CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Smithsonian Astrophysical Observatory Water Vapor Retrievals from OMI and TEMPO

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AC-VC #22

Remote, June 1st, 2026

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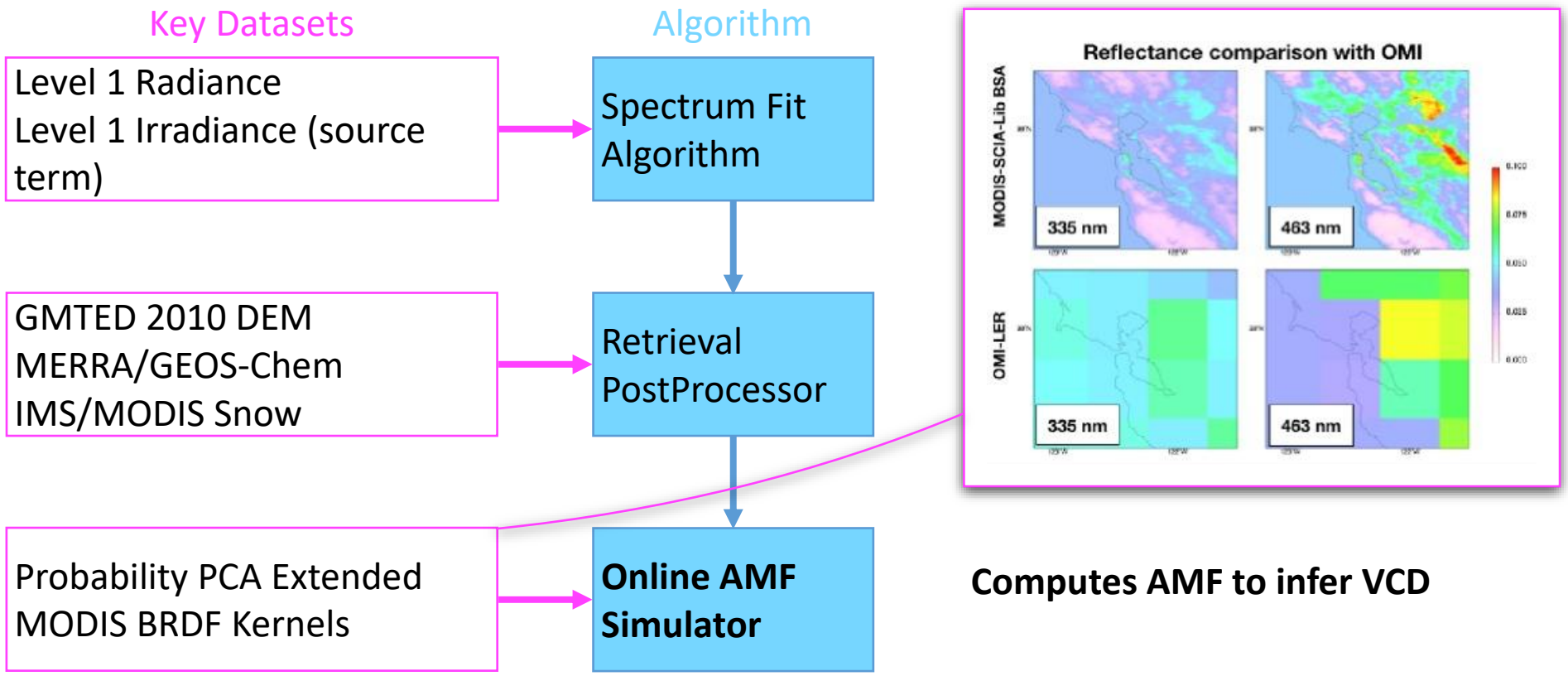


Wang et al., 2023: https://amt.copernicus.org/preprints/amt-2023-66/

OMI H_2O: Retrieval set up

OMI H_2O SCD retrieval algorithm set up

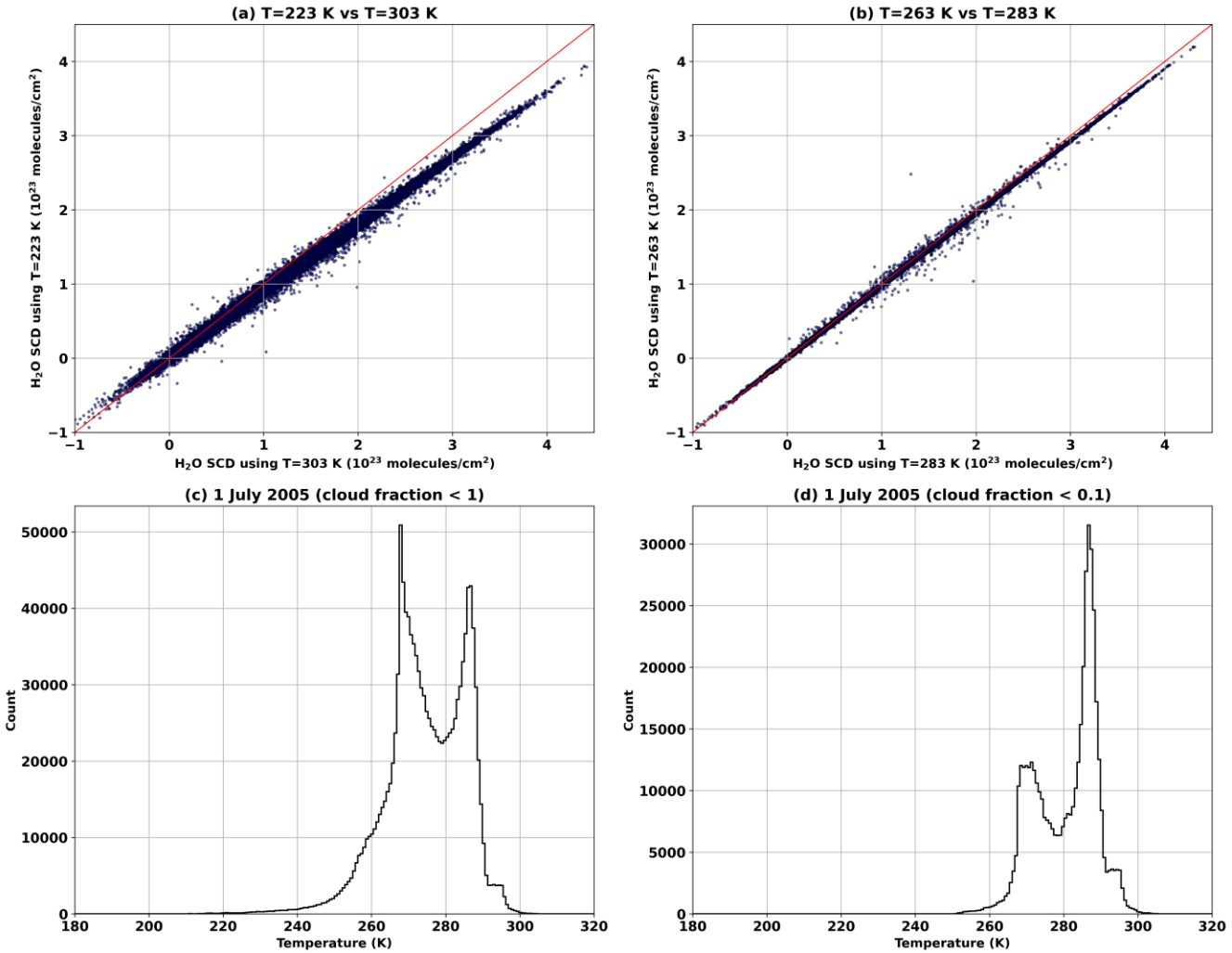
Ingredients	Details
window	[432, 466] nm
closure polynomials	Baseline: 3rd order Scaling: 3rd order
calibration	wavelength shift slit function: Super-Gaussian HW1e and shape parameter k
reference spectra	solar: [Chance and Kurucz, 2010] H_2O: HITRAN 2020 [Gordon et al., 2022] (283 K) NO_2: [Vandale et al., 1998] (220 K & 294 K) O_3: [Serdyuchenko et al., 2014] (223K) O_2-O_2: [Finkenzeller and Volkamer, 2022] (293 K) $C_2H_2O_2$: [Volkamer et al., 2005] (296 K) IO: [Spietz and Burrows, 2005] liquid water (lqh2o): [Mason and Fry, 2016] Ring effect: [Chance and Spurr, 1997] water Ring (vraman): [Chance and Spurr, 1997]
other	Under-sampling correction [Chance et al., 2005]

OMI H_2O AMF retrieval algorithm set up & ancillary data

Parameter	Description
Calculation wavelength	442 nm
Viewing geometry & terrain height	OMI L1B
Cloud information	OMCLDO2 (cloud fraction & pressure)
Surface reflectance over land	MODIS BRDF products MCD43C1 v6.1 (Schaaf & Wang, 2021), extended to 440 nm (Zoogman et al., 2016)
Surface reflectance over water	Cox-Munk slope distribution (Cox & Munk, 1954)
Surface wind & pressure	MERRA-2
Snow information	IMS 4km
Ocean chlorophyll	Terra-MODIS Chlorophylle concentration (Hu et al., 2012)
Ocean salinity	World Ocean Atlas 2009 (Antonov et al., 2010)
Temperature & trace gas profiles	GEOS-Chem high-performance simulation monthly climatology of hourly profiles in 2018 (0.5° x 0.5° resolution)

