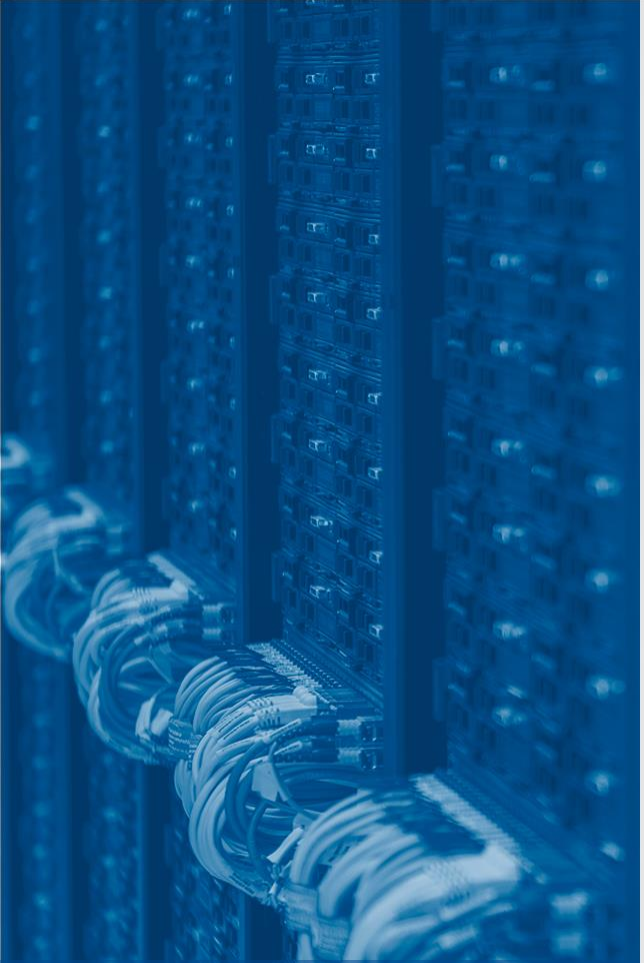

ICREA

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A Digital Twin of the Earth for Climate Change Adaptation

F.J. Doblas-Reyes

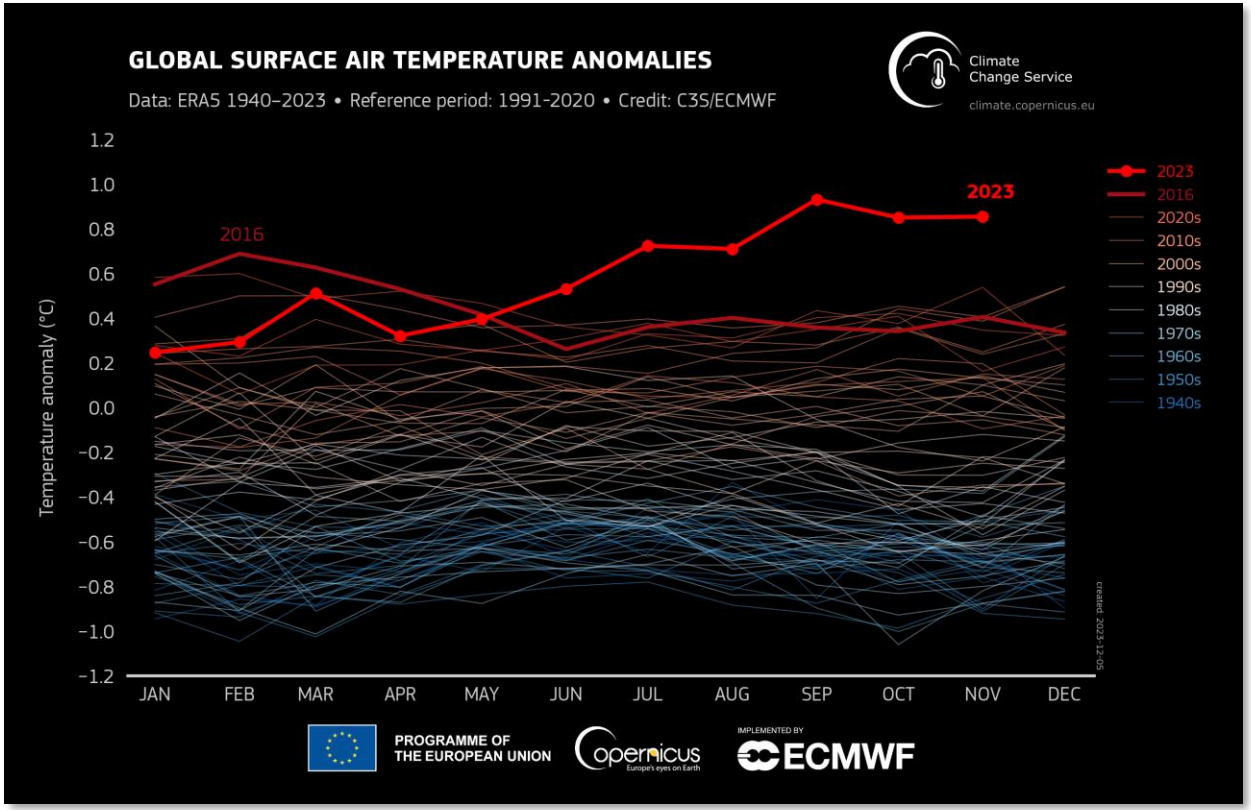
on behalf of the Climate DT DestinE team

22 February 2024

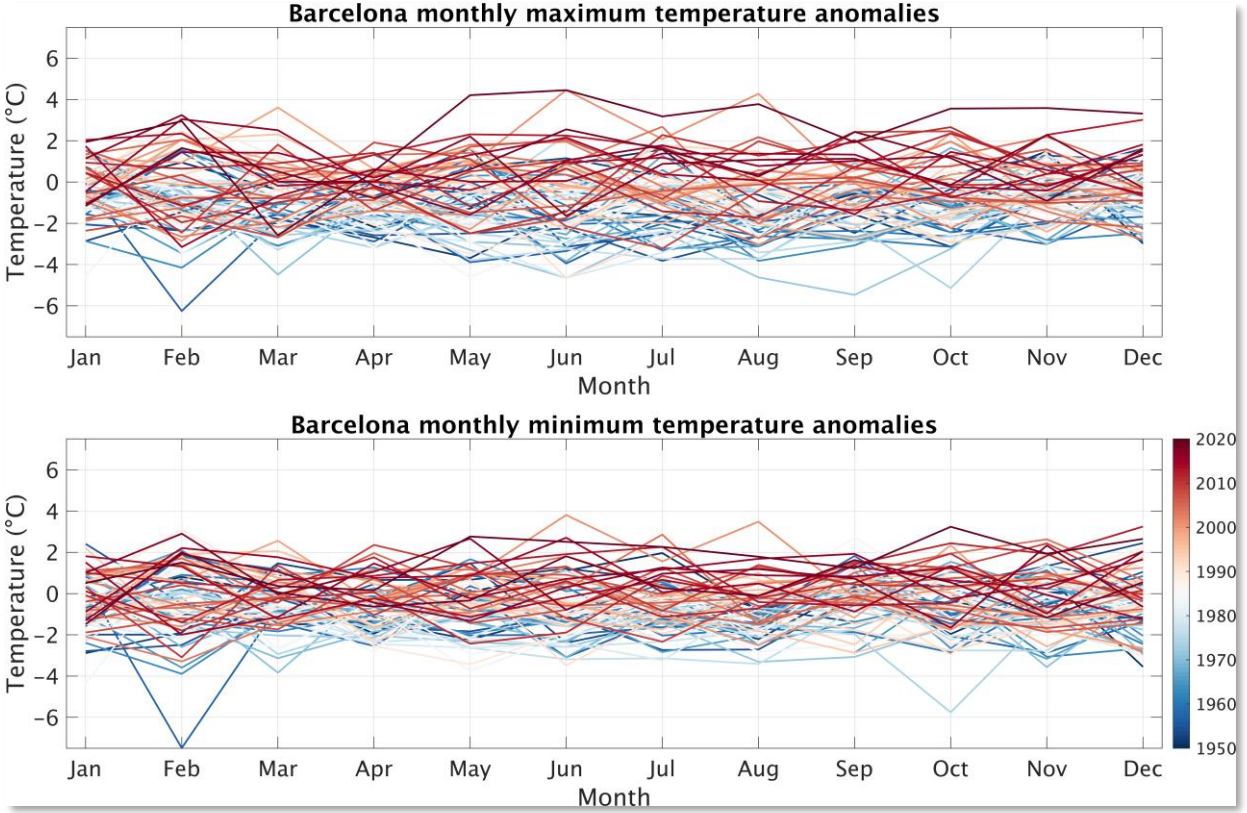
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

