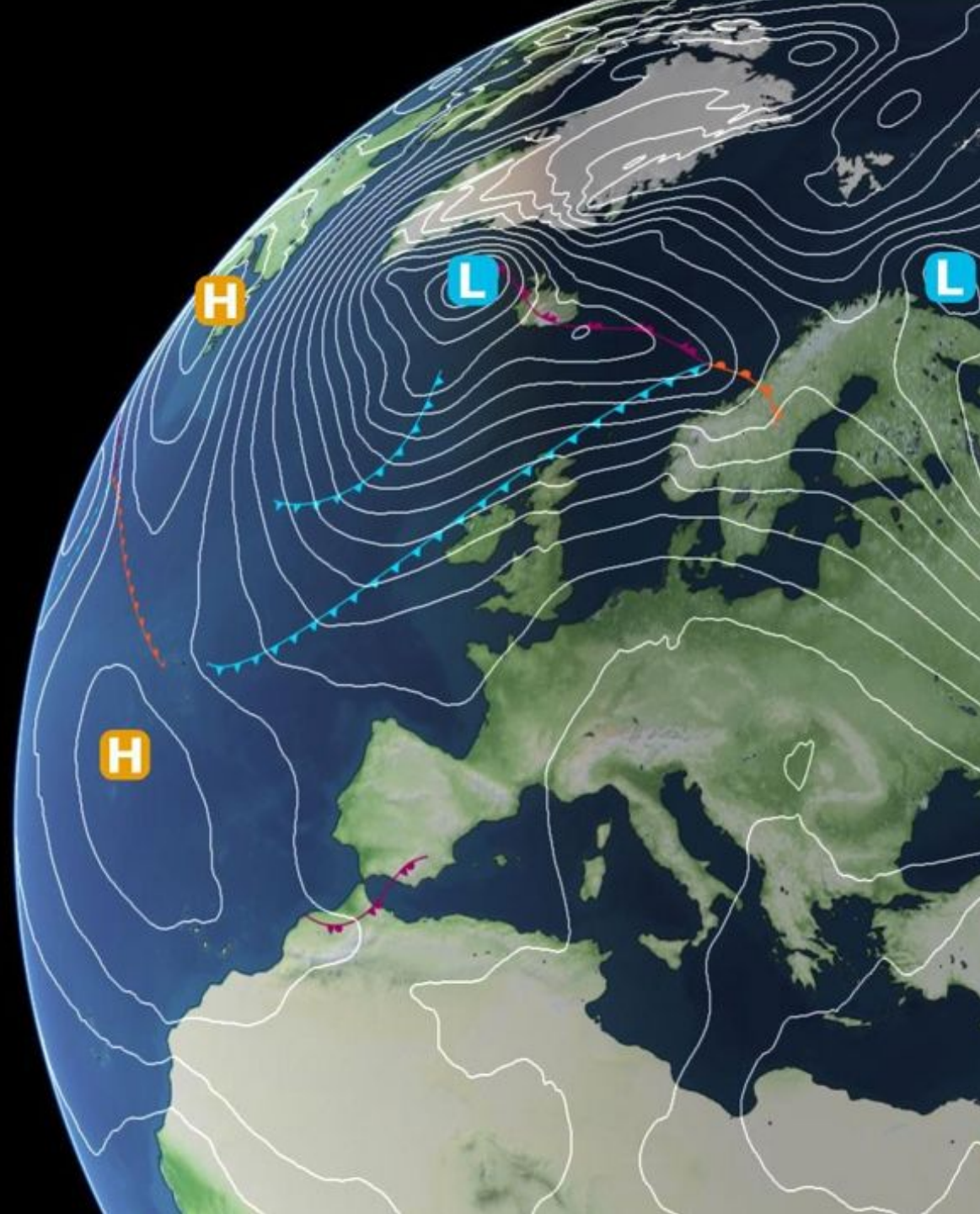


Hybrid machine-learning / physical model developments

Cyril Morcrette

June 2025



Model grid-length is like a fishing net.
The size of the mesh determines what it can catch.



The finer the mesh, the smaller the fish.

We want to use a coarse mesh but still be able to catch the small fish.

Seamlessness: for any size mesh, still catch fish of all sizes, even the small ones.

This talk is NOT about using AI/ML to make forecasting *faster* !

This talk is about using AI/ML to make the model *better* !

Kilometre-scale models are better at predicting clouds.

