IS-ENES3 Deliverable D4.5

White paper on innovation on tools, platforms, and techniques

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ABSTRACT

The white paper describes the range and impact of the innovation support activity in IS-ENES3 work on developing models and tools. This covers networking activities, service activities, and development activities. The context for this work is set by Milestone M2.2: Innovation Plan which defines innovation as "*Putting new ideas into use to deliver real societal benefits, including, but not limited to, commercial activity. This goes beyond proof-of-concept work, but does not depend on quantification of the impact*."

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Executive Summary

Innovation on models and tools occurs through networking (WP4), services (WP6), and research and development (WP8). Three broad categories of innovation work have been identified here: (1) training which informs potential users outside the research community of the potential benefits of tools developed and promoted by IS-ENES3; (2) feeding into well-established innovation workflows in operational weather centres where efficient coordination between operations and research ensures that research outcomes can feed smoothly into enhancements of operational services; (3) feeding through to non-academic users through established user networks.

The development of climate models is a long-term process in which products may require more than 10 years between conception and achieving impact. This is equally true for the software tools needed to exploit new data products and make information accessible to emerging user communities. One side effect of this long-time scale is that, in many cases, there is a lack of clear information about the steps between research and impact. The production workflow, taking ideas through the technology readiness levels, is embedded in the organisational structure of climate modelling institutions. There is a strong academic research element in the development of new products, with greater emphasis set on reporting the creative step of research and the final step of achieving impact.

1. Objectives

The white paper describes the range and impact of innovation support activity in IS-ENES3 work on developing models and tools. This covers networking activities in WP4, service activities in WP6, and development activities in WP8. Additional innovation activities on data and standards will be covered in D2.3.

The context for this work is set by Milestone M2.2: Innovation Plan. Innovation is a critical phase in the progression of a new research idea towards operational deployment delivering societal benefit. M2.2 defines innovation as "*Putting new ideas into use to deliver real societal benefits, including, but not limited to, commercial activity. This goes beyond proof-of-concept work, but does not depend on quantification of the impact*."[1] Innovation in this sense is, by definition, something which is done by external parties, commercial organisations, and operational services, rather than by project partners. This report covers the activities in IS-ENES3 supporting and promoting innovation, and the evidence that these support and promotional activities are successful.

2. Methodology

The innovation report has been compiled on the basis of meetings with project members involved in WP4, WP6, and WP8, building on the definitions and scoping work reported in M2.2.

From the perspective of Technology Readiness Levels (TRLs), innovation can be seen as the activities which move a product or concept through TRL 5, 6 and 7 (see Box1).

Box 1: **Technology Readiness Levels** (see e.g. [TRL]) can be used to map the progression of ideas from research through innovation to delivering impact (Herbert 2016). Herbert identifies TRLs 4-7 in the list below as innovation.
• TRL 1 – Basic principles observed • TRL 2 – Technology concept formulated • TRL 3 – Experimental proof of concept • **TRL 4 – Technology validated in lab**

[1] The agricultural European Innovation Partnership (EIP-AGRI) defines innovation as "a new idea that proves successful in practice" (https://ec.europa.eu/eip/agriculture/en/what-innovation)

- **TRL 5 – Technology validated in relevant environment**
- **TRL 6 – Technology demonstrated in relevant environment**
- **TRL 7 – System prototype demonstration in operational environment**
- TRL 8 – System complete and qualified
- TRL 9 – Actual system proven in operational environment

3. Results by Workpackage

• WP4: Networking on Models, Tools, and efficient use of HPC

A workshop on "New Technical Opportunities in Machine Learning and Artificial Intelligence", supporting and promoting innovation, was convened to bring together climate scientists and experts from academia and industry to share knowledge and experience, and to identify new opportunities in the areas of machine learning, artificial intelligence, and big data techniques for Weather and Climate.

Of the total of 21 speakers, 14 were from academic institutions and weather and climate centres around the world and 7 were from industry, representing both software and hardware technology developers as well as service providers.

The participants had a range of backgrounds from across academia, weather and climate centres, and industry around the world. There were representatives from the following companies registered for the workshop: Ramboll, Arm, Google, Cervest Ltd., Wikilimo, GEOMAR, NVIDIA Ltd., Predictia Intelligent Data, SISTEMA GmbH[2], ARCADIS[3], Airbus, Benchmark Labs, Climate Scale, Descartes Labs, Lobelia Earth, CIEMET[4], Randbee Consultants, Eötvös Loránd, ClimateAi, ClimaCell, NUS, Kyrgyzhydromet, Arpae, ULB Brussels Physics, Verisk Maplecroft, Simula, Jupiter Intelligence, Microsoft.

