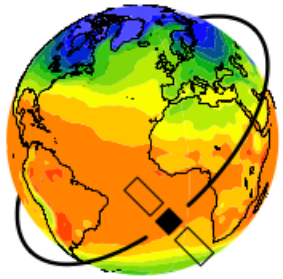

ESMValTool

Earth System Model Evaluation Tool

An Introduction to ESMValTool

Online Tutorial

Dec 3rd, 2025

Ranjini Swaminathan[1], Birgit Hassler and Julien Lenhardt

[1]University of Reading and National Centre for Earth Observation

[2] DLR

[3]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

ESMValTool
Earth System Model Evaluation Tool

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ESMs are Complex – and there are Plenty!

Latest Assessment Report of the IPCC (AR6):

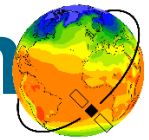
- ~60 ESMs analyzed
- >30 international institutions participated

→ **Coordination** necessary!

Institution Full Country or Region Name	Models	Main References	Atmosphere 1) Component Name 2) Resolution (km) and Number of Levels (L) 3) Top 4) References	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 4) References	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										
CCCR-IITM 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 and CERFACS Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique France										
CNRM and CERFACS										
CSIRO Commonwealth Scientific and Industrial Research Organisation Australia										
CSIRO-ARCCSS CSIRO and Austr. Res. Council Centre of Excellence for Climate System Science Australia										
E3SM National Laboratories Consortium USA										
EC-Earth Consortium Europe										
EC-Earth										
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) Hunke and Lipscomp (2010)	1) CLM4.0 2) Lawrence et al. (2011)	Land carbon N cycle	BEC
HAMMOZ-Consortium Switzerland, Germany, UK, Finland	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) Tegen et al. (2019)	2) Specified oxidants, sulphur chemistry 3) Feichter et al. (1996); Inness et al. (2013)	1) MPIOM 1.63 2) 100 km, 40 L 3) z	2) Notz et al. (2013)	1) JSBACH3.20 2) Reick et al. (2021)	Land carbon N cycle Prog. veg. Fires	HAMOCC6
INM Institute for Numerical Mathematics Russian Federation	INM-CM4-8 INM-CM5-0	INM-CM4-8: (Volodin et al., 2018) INM-CM5-0: (Volodin et al., 2017)	CM4: 1) INM-AM4-8 2) 150 km, 21 L 3) Top 31 km CM5: 1) INM-AM5.0 2) 150 km, 73 L 3) Top 61 km	1) INM-AER1 2) Emissions-driven 3) Volodin and Kostrykin (2016)	None	INM-OM5 2) CM4: 70 km, 40 L CM5: 30 km, 40 L 3) Sigma 4) Zalesny et al. (2010)	1) INM-ICE1 2) Yakovlev (2009)	INM-LND1	Land carbon	None
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) 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) Interactive 3) Hauglustaine et al. (2014)	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

IPCC AR6, Annex 2

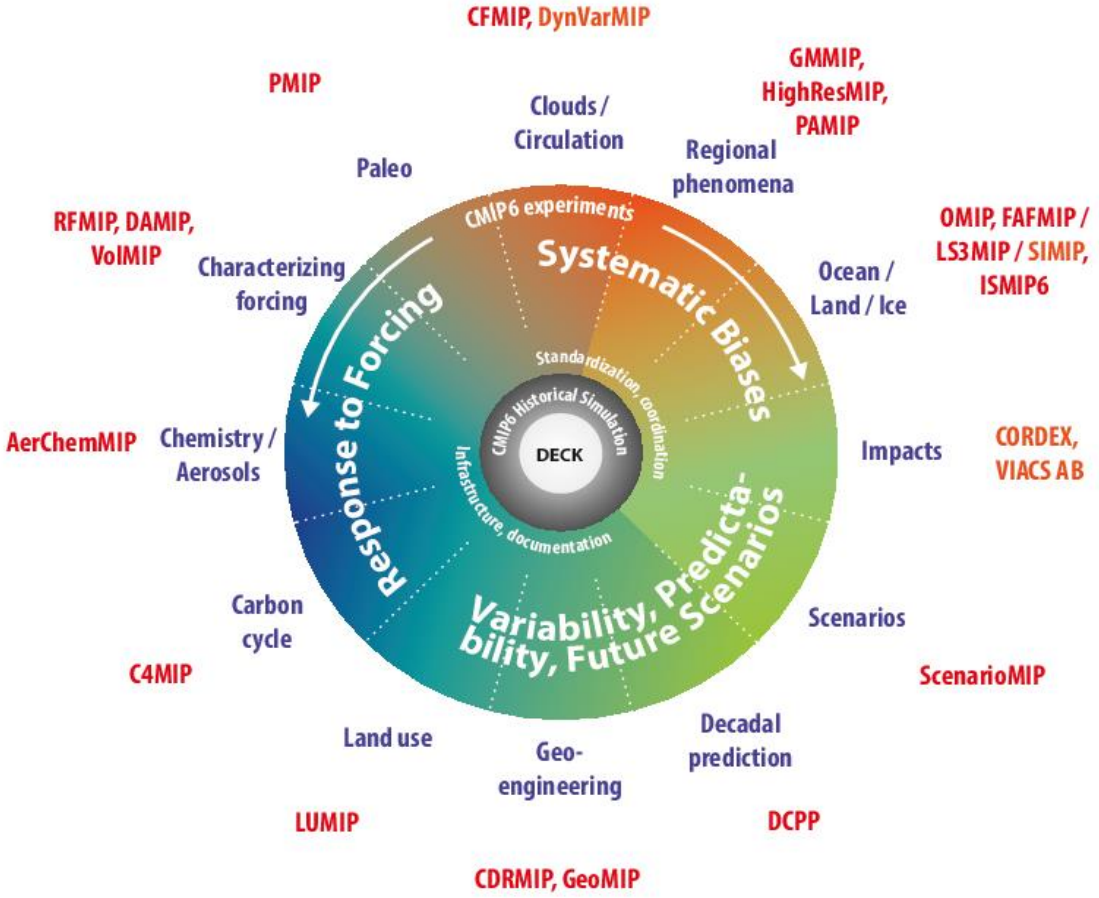
CMIP – Coupled Model Intercomparison Project



ESMValTool
Earth System Model Evaluation Tool

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_2 increase
   - iv. Abrupt 4xCO_2 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

We have:

Many complex CMIP models with standardized output

Crucial question:

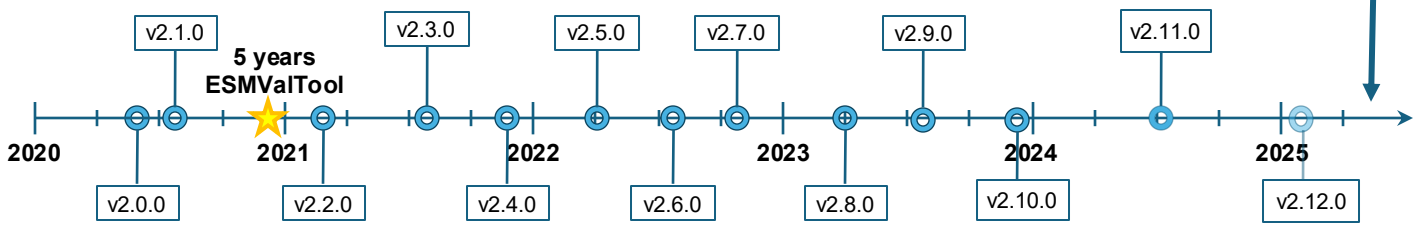
How well do these models perform relative to reference data sets (e.g., observations)? → **Standardized model evaluation**

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 10th 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

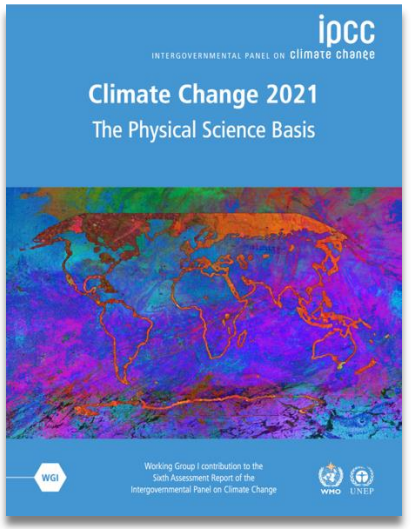
Schlund et al., GMD, 2023
Evaluation of native ESM output

