DESTINATION EARTH: THE CLIMATE CHANGE ADAPTATION DIGITAL TWIN

Ioan Hadade, Daniel Klocke, Jussi Enkovaara, Tuomas Lunttila, Thomas Rackow, Jan Frederik Engels, Claudia Frauen, Rene Redler, Jenni Kontkanen, Thomas Jung, Dmitry Sein, Irina Sandu, Balthasar Reuter, Nils Wedi, **Sebastian Milinski**, Francisco Doblas-Reyes, Miguel Castrillo, Mario Acosta, Sergi Girona, Pekka Manninen (and many more)

Funded by the European Union

Destination Earth implemented by ECMWF esa EUMETSAT

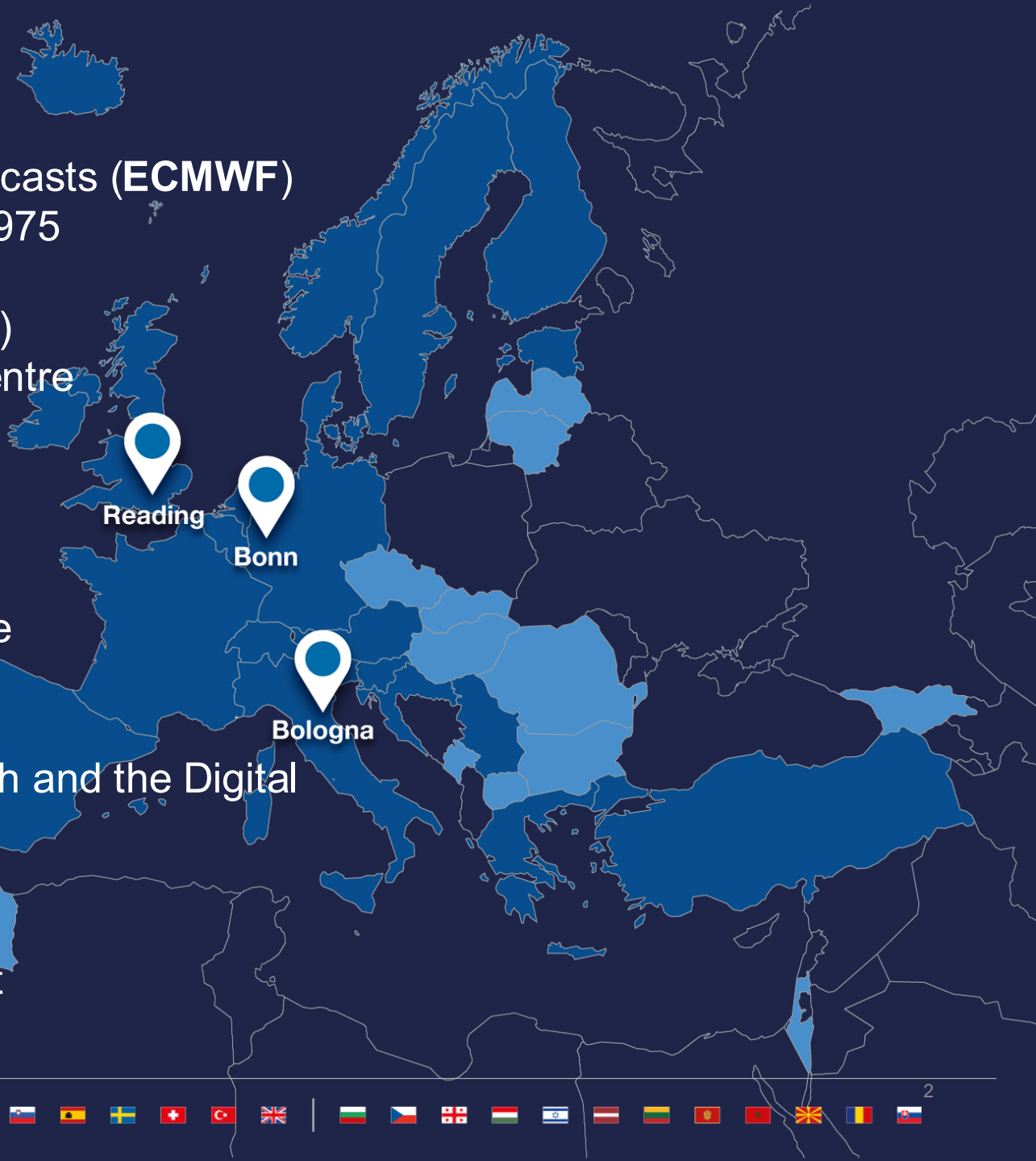
Who we are:

- European Centre for Medium Range Weather Forecasts (**ECMWF**)
- Independent intergovernmental organisation est. 1975
- 23 **member states** and 12 **co-operating states**
- Duty stations in Reading (HQ), Bonn, Bologna (DC)
- Research institute and 24/7 operational weather centre

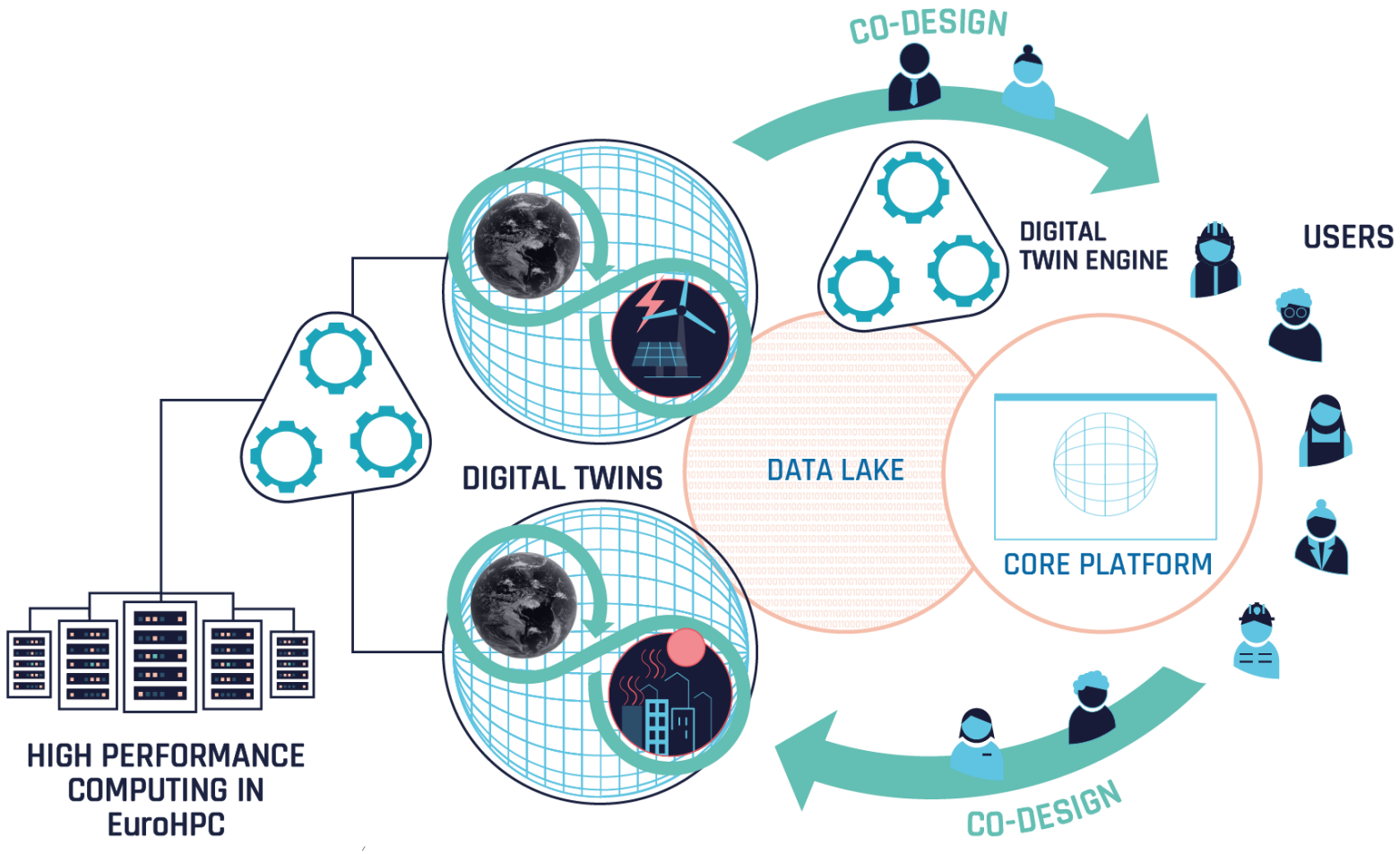
What we do:

- Produce and disseminate global NWP products
- Operate world's largest meteorological data archive
- Deliver Copernicus services (CAMS and C3S)
- Provide computing resources to Member States
- Develop Destination Earth Digital Twins of the Earth and the Digital Twin Engine

ECMWF's role is to address the critical and most difficult research problems in medium-range NWP that no one country could tackle on its own.



A NOVEL INFORMATION SYSTEM



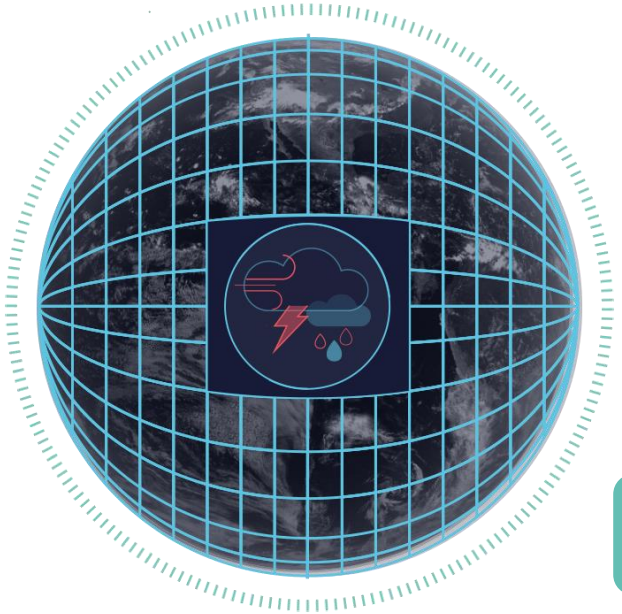
TWO HIGH PRIORITY DIGITAL TWINS

To support decision making for real-time response to extreme events

To support the efforts of defining and planning activities linked to climate change adaptation

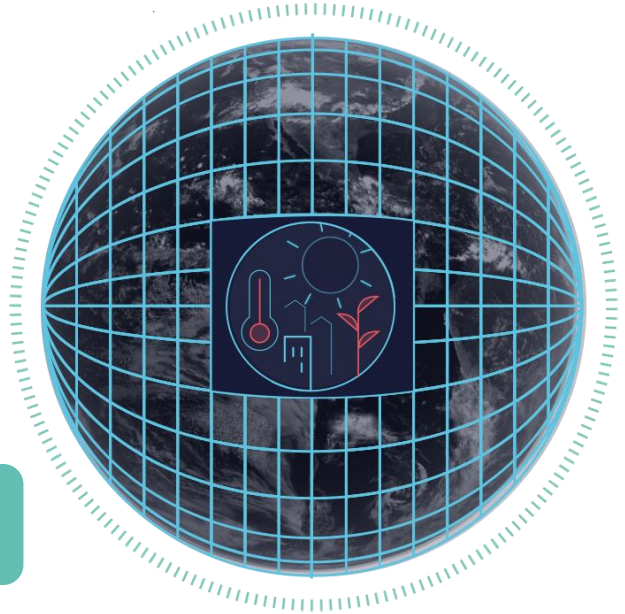
Timescale of 2-5 days ahead (1h to sub-hourly output)

Km-scale resolution 1-4 km globally, 500-750m regionally



Run regularly & on demand & configurable

Decision-driven data analytics

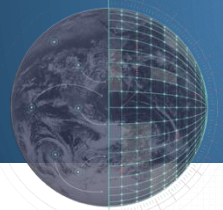


Multi-decadal timescales (2020 to ~2050) (1h to 6 hours output)

Km-scale resolution globally (5km)

Weather-induced extremes

Climate change adaptation

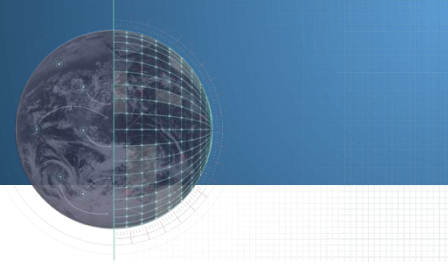


THE CLIMATE CHANGE ADAPTATION DIGITAL TWIN

New type of climate information system used **to assess impacts of climate change and different adaptation strategies** at local and regional levels over multiple decades.

