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Analysis of global trends of total column water vapour from multiple years of OMI observations

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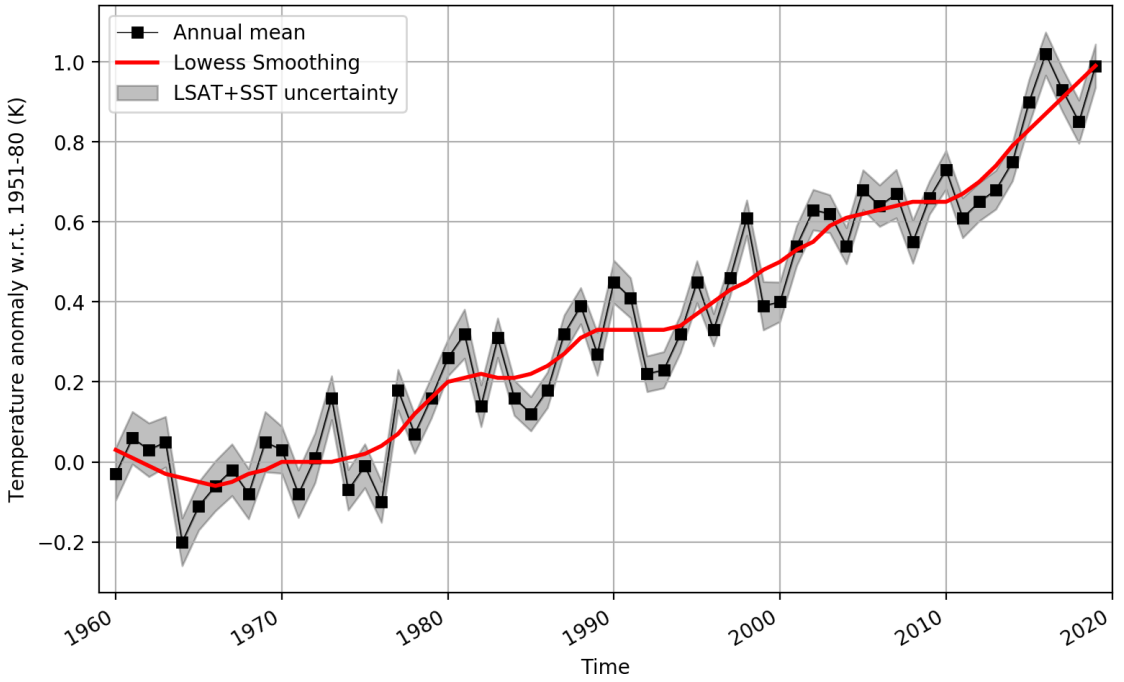
Motivation

Water vapour closely linked to changes in temperature via Clausius-Clapeyron relation:

$$dE/E = L_v/R_v T^2 \, dT$$

→ Accurate monitoring is essential for a better understanding of the Earth‘s hydrological cycle and the climate system.

We retrieve total column water vapour (TCWV) in the visible „blue“ spectral range (430-450nm; Wagner et al., 2013) using Differential Optical Absorption Spectroscopy (DOAS; Platt and Stutz, 2008).



NASA/GISS/GISTEMP v4 (Lenssen et al., 2019)

TCWV from Ozone Monitoring Instrument (OMI)

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- OMI offers great potential for climate investigations: More than 16 years of observations.
- Apply TROPOMI water vapour retrieval (Borger et al., 2020) to OMI measurements.
- OMI TCWV data set:
  - Time range: Jan. 2005 – Dec. 2020
  - Filter: eCF < 20%, AMF > 0.1, snow/ice-free, „row anomaly“
  - Grid: 1° x 1°, monthly mean

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https://doi.org/10.5194/amt-13-2751-2020

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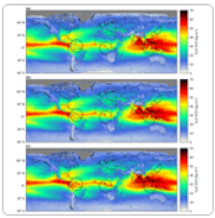
Research article

28 May 2020



Total column water vapour retrieval from S-5P/TROPOMI in the visible blue spectral range

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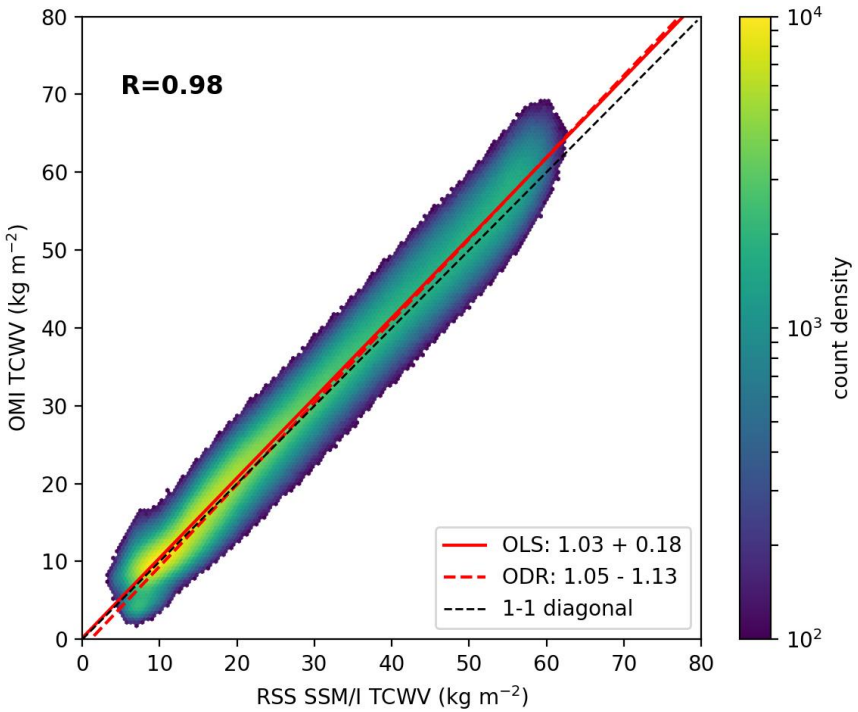
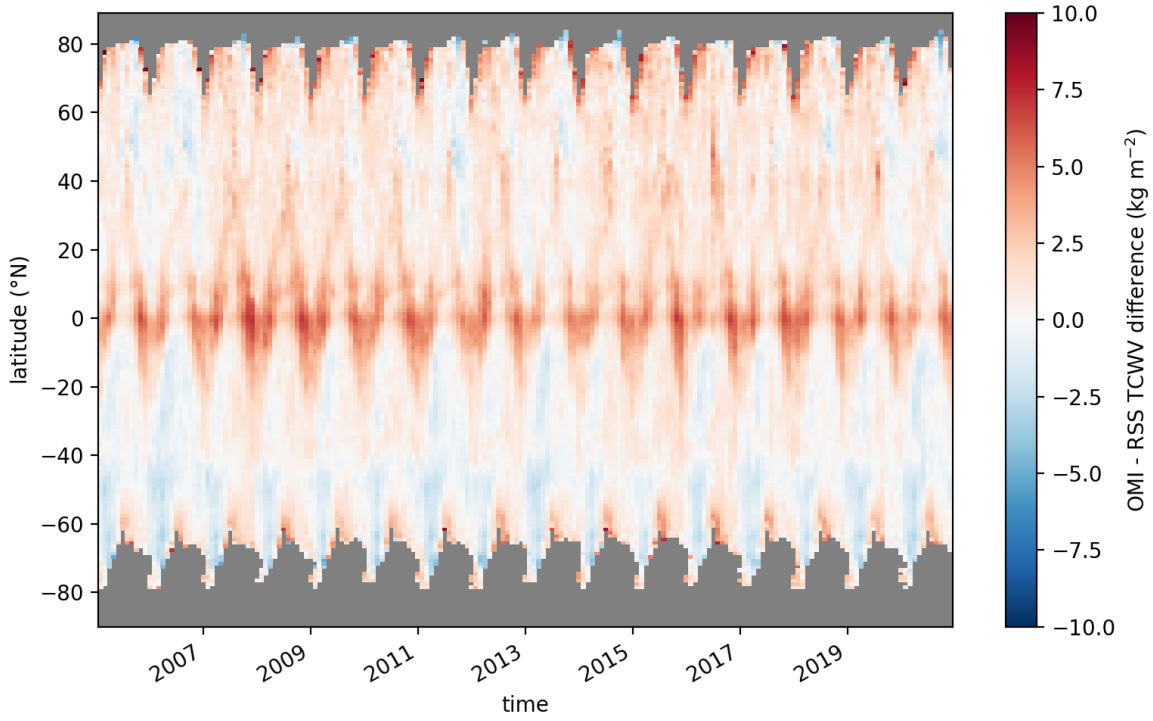
Borger et al., AMT, 2020

