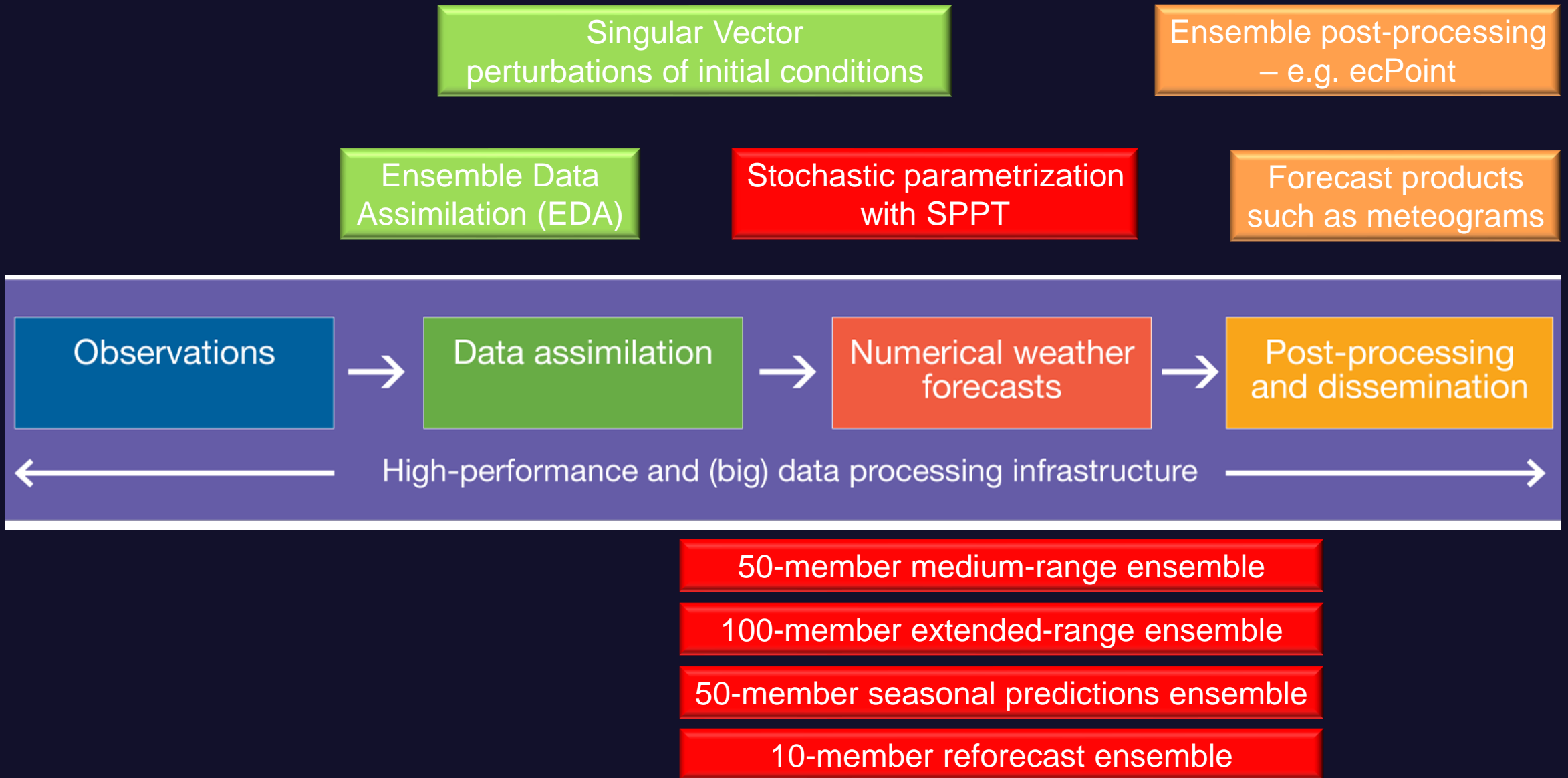# Ensemble Forecasting at ECMWF

Yesterday, Today, Tomorrow, …

Gianpaolo Balsamo, Andy Brown, Peter Dueben, Martin Leutbecher, Sarah-Jane, Lock, Florence Rabier, Irina Sandu

Ensemble simulations are at the heart of ECMWF's predictions

Singular Vector perturbations of initial conditions

Ensemble post-processing – e.g. ecPoint

Ensemble Data Assimilation (EDA)

Stochastic parametrization with SPPT

Forecast products such as meteograms

Observations → Data assimilation → Numerical weather forecasts → Post-processing and dissemination

← High-performance and (big) data processing infrastructure →

50-member medium-range ensemble

100-member extended-range ensemble

50-member seasonal predictions ensemble
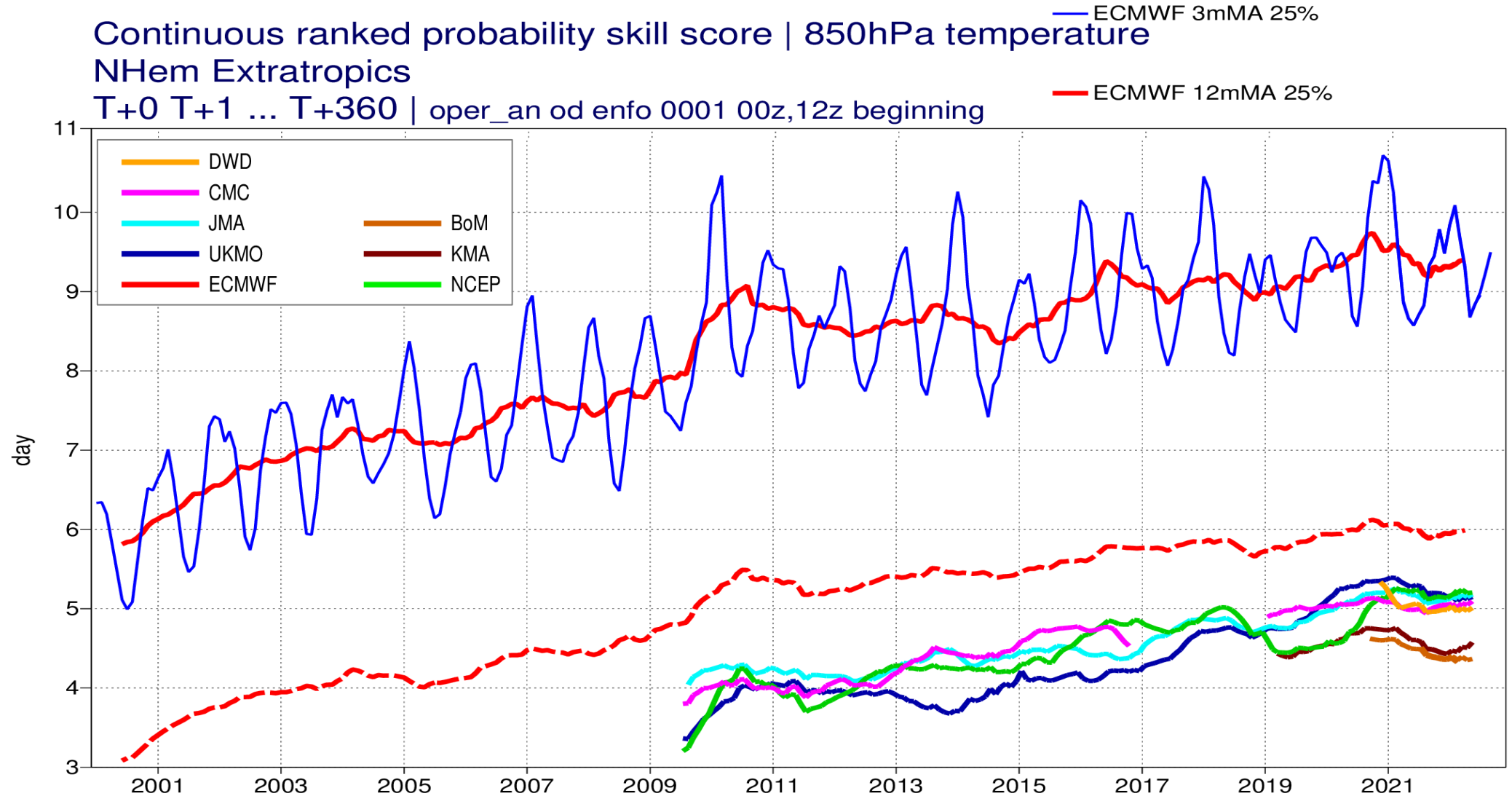
10-member reforecast ensemble

ENS upper-air headline scores

Continuous ranked probability skill score | 850hPa temperature
NHem Extratropics
T+0 T+1 ... T+360 | oper_an od enfo 0001 00z,12z beginning

Legend:
- ECMWF 3mMA 25%
- ECMWF 12mMA 25%
- DWD
- CMC
- JMA
- UKMO
- ECMWF
- BoM
- KMA
- NCEP

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%
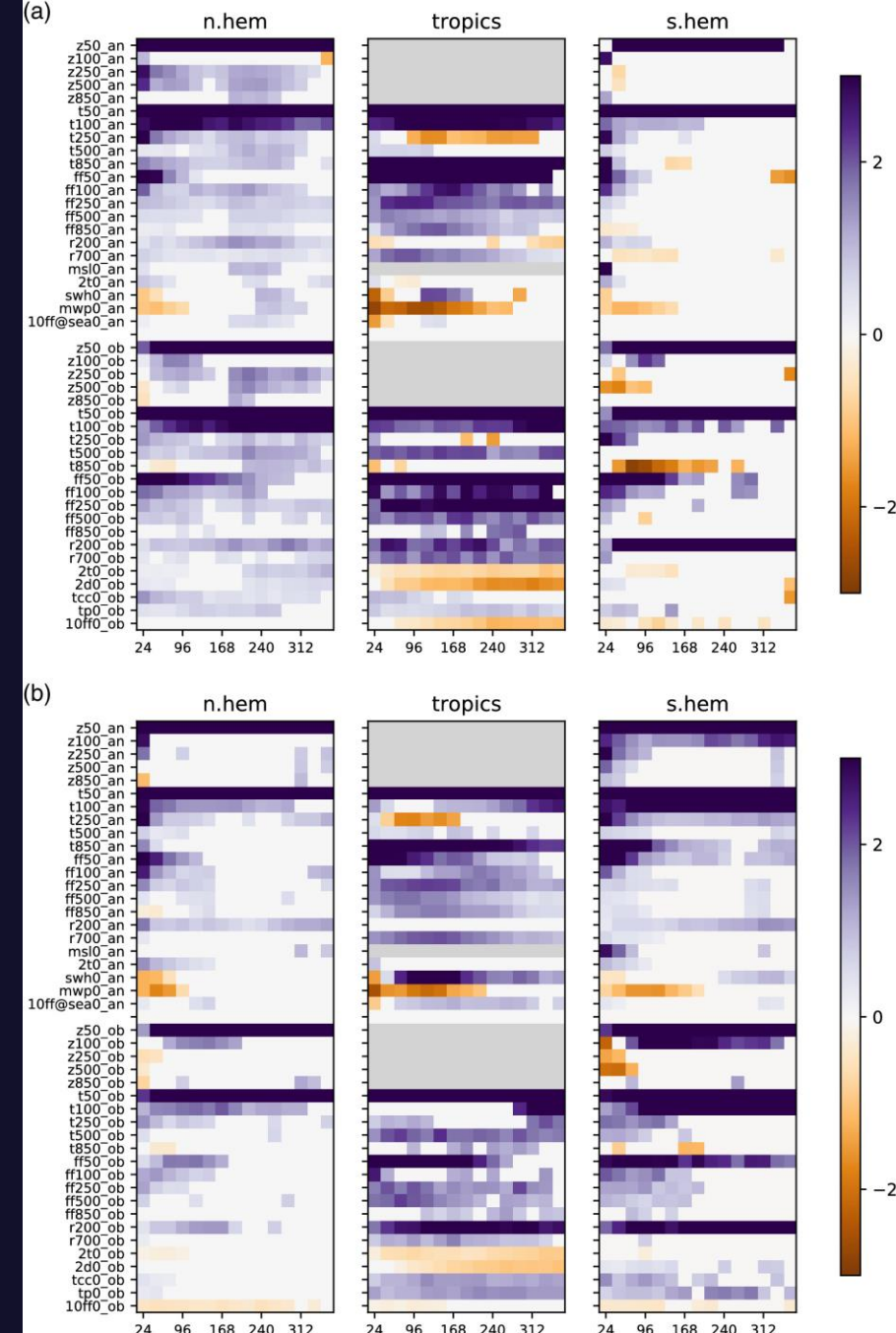
Relative changes in CRPS in % between SP137L and DP91L

Enhancing Moist physics in IFS Cycle 47r3 (12ᵗʰ of October 2021)

