

climate change initiative

→ CLIMATE MODELLING USER GROUP

ESMValTool and feedthrough to AR6

A. Lauer and the ESMValTool development team



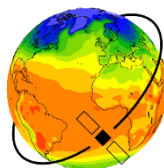


Outline

- Earth System Model Evaluation Tool (ESMValTool)
- Coupled Model Intercomparison Project Phase 6 (CMIP6)
- Evaluation of CMIP6 models with ESA CCI data
- Summary



Earth System Model Evaluation Tool



ESMValTool

Earth System Model Evaluation Tool





➤ Easier and faster evaluation of complex Earth System Models

- Easy analysis of CMIP models
- Fast overview due to standard diagnostics, figures and variables
- Easy comparison of new model simulations with already existing runs and observations

Development and documentation



GitHub repository allows development with many users



Issue tracking system (GitHub)



Online documentation (readthedocs)

Automatized quality control



Automatized code checking (Codacy)



Automatized testing (CircleCI)



➤ Improved quality standard for model evaluation

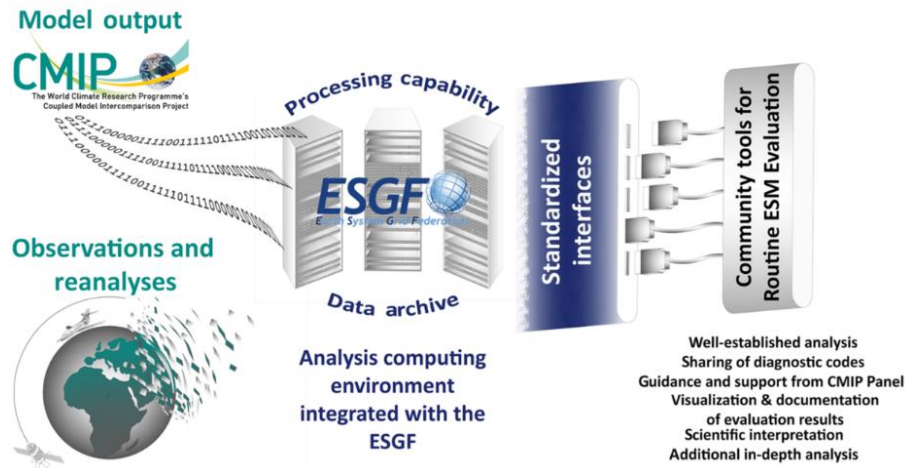
- Growing number of included diagnostics
- Reproduction of special reports or scientific papers with standard „recipes“
- Traceability and reproducibility of results

➤ Easily expandable

- Synergy with other software projects to expand the ESMValTool (e.g. NCAR CVDP)

➤ Coupling to Earth System Grid Federation (ESGF)

- Complete and timely analysis of CMIP simulations with observations

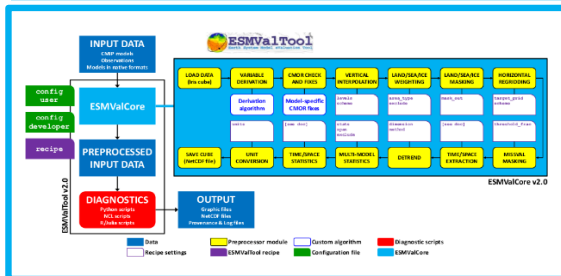




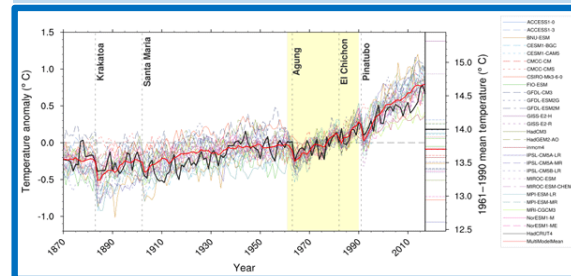
Release v2.0 August 2020

- **Open source community development on GitHub** (> 200 developers, > 60 international institutes)
- **Rapid development** since the first release in 2016 with support of many international projects such as CMUG
- **Online documentation**
- **Now a well-tested tool** providing end-to-end provenance to ensure reproducibility
- Used in several **IPCC WGI AR6** chapters

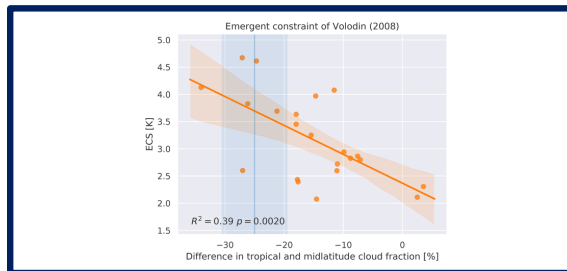
Righi et al., 2020 Technical overview



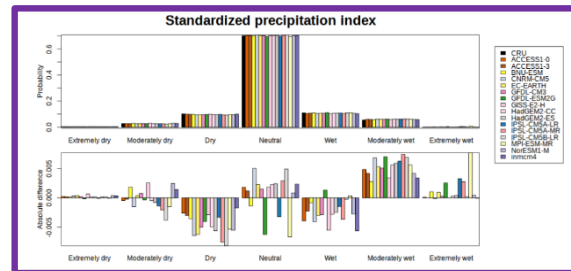
Eyring et al., 2020 Large-scale diagnostics



