

GEO-Ring Project of NIER

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Overview of GEO-Ring project



► **GEO-Ring project:** Validation of Environmental Satellites and Air Pollution Studies in the Northern Hemisphere through the Geo-Ring International Collaborative Research

► **Project period:** 2025–2028 (4 years)

► **Supporting Organization:** NIER ESC



► **Objective:**

- Establishment of the **GEO-Ring Air Quality framework** for air quality monitoring in the Northern Hemisphere
- **Algorithm refinement and assessment** through advanced technologies in joint research efforts
- **Data Harmonization** of three major GEO satellites—**GEMS, TEMPO, and Sentinel-4 (GTS) (+TROPOMI, OMI)**

Target:





Level 1	O ₃ profile	Trop. O ₃	HCHO	SO ₂	HONO
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Contributions:



Roadmap for GEO-Ring project



Work scope	Phase I (2025')	Phase II (2026')	Phase III (2027')	Phase IV (2028')
GEO intercomparison strategies	Review of LEO–GEO intercomparison methodologies	Review of harmonized GEO sat. intercomparison approaches + short-term analysis	TBD	TBD
L1/L2 Algorithm assessment, validation, evaluation HCHO, O3P, trop. O₃				
L1/L2 Algorithm refinements L1, HCHO, HONO, SO₂, O3P				
Data harmonization of GEMS, TEMPO, and Sentinel-4 (GTS)	Investigation on GTS data harmonization approaches (1)	Review of GTS data harmonization approach (2)	Proposal of GTS data harmonization framework	Establishment of GTS data harmonization framework
Large scale AP event demonstration using GTS data	Literature review & Case study	Pilot application of large scale AP event demonstration techniques (1)	Pilot application of large scale AP event demonstration techniques (2)	Establishment of large scale AP event using GTS data(3)

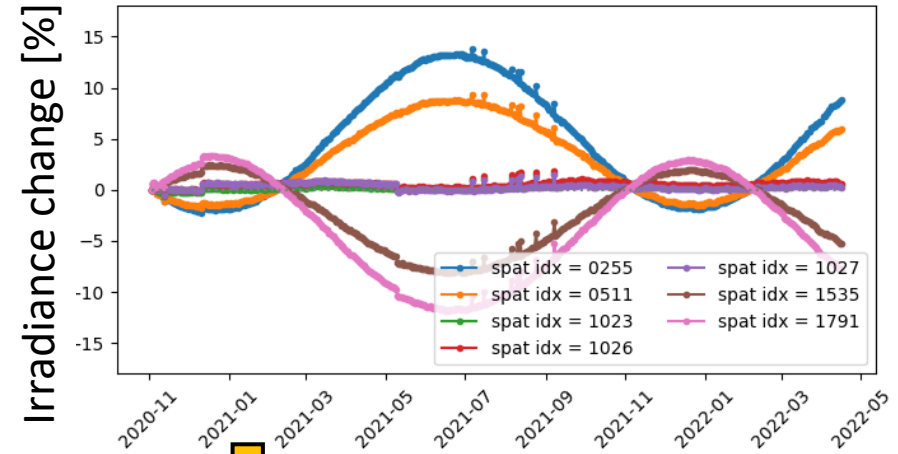
GEO-Ring Phase I Activities: Level 1



- Detailed comparison of Level 0-1 processing steps between GEMS and TEMPO
- Recommendations from the TEMPO team for GEMS LO-1 processing: absolute calibration, electronic offset correction, smear correction, and BTDF correction method
- Example: Application of TEMPO V4 BTDF correction to GEMS solar irradiance

GEMS V02 IRR data, Earth-Sun-distance-corrected

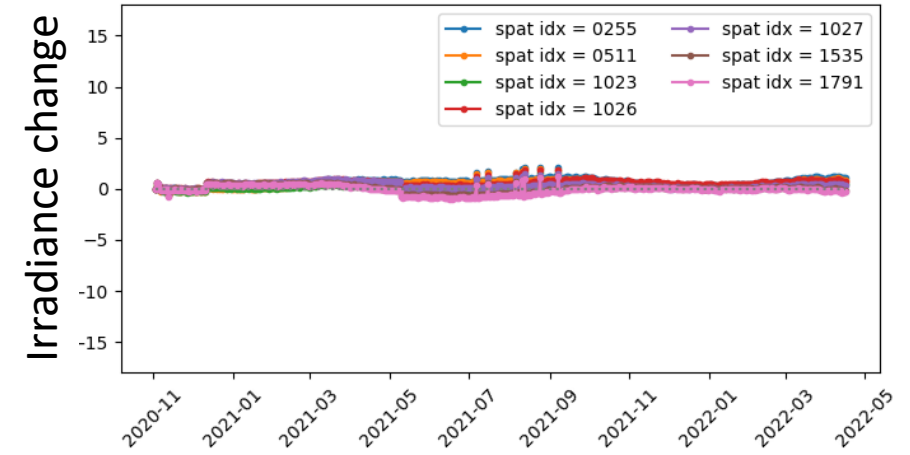
Irradiance change since the first date available: 500.2 nm



