Ensemble forecasts at ECMWF
yesterday / today / tomorrow / next month / next year / next decade

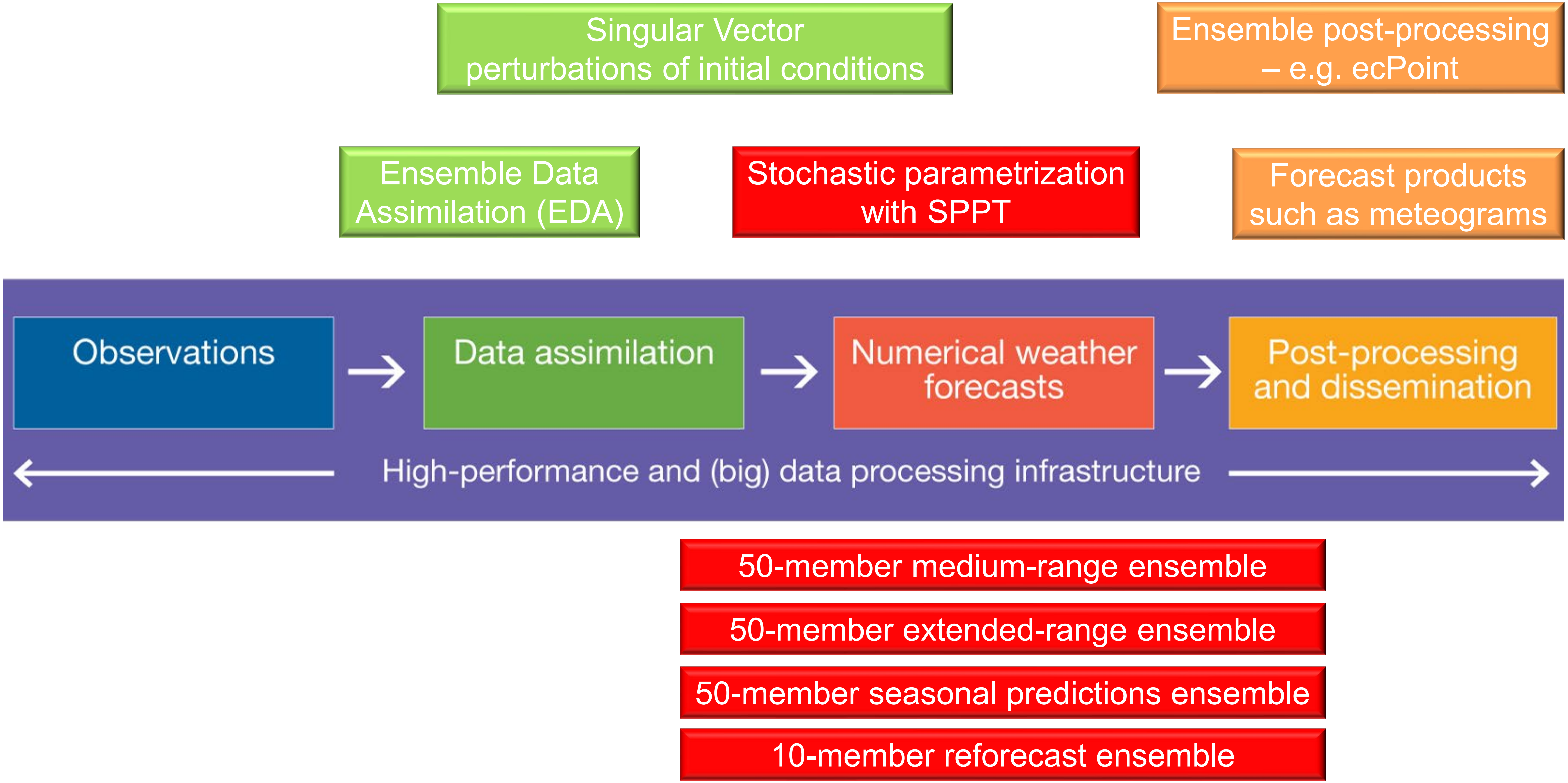
Peter Dueben with many contributions from the Model Uncertainty Team around Martin Leutbecher

