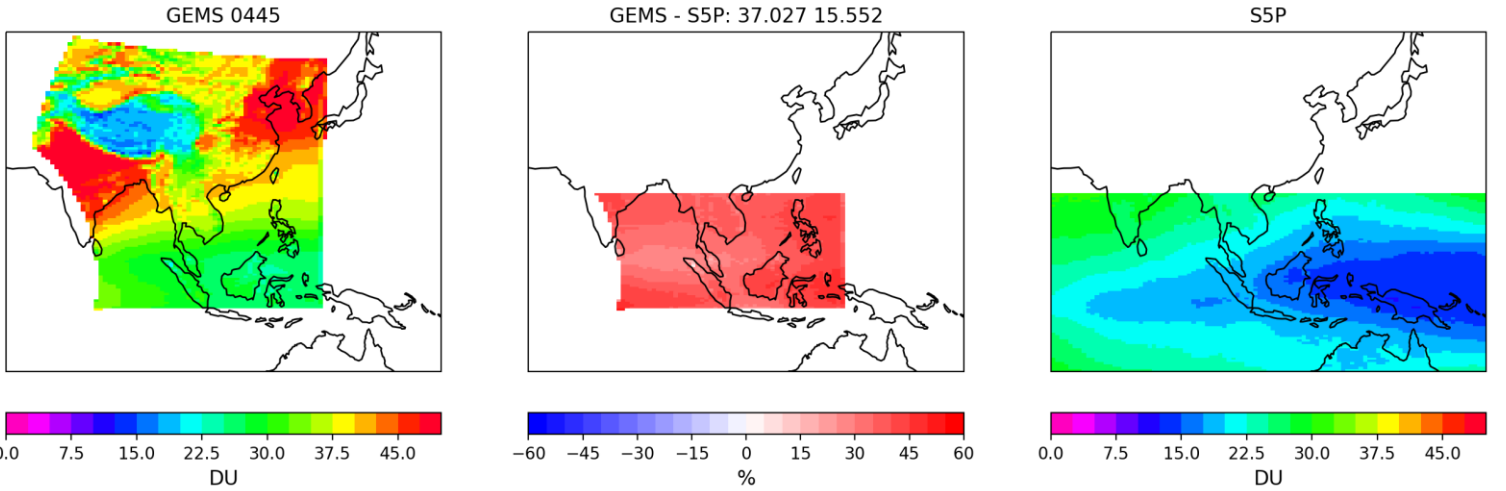
The mean percentage difference between the O3T observations from GEMS and other satellite missions (left:S5P, right: GOME2C), over the GEMS FOV.

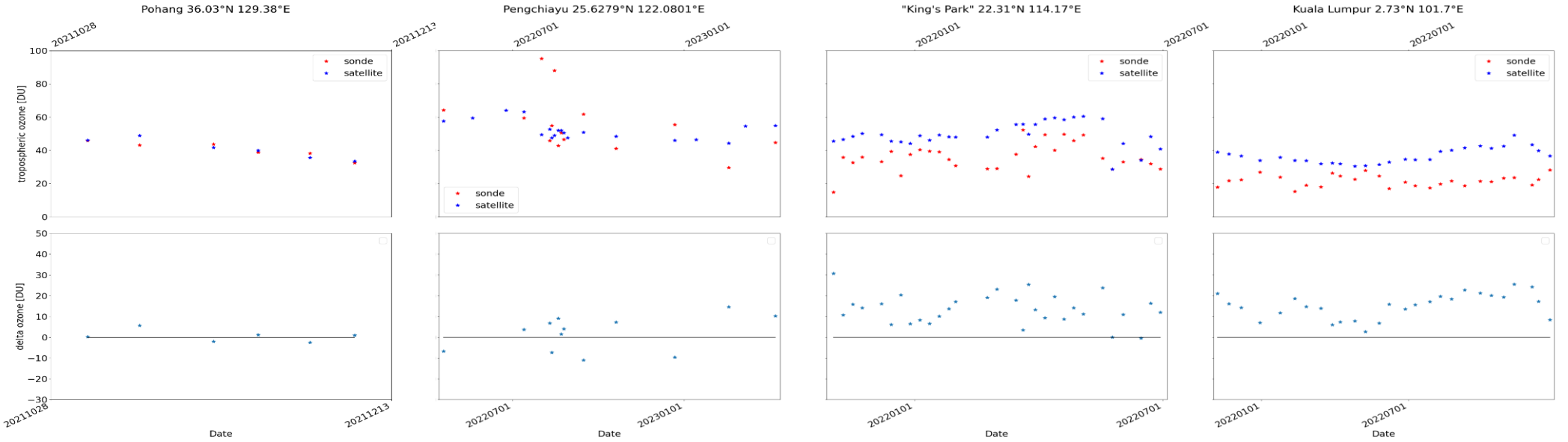
Ozone (tropospheric)

Team: K.-P. Heue, D. Hubert

Results:

- Based on version 2.0
- Bias 30-40% relative to S5P and GOME_2
  - Within the tropics (up to 20°S)
  - Confirmed by sondes in Hong Kong and Kuala Lumpur
- Lower bias over Korea relative to sondes





Ozone (profile)