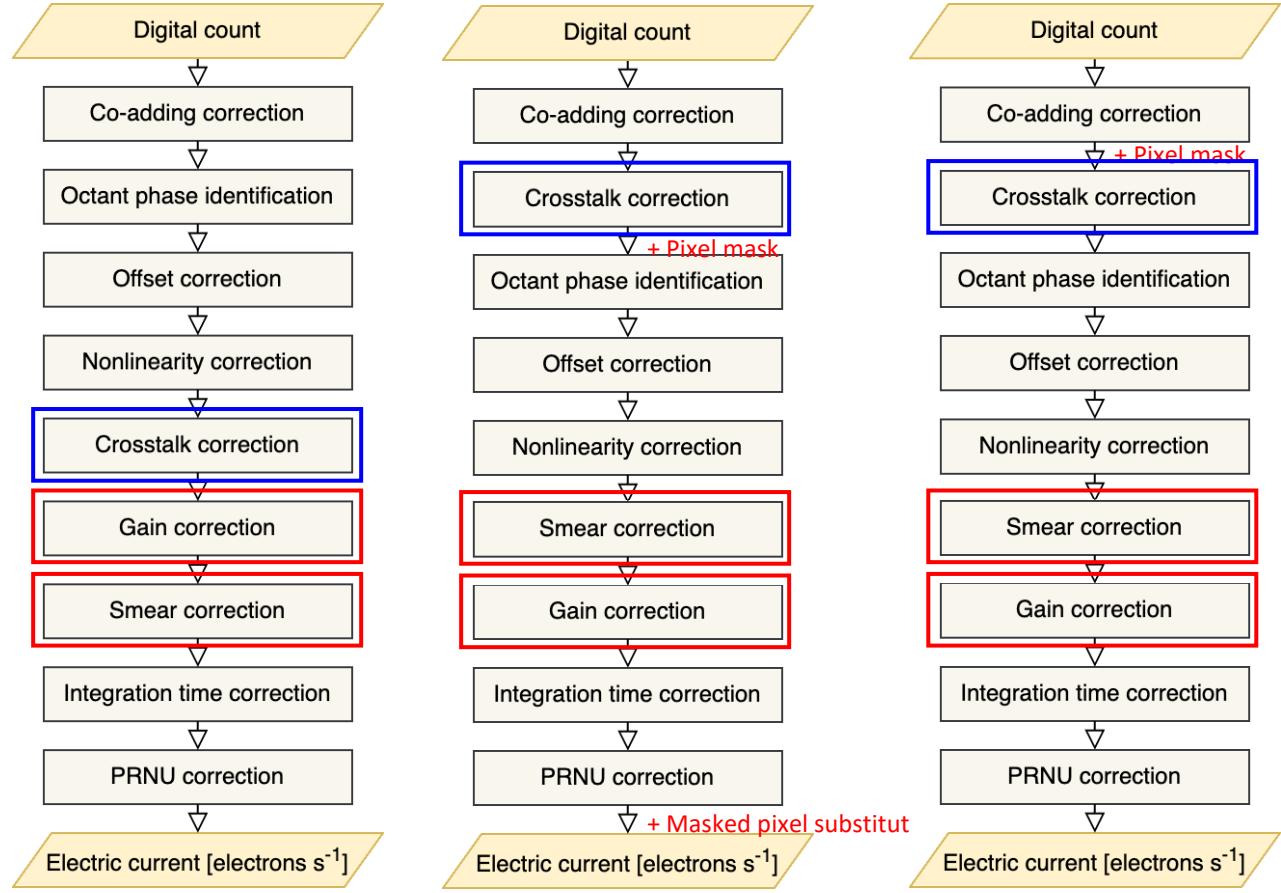
Applying TEMPO V4 BTDF correction to GEMS solar irradiance

Test result, Earth-Sun-distance-corrected

Irradiance change since the first date available: 500.2 nm



SAO's order for TEMPO BATC's order for TEMPO and GEMS Ewha's order for GEMS



GEO-Ring Phase I Activities: SO₂



- Evaluation of **GEMS operational SO₂ retrievals** against **LEO satellite datasets** and **GEMS GSFC retrieval algorithm**
- TEMPO team recommendations for improving GEMS SO₂ retrievals:
 - Retrieval using the native resolution L1C
 - SNR-based filtering in the PCA method

Differences between the GEMS and GSFC retrieval algorithms

GEMS Algorithm

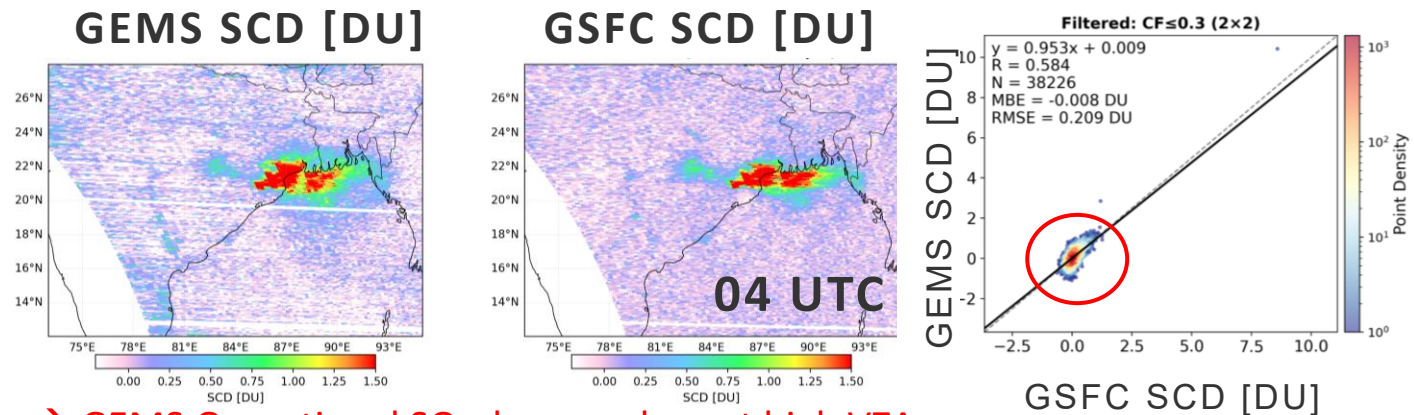
- DOAS-PCA hybrid
- Retrieved using 2x2 pixels binned L1C

GSFC Algorithm

- PCA only
- Retrieved on native GEMS pixels

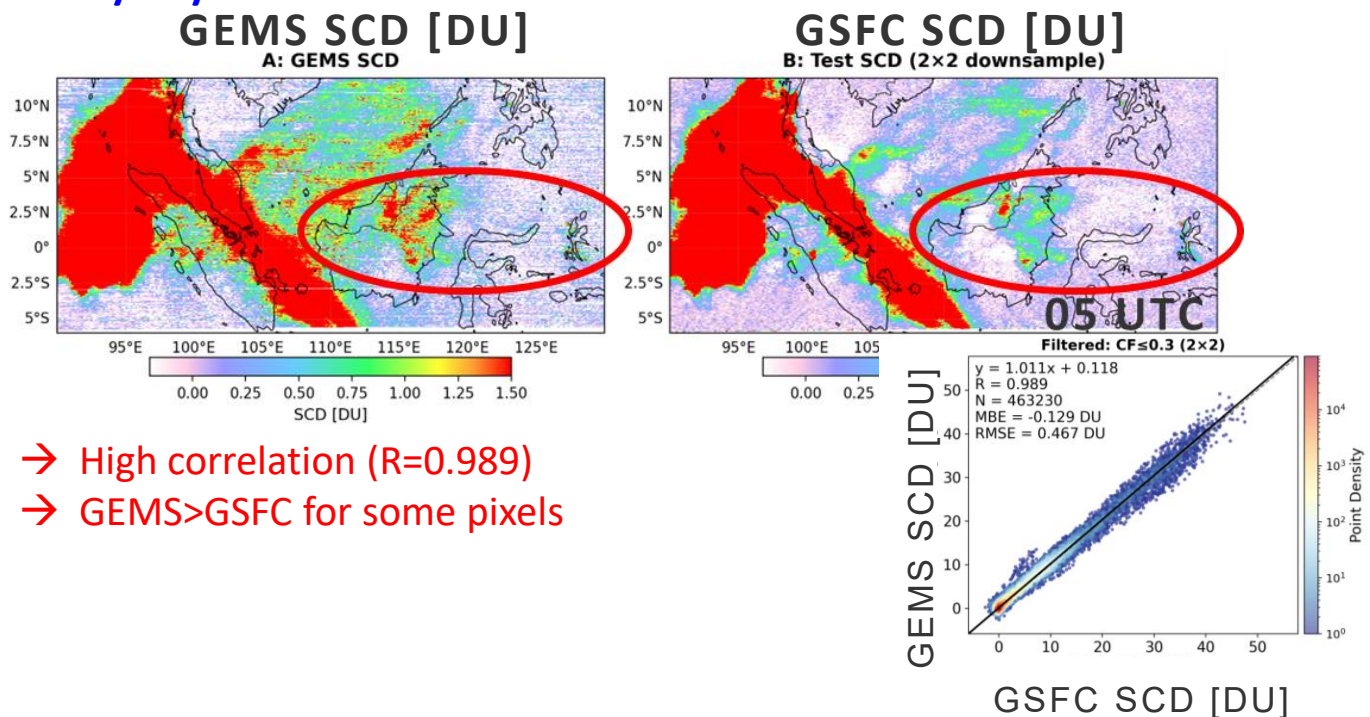
→ Applied 2×2 pixel binning to the GSFC research data to match the spatial resolution.

