

# ESMValTool

Earth System Model Evaluation Tool

# An Introduction to ESMValTool

Online Tutorial  
Dec 3rd, 2025

Ranjini Swaminathan<sup>1</sup>, Birgit Hassler and Julien Lenhardt

<sup>1</sup>University of Reading and National Centre for Earth Observation

<sup>2</sup> DLR

<sup>3</sup>SMHI

# Motivation

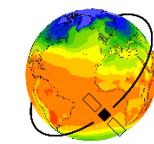
→ **Earth System Models (ESMs)** are important tools for

- improving our understanding of the climate system
- projecting future climate change

→ The **evaluation** of earth system models with earth observations (satellite, airborne...) is crucial for

- model improvements,
- a better process understanding of the climate system and
- more trustworthy climate projections are to be used for policy guidance.

**Challenge: Climate models increase in complexity and resolution**



# ESMs are Complex – and there are Plenty!

Latest Assessment Report of the IPCC (AR6):

- ~60 ESMs analyzed
- >30 international institutions participated

→ Coordination necessary!

Institution Full Country or Region Name	Models	Main References	Atmosphere 1) Component Name 2) Resolution (km) 3) Number of Levels (L)	Aerosol 1) Component Name 2) Emissions- driven or Prescribed 3) References	Atmospheric Chemistry 1) Component Name 2) Details 3) References	Ocean 1) Component Name 2) Horizontal Resolution and Number of Levels 3) Vertical Grid	Cryosphere 1) Sea Ice 2) Land Ice	Land 1) Component Name 2) Reference	Land Carbon Active Processes	Ocean Interactive Biogeochemistry 1) Component Name 2) Reference	
CAS Chinese Academy of Sciences China											
CAS											
CCCMa Canadian Centre for Climate Modelling and Analysis Canada											
CSIRO Commonwealth Scientific and Industrial Research Organisation Australia											
CCCR-ITM Centre for Climate Change Research, Indian Institute of Tropical Meteorology India											
CMCC Centro Euro- Mediterraneo sui Cambiamenti Climatici Italy											
CNRM Centre National de Recherches Météorologiques et CERFACS Centre National de Recherche et de Formation Avancée en Calcul Scientifique France											
FIO-QNLM First Institute of Oceanography and Pilot National Laboratory for Marine Science and Technology (Qingdao), China	FIO-ESM-2-0	Bao et al. (2020)	1) CAM5 2) 100km, 26 L 3) Top 43 km	2) Prescribed, MACv2-SP (Stevens et al., 2017)		None	POP-W with MASNUM surface wave model 2) 60 km, 60 L 3) z 4) Qiao et al. (2013)	1) CICE4.0 2) Hunkie and Lipscomb (2010)	1) CLM4.0 2) Lawrence et al. (2011)		Land carbon N cycle BEC
E3SM National Laboratories Consortium USA	MPI-ESM-1-2-HAM	Neubauer et al. (2019a)	1) ECHAM6.3 2) 170 km, 47 L 3) Top 80 km	1) HAM2.3 2) Emissions-driven 3) Teguer et al. (2019)	1) HAM2.3 2) Emissions-driven 3) Teguer et al. (2019)	2) Specified oxidants, sulphur chemistry 3) Feichter et al. (1996); Inness et al. (2013)	1) MPIOM 1.6.3 2) 100 km, 40 L 3) z	2) Notz et al. (2013) 1) JSBACH3.20 2) Reich et al. (2021)		Land carbon N cycle Prog. veg. Fires HAMOCC6	
EC-Earth Consortium Europe											
IPSL Institut Pierre- Simon Laplace France	IPSL-CM6A-LR	Boucher et al. (2020g)	1) LMDZ NPv6 2) 160 km, 79 L 3) Top 80 km 4) Hourdin et al. (2020)	2) Prescribed 3) Lurton et al. (2020)	2) Prescribed 3) Lurton et al. (2020)	2) Specified oxidants for aerosols	1) NEMO 3.6 2) 70 km, 75 L 3) z	1) NEMO-LIM3 2) Rousset et al. (2015)	ORCHIDEE (v2.0, Water/Carbon/ energy mode)	None PISCES	
IPSL	IPSL-CM5A2-INCA		1) LMDZ APv5 2) 240 km, 79 L 3) Top 80 km 4) Hourdin et al. (2020)	1) INCA 2) Emissions-driven	1) INCA 2) Emissions-driven	1) NEMO 3.6 2) 150 km, 30 L 3) z	1) NEMO-LIM3 2) Rousset et al. (2015)	ORCHIDEE (IPSLCM5A2.1, Water/ carbon/energy mode)	Land carbon PISCES		
KIOST Korea Institute of Ocean Science & Technology Republic of Korea	KIOST-ESM	Pak et al. (2021)	1) GFDL-AM2.0 2) 190 km, 32 L 3) Top 43 km 4) Anderson et al. (2004)	1) GFDL-AM2.0 2) Emissions-driven 3) Anderson et al. (2004)	None	1) GFDL-MOM5.0 2) 90 km, 52 L 3) z	1) GFDL-SIS GFDL-LM3.0 (Milly et al., 2014)	Land carbon N cycle Prog. veg.	TOPAZ2		

# CMIP – Coupled Model Intercomparison Project



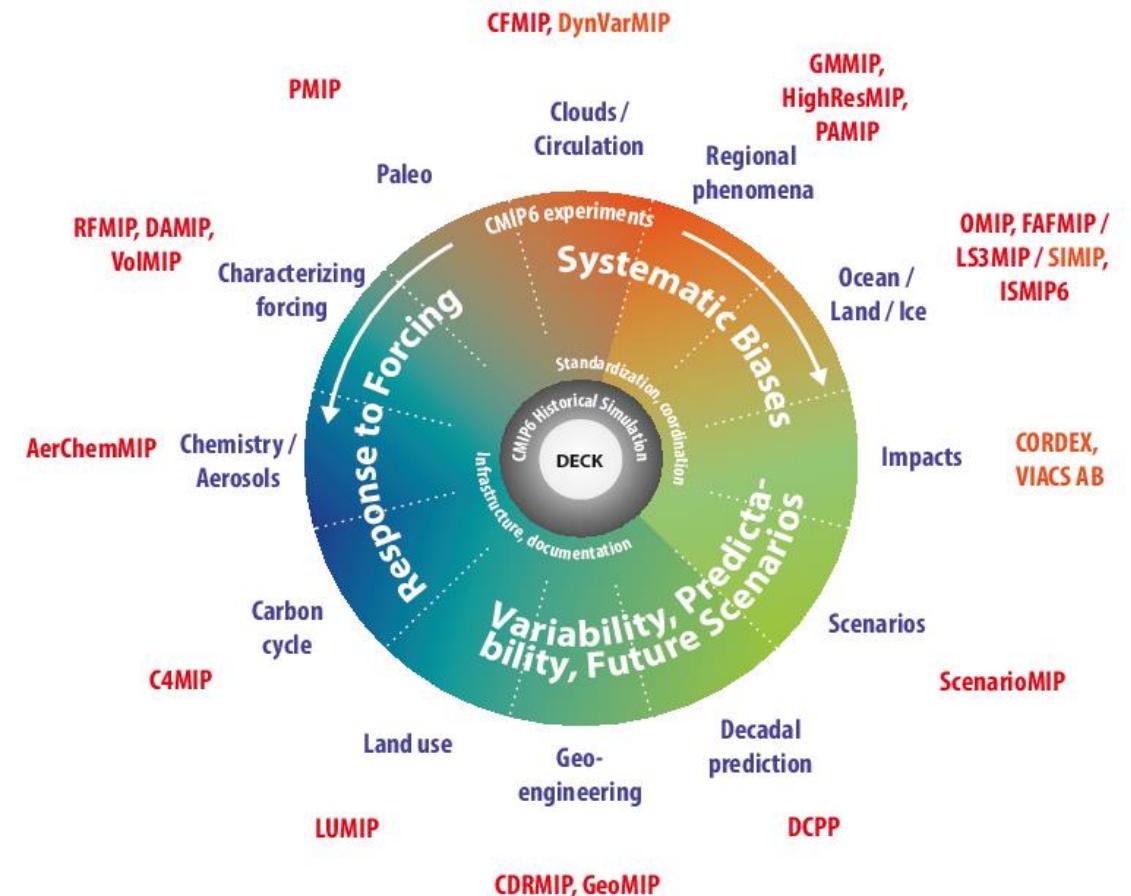
**Aim of CMIP:** Better understand past, present and future climate changes arising from natural and anthropogenic forcing in a multi-model context.

