ECMWF's Journey in Advancing Extreme Weather Prediction

INTERNATIONAL WORKSHOP ON
Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX)

Dr. Estibaliz Gascon
Senior Scientist Weather-induced Extremes Digital Twin
ECMWF

Funded by the European Union

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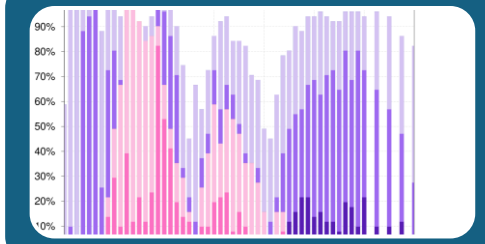
ECMWF strategies in severe weather forecast

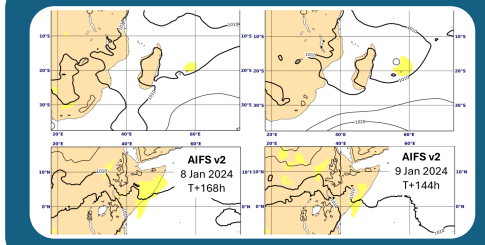


New severe weather products and model improvements

- Post-processed products (EFI, ecPoint, precipitation type)
- Model improvements and new output variables

Destination Earth initiative

- 4.4 km resolution IFS forecast to better predict extremes
- Uncertainty quantification

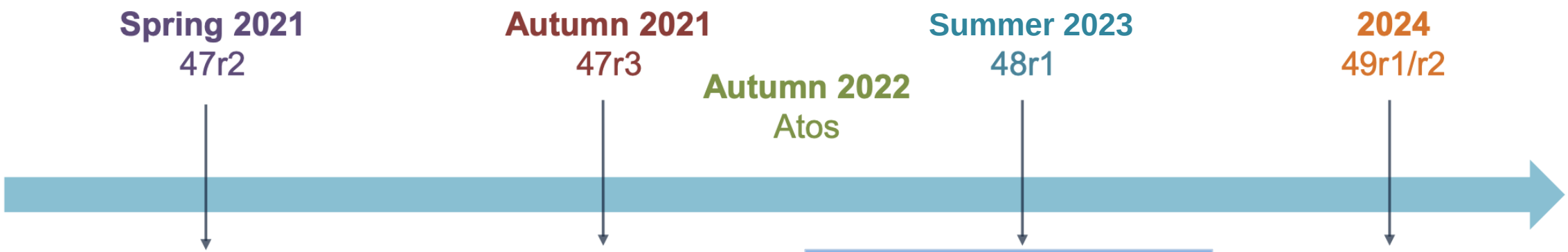


Machine learning models (AIFS)

- Increase the predictability of some severe weather events (i.e.TCs)?
- Use as a diagnostic tool to improve our IFS forecast

New products and model improvements

ECMWF Integrated Forecasting System (IFS) upgrades



Spring 2021
47r2

Single precision
(HRES, ENS, ENS-Ext)

Unified vertical resolution
(ENS, ENS-Ext to L137)

Autumn 2021
47r3

Moist physics upgrade
Observation use and data assimilation (DA) changes

Autumn 2022
Atos

Summer 2023
48r1

ENS resolution increase (18 -> 9 km)

Daily ENS-Ext 100 mem (36 km)

OOPS 4D-Var

Multi-layer snow scheme

Hybrid linear ozone scheme

Upgrades in the CEMS-Floods hydrological suites

2024
49r1/r2

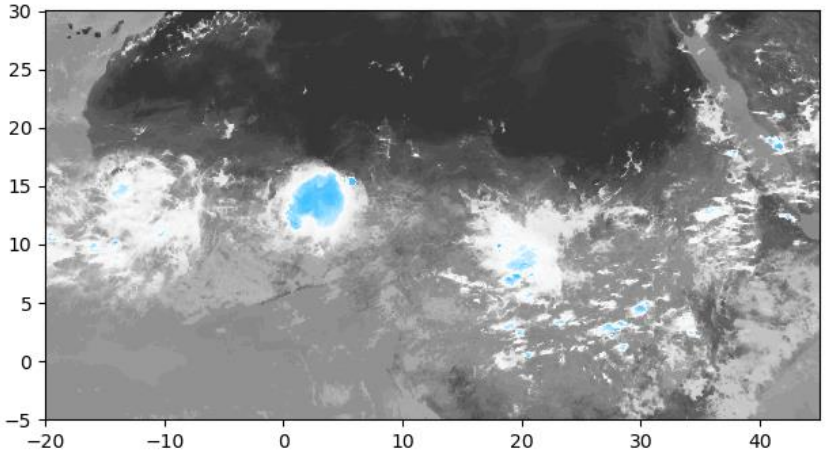
Improved surface
New ocean–sea ice
Updated land fields
Implementation of SPP
COMPO update

SEAS6: 100 ENS members
ERA6 coupled

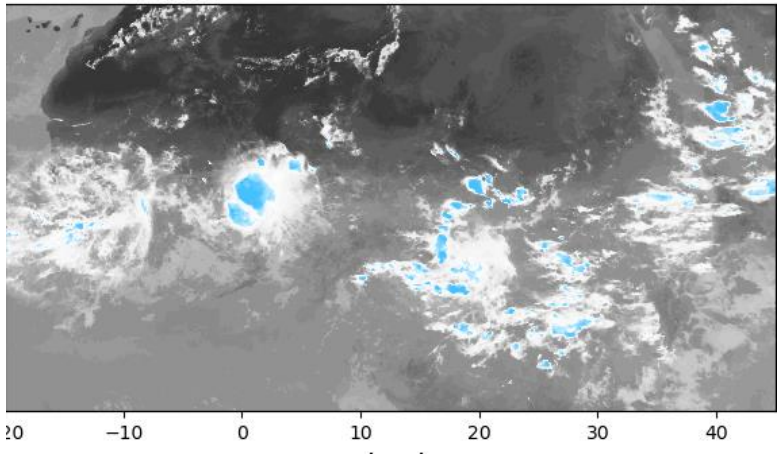
Reconfiguration of ENS and ENS-Ext reforecasts

Towards realistic cloud/convective organization:
African squall lines, with 47r3 more intense and moving west

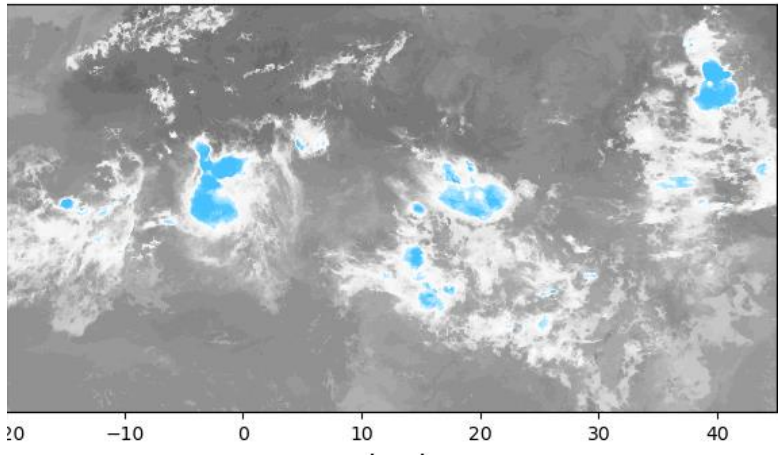
12UTC



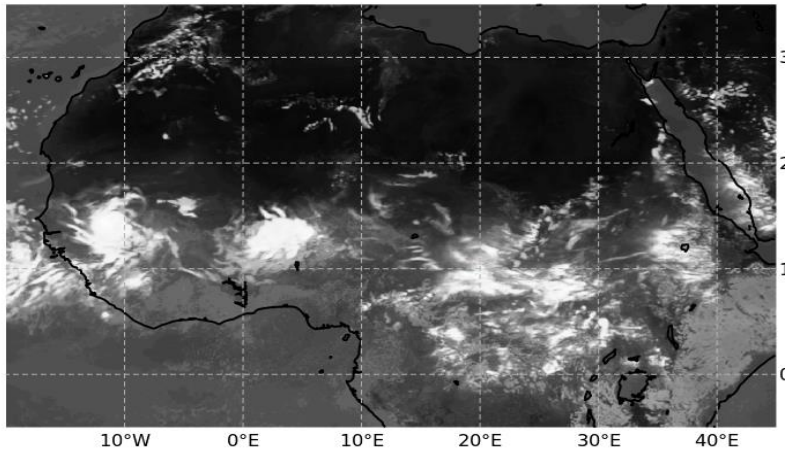
15 UTC



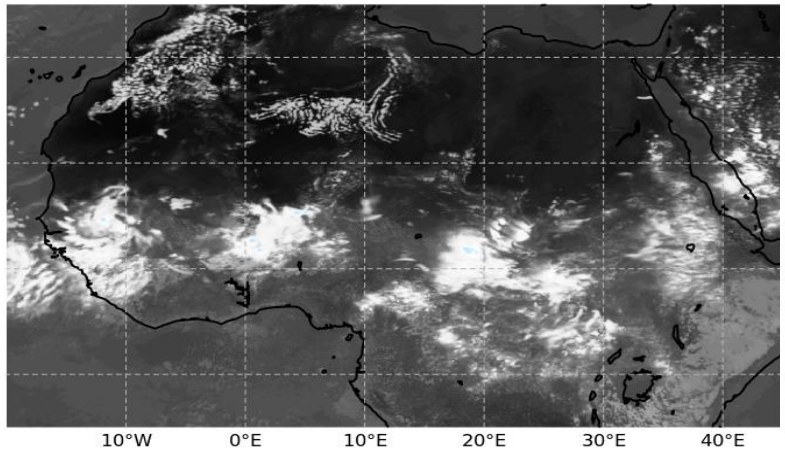
21 UTC. OBS



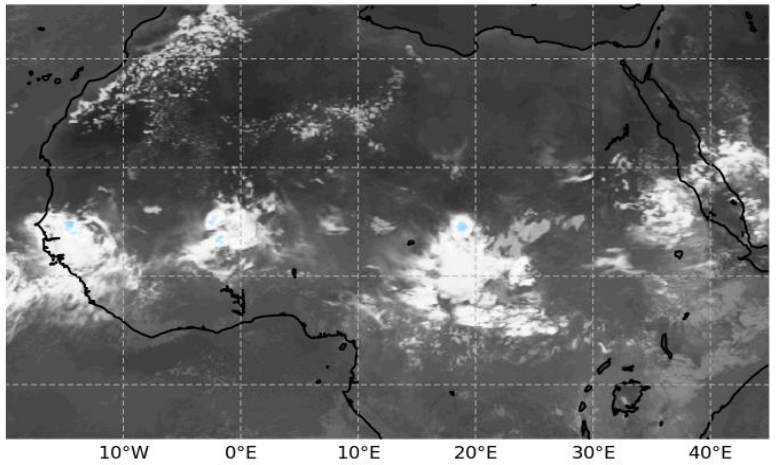
12UTC



15 UTC



21 UTC Forecast



Note: if we run without convection scheme at 9 or 4 km, we get bad results, ie no organization for these systems

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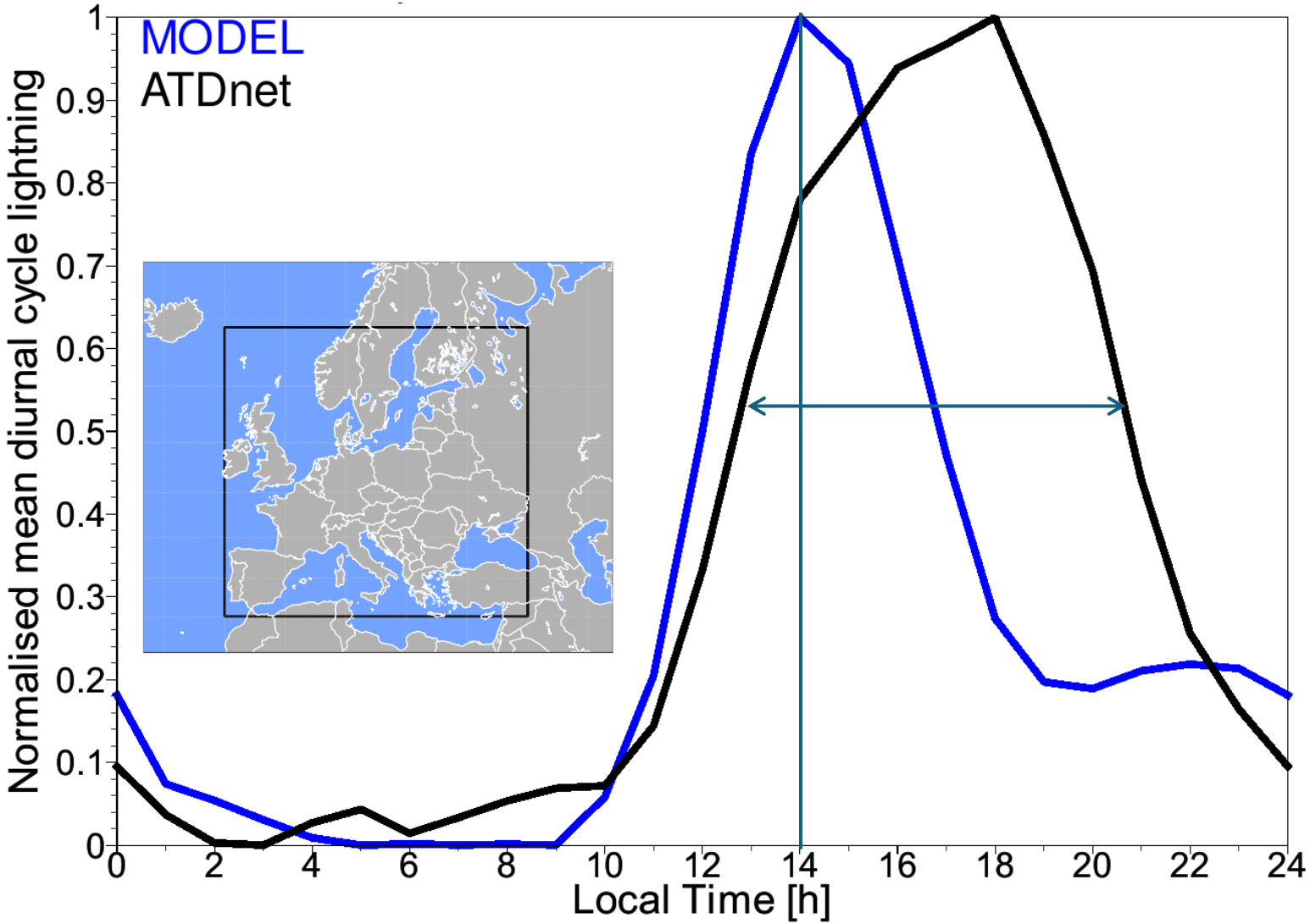
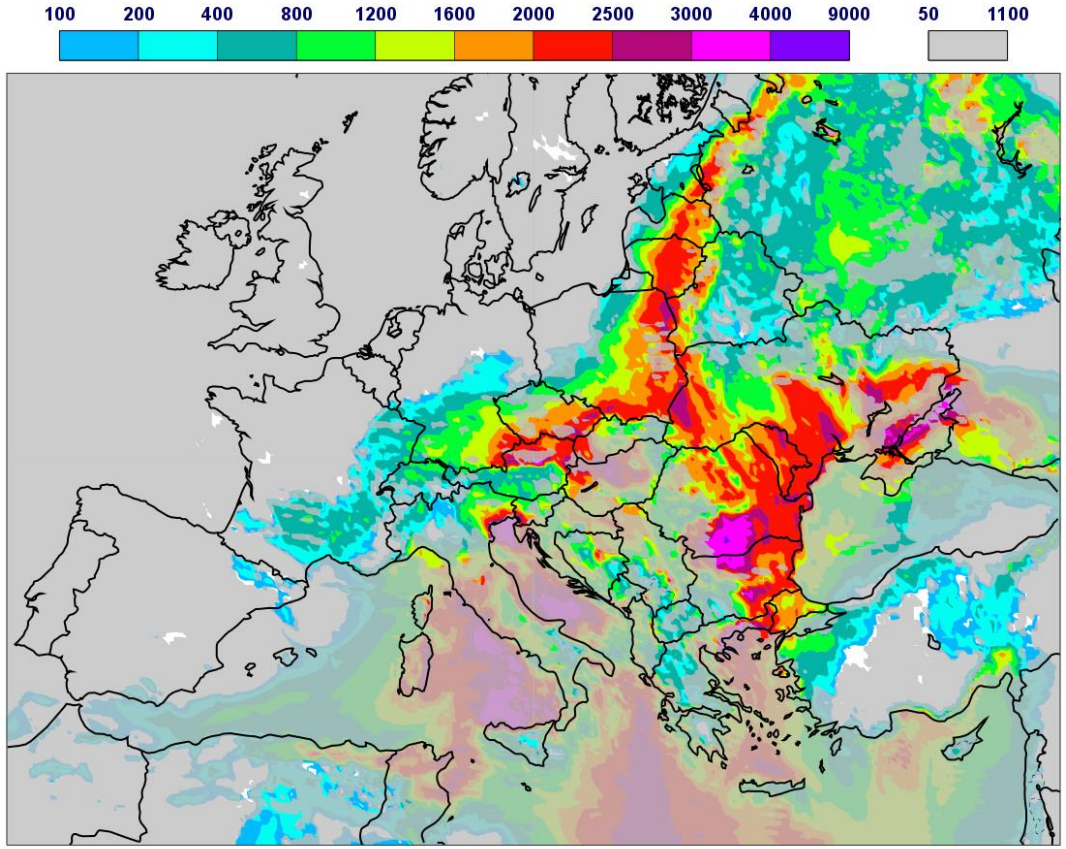
Diurnal cycle of convection - model world vs. real world