OMI H_2O: temperature correction

Orbit 5108 (July 1, 2005)

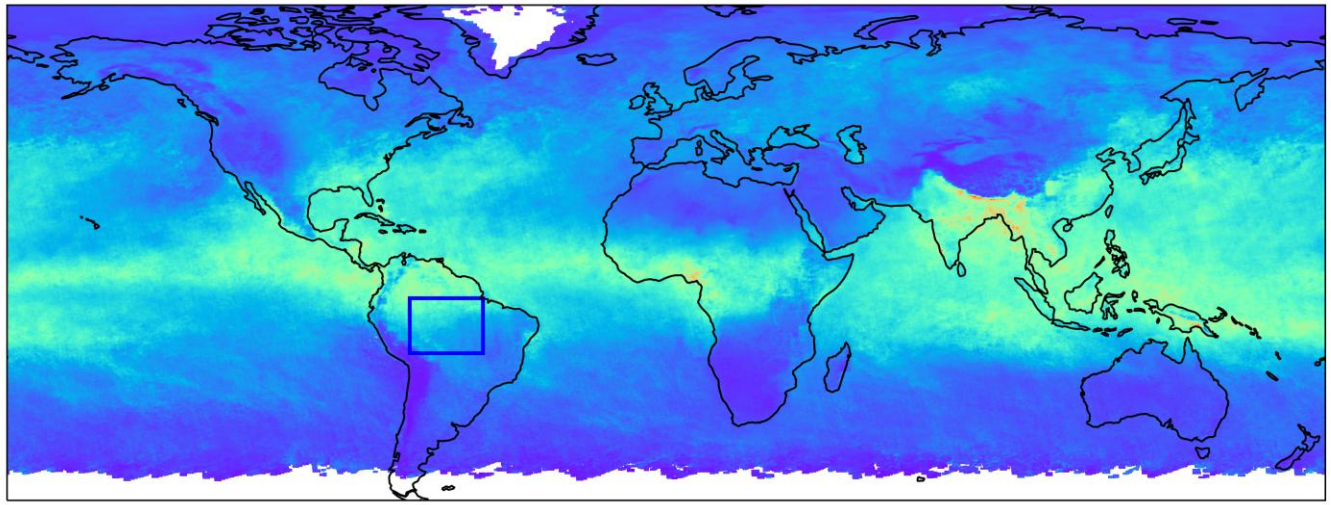


Temperature	Slope	Intercept
223 K	0.916	0.011
233 K	0.932	0.009
243 K	0.947	0.007
253 K	0.962	0.005
263 K	0.975	0.003
273 K	0.988	0.002
283 K	1.000	0.000
293 K	1.012	-0.001
303 K	1.023	-0.003

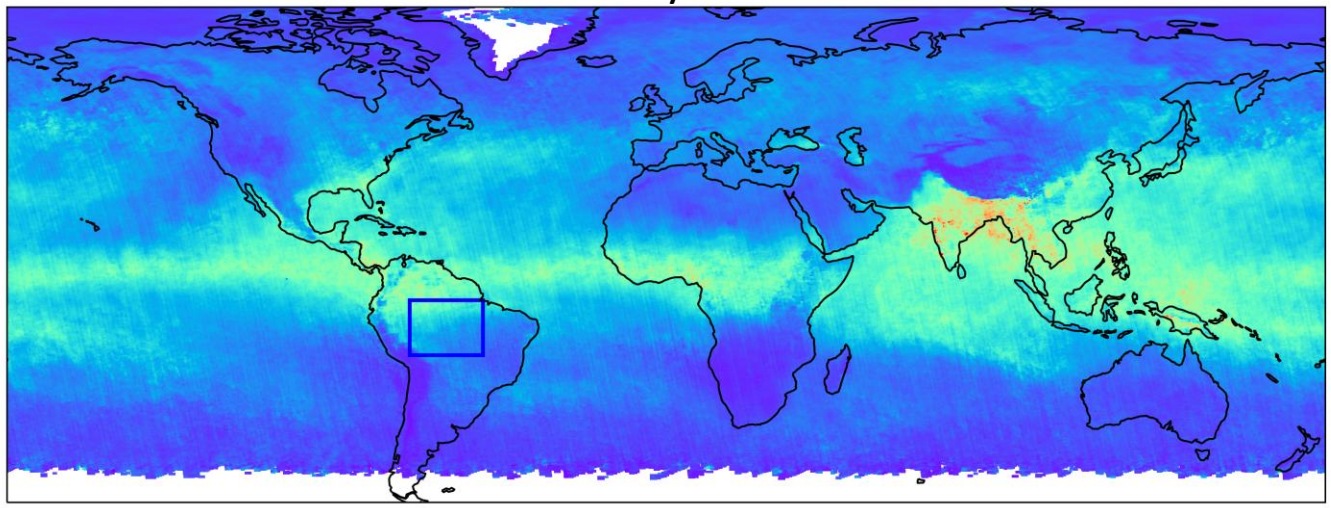
We perform SCD temperature correction by deriving a series of linear regressions between the SCDs retrieved using cross sections at different temperatures for a series of typical orbits.

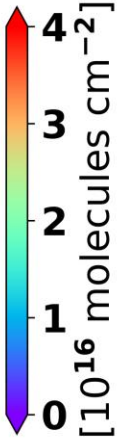
OMI H_2O: Global monthly mean examples & histograms of fitting RMS

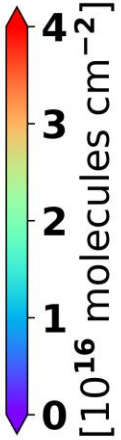
July 2005



July 2024

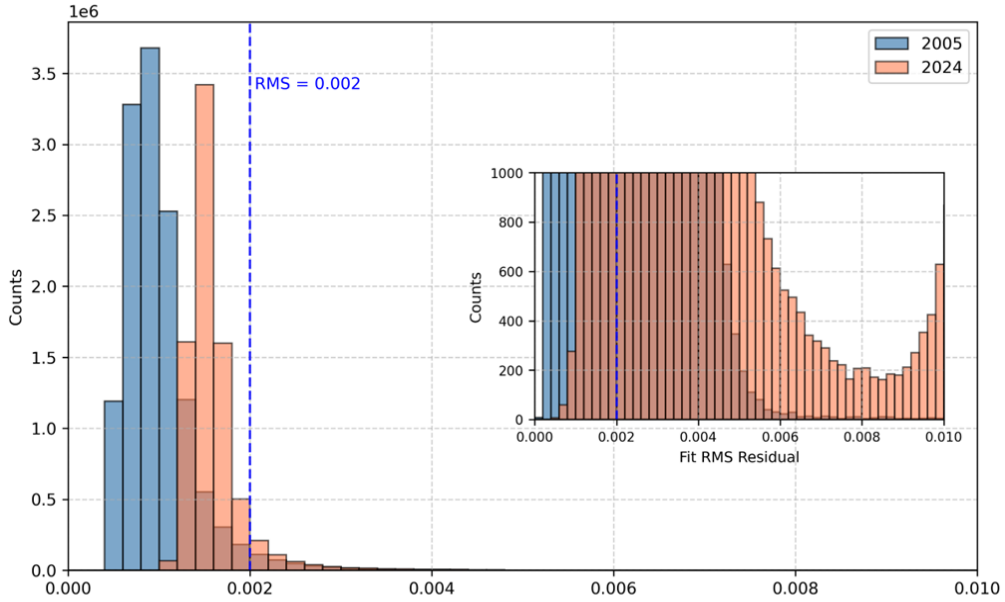






Stripes increase in 2024 compared to 2005 due to row anomaly effects in monthly co-adding.