- Major development to moist physics parametrizations (cloud, convection, turbulent mixing, microphysics)
- **Simpler interactions, more consistency, improved physical processes, better numerics**
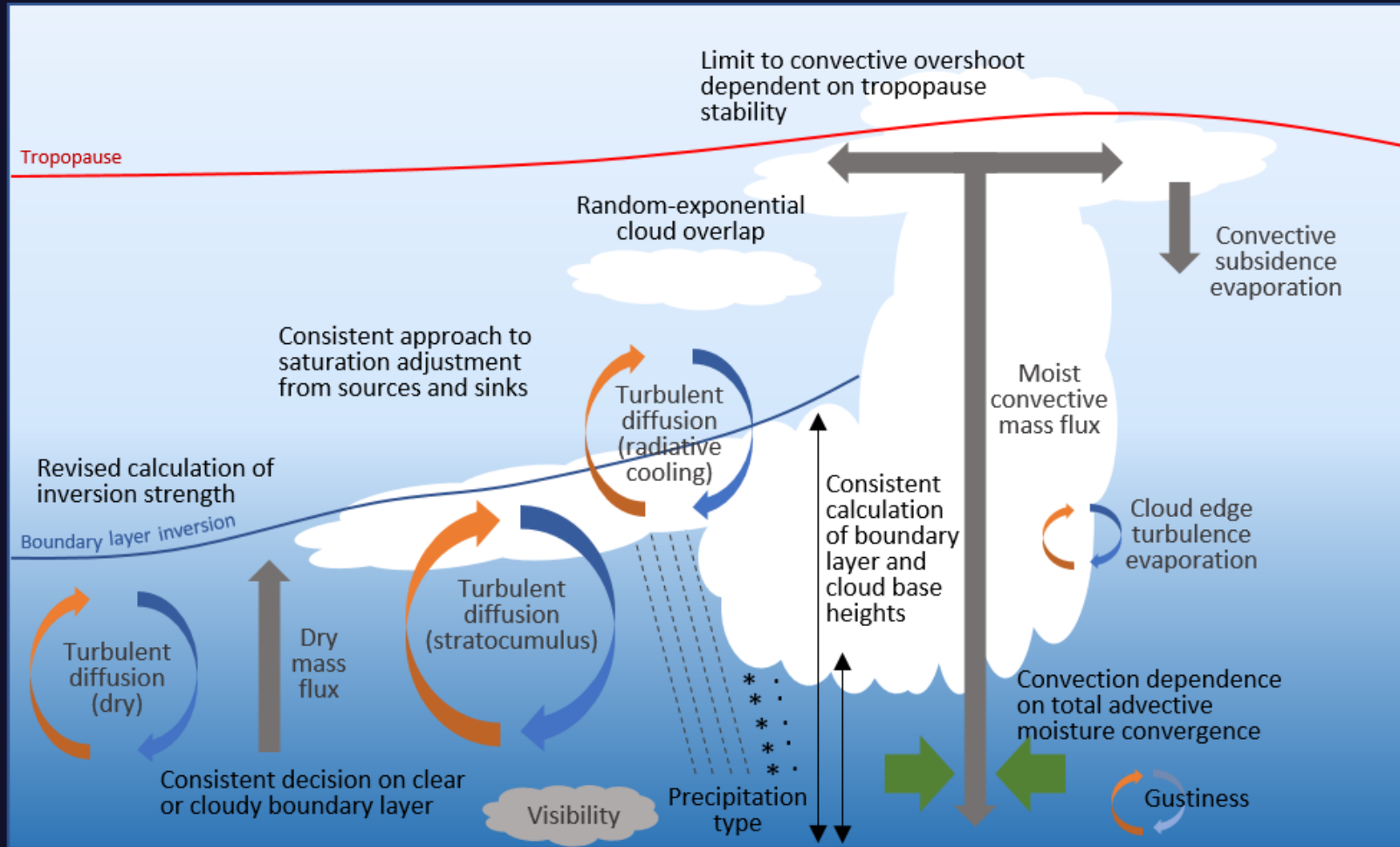
Today: Ensemble simulations at ECMWF
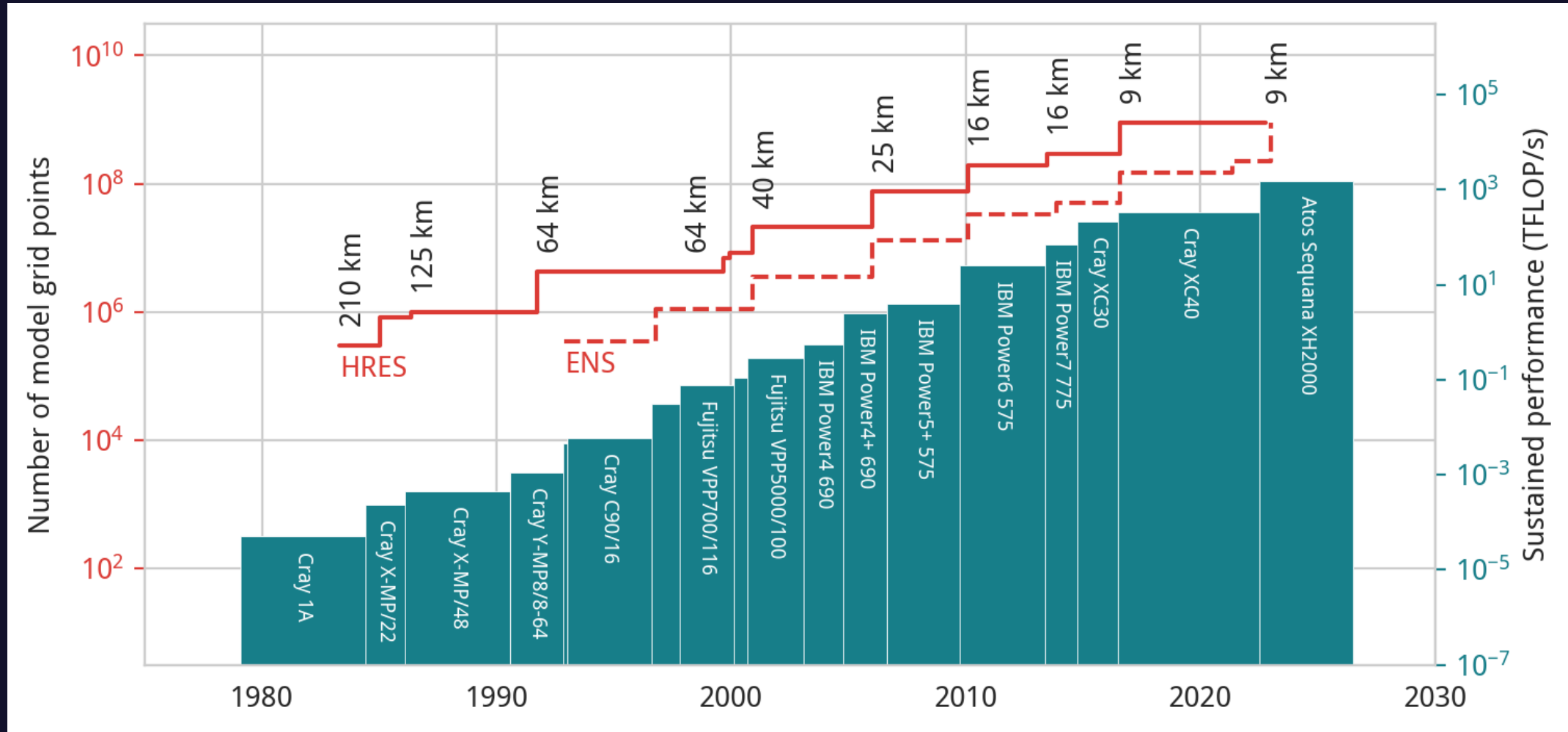
In IFS cycle 48r1, the resolution of the extended range ensemble will catch up with the resolution of the deterministic "high-resolution" forecast

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

Figure courtesy of Sam Hatfield

ECMWF new data-centre

ATOS – HPC **4 clusters** a total of **7680 nodes** **30 PetaFlops** speed (10^{15}) **700 PetaByte** archive

ECMWF a European
multi-site organisation

Reading
Bonn
Bologna

IFS cycle 48r1 (27th of June 2023)

ENS up to day+15 goes from **18 km → 9 km** (same as the HRES)

Extended-range day+46 goes from **50+1 members twice weekly → 100+1 members daily**

18 km

9 km
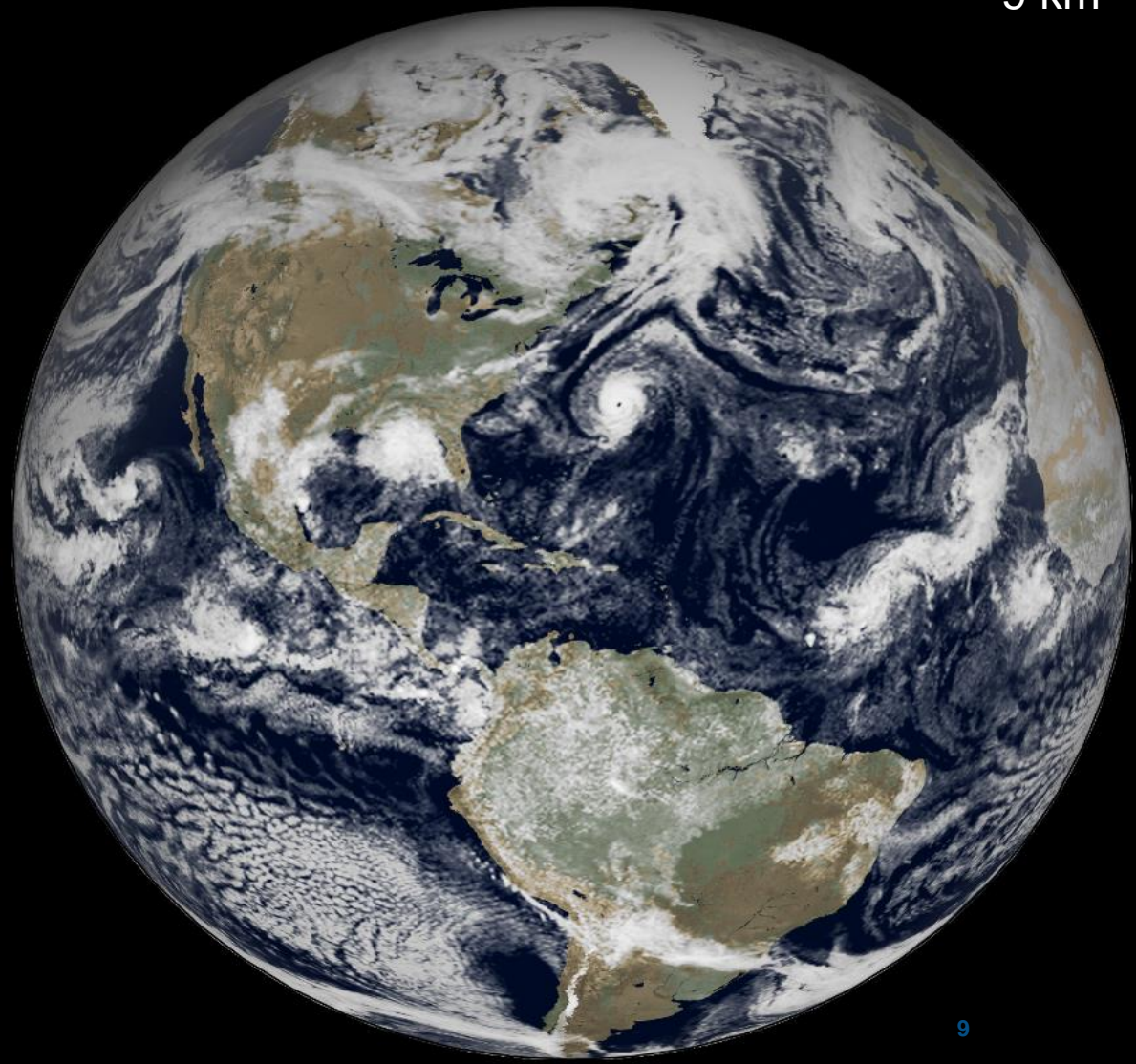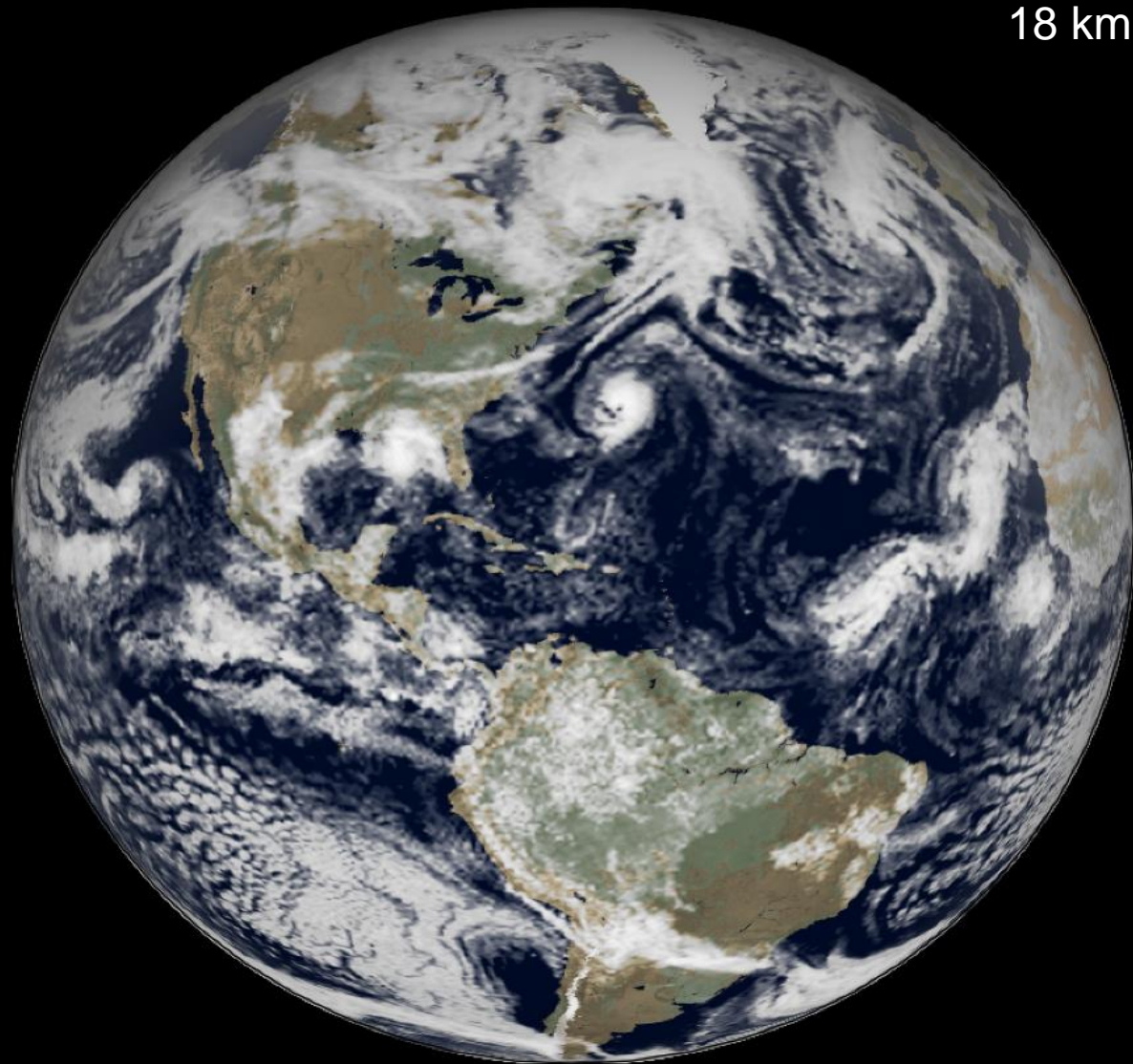
Resolution matters: the case of Medicane Ianos

