

Earth System Model Evaluation Tool (ESMValTool)

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AGCI Session

Earth System Model Evaluation to Improve Process Understanding

July 30 – August 4, 2017

Aspen, CO

Knowledge for Tomorrow



CMIP6: Participating Model Groups

	Institution	Country		Institution	Country		Institution	Country
1	AWI	Germany	12	DOE	USA	23	MRI	Japan
2	BCC	China	13	EC-Earth-Cons	Europe	24	NASA-GISS	USA
3	BNU	China	14	FGOALS	China	25	NCAR	USA
4	CAMS	China	15	FIO-RONM	China	26	NCC	Norway
5	CasESM	China	16	INM	Russia	27	NERC	UK
6	CCCma	Canada	17	INPE	Brazil	28	NIMS-KMA	Republic of Korea
7	CCCR-IITM	India	18	IPSL	France	29	NOAA-GFDL	USA
8	CMCC	Italy	19	MESSY-Cons	Germany	30	NUIST	China
9	CNRM	France	20	MIROC	Japan	31	TaiESM	Taiwan, China
10	CSIR-CSIRO	South Africa	21	MOHC	UK	32	THU	China
11	CSIRO-BOM	Australia	22	MPI-M	Germany	33	Seoul Nat.Uni	Republic of Korea

New in CMIP:

- 2 new model groups from Germany (AWI, MESSY-Consortium)
- 4 new model groups from China (CAMS, CasESM, NUIST, THU)
- 1 new model group from Brazil (INPE)
- 1 new model group from India (CCCR-IITM)
- 1 new model group from Taiwan, China (TaiESM)
- 1 new model group from USA (DOE)
- 2 new model group from Republic of Korea (NIMS-KMA, SAM0-UNICON)
- 1 new model group from South Africa / Australia (CSIR-CSIRO)

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13 new model groups so far

* Other models can join providing DECK and historical simulations are submitted

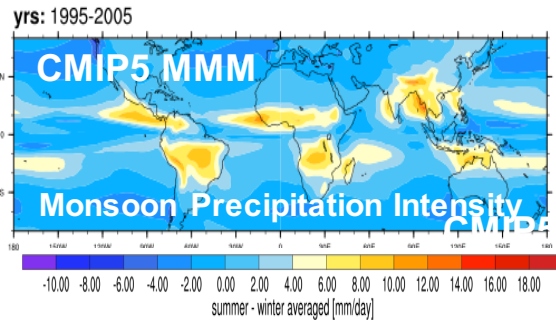
More models (>70)
New models
More complex models
Higher resolution models

How to characterize the wide variety of models in CMIP6?

- Routine Benchmarking and Evaluation Central Part of CMIP6 -

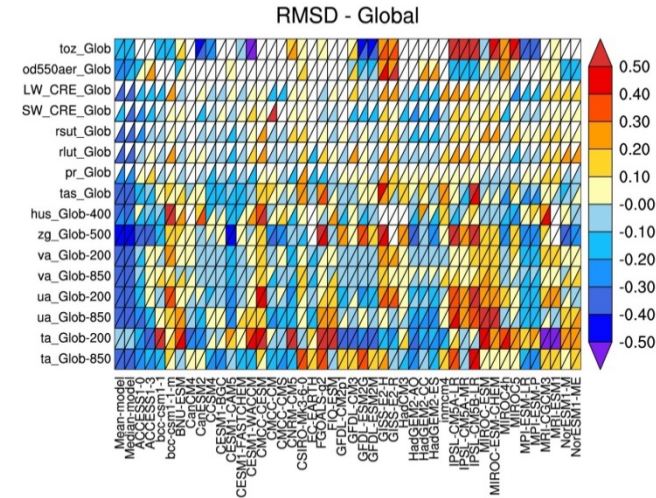
Tools such as the community-developed **Earth System Model Evaluation Tool (ESMValTool, Eyring et al., ESMValTool, GMD (2016b))** that includes other software packages such as the **NCAR CVDP (Phillips et al., 2014)**, and the **PCMDI Metrics Package (PMP, Gleckler et al., EOS (2016))** to produce well-established analyses as soon as CMIP model output is submitted.

Similar to **Figure 9.7 of AR5**



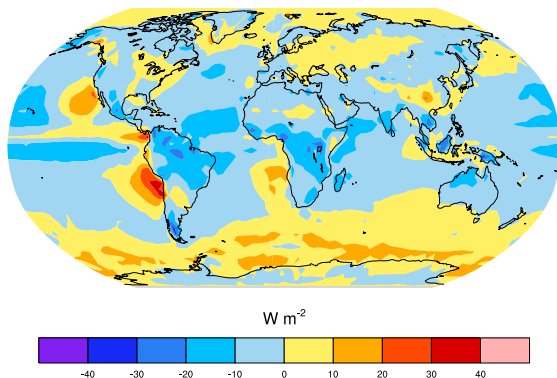
**Broad Characterization
of Model Behavior**
(incl. IPCC AR5 Chap 9 & 12
diagnostics in ESMValTool)

**Running alongside
the ESGF**

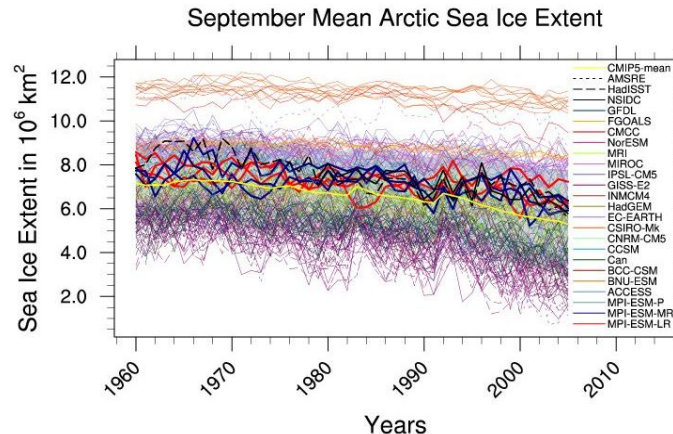


Similar to **Figure 9.5 of AR5**

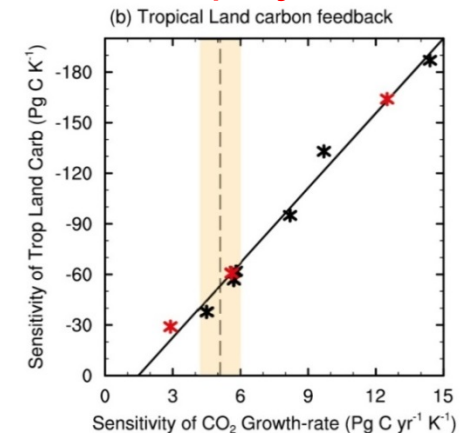
Net Cloud radiative effect against CERES EBAF



