Km-scale simulations with IFS and lessons learned for physics parametrizations development

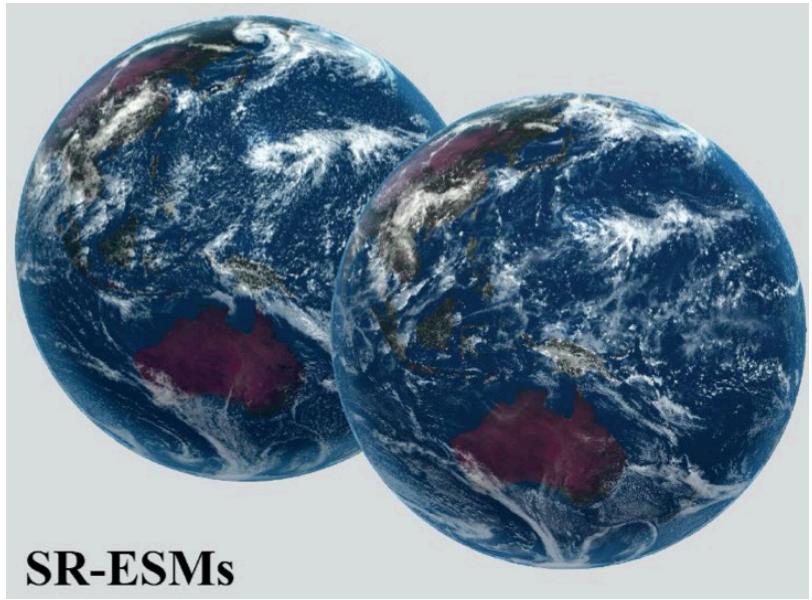
Irina Sandu

Gabriele Arduini, Gianpaolo Balsamo, Peter Bauer, Peter Bechtold, Tobias Becker, Anton Beljaars, Jean Bidlot, Andy Brown, Jasper Denissen, Michail Diamantakis, Richard Forbes, Estibaliz Gascon, Ioan Hadade, Sam Hatfield, Olivier Marsden, Josh Kousal, Simon Lang, Llorenc Lledo, Linus Magnusson, Michael Maier-Gerber, Sebastian Milinski, Kristian Mogensen, Xabier Pedruzo, Inna Polichtchouk, Thomas Rackow, Josef Schroettle, Annelize van Niekerk, Benoit Vanniere, Nils Wedi

Horizon 2020 nextGEMS' objectives

https://nextgems-h2020.eu
@nextgems_eu

Two Storm & Eddy - Resolving Earth System Models

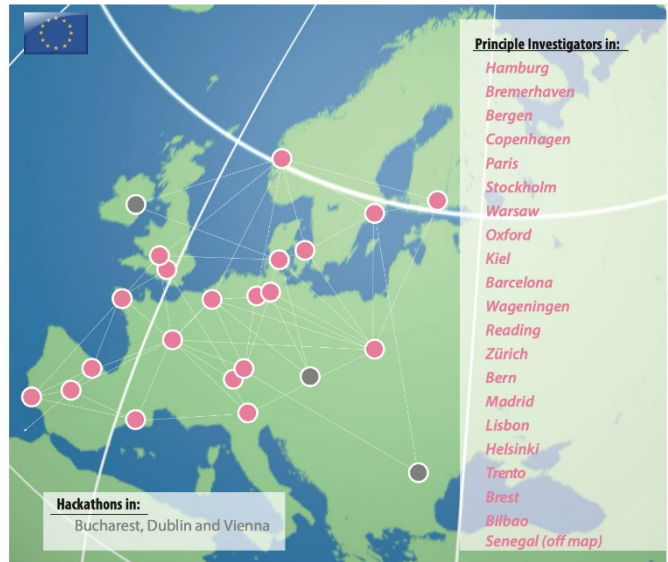


ECMWF IFS – NEMO/ AWI FESOM
MPI-M / DWD ICON

Develop two SR-ESMs (O(3km) in the atmosphere & ocean)

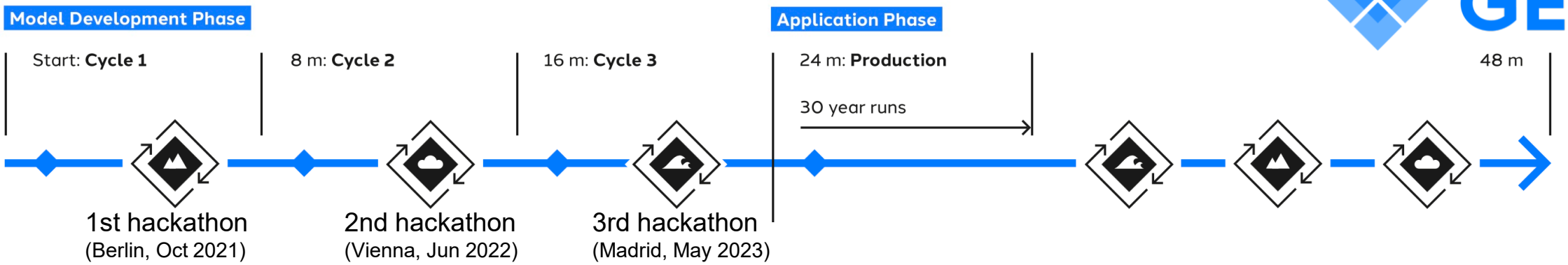
Use SR-ESMs to study the Earth-system and test emerging and long-standing hypotheses underpinning our understanding of climate change

Build new, more integrated communities of ESM users through Knowledge-Coproduction activities

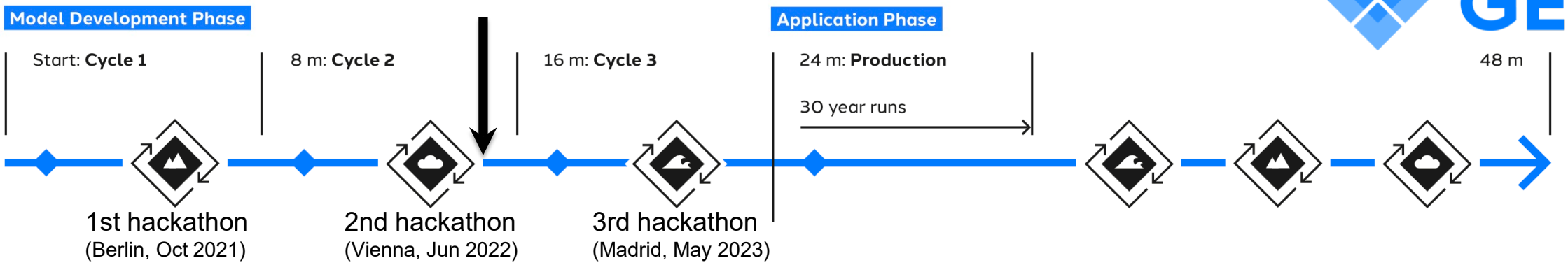


ECMWF
MAX-PLANCK-INSTITUT FÜR METEOROLOGIE
AWI ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Different development cycles



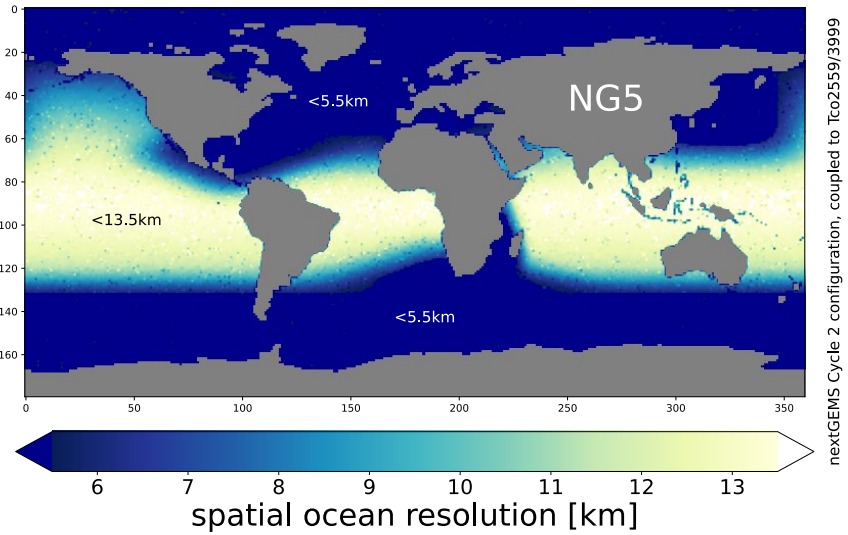
Different development cycles : IFS – NEMO/FESOM2



- **Cycle 1 and 2:** from **75 days to - 2 years**
- **Atmosphere**: **9 km / 4.5 km / 3km**
- **Ocean**: **25km** NEMO; **4-13km** FESOM2 NG5 grid

8 months at 3km & FESOM NG5 grid

*Ocean resolution of the **NG5** FESOM2 grid (Fig courtesy: T. Rackow)*



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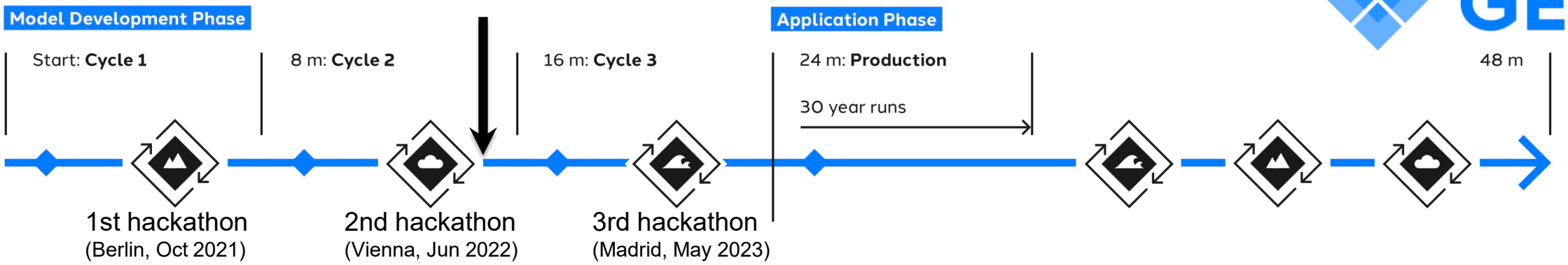
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Different development cycles : IFS – NEMO/FESOM2



- **Cycle 1 and 2:** from **75 days to - 2 years**
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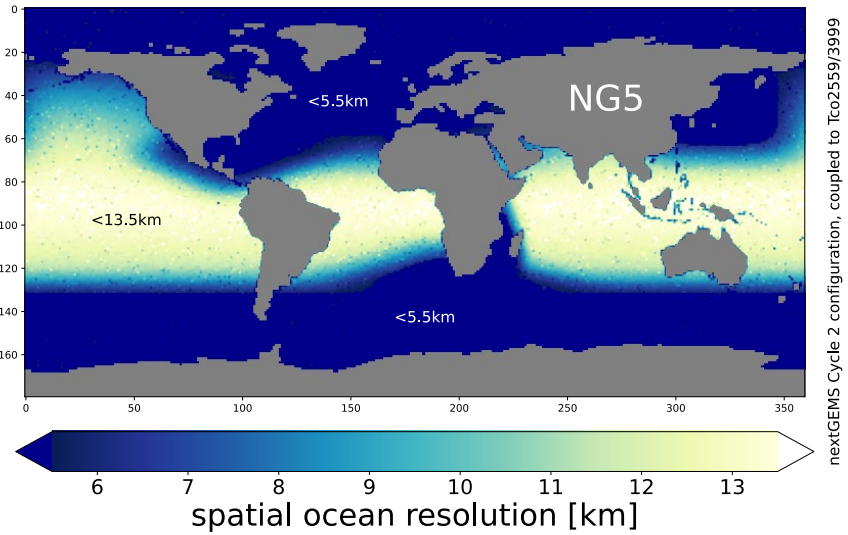
- **Ocean**: **25km** NEMO; **4-13km** FESOM2 NG5 grid