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



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





International ESMValTool development team

- 19 funded projects
- 66 institutions
- 206 developers

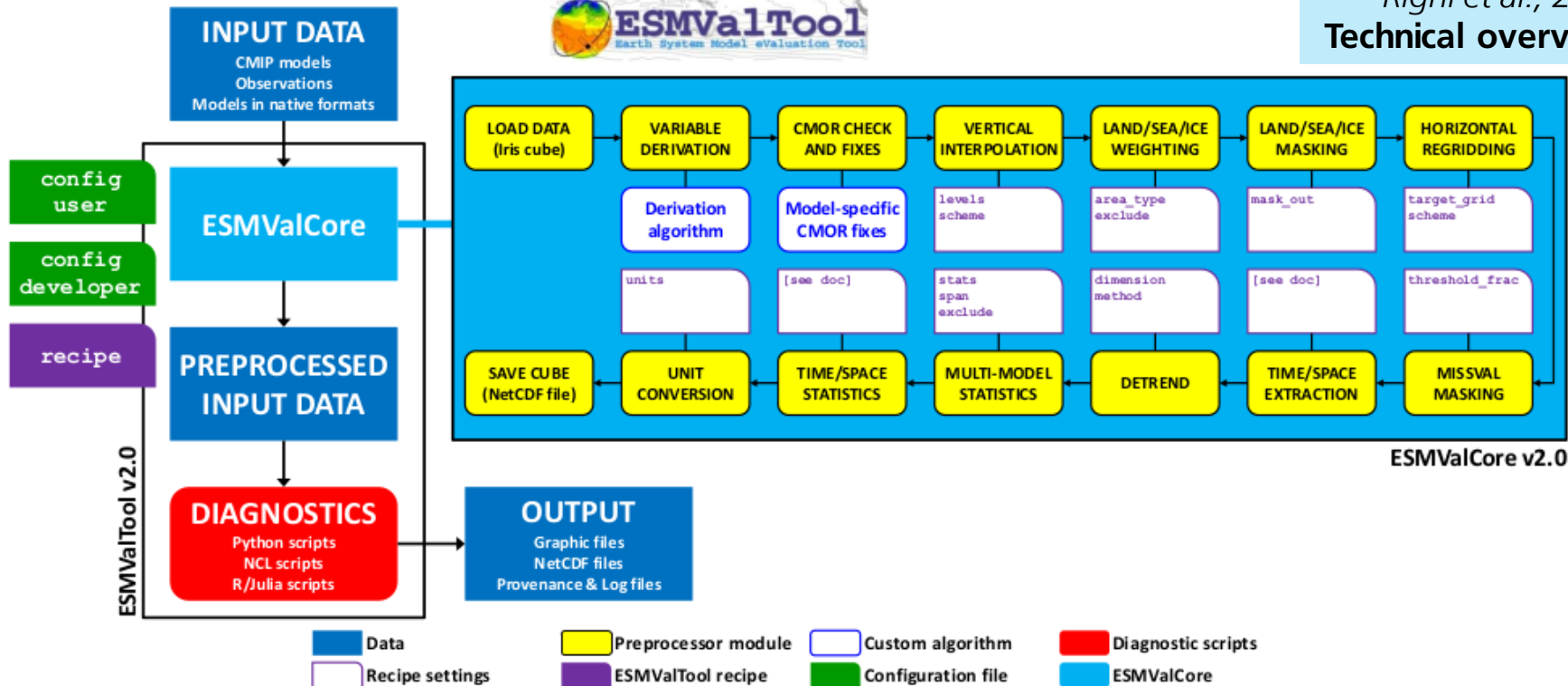
Release v2.0 August 2020

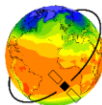
- 3.5 years of work
- 8 coding workshops
- 416 pages documentation
- 776 solved issues
- 1276 merged pull requests
- 1725 files
- 544,971 lines of code





Righi et al., 2020
Technical overview





ESMValTool

Earth System Model Evaluation Tool

1. Github repositories

<https://github.com/ESMValGroup/ESMValTool>

2. Documentation

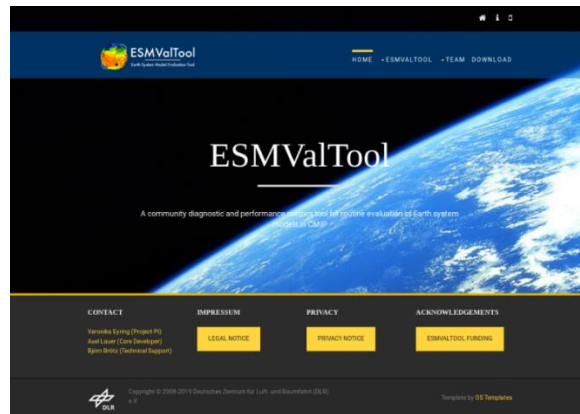
<https://docs.esmvaltool.org/>

3. Tutorial

https://esmvalgroup.github.io/ESMValTool_Tutorial/

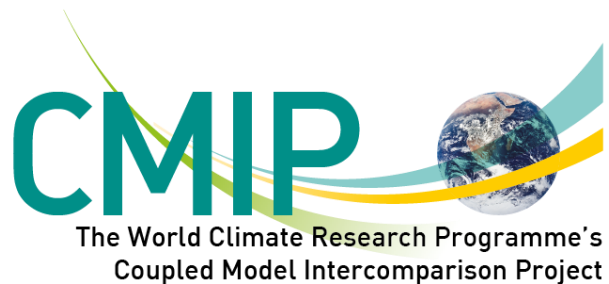
4. Webpage

<https://www.esmvaltool.org/>





Coupled Model Intercomparison Project





- 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 is 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**
- Important goal of CMIP is to make the multi-model output publicly available in a standardized format

