

Towards km-scale uncertainty representation using ensembles

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With many thanks to Martin Leutbecher, Simon Lang, Sarah-Jane Lock, Benoit Vanniere, Mariana Clare and many others

All models are imperfect

Earth System

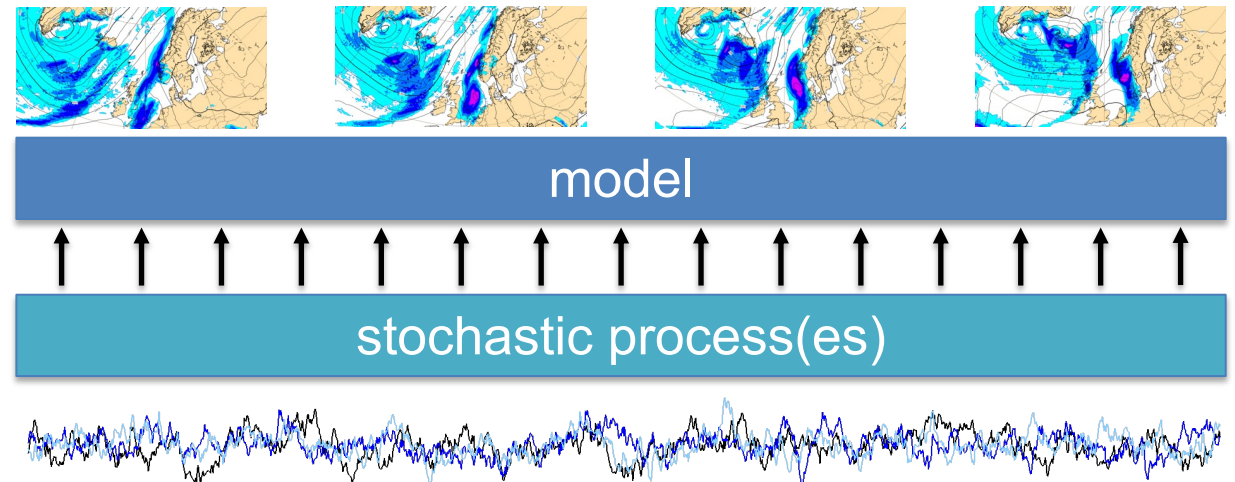
$$\mathbf{x}(t) \rightarrow \mathbf{x}_S(t + \Delta t)$$

Model

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



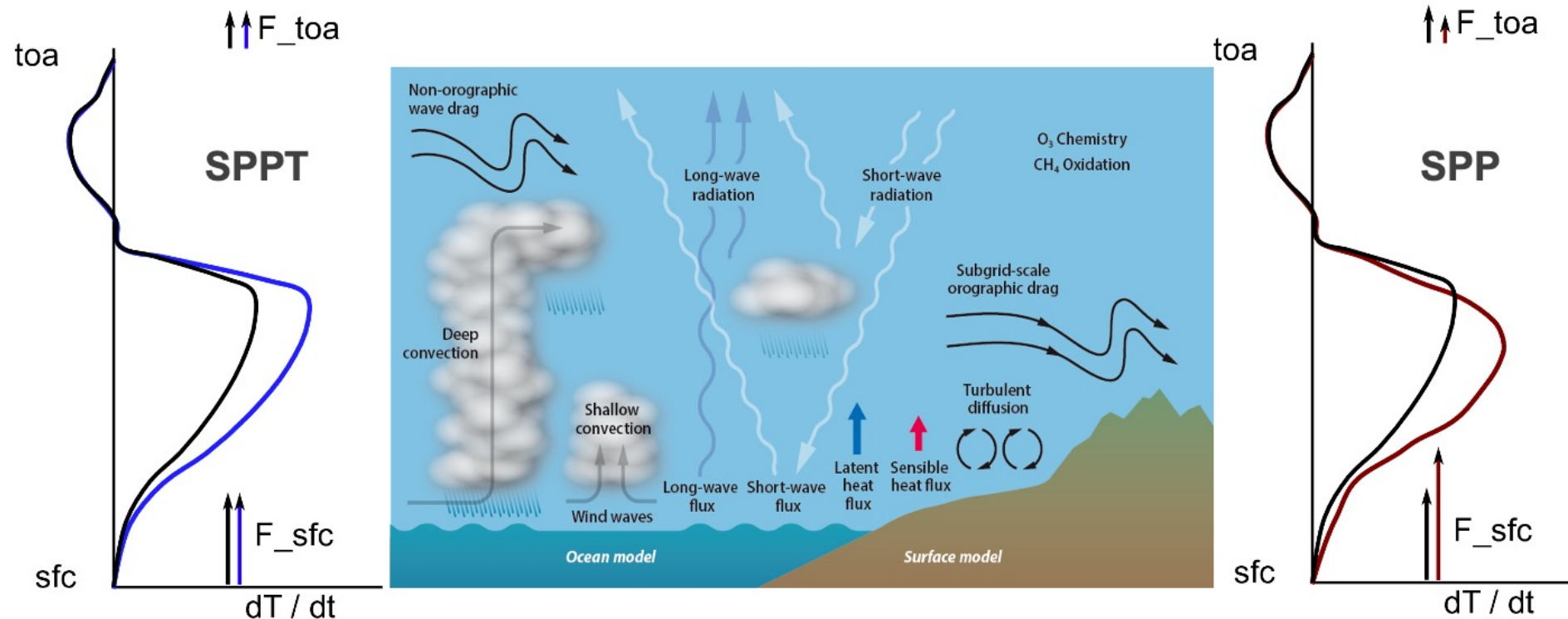
- representing random errors of model improves reliability of ensemble
- Stochastic representation of model uncertainties



