

CLIMATE MODELLING USER GROUP

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CLIMATE CHANGE INITIATIVE MID-TERM REVIEW

“CMUG brings a climate system perspective to the CCI programme and provides a dedicated forum in which the **Earth observation** community, **climate modelling** community and **climate research** community work together.”

The overarching aim of CMUG is to ensure state of the art climate datasets developed by ESA are accessible to and applied in the climate modelling and research community with the broadest possible range of applications

CMUG – Project Structure



European Space Agency (ESA) Climate Change Initiative (CCI)



Essential Climate Variables (ECVs)

Sea level
Land surface temperature
Sea ice
Antarctic ice sheet
Snow

Aerosols
Greenhouse gases
Sea surface temperature
Glaciers
Greenland ice sheet

Permafrost
Clouds
Water vapour
Sea state
Ocean colour

High resolution land cover
Above ground biomass
Fire
Ozone
Sea salinity

Land cover
Soil moisture
Lakes
Other long-lived
greenhouse gases

Vegetation parameters
River discharge
Precursors for aerosols
and ozone



CMUG Climate Modellers

Swedish
Meteorological
& Hydrological
Centre (SMHI)

European Centre
for Medium-Range
Weather Forecasts
(ECMWF)

Centro
Euro-Mediterraneo
sui Cambiamenti
Climatici (CMCC)

Deutsches
Zentrum
für Luft- und
Raumfahrt (DLR)

Institut
Pierre-Simon
Laplace (IPSL)

Barcelona
Supercomputing
Center(BSC)

NCEO (University
of Edinburgh)

NCEO (University
of Leicester)

Danish
Meteorological
Institute (DMI)

Météo-France
(MF)

Centre for
Environmental
Data Analysis
(CEDA)

Met Office
Hadley Centre
(MOHC)

Met Office Hadley Centre – CMUG Project Management

Outline of work packages:

- User Requirements for new ECVs with updates for existing ECVs
- Support for the future evolution of obs4MIPs
- CCI contributions to ESMValTool
- Science studies including:
 - Machine learning for climate model evaluation and process understanding
 - Use of multiple ECVs to study earth system processes and improve models and their predictions
 - Atmospheric drivers and feedback processes affecting the Greenland and Antarctic ice-sheets
- Communications and Outreach

CMUG areas of focus and example results



Understanding the climate system through evaluating the quality of observations for constraining climate models and processes studies to provide a more comprehensive assessment of the state and evolution of the system

Evaluating and improving modelling of components through detailed assessment of drivers of model biases, implications for and demonstration of model improvements

Initialising seasonal climate predictions

Assessing improvements and errors in model ensembles and related technical infrastructure

Feedback/integration between data users, producers and technical system developers

