Universität Bremen

# Evaluation of atmospheric water vapour in CMIP6 models using the ESMValTool

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# Outline

- ESMValTool
- Data
- Analysis for water vapour path:
  - Trends
  - Time series
- Analysis for specific humidity profiles:
  - Vertical profiles
  - Zonal mean climatology

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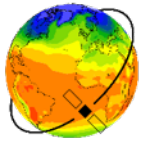


ESMValTool
Earth System Model Evaluation Tool

# ESMValTool

- Tool for fast and easy routine **evaluation and analysis** of Earth system models including provenance records for all results (**traceability and reproducibility**)
- Well-established analysis based on **peer-reviewed literature**
- Many diagnostics and performance metrics covering **different aspects of the Earth system** (dynamics, radiation, clouds, carbon cycle, chemistry, aerosol, sea-ice, etc.) and their interactions
- Extensive **documentation** (user guide, peer-reviewed papers)
- Was used in support of production of a subset of figures of the **IPCC WGI AR6**

## Scientific documentation

*Righi et al., GMD, 2020*
**Technical overview**

*Eyring et al., GMD, 2020*
**Large-scale diagnostics**

*Lauer et al., GMD, 2020*
**Diagnostics for emergent constraints and future projections**

*Weigel et al., GMD, 2021*
**Diagnostics for extreme events, regional and impact evaluation**

**Website:** https://www.esmvaltool.org/
**Code:** https://github.com/ESMValGroup/ESMValTool
**Documentation:** https://docs.esmvaltool.org/
**Tutorial:** https://esmvalgroup.github.io/ESMValTool_Tutorial

**International ESMValTool development team**

- 17 funded projects / 63 institutions
- 203 developers

# Observation and reanalysis data

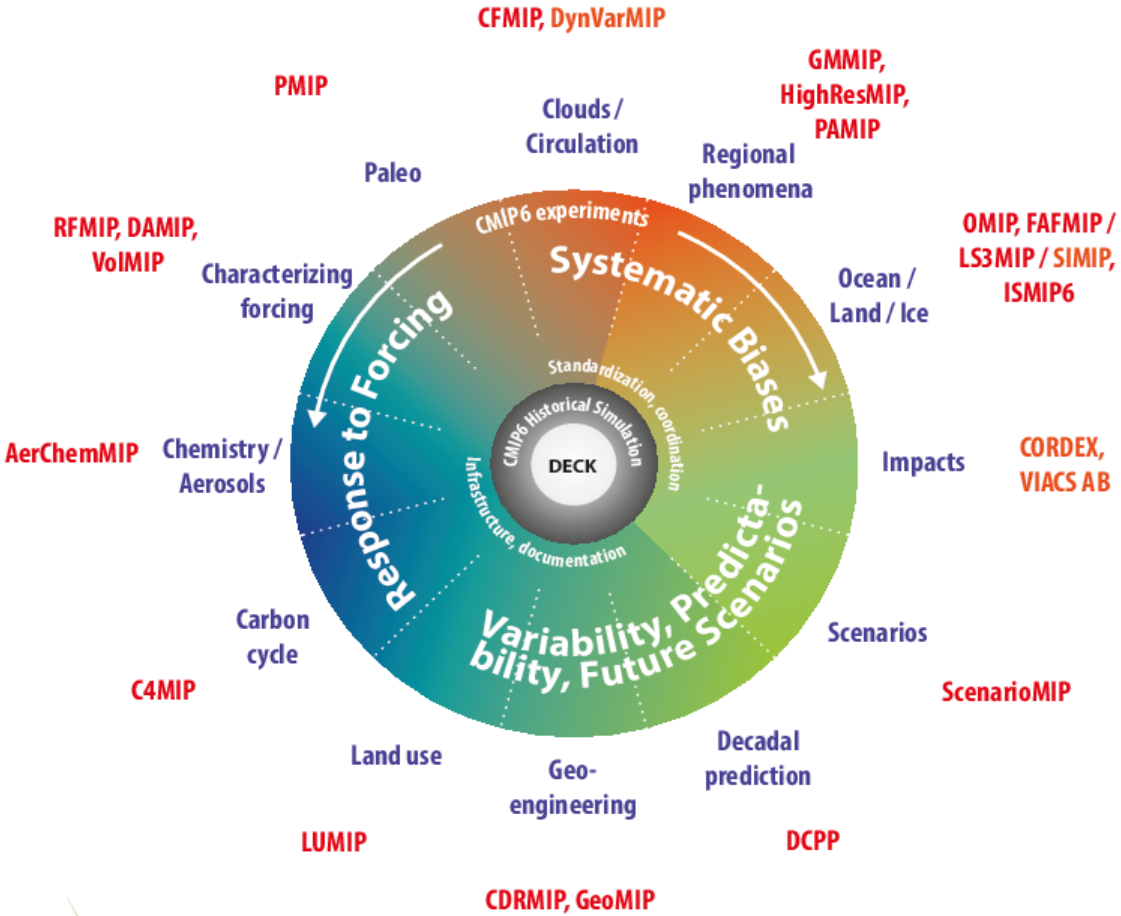
| Data Set | ERA5 | ESA-CCI water vapour | RSS (Remote Sensing Systems) | SWOOSH (Stratospheric Water and Ozone Satellite Homogenized) |
|---|---|---|---|---|
| **Type** | Reanalysis | Merged near-infrared and micro-wave imager observations | Merged microwave radiometer data | Merged limb sounding and solar occultation satellite data |
| **Version** | | CDR-1 V3.2<br>CDR-2 V3.1 (**preliminary**) | V7 | V2.6 |
| **Grid** | 0.25° | 0.05 and **0.5°** | 1° | 5° latitude, zonal mean<br>31 vertical level |
| **Time** | hourly, **monthly**<br>1979-present | daily, **monthly**<br>07/2002-2017 | monthly<br>1988-present | monthly<br>1984-present |
| **Variables shown** | Water vapour path<br>Specific humidity | Water vapour path | Water vapour path | Specific humidity |
| **Source** | https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5<br>Hersbach et al., (2020) | https://climate.esa.int/en/projects/water-vapour/data | https://www.remss.com/measurements/atmospheric-water-vapor/tpw-1-deg-product/<br>Wentz (2015) | https://csl.noaa.gov/groups/csl8/swoosh/<br>Davis et al. (2016) |

# Coupled Model Intercomparison Project (CMIP)

- **CMIP** began in 1995 under the auspices of the Working Group on Coupled Modelling (WGCM) which is part of the **World Climate Research Program** (WCRP).
- Objective of CMIP: to better understand past, present and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing
- Analyses are based on a **multi-model context**
- Coordinated experiments to estimate the influence of the different uncertainties.
- Important goal of CMIP is to make the multi-model output publicly available in a standardized format