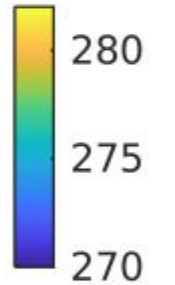
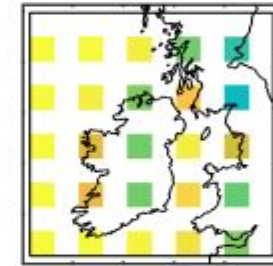
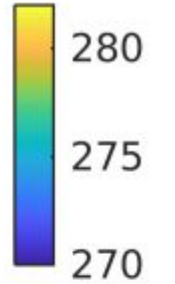
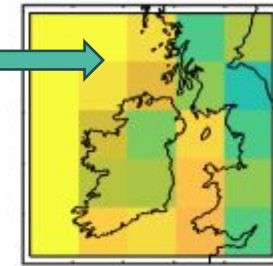
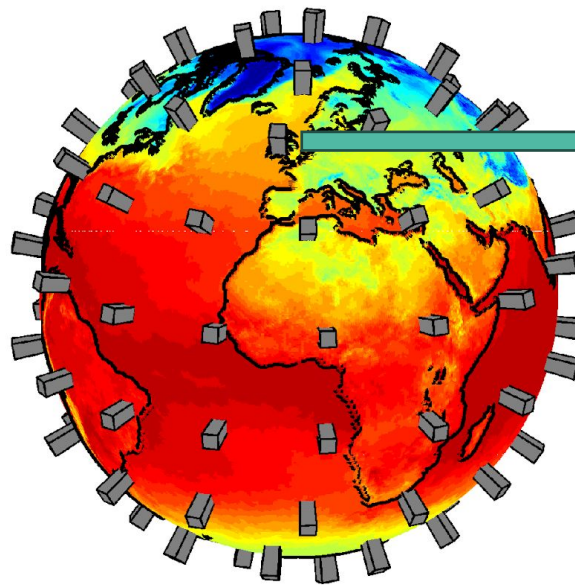
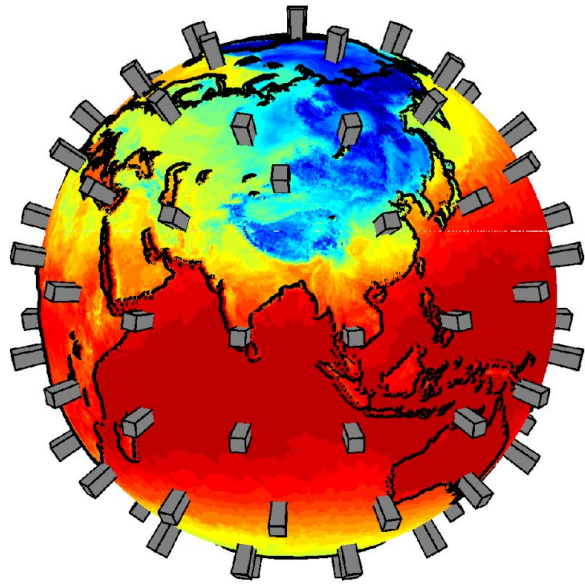
Going from a global climate model with $dx=100$ km to $dx=1$ km would lead to needing $100^3=1,000,000$ more compute.

If we can get some of the benefit for less than that, that is a massive WIN!

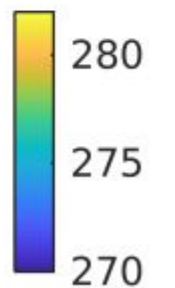
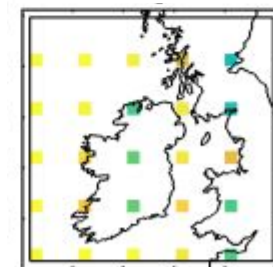
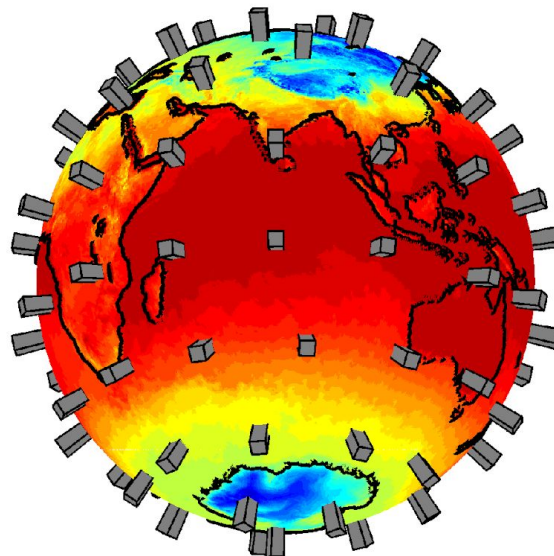
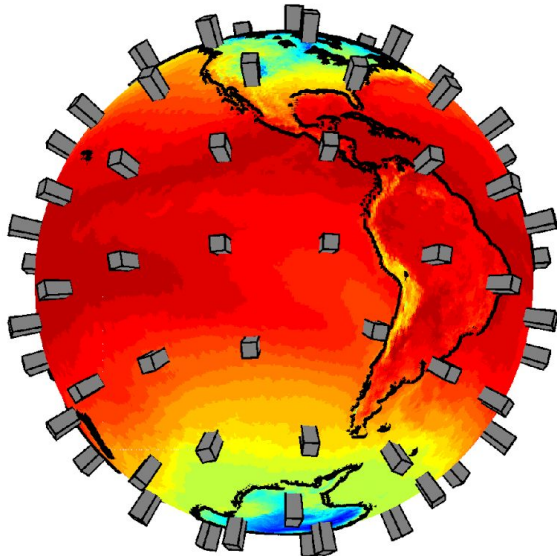
So not faster as such, perhaps slower even, but faster than what an increase in resolution would cost!