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

Something is going on with global climate



Global warming has also a local expression



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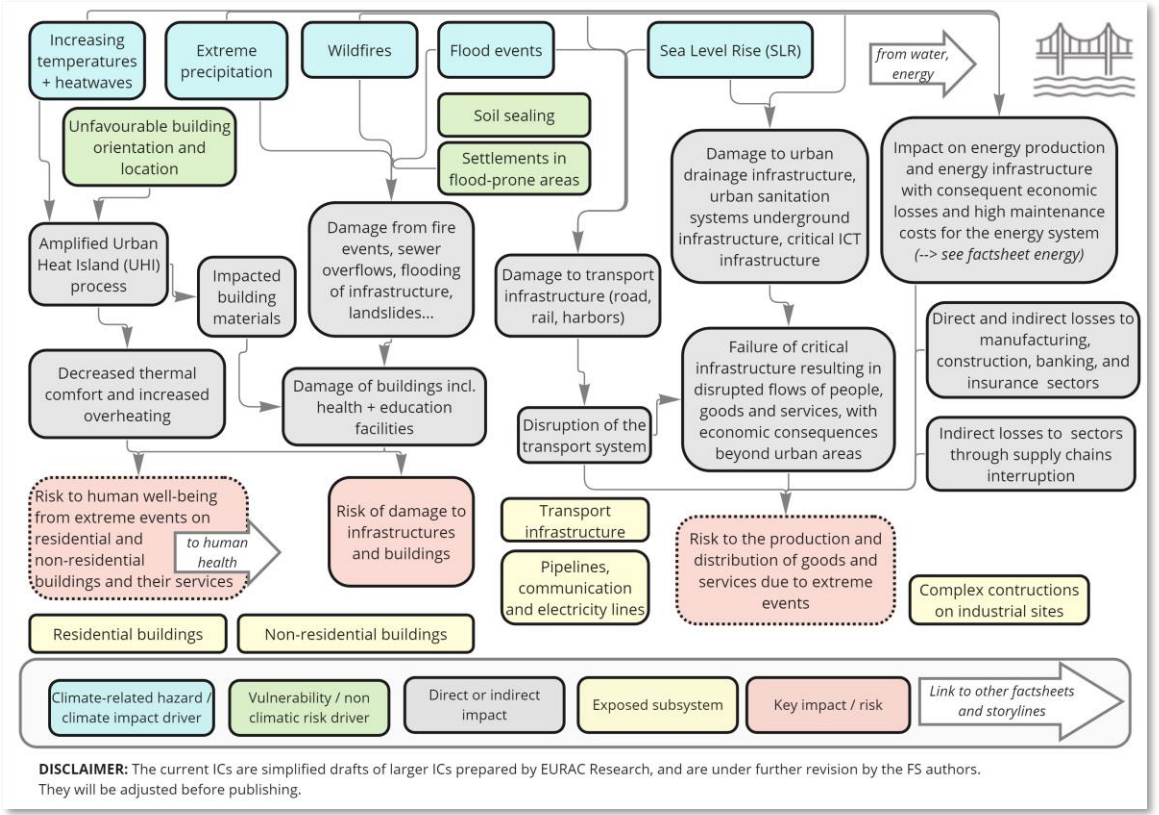
D. Campos (BSC, data source Meteocat)

Let’s focus on climate adaptation

Adaptation is the action that leads to limiting the consequences of a warming climate and requires, among many other elements, climate information about climate hazards.

A digital twin for climate adaptation is a system that supports decision-making in adaptation to climate change using the best models available in an environment that allows an interactive relation with the user.



EUCRA report (2024)

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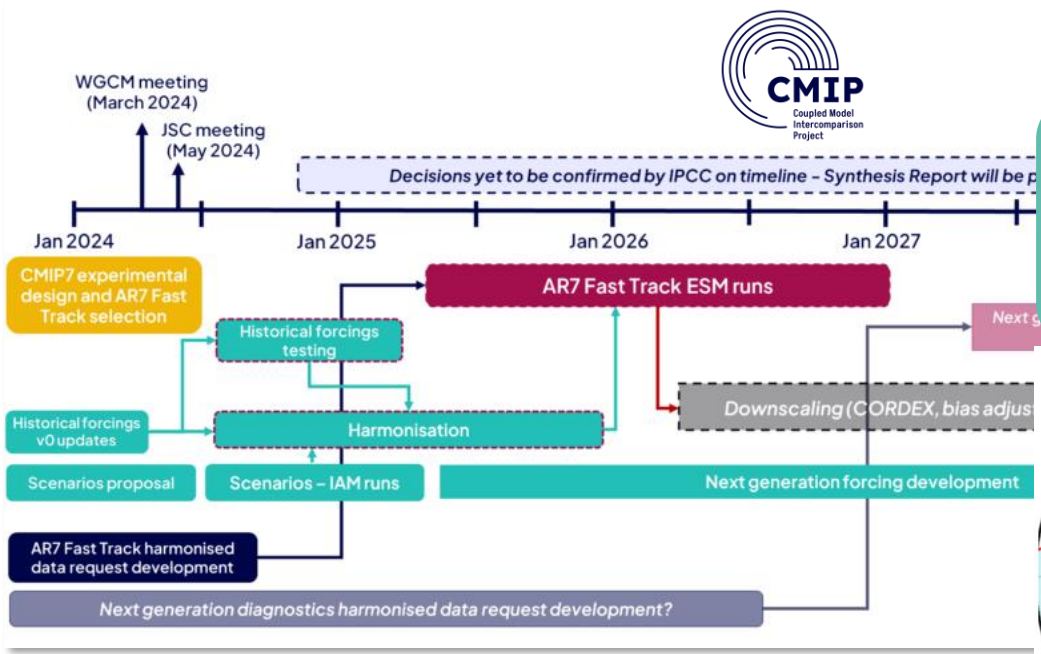
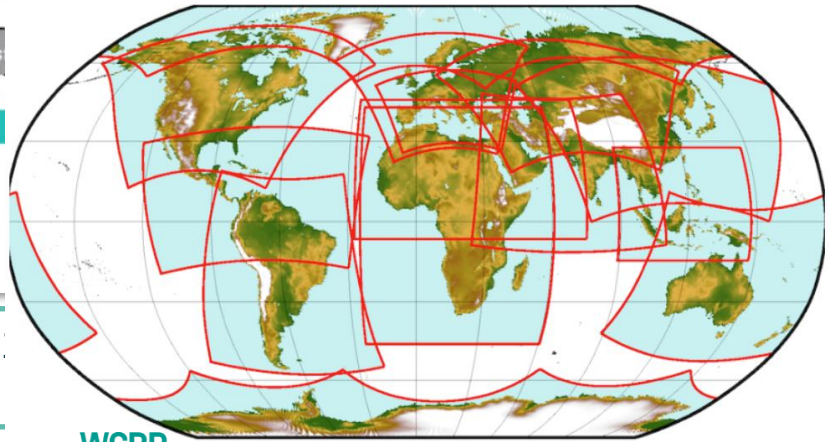
CURRENT SOURCES OF CLIMATE INFORMATION: CMIP AND CORDEX



Many global models, research driven, resolutions 50-
many years between update cycles, static archive

Many regional models, research driven, resolution 10-50 km, long time between cycles, often no ocean, inconsistent across regions, static archive



WCRP CORDEX

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OPERATIONAL CLIMATE PROJECTIONS

Are the needs taken care of? Are timing, quality, adequacy, and authority addressed?

