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Climate Model Evaluation and ESMValTool

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Outline

History of Model Evaluation

Basics of Model Evaluation

ESMValTool

Available Diagnostics

Why to do Model Evaluation?

What is Model Evaluation?
Visualization and analysis of climate model output

Why do we do it?

Validation to show simulations are "right"

Evaluation to understand aspects of the Earth system

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Three Phases

- Early Days (1970s–1990s)
- Beginning Standardization and Application (1990s–2000s)
- Standardization and Operationalization (2000s–2010s)

Early Days (1970s–1990s)

- Individual Evaluation
- Performed by Modelers
- Evaluation across models and by third parties difficult due to wildly different data formats and outputs

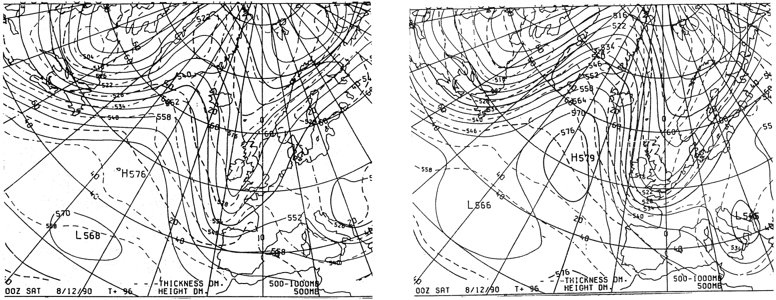

Figure: Cullen, M. J. P. "The unified forecast/climate model." Meteorological Magazine 122, no. 1449 (1993): 81-94.

Beginning Standardization and Impact (1990s–2000s)

- First Agreement on Model Output
- Communication with Policymakers

Important Events

- Formation of IPCC (1988)
- First Assessment Report (FAR) (1990)
- Second Assessment Report (SAR) (1995)
- Launch of CMIP (1995)
- Third Assessment Report (TAR) (2001)

Standardization (2000s–2010s)

- Regular IPCC Assessment reports and CMIP
- Standardization of
  - Experiments
  - Data Formats
  - Model Output
- Establishment of ESGF for Data Exchange

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Future

Standardization of Evaluation

Outline

Statistical Nature of Climate Model Evaluation

No Single Climate Simulation is Exactly as Reality!

- No scenario simulation can tell us that year 2080 will be wet
- No historical simulation shows the world as it was everywhere

Comparison with Reality only by Statistics

Need Statistical Aggregation

- Temporal averages
- Spatial averages
- Ensembles
- Combinations

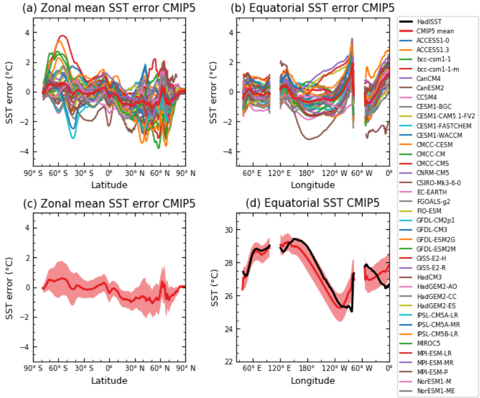

Figure: Figure 26 from Eyring et al., 2020

Nature of Data

Earth System Models

- Gridded
- Global
- Freely available (CMIP, ESGF)
- Well standardized $\rightarrow$ easy to use

Nature of Data

Observations

- Pointwise
- Local
- Sometimes under license
- Less well standardized

Nature of Data

Reanalyses

- Processed observations
- Convenient comparison with models
- May contain model data!