8 months at 3km & FESOM NG5 grid

- **Cycle 3: 2 - 4 years** at 4.5/3 km atmo; 4-7km FESOM2 NG5 ocean
- **Production runs: up to 30 years**

*Ocean resolution of the **NG5** FESOM2 grid (Fig courtesy: T. Rackow)*



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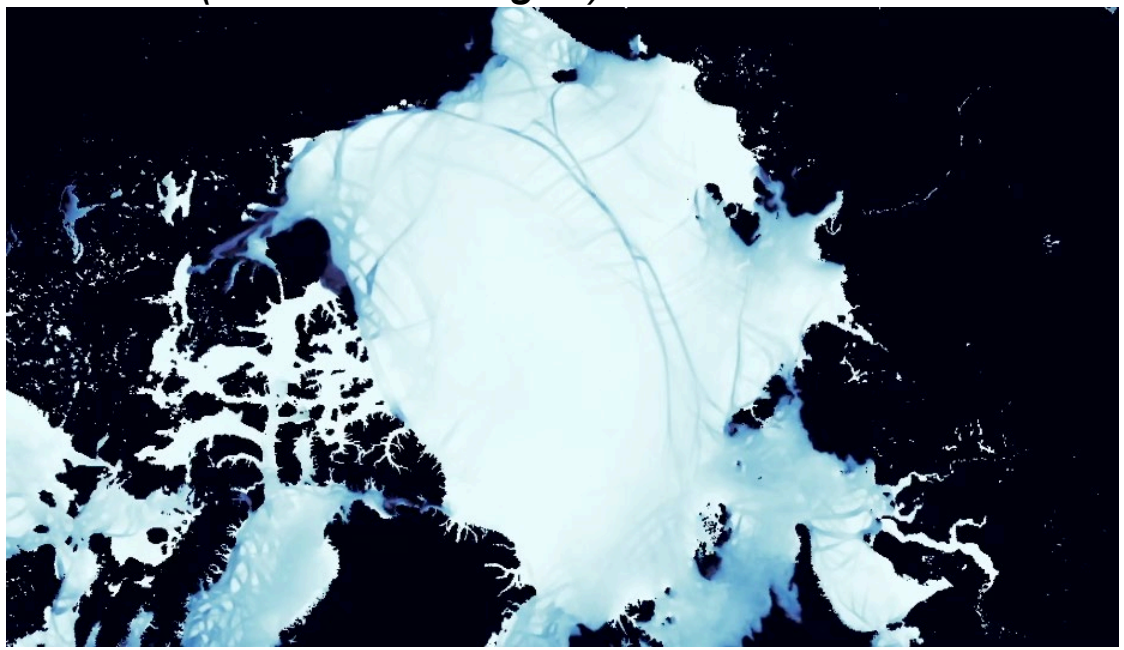
Cycle 1 & 2 simulations with IFS-FESOM2

Wind gusts over Europe (IFS@4.5km)

Simulated sea ice leads/cracks in the Arctic Ocean (FESOM NG5 grid)



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N. Koldunov, AWI, T. Rackow, ECMWF
@oceanographer ; @thomas_rackow

Hackathons and their surprises…..

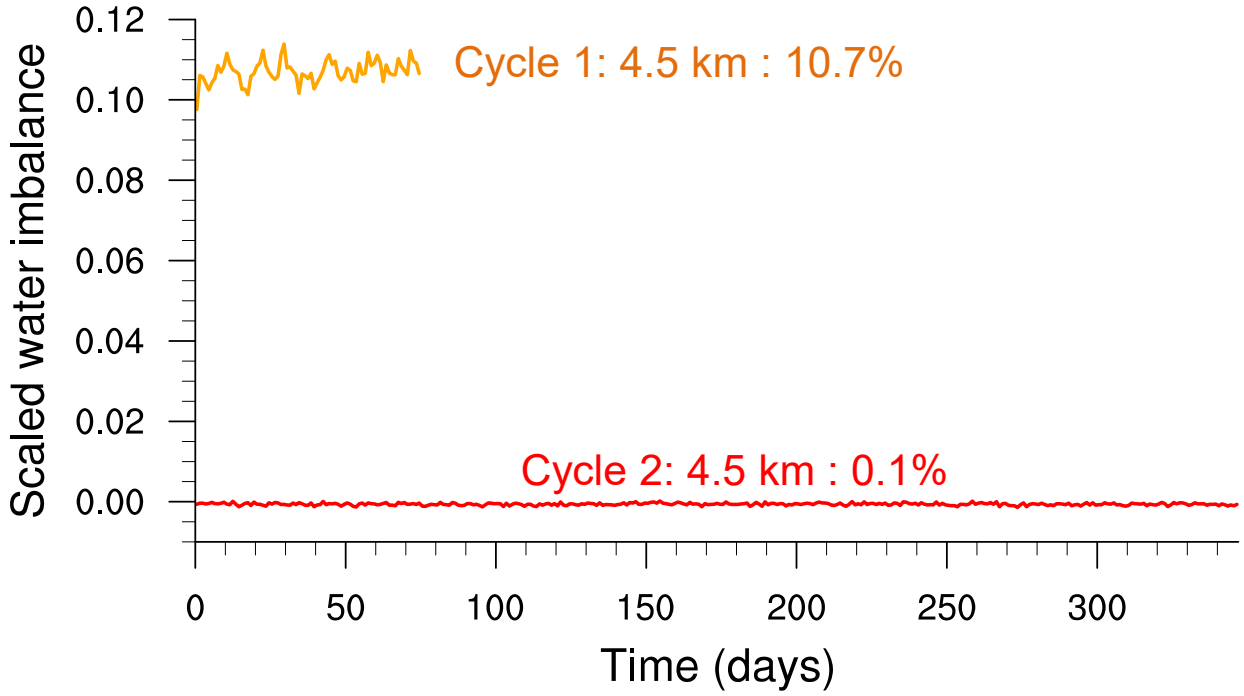
ECMWF

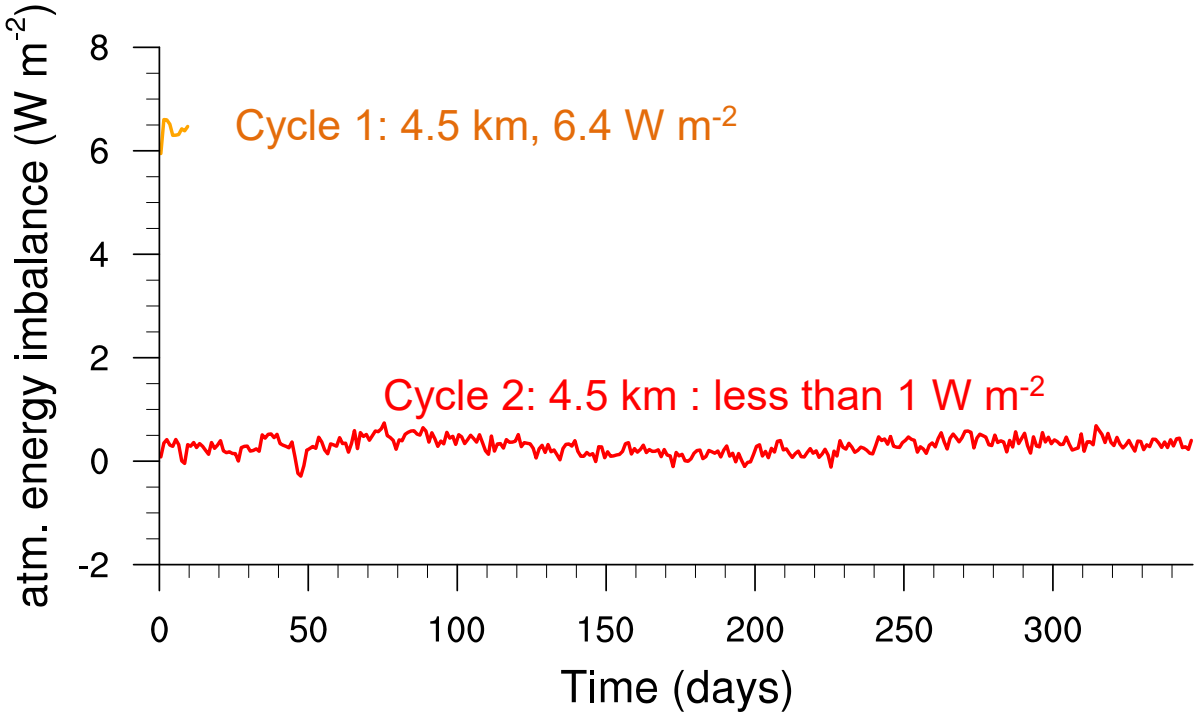
B. Stevens, MPI-M

Hackathon 1 surprise: water and energy imbalance in IFS

IFS: semi-Lagrangian dynamics is non-conserving:
worse at higher resolution & when deep convection is switched off

To fix the water imbalance for Cycle 2, we activated tracer mass fixers for all moist species

