Towards uncertainty quantification in the Extremes DT

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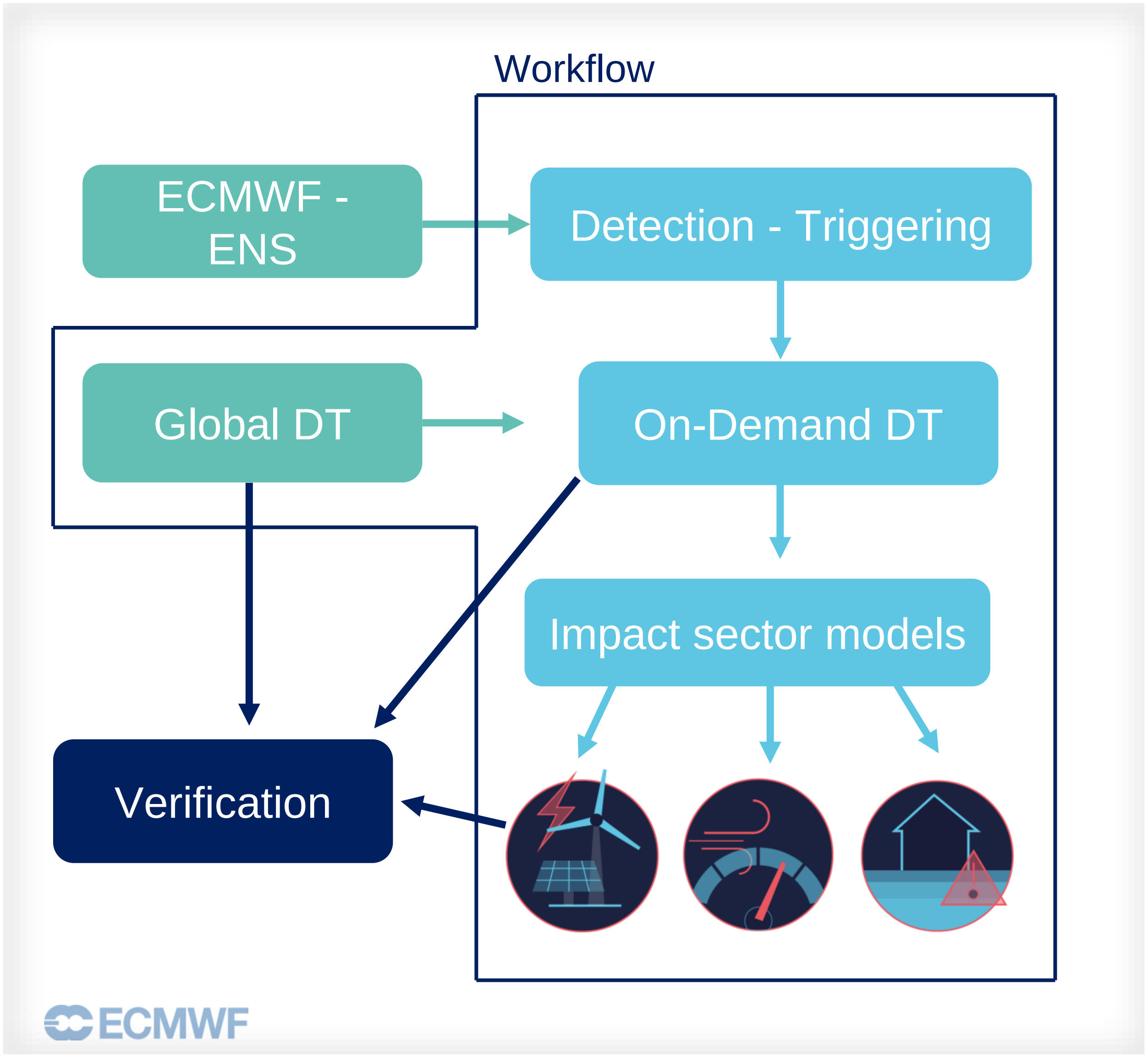
Funded by the European Union
Destination Earth implemented by ECMWF esa EUMETSAT

THE EXTREMES DT



What is the role of Uncertainty Quantification in the Extremes DT?

Uncertainty information is/can be used in almost every component of the extremes DT as:

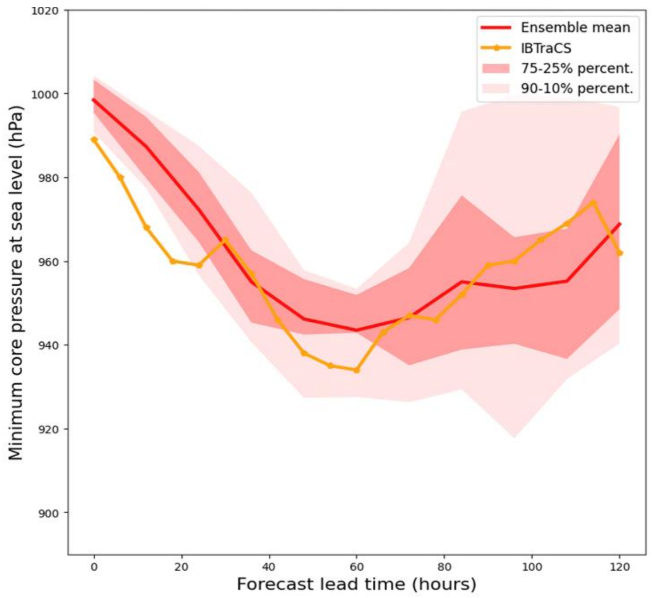
- Input (e.g., EFI index for triggering the On-Demand DT, boundary condition uncertainty from Global to On-Demand)
- Output (e.g., probability of exceeding specific precipitation thresholds from Global DT)

