

# **Workflow for routine evaluation of CMIP6 models with the ESMValTool**

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Knowledge for Tomorrow

# Motivation

## Difficulties with the workflow for model evaluation during CMIP5

- Local download of high volume data => multiple copies at many institutions
  - Time and resource intensive
  - Need to manage versioning of data **by non-data specialist**
  - Need to preserve metadata in the final result **by non-data specialist**
- Duplication of efforts by non coordinated development of evaluation routines
- Evaluation by individual scientists (whenever they had time) => delays in the availability of the evaluation results

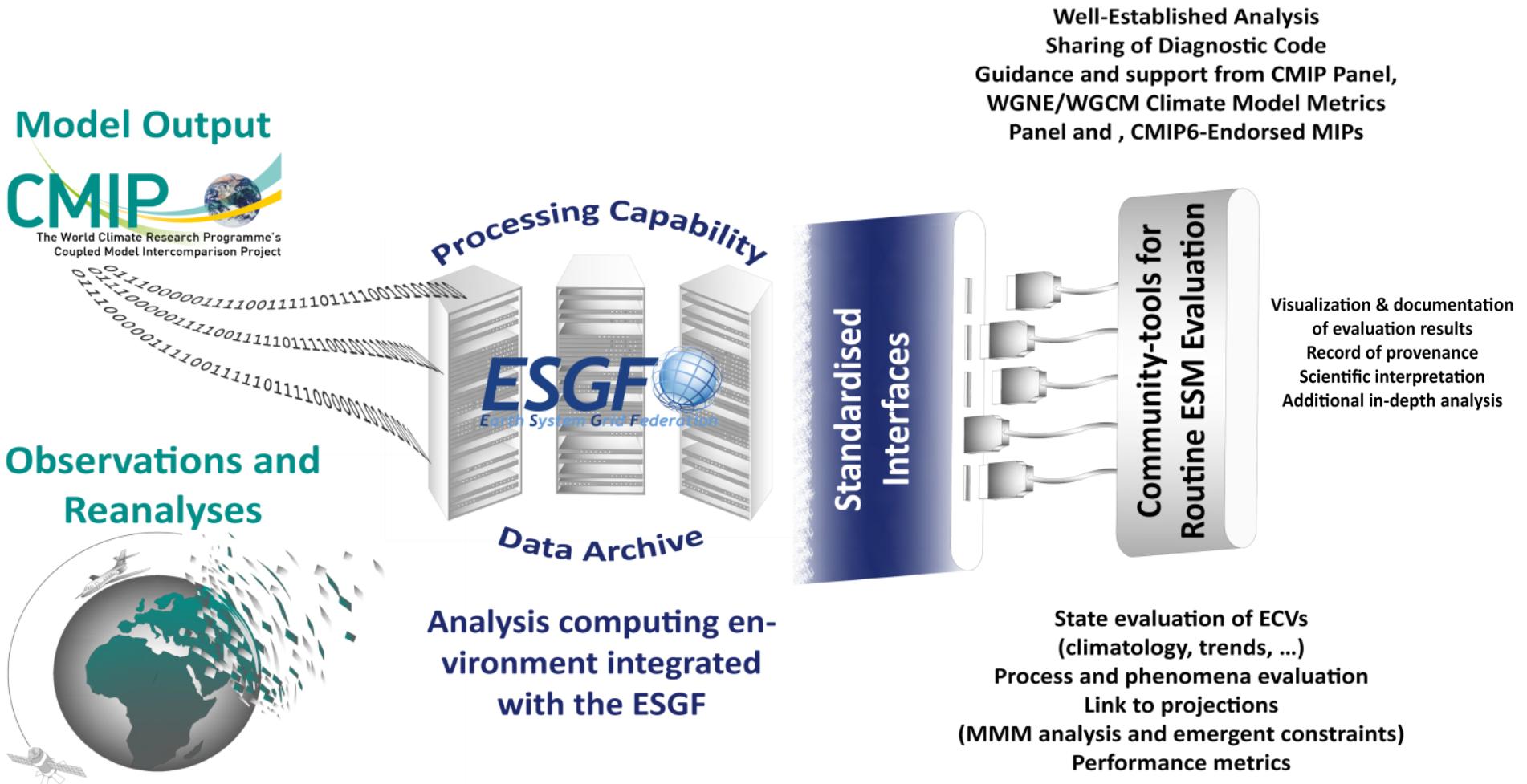
## Envisaged workflow for model evaluation in CMIP6

- More coordination of software efforts through development of **community evaluation tools** as open source software
- **Processing capabilities** at the ESGF nodes so that the tools can run **alongside the ESGF** as soon as the output is published
- Ensuring **traceability & reproducibility** of evaluation results
- Support for model development & assessments (via **quick and comprehensive feedback**)



# Routine Benchmarking and Evaluation – A central Part of CMIP6

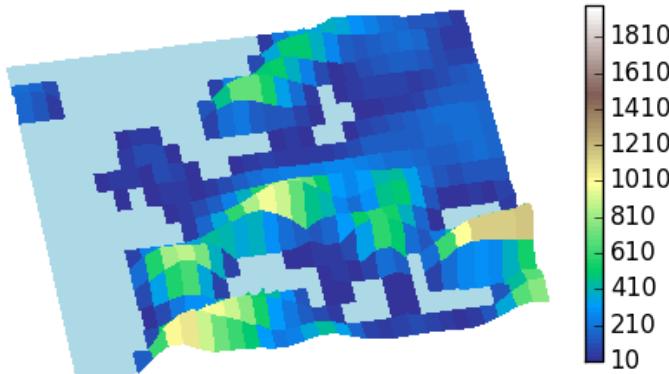
- Many aspects of ***ESM evaluation need*** to be performed much ***more efficiently***
- The resulting enhanced systematic characterization of models will identify ***strengths & weaknesses*** of the simulations ***more quickly and openly to the community***



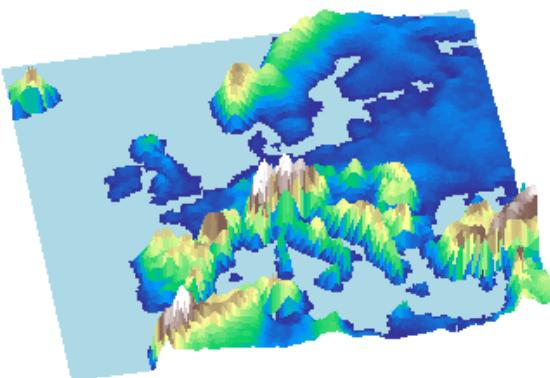
# Models are Increasing in Complexity and Resolution

From AOGCMs to Earth System Models  
with biogeochemical cycles, from lowres to highres

130 km resolution orography

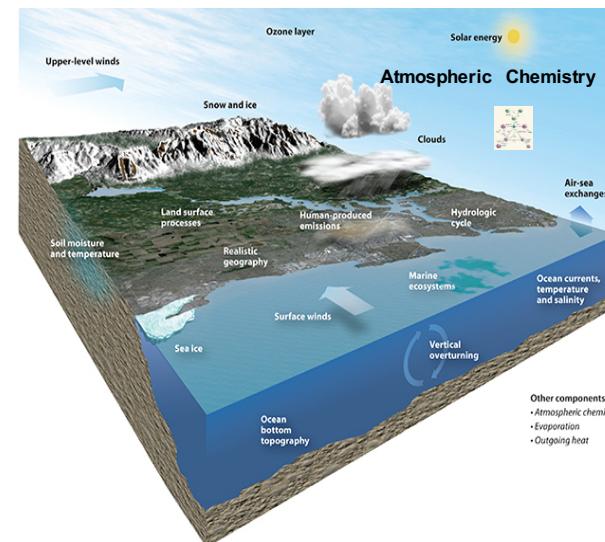


25 km resolution orography



I. Allows to study processes as horizontal resolution is increased to “weather-resolving” global model resolutions (~25km or finer)

II. Allows to study new physical & biogeochemical processes & feedbacks (e.g., carbon cycle, chemistry, aerosols, ice sheets)



**Increase in complexity and resolution  
More (and new) models participating in CMIP6**

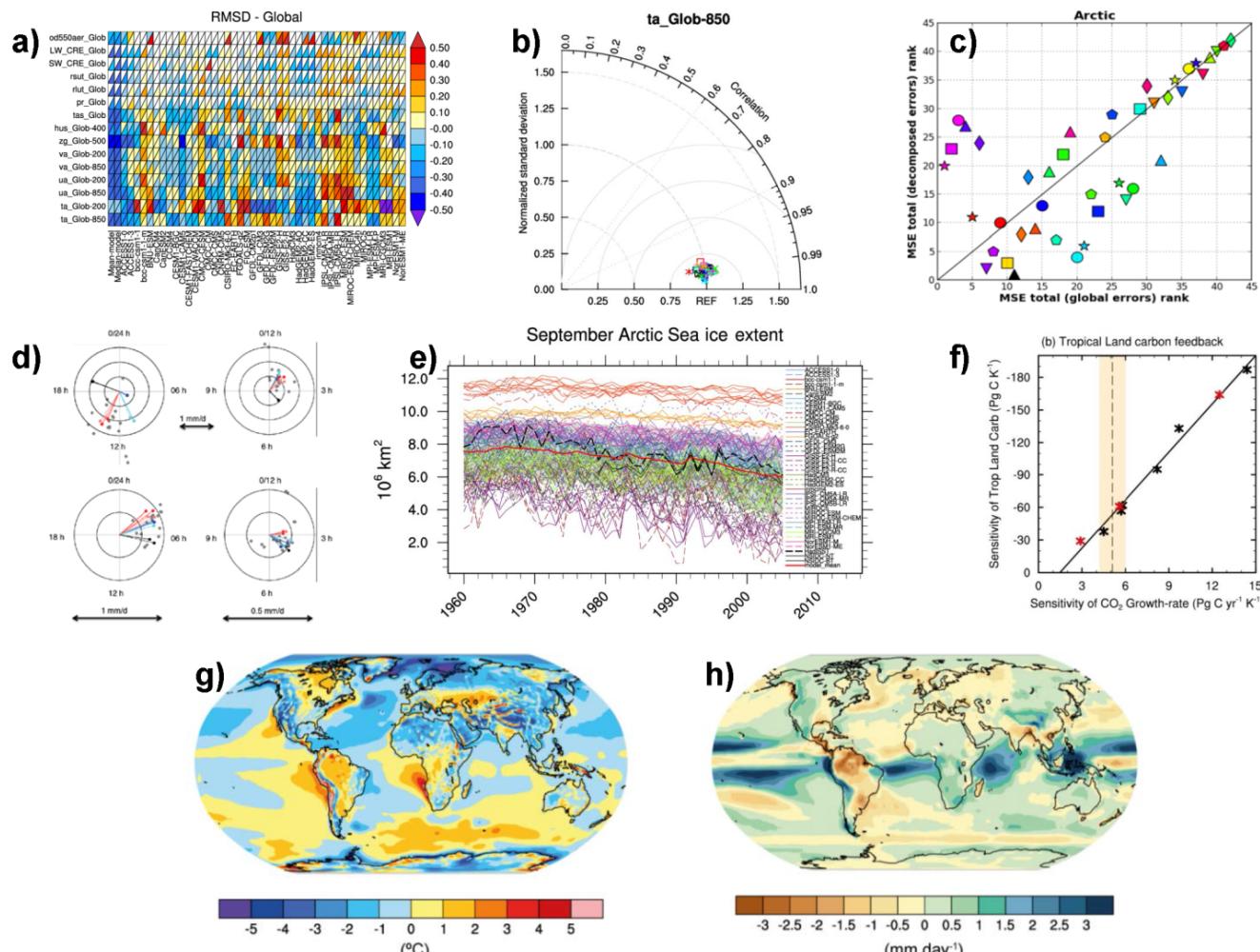
- Increase in data volume (from ~2PB in CMIP5 to ~20-40 PB in CMIP6)
- Large zoo of models in CMIP6