## 1) A handful of common experiments

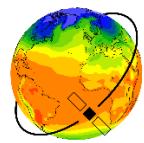
- i. AMIP simulation (~1979-2014)
- ii. Pre-industrial control simulation
- iii. 1%/year CO<sub>2</sub> increase
- iv. Abrupt 4xCO<sub>2</sub> run
- v. Historical simulation using CMIP6 forcings (1850-2014)

## 2) Standardization, coordination, infrastructure, documentation

## 3) CMIP-Endorsed Model Intercomparison Projects (MIPs)



*Eyring et al., GMD (2016)*



**ESMValTool**

Earth System Model Evaluation Tool

# ESMValTool

We have:

Many complex CMIP models with standardized output

Crucial question:

How well do these models perform relative to reference data sets  
(e.g., observations)? → **Standardized model evaluation**



# ESMValTool in a nutshell

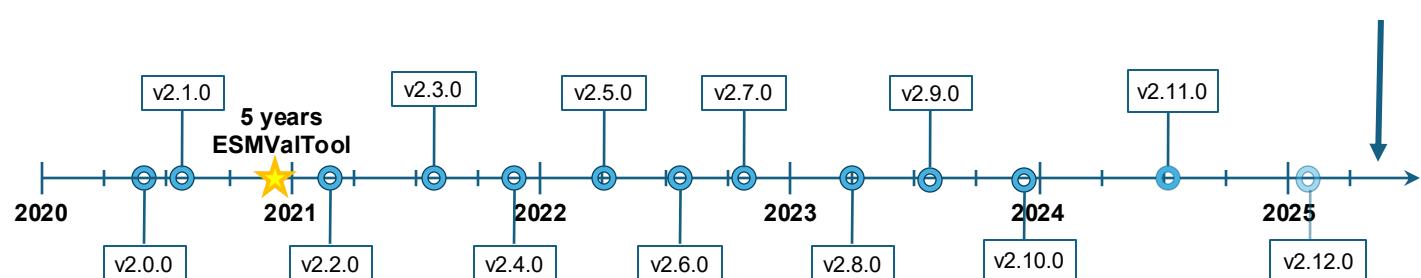


# ESMValTool

Earth System Model Evaluation Tool

- Community diagnostic and performance metrics tool for **evaluation and analysis of Earth system models**, primarily focused on multi-model context
- Open source community development on GitHub** (> 200 developers, > 60 international institutes, funded by many national and international projects)
- Used in several chapters of the **Assessment Report 6** of the IPCC's WG1 and provenance records available for all results
- Release of v2.0.0 in August 2020, currently at v2.12.0

V2.13.0 and 10<sup>th</sup> anniversary!!!



## Scientific Documentation

*Righi et al., GMD, 2020*

**Technical overview**

*Eyring et al., GMD, 2020*

**Large-scale diagnostics**

*Lauer et al., GMD, 2020*

**Diagnostics for emergent constraints and future projections**

*Weigel et al., GMD, 2021*

**Diagnostics for extreme events, regional and impact evaluation**

*Schlund et al., GMD, 2023*

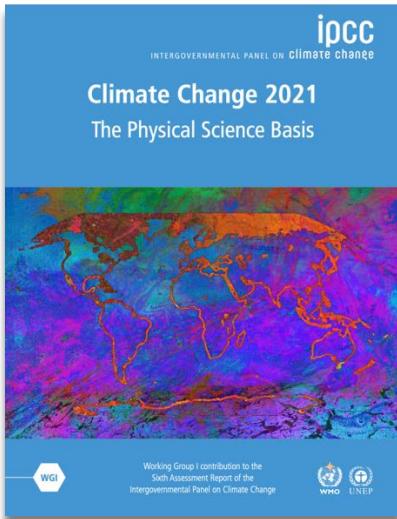
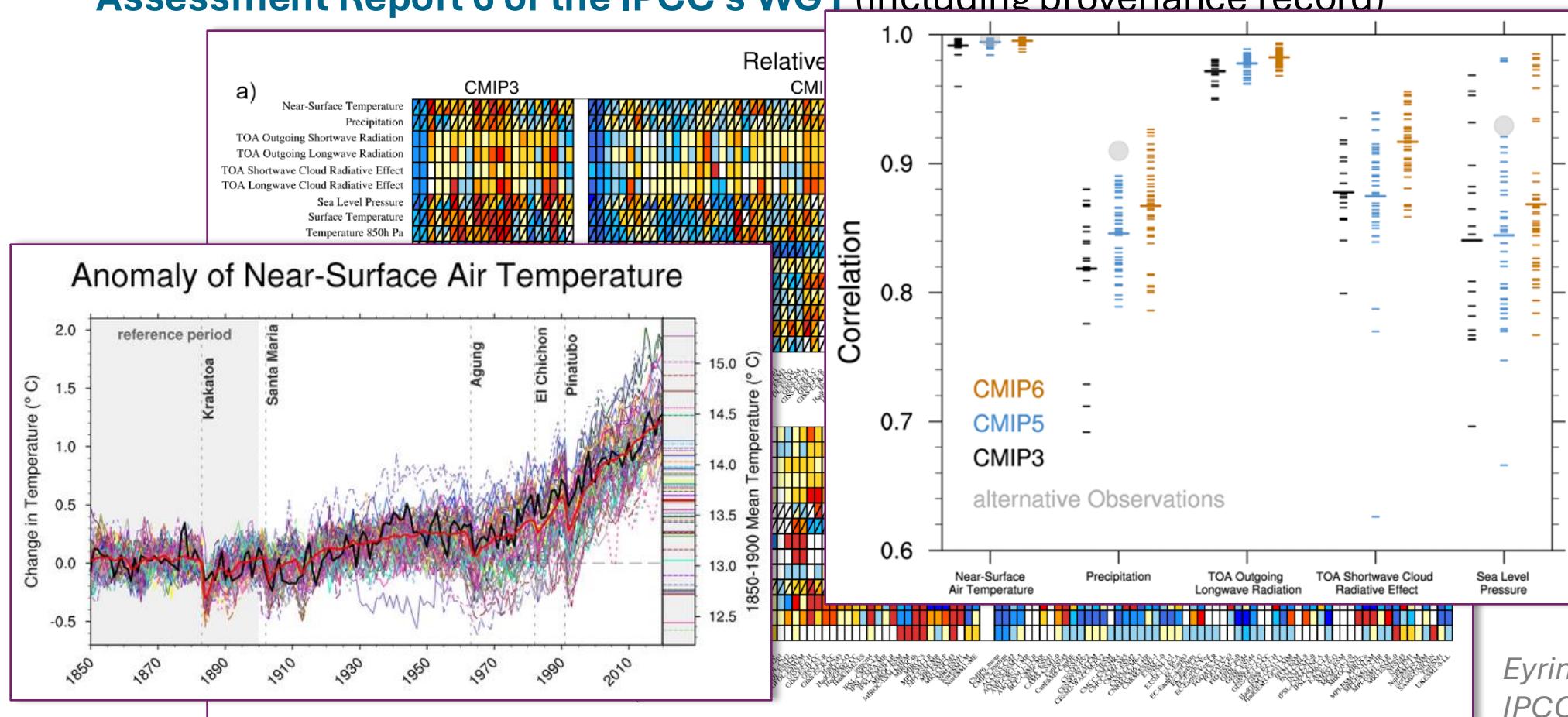
**Evaluation of native ESM output**

