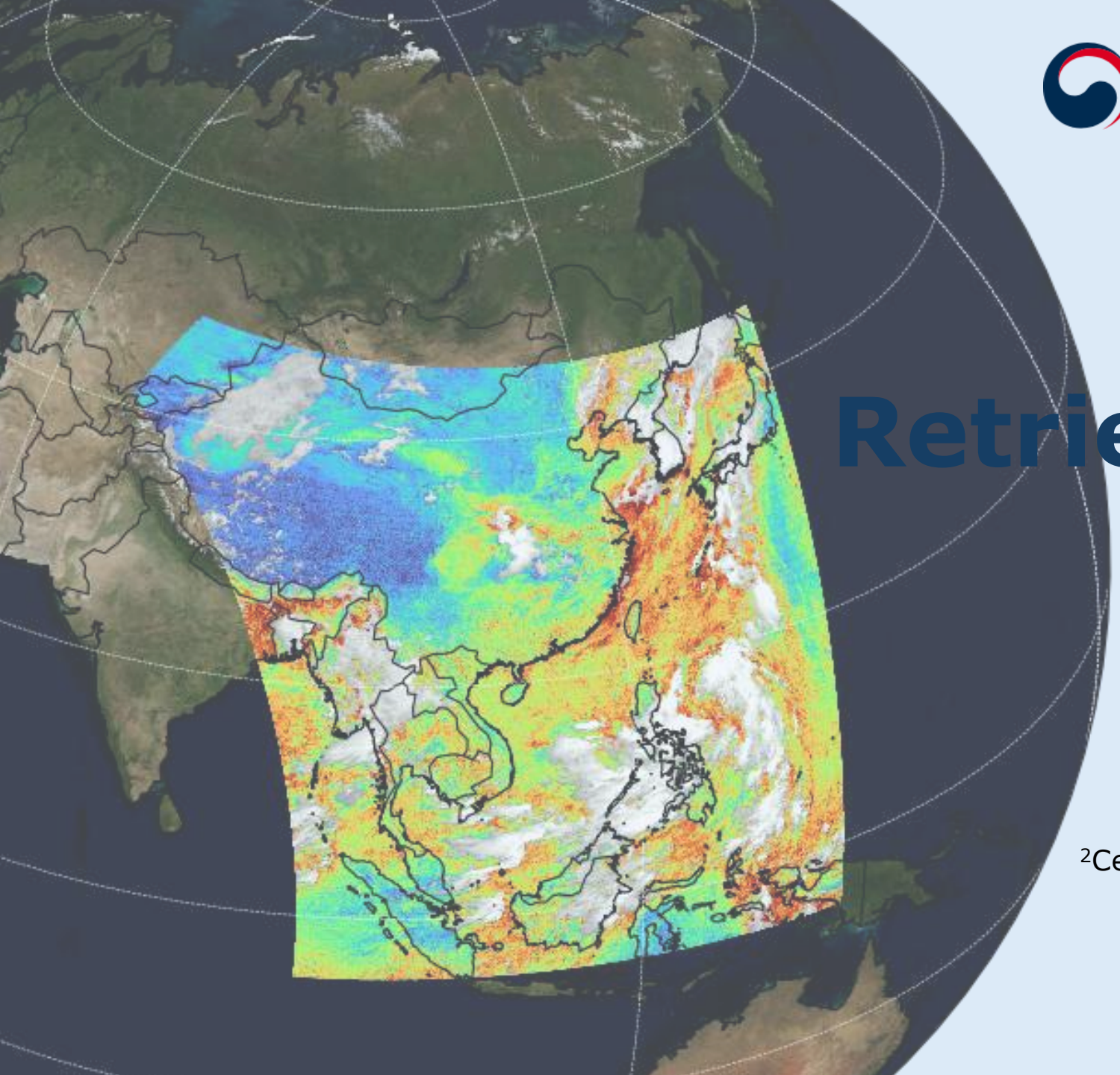

국립환경과학원
National Institute of Environmental Research

GEMS

CEOS AC-VC #22, 1 June 2026, Leiden

GEMS TCWV Retrieval Algorithm

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Geostationary Environment Monitoring Spectrometer (GEMS)

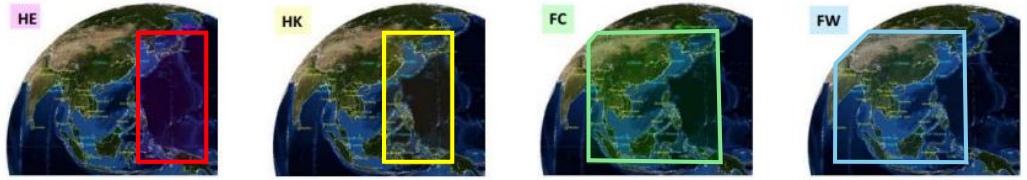
Major specification of GEMS

Spatial resolution (km)	Spatial resolution (km) 3.5 km×7.7 km @ Seoul Spatial Coverage Asia Temporal resolution 1 hour Wavelength range 300–500 nm Spectral sampling 0.2 nm FWHM 0.6 nm
Spatial Coverage	Asia
Temporal resolution	1 hour
Wavelength range	300–500 nm
Spectral sampling	0.2 nm
FWHM	0.6 nm

- Nominal spatial resolution required to satisfy the SNR for GEMS gas products: 7 km×8 km (Kim et al., 2020)

→ For **GEMS TCWV retrievals**, the native spatial resolution of **3.5 km×7.7 km** is used to examine the feasibility of water vapor retrievals at the highest satellite resolution.

