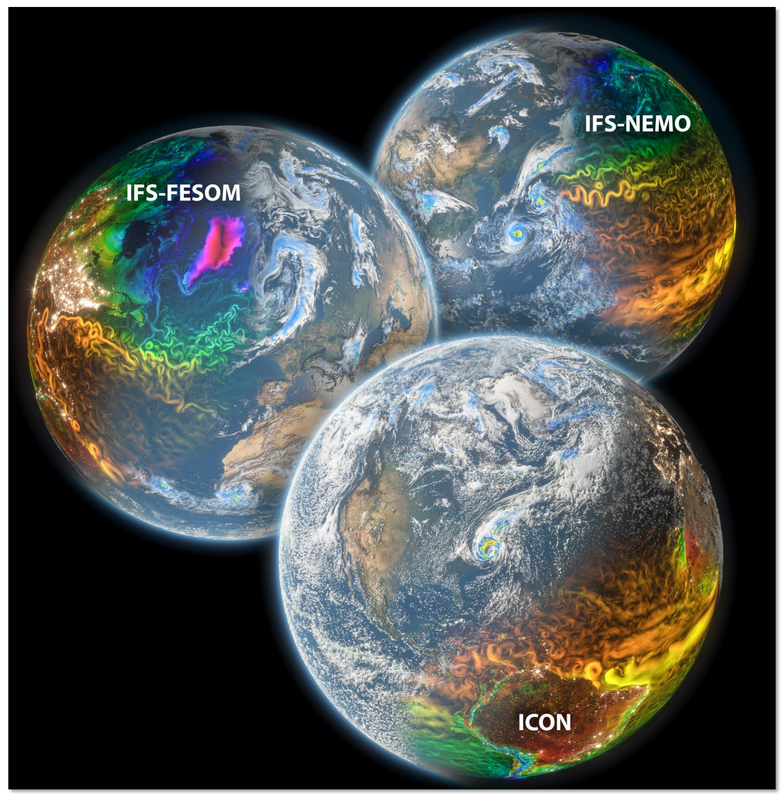
Destination Earth's Climate Change Adaptation Digital Twin on EuroHPC supercomputers

ECMWF authors: Ioan Hadade, Thomas Rackow, Balthasar Reuter, Sebastian Milinski, Nils Wedi, Irina Sandu
In Collaboration with the Climate DT consortium

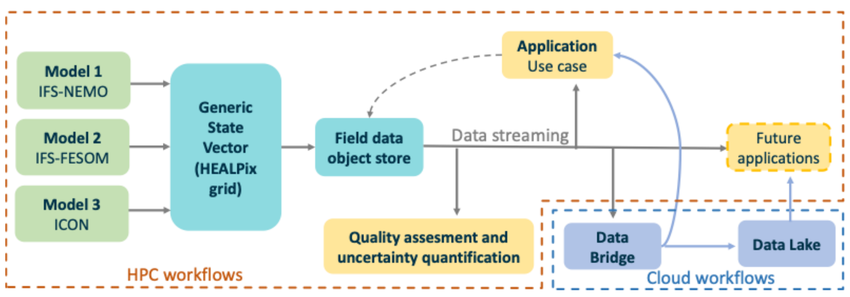
Finalist for ACM Gordon Bell Prize for Climate Modelling

The Destination Earth Climate Change Adaptation Digital Twin

- Developed since November 2022 by a **partnership led by the CSC-IT Center for Science**, including leading European climate, weather, and supercomputing centres and academia, in close collaboration with ECMWF
- The Climate DT integrates **three coupled Earth system models** (IFS-NEMO, IFS-FESOM, ICON), several **impact-sector applications** and observations in unified **end-to-end workflows**
- **Workflows** enable routine (yearly) and on-demand production of **multi-decadal simulations at km-scales,** allowing relevant "what-if" scenarios to be explored in support of adaptation strategies



Snapshots of future climate states in the Climate digital twin simulations, with different views of key atmospheric and oceanic features.