OMI TCWV data set – Validation with RSS SSM/I





- Very high correlations
- Slight overestimation of 3-5%
- Overestimations mainly occur in the tropics

OMI TCWV data set – Validation with ERA5

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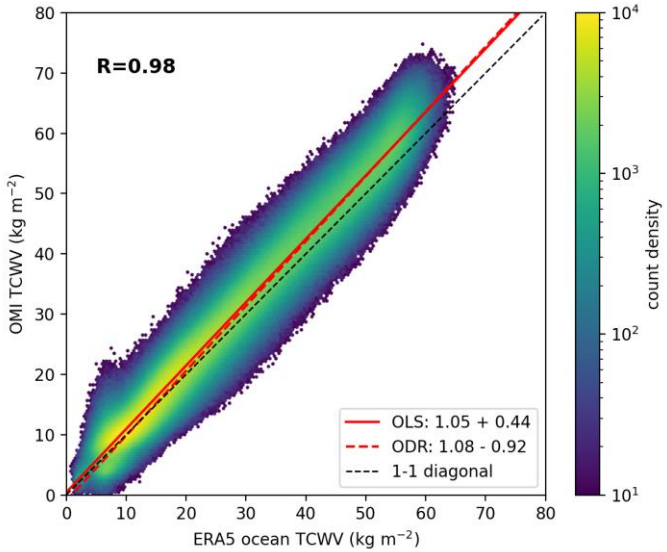
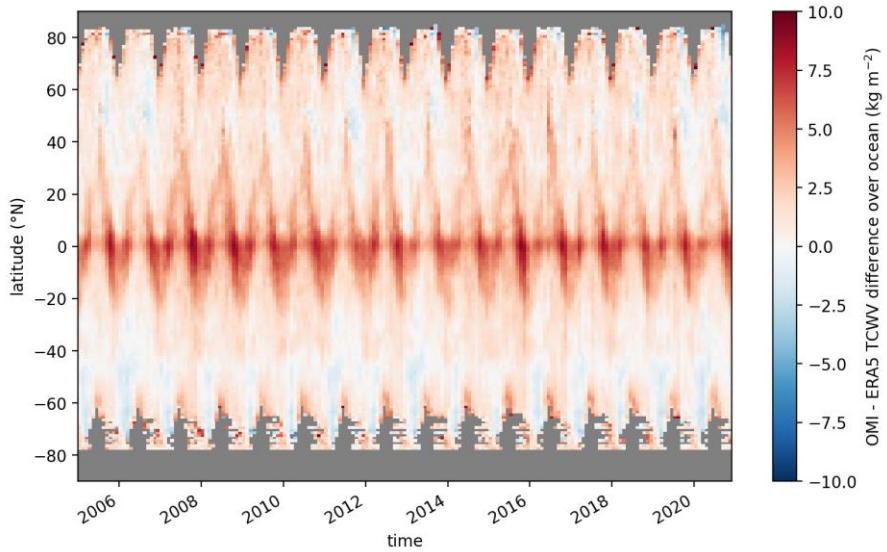
Top row: ocean

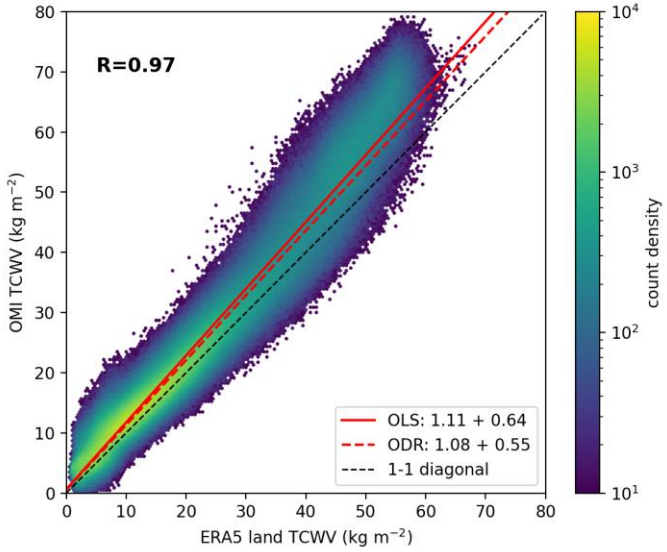
- Very high correlations
- Overestimation of 5-8% mainly occuring within the tropics

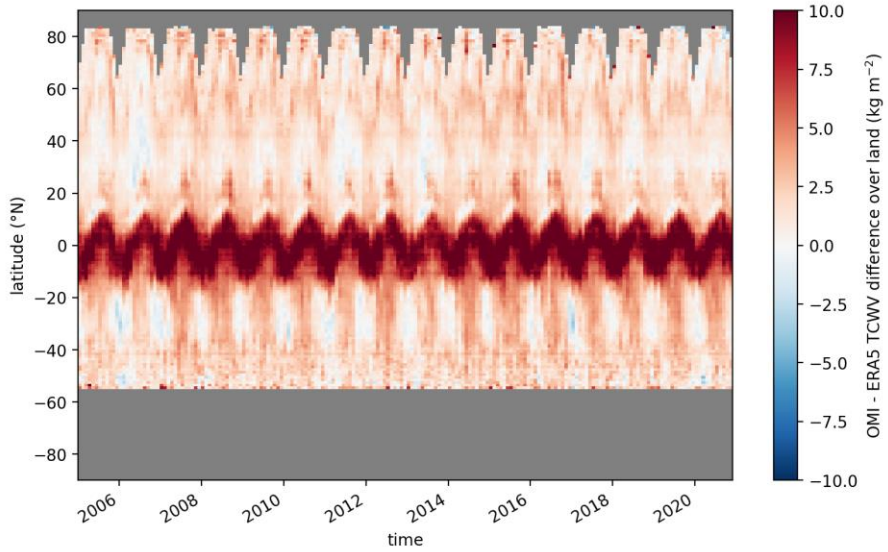




Bottom row: land

- Very high correlations
- Overestimation of 8-11%
- Overestimation in the tropics now much stronger
- Closer look: overestimations mostly occur in regions with frequent cloud cover (e.g. Amazon basin)