- **Annual operation schedule**: changed since 1st Feb 2024
  - # of observations:
    - 2021–2023: 6 (winter, DJF)–10 (Apr–Sep)
    - 2024– : 7 (Dec–Jan)–10 (Apr–May)



Annual Operation Schedule (2021–2023)

No.	1	2	3	4	5	6	7	8	9	10	11	Total Observation Time
UTC	22:45	23:45	0:45	1:45	2:45	3:45	4:45	5:45	6:45	7:45	8:45	
KST	7:45	8:45	9:45	10:45	11:45	12:45	13:45	14:45	15:45	16:45	17:45	
Jan	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6
Feb	X	X	HE	HK	FC	FW	FW	FW	FW	X	X	7
Mar	X	HE	HK	FC	FC	FW	FW	FW	FW	X	X	8
Apr	HE	HK	FC	FC	FC	FW	FW	FW	FW	FW	X	10
May	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Jun	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Jul	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Aug	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Sep	HE	HK	FC	FC	FW	FW	FW	FW	FW	FW	X	10
Oct	X	HE	HK	FC	FC	FW	FW	FW	FW	X	X	8
Nov	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6
Dec	X	X	HE	HK	FC	FW	FW	FW	X	X	X	6

Annual Operation Schedule (2024–present)

No.	1	2	3	4	5	6	7	8	9	10	11	Total Observation Time
UTC	22:45	23:45	0:45	1:45	2:45	3:45	4:45	5:45	6:45	7:45	8:45	
KST	7:45	8:45	9:45	10:45	11:45	12:45	13:45	14:45	15:45	16:45	17:45	
Jan	X	X	FC	FC	FC	FC	FW	FW	FW	X	X	7
Feb	X	HE	FC	FC	FC	FC	FW	FW	FW	X	X	8
Mar	X	HE	FC	FC	FC	FC	FW	FW	FW	X	X	8
Apr	HE	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	10
May	HE	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	10
Jun	X	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	9
Jul	X	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	9
Aug	X	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	9
Sep	X	HK	FC	FC	FC	FC	FW	FW	FW	FW	X	9
Oct	X	HE	FC	FC	FC	FC	FW	FW	FW	X	X	8
Nov	X	HE	FC	FC	FC	FC	FW	FW	FW	X	X	8
Dec	X	X	FC	FC	FC	FC	FW	FW	X	X	X	6

GEMS TCWV retrieval algorithm

Spectral fitting:

$$F(\lambda) = \left[[I_0(\lambda = \lambda' + x_{shift}) + x_u b_u(\lambda) + x_r b_r(\lambda)] exp\left(-\sum_i x_i b_i(\lambda) \right) \right] P_{sc}(\lambda) + P_{bl}(\lambda)$$

- Fitting window: 435–467 nm
- Source spectrum: GEMS daily solar irradiance

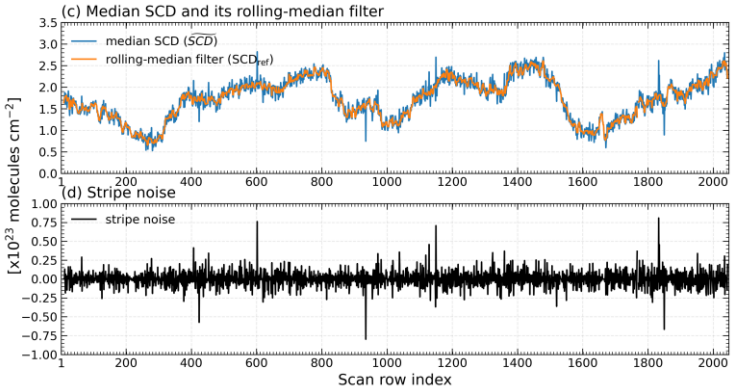
De-striping:

stripe_noise= $\widetilde{SCD} - SCD_{ref}$

$SCD_{de\text{-}striped}$= SCD– stripe_noise

$\widetilde{SCD}$: median SCD

SCD_{ref}: rolling-median filter

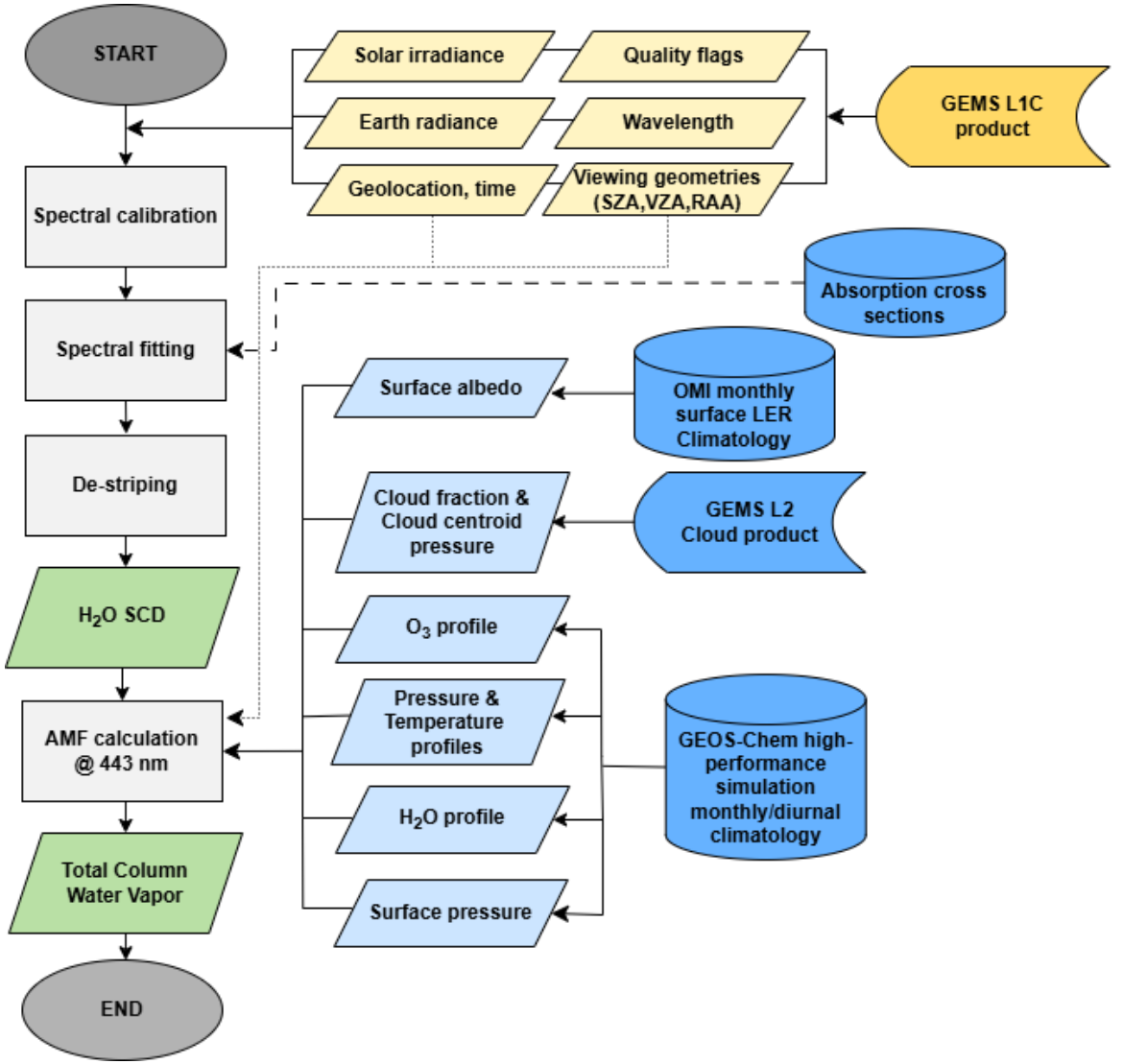


- Median SCD calculation: depending on cloud occupancy for each scan row
- Rolling-median filter (kernel size=5) : conservative choice for potential operational use

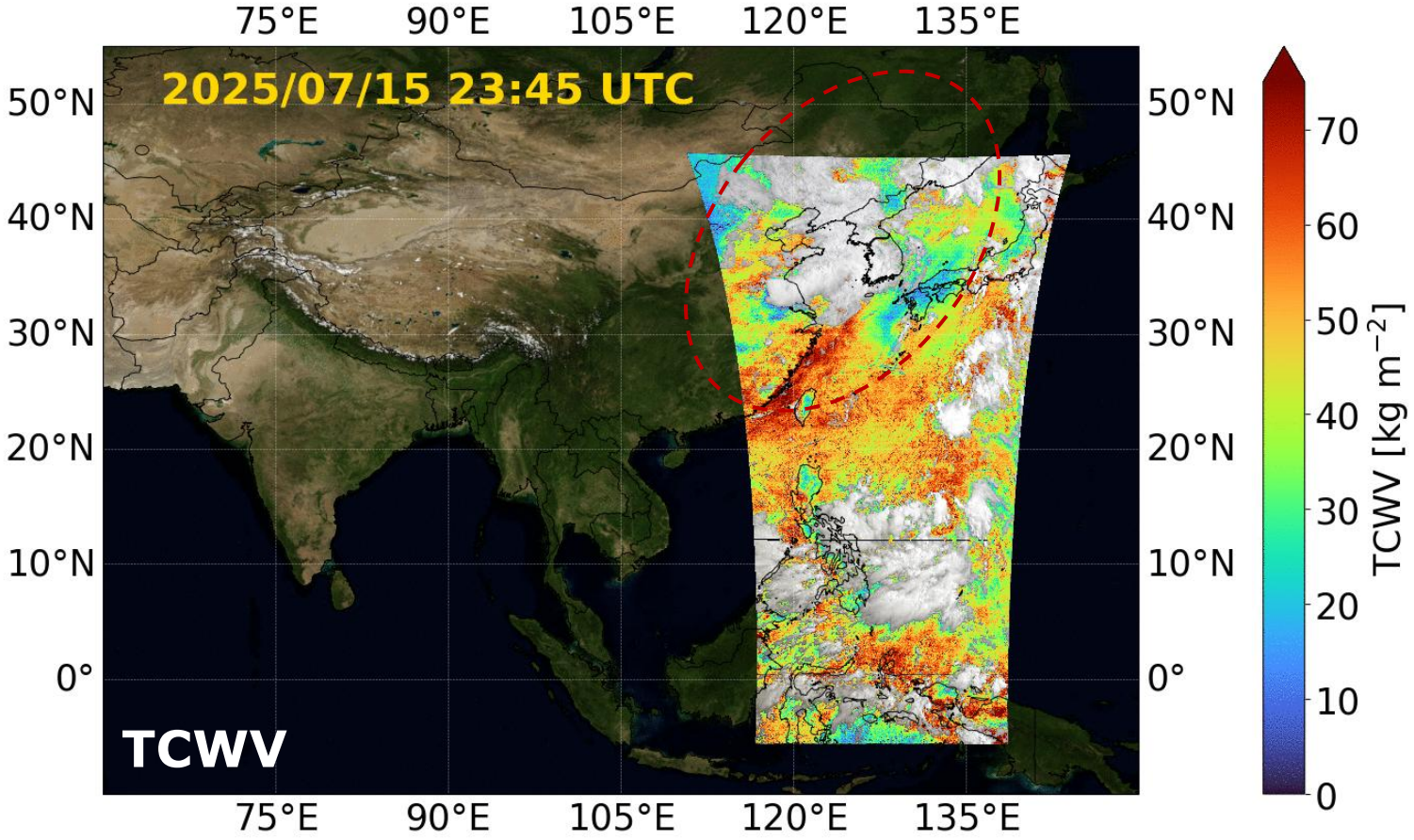
AMF calculation:

$$AMF = \frac{SCD}{VCD} = \frac{\sum_{l=1}^{n_z} W(SZA, VZA, RAA, \alpha_{sfc}, c_{eff}, P_{cld}) C_{a,l}(lat, lon, month, hour)}{\sum_{l=1}^{n_z} C_{a,l}(lat, lon, month, hour)}$$