*Lauer et al., GMD, 2025*

**Monitoring and benchmarking**

# ESMValTool and IPCC

- ~ 60 scientific peer-reviewed publications
- > 20 national and international science projects, including large EU projects
- ESMValTool has been used for the production of figures for **several chapters of the Assessment Report 6 of the IPCC's WG1** (including provenance record)

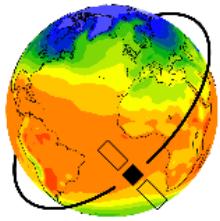


Eyring et al., Chapter 3 of  
IPCC AR6 WGI, 2021

# ESMValTool and Climate-REF

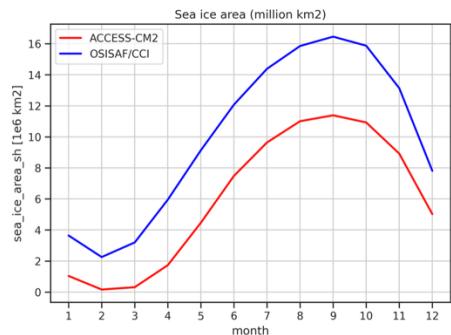


- Rapid Evaluation Framework (REF).
- ESMValTool one of four open-source software providers.
- Diagnostics include – climate drivers of fire, climate at global warming levels, cloud properties, ENSO and climate sensitivity.
- Explore : <https://dashboard.climate-ref.org/>



# ESMValTool

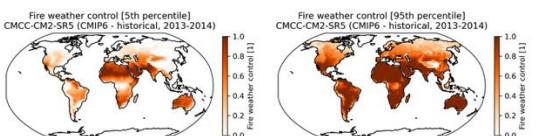
Earth System Model Evaluation Tool



20-year average seasonal cycle of the sea ice area in million km<sup>2</sup> from ACCESS-CM2\_r1i1p1f1\_gn compared with OSI-450.

Execution Group: cmip6\_gn\_r1i1p1f1\_ACCESS-CM2

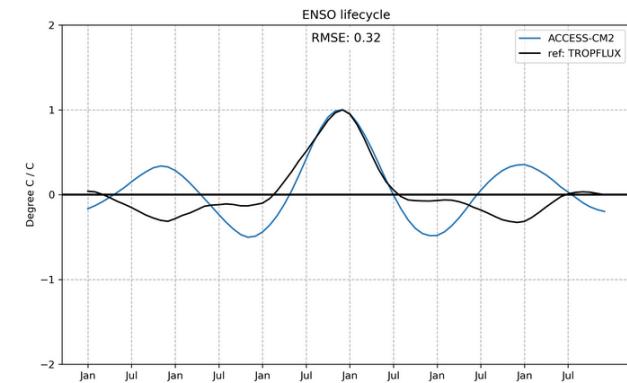
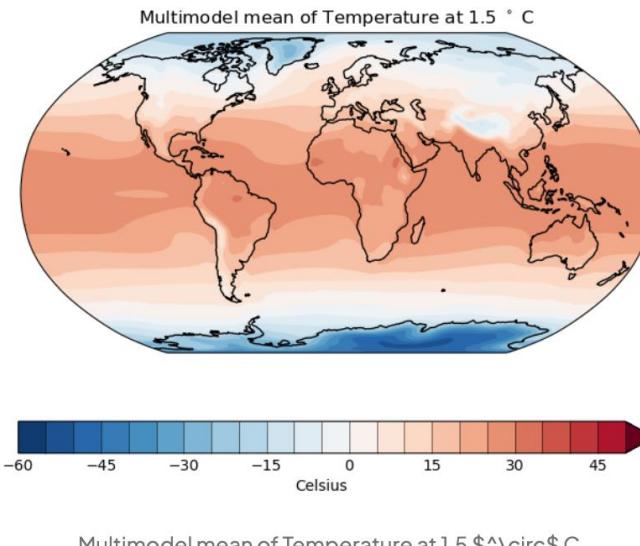
Filename: executions/recipe\_20251003\_125750/plots/siarea\_s



Fire weather control for the CMCC-CM2-SR5 (CMIP6-historical) for the time period 2013/2014 as computed with the ConFire model (Jones et al., 2024).

Execution Group: cmip6\_gn\_r1i1p2f1\_CMCC-CM2-SR5

Filename: executions/recipe\_20251002\_035023/plots/fire\_ev

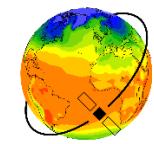


Temporal evolution of sea surface temperature anomalies in the central equatorial Pacific (Niño 3.4 region average), illustrating the ENSO-associated variability.