Team: A. Keppens, D. Hubert, J.-C. Lambert

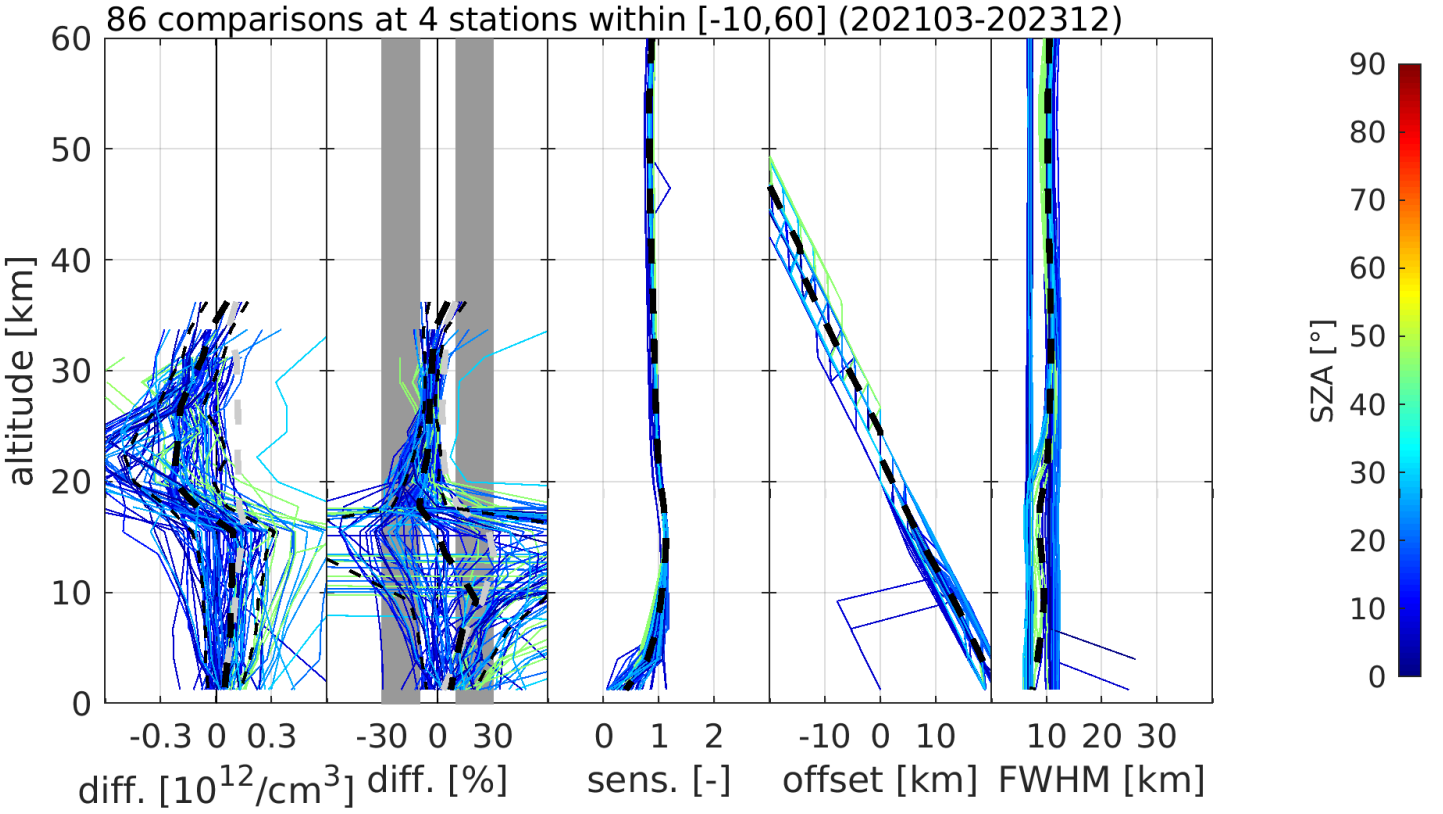
Results:

GEMS O3P v3 information content:

- Mostly off-diagonal sensitivity
- DFS ~1.5 from lower stratosphere (15-30 km)
- 5-10 km effective vertical resolution (FWHM)

GEMS O3P v3 uncertainty:

- Order of 5-10 % negative bias and 10 % dispersion in lower stratosphere
- 10-20 % positive tropospheric bias & dispersion (increase in UTLS)
- AK smoothing systematically reduces tropospheric uncertainties
- Clear effect of clouds and SZA / VZA



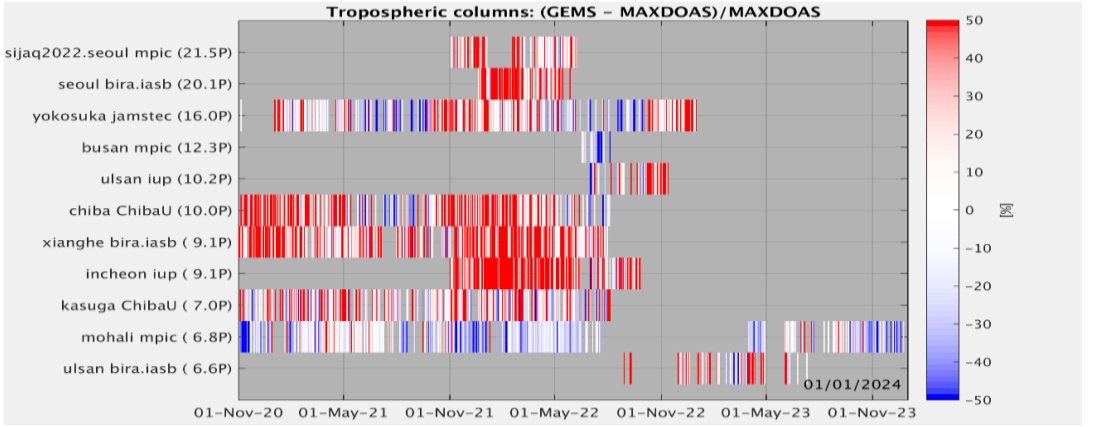
GEMS L2 v3 ozone profile data in comparison with vertically smoothed ozonesonde data from four stations (2021/03 – 2023/12)

Nitrogendioxide (NO2)

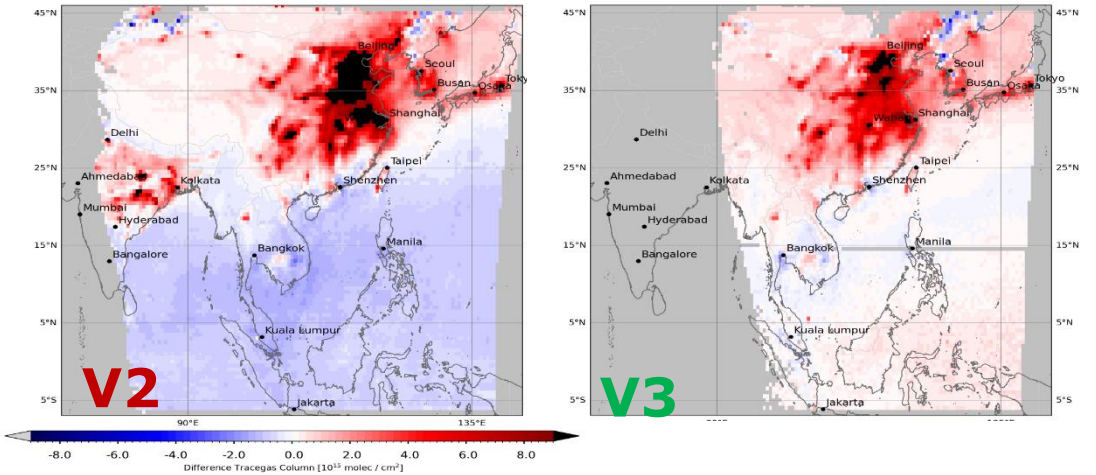
Team: K.-U. Eichmann, G. Pinardi, S. Compernolle, T. Verhoelst

Results:

- **MAX-DOAS** (11 stations) tropospheric NO2 (V2): median bias 2.3 Pmolec/cm² (23.3%) and network dispersion 3.9 Pmolec/cm² (34%).
- **PGN** (5 stations) total NO2 (V2): median bias ~5 Pmolec/cm² (30 %) and network dispersion 7 Pmolec/cm² (50%).
- GEMS total NO2 (**V2**) versus **TROPOMI**: low bias in South and over Ocean, TROPOMI low bias in North and polluted areas
- GEMS total NO2 (**V3**) preliminary checked: **NO2 improved** -> negative GEMS bias over Ocean removed and high bias over polluted scenes reduced.