Key features:

- **User-driven** approach focused on **user interactivity**.
- **Global multi-decadal climate simulations** at unprecedented horizontal **resolution**.
- Configurable and scalable **end-to-end workflows.**
- Deployment on **EuroHPC supercomputers across different hardware architectures**.
- Novel approach with **streaming of climate model output to impact models**
- **Quality assessment and uncertainty quantification** based on observations.



CSC

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

HELMHOLTZ

Hewlett Packard Enterprise

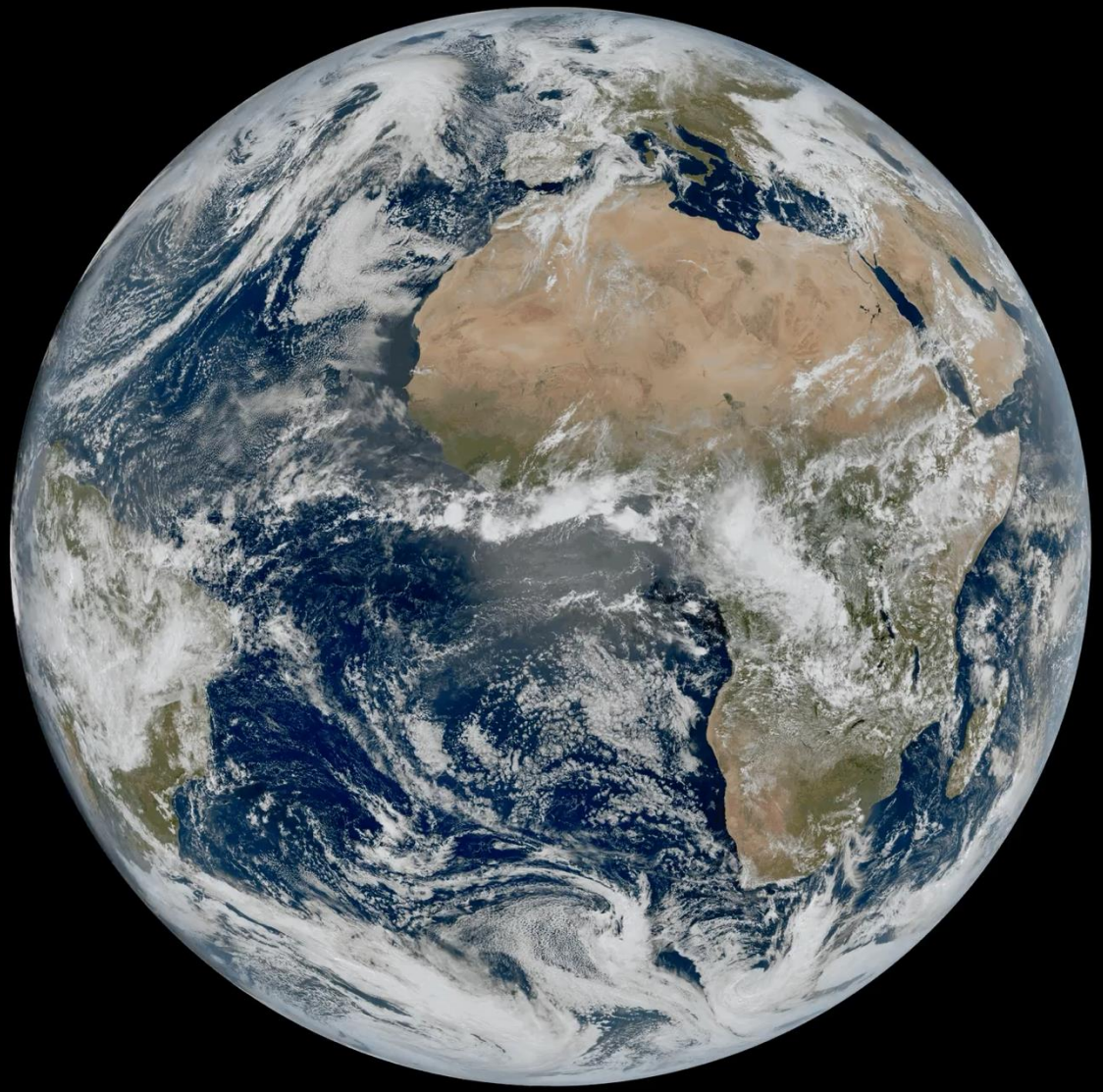
ILMATIETEEN LAITOS

ISAC

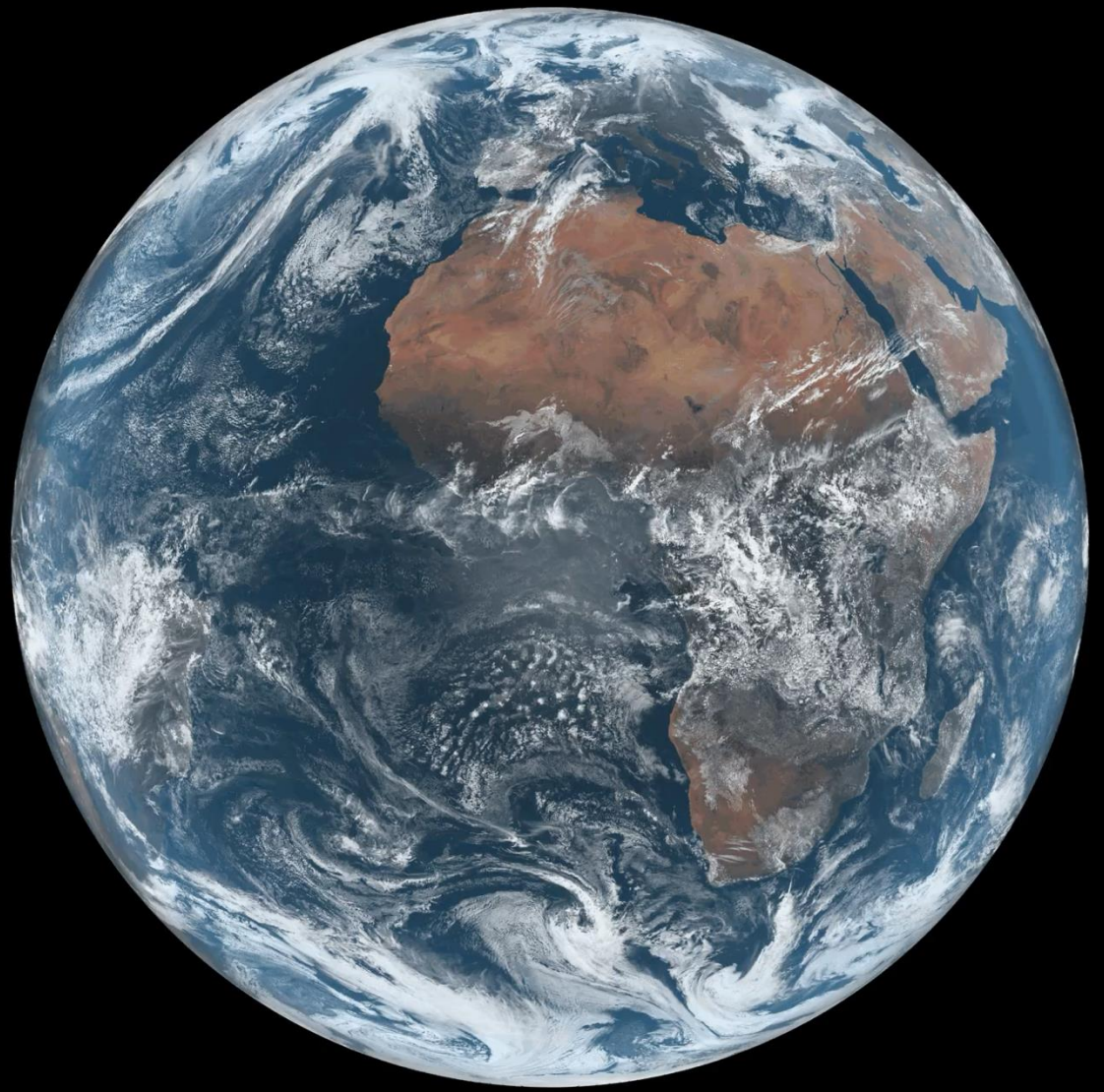
MAX-PLANCK-INSTITUT FÜR METEOROLOGIE

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

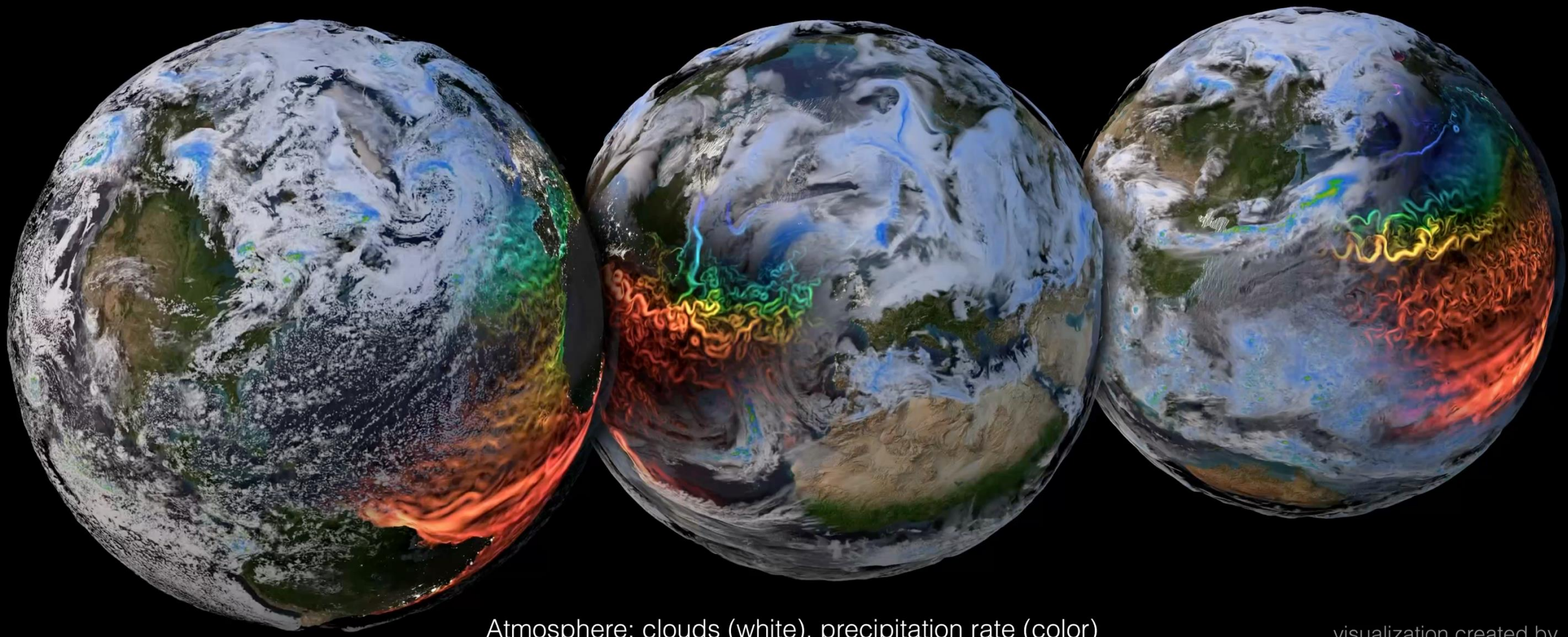
Politecnico di Torino
1859



MTGI observations



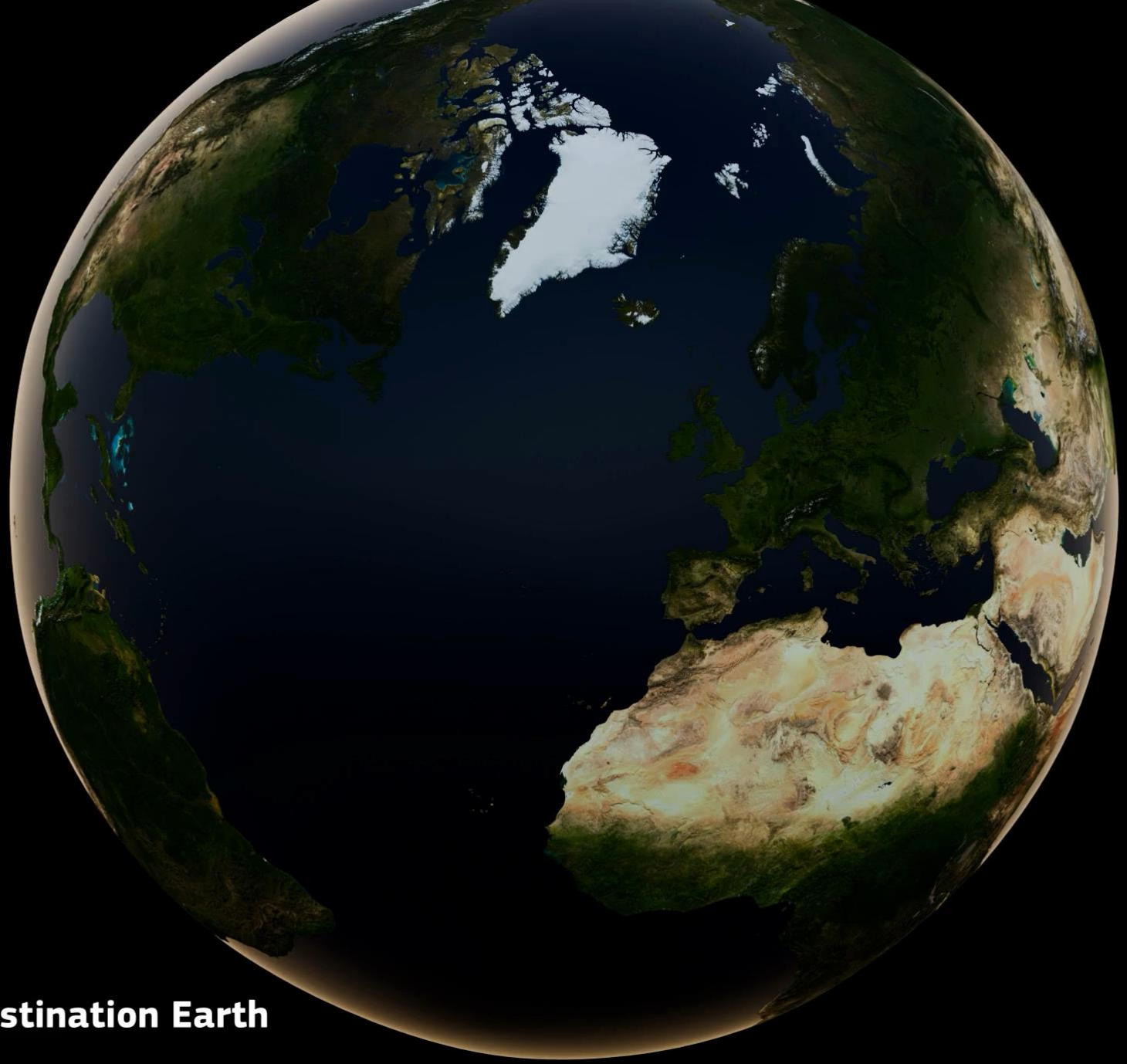
ECMWF IFS 2.8km simulation



Atmosphere: clouds (white), precipitation rate (color)