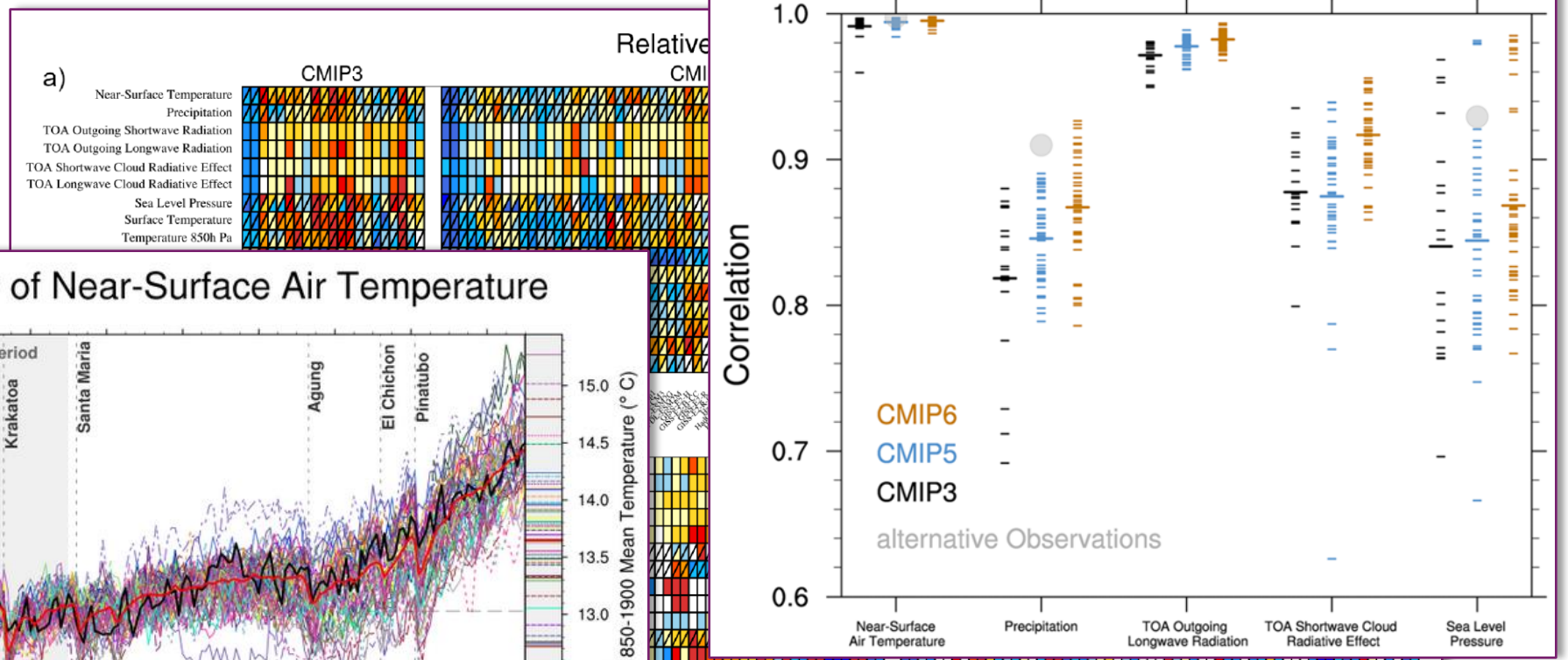
Lauer et al., GMD, 2025
Monitoring and benchmarking

ESMValTool and IPCC

ESMValTool
Earth System Model Evaluation Tool

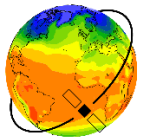
- ~ 60 scientific peer-reviewed publications
- > 20 national and international science projects, including large EU projects
- ESMValTool has been used for the production of figures for **several chapters of the Assessment Report 6 of the IPCC's WG1** (including provenance record)





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

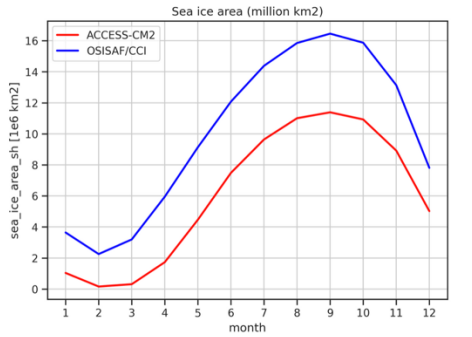
ESMValTool and Climate-REF



- 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

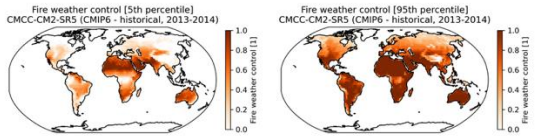
Earth System Model Evaluation Tool



20-year average seasonal cycle of the sea ice area in million km2 from ACCESS-CM2.r10i1p1f1.gn compared with OSI-450.

Execution Group: cmip6_gn_r10i1p1f1_ACCESS-CM2

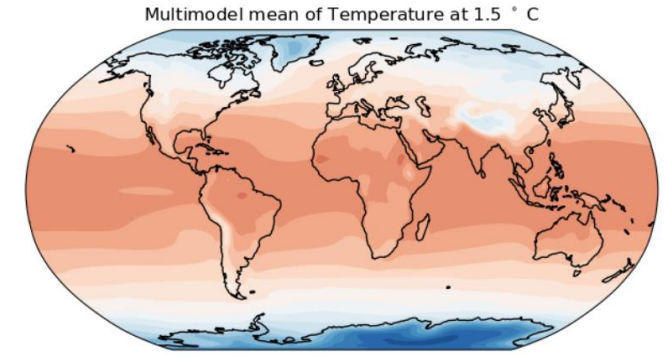
Filename: executions/recipe_20251003_125750/plots/siarea_s



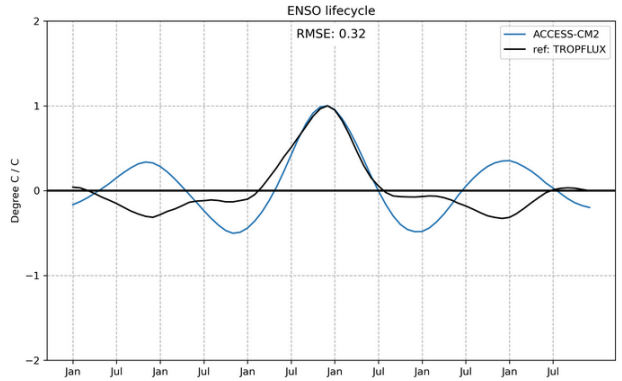
Fire weather control for the CMCC-CM2-SR5 (CMIP6-historical) for the time period 2013/2014 as computed with the ConFire model (Jones et al., 2024).