Pollution area over India (01/25/2025)



→ GEMS Operational SO₂: lower values at high VZAs

05/02/2024: Volcano



→ High correlation (R=0.989)

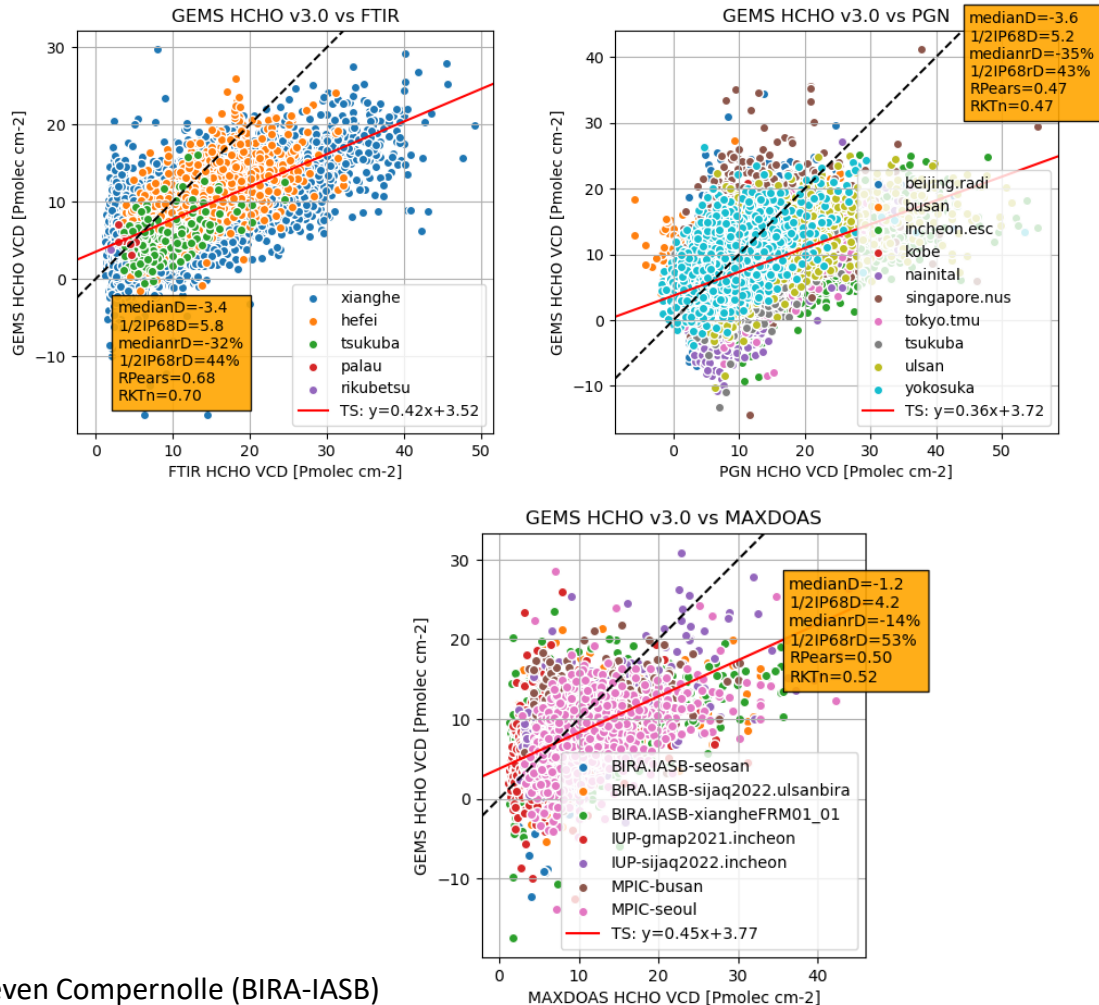
→ GEMS>GSFC for some pixels

GEO-Ring Phase I Activities: HCHO

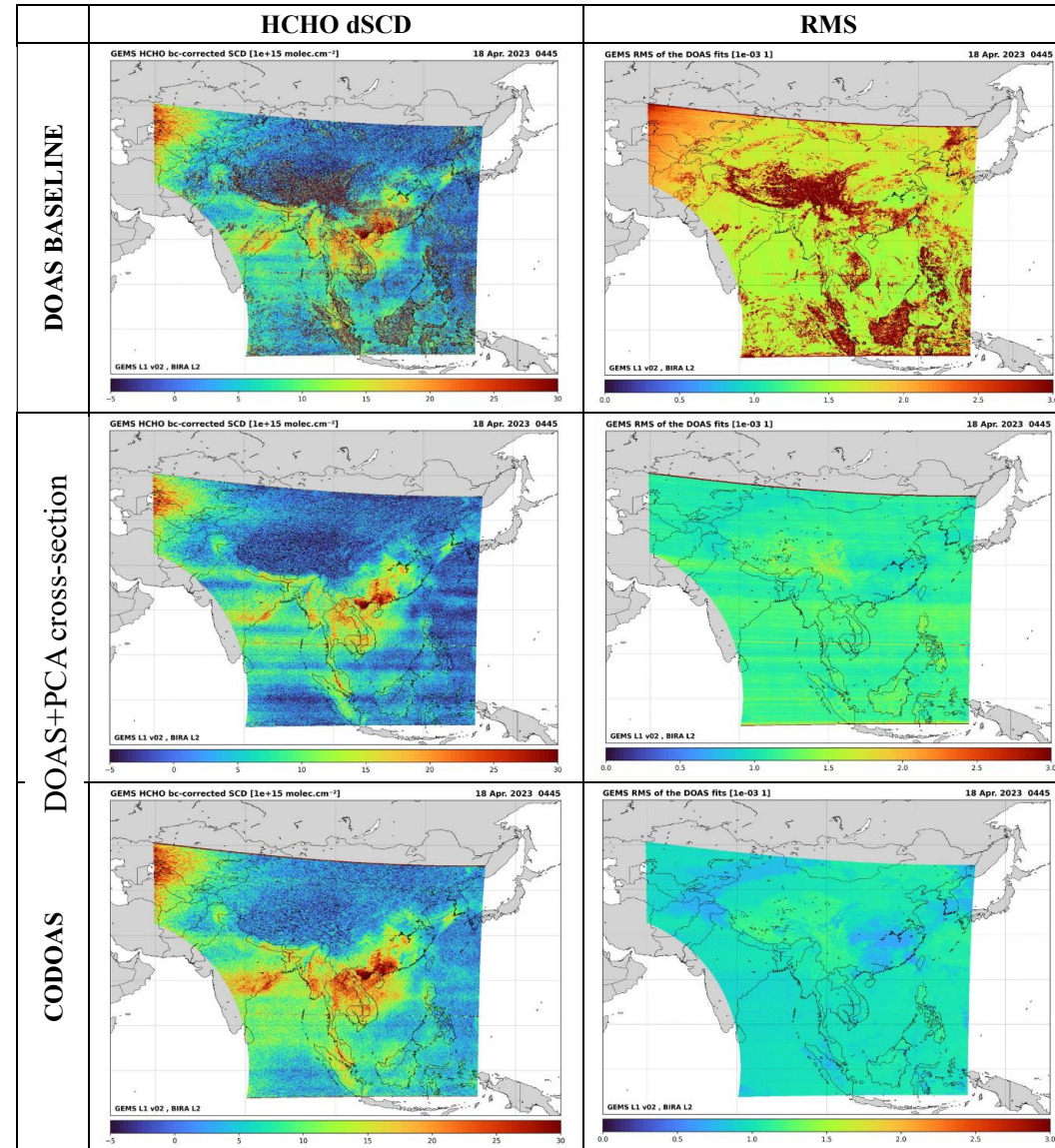


Ground-based validation of GEMS HCHO v3.0

- Reference datasets: FTIR, PGN direct sun, MAX-DOAS
- Slope: ~ 0.4