Histogram of fit RMS
(1st day of each month in 2005 and 2024)



Fit RMS

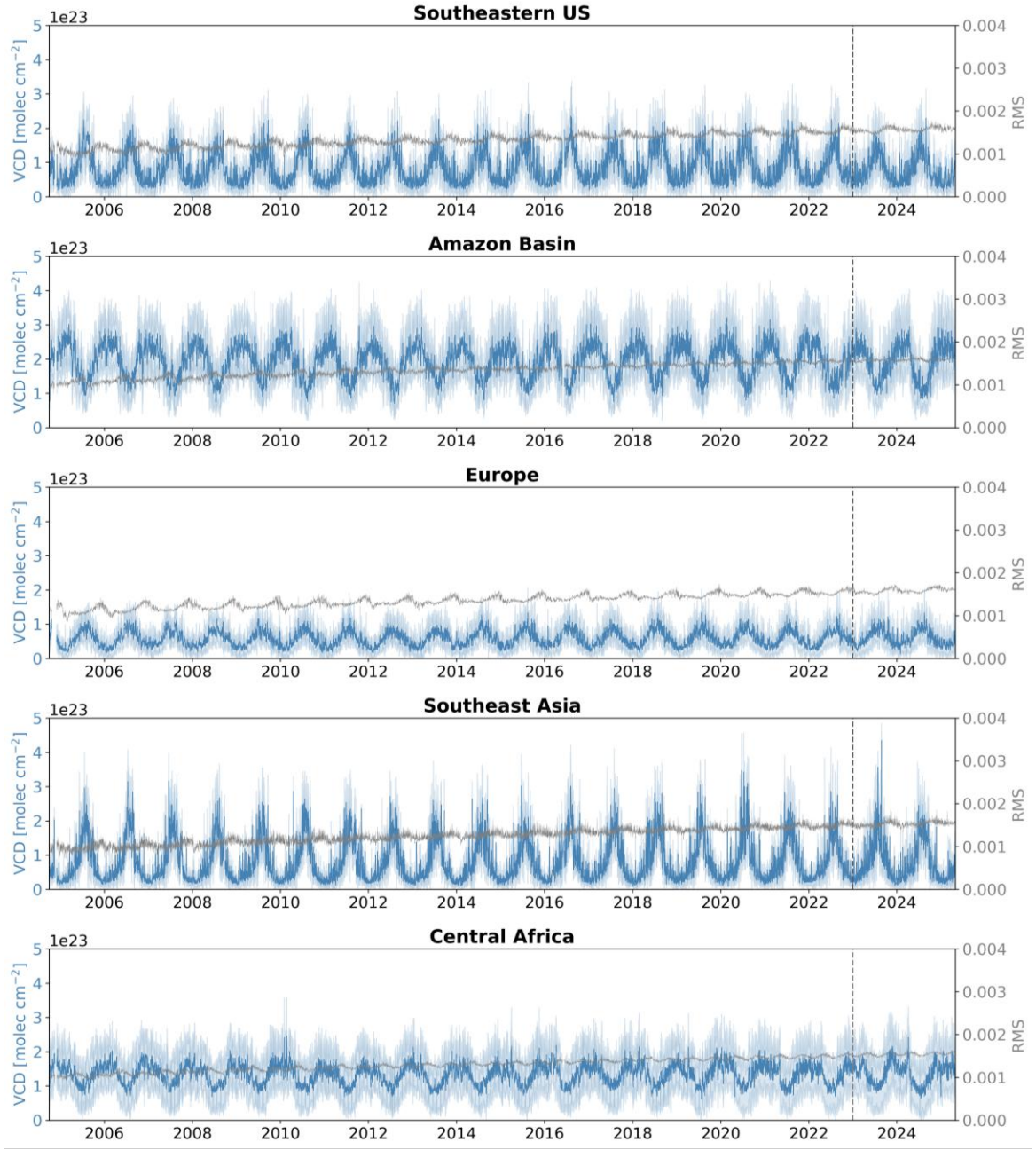
Fitting RMS increase from 2004 till 2025 is due to instrument aging, in particular x2 increase in solar irradiance noise since the beginning of the mission.

OMI H_2O: Long term time series stability

OMI H_2O provides a long data record since October 2004, including the period since Aura's orbital drift started in 2023

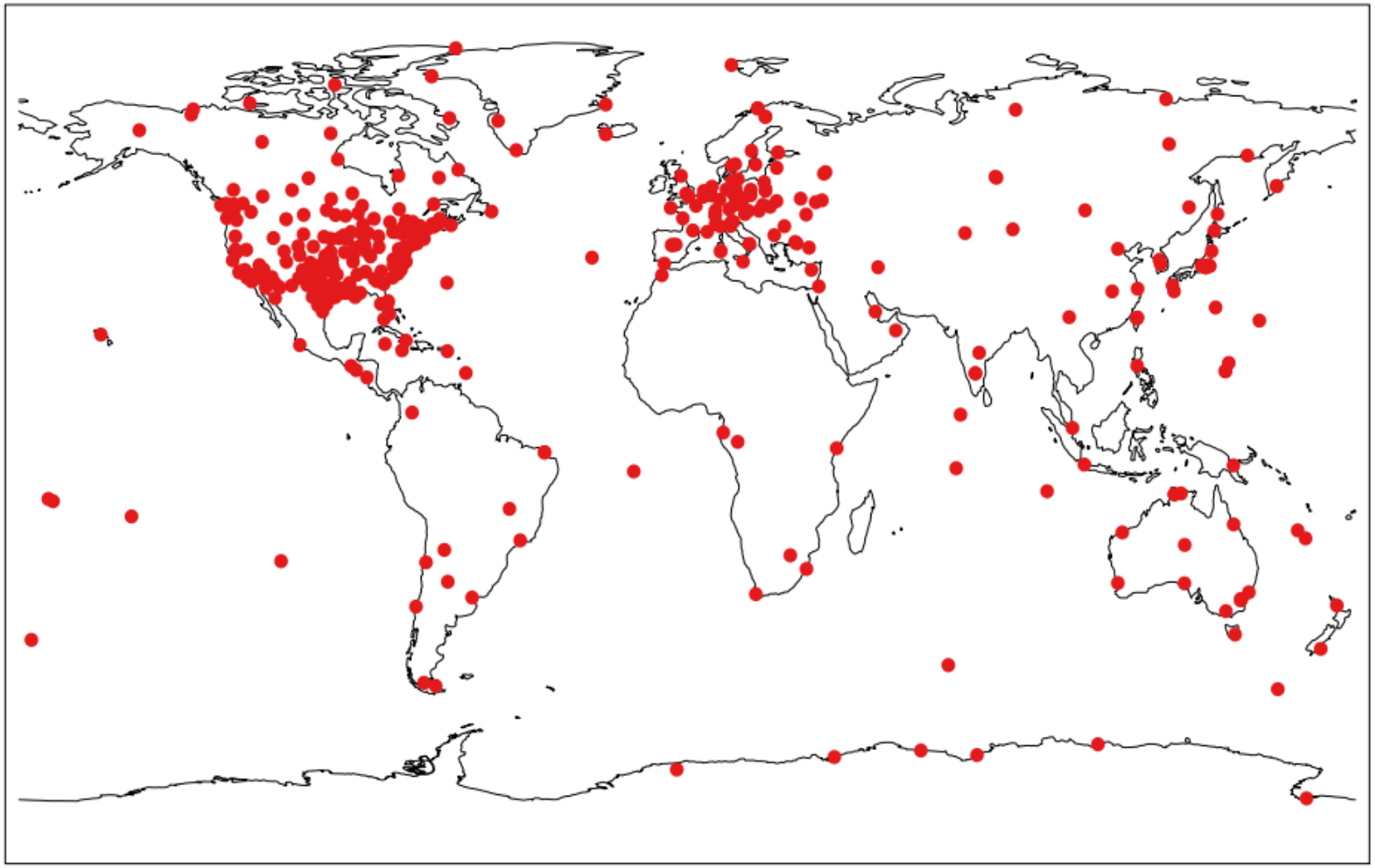
As mentioned in the previous slide, increase of fitting residuals is expected due to instrument aging.

Setting a threshold of < 0.002 RMS only 5% of the observations in 2024 are filtered out because of increased fitting residuals ensuring a stable long-term record.



