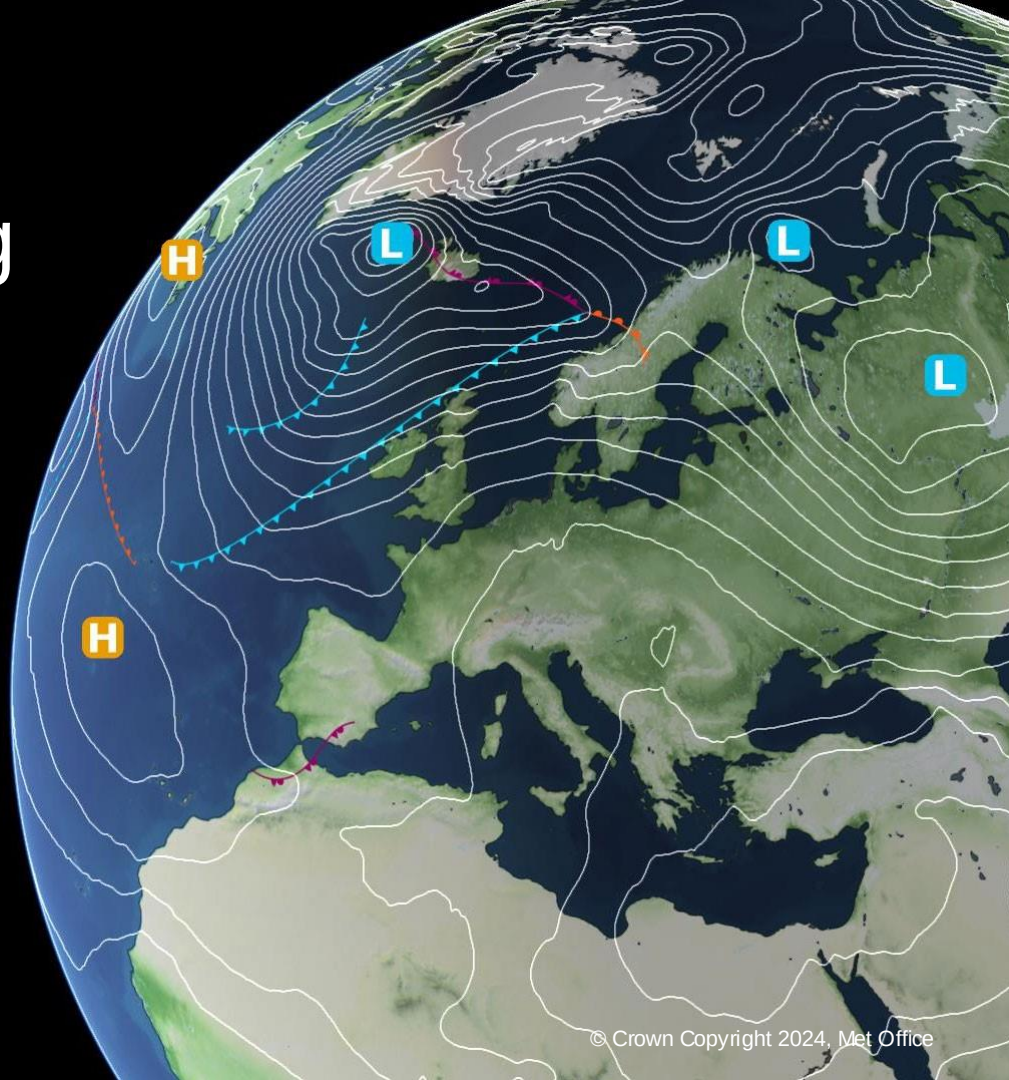
UK* Machine Learning Activities

*And a bit from South of the English channel too



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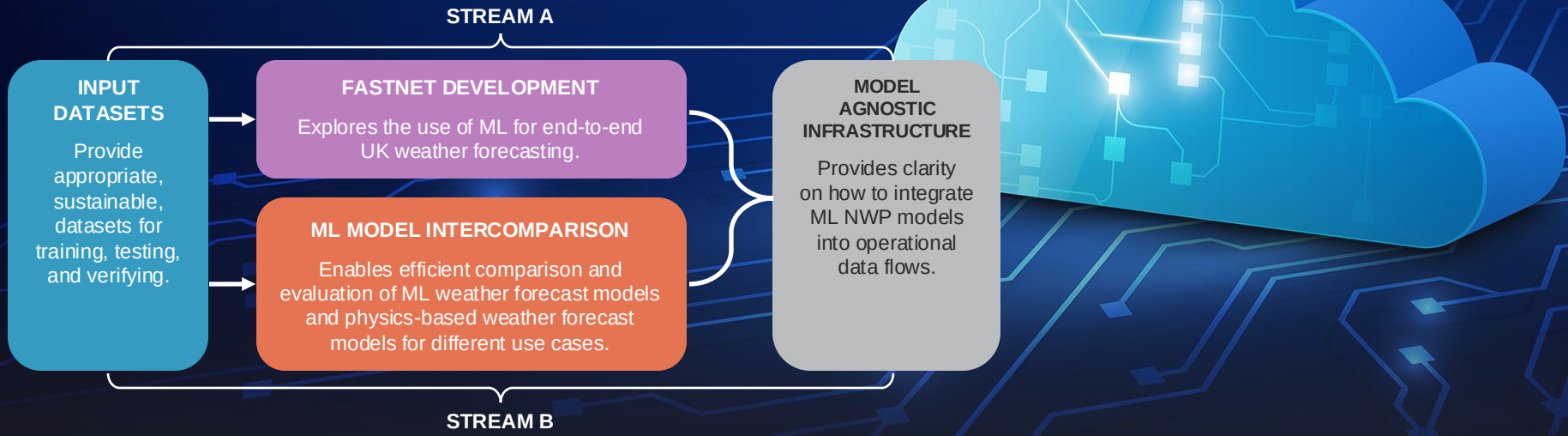
Contents

- AI4NWP
  - Machine Learning Intercomparison (MLInt)
  - FastNet development
- AI4Climate
- Intra-model AI
- AI and NEMO

AI for Numerical Weather Prediction (AI4NWP)

The Met Office launched the AI for Numerical Weather Prediction (AI4NWP) programme in 2023 to realise the opportunity presented by AI.

AI4NWP draws together our AI projects and drives development for data-driven approaches to weather forecasting:



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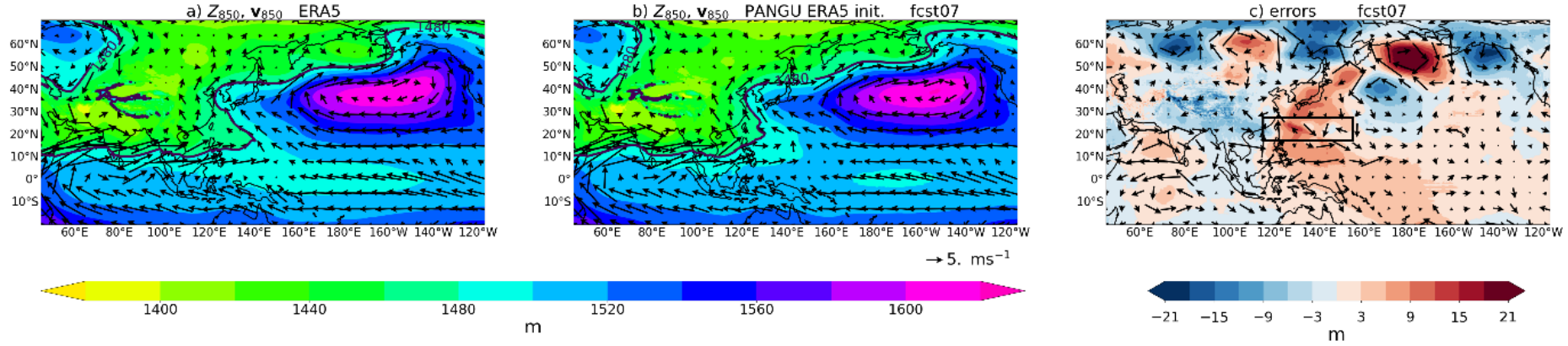
ML Intercomparison Project

- 4 Main Themes:
  - **Unified Workflow**: Create a reusable, user-friendly workflow for running multiple ML models and associated verification, evaluation and visualisation tasks.
  - **Models and Metrics:** Add new functionality to the workflow in terms of running additional ML models from multiple initial conditions, calculation of additional metrics for comparison and other components.
  - **Subjective Evaluation:** Engaging with expert users of weather models, and building tools for doing that, such as a dashboard for forecasts and verification scores, and doing user research to understand requirements and get feedback on tools that have been developed
  - **Building Trust:** Running and analysing experiments to understanding the representation of physical processes in ML models. This will start with existing tools and methodology, and over time develop the use of Explainable AI (XAI)