CMIP1+2
1995-1996

CMIP3
2005-2006

CMIP5
2010-2014

CMIP6
2018-2021

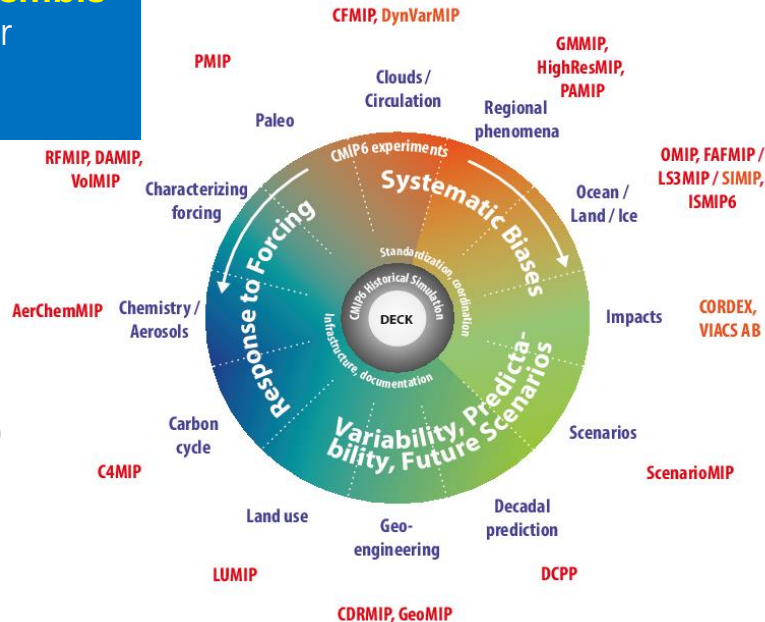




The challenge of analysing and evaluating the CMIP6 ensemble

Compared with CMIP5: more models, more experiments, higher model complexity, higher resolution, increased data volume

- 48 institutions/consortia have registered (CMIP5: 31)
- 126 models are registered (CMIP5: 59)
- 299 experiments defined (CMIP5: 33)
- 10 – 50 PB of model output expected (CMIP5: ~2 PB)
- Higher complexity and resolution compared to CMIP5



Eyring et al., *Geosci. Model Dev.*, 2016



... with ESA CCI data and the ESMValTool



Examples

- (1) clouds
- (2) water vapor
- (3) XCO₂
- (4) climate parameters



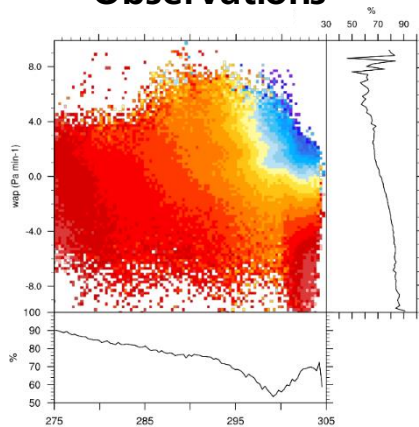
Cloud properties by dynamical regime

($x = \text{SST}$, $y = \omega_{500}$)

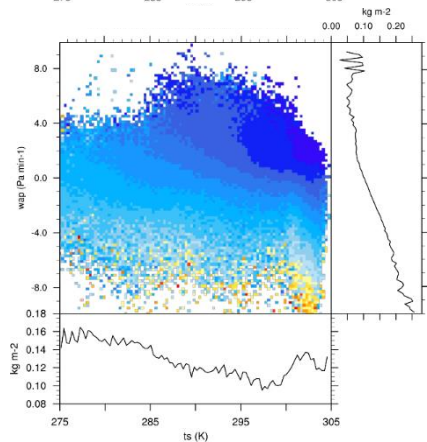


Observations

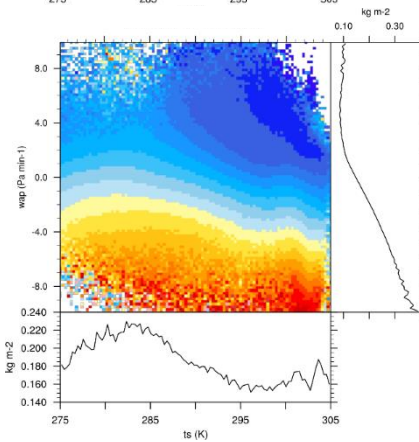
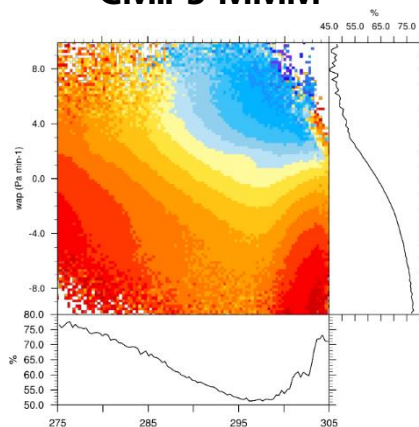
Total cloud cover (%)