- The **peak of convection – much earlier in the model**
  - 14 vs. 18 local time (~4 hours earlier!)
- Convection dies out too quickly in the model compared to reality
  - Convection consumes CAPE too quickly in the model (this may lead to weaker convection)

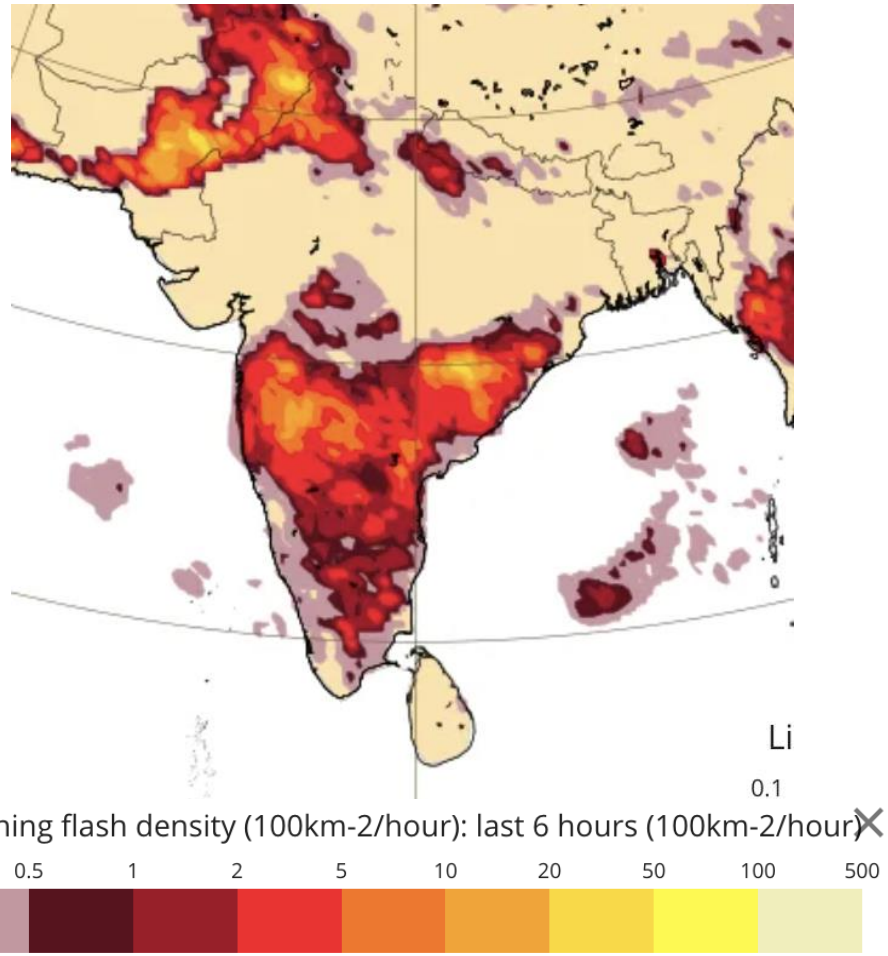
Revised CAPE and CIN from the IFS



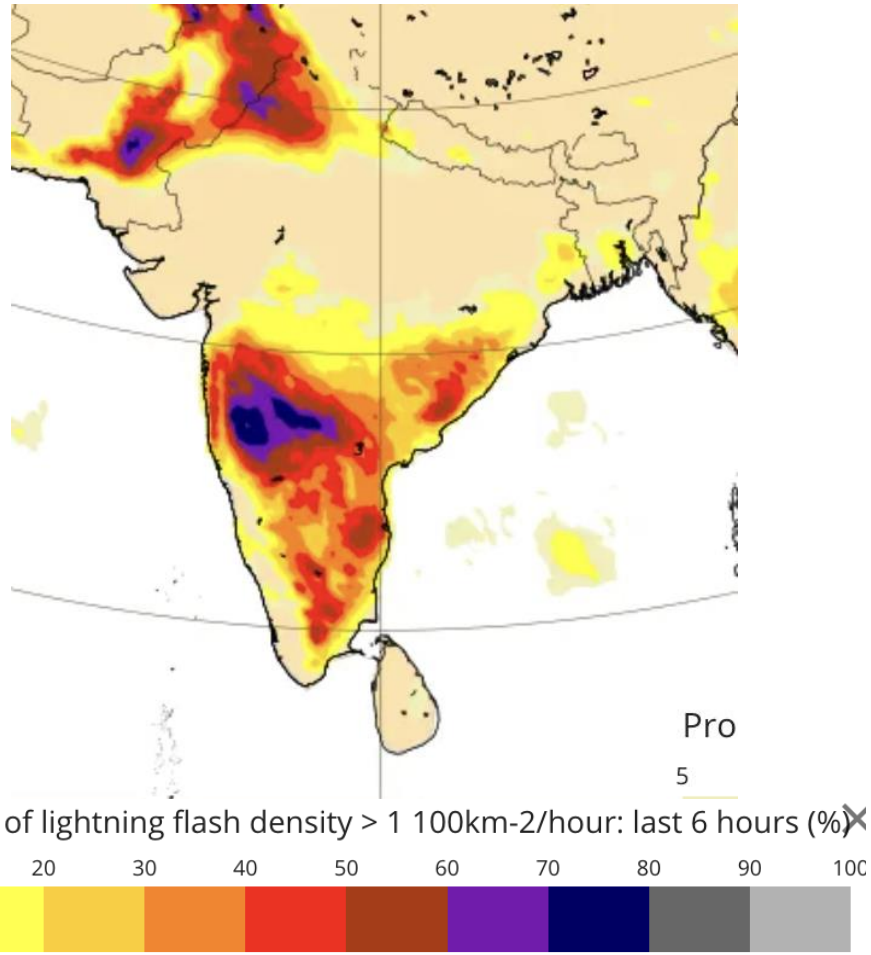
- Various CAPE and CIN parameters:
  - ✓ MUCAPE/MUCIN
  - ✓ MLCAPE/MLCIN for 50- and 100-hPa mixed layers;
- MUCAPE/MUCIN:
  - ✓ no surface layer considered, instead 30-hPa mixed layer parameters for each model level in the lowest 60-hPa layer;
  - ✓ as before the search for the most-unstable parcel goes up to 350-hPa pressure level
  - ✓ departure level in Pa of the most-unstable parcel provided as a model output
- **Revised computation:**
  - ✓ **uses virtual potential temperature instead of equivalent potential temperature as before**
- Still few technical things to sort out.

Deterministic and probabilistic lightning prediction

Lightning flash density (100km2/h):
Last 6h (valid 6th June 12 UTC)

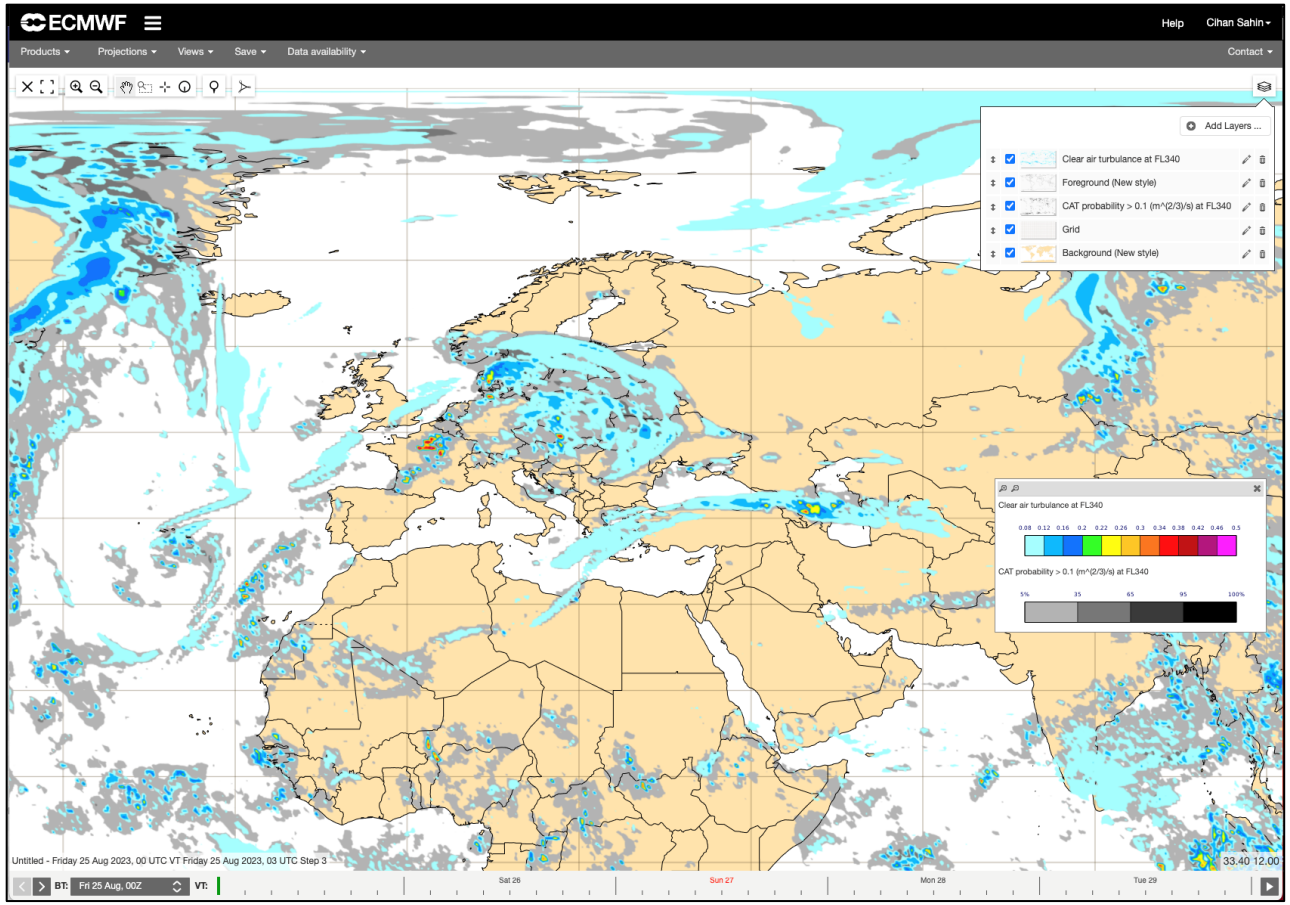


Probability of lightning flash density > 1 (100km2/h):
Last 6h (valid 6th June 12 UTC)



48r1 new ensemble product: **Clear Air Turbulence CAT** ($m^{2/3}s^{-1}$) Probability

Clear Air Turbulence (CAT) in operations and Eddy Dissipation Rate ($m^{2/3}\ s^{-1}$) research



E.G.: CAT on flight levels (FL 300) and Ensemble Probability

- Data on model levels (huge!) –we only archive unperturbed fc
- "On the fly" conversion: model levels -> height levels-> flight levels

- Will be available in ERA6 (CAT climatology based on ERA5 has been established by Juheon Lee et al. 2022)