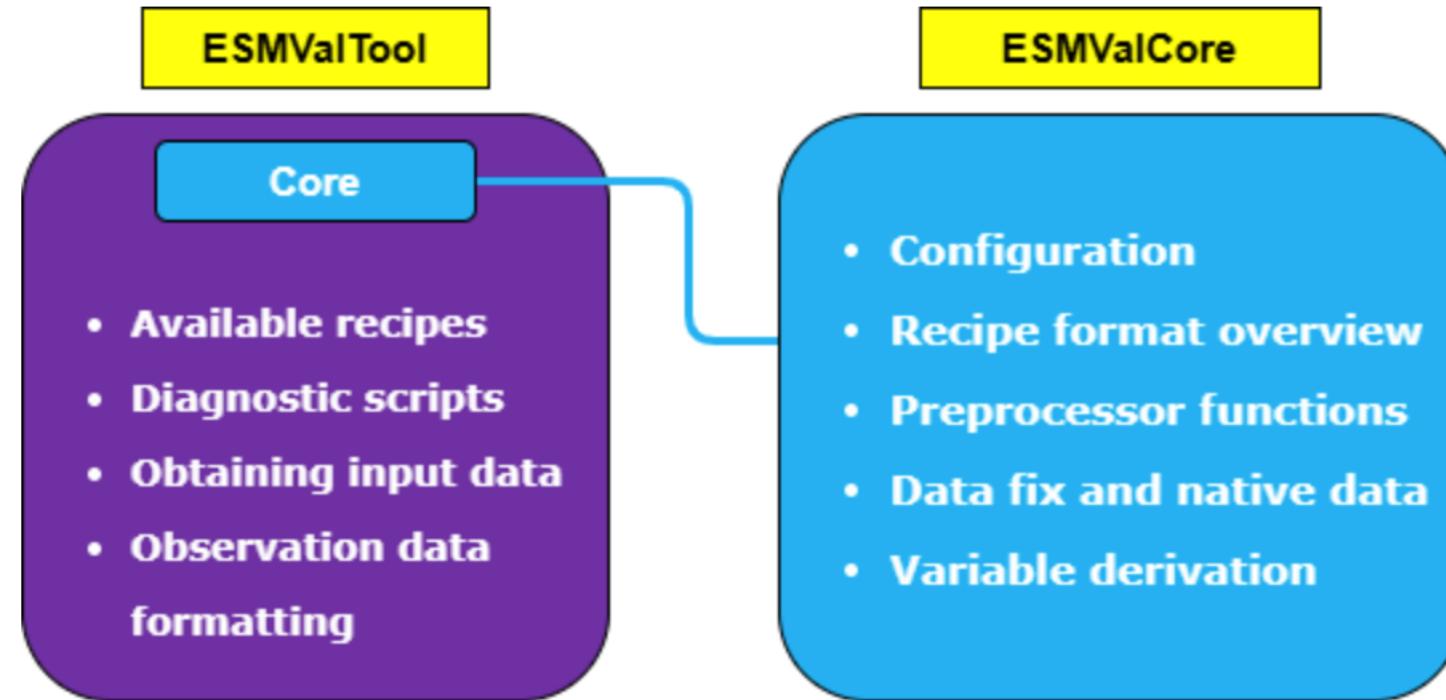
Execution Group: cmip6\_gn\_r1i1p1f1\_ACCESS-CM2

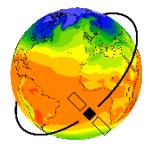
Filename: executions/recipe\_20251002\_035527/plots/diagno