# How to evaluate the wide variety of models in CMIP6?

Community-tools that will be applied for routine evaluation of CMIP6 models:

- **Earth System Model Evaluation Tool (ESMValTool, Eyring et al., GMD (2016b) that includes other software packages such as the NCAR CVDP (Phillips et al., 2014)) and**
- **PCMDI Metrics Package (PMP, Gleckler et al., EOS (2016))**

To produce well-established analyses as soon as CMIP model output is available

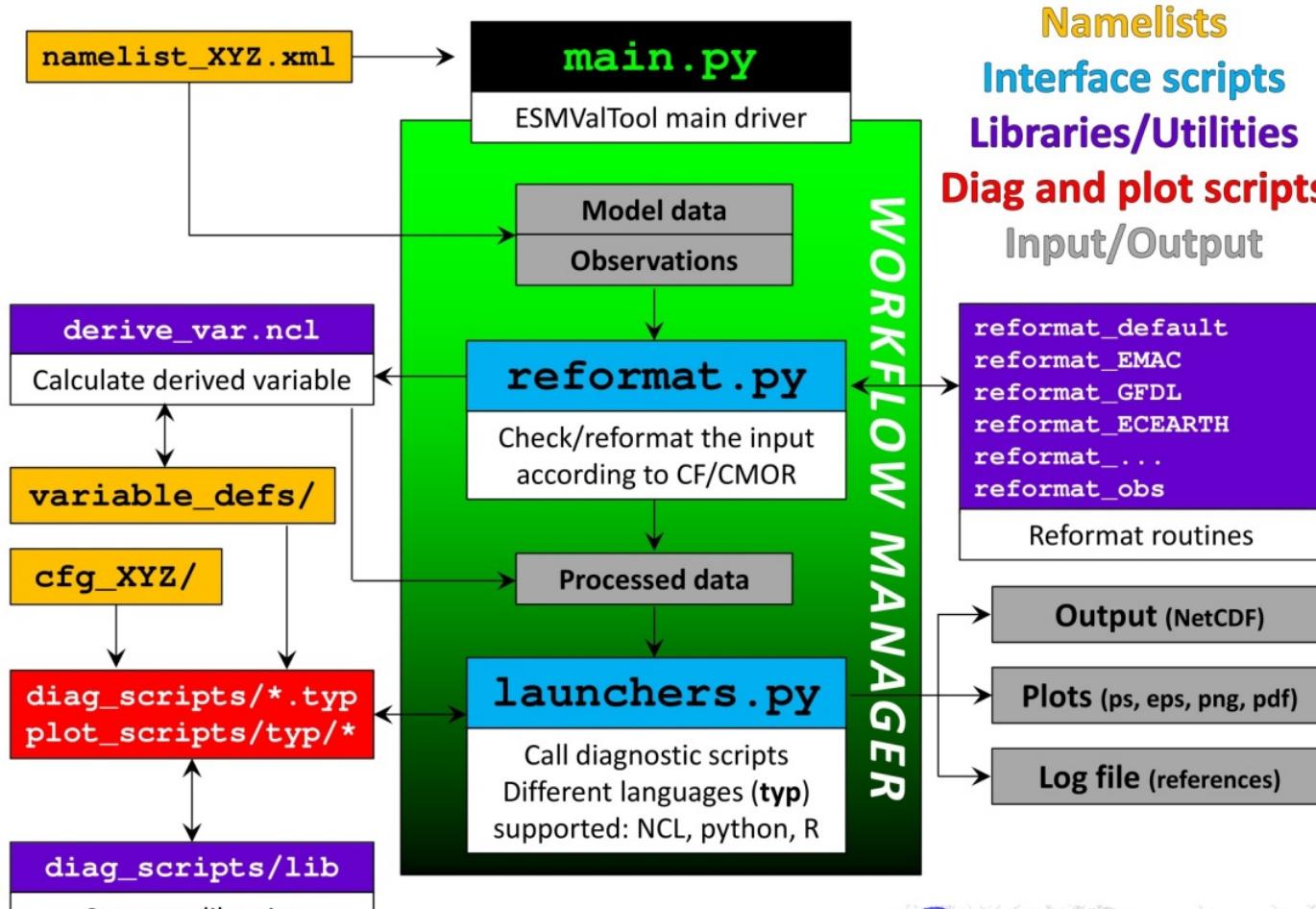


# ESMValTool integration into the ESGF Infrastructure

- A ***community diagnostic & performance metrics tool*** for routine evaluation of ESMs in CMIP
  - <https://www.esmvaltool.org> and <https://github.com/ESMValTool-Core/ESMValTool>
- **Community development** under a source controlled repository
  - Currently ~70 scientists part of the development team from ~30 institutions
  - Allows multiple developers from different institutions to contribute and join
  - Regular releases as open source software (latest release version 1.0.1)
- Allows ***traceability and reproducibility*** by preserving and logging metadata and details of analysis software
- **Goals:**
  - Improve ESM evaluation beyond the state-of-the-art
  - Reproducing well established and additional analyses
  - Routine evaluation of the CMIP DECK and historical simulations as soon as the output is published to the ESGF
  - Support of individual modelling centers:
    - ESMValTool integrated in local evaluation workflow (e.g. at GFDL)
    - Run the tool locally to compare to different model versions or other CMIP models
    - Run the tool locally before publication to the ESGF as quality control



