natESM: Building a future-proof Earth System Modeling capability for Germany

Iris Ehlert ▪ German Climate Computing Center (DKRZ) ▪ ehlert@dkrz.de

𝄢 1/5 From solo efforts to a unified ensemble

Foundations & Motivation

Exascale HPC opens new frontiers for Earth system modeling (ESM), offering unprecedented resolution, complexity, and capability.
However, **harnessing this potential requires major adaptation** of models and software to run efficiently on cutting-edge architectures.
System management is complex and resource-intensive → effort must be minimized to enable sustainable scientific progress.
Cross-institutional cooperation is key to achieving this – no single institution can meet all demands alone.

The natESM Initiative

natESM was launched to **develop a national strategy** for:
→ Enabling sustainable, cross-institutional cooperation
→ Optimizing operational efficiency of Earth system modeling in Germany

The German ESM community defined **ambitious criteria** for a **world-class ESM system** – most of which **center on software engineering** and require collective effort.

In response, a **small group of forward-looking scientists** initiated natESM to:
→ **Build a dedicated support team**
→ Provide **technical and strategic guidance** to the steering group and the wider community
→ Ultimately enable a **sustainable, ready-to-use ESM system** for **research, operations, and education**

𝄢 2/5 The overture – Phase 1: Building the foundation

Sprints – a new format of collaboration

- Scientists can apply for RSE support in agile, focused projects (up to 6 months)
- Scientists and software experts work side by side
- Codes are ported to new HPC architectures and are tested in real scenarios
- Core, Extended Core, and Infrastructure components are integrated into an initial system (see figure below)

Community building and coordination

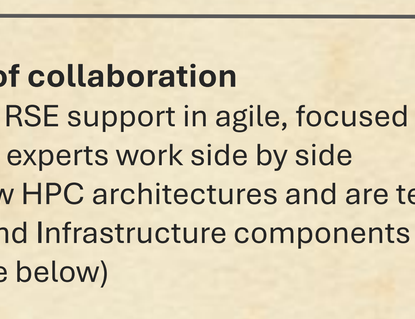
- Regular workshops, trainings, and community meetings strengthen exchange
- Continuous communication via newsletters, GitLab, and Mattermost

Agile strategy based on community feedback

- Based on input from sprint teams and the broader community, we have jointly developed an agile strategy
- Focus: building a structure that works both **technically** *and* **communicatively**.

Core
Fundamental models for basic Earth system modeling.
Currently: **ICON-A, ICON-O, FESOM**

Extended Core
Comprehensive models for Earth-system interactions.
Currently: **ICON-ART**



Impact
Specialized models enabling one-way interactions within the system. natESM assists with their integration to expand the modeling system's reach and functionality.
Currently: **None**

Infrastructure
Tools and interfaces that connect core and extended core components, ensuring seamless functionality.
Currently: **YAC, ComIn**

Optional
Community-suggested models for future integration, visible for exploration but not part of the main system. These can become extended core components if they meet our acceptance criteria as outlined in the natESM strategy.
Currently: 46 (30 with more details)

𝄢 3/5 The crescendo – Phase 2: Expanding impact

AI methods become an integral part of the modeling workflow

Advanced artificial intelligence techniques are being introduced to accelerate simulations, support complex data analyses, and improve the usability of model output across scientific and societal applications.

Model configurations are defined for diverse scientific and practical goals

natESM aims to provide well-defined model setups tailored to key use cases:
1. Long-term climate projections (century-scale ensembles)
2. Paleoclimate simulations
3. Air-quality simulations
4. Ultra-high-resolution simulations of atmosphere and ocean

New interfaces toward impact communities

natESM builds bridges between Earth system modeling and societal sectors. Interfaces to urban systems, risk research, health, agriculture, and hydrology allow for better connection between global-scale simulations and local needs.

Training the next generation

To ensure long-term capacity, natESM is investing in education and training:
- A new Master's course at the University of Cologne will begin in 2025/26
- The first natESM Summer School will be held in 2026 in Tübingen (planned as a biennial format)
- Community-wide workshops and trainings foster skills and knowledge exchange

Expanding the infrastructure and securing RSE expertise

The Research Software Engineering team at DKRZ has been strategically expanded to:
- Ensure robust integration of AI methods
- Guarantee model maintainability on future HPC platforms
- Support the long-term operability and evolution of the natESM system

→ Research codes are living infrastructure – they require permanent, embedded expertise. natESM Phase 2 addresses this by advocating for **long-term institutional anchoring of RSE capacity** as a core pillar of national ESM capability.

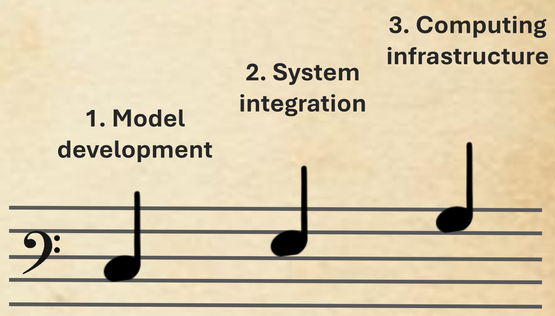
👉 **Phase 2 sets the stage for expanding the scientific scope and societal relevance of Earth system modeling.**

𝄢 4/5 The triad: Strength through synergy

A strong Earth system modeling capability requires more than just scientific excellence – it needs coordination, integration, and computing power.

Three interlocking efforts form the foundation of Germany's national strategy:

1. **WarmWorld** advances the physical core of next-generation climate models by optimizing ICON for km-scale resolution.
2. **natESM** provides the framework to integrate and expand these components into a shared, modular modeling system.
3. **DKRZ** delivers the high-performance computing platform that enables development, testing, and application of these models at scale.



👉 Like a musical chord: **Only in harmony do we achieve our full potential.**

𝄢 5/5 Coda: With thanks to our supporters

Our values

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← **Website**: www.nat-esm.de **Explore the natESM system on GitLab**: https://nat-esm-system.dkrz.de/index.html →
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