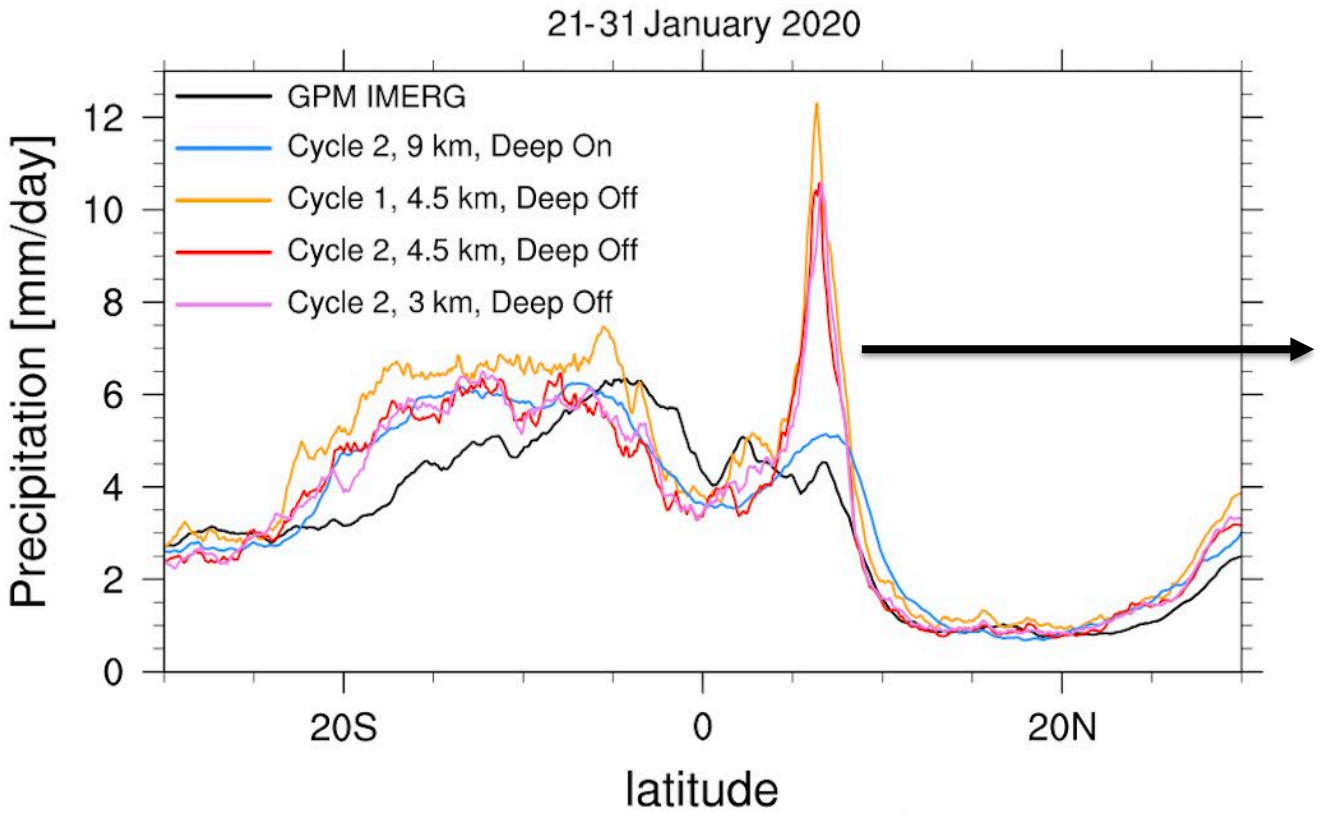


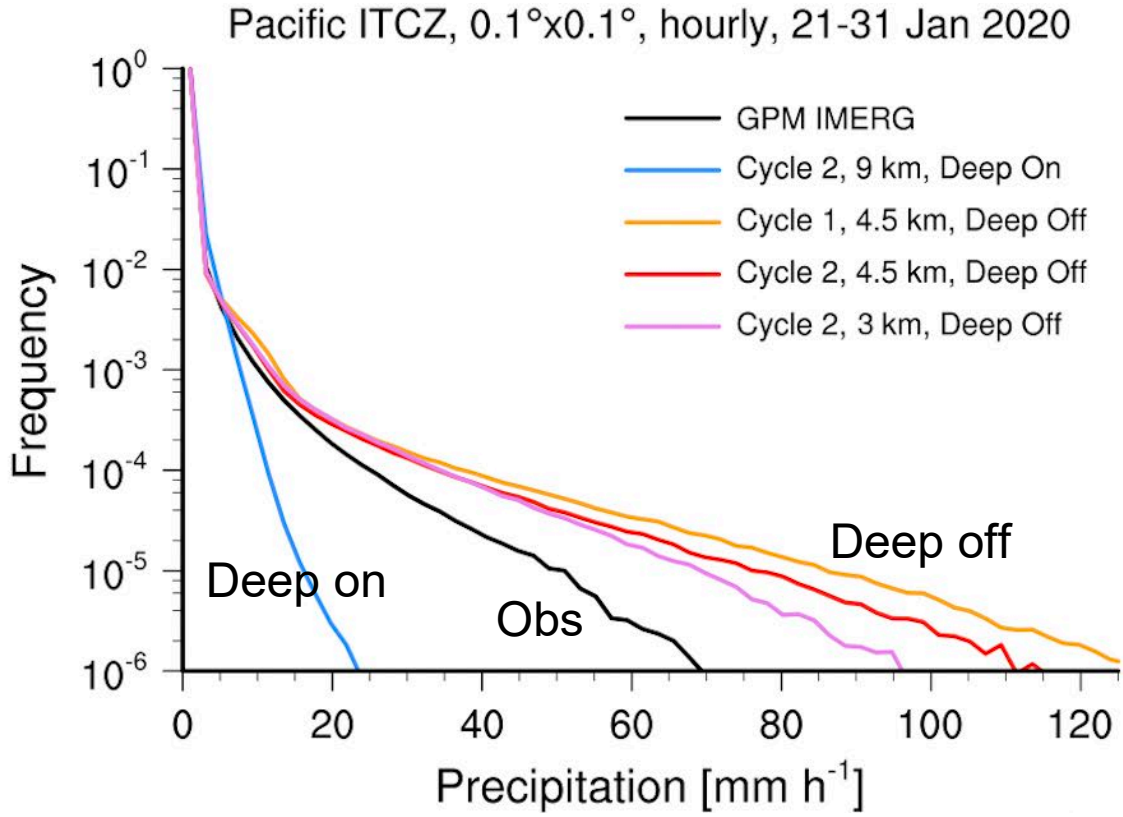


ECMWF

T. Becker & modelling teams at ECMWF

Impact of water conservation changes on precipitation





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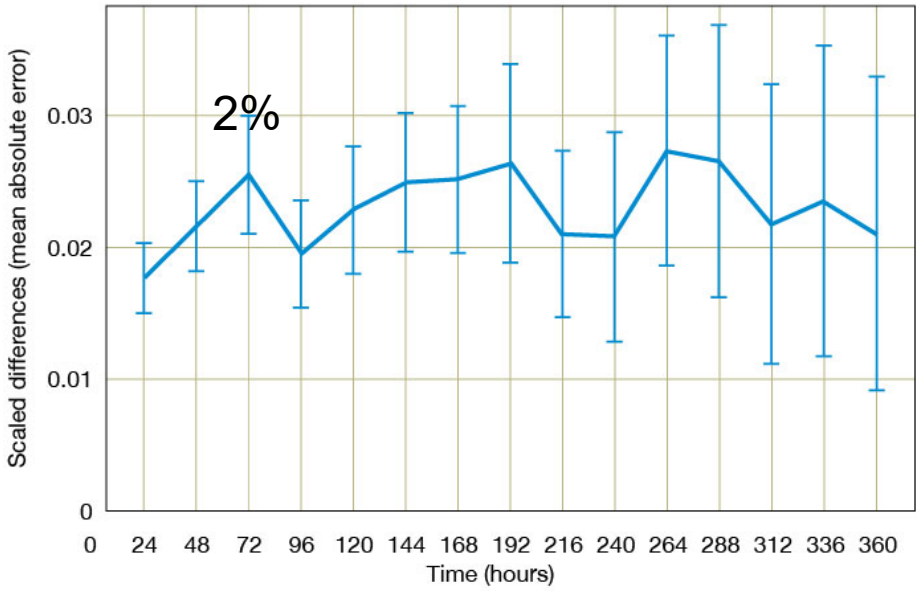
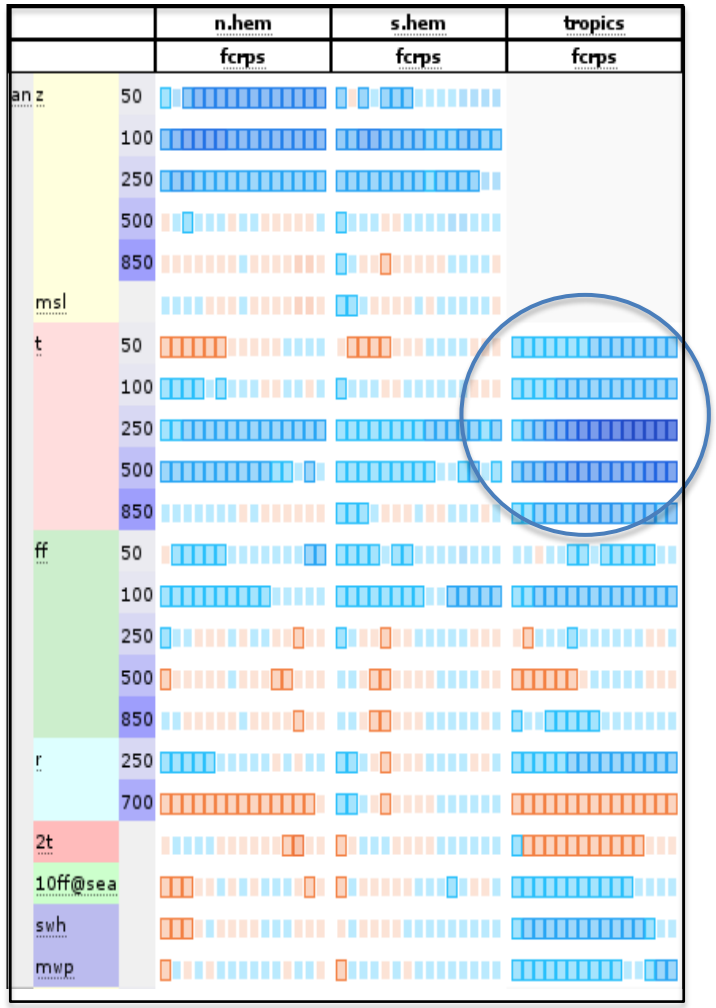
T. Becker

Impact of water conservation changes on forecast skill across resolutions

Precipitation mean absolute error

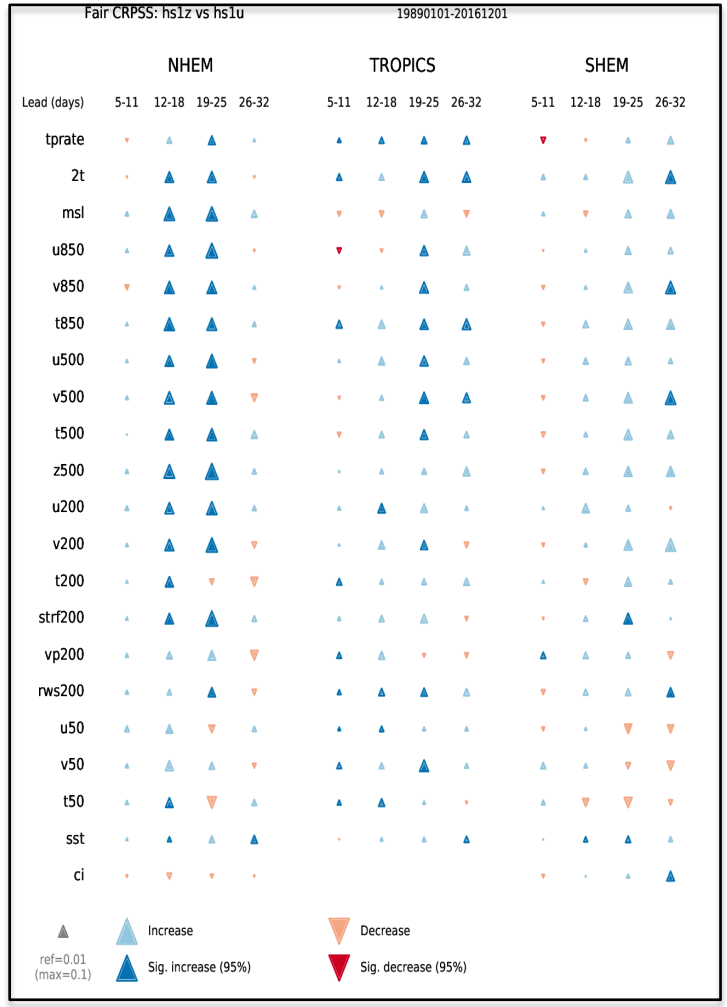


9km ENS



8-member d(fCRPS)

Monthly forecast (Tco 199)