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

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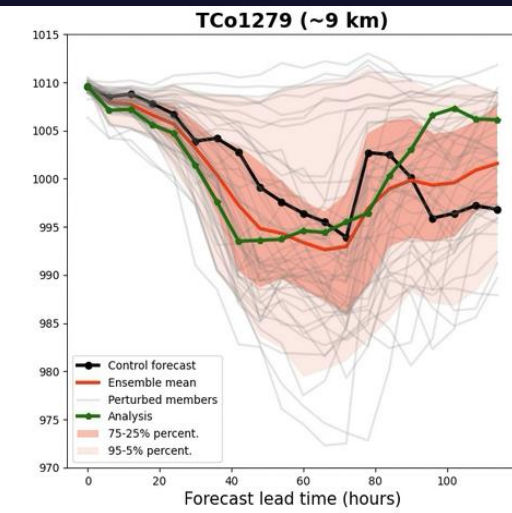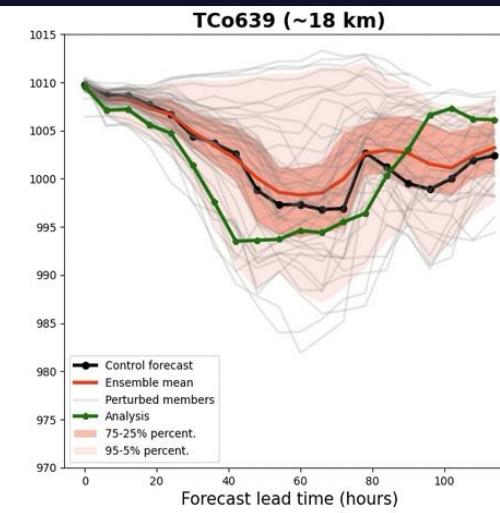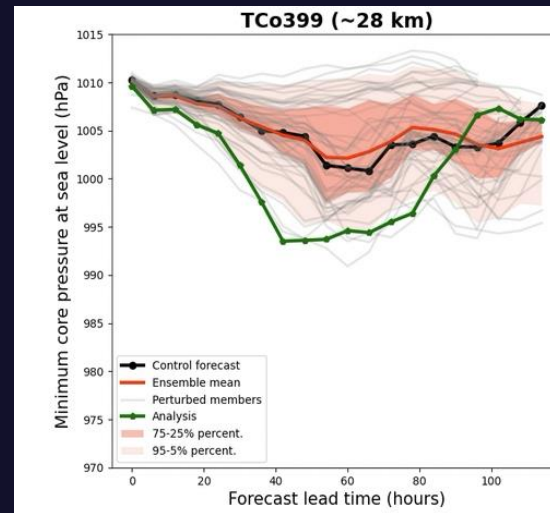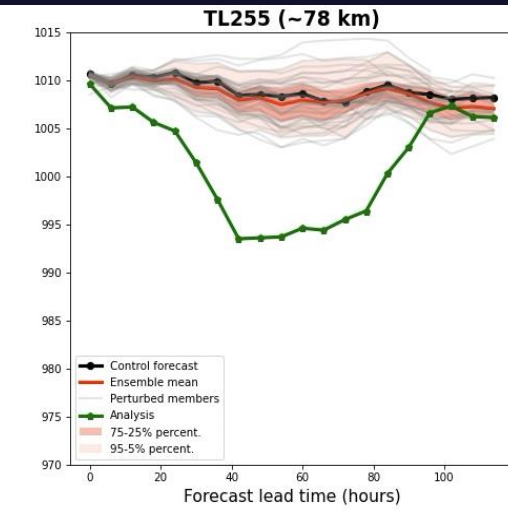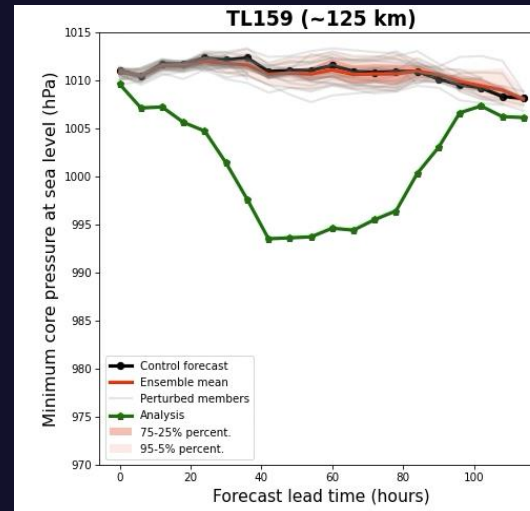

Special thanks to Aristofanis Tsiringakis

4D-Var resolution increase for large-scale fidelity & assimilation

- Higher-density assimilation of ASCAT L2 winds

- Improved assimilation of hyperspectral IR sounders

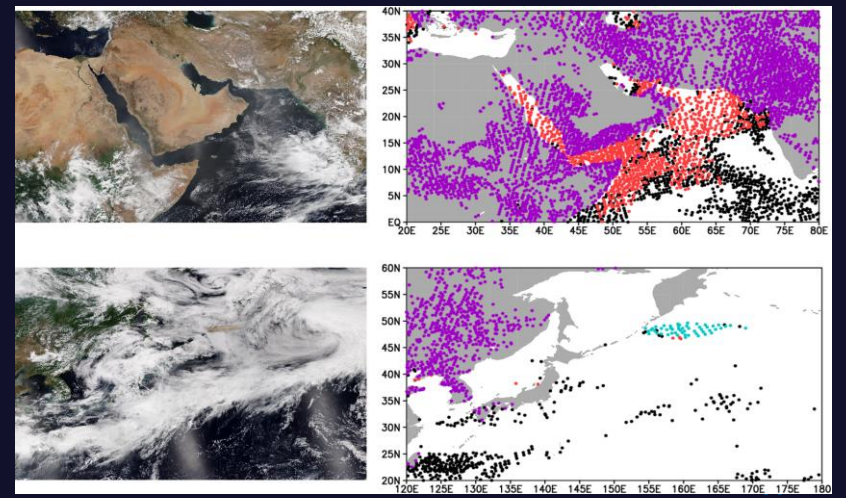- TL399 → TL511 in the last 4D-VAR inner-loop minimization

Forecast scores improvement moving from TL399 (50km) to TL511(40km) inner-loop resolution

TC PAULETTE, Sept 2020

Current OPS: thinning=4 and OE=1.5 m/s

CY48r1 thinning=2 and OE=2.25 m/s
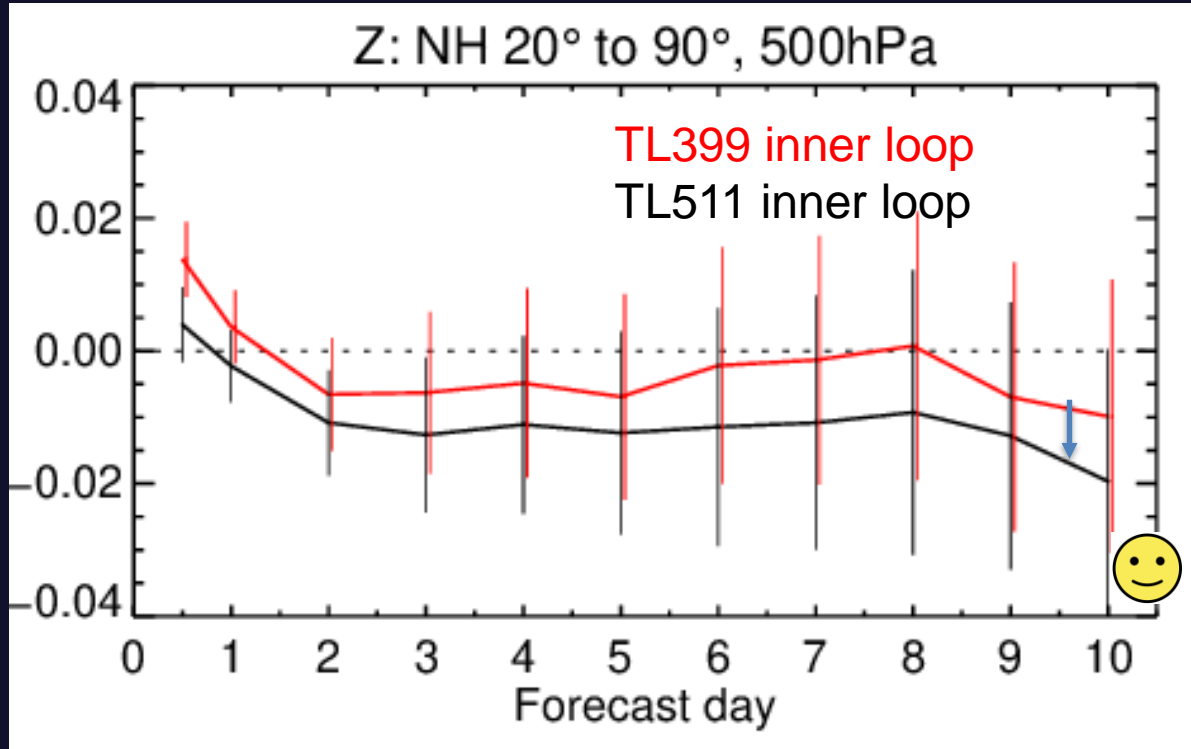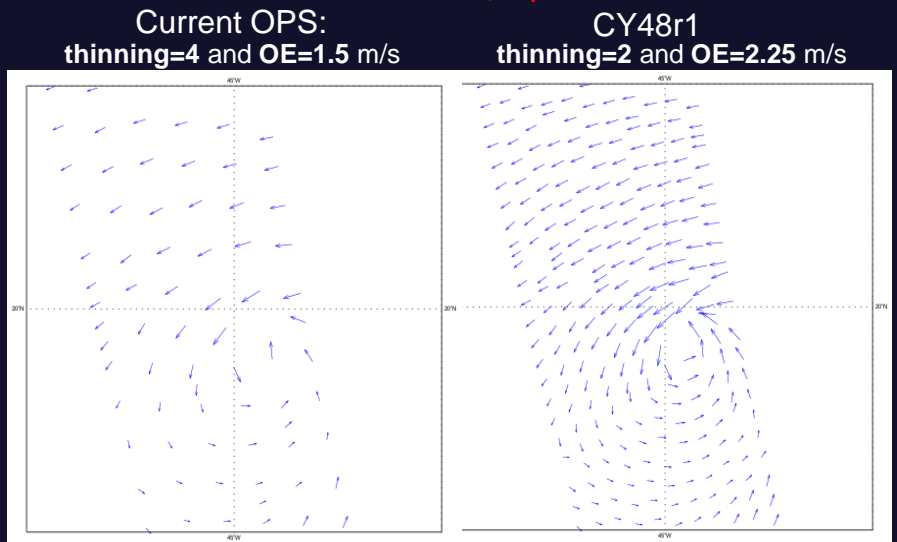
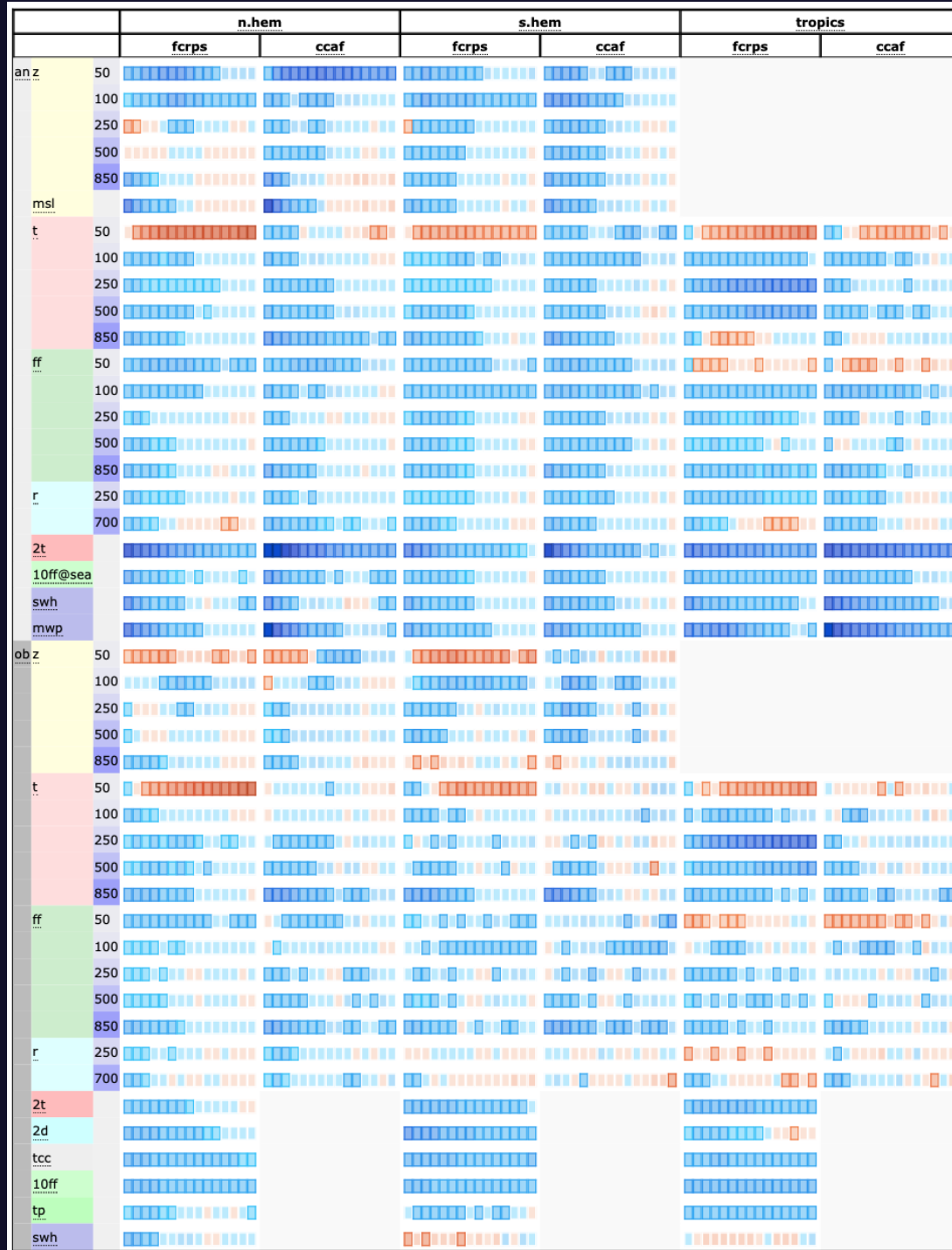Enhanced classification and rejection of aerosols for hyper-spectral IR (e.g. dust volcanic ash)
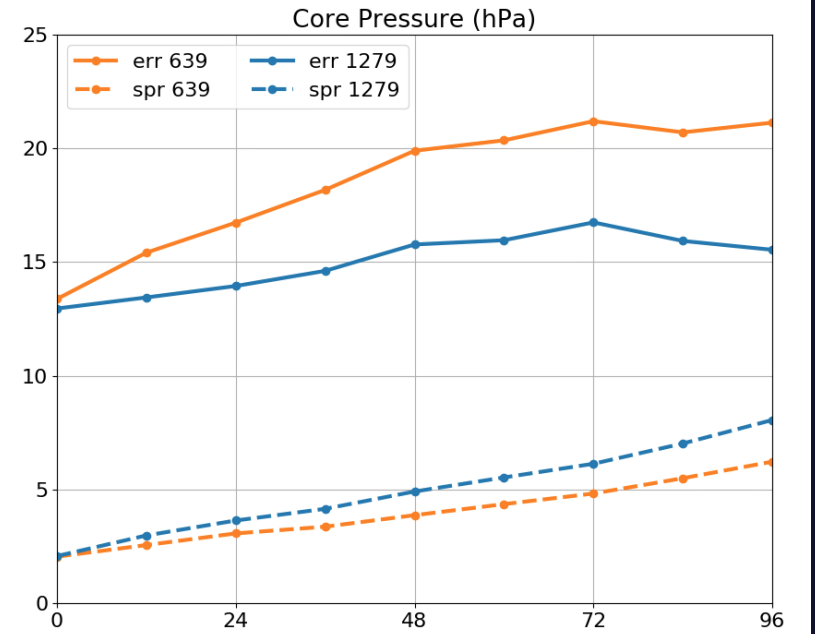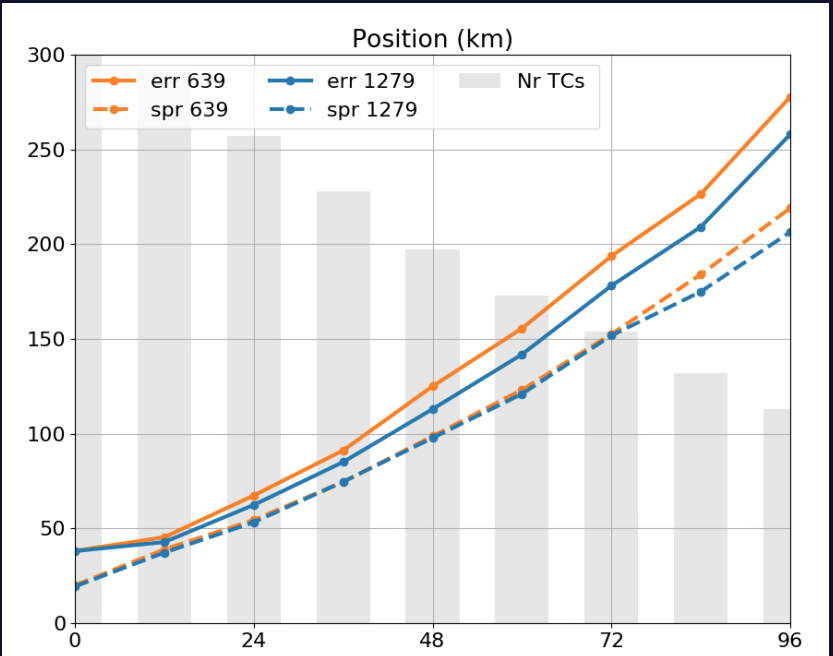
Ensemble resolution upgrade introduced in 48r1