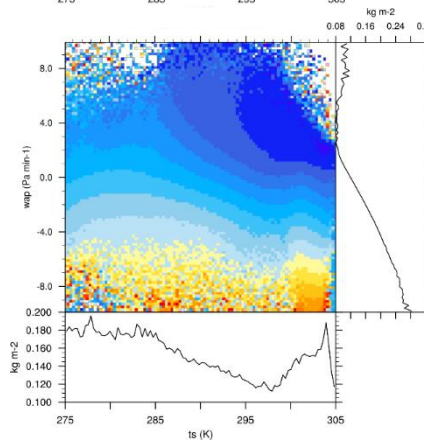
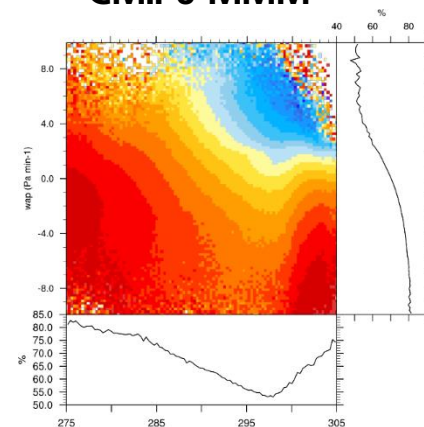
Total cloud water (kg m⁻²)



CMIP5 MMM



CMIP6 MMM



- Observations: ESACCI-CLOUD, ERA-Interim
- Increased cloud cover in CMIP6 in moderately descending and ascending regions ($\omega_{500} < 4 \text{ Pa min}^{-1}$)
- Improved agreement of CMIP6 MMM with ESACCI-CLOUD (higher cloud fraction, reduced total cloud water in ascending regions ($\omega_{500} < -4 \text{ Pa min}^{-1}$))

From: Lauer et al. (in prep.)



CMIP6 evaluation - Southern Ocean clouds

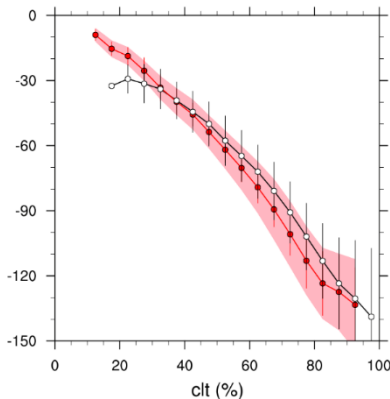
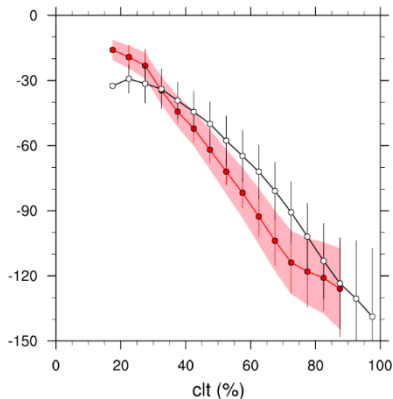
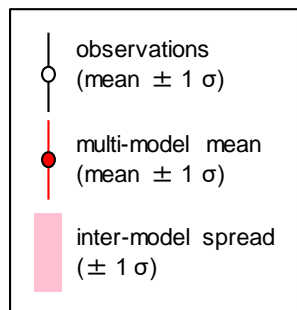


Shortwave cloud radiative effect ($W m^{-2}$)

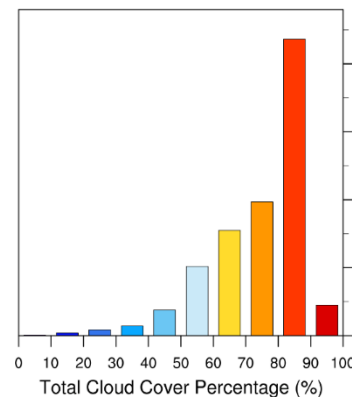
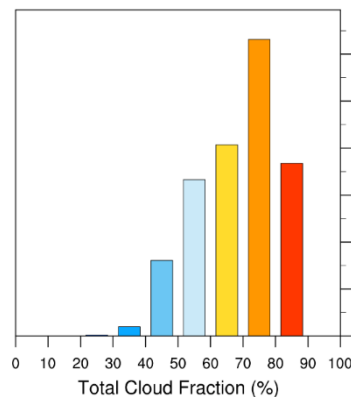
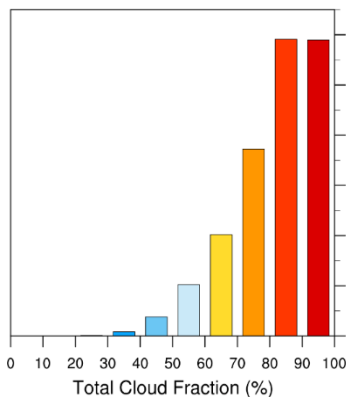
Total cloud cover (%)

CMIP5 MMM

CMIP6 MMM



OBS



From: Lauer et al. (in prep.)

