

Earth System Model Evaluation Tool (ESMValTool)

Veronika Eyring

¹Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Atmospheric Physics, Oberpfaffenhofen, Germany

²University of Bremen, Institute of Environmental Physics, Bremen, Germany



WGCM/WGNE Meeting

10 October 2017

Exeter, UK



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

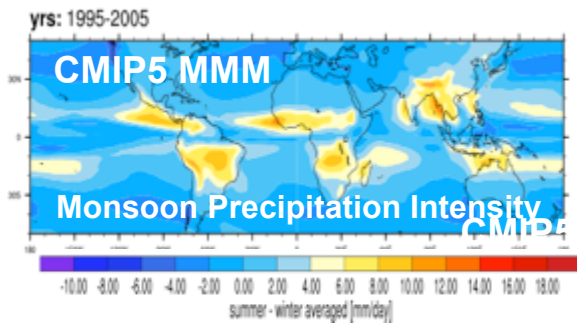
More models (>70)
 New models
 More complex models
 Higher resolution models

How to characterize the wide variety of models in CMIP6?

- Routine Benchmarking and Evaluation Central Part of CMIP6 -

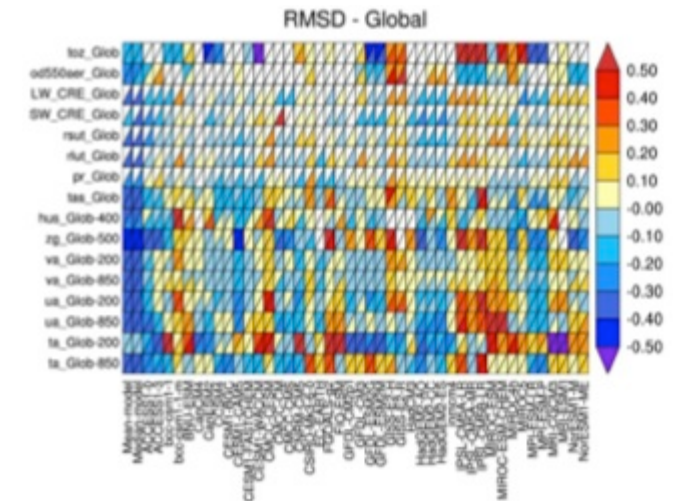
Tools such as the community-developed **Earth System Model Evaluation Tool (ESMValTool, Eyring et al., ESMValTool, GMD (2016b))** that includes other software packages such as the **NCAR CVDP (Phillips et al., 2014)**, and the **PCMDI Metrics Package (PMP, Gleckler et al., EOS (2016))** to produce well-established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

Similar to **Figure 9.7 of AR5**



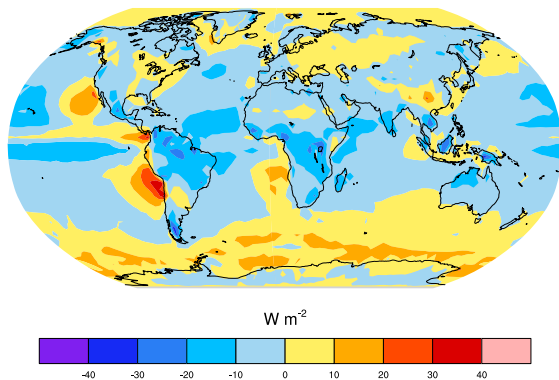
Broad Characterization of Model Behavior
(incl. IPCC AR5 Chap 9 & 12 diagnostics in ESMValTool)

Running alongside the ESGF

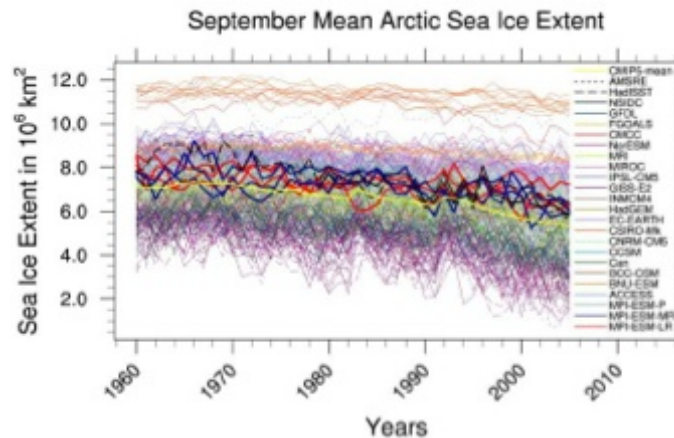


Similar to **Figure 9.5 of AR5**

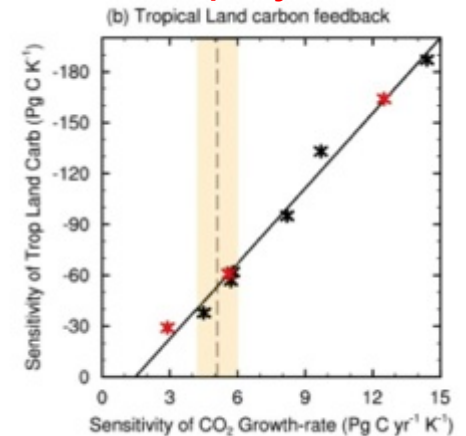
Net Cloud radiative effect against CERES EBAF



Similar to **Figure 9.24 of AR5**



Link to projections

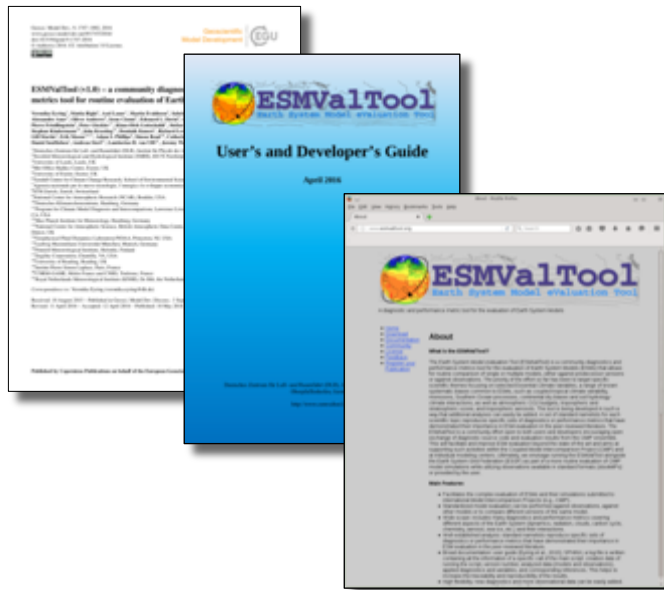


Similar to **Figure 9.24 of AR5**

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)
- **Documentation and user guide**
- 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**

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 C3S- SQUARE4ECVs | Copernicus Climate Change Serv. | 10/16-03/ 19 | Metrics incl. extreme events, coastal, water, energy and insurance Quality Control Observations | 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 BADG; 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 |