OMI TCWV trends (2005-2020)

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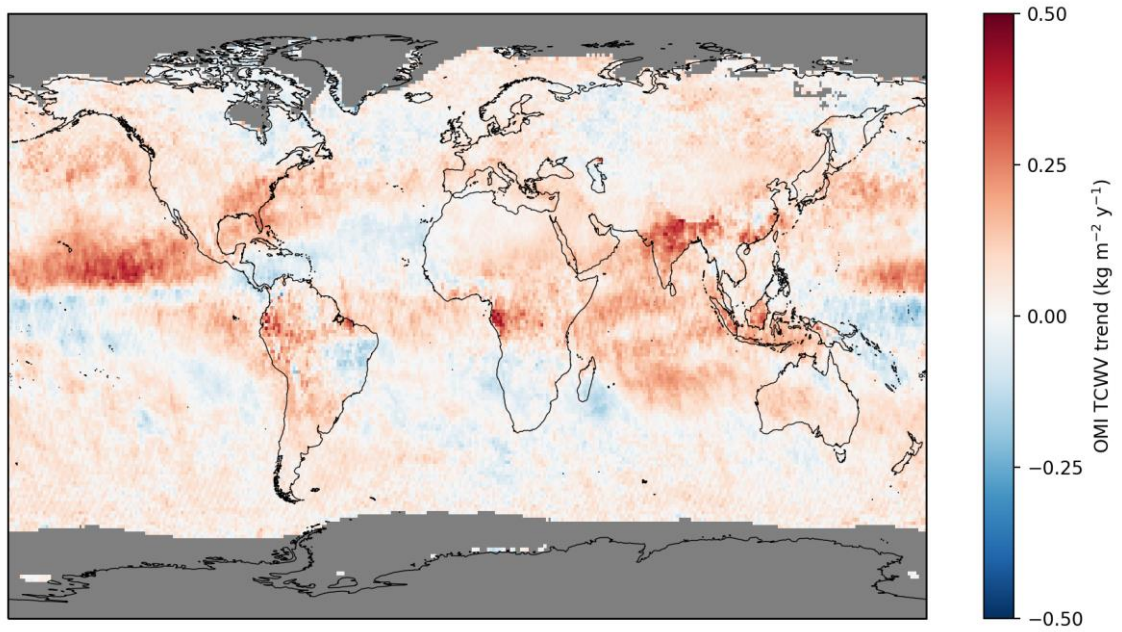
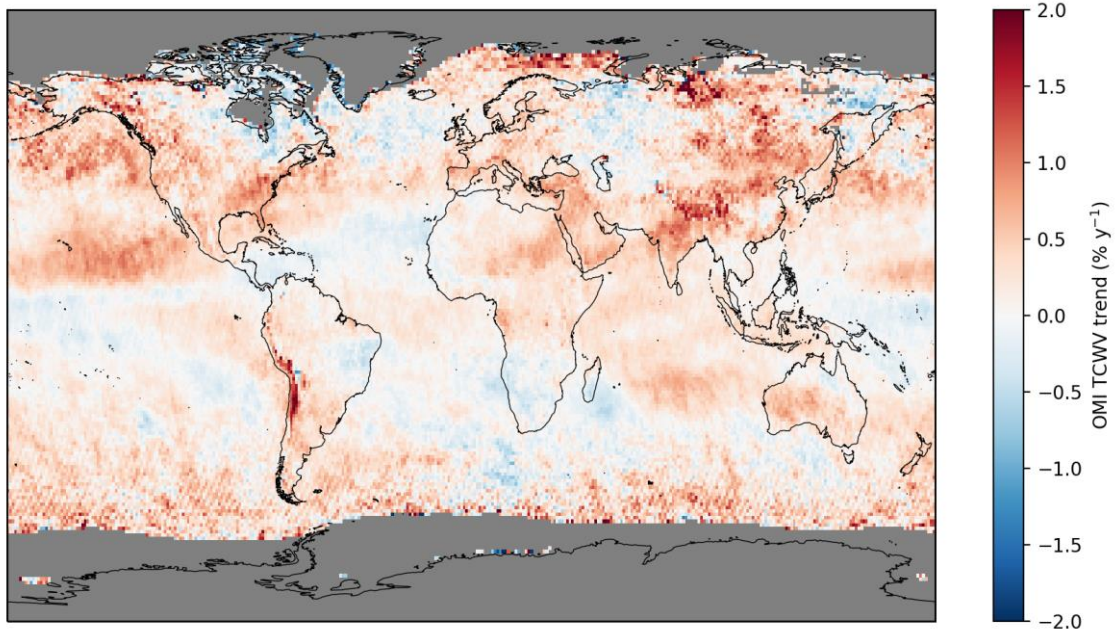
absolute trends



relative trends



- Follow approaches of Weatherhead et al. (1998), Mieruch et al. (2008), and Schröder et al. (2016)
  → account for autocorrelation of residuals assuming AR(1) process
- Increasing trends e.g. in subtropical North Pacific, India, East Asia, North America
- Decreasing trends e.g. in SPCZ region, South Africa, Brasil, and equatorial/subtropical Atlantic