Similar to **Figure 9.24 of AR5**



Link to projections

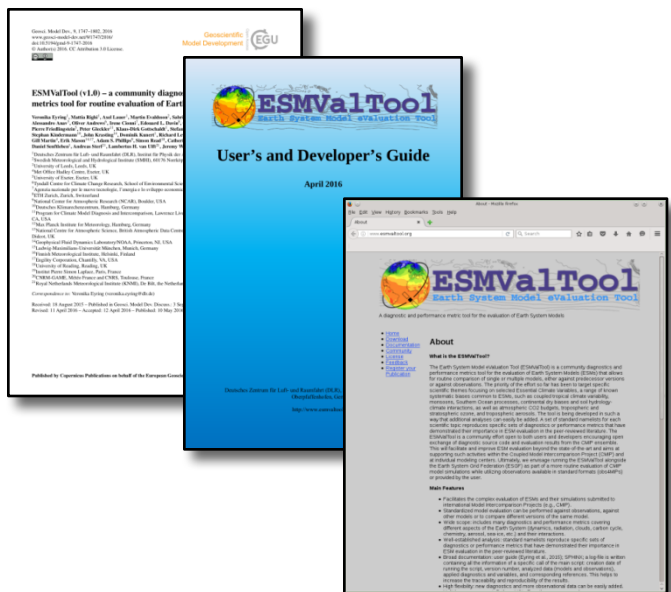


Similar to **Figure 9.24 of AR5**

ESMValTool version 1.0 released as open source software

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

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

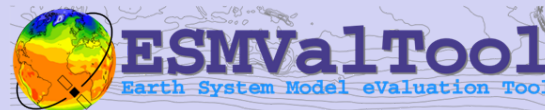


GitHub

public

GitHub

private



- **Community diagnostics and performance metrics tool** for the evaluation of Earth System
- **Standardized model evaluation** can be performed against observations, against other models or to compare different versions of the same model
- 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
- Well-established analysis based on **peer-reviewed literature**
- Ensuring **traceability** and **provenance** (e.g. input data, metadata, diagnostics (incl .citation), tool version, doi)
- Currently **≈ 80 scientist** from >30 institutions part of the development team and **> 120 users**
- **Development in several projects** (e.g. APPLICATE, CRESCENDO, C3S-MAGIC, ESA CMUG, PRIMAVERA)
- **Rapidly expanding**



Current Status: Contributing Institutions

(currently ~80 scientist from >30 institutions part of the development team)

1. Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Germany **PI**
2. Alfred-Wegener-Institute Bremerhaven (AWI), Germany Core Developer **APPLICATE**
3. Barcelona Computing Center (BSC), Spain, Core Developer **PRIMAVERA**
4. Ludwig Maximilian University of Munich, Germany, Core Developer **CRESCENDO**
5. British Atmospheric Data Centre (BADC), UK
6. Colorado State University, USA
7. Deutsches Klimarechenzentrum (DKRZ), Germany
8. Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
9. ETH Zurich, Switzerland
10. Finnish Meteorological Institute (FMI), Finland
11. GERICS Climate Service Center, Hamburg, Germany
12. Geophysical Fluid Dynamics Laboratory (GFLD) NOAA, USA
13. Instituto Nacional de Pesquisas Espaciais (INPE), Brazil
14. Institute of Atmospheric Sciences and Climate – Consiglio Nazionale delle Ricerche (ISAC-CNR), Italy
15. IPSL, France
16. Ludwig Maximilian University of Munich, Germany
17. Max-Planck-Institute (MPI) for Meteorology, Hamburg, Germany
18. MPI for Biogeochemistry, Jena, Germany
19. Met Office Hadley Centre, UK
20. Meteo France, France
21. MetNorway, Norway
22. New Mexico Tech, USA
23. Nansen Environmental and Remote Sensing Center, Norway
24. National Center for Atmospheric Research (NCAR), USA
25. Netherlands e-Science Center (NLeSC)
26. KNMI, The Netherlands
27. SMHI, Norrköping, Sweden
28. Tyndall Centre, UK
29. University of Arizona, USA
30. University of East Anglia (UEA), UK
31. University of Exeter, Exeter, UK
32. University of Hamburg, Germany
33. University of Leeds, UK
34. University of Reading, UK
35. Wageningen University, The Netherlands

