# REQUEST FOR AN EMI R&D PROJECT 2027–2029

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|---|---|
| **Country/Organisation:** | Italy |
| **Principal Investigator[1]:** | Vincenzo Senigalliesi |
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| **Other researchers:** | Andrea Alessandri (ISAC-CNR), Annalisa Cherchi (ISAC-CNR) |
| **Project Title:** | Assessing the Atmospheric Response to Improved Subsurface Hydrology in High-Resolution ESMs |

To make changes to an existing project please submit an amended version of the original form

| | | |
|---|---|---|
| If this is a continuation of an existing project, please state the computer project account assigned previously. | **SP** ............. | |
| Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.) | 2027 | |
| Would you accept support for 1 year only, if necessary? | YES ☐ | NO ☐ |

| **Computer resources required for project year:** | | **2027** | **2028** | **2029** |
|---|---|---|---|---|
| High Performance Computing Facility | [SBU] | 30000000 | - | - |
| Graphics Processing Unit Cluster-A | [GBU] | - | - | - |
| Graphics Processing Unit Cluster-B | [GBU] | - | - | - |
| Accumulated data storage (total archive volume)[2] | [GB] | 40000 | - | - |

| **EWC resources required for project year:** | | **2027** | **2028** | **2029** |
|---|---|---|---|---|
| Number of vCPUs | [#] | - | - | - |
| Total memory | [GB] | - | - | - |

[1] The Principal Investigator will act as contact person for this EMI R&D Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

| | | | | |
|---|---|---|---|---|
| Storage [GB] | - | - | - |
| Number of vGPUs[3] [#] | - | - | - |

*Continue overleaf.*

**Principal Investigator:** Vincenzo Senigalliesi

**Project Title:** Assessing the Atmospheric Response to Improved Subsurface Hydrology in High-Resolution ESMs

# Extended abstract

The Institute of Atmospheric Sciences and Climate at the National Research Council of Italy (ISAC-CNR) is a member of the EC-Earth consortium, which brings together research institutes across Europe to collaboratively develop an European state-of-the-art Earth System Model (ESM). Within EC-Earth, ISAC-CNR coordinates the Land and Vegetation working group as well as the CMIP and Tuning working groups. ISAC-CNR is also a partner in the EU Horizon Europe project OptimESM ("Optimal High Resolution Earth System Models for Exploring Future Climate Change"), whose main objective is to advance the development of the next generation of CMIP7 Earth System Models through a more realistic representation of Earth system processes and their interactions and feedbacks. In this framework, ISAC-CNR contributions focus particularly on enhancing the representation of hydrological processes and their biophysical couplings with the atmosphere.

**Scientific motivation**

Water-limited regions are among the most vulnerable to ongoing climate change, facing intensifying drought conditions, declining groundwater levels, and the risk of transitions towards drier eco-hydro-climatological regimes (Maestre et al., 2021; Alessandri et al., 2014; Garreaud et al., 2017). The progressive depletion of subsurface water storage, combined with sea-level rise, further exacerbates saltwater intrusion in coastal aquifers, threatening groundwater-dependent ecosystems and increasing the risk of desertification with associated regional climate feedbacks (McFarlane et al., 2020; Gleeson et al., 2020). Despite their recognized importance, the key hydrological processes governing these dynamics — in particular groundwater storage and water table dynamics — remain crudely represented in current state-of-the-art ESMs.

The land surface model component of EC-Earth, ECLand-LPJGuess (Balsamo, 2009; Alessandri et al., 2017; Boussetta et al., 2021; Doescher et al., 2022), currently lacks an explicit representation of groundwater, relying instead on a free-drainage condition at the bottom of the unsaturated soil column. This structural limitation prevents the model from capturing the feedback between subsurface water storage, soil moisture, vegetation water stress and the atmosphere that is critical in transitional and semi-arid climates. Building on recent developments in ECLand-LPJGuess, a more physically consistent representation of subsurface hydrology is being implemented as part of ongoing model development activities at ISAC-CNR (see also the companion SPITALES 2025-2027 Special Project). Specifically, a global-scale water table depth parameterization replaces the free-drainage lower boundary condition. A simple prognostic groundwater model is further implemented to represent recharge and discharge processes in an

unconfined aquifer, coupled to the unsaturated soil column and to the effective root zone water storage capacity. Building on the implementation and validation activities carried out within

SPITALES, this EMI R&D project represents a further and complementary step by evaluating the atmospheric impact of dynamic groundwater in a high-resolution EC-Earth4 AMIP framework (TCO399, roughly corresponding to 25 km). Specifically, the project aims to evaluate and quantify the atmospheric effects of advanced subsurface hydrology on land-atmosphere coupling, feedback, and climate variability in water-limited regions, using a high-resolution configuration that provides the spatial detail needed to represent key surface-atmosphere coupling processes. By better resolving land-surface heterogeneity, boundary-layer development, and circulation features, the TCO399 configuration allows groundwater-mediated surface-flux anomalies to be assessed under conditions in which their coupling to the atmosphere can be more realistically represented. This provides a scientifically motivated high-resolution extension of the SPITALES developments and represents a distinct and novel scientific endeavour.