Ocean: temperature (color), current speed (brightness)

visualization created by
Andreas Müller (ECMWF)

ECMWF
Funded by the European Union
EuroHPC Joint Undertaking



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Funded by the European Union

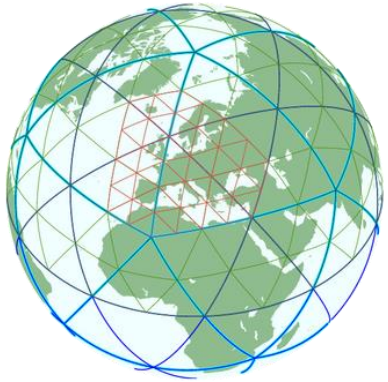
Destination Earth

EuroHPC Joint Undertaking

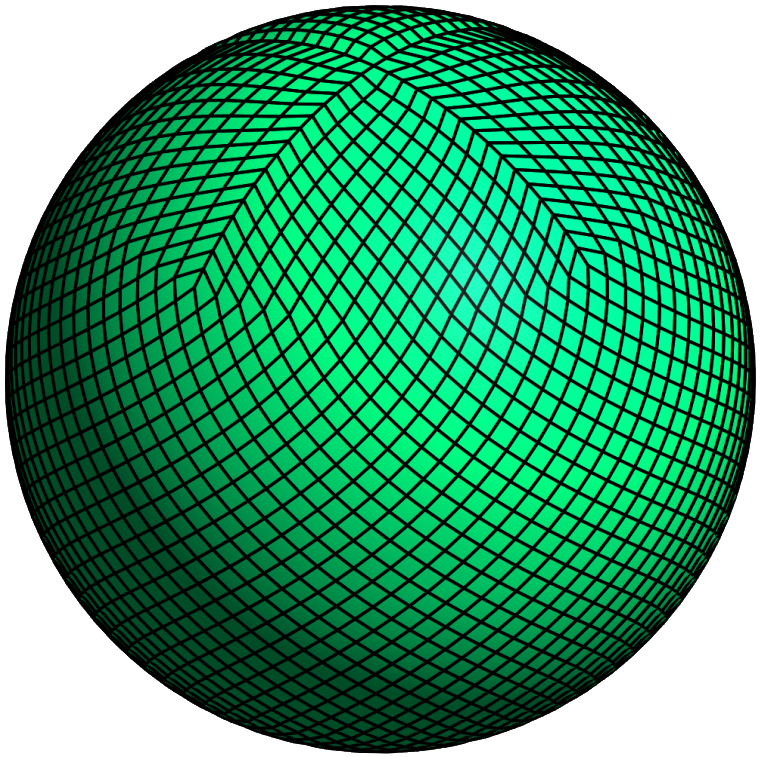
LUMI

ONE GRID (AND PARAMETER SET) TO RULE THEM ALL

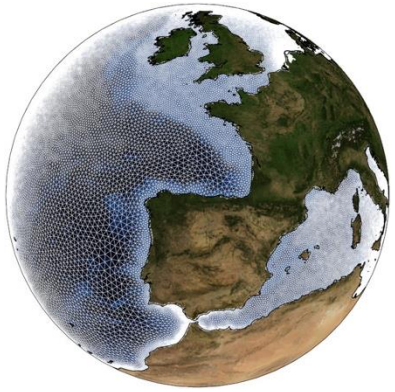
IFS Reduced Gaussian grid



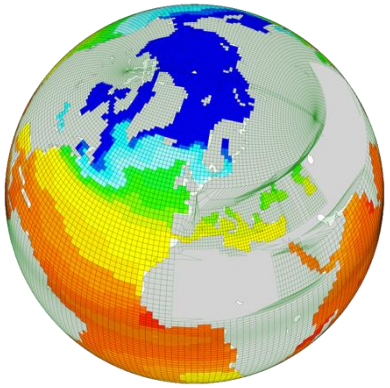
ICON icosahedral grid



HEALPix grid

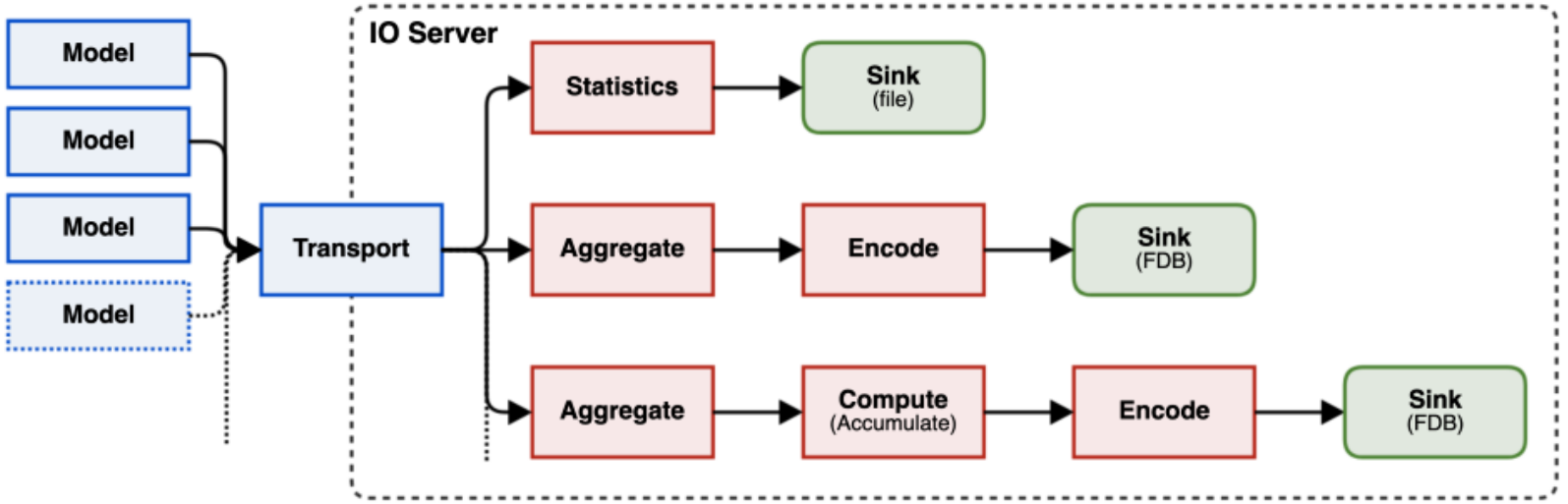


FESOM2 unstructured grid



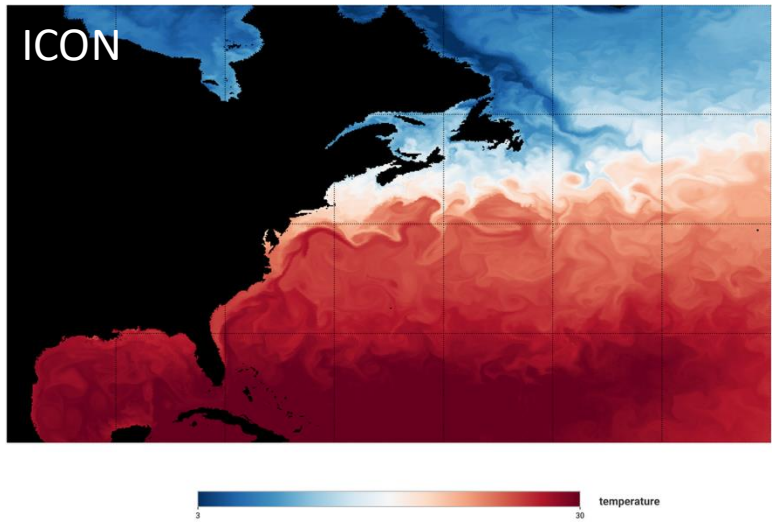
NEMO ORCA grid

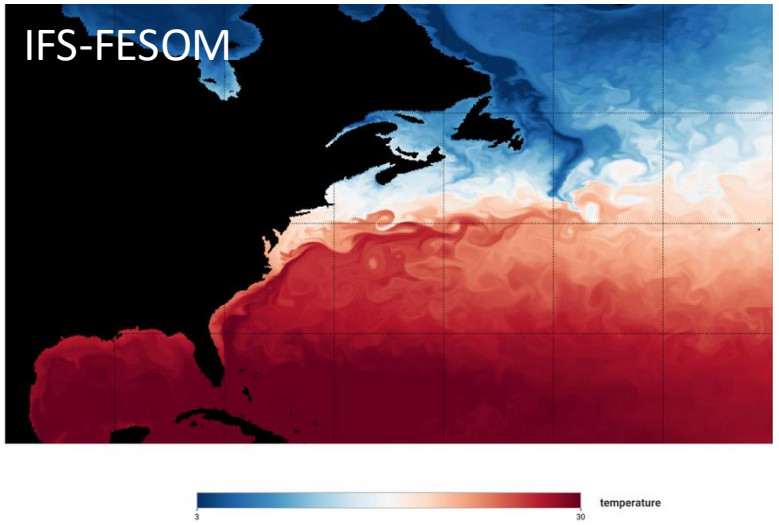
ON-THE-FLY I/O POST-PROCESSING AND STATISTICS

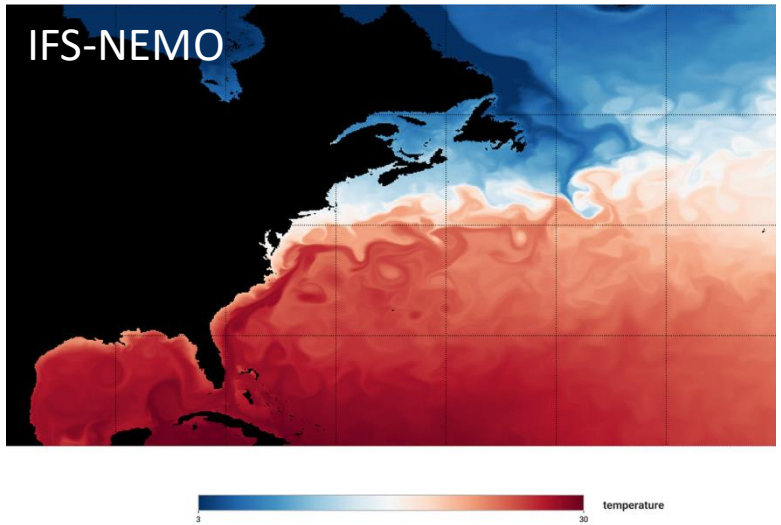


Sarmany et al. (2024), *MultIO: A Framework for Message-Driven Data Routing for Weather and Climate Simulations*, PASC '24. https://doi.org/10.1145/3659914.3659938