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
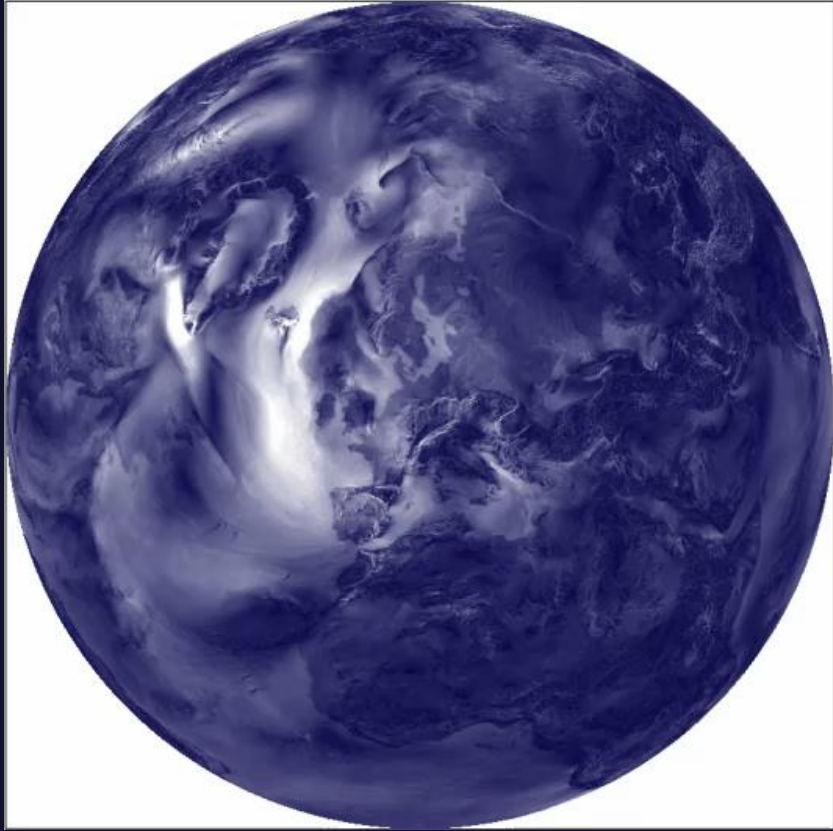

Impact on TCs
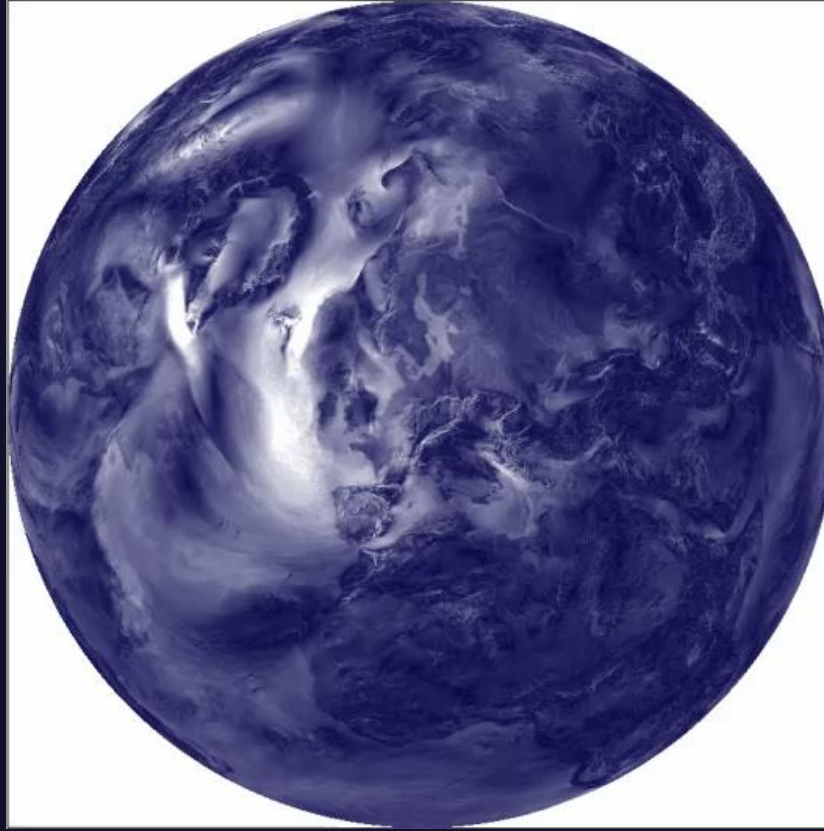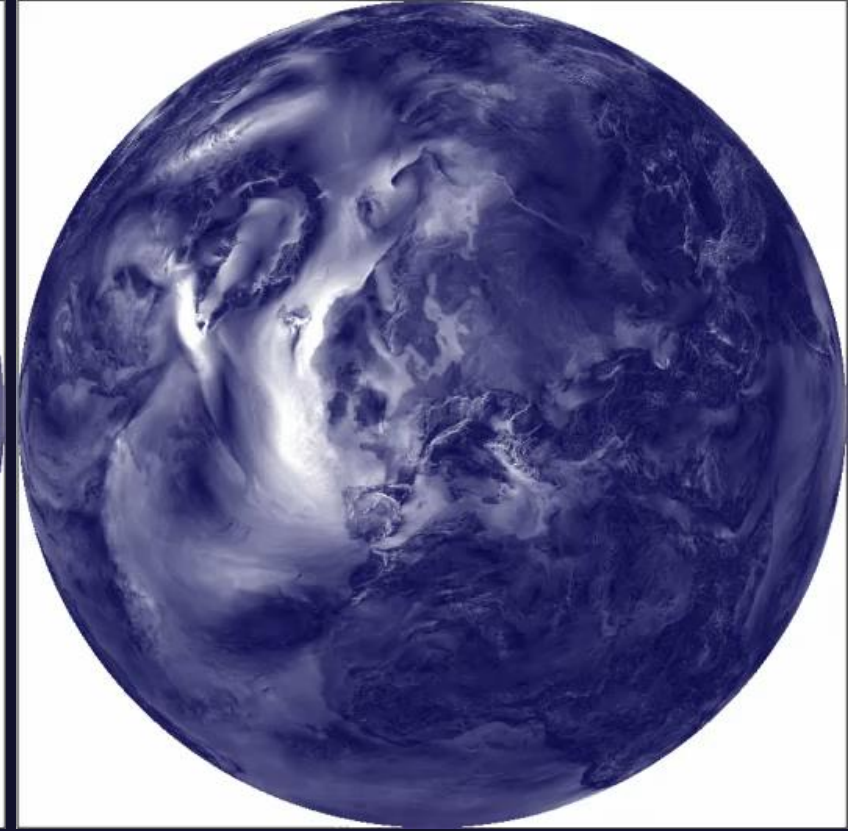

Special thanks to Simon Lang

Animation of max wind gust at TCo1279L137

Control forecast   Perturbed forecast 1   Perturbed forecast 2

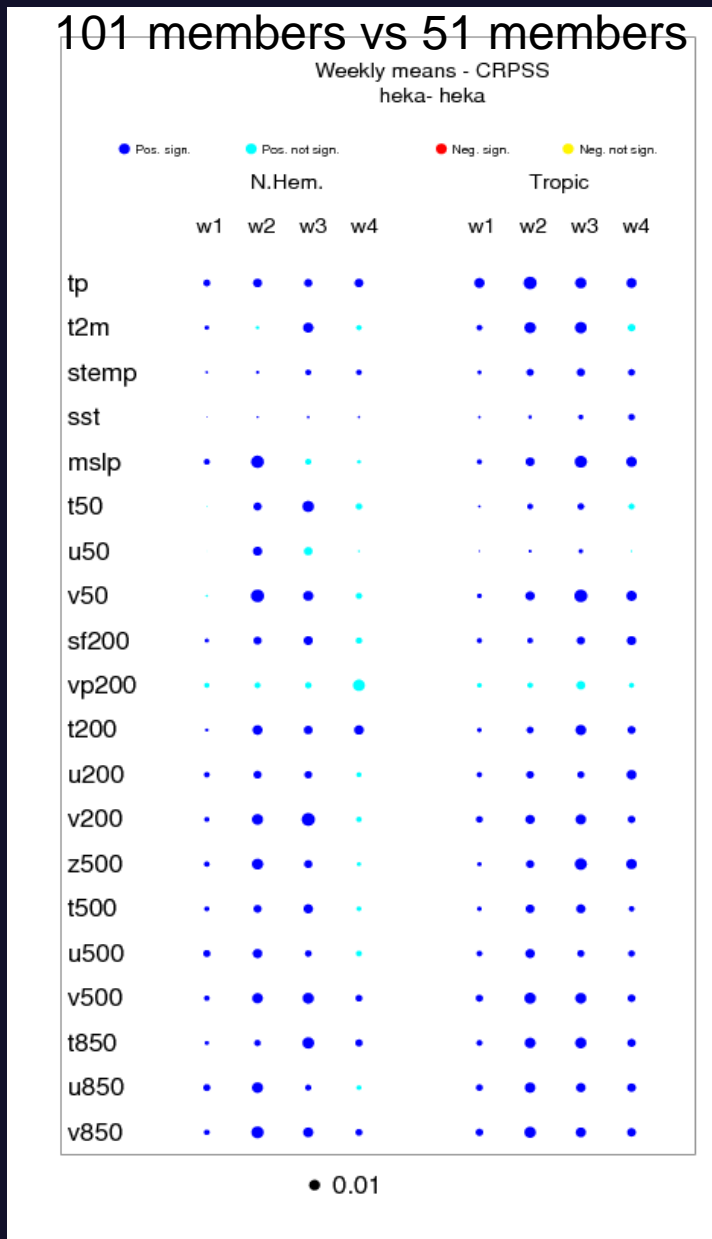# Extended-range forecast configuration & performance

Daily real-time forecasts (00Z) instead of twice weekly

100+1 members instead of 50+1

Extended-range ensemble (consistent resolution ~32 km)

separate from

15-day medium-range ensemble (higher resolution, ~9km)

101 members vs 51 members

Weekly means - CRPSS
heka- heka

- Pos. sign. • Pos. not sign. • Neg. sign. • Neg. not sign.