- Observations: CERES-EBAF, ESACCI-CLOUD
- Reduced shortwave cloud radiative effect for given total cloud fraction
- Improved agreement of CMIP6 MMM with observations compared with CMIP5
- Increased frequency of high total cloud amounts in CMIP6 compared with CMIP5
- Improvement of "too few, too bright problem" in CMIP6



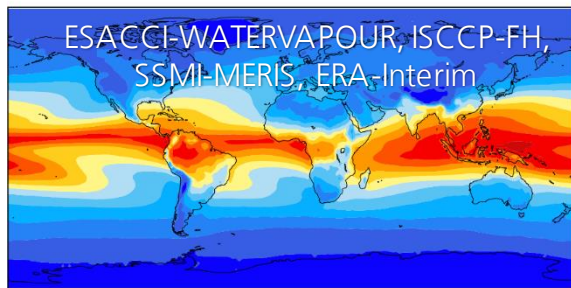


Water vapor



mean = 24.756

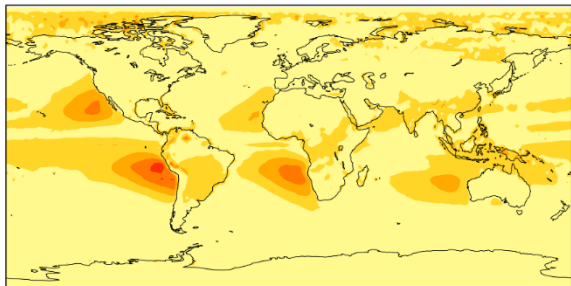
multi-obs mean



total column water vapor (kg m⁻²)



multi-obs
„uncertainty“



variability total column water vapor (kg m⁻²)



multi-obs mean

$$\bar{X} = \frac{1}{N_{obs}} \sum_{n=1}^{N_{obs}} \bar{x}_n$$

multi-obs „uncertainty“

$$\bar{\sigma} = \sqrt{\frac{1}{N_{obs}} \sum_{n=1}^{N_{obs}} \sigma_n^2}$$

The **deviation** of dataset n from the multi-obs mean \bar{X} including its **year-to-year variability** is estimated as standard deviation of the individual years to the multi-observational mean:

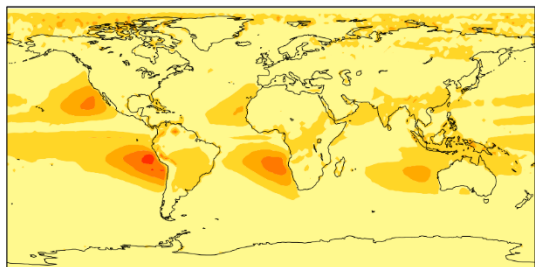
$$\sigma_n = \sqrt{\frac{1}{N_n - 1} \sum_{i=1}^{N_n} (\bar{X} - x_{i,n})^2}$$



Water vapor - climatology



multi-obs „uncertainty“



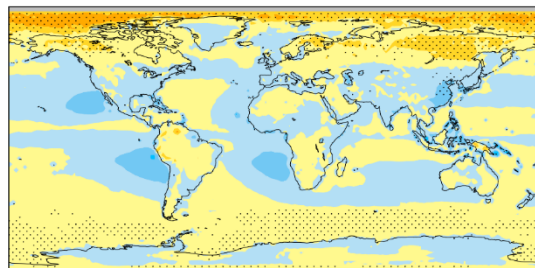
variability total column water vapor (kg m^{-2})



ESACCI-WATERVAPOUR - REF

bias = -0.067

rmsd = 1.105



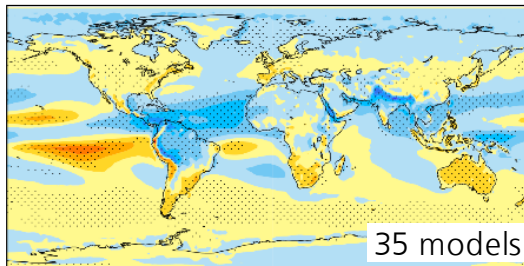
Δ total column water vapor (kg m^{-2})