# Software architecture of the ESMValTool

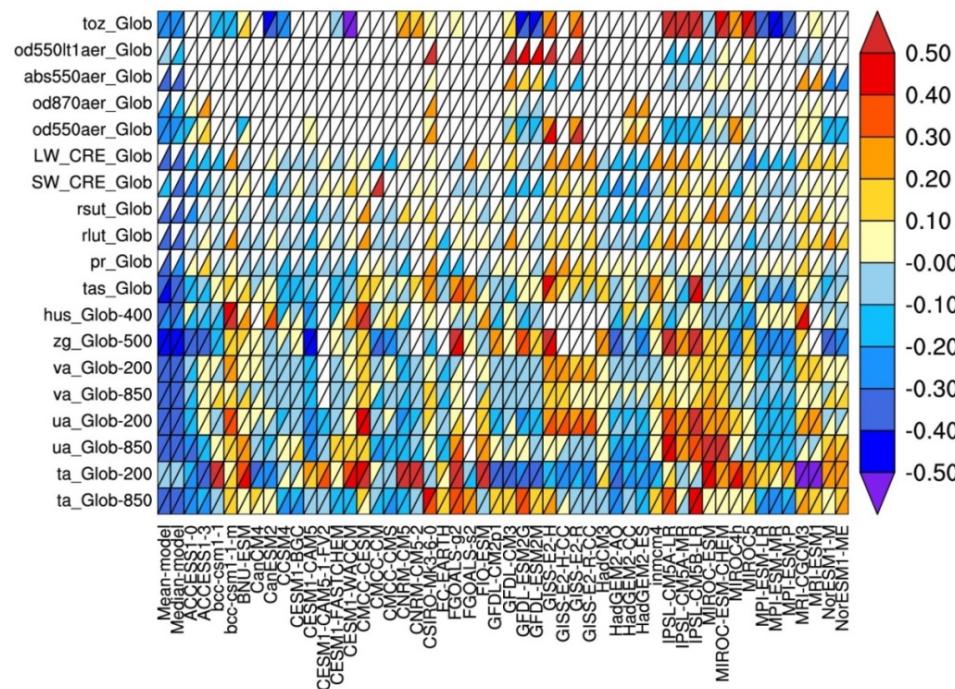


From: Eyring et al., ESMValTool v1.0, GMD, 2016

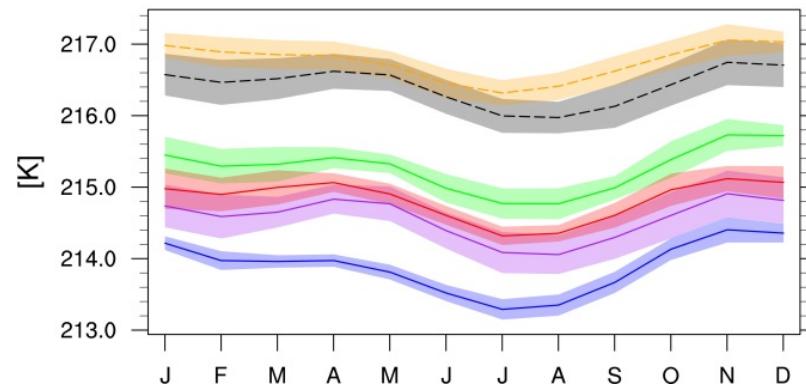


# Example Namelist – Performance Metrics

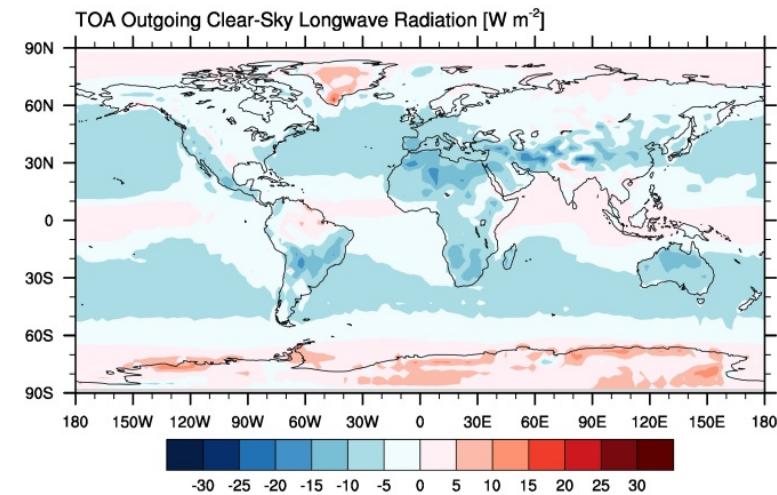
RMSD - Global



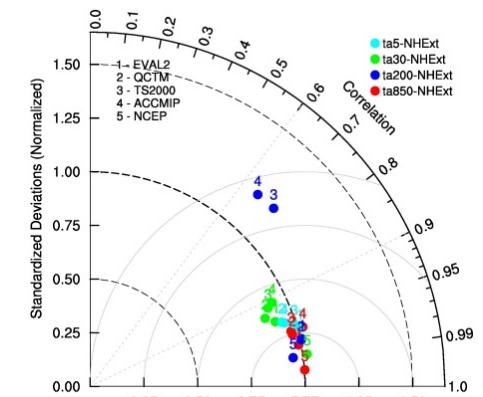
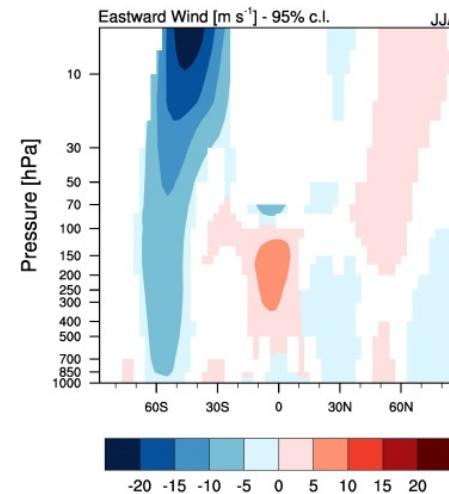
Air Temperature - Global - 30 hPa



EVAL2 - SRB

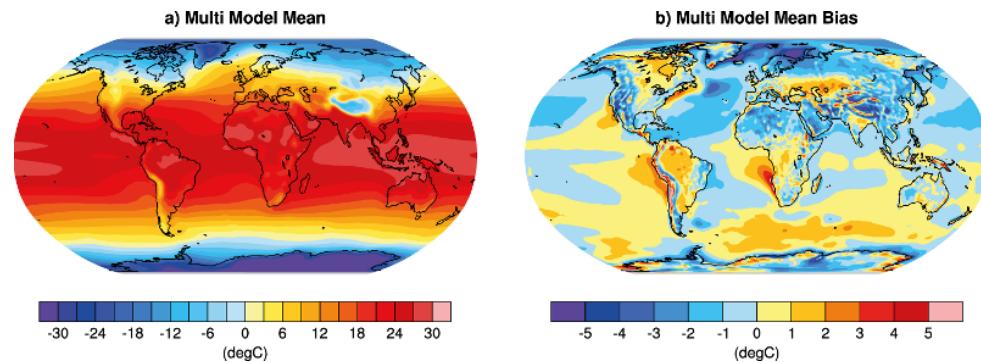


TS2000 - ERA-Interim



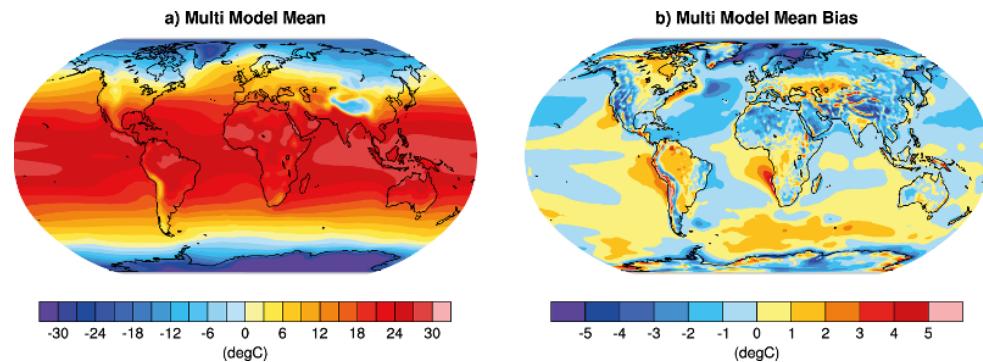
# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