## CMIP5 and CMIP6

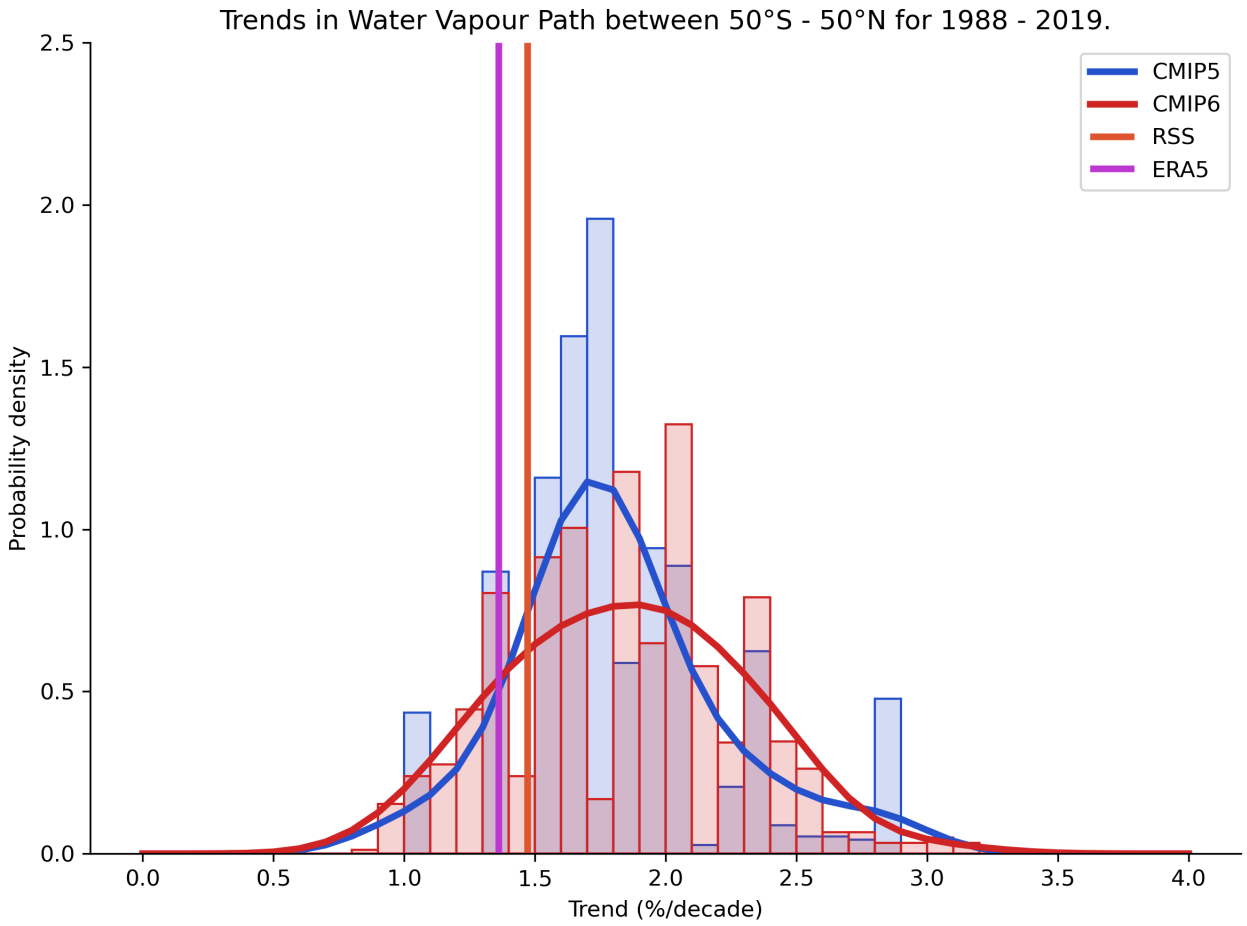
- Latest model generations
- 59/126 models from 31/48 institutions/consortia registered




*Eyring et al., GMD, 2016*

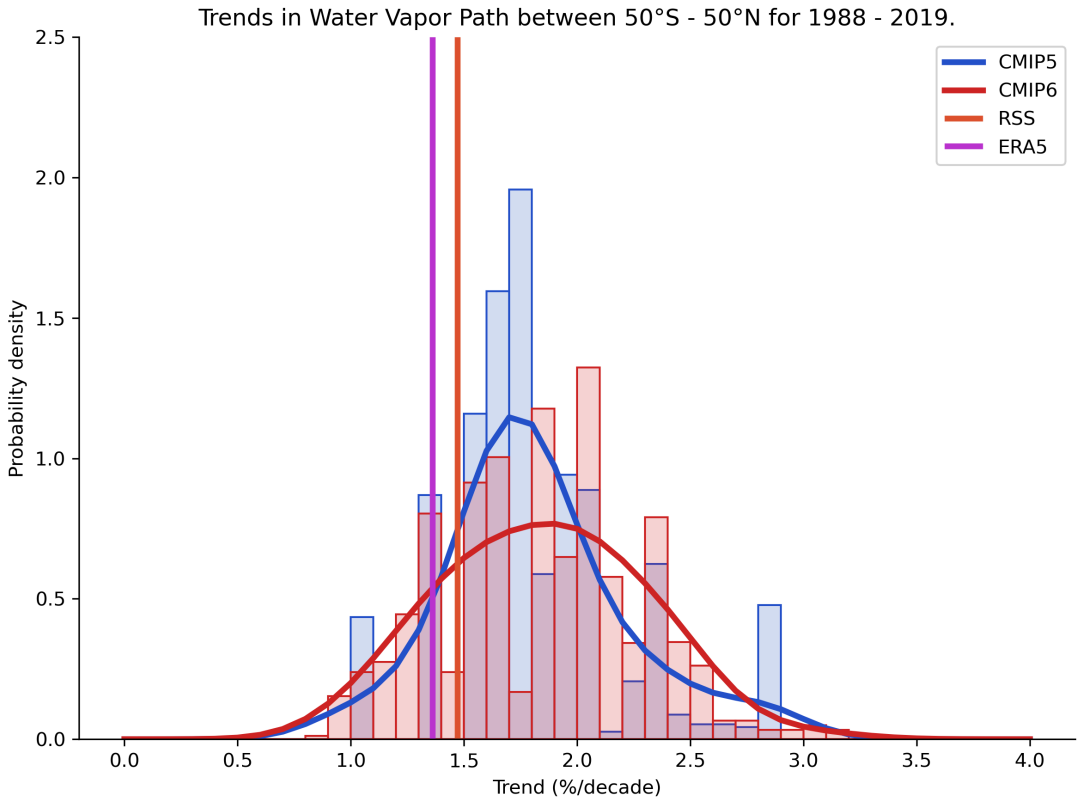
CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