CMIP5 multi-model mean

bias = -0.137

rmsd = 1.967

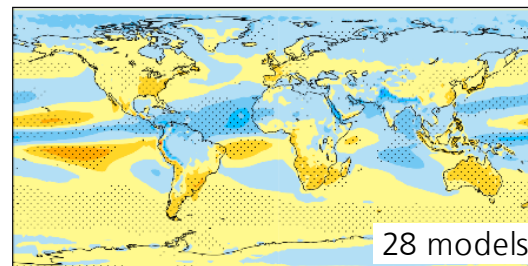


35 models

CMIP6 multi-model mean

bias = 0.086

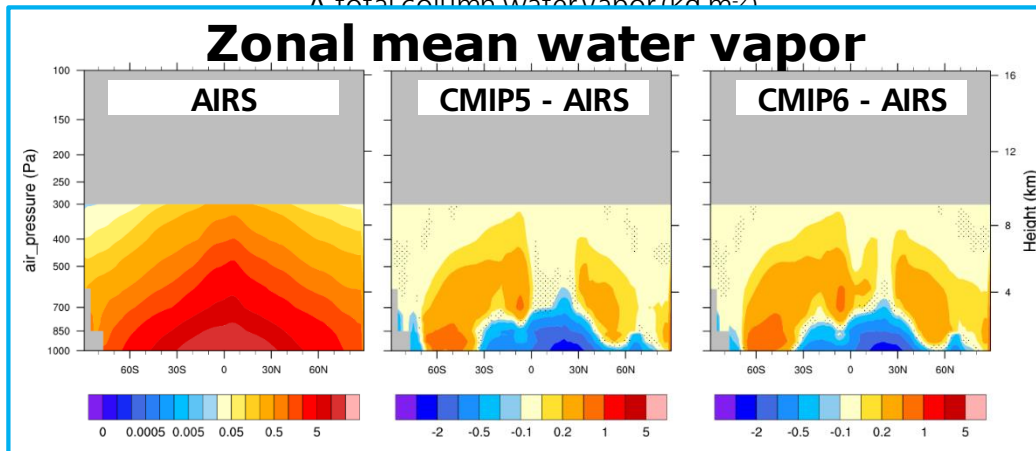
rmsd = 1.658



28 models

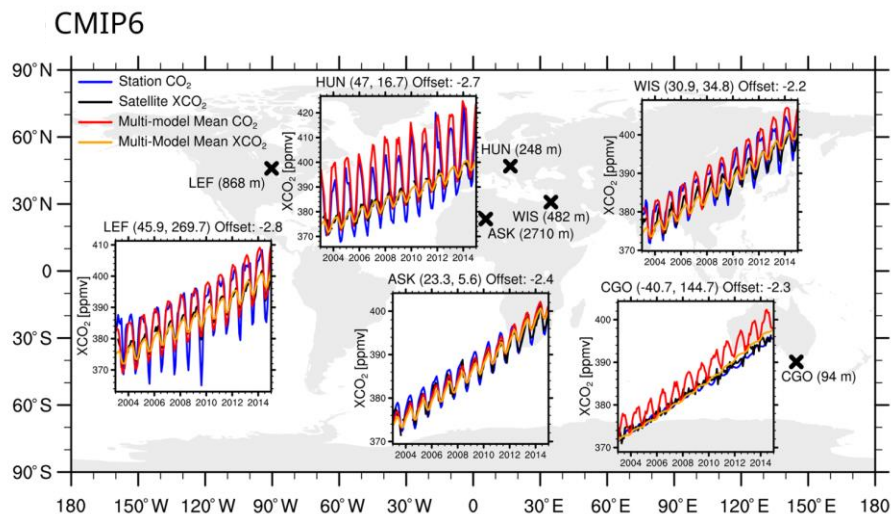