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Overview

ESMValTool aims to bring together *model data* and *diagnostics*

ESMValTool as standard tool in CMIP

- Gathers diagnostics
- Thanks to CMIP specification, offers model data in a uniform format
- Brings standardized forms of observations and reanalyses

Features

Supports model evaluation, analysis, and comparison with

- data handling, i.e. where is all the data
- data preprocessing, i.e. regridding, level extraction, . . .
- support for observational datasets

Data Sources

- Focus on CMIP5 and CMIP6
- Recently added CMIP3
- Recently added CORDEX (preliminary)

Development Model

Open Source Project on `github.com`
Two Parts

	ESMValCore	ESMValTool
Developed by	Programmers	Scientists
Focus on	Infrastructure, Performance, Generality	Individual Diagnostics, Science
Contributors	47	49
Issues (Open/Closed)	131/68	144/441
Languages	Python	Python, NCL, R, Julia

Development

Releases

Version	Release Date	Key Features
1.1.0	2017-02	legacy version
2.0.0	2020-07-03	complete rewrite, documented in papers
2.1.0	2020-10-26	new diagnostics, e.g. model weighting

Based on the Scientific Python Ecosystem, e.g.

- Iris & Dask
- ESMPy (ESMF)
- Specialized libraries

Recent Articles

- Weigel et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – diagnostics for extreme events, regional and impact evaluation and analysis of Earth system models in CMIP”
- Righi et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – technical overview”
- Eyring et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – an extended set of large-scale diagnostics for quasi-operational and comprehensive evaluation of Earth system models in CMIP”
- Lauer et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – diagnostics for emergent constraints and future projections from Earth system models in CMIP”

Online Resources

- Homepage: `https://www.esmvaltool.org`
- Documentation:
  `http://esmvaltool.readthedocs.io/en/latest/index.html`
- Development:
  `https://github.com/ESMValGroup/ESMValCore`
  `https://github.com/ESMValGroup/ESMValTool`

List of Supported Observations (non-exhaustive)

aura tes	esacci fire	lai3g
cds satellite lai fapar	esacci landcover	landflux eval
cds satellite soil moisture	esacci oc	landschuetzer2016
cds uerra	esacci ozone	modis
cds xch4	esacci soilmoisture	mte
cds xco2	esacci sst	ncep
ceres syn1deg	fluxcom	ndp
cru	gcp	niwa bs
duveiller2018	ghcn	nsidc 0116 nh
eppley vgpm modis	hadcrut3	nsidc 0116 sh
era5	hadcrut4	patmos x
era interim	hadisst	piomas
esacci aerosol	hwsd	uwisc

Outline

Selected Diagnostics

Here, we show a selection of ESMValTool diagnostics as described in

First Figure:
Eyring et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – an extended set of large-scale diagnostics for quasi-operational and comprehensive evaluation of Earth system models in CMIP”

Rest:
Weigel et al., “Earth System Model Evaluation Tool (ESMValTool) v2.0 – diagnostics for extreme events, regional and impact evaluation and analysis of Earth system models in CMIP”

Surface Temperature Annomalies

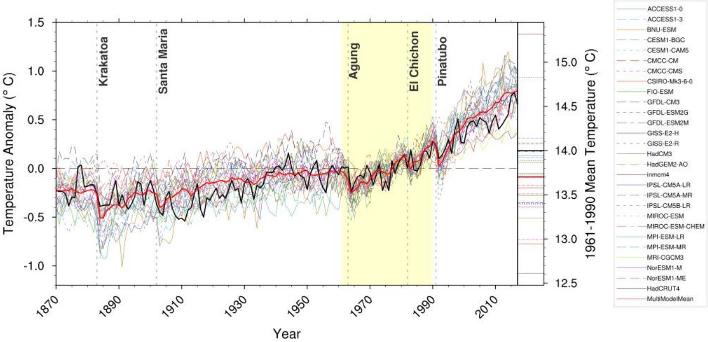

Figure: Figure 7 from Eyring et al., 2020. Anomalies in annual and global mean surface temperature of CMIP5 models and HadCRUT4 observations. Yellow shading indicates the reference period (1961–1990); vertical dashed grey lines represent times of major volcanic eruptions. The right bar shows the global mean surface temperature of the reference period. CMIP5 model data are subsampled by the HadCRUT4 observational data mask and processed as described in Jones et al. (2013). All simulations are historical experiments up to and including 2005 and the RCP 4.5 scenario after 2005. Extended from Fig. 9.8 of IPCC WG I AR5 chap. 9 (Flato et al., 2013) and produced with recipe_flato13ipcc.yml; see details in Sect. 3.2.1.