OMI TCWV trends (2005-2020) – significant trends

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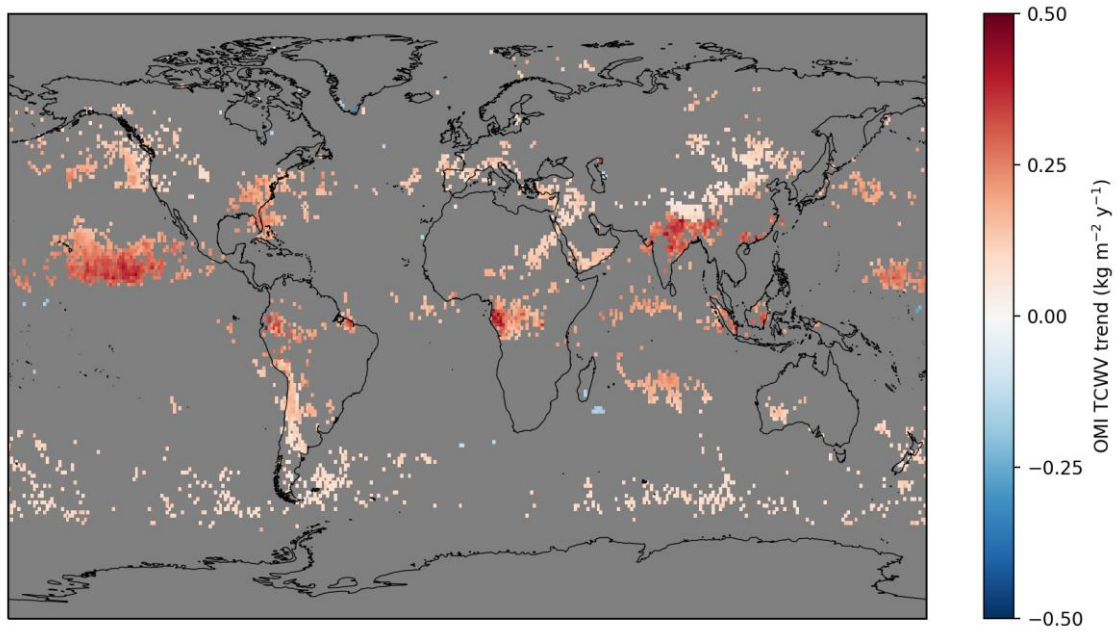
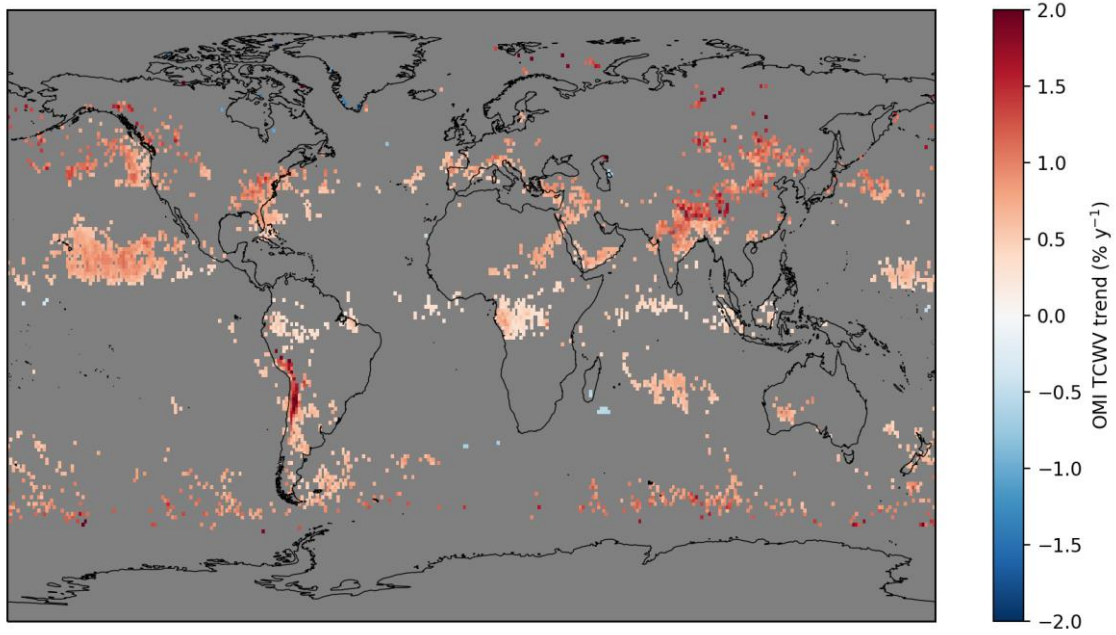
absolute trends



relative trends



- Z-test at significance level of 5%
- Test multiplicity → „false discovery rate“ (FDR) test (Wilks, 2006)
- Almost only positive trends remain!

TCWV trends (2005-2020): OMI vs ERA5

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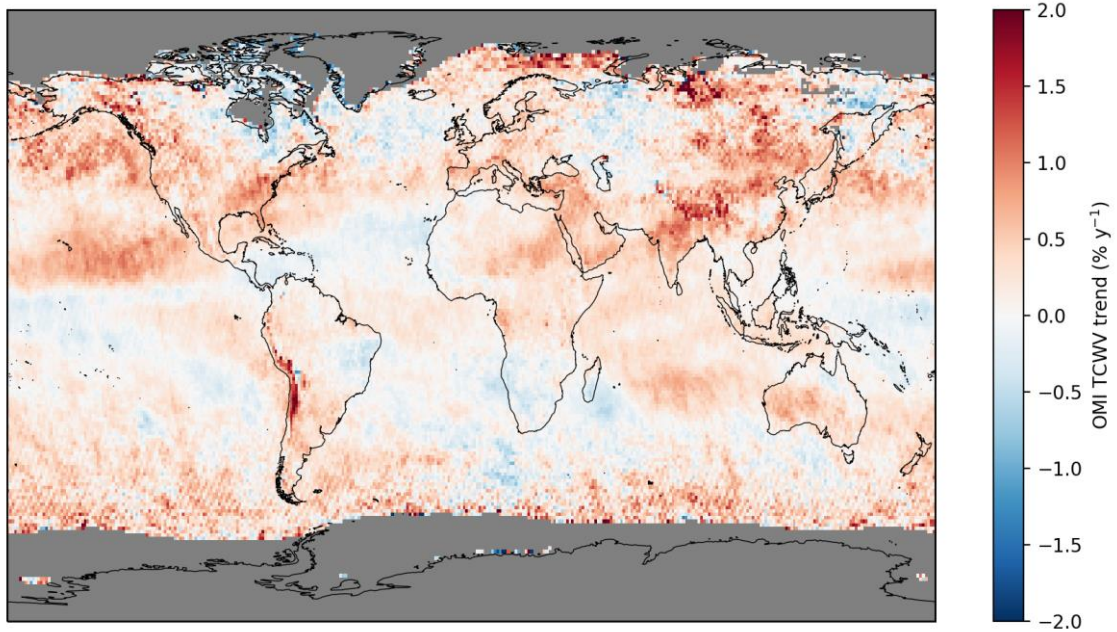
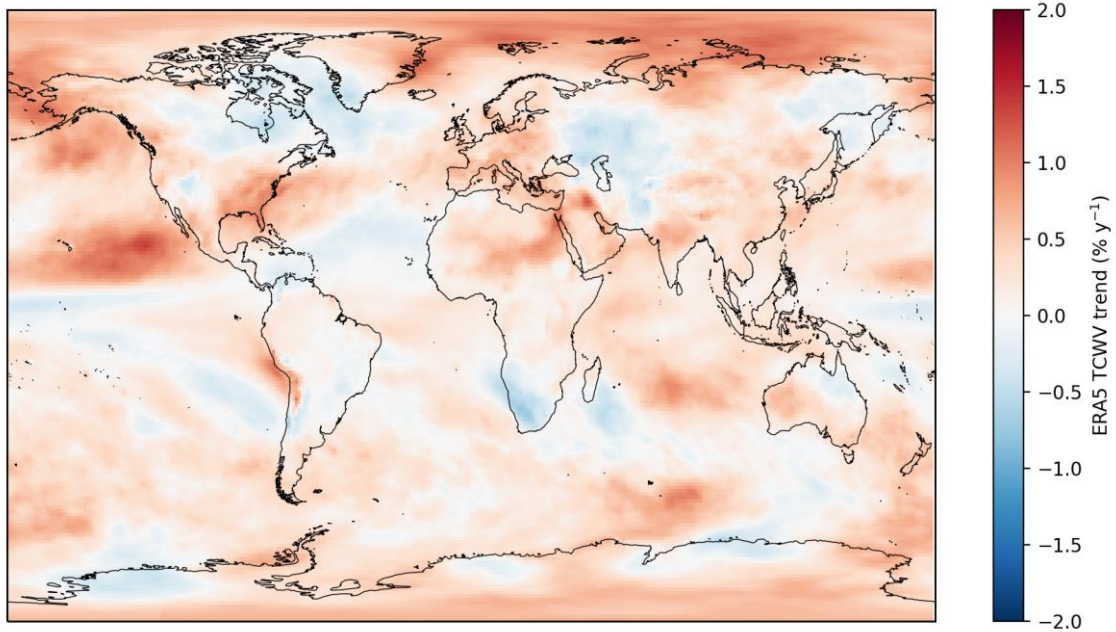
OMI