Time-series of relative differences (GEMS V2) at the different MAX-DOAS stations (Nov 2020 to end 2023).



Comparison of GEMS - TROPOMI total NO2 differences for version 2 and 3 for January 2023.

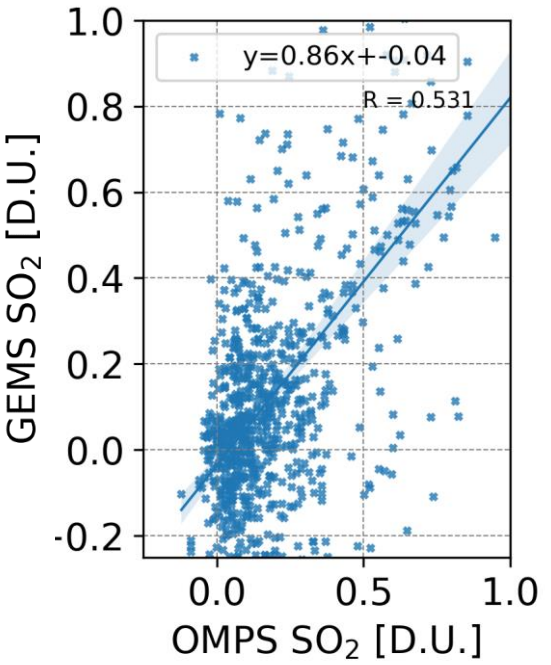
Sulphurdioxide (SO2)

Team: M.-E. Koukouli, N. Theys

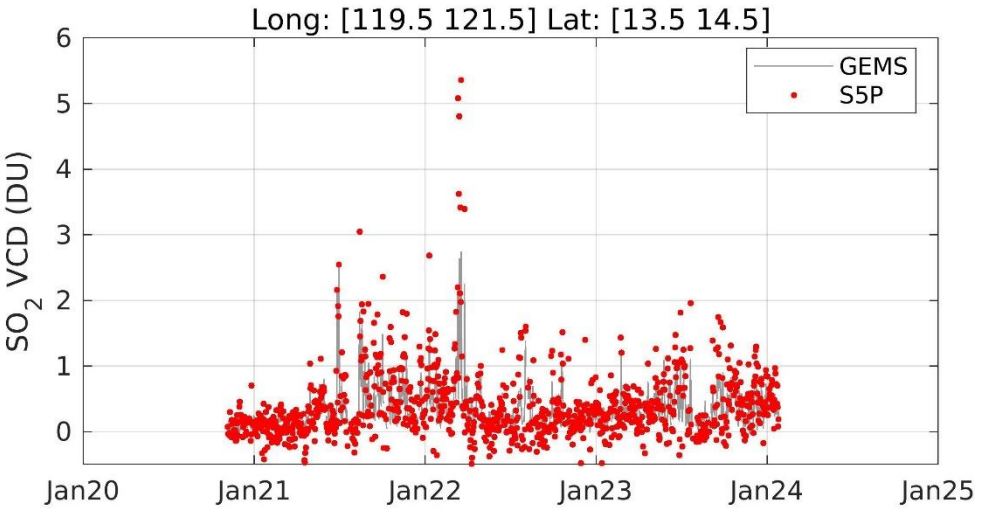
Results:

- Performed daily, monthly & seasonal comparisons of GEMS v2.0 with OMI/Aura, OMPS/NPP & S5P/TROPOMI SO_2
- For regions with low viewing angles (mostly volcanoes), similar patterns are observed. GEMS v2.0 VCDs agree with other sensors within 50% (even better for SCDs).
- For large viewing angles (India and North China), comparison is less conclusive as several artefacts are present in the GEMS data.

Power plants



Taal Volcano, Indonesia.



Left: Scatter plot of the L3 spatiotemporal collocated GEMS v2.0 and OMI/Aura SO_2 VCD over Power Plant locations in the GEMS FOV.

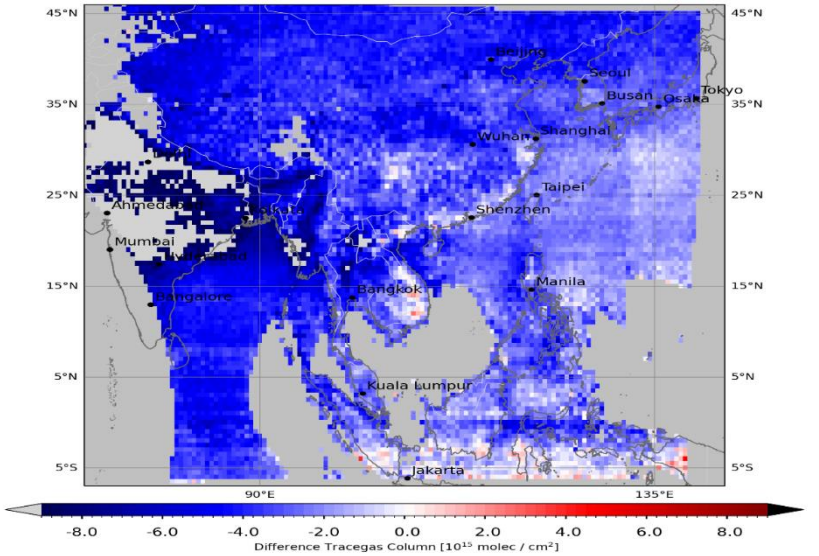
Right: Timeseries over the continuously outgassing Taal volcano in Indonesia for GEMS v2.0 and S5P.