Depending on the use can uncertainty can take many different forms :

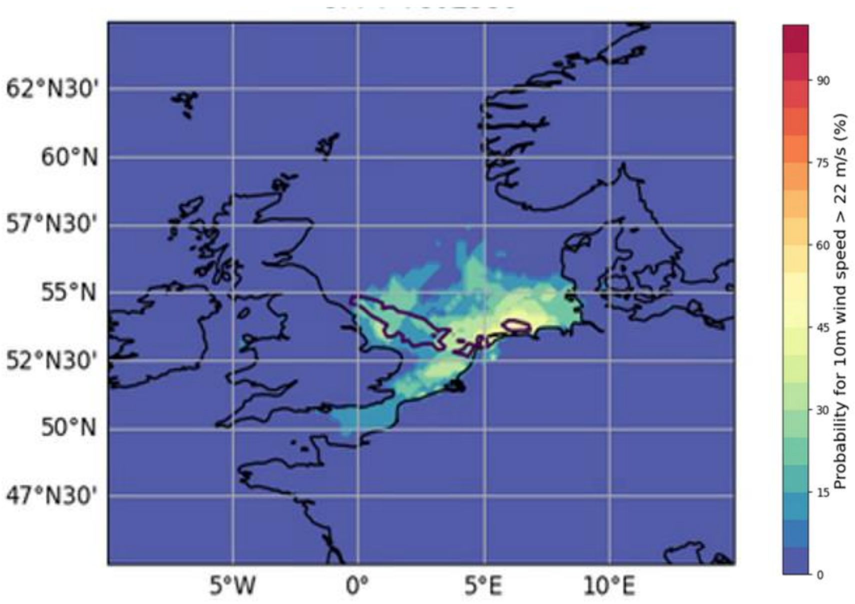
- **Ensemble spread** → Verification for Global or On-Demand DT
- **Probabilities** → Predicting likelihood of extreme events
- **Uncertainty at boundaries** → Forcing for the sub-km scale ensembles, impact sector models etc.