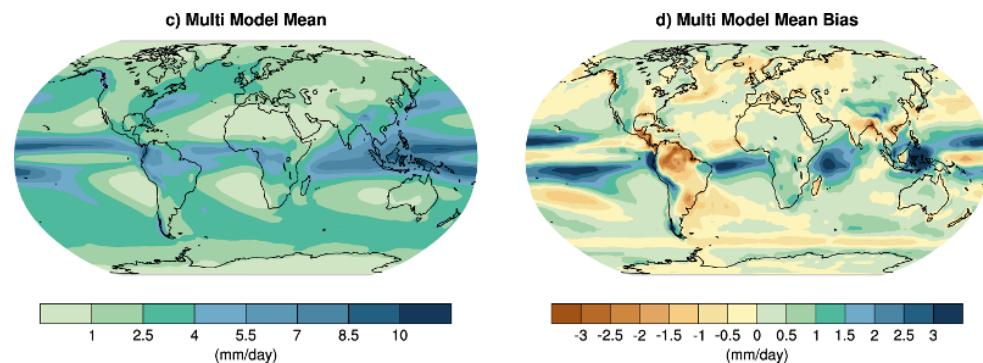


# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

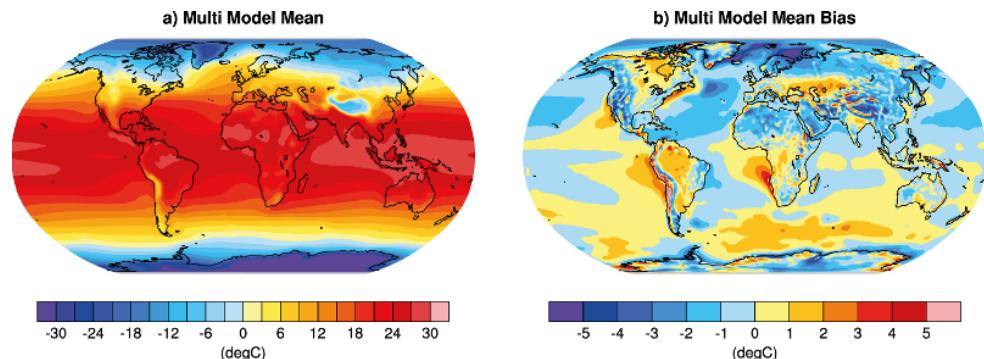


**Fig. 9.4**

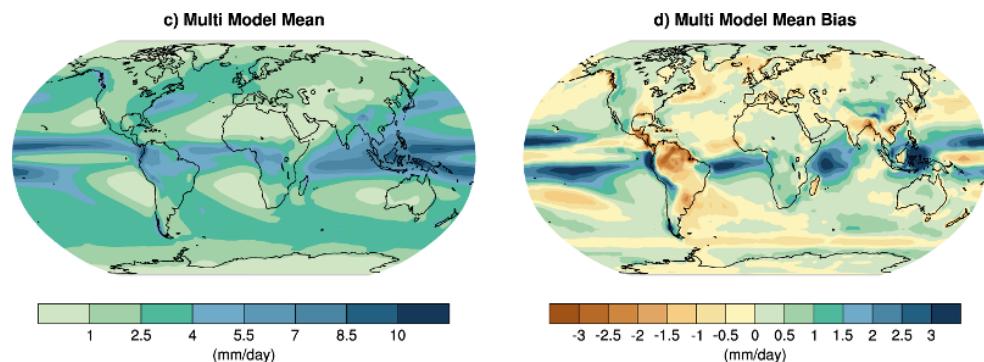


# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

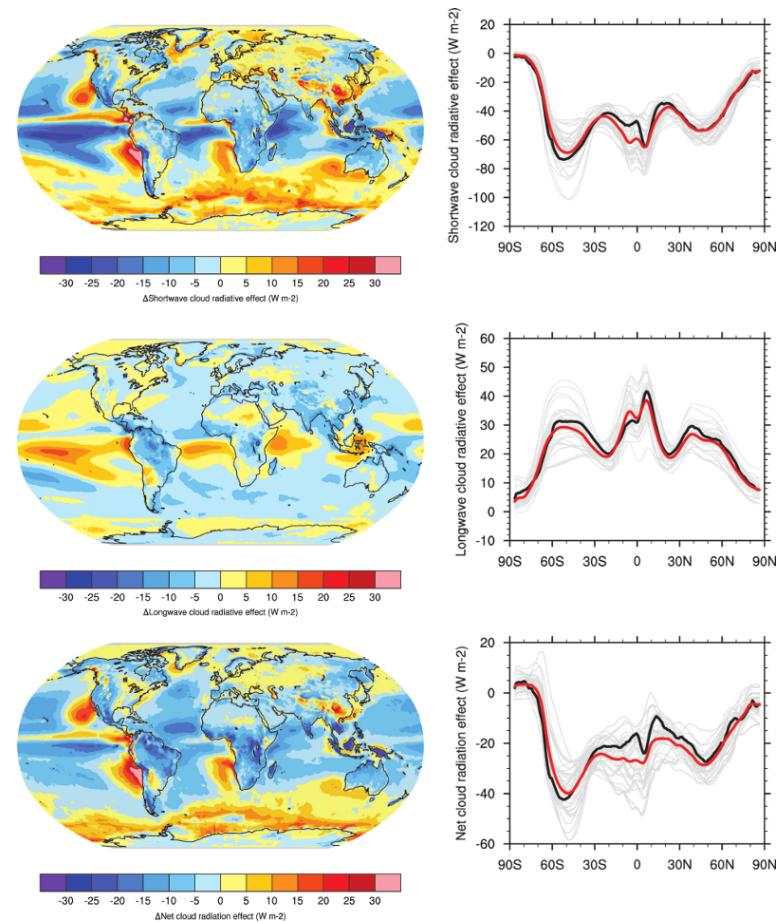
**Fig. 9.2**



**Fig. 9.4**

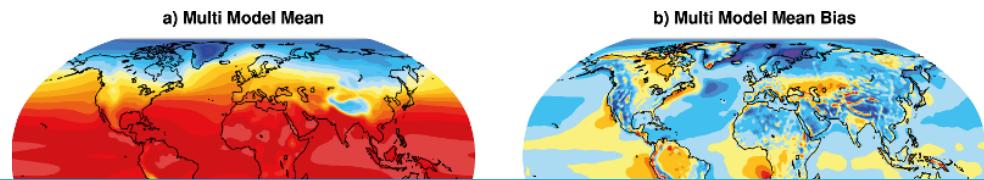


**Fig. 9.5**

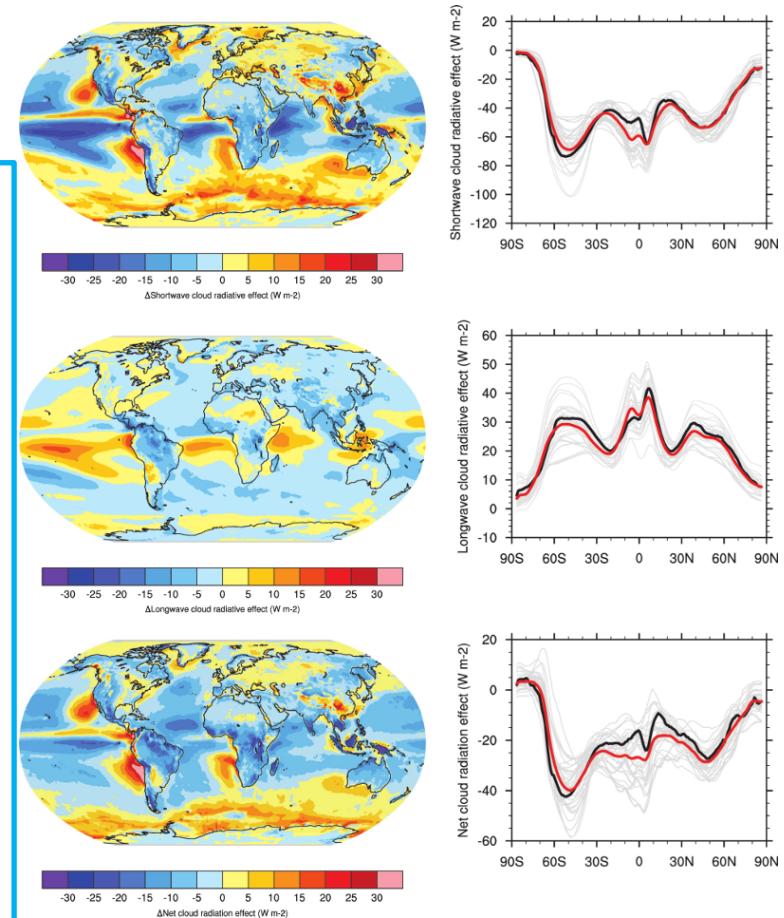


# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

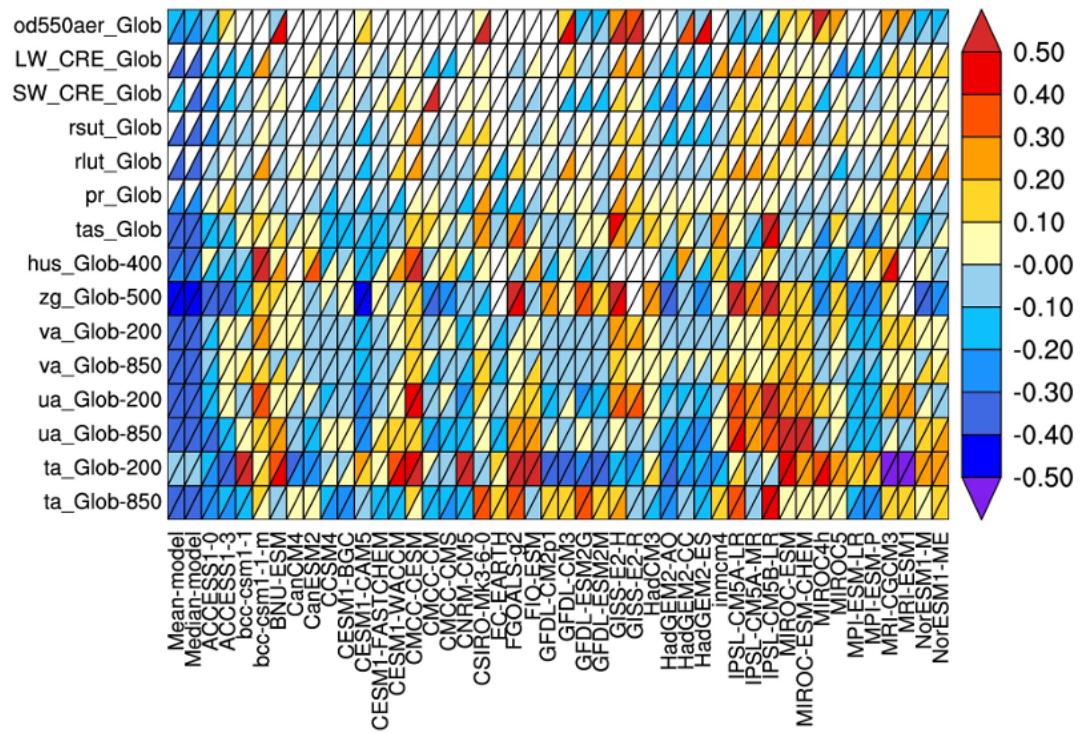


**Fig. 9.5**



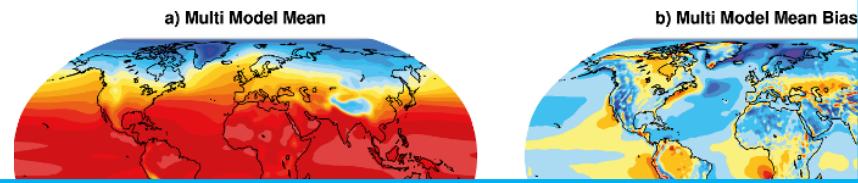
**Fig. 9.7**

RMSD - Global

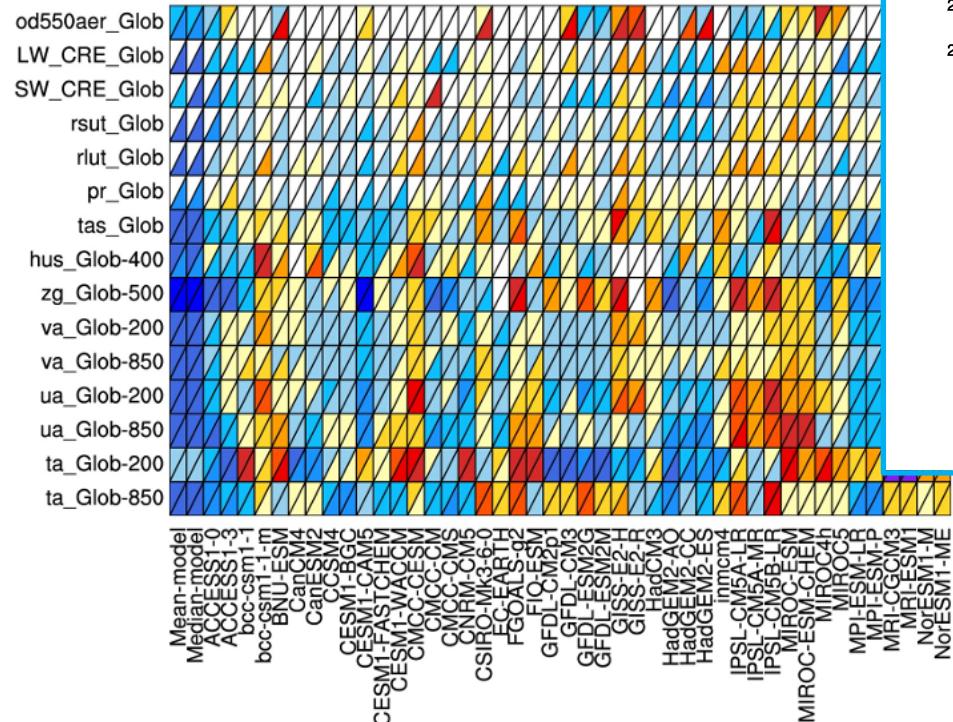


# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

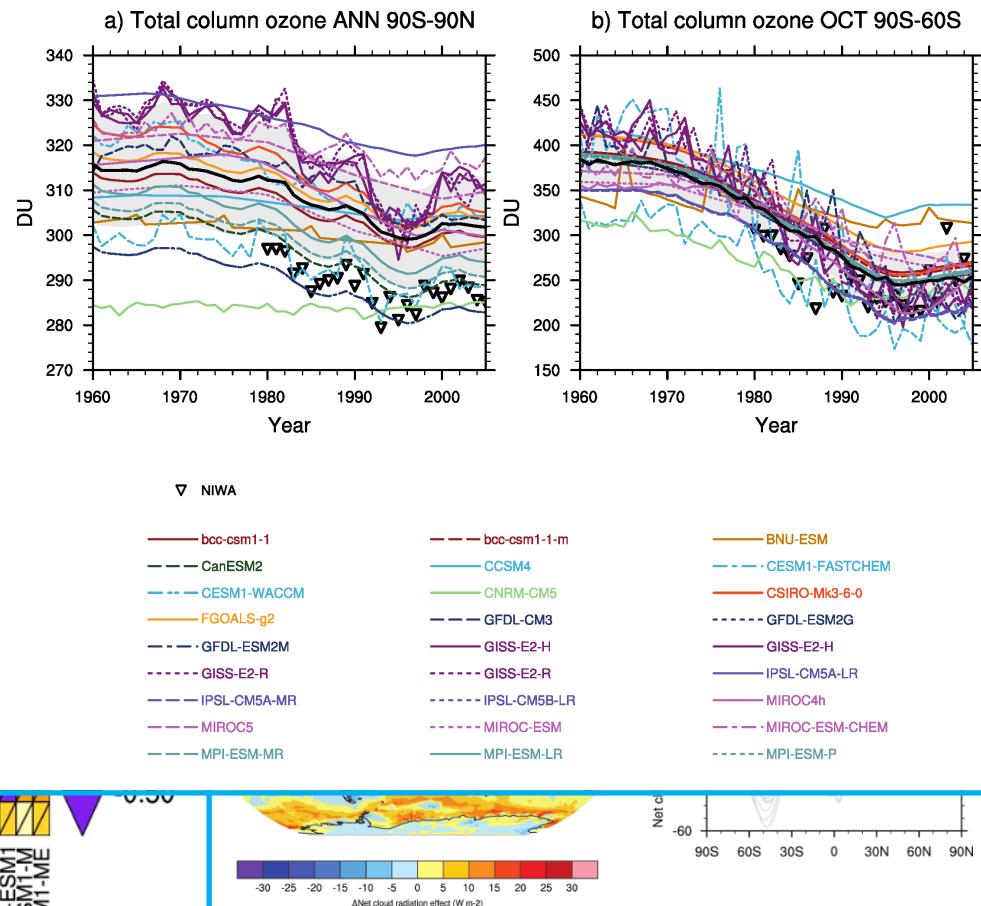
**Fig. 9.2**



**Fig. 9.7**  
RMSD - Global



**Fig. 9.10**



# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

a) Multi Model Mean

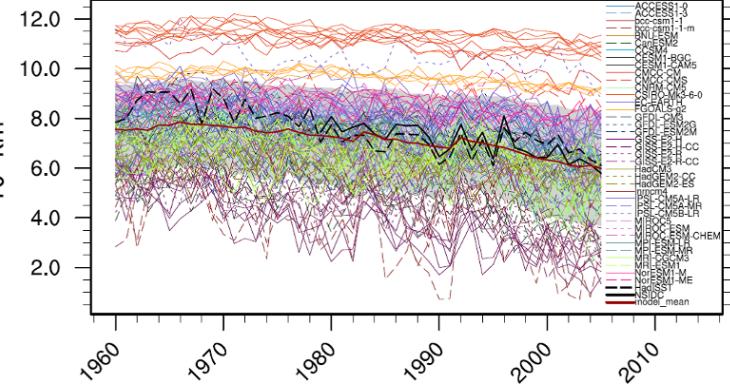
b) Multi Model Mean Bias

**Fig. 9.24**

September Arctic Sea Ice Extent

od550aer  
LW\_CRE  
SW\_CRE  
rsut  
rlut  
pr  
tas  
hus\_Glo  
zg\_Glo  
va\_Glob-200  
va\_Glob-850  