Formaldehyde (HCHO)

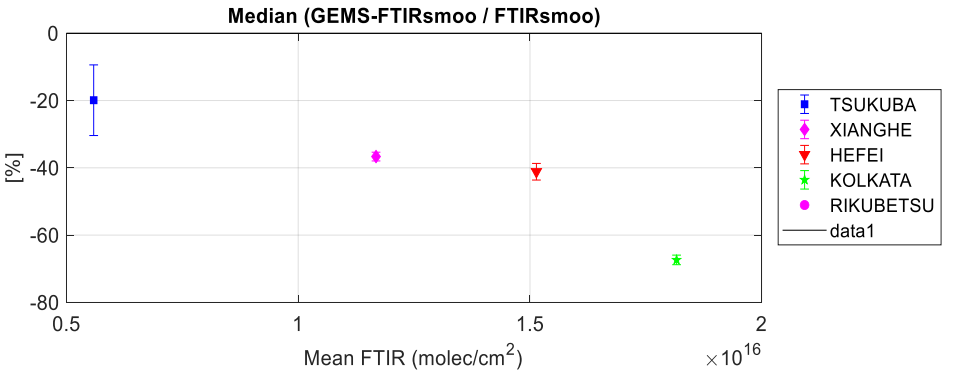
Team: K.-U. Eichmann, I. de Smedt, C. Vigouroux, G. Pinardi, S. Compernolle, T. Verhoelst

Results:

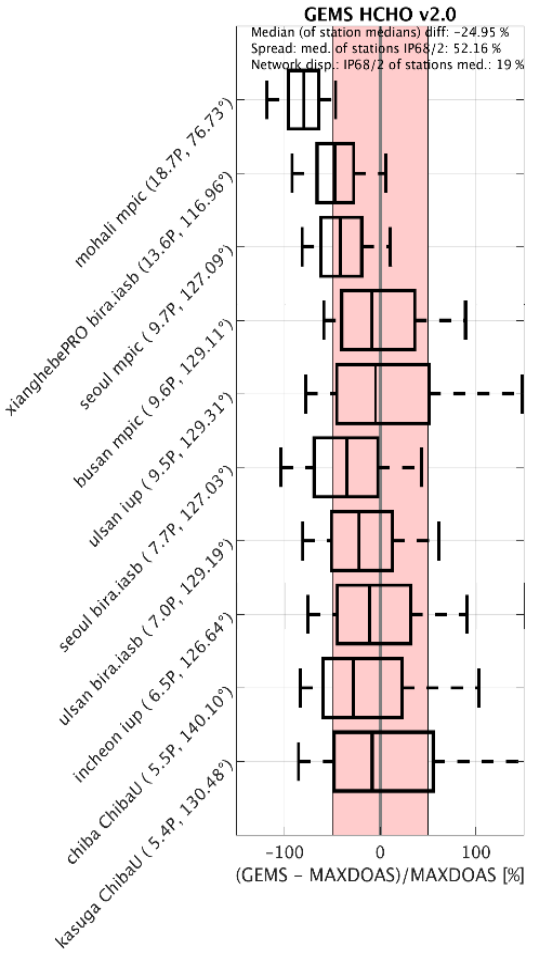
- **TROPOMI**: V2 GEMS HCHO has a low bias with a more negative bias towards the West. Overall bias < -60 %, dispersion 3 Pmolec/cm².
- **FTIR** (4 stations): V2 GEMS median bias < -67%, dispersion < 5.6 Pmolec/cm²
- **MAX-DOAS** (10 stations): V2 GEMS median bias -25%, dispersion 2.7 Pmolec/cm²



Monthly mean HCHO differences of GEMS V2 and TROPOMI (April 2023).



GEMS mean HCHO (V2) bias for the 4 FTIR sites.



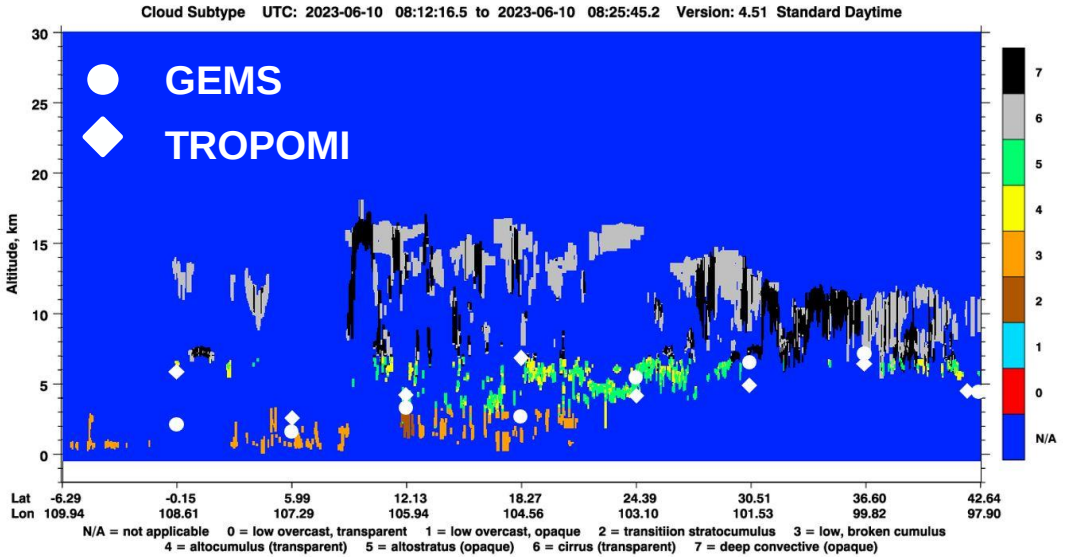
Box-whisker plots of GEMS V2 median HCHO [%] at MAX-DOAS sites.