Several institutes working on technical improvements and backend

Examples of European Projects with ESMValTool Development and Application

Name	Funder	Duration	Scientific Focus	Technical Focus	Partners
APPLICATE	EU Horizon 2020	11/16-10/20	Arctic, user-relevant impact metrics, linkages in atmosphere & ocean, sea ice	---	AWI and other APPLICATE partners
C3S-MAGIC	Copernicus Climate Change Serv.	10/16-03/19	Metrics incl. extreme events, coastal, water, energy and insurance	Quasi-operational on new C3S-Server, rewrite of backend with IRIS	NLeSC, KNMI, DLR, URead, BSC, ISAC-CNR, SMHI
CMIP6-DICAD	BMBF	07/16-06/20	Routine Benchmarking	Coupling to ESGF at DKRZ; visualization	DLR, DKRZ, FUB
CRESCENDO	EU Horizon 2020	11/15-10/20	IPCC Ch. 9&12, ESM diagnostics & metrics (terrestrial, marine, chemistry, aerosols)	Coupling to ESGF at BADC; reporting and testing	DLR, ETH, LMU, UREAD, ENEA, SMHI, UNEXE
DLR Projects	DLR	2010-ongoing	Emergent constraints, aerosols, chemistry, clouds, sea ice	ESMValTool coord., efficiency, provenance	DLR
EMBRACE	EU FP7	11/11-02/16	ESM diagnostics and metrics	Get it running on all CMIP5 models, Documentation	DLR, SMHI, KNMI, MPI-M, FMI, ETH, UEA, UNEXE, METUK, CNRS-IPSL, CNRS-MF
ESA CCI CMUG	ESA	07/14-06/17	ESA CCI data and diagnostics	Reporting	DLR, LMU, SMHI, MetOffice
PRIMAVERA	EU Horizon 2020	11/15-10/19	Assess added level of high res.; processes (e.g., AMO, Gulf stream, interactions of ice & polar storms, northward ocean heat transport	Improving the backend's efficiency	BSC and other PRIMAVERA partners

Diagnostics and metrics included

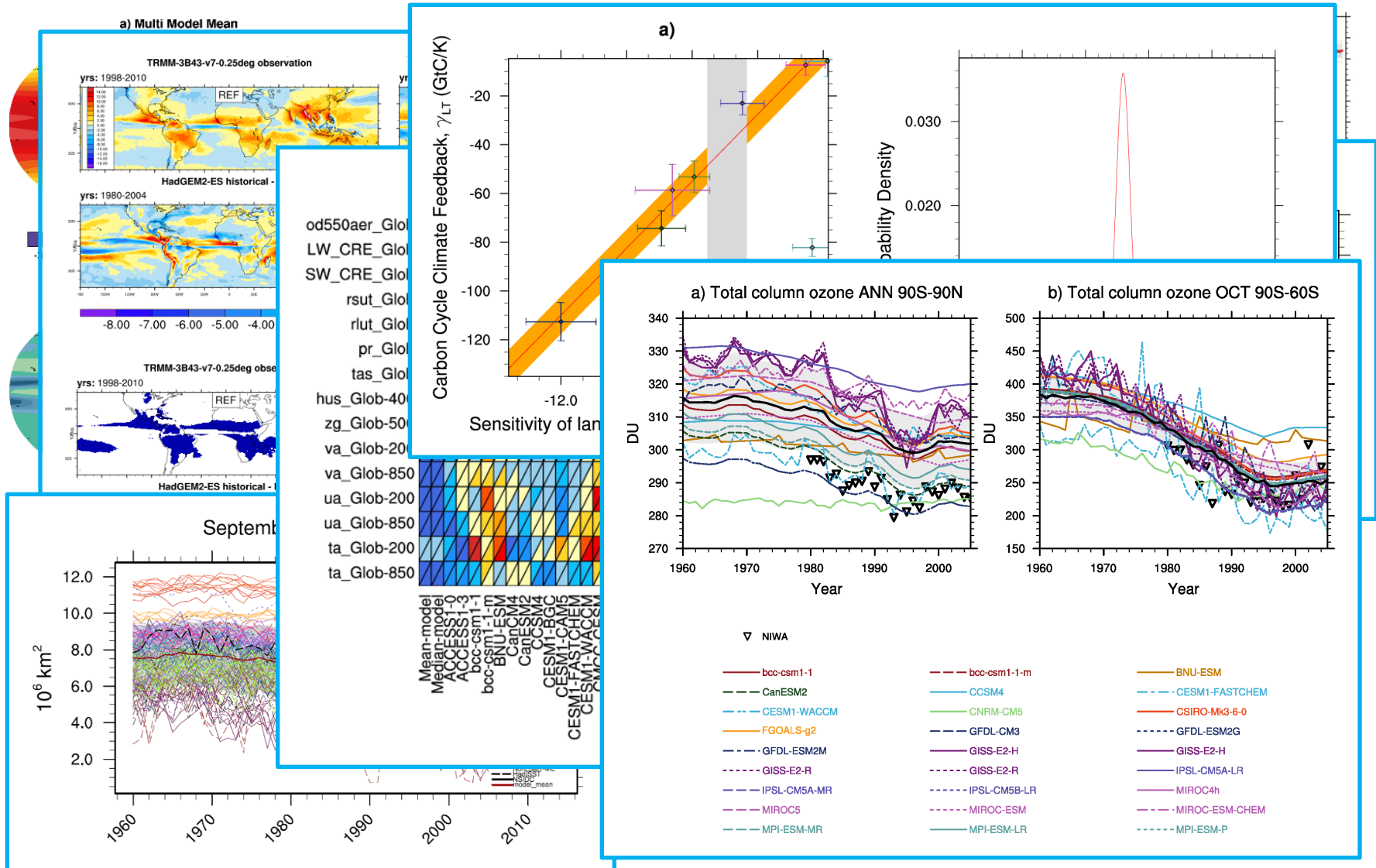
- Aerosol
- Blocking diagnostics
- Catchment analysis, runoff, ET
- Clouds
- Cloud regime error metric (CREM)
- CO₂ and CH₄
- Diurnal cycle of convection
- Emergent constraints
- Evapotranspiration
- **Indices for extreme events (Climdex)**
- IPCC AR5 chapter 9 and 12
- Land and ocean components of the global carbon cycle
- Land-atmosphere coupling
- Land cover
- Marine biogeochemistry
- Madden-Julian Oscillation (MJO)
- **NCAR climate variability diagnostics package (CVDP)**
- Ozone, precursors and climate impacts
- Performance metrics
- Shifts in Austral jets
- Snowfall
- Soil moisture
- Sea surface temperature
- South Asian monsoon
- Sea ice
- Soil moisture
- Southern Hemisphere
- **Southern Ocean (SOCCOM)**
- Standardized precipitation index (SPI)
- Tropical variability
- Tropospheric Ozone
- West African monsoon
- Land cover
- Precipitation – soil moisture