The digital twin emerges as an alternative to operationalise the on-demand production of climate information.

Comment | Published: 02 November 2023

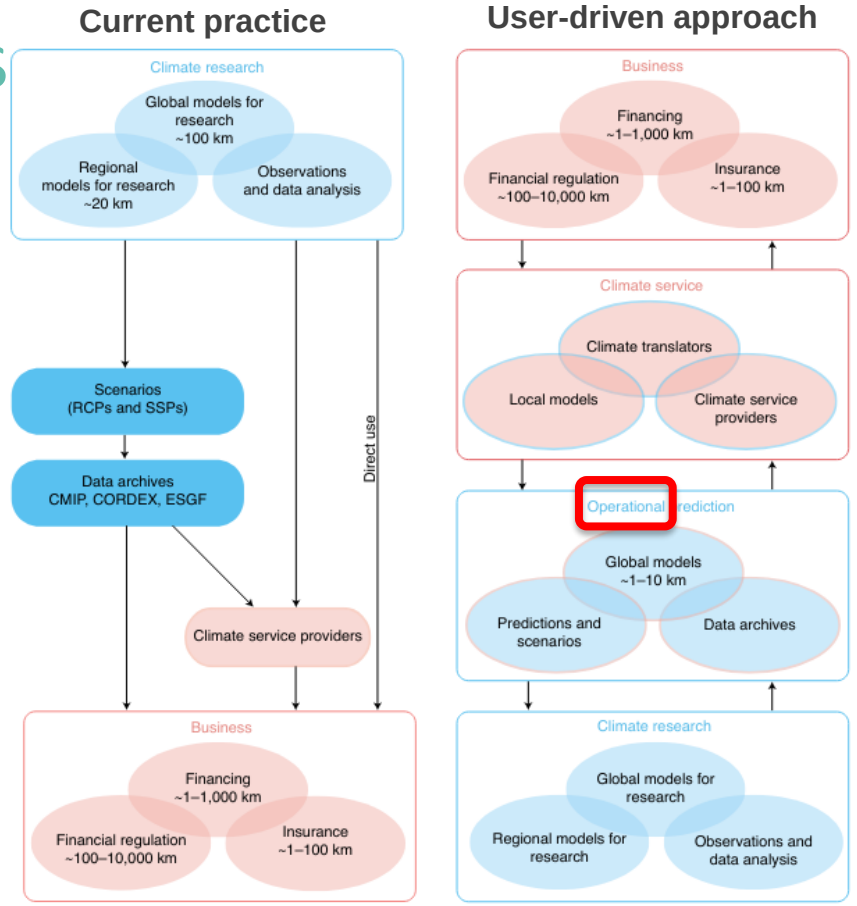
The need to operationalize climate modelling

Christian Jakob, Andrew Gettelman & Andrew Pitman

Nature Climate Change **13**, 1158–1160 (2023) | Cite this article

2168 Accesses | **35** Altmetric | Metrics

Climate models have evolved from research tools to underpin decision-making across the globe. To provide optimal value for society in the future, the models need to be made operational.



Fiedler et al. (2021, NCC)

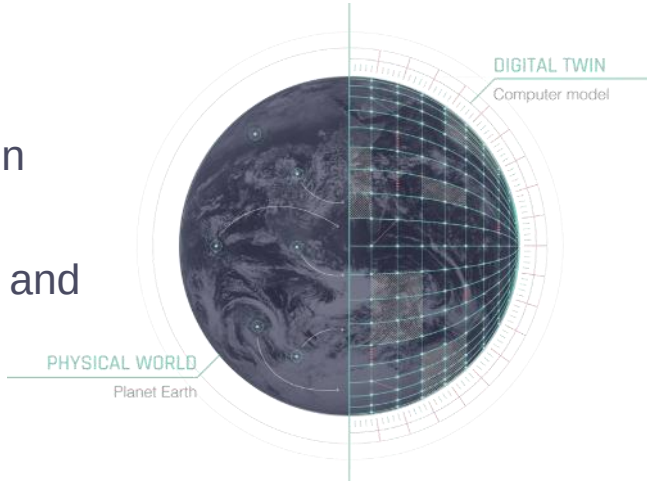
ECMWF

CLIMATE ADAPTATION DIGITAL TWIN (CLIMATE DT)

Climate DT is a new type of climate information system funded by the Destination Earth programme that focuses on **assessing the impacts of climate change and different adaptation strategies** at local and regional levels with a global perspective using a strategy where **user requests drive the production chain**.

The Climate DT includes

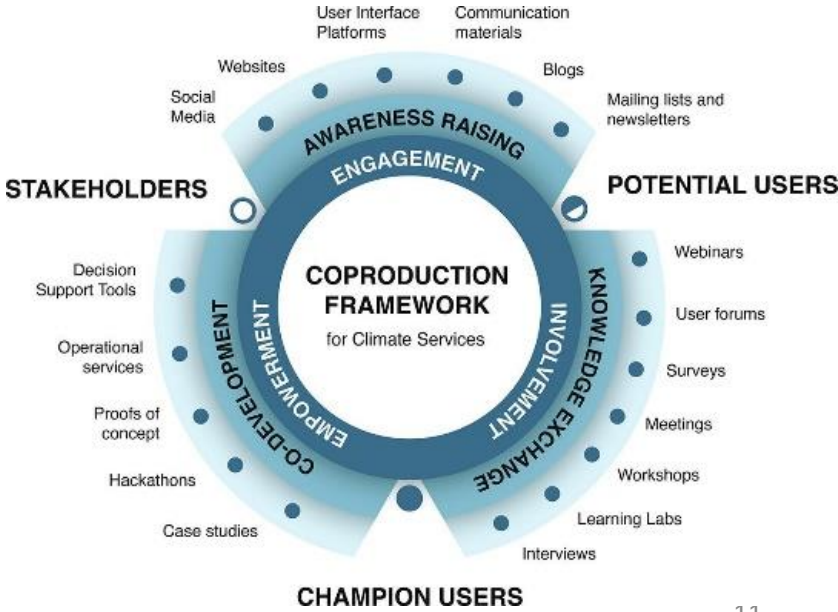
- A **user-driven approach**
- **Global climate simulations** at an unprecedented resolution
- **Quality assessment and uncertainty quantification**
- Deployment on **EuroHPC pre-exascale computers** (LUMI and MareNostrum5)
- Relevance of both **climatic and non-climatic drivers**
- **Integration of large amounts of relevant European R&D**



USERS AS A DRIVING FORCE OF THE DIGITAL TWIN

Challenge: The digital twin emerges in a busy context, with many requirements for climate information, a cacophony of sources, a strong political load, a growing market, increasing needs, no defined standards, and some well-positioned actors.

Opportunity: Social sciences and humanities play an increasingly important role in the services that provide climate information, leading to more efficient and successful links to both public administrations and the private sector.



Bojovic et al. (2021, GEC)

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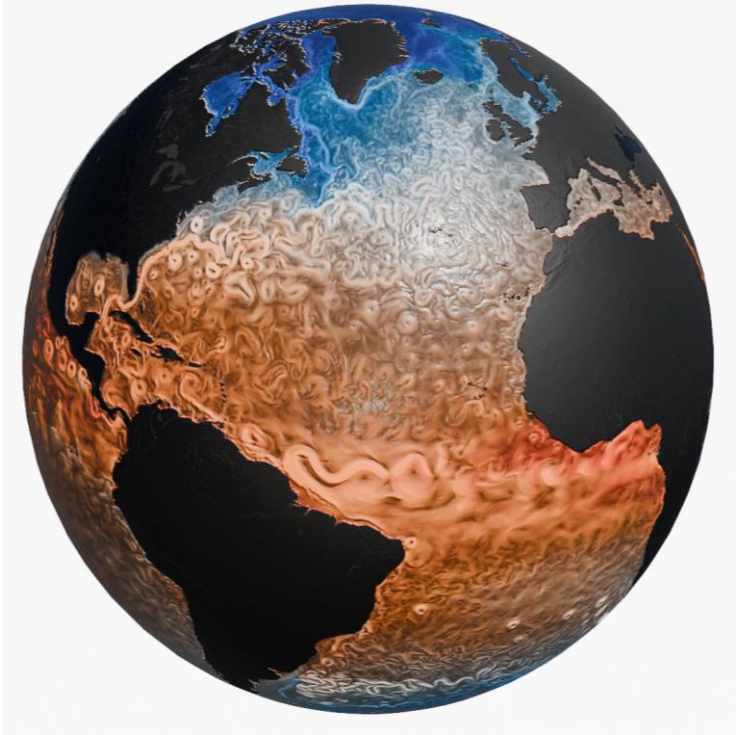
A NEW GENERATION OF CLIMATE MODELS IS NEEDED