Changes in model uncertainty representation

SPP is planned to replace SPPT in 2024

- SPP represents model uncertainties closer to the assumed sources of the errors
- SPP better maintains physical consistency: e.g., local budgets and flux perturbations
- SPPT represents amplitude errors while SPP also represents errors in the shape of a heating profile



Experiment design of uncertainty quantification with km-scale ensembles

Resolution testing: 28 km vs 9 km vs 4.4 km

Periods: DE extreme cases, each with 3 separate initialization days running up to 5 day forecast lead time

- 8 periods (21 forecast days) for all resolutions

Extreme events: 26-28 September 2018 (MC Zorbas), 14-16 September 2020 (MC Ianos), 01-03 December 2020 (Extreme precipitation Emilia-Romagna), 26-28 August 2021 (TC Ida), 13-15 December 2021 (TC Rai), 16-18 February 2022 (Storm Eunice/Franklin), 27-29 August 2023 (TC Idalia), 07-09 September 2023 (TC LEE)

Model uncertainty schemes : SPP vs SPPT for all periods, some tests also for only initial conditions (SV + EDA)

With this setup we can test the DE extreme cases, but also concatenate the periods to produce more robust scorecards if needed and test for systematic biases.

Experiment Summary Table

Resolution	28 km	28 km	9 km	9 km	4.4 km	4.4 km
Model version	48R1.0*	48R1.0*	48R1.0*	48R1.0*	48R1.0*	48R1.0*
Model Uncertainty scheme	SPPT	SPP	SPPT	SPP	SPPT	SPP
Timestep	900	900	450	450	200	200
Member size	50 + 1	50 + 1	8+1	8+1	8+1	8+1

* with SPP from Lang et al. 2021 + modification for operational introduction in 49r1

What we are going to look at

- Results from 5 case studies (TC Ida, TC Idalia, MC Ianos, Eunice/Franklin and Emilia Romagna floods)
- Differences in precipitation over the tropics between SPP/SPPT and TCo1279 (9 km)/TCo2559 (4.4 km)
- Scorecard 10+1 ensemble members (SV + EDA) for the winter period (15 days) Jan - Feb 2022
- Surface scores for SPP ensemble 4.4 vs 9 km

Results for TC Ida

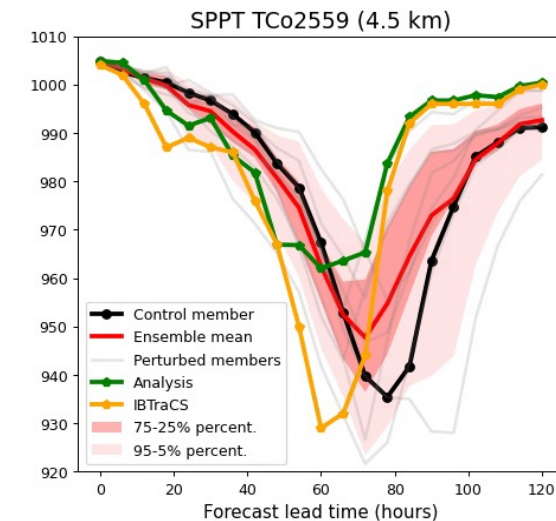
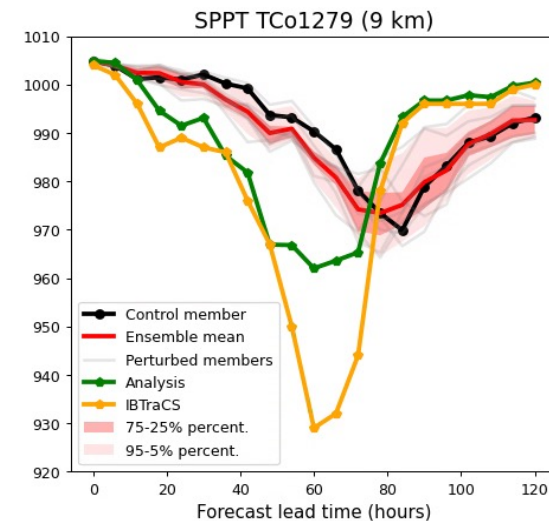
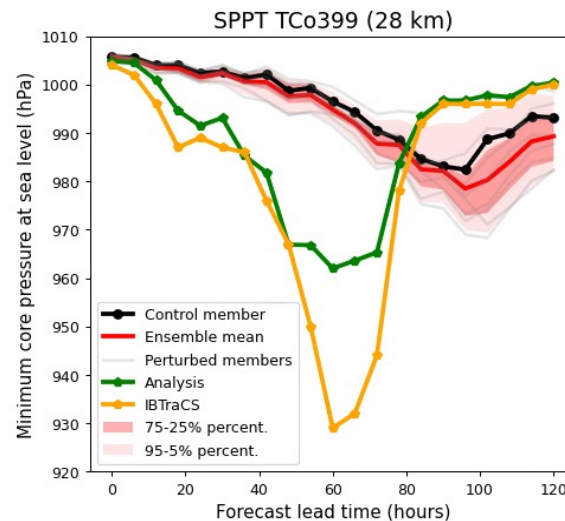
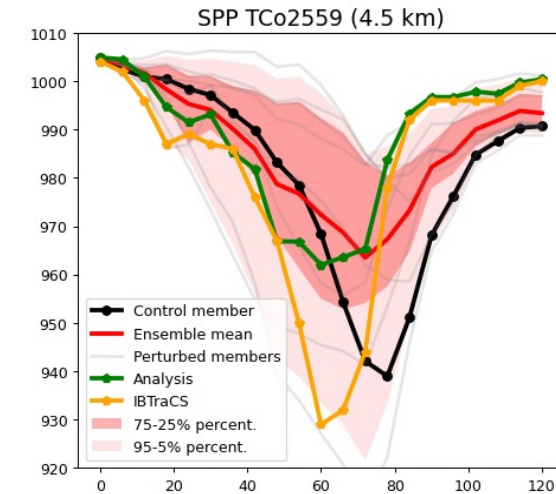
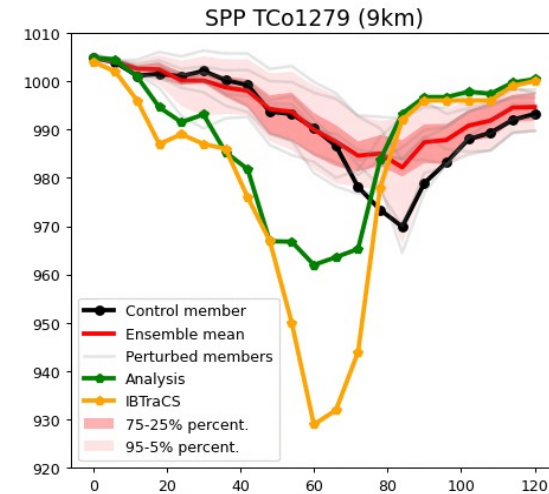
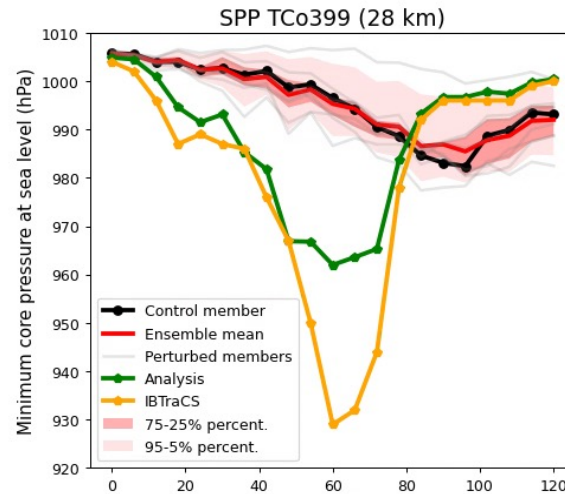
Initialization 27-08-2021 at 0000 UTC