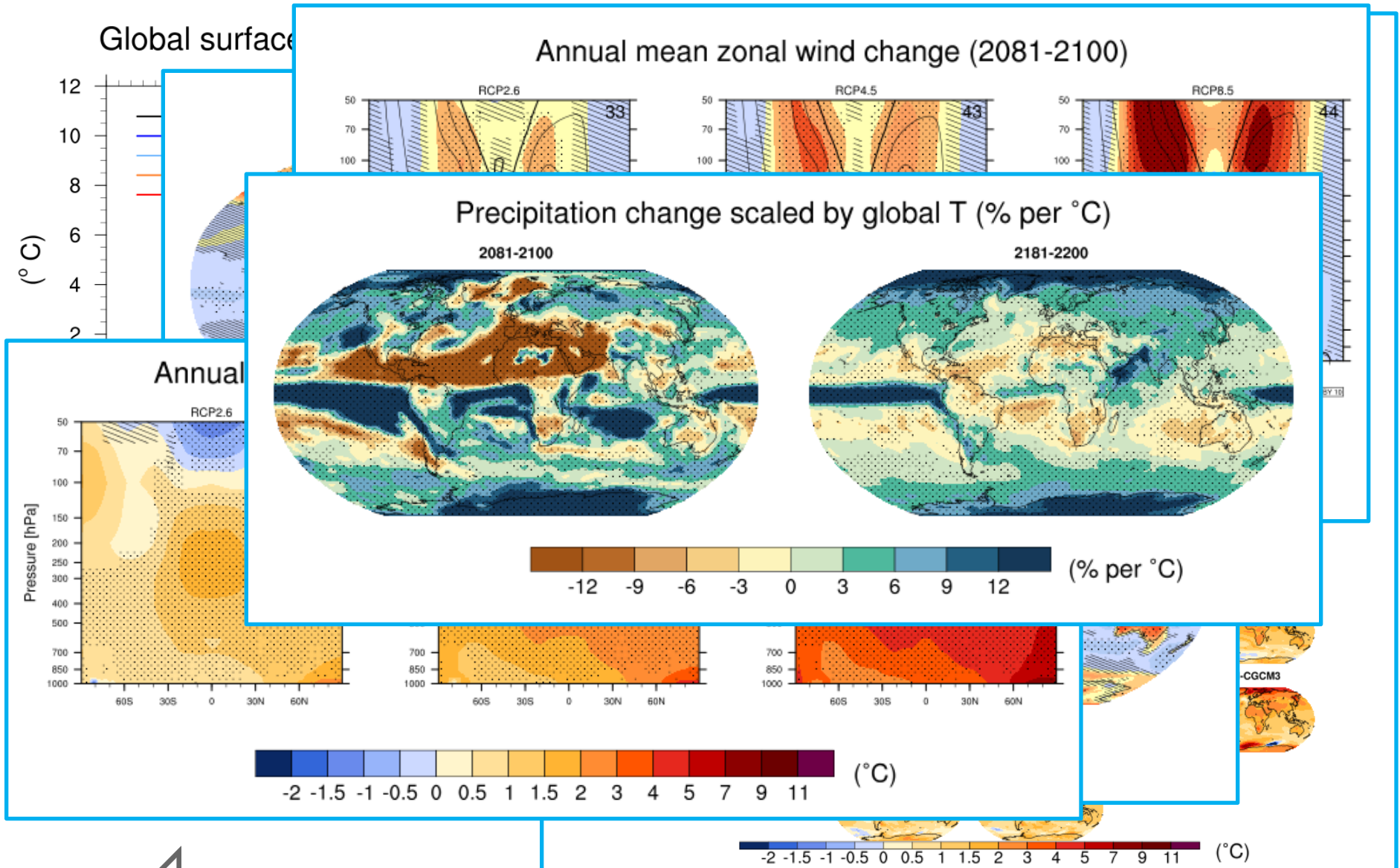
Examples of ESMValTool Namelist

- namelist_CVDP.xml
- namelist_DiurnalCycle_xxx.xml
- namelist_Emmons.xml
- namelist_EmergentConstraints.xml
- namelist_Evapotranspiration.xml
- namelist_GlobalOcean.xml
- namelist_SAMonsoon.xml
- namelist_SPI.xml
- namelist_Sealce.xml
- namelist_SouthernHemisphere.xml
- namelist_SouthernOcean.xml
- namelist_TropicalVariability.xml ESMV
- namelist_WAMonsoon.xml
- namelist_aerosol_CMIP5.xml
- namelist_anav13jclim.xml
- namelist_clouds_bias.xml
- namelist_eyring13jgr.xml
- namelist_flato13ipcc.xml
- namelist_lauer13jclim.xml
- namelist_lauer17rse.xml
- namelist_mjo_mean_state.xml
- namelist_mmm.xml
- namelist_perfmetrics_CMIP5.xml
- namelist_reformat.xml
- namelist_reformat_obs.xml
- namelist_righi15gmd_ECVs.xml
- namelist_righi15gmd_Emmons.xml
- namelist_righi15gmd_tropo3_CMIP5.xml
- namelist_runoff_et.xml
- namelist_sm_pr.xml
- namelist_wenzel14jgr.xml
- namelist_williams09climdyn_CREM.xml