Execution Group: cmip6_gn_r10i1p2f1_CMCC-CM2-SR5

Filename: executions/recipe_20251002_035023/plots/fire_ev



Multimodel mean of Temperature at 1.5 $^\circ$ C



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

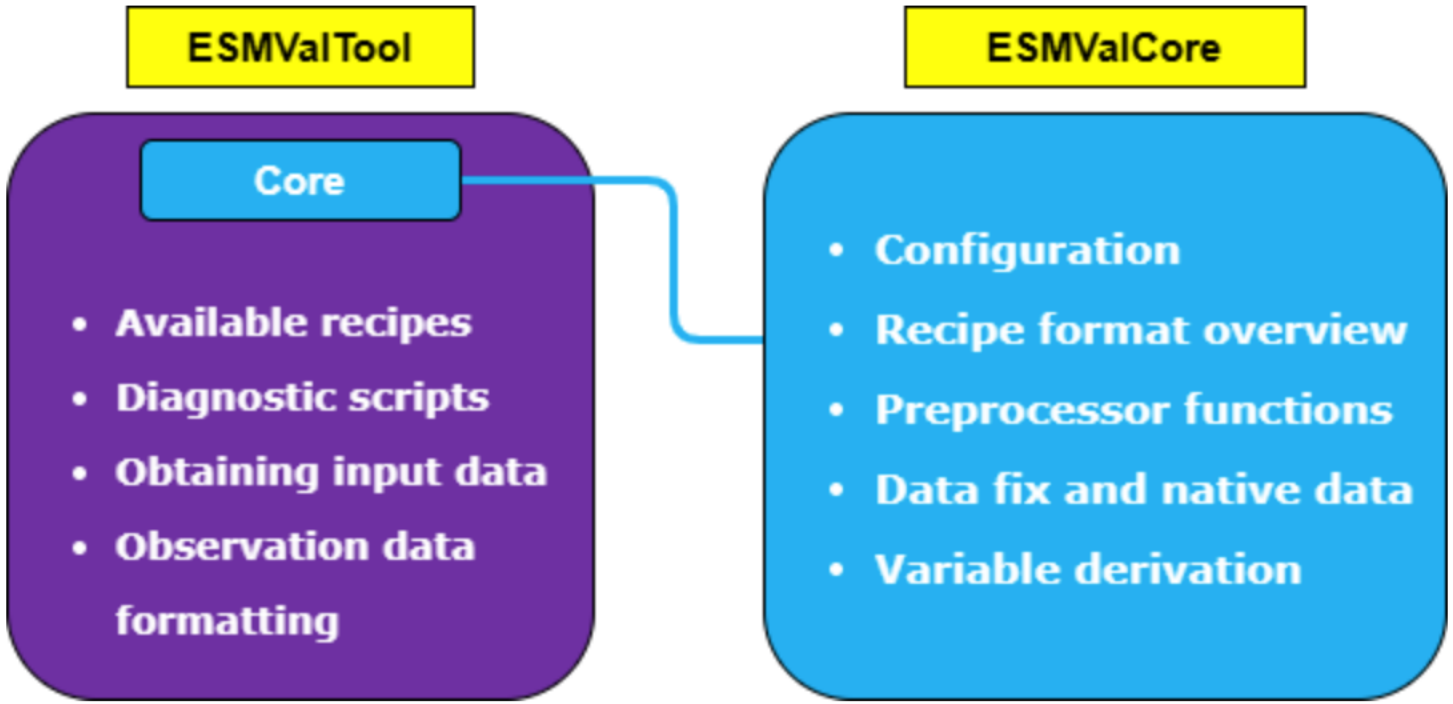
Execution Group: cmip6_gn_r10i1p1f1_ACCESS-CM2