TCo399 and TCo1279 struggle to capture the intensity of Ida

TCo2559 does a much better job at capturing the intensity

TCo2559 provides reasonable predictability of the TC intensity 1-day earlier than TCo1279 with members reaching up to 920 hPa in the run initialized at 26-08-2021

SPP generates more spread than SPPT and has members that exhibit more rapid intensification phase



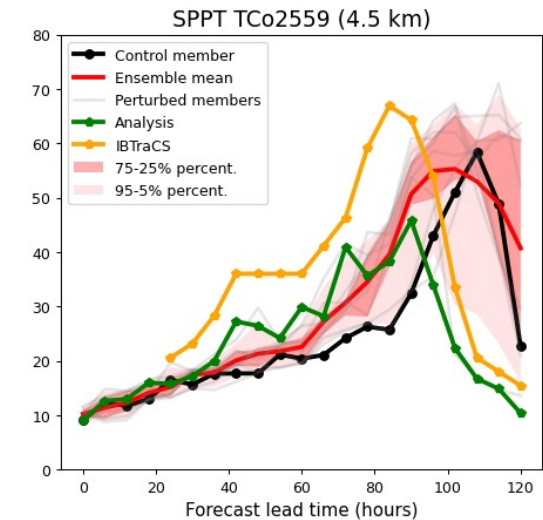
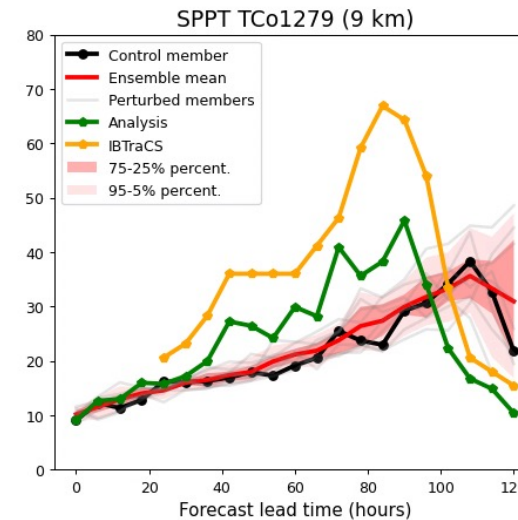
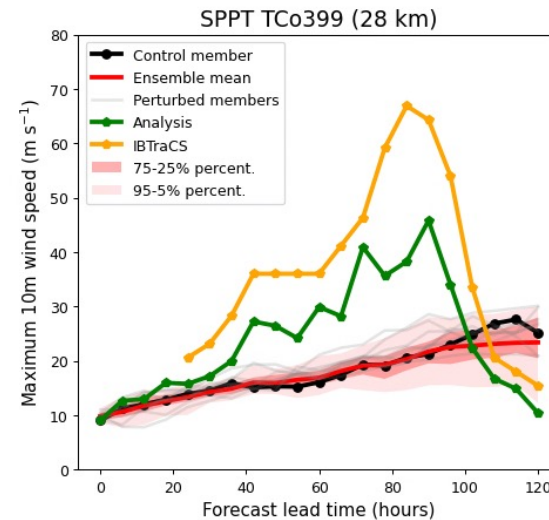
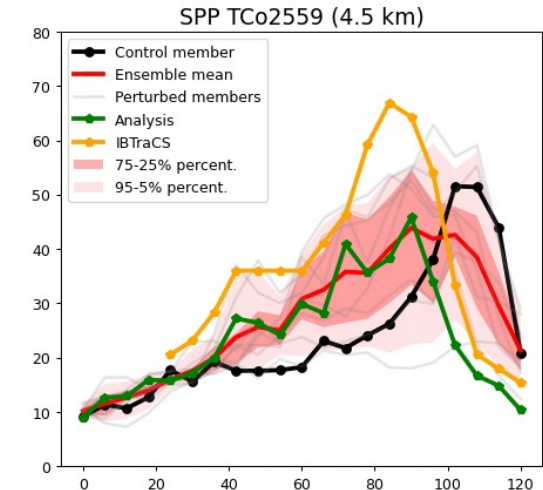
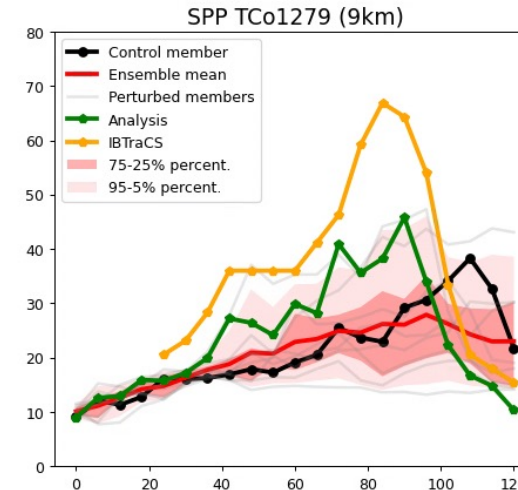
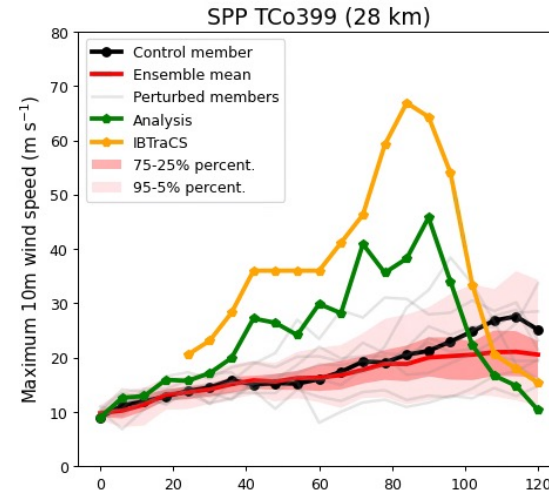
Results for TC Ida