Examples of Uncertainty Quantification outputs Global DT

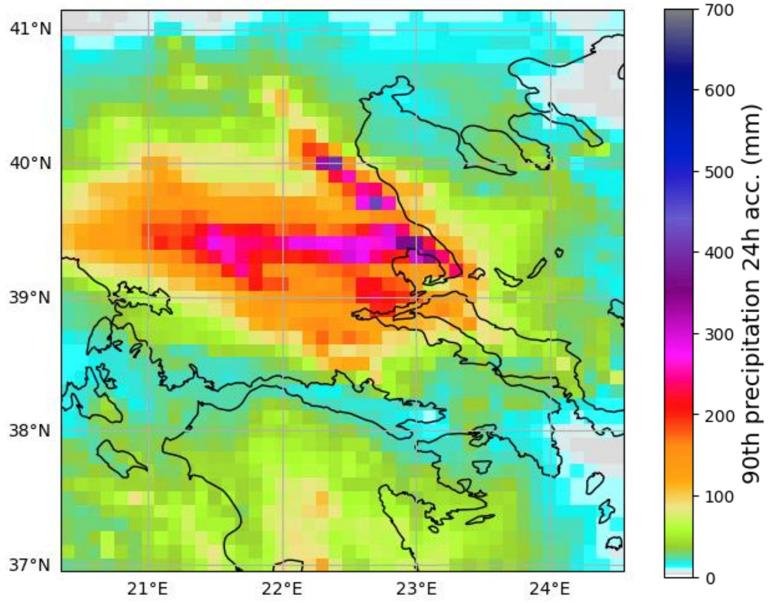
Uncertainty bands around estimate



Probability of exceedance

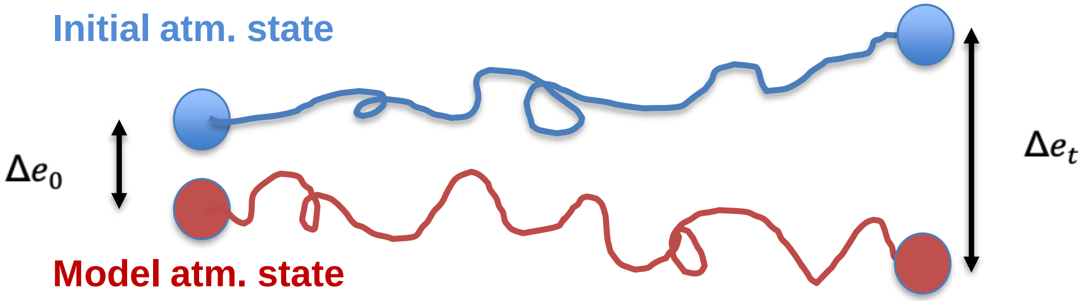


Precipitation percentiles



Errors at the initial atmospheric state

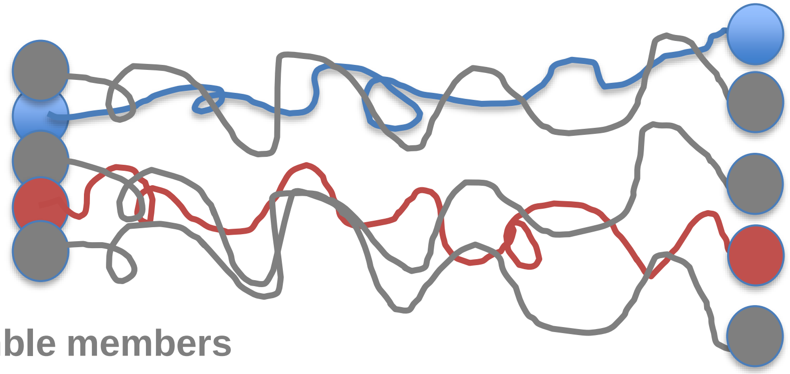
Due to the chaotic nature of the atmosphere (i.e. non-linear dynamics) errors in initial conditions can lead to substantial deviations in the modelled future atmospheric state.



$\Delta e_t >> \Delta e_0$

Small errors propagate quickly into larger errors

Ensembles are trying to sample uncertainties originating from errors in the initial atmospheric state and in model physics with the aim to reproduce multiple future atmospheric states.



Higher probability of capturing the future atmospheric state in at least some of the ensemble members