Filename: executions/recipe_20251002_035527/plots/diagnos

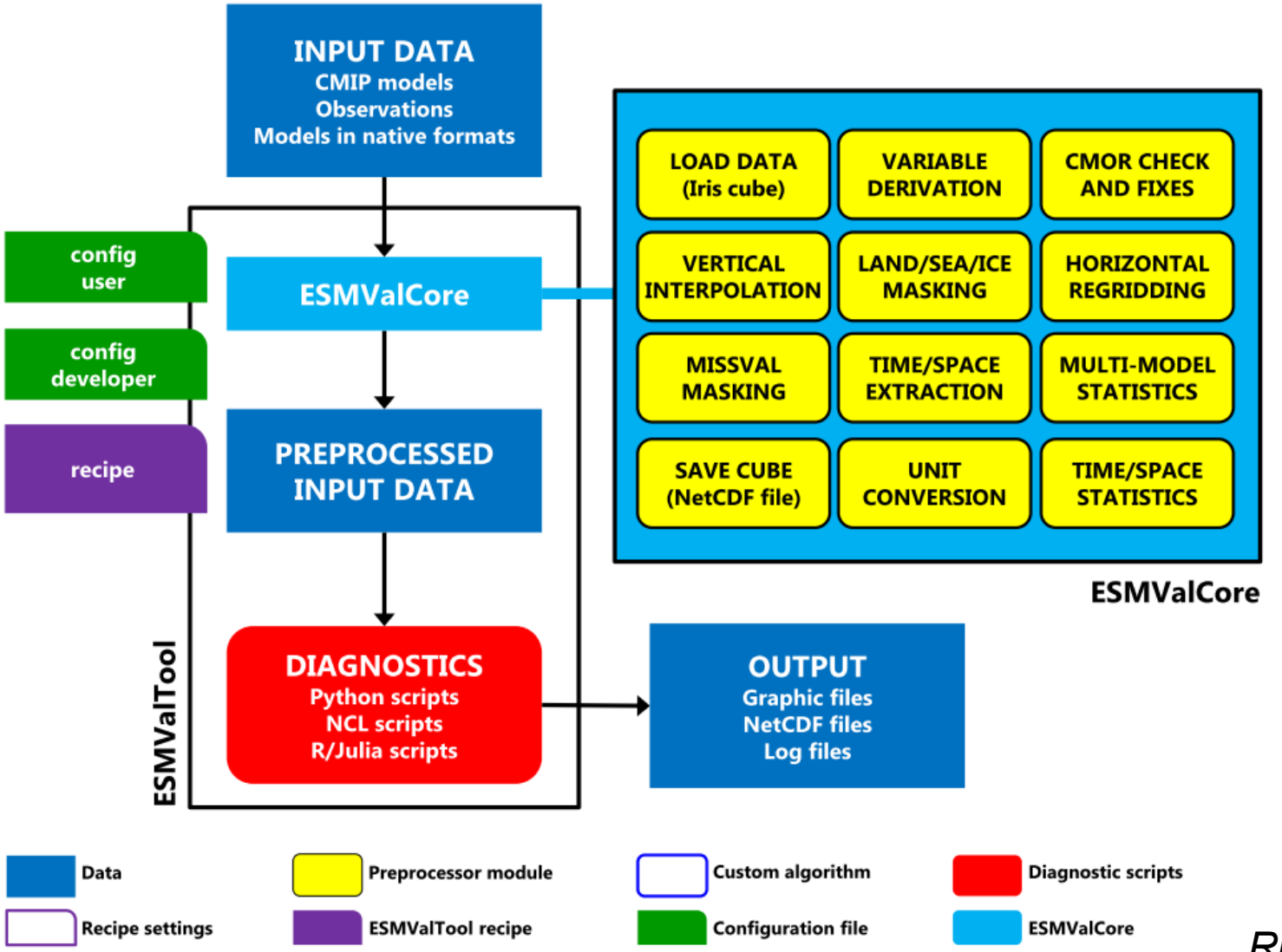
ESMValTool and Climate-REF

ESMValTool
Earth System Model Evaluation Tool

ESMValTool – Components

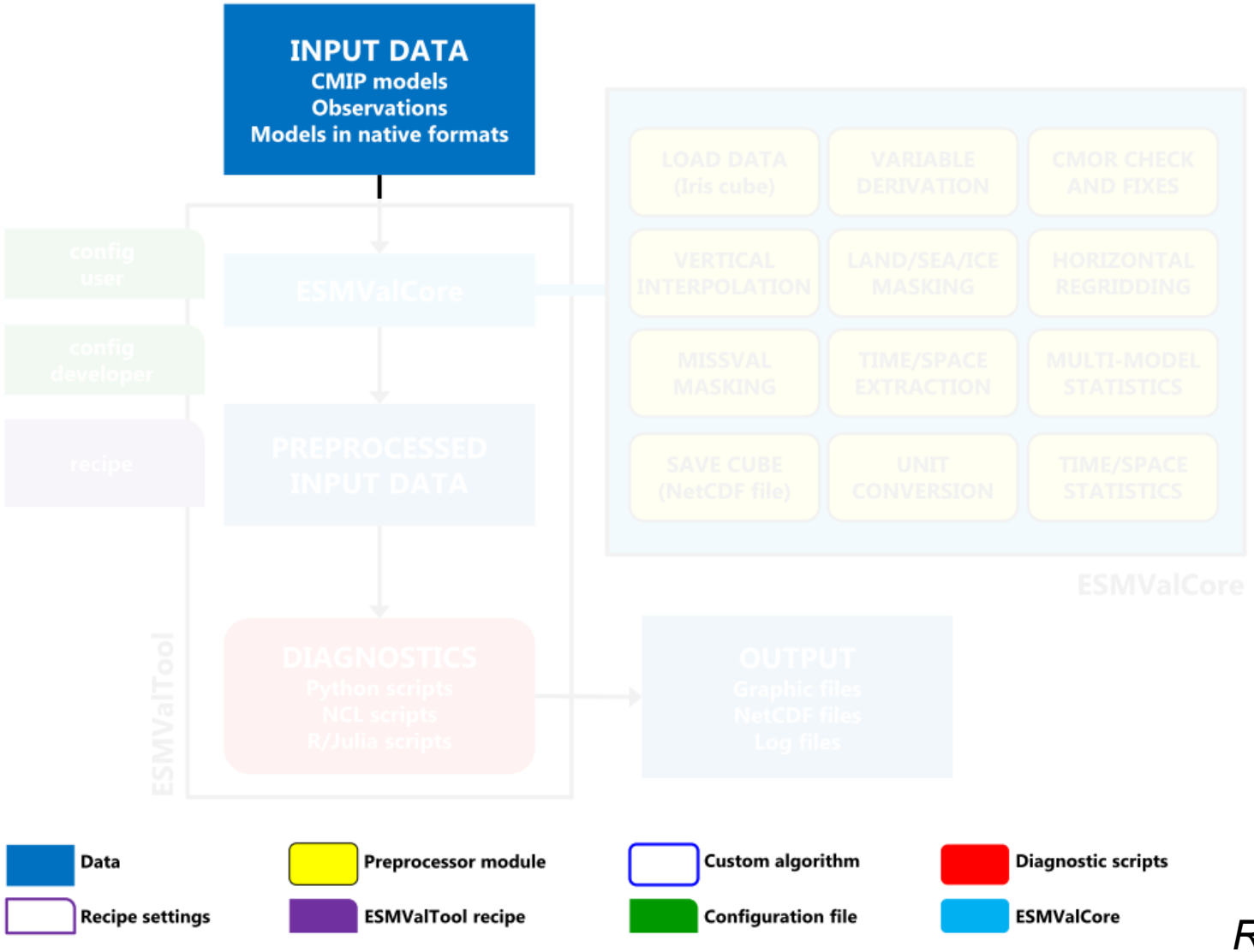


ESMValTool – Details



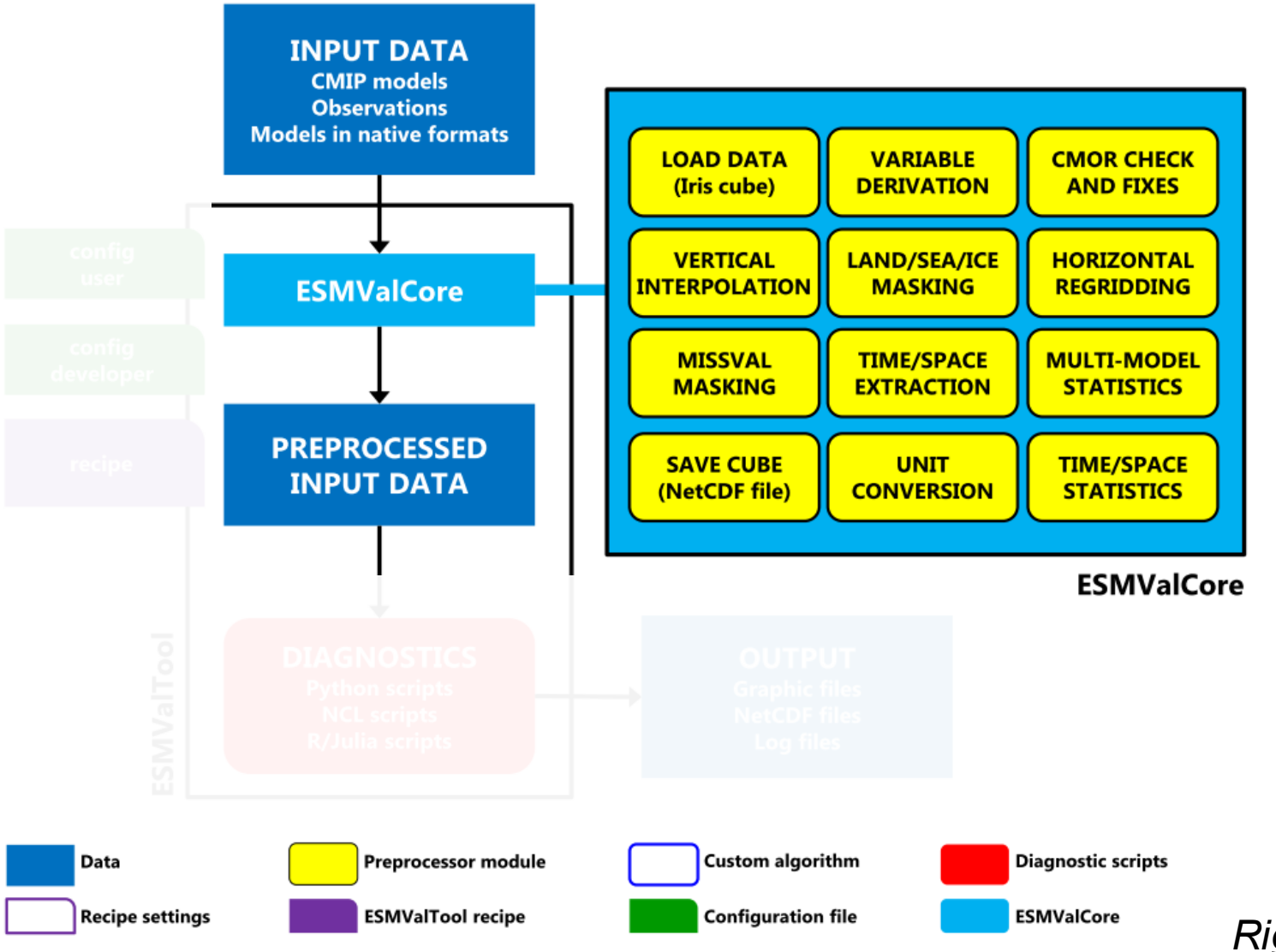
Righi et al., GMD (2020)

ESMValTool – Details



Righi et al., GMD (2020)