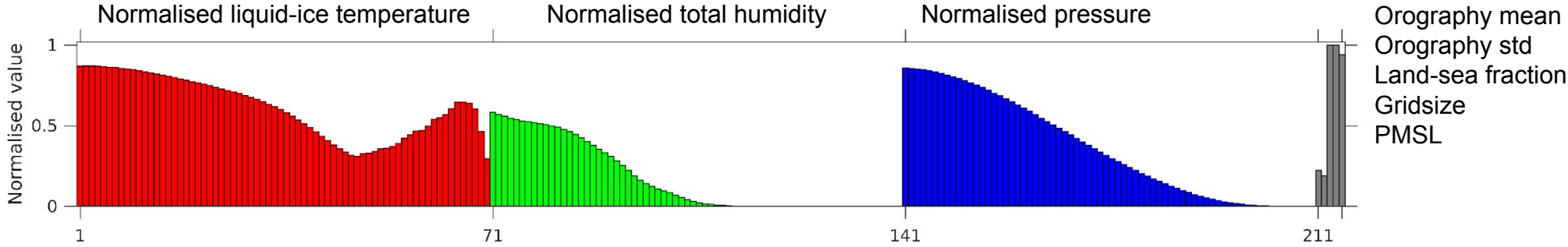


80 nested models,
each running
1.5 km
simulations
with
512x512
grid-points



Coarse-grain 1.5 km data
to a range of size from
144 km to 12 km

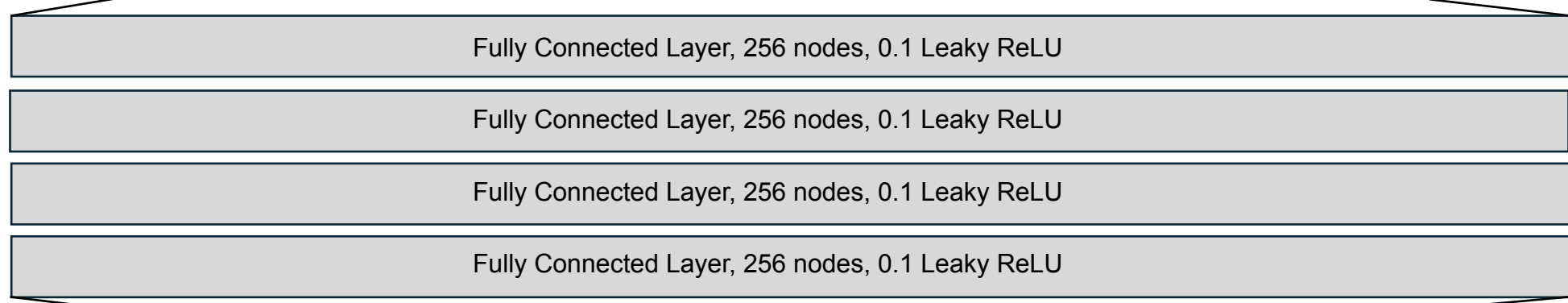




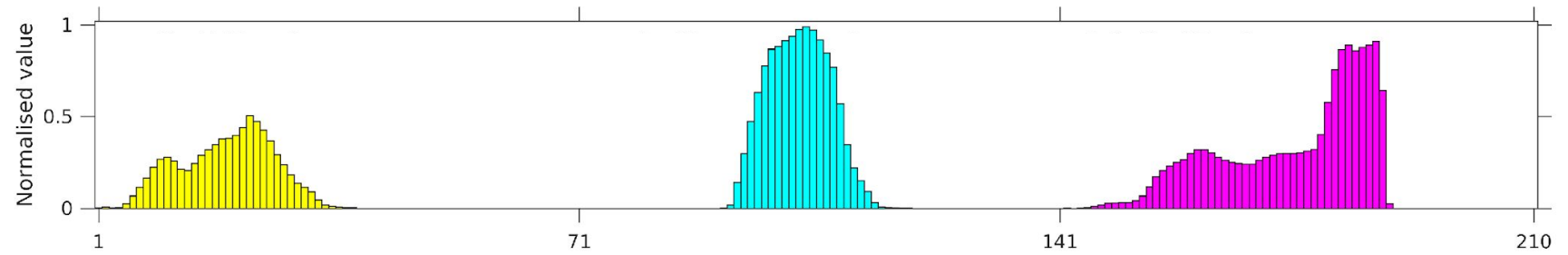
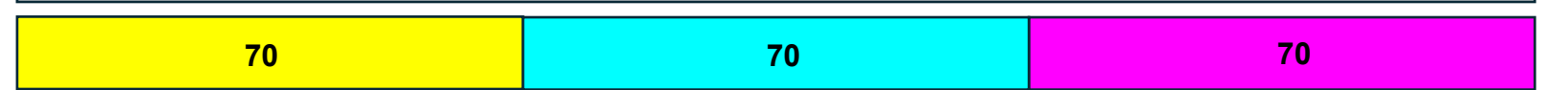
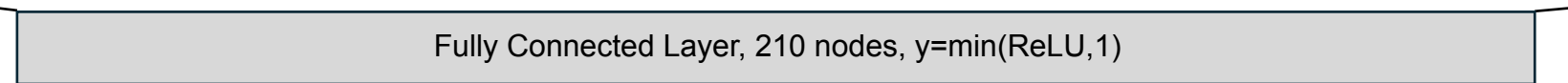
Input Layer