Feedback on wider societal relevance of CCI



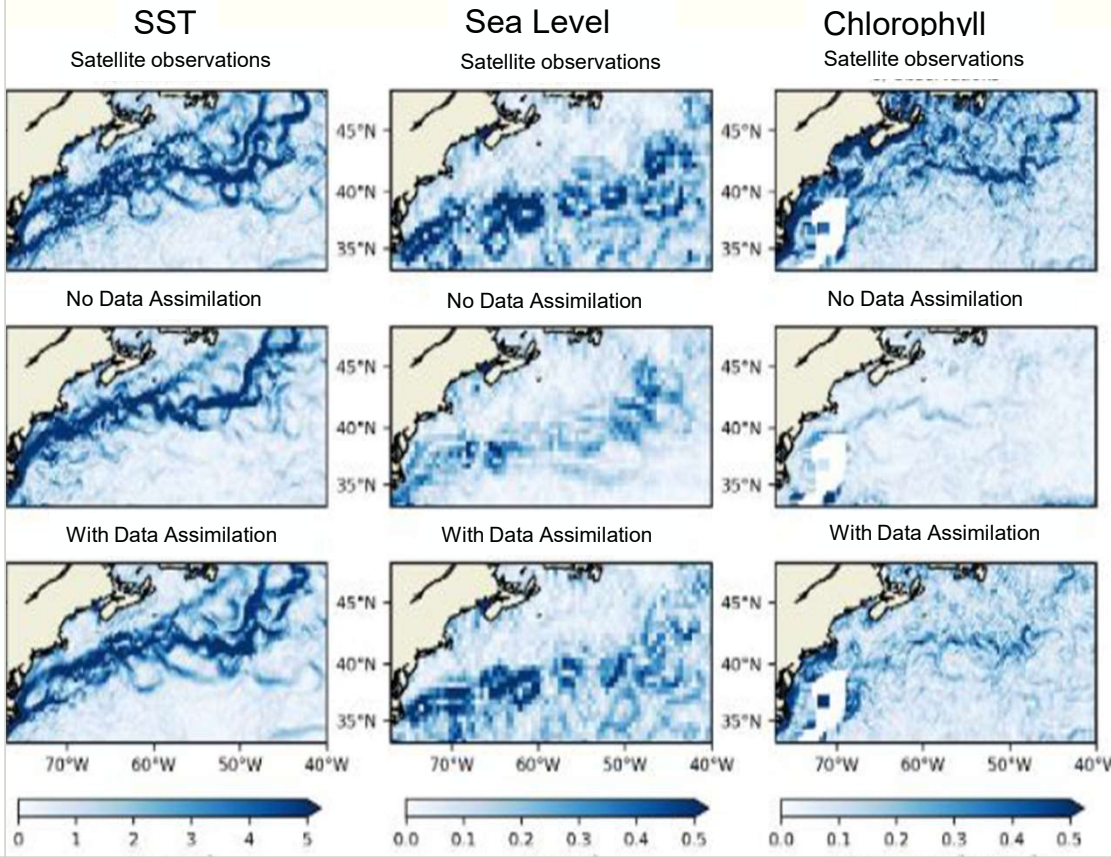
Using SST, Sea Level, Sea Ice, Ocean Colour in reanalysis with *in situ* measurements of temperature and salinity



Physical–biogeochemical ocean model assimilated different combinations of the ESA CCI ECVs

The aims of the study were to assess:

- The impact of assimilating ESA CCI datasets to characterize (drivers of) the marine carbon cycle and showed
- consistency between the ESA CCI datasets
- consistent physical–biogeochemical relationships in reanalyses assimilating different combinations of data
- strong positive correlation between phytoplankton and net air–sea heat flux
- seasonal variations in carbon-to-chlorophyll ratio



Temperature, sea level and chlorophyll in the Gulf Stream region during December 2010