MLInt Theme 4: Building Trust

- Comparison of systematic errors between ML models and Physical models
- E.g. West Pacific Subtropical High



Met Office | The Alan Turing Institute

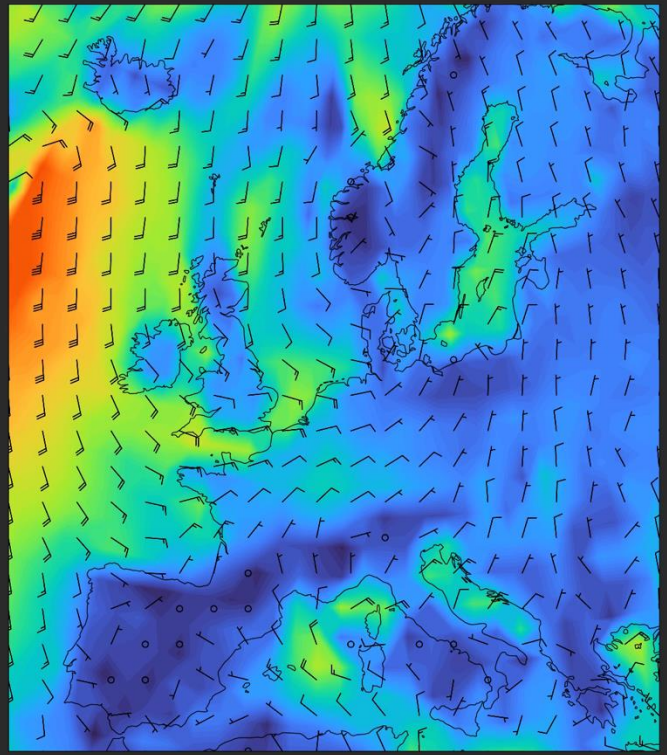
Combining Met Office and Turing expertise to develop a new model

In 2023 the Met Office entered a ground-breaking new partnership with The Alan Turing Institute, to enable the AI4NWP programme to accelerate work to deploy ML technology alongside traditional techniques.

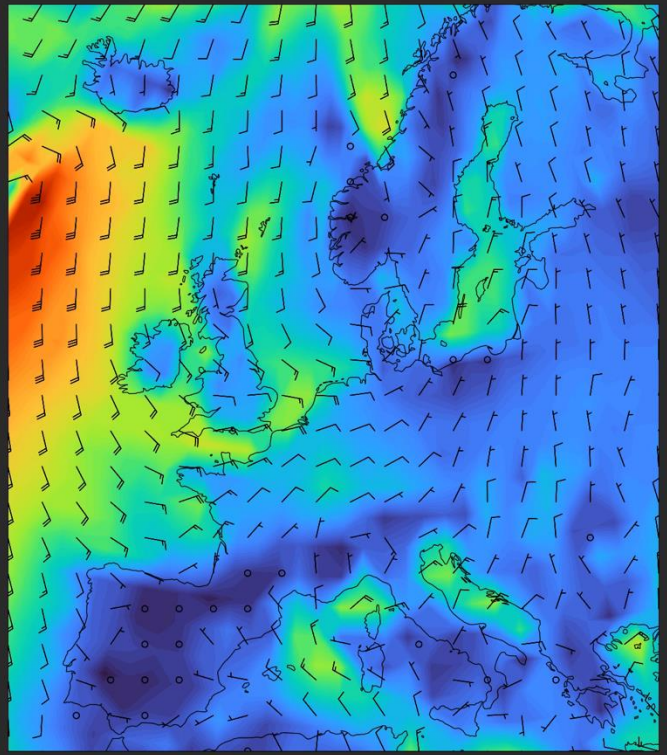
Phase 1: Researchers are developing a new AI model, known as a graph neural network, to forecast weather patterns. This will allow them to test the accuracy of their new model against existing NWP weather forecasting methods

Phase 2: Researchers plan to explore how to incorporate their new AI model into the Met Office's workflows and routinely compare its accuracy compared to existing physics-based forecasting methods

Ground truth (ERA5)



FastNet ML model prediction



2018-02-25 0600 UTC 6 hour forecast

Wind at 10 m above surface level

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AI4Climate

- Early days for the programme
- First flagship projects on
  - Using ML for downscaling of regional climate projections (lead by Ben Booth)
  - Data driven climate modelling (lead by Doug McNeall)

Climate Science Flagship AI projects

Ambitious high reward AI-enabled projects to transform Climate projections

1) Data-driven Climate Model (Lead: Doug McNeall) (type 3 fusion)

The opportunity

With an ML climate model, we can:

- Democratise climate modelling.
- Deliver a step change in access to climate data, climate simulation, and understanding.
- Hugely reduce **computationa**l and **organisational** expense for the end user [increase efficiency].