4 Hidden Layers



Output Layer

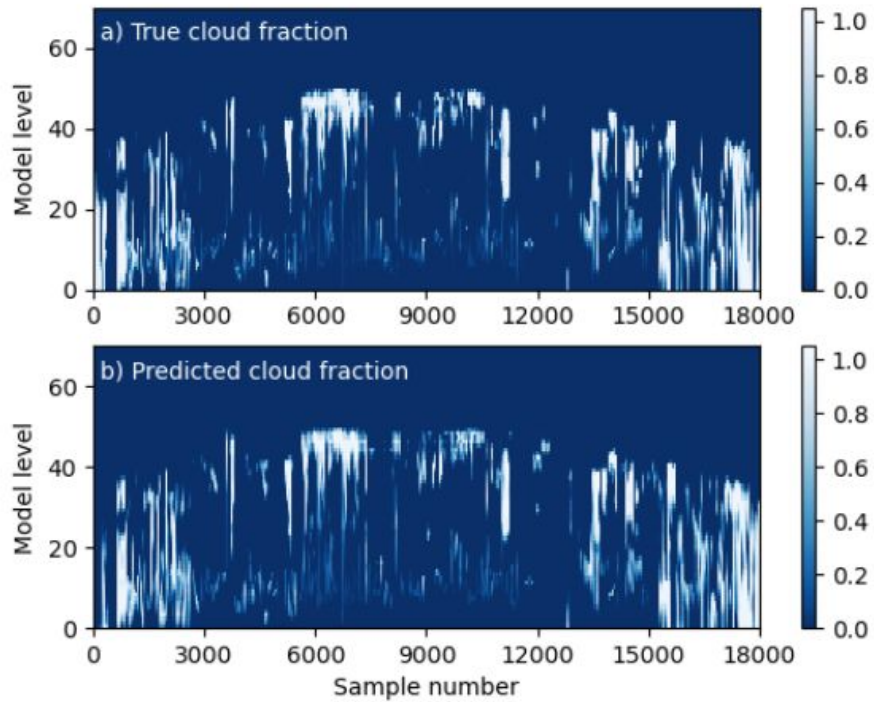


$10^3 \times \text{LWC} / \text{BCF}$

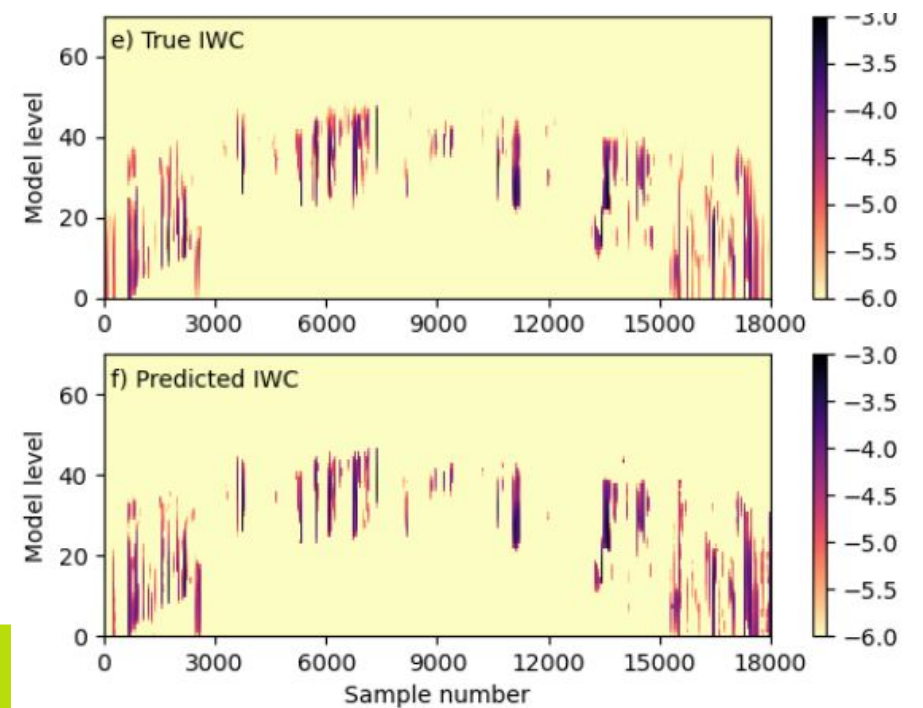
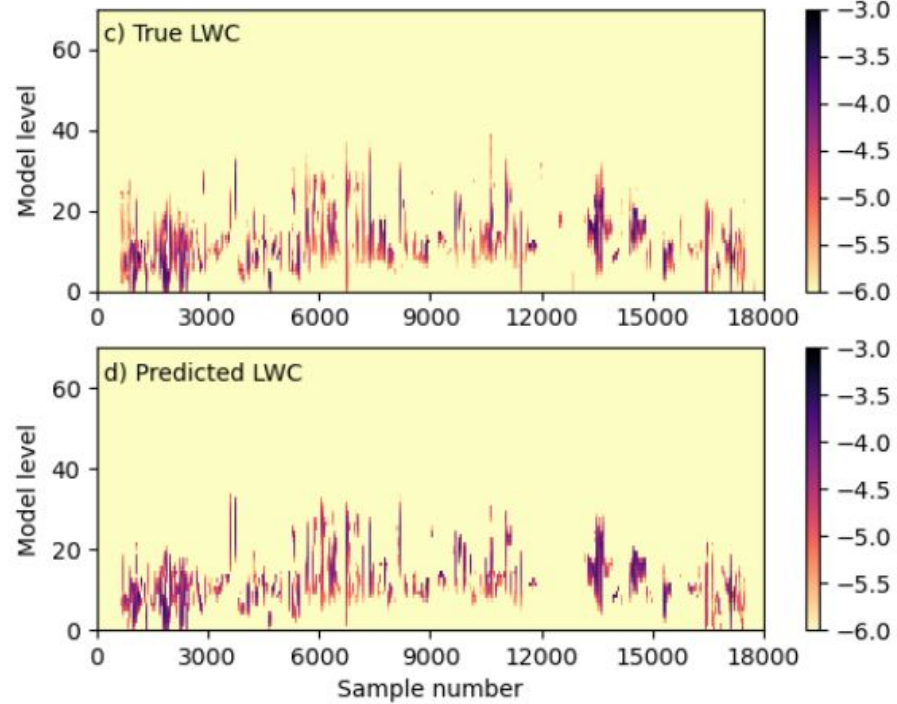
$10^3 \times \text{IWC} / \text{BCF}$