- Negative bias: FTIR & PGN ($\sim -35\%$), MAX-DOAS ($\sim -15\%$)
- Correlations: $r=0.47-0.68$



Improvement of GEMS HCHO retrieval: DOAS+PCA cross section & CODOAS

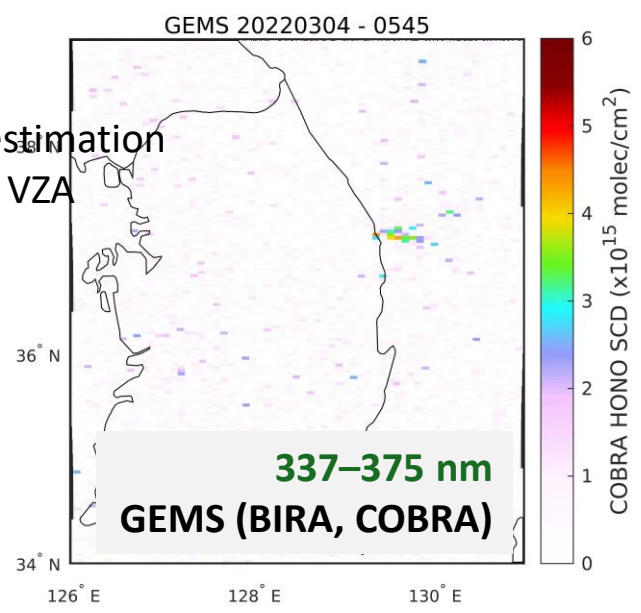


→ Both approaches lead to a significant reduction in SCD noise and fitting residuals, thus improving retrieval accuracy

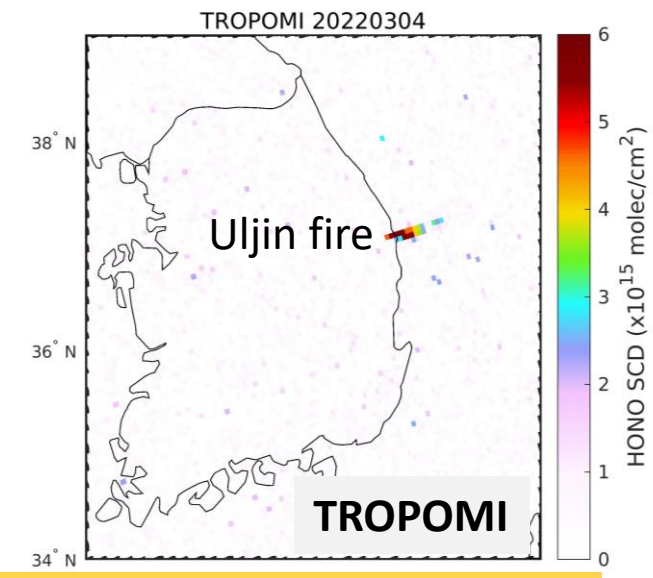
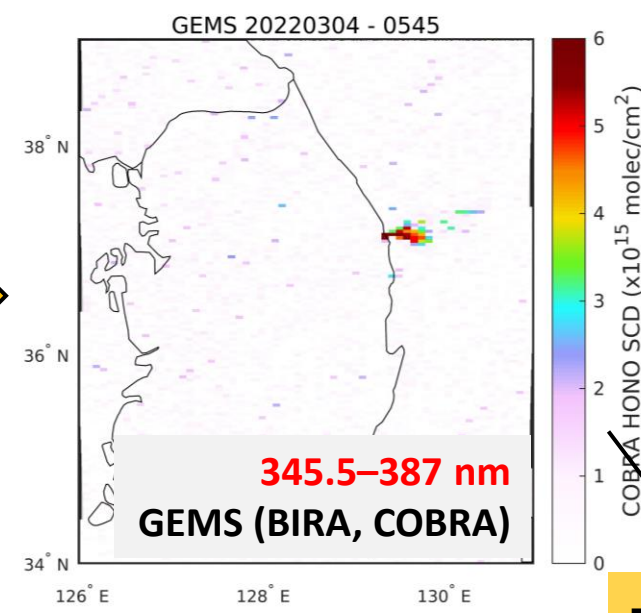
GEO-Ring Phase I Activities: HONO