ERA5



- ERA5 monthly mean values between 13:00-14:00 LT
- Both relative trend results have similar strength and show similar global distribution.

TCWV trends (2005-2015): OMI vs ESA GOME-Evolution

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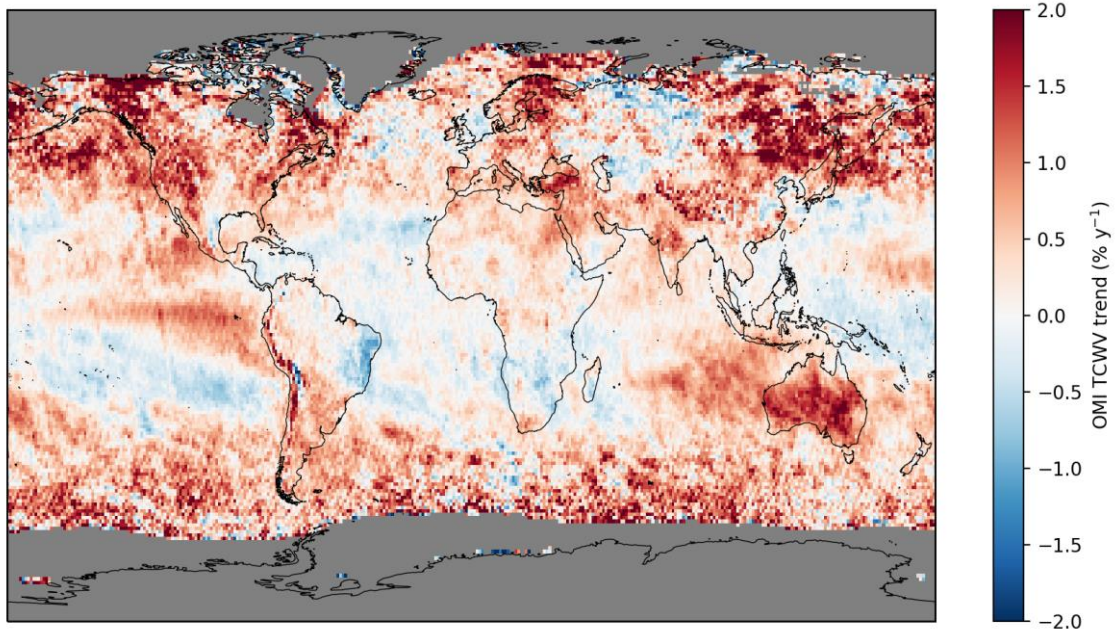
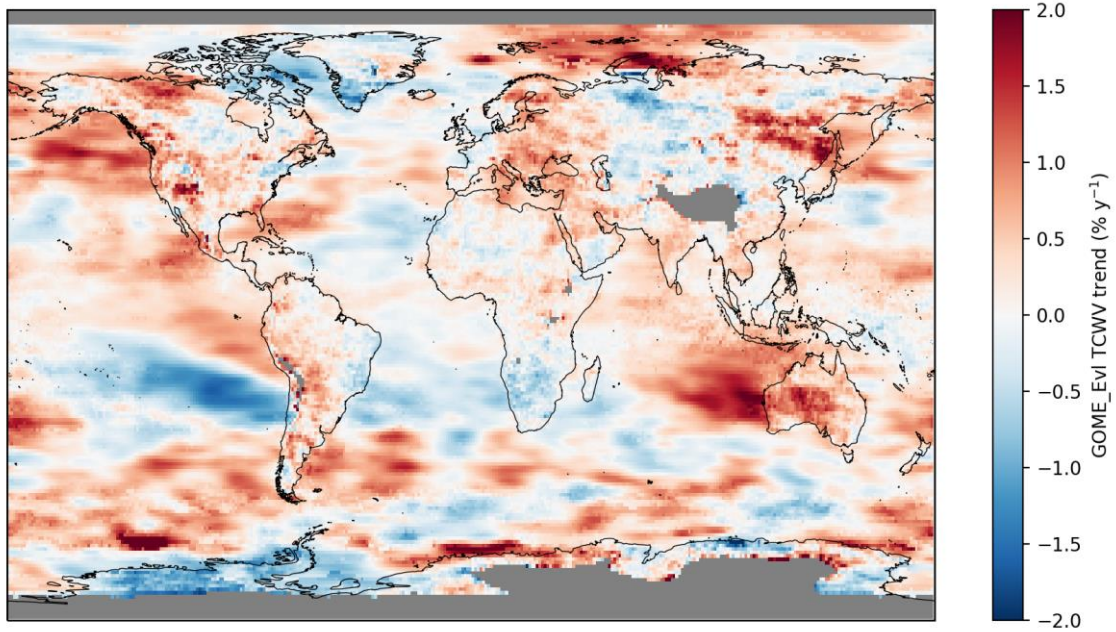
OMI



GOME-Evolution



- ESA GOME-Evolution (Beirle et al., 2018): merged time series of GOME-1/2 and SCIAMACHY
- **Modified time range: 2005 to 2015**
- Apart from some regions, both trend results share a lot of patterns and have similar magnitudes.
  → further confirmation of the reliability of the OMI TCWV trends.