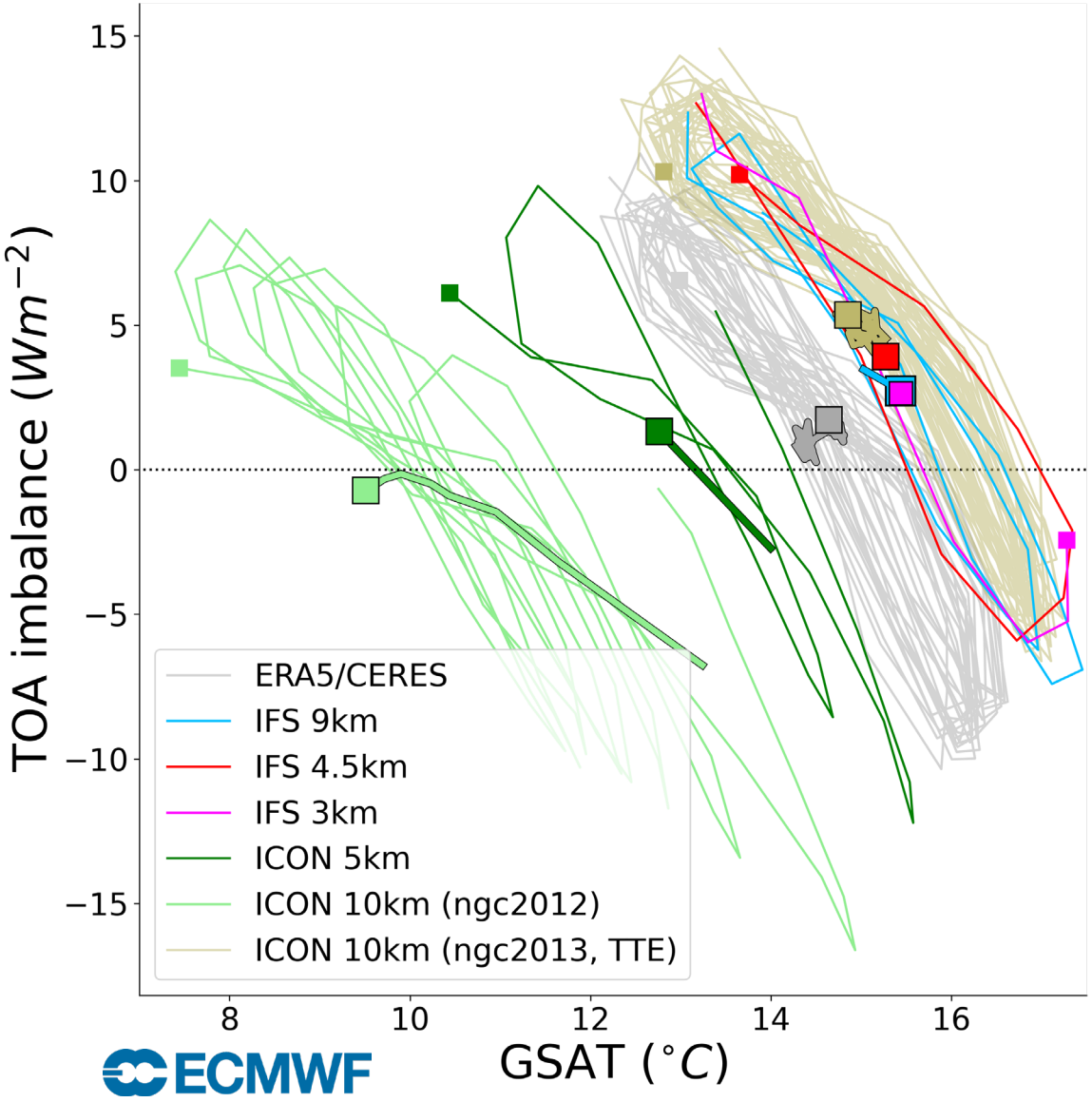


10 members , dCRPSS

ECMWF

T. Becker, R. Forbes, S. Lang, C. Roberts

Hackathon 2 surprise: TOA imbalance in nextGEMS Cycle 2



IFS 9km is warming slightly in the second year and has a positive TOA imbalance (~2 W/m^2)

ICON 5km is cooling and has a negative TOA imbalance (~ -2 W/m^2)

ICON 10km with TTE has a positive TOA imbalance but stable temperature

S. Milinski

ECMWF's role in EU's Destination Earth (DestinE) initiative

Towards a Digital Twin Earth

DestinE entrusted entities

ECMWF esa EUMETSAT

ECMWF is responsible for the delivery of:

The DestinE **Digital Twin Engine** (DTE):

- common approach for a unified orchestration of Earth-system simulations and their fusion with observations, requiring **large-scale HPC** and data handling resources

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

- capabilities and services for the assessment and prediction of **environmental extremes**

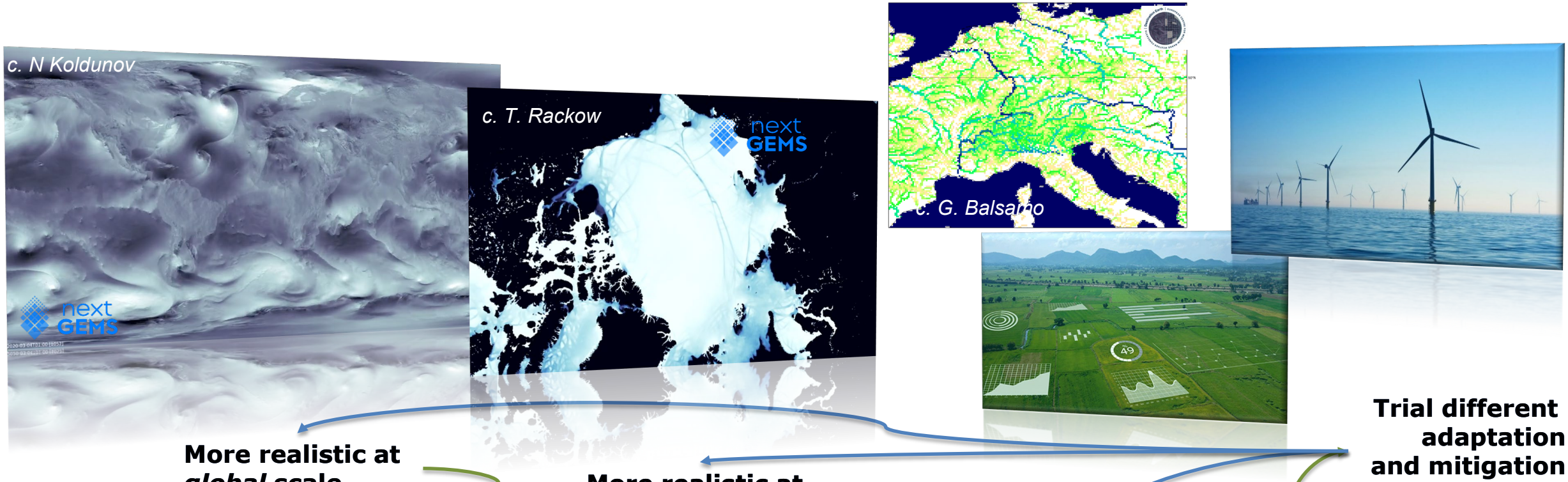
Climate Change Adaptation **Digital Twin**:

- capabilities and services in support of climate change **adaptation policies and mitigation scenario** testing

Funded by the European Union

DestinE's Digital Twins: Quality + Impacts + Interaction

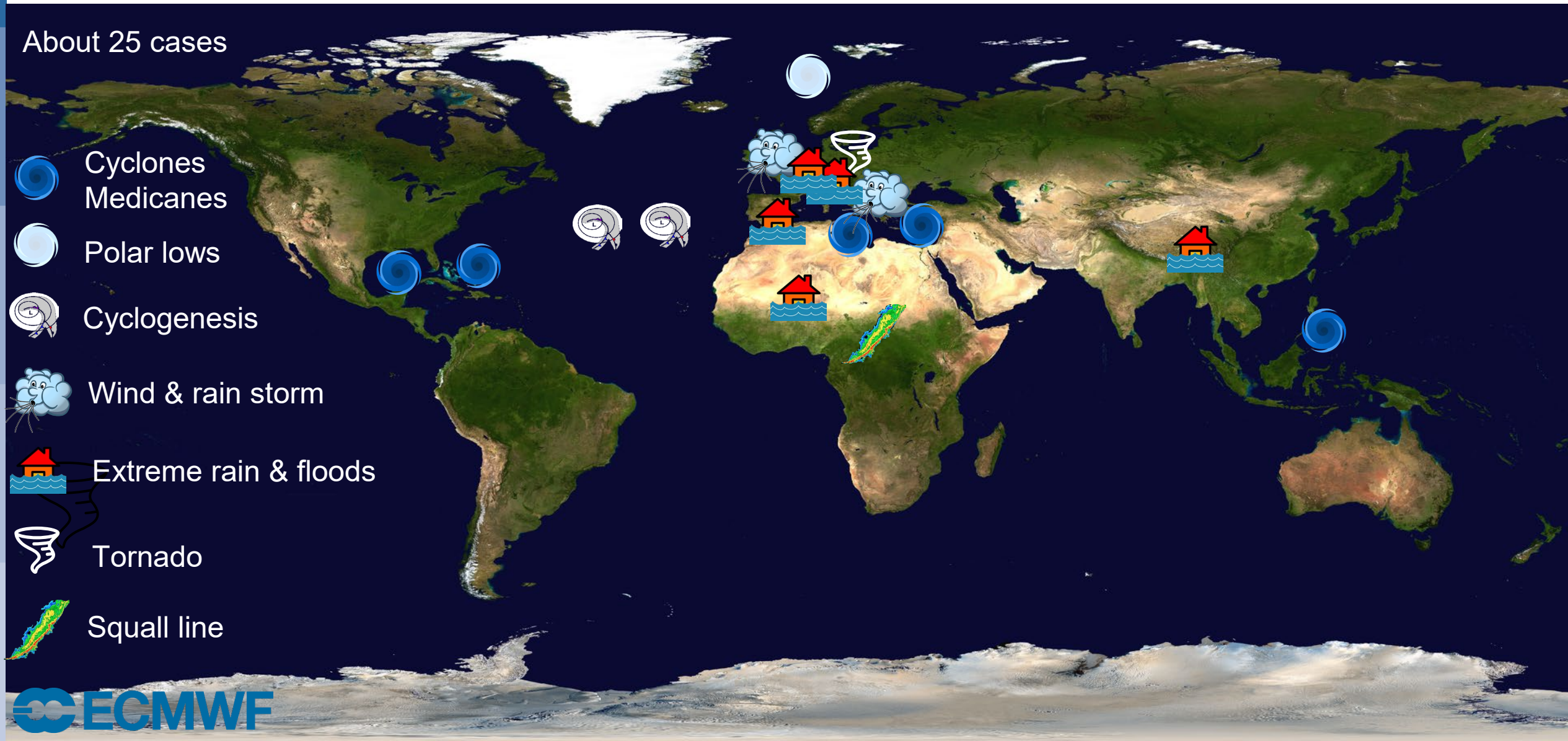
1. **Better simulations** based on **more realistic models**
2. **Better ways of combining all observed and simulated information** from entire Earth system = physical + food/water/energy/health **supporting action scenarios**
3. **Interactive and configurable access to all data, models and workflows**



ECMWF

Global Extremes DT – selected extreme event cases (2016-2022)

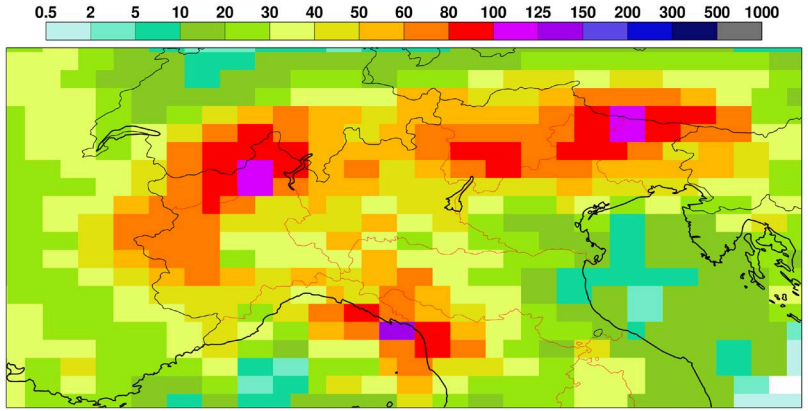
5 days forecasts at 4.5 km with ECMWF IFS (and 9 and 29km equivalents)



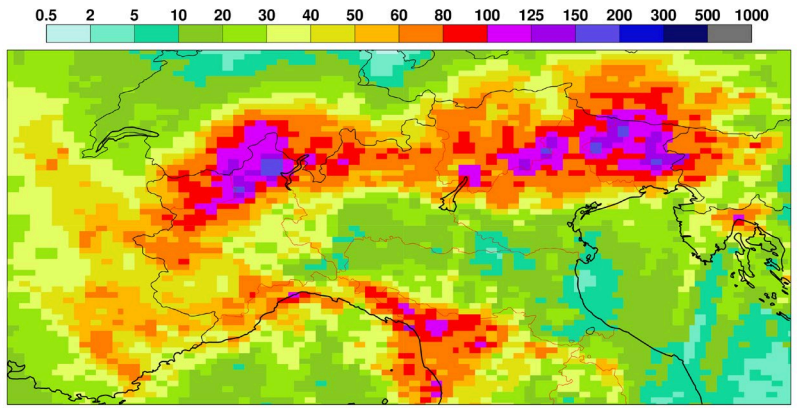
ECMWF

Global Extremes DT initial simulations : storm Adrian (ct 2018)