	N.Hem.				Tropic			
	w1	w2	w3	w4	w1	w2	w3	w4
tp		•	•	•	•	•	•	•
t2m	•	•	•	•	•	•	•	•
stemp	•	•	•	•	•	•	•	•
sst	•	•	•	•	•	•	•	•
mslp	•	•	•	•	•	•	•	•
t50	•	•	•	•	•	•	•	•
u50	•	•	•	•	•	•	•	•
v50	•	•	•	•	•	•	•	•
sf200	•	•	•	•	•	•	•	•
vp200	•	•	•	•	•	•	•	•
t200	•	•	•	•	•	•	•	•
u200	•	•	•	•	•	•	•	•
v200	•	•	•	•	•	•	•	•
z500	•	•	•	•	•	•	•	•
t500	•	•	•	•	•	•	•	•
u500	•	•	•	•	•	•	•	•
v500	•	•	•	•	•	•	•	•
t850	•	•	•	•	•	•	•	•
u850	•	•	•	•	•	•	•	•
v850	•	•	•	•	•	•	•	•

• 0.01

Tropical storm strike probability week 4 forecast
Start date:7/1/2021 – verification 1-7 Feb. 2021

51 members
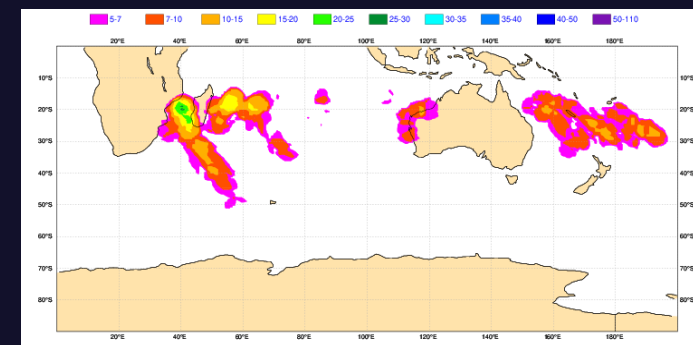
101 members
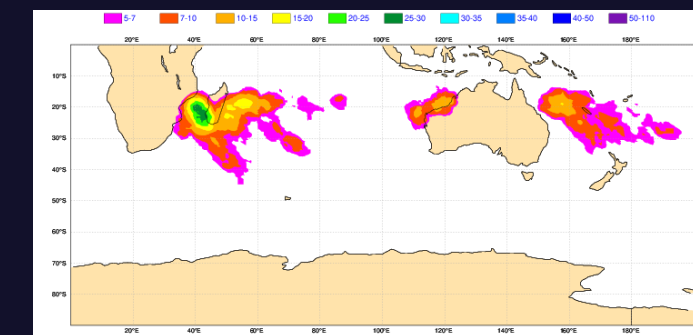
Today SPPT: Stochastically perturbed physics tendencies

- In the IFS, operates on the tendencies
- 1998: implemented (*Buizza et al., 1999*)
- 2009: revised (*Palmer et al., 2009*)
- 2016: global fix (*Davini et al., 2017*)
- 2018: clear-skies revision & seamless application (EDA .. seasonal) (*Lock et al., 2019*)

Tomorrow SPP: Stochastically Perturbed Parametrisations

- In the IFS, operates in: radiation, vertical mixing, cloud and convection schemes
- Represents MU close to their sources, preserves local conservation properties, enables multivariate description of uncertainties

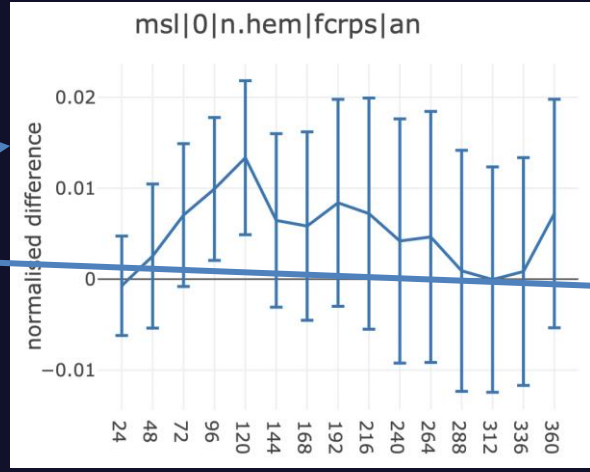2024: to be implemented in IFS cycle 49r1 (based on Lang et al, 2021, QJRMS)

Tomorrow: Ensemble simulations at ECMWF

IFS cycle 49r1 will replace SPPT with SPP.

■ *degradation*   ■ *improvement*
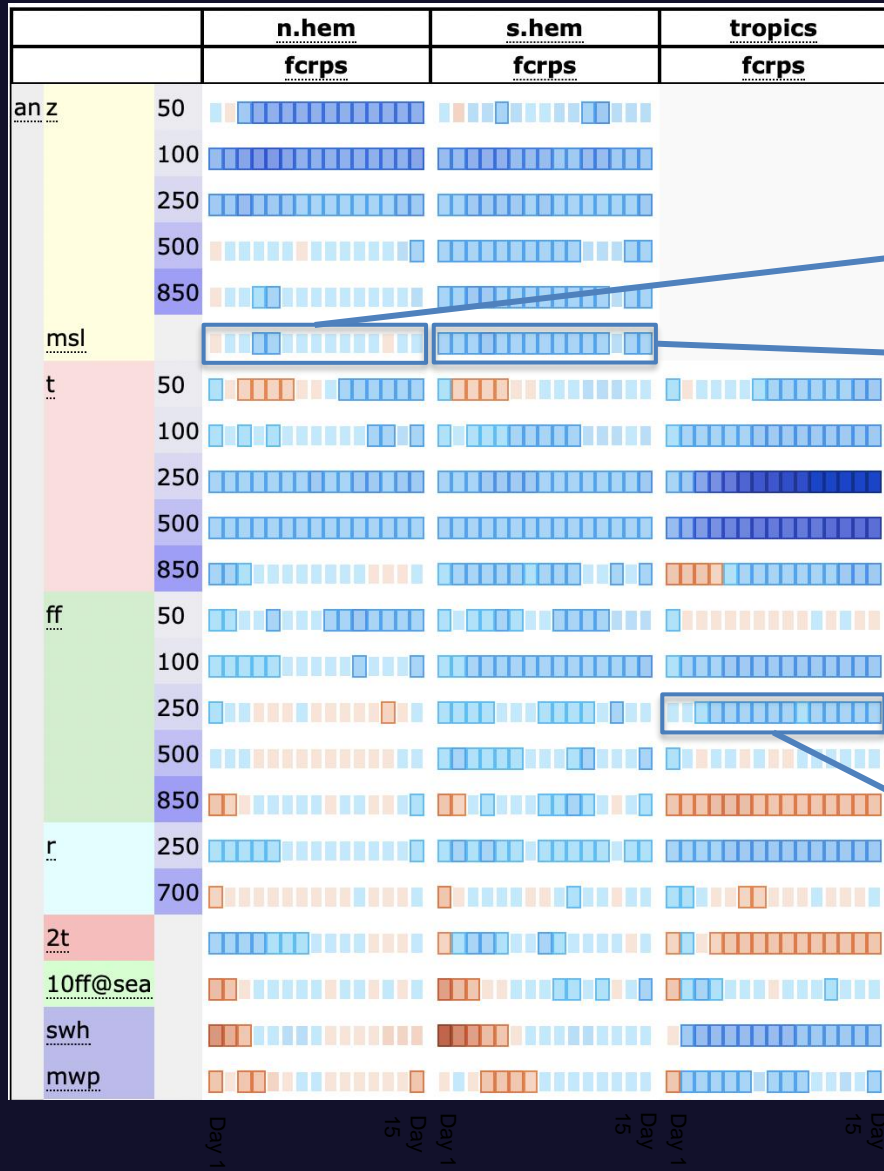
Preliminary results – full scale testing with 48r1 in progress
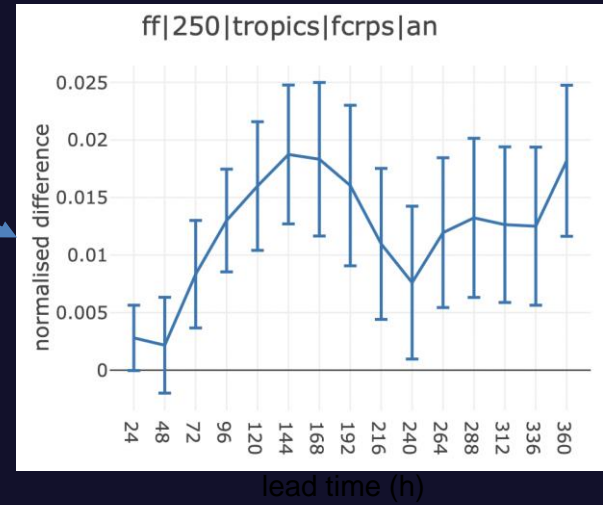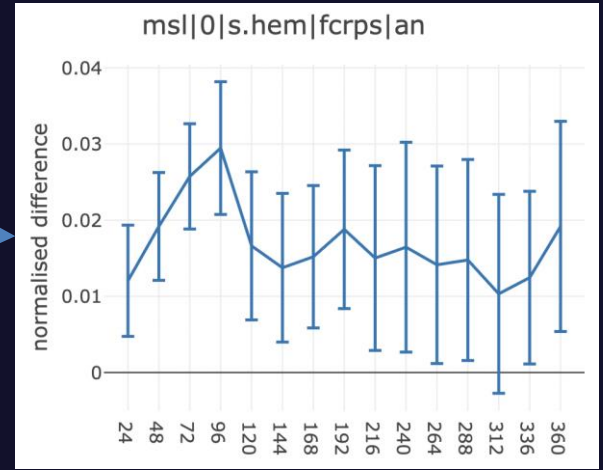
Experiments:
- CY47R3
- 9km ENS (TCo1279)
- 8+1 members
- fair CRPS (fcrps)
- Starts: every day, Jun+Jul+Dec+Jan 2020/21 at 00/12 UTC
- Forecast period: 15 days
- IC perturbations: EDA, SVs, ocean Ics

See also Lang et al. QJRMS 2021

Tomorrow: Ensemble simulations at ECMWF

IFS cycle 49r2 will introduce the new version 4 of the NEMO ocean model which will run in single precision

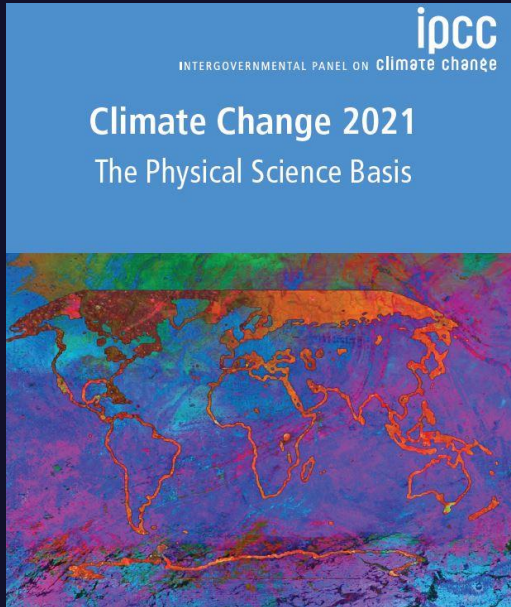**A reduction from double precision to single precision results in neutral forecast scores:**
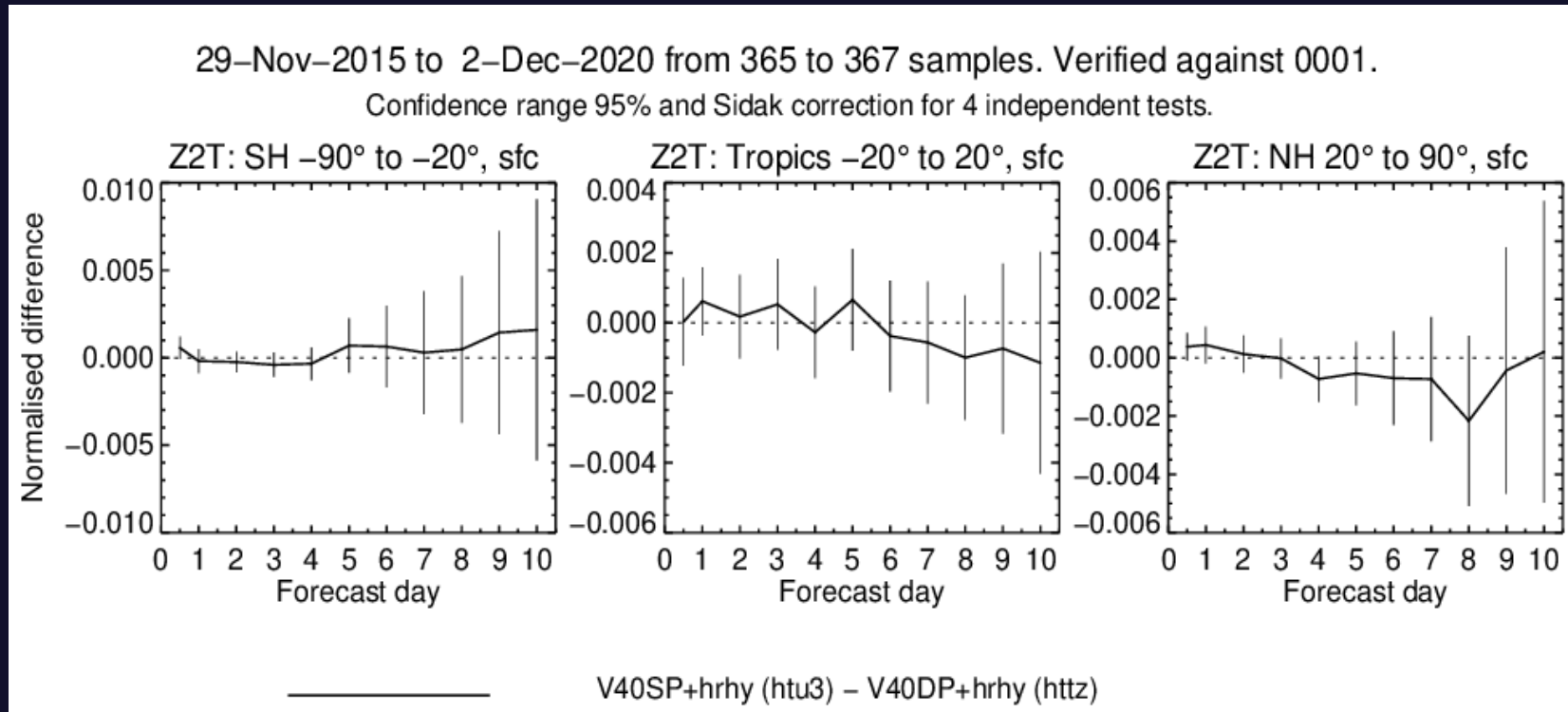
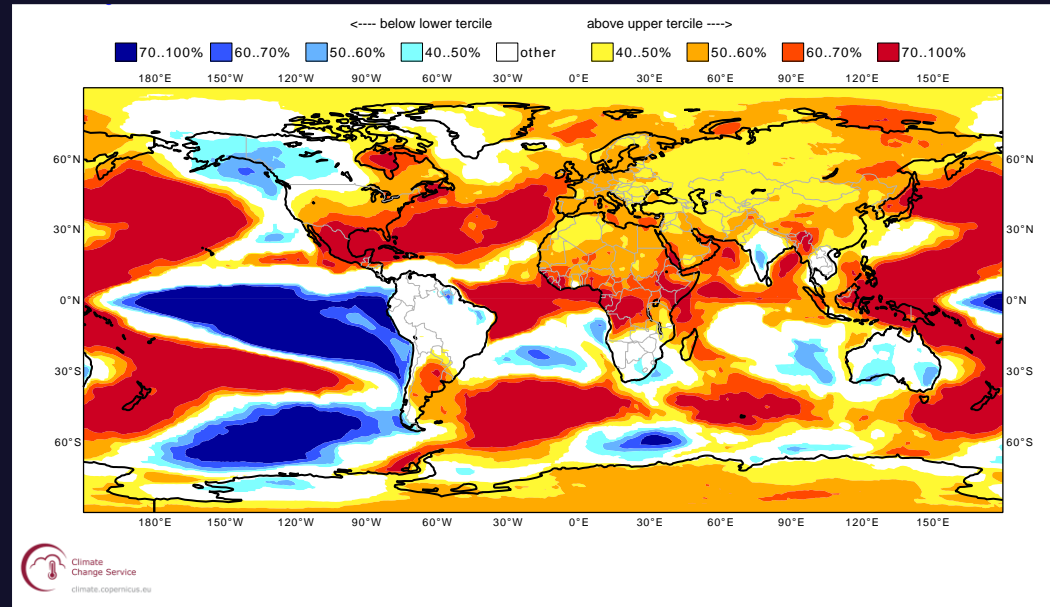**But the cost is reduced significantly:**