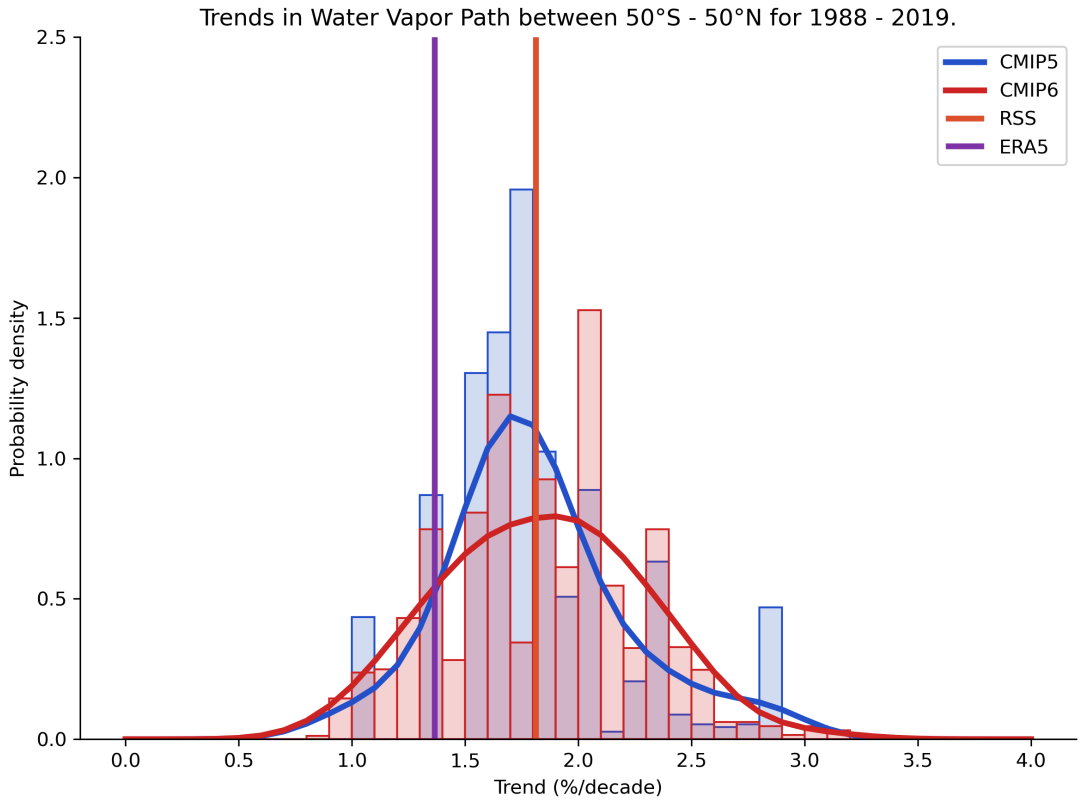
# Water vapour path trends, 50°S-50°N, 1988-2019




- Trends in water vapour path over ocean
- **Update of Figure 3.12 from IPCC AR6 WG I** (Eyring et al., 2021, Chapter 3) based on analysis of Santer et al., 2021
- Histogram of trends for 23 CMIP5 and 19 CMIP6 models, fit with kernel density estimation
- All data sets show **positive trends** as expected for rising temperatures
- The trends are **higher for CMIP** model data
  - RSS 1.4%/dec; ERA5 1.5%/dec
  - CMIP5 1.7%/dec; CMIP6 1.9%/dec
- RSS and ERA5 trends lay **within the multi-model range**
- Quality filter for RSS data applied to all data sets to unify sampling

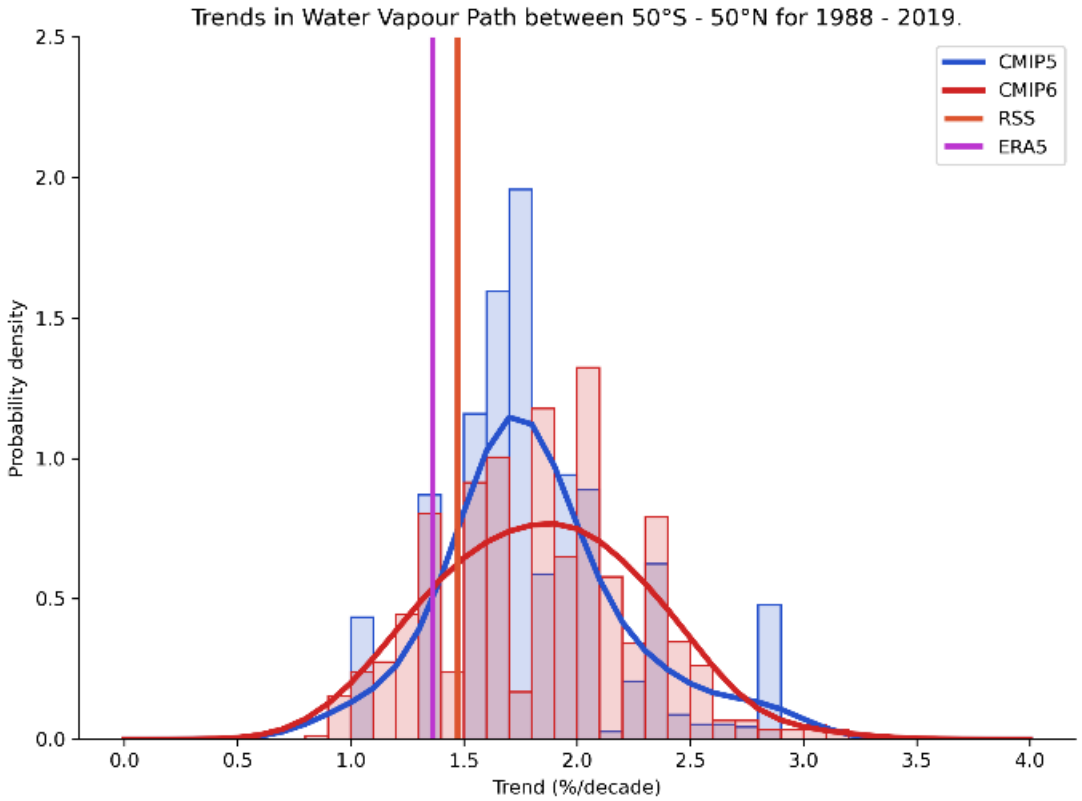
# Water vapour path trends, 50°S-50°N, 1988-2019