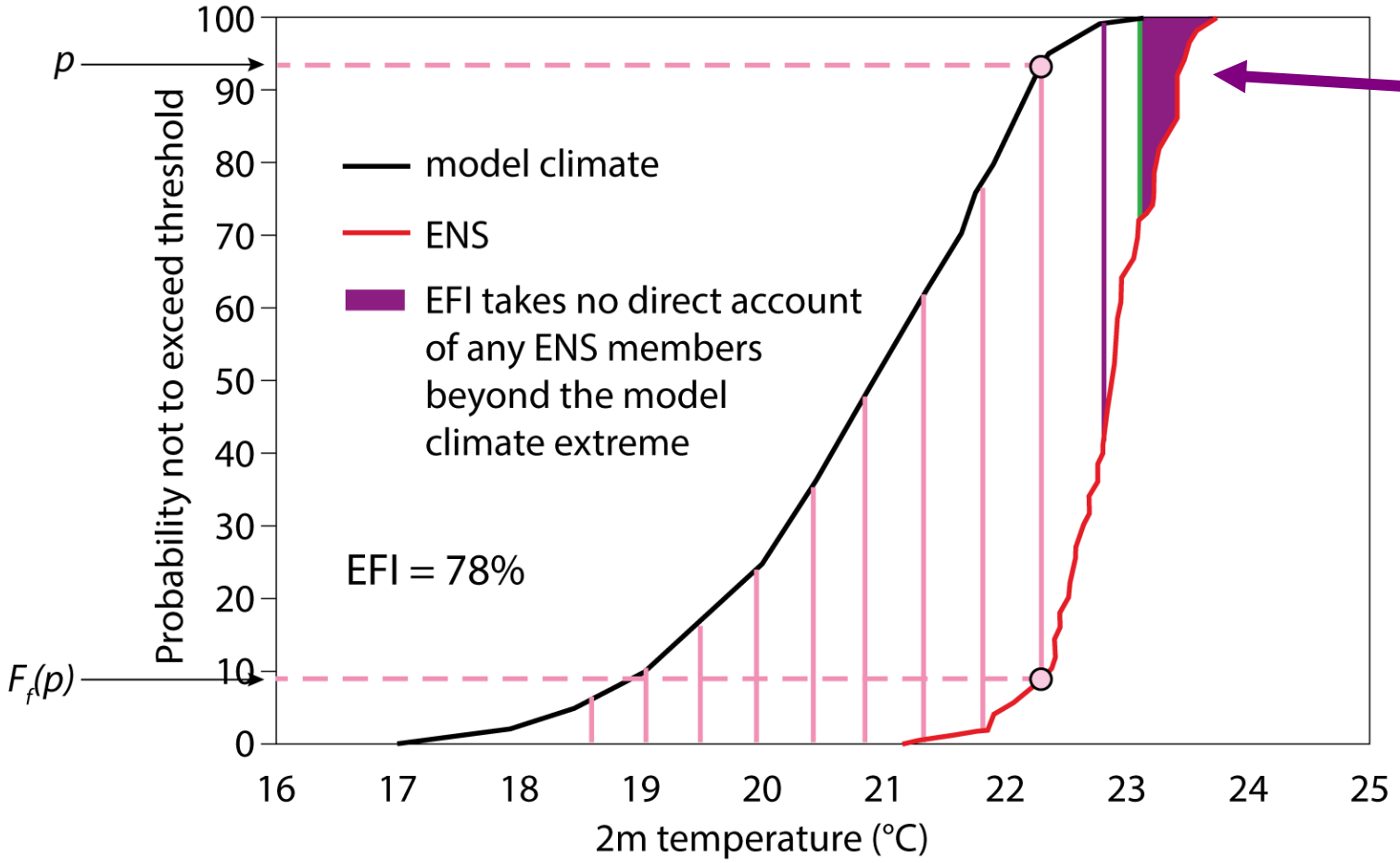
Details in: ECMWF Tech Memo 874
ECMWF Newsletter No 168, summer 2021
Dörnbrack, Bechtold, Schumann, JGR 2022
https://www.ecmwf.int/en/elibrary/81370-ifs-documentation-cy48r1-part-iv-physical-processes

$$EFI = \frac{2}{\pi}\int_0^1 \left(\frac{p - F_f(p)}{\sqrt{p(1-p)}}\right) dp$$

Represented by pink lines below

More weight to extremes of M-climate being a quadratic function of p

EFI = Extreme Forecast Index



EFI takes no direct account of any ENS members beyond the M-climate extremes

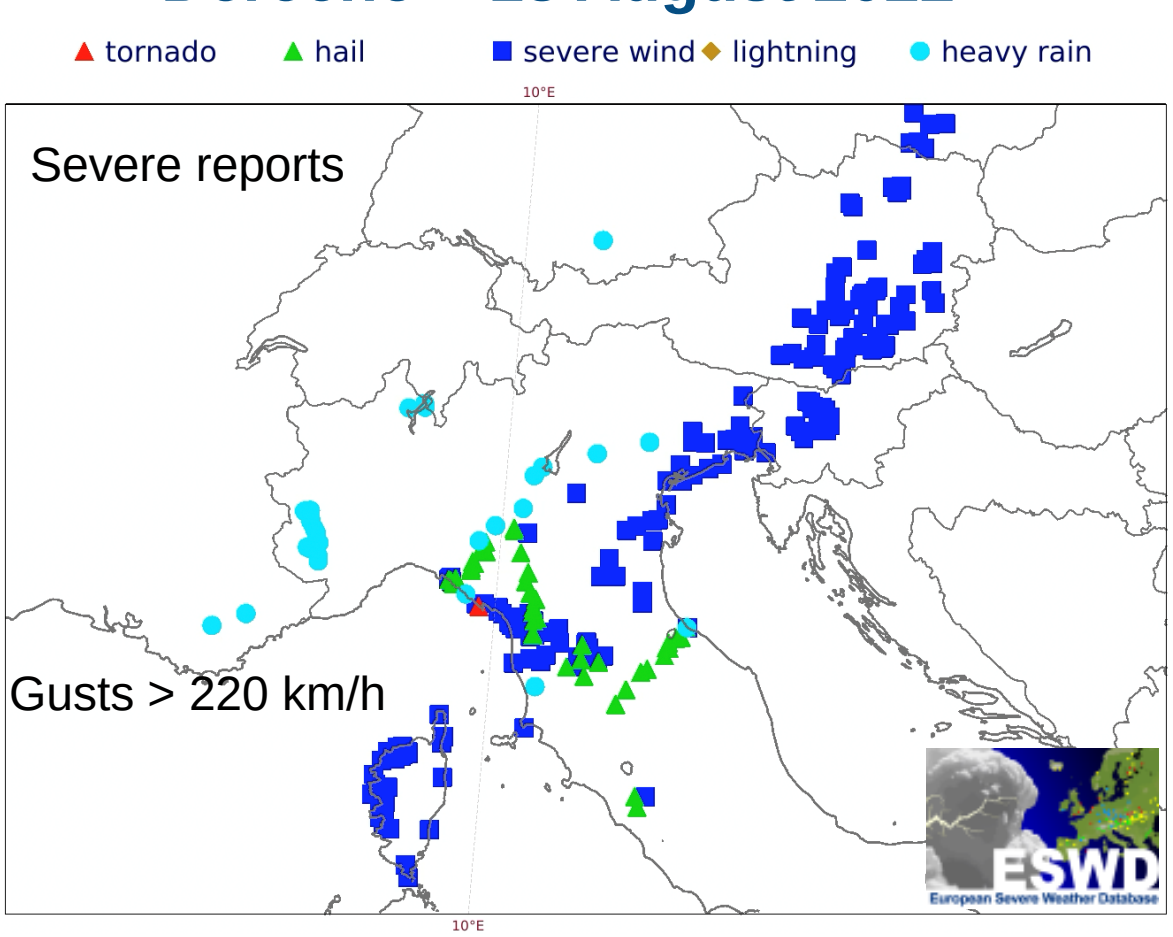
$-1 \le EFI \le 1$

$-100\% \le EFI \le 100\%$

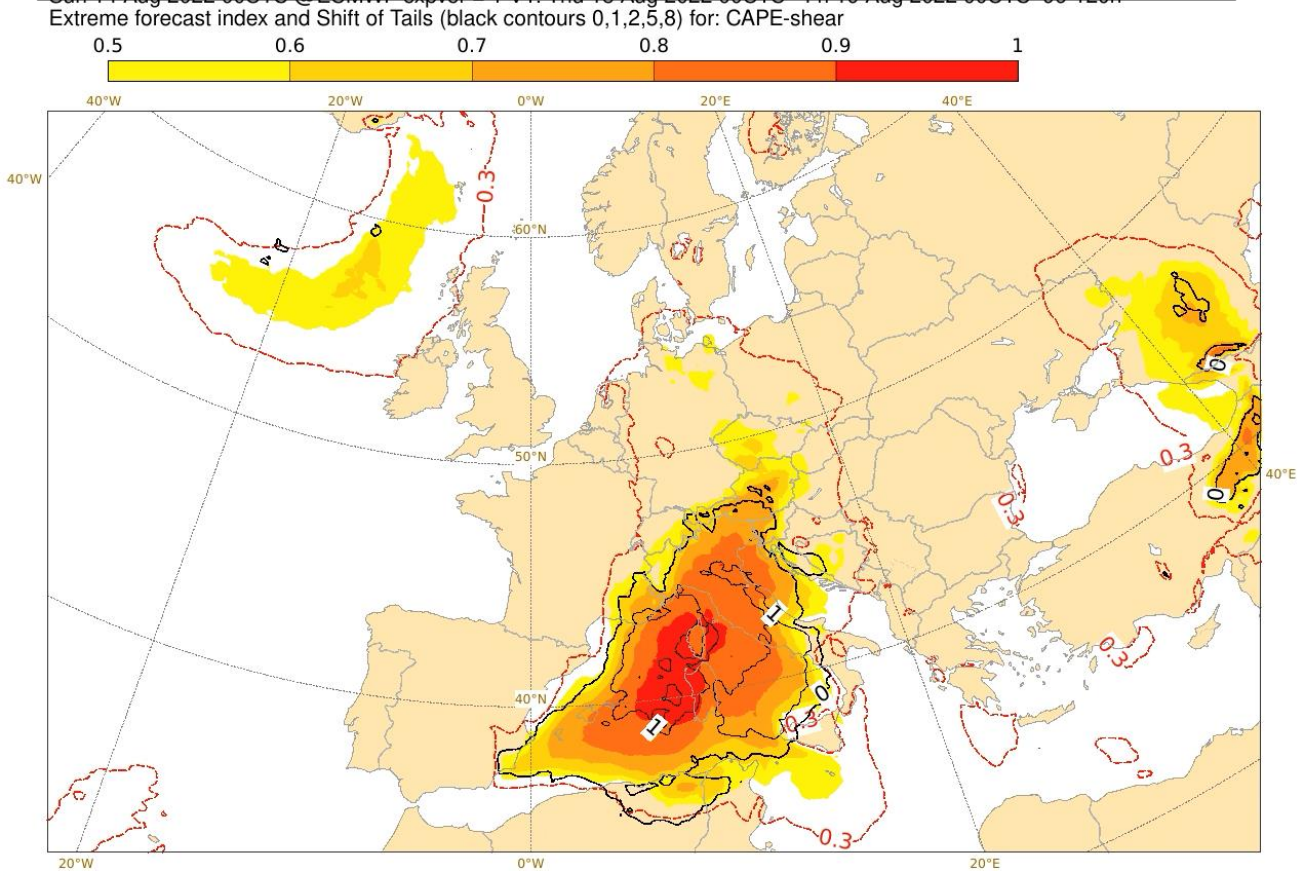
Used to denote how extreme a given ensemble forecast is, relative to (model) climatology

Used with the Ensemble, so we compare ***distributions***

Derecho – 18 August 2022



EFI CAPE-shear. T+96-120h



- 12 fatalities associated with the derecho. Gusts were truly phenomenal.
- EFI for CAPE-shear – highlighted this severe convective outbreak in the medium range (5 to 7 days in advance).

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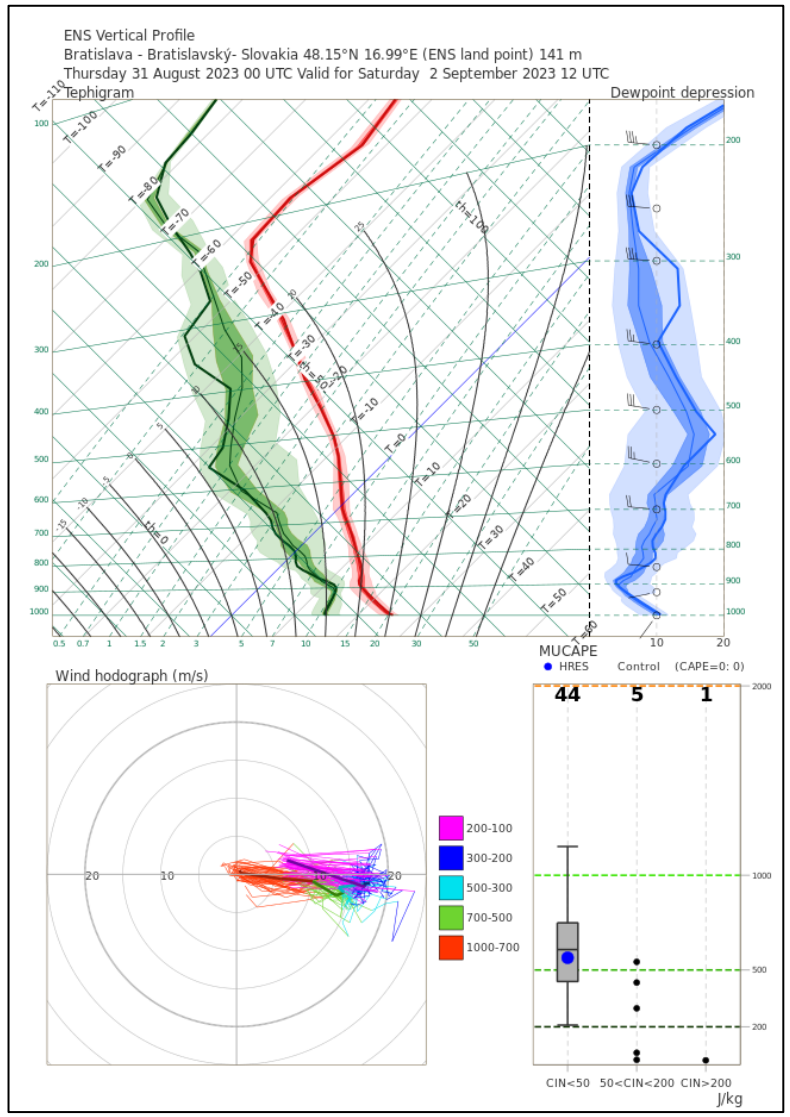
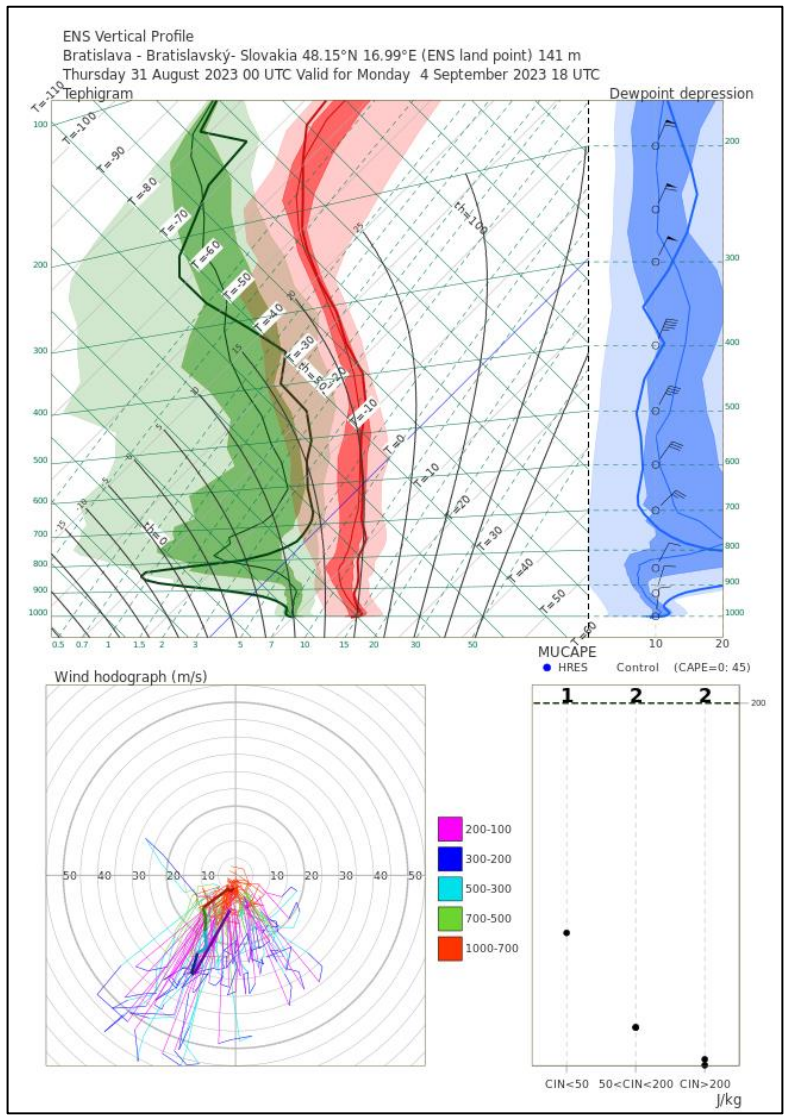
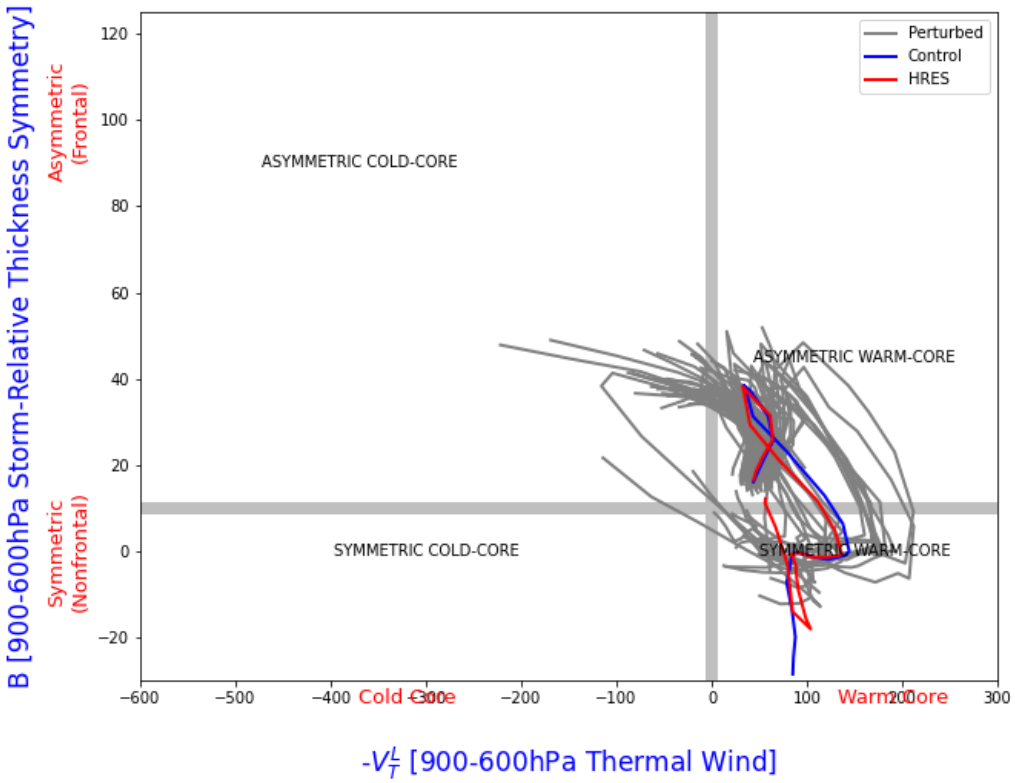
Ensemble vertical profiles