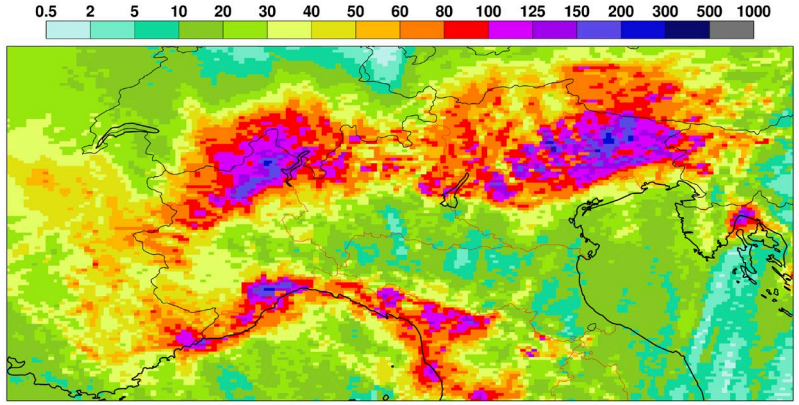
24h accumulated precipitation (T+54h - T+78h)



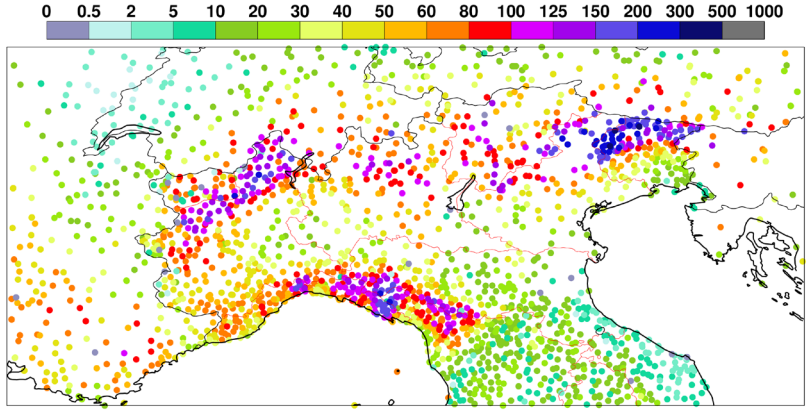
IFS 48r1 29 km



IFS 48r1 9 km



IFS 48r1 4.5 km



Observations

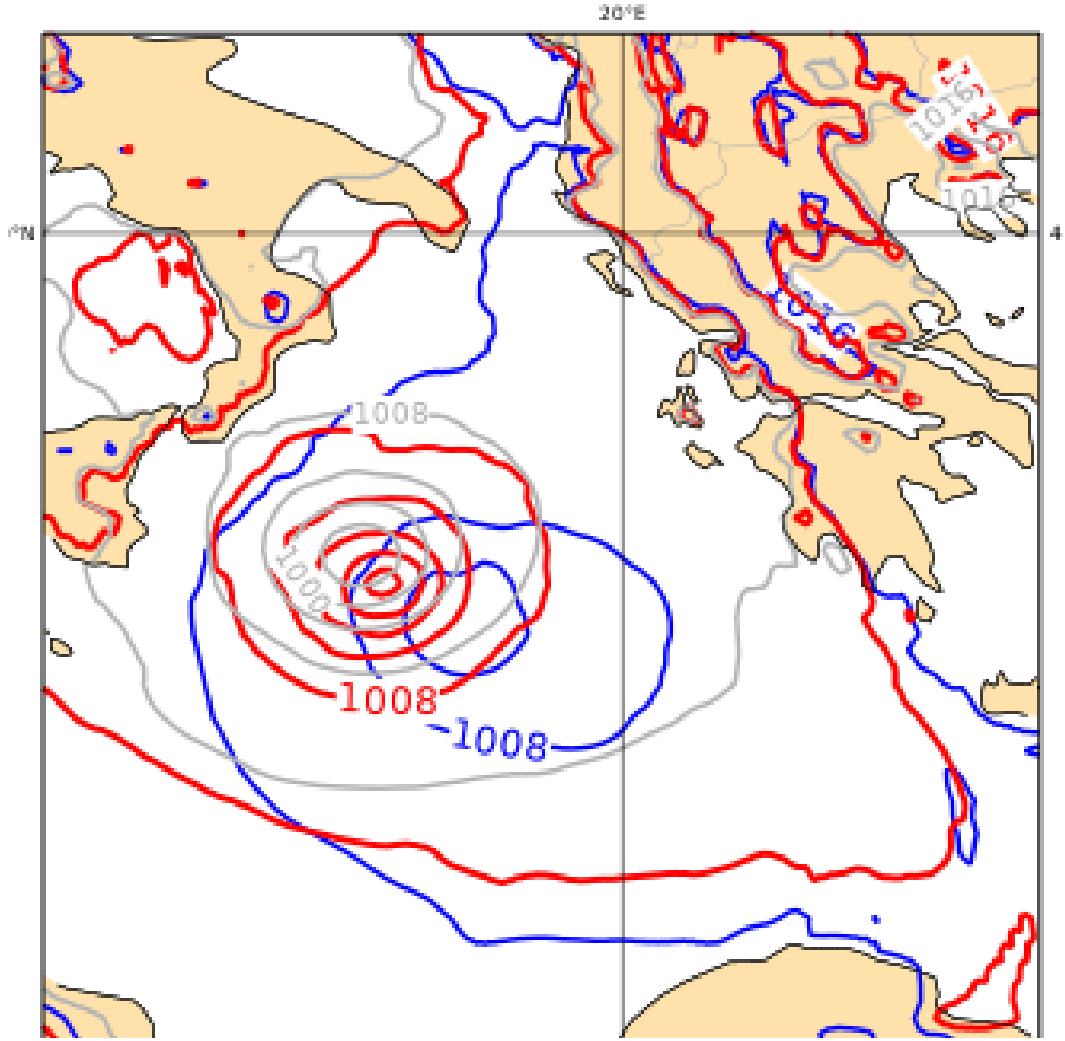
ECMWF

E. Gascon

Global Extremes DT initial simulations : medicane Ianos (Sep 2020)

Mean sea level pressure (T+48h)

48r1 9km
48r1 4.5km
analysis



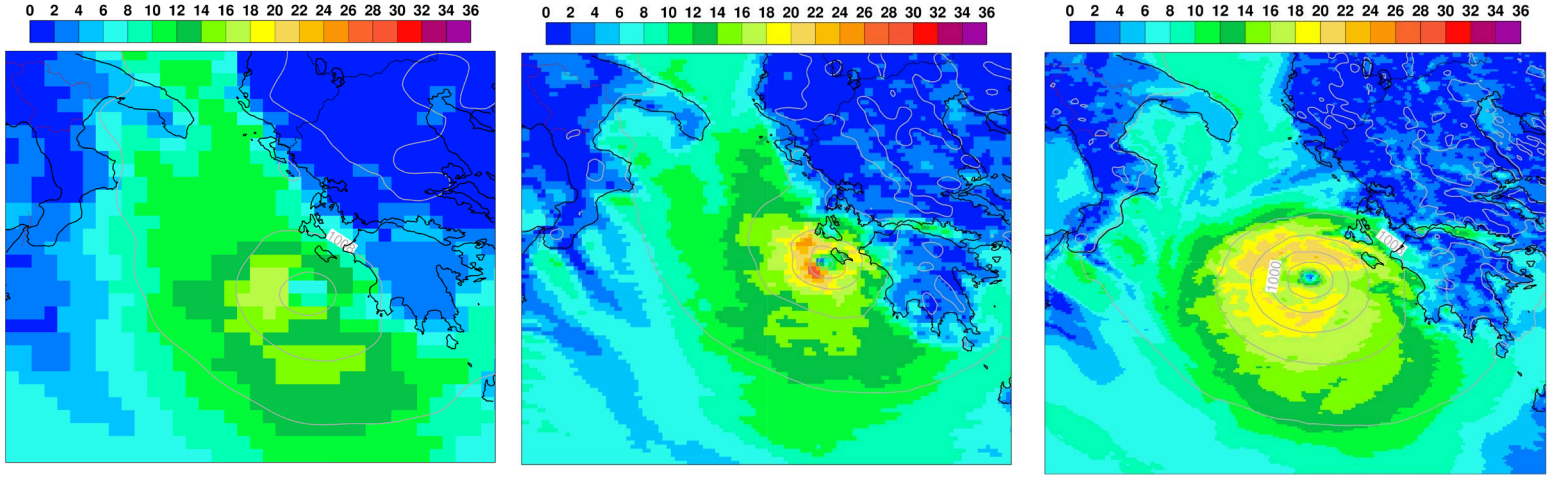
BT:2020-09-15 00:00:00. VT: T+48
minimum MSLP (blue, 48r1 9km): 1000 hPa
minimum MSLP (red, 48r1 4km): 990 hPa
minimum MSLP AN (grey): 993 hPa

ECMWF

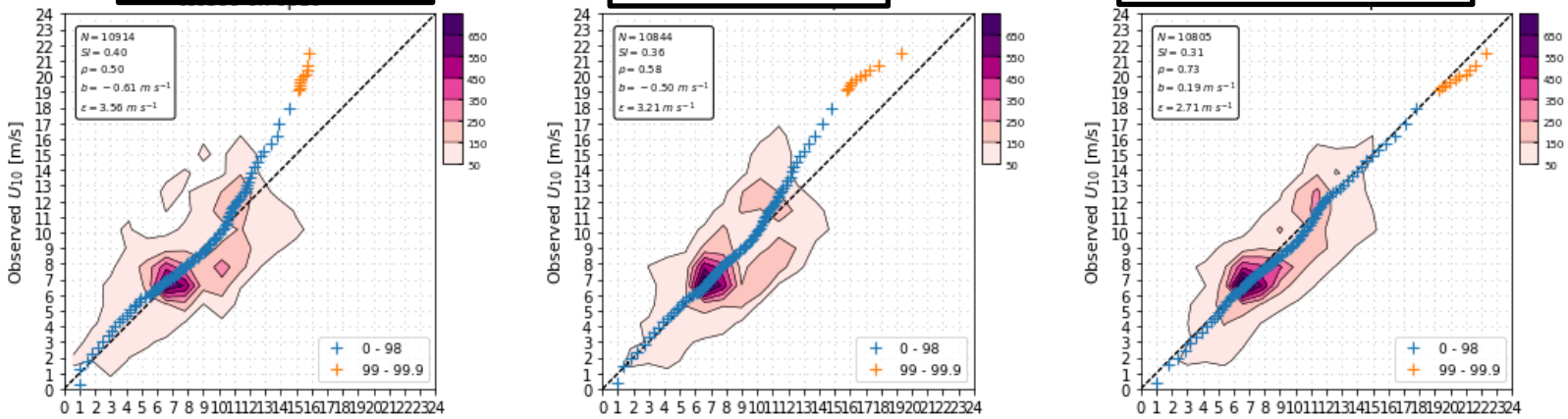
E. Gascon

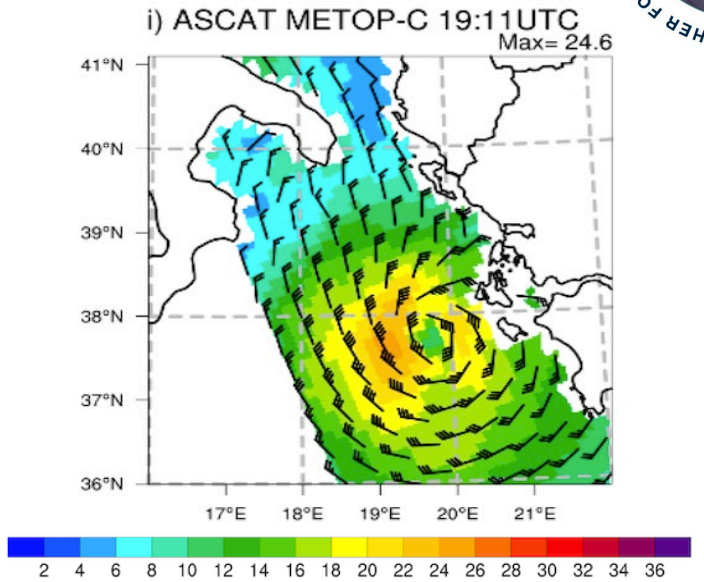
Global Extremes DT initial simulations : medicane Ianos (Sep 2020)