- Climate DT uses **three next-generation Earth system models**: ICON and IFS-NEMO/FESOM
- **Global multi-decadal simulations at 5 km,** following a common simulation protocol
- High-resolution simulations enable **smaller-scale processes** to influence the climate trajectory, and provide **local information** relevant to users at global scales



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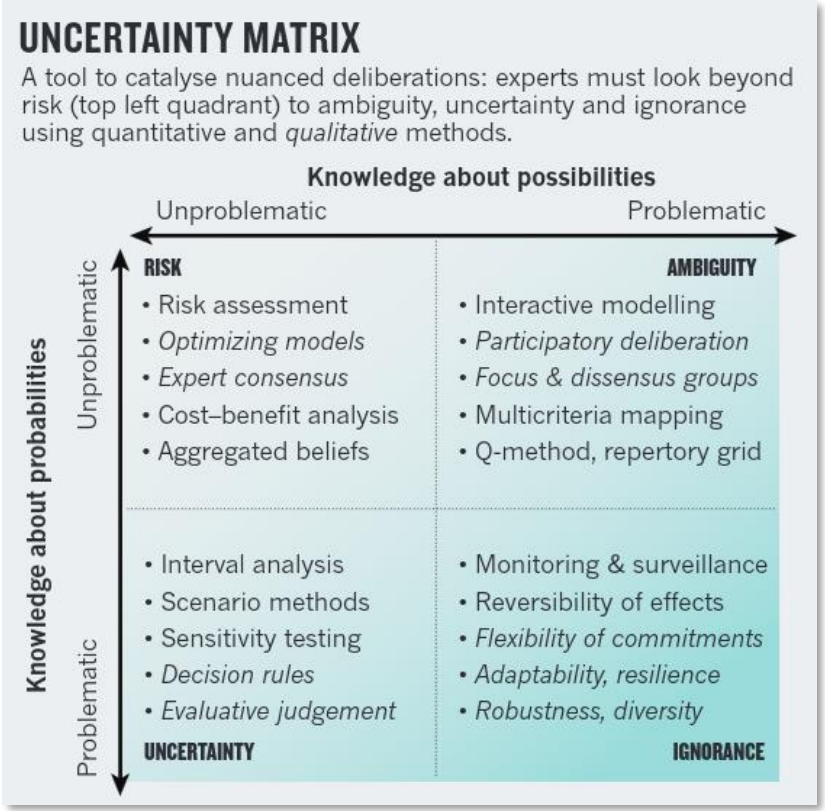
CONFIDENCE, WILDCARDS, AMBIGUITY AND IGNORANCE

- While schemes to interact with the users and produce salient information are indispensable, reliance on models that are not good enough leads to either overconfidence or underconfidence, which, in turn, leads to both inadequate uncertainty estimation and insufficiently credible risk assessments.

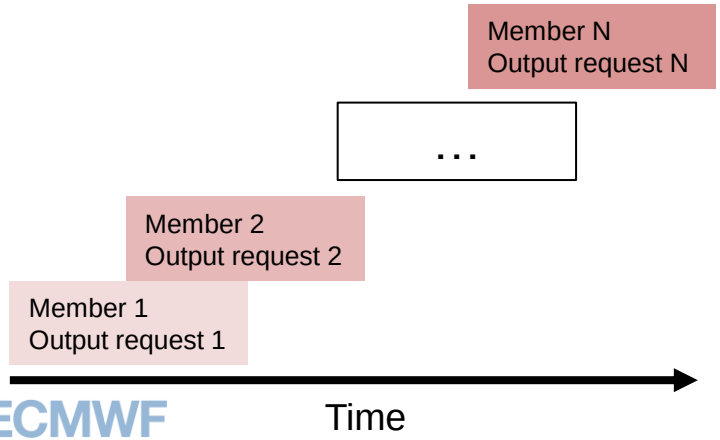
- Events and processes (unprecedented extremes, tipping points caused by land-ice melting) that make the climate trajectory non-monotonic are known as wildcards and are associated with ambiguity and ignorance.

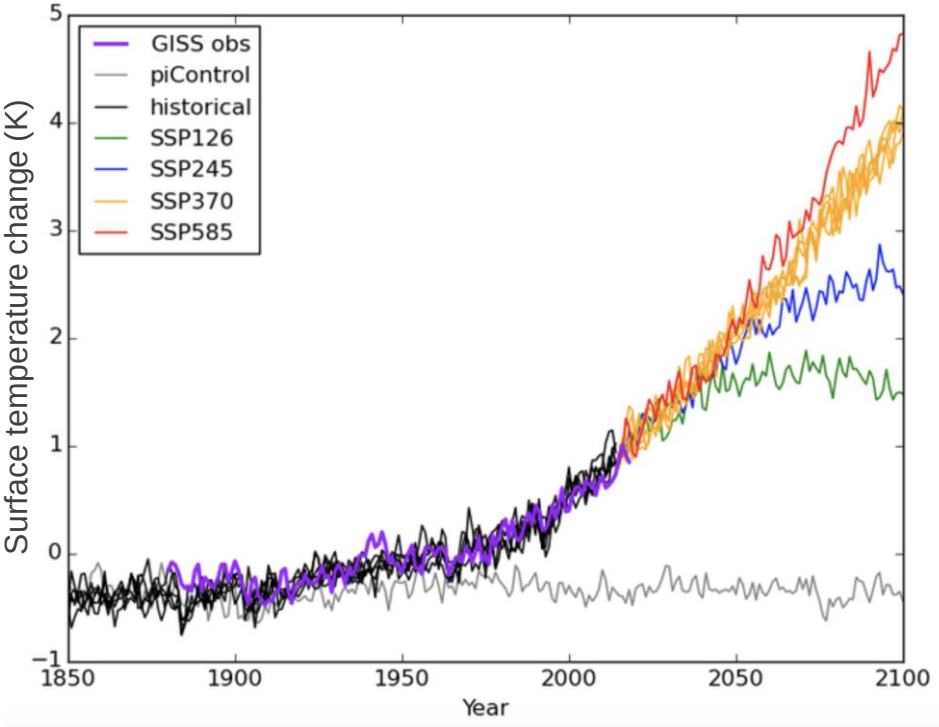


Stirling (2010, Nature)