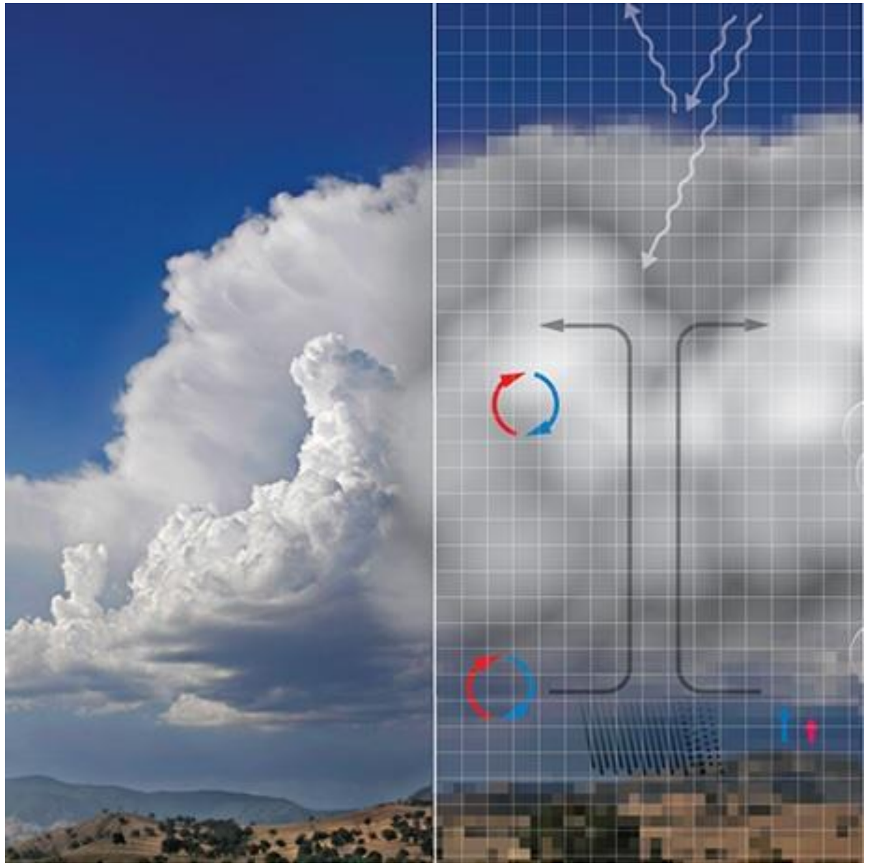
All models are imperfect

Earth System

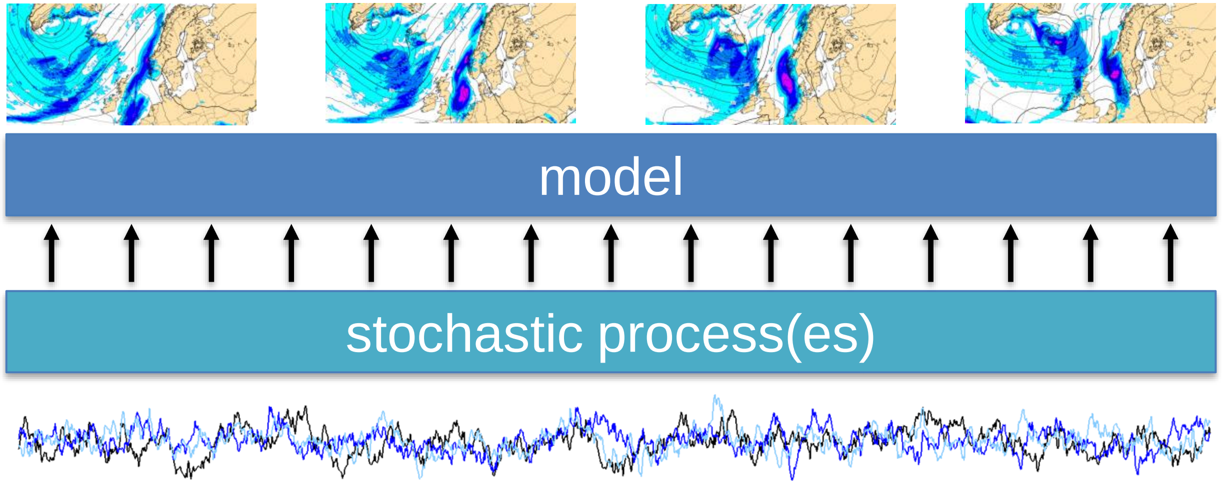
$$\mathbf{x}(t) \rightarrow \mathbf{x}_S(t + \Delta t)$$

Model

$$\mathbf{x}(t) \rightarrow \mathbf{x}_M(t + \Delta t)$$



- representing random errors of model improves reliability of ensemble
- Stochastic representation of model uncertainties

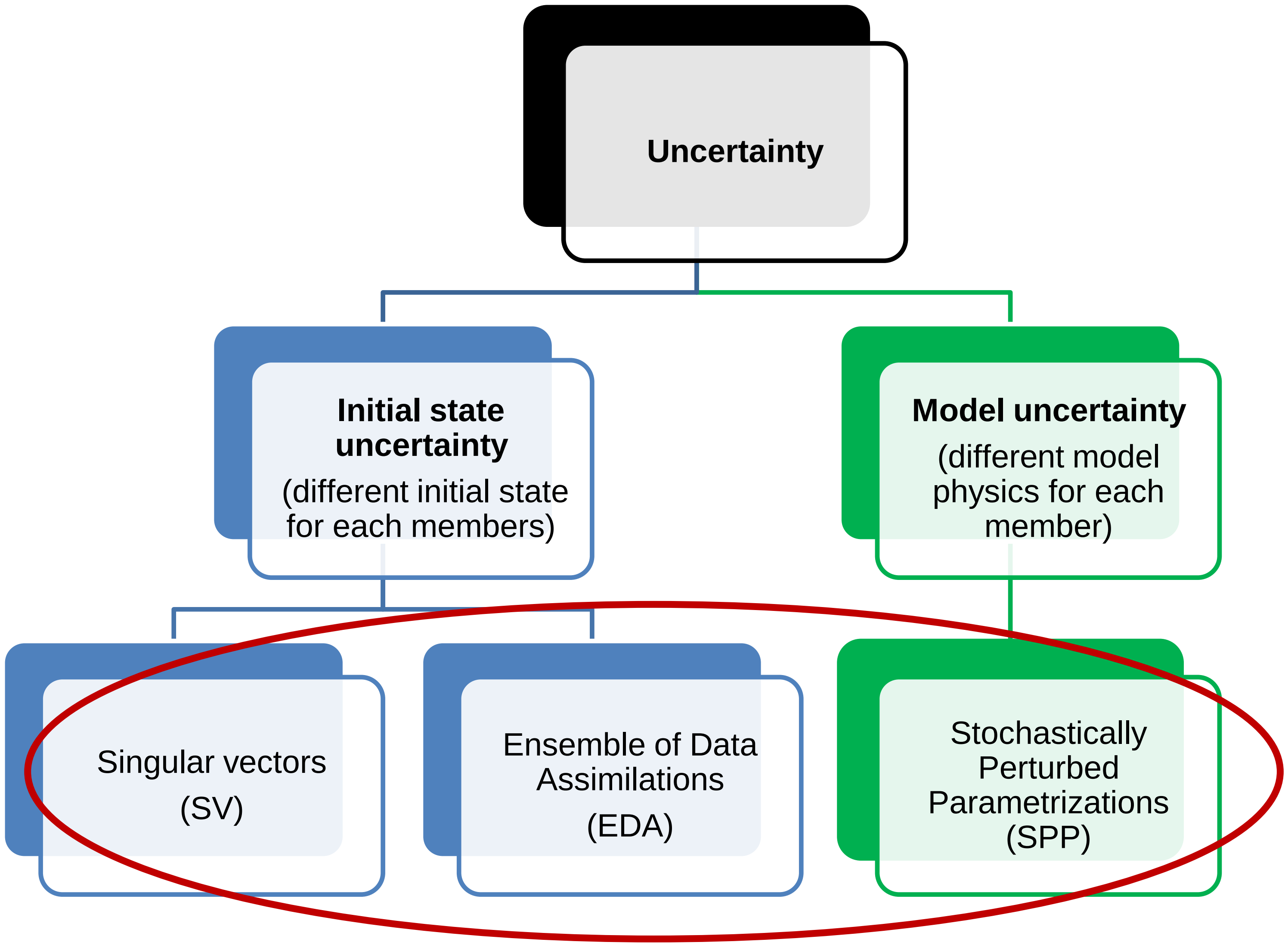


How do we create an ensemble?