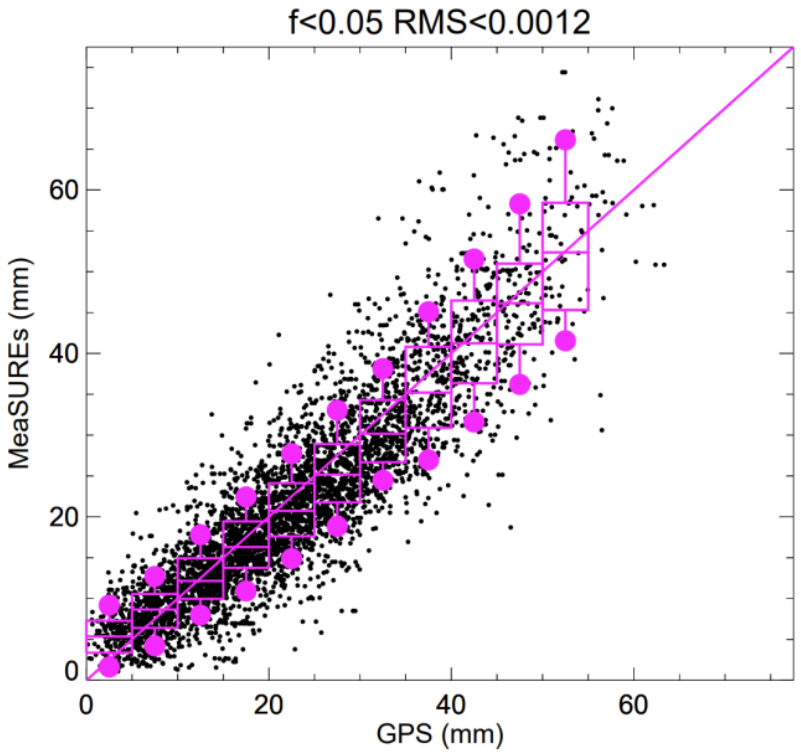
OMI H_2O: validation over land

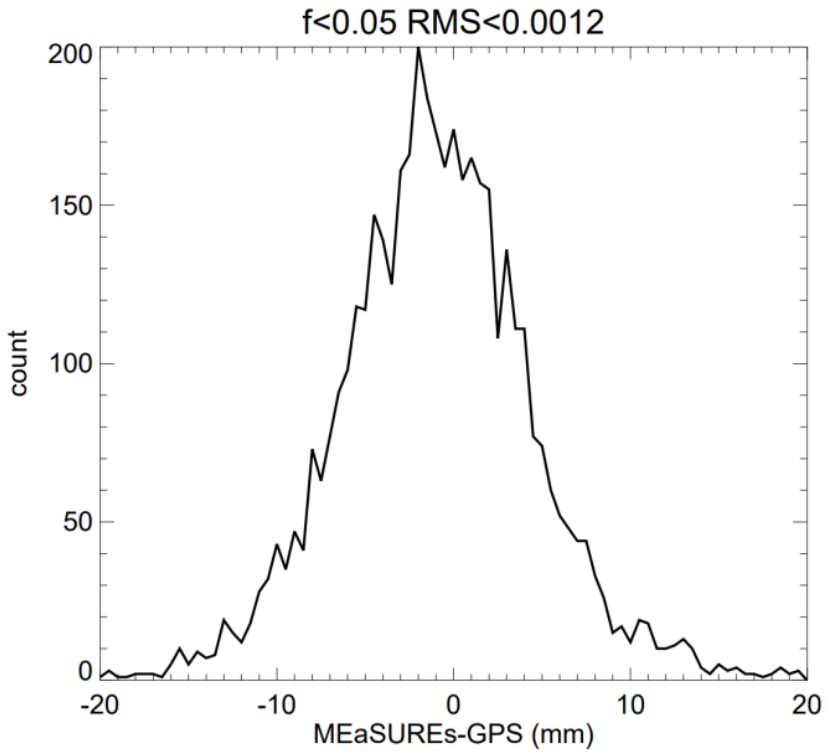
GPS stations



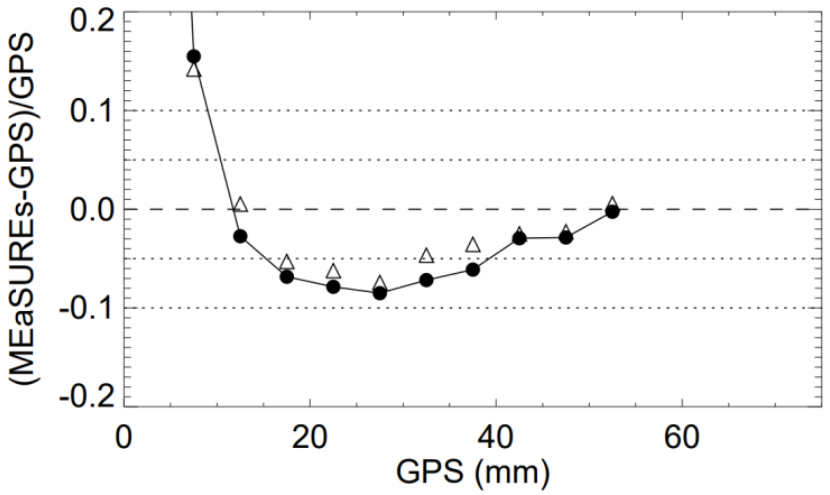
OMI H_2O: validation over land

Period of analysis: July 2005, January 2006 and July 2006





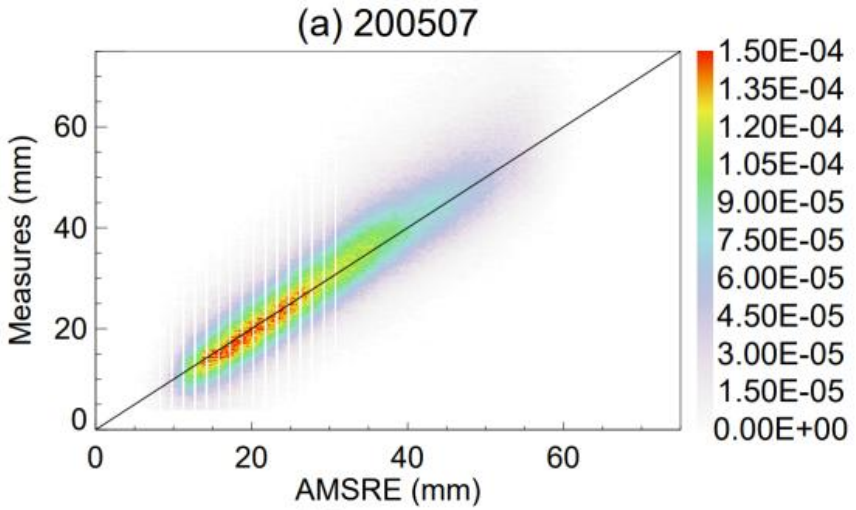
Relative difference as a function of TCWV

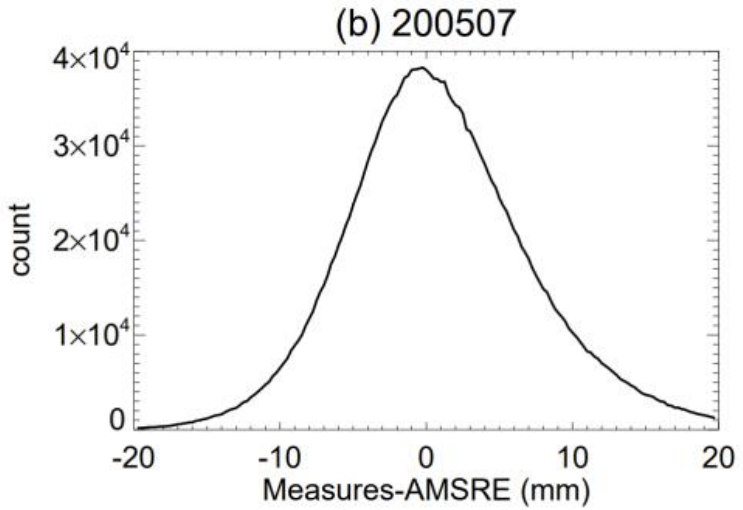


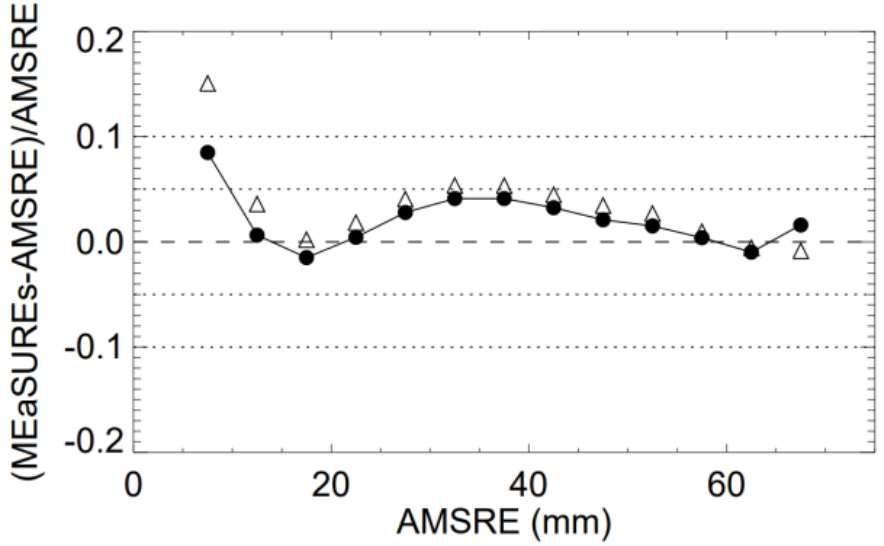
OMI and GPS (from the IGS network) compare well for clear sky conditions (R=0.9), with a mean difference of -0.5 mm and a standard deviation of 5.8 mm. OMI data tends to overestimate when TCWV < 10 mm and underestimate when 15 mm < TCWV < 50 mm.