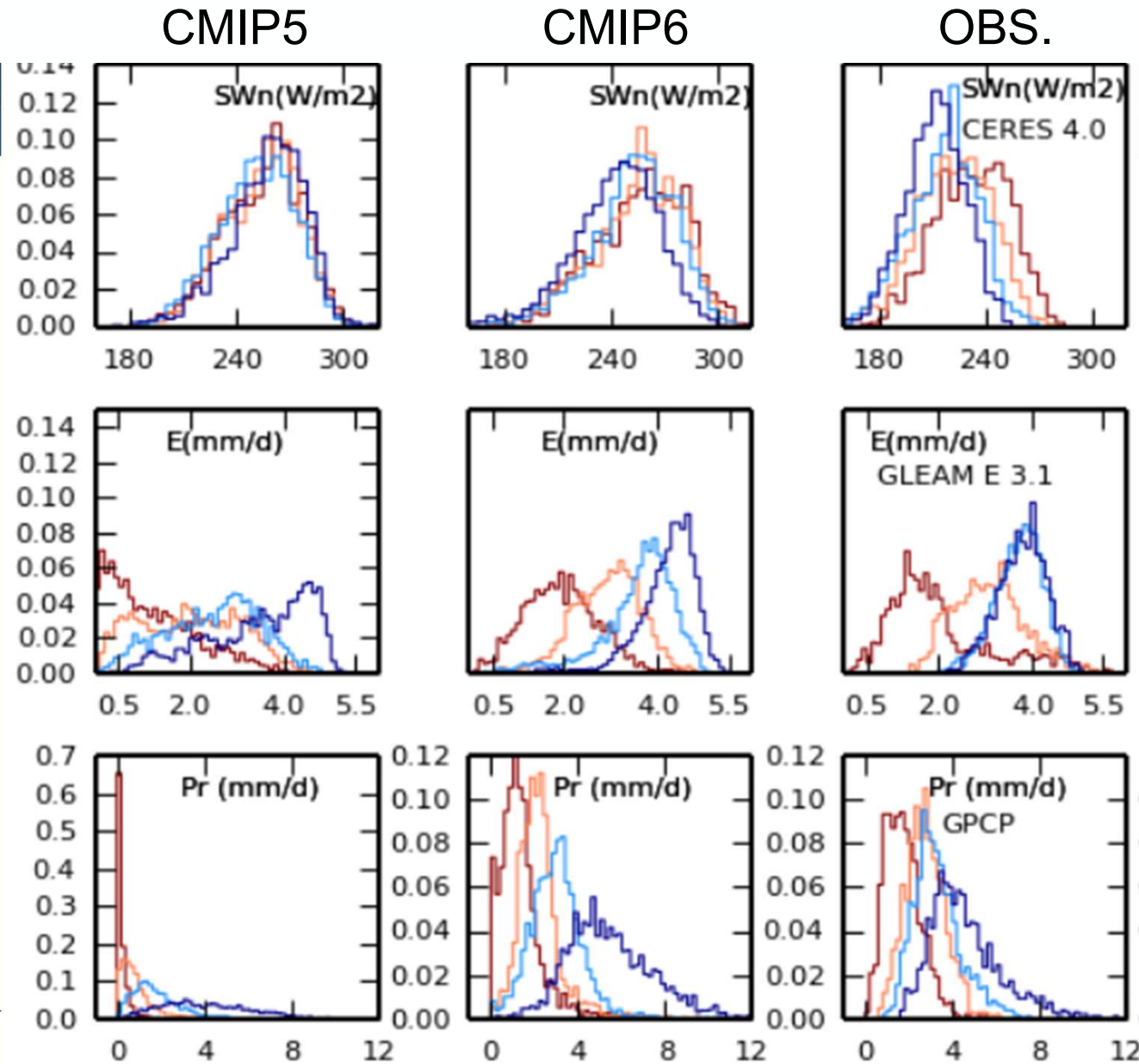
ESA CCI Soil Moisture product demonstrating improvement in a CMIP6 atmosphere-land-surface model

The study

Evaluating the evaporation and precipitation responses in CMIP5 and 6 versions of the IPSL land-atmosphere model (IPSL-CM6) for different soil moisture states (from very dry to very wet).

Results

- Significant improvement from CMIP5 to CMIP6
- Progress from use of ESA soil moisture to inform development of better atmosphere and land surface process modelling