ua\_Glob-200  
ua\_Glob-850  
ta\_Glob-200  
ta\_Glob-850

$10^6 \text{ km}^2$

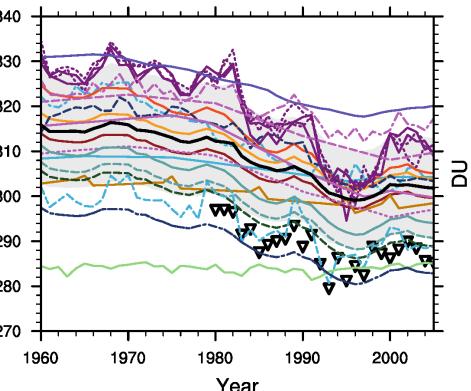


Mean-model  
Median  
ACCESM1  
bcc-csm1-1  
CanESM2  
CESM1  
CESM1-FASTCHEM  
CMOC  
CSIRO  
FGOALS-g2  
GFDL  
HadGEM2  
IPSL  
MIROC  
MIROC-ESM  
MIROC-ESM-CHEM  
MPI  
NorESM1-ME

**Fig. 9.10**

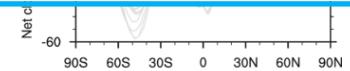
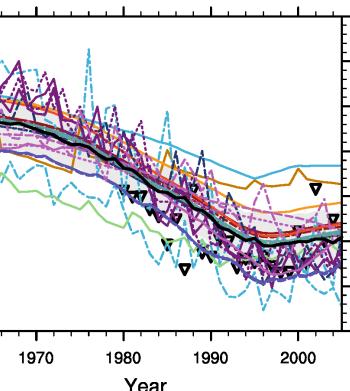
a) Total column ozone ANN 90S-90N

b) Total column ozone OCT 90S-60S



▽ NIWA

— bcc-csm1-1	— bcc-csm1-1-m	— BNU-ESM
— CanESM2	— CCSM4	— CESM1-FASTCHEM
— CESM1-WACCM	— CNRM-CM5	— CSIRO-MK3-6-0
— FGOALS-g2	— GFDL-CM3	— GFDL-ESM2G
— GFDL-ESM2M	— GISS-E2-H	— GISS-E2-H
— GISS-E2-R	— GISS-E2-R	— IPSL-CM5A-LR
— IPSL-CM5A-MR	— IPSL-CM5B-LR	— MIROC4h
— MIROC5	— MIROC-ESM	— MIROC-ESM-CHEM
— MPI-ESM-MR	— MPI-ESM-P	— MPI-ESM-P



# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

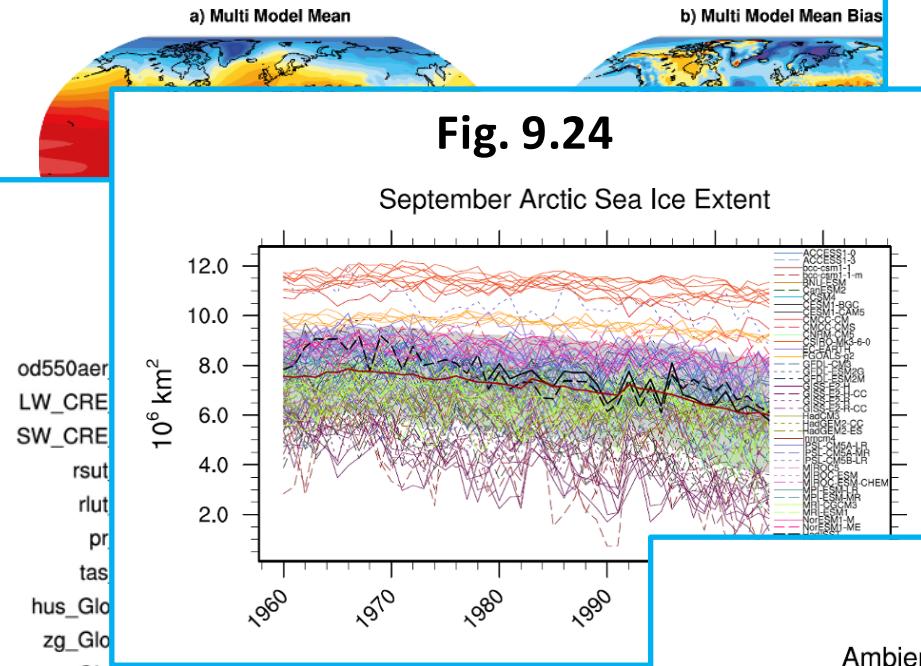
**Fig. 9.2**

a) Multi Model Mean

b) Multi Model Mean Bias

**Fig. 9.24**

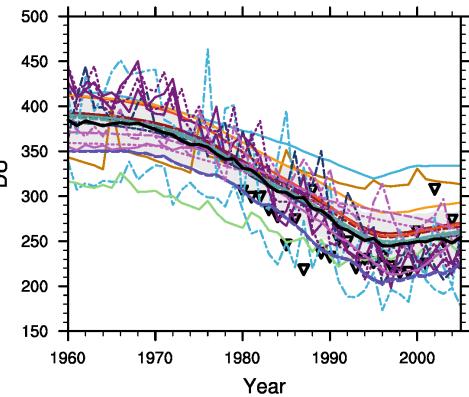
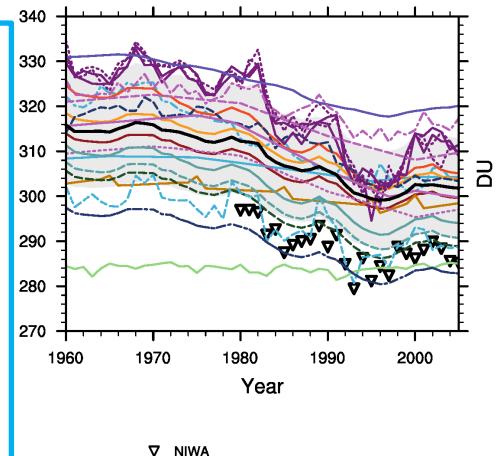
September Arctic Sea Ice Extent