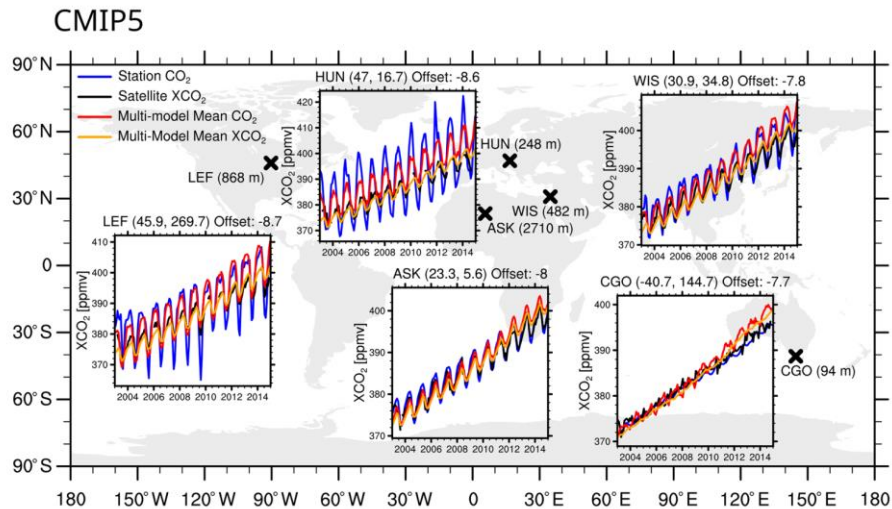
Δ total column water vapor (kg m^{-2})

Zonal mean water vapor





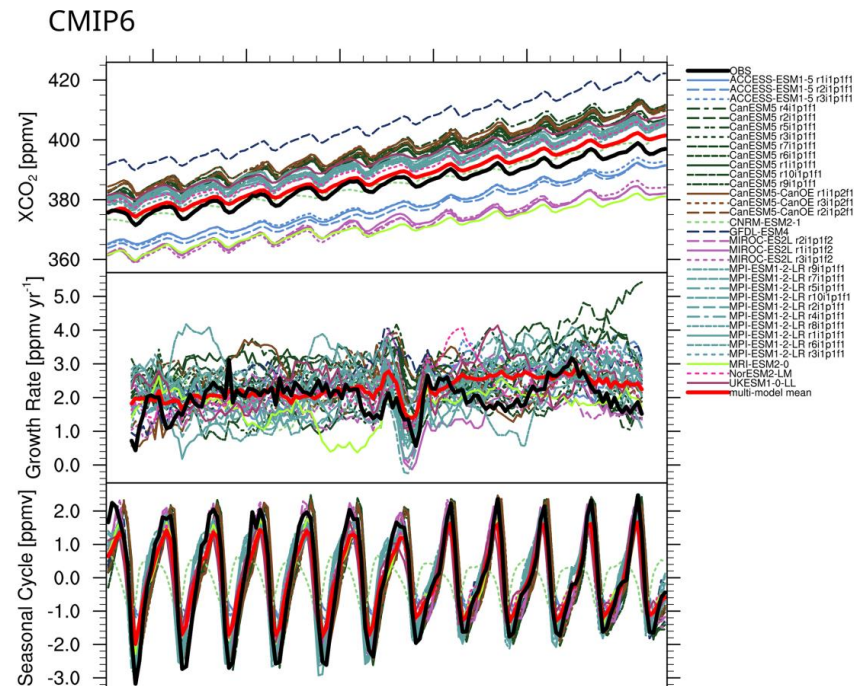
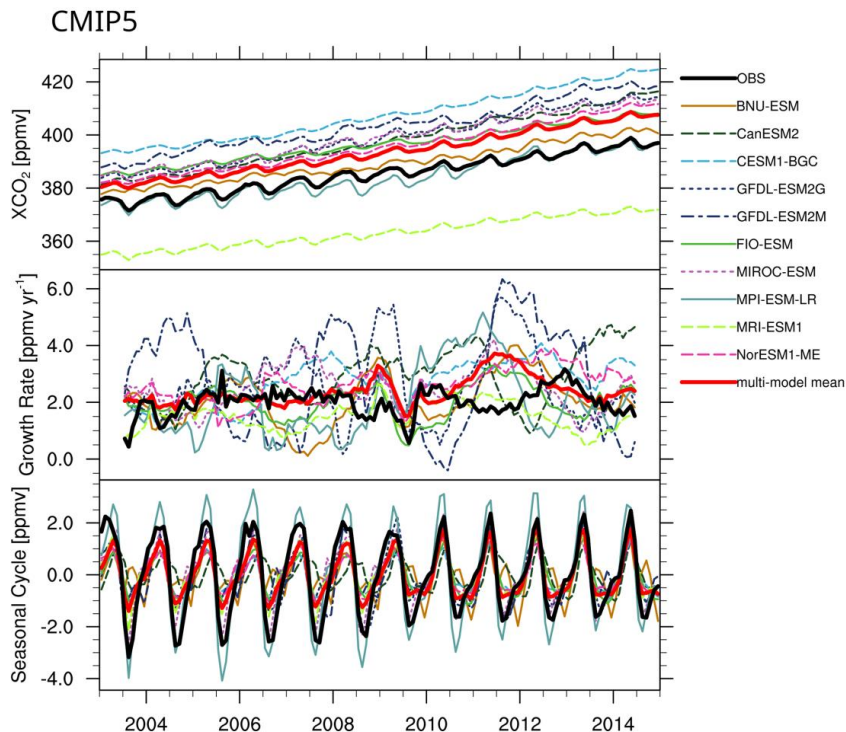
Global average XCO₂



