Project: **854**

Project title: **Erdsystemmodellevaluierung (DLR-Institut für Physik der Atmosphäre)**

Principal investigator: **Axel Lauer**

Report period: **2024-11-01 to 2025-10-31**

1. ESMValTool development

New versions of the Earth System Model Evaluation Tool (ESMValTool) are developed and tested within project 854 before being released. Within the reporting period, ESMValTool v2.12.0 (March 2025) and v2.13.0 (October 2025) have been released. New features in the two versions include several performance improvements such as addition of the iris-esmf-regrid scheme, which improves the regridding of 2D grids and adds the capability to regrid UGRID meshes. A new preprocessing function has been added to extract surface values of 3-dim variables. A set of new recipes allowing to plot arbitrary preprocessor output to benchmark a model simulation with other datasets has been added and documented.

The performance improvements are documented in:

Schlund, M., B. Andela, J. Benke, R. Comer, B. Hassler, E. Hogan, P. Kalverla, A. Lauer, B. Little, S. Loosveldt Tomas, F. Nattino, P. Peglar, V. Predoi, S. Smeets, S. Worsley, M. Yeo, and K. Zimmermann, Improving climate model evaluation with ESMValTool v2.11.0 using parallel, out-of-core, and distributed computing, Geosci. Model Dev., 18, 4009-4021, doi: 10.5194/gmd-18-4009-2025, 2025.

The set of benchmarking recipes is documented in:

Lauer, A., Bock, L., Hassler, B., Jöckel, P., Ruhe, L., and Schlund, M.: Monitoring and benchmarking Earth system model simulations with ESMValTool v2.12.0, Geosci. Model Dev., 18, 1169-1188, doi: 10.5194/gmd-18-1169-2025, 2025.

Other additions to the new versions include e.g. support for new datasets such as ESACCI-OZONE, ESACCI-SEAICE and OSI-450, a number of diagnostics for the CMIP7 Rapid Evaluation Framework (REF), diagnostics for Zero Emissions Commitment (ZEC) and selected ENSO metrics.

2. Analysis and evaluation with ESMValTool

The causal links between cloud properties and selected cloud-controlling factors are systematically analyzed by applying causal inference, an unsupervised machine learning method, to daily satellite and reanalysis data. All data are preprocessed with ESMValTool resulting in time series of the relevant quantities that can then be analyzed with causal inference. An example of these time series is shown in Figure 1. The aim of this approach is to identify and quantify the sensitivity of cloud properties to different factors to be able to assess how clouds react to climate change. Here, the focus is on marine stratocumulus clouds (Sc) off the coast of South America.

Specifically, dynamical and thermodynamical cloud controlling factors are analyzed to quantify the causal effects on macrophysical properties of marine Sc clouds. The results show that sea surface temperature, lower tropospheric stability, surface sensible heat flux, and 10-m wind speed are the main drivers influencing these clouds. While the causal links between these factors and the cloud properties total cloud cover, total cloud water path, and cloud optical depth show similar behavior, the cloud effective radius remains largely unexplained, suggesting that the background aerosol might play an important role. In contrast, the cloud top pressure is influenced by all cloud-controlling factors investigated, except the surface sensible heat flux. Future application of this approach to climate model output is seen as a step towards a more process-oriented evaluation of the sensitivity of simulated clouds to climate change.

This study has been submitted to Journal of Atmospheric Sciences for publication:

Bock, L., Lauer, A., and Runge, J.: Quantifying the causal effect of cloud controlling factors on marine stratocumulus *clouds, submitted to J. Atmos. Sci.*

Figure 1 Time series of the 12 deseasonalized and anomalized variables averaged over the 5°× 5° boxes over the Southeast Pacific stratocumulus region. The x-axis gives the days since 1 January 2003. From top to bottom: total cloud cover (%), cloud water path (ice + liquid) (kg m^{-2}), cloud optical depth (1), cloud effective radius (µm), cloud top pressure (hPa), sea surface temperature (°C), vertical velocity at 700 hPa (Pa s^{-1}), lower tropospheric stability (K), sea level pressure (Pa), water vapor path (kg m^{-2}), surface sensible heat flux (W m^{-2}), and 10-m wind speed (m s^{-1}). From Bock et al. (submitted).

Publications in 2025 related to project 854

Bock, L., Lauer, A., and Runge, J.: Quantifying the causal effect of cloud controlling factors on marine stratocumulus clouds, J. Atmos. Sci. (in revision).

Lauer, A., Bock, L., Hassler, B., Jöckel, P., Ruhe, L., and Schlund, M.: Monitoring and benchmarking Earth system model simulations with ESMValTool v2.12.0, Geosci. Model Dev., 18, 1169-1188, doi: 10.5194/gmd-18-1169-2025, 2025.

Schlund, M., Andela, B., Benke, J., Comer, R., Hassler, B., Hogan, E., Kalverla, P., Lauer, A., Little, B., Loosveldt Tomas, S., Nattino, F., Peglar, P., Predoi, V., Smeets, S., Worsley, S., Yeo, M., and Zimmermann, K.: Advanced climate model evaluation with ESMValTool v2.11.0 using parallel, out-of-core, and distributed computing, Geosci. Model Dev., 18, 4009-4021, doi: 10.5194/gmd-18-4009-2025, 2025.