natESM

Sprint documentation #11

Sprint "Modular Land Surface Coupling"

Stefan Poll[1] and Jörg Benke[1]

[1]Jülich Supercomputing Center, Forschungszentrum Jülich GmbH, Jülich, Germany

Contact: info@nat-esm.de

Published on 01.07.2025 on https://www.nat-esm.de/services/accepted-sprints

1 Summary

The aim of the sprint was to develop a proof-of-concept for the modular coupling of a land surface model (LSM) to the atmospheric model ICON, realized through the coupling of eCLM to ICON using the external YAC coupler. Such a modular coupling approach with an external coupler, that links compartmental models with each other, allows for an easier modularization of the land-surface parameterization than with a built-in subroutine coupling, is independent of individual model grids, and also enables to run component models on different supercomputer architectures. Using the ICON's coupler of choice infrastructure YAC leverages past developments, ensures compatibility with potential additional component models in the future.

In a proof-of-concept, this sprint could successfully demonstrate modular atmosphere-land-surface coupling by coupling a LSM dwarf model with ICON via the external coupler YAC. The challenges included the restructuring of the YAC coupling mechanism (see details in 4.1) and porting of the test case for YAC. Outstanding objectives of the sprint are the integration of the eCLM LSM and the Modular Supercomputing Architecture (MSA) approach. The development of the coupling concept within this sprint albeit lays the foundation on which the actual modular coupling between the atmosphere and the land surface can potentially be implemented.

2 General information

Start and end date:	January 2024 – July 2024
Intended period:	6 months
Responsible RSE:	Jörg Benke (Forschungszentrum Jülich, JSC)
Responsible scientist:	Stefan Poll (Forschungszentrum Jülich, IBG-3/JSC)

Yet Another Coupler (YAC, [6]) is a software library for efficient Earth System Models (ESM) coupling. Specifically designed for ESMs, YAC handles the data exchange between component models by, e.g., transferring mass (water, CO2, etc.), energy, and momentum fluxes. YAC is the coupler of choice by the ICON partnership and already implemented, e.g., in atmosphere-ocean coupling.

3 Sprint objectives

Our main objective was proof of concept of a modular coupling of land surface models to ICON. It was originally planned to implement the YAC coupler in the ICON-eCLM interface serving as a demonstrator for modular land surface coupling. This coupling was supposed to be based on the coupling concept developed within this sprint. A performance assessment of the newly YAC-coupled ICON-eCLM vs the existing OASIS3-MCT-coupled ICON-eCLM was planned. The modular coupled ICON-YAC-eCLM would finally be demonstrated with the use of Modular Supercomputing Architecture (MSA) for the land-atmosphere interface.

The starting point of the sprint was the already established fully functional ICON-eCLM coupling with the OASIS3-MCT coupler by the sprint's responsible scientist. This procedure was intended to serve as a blueprint for this sprint using YAC. This coupling approach has been proven to work in various research projects, starting off originally with COSMO-CLM coupling with OASIS3-MCT.

Following the demonstrator for modular coupling of land surface models, users would be enabled to select a land surface model that precisely meets their needs. Different land surface models offer varying degrees of complexity, which has increased significantly in land surface modeling over the past decades. The use of higher-resolution (than the atmosphere) spatial grids for the land surface allows for the inclusion of multivariate land surface heterogeneity, which is expected to be superior to the tile approach. However, this method is not yet commonly used in ESMs and climate applications.

4 Procedure and insights

4.1 Technical approach/procedure

The initial phase of the sprint was about the familiarization with the YAC coupler (existing use of YAC for ocean model coupling was only partly informative) and the planning of the coupling implementation on the ICON side. Valuable input on coupling strategies was from Warmworld project scientist Jan Weinkämmerer (IBG-3/FZJ), who has recently coupled the integrated hydrologic model ParFlow [4] with the JSBACH3 LSM [5] via YAC.

In the initial phase, we prepared a brief report outlining a generic coupling concept design for the atmosphere-land interface based on an already existing document about land atmosphere coupling with ICON [10]. The report proposes an interface layer for selecting coupled variables based on the coupled LSM. This document aims to spark discussions, while the details of the coupling concept is presented in an accompanying document [9] on DKRZ gitlab.

For ICON we chose the icon/icon repository (https://gitlab.dkrz.de/icon/icon) as the basis for our sprint developments and started out with git tag 2024.01, that matches the first public open-source ICON release (icon-model release-2024.01-public, [2]). This ensures that all spring developments could easily be made available without licensing constraints, while allowing us to keep up to date with the latest developments in

ICON. As the sprint's developments shall contribute to the overall ICON project, we have created a fork at gitlab.dkrz.de [1].

To ensure compatibility with other developments in the ICON land modelling realm, we met with the main developer Reiner Schnur (MPI-M) to discuss the interface of the TMX turbulent mixing package with ICON-LAND, which is currently under development, and possible integration of the NWP physics in TMX.

The strategy for an efficient development of the coupling between ICON and eCLM via YAC was to employ dwarf models of ICON and eCLM that only mimic the communication with the YAC coupler [6]. This facilitates intermediate testing and control over the development.