Sam Hatfield et al.
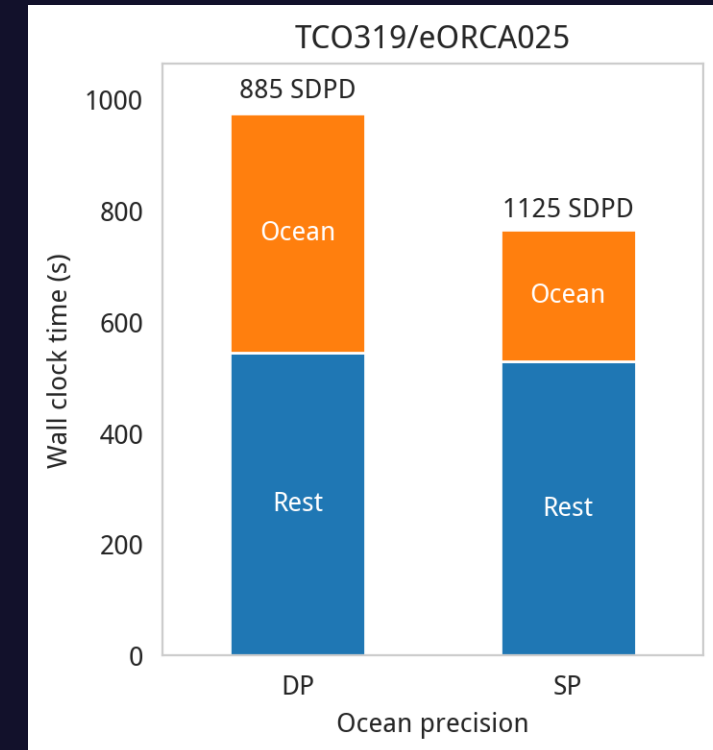
Synergies with European Programmes
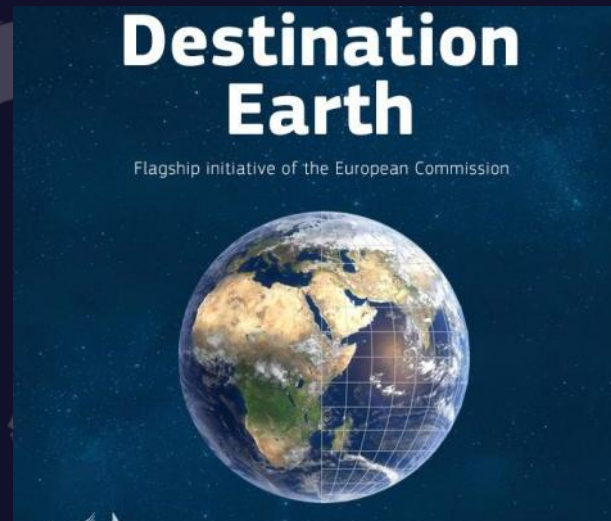
Copernicus Climate Change Service (C3S) Reanalysis and multi-model seasonal forecasts

- More than 130,000 active users of Climate Data Store
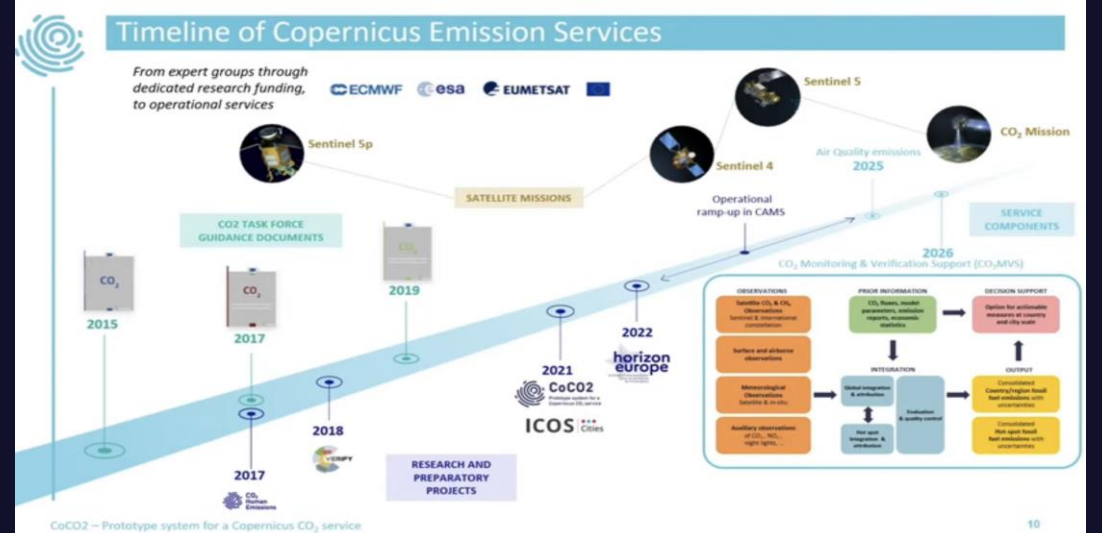
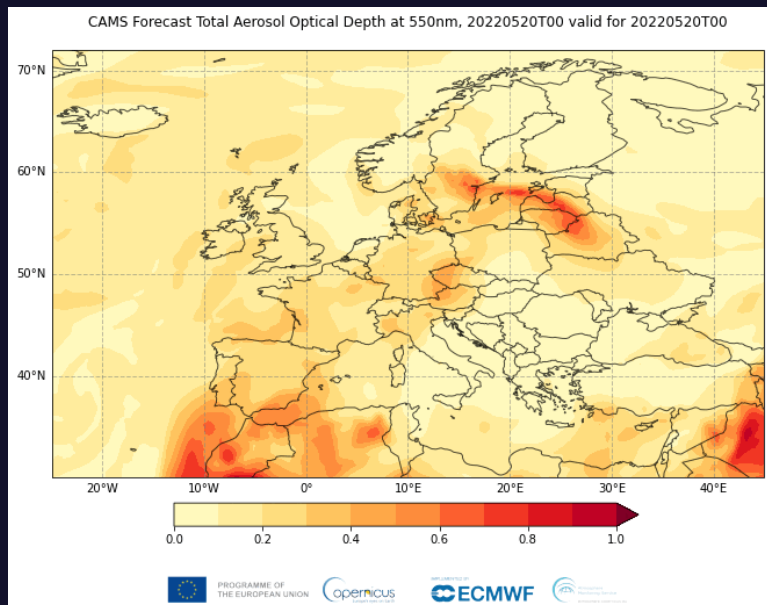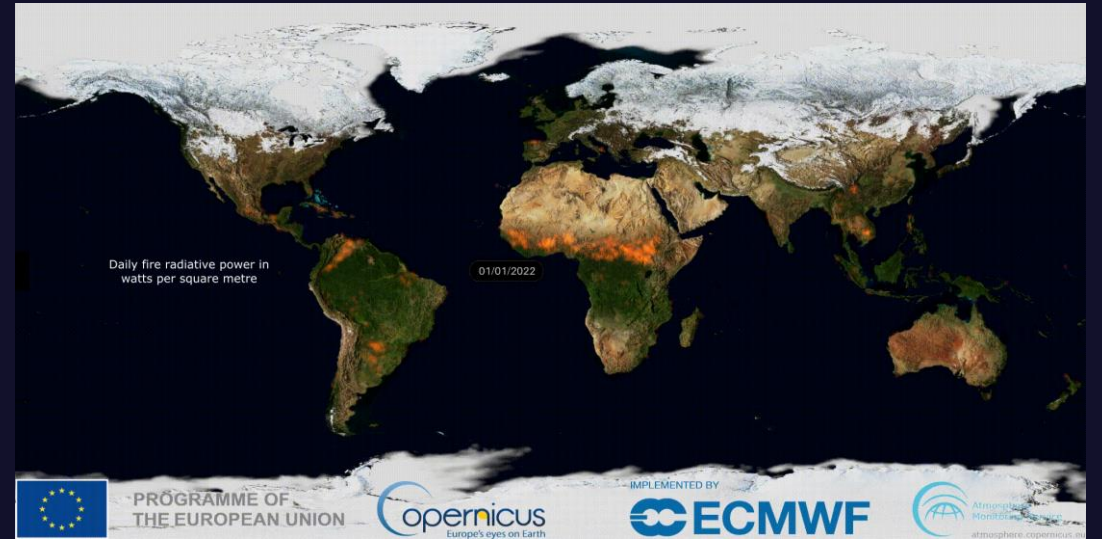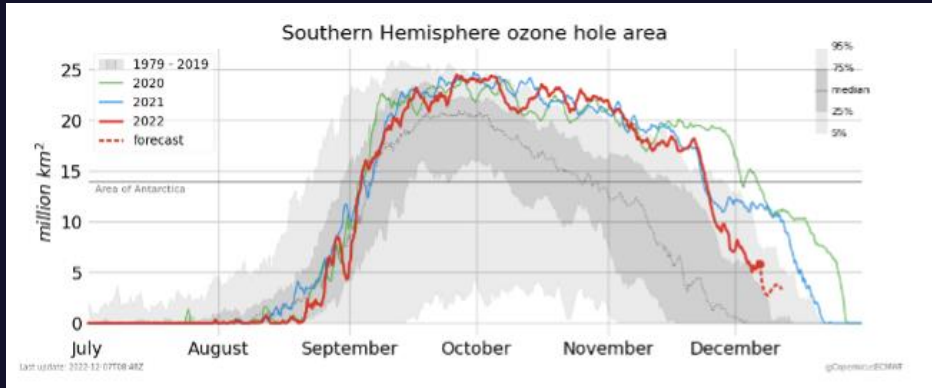- ERA5 quoted more than 200 times in the latest IPCC report

- Existing providers: CMCC, DWD, ECCC, ECMWF, JMA, Met Office, Météo-France, NCEP

- **Preparations under way for Australian contribution to the C3S multi-system**

Copernicus Atmosphere Monitoring Service (CAMS)
## Ozone hole, dusts, wildfires, CO2, methane and more..

Destination Earth

Will provide unique digital modelling capabilities of the Earth to enhance the EU's ability to monitor and model environmental changes, predict extreme events, and adapt EU actions and policies to climate-related challenges.

ECMWF's role is to deliver

- The Digital Twin Engine (DTE)

- The Weather-induced and Geophysical Extremes Digital Twin

- The Climate Change Adaptation Digital Twin
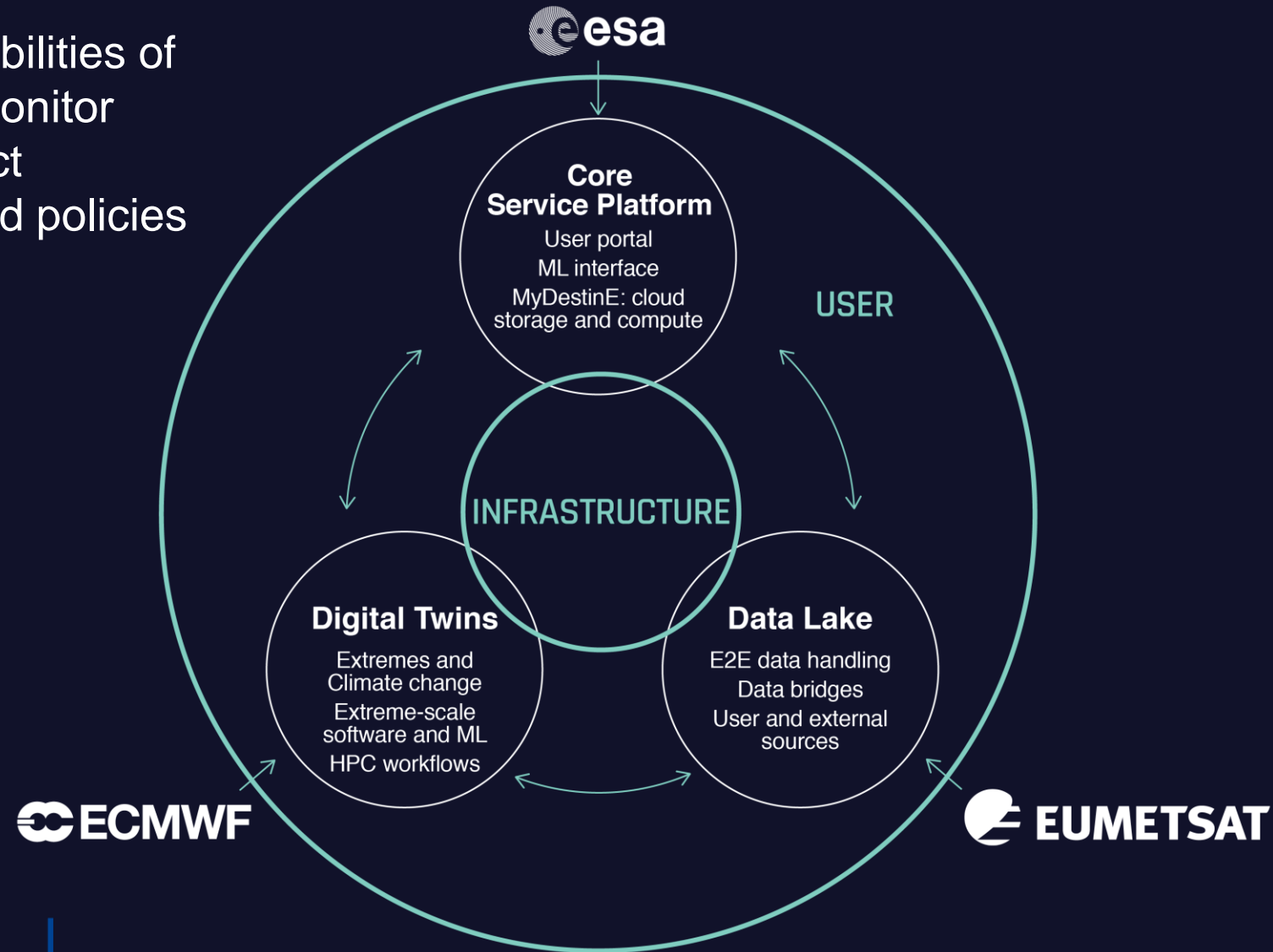
Towards km-scale ensemble simulations at ECMWF