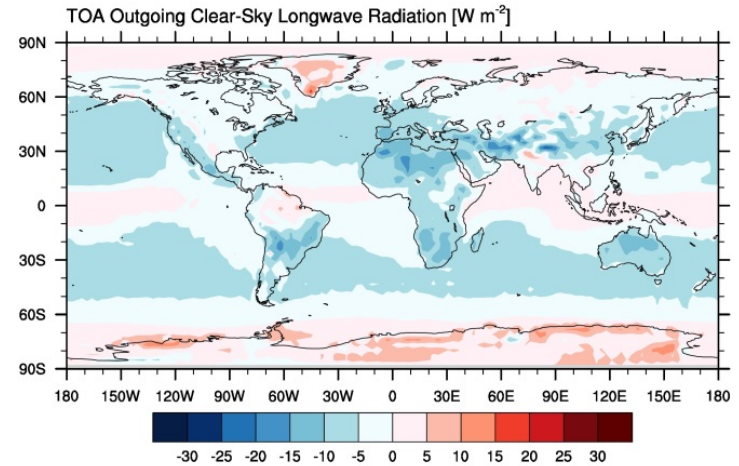




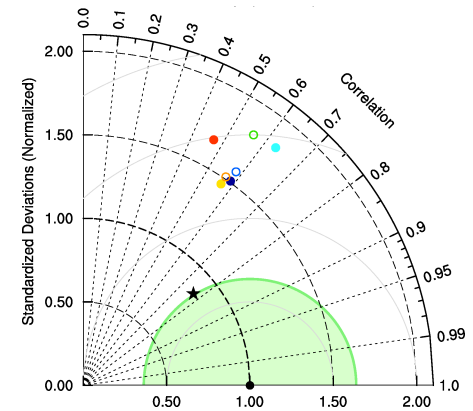
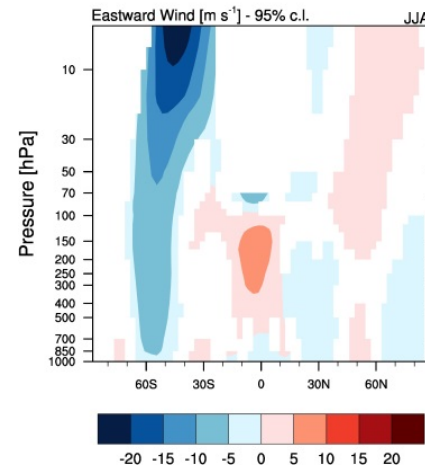
Diagnostics – IPCC AR5 chapter 12



EVAL2 - SRB



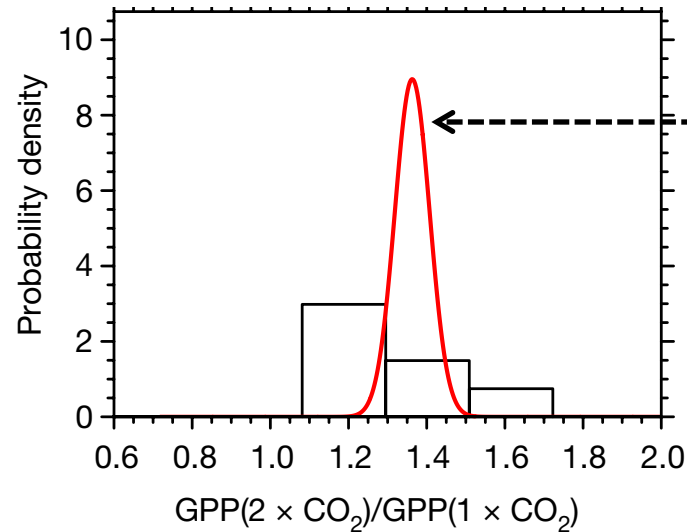
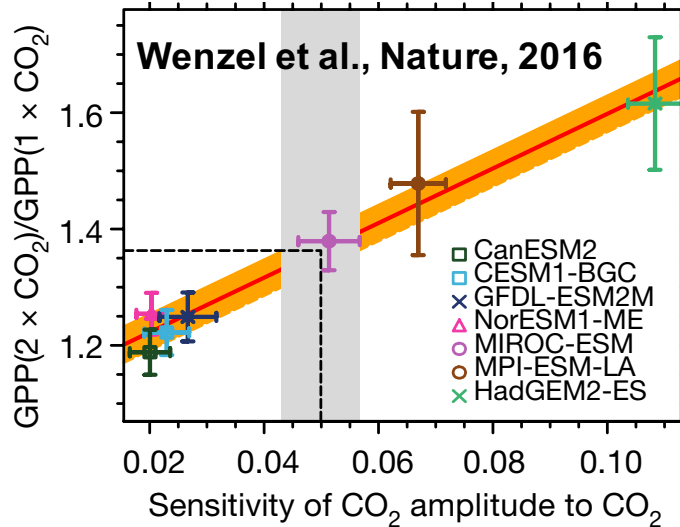
TS2000 - ERA-Interim



Emergent Constraints

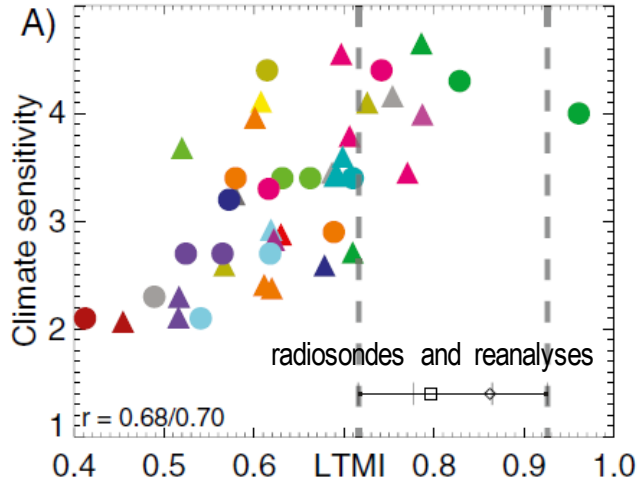
Emergent Constraints are relationships across an ensemble of models, between some aspect of Earth system sensitivity and an observable trend or variation in the current climate.