ESMValTool – Details



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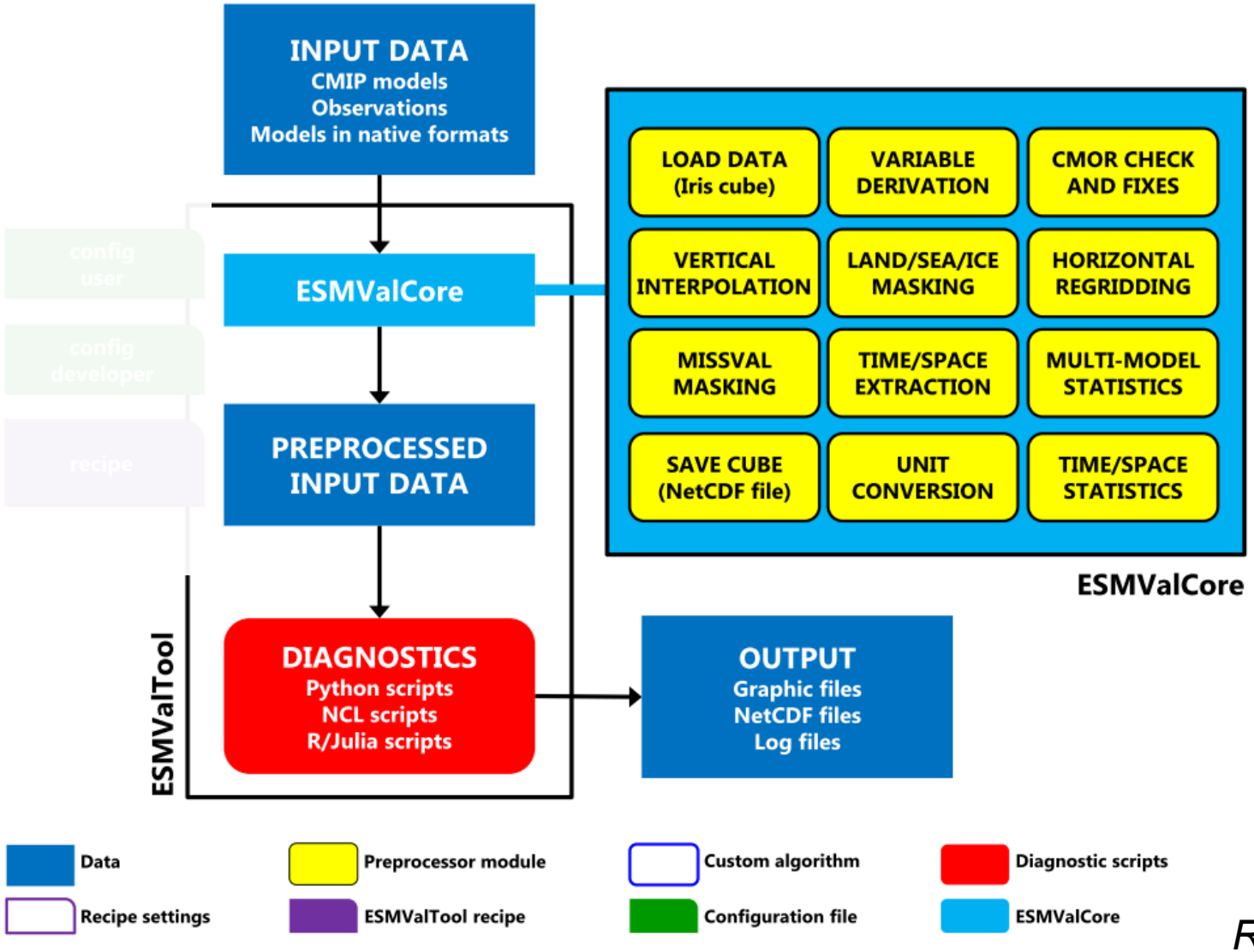
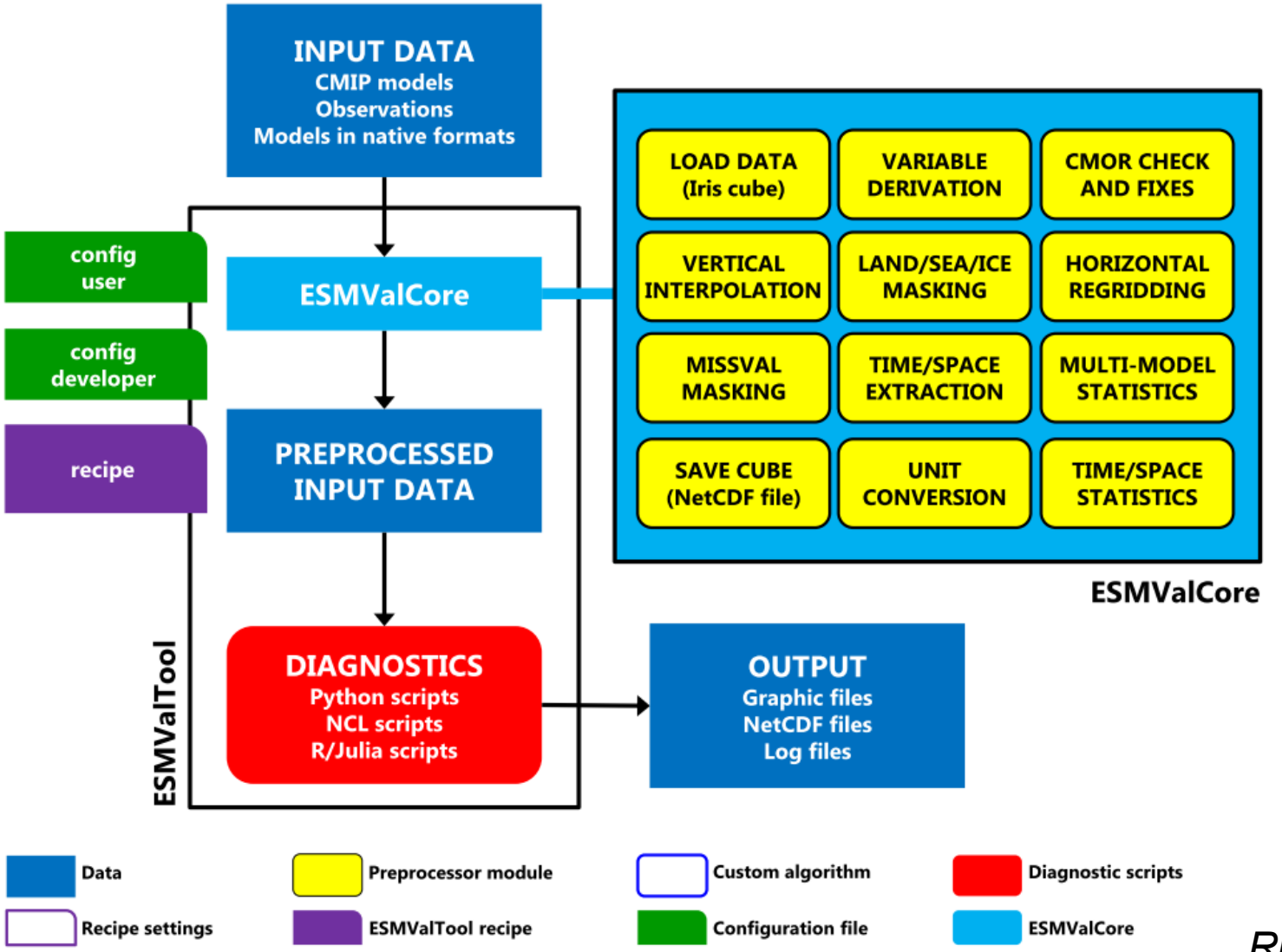


Righi et al., GMD (2020)

ESMValTool – Details



Righi et al., GMD (2020)

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}
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```

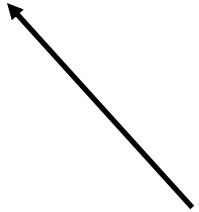

All datasets

ESMValTool Recipes

```
datasets:
  - {dataset: ERA5,        project: OBS6,  tier: 3,          type: reanaly,   version: 1}
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preprocessors:
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    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
```

Preprocessor settings

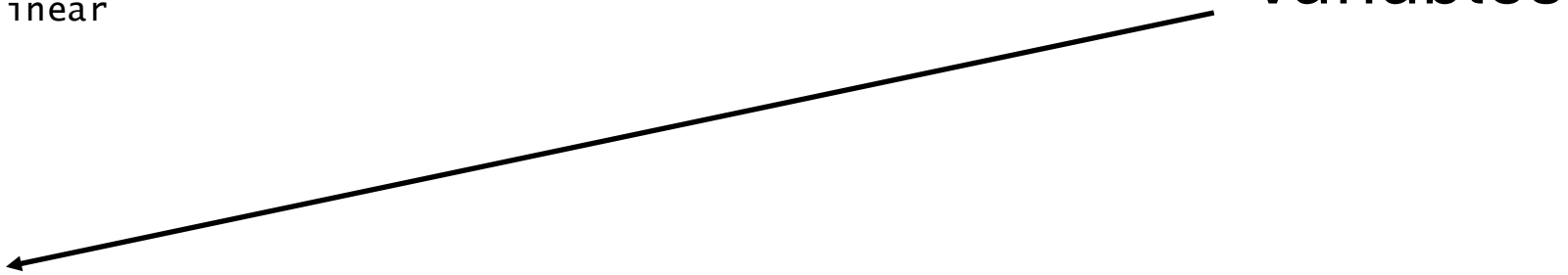
ESMValTool Recipes

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

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
```

Diagnostic scripts

ESMValTool Recipes

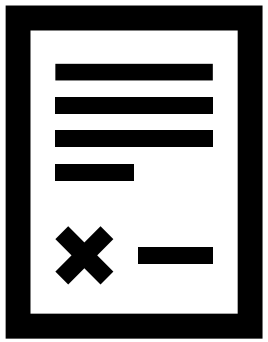
```
datasets:
  - {dataset: ERA5,        project: OBS6,  tier: 3,          type: reanaly,   version: 1}
  - {dataset: CanESM5,     project: CMIP6, exp: historical, grid: gn,         ensemble: r1i1p1f1}