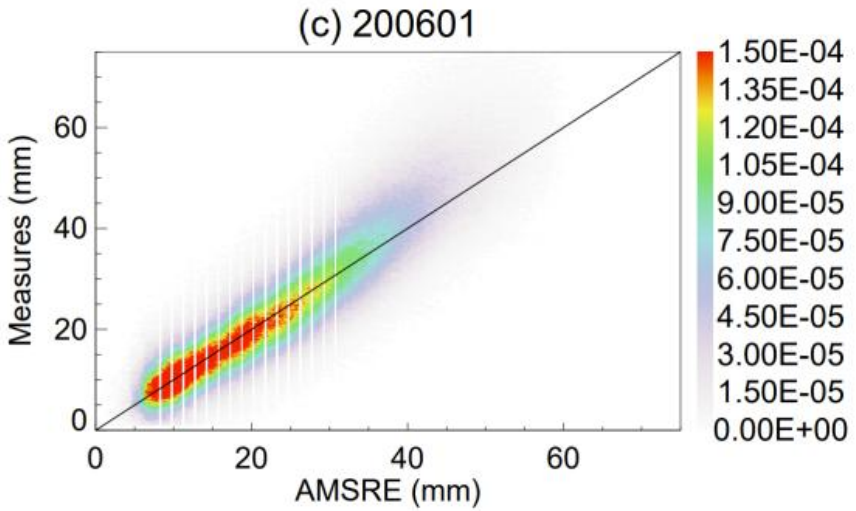
OMI H_2O: validation over water

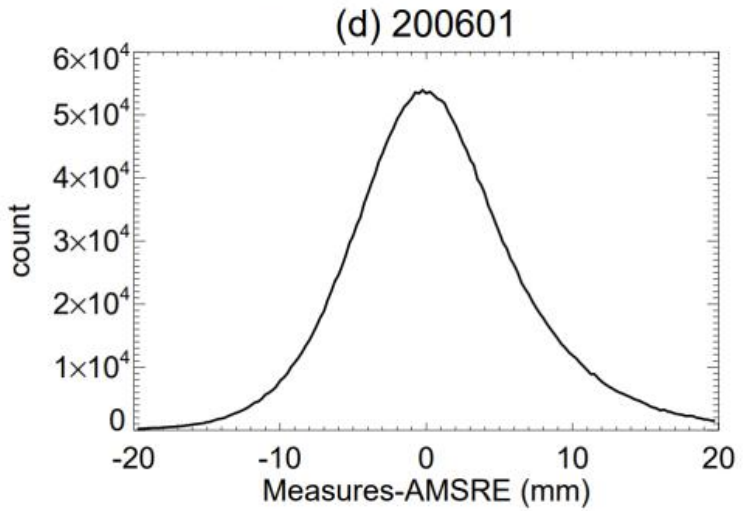
Comparison with the Advanced Microwave Scanning Radiometer for the Earth Observing System







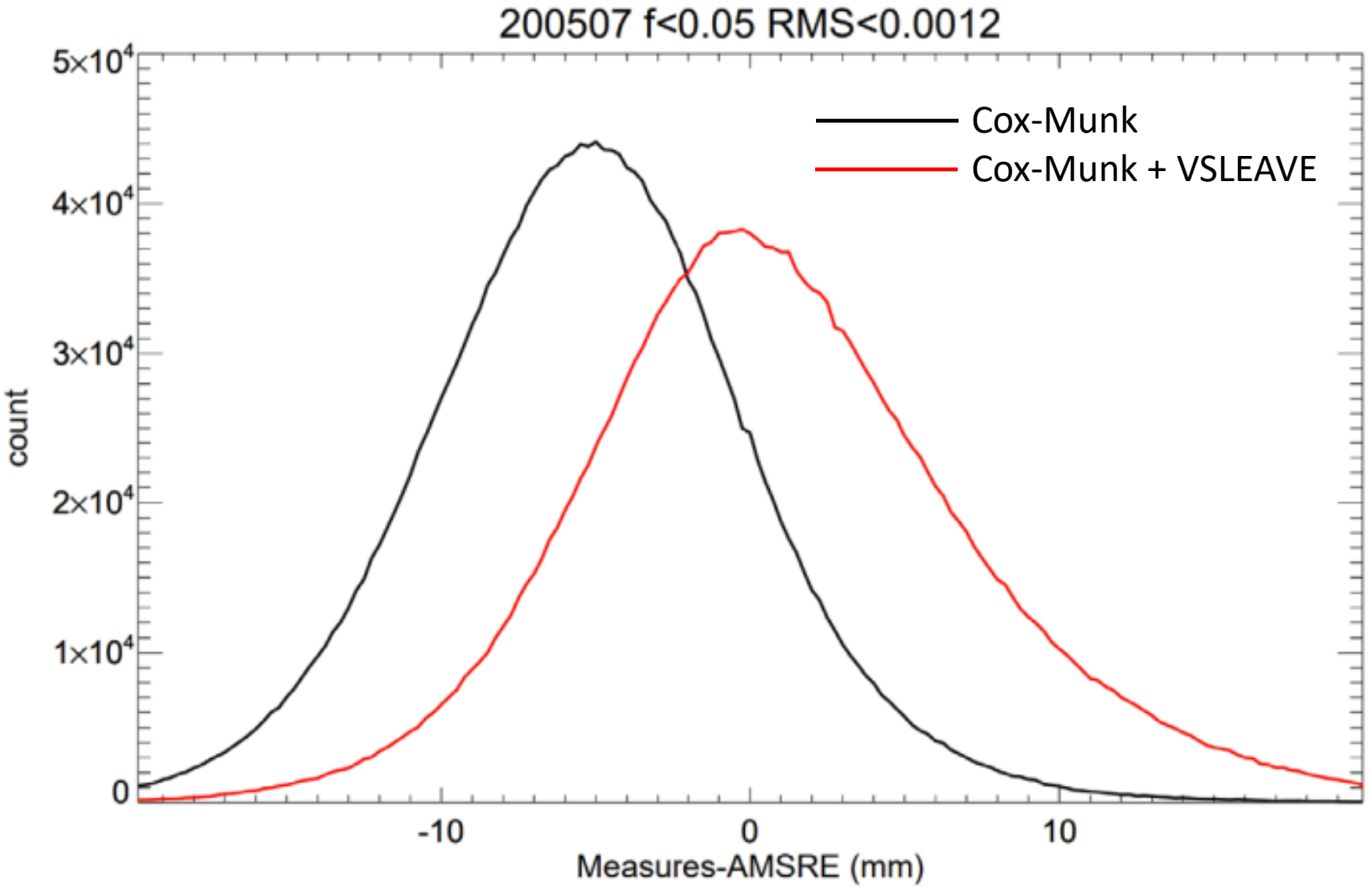




OMI and AMSRE compare well for clear sky conditions (R=0.9), with a mean difference of 1.1 mm and a standard deviation of 6.3 mm; biases are more consistent for different TCWV bins than over land.

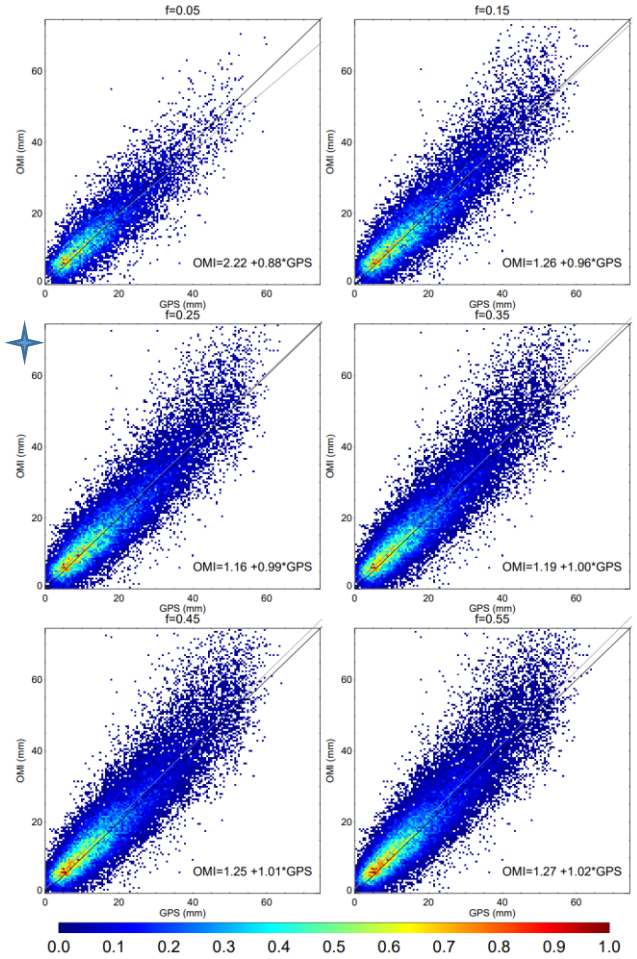
Wang et al., 2023

OMI H_2O: validation over water led to AMF calculation improvements



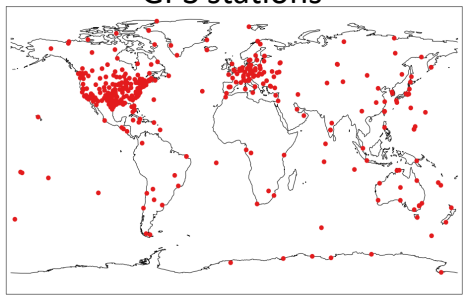
Including the effect of chlorophyll and salinity in the AMF. Considering it using the VLIDORT VSLEAVE's package results in the mitigation of a systematic bias of the retrievals over the oceans.