More details are reported in IS-ENES3 Milestone MS16 (M4.2) v1.0[5].

[2] https://sistema.at/
[3] https://www.arcadis.com/
[4] Centre for Energy, Environmental and Technological Research
[5] https://raw.githubusercontent.com/IS-ENES3/IS-ENES-Website/main/pdf_documents/IS-ENES3_M4.2_vf.pdf

- ## WP6 Services on European ESMs and Software Tools

WP6 also supported innovation through services and training activities, such as for the OASIS coupler. Among users are Meteorological services for OASIS and Cylc and operational oceanography for XIOS (through use of NEMO).
WP6 has also offered dedicated support through open calls of Transnational access (TA). This activity is reported in D6.4 (Report on new OASIS coupled models/interfaces). TA directly served Meteorological Services (UKMO, SMHI, DWD, and Météo-France) as well as the GEOMAR Marine Meteorology Team.

- ## WP8: Models & Tools developments

Work in WP8 supported innovation in three areas: coupling software, a workflow engine, and sea-ice modelling.

OASIS coupler

OASIS is used by major weather and climate centres to couple existing Fortran models (such as atmosphere and ocean models) together to form a more complex coupled model.

OASIS has been developed for the climate modelling community, but is finding use in operational Numerical Weather Prediction (NWP; e.g. Voldoire et al. 2017; Bengtsson et al. 2017). The IS-ENES3 product OASIS3-MCT5.0, the latest version of the OASIS coupler interfaced with the Model Coupling Toolkit (MCT) from the Argonne National Laboratory, will be used operationally for NWP at the UK Met Office.

The IS-ENES3 sponsored "5th Workshop on Coupling Technologies for Earth System Models" (CW2020)[6] brought together leading researchers and practitioners in the field of coupling infrastructure for Earth System Models and helped to inform practitioners from outside the research community of the capabilities of OASIS3-MCT.

The UK Met Office is currently using the OASIS3-MCT4.0 version of OASIS, not the latest OASIS3-MCT5.0 version which has been developed within IS-ENES3. The upgrade to OASIS3-MCT5.0 is scheduled for 2024. The long-planned lead time between completion of product development work and operational deployment is characteristic of the time scales for enhancements to immensely complex climate and Numerical Weather Prediction (NWP) codes.

Python bindings for OASIS3-MCT have also been developed within IS-ENES3. By providing Python bindings to OASIS3-MCT we open up the power of OASIS3 to communities that are

[6] On-line, **September 21st-24th** 2020, https://portal.enes.org/coupling-workshops-detailed/#CW2020

developing, or wish to develop, their codes in Python. It is hoped that this work will help smaller research centres, students, and communities outside of weather and climate (such as Integrated Assessment - IA) be able to make use of OASIS3-MCT and, where appropriate, couple their models with existing complex models used by the major weather and climate centres. The IA use case in particular, provides an example of innovation since IA is widely used as a tool for guiding policy development.

Cylc development and support

Cylc is a workflow engine specifically designed for activities that cycle through iterations (possibly indefinitely). Cylc manages the dependencies between suites of tasks and is configured by human-readable text control files. It is suitable for real-time, production environments. An example of pathways to impact in our community is that Cylc can manage the workflows of the complex production environments required to underpin real-time operational activities, such as seasonal and decadal forecasting systems and production activities such as CMIP which can then be exploited for the benefit of society. It should be noted that Cylc is in no way limited to climate and weather uses; it can be used for any workflow.

The Cylc team maintains a list of institutions using Cylc including representation in Africa (1), Asia (4), Europe (10), North America (5) and Oceania (3)[7], with Cylc being used in both Numerical Weather Prediction and Operational Oceanography. The commercial consultancy Altair is also providing support for Cylc[8].

Cylc was used by the U.S. Navy in a recent effort for doing real-time ensemble tropical cyclone forecasts using the Microsoft Azure cloud computing environment (Whitcomb et al, 2022).

More details about these tools are given in D8.4 "Cylc / Rose development summary: Report on the main developments to Cylc & Rose"[9].

Unified European platform for sea ice modelling

Development of the new "Sea Ice modelling Integrated Initiative" (SI3) code, and integration within the NEMO repository, has been supported by the IS-ENES3 project [D8.1[10]]. The SI3 model code is available for users directly through the NEMO code repository at https://forge.nemo-ocean.eu/nemo (see D8.1 for details).