SNAPSHOTS OF DESTINE CLIMATE PROJECTIONS

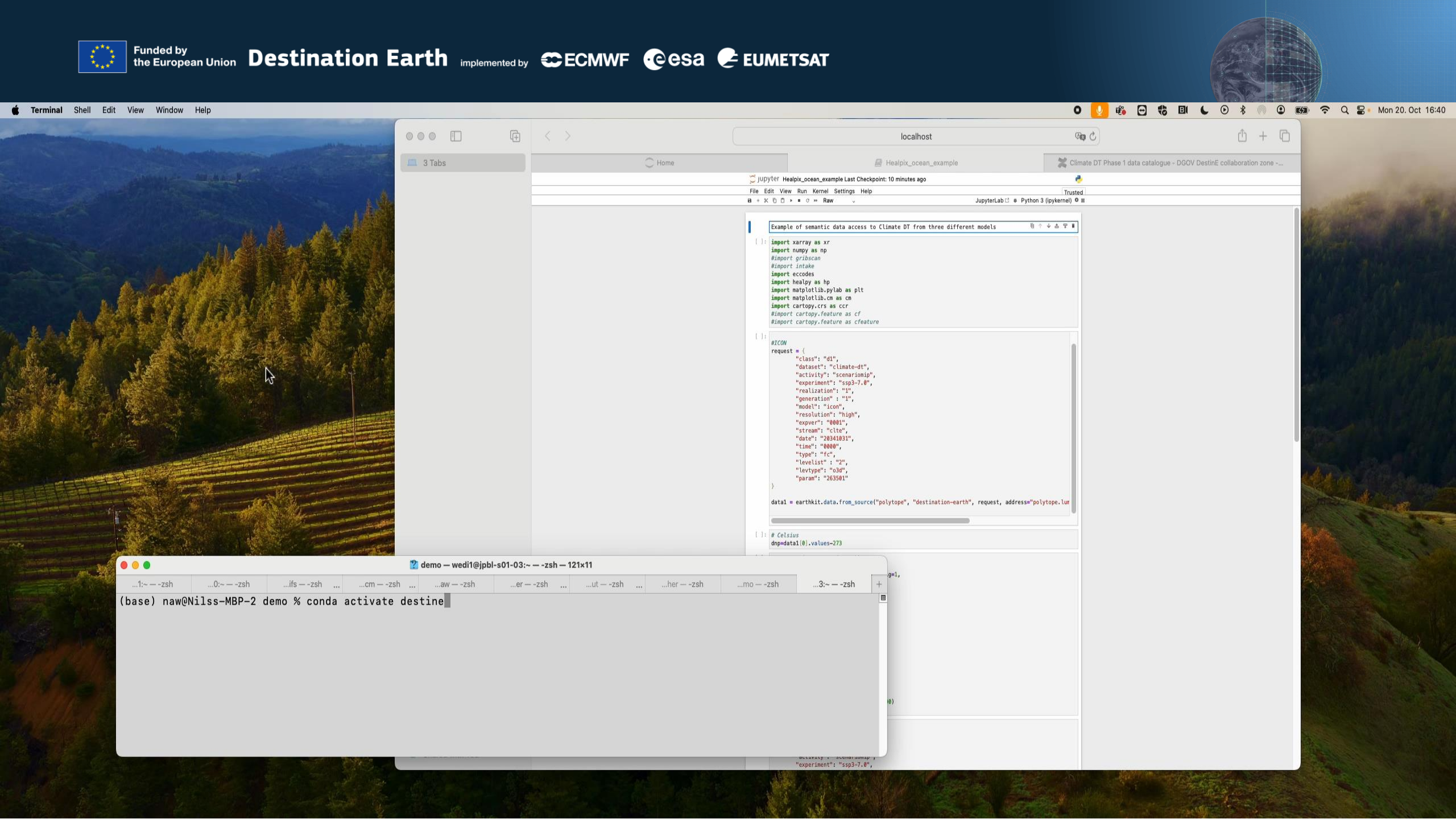


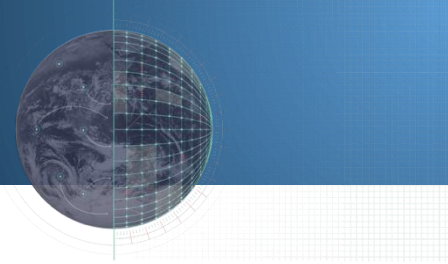




Gulf stream in Oct 2034 with ocean potential temperature between 2-4m depth from high-resolution ICON-ocean (left), IFS-FESOM2 (middle) and IFS-NEMO (right) data, with all three consistently stored on the common HEALPix H1024 grid.

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



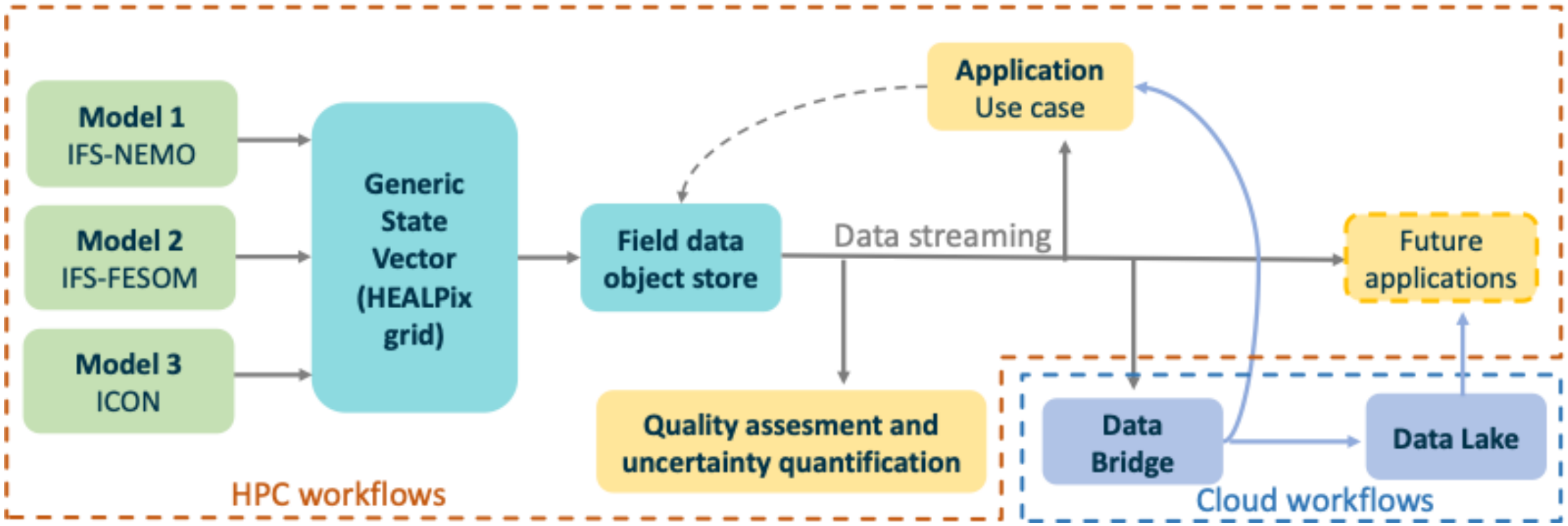


CLIMATE DT SIMULATIONS

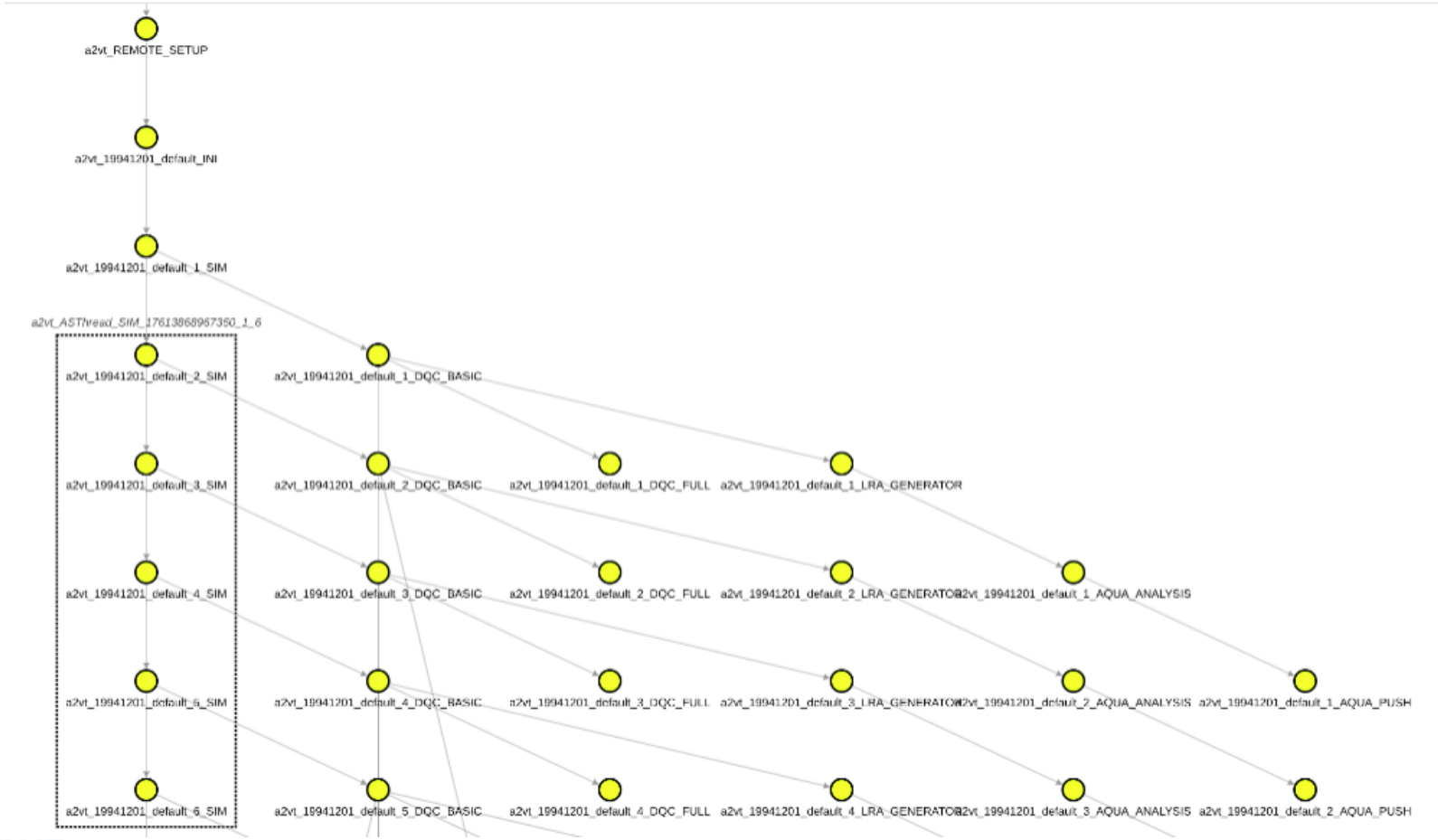
- **Control (10-15 years)**
  - 1990 forcing with no change in forcing over time to quantify model drift and simulated inter-annual variability
  - Provide relevant context for interpreting historical and scenario simulations
- **Historical (20-30 years)**
  - Starting in 1990, the forcing follows observed changes in greenhouse gases, aerosols etc. until 2020
  - Standardised CMIP6 forcing
  - Essential for model evaluation and quality control as it allows comparison to observations.
- **Future Projection (20-35 years)**
  - Project how climate will change on a global and local scale in the future
  - Forcing changes according to the Shared Socioeconomic Pathway (SSP) 3-7.0 scenario from ScenarioMIP
- **Storylines for past, present, future climate (8 years)**
  - What-if capability to explore how a weather event we experienced in the recent past would change in a warmer climate and how it would have looked in past pre-industrial conditions