OMI validation: performance dependence with cloud fraction (AMT, Wang et al., 2019)



OMI versus GPS network for 2006

GPS stations



NCAR (rda.ucar.edu/datasets/ds721.1)

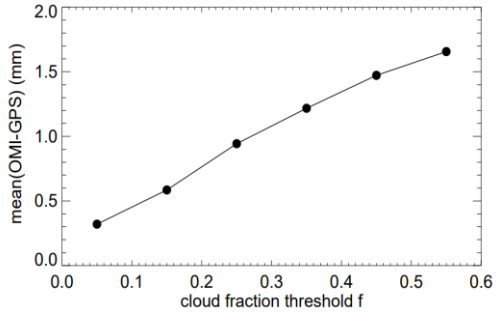
OMI Filtering Criteria:

- MainDataQualityFlag=0
- No row anomaly
- Fitting RMS<0.001
- 0<TCWV<75mm
- Cloud top pressure>750mb
- Cloud fraction < f

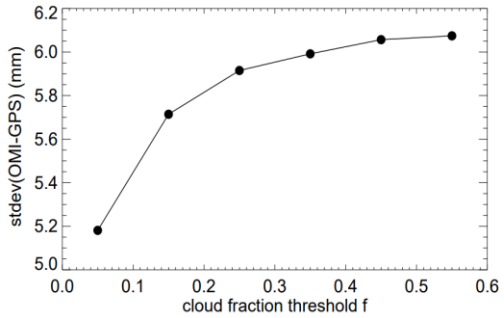
Co-location Criteria:

- Within 0.25° lat/lon
- Within 1.5 hours

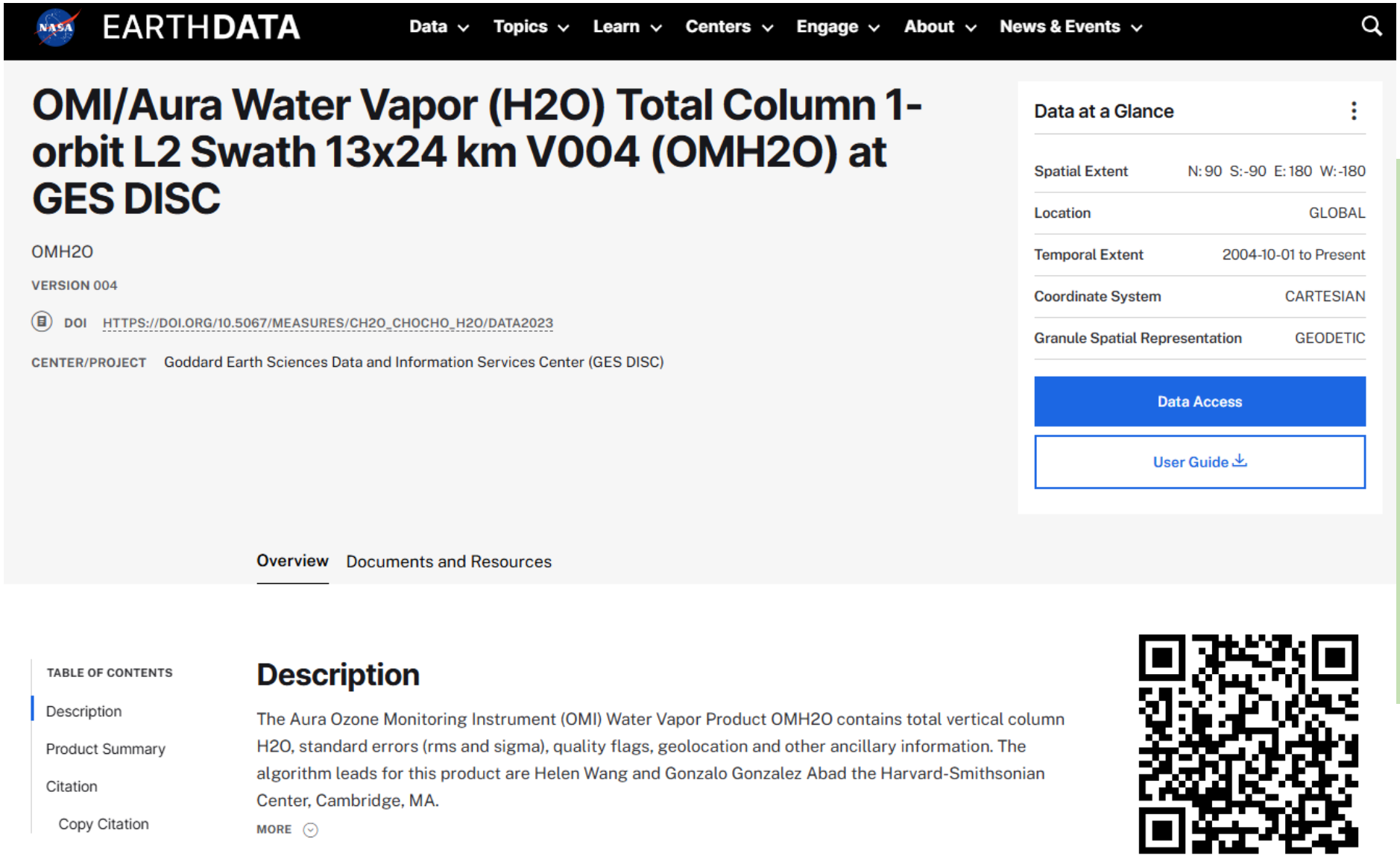
Mean (OMI-GPS)



Stdev (OMI-GPS)



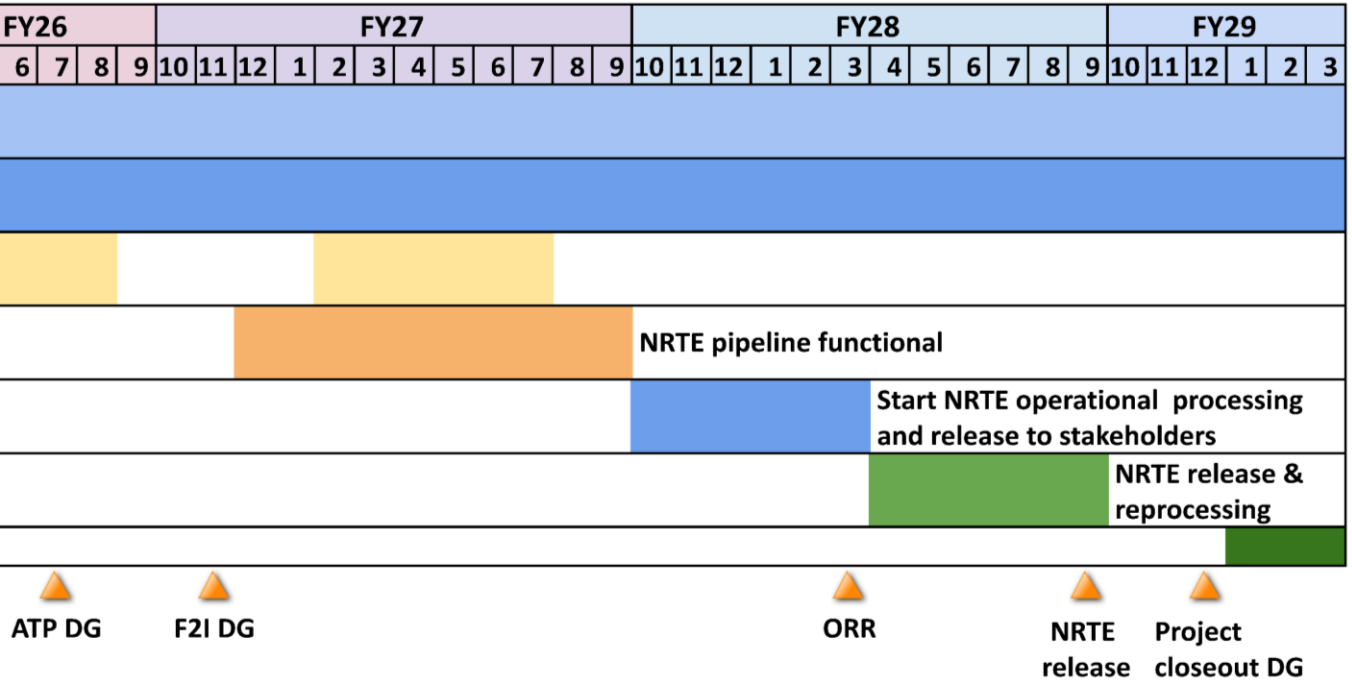
OMI H_2O: Data availability and future plans



- Complete record producing retrievals or the period 2025-05-01 to present
- Submit paper describing collection 4 retrieval and its validation, completing the interrupted submission of Wang et al., 2023

TEMPO H_2O: Satellite Needs Working Group Cycle 4 TEMPO NRT and Enhanced Products Solution

ID	Task/phase	Start	Finish
1	NRT operational & ongoing improvement	3/26/2026	3/25/2029
2	Development & optimization of NRTE algorithms	3/26/2026	3/25/2029
3	Purchase & setup computers and disk space	4/1/2026	7/31/2027
4	Implement SDPC NRTE processing pipelines	12/1/2026	9/30/2027
5	Test/update NRTE pipelines and start operational processing	10/1/2027	3/31/2028
6	Evaluate/update NRTE algorithms to start product release	4/1/2028	9/30/2028
7	Project closeout	12/25/2028	3/25/2029



Major Milestones:

- NRTE Authority to Proceed (ATP) Decision Gate (DG) review (summer 2026)
- NRTE Formulation to Implementation (F2I) DG review (fall 2026)
- NRTE processing system with processing pipeline and algorithms becomes functional (fall 2027)
- NRTE Operational Readiness Review (ORR) and NRTE operations start (spring 2028)
- NRTE products are released to the public and a webinar delivered to stakeholders (spring 2028)
- NRTE products are finalized (fall 2028)