# ESMValTool and Climate-REF

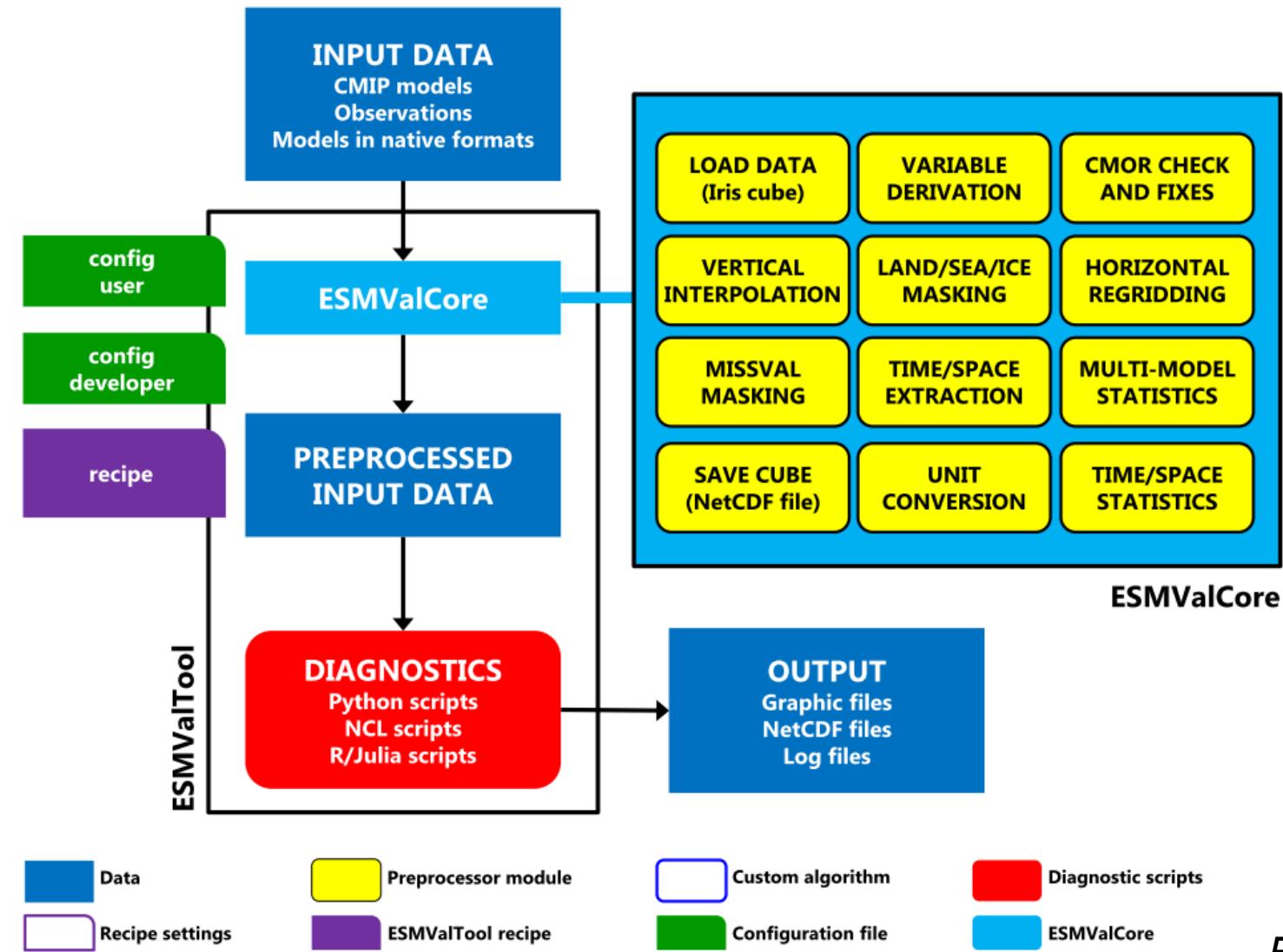


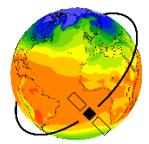
# ESMValTool – Components





# ESMValTool – Details

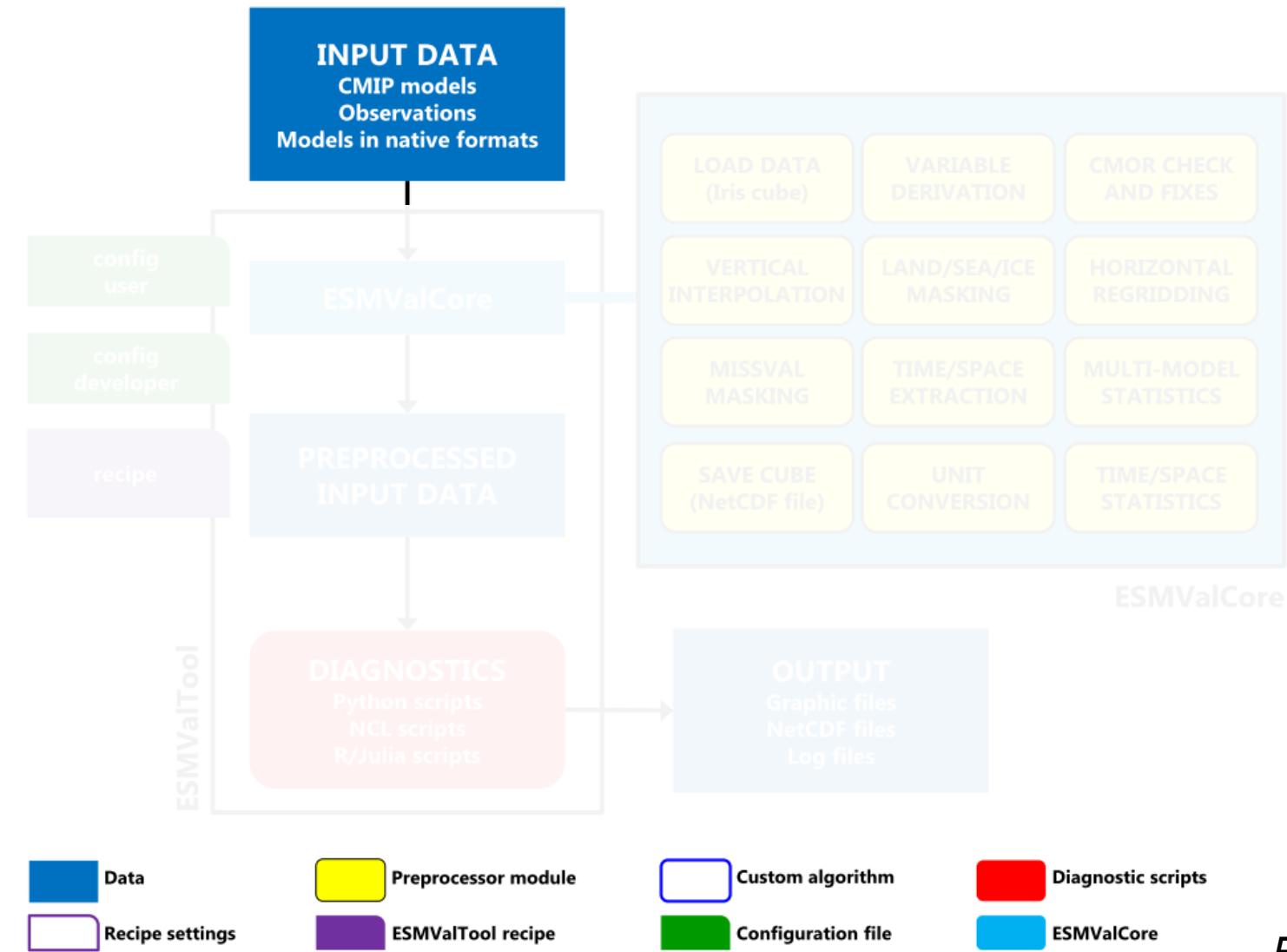


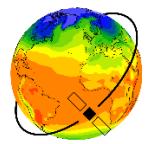


**ESMValTool**

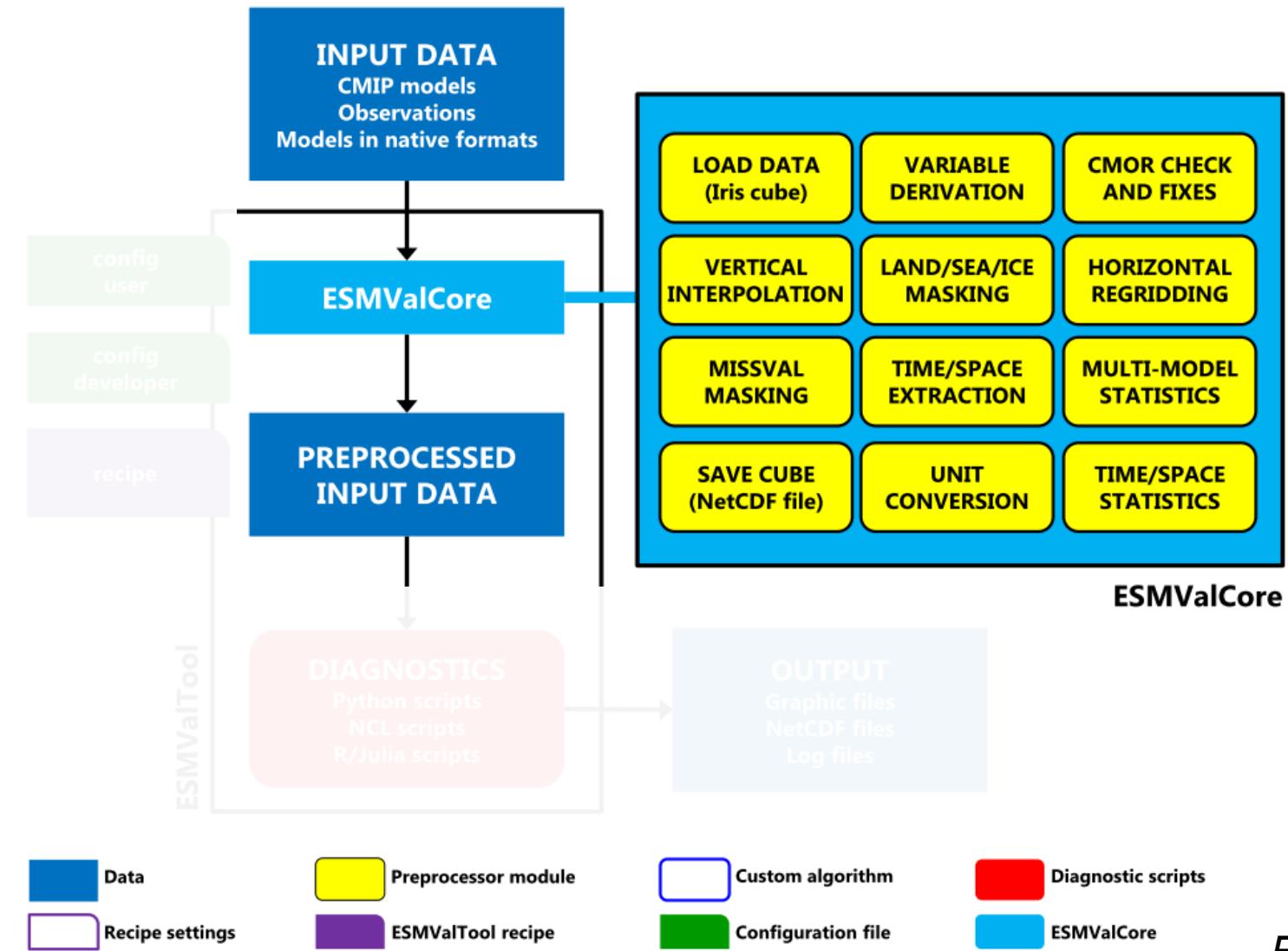
Earth System Model Evaluation Tool

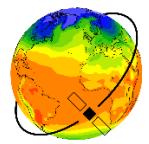