Initialization 26-08-2021 at 0000 UTC

TCo399 and TCo1279 struggle with maximum 10m wind speed

SPPT is somewhat out-of-phase with later development of the TC and very late weakening phase

SPPT somewhat better with the peak 10m wind speed at TCo1279, but under-dispersive during the intensification phase



RMSE and spread for core pressure/max wind speed for TCs

Results for two 2 TC (6 initialization days)

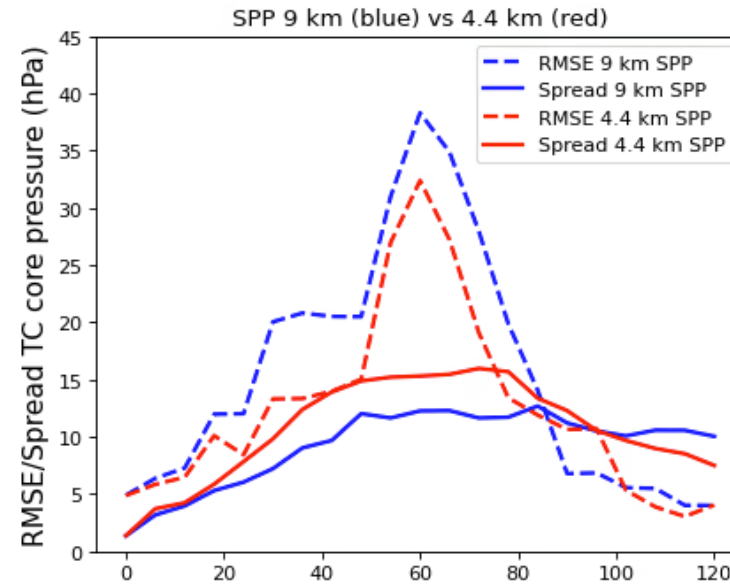
4.4 km vs 9 km SPP experiments:

- 13% smaller RMSE and 15% large spread for CP
- 19% smaller RMSE and 32% larger spread for max wind speed