Issue:
underestimation
at high VZA

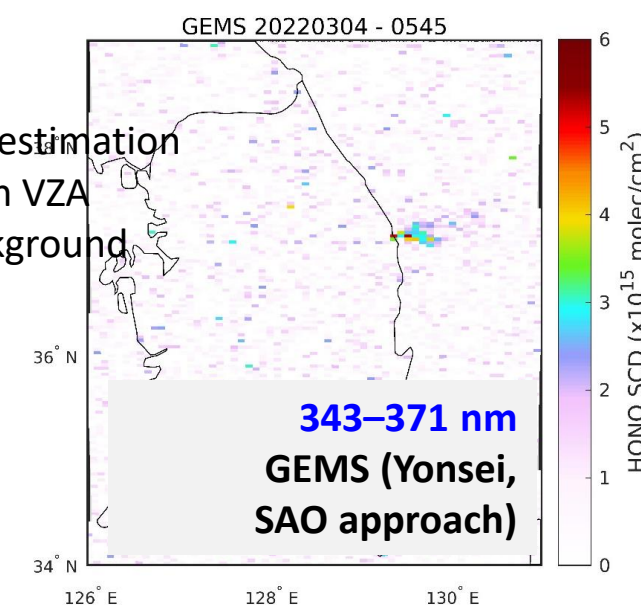


Updated fitting window

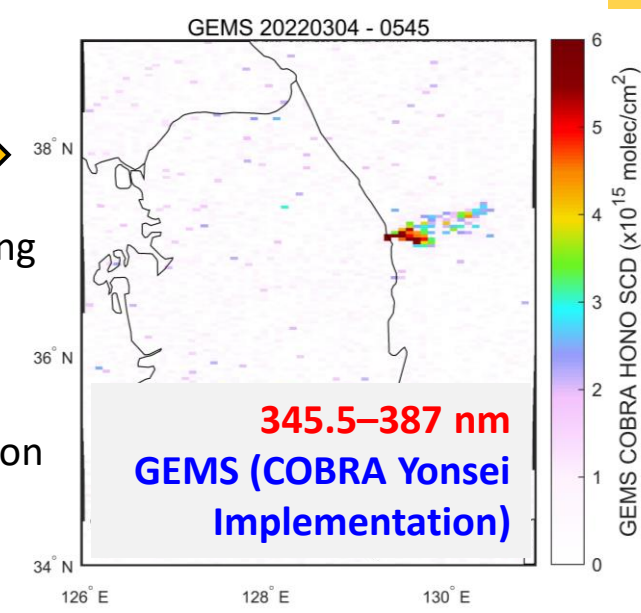


→ Improved consistency with TROPOMI

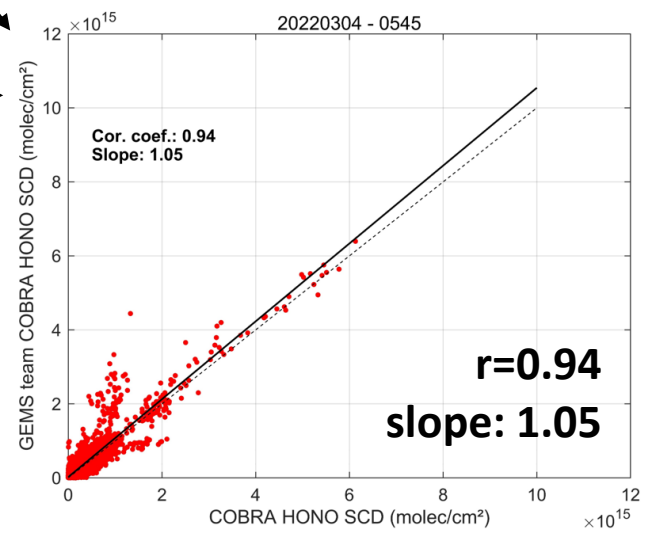
Issue:
underestimation
at high VZA
+ background
noise



Updated fitting window + COBRA implementation



GEMS YSU COBRA



GEMS BIRA COBRA

GEO-Ring Phase I Activities: O₃ profile



Validation of GEMS O3P v3 using ozonesondes

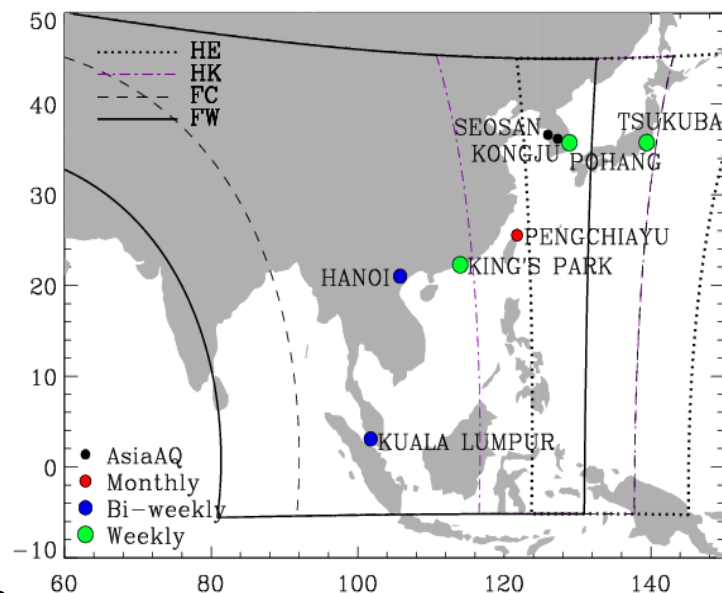
GEMS O3P v3 information content:

- Seasonal cycle of sensitivity, mostly off-diagonal
- DFS ~1.5, mainly from lower stratosphere
- 5-10 km effective vertical resolution

GEMS O3P v3 uncertainty:

- Below 5% bias and ~10% dispersion in lower stratosphere
- 5-10% positive bias & dispersion in troposphere upon averaging kernel smoothing
- Uncertainty peak in UTLS (10–20 km)