Current Status: Contributing Institutions

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

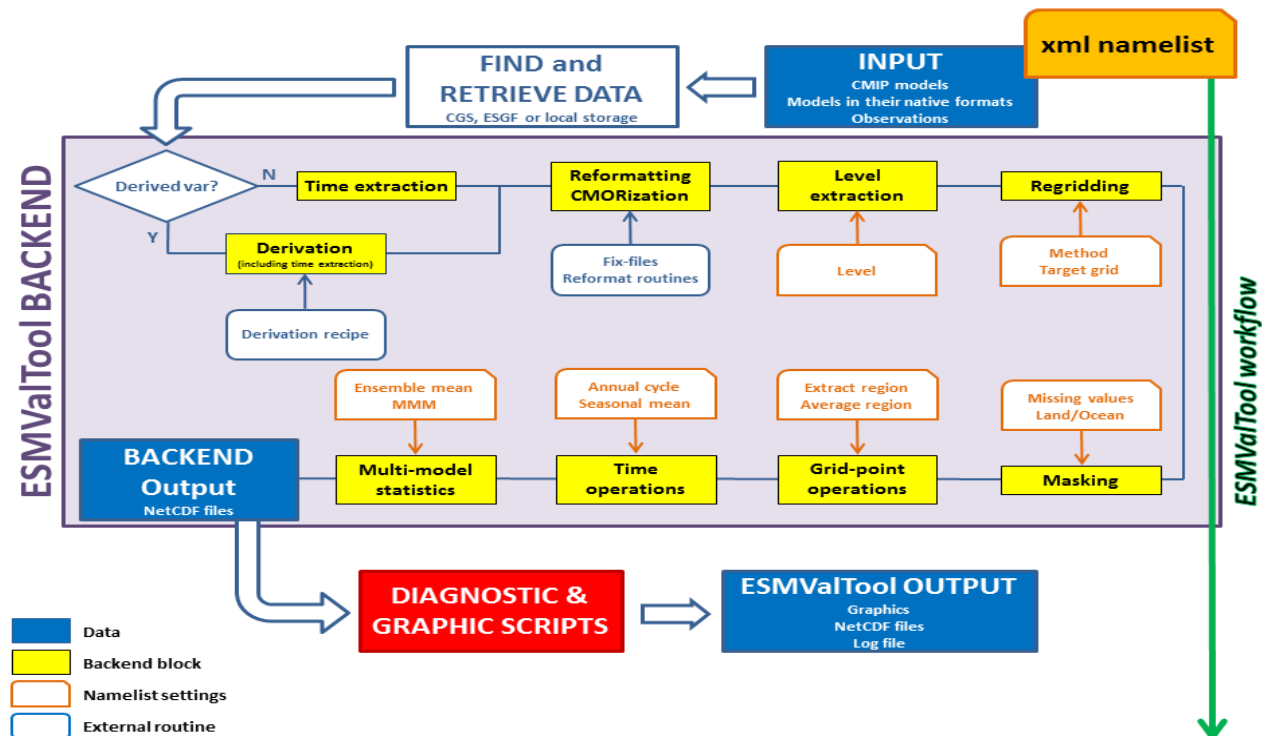
1. Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Germany **PI**
2. Alfred-Wegener-Institute Bremerhaven (AWI), Germany Core Developer **APPLICATE**
3. Barcelona Computing Center (BSC), Spain, Core Developer **PRIMAVERA**
4. Ludwig Maximilian University of Munich, Germany, Core Developer **CRESCENDO**
5. University of Reading, UK, Core Developer **Copernicus MAGIC / CRESCENDO**
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 (GFDL) 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. Météo 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. Wageningen University, The Netherlands

Several institutes working on technical improvements and backend

Technical Work ESMValTool

Maintenance, Technical Infrastructure, Interfaces, and Documentation

- Changed to versioning system git
- Documentation and user's guide converted (Sphinx)
- Tagging and improved provenance (work in progress)
- New backend using Iris, full merge with Auto-Assess (work in progress)
- Automated testing and reporting package
- Quicklook capability added
- Visualization with FREVA (work in progress)
- Several coding workshops were held to enhance the ESMValTool