Relative trends in relative humidity (RH)

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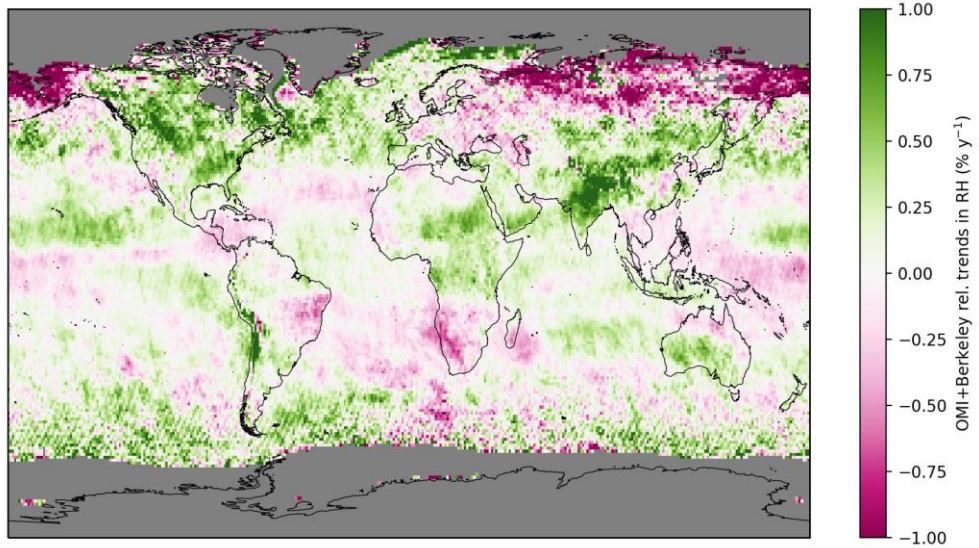
- Combine rel. OMI TCWV trends with temperature trends from Berkeley Earth (Rohde and Hausfather, 2020) to calculate rel. trends in RH:

$$\frac{dRH}{RH} = \frac{de}{e} - \frac{dE}{E} \approx \frac{dTCWV}{TCWV} - \frac{L_v}{R_v}\frac{dT}{T^2}$$

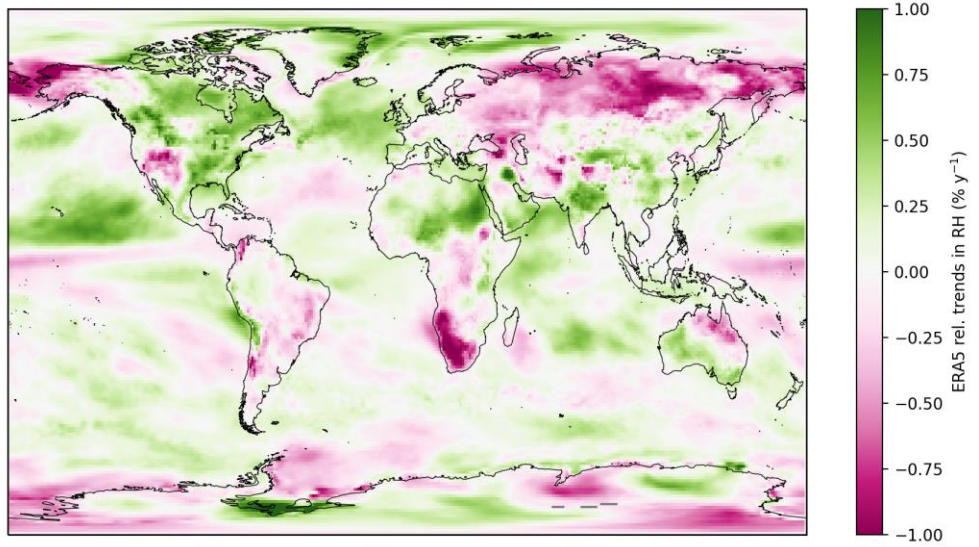
- Overall, global increase in RH.

- Positive/negative trends not limited to humid/arid regions.

OMI + Berkeley Earth



ERA5



Relative trends in relative humidity

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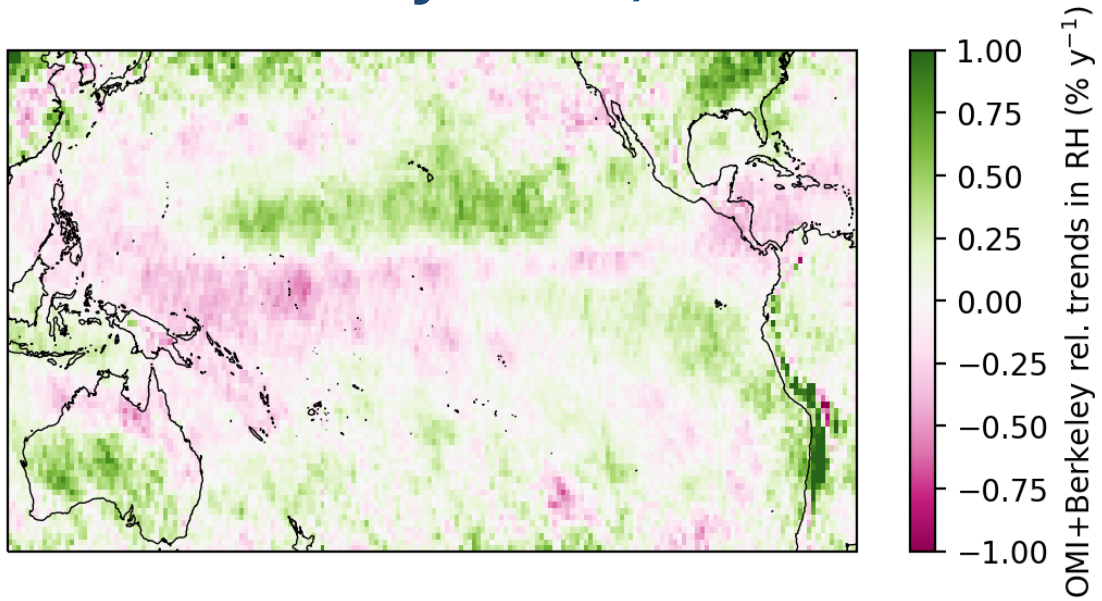
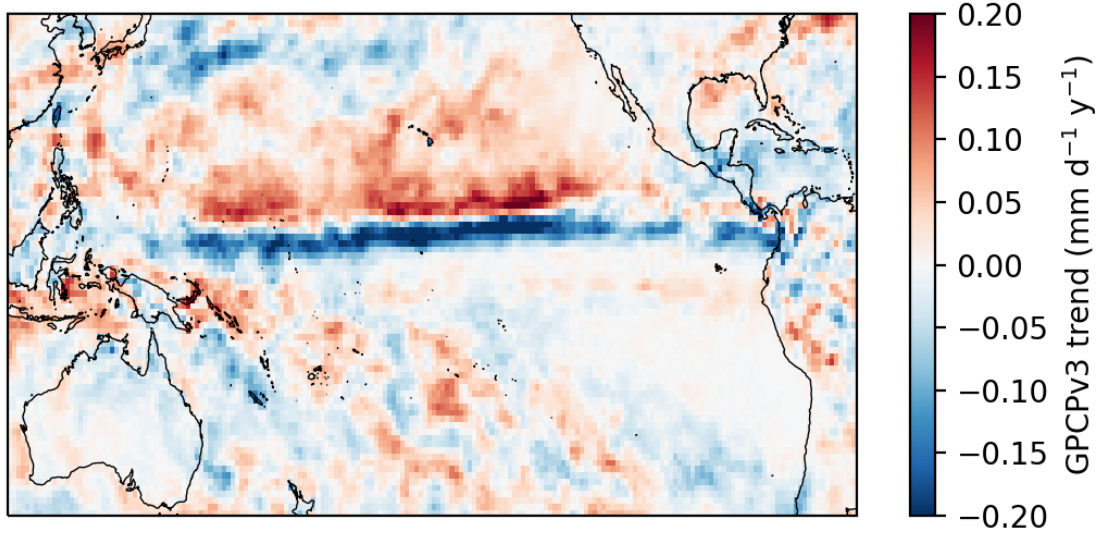
OMI + Berkeley Earth, 2005-2020