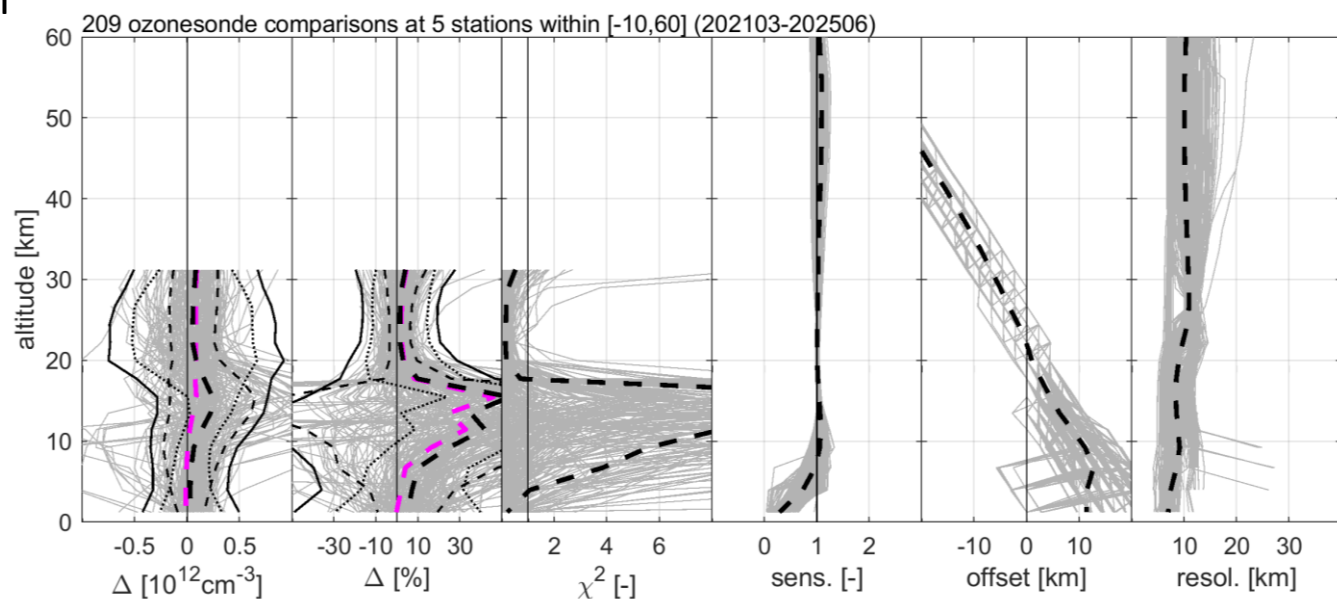
Ozonesondes



PNU



BIRA-IASB

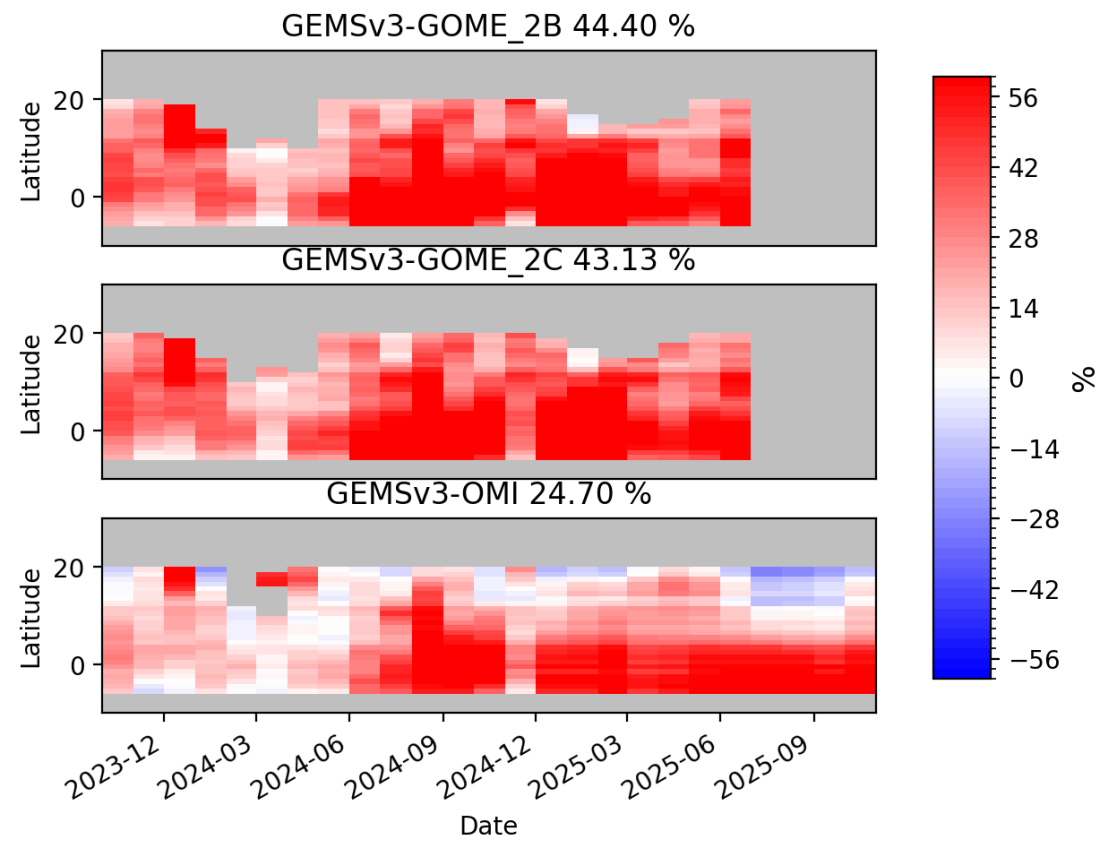
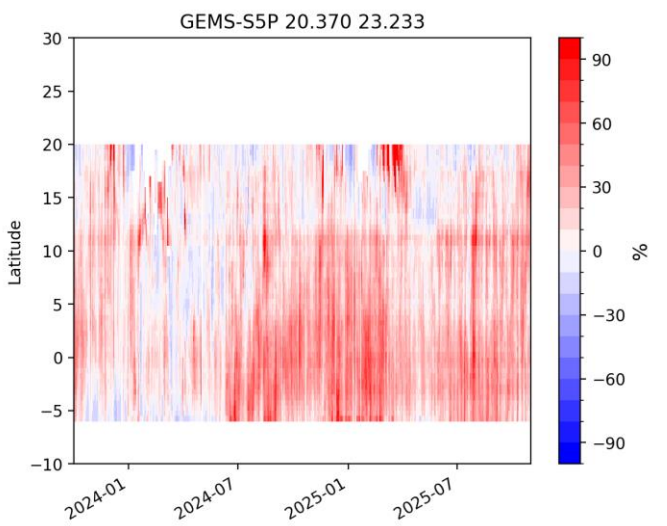
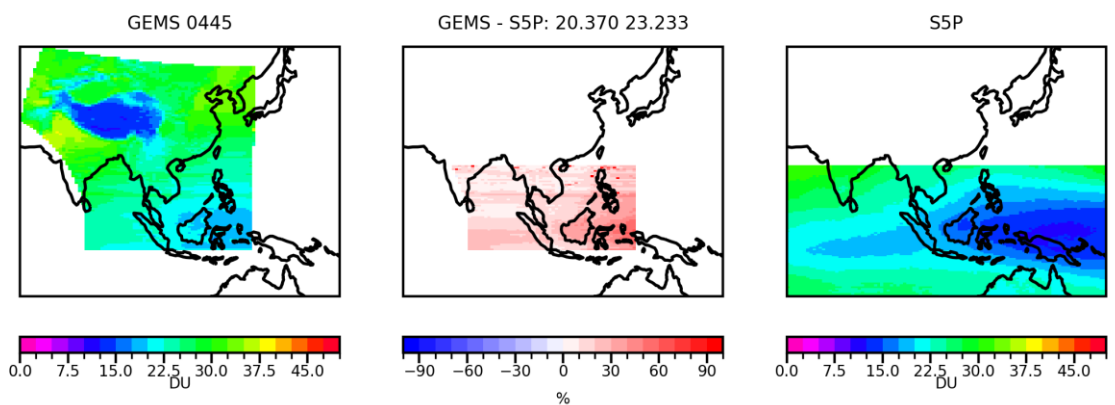