BCF

Orography mean
Orography std
Land-sea fraction
Gridsize
PMSL



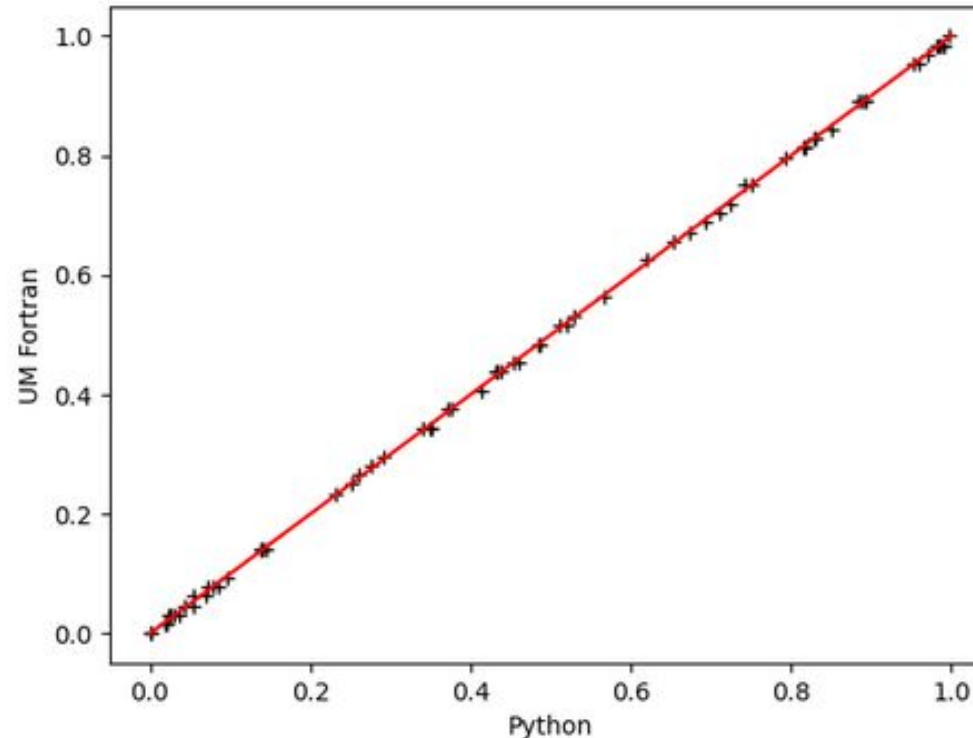
Validation against
not-used-in-training data



Coupling of Python-trained Neural Networks to the Unified Model written in Fortran.

Use the **ENNUF** frame-work *.

Includes sanity check that NN in Fortran reproduces known good output (KGO) from version in Python.

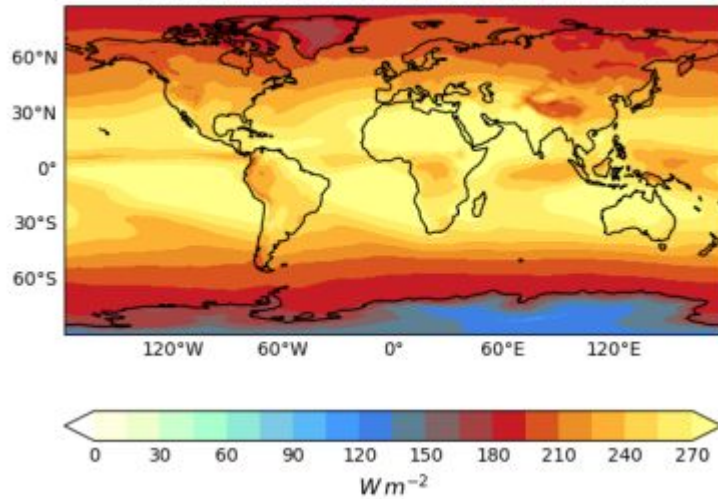


- ENNUF also works in LFRic model and in Exeter Uni's ISCA model.
- Beyond MLP, ENNUF also works for 1d CNN, RF and SVR.

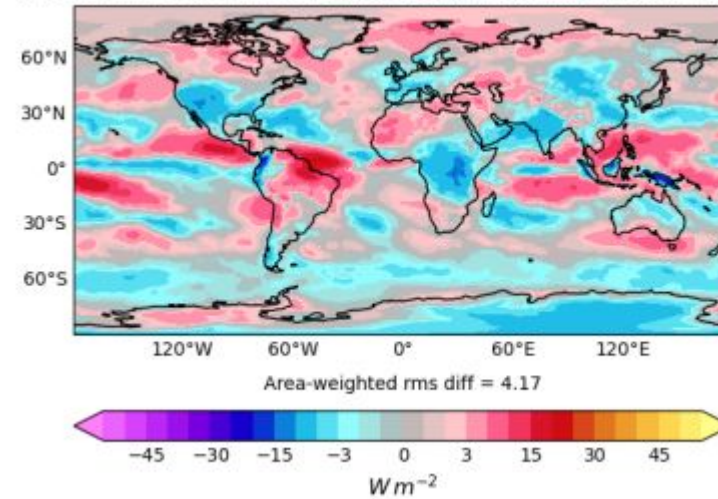
Replace the PC2 cloud scheme in the climate model with the ML one.

Runs stably for many years.