**EC-Earth4 for CMIP7: AMIP-type simulations**

This project focuses on Atmospheric Model Intercomparison Project (AMIP)-type simulations to assess the effects of the improved hydrological representation on land–atmosphere coupling, mean climate and variability, with a particular emphasis on water-limited regions. AMIP experiments are performed using the OpenIFS(cy48)+ECLand+LPJGuess configuration of EC-Earth, forced with observed sea surface temperatures and sea-ice concentrations consistently with the CMIP7 protocol (Dunne et al., 2025). The simulations span the period 1979–2021 and comprise 5 ensemble members to allow for a robust assessment of both forced signals and internal variability. To ensure a robust equilibration of the groundwater model—particularly in arid regions, which require significantly longer spin-up periods to reach an equilibrated water table depth—the AMIP experiments will include at least 50 years of coupled spin-up before the 1979–2021 simulation period. Importantly, to reduce the computational burden on the subsequent coupled AMIP integration, the AMIP spin-up will start, where possible, from land and groundwater states derived from ERA5-forced land-only simulations, thereby avoiding starting from arbitrary groundwater conditions and bringing the land and groundwater states closer to equilibrium before the coupled AMIP experiments.

**High-resolution assessment of groundwater-mediated land–atmosphere feedbacks**

High-resolution AMIP simulations are central to this project because they provide a suitable framework for assessing whether groundwater-mediated changes in root-zone moisture availability and surface energy partitioning can affect boundary-layer development, circulation, precipitation, and climate variability. This is particularly relevant because the representation of land–atmosphere coupling and feedback is increasingly recognized as sensitive to horizontal resolution (Dirmeyer et al., 2018; Müller et al., 2021; Jach et al., 2022). Finer grids can better represent orography, land-surface heterogeneity, atmospheric circulation, boundary-layer development, and the spatial organization of soil-moisture, evapotranspiration, and precipitation anomalies (Müller et al., 2021; Moreno-Chamarro et al., 2025). Models often underrepresent the feedback of surface fluxes on boundary-layer properties (Dirmeyer et al., 2018); horizontal resolution modulates both local and remote land–atmosphere coupling mechanisms (Müller et al., 2021); and coupling strength depends on atmospheric temperature and moisture pre-conditioning, especially over European transitional regions (Jach et al., 2022). Within the CMIP7/HighResMIP2 context, high-resolution ESM configurations are increasingly used to investigate how improved process representation affects regional climate variability, extremes, and feedback (Roberts et al., 2025; Moreno-Chamarro et al., 2025). The proposed TCO399 AMIP experiments therefore build on the SPITALES hydrological developments to assess, directly at high resolution, the atmospheric response to dynamic groundwater and its implications for land–atmosphere feedback over water-limited regions.

**Configuration and justification of resources**

A total of 265 years of AMIP-type simulations at high resolution are planned (43 years x 5 members + 50 years of spin-up). In terms of computational layout, each coupled execution will leverage 10 nodes (64 cores each) dedicated to OpenIFS (OIFS), 1 node for XIOS (I/O server), and 1 node for the runoff mapper. Computational costs are evaluated at 100 kSBU per year for this High-Resolution setup, resulting in a baseline resource allocation of 26500 kSBU. Factoring in a 13% technical buffer (3,5 kSBU) to account for workflow tuning, spin-up overheads, and optimization, the total requested resource is 30000 kSBU over the duration of the project. The simulations will make use of ECMWF's HPC infrastructure and will leverage the existing EC-Earth workflow, adapted to incorporate the new hydrological parameterizations. Details of the computational requirements are provided in Table 1.

| Experiment name | Description | Resource per year (kSBU/yr) | Total years | Total resource (kSBU) | Storage (TB) | Scheduled year |
|---|---|---|---|---|---|---|
| Amip-type testing (AMIP) | High Resolution (e.g., TCO399) simulations and developments | 100 | 265 | 26500 | 40 | 2027 |
| 13% buffer | | | | 3500 | | |
| Total | | | | 30000 | | |

*Table 1: Experiments planned in this project, resource costs (kSBU), storage requirements (TB) and scheduled year of simulation. See text for details.*

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