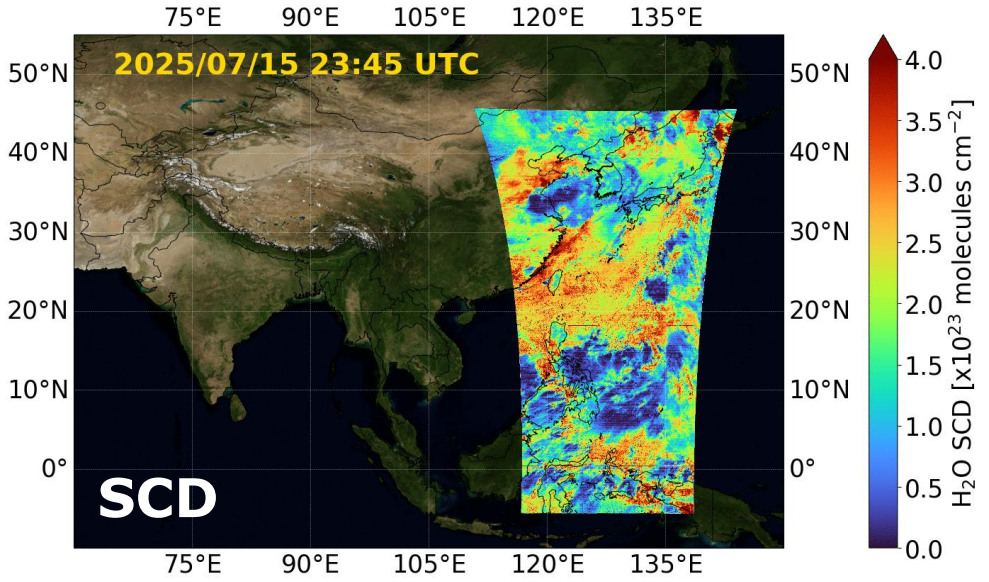
- 443 nm, LUT-based (VLIDORT)

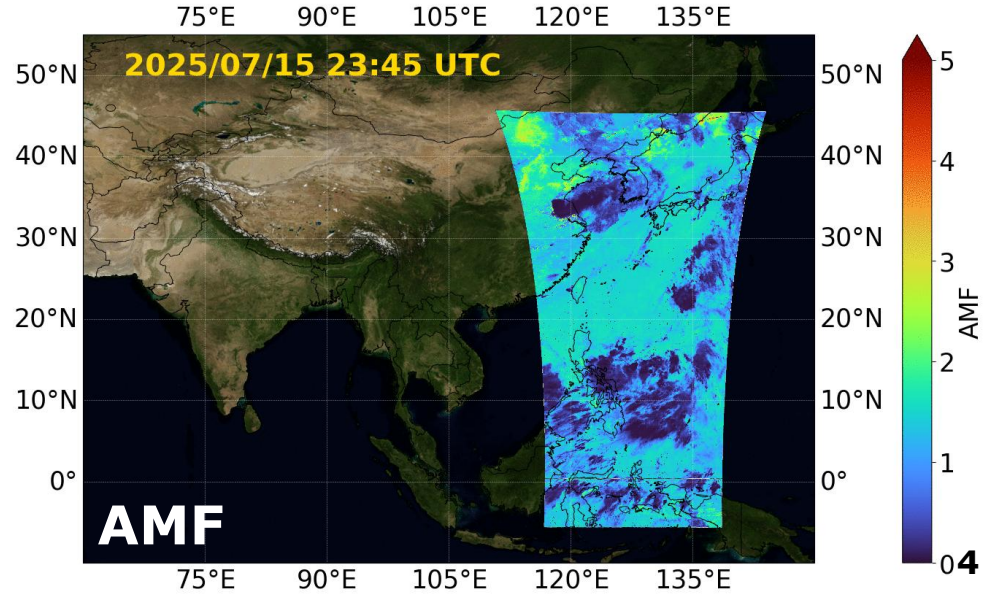


Retrieved result: 16 July 2025 (Atmospheric river event in East Asia)