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
```



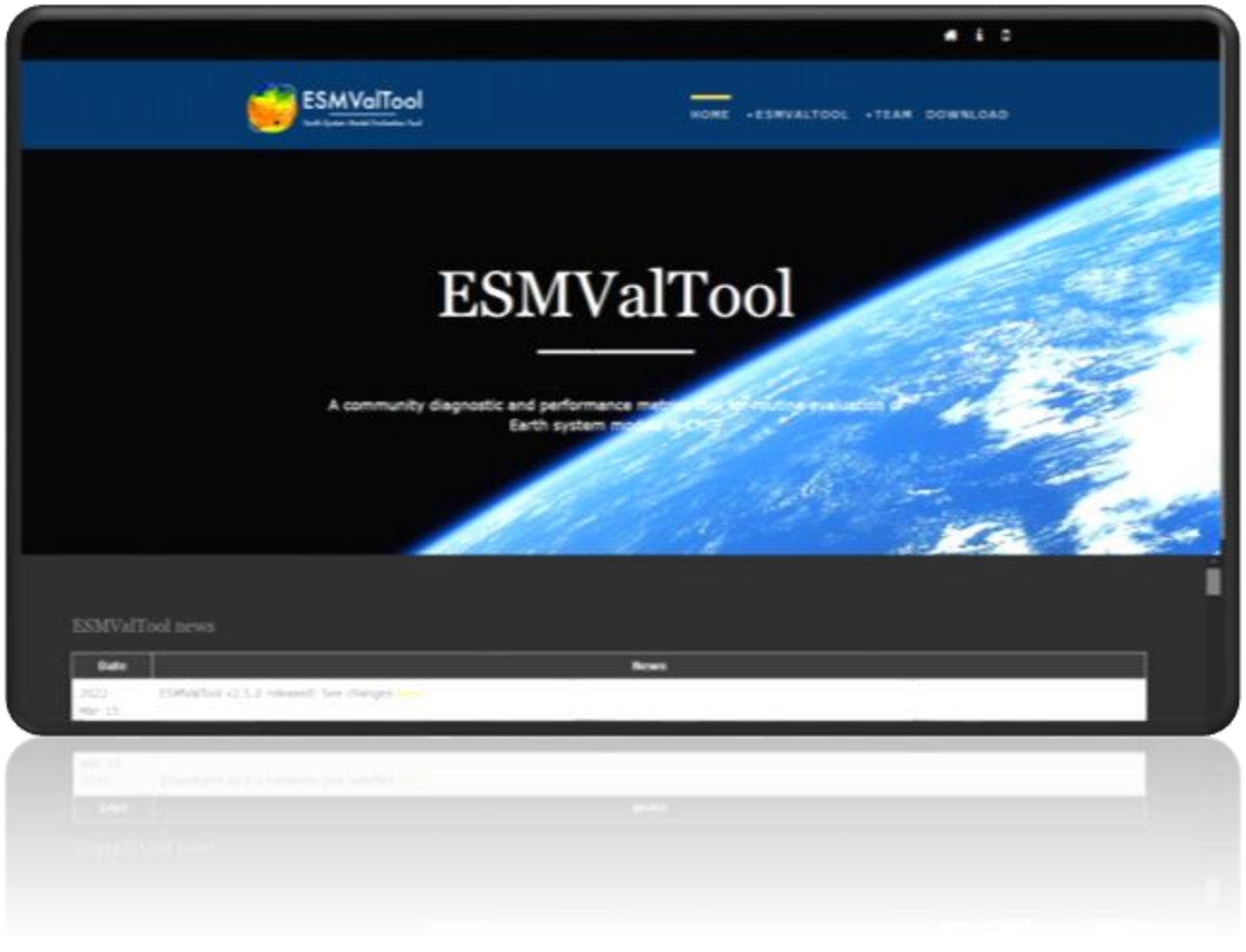
ESMValTool Consortium

Agreement signed in **December 2024** by:

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



Website



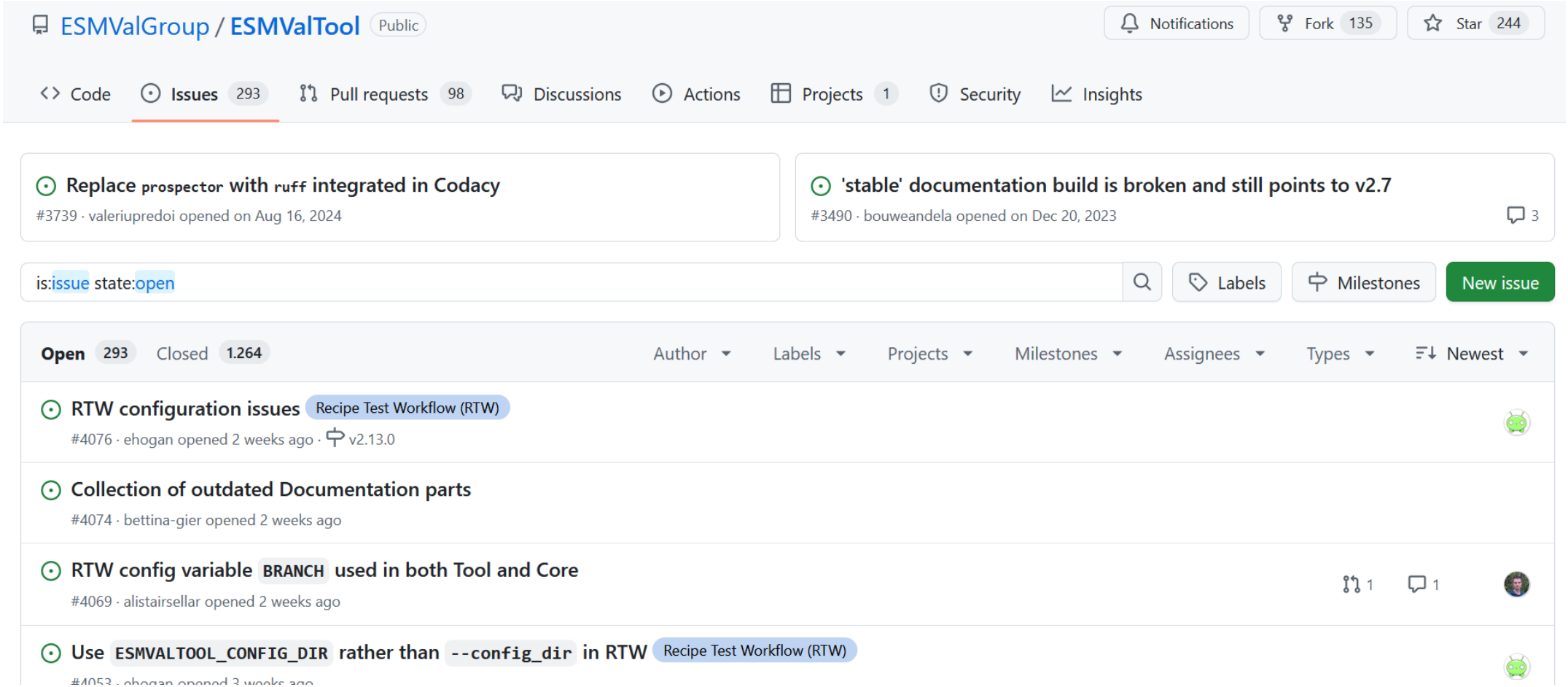
General presentation of ESMValTool:

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

https://www.esmvaltool.org

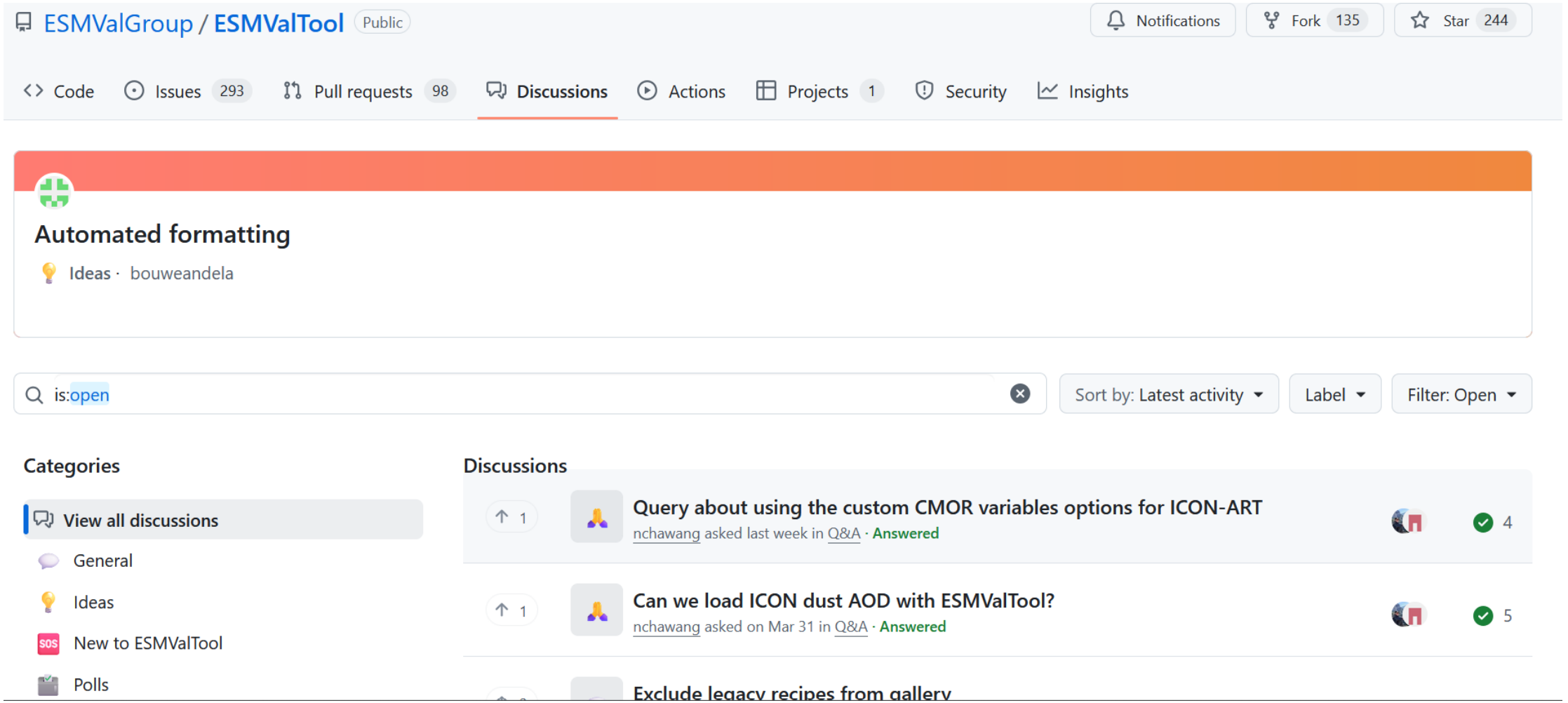
GitHub Issues

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