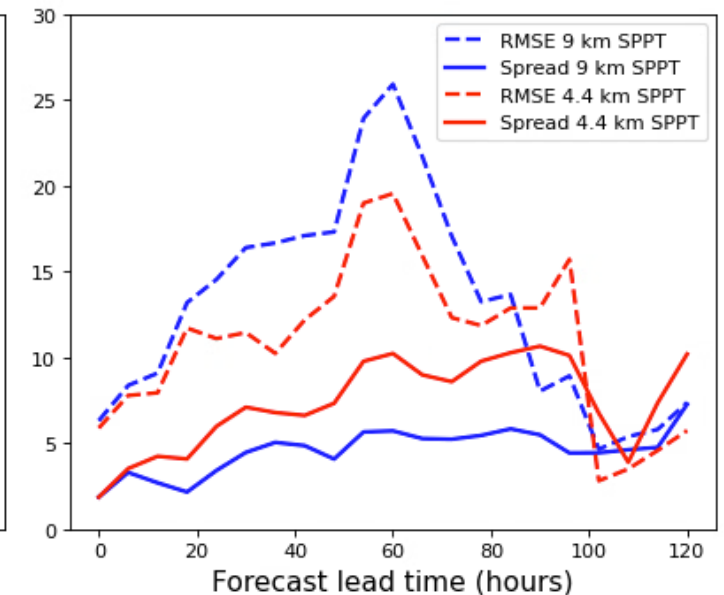
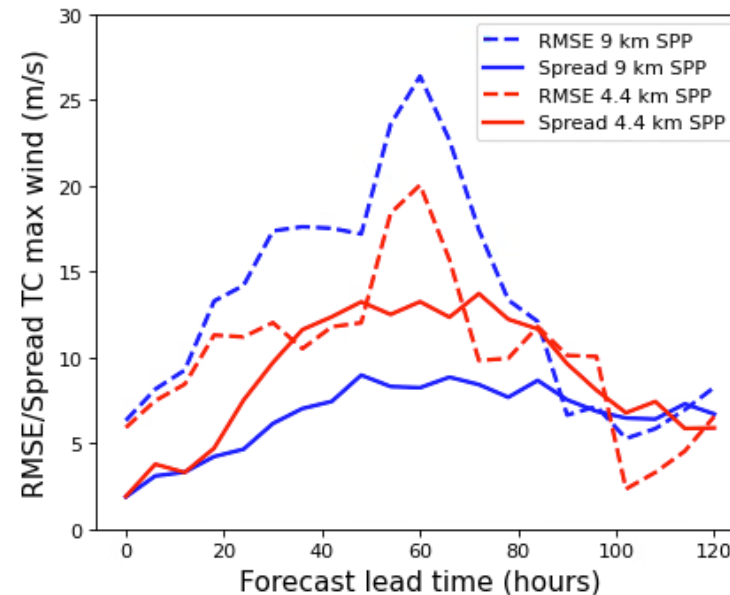
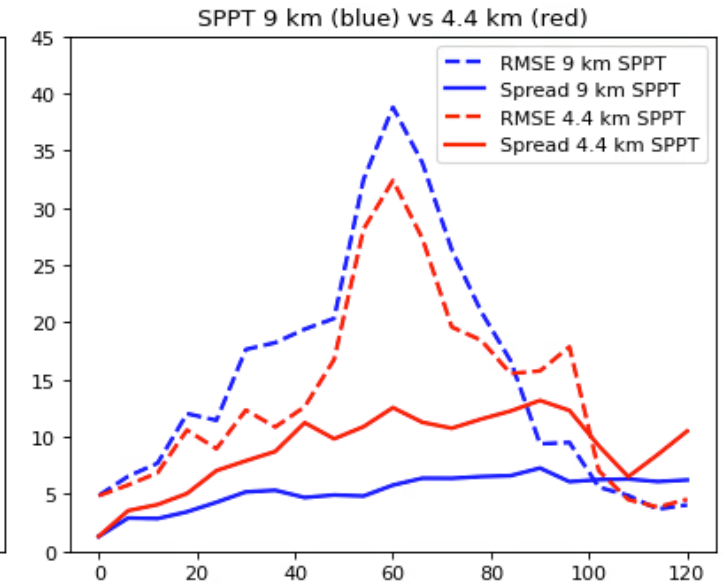
4.4 km SPP vs SPPT experiments:

- 8% smaller RMSE for CP, 17% more spread
- 5% smaller for max wind speed, 23% more spread

SPP



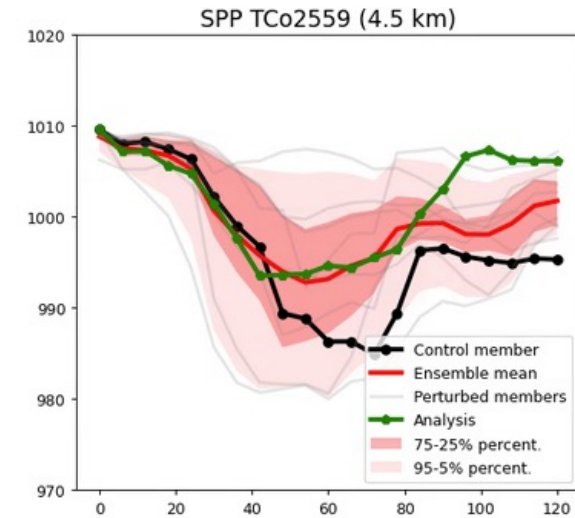
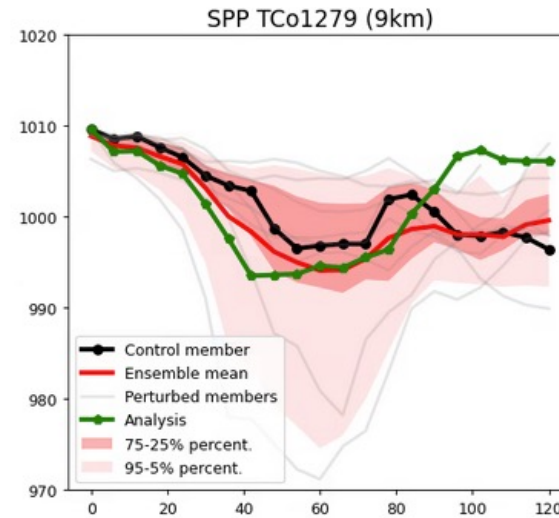
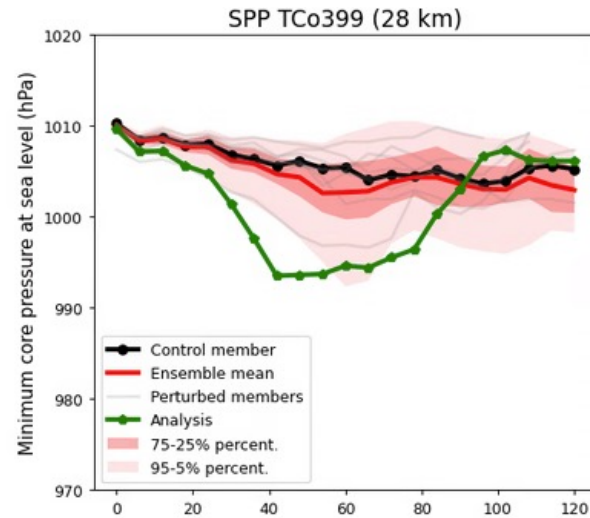
SPPT