Head of the Earth System Modelling Section

ECMWF | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

The strength of a common goal

Ensemble simulations are at the heart of ECMWF's predictions

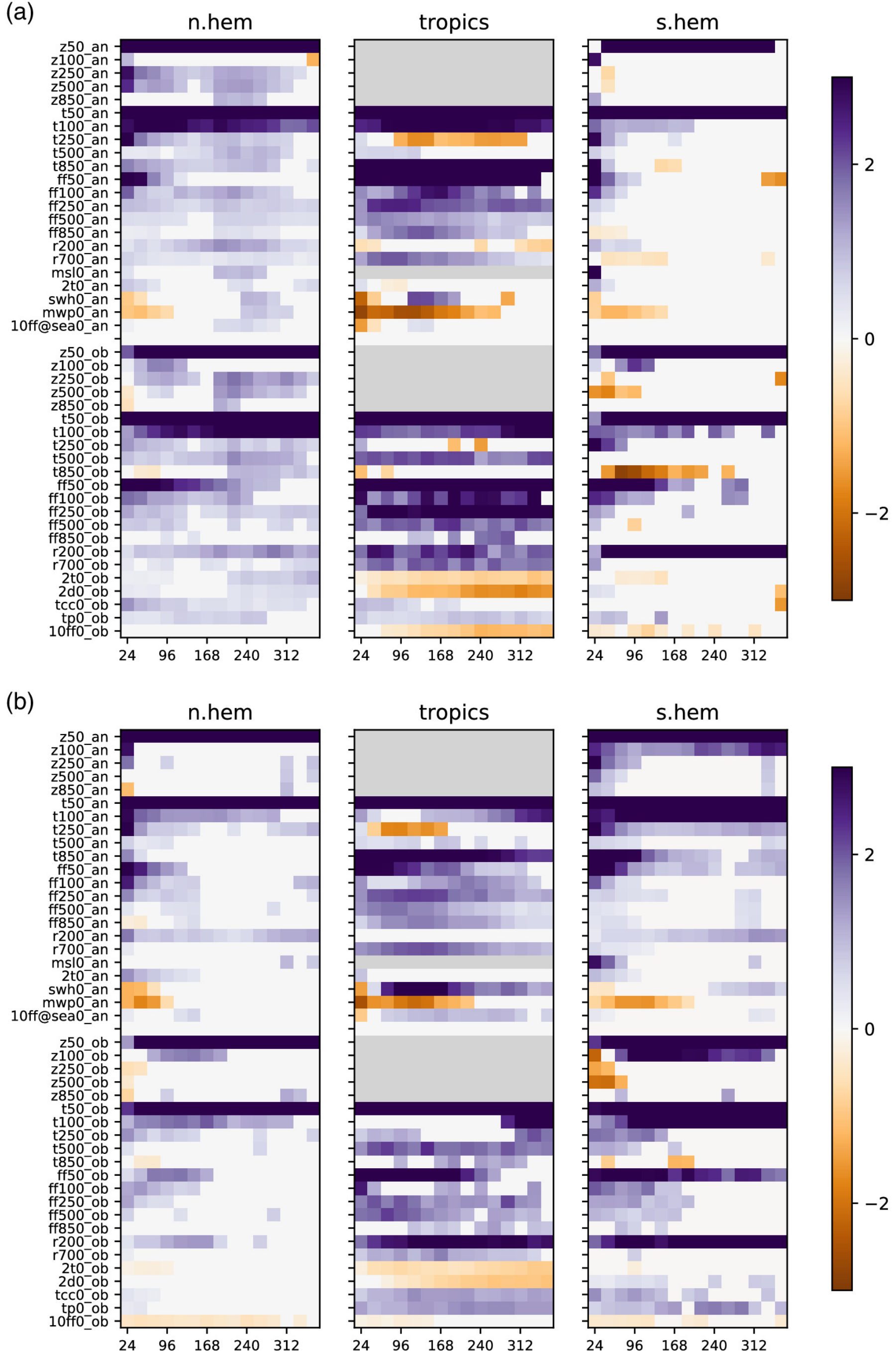


Yesterday: Ensemble simulations at ECMWF

More accuracy with less precision
Palmer 2012 → Lang et al. 2022

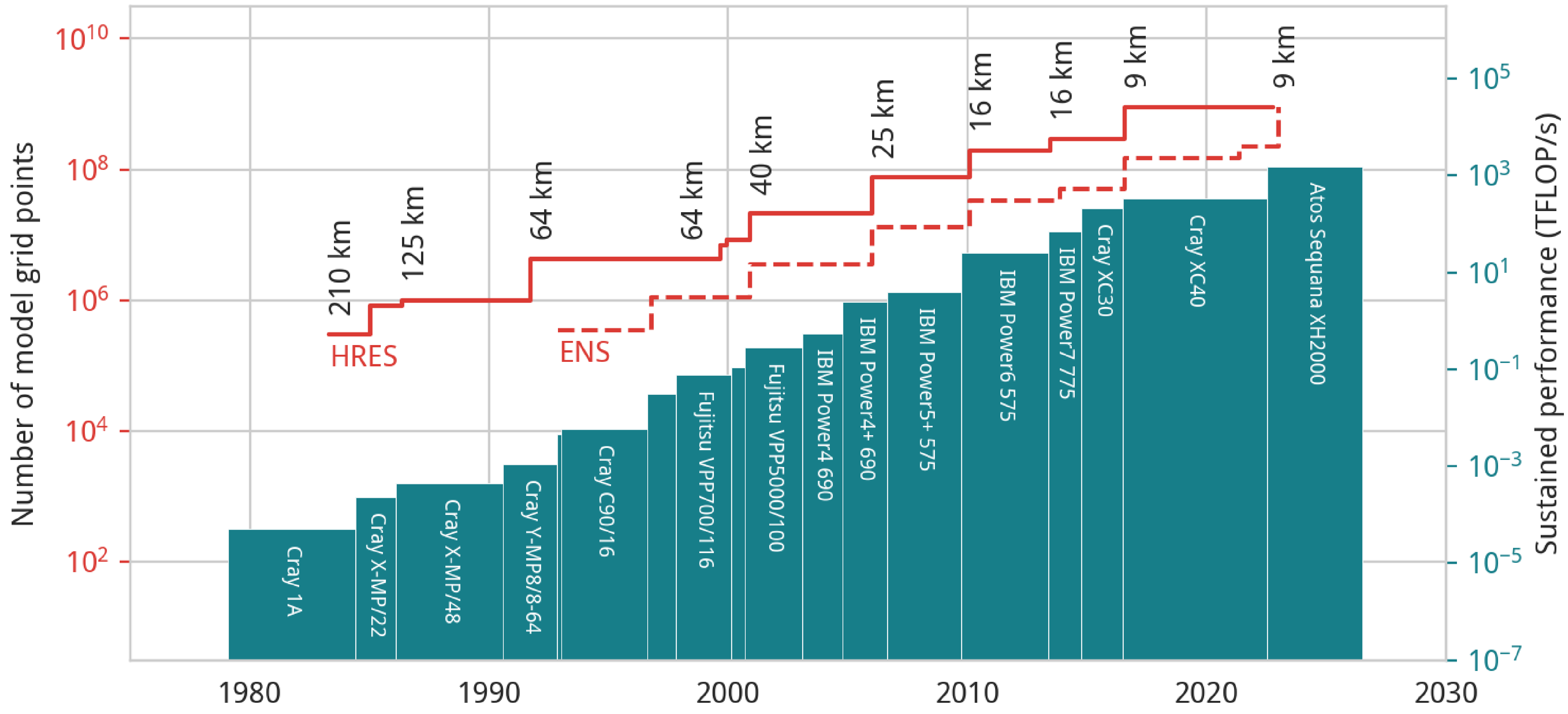
In IFS cycle 47R2, the change from double to single precision and from 91 to 137 vertical levels for the ensemble allows to reduce costs *and* improve predictions

Model configuration	Relative Cost
Double precision 91 levels	100%
Single precision 91 levels	57.9%
Double precision 137 levels	155.5%
Single precision 137 levels	87.5%



Relative changes in CRPS in % between SP137L and DP91L

Today: Ensemble simulations at ECMWF



In IFS cycle 48r1, the resolution of the extended range ensemble will catch up with the resolution of the deterministic “high-resolution” forecast

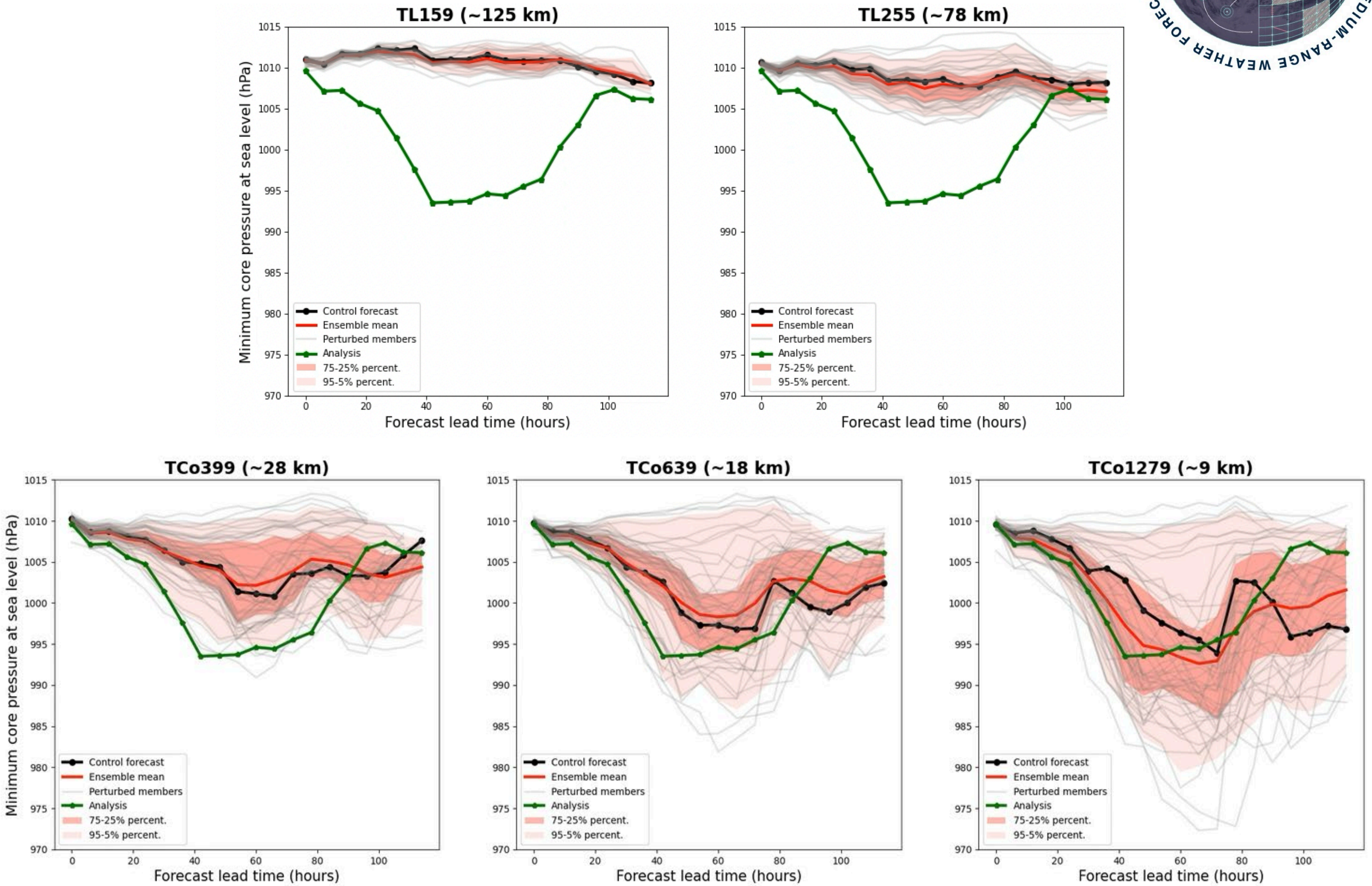
We will also have 100 ensemble members for extended range and seasonal

Figure courtesy of Sam Hatfield

Resolution matters: Core pressure at sea level for Medicane Ianos

- Ensemble prediction systems of older generations (~ 20 years ago) would have been unable to predict this event

- Current (18 km) and future (9 km) operational ensemble resolutions can reasonably predict the intensity of the medicane