SZA≤75°, VZA≤75°, AMF>0.25, CF<0.5

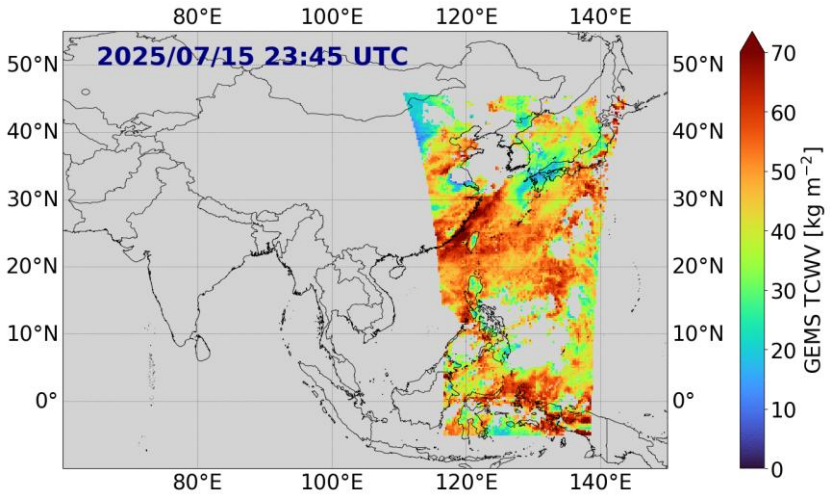




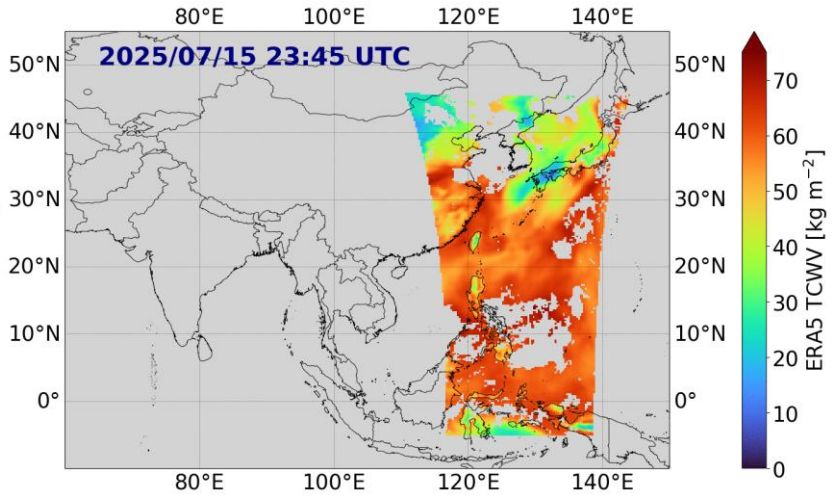
TCWV Comparison: 16 July 2025

- Pixel criteria: ECF<0.5 (※ Stricter ECF threshold of 0.2 is applied for validation.)
- GEMS: underestimation for high TCWVs (TCWV>30 kg m^{-2})