The first 6 months - scoping models

- What is technically feasible?
- Where do we put resources?

Task specific models

Foundation model

Met Office

Met Office Hadley Centre

Challenges

Scientific

- How do you train, evaluate and use MLs model for climate?
- What is the link between the ML model and the real system?
- How do we estimate uncertainty in climate futures?
- What is the best use of simulation capabilities?

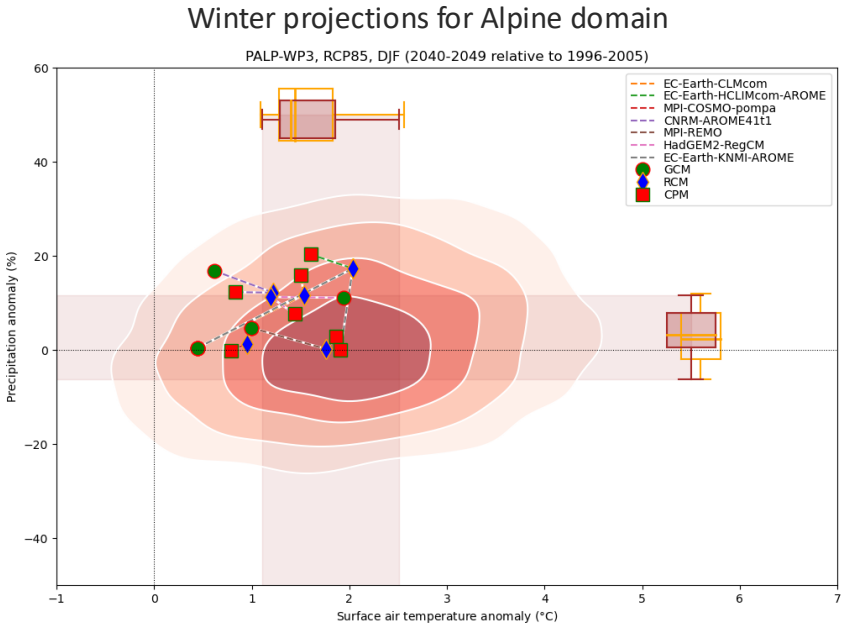
Practical

- Computational cost
- Access to GPUs
- Data pipeline construction
- Architecture decisions

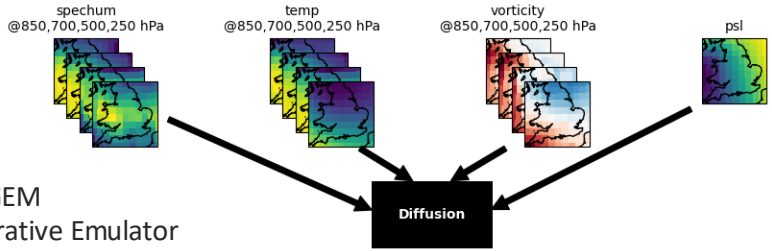
2) ML downscaling

ML has the potential to:

- Augment high resolution regional climate simulations at a fraction of the cost
- Provide a more comprehensive sampling of uncertainty (downscaling other GCMs/scenarios) to support decision making
- Downscale much richer set of global climate information (not just those for which LBCs are available)
- Provide regional information consistent with global projections, potentially including aerosol forcings that may be absent in RCMs
- Allow rapid production of local climate information
- Potentially enable km-scale attribution