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%

CLIMATE DT WORKFLOWS

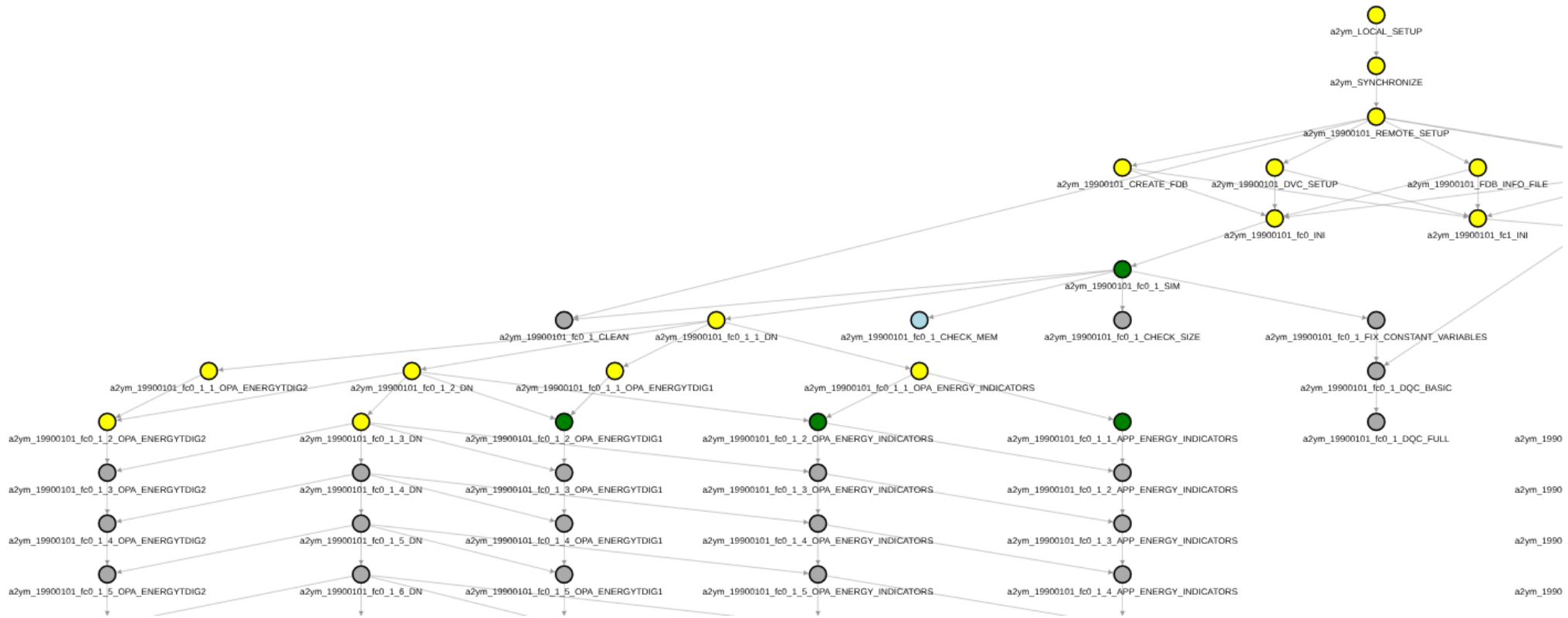


CLIMATE DT WORKFLOWS



Ayna Gayayavila, BSC

CLIMATE DT WORKFLOWS



Ayna Gayayavila, BSC

CLIMATE DT ON EUROHPC

Image courtesy of CSC

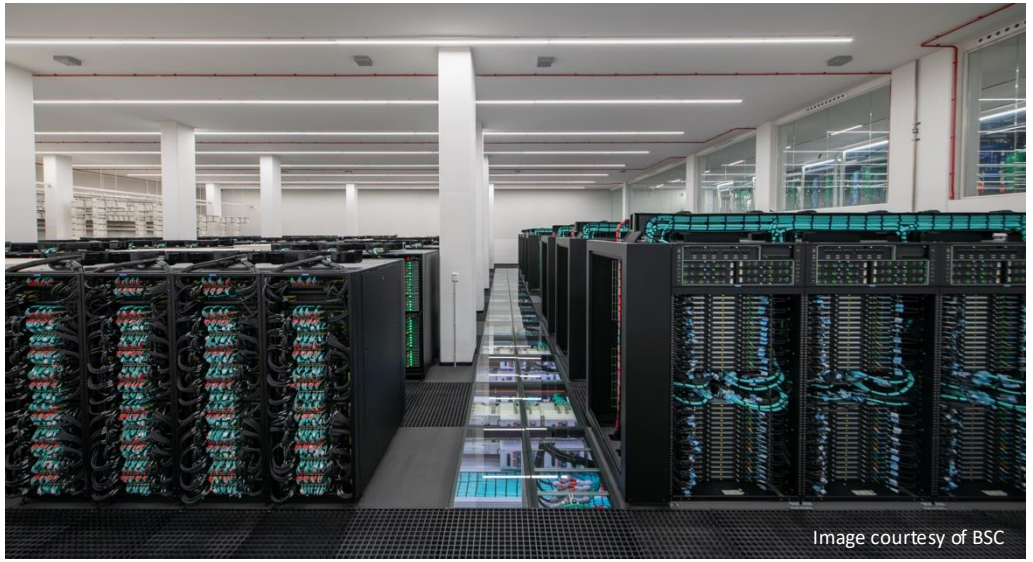


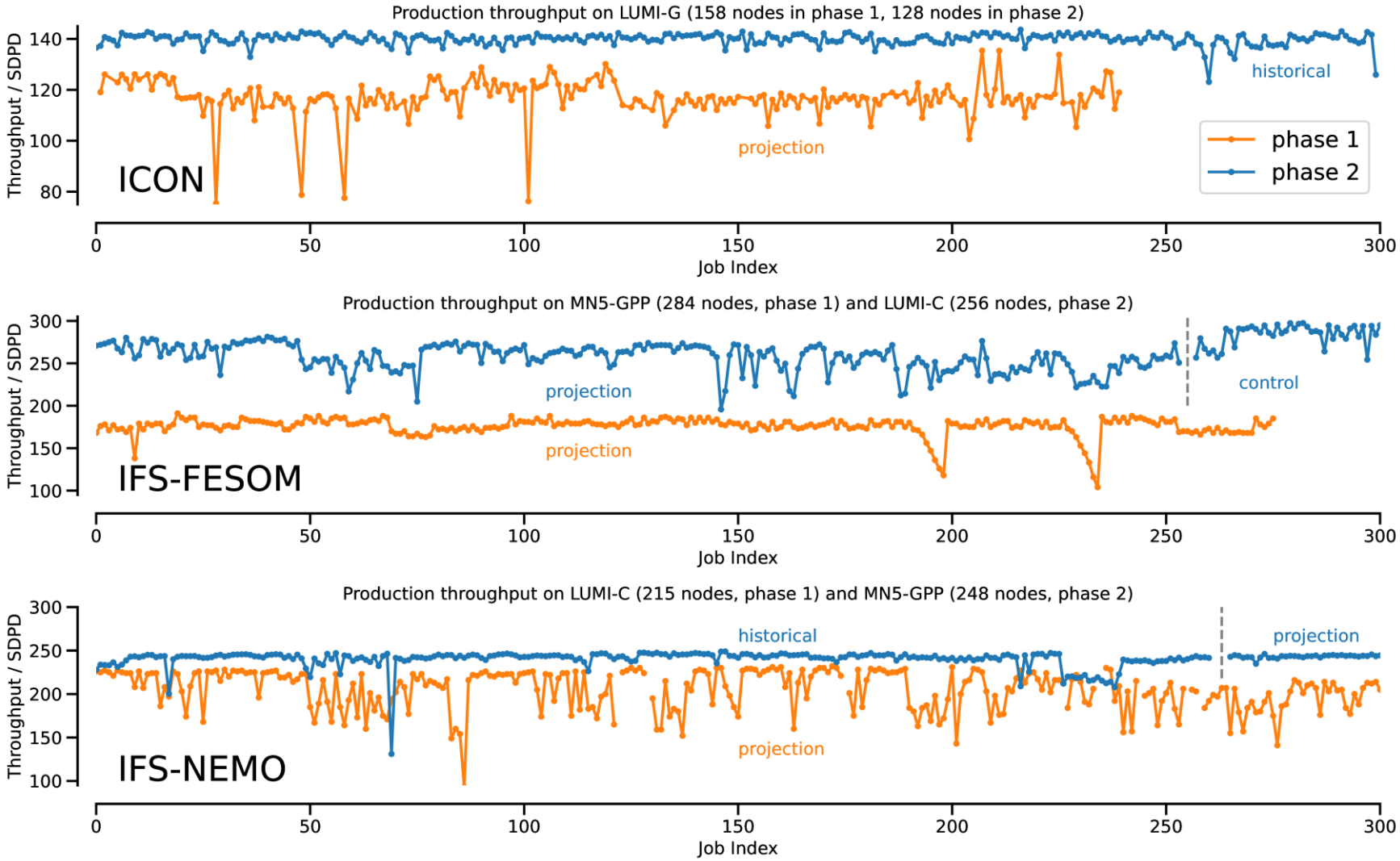
Image courtesy of BSC

LUMI (CSC) – HPE Cray EX

- Slingshot 11 high-speed interconnect
- GPU partition (LUMI-G)
  - 2978 nodes with 4 AMD MI250X GPUs
- CPU partition (LUMI-C)
  - 2048 nodes with 2 64-core AMD EPYC 7763 (Milan) CPUs

MareNostrum 5 (BSC) – Eviden Bullsequana XH3000 and Lenovo ThinkSystem

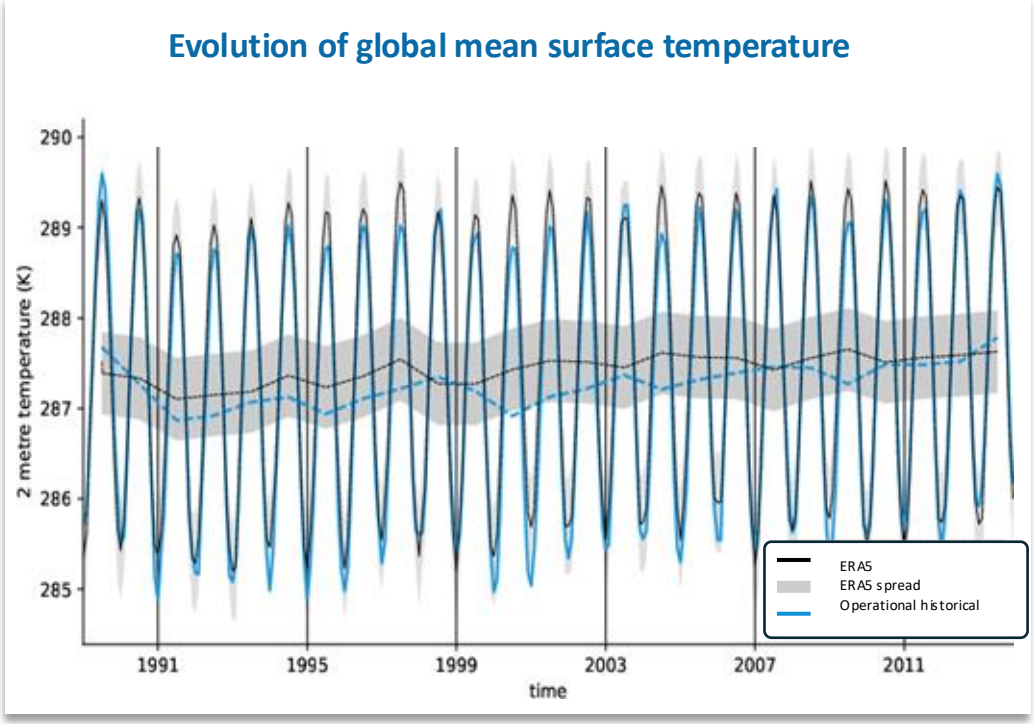
- NDR Infiniband
- GPU partition (MN5-ACC)
  - 1120 nodes with 4 NVIDIA H100 GPUs
- CPU partition (MN5-GPP)
  - 6480 nodes with 2 56-core Intel Sapphire Rapids 8480+ CPUs


Production throughput on LUMI-G (158 nodes in phase 1, 128 nodes in phase 2)
Throughput / SDPD
ICON
historical
projection
phase 1
phase 2
Job Index
Production throughput on MN5-GPP (284 nodes, phase 1) and LUMI-C (256 nodes, phase 2)
IFS-FESOM
projection
control
projection
Job Index
Production throughput on LUMI-C (215 nodes, phase 1) and MN5-GPP (248 nodes, phase 2)
IFS-NEMO
historical
projection
projection
Job Index