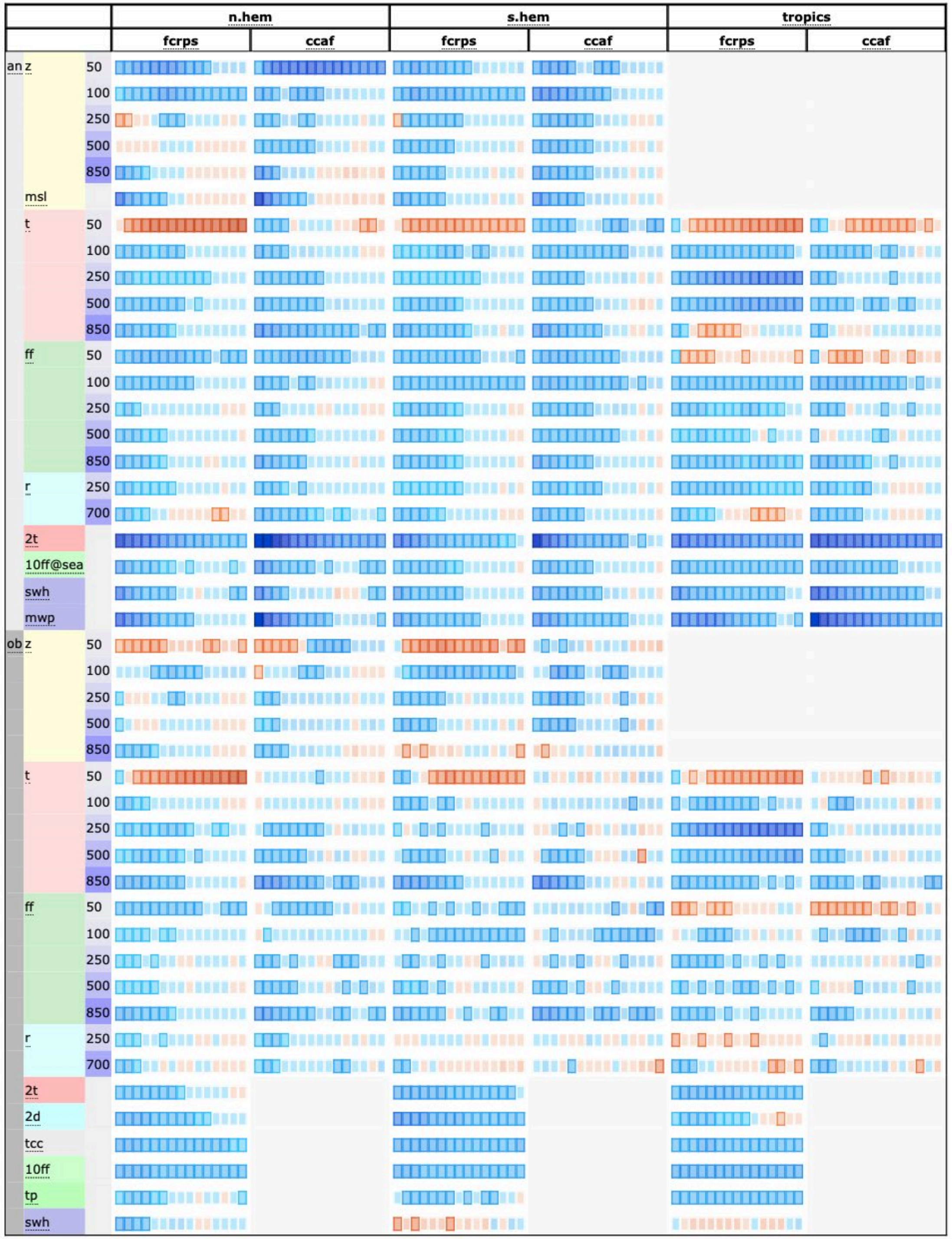
Special thanks to Aristofanis Tsiringakis

Ensemble resolution upgrade planned for 48r1

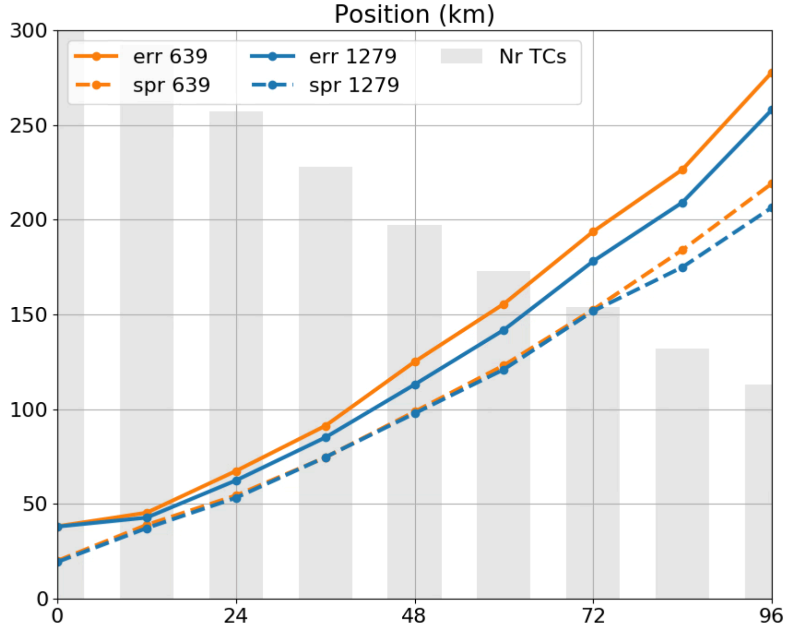
8 pert members,
00, 12 UTC
20200602 - 20200812,
20210901 - 20211031,
20201202 – 20210201

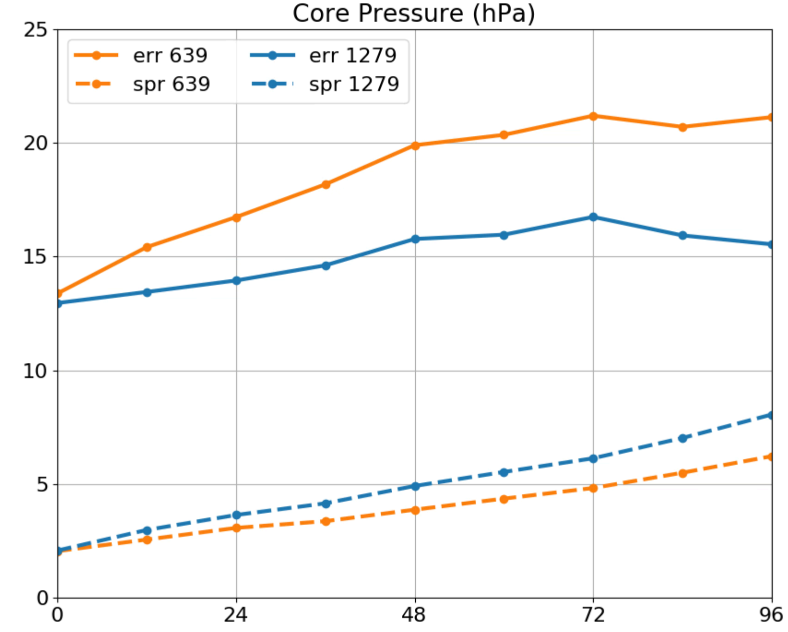
9 km (TCo1279)
vs 18 km (TCo639)