ECMWF's four-year plan:

*The new representation of model uncertainty via the Stochastically Perturbed Parametrization (SPP) scheme will be implemented in operations in 2024. 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.*
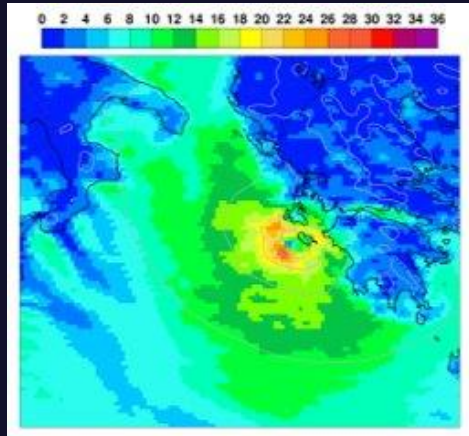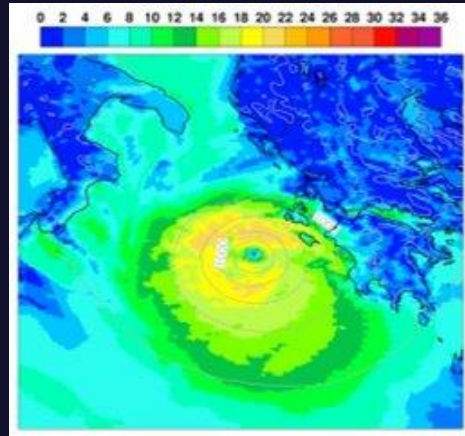
Global Extremes DT : Medicane Ianos (Sep 2020)
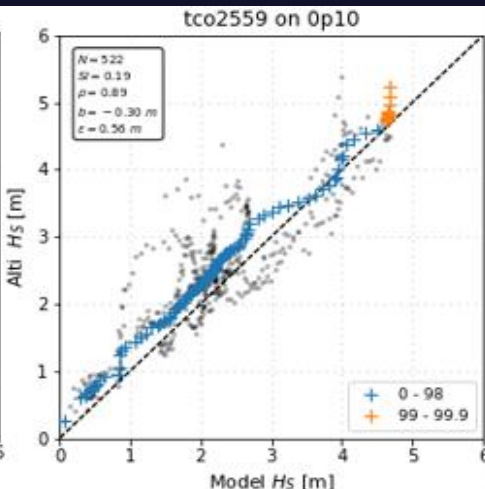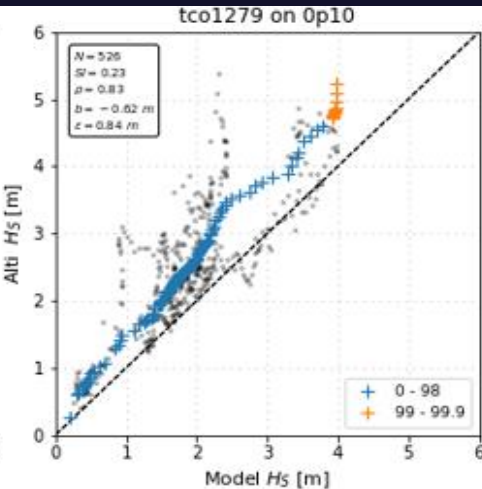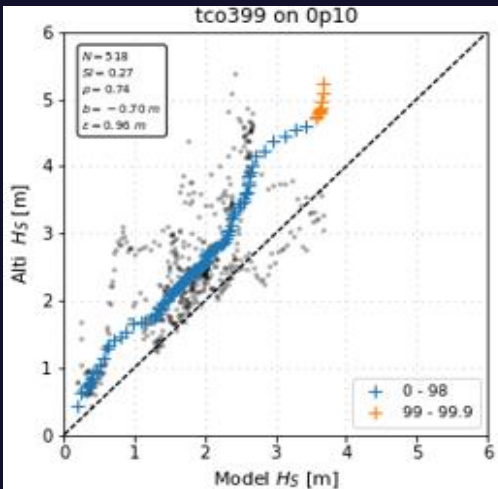
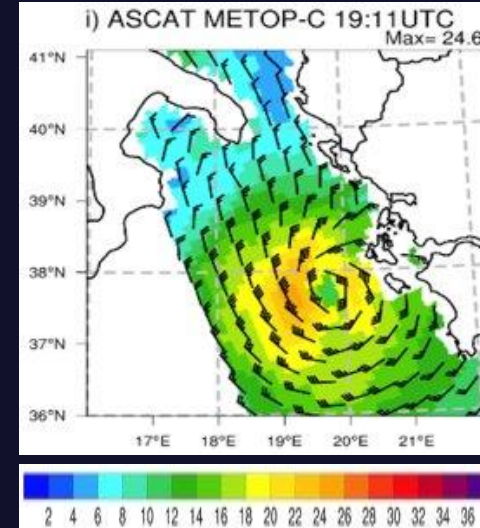Surface Wind speed (T+66h, m/s)
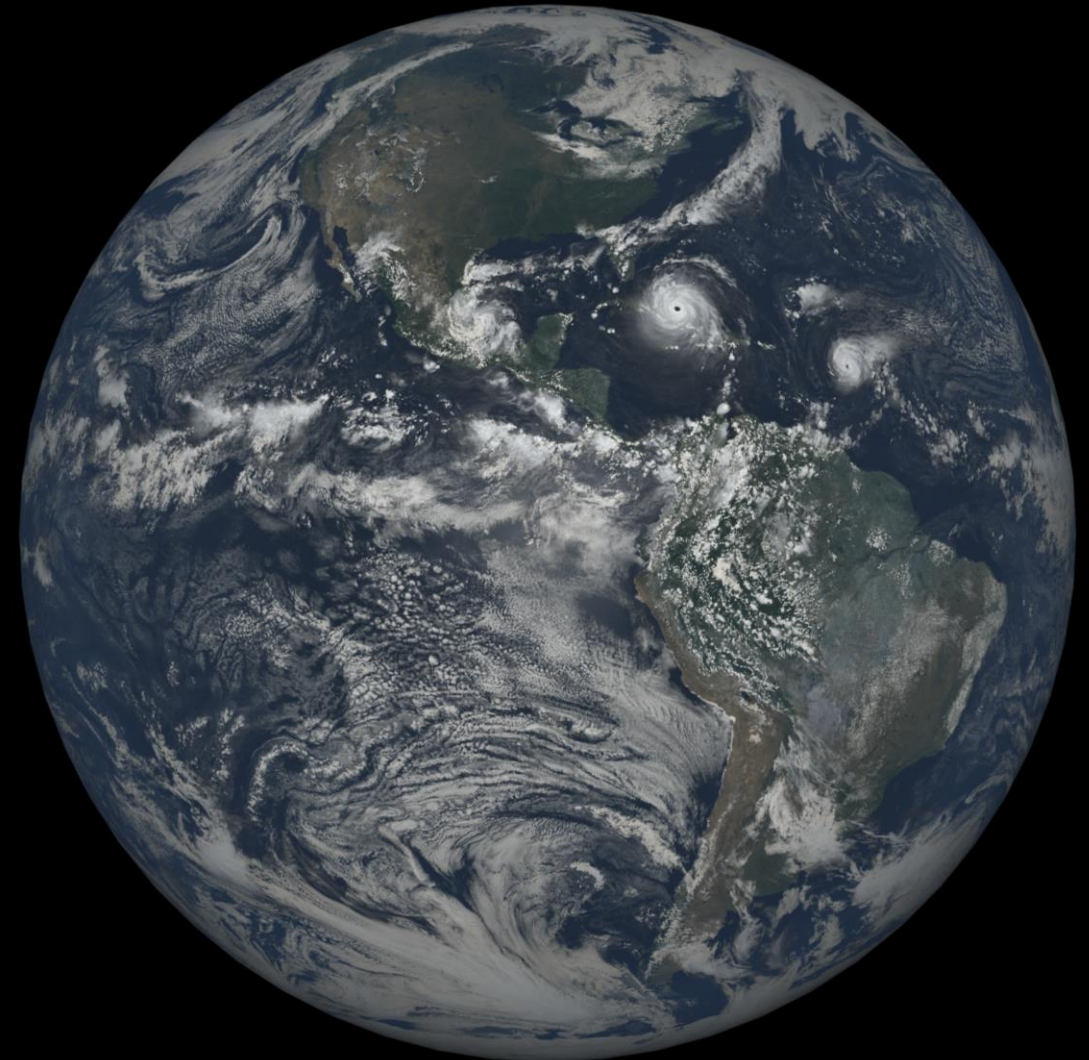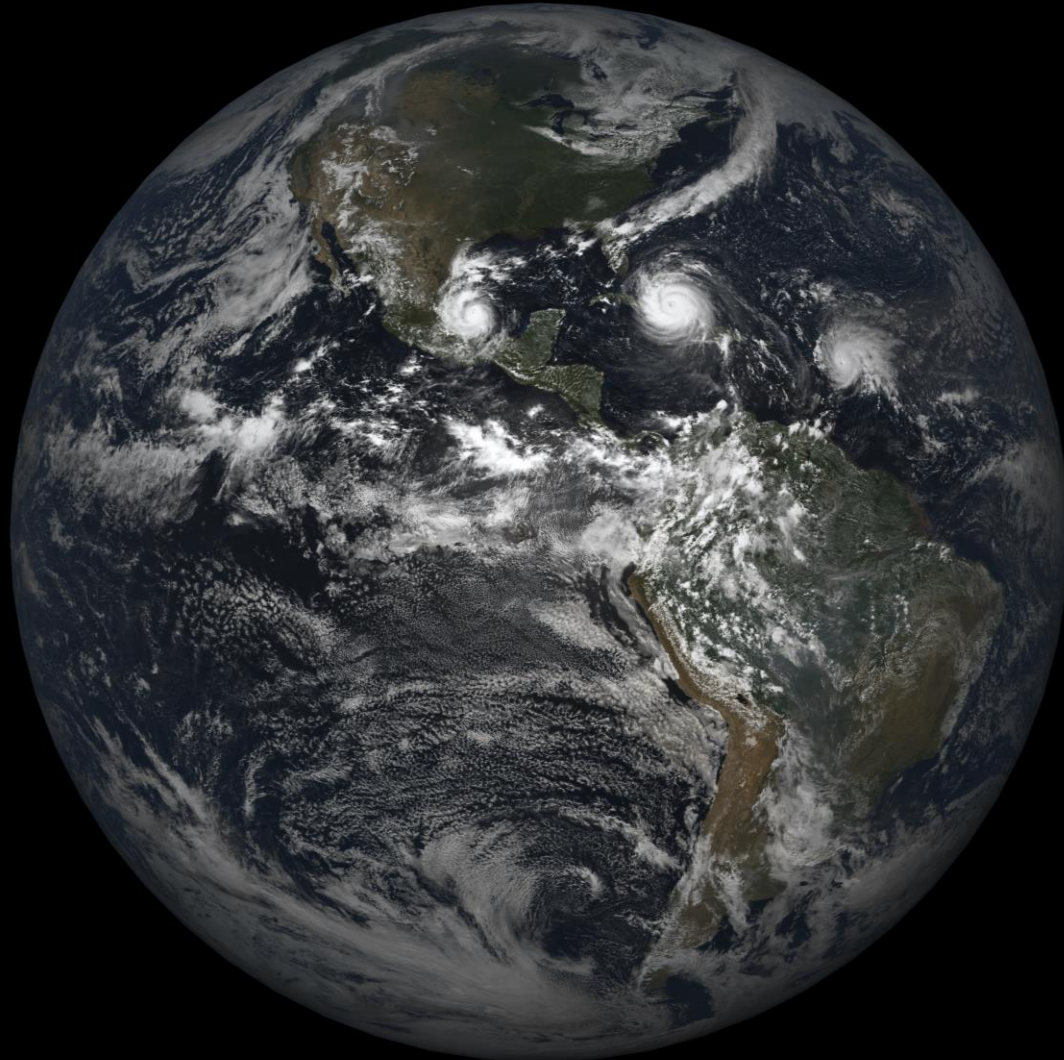

29km

9km

4.5km

i) ASCAT METOP-C 19:11UTC
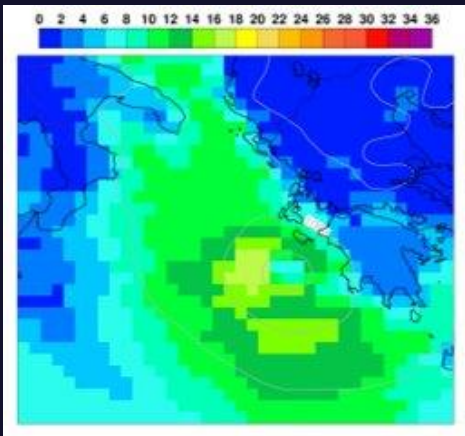
Waves (T+44h – T+84h): model vs altimeter

How a Digital Twin of the Earth-system would look like?