We sample uncertainty at the source of the errors:

Initial errors → sample uncertainty by perturbing the initial state of each member

Model physics errors → sample uncertainty by perturbing model physics for each ensemble member



Used currently for generating uncertainty in the ensemble of the Global DT

Uncertainty Quantification in the Global DT

Aim : Improve Uncertainty Quantification in the Global DT via the use of km-scale ensembles

- Improved representation of extreme events
- Improved UQ information provided to the On-Demand DT
- Better UQ provided for impact sector models

Starting Point

IFS operational ensemble

- 50 ensemble members
- 15 days forecasts
- EDA+SV+SPP/SPPT
- 9 km resolution

End of Phase 1

Km-scale ensemble Global DT v1 (first setup)

- 10 ensemble members
- 5 days forecasts
- EDA+SV+SPP
- 4.4 km resolution

End of Phase 2

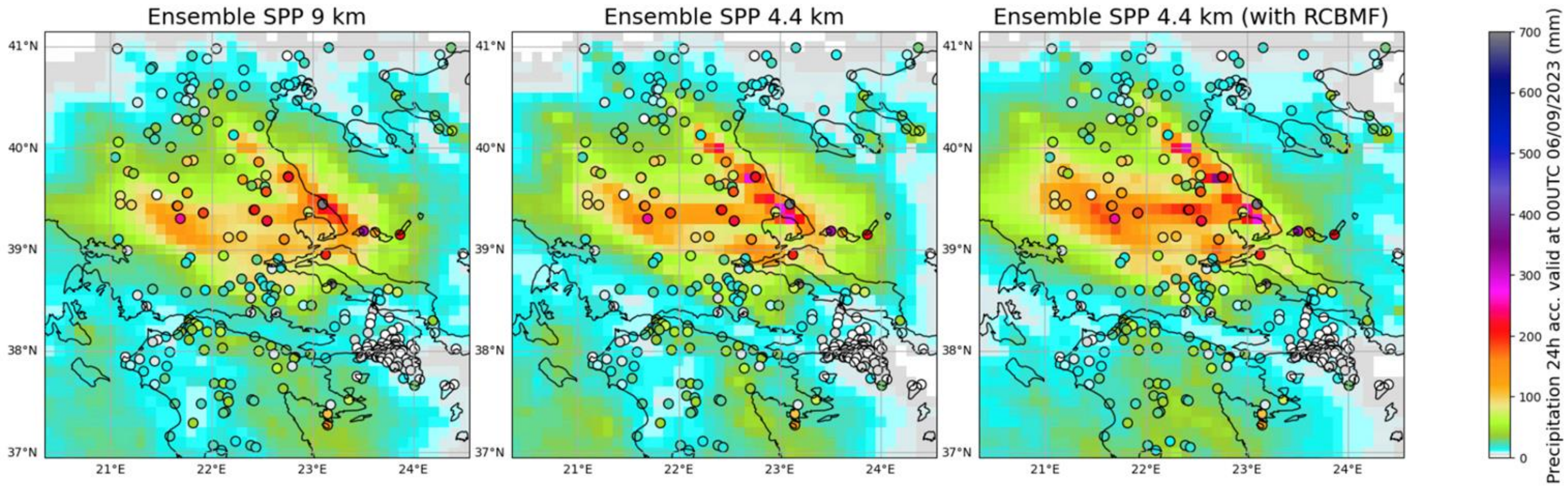
Km-scale ensemble Global DT v2

- Better initial conditions
- Km-scale appropriate physics
- Improved model uncertainty representation for km-scale