Key innovations

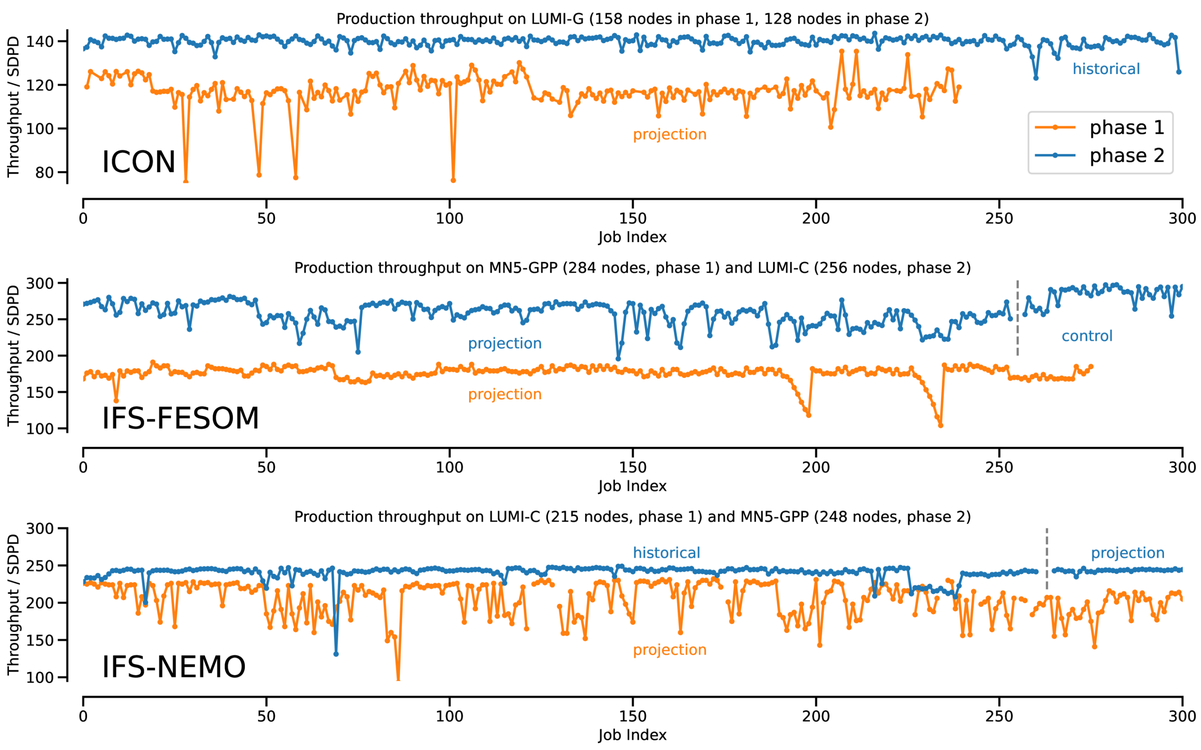
- Full traceability of simulations and **unified data handling** with common variables, grids, and formats, harmonised access patterns and data governance;
- **Real-time monitoring**, quality control, and evaluation of simulations;
- Flexibility to enable **bespoke "what-if" simulations** for exploring policy-relevant scenarios and extreme events;
- **On-the-fly computation of climate-relevant indicators** (e.g., for energy, water, health) during model execution.

Completed production simulations

Type of simulation	Model	Resolution (km) atmosphere	ocean	Period	System	Number of nodes	Output (TB)	Progress
Phase 1								
Future projection	ICON	5	5	2020-2039	LUMI-G	158	840	100%
Future projection	IFS-NEMO	4.4	8.3	2020-2039	LUMI-C	215	840	100%
Future projection	IFS-FESOM	4.4	5	2020-2039	MN5-GPP	284	840	100%
Historical simulation	ICON	10	5	1990-2019	LUMI-G	106	315	100%
Historical simulation	IFS-NEMO	9	8.3	1990-2001	LUMI-C	256	126	100%
Storyline simulation (past)	IFS-FESOM	9	5	2017-2024	LUMI-C	201	84	100%
Storyline simulation (present)	IFS-FESOM	9	5	2017-2024	LUMI-C	201	84	100%
Storyline simulation (future)	IFS-FESOM	9	5	2017-2024	LUMI-C	201	84	100%
Control simulation	IFS-NEMO	9	8.3	15 years	LUMI-C	256	262	100%
Control simulation	IFS-FESOM	9	5	17 years	MN5-GPP	284	157	100%
Phase 2								
Historical simulation	IFS-NEMO	4.4	8.3	1990-2014	MN5-GPP	260	1051	100%
Historical simulation	IFS-FESOM	4.4	5	1990-2014	LUMI-C	279	1051	100%
Historical simulation	ICON	5	5	1990-2014	LUMI-G	106	315	100%
Control simulation	ICON	5	5	10 years	LUMI-G	128	438	100%
Control simulation	IFS-FESOM	4.4	5	10 years	LUMI-C	279	438	100%
Control simulation	IFS-NEMO	4.4	8.3	15 years	MN5-GPP	248	262	100%
Future projection	IFS-NEMO	4.4	8.3	2015-2049	MN5-GPP	260	1260	57%
Future projection	IFS-FESOM	4.4	5	2015-2049	LUMI-C	279	1260	60%
Future projection	ICON	5	5	2015-2049	LUMI-G	128	1008	7%