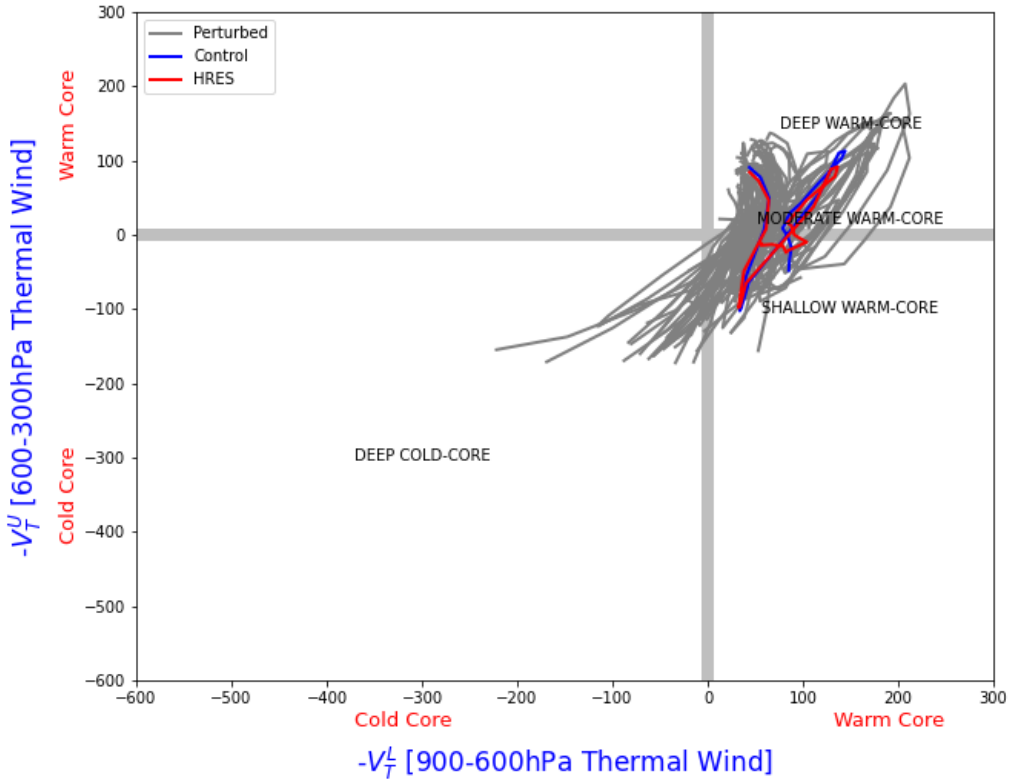




- Model level data from the perturbed ensemble members.
- Dew point depression in the vertical
- Wind hodographs
- CAPE/CIN diagram
- Every 6 hours from T+0h to T+120h

Graphical product under development: CPS trajectories for Tropical Cyclones





- We are currently developing a product showing cyclone phase space (CPS) trajectories for a given TC, a product that was requested by Portugal Meteorological Service.
- It provides insight into the symmetry and thermal structure of TCs and allows to analyse phase transitions.

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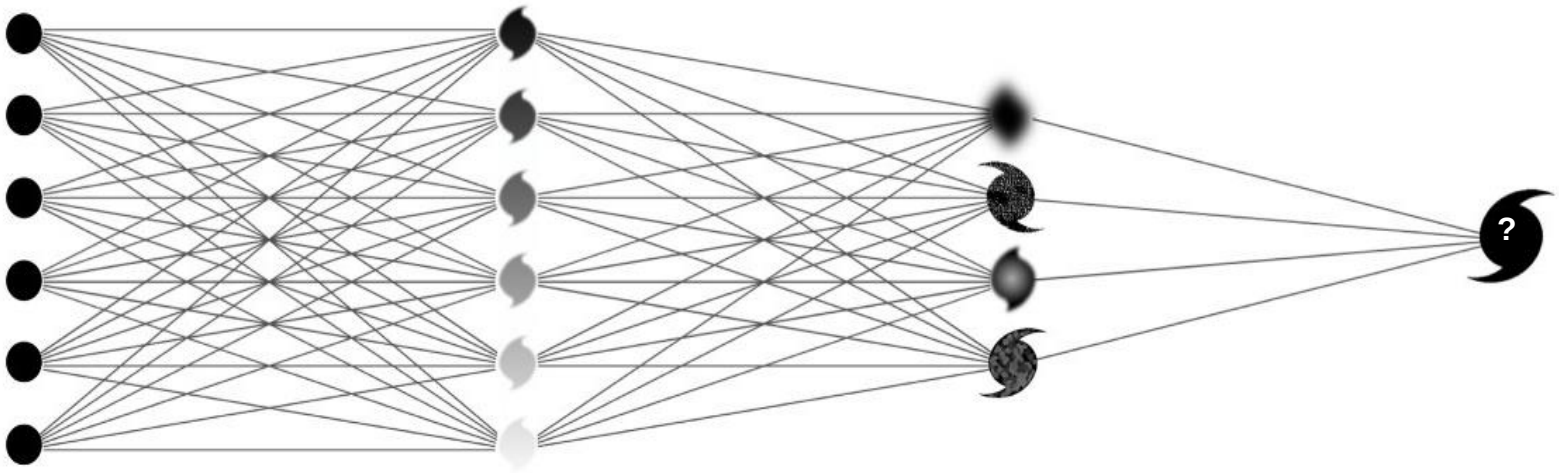
Tropical Cyclones in Global Data-Driven Forecasting Models: AIFS



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Destination Earth

© ECMWF July 22, 2024

Artificial Intelligence / Integrated Forecasting System (AIFS)

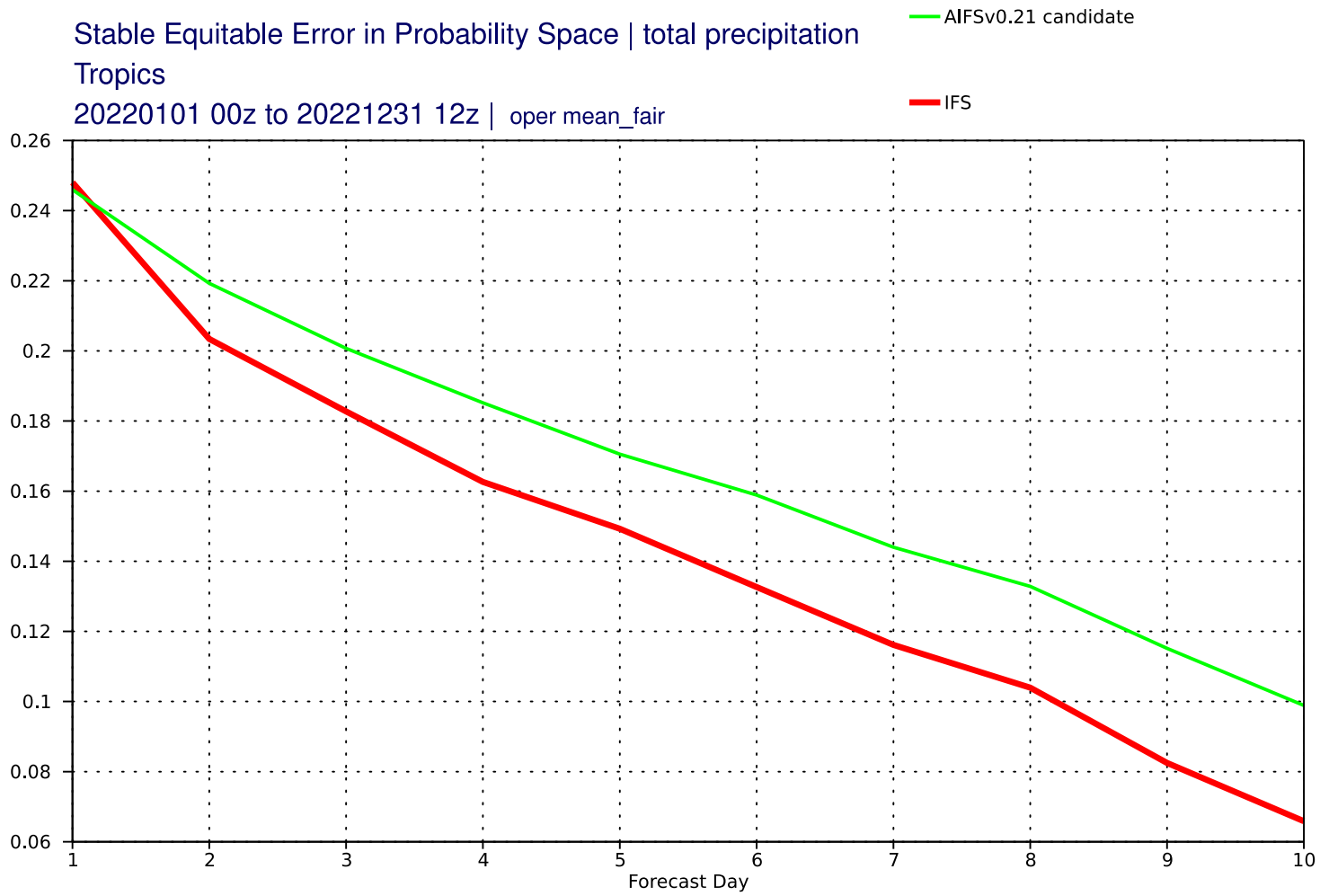
Goal: operational probabilistic forecasting system

v0.21

- Added precipitation variables.

Higher = better

Live forecasts from 28th Feb 2024.



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AIFS - Artificial Intelligence / Integrated Forecasting System

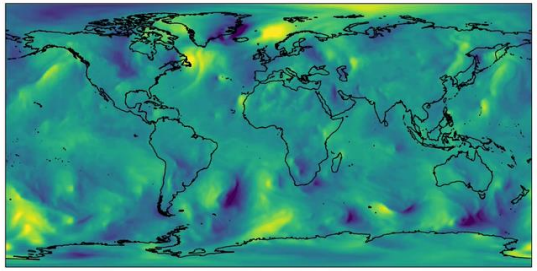
First implementation (~ 1deg resolution) in 2023, following Keisler 2022 and Lam et. al 2022:

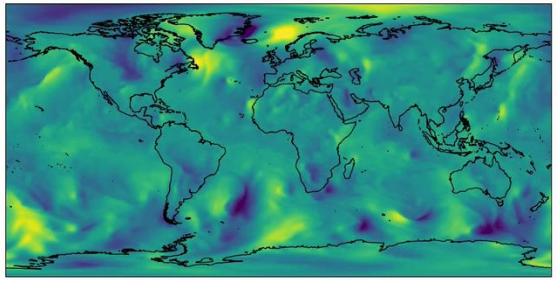
Update beginning of 2024, update to ~ 0.25 deg:

- Implement a forecast system based on Graph Neural Networks (GNNs). One attractive property of GNNs is that they can learn from data on arbitrary grids, and this allows the AIFS to work directly with the native IFS reduced Gaussian grids.

- Use a subset of the ERA5 reanalysis for 1979–2018 and fine-tuned on operational IFS data from 2019 to 2020.