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

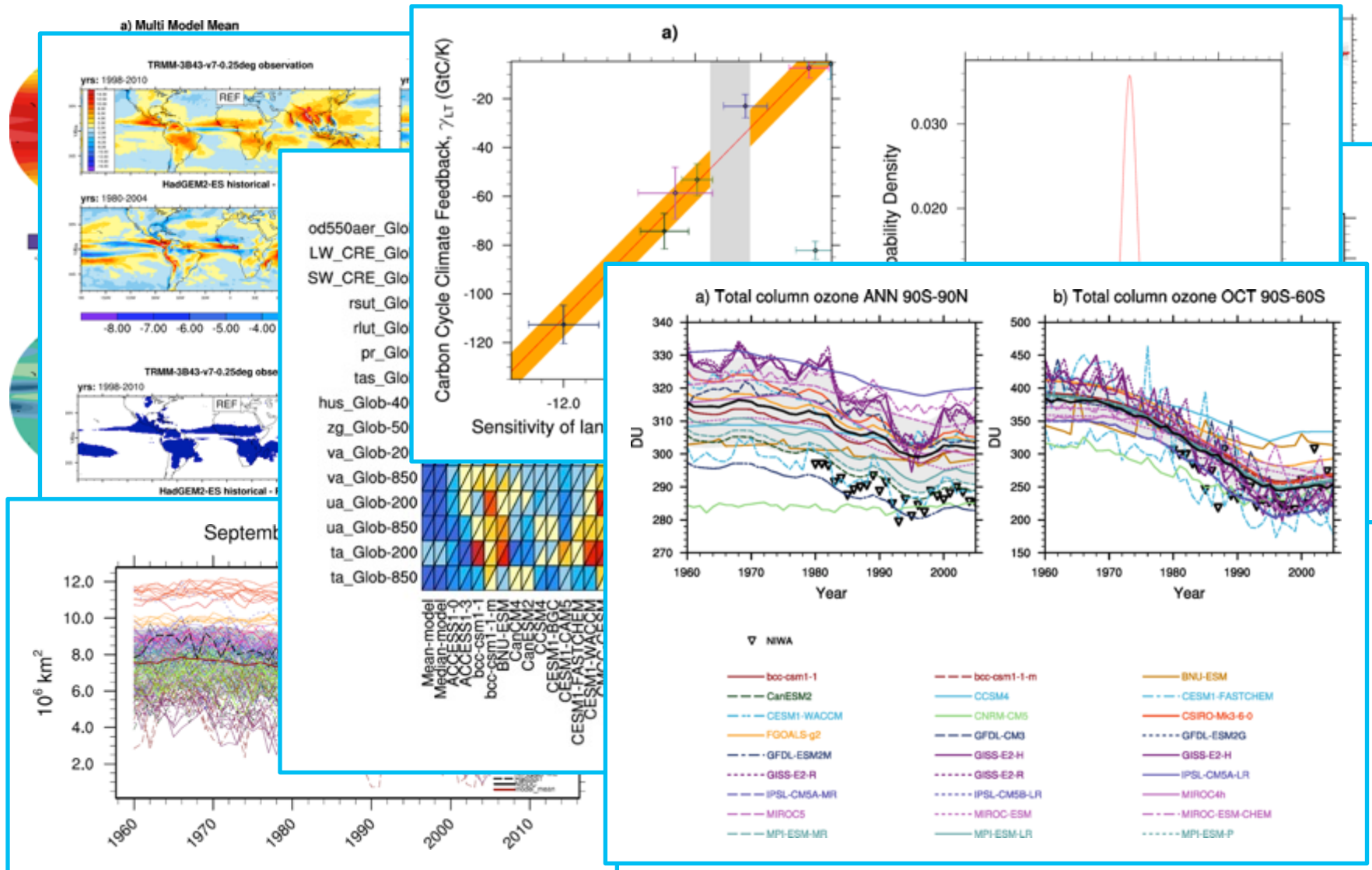


Examples of ESMValTool Namelist

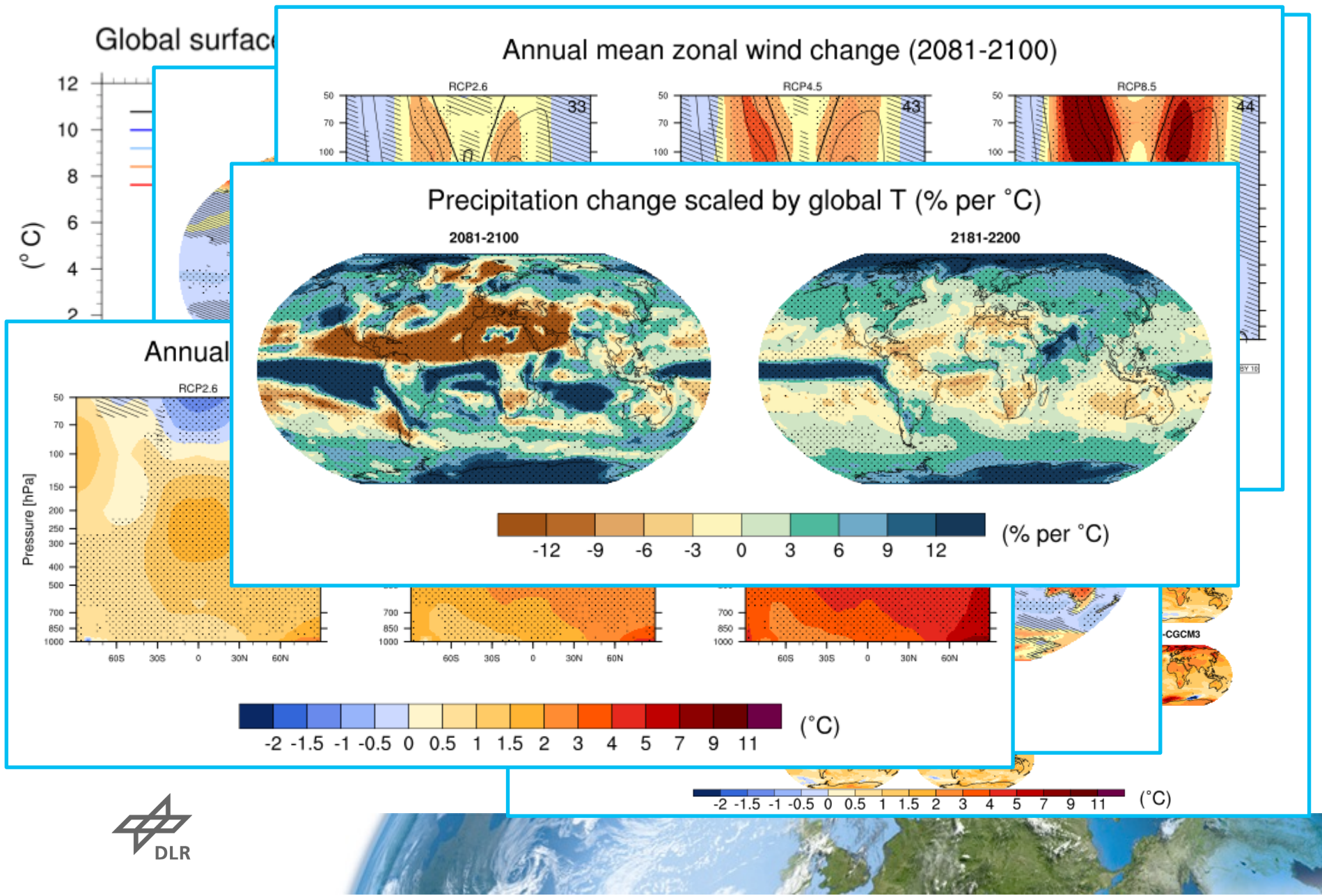
- namelist_CVDP.xml
- namelist_DiurnalCycle_xxx.xml
- namelist_Emmons.xml
- namelist_EmergentConstraints.xml
- namelist_Evapotranspiration.xml
- namelist_GlobalOcean.xml
- namelist_SAMonsoon.xml
- namelist_SPI.xml
- namelist_Sealce.xml
- namelist_SouthernHemisphere.xml
- namelist_SouthernOcean.xml
- 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 9