GPCP v3.1 (Huffman et al., 2020), 2005-2019



- Bretherton et al. (2004): relationship between (column) RH and precipitation over ocean
- Decreasing RH trends in the tropical Pacific ocean match well decreasing trends in precipitation.

Changes in Hadley cell

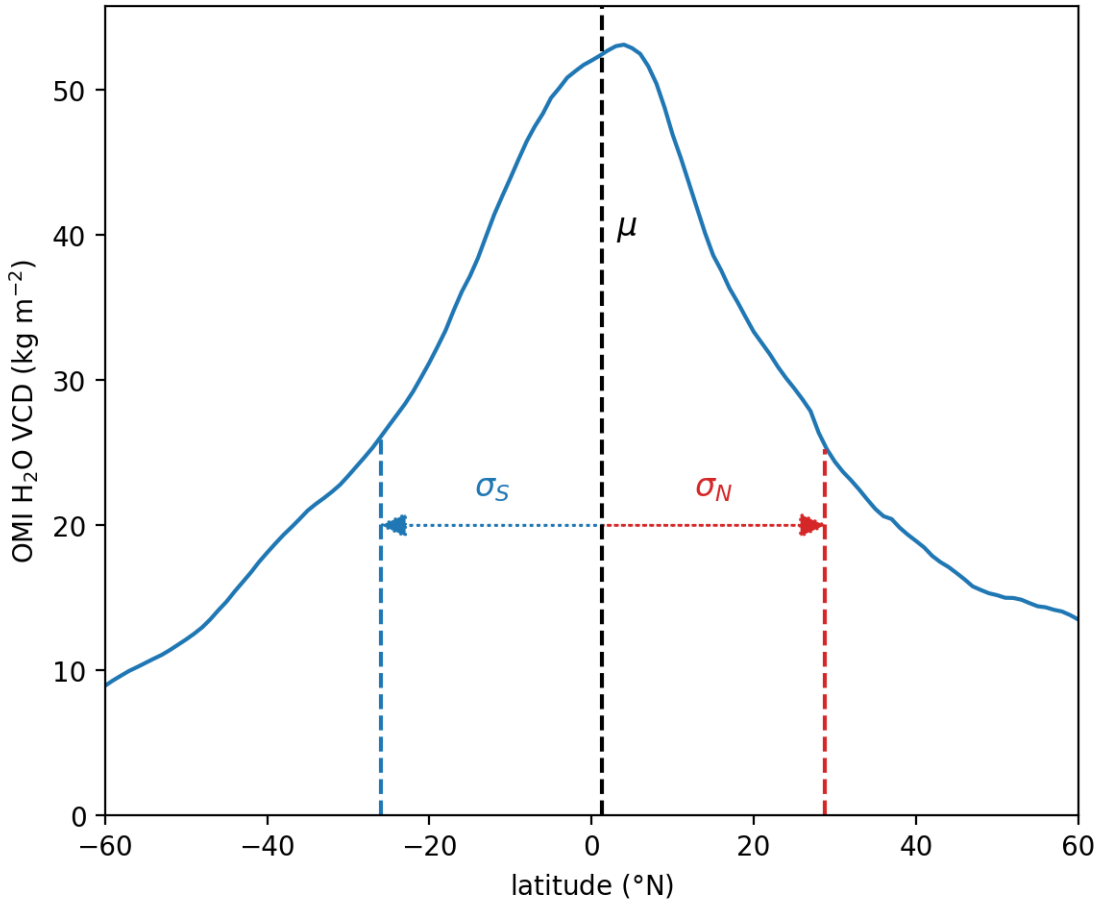
- **Shift**: center of mass

$$\mu = \frac{\int_{60°S}^{60°N} VCD \cdot \theta \, d\theta}{\int_{60°S}^{60°N} VCD \, d\theta} = \int_{60°S}^{60°N} f(\theta) \cdot \theta \, d\theta$$

- **Expansion**: 2nd central moment

$$\sigma_N^2 = \int_{\mu}^{60°N} (\theta - \mu)^2 f(\theta) \, d\theta$$

$$\sigma_S^2 = \int_{60°S}^{\mu} (\theta - \mu)^2 f(\theta) \, d\theta$$



- Derive parameters for each longitude bin for each month and perform trend analysis.