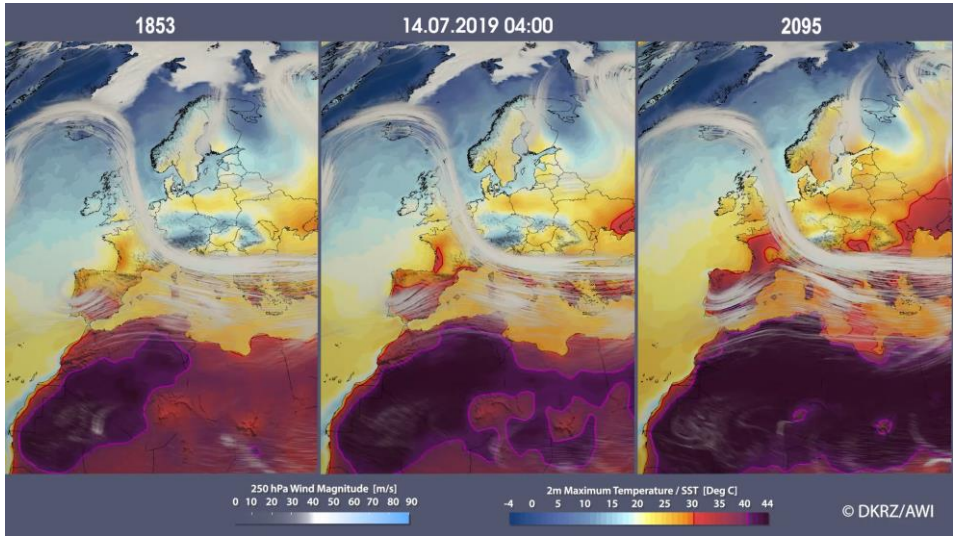
OPERATIONAL CLIMATE PROJECTIONS IN THE CLIMATE DT

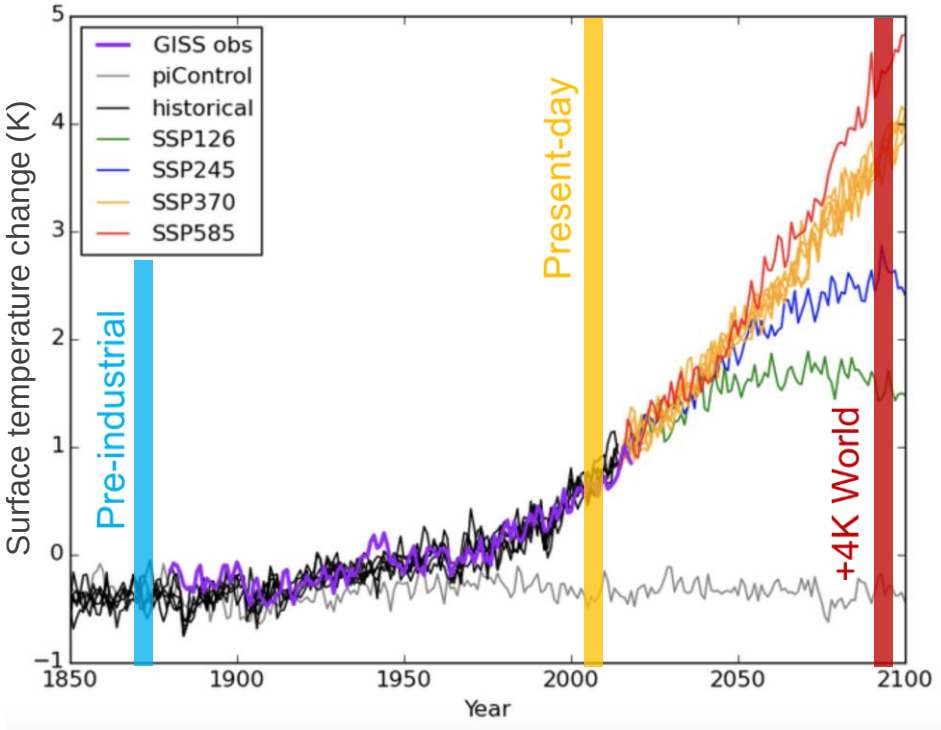
- Performing the global high-resolution projections is expensive: 360 node-days in LUMI-C (using 15% of the machine), 36 TB of output, per simulated year.
- Production of projections should be continuous, with on-demand output and ensemble members are staggered.