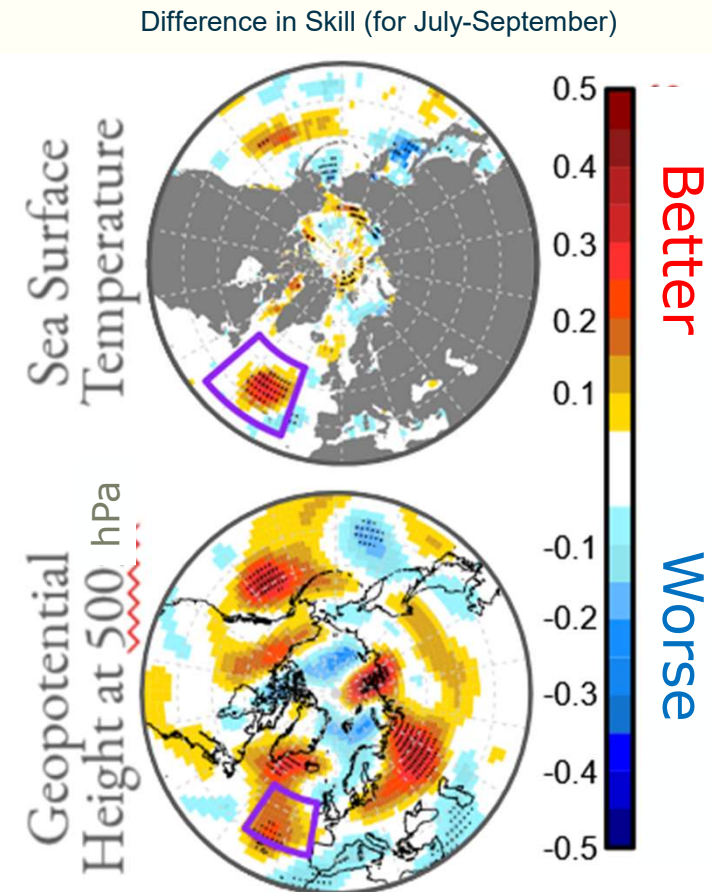
Assimilating ESA CCI sea ice observations to improve summer predictions in the Arctic and beyond



- The Arctic is a key region for understanding climate change.
- Enhanced warming and sea ice loss are linked through feedbacks.
- Arctic changes impact mid-latitude climates via teleconnection.

Assimilating sea ice concentrations improves sea ice prediction
... providing better forecasts of Arctic sea ice extent in the Atlantic

... and improves climate prediction in Eurasia ...
as Atlantic Sea Surface Temperature forecasts are improved (via a more realistic connection with ice in the Labrador sea) leading to better large-scale atmospheric circulation and thus surface temperature and precipitation prediction in Eurasia.



Improvement in SST and geopotential height when using SIC from Acosta Navarro et al. 2022

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EO data for evaluating CMIP models using ESMValTool

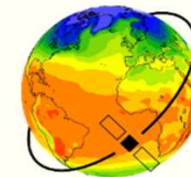


EO datasets¹ are vital for:

- 1) model development, highlighting areas for improvement future model versions;
- 2) assessment of model skill which informs interpretation of model future projections.

ESMValTool²: a tool for fast **and** easy evaluation and analysis of Earth system models

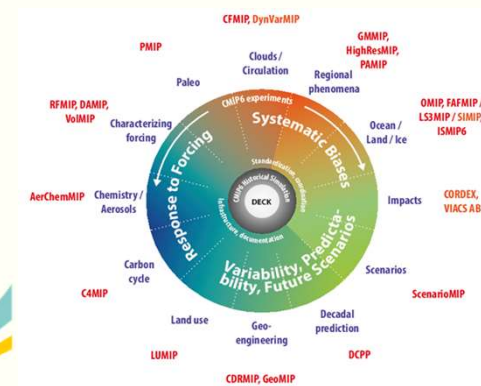
- Traceable and reproducible
- Model performance assessment and quality control
- Publicly available, international community effort



ESMValTool

Earth System Model Evaluation Tool

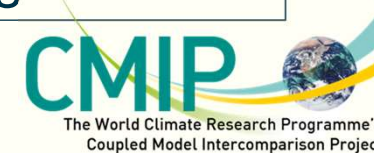
CCI data were used in the recently released **IPCC AR6** report³. Increasing the number of CCI datasets available through ESMValTool provides additional lines of evidence for future IPCC and other such reports advising on policy changes.