[7] https://cylc.github.io/community#sites-using-cylc (visited 2022-11-27).
[8] https://web.altair.com/en/cylc-weather-solution
[9] https://raw.githubusercontent.com/IS-ENES3/IS-ENES-Website/main/pdf_documents/IS-ENES3_D8.4.pdf
[10] https://is.enes.org/documents/deliverables/d8-1-nemo-sea-ice-model-code/view

The workshop "Sea ice model developers and expert users meet to discuss the future of sea ice modelling" [M4.1], held 23–26 September 2019 in Laugarvatn, Iceland, brought together developers of sea ice models, users of sea ice models in an ESM context, and users of sea ice models for operational forecasting and (re)analyses. Blockley et al. (2020) report on the workshop and note the "increasingly wide range of applications" of sea-ice models, "including operational weather and marine forecasts". Further details in D4.2 "Development strategy for sea ice modelling in NEMO"[11]. For further discussion of the use of NEMO in operational oceanography see O'Dea et al. (2012); Blockley et al. (2014); Graham et al. (2018); Hordoir et al. (2019).

IS-ENES3 has supported the development and release of NEMO's new sea ice model component SI3. Within IS-ENES3, several operational modelling and research centres have begun transitioning their systems to use the SI3 model - including Met Office, CNRS-IPSL, and CMCC - meaning that SI3 will be used for operational forecasts and climate projections in the near future. For example, SI3 has been incorporated into HadGEM3 within the GC5[12] version of the Met Office coupled model. This SI3-based model will be used for operational forecasting at the Met Office across all timescales and will be used for the UK's contributions to CMIP7 (including as the physical basis of the UKESM2 Earth System Model). The SI3 code could be described as being at TRL 9 as far as the code itself is concerned, as it is fully tested and characterised and has been used in many thousands of years of CMIP climate simulations. However, the pathway to impact in operational weather prediction involves entraining SI3 in the development of new model configurations which are at different stages of development in different institutions (around TRL6 at UK Met Office).

Within IS-ENES3, technical and scientific support has also been provided to several operational and research centres from outside the project to facilitate their uptake of SI3. This includes ECMWF, who are currently developing a future version of its atmospheric model IFS using SI3 (in place of the old LIM2 model) and the EC-Earth consortium, who will use SI3 within their CMIP7 climate model. Mercator Ocean International is also upgrading the global ocean forecasting system to use SI3 of the Copernicus Marine Service[13] (formerly CMEMS). Demonstrators are being developed as part of the EU-IMMERSE project[14]. Finally, there will also be wider uptake of SI3 facilitated by the Met Office Unified Model Partnership, for which several international partners join with the Met Office to use and develop its global coupled (GC) model system including Australia (Bureau of Meteorology; CSIRO), India National Centre for Medium-range

[11] https://is.enes.org/documents/deliverables/d4-2-development-strategy-for-sea-ice-modelling-in-nemo/view
[12] The GC5 version is aimed at CMIP7 simulations (which will support the 7th IPCC Assessment): https://projects.noc.ac.uk/class-project/blog/global-ocean-model-development-under-class
[13] https://marine.copernicus.eu/
[14] https://cordis.europa.eu/project/id/821926

Weather Forecasting, South Korea Meteorological Administration, and the New Zealand Earth System Model.

4. Conclusions and Recommendations

IS-ENES3 is contributing to innovation in models and tools in many ways.

- Feeding into well-established innovation workflows in operational weather centres where efficient coordination between operations and research ensures that research outcomes can feed smoothly into enhancements of operational services.
- Feeding through to non-academic users through established user networks.

There is also training which informs potential users outside the research community of the potential benefits of tools developed and promoted by IS-ENES3 which is described in D2.3.

The close relationship between operational NWP and climate model development in many national weather centres can make it difficult to isolate and quantify the precise actions that lead to innovation. Paradoxically, the relatively frictionless transfer of research products into operational use makes the phase of innovation, which is considered as part of the transition from research to operational use, difficult to recognise.

Anecdotal evidence suggests that individuals that devote time to the task of bringing products from the end of research up to operational maturity can struggle to find recognition for this work. Giving greater recognition to this work may make the effort that goes into the innovation process more visible.

It is not possible to clearly define a TRL in many cases because the standard definitions of the levels do not reflect the stages of integrating software tools into operational NWP services. It would be useful to develop a set of definitions taking into account this innovation pathway.

References

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