Hydroclimatic Intensity

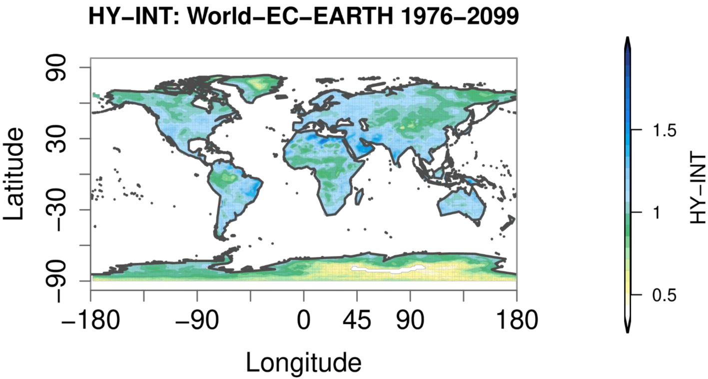

Figure 1: Mean hydroclimatic intensity (i.e., a combination of precipitation intensity and dry spell length) for the EC-EARTH model historical simulation + RCP 8.5 projection over 1976-2099. Data were normalized to the historical 1976-2005 period. The figure is an examples of a large number of different plots which can be produced with *recipe_hyint.yml*, similar to (Giorgi et al., 2014). For details see Section 3.1.1.

Drought Severity

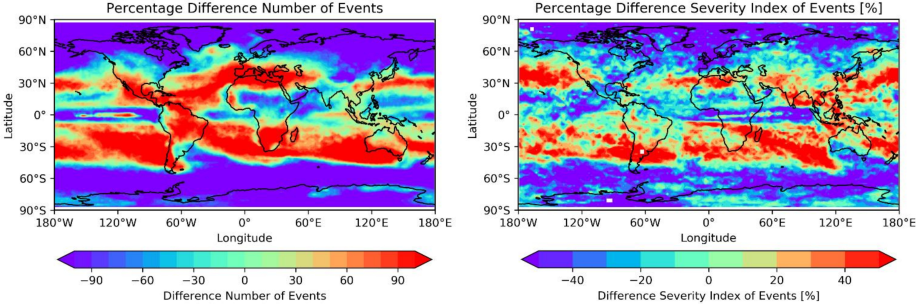

Figure 5: Difference in number (left) and severity index (right) of drought events between the RCP8.5 (2050-2100) and historic (1950 to 2100) multi-model mean of 13 CMIP5 models. Here, a drought event is defined as any number of consecutive months with an SPI < -2. For the SPI calculation a Gamma distribution and a representative time scale of 6 months is used. The Figure is similar to Figure 3 a – d of (Martin, 2018) and produced with recipe_martin18grl.yml, for details see Section 3.1.2.

Hot Summer Days

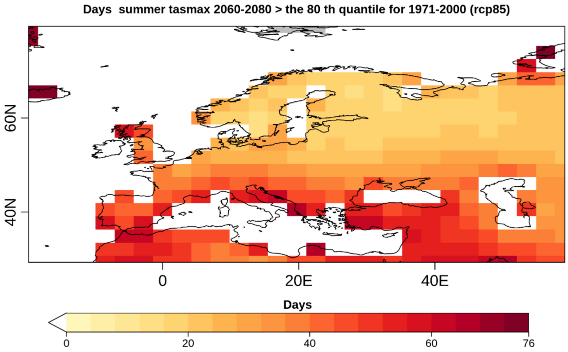

Figure 8: a) Average number of summer days during the time period 2060-2080 when the daily maximum near-surface air temperature exceeds the 80th quantile of the 1971-2000 reference period.

Results shown are for the RCP 8.5 scenario simulated by BCC-CSM1-1 (see Section 3.3.1 for details on *recipe_heatwaves_coldwaves.yml*).