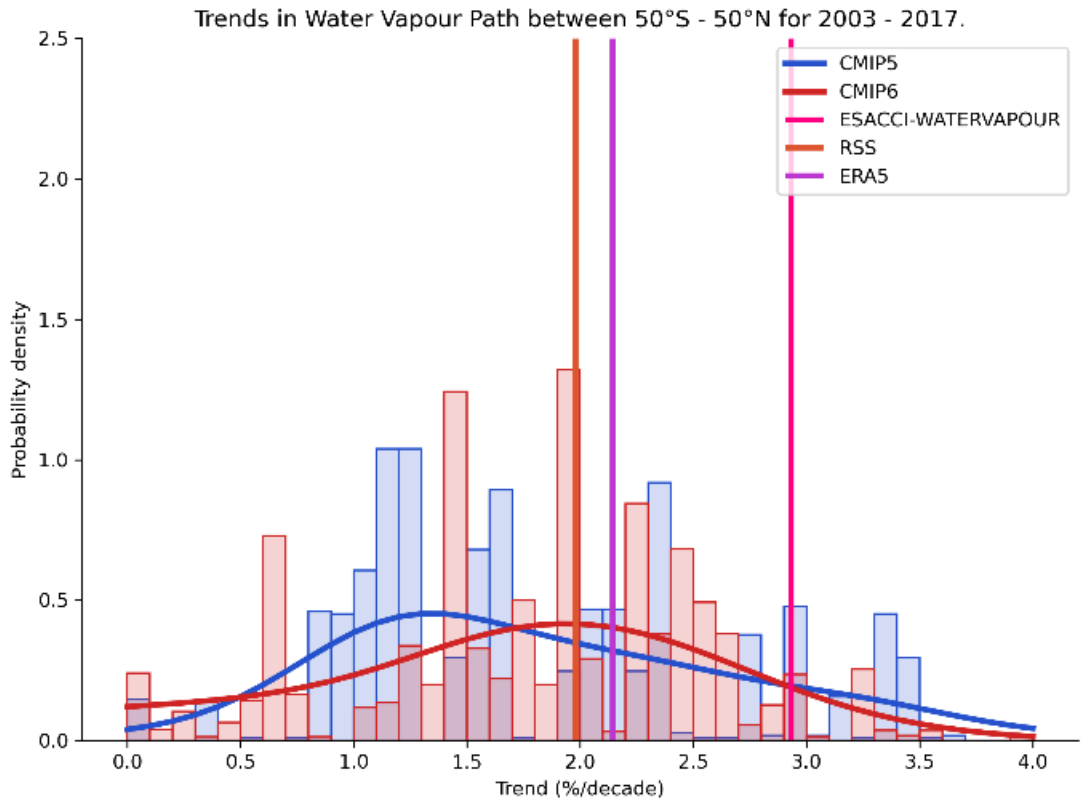



- **Quality filter effect:** with (left) and without (right) quality filter for RSS data
  - Filter applied to all data sets to account for sampling effects
- Mainly RSS data change: Improved quality of filtered data, no additional sampling issue