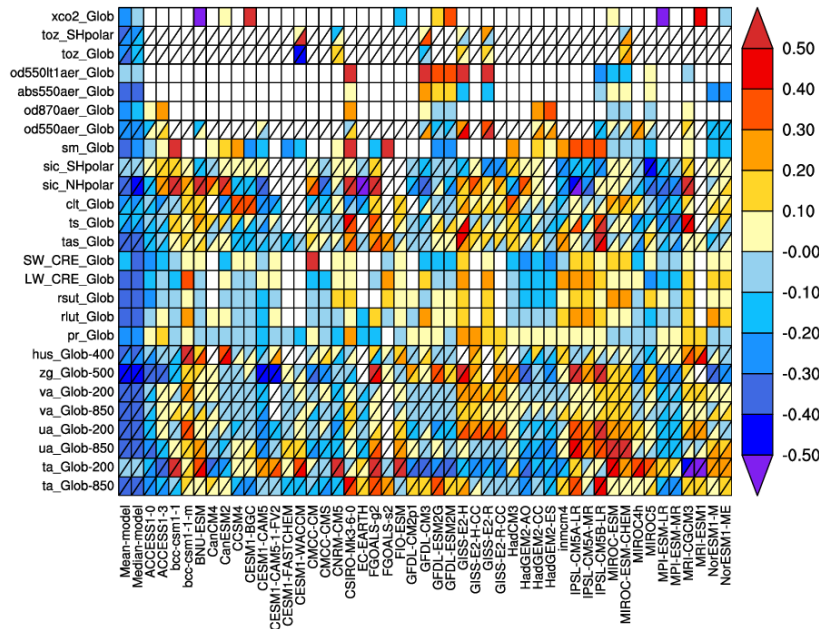


Diagnostics – IPCC AR5 chapter 12

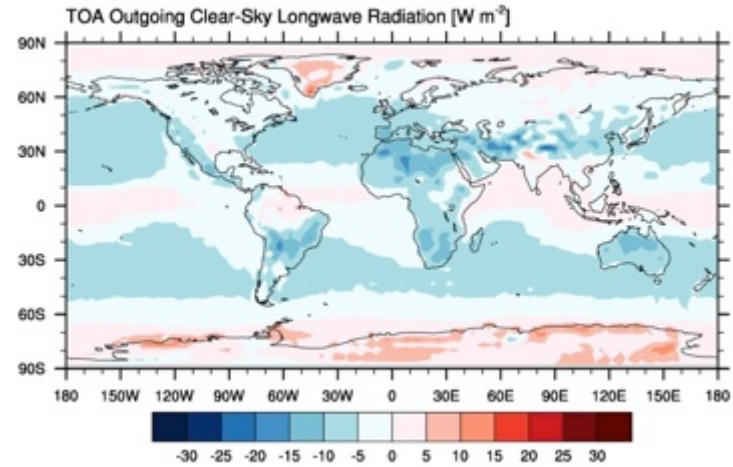


Diagnostics – Performance metrics

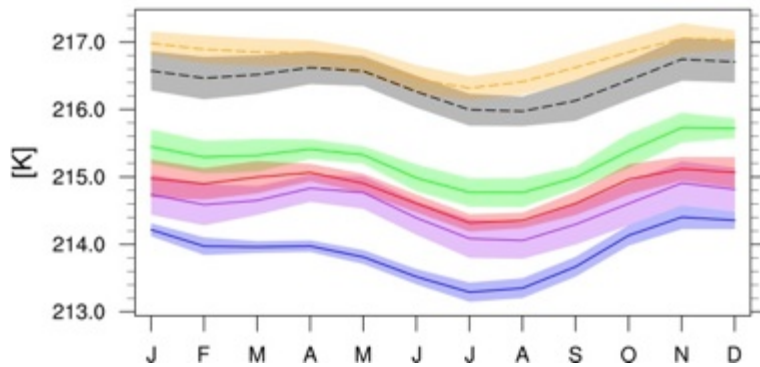
RMSD - Global



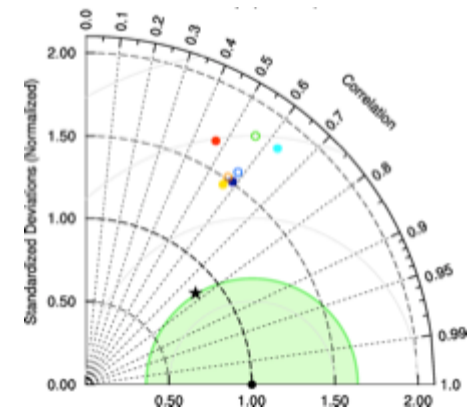
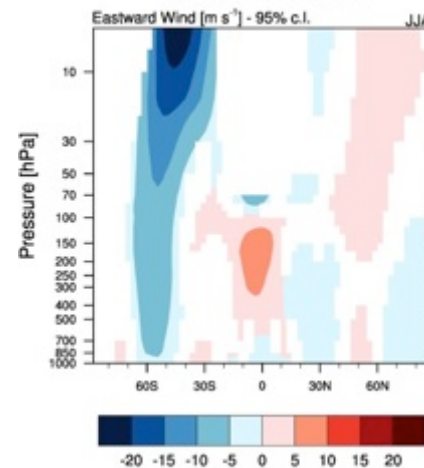
EVAL2 - SRB



Air Temperature - Global - 30 hPa

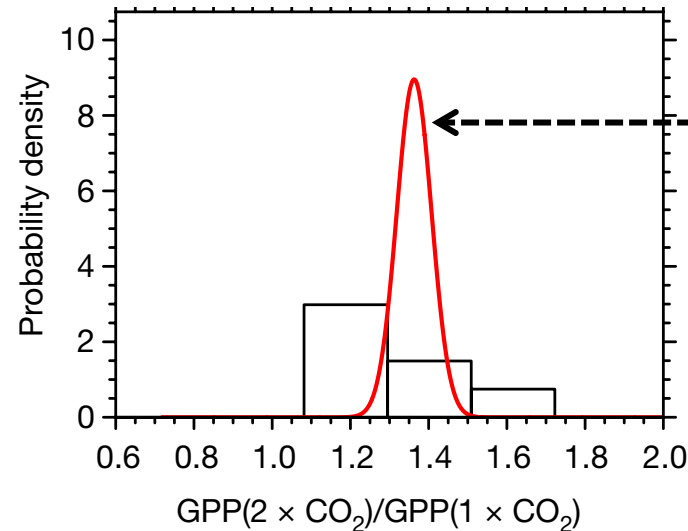
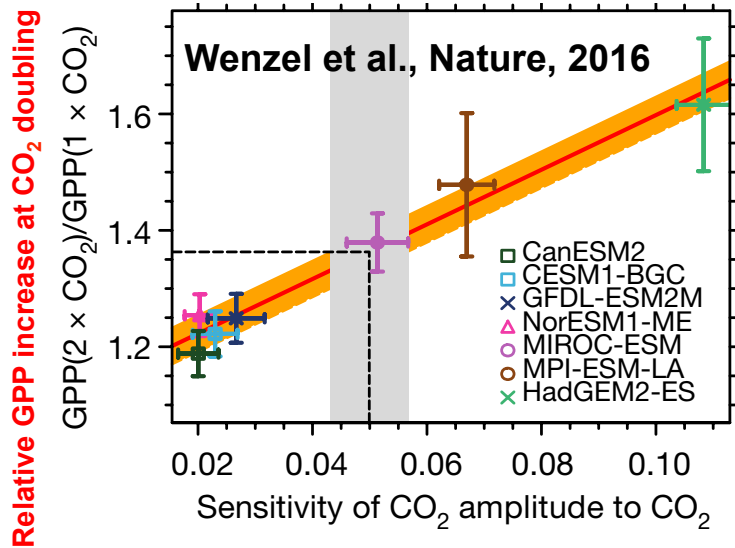