Clouds

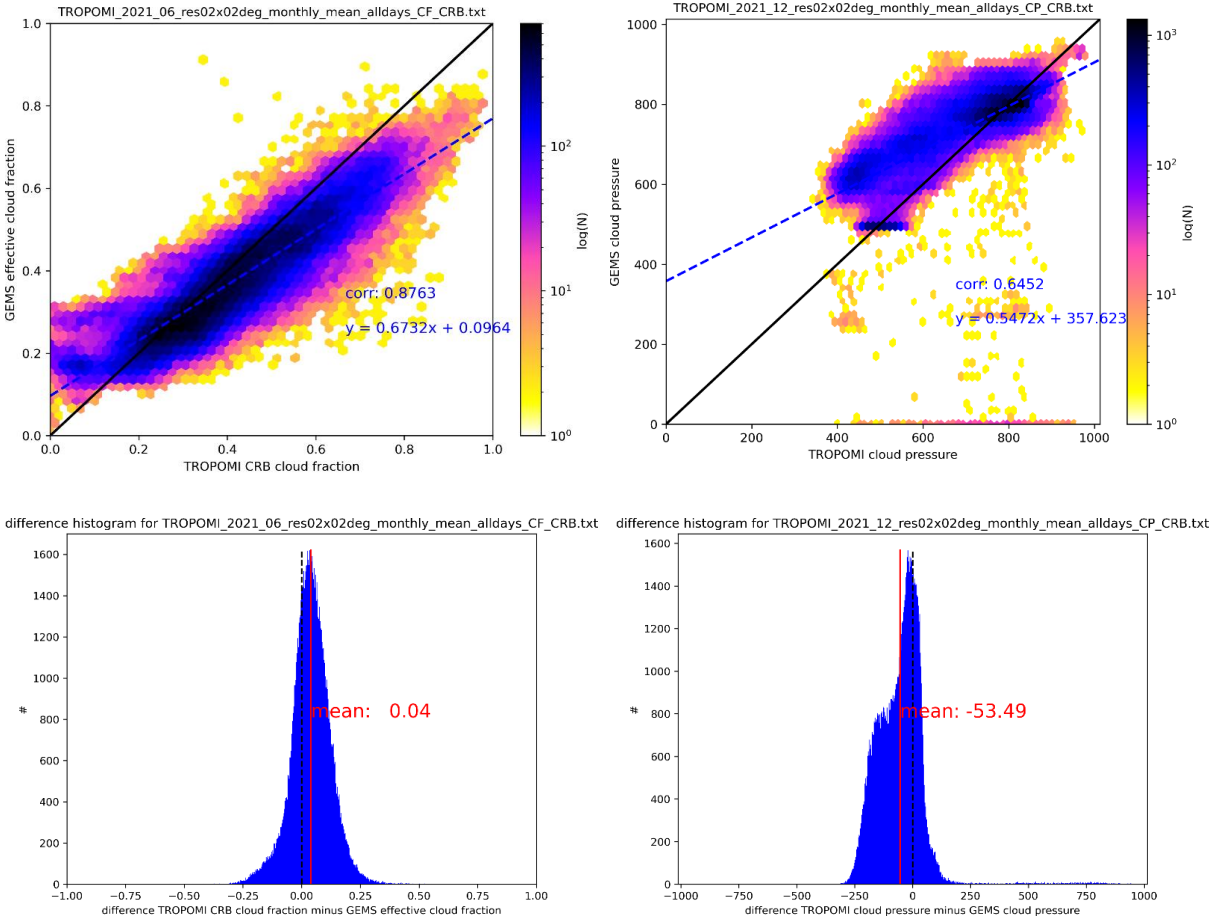
Team: R. Lutz, D. Loyola

Results:

- comparisons based on: TROPOMI, CALIOP
- good agreement for cloud fraction: corr: 0.87, mean diff: 0.04
- ok agreement for cloud pressure: corr: 0.65, mean diff: -50 hPa
- deviations appear over bright surfaces, for low cloud coverages and extreme viewing zenith angles



Comparison with CALIOP on 10 June 2023.



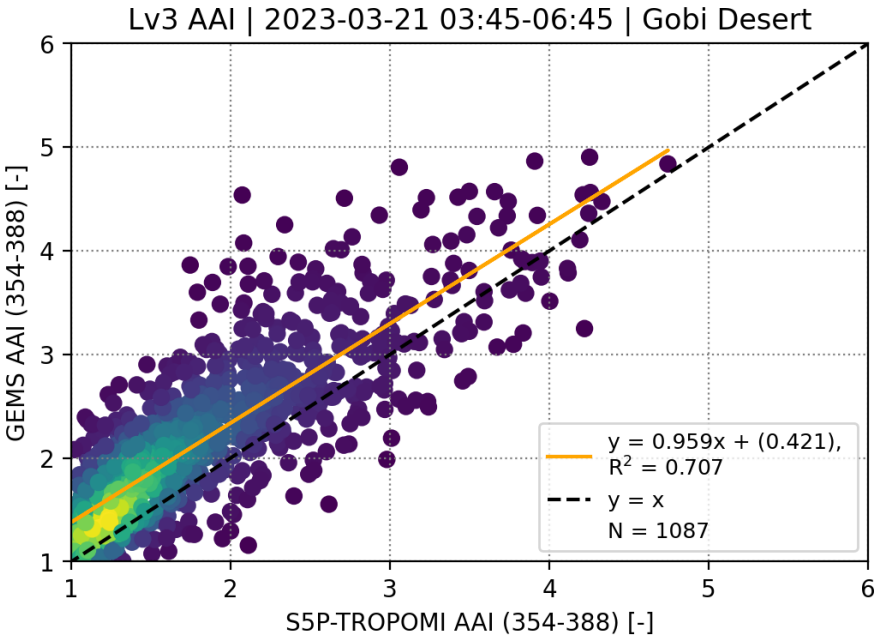
Comparison with TROPOMI/S5P cloud fraction (left) and cloud pressure (right) for June and December 2021.

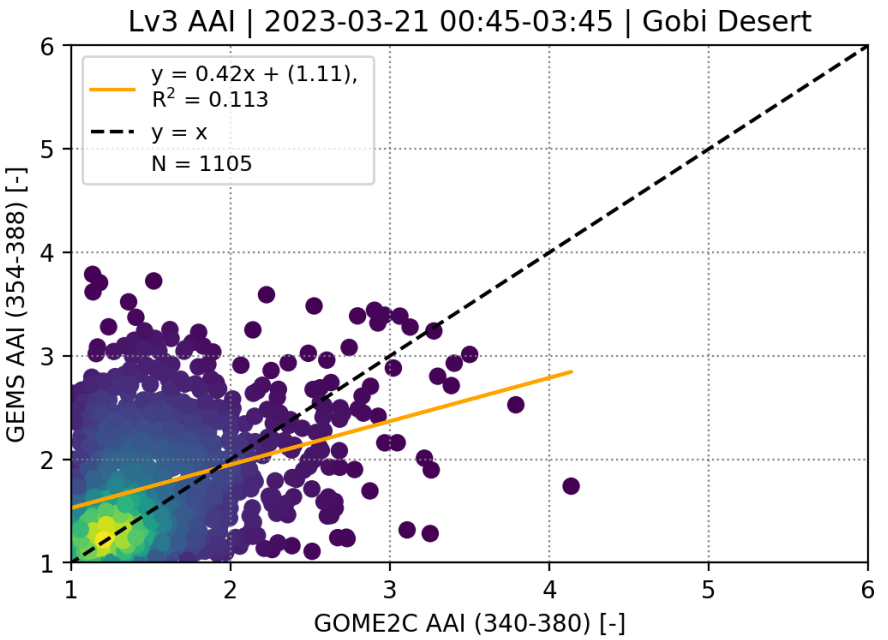
Aerosols (index)

Team: P. Fountoukidis, M.-E. Koukouli, D. Balis

Results:

- Sat-to-Sat comparisons between
  - S5P/GEMS
  - GOME-2B/GEMS
  - GOME-2C/GEMS
- Overestimation of the AAI by GEMS
- The comparisons have a high dependency in both the event and/or the sensor





Reference dataset	Mean (AAI ≥ 1)	Median (AAI ≥ 1)
S5P/TROPOMI – GEMS	-0.349±0.434	-0.300
GOME2B – GEMS	-0.141±0.68	-0.078
GOME2C – GEMS	-0.217±0.605	-0.148

Results for the satellite-to-satellite comparisons between the spatio-temporal collocated AAI datasets (upper panel). The mean and median of the distributions of the absolute differences between the datasets (lower panel)