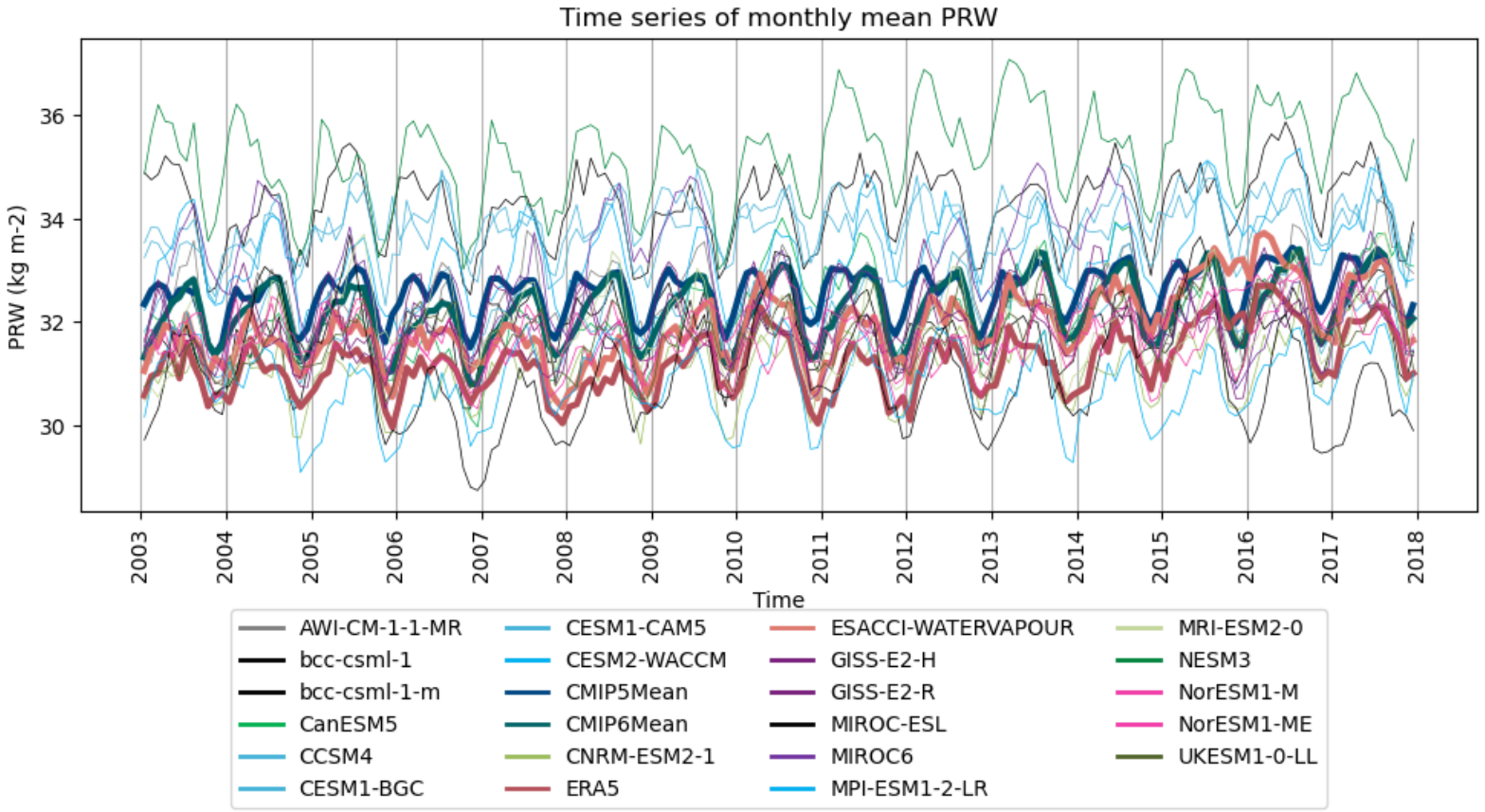
# Water vapour path trends, 50°S-50°N



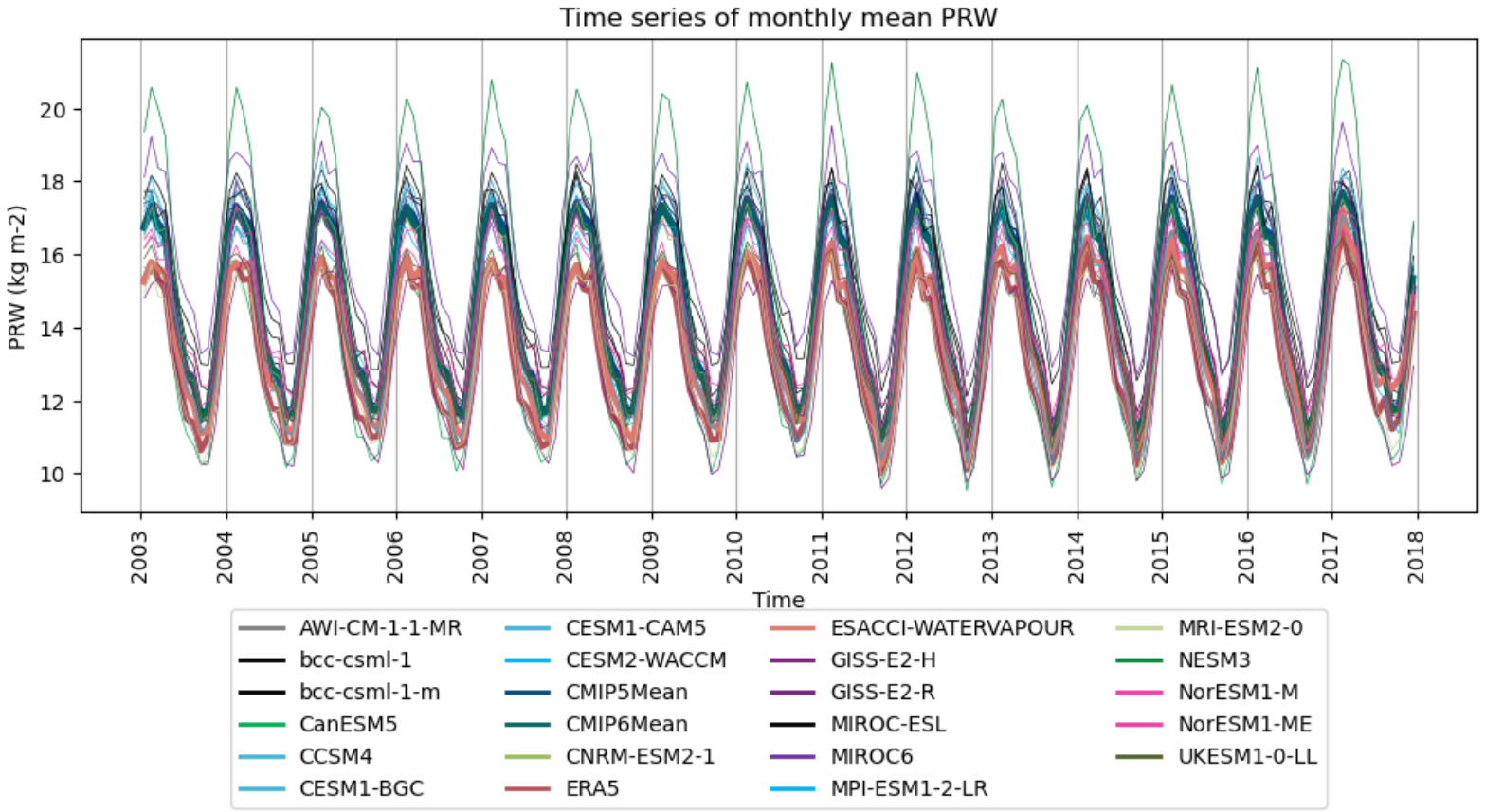

- **ESACCI:** right panel for **2003-2017**, including ESACCI CDR-2 water vapour path
- Trend distribution less distinct for **shorter time (15 vs. 42 years)**, however all data agree on positive trends
  - Higher positive trend for ESACCI CDR-2 water vapour path data compared to ERA5 and RSS

# Water vapour path time series, 50°S-50°N, 2003-2017



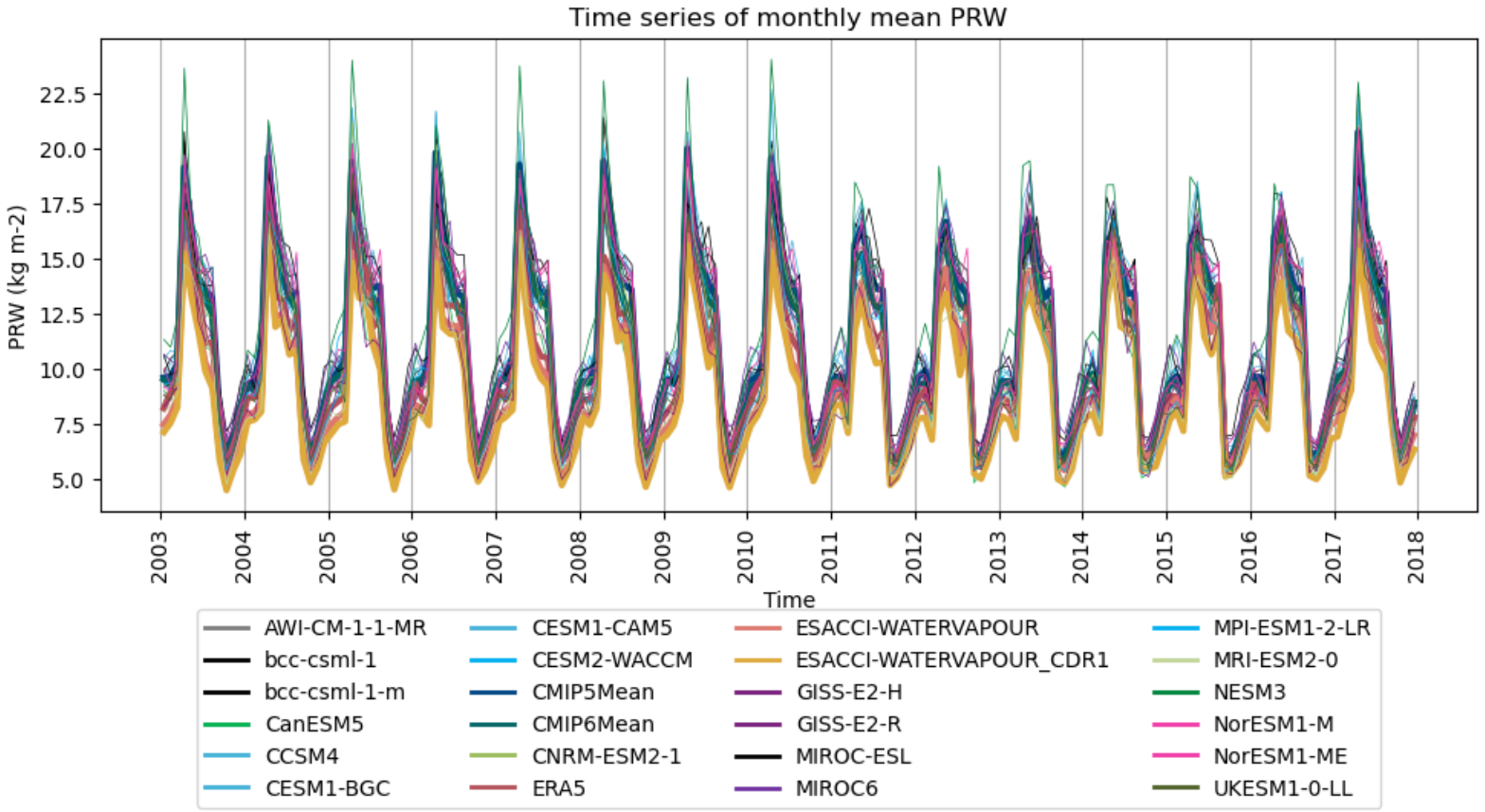

- Time series of water vapour path over ocean
- Masking all data to the **same sampling**
- CMIP models (thin lines), CMIP5 (thick blue) and CMIP6 (thick turquoise) multi-model mean, ERA5 reanalysis (thick red) and ESA-CCI CDR-2 data (thick orange)
- CMIP data on average higher than ERA5 and ESA-CCI CDR-2 data, but overall good agreement
- CMIP6 lower then CMIP5, but CMIP5 annual cycle more similar to reanalysis/observations