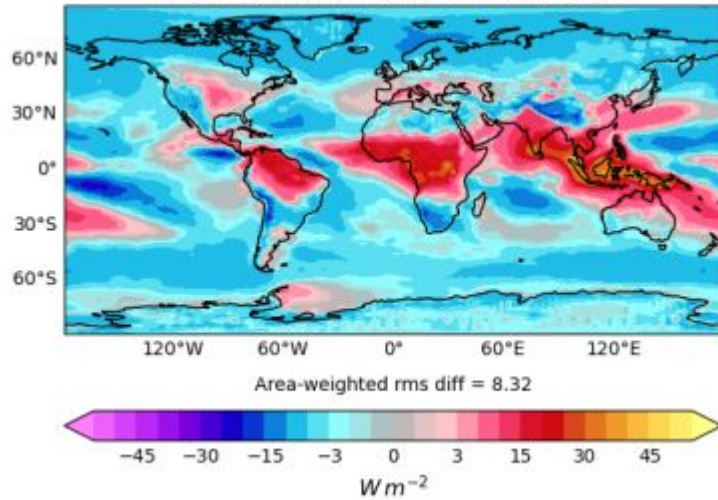
a) Outgoing longwave (TOA) for ann
U-DH644: MLcloud UM13.0 GAL8 N96 AMIP 5yr



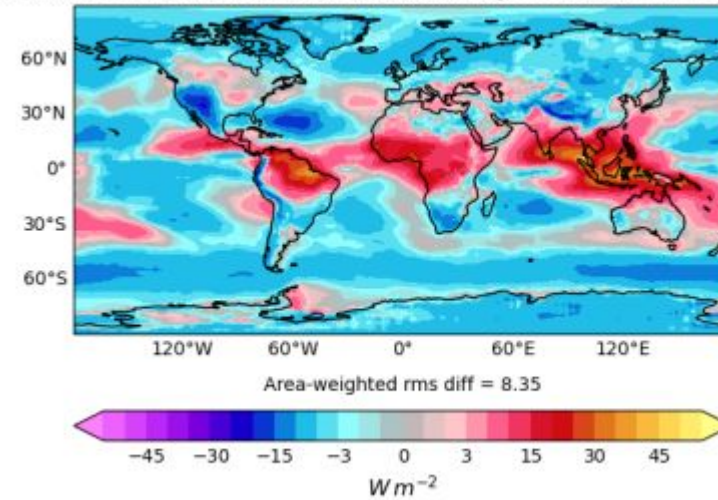
b) Outgoing longwave (TOA) for ann
U-DH644: MLcloud UM13.0 GAL8 N96 AMIP 5yr minus U-CP949: GAL8



c) Outgoing longwave (TOA) for ann
U-CP949: GAL8 minus CERES-EBAF Ed4.1



d) Outgoing longwave (TOA) for ann
U-DH644: MLcloud UM13.0 GAL8 N96 AMIP 5yr minus CERES-EBAF Ed4.1



From UM convective-scale simulations via
coarse-graining,
normalisation,
NN training & validation and
grafting into the UM

showing that convective-scale information can be machine-learned
and put back into the global model!

So convective-scale modelling is useful in itself (of course!)

but it is also useful as a source of high-res data to improve the
coarse model.

Seamlessness



What else could we machine learn and fuse back into UM/LFRic/Momentum?