Eyring et al., Geosci. Model Dev., 2016

References

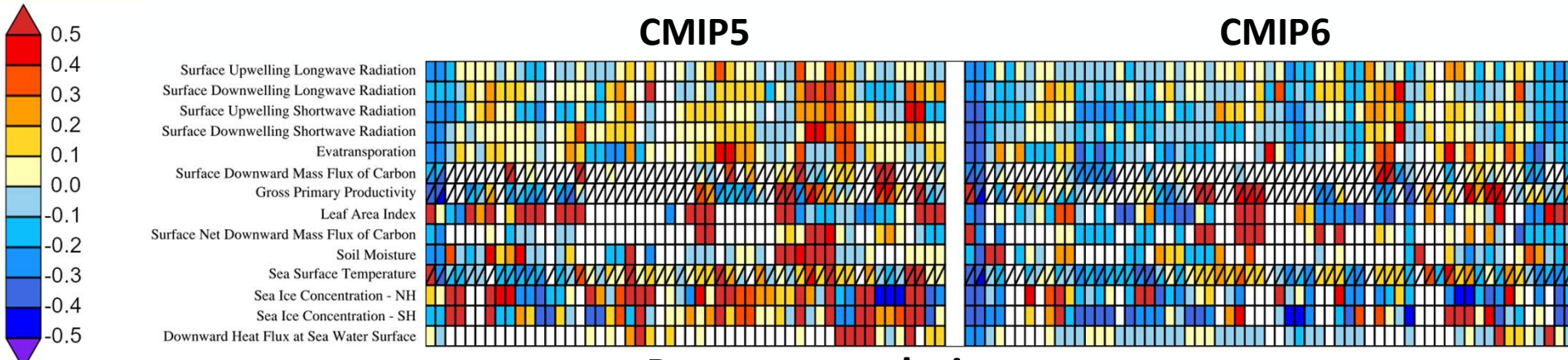
- ¹ <https://climate.esa.int/en/odp/#/dashboard>
- ² <https://www.esmvaltool.org/>
- ³ <https://www.ipcc.ch/assessment-report/ar6/>



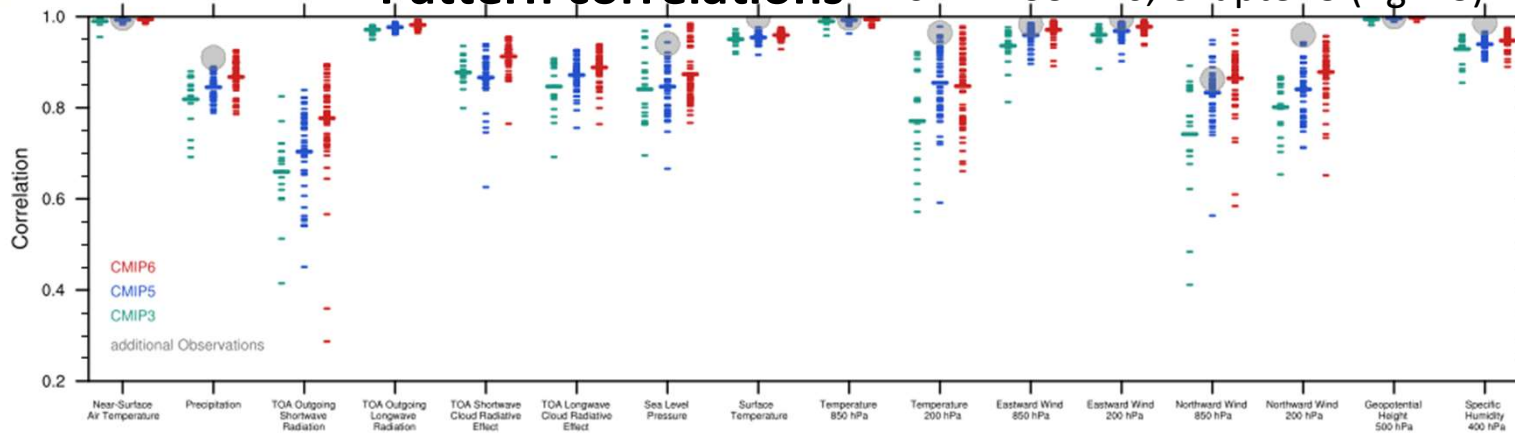
Evaluation of CMIP6 models with ESMValTool