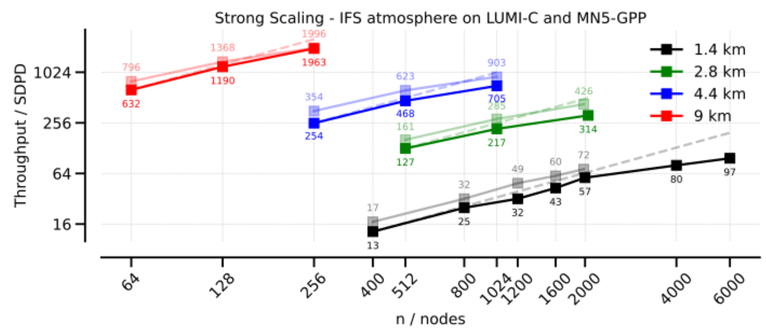
Throughput of DestinE models

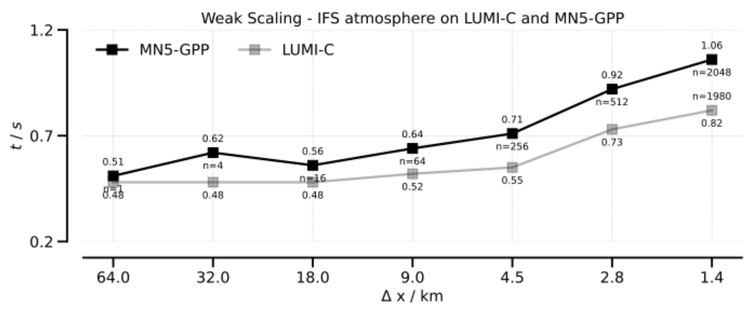
- Multi-decadal climate projections on **EuroHPC supercomputers LUMI and MareNostrum5** are produced in chunks with checkpointing and restarting
- Sustained throughput performance of **120-230 simulated days per day** (SDPD) at 5km resolution [1]

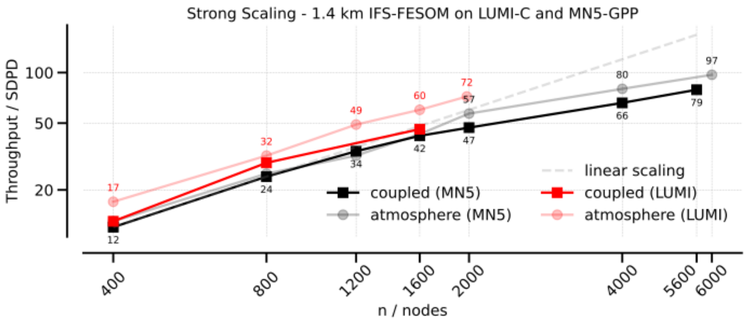


Scaling simulations up to 1km

- For a submission to the **ACM Gordon Bell Prize for Climate Modelling**, IFS-FESOM and ICON have been **scaled up to 1km resolution** across Earth-system components
- **IFS (atmosphere-only) and IFS-FESOM** have been scaled up **to full machine execution** on the EuroHPC supercomputers LUMI-C and MareNostrum 5
- Observed **good strong scalability across all tested resolutions and both systems**

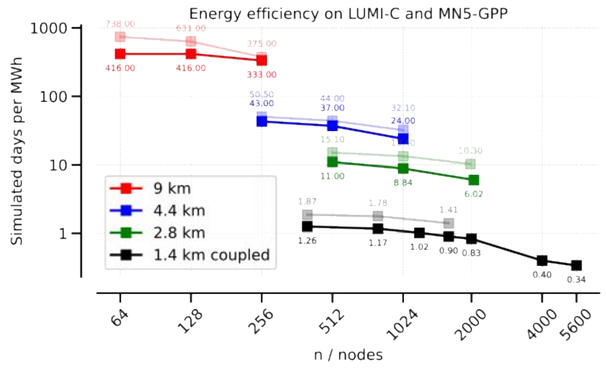






Energy efficiency

- **Energy cost is an important consideration** for large production runs and long integrations such as climate projections
- Due to less-than-ideal scaling, **energy efficiency decreases when strong-scaling to larger node counts**, implying a need to compromise throughput and energy efficiency



Funded by the European Union
Destination Earth
implemented by ECMWF esa EUMETSAT