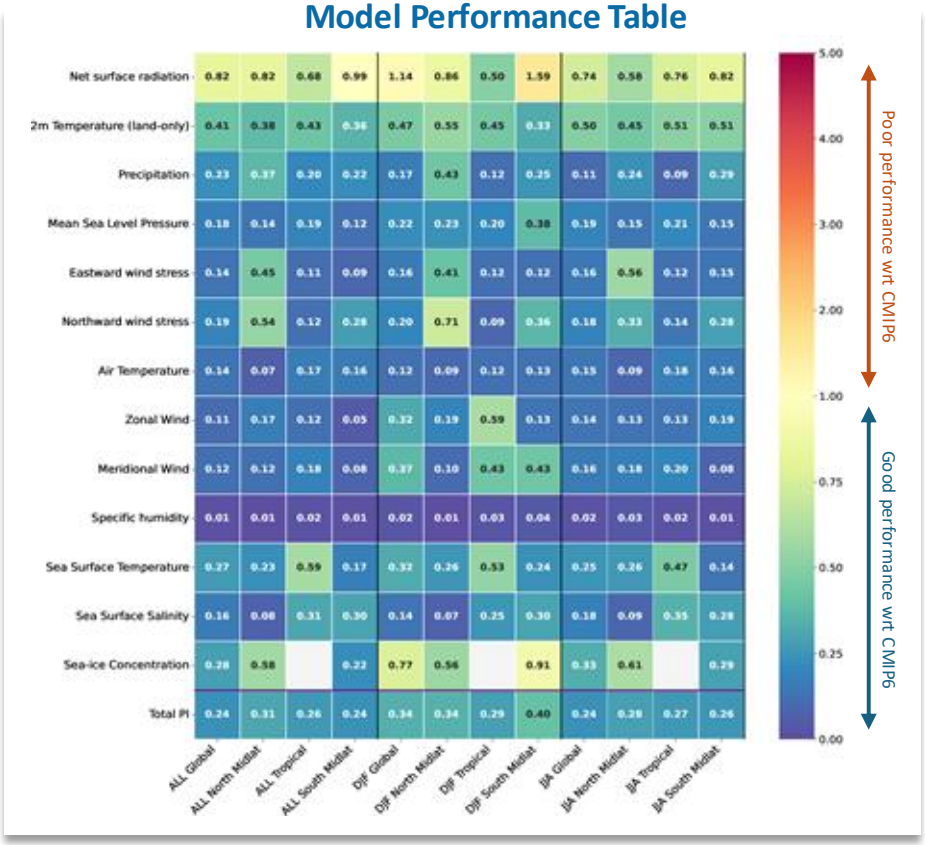
AQUA: REAL TIME MODEL EVALUATION

5km simulation IFS-NEMO

Evolution of global mean surface temperature

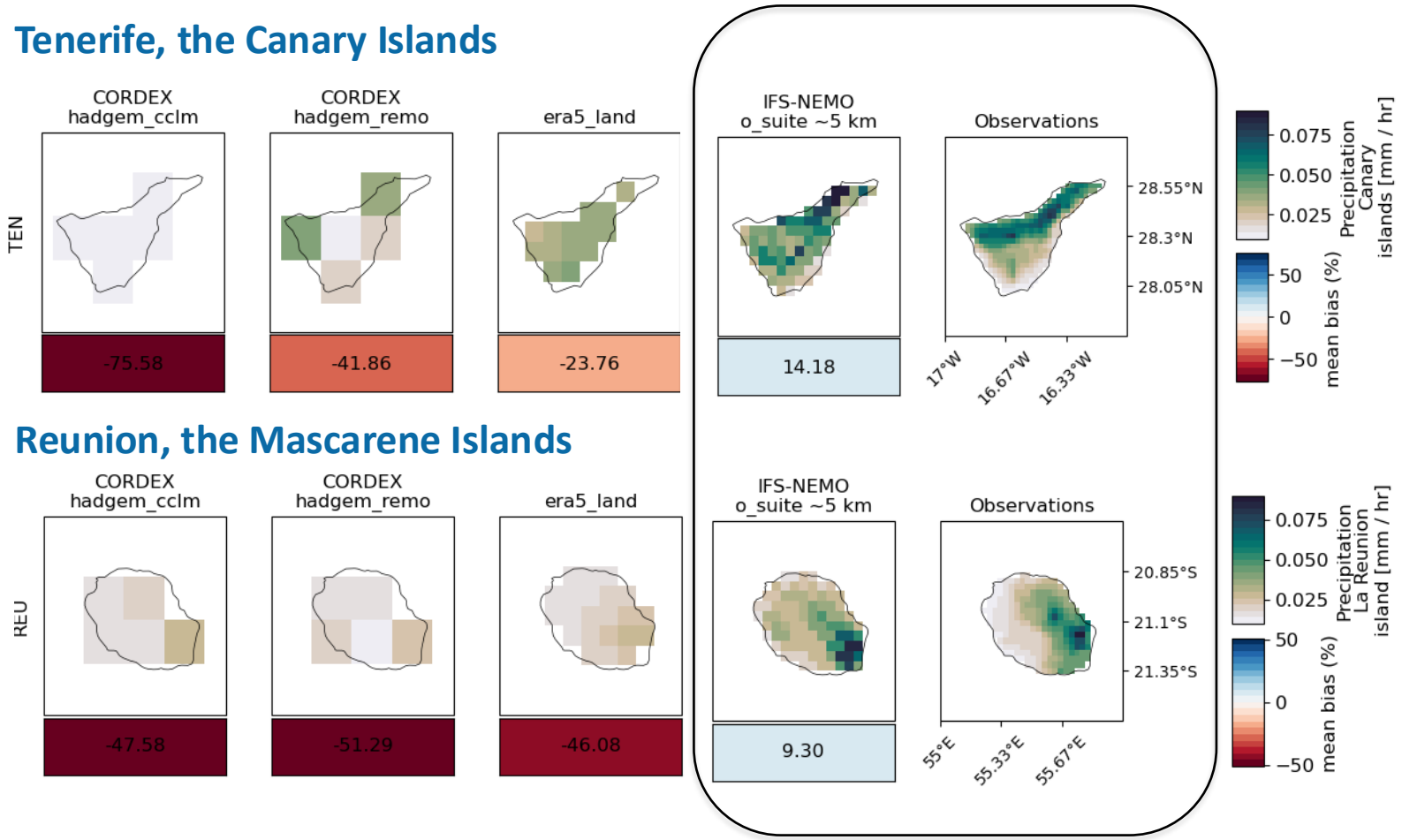


Model Performance Table



MODEL EVALUATION AGAINST OBSERVATIONS

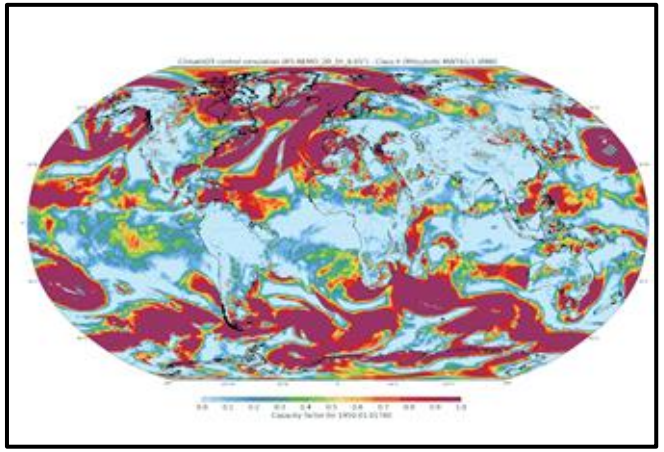
Tenerife, the Canary Islands

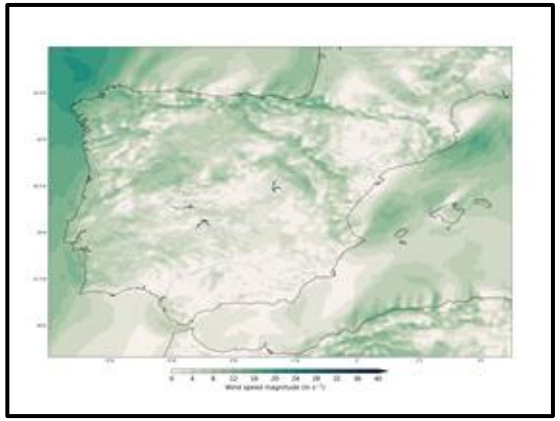


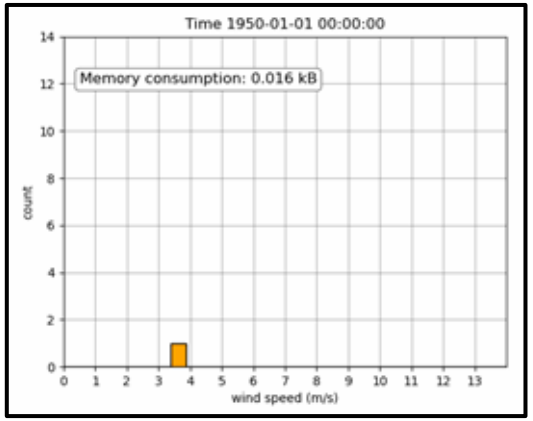
Reunion, the Mascarene Islands

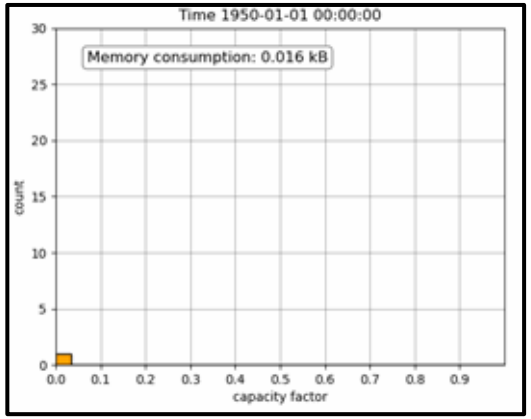
ONE-PASS ALGORITHMS (OPA)

Model outputs **raw climate variables** → Data notifier triggers application workflow. **Spatial selection** of specific variables → One-pass algorithms compute distribution **of weekly wind speed** → Use case applications compute climate indicators **Weekly CF = 0.3861**







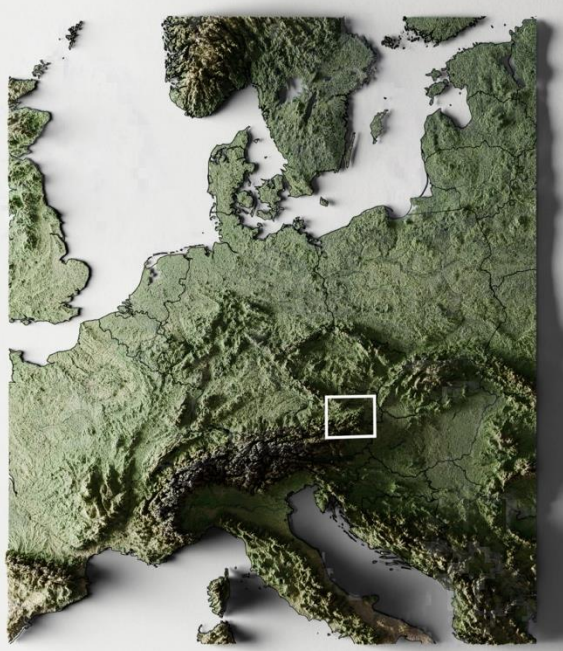


K. Grayson, BSC

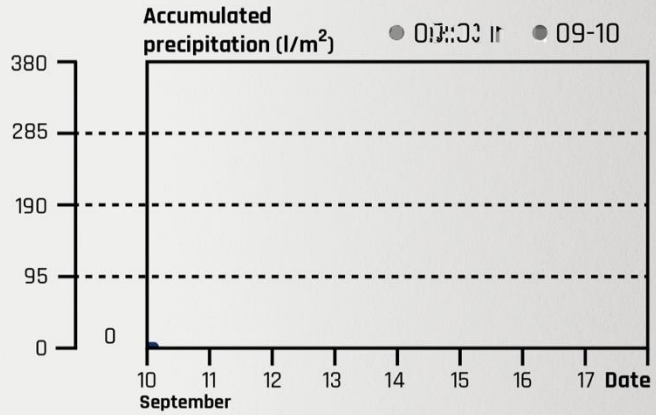
Resolution **9km Global**	Time **2024.09.10 - 2024.09.17**	Location **Area Vienna**	Data **Average Accumulated Precipitation**

Central European Floods, 2024

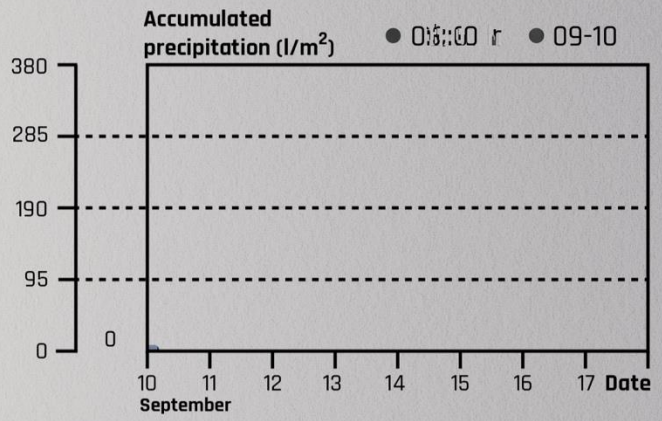
Simulating ...