**Fig. 9.10**

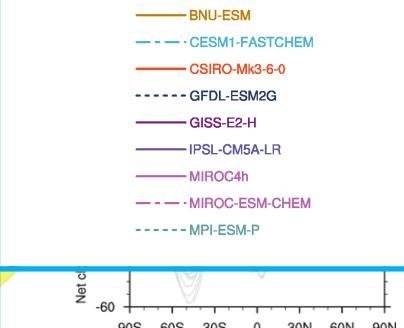
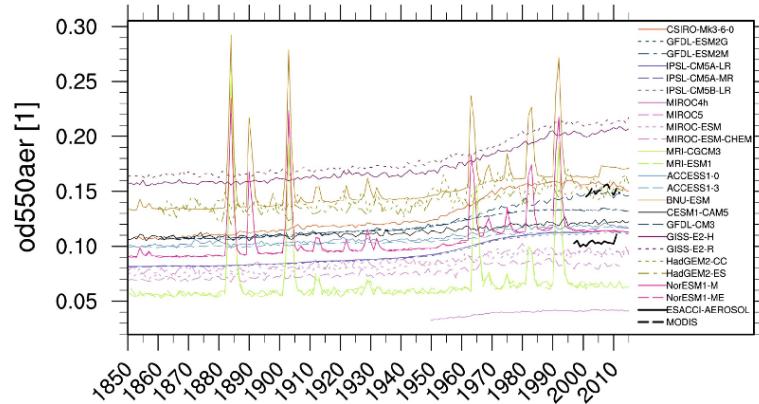
a) Total column ozone ANN 90S-90N

b) Total column ozone OCT 90S-60S



**Fig. 9.23**

Ambient Aerosol Optical Thickness at 550 nm



# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

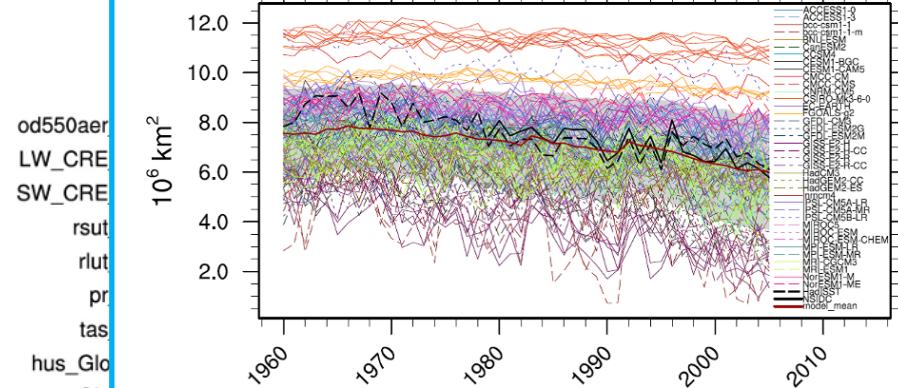
a) Multi Model Mean

b) Multi Model Mean Bias



**Fig. 9.24**

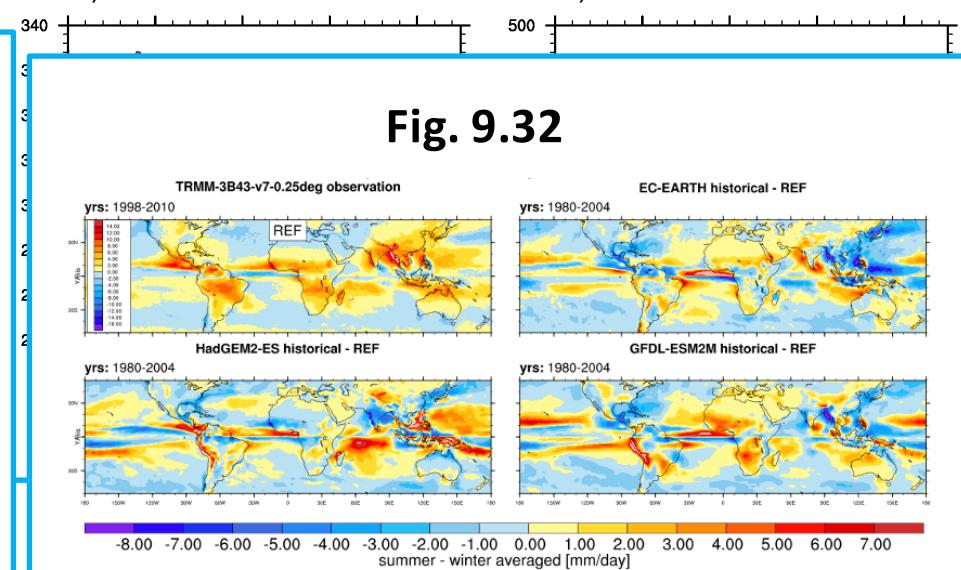
September Arctic Sea Ice Extent



**Fig. 9.10**

a) Total column ozone ANN 90S-90N

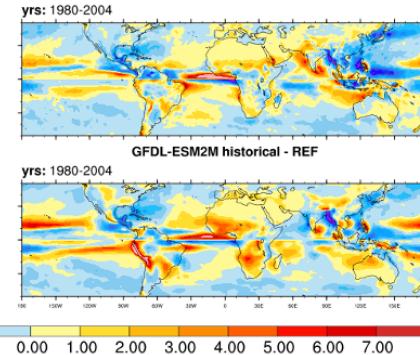
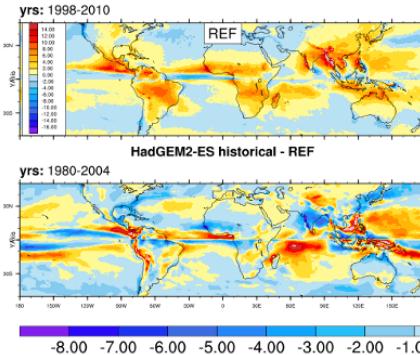
b) Total column ozone OCT 90S-60S



**Fig. 9.32**

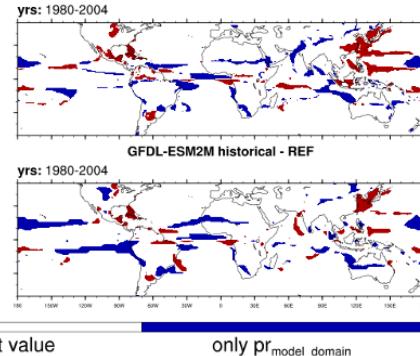
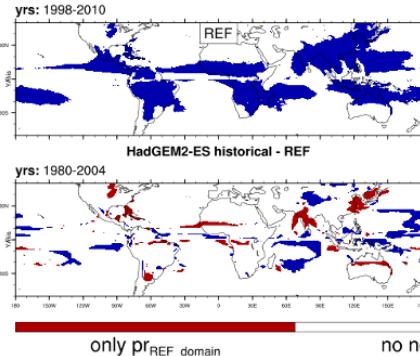
TRMM-3B43-v7-0.25deg observation

EC-EARTH historical - REF



TRMM-3B43-v7-0.25deg observation

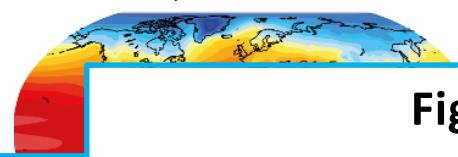
EC-EARTH historical - REF



# Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

**Fig. 9.2**

a) Multi Model Mean

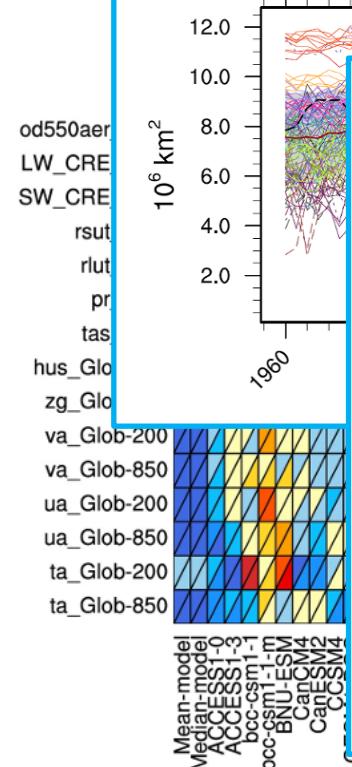


b) Multi Model Mean Bias

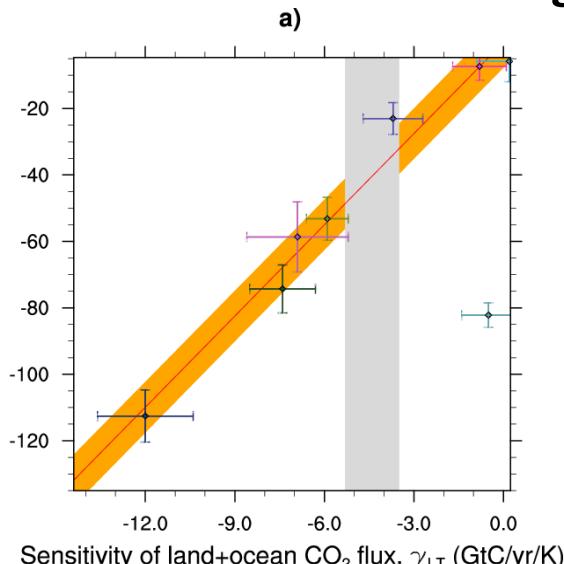


**Fig. 9.24**

September Arctic Sea Ice Extent



Carbon Cycle Climate Feedback,  $\gamma_{LT}$  (GtC/K)

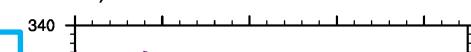


CESM1  
CS  
GFDL  
GHCN  
HadGEM2-  
MIROC3-  
2-T42  
MIROC4-  
2.3-  
20c  
MIROC5  
MRI-CGCM2-  
A213  
MRI-CGCM3-  
A  
MRI-  
E21  
UKMO-  
HadGEM2-  
A30  
UKMO-  
HadGEM2-  
A31