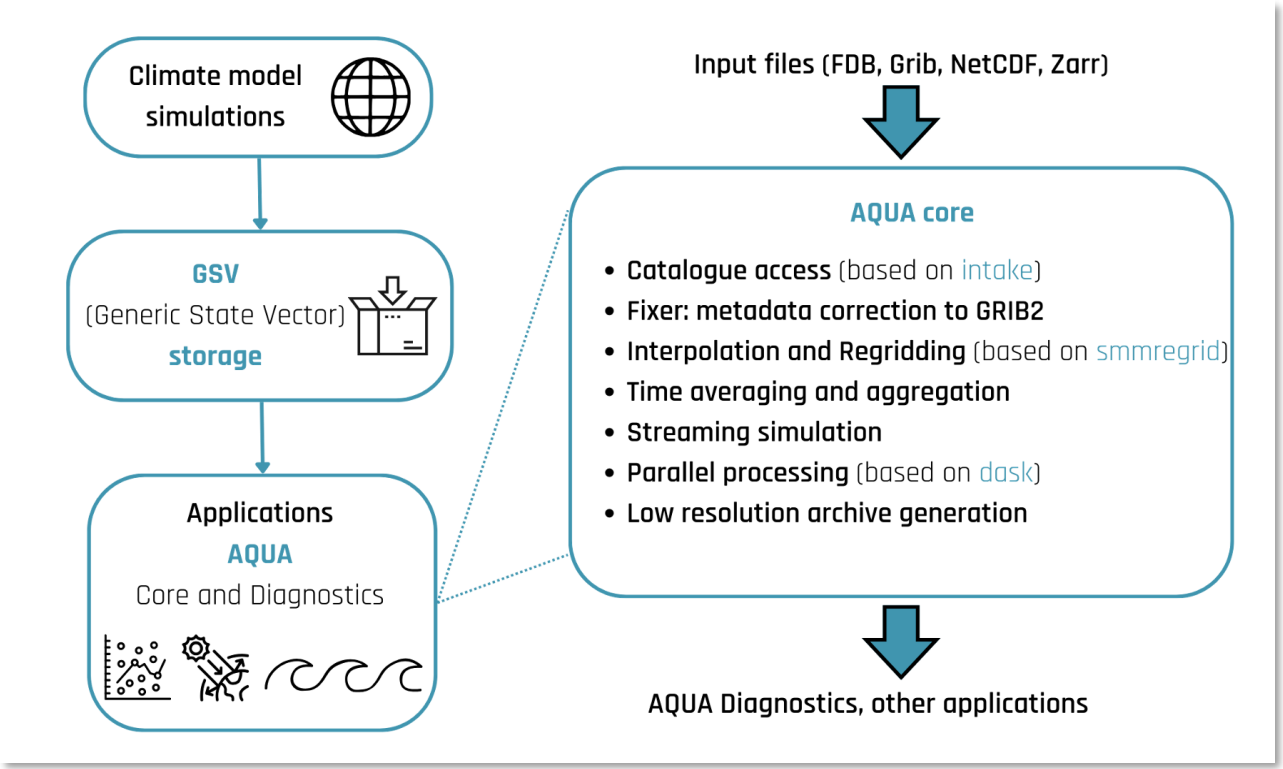
OPERATIONAL PROJECTIONS IN THE CLIMATE DT



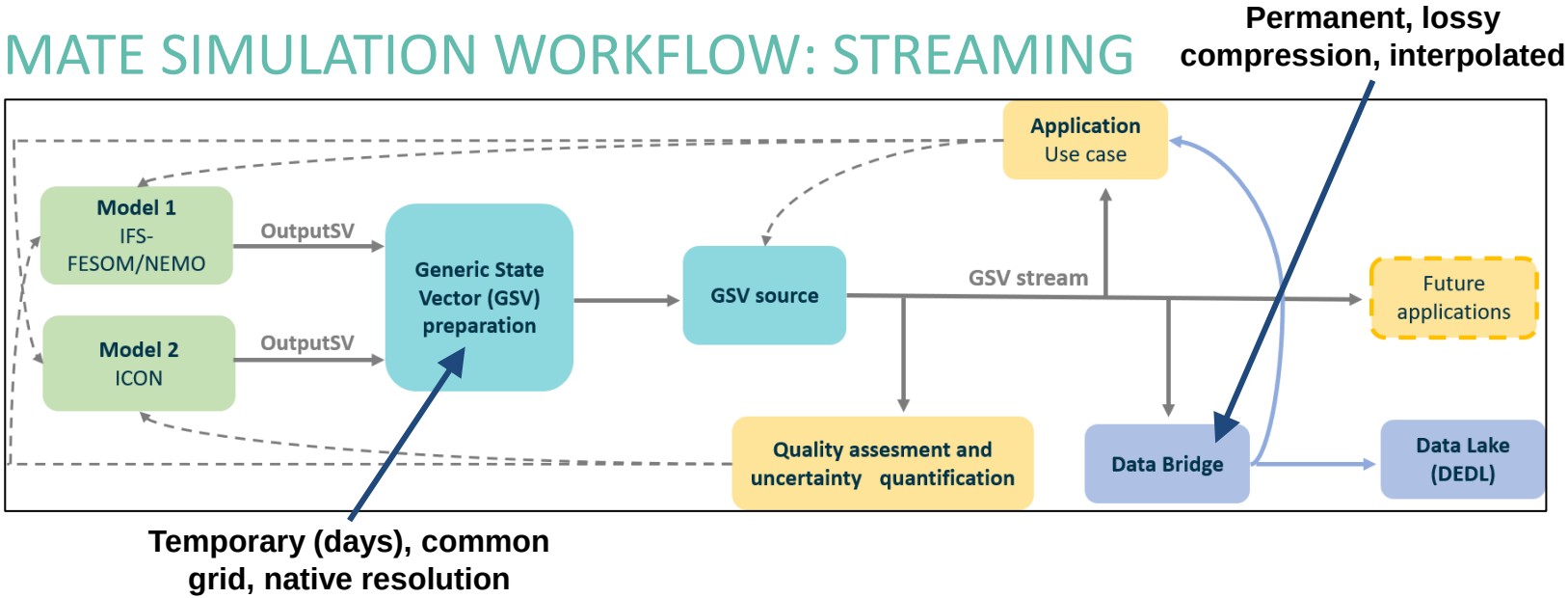


OPERATIONAL PROJECTIONS IN THE CLIMATE DT: MONITORING

- A long list of data checks are implemented and run as part of the whole workflow.
- Model validation is performed at regular intervals, with a purpose-built set of metrics that take into account the high resolution of the climate models.



CLIMATE SIMULATION WORKFLOW: STREAMING



Streaming of model output in a standardized form (*generic state vector, GSV*) enables

- **Data consumers have access to the full model state** as soon as it is produced
- **Interactivity:** development to allow simulations and variables on demand
- **Scalability**: new applications and requirements can be added

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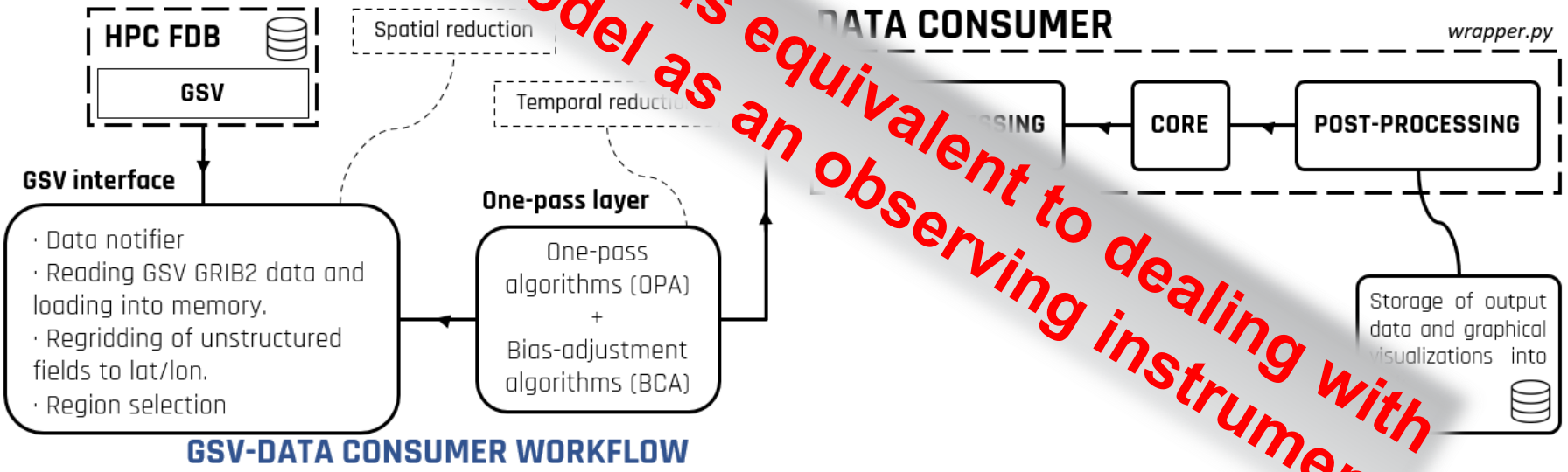
STREAMIN TA FOR A MANAGEABLE SYSTEM

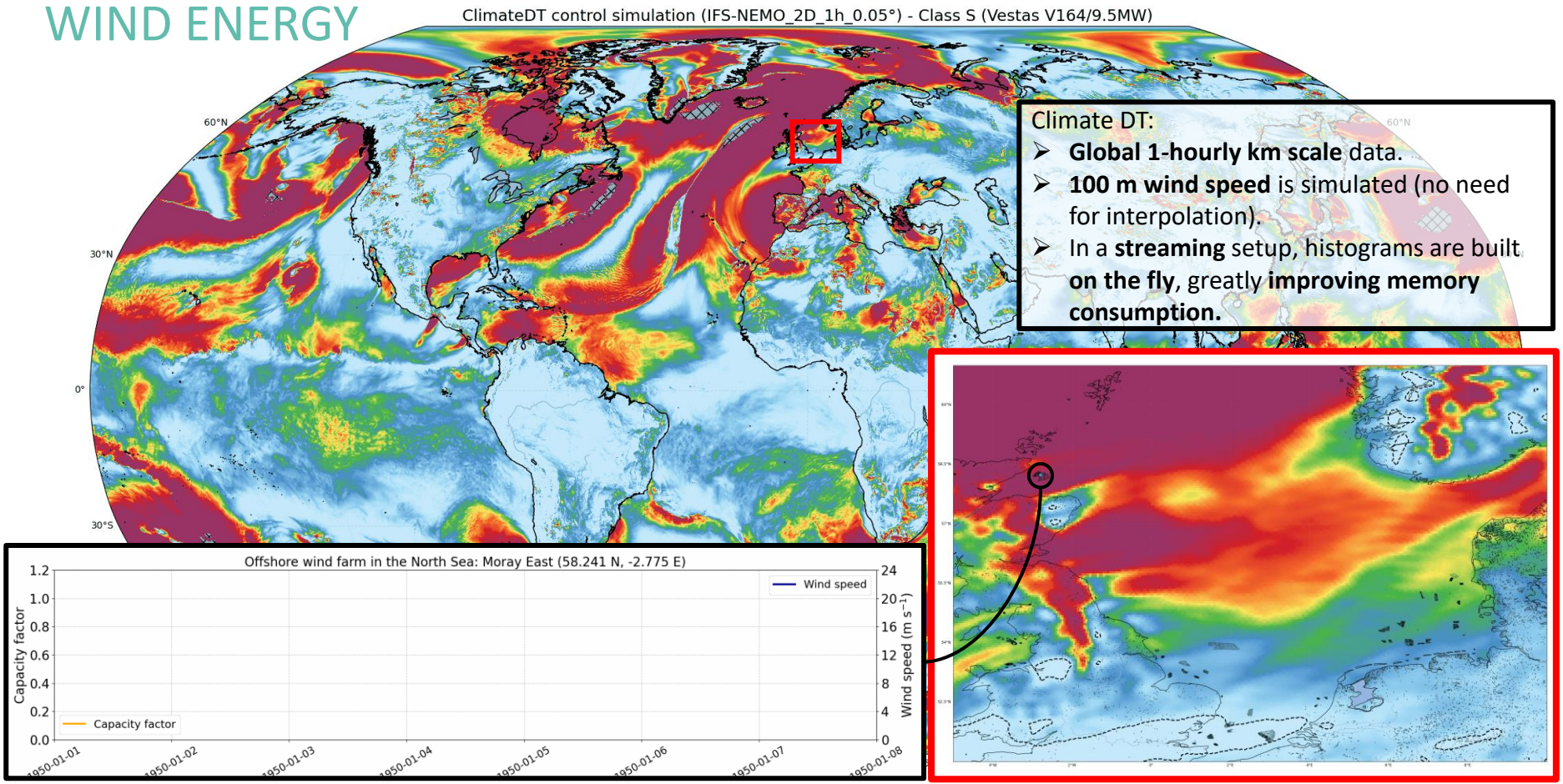
- The strea damental in the Climate DT because it gives data consumers access to the vector (limited in time) to generate unprecedented indicators.
- Streaming at will is p achine learning-based emulators of the climate trajectory.