Note: only resolution upgrade contribution, not final scorecard for CY48r1



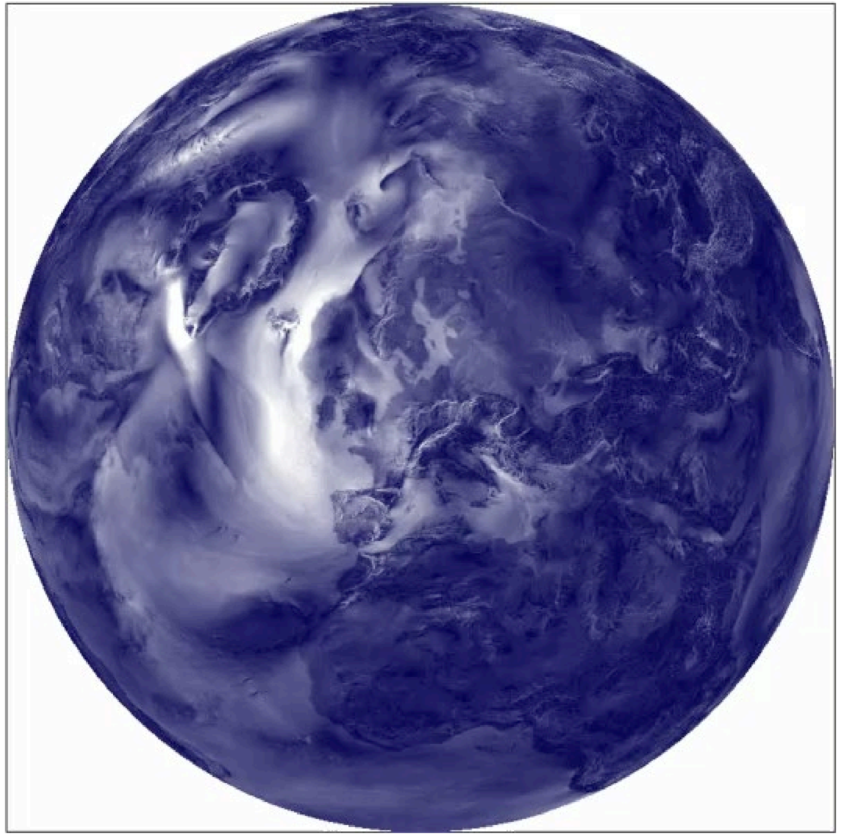
Impact on TCs



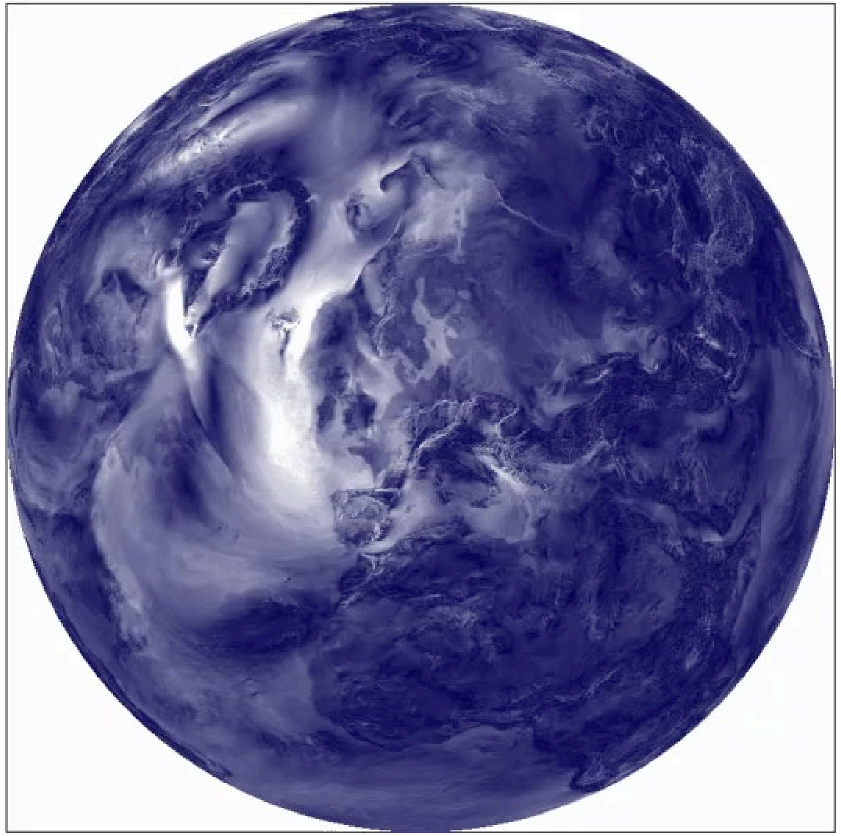


Special thanks to Simon Lang

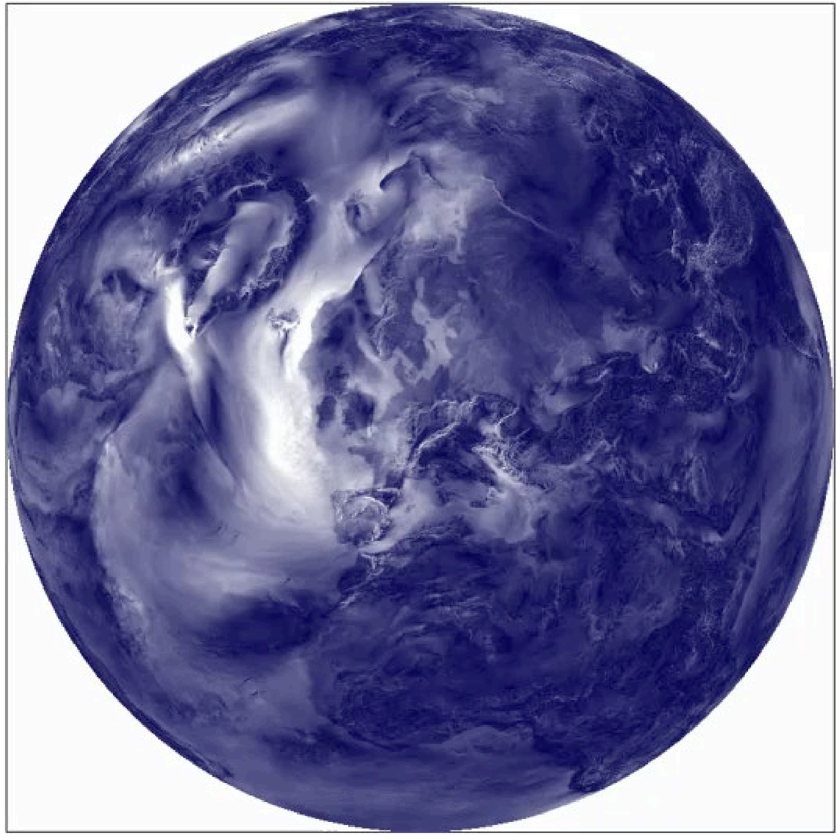
Animation of max wind gust at TCo1279L137