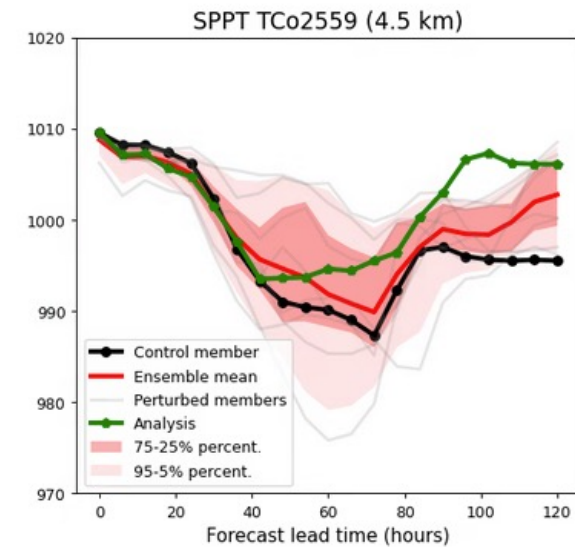
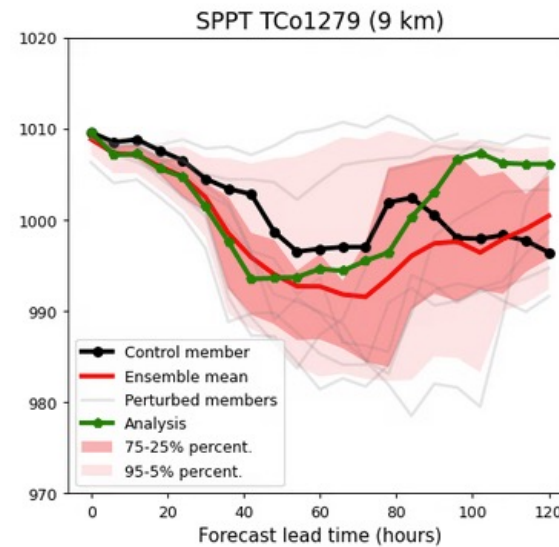
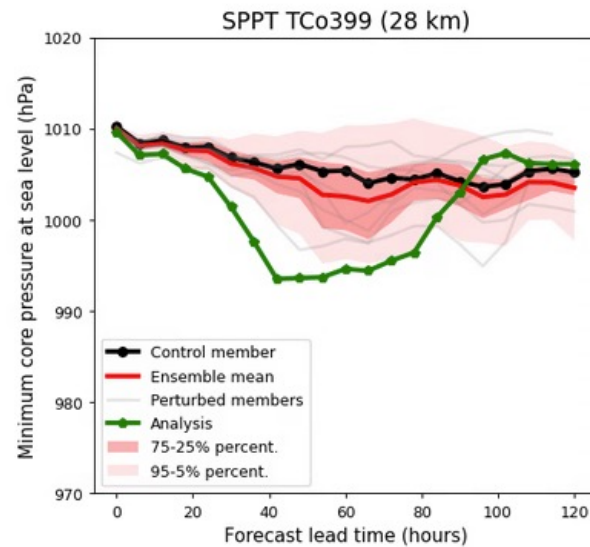
Results for MC Ianos