Important: This is equivalent to dealing with a climate model as an observing instrument

ECMWF

WIND ENERGY



Climate DT:

- **Global 1-hourly km scale** data.
- **100 m wind speed** is simulated (no need for interpolation).
- In a **streaming** setup, histograms are built **on the fly**, greatly **improving memory consumption.**

North Sea - Moray East wind farm: 58ºN, -2ºE

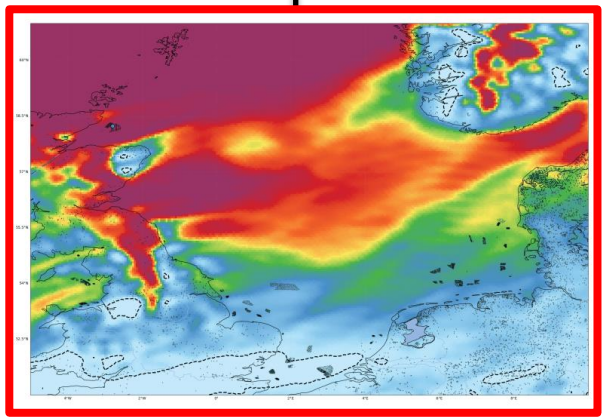
CONSUMING STREAMED CLIMATE DATA

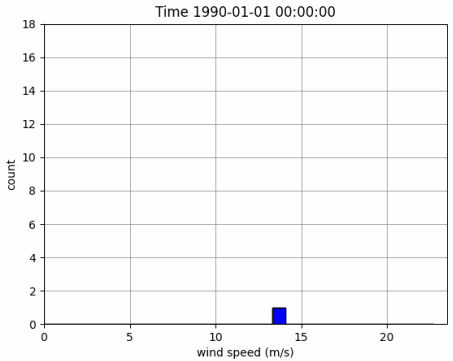
- Streams raw climate variables through the one-pass layer (data-reduction tasks that compute indicators) to the data consumer computing user-relevant indicators on-the-fly.
- Implemented either in the climate model workflow or a separate one.

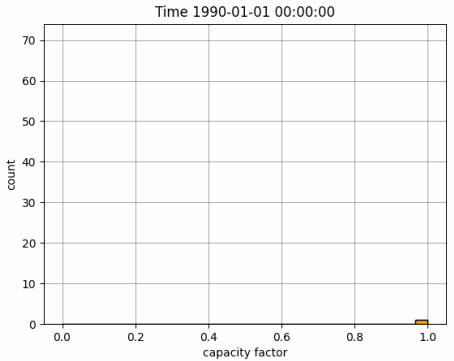
Model outputs **raw climate variables** (e.g., 100u, 100v)

One-pass algorithms compute on-the-fly distribution **of wind speed**

Data consumers can use it to compute climate indicators (e.g., weekly capacity factor of any turbine)







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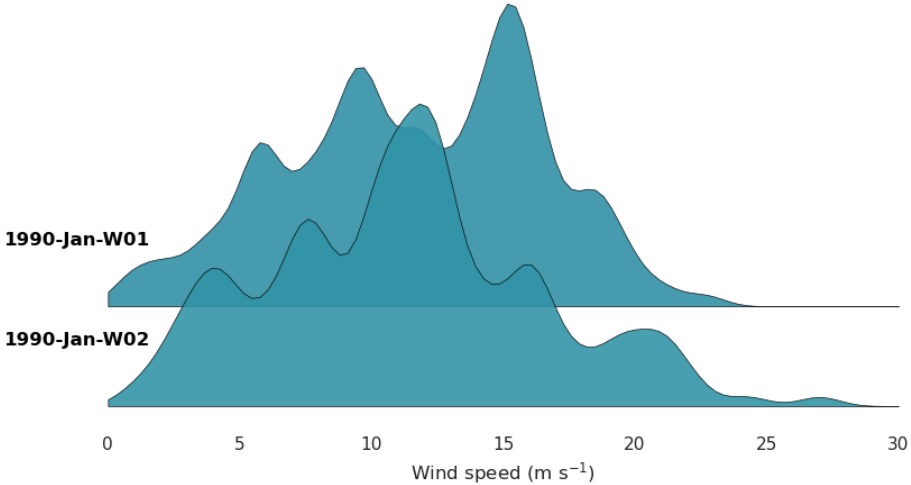

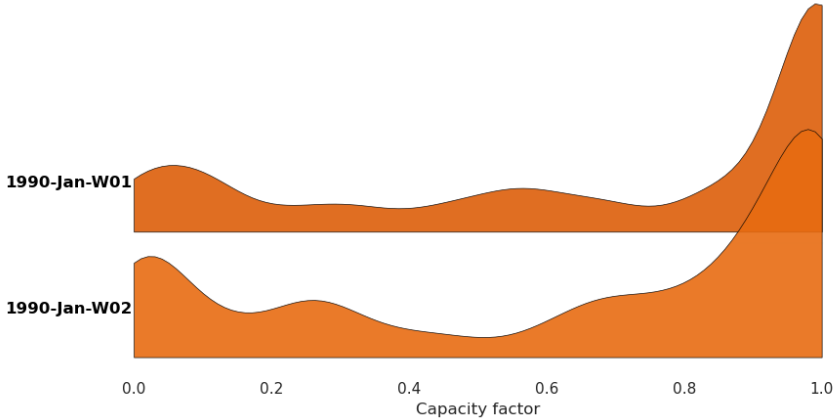

A. Lacima and K. Grayson (BSC)

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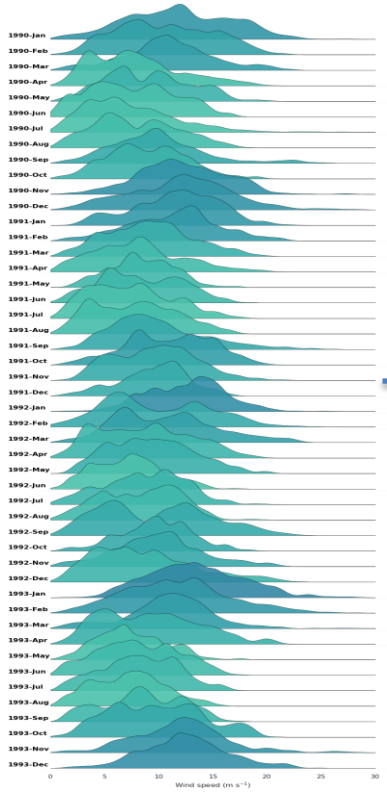
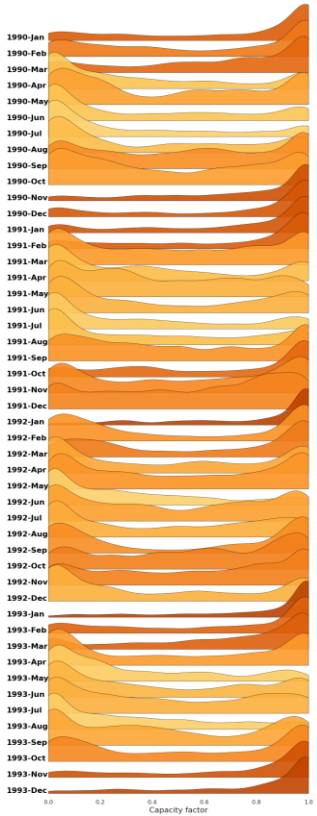
CONSUMING STREAMED CLIMATE DATA



Data bridge



Possibility to compute the capacity factor for any turbine anywhere in the world with access to a manageable data set of indicators