Wind Capacity

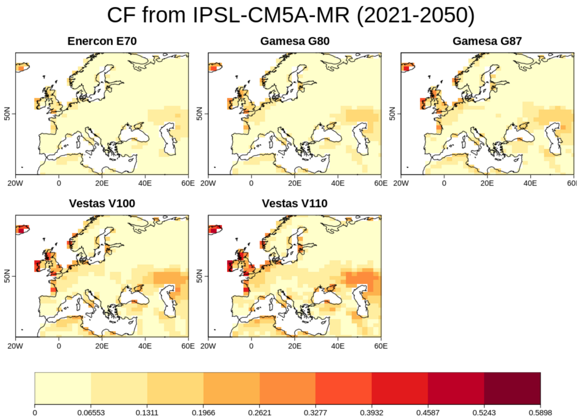

Figure 11: Wind capacity factor for five kinds of wind turbines: Enercon E70 (top-left), Gamesa G80 (middle-top), Gamesa G87 (top-right), Vestas V100 (bottom-left) and Vestas V110 (middle-bottom) using the IPSL-CM5A-MR simulation for the rcp8.5 scenario during the period 2021-2050 (see Section 3.3.4 for details on *recipe_capacity_factor.yml*).

Precipitation Downscaling

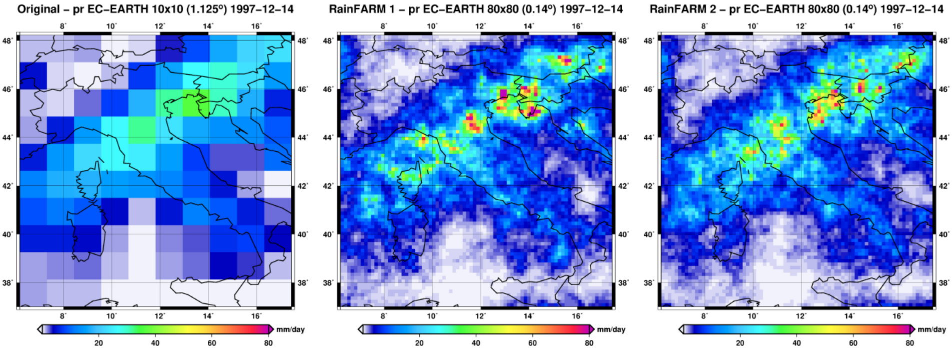

Figure 16: Left panel: Example of daily accumulated precipitation from the EC-EARTH CMIP5 model on a specific day, downscaled using RainFARM from its original resolution (1.125°).,Central and right panel: Two stochastic realizations for increasing the spatial resolution by a factor of 8 to 0.14°; A fixed spectral slope of *s*=1.7 was used. The data were produced by *recipe_rainfarm.yml* but this plot was not produced by ESMValTool - the recipe output is netCDF only.

Cluster Analysis

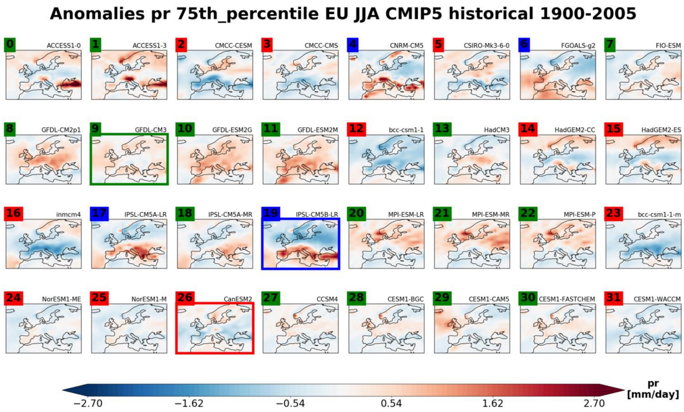

Figure 17: Clustering based on the 75th percentile of historical summer (JJA) daily precipitation rate for 32 CMIP5 models over the period 1900-2005. The colour of the model number of each ensemble member indicates the cluster to which they belong. The most representative members of each cluster is marked with a coloured border. See section 3.5 for details on *recipe_ensclus.yml*.

Summary

ESMValTool...

- is an efficient tool for routine evaluation of ESMs.
- invites contributions by open source approach.
- will be used strongly in IPCC AR6.

- Outlook
  - Support for RCMs is being improved (CORDEX).
  - Will be used in model development.

Bibliography

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