Relative GPP increase at CO₂ doubling

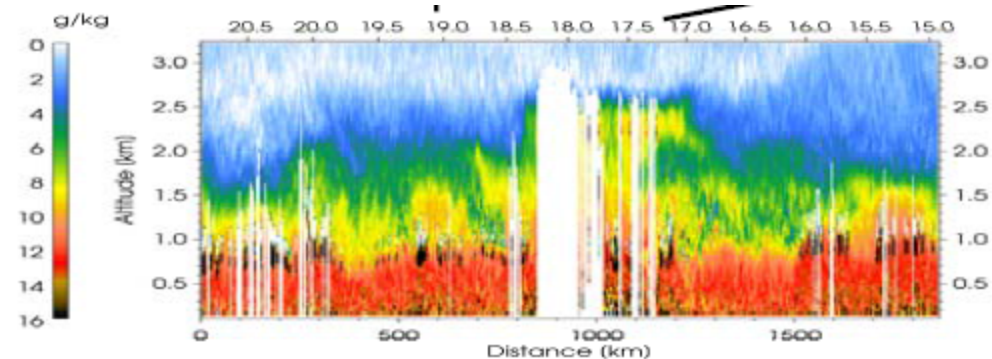


Doubling CO₂ concentration will lead to an increase in land photosynthesis of about a third.

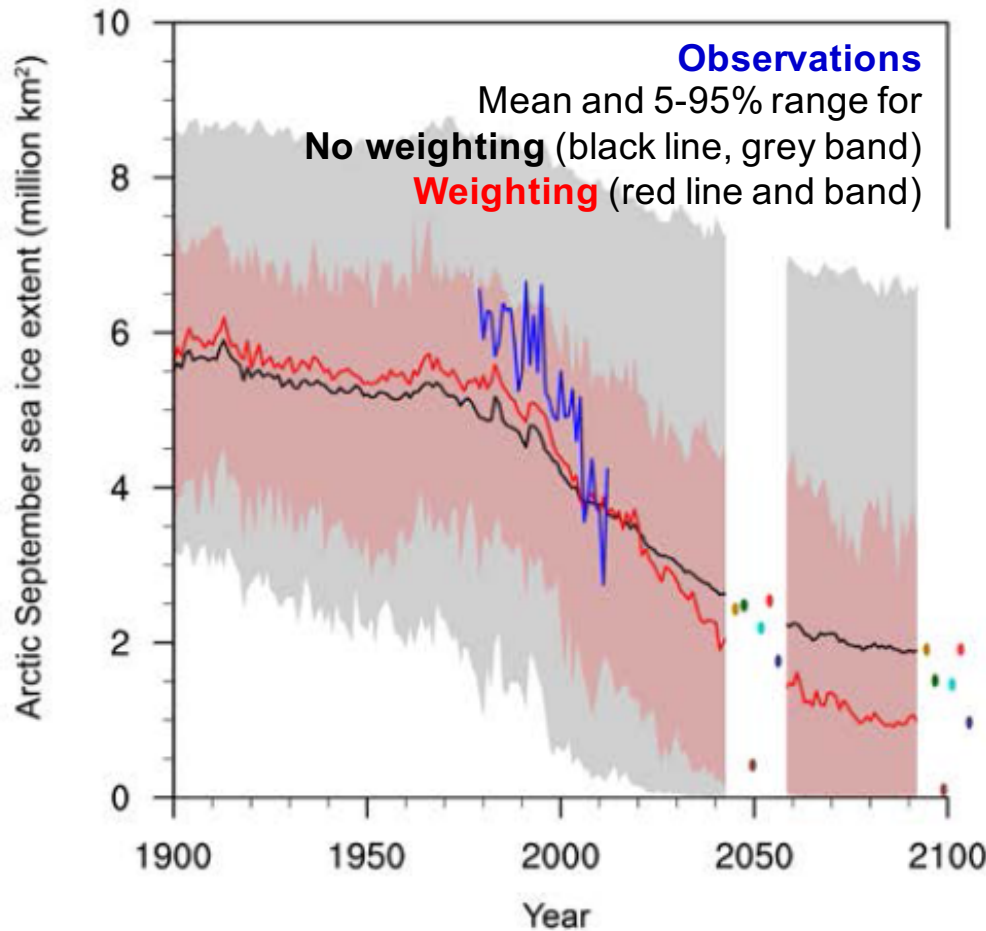
Sherwood et al., 2014



Airborne Water Vapor Lidar Observations of Tropical Shallow Convection; See Poster by Kiemle et al.



Weighted sea-ice projections based on model-performance and interdependence



$$w_i = e^{-\frac{D_i^2}{\sigma_D^2}} / \left(1 + \sum_{j \neq i}^M e^{-\frac{S_{ij}^2}{\sigma_S^2}} \right)$$

D_i : distance metric of model i to observations (here RMSD)

S_{ij} : distance metric between model i and model j (here RMSD)

σ_D and σ_S determine how strongly the model performance and similarity are weighted

Diagnostics included in this example:

1. (unweighted)
2. Climatological mean (1980-2013) Sep sea ice extent,
3. Sep sea ice extent trend 1980-2013,
4. Climatology of monthly surface temperature (1980-2013)
5. Interannual variability of monthly surface temperature,
6. All diagnostics 2-5

Knutti et al., GRL, submitted, 2016



Observational data

Data sets are grouped into 3 classes

- **Tier 1**
Data sets from the **obs4MIPs** and **ana4MIPs** archives:
<https://www.earthsystemcog.org/projects/obs4mips/>
<https://www.earthsystemcog.org/projects/ana4mips/>
- **Tier 2**
Other **freely available** data sets
- **Tier 3**
Restricted data sets (e.g., license agreement required)