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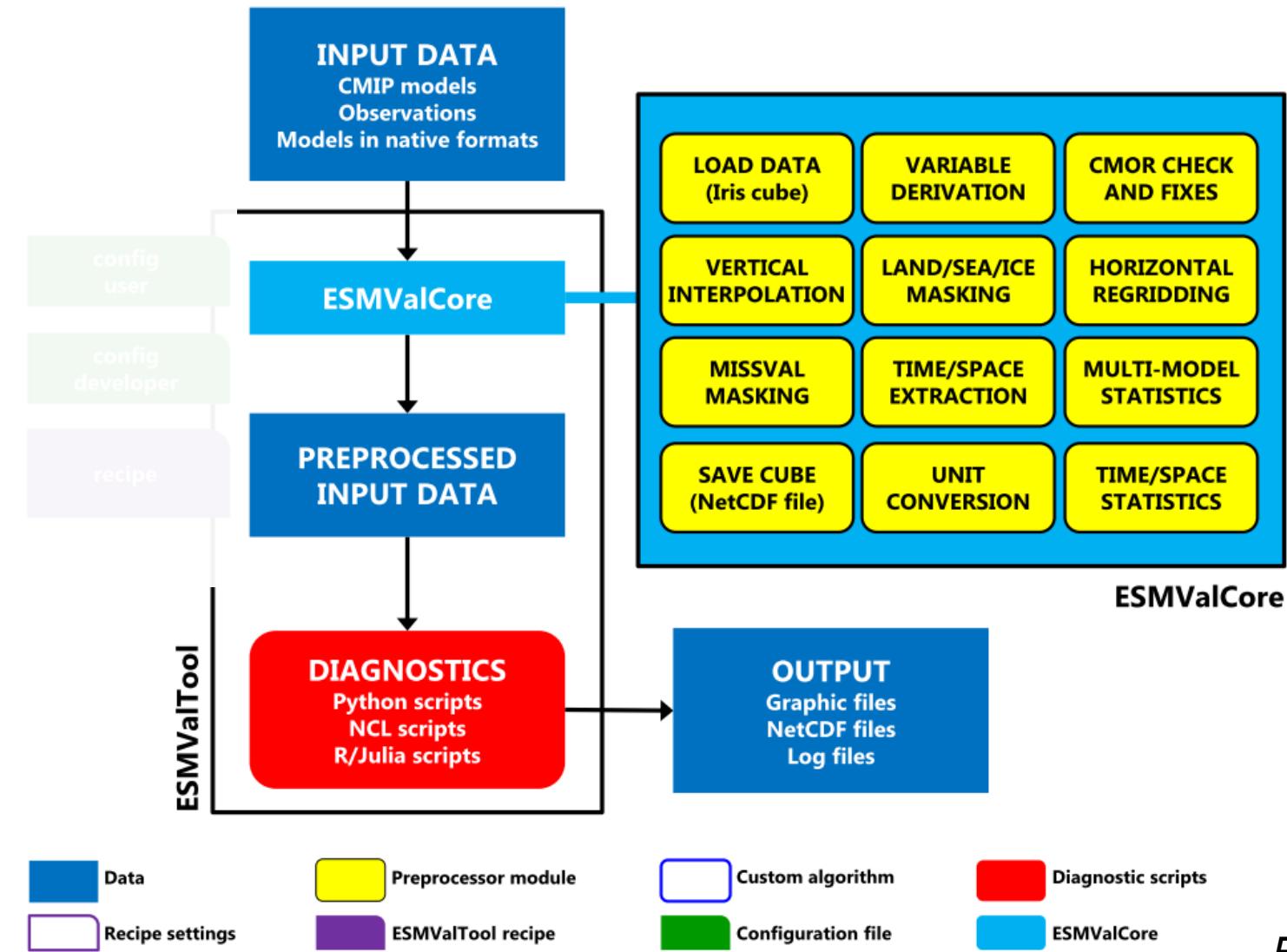


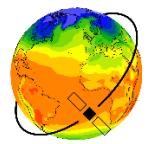
# ESMValTool – Details



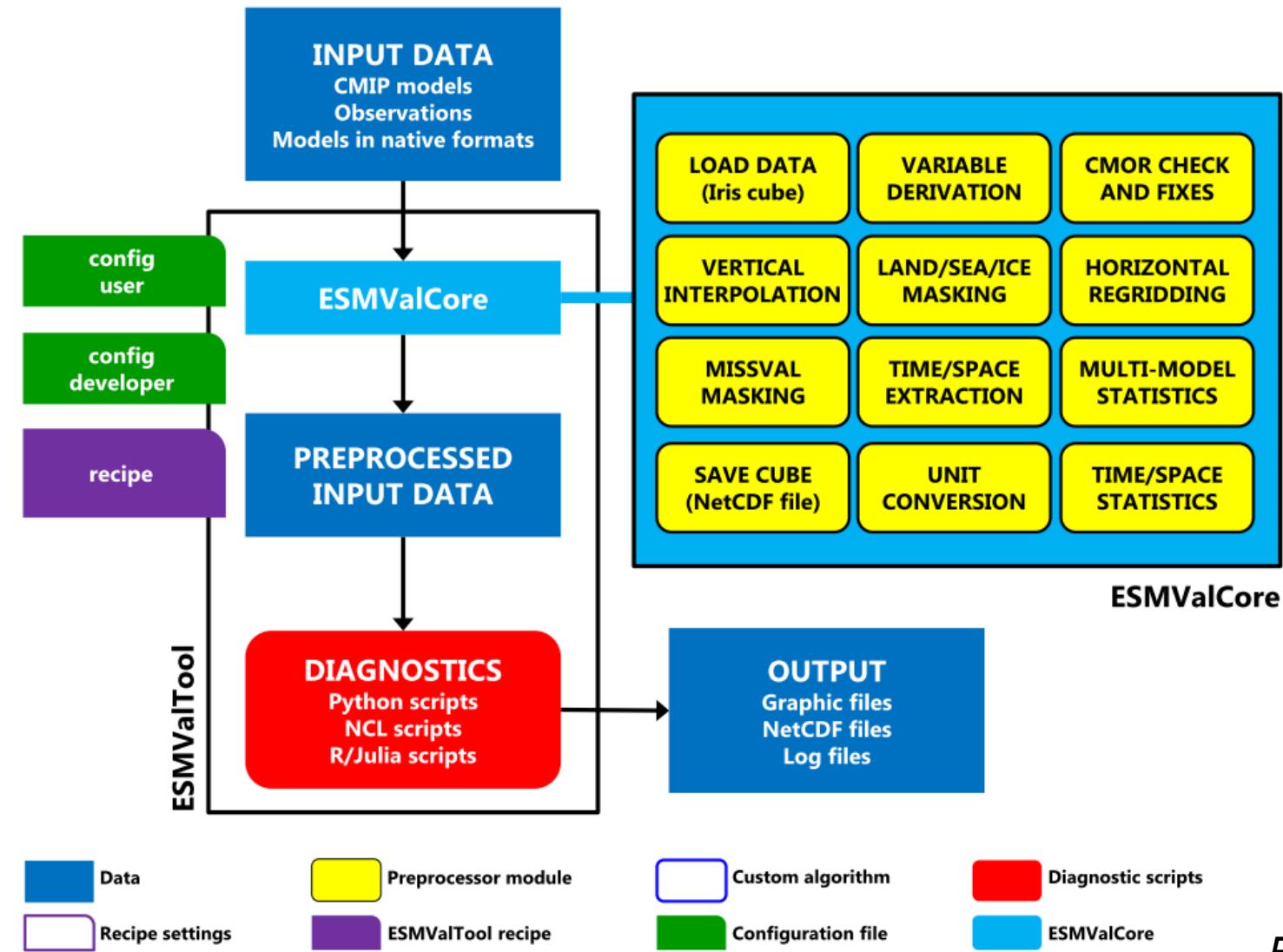


# ESMValTool – Details





# ESMValTool – Details

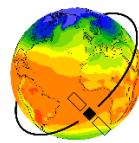


# ESMValTool Recipes

ESMValTool is controlled through a **recipe** (text file in YAML format).