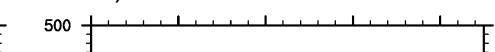
1850 1860 1870 1880 1890 1900

**Fig. 9.10**

a) Total column ozone ANN 90S-90N



b) Total column ozone OCT 90S-60S



**Fig. 9.32**

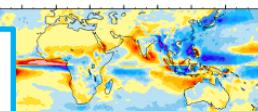
TRMM-3B43-v7-0.25deg observation

yrs: 1998-2010

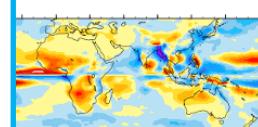
REF

yrs: 1980-2004

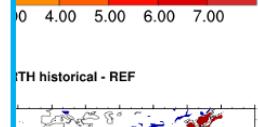
EC-EARTH historical - REF



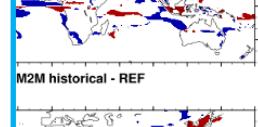
SM2M historical - REF



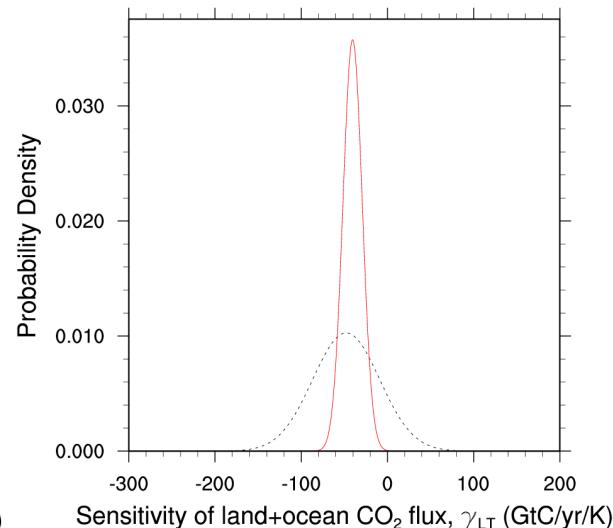
ETH historical - REF



M2M historical - REF



**Fig. 9.45**



only pr<sub>REF\_domain</sub>

no net value

Model domain minus reference domain

only pr<sub>model\_domain</sub>



# Examples of ESMValTool Namelists implemented so far

Emphasis on *diagnostics & metrics* with demonstrated importance for ESM evaluation

## Physics

- Clouds
- Cloud regime error metric (CREM)
- Diurnal cycle of convection
- Evapotranspiration
- Madden-Julian Oscillation (MJO)
- Performance metrics for essential climate parameters
- South Asian monsoon
- Southern Hemisphere
- Standardized precipitation index (SPI)
- Tropical variability
- West African monsoon
- Extreme events (in progress)
- Regional diagnostics (in progress)

## Atmospheric composition

- Aerosol
- Land and ocean components of the global carbon cycle
- Emergent constraints on carbon cycle feedbacks
- Ozone and associated climate impacts
- Ozone and some precursors

## Ocean

- Marine biogeochemistry
- NCAR climate variability diagnostics package (CVDP)
- Southern Ocean

## Cryosphere

- Sea ice

## Land

- Catchment analysis

## General

- IPCC AR5 chapter 9 and 12 (in progress)

# Reproducibility & Traceability of evaluation results

## Namelist

Evaluation analysis is controlled by the namelist file that defines the internal workflow for the desired analysis.

It defines:

- **Input datasets** (observations, models)
- **Regridding** operation (if needed)
- Set of **diagnostics**
- Misc. (output formats, output folder, etc...)

## Output files (NetCDF)

Contain meta data from input files and meta data generated by ESMValTool

## Observational data

- Well defined processing chain
- creation of metadata

## Logfile

At each execution of the tool a log file is automatically created

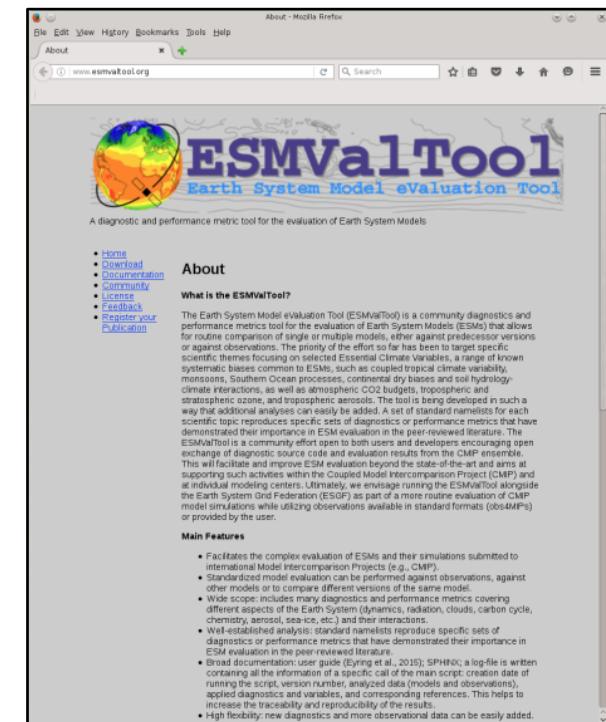
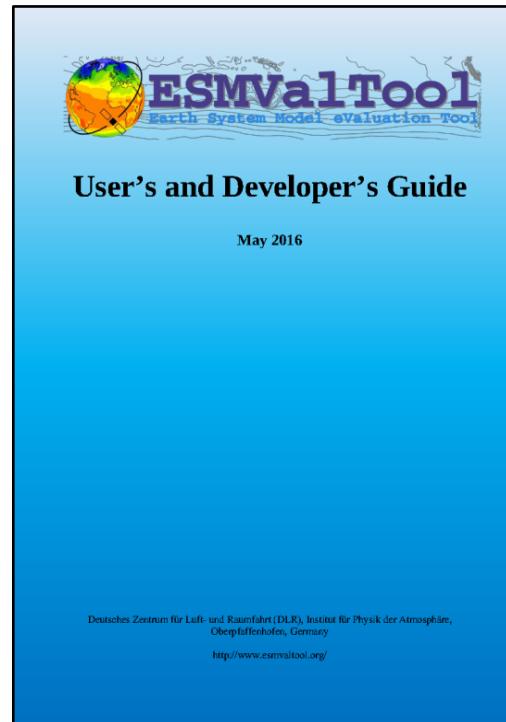
The log file contains:

- The list of **all input data** which have been used (version, data source, etc.)
- The list of **variables** that have been processed
- The list of **diagnostics** that have been applied
- The list of **authors and contributors** to the given diagnostic, together with the relevant references and projects
- Software **version** of ESMValTool that was used



# ESMValTool version 1.0

- [www.esmvaltool.org](http://www.esmvaltool.org)
- Eyring et al., *Geosci. Model Dev.*, 2016
- [www.github.com/ESMValTool-Core/ESMValTool](https://github.com/ESMValTool-Core/ESMValTool)
- doi:10.17874/ac8548f0315



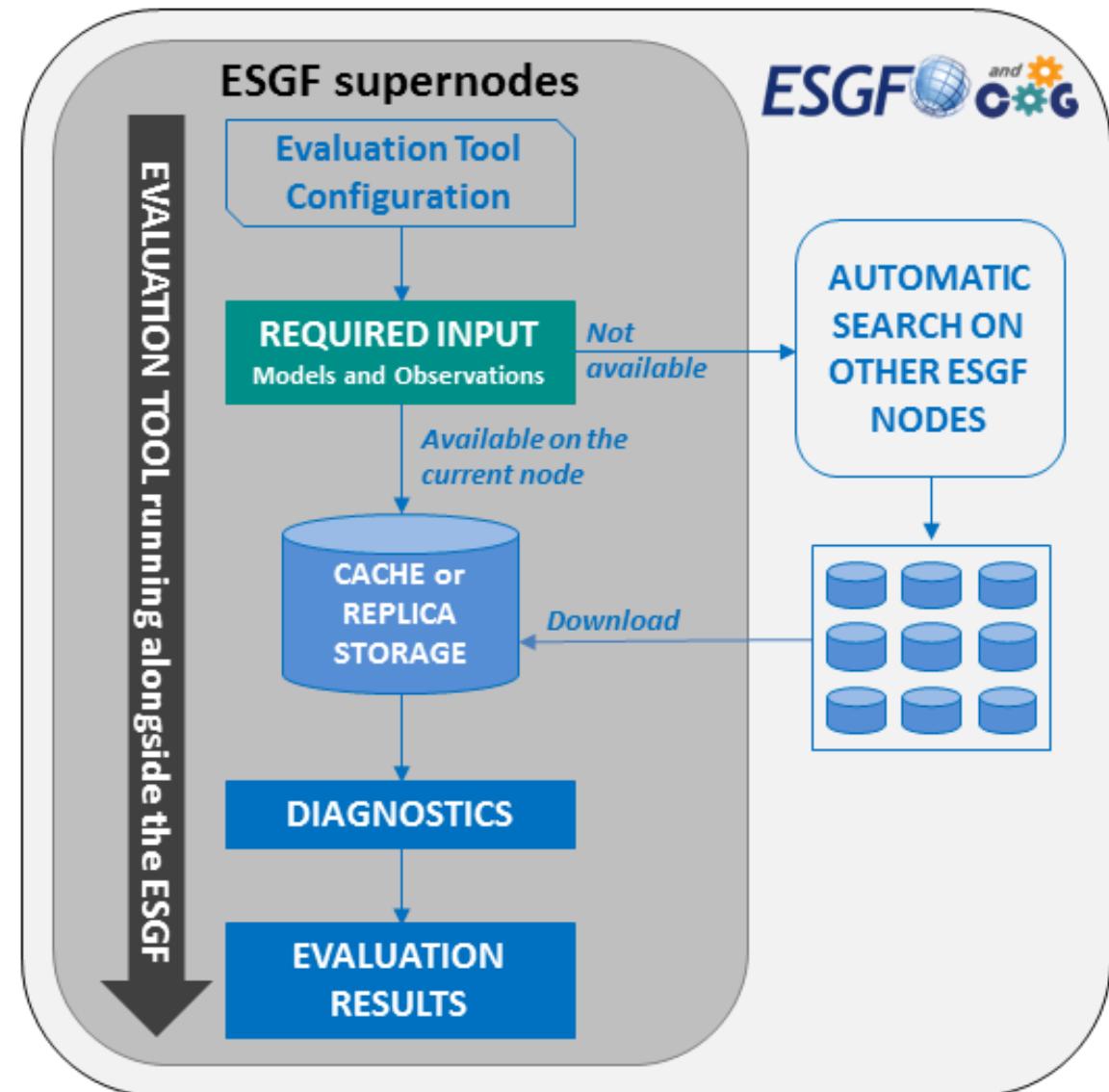
# Routine Benchmarking and Evaluation in CMIP6