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



IFS 48r1 29 km | **IFS 48r1 9 km** | **IFS 48r1 4.5 km**





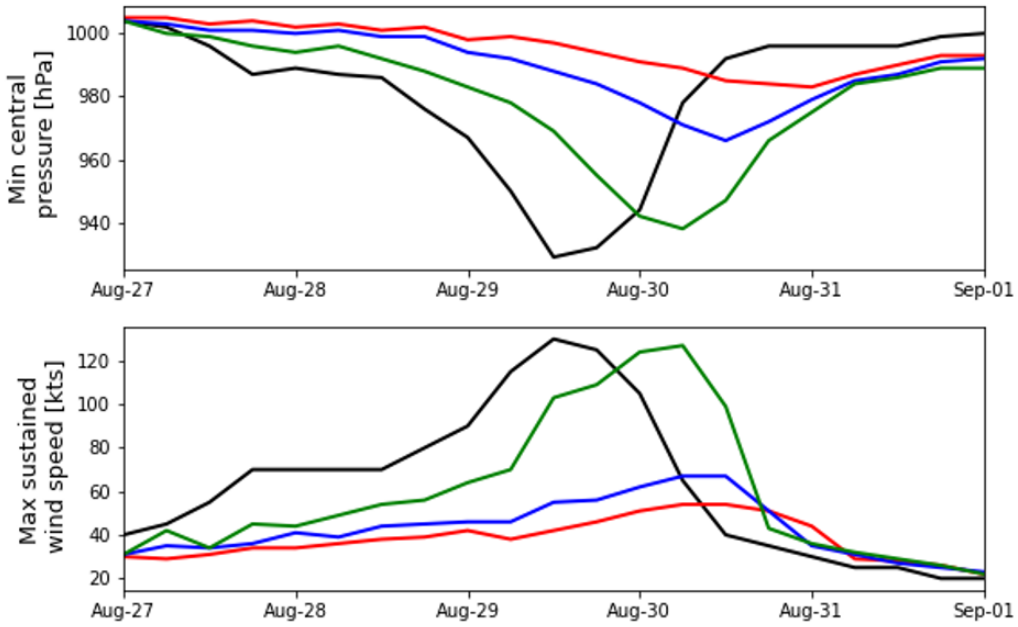
Observations

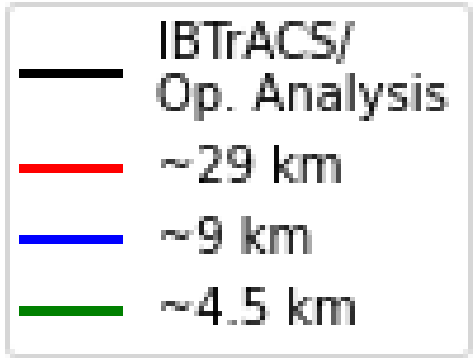
Model vs. Observations (ASCAT).
Contours show scatter density of collocated points. Crosses show quantile-quantile comparison.

E. Gascon & J. Kousal

Global Extremes DT initial simulations : TC Ida (August 2021)

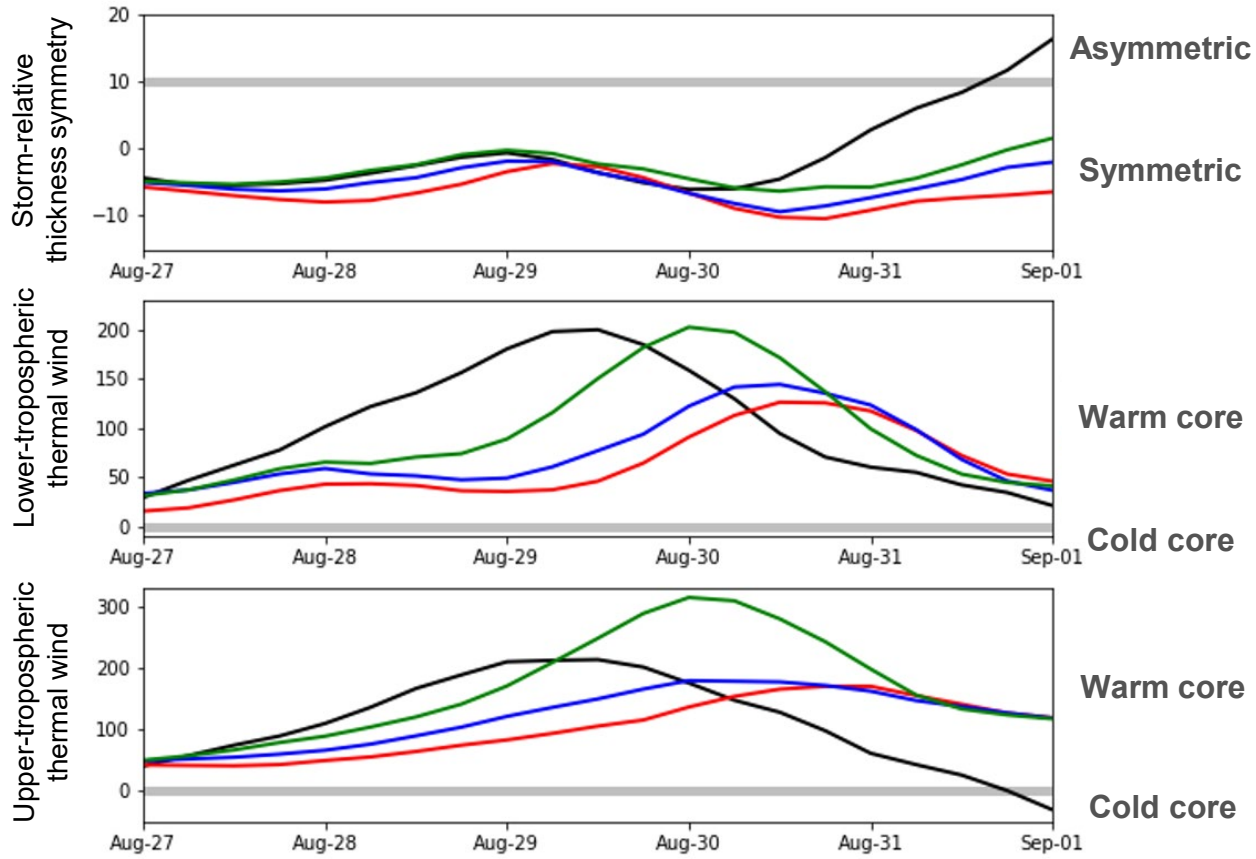
Intensity





Cyclone phase space metrics

(Assesses symmetry and thermal structure)



ECMWF

M. Maier-Gerber

INCITE22: New window into tropical meteorology with km-scale coupled simulations

U.S. DEPARTMENT OF ENERGY INCITE LEADERSHIP COMPUTING

OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY

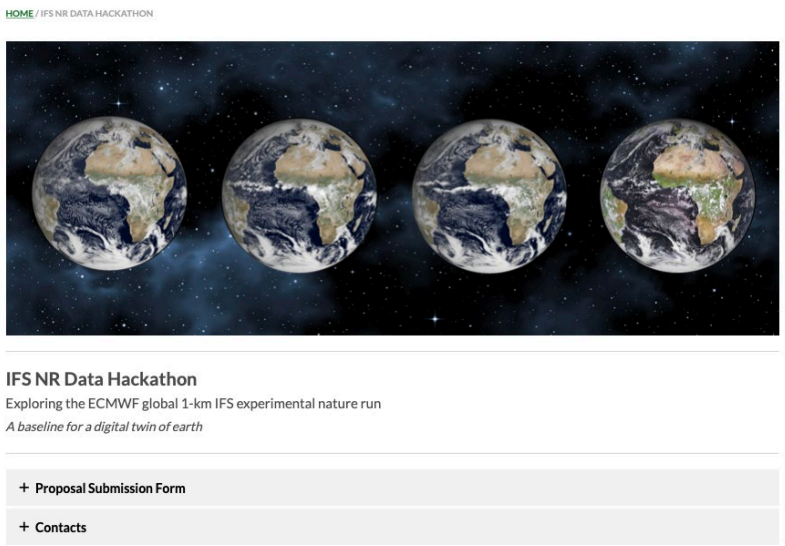
Simulations performed on Summit:

Global 7-day forecasts of TC Irma, Florence, Teddy and Ida (several initializations per TC):

- At **1.5 km, 3 km, 4.5km and 9 km** atmospheric grid-spacing.
- Coupled to **1/12^0** and **1/4^0** NEMO4 ocean model and wave model.
- Spectral transforms on GPUs.

Scientific goals is to elucidate the impact of:

- Atmospheric horizontal resolution on the representation of TCs and ocean response.
- Relaxing hydrostatic approximation on TCs and ocean response.



IFS NR Data Hackathon

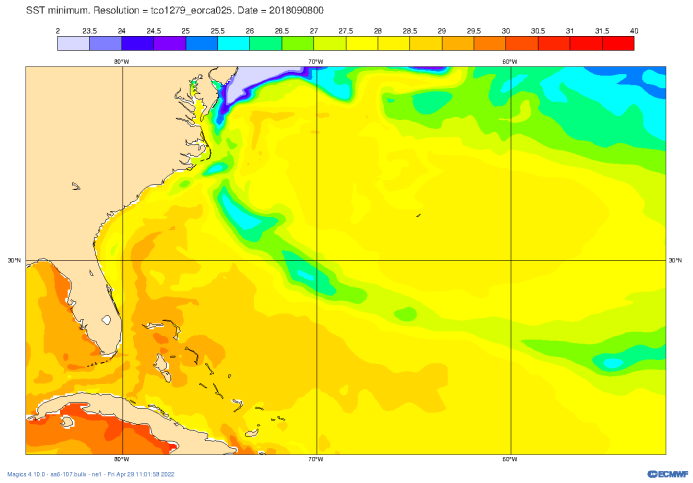
For more information and to apply, visit:
https://www.olcf.ornl.gov/ifs-nr-data-hackathon/

ECMWF

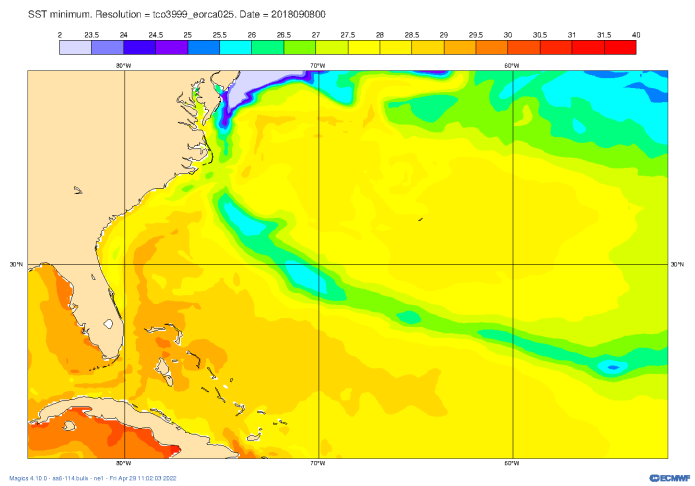
I. Polichtchouk et al.