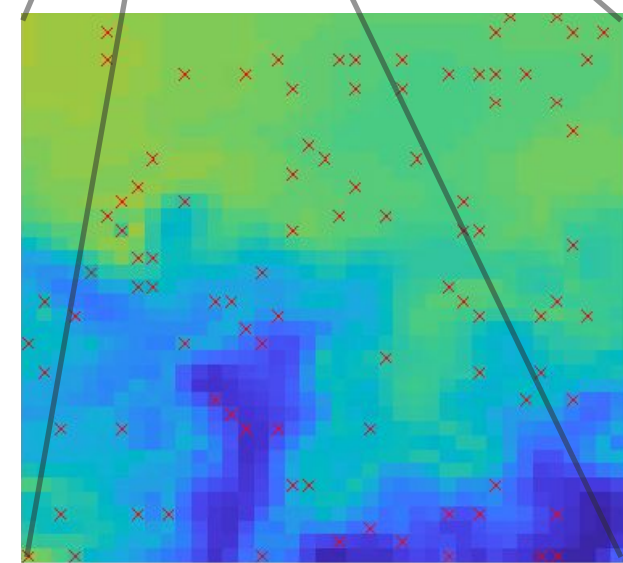
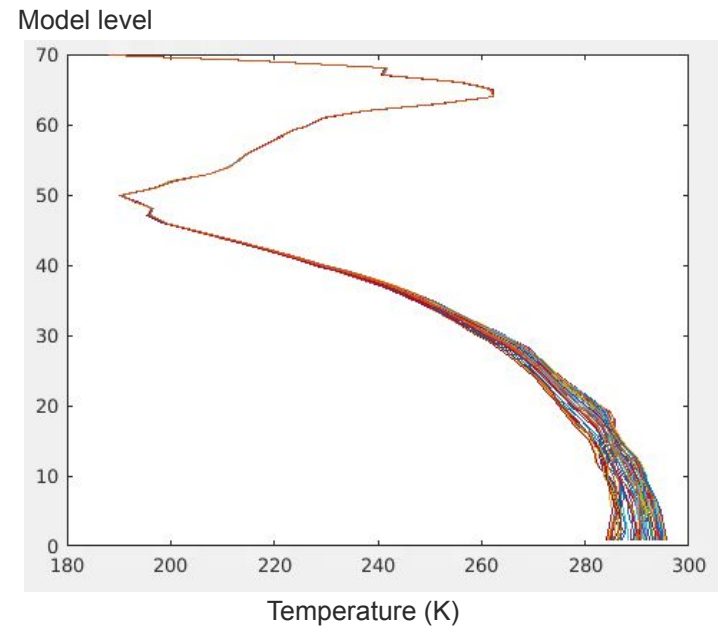
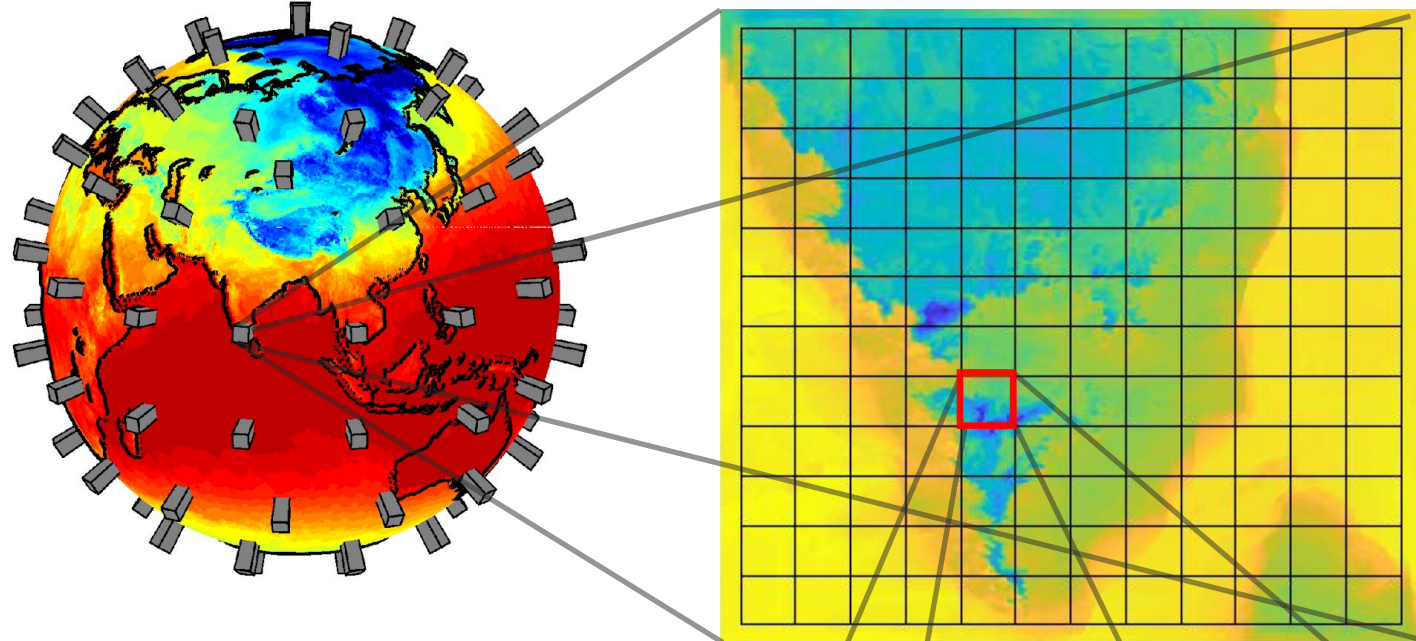
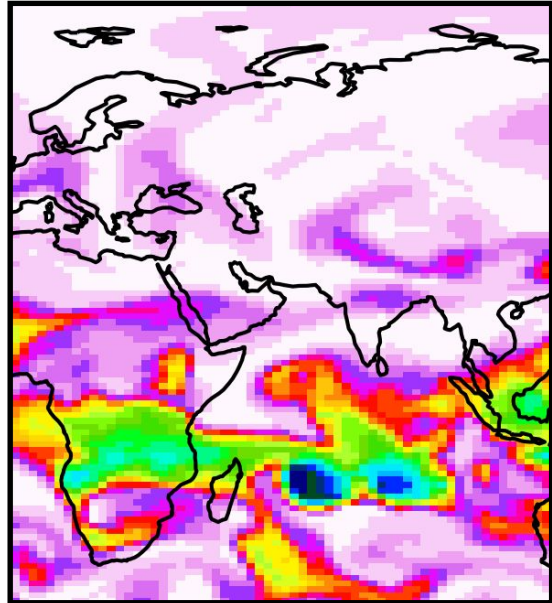
We are currently developing:

1. Emulation of raindrop-raindrop collection from bin microphysics scheme (Paul Field)
2. Emulation of heating rate profiles (Stephan Havemann)
3. Prediction of dynamic Smagorinsky diffusion coefficient (Paul Burns)
4. Emulation of difference between convection-parametrized and convection-permitting thermodynamic tendencies (Leon Borek). [See poster]
5. Stochastic perturbation of inputs to parametrization schemes (Helena Reid)
6. Refining vertical profiles of temperature and humidity (Joana da Silva Rodrigues)



PAPILLON

Plausible
Alternative
Profiles
Intelligently
Learned from
Lots of
Output from
NWP

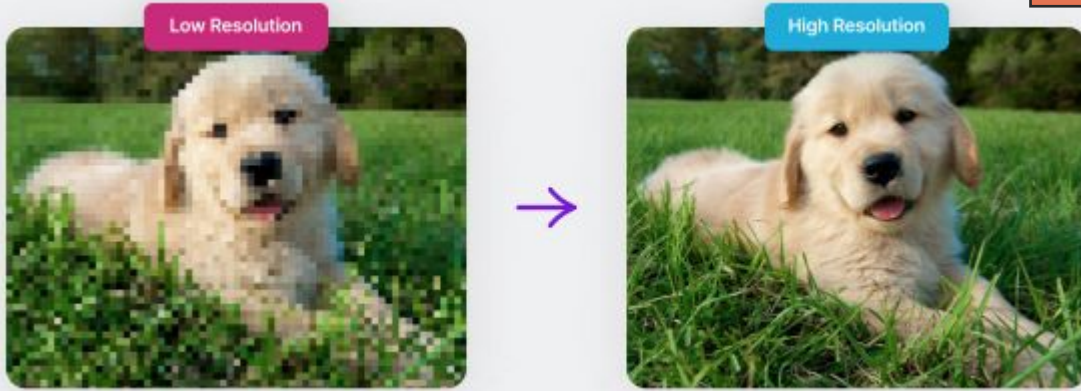


What about all the unresolved variability?