Due to the **high volume of the data** in CMIP6, ESGF replication is likely to be **slow** (took months in CMIP5)

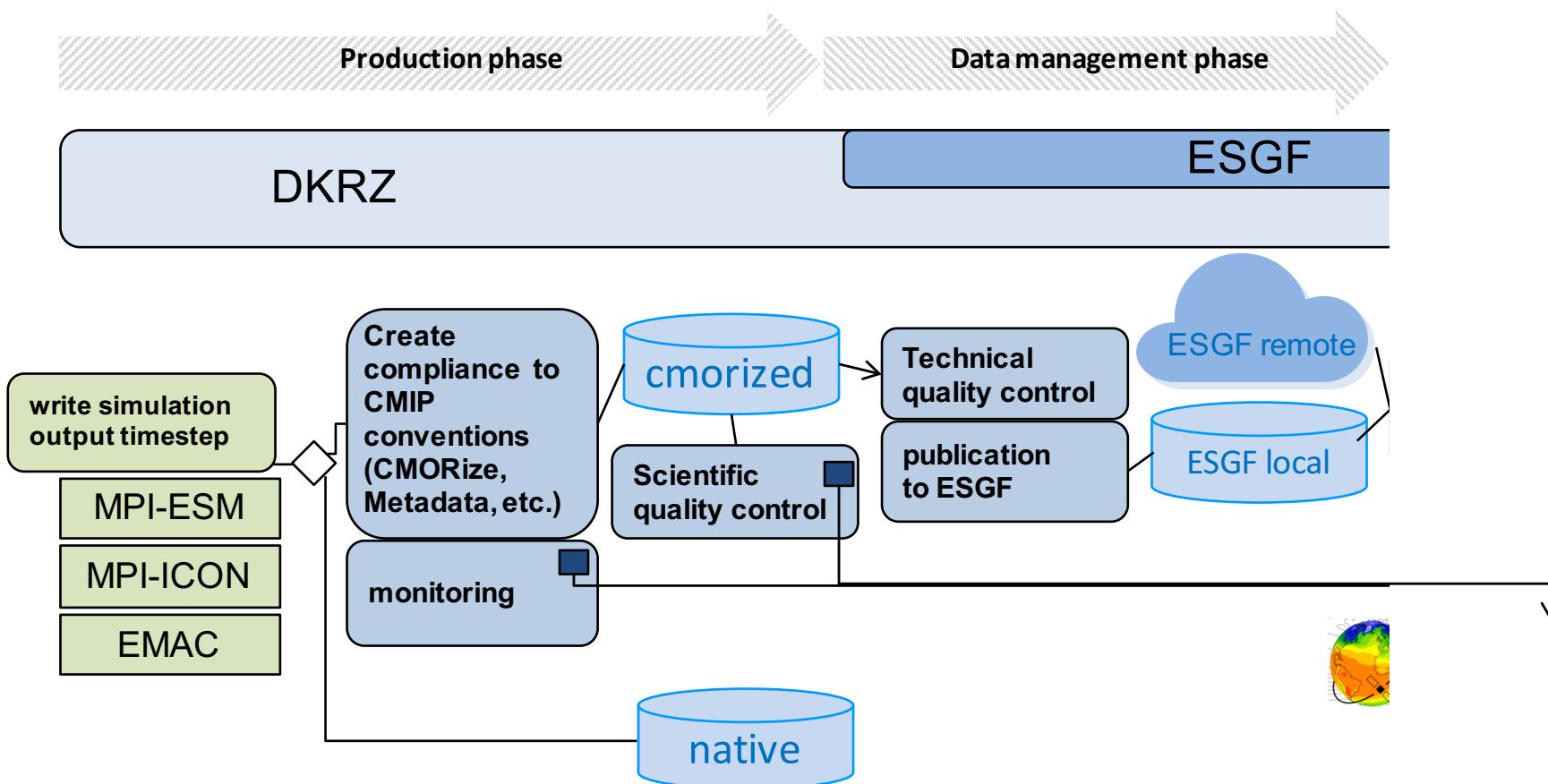
It was therefore recommended to the ESGF teams that the **data used by the CMIP evaluation tools** be replicated with **higher priority**.

This should substantially **speed up** the evaluation of model results after submission of the simulation output to the ESGF

*Eyring et al., ESD, in rev.. (2016)*

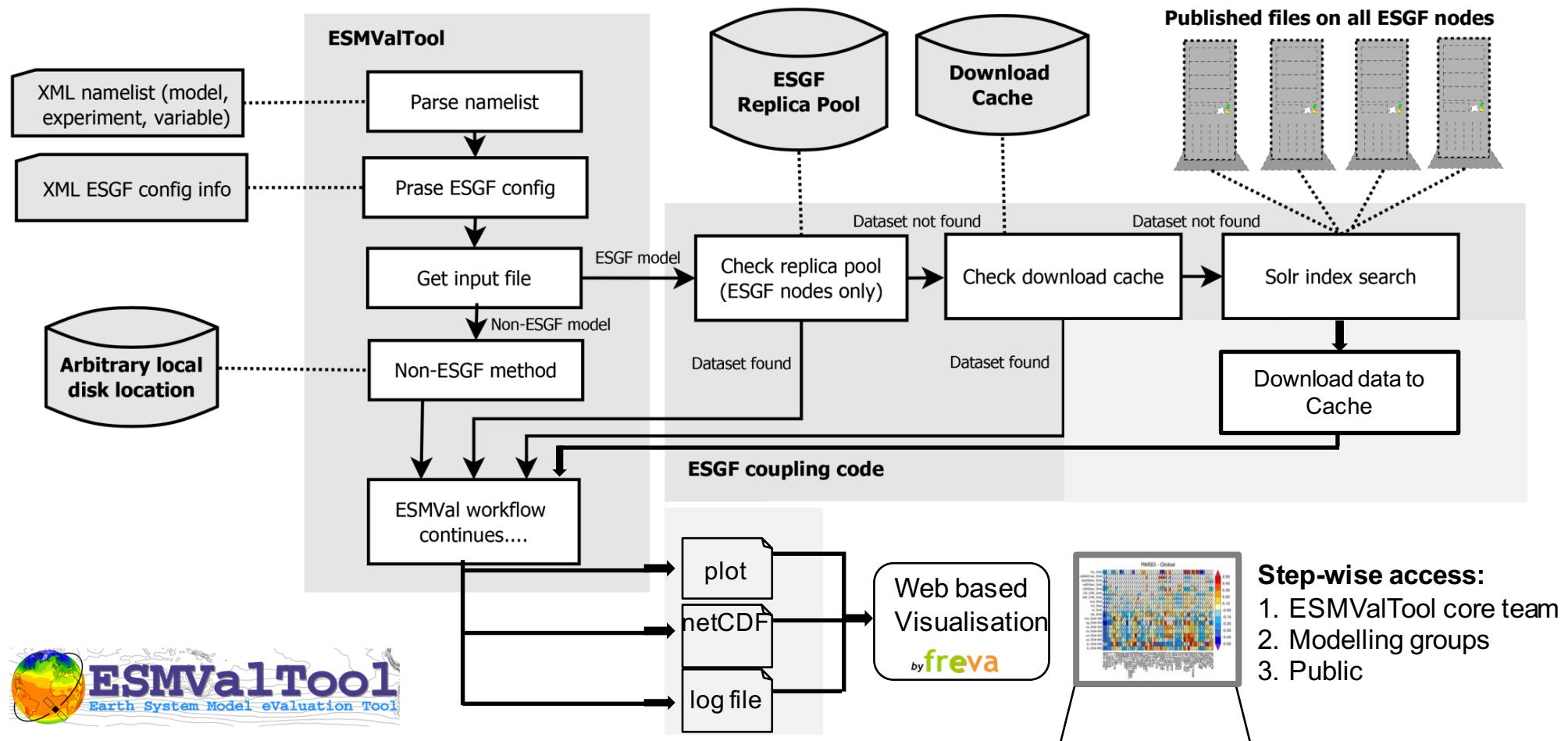


# Example for extended CMIP6 Workflow with the ESMValTool at the DKRZ\*



\*Defined in the Project CMIP6-DICAD  
freva: <https://freva.met.fu-berlin.de>

# ESMValTool Workflow for routine evaluation at the ESGF (CMIP6-DICAD)



Derived from: Eyring et al., ESMValTool v1.0, GMD, 2016



# Challenges for CMIP6

- Getting the new CMIP6 data fast
  - Discovery via ESGF/DKRZ metadata search engine
  - Possibility of using OPeNDAP
- Queuing
  - Scheduling of diagnostics according to data availability
  - Minimize idle time
- Fault tolerance
  - In case replication/(remote) data access fails decide to retry or abort the affected diagnostic without stopping the rest
  - In case of failure tool should restart where it stopped
- Parallel computation (development)
  - Multinode parallelization due to data intense tasks
- Distributed computing (possibly future phases of CMIP)
  - Optimal for data intense computation on distributed storage
  - But infrastructure for grid computing missing



# Summary

- **Routine evaluation of CMIP simulations with community-based tools like the ESMValTool are needed to:**
  - Advance scientific understanding more efficiently (less re-inventing the wheel)
  - Facilitate model development (via quick feedback) and benchmarking
  - Contribute to a variety of applications (including Climate Assessment Reports)
- **The CMIP infrastructure and conventions allow for routine evaluation**
- **Workflows are defined for different steps**
  - Quality control of MPI-ESM/ICON/EMAC during the simulation
  - Quality control before submission to the ESGF
  - Evaluation of CMIP6 ensemble as soon as the output is published to the ESGF
- **ESMValTool will be run alongside selected ESGF supernodes (e.g. DKRZ, BADC) to evaluate CMIP6 models as soon as the output is published to ESGF**



# Thank you

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