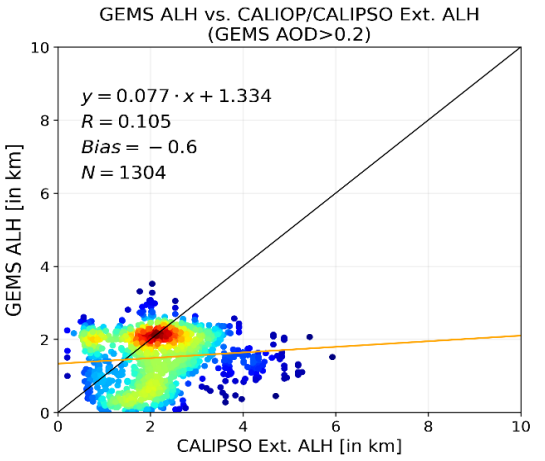
Aerosols (layer height)

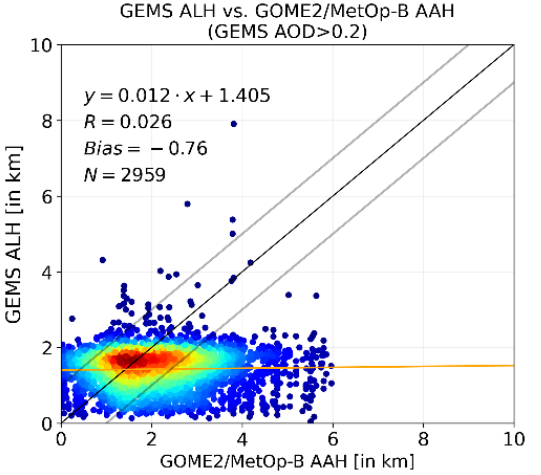
Team: K. Michaelidis, M.-E. Koukouli, D. Balis

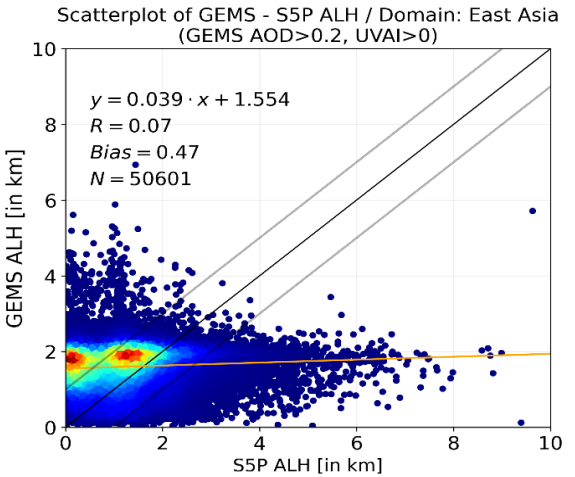
Results:

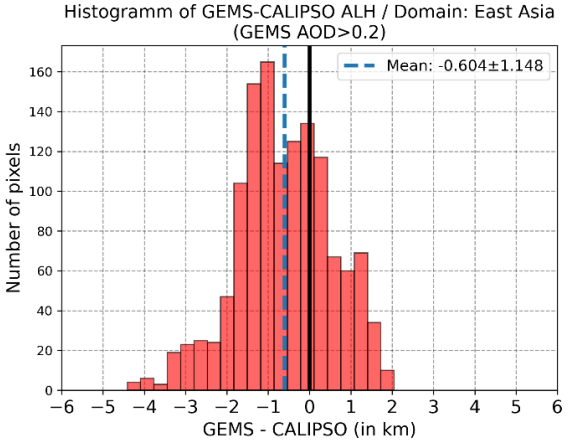
- Sat-to-Sat comparisons between
  - S5P/GEMS
  - GOME-2B/GEMS
  - GOME-2C/GEMS
  - CALIPSO/GEMS
- L2 GEMS v2.0 Aerosol datasets, from Nov. 2021 to Dec. 2023 have been used.
- GEMS ALH product is strongly associated to the AOD levels.
- GEMS ALH has a smaller flexible range than that of TROPOMI, GOME-2 and CALIPSO.

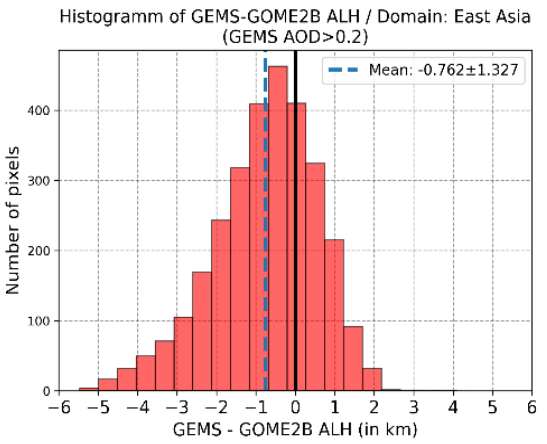
Reference dataset	Mean bias (km)
GEMS - GOME2B	-0.76±1.32
GEMS - GOME2C	-0.76±1.38
GEMS - CALIOP	-0.60±1.15
GEMS - TROPOMI	0.47±1.00