Initialization 15-09-2020 at 0000 UTC

SPP

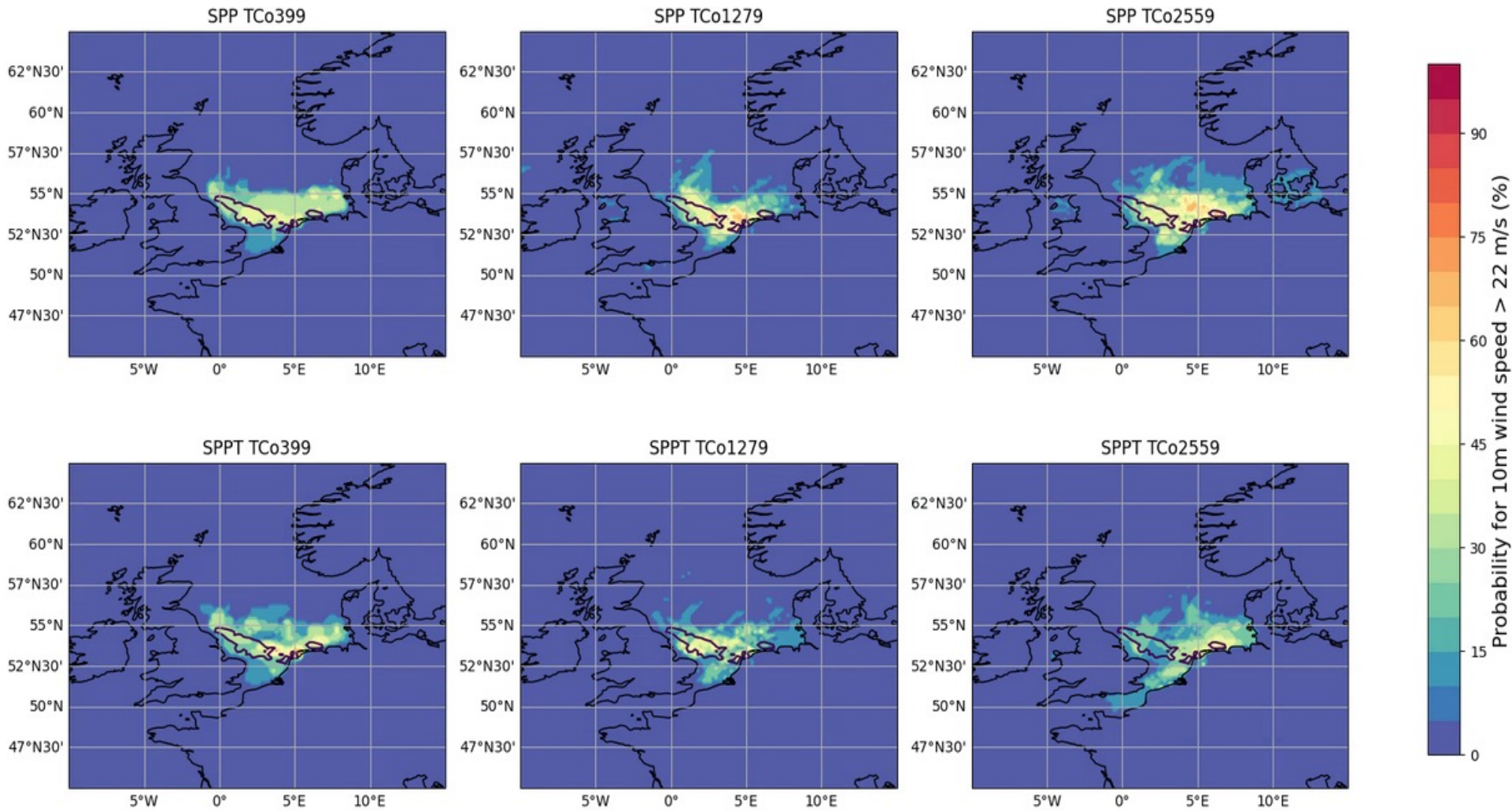


SPPT



Probability for 10 m wind speed > 22 m/s
(black line depicts 22 m/s contour from analysis)