Ocean response, min SST forecast for TC Florence

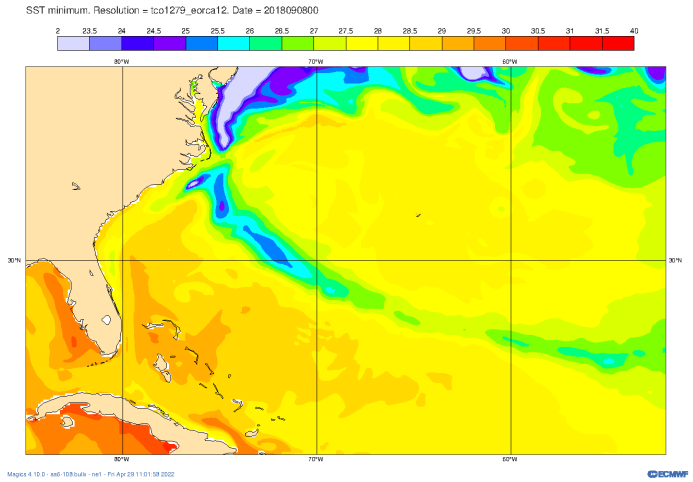
9 km atm, ¼^0 ocean



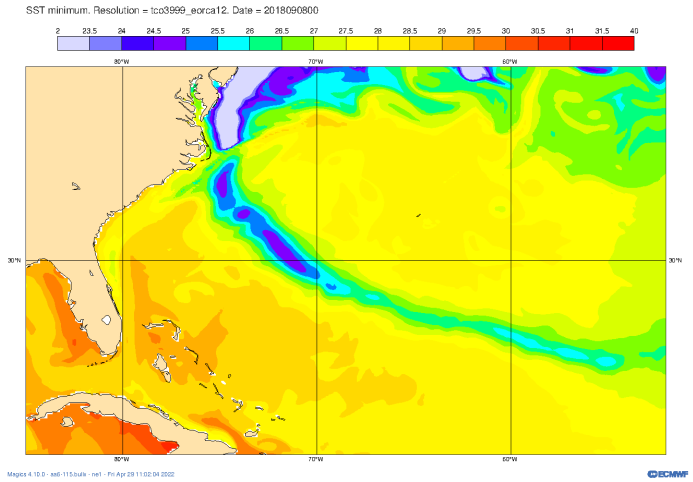
3 km atm, ¼^0 ocean



9 km atm, 1/12^0 ocean

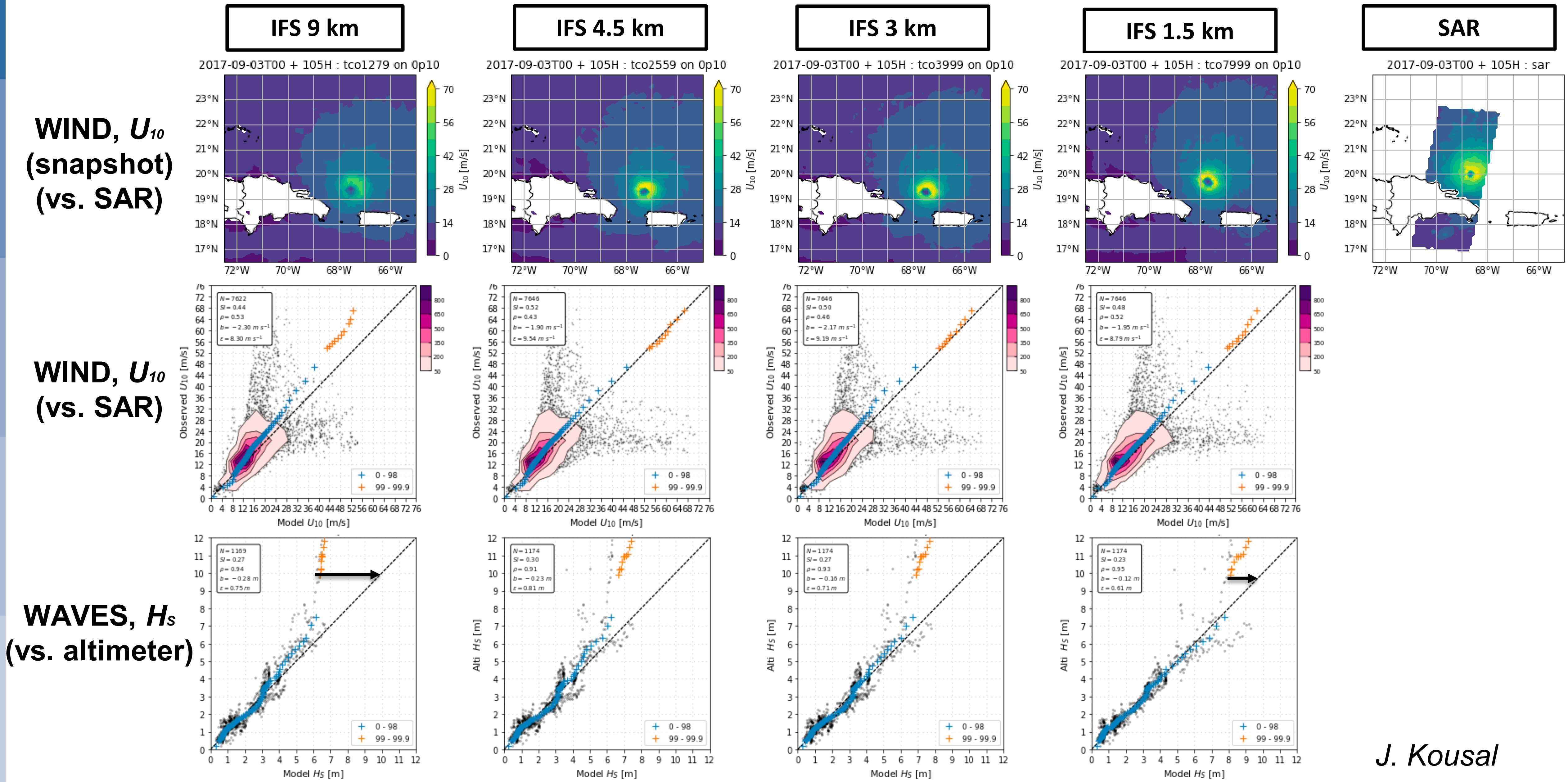


3 km atm, 1/12^0 ocean



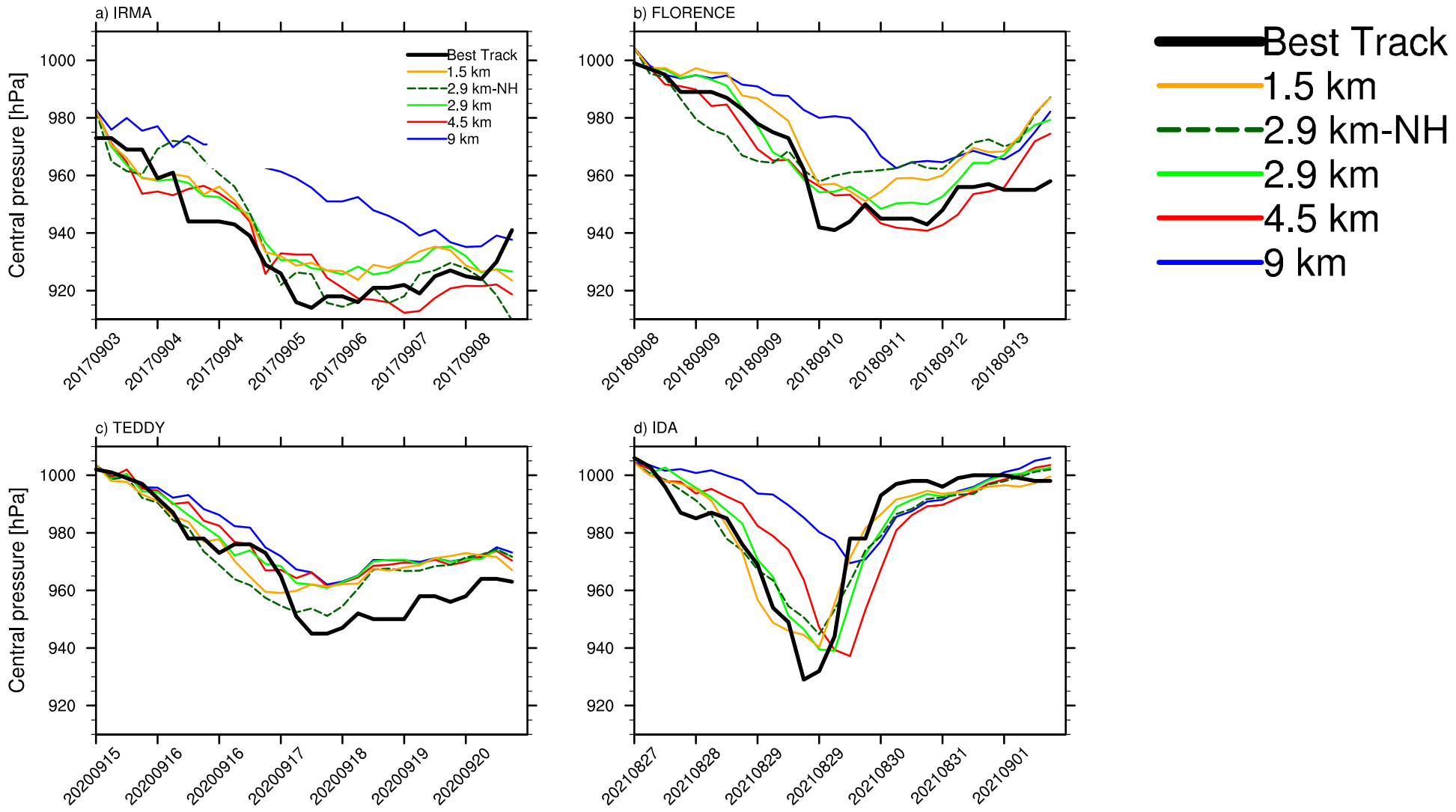
K. Mogensen

Wind and wave extremes in TC Irma



J. Kousal

TC intensity 7d-fcsts coupled to 1/12^0 ocean (deep convection on)