Changes in Hadley cell

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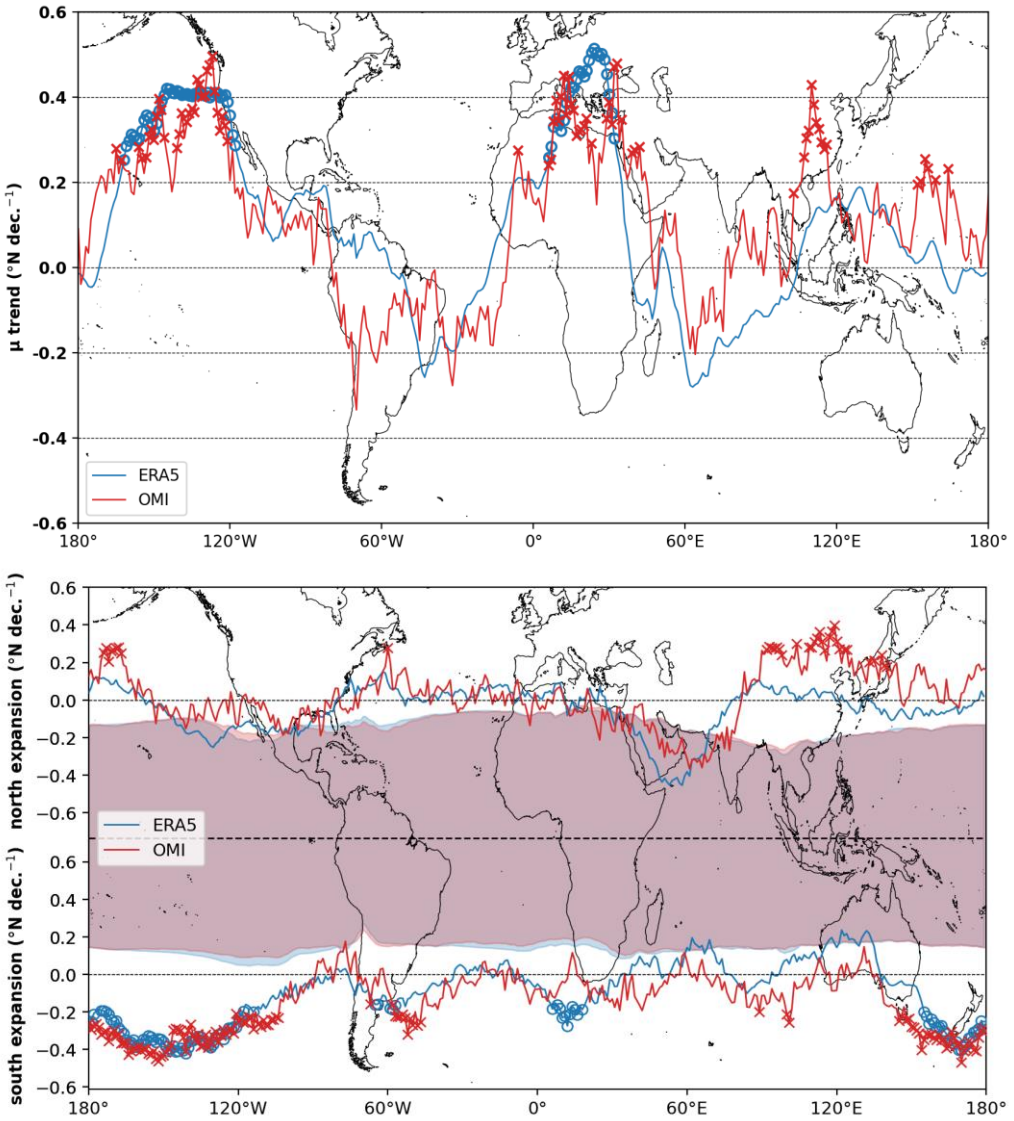
Top row: shift

Significant northward shift in East Pacific, at 30°E, and 120°E (values around 0.3-0.5°N/decade).

Bottom row: expansion

- Asymmetric expansion trends
- Up to 0.4°N/decade at 120°E
- 0.4°S/decade in Pacific
- Staten et al. (2018): ~0.2-0.5°/decade

→ Northward shift in East Pacific is balanced by southward expansion



Summary & outlook

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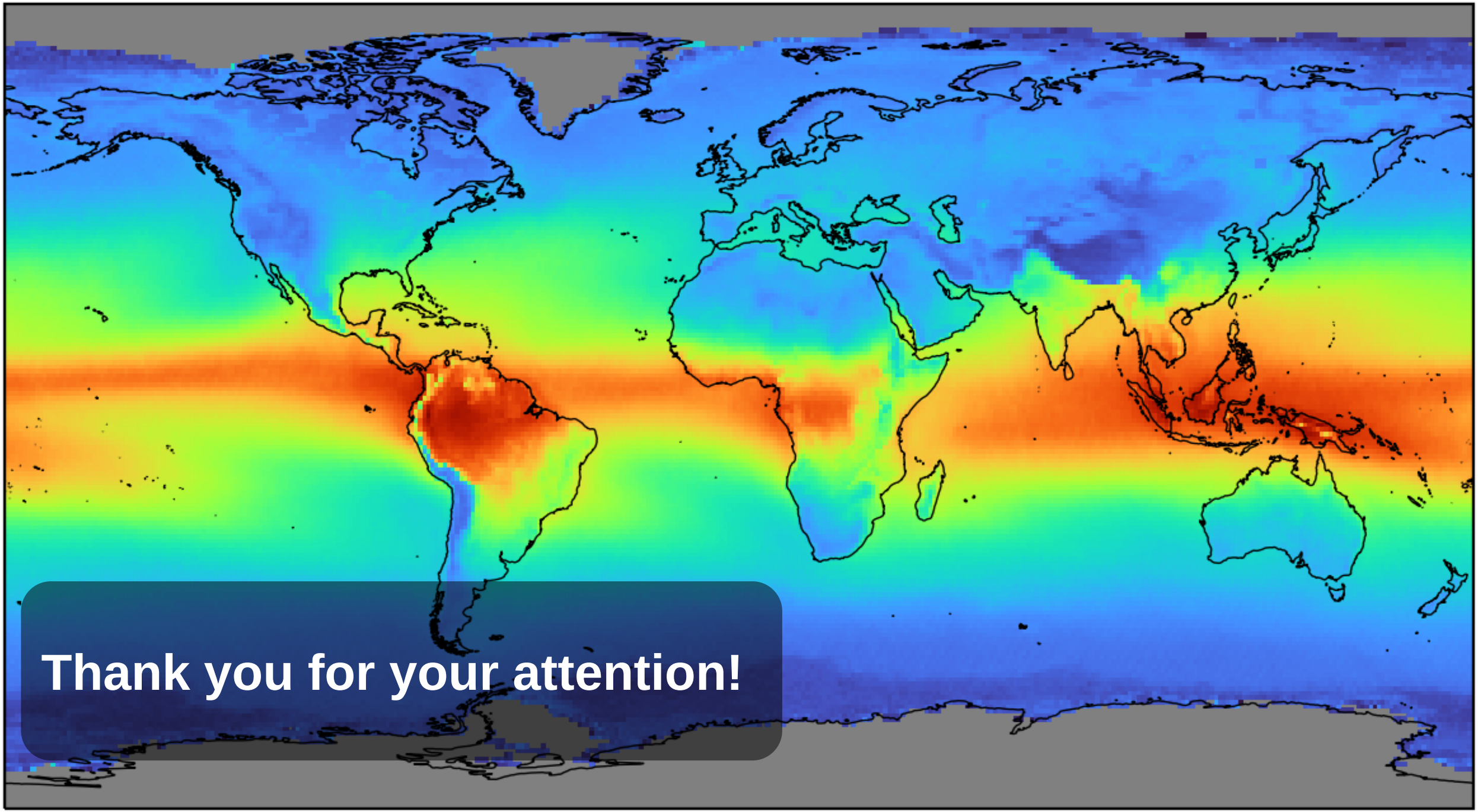
- We created a TCWV data set from multiple years of OMI observations and performed global trend analyses.
- TCWV trends:
  - Almost all significant OMI TCWV trends are positive.
  - OMI TCWV trend patterns are similar to ERA5 & ESA GOME-Evolution.
- RH trends:
  - Overall increasing trends.
  - Positive/negative trends not limited to humid/arid regions.
- Investigations of Hadley cell reveal northward shift over parts of the Pacific ocean that is balanced by a southward expansion.

<u>Outlook:</u>

- Papers in preparation (OMI TCWV data set submitted to ESSD)
- Combination of OMI and TROPOMI TCWV data set
- Application of TCWV retrieval to GOME-1/2 and SCIAMACHY and upcoming geostationary satellite instruments (e.g. GEMS, Sentinel-4)


Thank you for your attention!

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