TS2000 - ERA-Interim

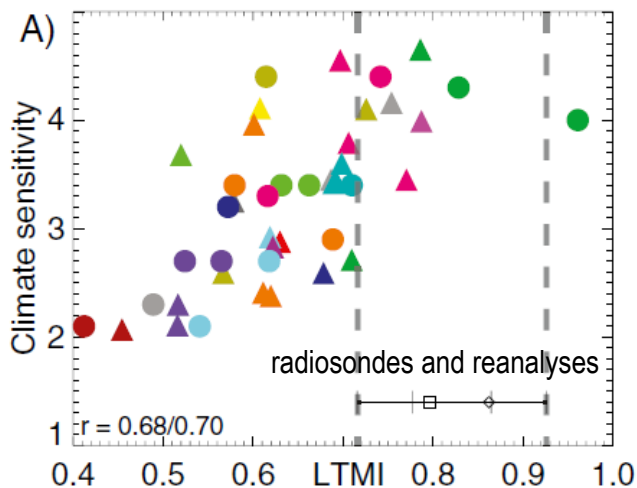


Emergent Constraints

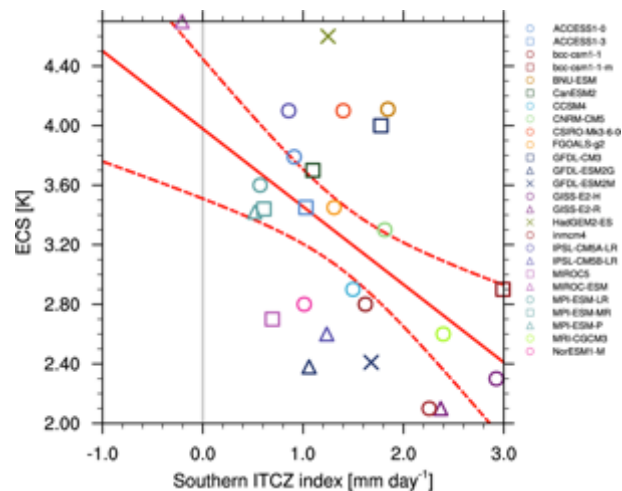
Emergent Constraints are relationships across an ensemble of models, between some aspect of Earth system sensitivity and an observable trend or variation in the current climate.



Sherwood et al., 2014



Tian, 2015: Southern ITCZ index



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, rdsdcs, rdsd, rluscs, rlus, rlds, rdsdcs, 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)
- GPCP (pr)
- HadCRUT (tas)
- HALOE (vmrh2o)
- MERRA (pr)
- MODIS (clivi, clwvi, clt)
- NCEP (ta, ua, va, zg, hus, tas)
- NOAA-PSD (rlut)
- OAFflux (hfls)
- SRB (rsut, rlut, rlutcs)
- TRMM (pr)
- Uwisv (clwvi)



Available observational data v1.0

Land

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

Sea ice

- HadISST (sic)
- NSIDC (sic)

Ocean

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



Examples of new observational datasets

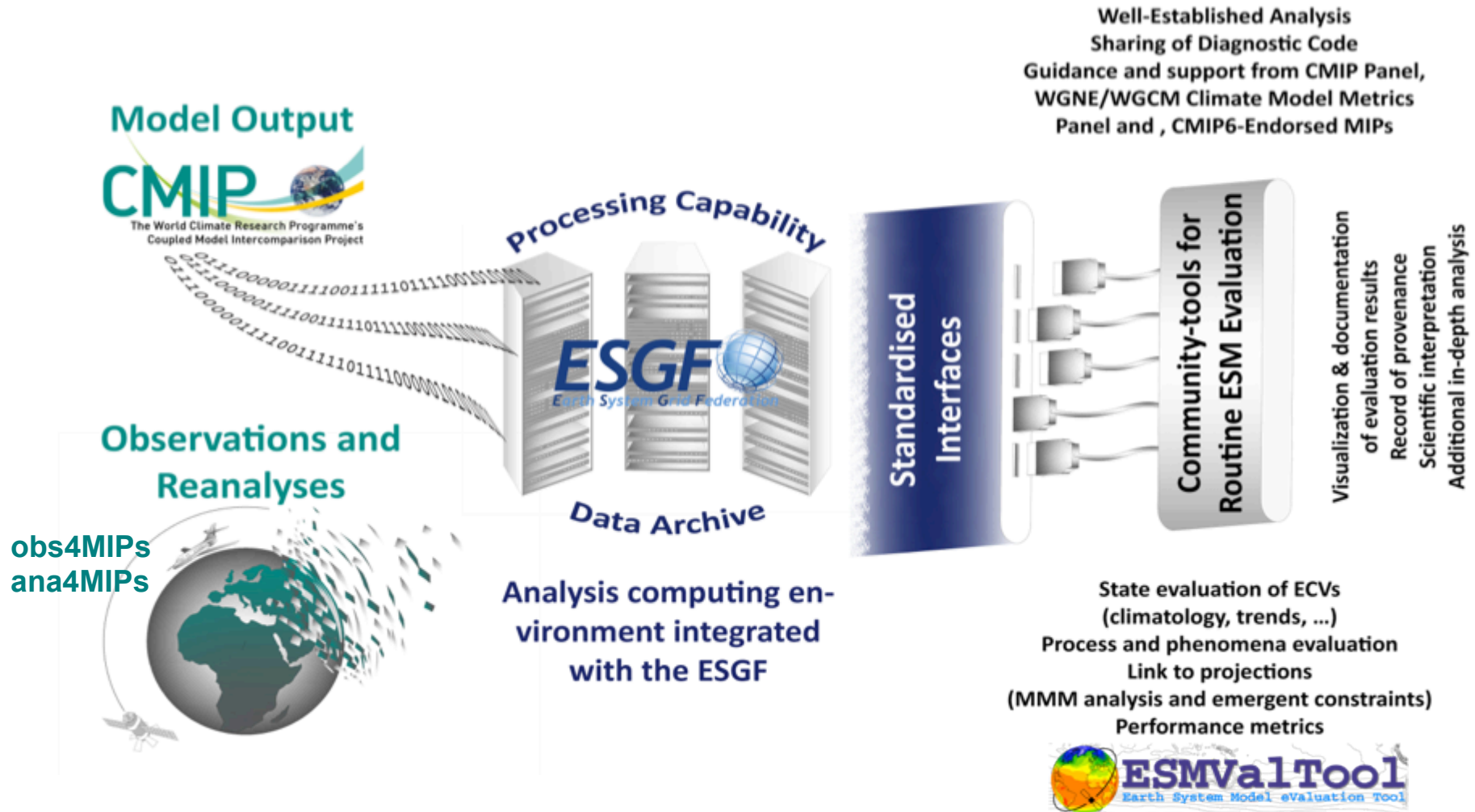
Aerosols/chemistry/meteorology/land/ocean/sea ice

- 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, cliscpp, cltiscpp, cttiscpp)
- 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