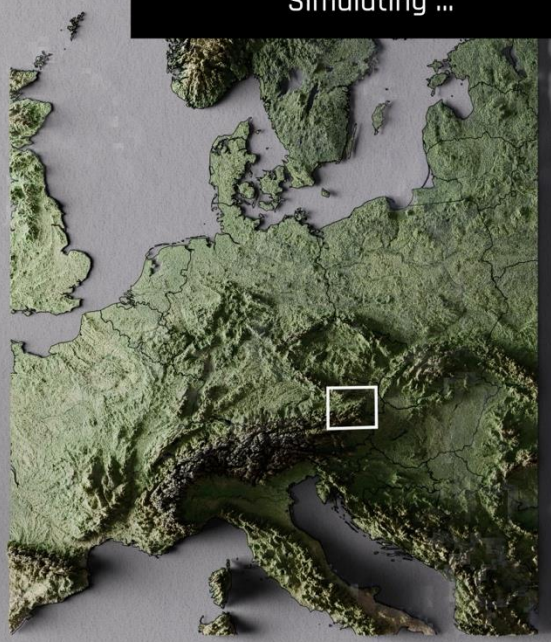


Climate	**Past** (1950)

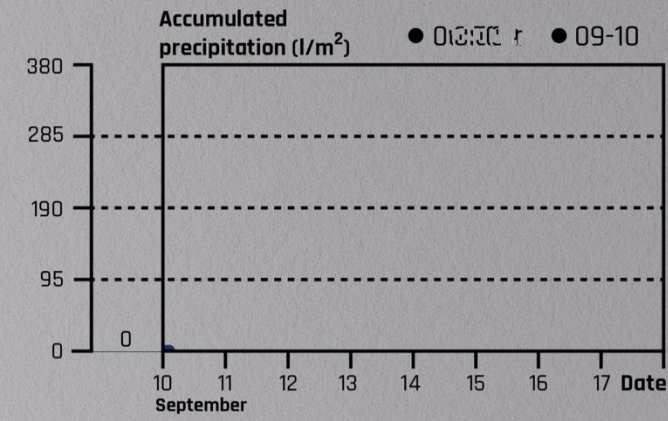


Climate	**Present** (+1.2°C)





Climate	**Future** (+2°C)



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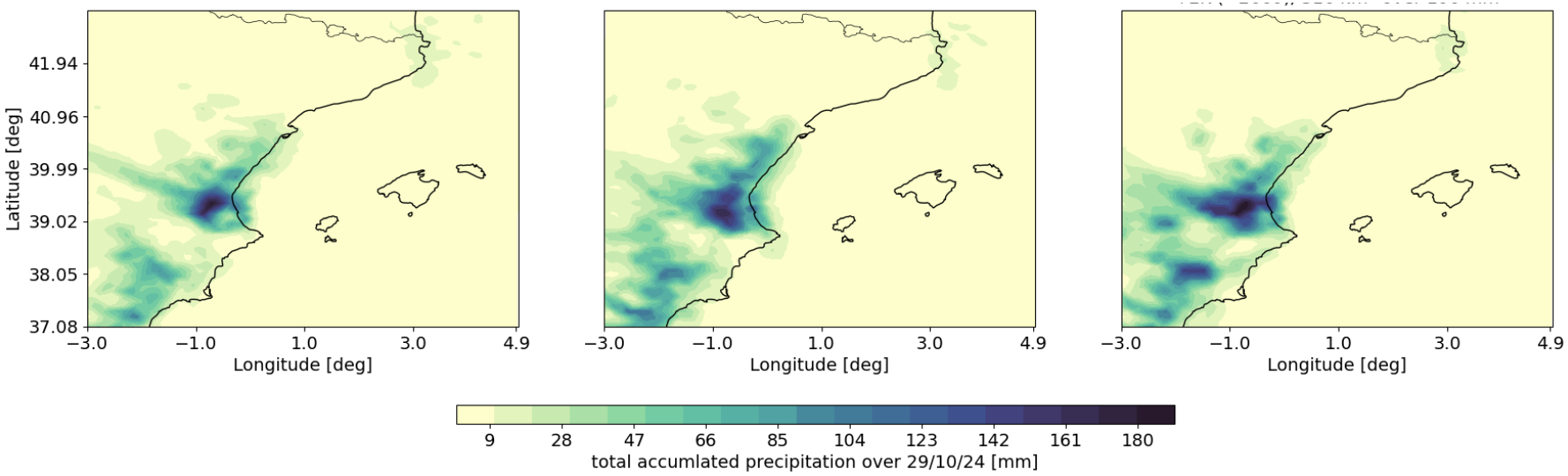
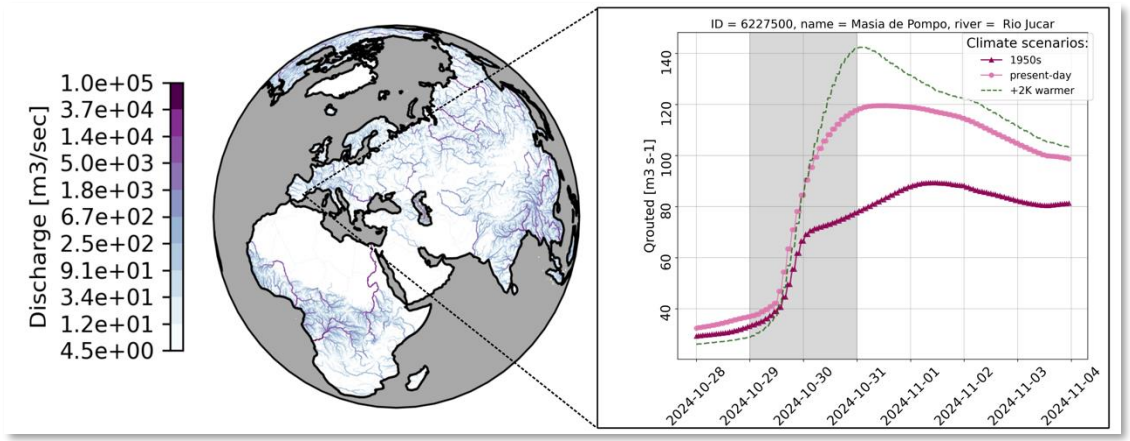
REPLAYING THE 2024 VALENCIA FLOODS

1950: 180 km² over 100 mm

2024: 340 km² over 100 mm

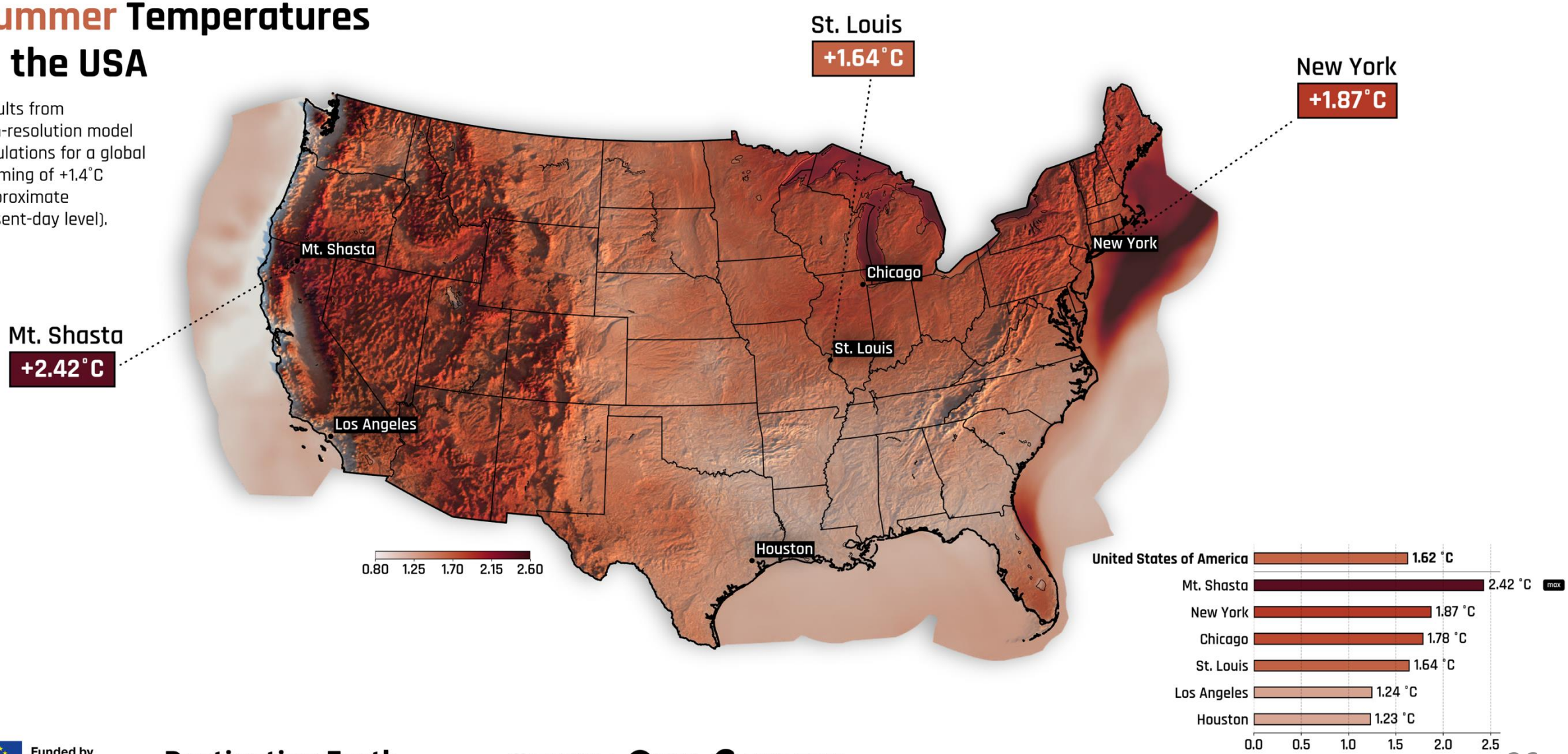
2050 (+2C): 510 km² over 100 mm



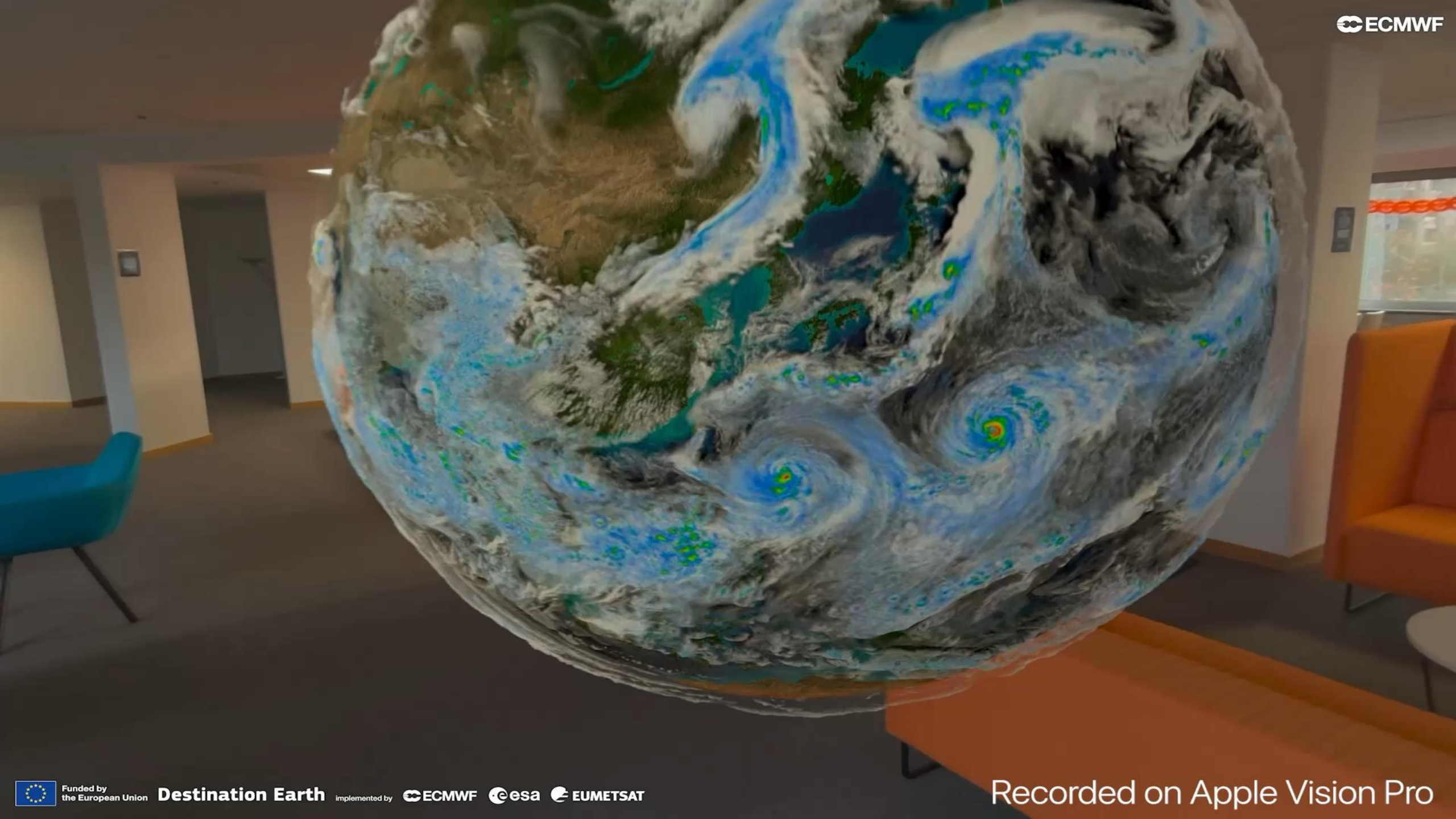


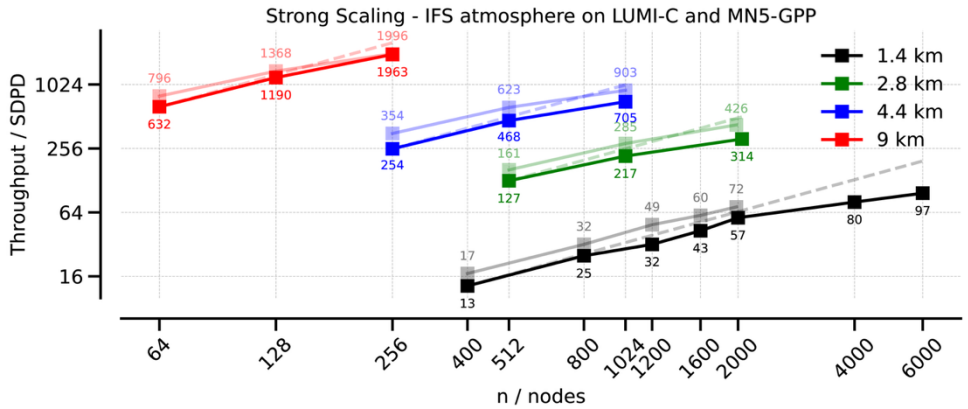
How Climate Change Affects Summer Temperatures in the USA