What if we could estimate it and use it to perturb our models?

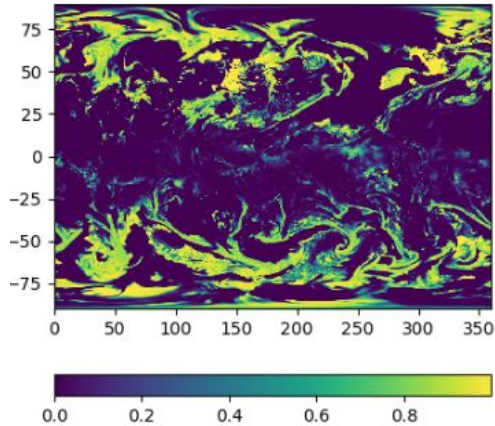
Improving vertical detail in temperature and humidity data using machine learning

“Super resolution” can be used to sharpen pictures of cute dogs.

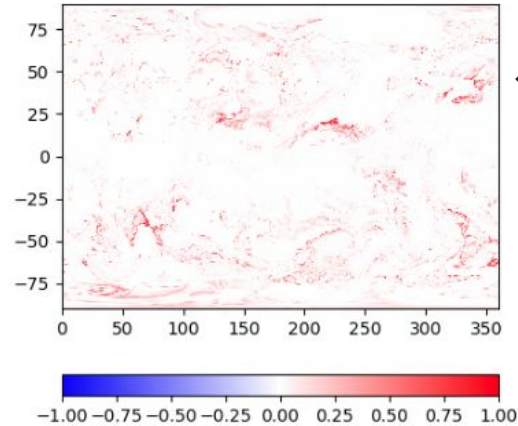


Uses 2d convolutional neural network (CNN) with 3 channels (red, green, blue).

Non-interactive test



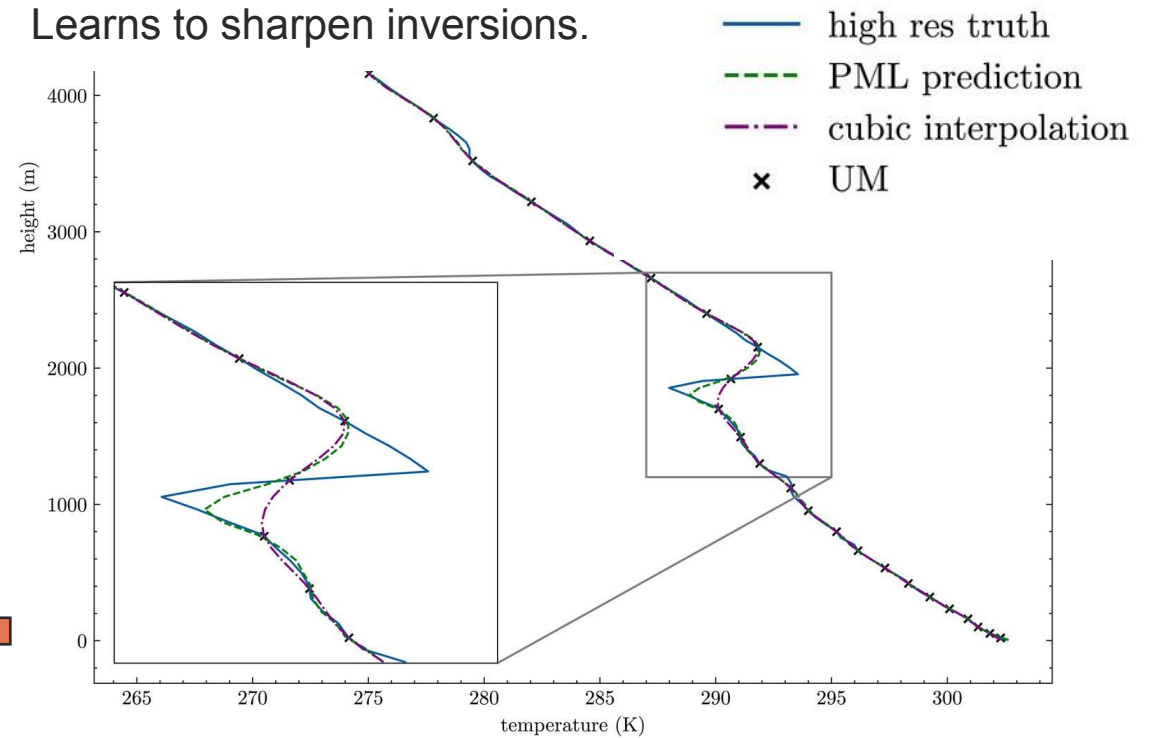
Difference



We use lots of radiosonde data for training.

Develop a 1d CNN, with 2 channels (temperature, humidity).

Learns to sharpen inversions.



Can be coupled to UM:

Take 70-level profile, refine, calculate high-res cloud, coarse-grain back.

Increases cloud cover.

Adjust T and q