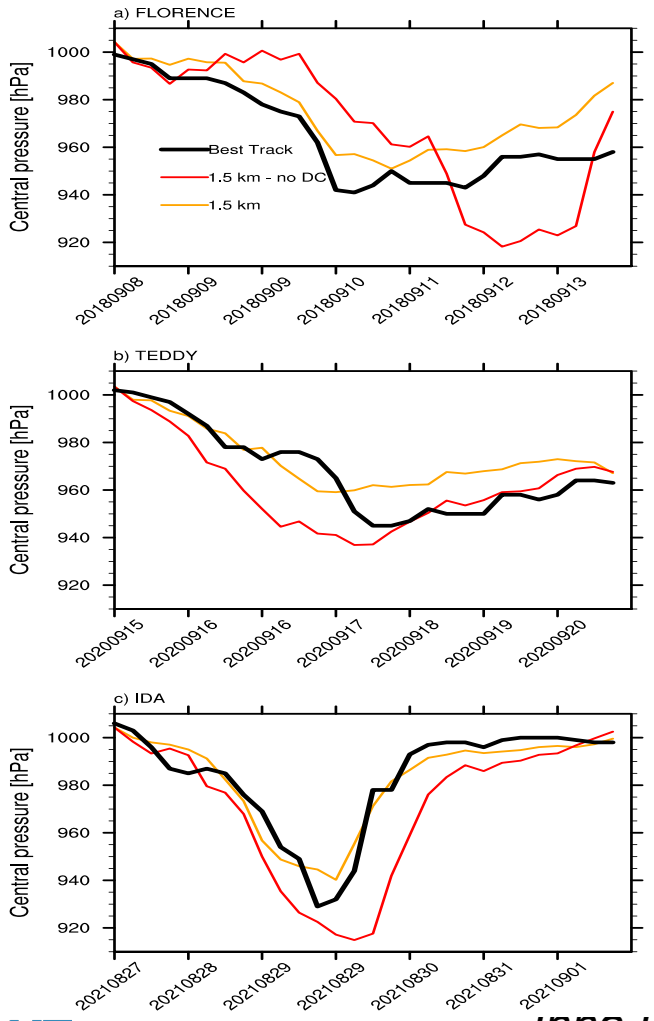


ECMWF

Inna Polichtchouk

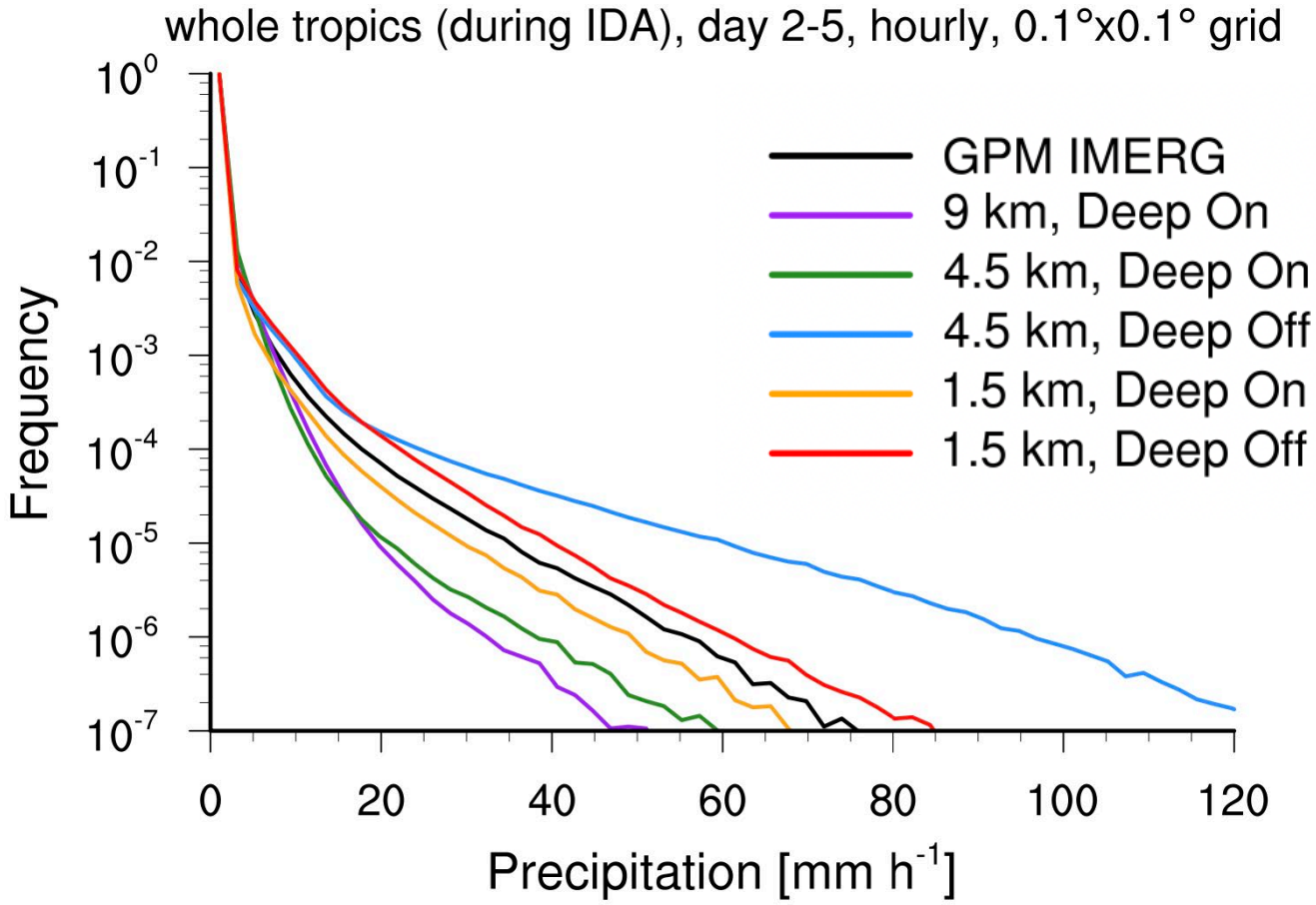
Impact of parametrized deep convection on TC & precipitation at 1.5 km

TC intensity



Inna Polichtchouk

Precipitation



Tobias Becker

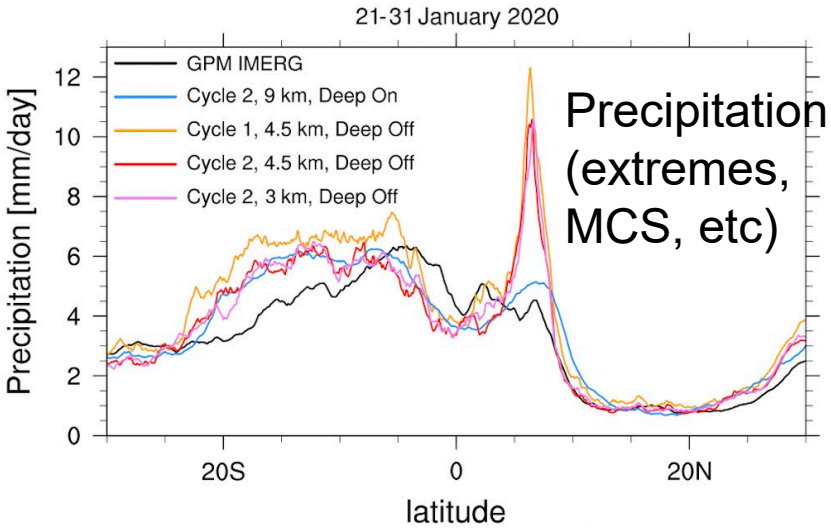
ECMWF

Towards Digital Twins of the Earth-system

Further work on km-scale models is ongoing to fully exploit their advantages, e.g.

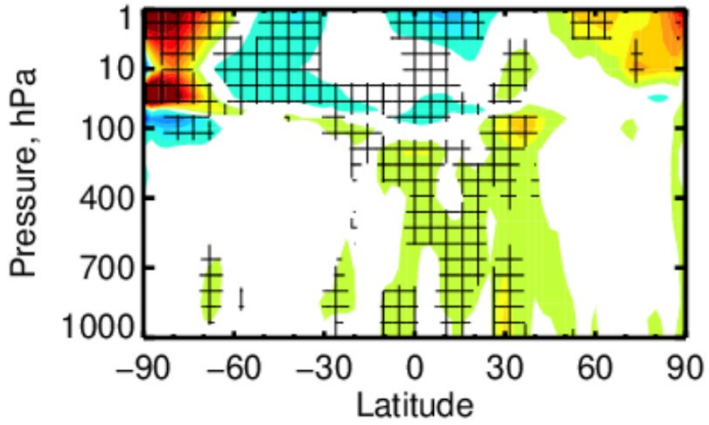
1. that the large-scale evolution is better, because of a better representation of convection, orography, ocean eddies etc and of their coupling to large scale

2. that given the large-scale, the km-scale models better downscale the information into near surface weather

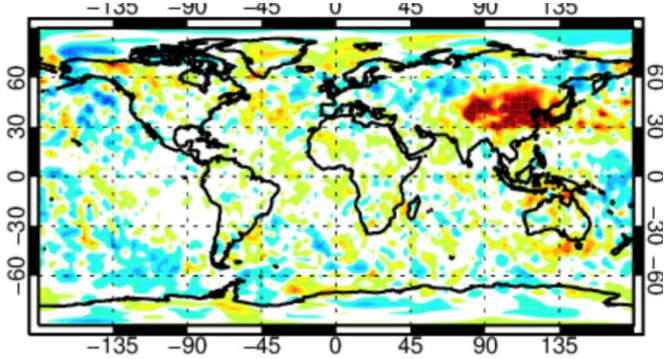


Precipitation (extremes, MCS, etc)

Geopotential RMSE
4.5 km - 9 km , T+72h

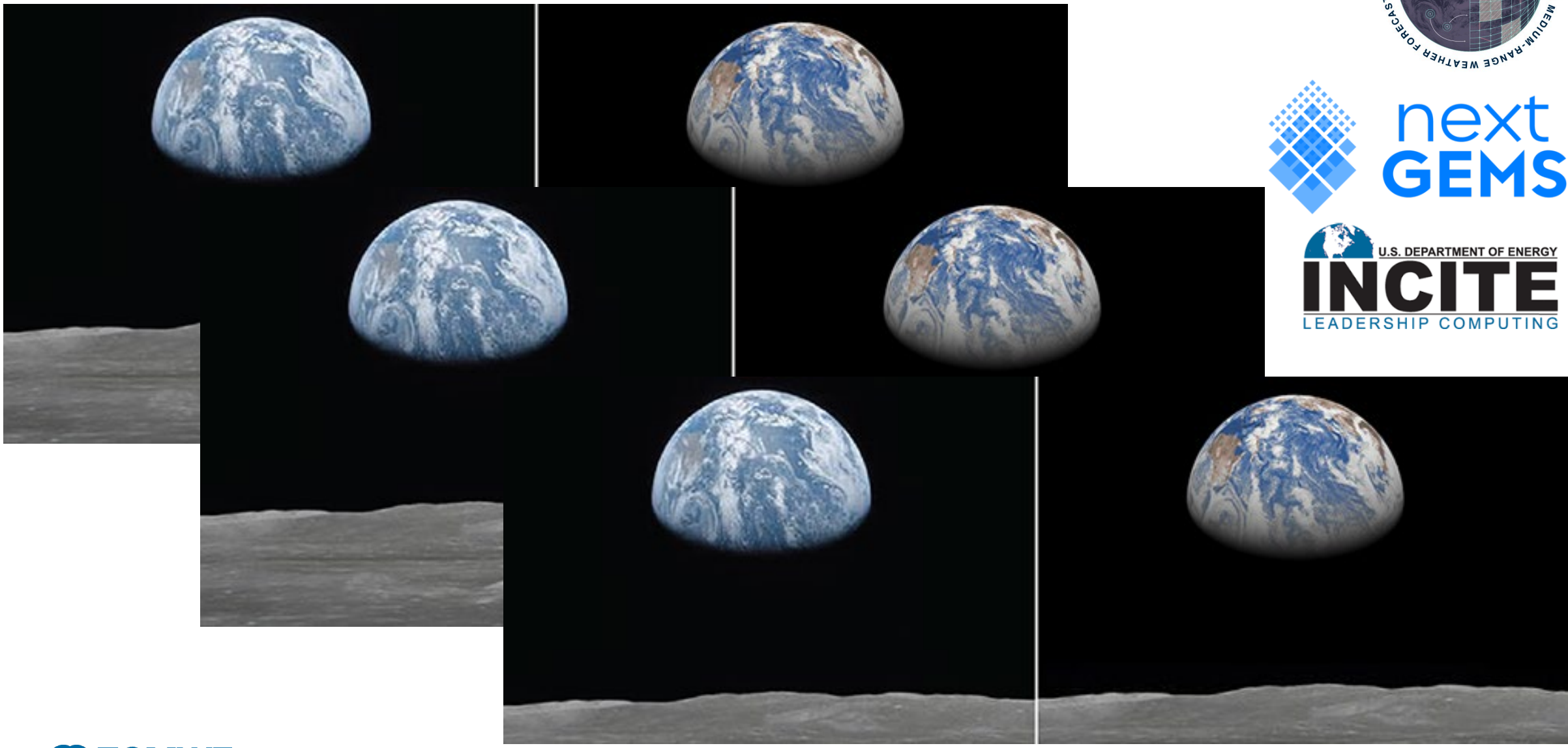


Winds RMSE 100hPa
4.5 km – 9km, T+72h



ECMWF

Towards Digital Twins of the Earth-system



ECMWF

Lopez, BAMS, 2020