# Water vapour path time series, 90°S-30°S, 2003-2017



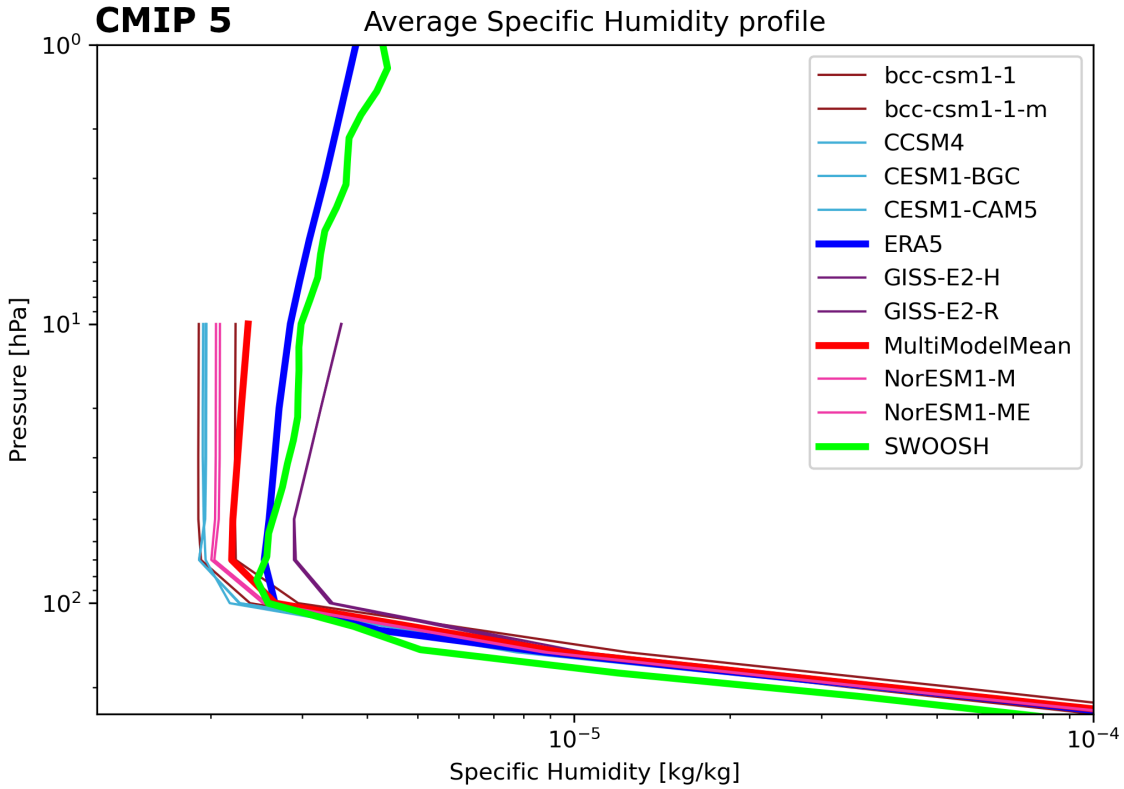

- Time series of water vapour path over land
- Masking all data to the **same sampling**
- CMIP models (thin lines), CMIP5 (thick blue) and CMIP6 (thick turquoise) multi-model mean, ERA5 reanalysis (thick red) and ESA-CCI CDR-2 data (thick orange)
- CMIP data on average higher than ERA5 and ESA-CCI CDR-2 data, but overall good agreement

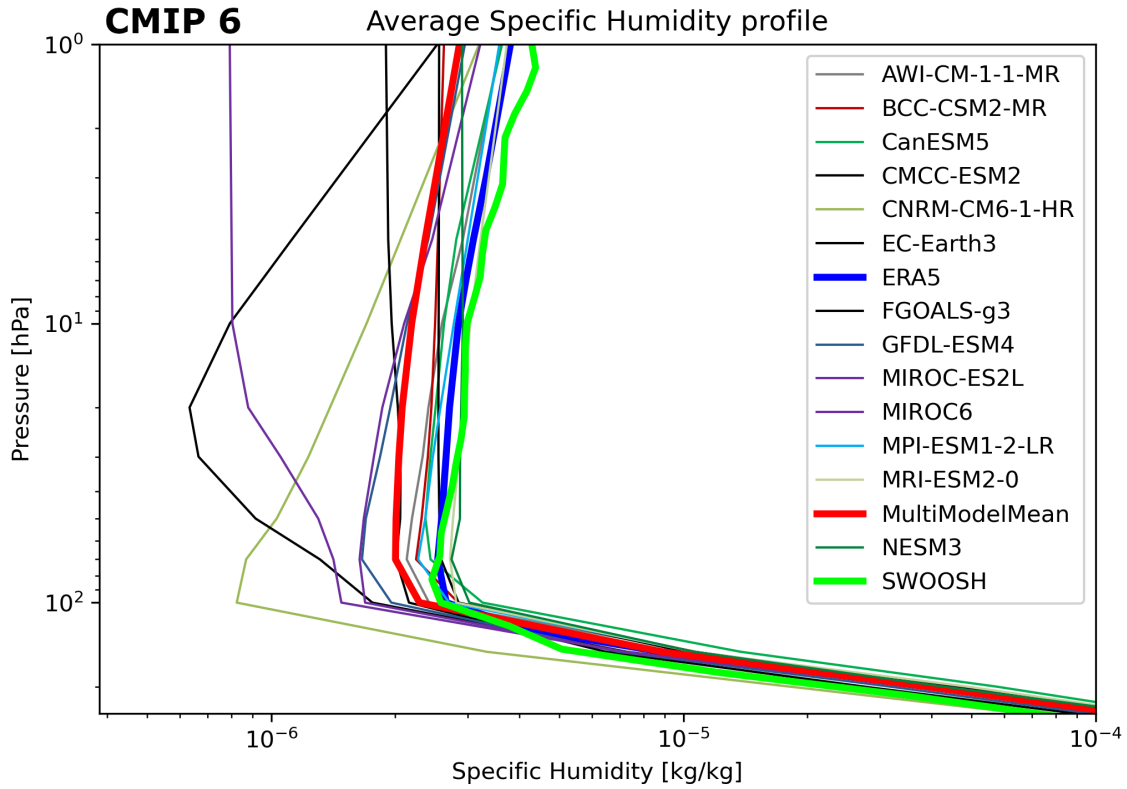
# Water vapour path time series, 90°S-30°S, 2003-2017




- Time series of water vapour path over land
- Masking all data to the **same sampling**
- CMIP models (thin lines), CMIP5 (thick blue) and CMIP6 (thick turquoise) multi-model mean, ERA5 reanalysis (thick red) and ESA-CCI CDR-2 data (thick orange)
- CMIP data on average higher than ERA5 and ESA-CCI CDR-2 data, but overall good agreement
- Sampling of CDR-1 effects time series