GEO-Ring Phase I Activities: Tropospheric O₃



Comparison to LEO satellites

- Reference datasets: S5P, GOME-2B/2C, OMI
- Mean bias: 20.37–44.4%
- Positive bias relative to the CCD data stronger for GOME-2 than for OMI and S5P



[%]	GOME-2B	GOME-2C	OMI	S5P
Mean bias	44.4	43.13	24.7	20.37
Standard deviation	24.7	20.8	23.5	23.33

GEO-Ring Phase I Activities: O₃ profile

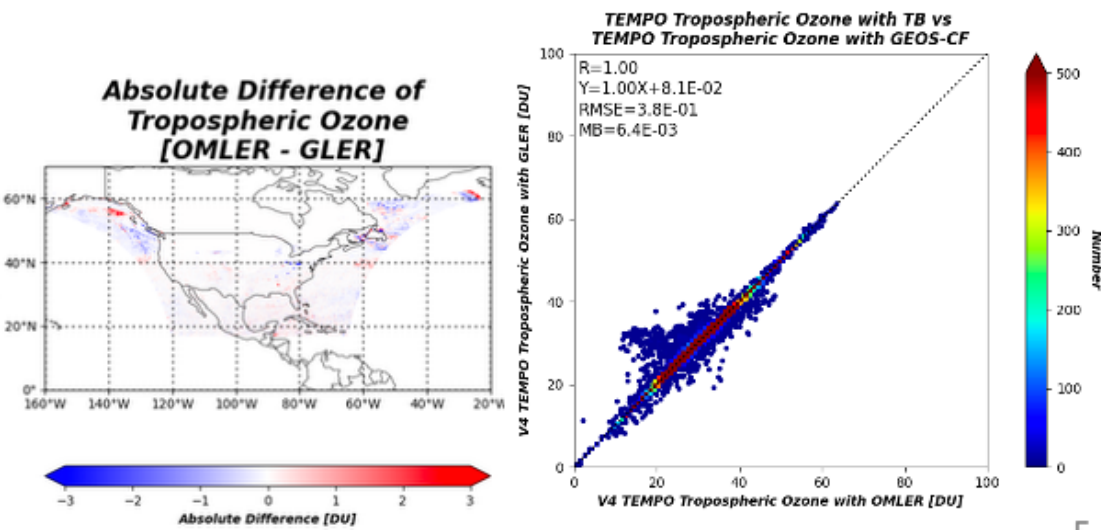


Detailed comparisons of GEMS and TEMPO O₃ profile retrieval algorithms and data format

- Impacts of surface reflectance and a priori profiles on O₃ profile retrieval have been investigated.
- TEMPO team recommendations for GEMS O3P retrieval: GLER surface reflectance & GEOS-CF a priori profiles

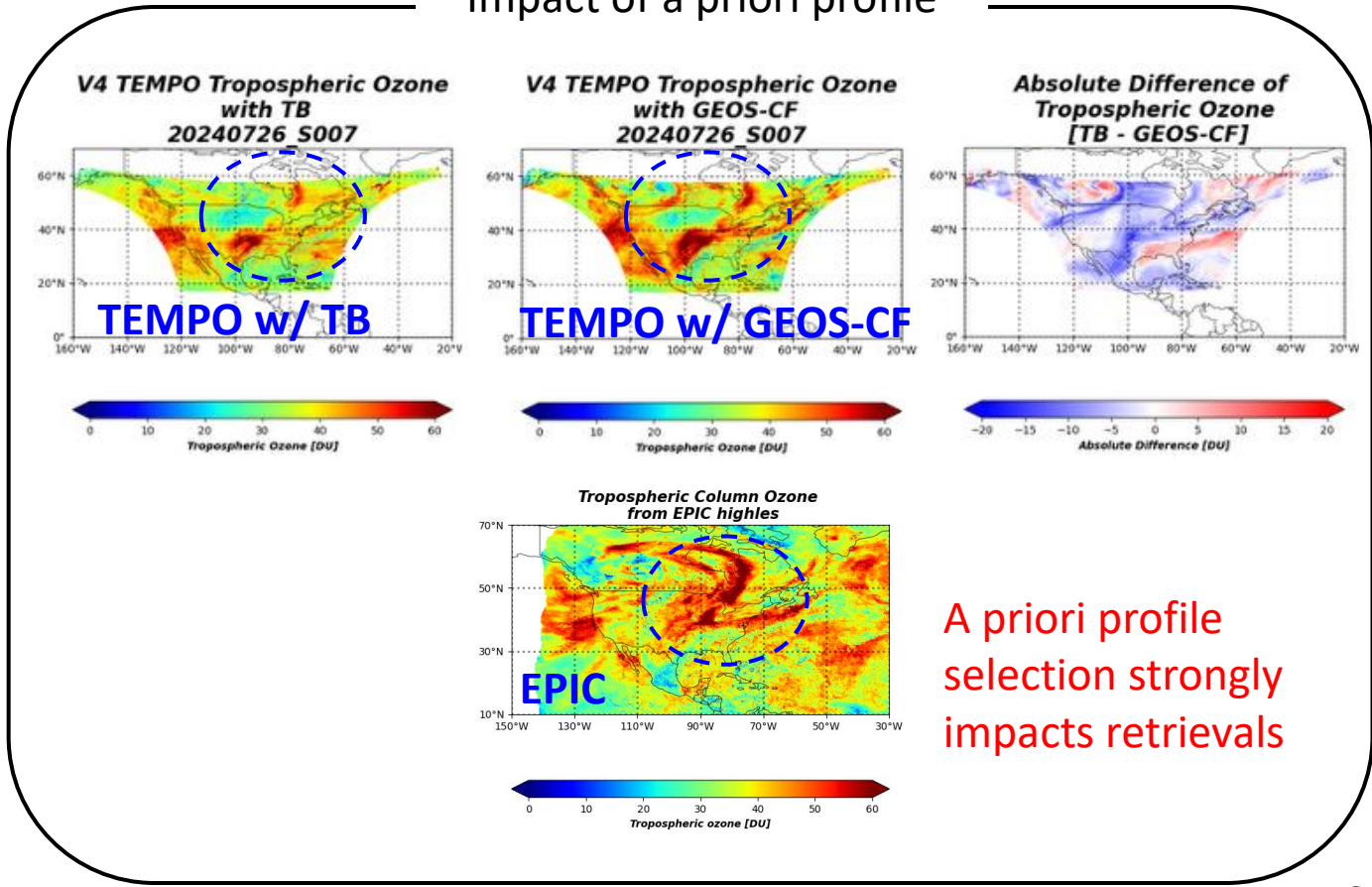
→ GLER surface reflectance and GEOS-CF a priori profiles produce more realistic ozone structures and lower spectral residuals than current GEMS operational inputs.