Relative model performance (RMSD) From: IPCC AR6, Chapter 3 (fig. 42)



Pattern correlations From: IPCC AR6, Chapter 3 (fig. 43)



Obs4MIPs, making EO data easily accessible and deployable for model intercomparison projects



Obs4MIPs (Observations for Model Intercomparison Projects) is a climate model community initiative to encourage widespread uptake of satellite observations for climate model verification and development.

Example CCI products currently included ...

- Aerosol
- GHG (CO2 and Methane)
- SST
- Cloud

... more planned from all new CCI (ECV) projects

These data can easily be deployed, alongside other Obs4MIPs data, for individual and ensemble model and climate process diagnostic work

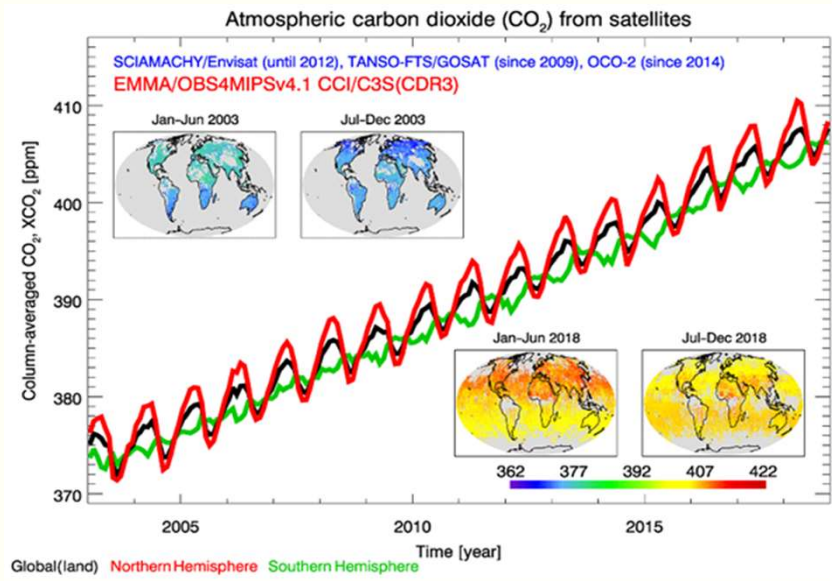


Figure 1: Overview of the XCO2 CCI_GHG data set from obs4MIPs. Shown are the time series over land for three latitude bands (global, black line; N (red) and S (green) Hemispheres green) and global maps (half-year averages at 1° x 1° obtained by gridding the merged Level 2 product). From Reuter et al. (2020).



CMUG – Future Evolution of Obs4MIPs



esa

A wide variety of observationally-based datasets are used for climate model evaluation. Obs4MIPs (Observations for Model Intercomparisons Project) refers to a set of documented datasets organised according to the Coupled Model Intercomparison Project (CMIP) model output requirements and made available on the Earth System Grid Federation (ESGF). Obs4MIPs underpins model evaluation in CMIP (and beyond) and thus makes a significant contribution to the assessment of and sustained improvement in model quality, e.g. as reported by IPCC. The CCI ECV projects contribute ECV data sets, which are decided to be of most interest to the CMIP community, to Obs4MIPs.

<https://pcmdi.github.io/obs4MIPs/>

Progress to date:

- CMUG held the kick off meeting for the obs4MIPs requirements deliverable (D5.7f) on 29th February 2024
- Interviews were agreed as the method to collate obs4MIPs requirements (D5.7f) and these were carried out with sign up from ESMO, CORDEX, and CMIP IPOs. and findings will be collated into a report.