Control forecast



Perturbed forecast 1



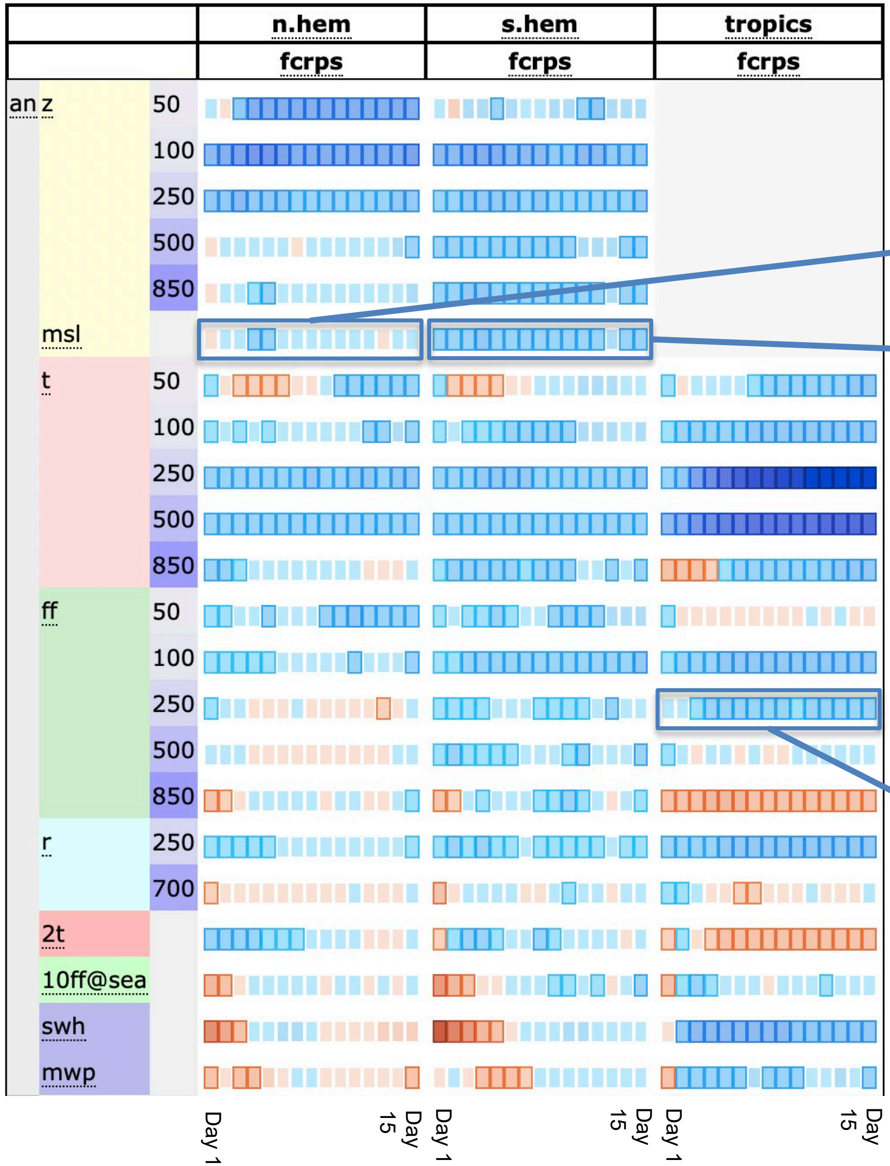
Perturbed forecast 2

Special thanks to Simon Lang

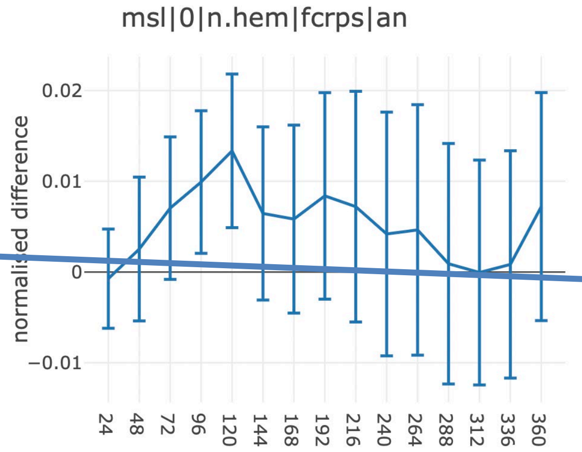
Tomorrow: Ensemble simulations at ECMWF

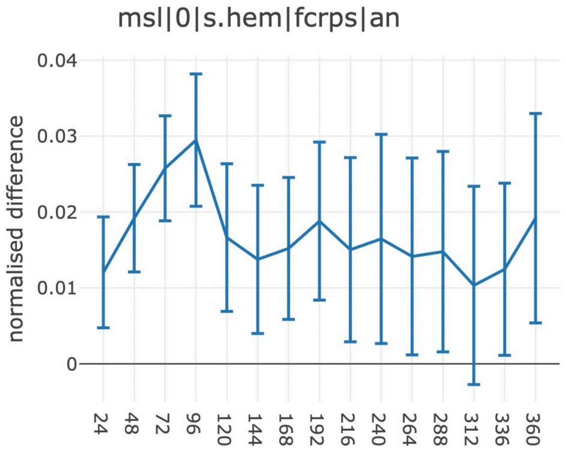
IFS cycle 49r1 will replace SPPT with SPP.

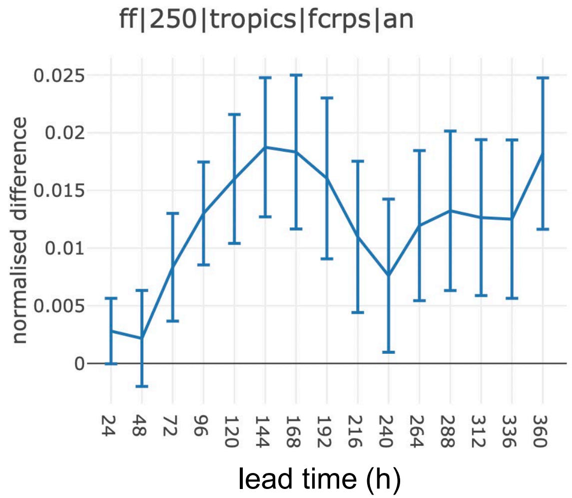
degradation *improvement*



Preliminary results – full scale testing with 48r1 in progress







Experiments:

- CY47R3
- 9km ENS (TCo1279)
- 8+1 members
- fair CRPS (fcrps)
- Starts: every day, Jun+Jul+Dec+Jan 2020/21 at 00/12 UTC
- Forecast period: 15 days
- IC perturbations: EDA, SVs, ocean Ics

See also Lang et al. QJRMS 2021

Tomorrow: Ensemble simulations at ECMWF

Tim does not approve the change from SPPT to SPP…

Slide from Tim Palmer's presentation at the Uncertainty Workshop at ECMWF in May 2022:

SPPT: Devised as an alternative to parameter perturbation.

MM: Perturbing parameter values as if they were independent of one another makes no physical sense. We should treat model uncertainty more holistically.

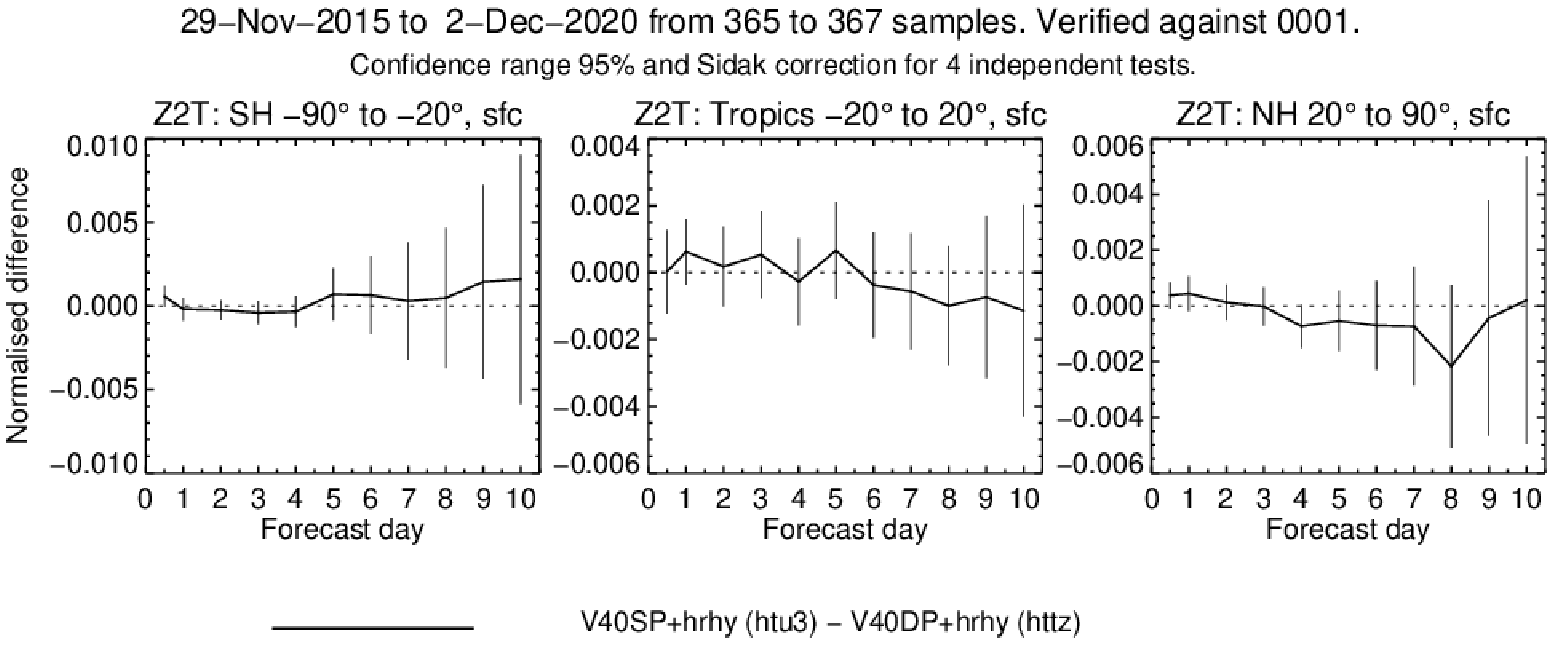
TP: We need to address the representation of ontological model uncertainty associated with the need to truncate the underlying PDEs and hence go beyond parameter perturbation schemes.

SPPT is easy to maintain across model cycles. By contrast, parameter perturbation schemes will have to be retuned each time new or revised parametrisations are introduced.

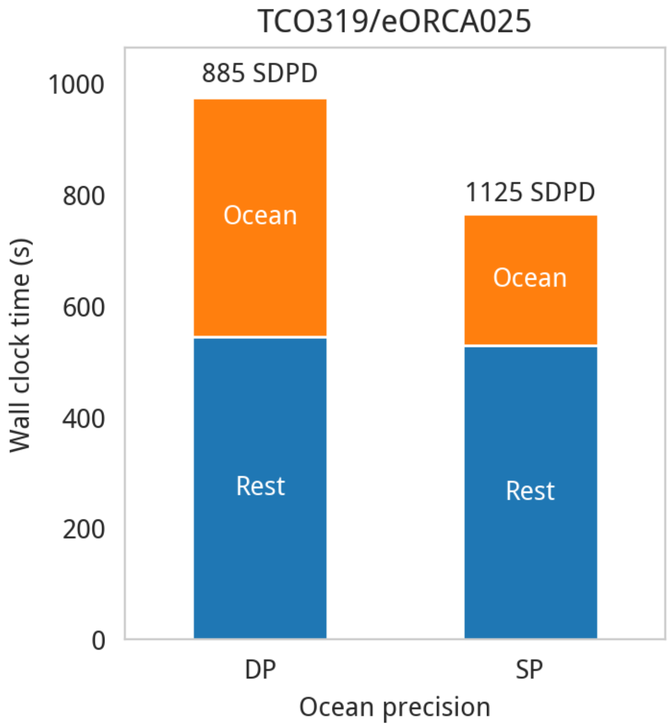
Tomorrow: Ensemble simulations at ECMWF

IFS cycle 49r1 will, among other changes, introduce the new version 4 of the NEMO ocean model which will run in single precision

A reduction from double precision to single precision results in neutral forecast scores:



But the cost is reduced significantly:



Sam Hatfield et al.