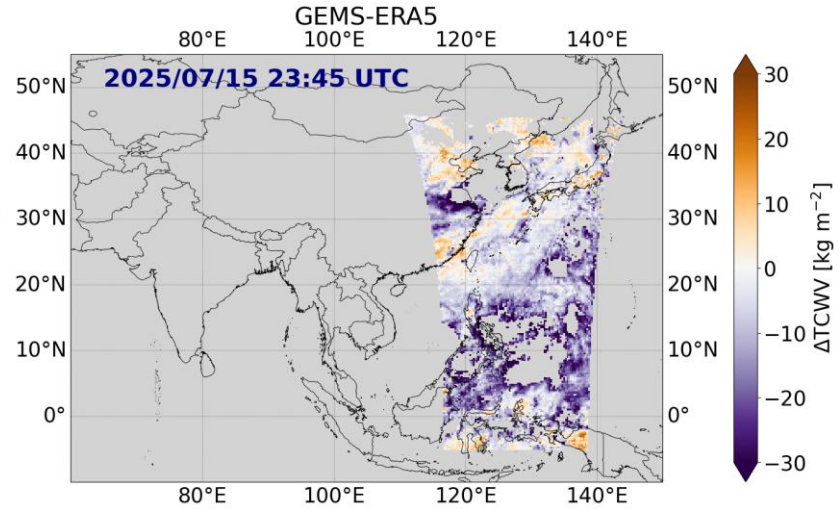
GEMS



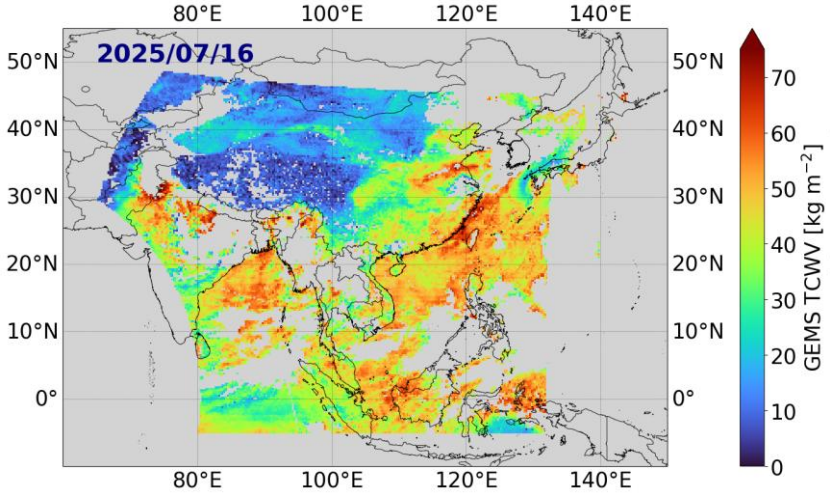
ERA5



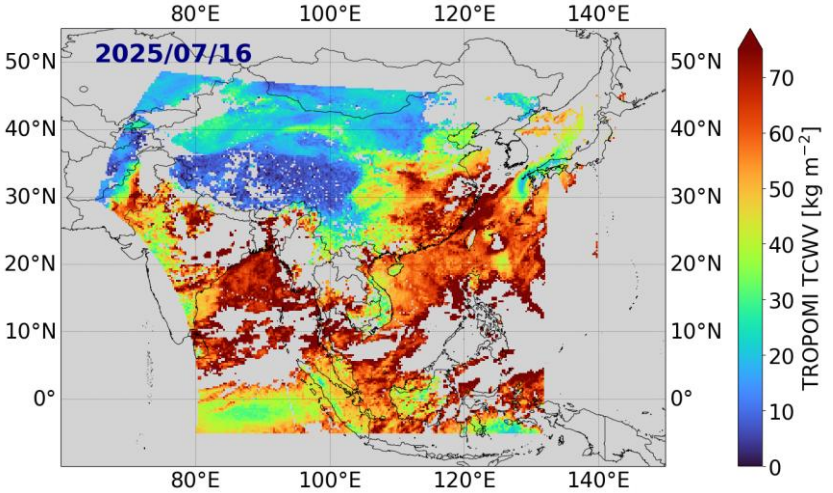
GEMS-ERA5



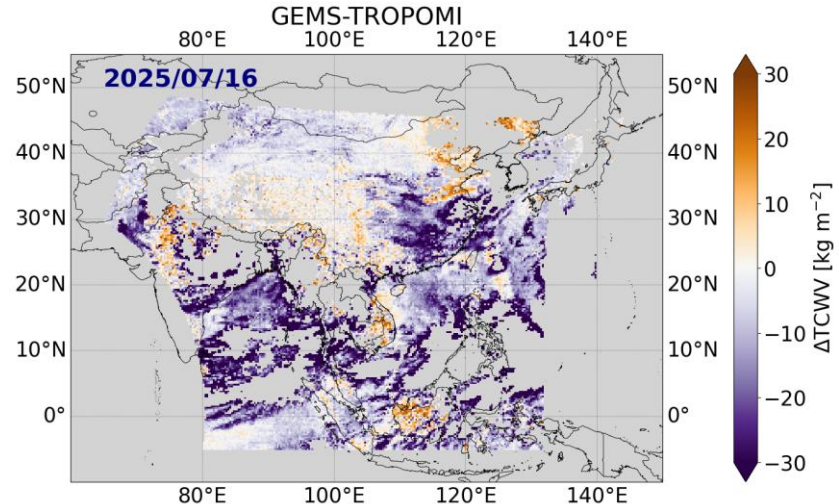
GEMS
(± 30 min of TROPOMI overpass)



TROPOMI



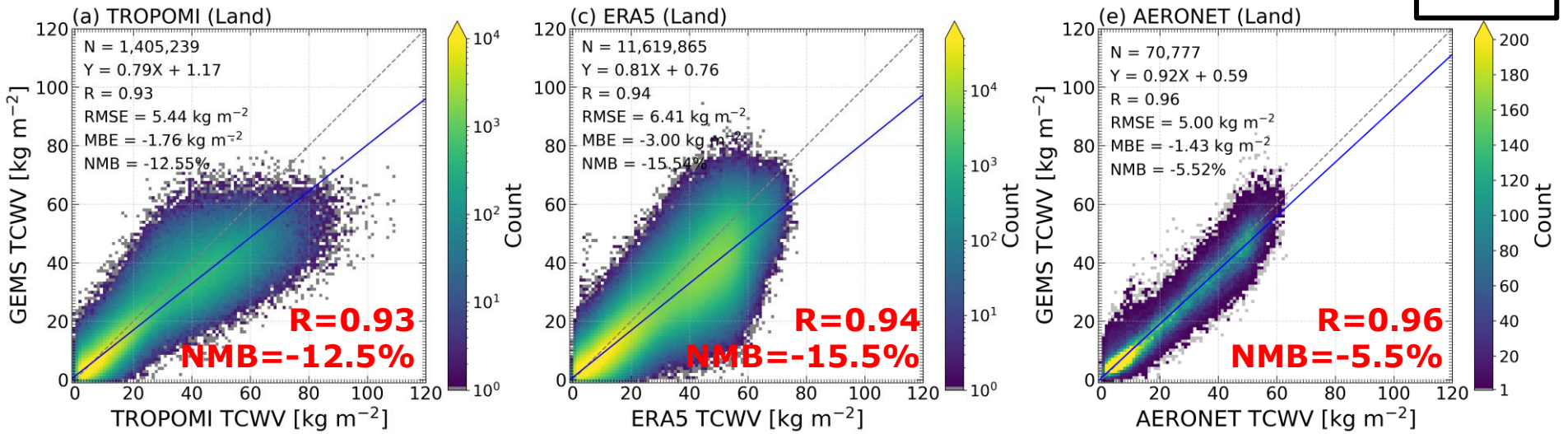
GEMS-TROPOMI



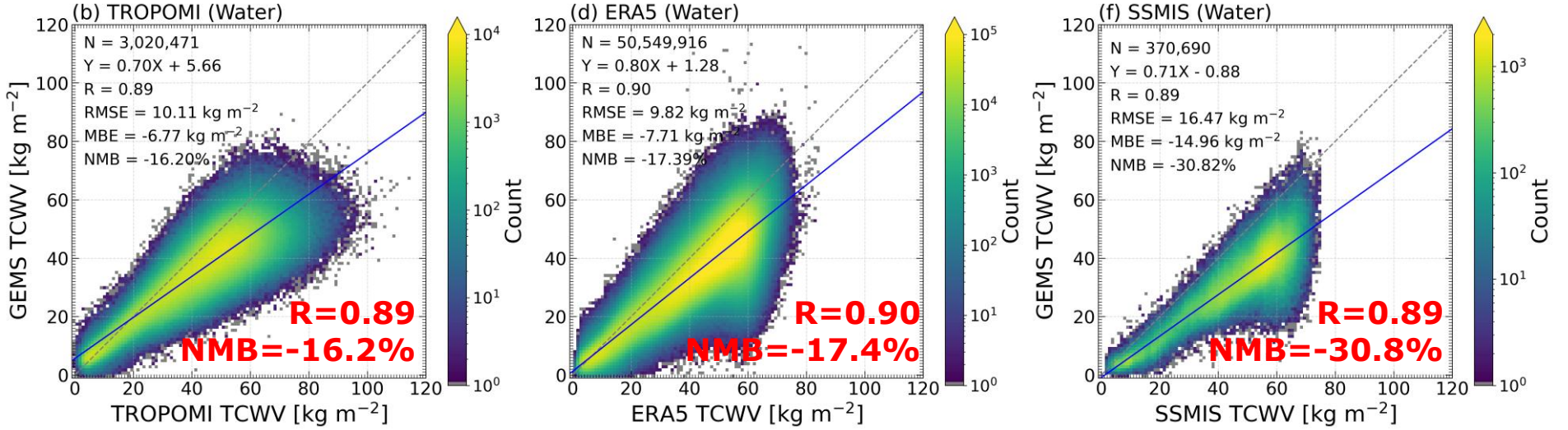
Validation

※ Evaluation period: Mar 2021–Feb 2023 (2 yrs)