HRES





AIFS

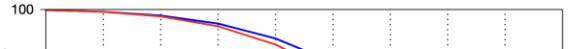
Meridional wind at 850 hPa

news

AIFS: a new ECMWF forecasting system

Simon Lang, Mihai Alexe, Matthew Chantry, Jesper Dramsch, Florian Pinault, Baudouin Raoult, Zied Ben Bouallègue, Mariana Clare, Christian Lessig, Linus Magnusson, Ana Prieto Nemesio

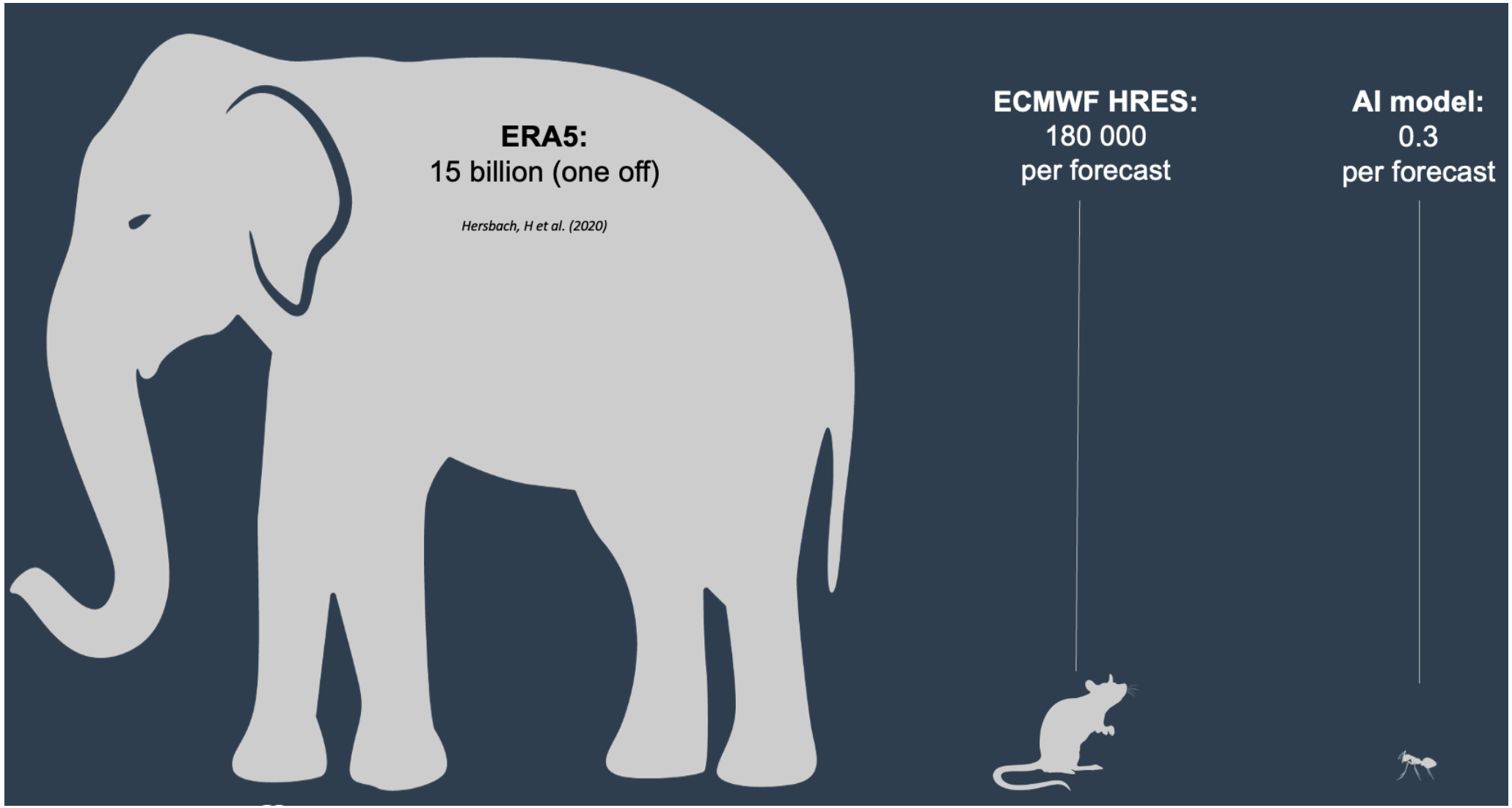
There has been substantial progress recently in the realm of data-driven



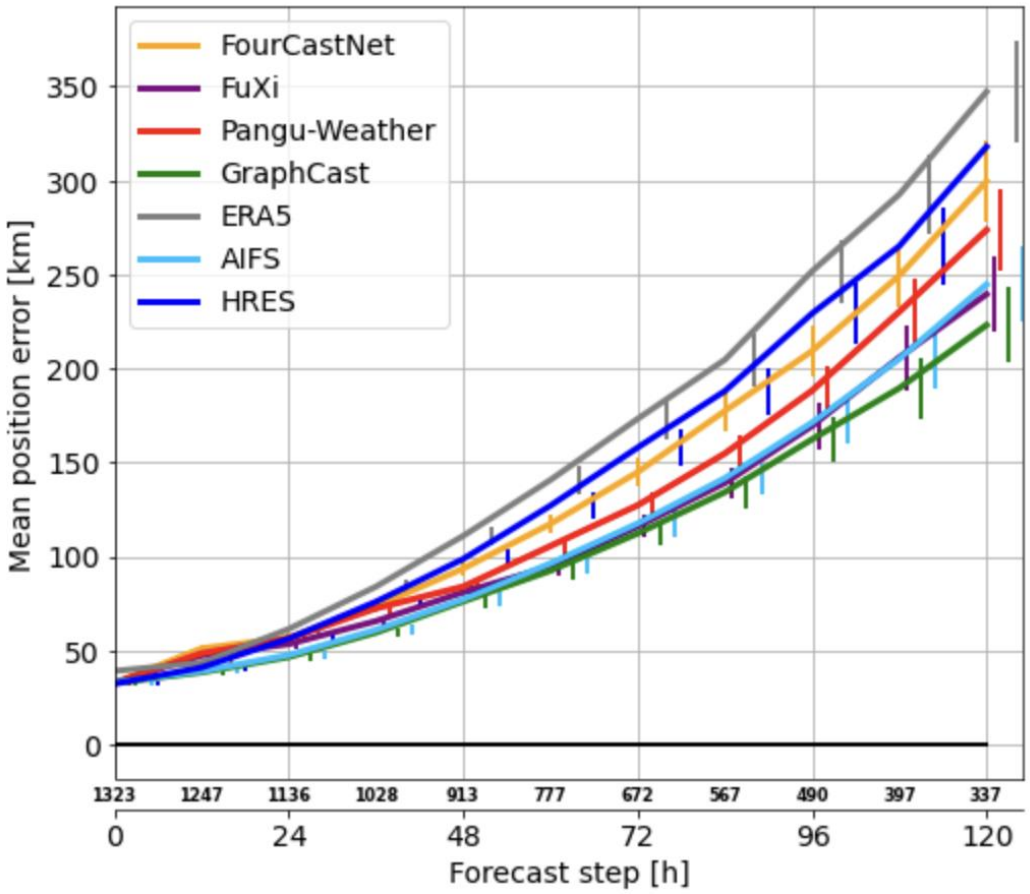
Simon Lang, Mihai Alexe, Matthew Chantry, Jesper Dramsch, Florian Pinault et al. . **AIFS - ECMWF's data-driven forecasting system**

Available from 4 June 2024 !! https://arxiv.org/abs/2406.01465

How costly?


ERA5:
15 billion (one off)
Hersbach, H et al. (2020)
ECMWF HRES:
180 000
per forecast
AI model:
0.3
per forecast

Tropical cyclone track verification



- Compared to HRES, track errors improved by up to 30% for days 3-5.

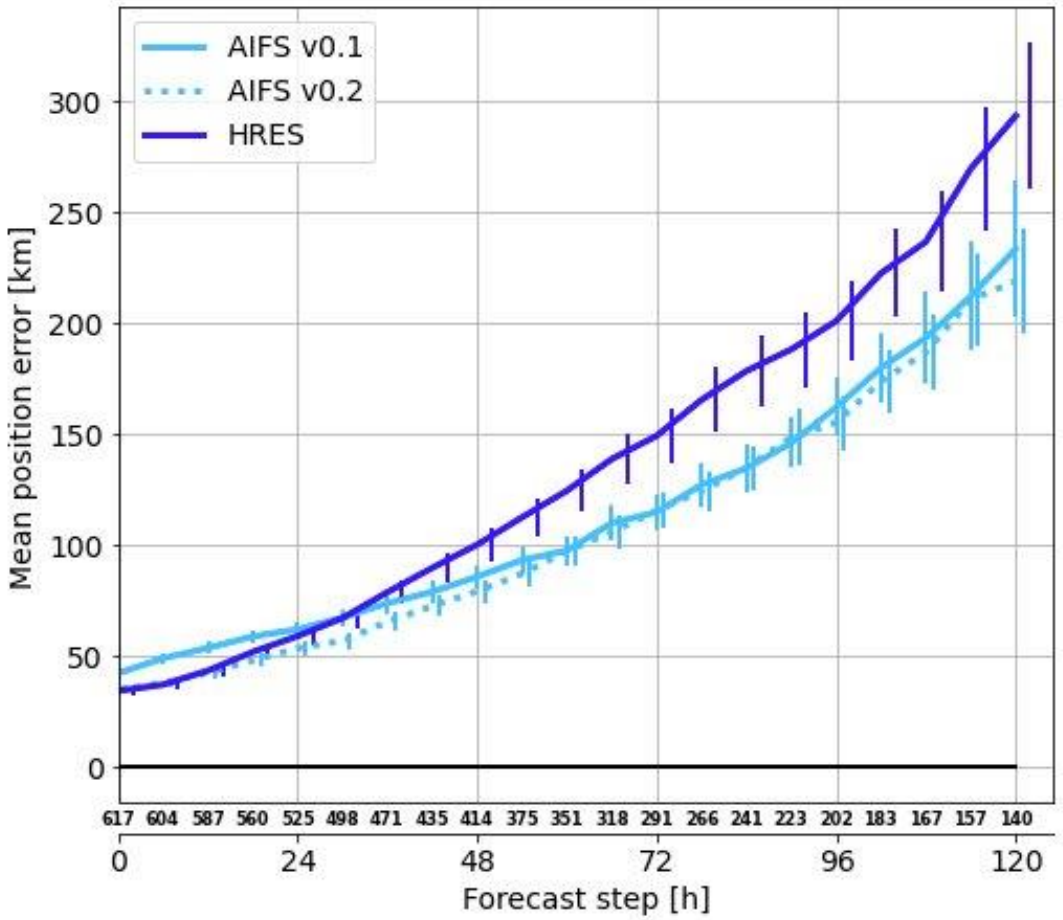
HAVE WE REACHED THE LIMITS OF PREDICTABILITY FOR TROPICAL CYCLONE TRACK FORECASTING?

"Evidence has been presented hinting that the approaching limit of predictability for tropical cyclone track prediction is near or has already been reached."

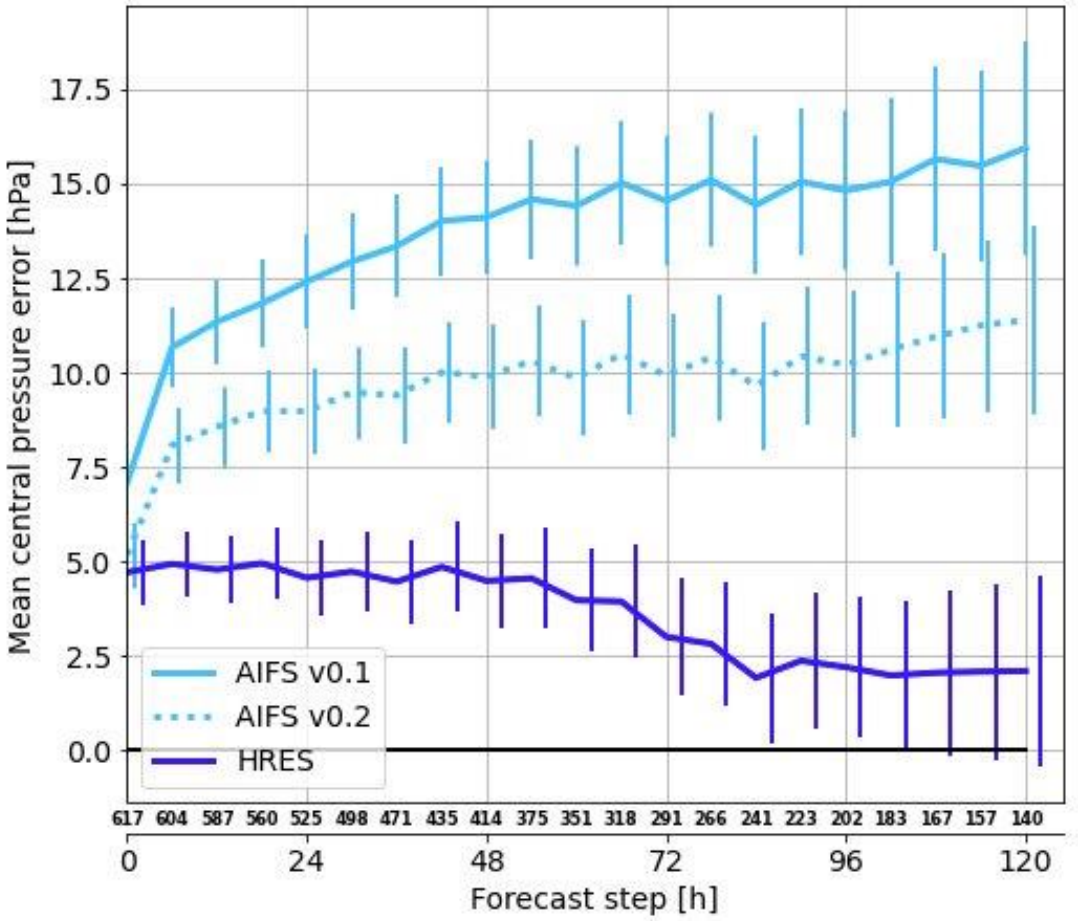
BAMS essay by Landsea and Cangialosi (2018)