- Ensuring traceability and provenance of the results -

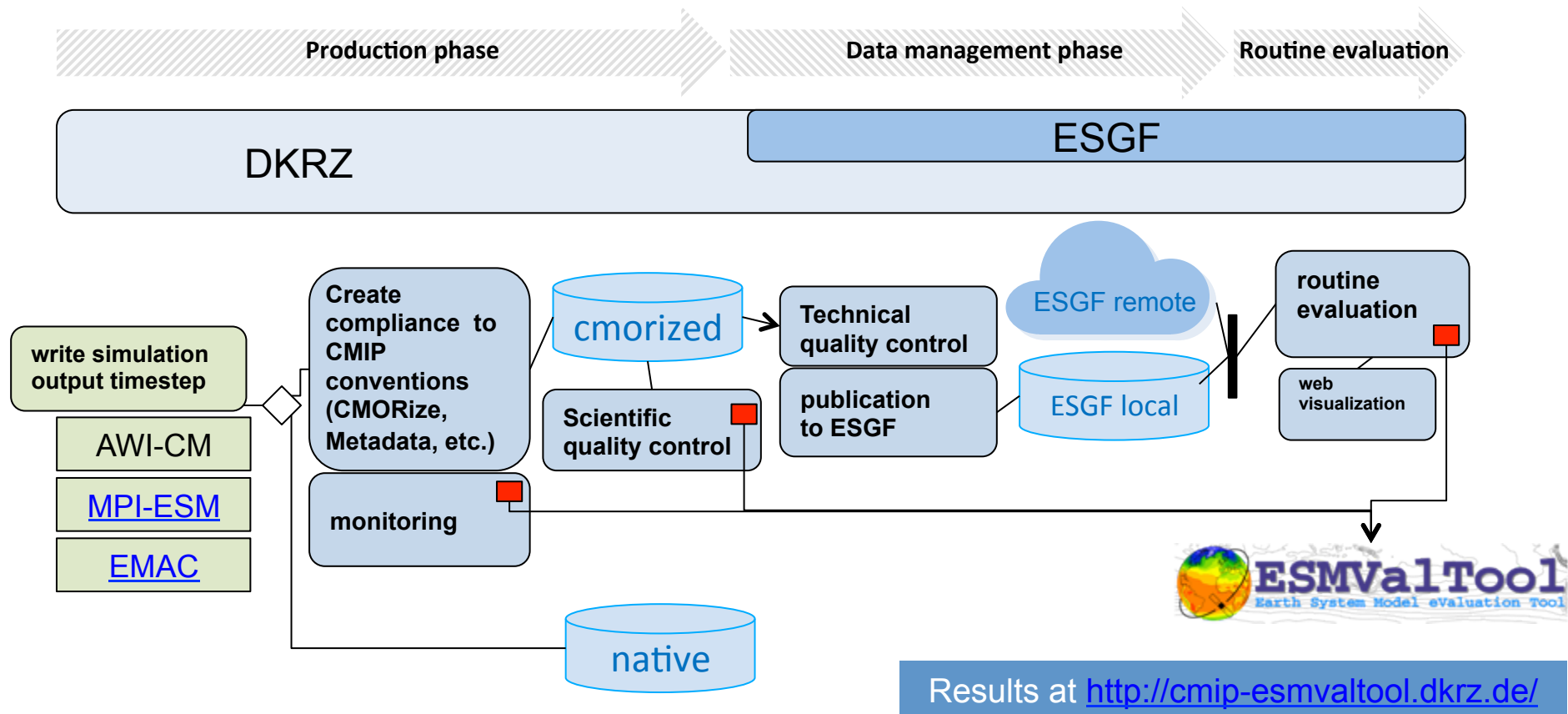


Eyring et al., ESD (2016)

Results at <http://cmip-esmvaltool.dkrz.de/>

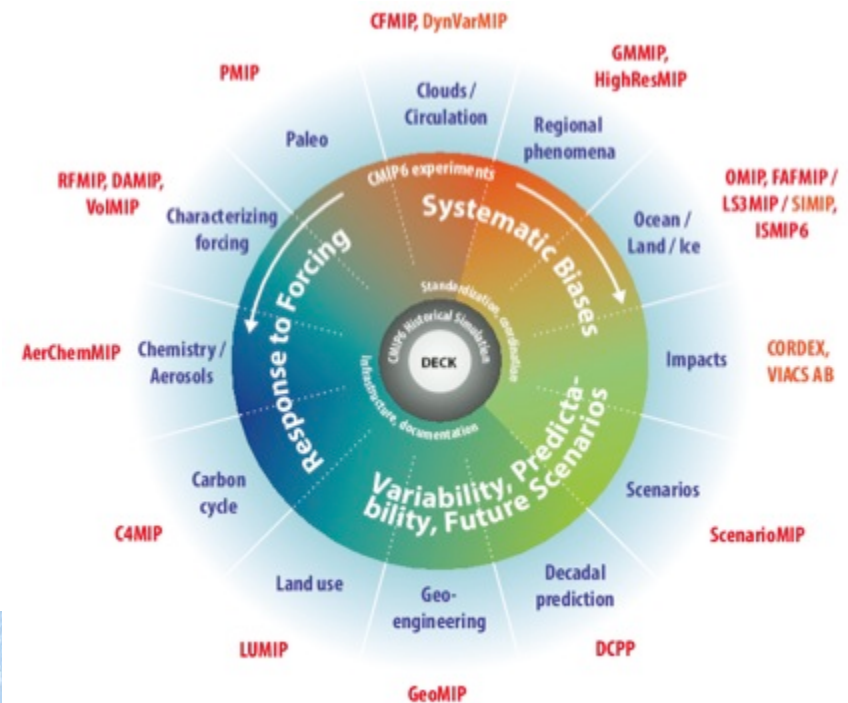


Example for integration of the ESMValTool into the CMIP6 Workflow at the DKRZ*



Some Questions

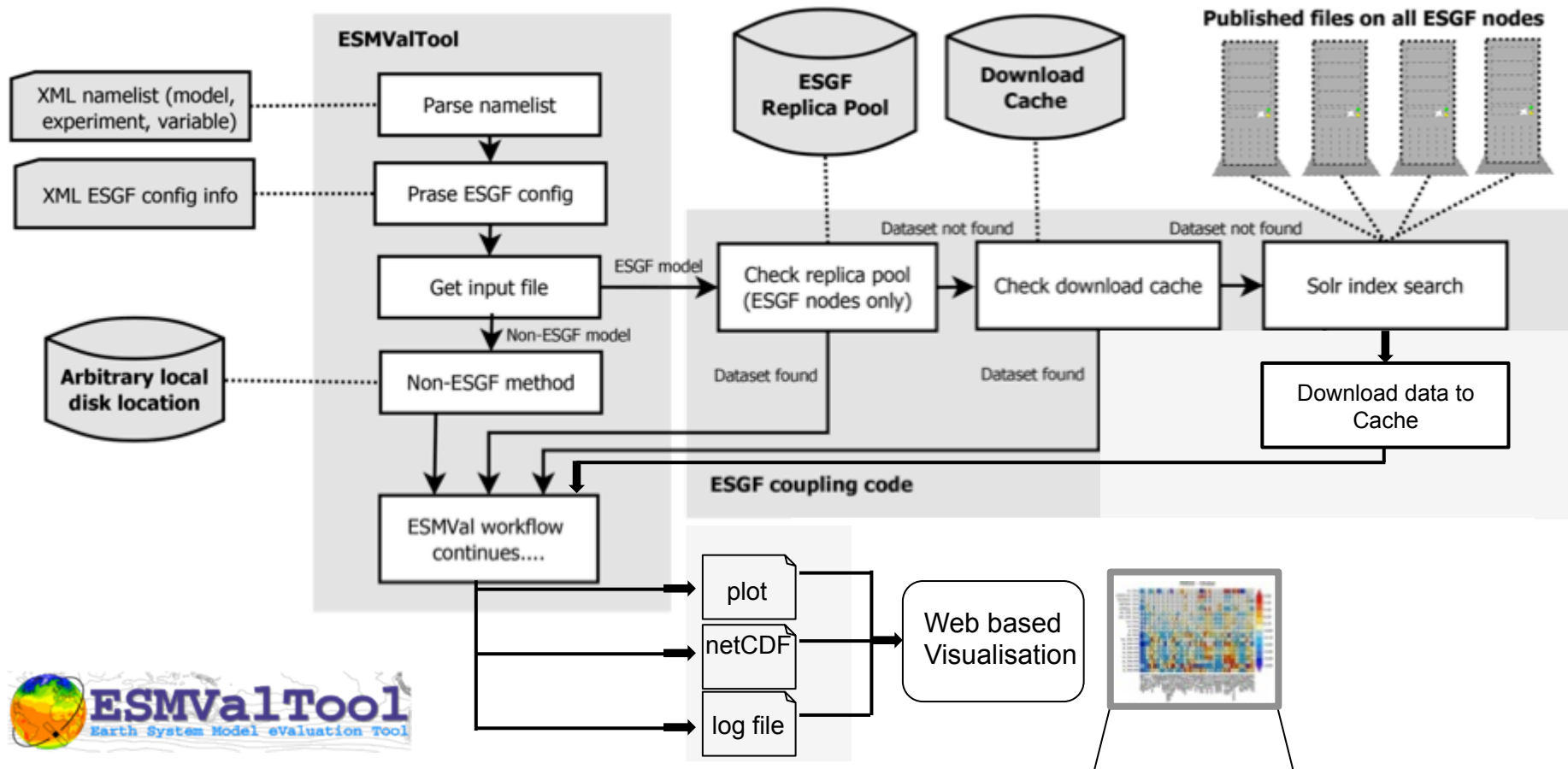
- When do we make the results publically available?
- Can we establish common terms of use for the CMIP evaluation tools?
- How can we encourage active participation of the model groups in the quality control of the CMIP evaluation results?
- How can we coordinate and quality control results from different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