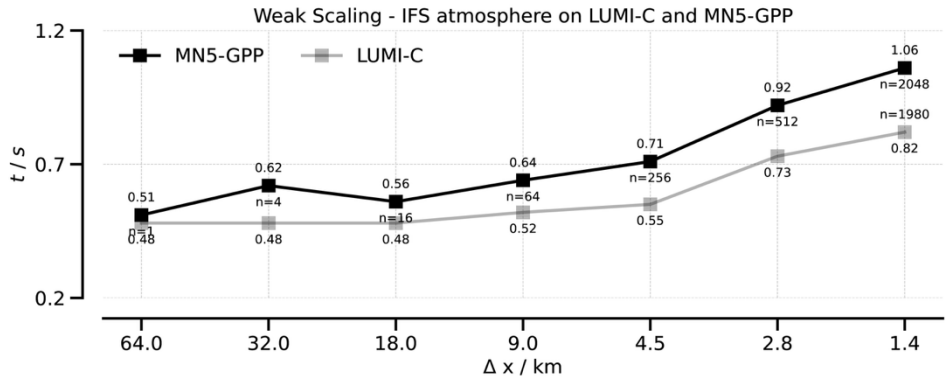
Results from high-resolution model simulations for a global warming of +1.4˚C (approximate present-day level).

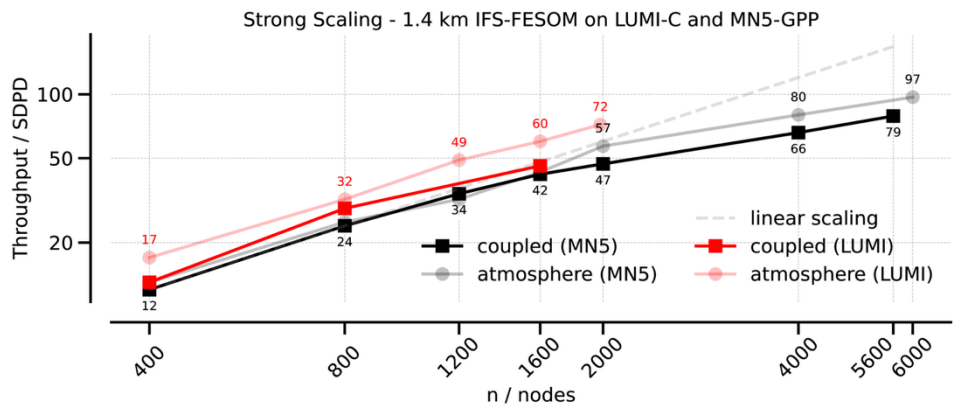


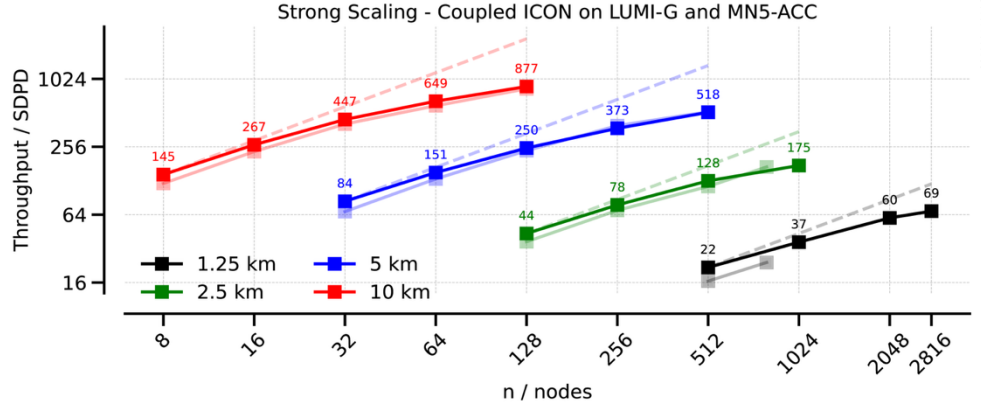
Funded by the European Union Destination Earth implemented by ECMWF esa EUMETSAT

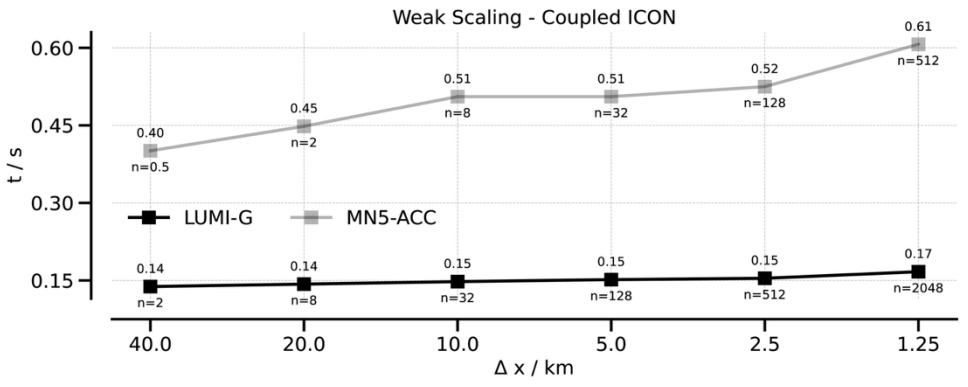

ECMWF
Funded by the European Union
Destination Earth
implemented by
ECMWF
esa
EUMETSAT
Recorded on Apple Vision Pro

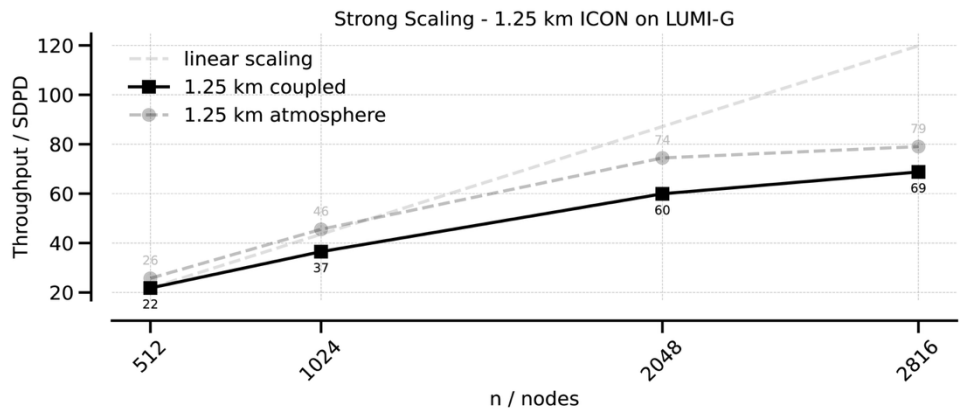

Strong Scaling - IFS atmosphere on LUMI-C and MN5-GPP
Throughput / SDPD
n / nodes
1.4 km
2.8 km
4.4 km
9 km


Weak Scaling - IFS atmosphere on LUMI-C and MN5-GPP
MN5-GPP
LUMI-C
t / s
Δ x / km


Strong Scaling - 1.4 km IFS-FESOM on LUMI-C and MN5-GPP
Throughput / SDPD
n / nodes
coupled (MN5)
atmosphere (MN5)
linear scaling
coupled (LUMI)
atmosphere (LUMI)


Strong Scaling - Coupled ICON on LUMI-G and MN5-ACC
Throughput / SDPD
n / nodes
1.25 km
2.5 km
5 km
10 km

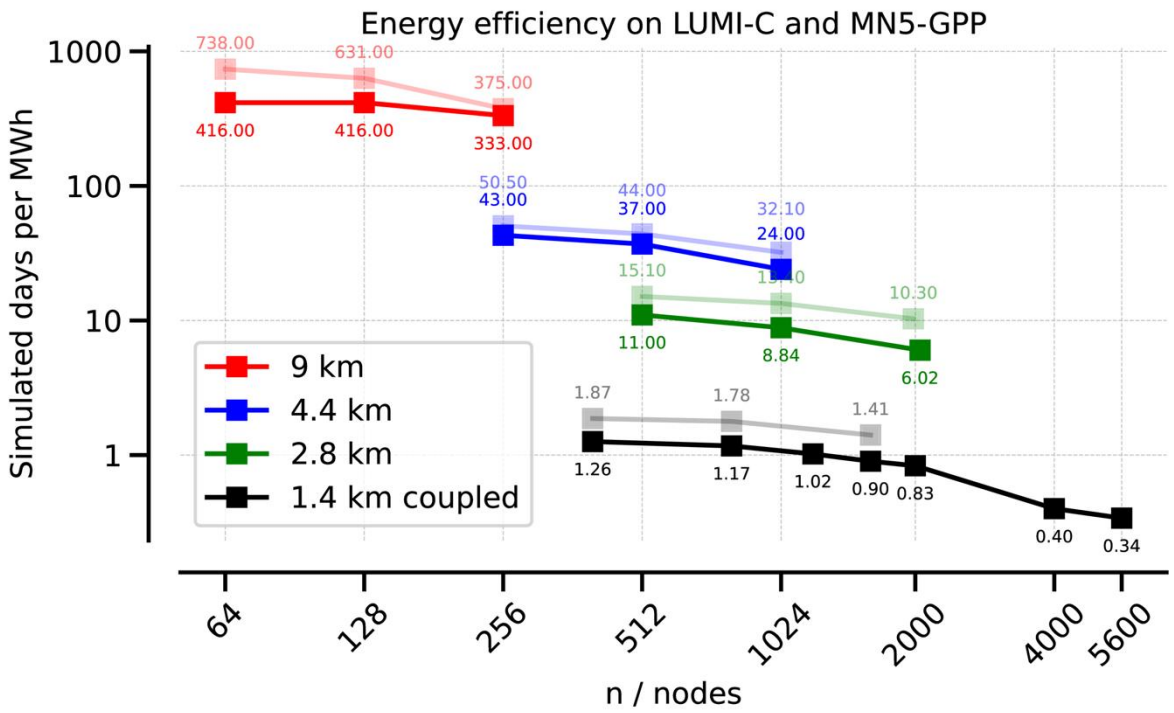

Weak Scaling - Coupled ICON
t / s
Δ x / km
LUMI-G
MN5-ACC


Strong Scaling - 1.25 km ICON on LUMI-G
Throughput / SDPD
n / nodes
linear scaling
1.25 km coupled
1.25 km atmosphere

ENERGY EFFICIENCY

SDPD required on larger machines to match energy efficiency of 1km coupled run on 5600 nodes MN5:

- 237 SDPD on 5600 JUPITER nodes
- 134 SDPD on 5600 Frontier nodes
- 244 SDPD on 5600 El Capitan nodes



CONCLUSIONS

- First ever operational multi-decadal simulations at 5 km resolution
  - > 200 years of simulations already performed
  - Three leading and well-established Earth System Models
- Actionable information for different sectors by impact sector applications
- Efficient use of leading EuroHPC systems across diverse hardware architectures
  - Unprecedented performance and energy efficiency at up to 1km resolution
- A climate data portfolio exceeding 10PB and growing
  - Largest available treasure trove for training future climate emulators