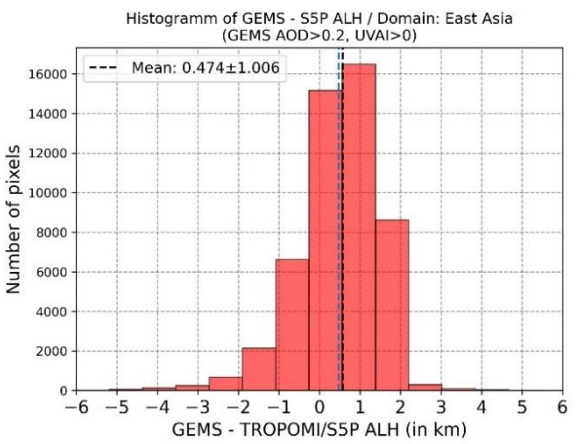












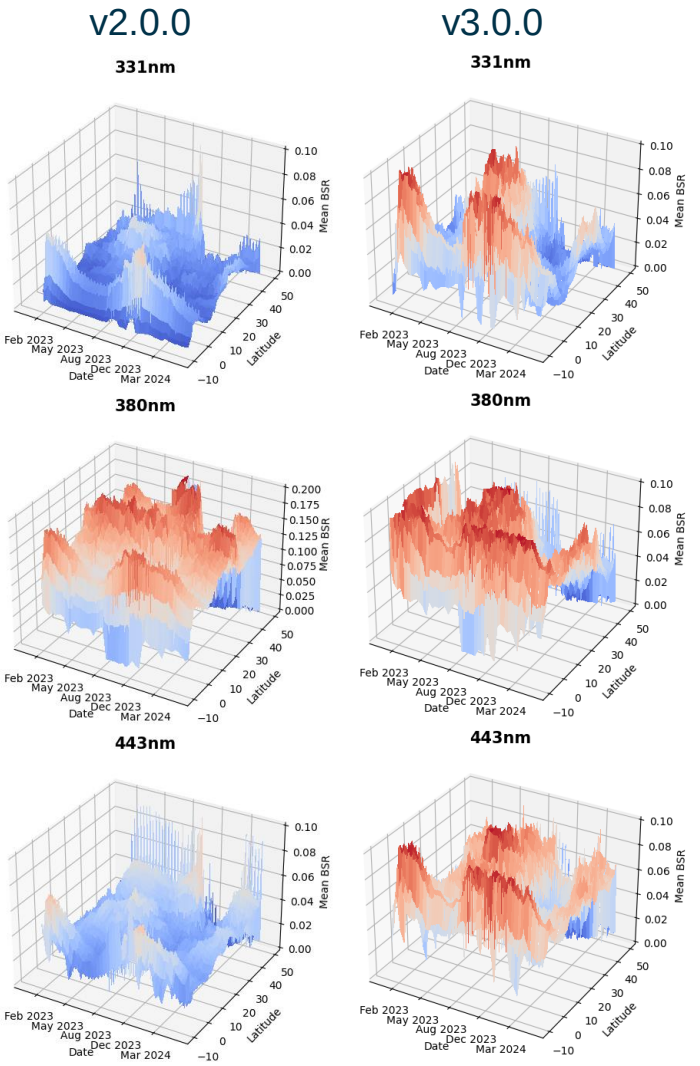
Surface Properties

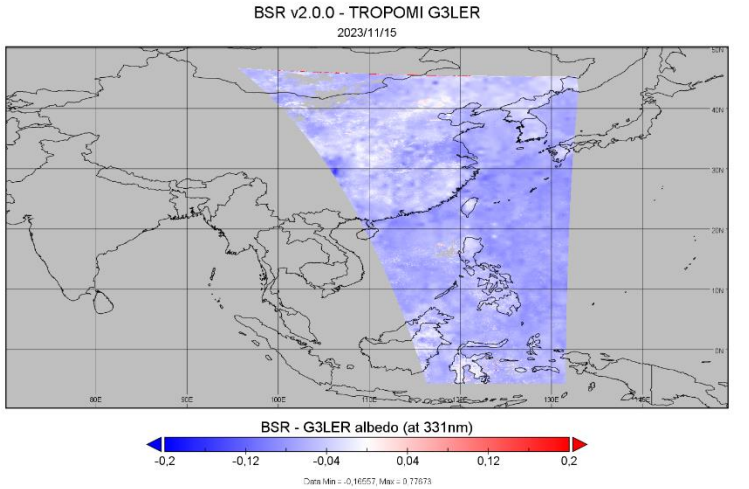
Team: P. Hedelt

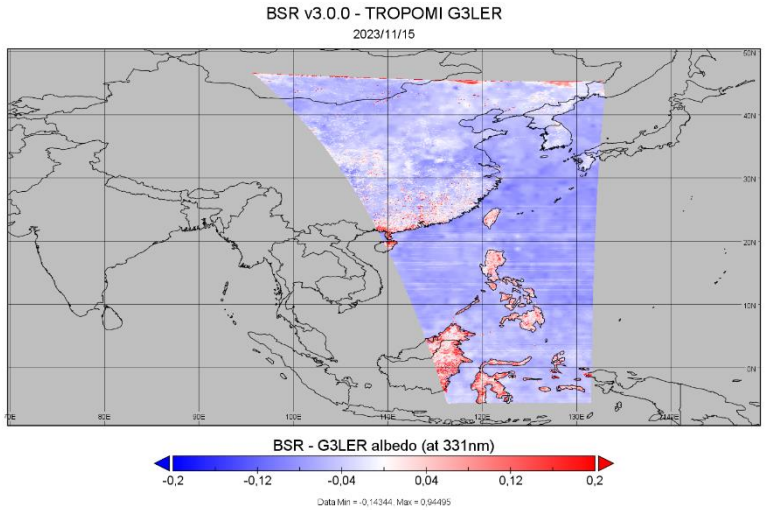
Results:

3 years of GEMS BSR v2.0 data showed:

- Reasonable agreement of monthly averaged surface albedo with DLER climatologies only for few wavelengths
- 380nm surface reflectance shows significant higher surface albedo compared to DLER.
- Analysis of zonal mean showed significant seasonal North-South dependence at all wavelengths and a significant bias as 380nm.
- Mean surface albedo at 331nm (O_3 fitwindow) shows slightly lower albedo wrt to TROPOMI G3_LER surface albedo.
- Preliminary analysis of v3.0.0 data shows better agreement across wavelengths, and overall higher albedos. The seasonal N-S dependency is still present. Also direct comparison shows positive bias over land.







Outlook

PEGASOS:

- ends in Sept. 2024 ☹
- to be extended by 2 years ☺
- inclusion of TEMPO ☺

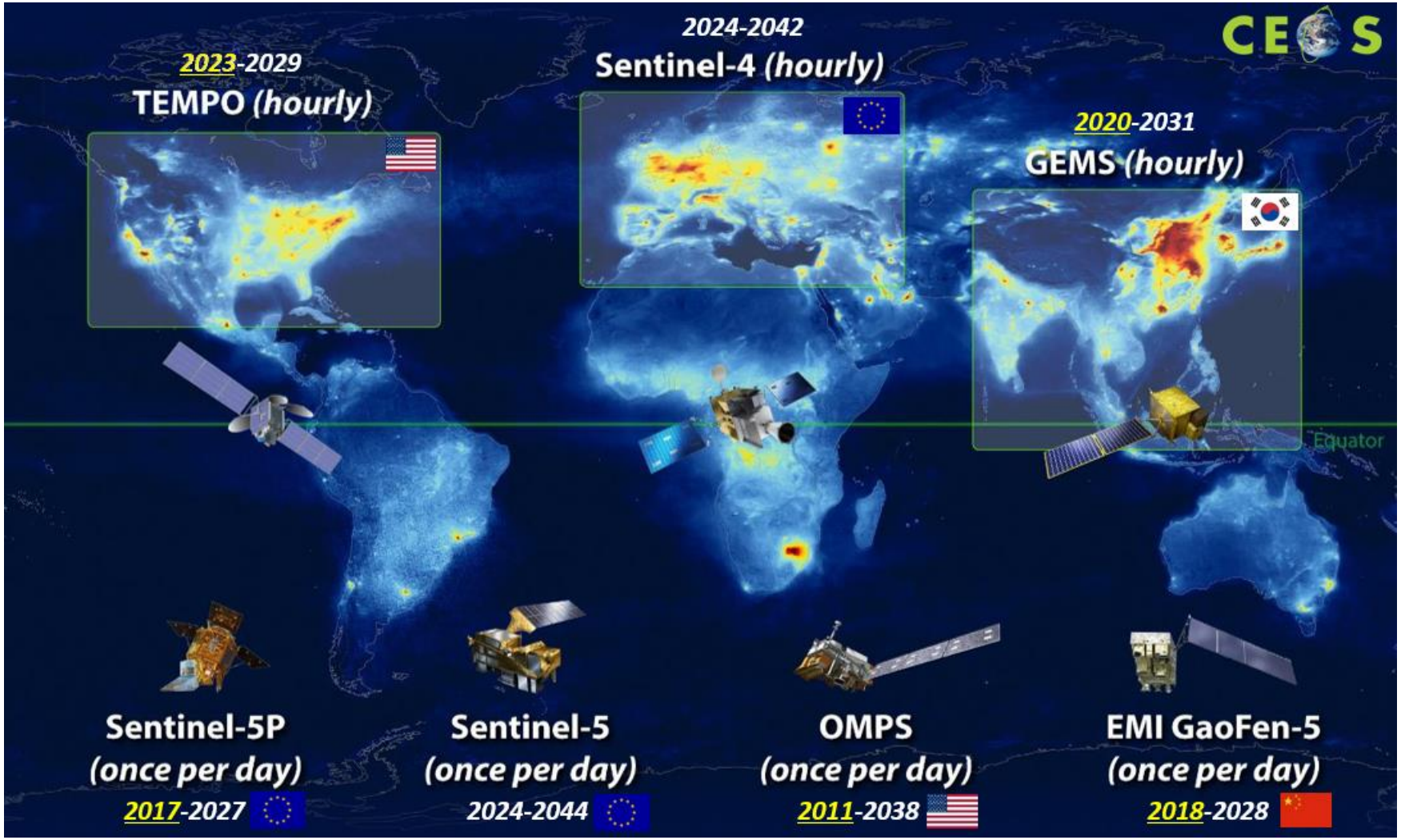
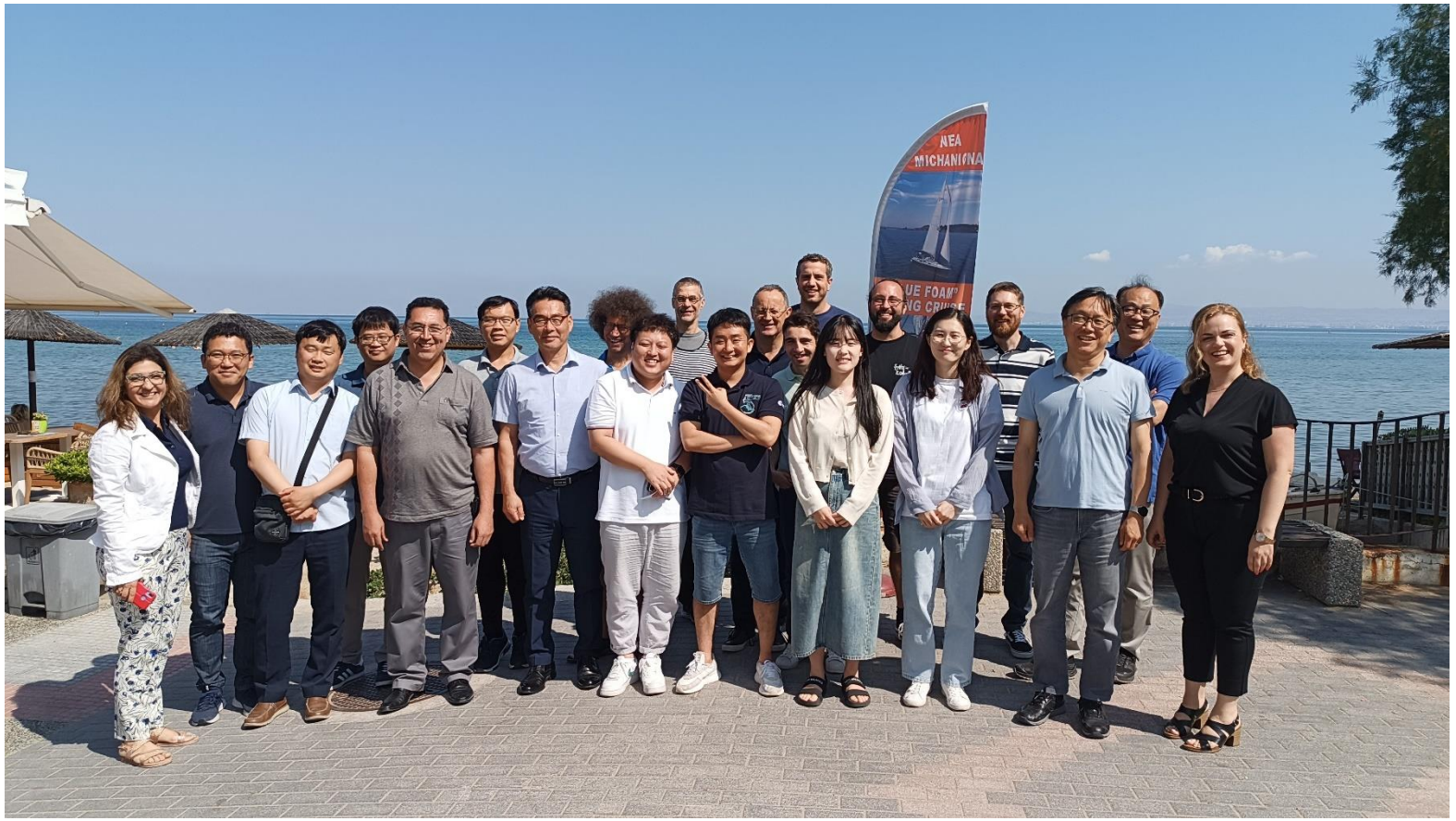


image courtesy: CEOS

Credits to the GEMS team

Thanks particularly to: Jhoon Kim, Won-Jin Lee, Hyunkee Hong, and all GEMS L2 developers!



Picture taken at the 2nd PEGASOS project meeting in June 2023, Greece

Credits to the PEGASOS team

Claus Zehner

Pascal Hedelt, Klaus-Peter Heue, Diego Loyola, Ronny Lutz, Sora Seo

Dimitris Balis, Panagiotis Fountoukidis, Katerina Garane, Maria-Elissavet Koukouli, Konstantinos Michaelidis

Steven Compernolle, Martine de Maziere, Isabelle de Smedt, Daan Hubert, Arno Keppens, Jean-Christopher Lambert, Gaia Pinardi, Nicolas Theys, Michel van Roozendael, Tijl Verhoelst, Corinne Vigouroux

Kai-Uwe Eichmann, Mark Weber