Veronika Eyring (DLR, Germany), Peter Cox (University of Exeter, UK), Greg Flato (CCCma, Canada) and Peter Gleckler (PCMDI, USA)
organized a workshop at the
Aspen Global Change Institute on
Earth System Model Evaluation and Emergent Constraints
(involving 6 CRESCENDO Researchers)



ESMValTool Workflow for routine evaluation at DKRZ

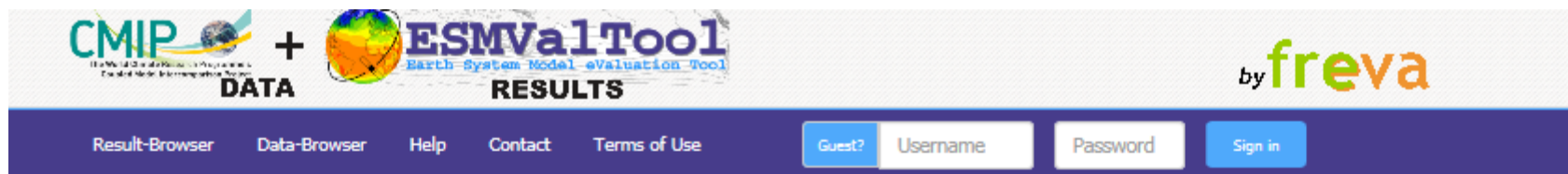


Derived from: Eyring et al., ESMValTool v1.0, GMD, 2016

Results at <http://cmip-esmvaltool.dkrz.de/>



Visualization with FREVA (Cooperation with FUB in BMBF CMIP6-DICAD) project, see <http://cmip-esmvaltool.dkrz.de/>



Resultbrowser

- ESMValTool namelists (19)
- Projects (4)
- CMIP6 Realms (6)
- Themes (12)
- Domain (7)
- Plot Type (12)
- Statistics (11)
- References (18)
- Variables (44)
- Models (516)

Filter by:

- theme
- variable
- model
- etc.



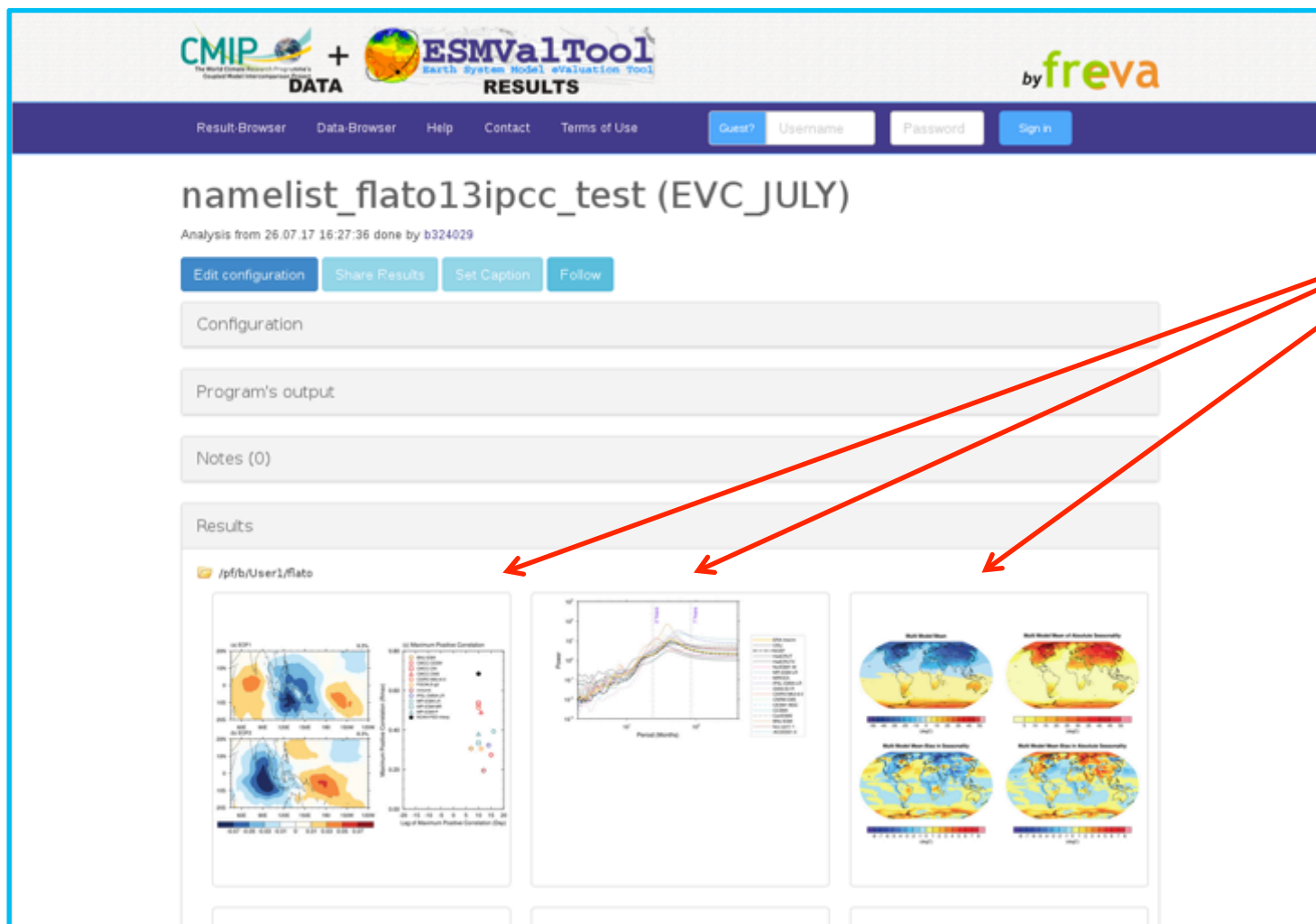
Variables (33)