Impact of surface reflectance



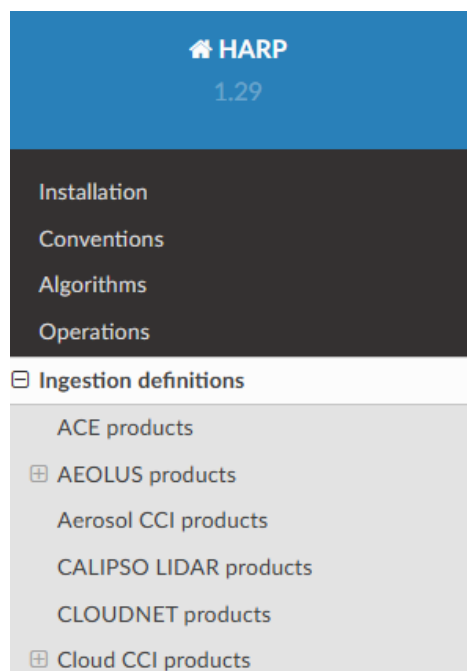
→ Minor changes in retrieved ozone columns

Impact of a priori profile



A priori profile selection strongly impacts retrievals

- A proposed approach for data harmonization: **HARP** (<https://stcorp.github.io/harp/doc/html/conventions>)
 - A toolkit for harmonizing and inter-comparing multi-sensor datasets
 - Standardizes data structures, physical units, and spatial/temporal grids
 - Sentinel-4 products: supported by HARP
 - Implementation of HARP ingestion for GEMS: under consideration



HARP 1.29

- Installation
- Conventions
- Algorithms
- Operations
- Ingestion definitions
 - ACE products
 - AEOLUS products
 - Aerosol CCI products
 - CALIPSO LIDAR products
 - CLOUDNET products
 - Cloud CCI products

Sentinel-4 products

HARP product name	CODA product type	description
S4-L2-ALH	MTG/UVN-2-ALH	Sentinel-4 L2 Aerosol Layer Height
S4-L2-AUI	MTG/UVN-2-AUI	Sentinel-4 L2 UV Aerosol Index
S4-L2-CHO	MTG/UVN-2-GLY	Sentinel-4 Tropospheric Glyoxal
S4-L2-CLD	MTG/UVN-2-CLD	Sentinel-4 L2 Cloud
S4-L2-HCH	MTG/UVN-2-FDY	Sentinel-4 Formaldehyde
S4-L2-NO2	MTG/UVN-2-NO2	Sentinel-4 Nitrogen Dioxide
S4-L2-OTO	MTG/UVN-2-O3	Sentinel-4 Ozone Total Column
S4-L2-OTR	MTG/UVN-2-O3-TSC	Sentinel-4 Tropospheric Ozone
S4-L2-SO2	MTG/UVN-2-SO2	Sentinel-4 Sulphur Dioxide

<https://stcorp.github.io/harp/doc/html/ingestions/index.html>

GEO-Ring Phase II activities (2026')



Work scope	Details
<p>GEO intercomparison strategies</p>	<ul style="list-style-type: none"> Review of harmonized GEO sat. intercomparison approaches + short-term analysis
<p>L1/L2 Algorithm assessment, validation, evaluation</p> <p>HCHO, O3P, trop. O₃</p>	<ul style="list-style-type: none"> O3P & Tropospheric O₃: GEMS & TEMPO validation + uncertainty assessments from multiple collocations HCHO: validate CODOAS product against ground-based measurements and CCI CDRs / comparison with updated GEMS operational product
<p>L1/L2 Algorithm refinements</p> <p>L1, HCHO, HONO, SO₂, O3P</p>	<ul style="list-style-type: none"> HCHO: continue CODOAS + AMF calculations + background correction improvement HONO: AMF calculations within fire plumes using GEMS AERAOD product + comparison with TROPOMI <p>GEMS-TEMPO comparison of</p> <ul style="list-style-type: none"> L1: stray light correction, spectral calibration O3P: fitting windows, measurement floor noise, common mode correction, coadding SO₂: apply phase I updates to GEMS operational algorithm & comparison
<p>Data harmonization of GEMS, TEMPO, and Sentinel-4 (GTS)</p>	<ul style="list-style-type: none"> Consideration of implementing HARP ingestion for GEMS
<p>Large scale AP event demonstration using GTS data</p>	<ul style="list-style-type: none"> Pilot application of optical flow algorithm to GEMS AOD, SO₂

- **GEO-Ring project:** Establishment of a GEO-Ring air quality framework through **algorithm refinement, validation/intercomparison, and data harmonization**
 - **Joint evaluation of GEMS L1/L2 products (HCHO, O3P, tropospheric O₃, SO₂) through collaboration among BIRA-IASB/DLR, TEMPO team, and GEMS science team**
 - GEMS HCHO v3: negative bias (15–30%) relative to ground-based
 - GEMS O3P v3: <5% (lower stratosphere), 5–10% positive bias (troposphere), 5–10 km effective vertical resolution
 - GEMS tropospheric O₃: 20–40% mean bias relative to LEO observations
 - **Identification of algorithm improvements for GEMS retrievals: HONO, HCHO, Level 1, SO₂**
 - HCHO: DOAS+PCA cross-sections & CODOAS
 - HONO: COBRA implementation
 - Level 1: Refinements in absolute calibration, electronic offset correction, smear correction, and BTDF correction method
 - SO₂: Retrievals using native-resolution L1C, SNR-based filtering in the PCA method recommended
 - O3P: GLER surface reflectance and GEOS-CF a priori profiles for improved GEMS O3P retrievals
 - **Investigation of GEO-Ring data harmonization strategies:**
 - Comparison of GEMS, TEMPO, (and Sentinel-4) data format
 - Assessment of HARP as a data harmonization tool

**Thank you for
your attention**