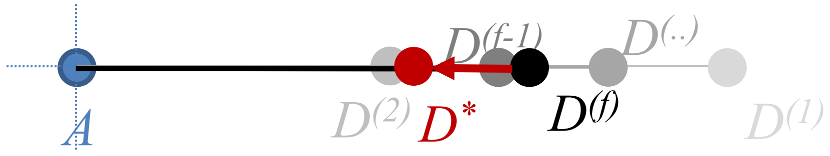
Next week: Ensemble simulations at ECMWF

ECMWF's four-year plan:
The new representation of model uncertainty via the Stochastically Perturbed Parametrization (SPP) scheme will be implemented in operations in 2023. Then, work will focus on ***extending SPP to represent uncertainties in surface processes of land, snow and ocean waves****. In parallel, work will explore options to incrementally improve the scheme at* ***all lead times****, for example through modifications of the probability distributions of the perturbed parameters.* ***Work on the use of SPP in km-scale simulations and an evaluation of ensemble scores if conventional forecast products are combined with simulations with up to 1.5 km grid spacing*** *will be performed in preparation for the digital twin on weather-induced extremes from DestinE and will help inform the future evolution of the operational ensemble configuration.*

Next week:

STOCHDP: *Stochastically perturbed semi-Lagrangian (SL) departure point (DP) estimate*

The semi-Lagrangian scheme in IFS is converging towards the final departure point D^*:



Convergence rate of the iterative departure point estimate is flow-dependent

Slowest convergence ←→ most complex flow (strong shear / curvature)

Model uncertainty (MU) scheme, “STOCHDP” is using the departure point estimate convergence rate to attribute model uncertainty by:

final DP estimate

random number

$$D^* = D^{(f)} + r\left(D^{(f)} - D^{(f-i)}\right), i = 1..f-1$$

perturbed DP estimate

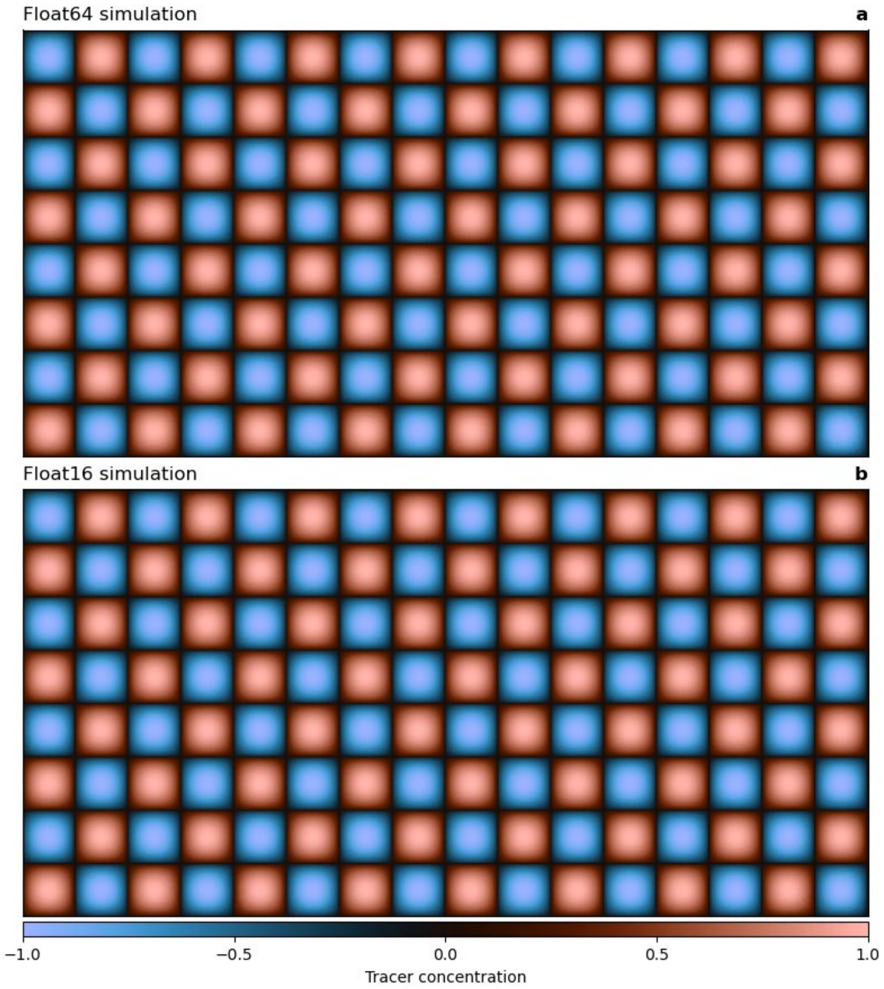
Δ between final and earlier DP estimate

New SLDP scheme: STOCHDP acts on D(3) - D(2)

➢ Testing underway: sensitivities to random pattern & resolution, skill impact in ENS

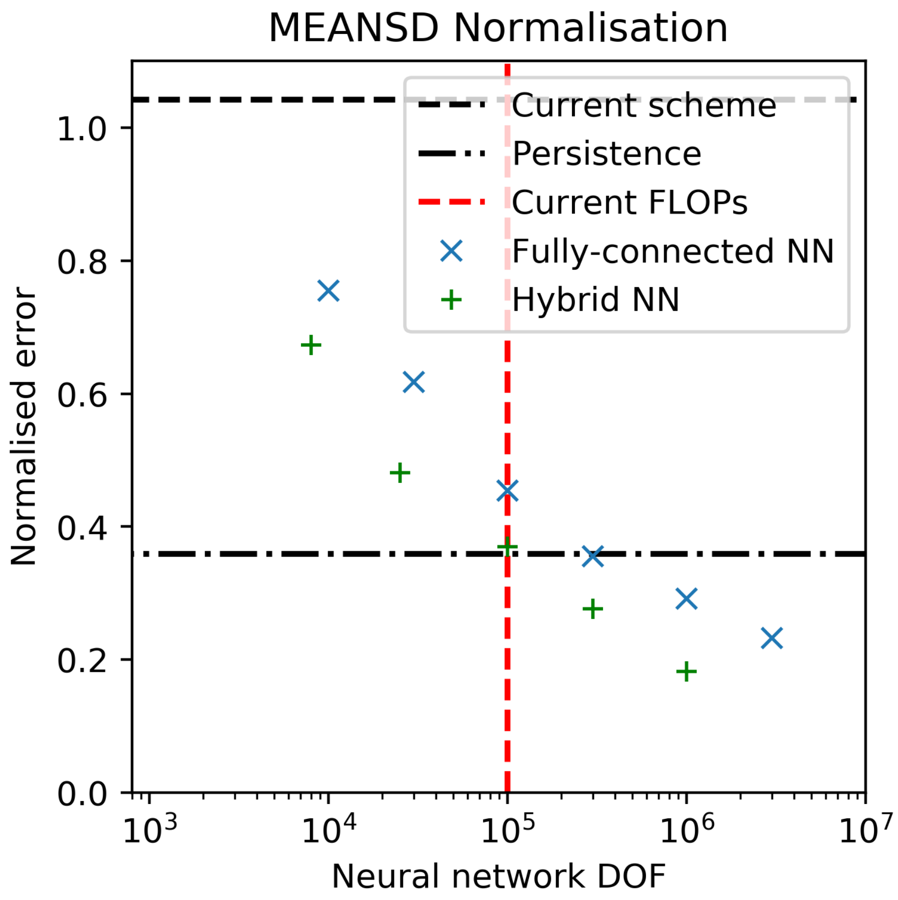
Lock, Diamantakis, Leutbecher and Lang

Next month: Will we trade precision against performance even more?



A shallow water simulations in double precision and in half precision achieving a speed-up factor of 3.8x on A64FX on ISAMBARD-2.