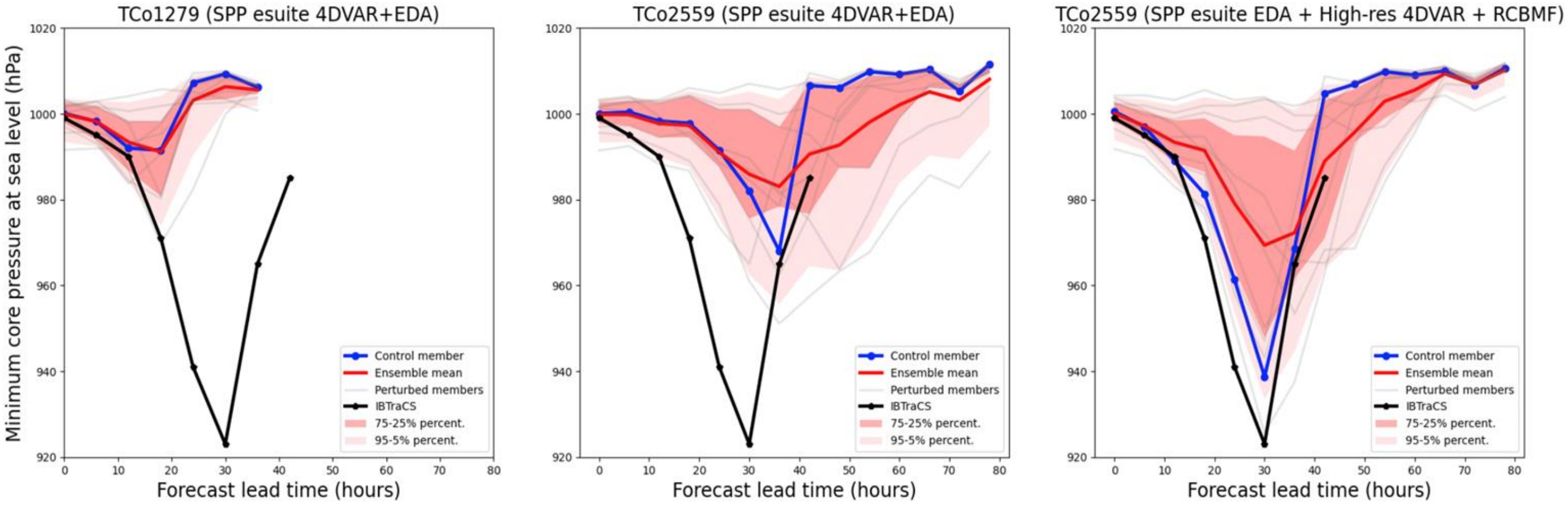
Pioneering km-scale ensembles and addressing uncertainty

Evaluating 4.4 vs 9 km ensembles with SPP + additional physics changes (e.g., RCBMF) for extreme events

Extreme precipitation over Greece (5th – 6th Sept. 2023)



Tropical Cyclone Otis (24th – 25th Oct. 2023)



Improved predictions for both events with increasing resolution + RCBMF!

Uncertainty Quantification in the On-Demand DT

EPS in DE-330

Our approach:

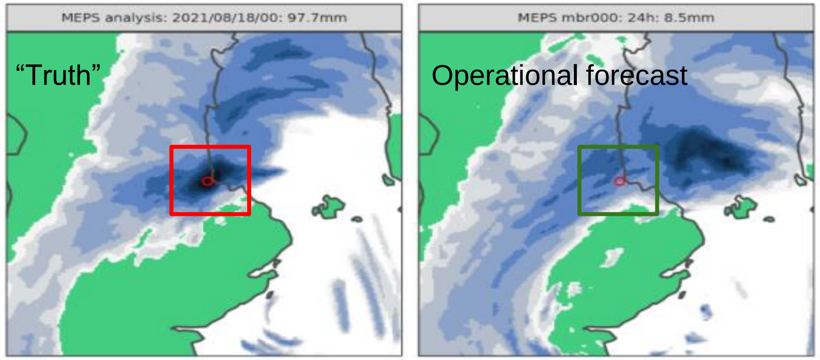
- Running mini-ensembles (1+6 members) @ 750m for ~week long periods with interesting case(s) included
- Focus is on boundary nesting and model uncertainty description at 750m
- To be compared with other ways of doing UQ and probabilistic forecasts (PP, ML), as well as how it compares to coarser resolution EPS (~2-3 km as in operational LAMs and global experiential EPS at 4.4km)

First example with 750m EPS:

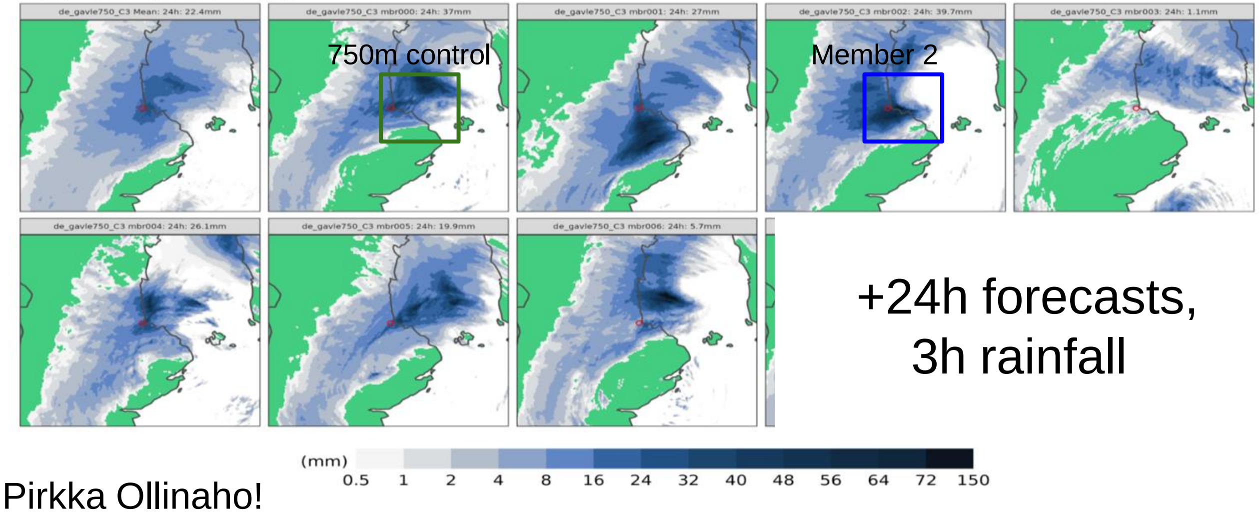
Heavy precipitation event in Sweden

Not well predicted/placed deterministically by either opr 2.5km forecast nor control forecast @ 750.