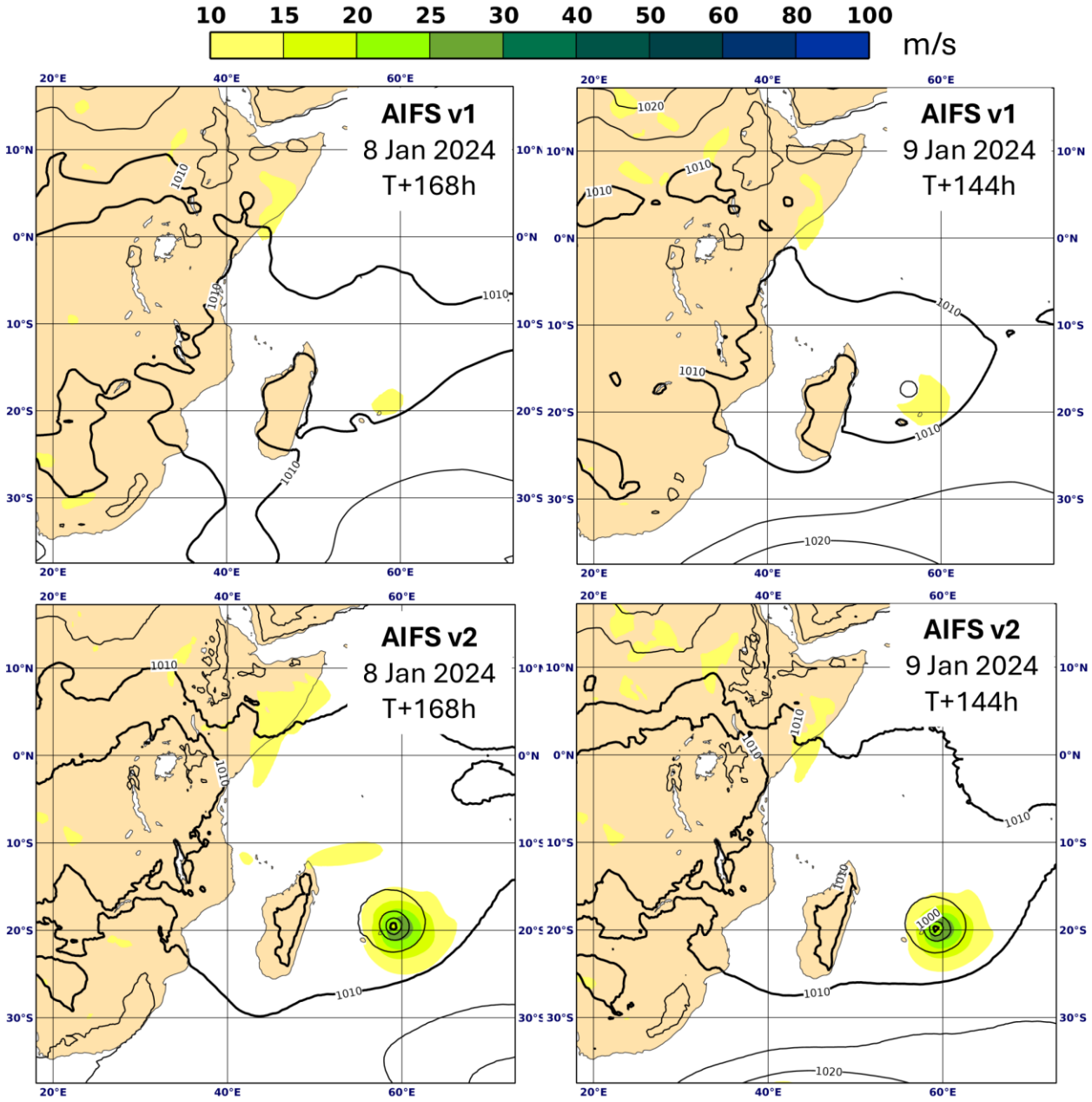
Forecast skill Tropical cyclones 2022:

Position error



Central pressure bias





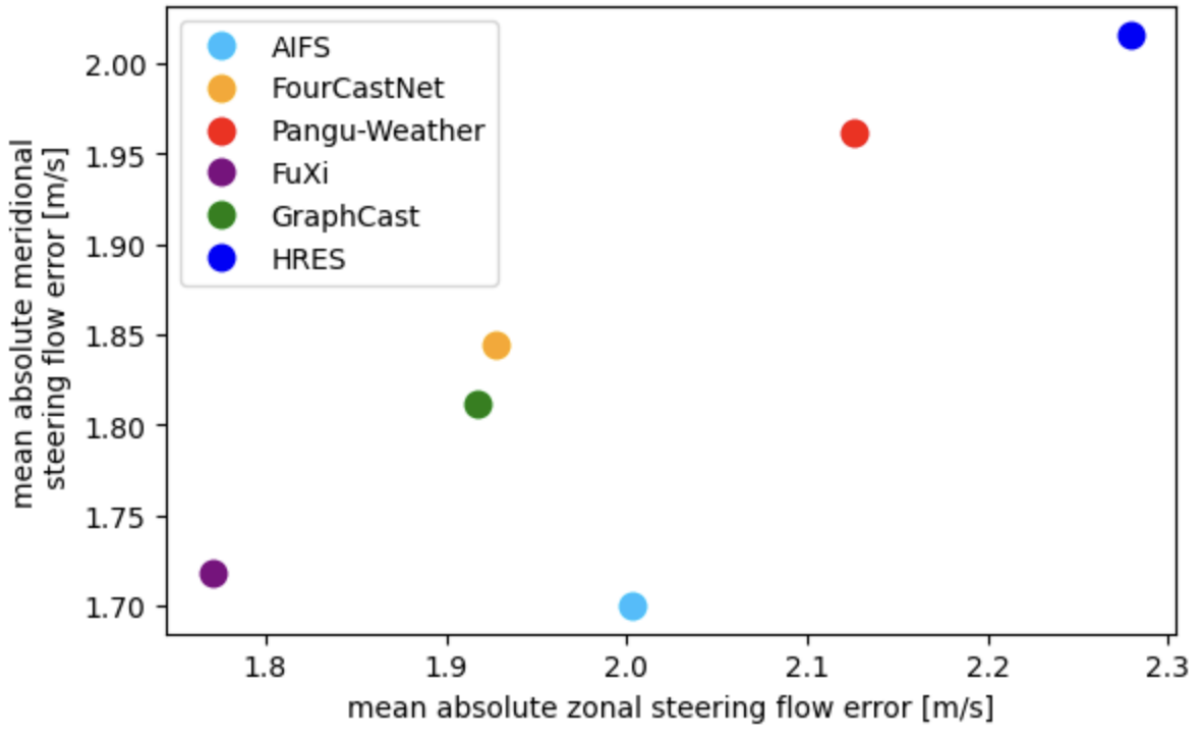
AIFS v2 predicted the formation of TC Belal 2 days before **AIFS v1**, mainly due to the improvement in horizontal resolution (among other model improvements) between 1 to 0.25 degrees.

Why are these models so much better in predicting TC tracks?

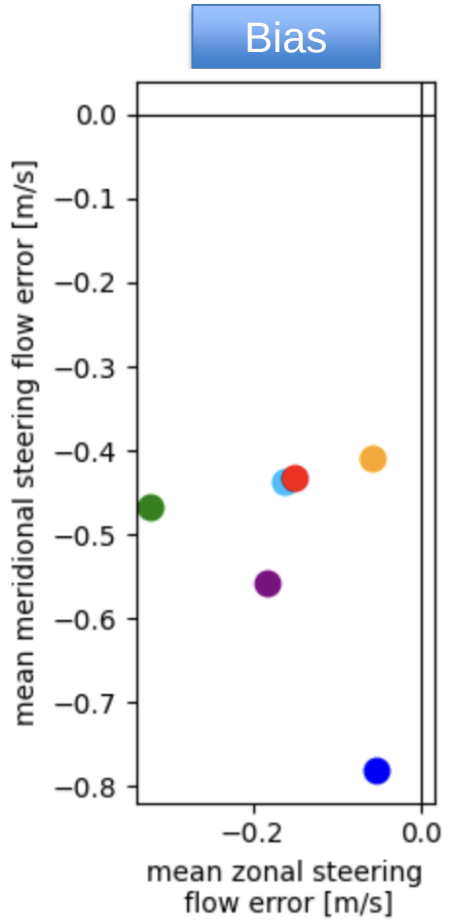
- Results are for the Northern hemisphere, Jul-Oct, 2022+2023, 72h lead time.
- IFS operational analysis is used as ‘truth’.
- For the data-driven models, reduced steering flow errors are found, which translate into reduced TC motion biases.

Steering flow

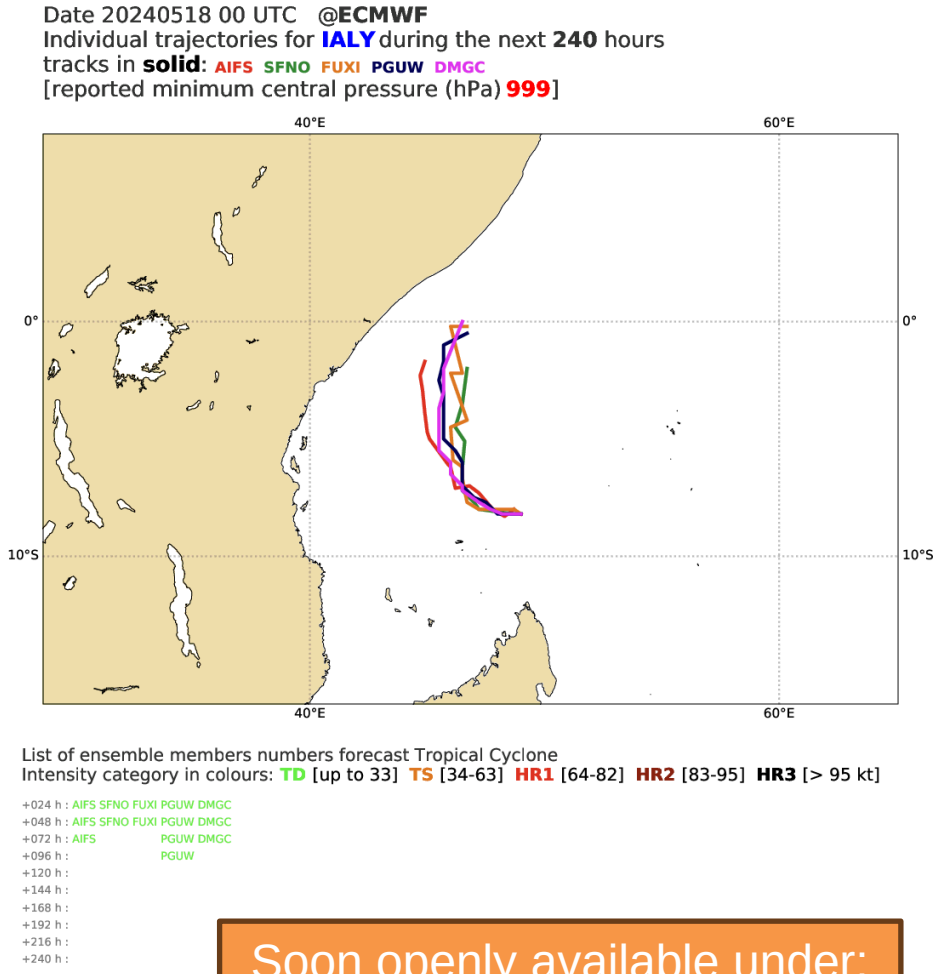
MAE



Bias

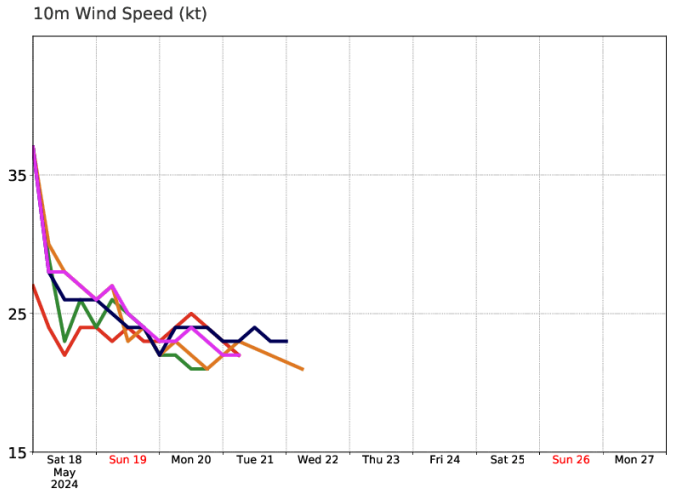


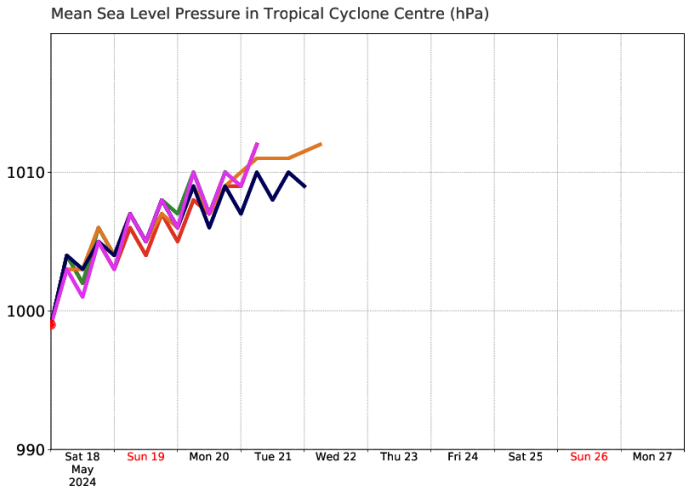
Future ECMWF products: ML TC tracks



Soon openly available under:
https://charts.ecmwf.int

10m wind speed





Mean sea level Pressure

Also soon available:
ML TC tracks in
BUFR format

EU’s Destination Earth (DestinE) initiative

Towards a Digital Twin Earth

Entrusted entities

ECMWF esa EUMETSAT

Key elements

- Digital Twin Engine
- Digital Twins
- Data lake
- Core platform

A European Green Deal (2019)

A European strategy for data (2020)

Shaping Europe's digital future (2020)

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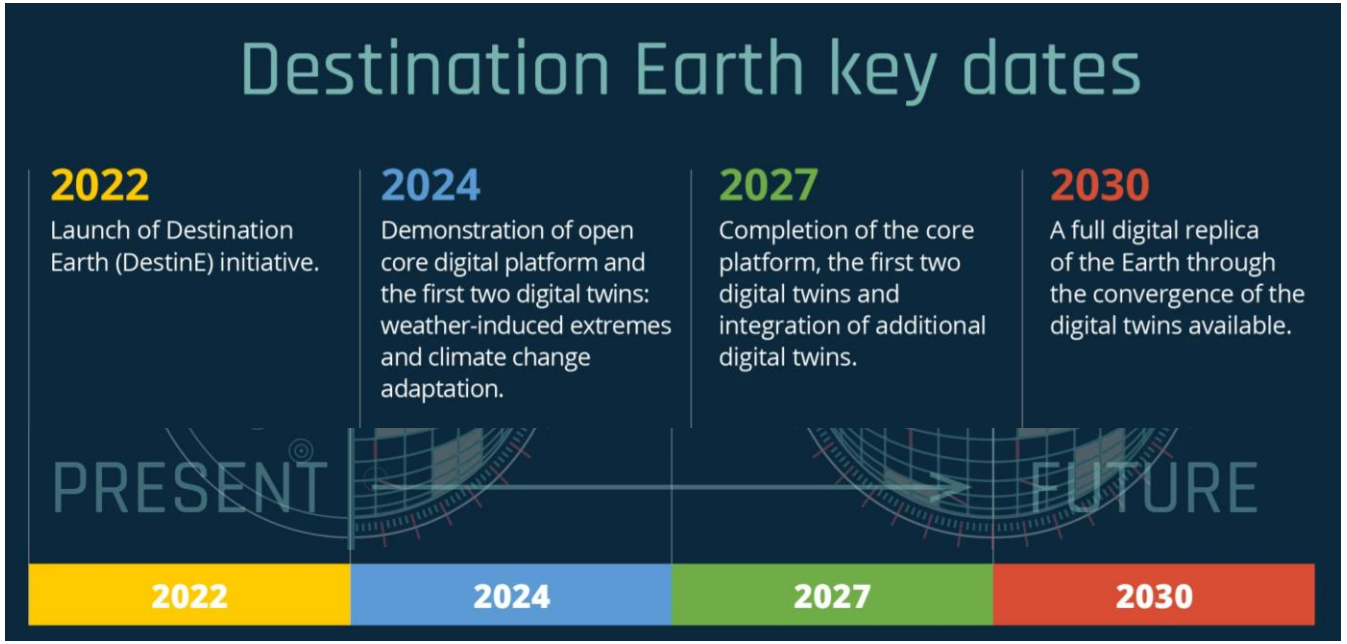