Recipes contain

- Datasets to analyze
- Preprocessors to use
- Variables to analyze
- Diagnostic scripts to use (Python, NCL or R scripts)



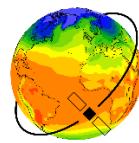
# ESMValTool Recipes

```
datasets:
  - {dataset: ERA5,          project: OBS6,    tier: 3,        type: reanaly,   version: 1}
  - {dataset: CanESM5,        project: CMIP6,   exp: historical, grid: gn,      ensemble: r1i1p1f1}

 preprocessors:
  regridding_step:
    regrid:
      target_grid: 1x1
      scheme: linear

 diagnostics:
  example:
    variables:
      tas:
        mip: Amon
        timerange: '1980/2005'
        preprocessor: regridding_step

 scripts:
  example_script:
    script: ~/diag_scripts/example.py
```



# ESMValTool Recipes

## datasets:

- {dataset: ERA5, project: OBS6, tier: 3, type: reanaly, version: 1}
- {dataset: CanESM5, project: CMIP6, exp: historical, grid: gn, ensemble: r1i1p1f1}

## preprocessors:

```
regridding_step:  
    regrid:  
        target_grid: 1x1  
        scheme: linear
```

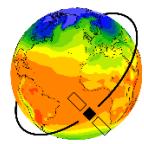
## diagnostics:

```
example:  
variables:  
    tas:  
        mip: Amon  
        timerange: '1980/2005'  
        preprocessor: regridding_step
```

## scripts:

```
example_script:  
    script: ~/diag_scripts/example.py
```

All datasets



# ESMValTool Recipes

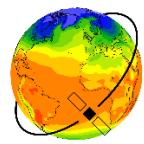
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 scripts:
   example_script:
     script: ~/diag_scripts/example.py
```

Preprocessor  
settings



# ESMValTool Recipes

```
datasets:
  - {dataset: ERA5,          project: OBS6, tier: 3, type: reanaly, version: 1}
  - {dataset: CanESM5,        project: CMIP6, exp: historical, grid: gn, ensemble: r1i1p1f1}

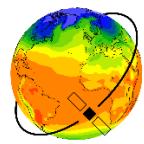
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   example_script:
     script: ~/diag_scripts/example.py
```

Diagnostic scripts





# ESMValTool Recipes

```
datasets:
  - {dataset: ERA5,          project: OBS6, tier: 3, type: reanaly, version: 1}
  - {dataset: CanESM5,        project: CMIP6, exp: historical, grid: gn, ensemble: r1i1p1f1}

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```

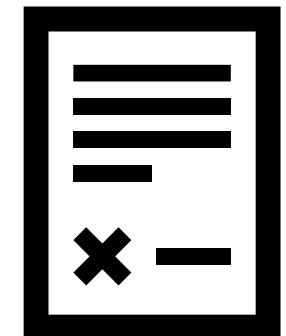
Variables



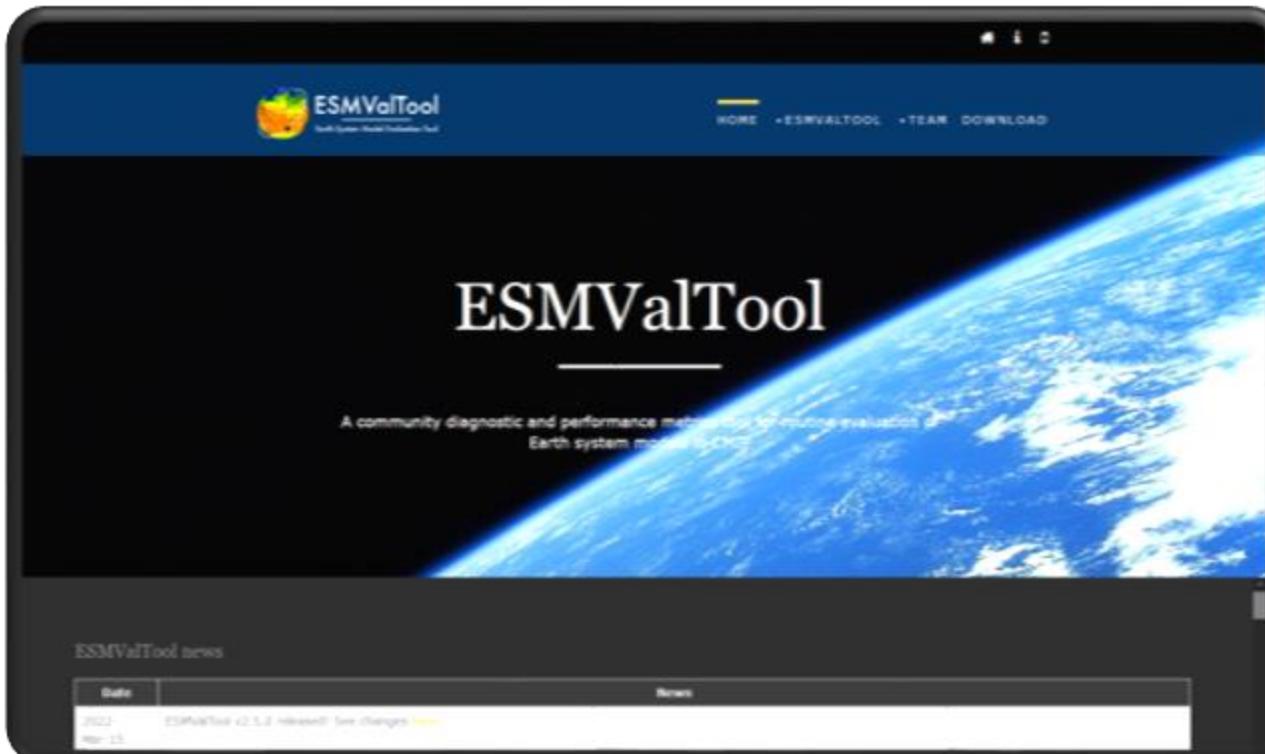
# ESMValTool Consortium

Agreement signed in **December 2024** by:

- DLR, Germany (Co-PI)
- Met Office, UK (Co-PI)
- Barcelona Supercomputing Center (BSC), Spain
- SMHI, Sweden
- NCAS and NCEO, UK
- NLeSC, Netherlands



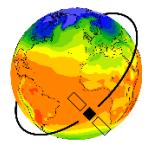
# Website



General presentation of  
ESMValTool:

- Important links,
- gallery,
- license,
- presentations,
- meeting notes,...