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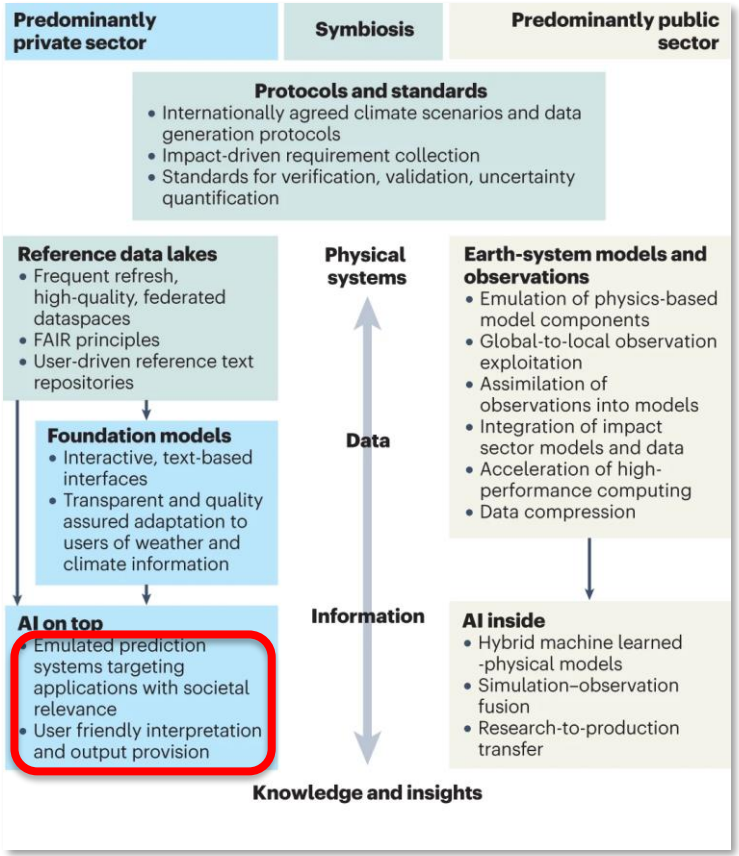
WHAT ROLE FOR AI?

- Why not building a climate model fully based on AI?

ECMWF

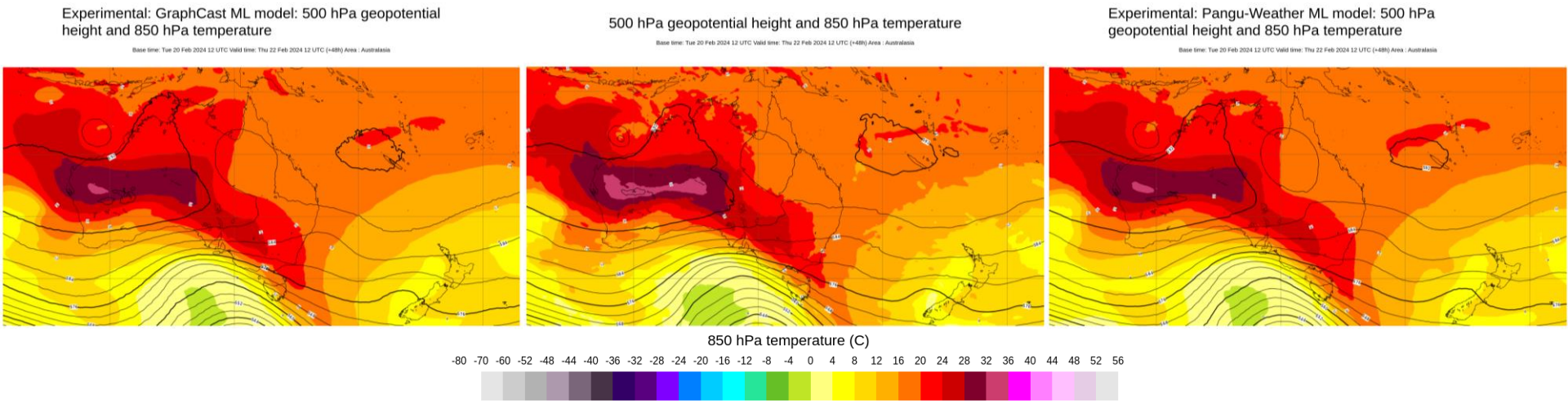
WHAT ROLE FOR AI?



Bauer et al. (2023, NREE)

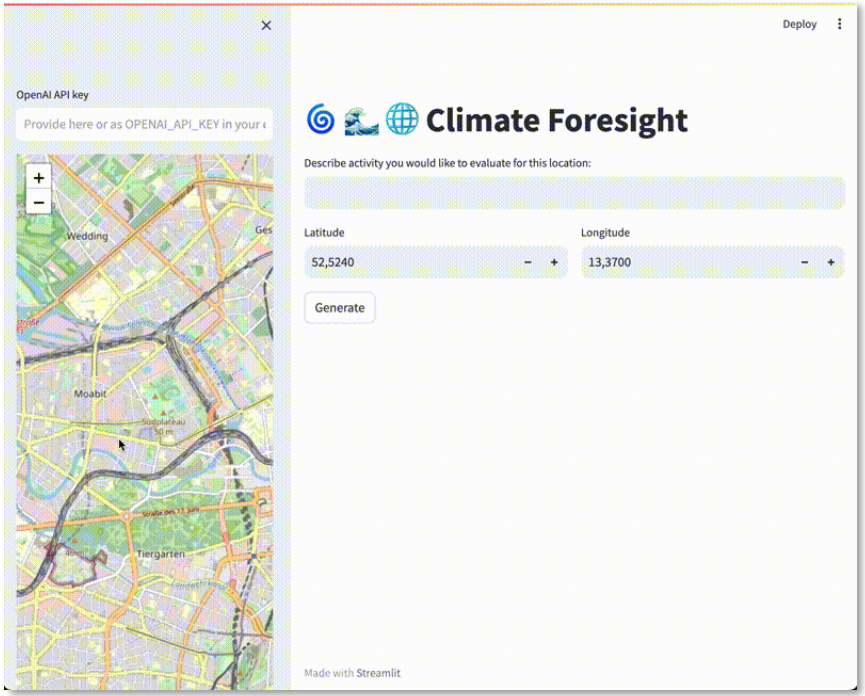
WHAT ROLE FOR AI? MORE EFFICIENT DATA ACCESS SERVICE

- GenAI weather forecast systems emerged in the last couple of years. They are competitive (though not necessarily better) with traditional (based on first principles) systems.
- Climate data for the atmosphere can be recreated and quickly served for any model trajectory by interpolating (tethering) between checkpoints (every five days, 15 GB each) stored during the simulation. Model training needs to be done while streaming !!



WHAT ROLE FOR AI? SCALABLE CLIMATE ADAPTATION REPORTS

- ClimSight is a prototype tool for a climate information system that uses ChatGPT to provide structured reports on local climate changes and their impacts.



Koldunov and Jung (2024, CEE)

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WHAT ROLE FOR AI? SCALABLE CLIMATE ADAPTATION REPORTS

- Climate adaptation is a specific domain. More salient results are sought with a fine-tuned LLM and retrieval augmented generation.

REQUIREMENT

Prompt the question

SMART SEARCH

Question + relevant documents

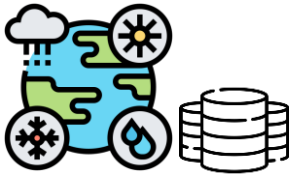
CLIMATE-AWARE LLM

Generate answer

GENERATED ANSWERS BASED ON FINE TUNED MODEL WITH REFERENCE

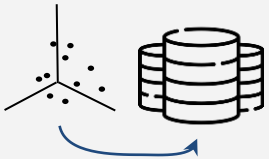
Similarity search

Retrieve relevant documents



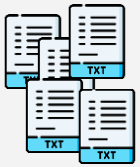
SPECIFIC KNOWLEDGE DATABASE

SPECIFIC KNOWLEDGE DATABASE



VECTOR DATABASE

Produce vector representation of text



PIECES OF TEXT

Text chunking

DOCUMENTS

Climate ADAPT

ipcc

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SUMMARY: CLIMATE ADAPTATION DIGITAL TWIN

- **A new type of climate information system** based on high-resolution global climate simulations, interactive impact modelling, and high-performance computing.
- **It enables data consumers to access** climate information in a completely new way.
- **Designed to support decision-making** for climate change adaptation strategies.
- **Prototype of operational system currently running**, with many extensions considered for a second phase.
- **Fully compatible with (and complementary to) the Copernicus services** as an interactive source of climate information for the future.

ECMWF