Available observational data v1.0

Aerosols + chemistry

- ACCESS (mmrbc)
- AERONET (od550aer)
- AURA-MLS-OMI (tropoz)
- AURA-TES (vmro3)
- CARSNET (od550aer)
- CASTNET (concso4, concno3, concnh4)
- CIRRUS (mmrbc, mmrbcfree)
- CONCERT (mmrbc, conccnSTP14)
- CR-AVE (mmrbc)
- DC3 (mmrbc)
- EANET (concso4, concno3, concnh4)
- EMEP (concso4, concno3)
- EMMONS (various trace gases)
- ESRL (co2)
- GLOBALVIEW (vmrco)
- GTO-ECV (toz)
- HIPPO (mmrbc)
- IMPROVE (concso4, concno3, concnh4, concbc, concoa, concpm2p5, concpm10)
- INCA (conccnSTP5, conccnSTP14, conccnSTP120)
- LACE (sizecn)
- Melpitz (sizecn)
- MODIS (od550aer)
- NIWA (toz)
- Putaud (sizecn)
- SALTRACE (mmrbc)
- TC4 (mmrbc)
- Texas (mmraer, mmrbc)
- Tilmes (vmro3)
- UCN-Pacific (conccnSTP3)



Available observational data v1.0

Meteorology

- AIRS (hur, ta)
- CERES (rsuscs, rsus, rsdscs, rsds, rluscs, rlus, rldscs, rlds, rsutcs, rsut, rlutcs, rlut)
- CloudSat (clt)
- CMAP (pr)
- CRU (tas, pr)
- ERA-40
- ERA-Interim (ta, ua, va, zg, hus, tas, tos, ps, psl, tauu, tauv, clwvi, clivi, sftlf, pr, evspsbl, hfls, hfss, rsns, rlms)
- GPCC (pr)
- HadCRUT (tas)
- HALOE (vmrh2o)
- MERRA (pr)
- MODIS (clivi, clwvi, clt)
- NCEP (ta, ua, va, zg, hus, tas)
- NOAA-PSD (rlut)
- OAFlux (hfls)
- SRB (rsut, rlut, rlutcs)
- TRMM (pr)
- Uwisc (clwvi)



Available observational data v1.0

Land

- GCP (co2flux)
- LandFlux-EVAL (et, et-sd)

Sea ice

- HadISST (sic)
- NSIDC (sic)

Ocean

- Dong08-ARGO (mlofst)
- ETH-SOM-FFN (spco2)
- HadISST (ts)
- SeaWIFS (chl)
- SOCAT (spco2)
- Takahashi14 (talk)
- WOA09 (so, sos, to, tos)
- Woa2005 (o2)



Examples of new observational datasets

Aerosols/chemistry/meteorology/land/ocean/sea ice

- ACCESS-2 (conccnd5, conccnd10)
- Asmill (aerosol size)
- CFSR (psl)
- CloudSat (clt)
- ESA CCI AEROSOL (od550aer, abs550, od550lt1aer, od870aer)
- ESA CCI CLOUD (clt, clwvi, clivi)
- ESA CCI GHG (xco2, xch4)
- ESA CCI OZONE (tro3, tropoz, toz)
- ESA CCI SEAICE (sic)
- ESA CCI SOILMOISTURE (sm)
- ESA CCI SST (ts)
- ESRL (surface CO₂)
- HadCRUT4 (tas)
- HIPPO (mmrbc)
- HWSD (soil carbon content)
- ISCCP (albiscpp, clisccp, cltisccp, cttisccp)
- JMA-TRANSCOM (CO₂ exchange)
- LAI3g (leaf area index)
- MTE (gross primary productivity of carbon)
- NDP (vegetation carbon content)
- NIWA (toz)
- TOMS (toz)
- WHOI-OAFlux (hfls, hfss)



Envisaged Workflow for Routine Evaluation in CMIP

Well-Established Analysis
Sharing of Diagnostic Code
Guidance and support from CMIP Panel,
WGNE/WGCM Climate Model Metrics
Panel and , CMIP6-Endorsed MIPs

Model Output



Observations and
Reanalyses

obs4MIPs
ana4MIPs



Processing Capability



Data Archive

Analysis computing en-
vironment integrated
with the ESGF

Standardised
Interfaces

Community-tools for
Routine ESM Evaluation

Visualization & documentation
of evaluation results
Record of provenance
Scientific interpretation
Additional in-depth analysis

State evaluation of ECVs
(climatology, trends, ...)
Process and phenomena evaluation
Link to projections
(MMM analysis and emergent constraints)
Performance metrics

