Workflow for routine evaluation of CMIP6 models with the ESMValTool

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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

Eyring et al., ESD, in rev. (2016)
Models are Increasing in Complexity and Resolution
From AOGCMs to Earth System Models
with biogeochemical cycles, from lowres to highres

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)

130 km resolution orography

25 km resolution orography

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](https://www.esmvaltool.org) and [https://github.com/ESMValTool-Core/ESMValTool](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

EVAL2 - SRB

TOA Outgoing Clear-Sky Longwave Radiation [W m⁻²]

Air Temperature - Global - 30 hPa

TS2000 - ERA-Interim

Eastward Wind [m s⁻¹] - 95% c.l.
Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2

a) Multi Model Mean

b) Multi Model Mean Bias
Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2

a) Multi Model Mean

b) Multi Model Mean Bias

Fig. 9.4

c) Multi Model Mean

d) Multi Model Mean Bias
Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2
a) Multi Model Mean

Fig. 9.4
c) Multi Model Mean

Fig. 9.5
b) Multi Model Mean Bias

d) Multi Model Mean Bias

Chart 11

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Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2
a) Multi Model Mean

Fig. 9.4
b) Multi Model Mean Bias

Fig. 9.7
RMSD - Global

Fig. 9.5
Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2
a) Multi Model Mean
b) Multi Model Mean Bias

Fig. 9.7
RMSD - Global

Fig. 9.10
a) Total column ozone ANN 90S-90N
b) Total column ozone OCT 90S-60S

Example Namelist:
- IPCC AR5
- Climate Model Evaluation Chapter
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

Example Namelist:
- IPCC AR5
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Example Namelist: IPCC AR5 Climate Model Evaluation Chapter

Fig. 9.2

Fig. 9.4

Fig. 9.7

Fig. 9.10

Fig. 9.24

September Arctic Sea Ice Extent

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

- od550aer
- LW_CRE
- SW_CRE
- rsut
- ruit
- pr
- tas
- hus_Glob
- zg_Glob
- va_Glob-200
- va_Glob-850
- ua_Glob-200
- ua_Glob-850
- ta_Glob-200
- ta_Glob-850

**Fig. 9.32**

- TRMM-3B43-v7-0.25deg observation
- HadGEM2-ES historical - REF
- GFDL-ESM2M historical - REF

- only p<sub>REF</sub> domain
- no net value
- Model domain minus reference domain

**Fig. 9.10**

a) Total column ozone ANN 90S-90N

b) Total column ozone OCT 90S-60S
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
EC-EARTH historical - REF

Fig. 9.45
a) Sensitivity of land+ocean CO₂ flux, $\gamma_{LT}$ (GtC/yr/K)
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
- Eyring et al., Geosci. Model Dev., 2016
- www.github.com/ESMValTool-Core/ESMValTool
- doi:10.17874/ac8548f0315
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*

Production phase

DKRZ

Data management phase

ESGF

write simulation output timestep

MPI-ESM

MPI-ICON

EMAC

Create compliance to CMIP conventions (CMORize, Metadata, etc.)

cmorized

Scientific quality control

monitoring

Technical quality control

publication to ESGF

ESGF remote

ESGF local

native

*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