ECMWF's role in EU's DestinE initiative

ECMWF is responsible for the delivery of:

Weather-induced and Geophysical* **Extremes Digital Twin**:

- capabilities and services for the assessment and prediction of **environmental extremes (4.4 km IFS and hourly outputs for 4 days)**

Climate Change Adaptation **Digital Twin**:

- capabilities and services in support of climate change **adaptation policies and mitigation scenario** testing **(multi-decadal): 5-10 km, with ICON and IF models**

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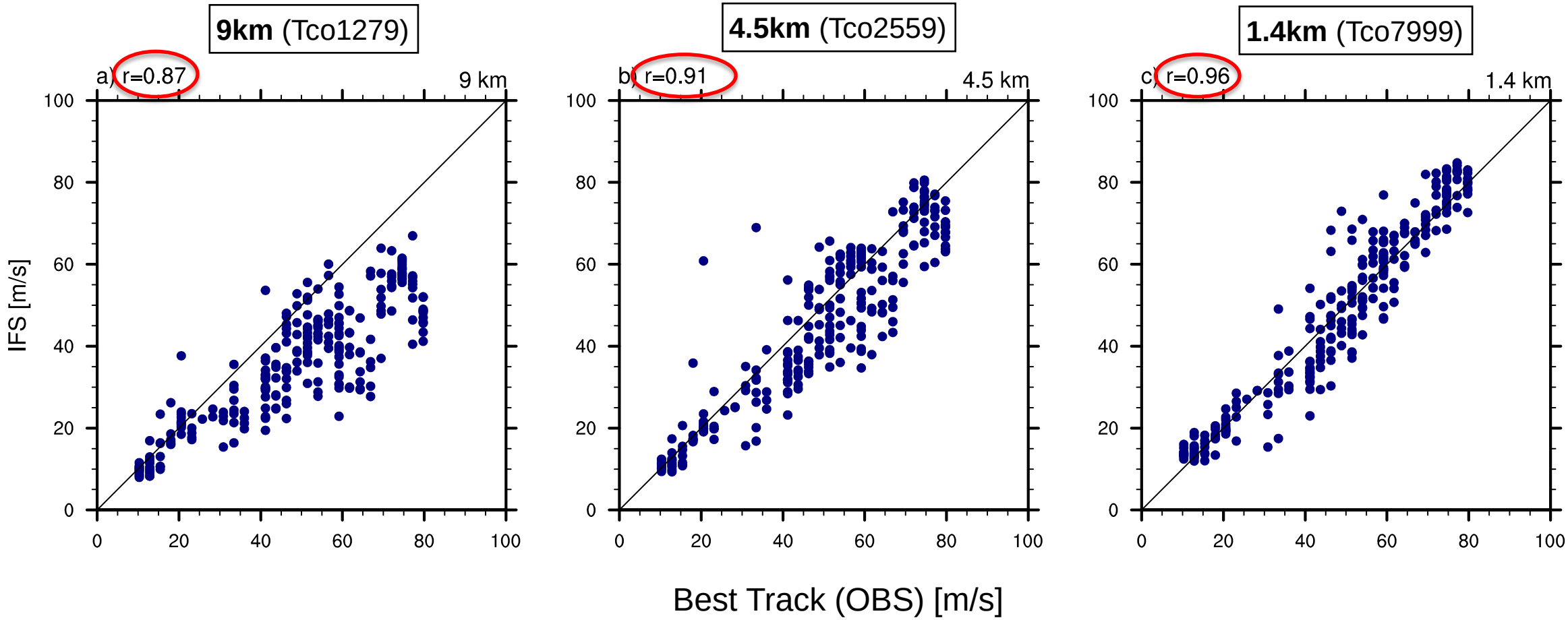
EuroHPC Joint Undertaking

Funded by the European Union

TC intensity better predicted as resolution increases from 9 to 1.4km

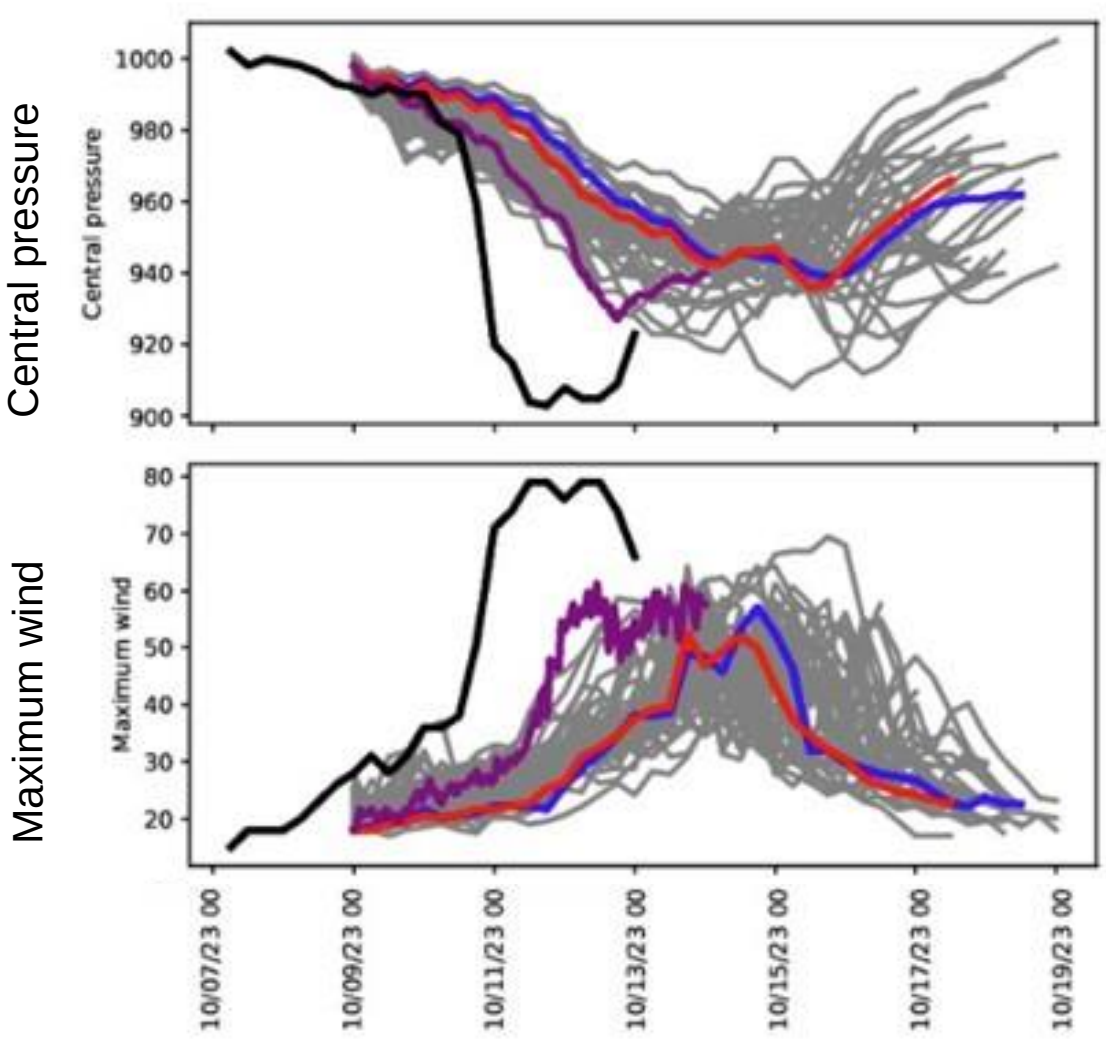
4 TCs (Irma, Ida, Florence, Teddy)
Improved max wind speed

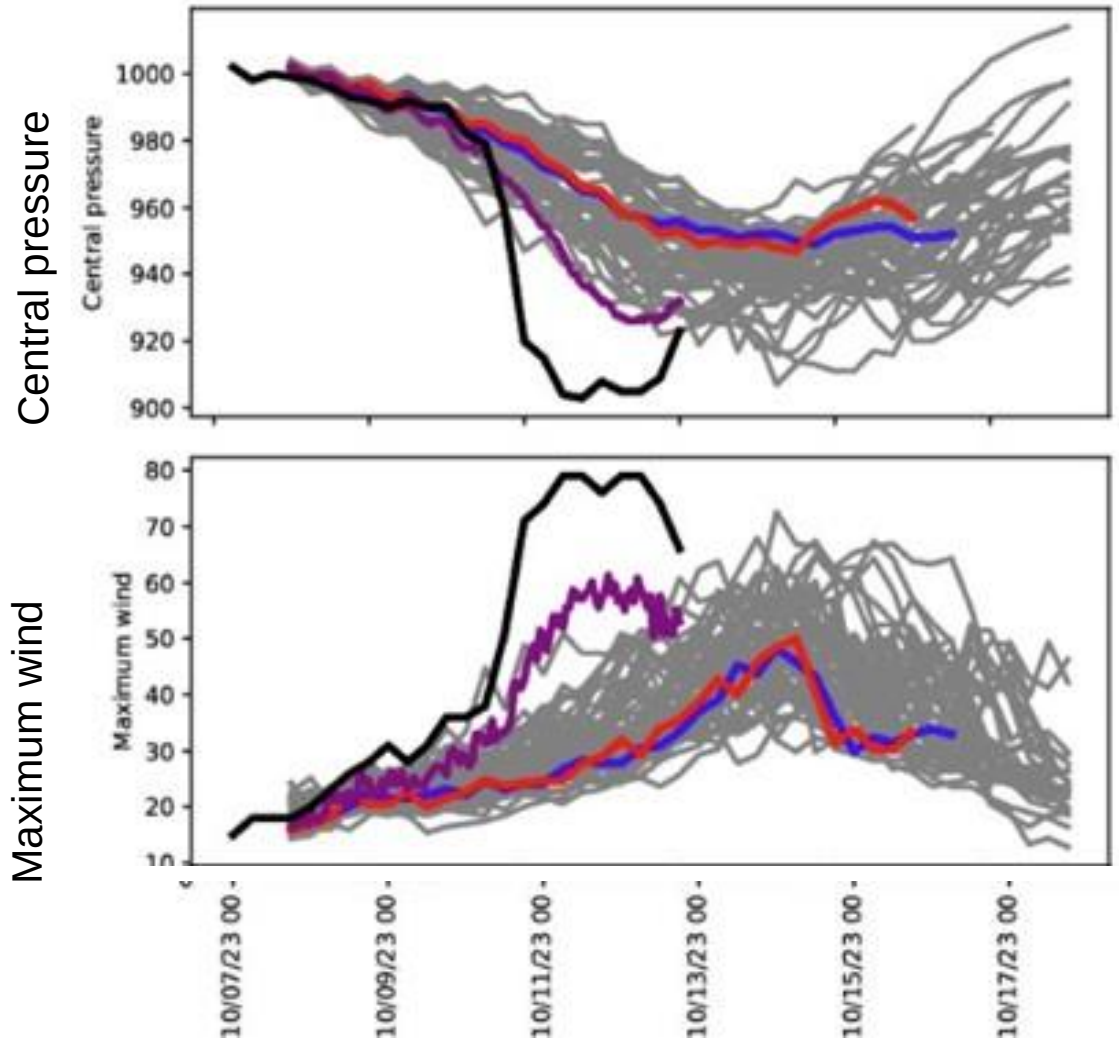


Super Typhoon Bolaven in the Pacific (11 Oct 2023)

HRES
DestinE 4.4 km

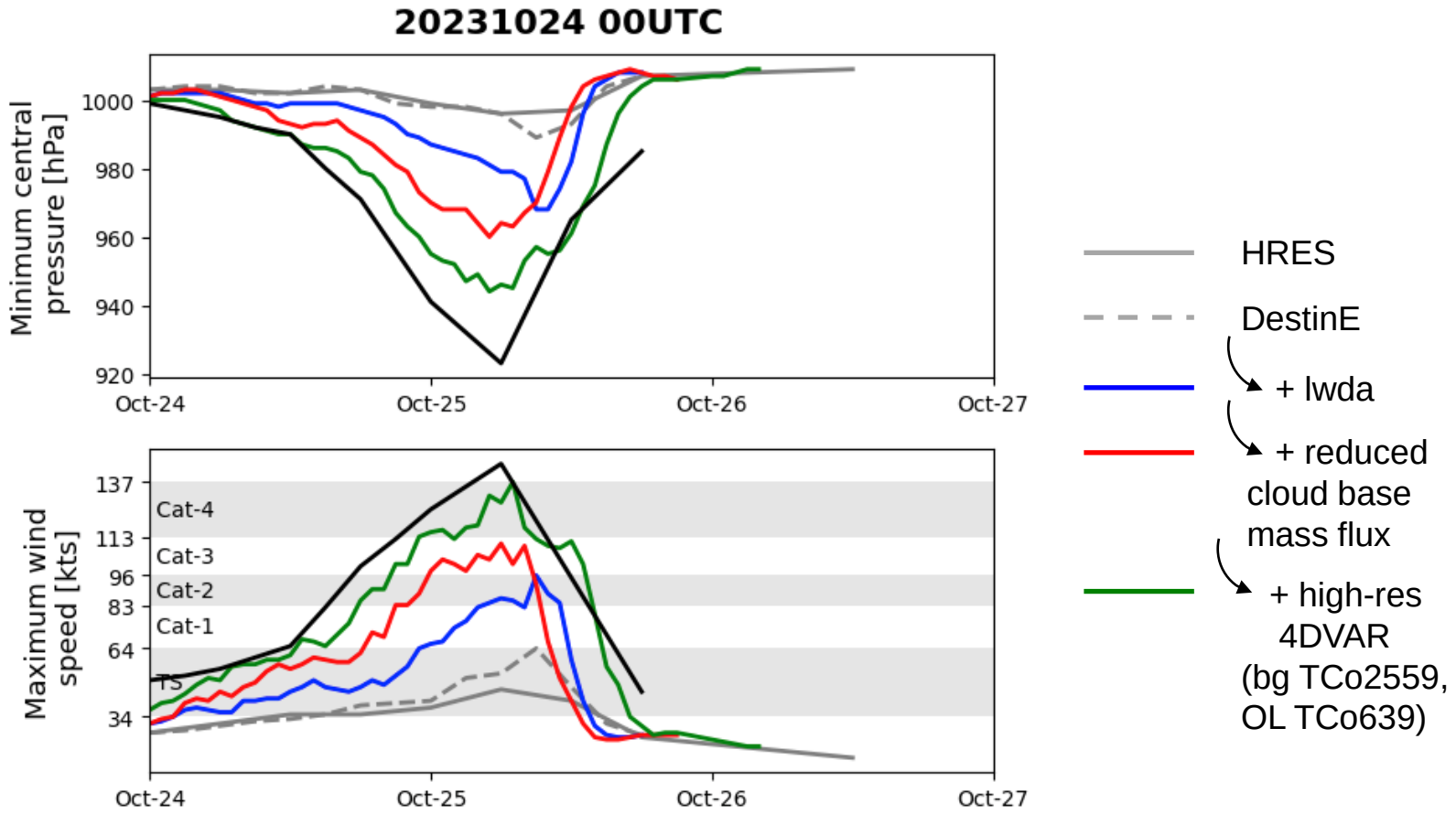
Observation
Ensemble
Control forecast





Predicting the supposedly unpredictable TC Otis (Central America)

Combining successively extra observations, reduced parametrized convection and higher resolution 4D-Var dramatically increases the forecast skill of Otis.