TEMPO H_2O: Retrieval set up as of today

Spectral fitting to be optimized

Ingredients	Details
window	[432, 466] nm
closure polynomials	Baseline: 3rd order Scaling: 3rd order
calibration	wavelength shift slit function: Super-Gaussian HW1e and shape parameter k
reference spectra	solar: [Chance and Kurucz, 2010] H_2O: HITRAN 2020 [Gordon et al., 2022] (283 K) NO_2: [Vandale et al., 1998] (220 K & 294 K) O_3: [Serdyuchenko et al., 2014] (223K) O_2-O_2: [Finkenzeller and Volkamer, 2022] (293 K) $C_2H_2O_2$: [Volkamer et al., 2005] (296 K) IO: [Spietz and Burrows, 2005] liquid water (lqh2o): [Mason and Fry, 2016] Ring effect: [Chance and Spurr, 1997] water Ring (vraman): [Chance and Spurr, 1997]
other	Under-sampling correction [Chance et al., 2005]

AMF calculation using NO_2 and HCHO methodology with ad-hoc (442nm) pre-calculated scattering weights LUTs

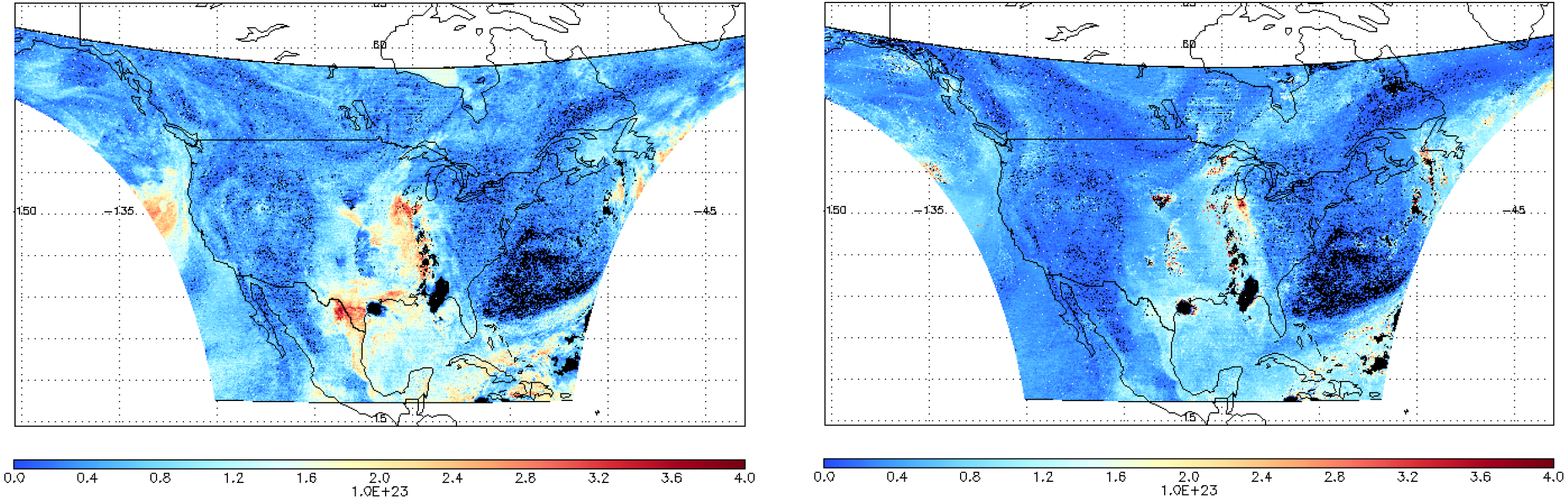
Parameter	Description
Calculation wavelength	442 nm
Viewing geometry & terrain height	TEMPO L1B
Cloud information	TEMPO Cloud product CLDO2 (cloud fraction & pressure)
Surface reflectance over land	TEMPO GLER
Surface reflectance over water	Cox-Munk slope distribution (Cox & Munk, 1954)
Surface wind & pressure	GEOS-CF V2
Snow information	IMS
Ocean chlorophyll	Further development required
Ocean salinity	Further development required [World Ocean Atlas 2009 (Antonov et al., 2010)]
Temperature & trace gas profiles	GEOS-CF V2