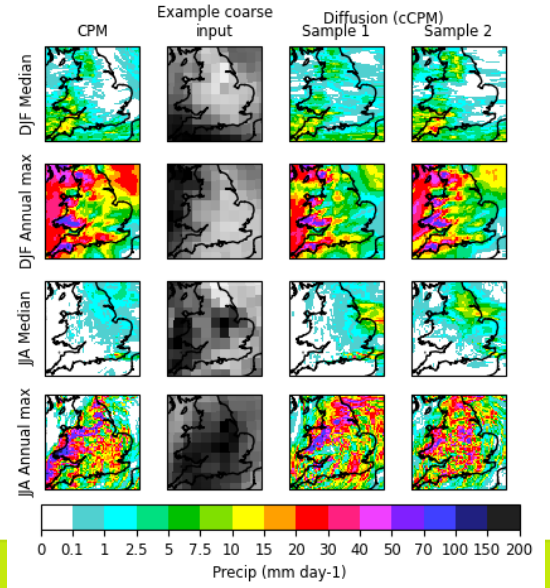


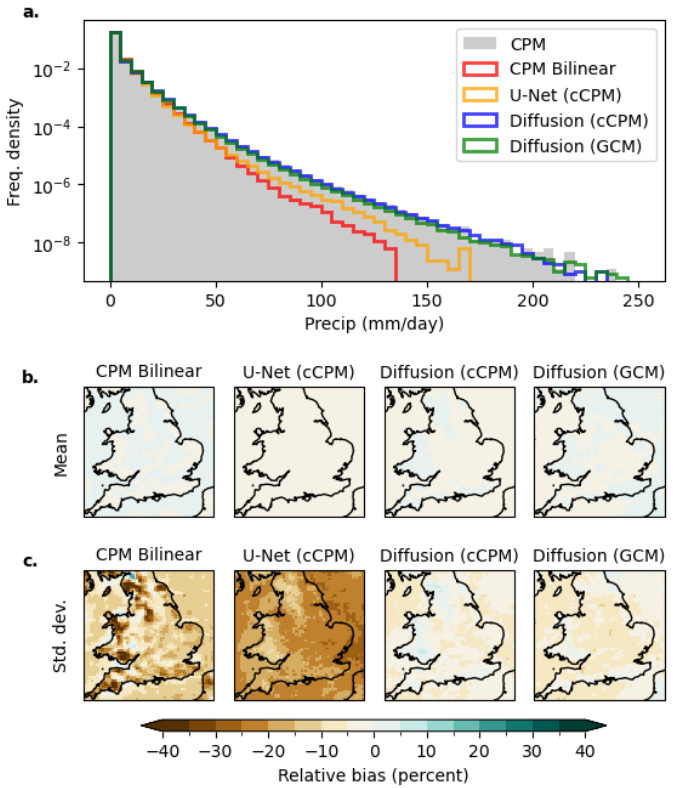
Emulating UKCP Local precipitation using ML



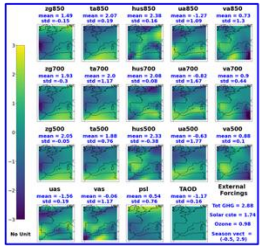
UoB-CPMGEM
CPM Generative Emulator

Addison et al, 2024

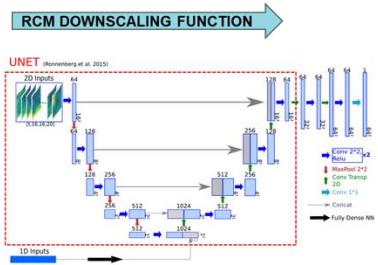




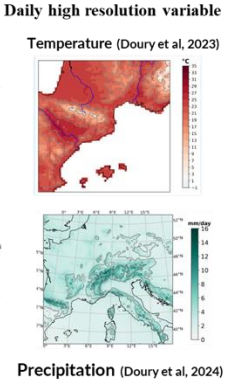
Emulating 12km RCM temperature/precipitation using a CNN



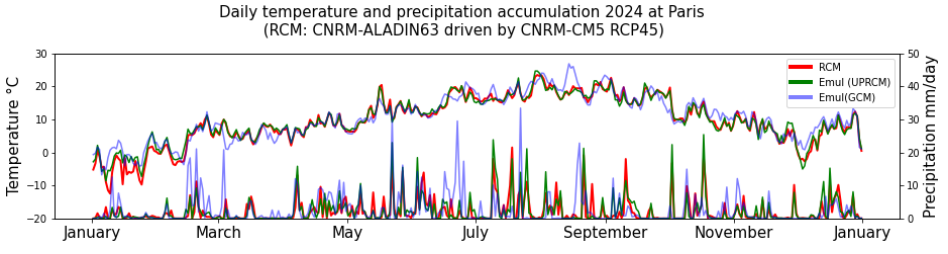
Low resolution inputs: Description of the daily atmospheric conditions