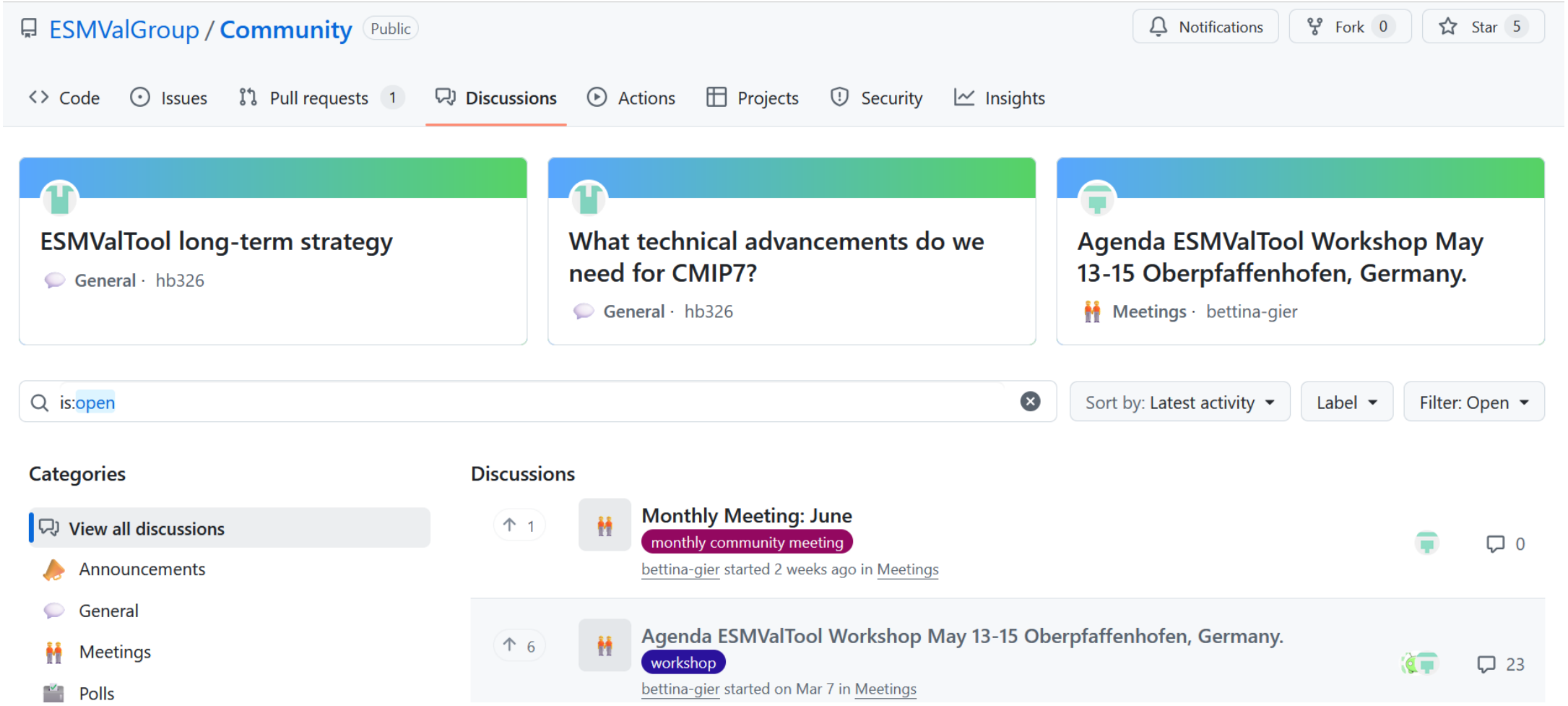
Discussions

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



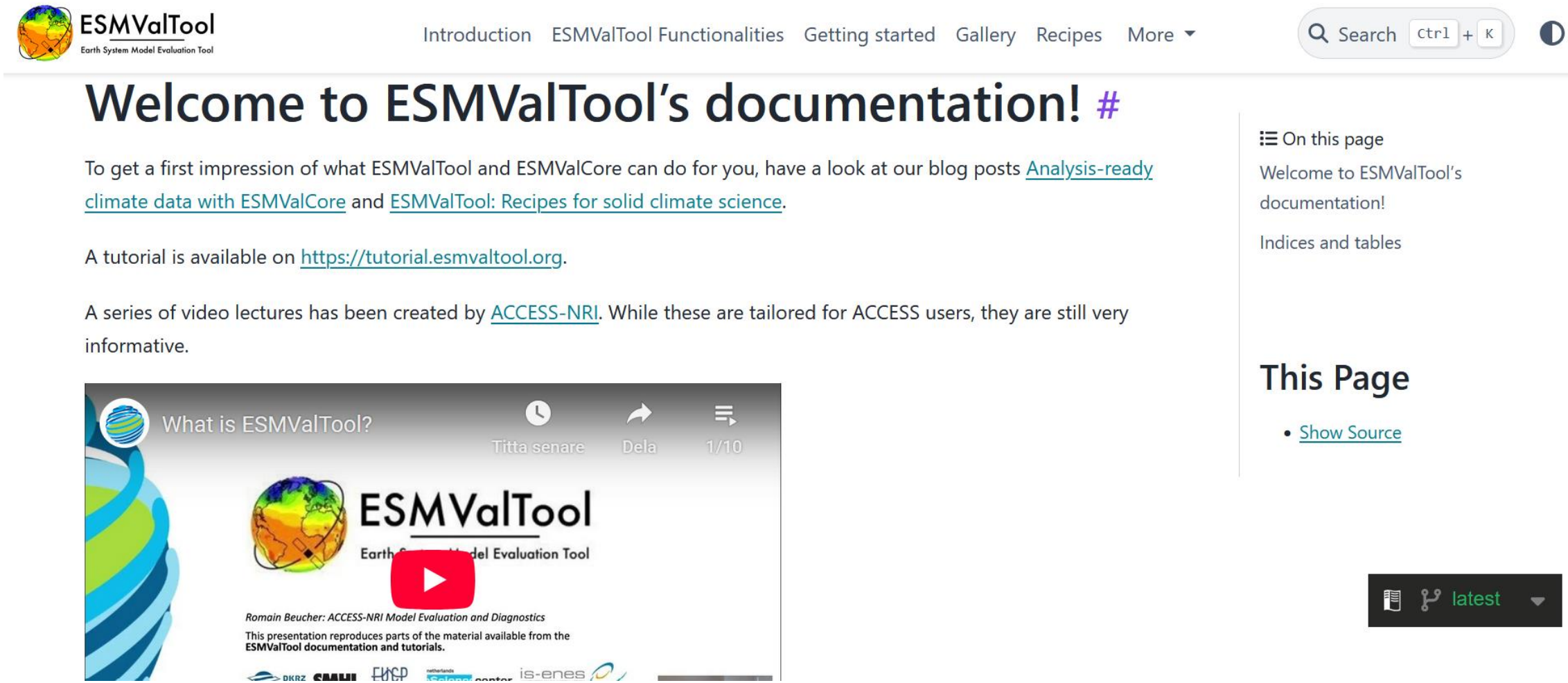
Community Discussions

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



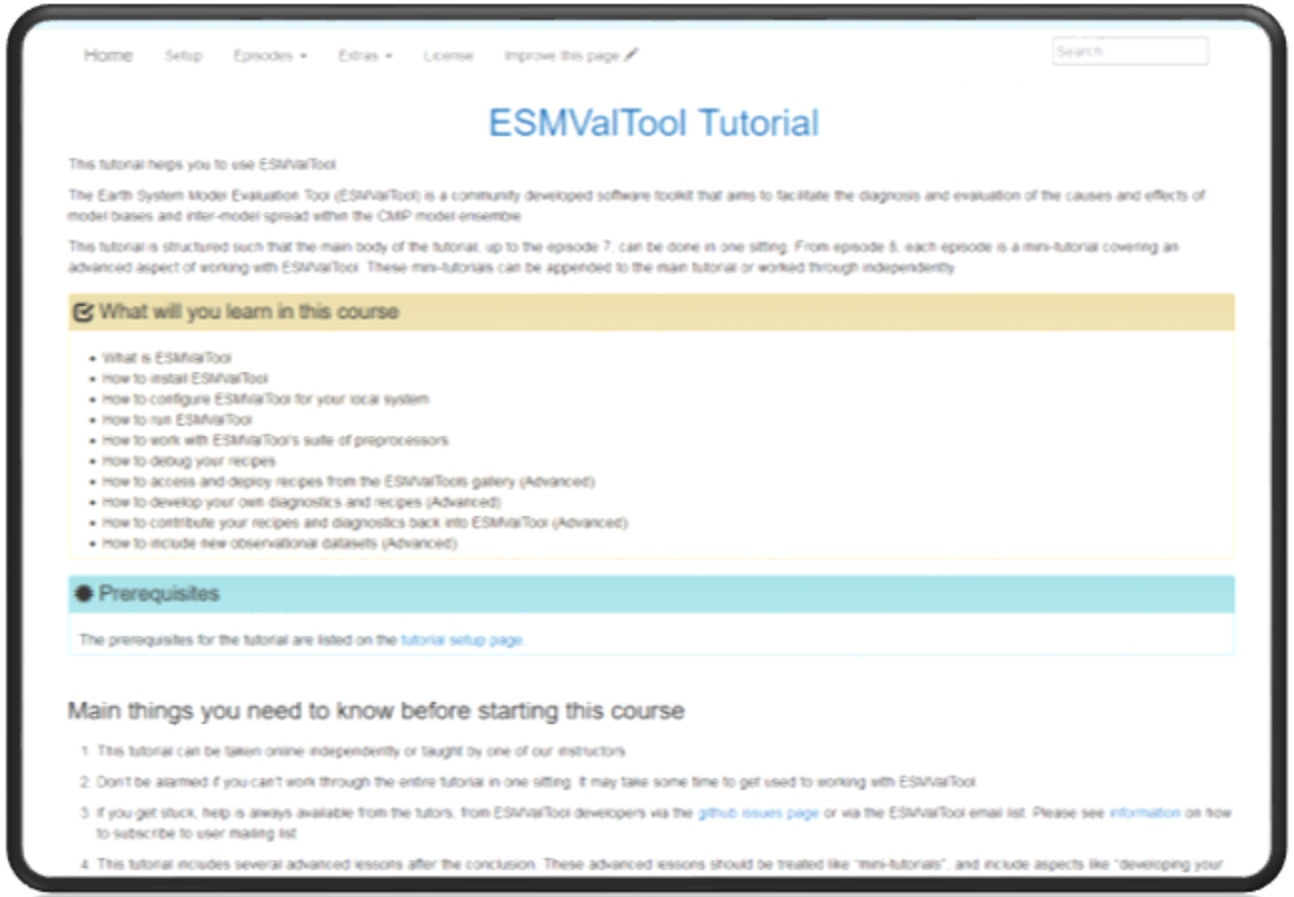
Documentation

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



Tutorial

https://esmvalgroup.github.io/ESMValTool_Tutorial

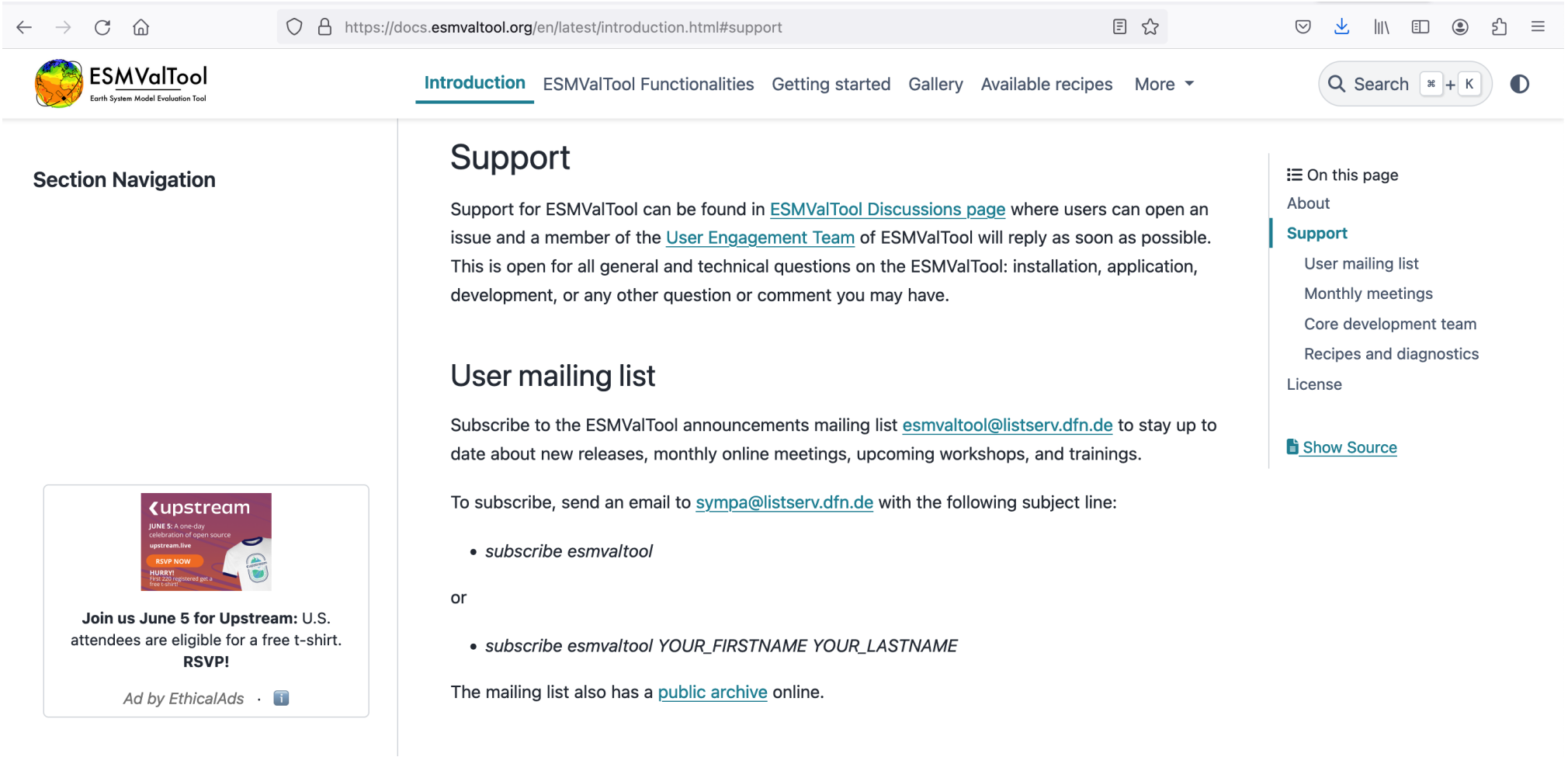


→ basic and an advanced tutorial

User Engagement Team Tasks:

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

Questions?


https://docs.esmvaltool.org/en/latest/introduction.html#support
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Earth System Model Evaluation Tool
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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.
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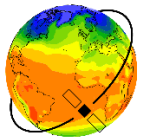

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Thanks!

- Eso4Clima
- AI4PEX
- AIVAL
- TerraFIRMA