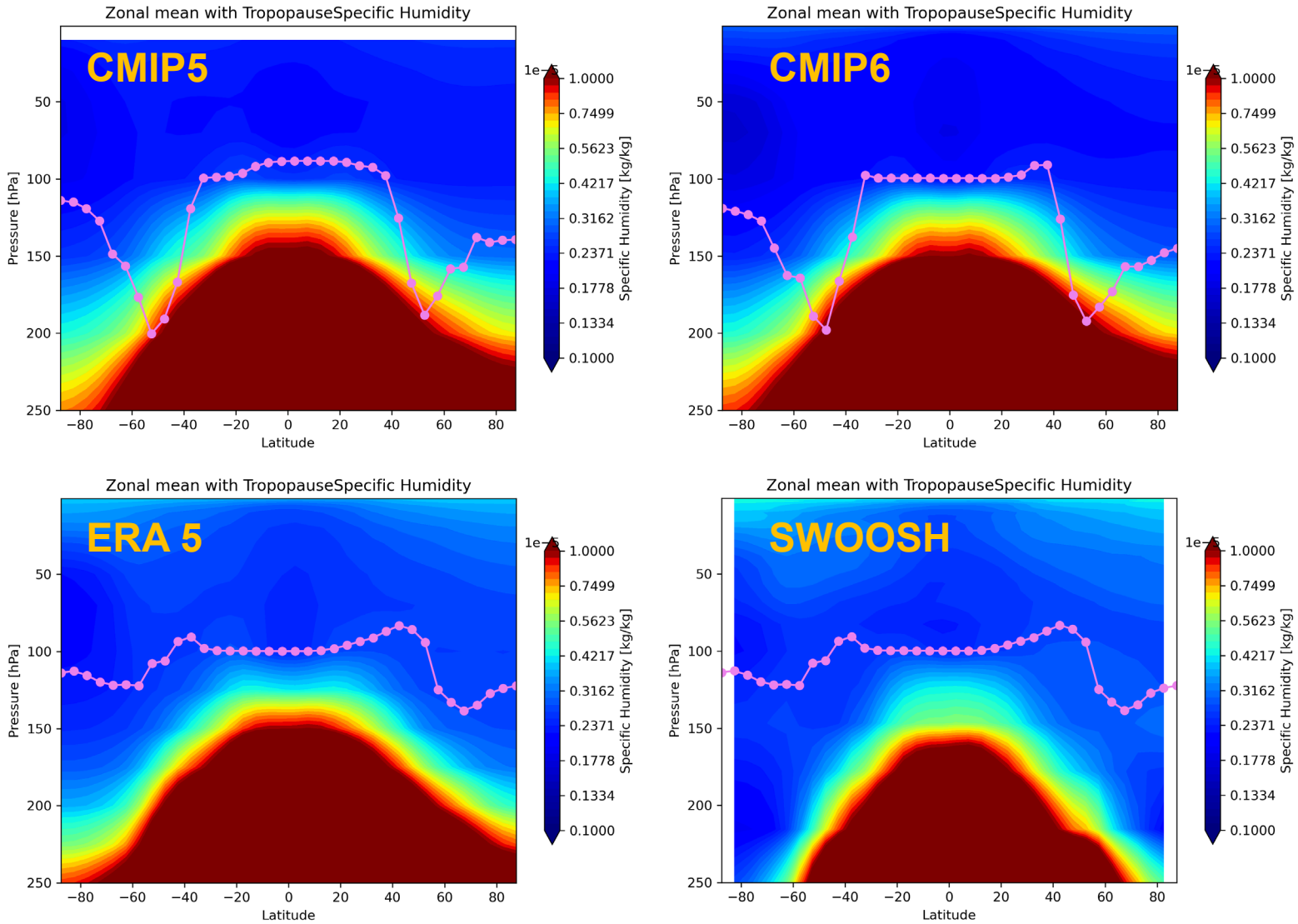
# Specific humidity profile 30°S – 30°N, 1985-2005




- Vertical profiles of specific humidity for 9 CMIP5 (left) and 13 CMIP6 (right) historical runs,ERA5 reanalysis data and SWOOSH
- CMIP5 profiles stop at 10hPa, higher variability of stratospheric water vapour profiles for CMIP5
- CMIP5 and CMIP6 multi-model mean stratospheric water vapour lower than ERA5 and SWOOSH
- More vertical structures in SWOOSH compared to ERA5, difference small

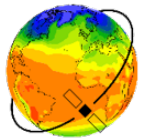
# Specific humidity zonal mean, 1985-2005