The development was started by coupling ICON with a dwarf model that mimics a LSM. The dwarf model originated from the YAC tutorial [3]. As a first step, the dwarf model system was ported from the Levante HPC (DKRZ) to the JUWELS-Cluster (JSC); a second step saw the adaptation to mimic a surface model.

We then proceeded to implement the coupling in ICON, i.e., have YAC as a coupler interface to an LSM. While our implementation was ongoing, the coupling procedure and architecture of ICON was refactored (commit 71c71690, 4th of March 2024 [2]). The main YAC developer confirmed that this restructuring from a component centric coupling to a general-purpose coupling structure with action if-statements was performed to facilitate expansion and maintenance of YAC (personal communication).

These changes also seemed very reasonable to us and relevant for our YAC LSM coupling approach. In order to make use of these new developments, our code had to be adapted to follow the new code structure, which unifies the coupling calls instead of having the coupling calls for each code. All code for a particular coupling is now restricted to a single module per component model and - where possible - to the common YAC utilities module. Further structural changes have also been considered and adapted including the component interface and namelist module.

For testing and debugging we created an idealized one-day test case [details in 9]). This testbed made the identification and solution of implementation flaws very efficient. During this implementation phase we kept close contact with Moritz Hanke of DKRZ as the main YAC developer.

The outcome of this development is a working implementation of the YAC coupler in ICON that correctly exchanges data with the dwarf LSM through a two-way coupling. The LSM-dwarf is able to send either constant values or values based on the input of ICON. The first case is very valuable for debugging purposes, even though it results in a logical one-way coupling. The second case is mimicking a full-fledged land-surface model with feedback in both directions.

4.2 General insights

Through the implementation of the YAC coupler into ICON for LSM coupling via an LSM-dwarf, we gained some general insights.

With respect to the use of an alternative LSM towards a modular ESM approach there is one general insight.

- By and large, we found that the functions of coupling ICON and eCLM with either the existing OASIS3-MCT coupler solution or the YAC coupler implemented in this sprint are quite similar, except for the grid definition part. The working version of the YAC coupler interface with the dwarf

LSM can be used as a blueprint for further developments. With respect to eCLM, the YAC implementation is still to be done.

During the configuration and application of the test case we discovered some issues when using YAC that may be of interest for the YAC community.

- The start and end time of the dwarf model was explicitly defined in the YAC configuration file (coupling.yaml). However, this caused problems with the date and time format of ICON. As a consequence, the lead developer of YAC suggested that this should be omitted from the coupling configuration file, as ICON takes the model time from the ICON name list and distributes it to all processes of the models. This has prompted action in the core YAC development resulting in a fix for the underlying issue and is a nice example of feedback and potential co-design.
- Our target machine was the JUWELS-Cluster (JSC). First, we started the test jobs with the two model components as a hetjob. In contrast to Levante (DKRZ), the hetjobs did not run and failed already at the beginning of the jobs with the following error message (excerpt): "MPIDU_Init_shm_init(180): unable to allocate shared memory". Switching to srun –multiprog multiprogfile, where the process numbers for each component are explicitly defined in the multiprogfile, solved the problem, at least for the CPU only version.

5 Results

A first outcome of the sprint was the development of a coupling concept that could serve as a basis for a modular atmosphere-land surface coupling in ICON. The second outcome demonstrates the proof of concept for a modular land surface coupling. This was accomplished through a bidirectional coupling of ICON with a dwarf land surface model.

The progress made during the sprint provided a solid foundation, enabling the applicant's research team to achieve this outcome shortly after the reporting period. The experience and results of the sprint provide an excellent basis for continuing and successfully completing the development of a YAC-externally coupled LSM in ICON.

6 Conclusions and outlook

In a proof-of-concept development, we have implemented a prototype for modular coupling of a land surface model to ICON using the YAC external coupler. This was the main goal of this sprint. The applicant's research team is continuing to eventually finalize the coupling with a full-fledged LSM, i.e. eCLM.

A logical continuation of the work started with this sprint would be a generalization of the coupling interface and to integrate the coupling procedure with the development of the TMX package and its interface to ICON-LAND, i.e. replacing the current subroutine-based coupling between TMX and ICON-LAND with the YAC-based coupling.

7 References

1. Sprint repository: https://gitlab.dkrz.de/b380388/icon-fork
2. ICON repository: https://gitlab.dkrz.de/icon/icon-model

3. YAC tutorial repository: https://gitlab.dkrz.de/YAC/2407_tutorial/-/tree/tutorial?ref_type=heads
4. ParFlow: https://parflow.org/
5. JSBACH3: https://pure.mpg.de/pubman/faces/ViewItemOverviewPage.jsp?itemId=item_3279802
6. YAC coupler: https://gitlab.dkrz.de/dkrz-sw/yac
7. OASIS3-MCT coupler: https://oasis.cerfacs.fr/en/home/
8. Coupling test-case repository: https://gitlab.dkrz.de/b380388/natesm_ideal-ccs-snwp_icon
9. Coupling concept: https://gitlab.dkrz.de/b380388/modLSM-coupling-concept
10. Land Atmosphere Coupling: https://gitlab.dkrz.de/b380791/land_atmosphere_coupling