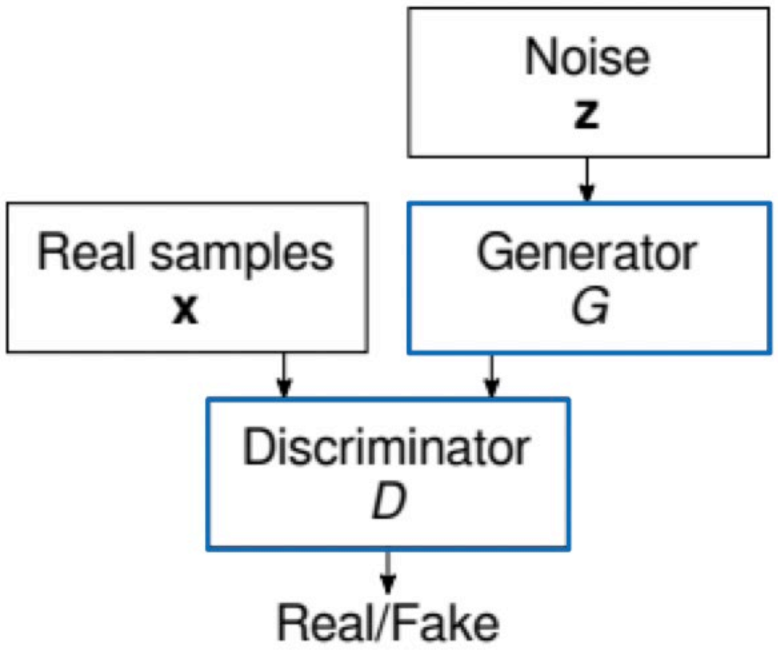
Kloewer, Hatfield, Croci, Dueben, Palmer JAMES 2022



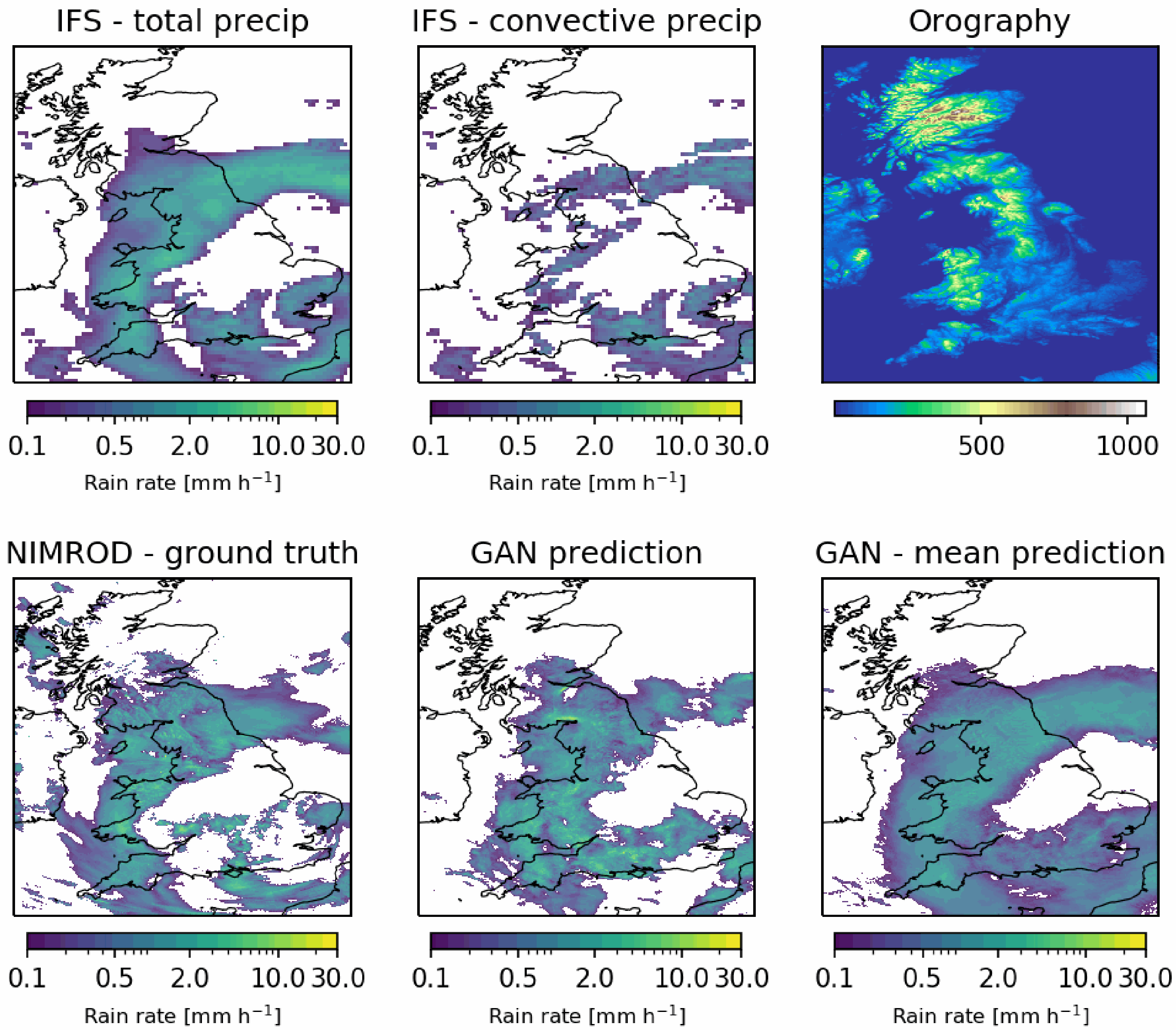
A machine learning emulator for the non-orographic gravity wave parametrisation scheme.

Chantry, Hatfield, Dueben, Polichtchouk and Palmer JAMES 2021

Next month: Shall we combine forecast models more with machine learning?
Downscaling with Generative Adversarial Networks

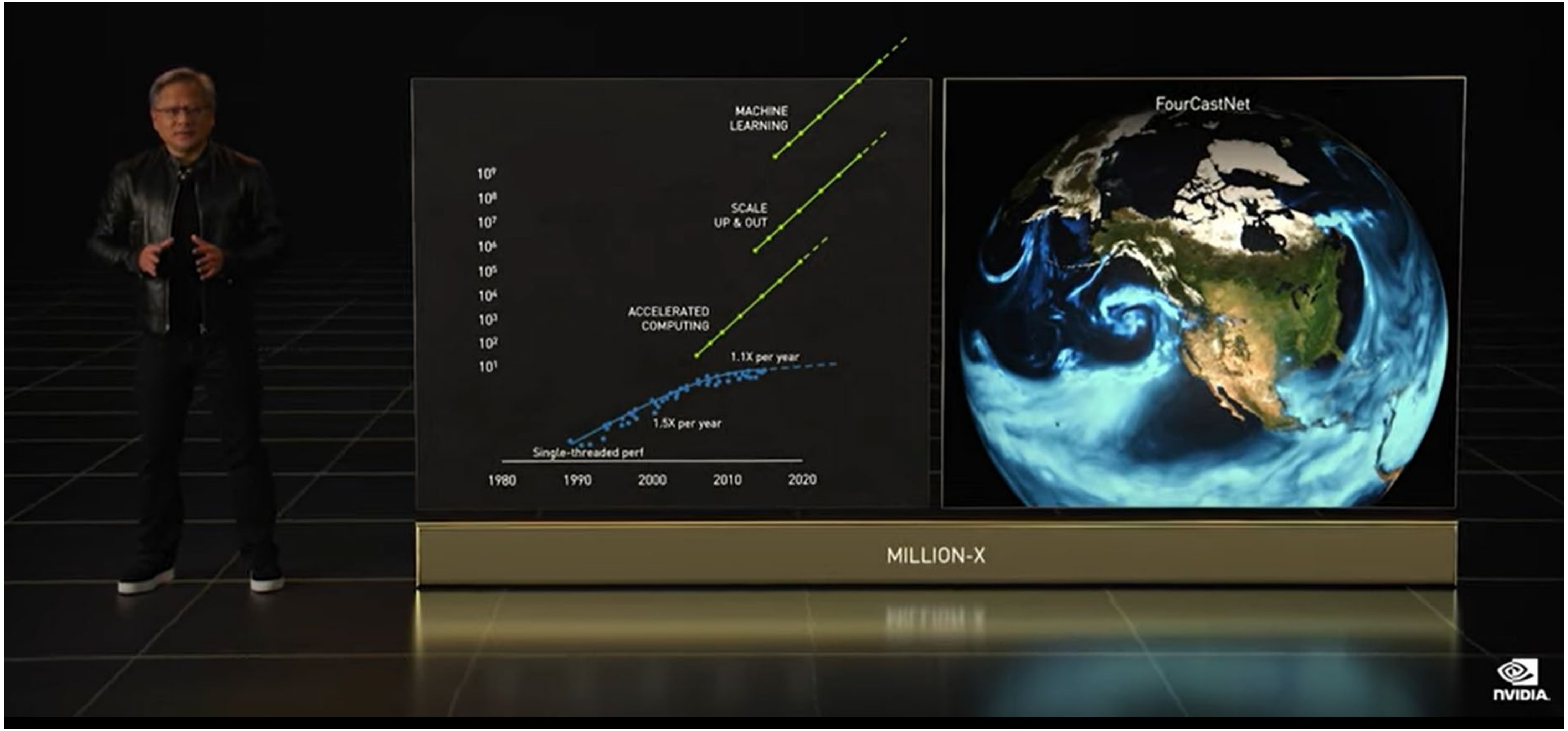


Input: IFS Model Simulation fields on coarse (9 km) grid
Output: Precipitation observation on fine (1 km) grid