CMUG – ESMValTool



The Earth System Model Evaluation Tool (ESMValTool) is an open-source community-developed diagnostics and performance metrics tool for the evaluation and analysis of Earth System Models (ESMs). ESMValTool allows for a comparison of single or multiple models against predecessor versions and observations. The aim of the ESMValTool is to take model evaluation to the next level by facilitating analysis of many different ESM components, providing well-documented source code and scientific background of implemented diagnostics. CMUG's role is to enhance the ESMValTool with additional diagnostics and performance metrics enabling tailored analysis for the evaluation of models with ESA CCI and CCI+ data. <https://esmvaltool.org/>

Progress to date:

- ESMValTool v2.10.0 released (January 2024)
- snow_cci v2.0 daily values of snow area fraction and snow water equivalent implemented (February 2024)
- permafrost_cci v3.0 yearly active layer thickness, extent and ground temperature values implemented (March 2024)
- Work on evaluating cloud properties from reanalyses using cloud_cci presented at EGU 2024 (April 2024)
- ESMValTool Community Workshop held, Oberpfaffenhofen, Germany, 27-29 May 2024 (May 2024)
- Prototype for calculation of permafrost extent from CMIP models implemented (June 2024)
- ESMValTool 2.11.0 released (July 2024)
- Exploration of possibilities to take advantage of uncertainty information provided with CCI datasets for model evaluation using LST data (work in progress)



CMUG – Scientific Studies



WP5.1 Machine Learning

This study focuses on 1) enhancing observational products for climate model evaluation with machine learning, 2) causal model evaluation for cloud regimes and land cover types using timeseries of several cloud variables, and 3) evaluation of CMIP6 models with ESMValTool.



WP5.2 Vegetation Phenology

This study will 1) provide testing and feedback on preliminary LAI and FAPAR data, 2) analyse relationships between phenology and land-atmosphere processes.



WP5.4 Ocean Biogeochemistry

This study will assimilate ESA CCI variables to produce forced ocean/sea-ice reconstructions. Then the impact of assimilation choices of these reconstructions on physical and biogeochemical properties will be explored.



WP5.6 Snow Dynamics

This study aims to improve our understanding and modelling of snow-vegetation-atmosphere feedbacks, with the IPSL climate model and various CCI products (especially snow products).



WP5.8 Tropical Wetland Methane Emissions

This study aims to develop an emulator for JULES wetland methane, use its explainability to show which factors matter in the model, drive the emulator with CCI Earth Observation data to generate wetland fluxes, and compare those to methane inversions performed on GOSAT/TROPOMI ESA CCI data.



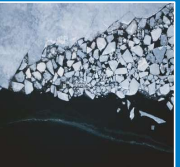
WP5.3 CCI Land Cover

This study will assimilate CCI Snow Water Equivalent (SWE) in the ISBA land surface model. CCI Soil Moisture & LST will be used as benchmarks to compare simulations.



WP5.5 Cloud and Aerosol Analysis

This study will undertake 1) dust aerosol analysis with the BSC system, and 2) Cloud / Aerosol analysis with the ECMWF system.



WP5.7 Ice Sheets

This study investigates: 1) if regional/global climate models accurately represent atmospheric and surface processes affecting ice-sheets 2) if they capture variability of ECVs, albedo and emissivity feedbacks over ice sheets 3) mass balance performance of models and which EsurfaceCVs show largest biases 4) can observations be used to reduce spread of ice sheet model sea level rise contributions?



Underpinning work to develop new observations and maintaining/enhancing current observations

Integrated multi-ECV and modelling work focused on important processes/system component and earth system cycles

Technical work on collating, documenting and disseminating data products including assessments of their uncertainties

Design project/programme information or service outcomes in collaboration with all those involved in using, communicating and producing them. Where necessary build capability in those involved to understand and engage effectively with the different sets of knowledge and experience/expertise involved.