But is by some 750m members



2021-08-17 cycle, 3h rainfall



+24h forecasts, 3h rainfall

Thanks to Inger-Lise Frogner, James Fannon and Pirkka Ollinaho!

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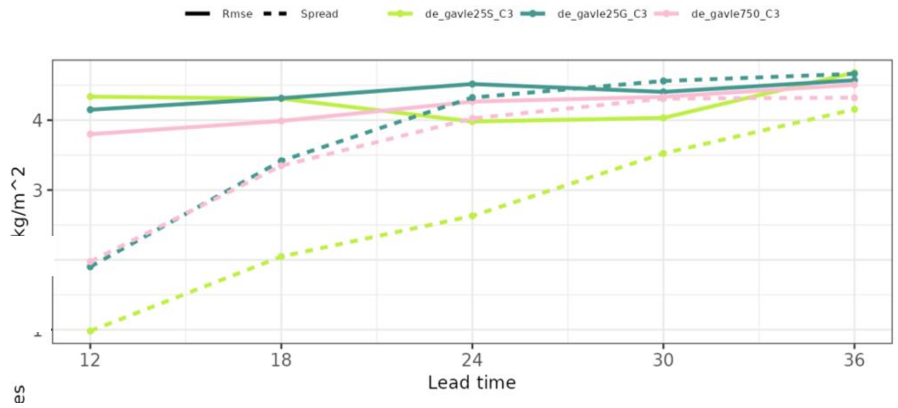
EPS in DE-330

Challenges:

- The size of the area has big impact on the spread of the ensemble
- Big resolution gap between boundary conditions (IFS ENS 9km) and our resolution at 750m -> in cooperation with ECMWF test nesting in 4.4km IFS ENS
- Need to adjust SPP to the new resolution as its impact on scores is relatively small using the current operational settings