From: Gier et al. (2020)



Evaluation of CMIP6 models



From: Gier et al. (2020)

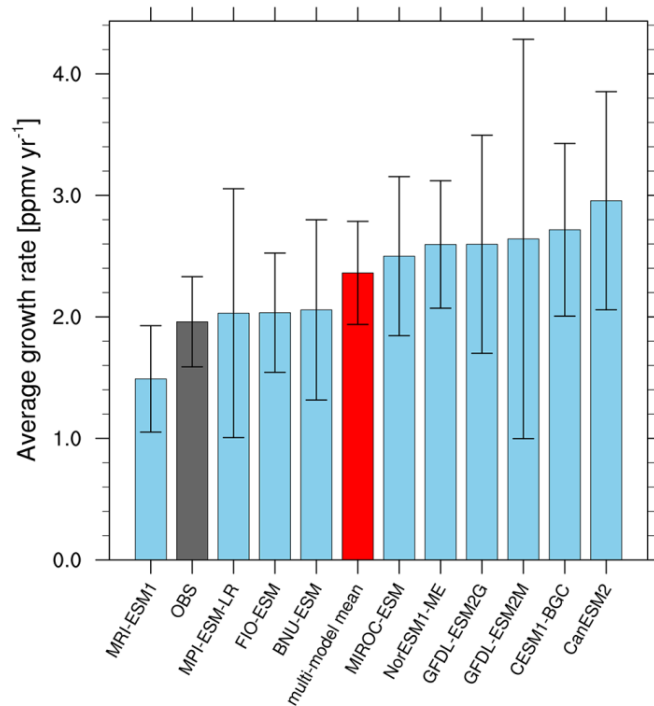




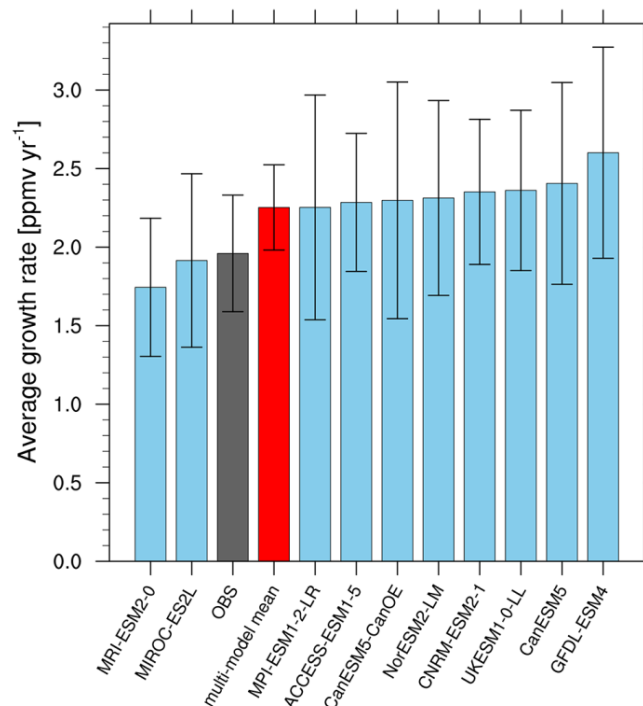
Evaluation of CMIP6 models



CMIP5



CMIP6

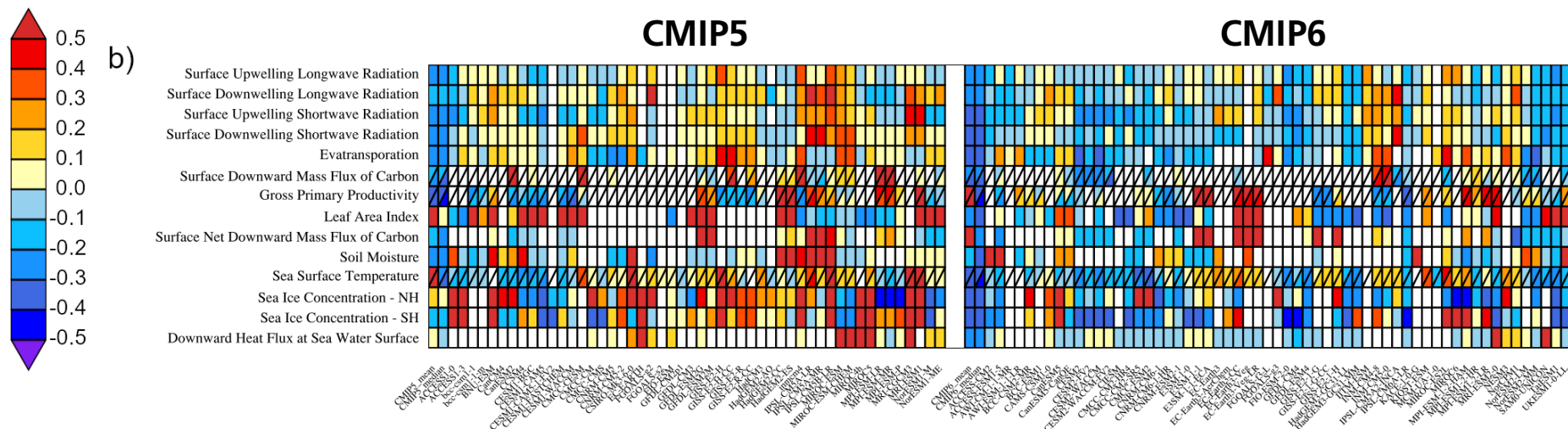


From: Gier et al. (2020)





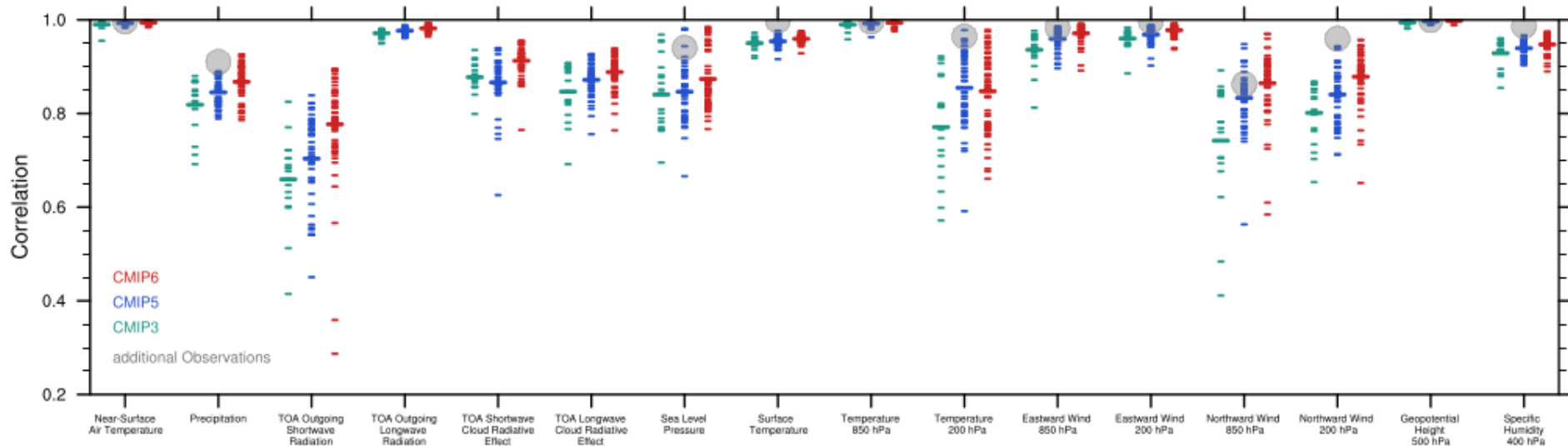
Relative model performance (RMSD)



From: IPCC AR6, Chapter 3, Fig. 42



Pattern correlations



From: IPCC AR6, Chapter 3, Fig. 43



- **ESMValTool**: tool for fast and easy evaluation and analysis of Earth system models including provenance records for all results (traceability and reproducibility)
- ESMValTool coupled to ESGF provides a systematic, rapid and comprehensive **performance assessment** that can also enhance quality control
- **Publicly** available and developed in an international **community** effort
- **v2.0 vs v1.0**: clear improvements in core capabilities (pre-processing options), code quality (automatized code checking), and documentation
- **Diagnostics**: more large-scale diagnostics, emergent constraints and future projections diagnostics, extreme events and regional and impact diagnostics available than before
- Supported production of a subset of figures of **IPCC WGI AR6**
- **ESA CCI data** used for model evaluation and analysis



- ESMValTool development is growing
- Current release: v2.3 (July 2021)
- Evaluation of CMIP6 models with ESA CCI data ongoing
- Development of the ESMValTool will continue beyond the end of this CMUG phase



<https://www.esmvaltool.org/>