Land



Water



ERA5: closest reference dataset to truth

Land

- good agreement

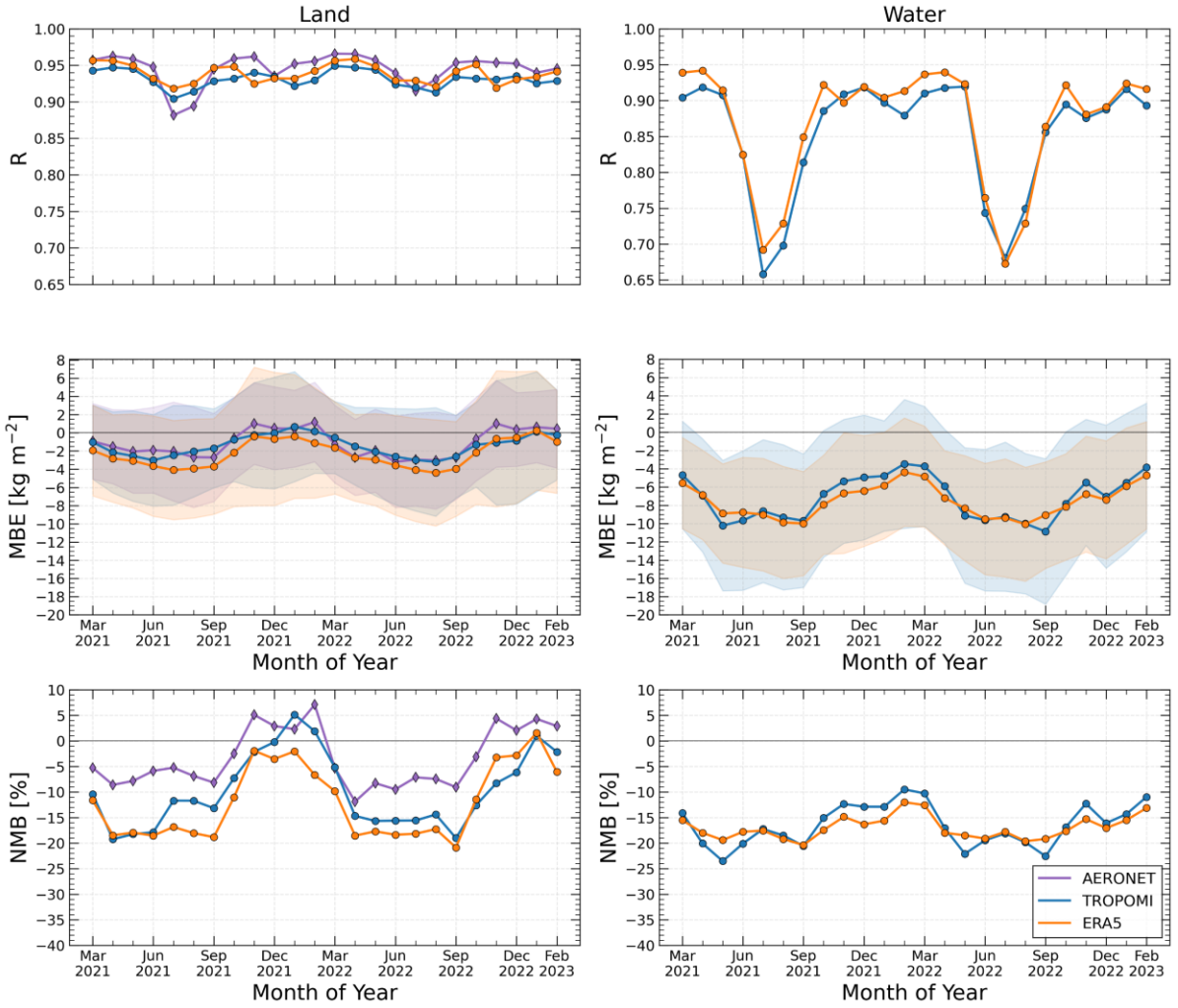
Water

- Weaker performance than land (R~0.9)
- Stronger underestimation

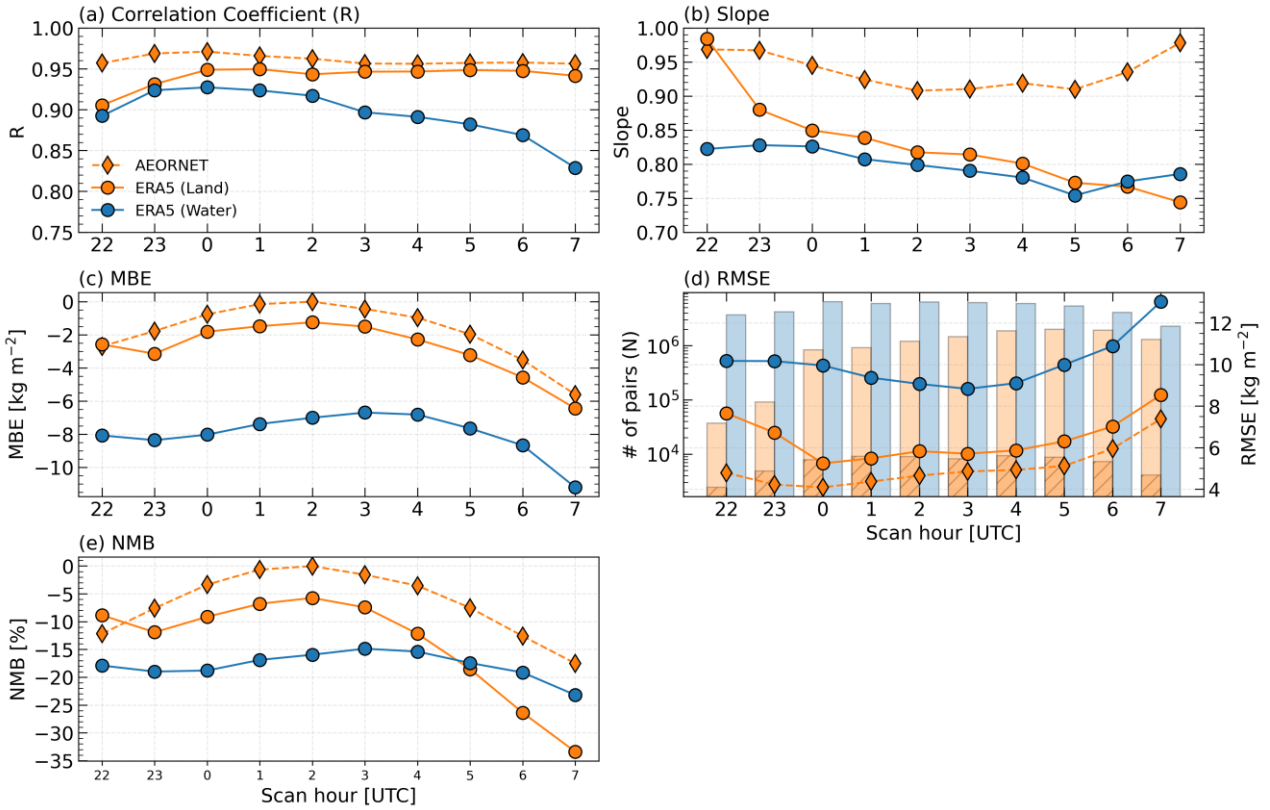
※ Larger negative bias relative to SSMIS: wavelength ranges, positive bias (2–3 kg m^{-2}) inherent in SSMIS, diurnal variations in GEMS TCWV biases

Validation

Monthly variation



Hourly variation



Discussion

Uncertainty estimation:

- SCD uncertainty: 5–10 kg m^{-2} (corresponding to 4–50%, depending on scan hour and season)
- AMF uncertainty: 9–40% → strongly dependent on cloud conditions
  - Clear-sky conditions: ECF<0.2

    → Lowest uncertainty (9–16%) with minimal temporal variability
- TCWV uncertainty: 4–17 kg m^{-2}
  - Clear-sky conditions: 10–20% (tropics), 30–100+% (mid-latitudes, due to low TCWVs)

(Potential) Sources of error:

- SCD uncertainty:
  - Underestimation of water vapor cross section (HITRAN 2020)
  - Polarization correction (not applied)
- AMF uncertainty:
  - Clear-sky condition: water vapor vertical profile (~ 45–60%), surface albedo (~30–40%)
  - Cloudy condition: Water vapor vertical profile (~40–80%), cloud pressure (~10–40%)

Summary

GEMS TCWV Retrieval:

- Operational implementation: ready for operational processing (Public Release: TBD)
- Performance comparable to LEO satellites: (Land) R=0.94, NMB=-15.5%; (Water) R=0.90, NMB=-17.4%
  - Relatively lower performance on water surfaces, summer months
    - Potential sources of error: Polarization correction(not applied), underestimation of water vapor cross section, AMF scheme with fixed a priori profiles, AMF inputs...