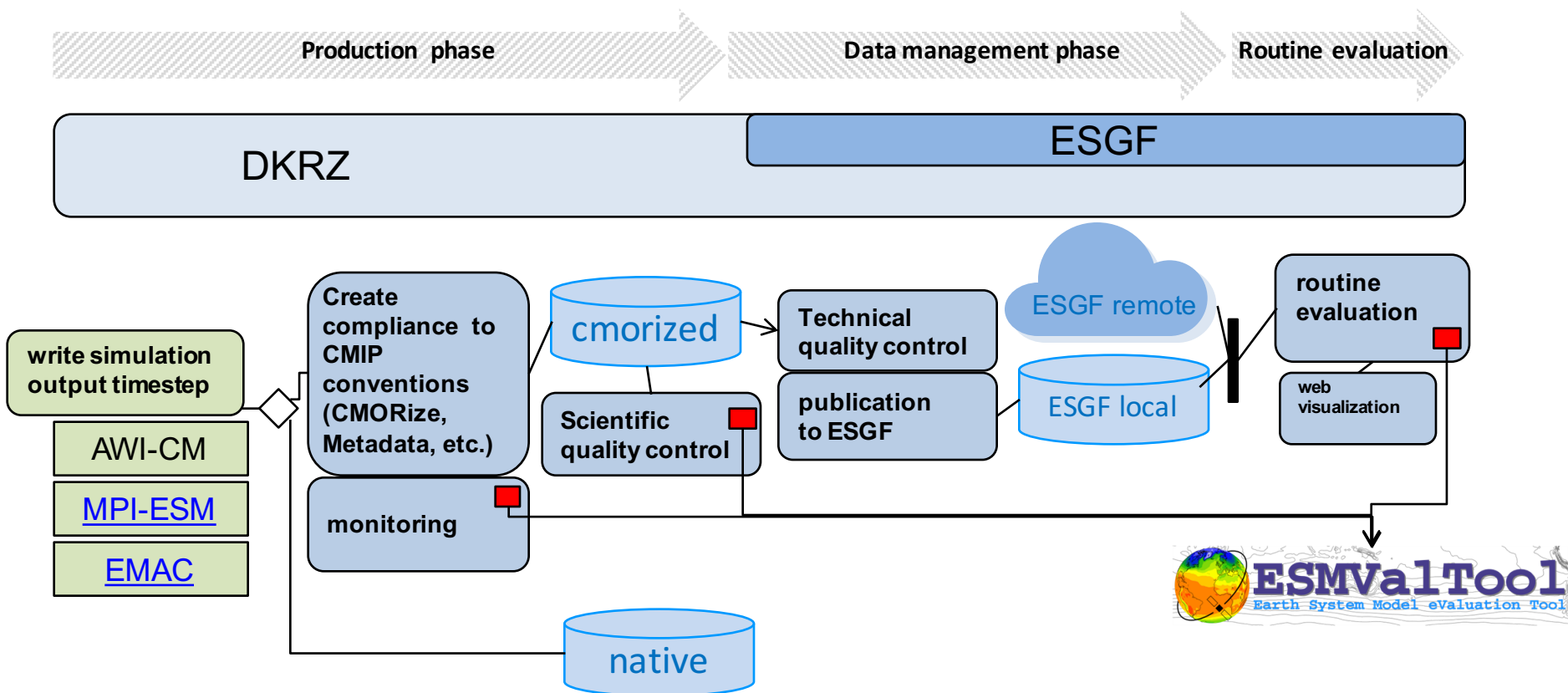


PCMDI Metrics Package (PMP)

Eyring et al., ESD (2016)



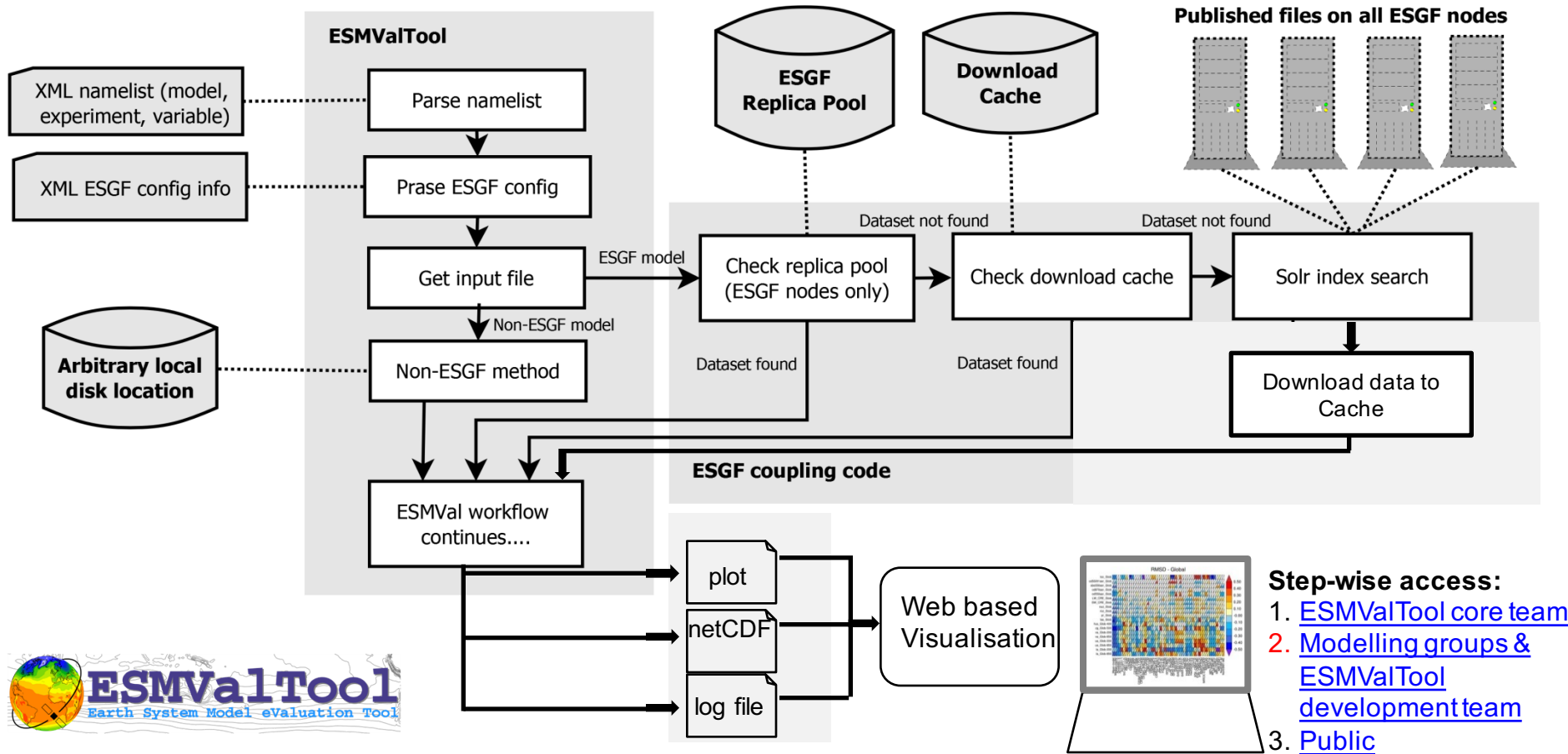
Example for integration of the ESMValTool into the CMIP6 Workflow at the DKRZ*



*Defined in the Project CMIP6-DICAD



ESMValTool Workflow for routine evaluation at DKRZ



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



Some Questions

- When do we make the results publically available?
- Can we establish common terms of use for the CMIP evaluation tools?
- How can we encourage active participation of the model groups in the quality control of the CMIP evaluation results?
- How can we coordinate and quality control results from different tools (e.g. performance metrics plot from PMP versus ESMValTool)?
- How can we encourage the CMIP6-Endorsed MIPs to contribute additional diagnostics and metrics?