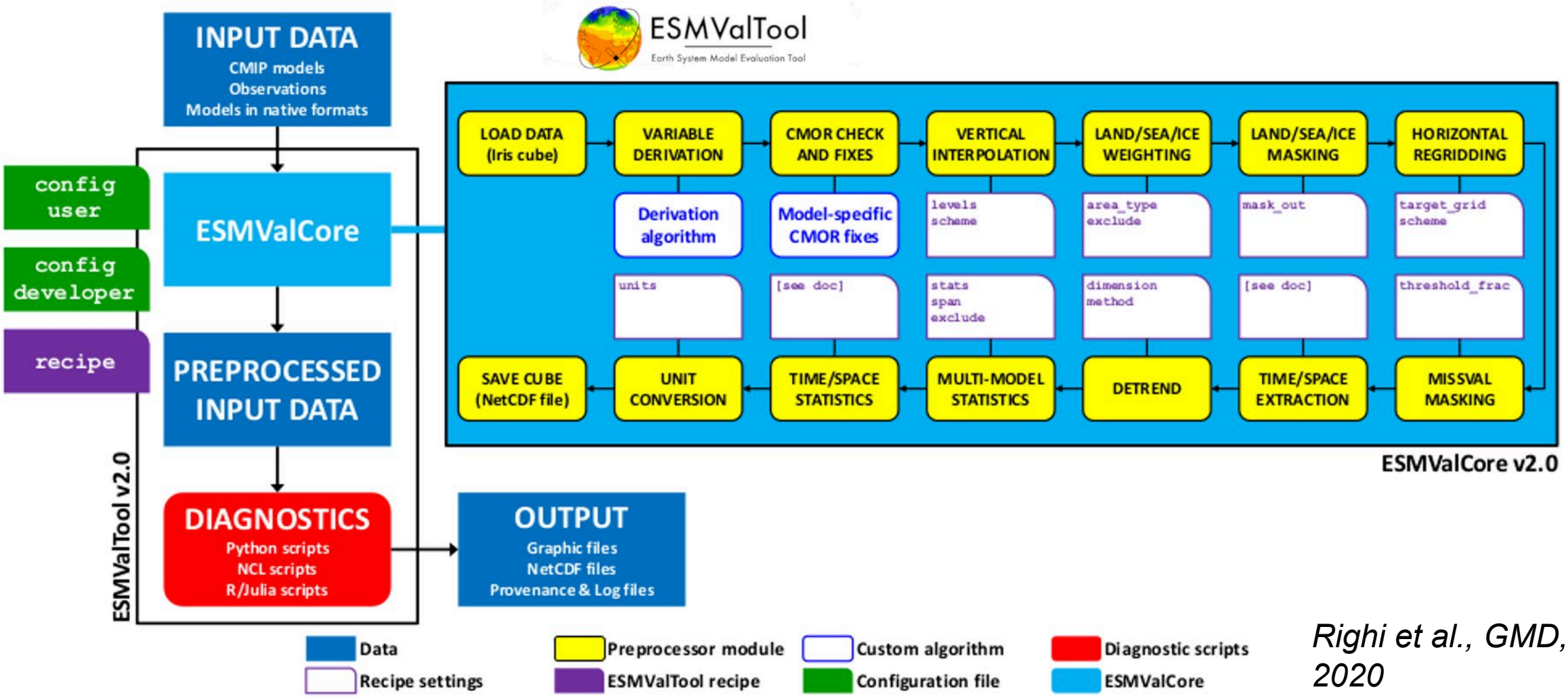

- Zonal mean specific humidity and cold point tropopause, 1985-2005
- CMIP5 (upper left) and CMIP6 (upper right) historical runs multi-model mean
- ERA5 (lower left), SWOOSH (lower right) with ERA5 cold point tropopause
- CMIP5 and CMIP6 similar
- Structures in stratospheric water vapor are not seen in multi-model mean
- Differences in Tropopause region, for polar regions also between ERA5 and SWOOSH

# Summary

- **ESMValTool:** Tool to facilitate comprehensive and routine evaluation of Earth system models with observations
- **Publicly** available (https://www.esmvaltool.org/) developed in an international **community** effort
- Comparisons of CMIP models with observational / reanalysis atmospheric water vapour:
  - **Water vapour path**:
    - Positive trends over near global ocean in CMIP models as well as RSS and ERA5, within multi-model range, higher for CMIP models (**IPCC AR6 WGI, Eyring et al., 2021, Ch. 3**)
    - Time series: CMIP models higher than observations/reanalysis
    - Quality filters and sampling effects need to be considered
  - **Specific humidity profiles**:
    - Lower water vapour in the tropical stratosphere for CMIP models
    - Differences in Upper Troposphere Lower stratosphere

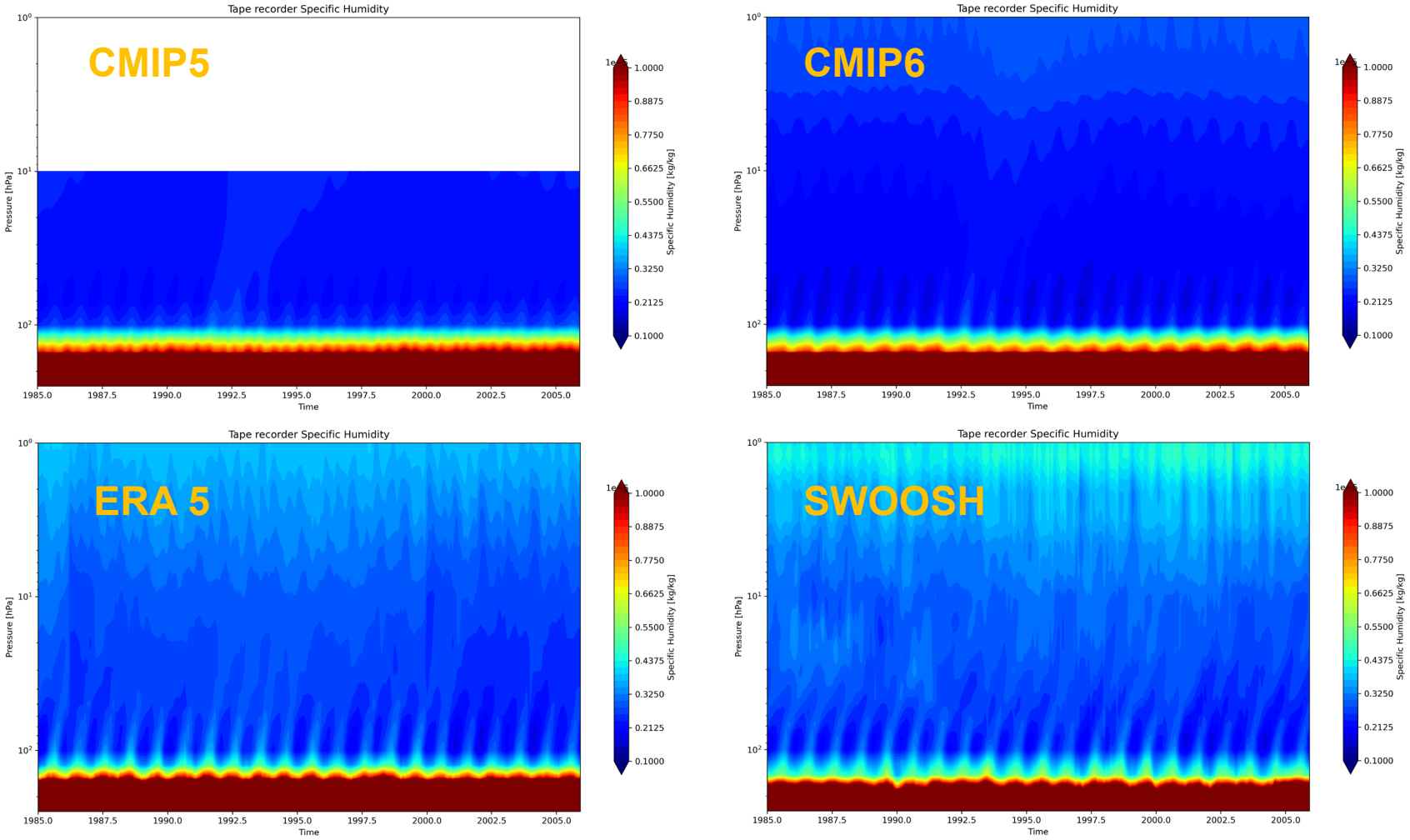


# ESMValTool and ESMValCore




*Righi et al., GMD, 2020*

# Specific humidity tape recorder, 1985-2005




- Zonal mean specific humidity 30°S-30°N, 1985-2005
- CMIP5 (upper left) and CMIP6 (upper right) historical runs multi-model mean
- ERA5 (lower left) SWOOSH (lower right)
- Many structures in stratospheric water vapor are not seen in multi-model mean
- Differences in tape recorder also between ERA5 and SWOOSH

# Evaluate water vapour short wave absorption

- Sensitivity of solar absorption to variations in atmospheric water vapour varies considerably among models due to differences in radiative transfer parameterizations
- Models with more modern short wave absorption schemes agree better with observations
- Update from version Lauer et al. (2020) based on analysis of DeAngelis et al. (2015)
- Width of horizontal shading/vertical dashed lines: uncertainties of the ratio (95% confidence interval of the regression slope to the rsnst versus prw curve)
- CMIP5 data sets compared to ESACCI CDR-2 data from 2003 to 2011 (red, instead of ERA-Interim and SSMI 2001-2009, black), water vapour path over tropical ocean
- ESACCI CDR-2 agrees with ERA-Interim and SSMI, smaller confidence interval