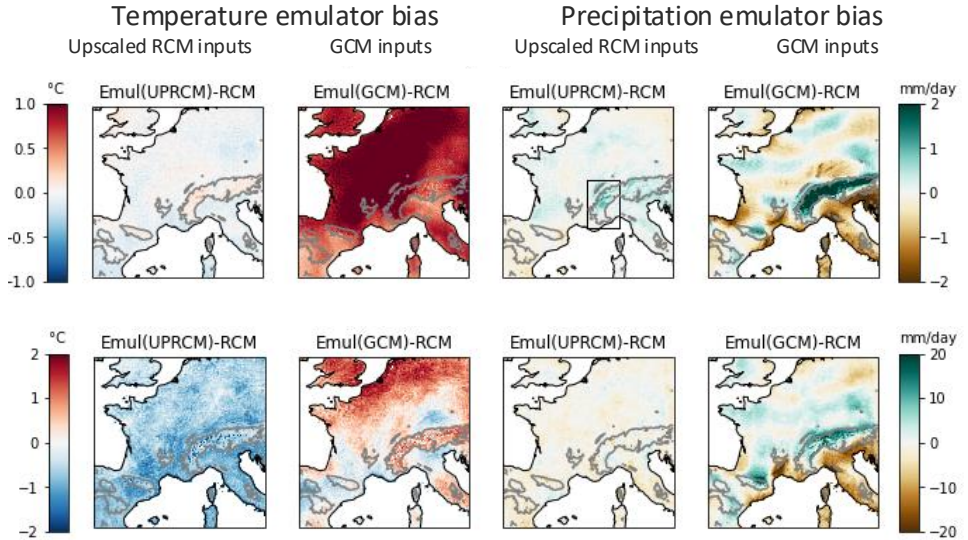


CNRM-UNET RCM-emulator



Doury et al, 2023, 2024

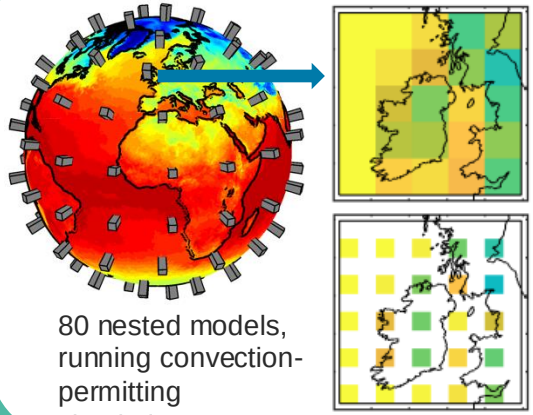




Intramodel ML

“Caramel”: Cloud Resolving Model Machine Learning

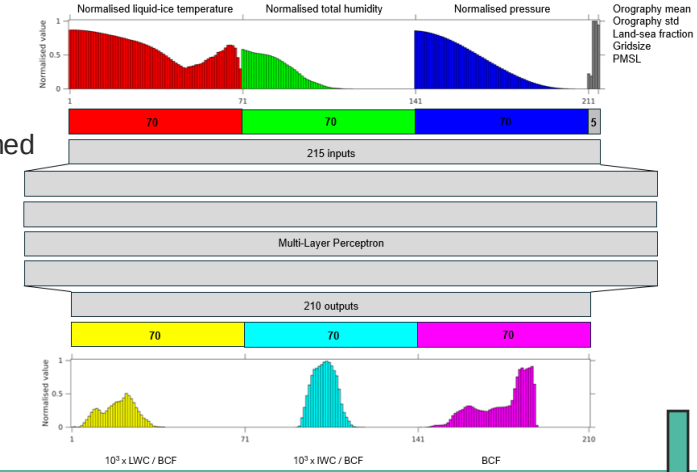
Use ML and our ability to run km-scale to improve our global model.



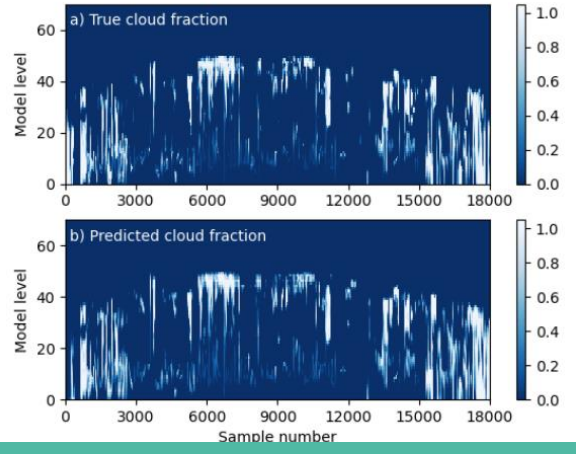
80 nested models, running convection-permitting simulations.