| | | | |
|---------------|----------------|----------------|---------------|
| va [7] | ua-700 [7] | tas [14] | va-200 [41] |
| NET_CRE [4] | rlutos [32] | rsutos [32] | va-700 [7] |
| et [120] | LW_CRE [8] | rlut [39] | pr-mmday [48] |
| hwp [8] | va-200-850 [9] | ua-200-850 [9] | tas-degC [2] |
| sconcoa [208] | sic [118] | pr-mmh [44] | MyVar [2] |
| theta [7] | ta [29] | ua-200 [41] | sconcbc [228] |
| ua-850 [32] | clt [8] | tro3 [5] | sconco4 [555] |
| va-850 [32] | SW_CRE [16] | ua [9] | theta-850 [1] |
| rsut [32] | | | |

<http://cmip-esmvaltool.dkrz.de/>

Visualization with FREVA (Cooperation with FUB in BMBF CMIP6-DICAD) project, see <http://cmip-esmvaltool.dkrz.de/>

<http://cmip-esmvaltool.dkrz.de/>



Preview Results

Visualization with FREVA (Cooperation with FUB in BMBF CMIP6-DICAD) project, see <http://cmip-esmvaltool.dkrz.de/>

<http://cmip-esmvaltool.dkrz.de/>

The screenshot displays the ESMValTool web interface. At the top, there are logos for CMIP DATA, ESMValTool RESULTS, and freva by. Below the logos is a navigation bar with links for Result-Browser, Data-Browser, Help, Contact, and Terms of Use, along with a login form (Guest?, Username, Password, Sign in). The main content area shows the title "namelist_flato13ipcc_test (EVC_JULY)" and a sub-header "Analysis from 26.07.17 16:27:36 done by b324029". Below this are buttons for "Edit configuration", "Share Results", "Set Caption", and "Follow". The "Configuration" section is expanded, showing a table of settings:

| Tool configuration | |
|--------------------|--|
| namelist: | namelist_flato13ipcc_test |
| Domain: | global, reg, globe |
| Statistics: | clim, dif, spectrum, eof, anomaly, stddev, mean |
| Models: | multi-model-mean, ACCESS1-0, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CNRM-CM5, CSIRO-Mk3-6-0, GISS-E2-R, IPSL-CM5A-LR, MIROC5, MPI-ESM-LR, NorESM1-M, ESACCI-CLOUD, HadCRUT4, HadCRUT, NCEP, CRU, ERA-Interim, CMCC-CESM, CMCC-CM, CMCC-CMS, FGOALS-g2, Inmcm4, MPI-ESM-MR, MPI-ESM-P, NOAA-PSD-Interp, HadCM3, HadSST |
| Variables: | clt, tas, flut, tas-degC |
| Themes: | phys, varmodes |
| References: | flato13ipcc |
| Projects: | crescendo, embrace, cmug, esmval |
| CMIP6 Realms: | atmos, ocean |
| Plot Type: | geo, pro, scatter, time |

At the bottom of the configuration section are buttons for "Additional information" and "Copy analyze command". Below the configuration section is a section for "Program's output".

Show
ESMValTool
configuration

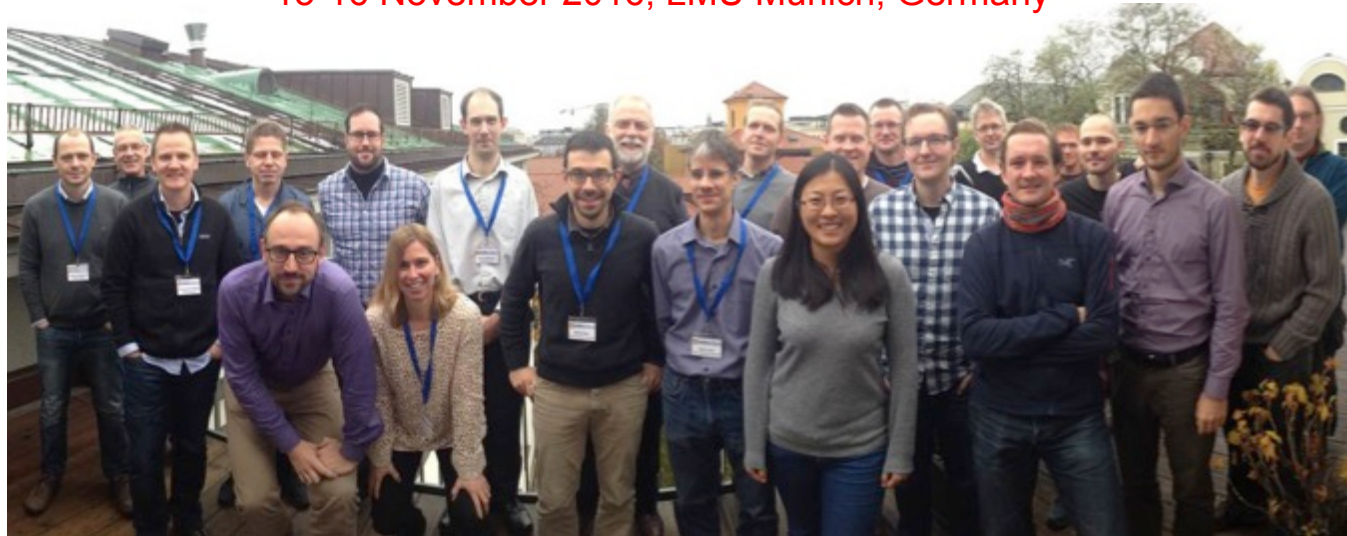
Alex was a member of the ESMValTool core development team, hosted several ESMValTool workshops in his department at the LMU, and was a great partner in CRESCENDO RT3 and other ESMValTool projects. He was an excellent scientist, full of humor, ideas, commitment, and professionalism. It was just so enjoyable to work with him.

Our great friend and colleague, Alexander Loew, lost his life in a tragic traffic accident. Our thoughts are with his family and his department.



Alex, we are shocked beyond words and will miss you greatly!

2nd Technical ESMValTool Workshop
15-16 November 2016, LMU Munich, Germany



1st ESMValTool Documentation and Visualization Workshop
15-19 May 2017, LMU Munich