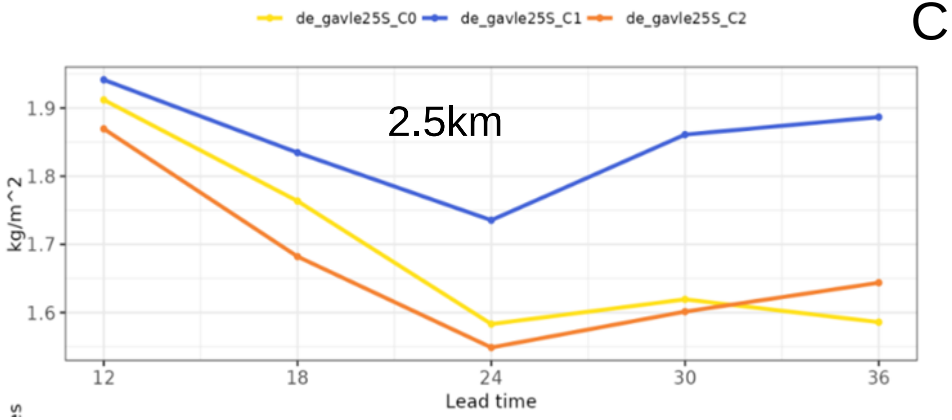
Spread - Skill

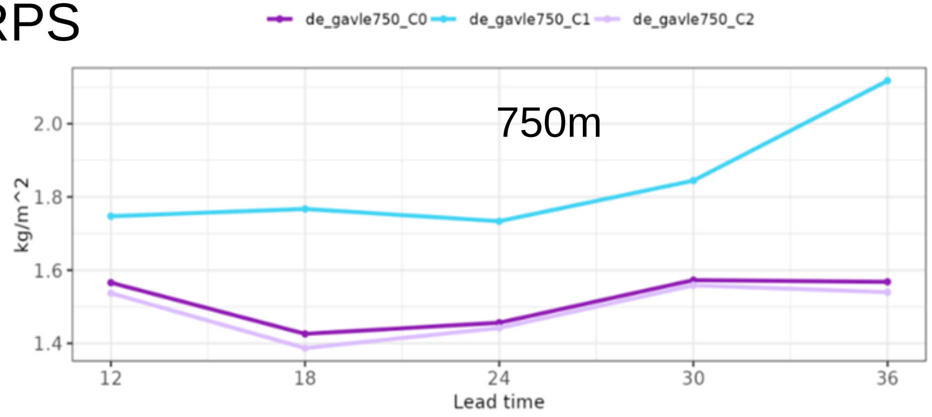


Big domain 2.5km
Small domain 2.5km
Small domain 750m

To be completed with big domain 750m

CRPS





2.5km only SPP
2.5km only bnd pert
2.5km SPP + bnd

750m only SPP
750m only bnd pert
750m SPP + bnd

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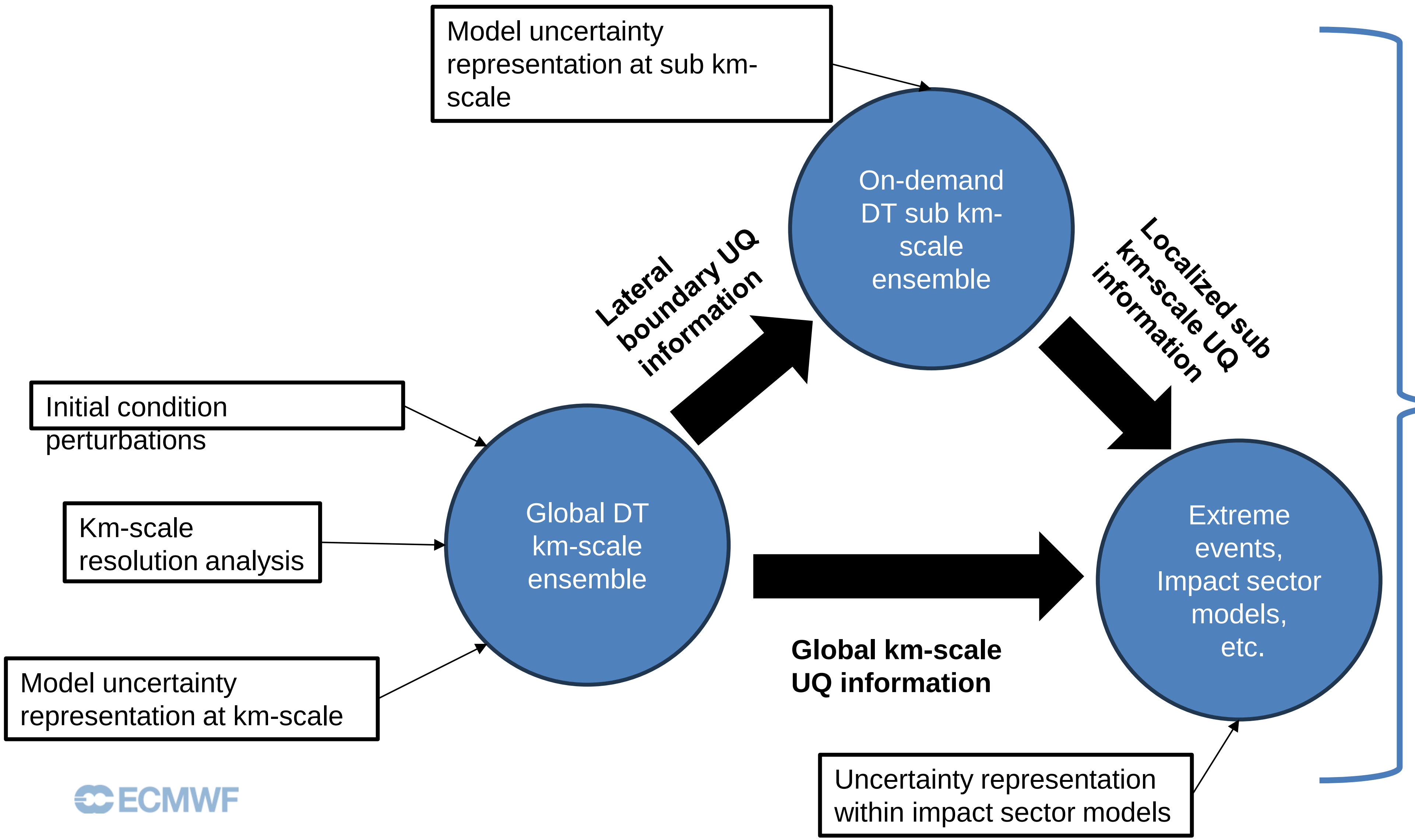
A potential way to cascade UQ through the Extremes DT



Comprehensive UQ from global to regional scales!

What can we get through UQ :

- Distributions (e.g., temperature)
- Percentiles (e.g., precipitation)
- Probabilities (e.g., wind speed over a specific thresholds)
- Ensemble members (e.g., scenario analysis)

Steps Ahead

- Test initialization of sub-km scale On-Demand ensemble with the use of boundary and initial UQ information from the Global DT km-scale ensemble
- Investigate the use of optimization tools for efficient data handling (e.g., Mutli-IO, Polytope)
- Test adjustments in initial conditions perturbations and model uncertainty representation
- Test km-scale appropriate physics and initial conditions
- Looking for synergies between physics-based and machine-learning based approaches for UQ

Concluding Remarks

A different, yet complimentary, approach for UQ in the Extremes DT is based on machine learning, for details see **Joffrey Dumont Le Brazidec's presentation on "Machine Learning for DestinE at ECMWF"**

For potential approaches for spatial UQ based on deterministic forecasts please see **Balazs Szintai's poster**