Coarse-grain 1.5 km data to a range of sizes from 100 km to 10 km

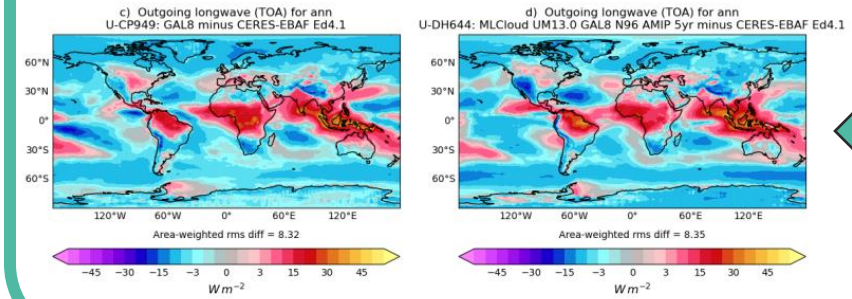
Train NN to predict coarse-grained high-res (CGHR) cloud from CGHR T,q,p and gridsize



Validate on with-held data.



Couple it to UM and run stable multi-year climate simulation.



Submitted paper by Cyril Morcrette, Helena Reid, Joana Rodrigues and colleagues at Bath University →

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AI and NEMO

Thanks to Julien le Sommer

NEMO WG on ML/AI and model uncertainties (2/2)

Roadmap objectives in terms of ML / AI (as of Jan 2023)

- Define how ML-based components should be included and delivered with the NEMO codebase **(interface, distribution/versioning)** [2 years]
- Deliver a proof of concept practical **implementation of a ML-based subgrid parameterization** in NEMO [2 years]
- Deliver a proof-of-concept **demonstration of the differentiable emulation** of (one of) NEMO (components) [3 years]
- NEMO reference codebase to comprise **several (peer-reviewed) ML-based components** usable in full scale production simulations [5 years]
- Inform **whether deep emulation is a viable option** for accelerating NEMO simulations on various architectures, and for approximating a linear tangent model for DA [5 years]

European Digital Twin Ocean EDITO Model Lab

AI4PEX

M2LiNES

MIAI Grenoble Alpes

TRACCS

implemented through projects

Parameterization of mixed layer eddies

$$\overline{w'b'} = \underline{\psi} \times \nabla_H \overline{b^z}$$

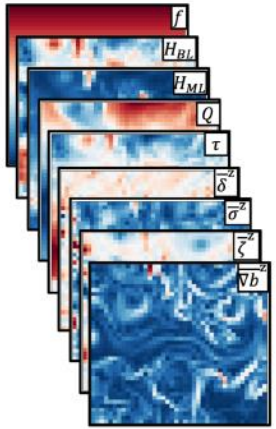
$$\underline{\psi} = f\left(\left|\overline{\nabla b^z}\right|, \overline{fc}, \overline{H}, \overline{Q^*}, div(u), rot(u), |\tau|, \overline{\sigma^z}\right)$$

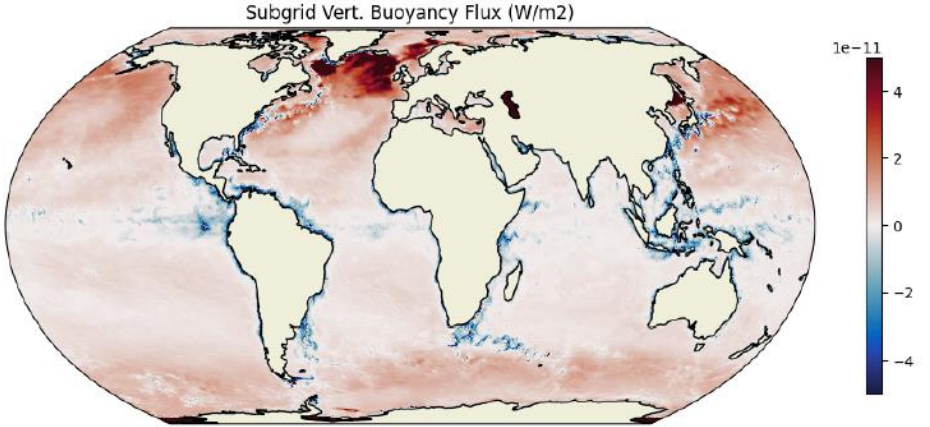
CNN inputs, X

Depth-averaged buoyancy gradient magnitude
Coriolis parameter
Mixed layer depth
Surface heat flux
Surface wind stress magnitude
Boundary layer depth
Depth-averaged strain magnitude
Depth-averaged vertical vorticity
Depth-averaged horizontal divergence