Future Plans:

- Realistic representations of surface albedo, water vapor vertical profiles, cloud properties are required.
  - Implementation of an iterative optimization scheme for AMF calculations (Borger et al., 2020; Chan et al., 2020, 2022)
  - Use of updated version of GEMS Cloud, SFC products, ...

- **Data**: doi.org/10.1016/j.rse.2026.115401

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Backup Slide

Spectral fit setting

Fitting window	435–467 nm
Source spectrum	GEMS daily solar irradiance
Solar reference spectrum	Chance and Kurucz (2010)
Slit function	Super Gaussian (Beirle et al., 2017)
Parameter	**Note**
Undersampling correction spectrum	Chance et al. (2005)
Rotational Raman scattering spectrum	Chance and Spurr (1997)
Vibrational Raman scattering	Chance and Spurr (1997)
Water vapor cross-section	Gordon et al. (2022), 293K
NO_2 cross-section	Vandaele et al. (1998), 220K
O_2–O_2 cross-section	Finkenzeller and Volkamer (2022), 293K
Liquid H_2O cross-section	Mason et al. (2016), 296K
O_3 cross-section	Serdyuchenko et al. (2014), 233K
Scaling polynomial	2^{nd} order
Baseline polynomial	-

AMF calculation setting

Wavelength	443 nm
Geographic locations and viewing geometries	GEMS Level 1C product
Surface reflectance	OMI monthly surface LER climatology (OMI LER climatology, Kleipool et al., 2008)
Cloud fraction and cloud pressure	GEMS Version 2.0 Level 2 Cloud product
Gas profiles	GEOS-Chem high-performance simulation monthly diurnal climatology in 2018 (Ayazpour et al., 2025; Kwon et al., 2024)
Pressure and temperature profiles	
Surface pressure	
Vertical layers	72 layers
Aerosol correction	not applied