TEMPO H_2O: Preliminary Results

Fitted Slant Column

June 1, 2024

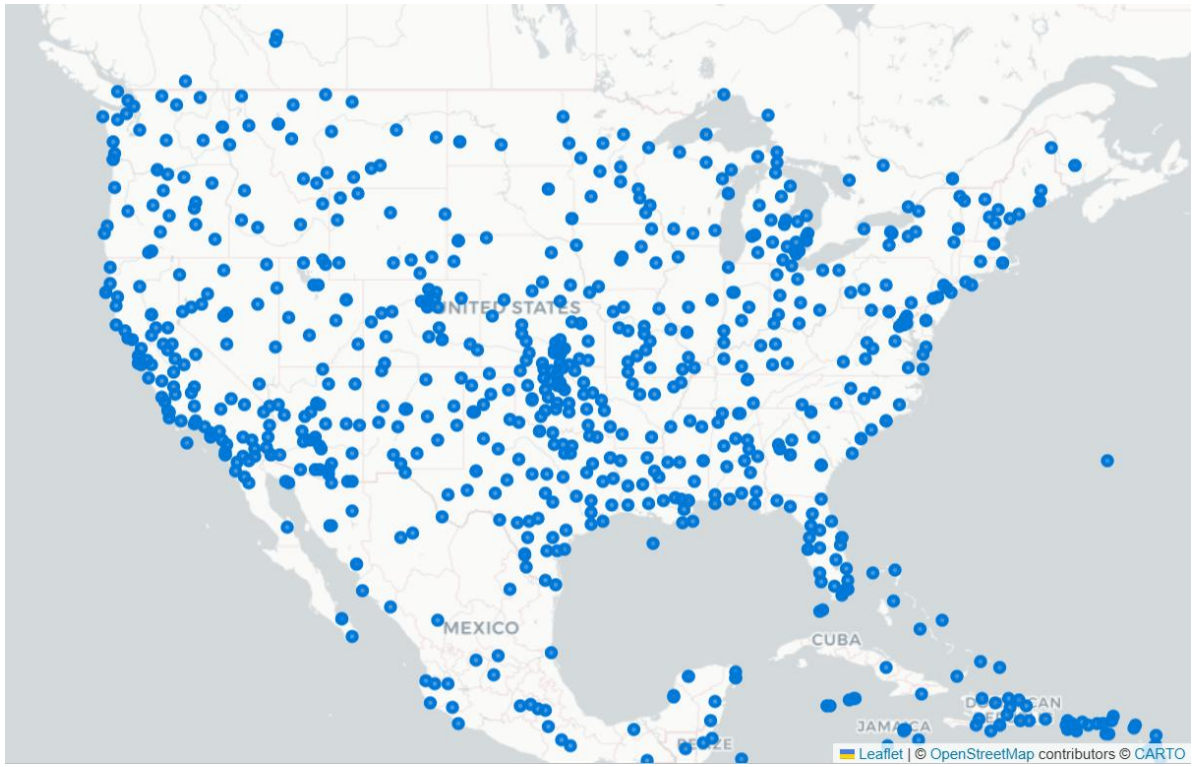
Vertical Column



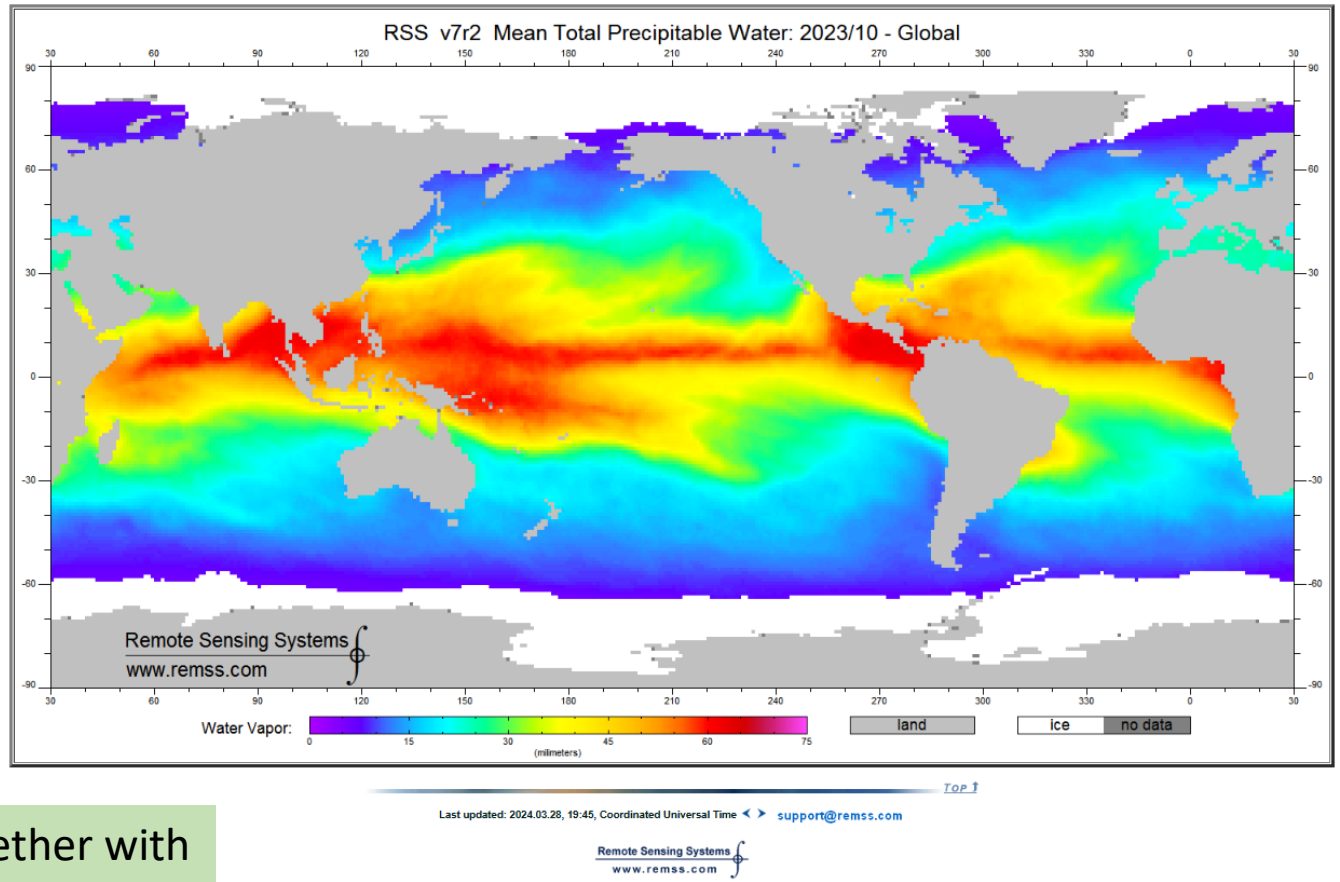
High water vapor content in central US correlates with a heat wave passing through. This links to evapotranspiration enhancement pumping H_2O into the atmosphere under a large temperature anomaly.

TEMPO H_2O Validation will use SuomiNET (land) and RSS retrievals (ocean)

SuomiNET GPS stations in TEMPO domain



Independent satellite measurements (most likely RSS)

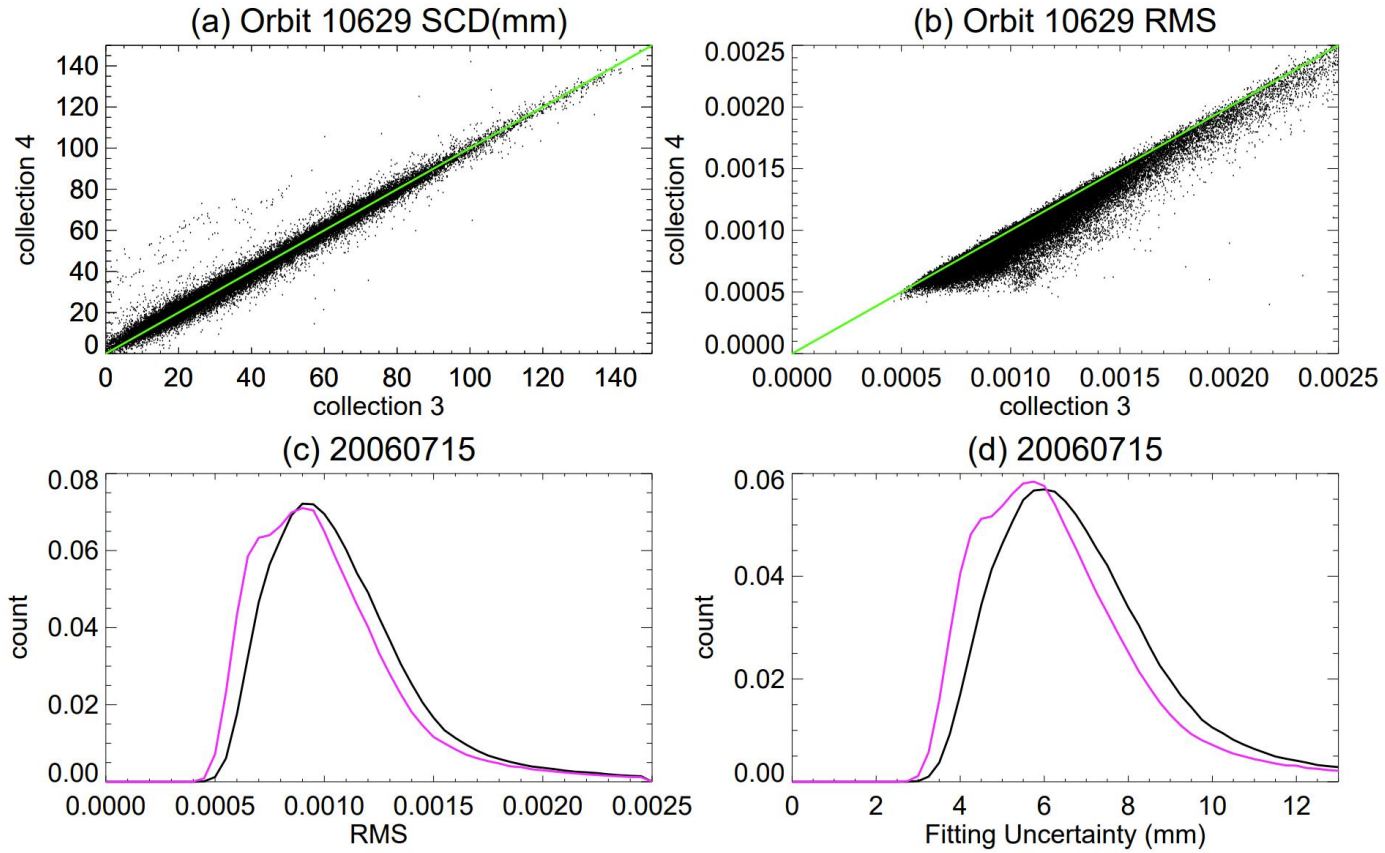


To be integrated in the unsupervised validation pipeline together with NO_2, HCHO and O_3 evaluations.

Thanks for your attention

…and thanks to the support we have received over the years by NASA and the Satellite Needs Working Group

Backup Slide I: Collection 3 vs. 4



Comparison between Collection 3 and Collection 4 spectral fitting. Top panels are Collection 3 versus Collection 4 scatter plots of (a) SCD and (b) fitting RMS for Orbit 10629. Bottom panels are histograms of (c) fitting RMS and (d) fitting uncertainty for July 15, 2006, where Collection 3 is in black and Collection 4 in magenta.

SNWG C3 NRT & C4 NRTE Data Products

- **SNWG C3 2020 Survey:** TEMPO data products of short latency of a few hours is critical for EPA, NOAA, and other federal agencies to use TEMPO data products for operational applications.
- **SNWG C4 2022 Survey:** Add TEMPO NRT SO_2 to the list of NRT products, produce enhanced data products using robust science algorithms adapted from other sensors with similar capabilities

Product (main product variables)	Latency after observation [1] (hrs)	Solution
Level 1b	~1-1.25	C3 NRT
O_2-O_2 cloud (cloud pressure and cloud fraction)	~1-1.5	C3 NRT
NO_2 (tropospheric and stratospheric vertical column densities)	~1.5-2.5	C3 NRT
HCHO (vertical column density)	~1.5-2.5	C3 NRT
SO_2 (volcanic/anthropogenic vertical column densities) [2]	~1.5-2.5	C4 NRT
O3TOT (total ozone)	~1.5-2.5	C4 NRT
SO_2 (volcanic/anthropogenic vertical column densities)	< 24	C4 E
UVAOD (UV AOD, SSA, AAOD, UV aerosol index)	< 24	C4 E
AOCH (Aerosol optical centroid height, aerosol optical depth)	< 24	C4 E
UVI (surface spectral irradiance at selected wavelengths, UV index)	< 24	C4 E
H_2O (vertical column density)	< 24	C4 E
CHOCHO (vertical column density)	< 24	C4 E
BrO (tropospheric and stratospheric vertical column densities)	< 24	C4 E

[1] Raw data acquisition at SAO takes ~10-20 mins from the TEMPO observation time.
[2] An NRT total ozone product will be produced since it is required for the NRT SO_2 product.

- Propose a three-year effort (1 year + 2 optional years) to **continue producing and improving existing TEMPO NRT products (L1b, clouds from O_2-O_2, NO_2, HCHO)**, while **continuing to reduce their latency**

- Propose a three-year effort (1 year + 2 optional years) to **develop eight additional operational (NRT Enhanced or NRTE) data products** including both **NRT and standard science SO_2, UVAOD, AOCD, UVB (or UVI), H_2O, CHOCHO, and BrO**