Harris, McRae, Chantry, Dueben, Palmer

Next year: Hard AI

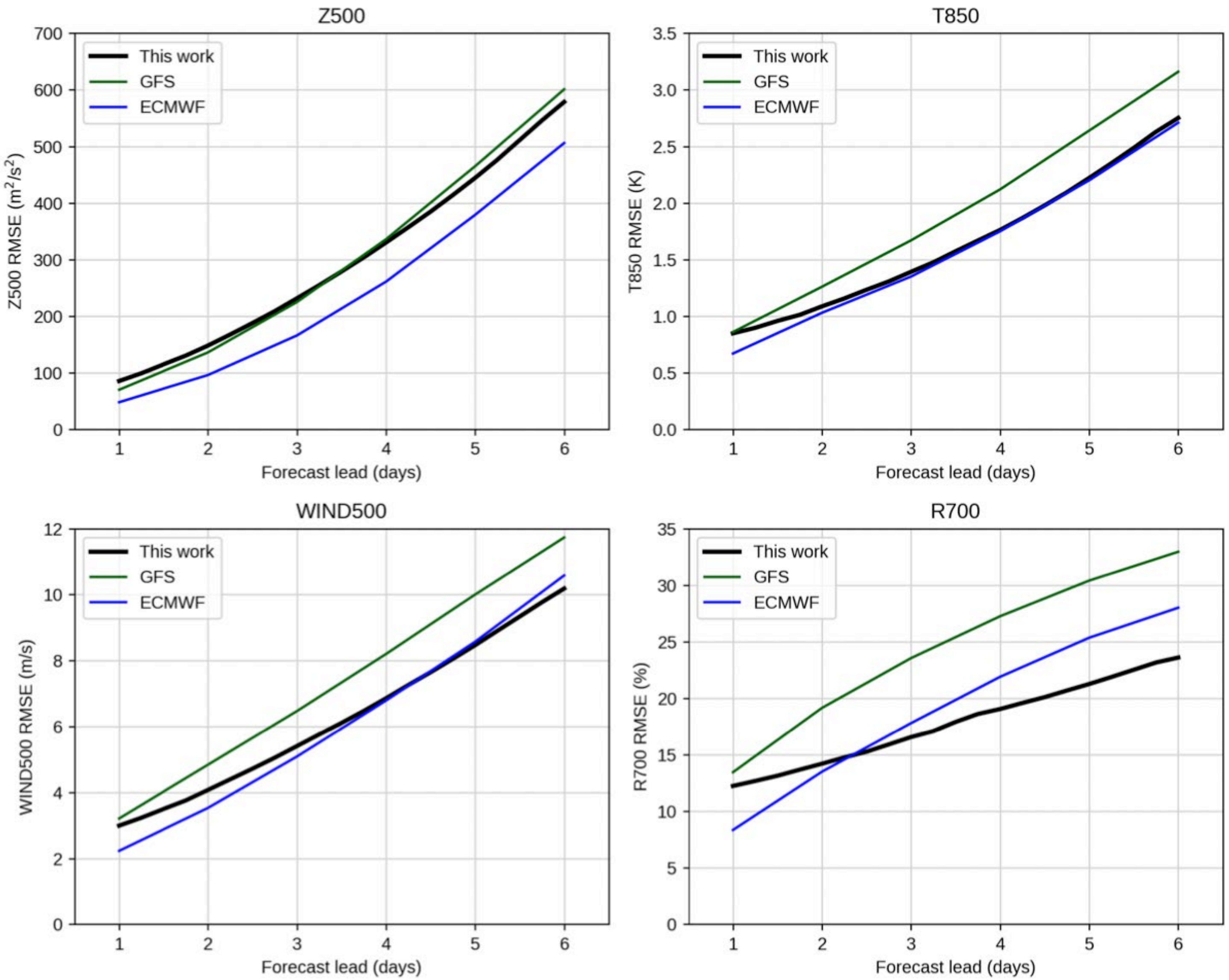


NIVIDA's Earth-2 is coming with FourCastNet

Nowcasting! – Medium Range? S2S? Climate?

Next year: Hard AI

Medium Range?



Keisler 2022

But if you want to get rid of the model, how can you…

…extrapolate?

…learn 10^{10} variables from 10^7 observations?

…learn large scale dynamics from 40 years of data?

…train for variables that do not have good observations?

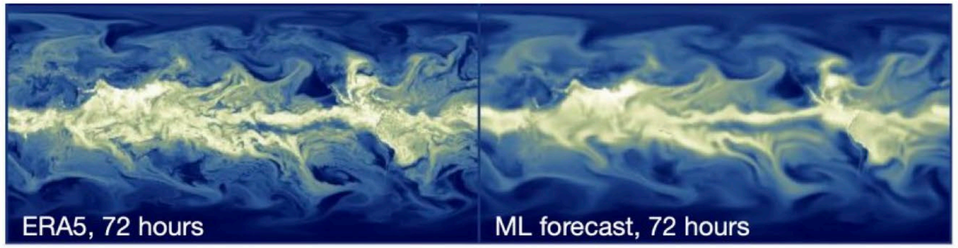
…deal with the avalanche of data if you want to train high-resolution models?

Next year: Hard AI will need a lot of focus on ensemble simulations

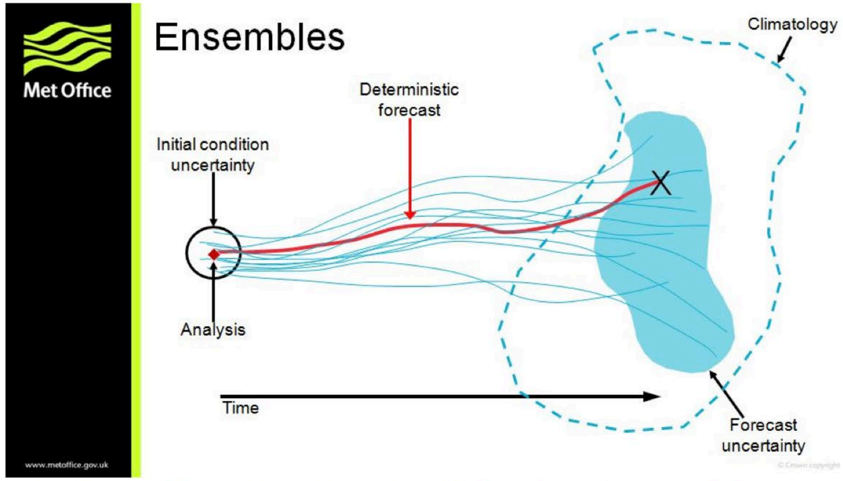
Slide from Stephan Rasp when discussing WeatherBench 2.0:

Focus on probabilistic forecasting

- Medium-range forecasting is fundamentally probabilistic
- Include CRPS and spread-skill ratio
- Include IFS ENS baseline
- Ensemble mean as a deterministic baseline baseline
- Spectra to evaluate realism



Keisler 2022



https://www.metoffice.gov.uk/research/weather/ensemble-forecasting/what-is-an-ensemble-forecast

Google Research

Next decade: Ensemble simulations at ECMWF

Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

arXiv > quant-ph > arXiv:2210.17460

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Quantum Physics

[Submitted on 31 Oct 2022]

Quantum Computers for Weather and Climate Prediction: The Good, the Bad and the Noisy

Felix Tennie, Tim Palmer

Over the past few years, quantum computers and quantum algorithms have attracted considerable interest and attention from numerous scientific disciplines. In this article, we aim to provide a non-technical, yet informative introduction to key aspects of quantum computing. We discuss whether quantum computers one day might become useful tools for numerical weather and climate prediction. Using a recently developed quantum algorithm for solving non-linear differential equations, we integrate a simple non-linear model. In addition to considering the advantages that quantum computers have to offer, we shall also discuss the challenges one faces when trying to use quantum computers for real-world problems involving "big data", such as weather prediction.

Subjects: **Quantum Physics (quant-ph)**; Atmospheric and Oceanic Physics (physics.ao-ph)
Cite as: arXiv:2210.17460 **[quant-ph]**
(or arXiv:2210.17460v1 **[quant-ph]** for this version)
https://doi.org/10.48550/arXiv.2210.17460

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Uncertainty representation is here to stay…

Conclusions

- Ensemble predictions have had a fundamental impact on the way we predict weather at all lead times – from hours to centuries.

- The resolution of ensemble simulations is about to catch up with the resolution of the deterministic high-resolution forecast and ensemble simulations have never been more important.

- Reduced numerical precision, machine learning, and maybe even quantum computing are opening new options for ensemble predictions.

Many thanks! **Peter.Dueben@ecmwf.int** **@PDueben**