GOES16_ABI CH2_3_1 composite 20170908 1800 UTC
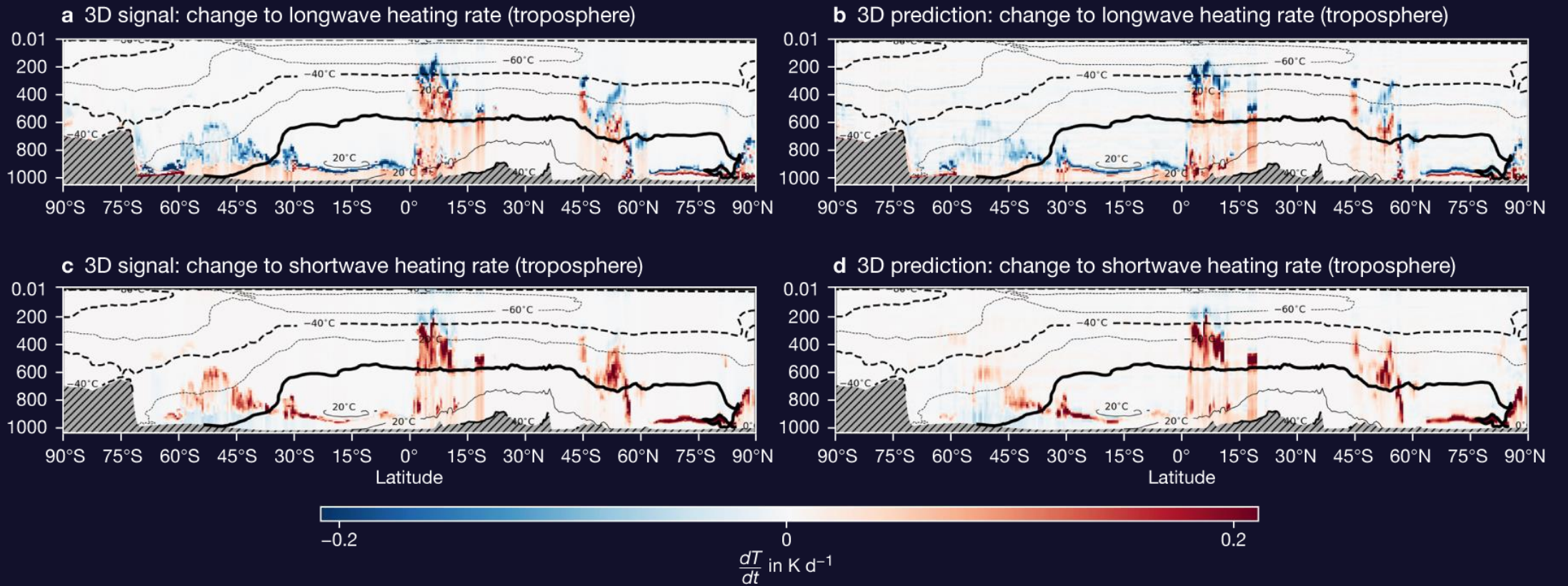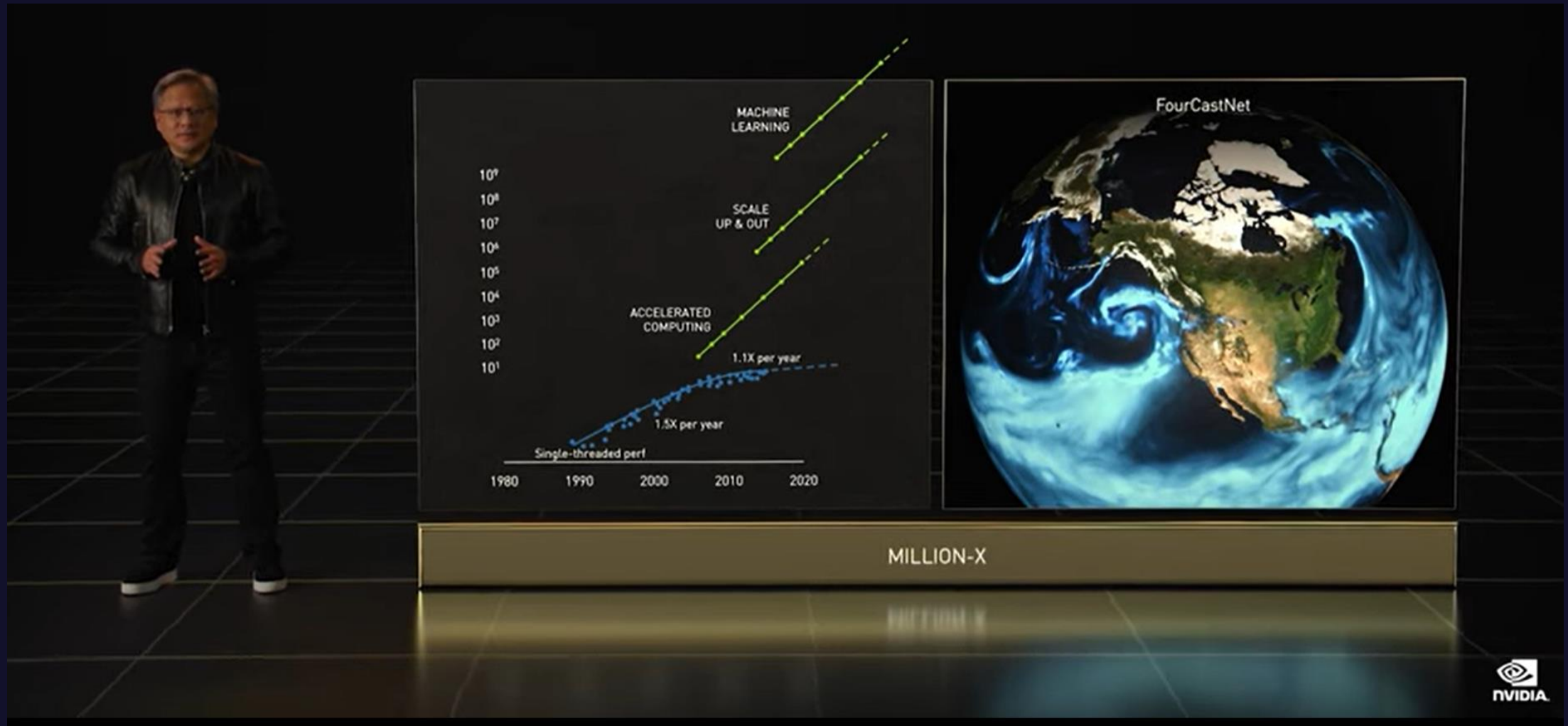
IFS FC+18h at 2.5 km

Philippe Lopez

RTTOV-MFASIS: simulated imagery in the visible.

Towards greater use of AI/ML for modelling

Emulators in IFS are capable of representing the effect of 3D cloud effects using neural network

# AI/ML allowing to reach km-scale ensemble forecasting sooner?

NVIDIA's Earth-2 based FourCastNet, DeepMind GraphCast, … demonstrated
Efficient AI/ML applications interesting from Nowcasting to Medium-Range & S2S

Summary and Outlook

- The ECMWF Integrated Forecasting System has reached an historical milestone with High Resolution Ensembles (9km) on the 27th of June 2023 powered by HPC enhancement

  - IFS 47R2 same vertical resolution in HRES and ENS

  - IFS 47R3 enhanced modelling of moist physics

  - IFS 48R1 ENS HRES horizontal resolution 9 km

  - IFS 49R1 ENS will employ SPP for improved physical consistency

- European Programmes as Destination Earth & Copernicus enhance monitoring & prediction to bridge into km-scale for weather, climate and environmental applications and services

  - ERA5 ¼ degree hourly climate reanalysis from 1940 in C3S

  - Ozone, Aerosols, Pollutants, GHGs monitoring/prediction in CAMS

  - ERA6, DTE promise for higher spatial resolutions and process fidelity

- Ensemble predictions have had a fundamental impact on the way we predict weather at all lead times…and will continue to be our focus

https://www.ecmwf.int/en/publications/**newsletters**

Sally

Paulette

Rene

Vicky

Teddy
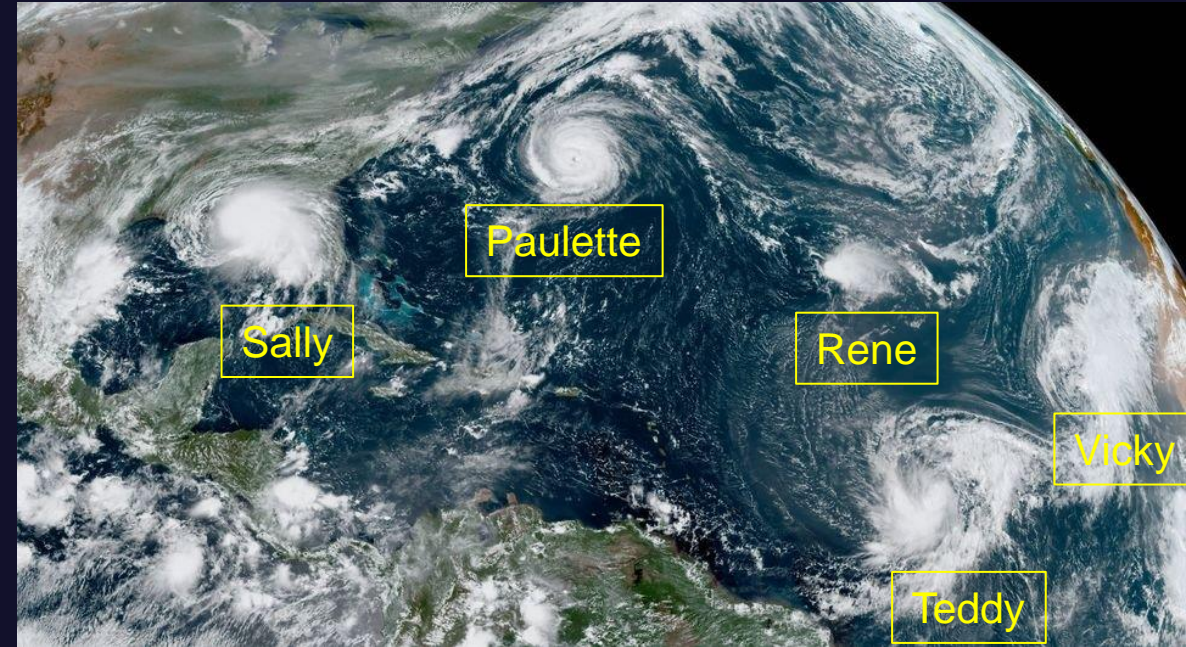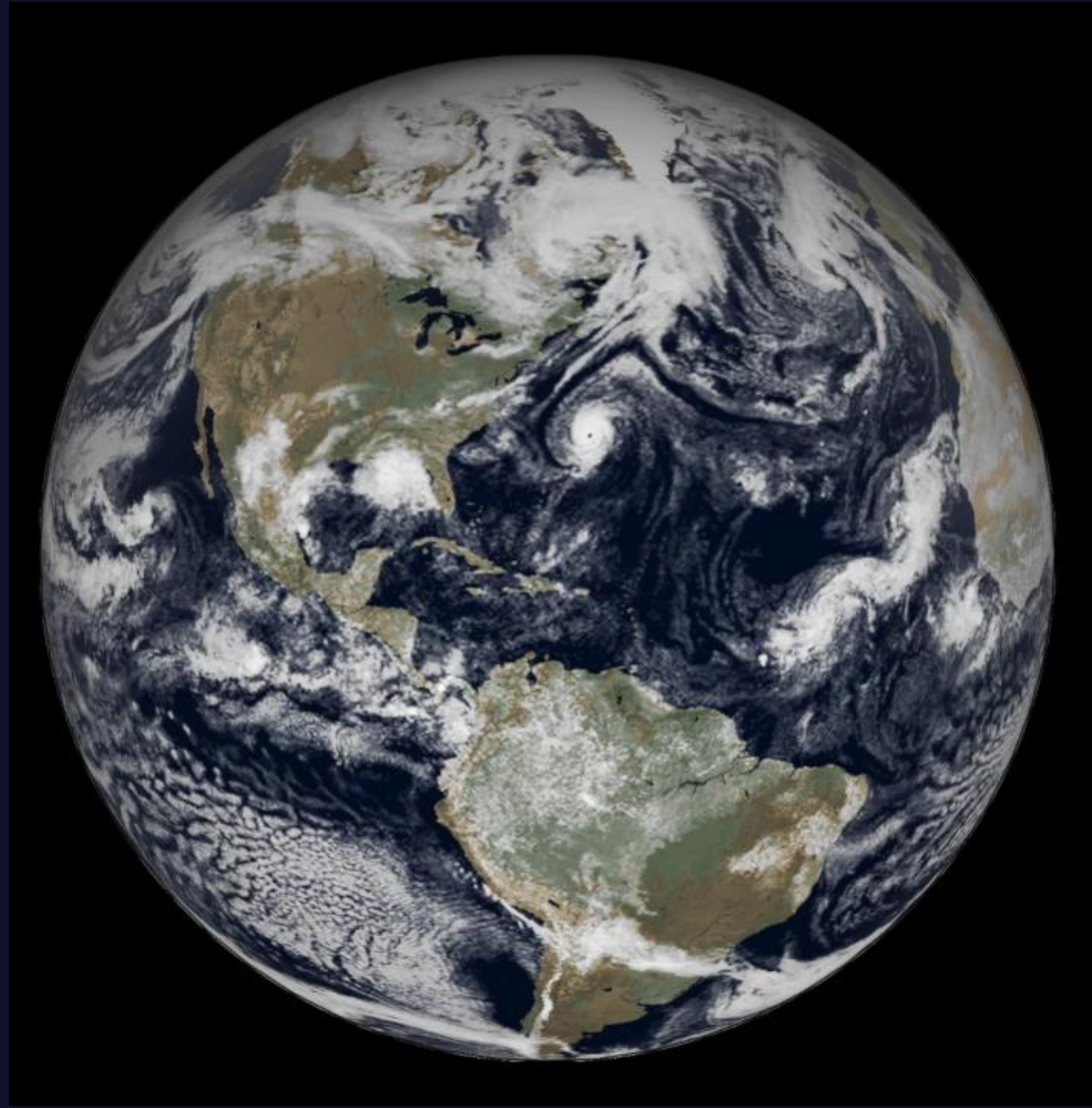
NOAA

Take-home, Cycle 48r1 since 27th June 2023:

ECMWF 9 km medium-range global ensemble provide enhanced ensemble prediction skill for extreme events

Gianpaolo.Balsamo@ecmwf.int   @gpbalsamo