**<https://www.esmvaltool.org>**



# ESMValTool

Earth System Model Evaluation Tool

# GitHub Issues

<https://github.com/ESMValGroup/ESMValTool/issues>

ESMValGroup / ESMValTool Public Notifications Fork 135 Star 244

<> Code Issues 293 Pull requests 98 Discussions Actions Projects 1 Security Insights

Replace prospector with ruff integrated in Codacy #3739 · valeriupredoi opened on Aug 16, 2024

'stable' documentation build is broken and still points to v2.7 #3490 · bouweandela opened on Dec 20, 2023 3

is:issue state:open

New issue

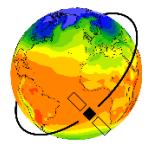
Open 293 Closed 1.264 Author Labels Projects Milestones Assignees Types Newest

RTW configuration issues Recipe Test Workflow (RTW) #4076 · ehogan opened 2 weeks ago v2.13.0

Collection of outdated Documentation parts #4074 · bettina-gier opened 2 weeks ago

RTW config variable BRANCH used in both Tool and Core #4069 · alistairsellar opened 2 weeks ago 1 1

Use ESMVALTOOL\_CONFIG\_DIR rather than --config\_dir in RTW Recipe Test Workflow (RTW) #4053 · ohogan opened 2 weeks ago



# Discussions

<https://github.com/ESMValGroup/ESMValTool/discussions>

ESMValGroup / ESMValTool Public

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Code Issues 293 Pull requests 98 Discussions Actions Projects 1 Security Insights

Automated formatting

Ideas · bouweandela

Q is:open

x

Sort by: Latest activity ▾

Label ▾

Filter: Open ▾

## Categories

View all discussions

General

Ideas

New to ESMValTool

Polls

## Discussions

↑ 1



Query about using the custom CMOR variables options for ICON-ART  
nchawang asked last week in Q&A · Answered



4

↑ 1

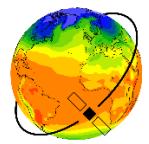


Can we load ICON dust AOD with ESMValTool?  
nchawang asked on Mar 31 in Q&A · Answered



5

Exclude legacy recipes from gallery



# Community Discussions

<https://github.com/ESMValGroup/Community/discussions>

ESMValGroup / Community Public

Notifications Fork 0 Star 5

Code Issues Pull requests 1 Discussions Actions Projects Security Insights

ESMValTool long-term strategy General · hb326

What technical advancements do we need for CMIP7? General · hb326

Agenda ESMValTool Workshop May 13-15 Oberpfaffenhofen, Germany. Meetings · bettina-gier

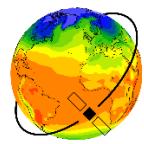
is:open Sort by: Latest activity Label Filter: Open

Categories

- [View all discussions](#)
- Announcements
- General
- Meetings
- Polls

Discussions

- [Monthly Meeting: June](#)  
monthly community meeting  
bettina-gier started 2 weeks ago in Meetings
- [Agenda ESMValTool Workshop May 13-15 Oberpfaffenhofen, Germany.](#)  
workshop  
bettina-gier started on Mar 7 in Meetings



# Documentation

<https://docs.esmvaltool.org/en/latest/>



Introduction ESMValTool Functionalities Getting started Gallery Recipes More ▾

Search ctrl + K



## Welcome to ESMValTool's documentation! #

To get a first impression of what ESMValTool and ESMValCore can do for you, have a look at our blog posts [Analysis-ready climate data with ESMValCore](#) and [ESMValTool: Recipes for solid climate science](#).

A tutorial is available on <https://tutorial.esmvaltool.org>.

A series of video lectures has been created by [ACCESS-NRI](#). While these are tailored for ACCESS users, they are still very informative.



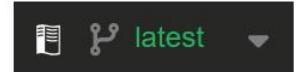
On this page

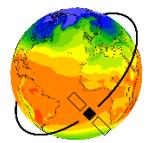
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Indices and tables

## This Page

- [Show Source](#)





# Tutorial

[https://esmvalgroup.github.io/ESMValTool\\_Tutorial](https://esmvalgroup.github.io/ESMValTool_Tutorial)

The screenshot shows the ESMValTool Tutorial website. At the top, there is a navigation bar with links for Home, Setup, Episodes, Extras, License, and Improve this page. A search bar is also present. The main title is "ESMValTool Tutorial". Below the title, a brief introduction states: "This tutorial helps you to use ESMValTool. The Earth System Model Evaluation Tool (ESMValTool) is a community developed software toolkit that aims to facilitate the diagnosis and evaluation of the causes and effects of model biases and inter-model spread within the CMIP model ensemble. This tutorial is structured such that the main body of the tutorial, up to the episode 7, can be done in one sitting. From episode 8, each episode is a mini-tutorial covering an advanced aspect of working with ESMValTool. These mini-tutorials can be appended to the main tutorial or worked through independently." A yellow box highlights the section "What will you learn in this course", which lists various topics such as what ESMValTool is, how to install it, configure it, run it, work with its preprocessors, debug recipes, access and deploy recipes from the gallery, develop diagnostics and recipes, contribute recipes, and include observational datasets. Another blue box highlights the "Prerequisites" section, which links to the tutorial setup page. Below these sections, a list of main things to know before starting the course includes: 1. The tutorial can be taken online independently or taught by one of our instructors. 2. Don't be alarmed if you can't work through the entire tutorial in one sitting; it may take some time to get used to working with ESMValTool. 3. If you get stuck, help is always available from the tutors, from ESMValTool developers via the GitHub issues page or via the ESMValTool email list. Please see information on how to subscribe to user mailing list. 4. This tutorial includes several advanced lessons after the conclusion. These advanced lessons should be treated like "mini-tutorials", and include aspects like "developing your own diagnostic", "using specific diagnostic types", "modifying your diagnostic", and "developing your own diagnostic".

→ basic and an advanced tutorial

## User Engagement Team Tasks:

- Maintaining tutorial on GitHub
- Keeping the tutorial updated with the releases
- Handling with user feedback
- Contact for tutorial hosts

# Questions?

The screenshot shows a web browser displaying the ESMValTool documentation at <https://docs.esmvaltool.org/en/latest/introduction.html#support>. The page title is "Support". The left sidebar has a "Section Navigation" heading and an advertisement for Upstream. The main content area contains sections for "Support" and "User mailing list", with instructions for subscribing to the mailing list via email or the command line. A sidebar on the right lists "On this page" items like "About", "Support", and "Show Source".

ESMValTool  
Earth System Model Evaluation Tool

Introduction ESMValTool Functionalities Getting started Gallery Available recipes More ▾

Search ⌘ + K

Section Navigation

**Support**

Support for ESMValTool can be found in [ESMValTool Discussions page](#) where users can open an issue and a member of the [User Engagement Team](#) of ESMValTool will reply as soon as possible. This is open for all general and technical questions on the ESMValTool: installation, application, development, or any other question or comment you may have.

**User mailing list**

Subscribe to the ESMValTool announcements mailing list [esmvaltool@listserv.dfn.de](mailto:esmvaltool@listserv.dfn.de) to stay up to date about new releases, monthly online meetings, upcoming workshops, and trainings.

To subscribe, send an email to [sympa@listserv.dfn.de](mailto:sympa@listserv.dfn.de) with the following subject line:

- `subscribe esmvaltool`

or

- `subscribe esmvaltool YOUR_FIRSTNAME YOUR_LASTNAME`

The mailing list also has a [public archive](#) online.

On this page

About

**Support**

User mailing list

Monthly meetings

Core development team

Recipes and diagnostics

License

Show Source

Upstream

JUNE 5: A one-day celebration of open source upstream.live

RSVP NOW

HURRY! spots are limited per a free t-shirt!

Join us June 5 for Upstream: U.S. attendees are eligible for a free t-shirt.

RSVP!

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# Thanks!

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- AI4PEX
- AIVAL
- TerraFIRMA