CNN Output, Y

Depth-averaged subgrid vertical buoyancy flux



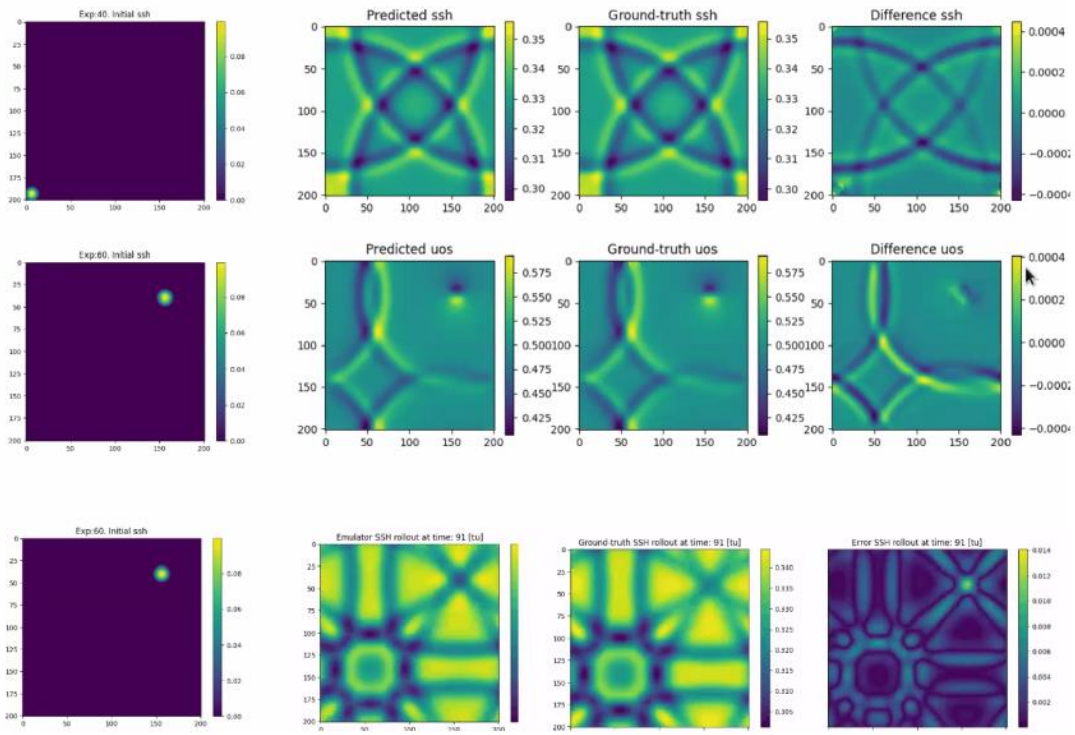


Online inference in eORCA25
with eophis interface

CNN model trained on MITgcm LLC4320
Bodner et al. 2024 : https://arxiv.org/abs/2312.06972

work at IGE by M. Contreras in collab.
with A. Bodner and D. Balwada

Emulating NEMO 2D barotropic dynamics



work at Hereon by Minh Nguyen

and David Greenberg (EDITO Model Lab)

European Digital Twin Ocean

EDITO ModelLab

Helmholtz-Zentrum hereon

NEMO standard TSUNAMI test case

NEMO

Ambition :

emulation of NEMO 2D dynamics for tide-related inverse problems

eg : estim. bottom friction, bathymetry

On-going work with **proof-of-concept** use for inversion in an **idealised set-up**

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Summary

- Programmes running within the Met Office for NWP and climate timescales
- NWP:
  - Investigation of existing models (e.g. Pangu)
  - Development of FastNet in collaboration with Turing Institute
- Climate:
  - Scoping stages of AI for climate projections
  - AI for downscaling
- NEMO (outside Met Office):
  - AI development as part of the NEMO work plan