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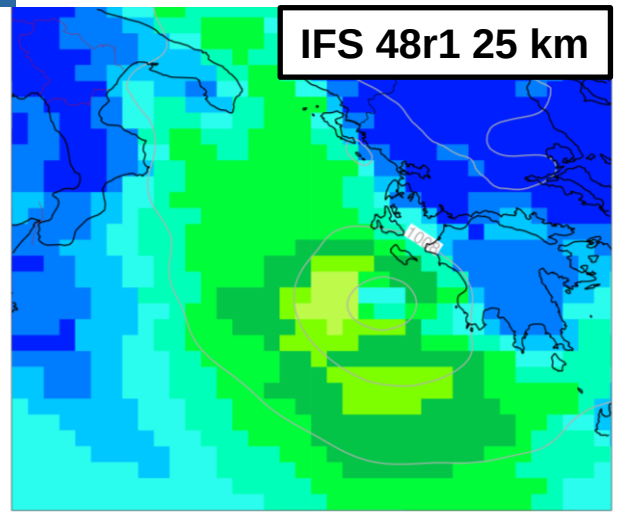
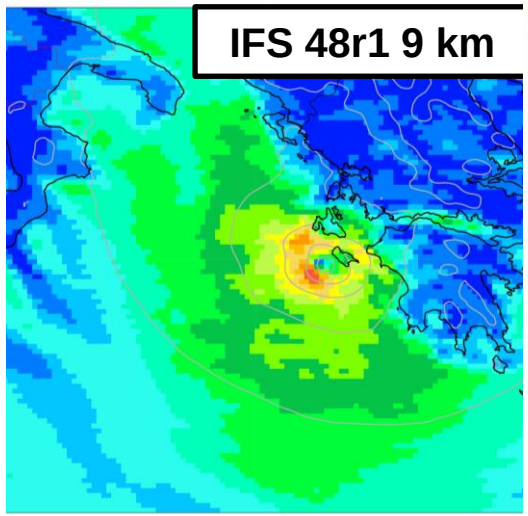
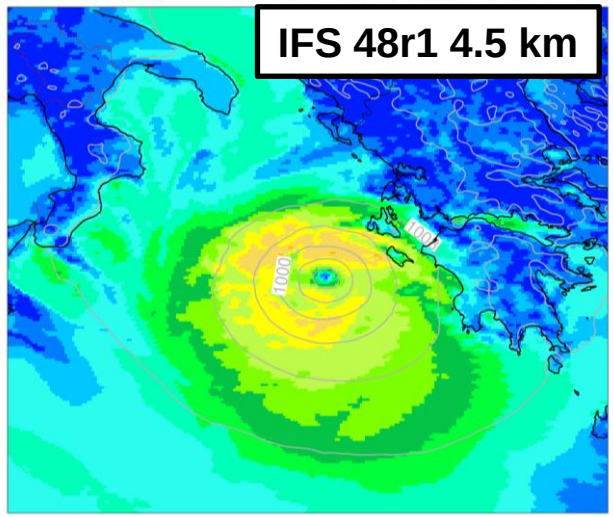
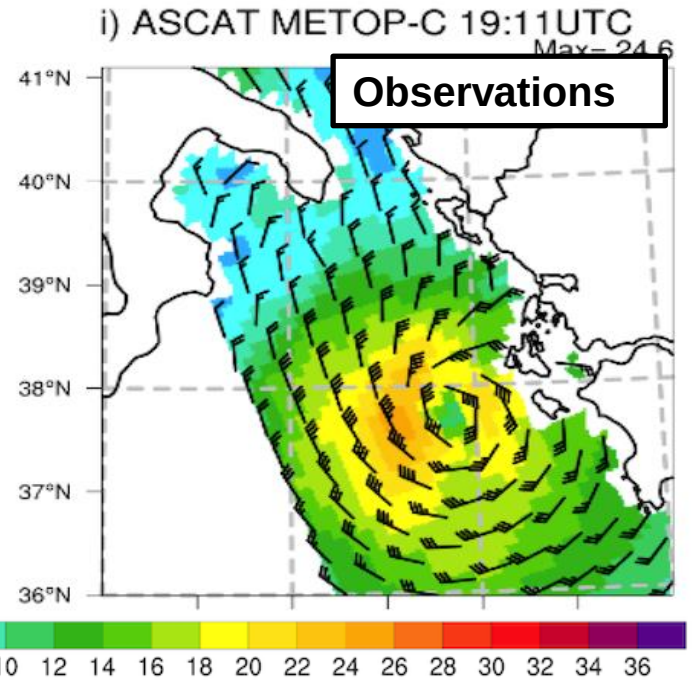
Ziga Zaplotnik, Michael Maier-Gerber, Benoît Vannière

Surface wind speed (T+66h, m/s)

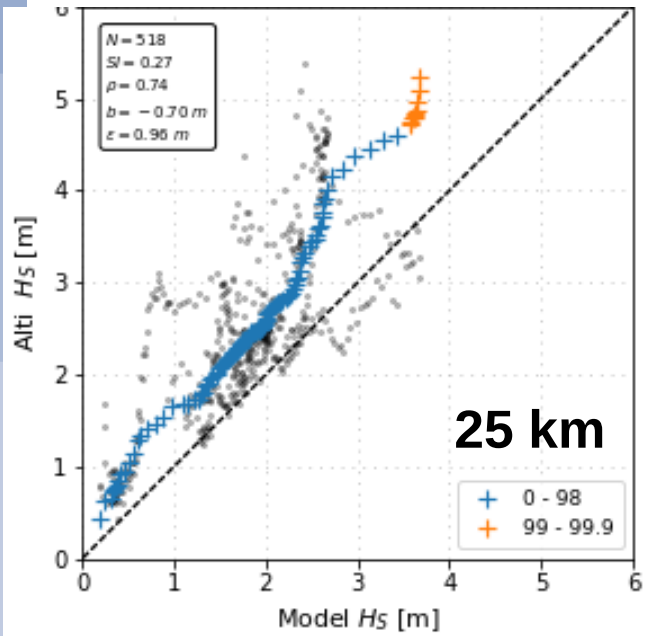


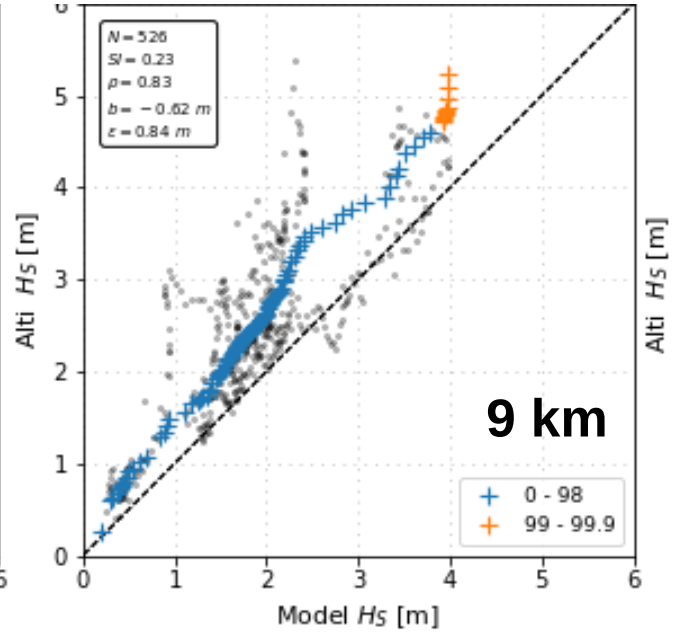


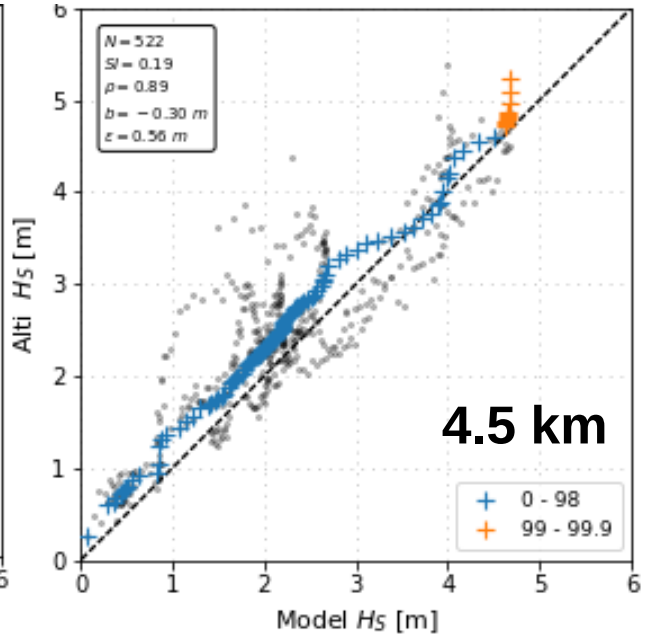




Waves (T+44h – T+84h) : Model vs. Observations (altimeter)



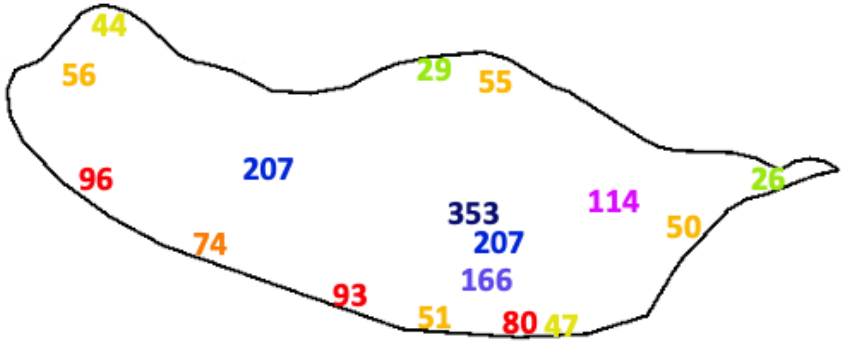




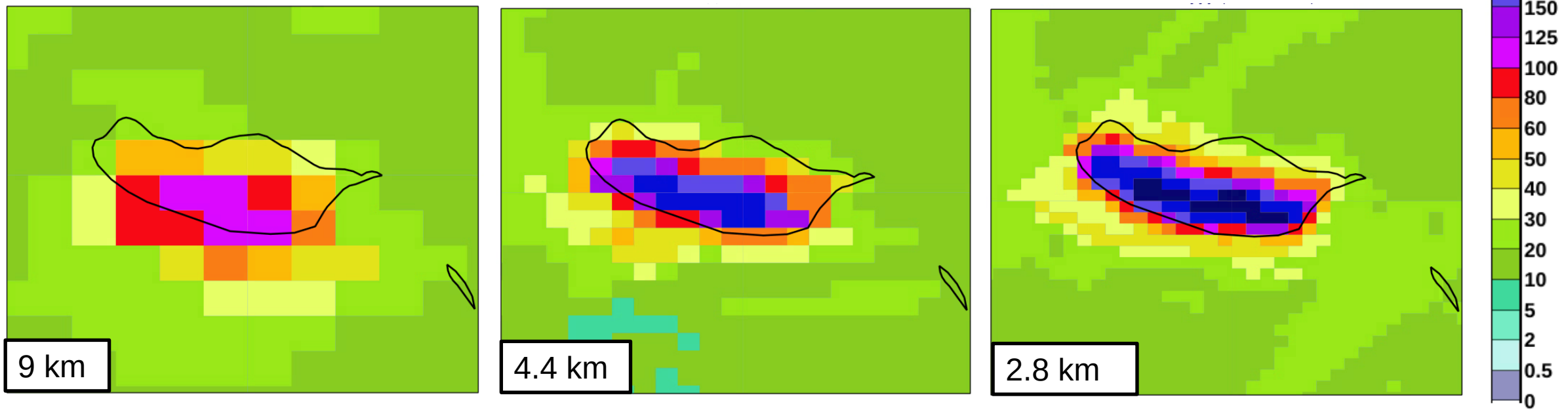
MEDICANE IANOS

What about Ocean wind speed and ocean waves?

6-7 June 2023: heavy rainfall in Madeira (T+48h)



Accumulated 24h
(mm) precipitation on
the 6th June 2023



Precipitation in Israel

Total precipitation in 24h (mm)
Valid on 2023-02-01 at 00 UTC

Test experiments with modifications in the model physics (parametrizations)

IFS @ T+48 (init 2023-01-30)

OBS

9km

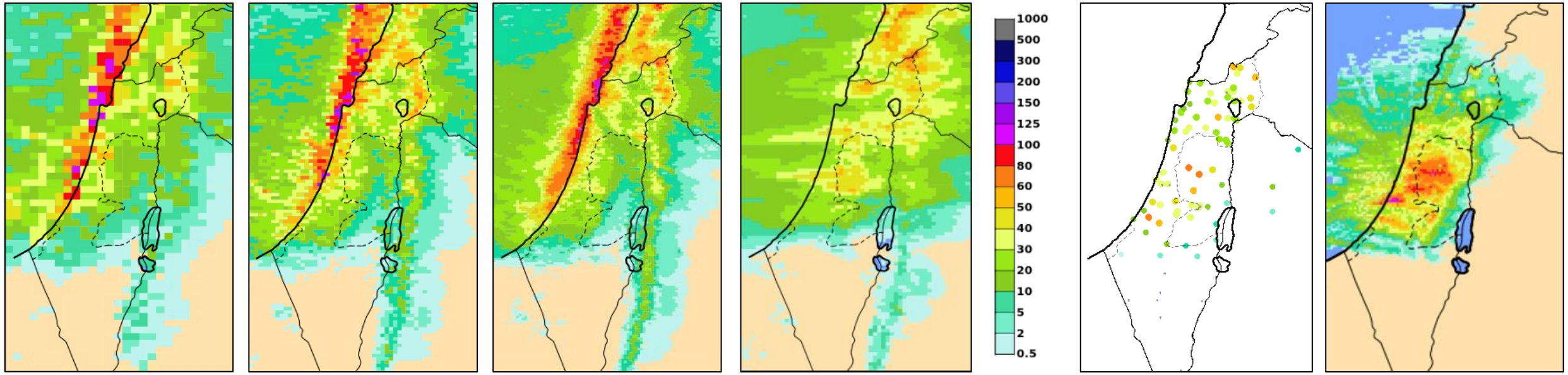
4.4km

2.8km

4.4km (reduced CBMF)

SYNOP

IMS radar



Reduced cloud base mass flux

ECMWF

Estibaliz Gascon

Thanks for your attention!

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estibaliz.gascon@ecmwf.int

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