SPP

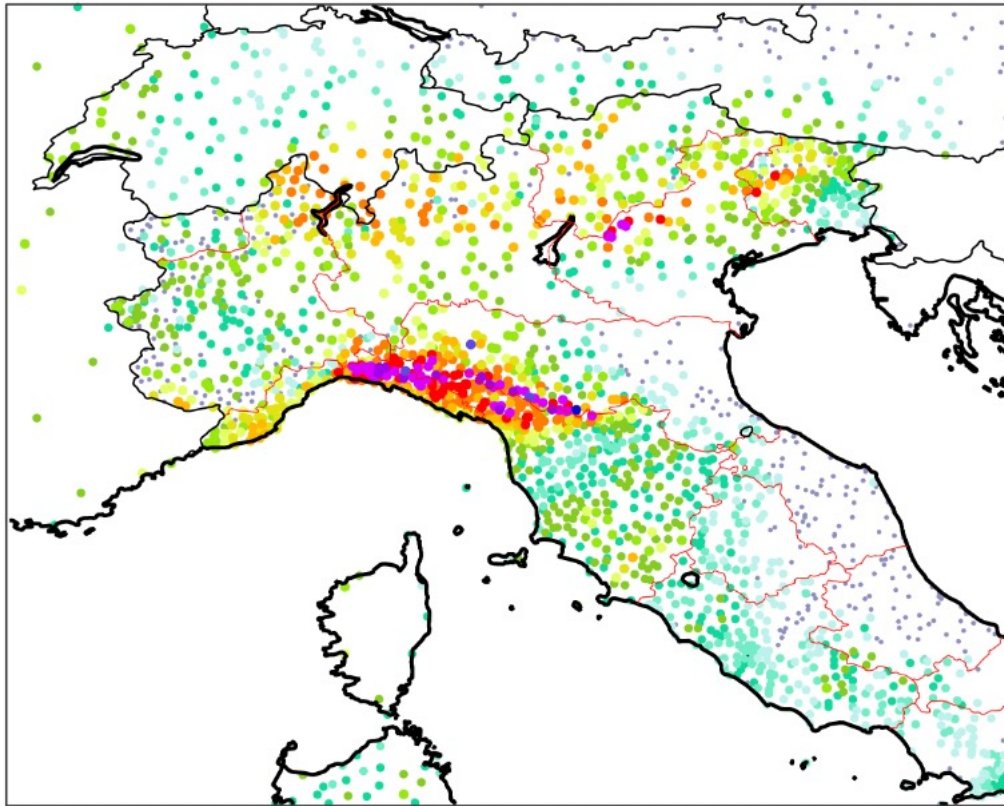


SPPT

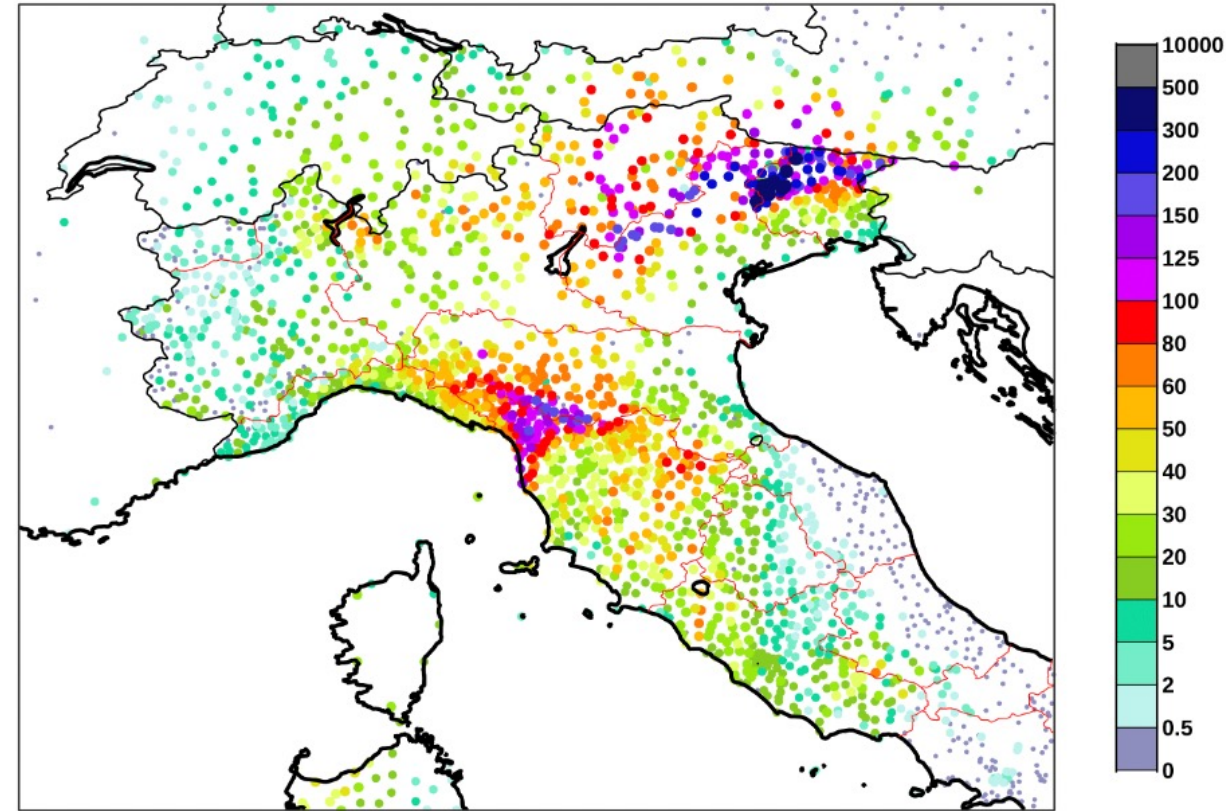
Extreme precipitation at Northern Italy (05-06 Dec 2020)

Observations

24-hour accumulated precipitation
(mm) valid at 0000 UTC 05-12-2020

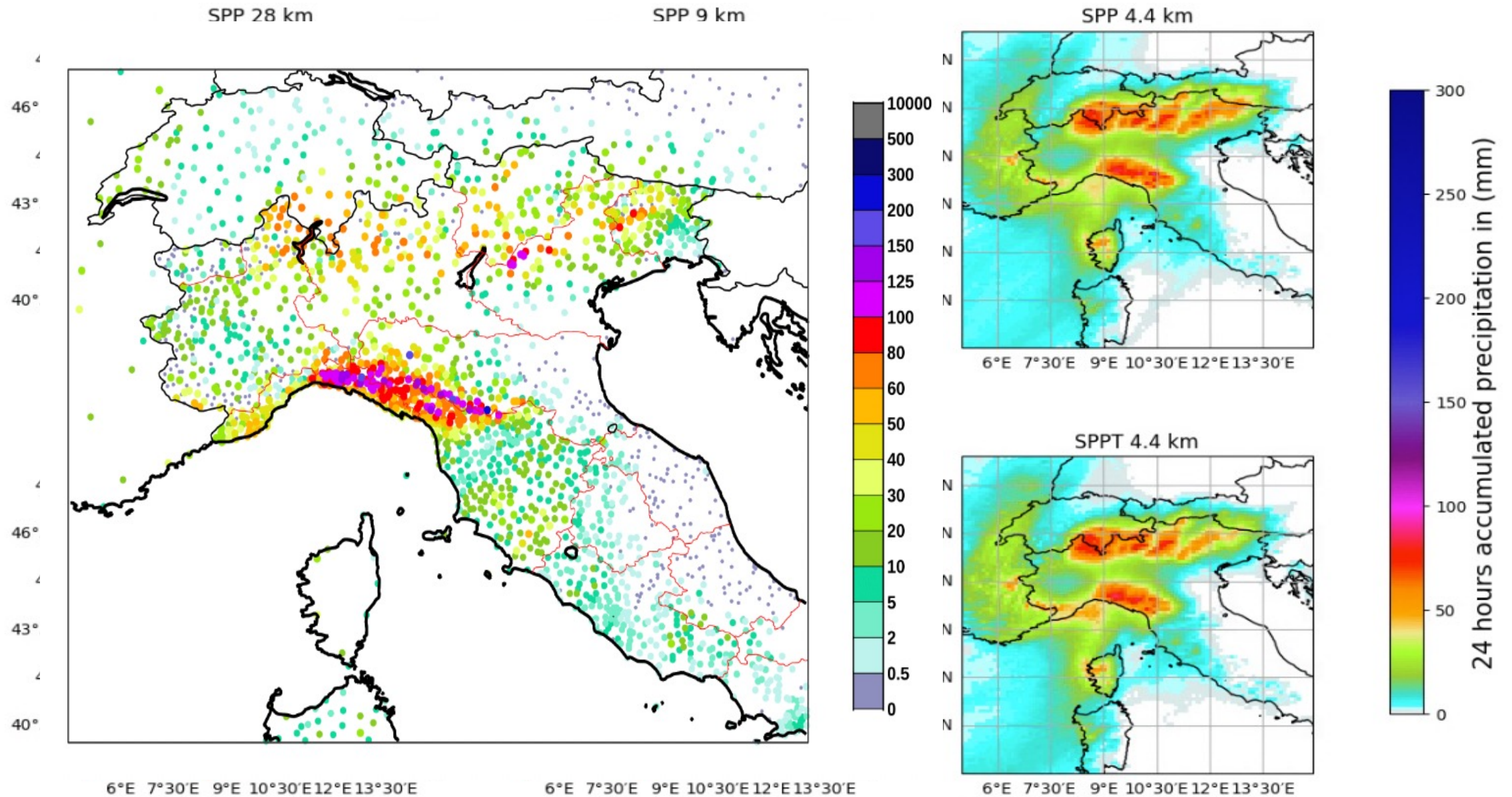


24-hour accumulated precipitation
(mm) valid at 0000 UTC 06-12-2020



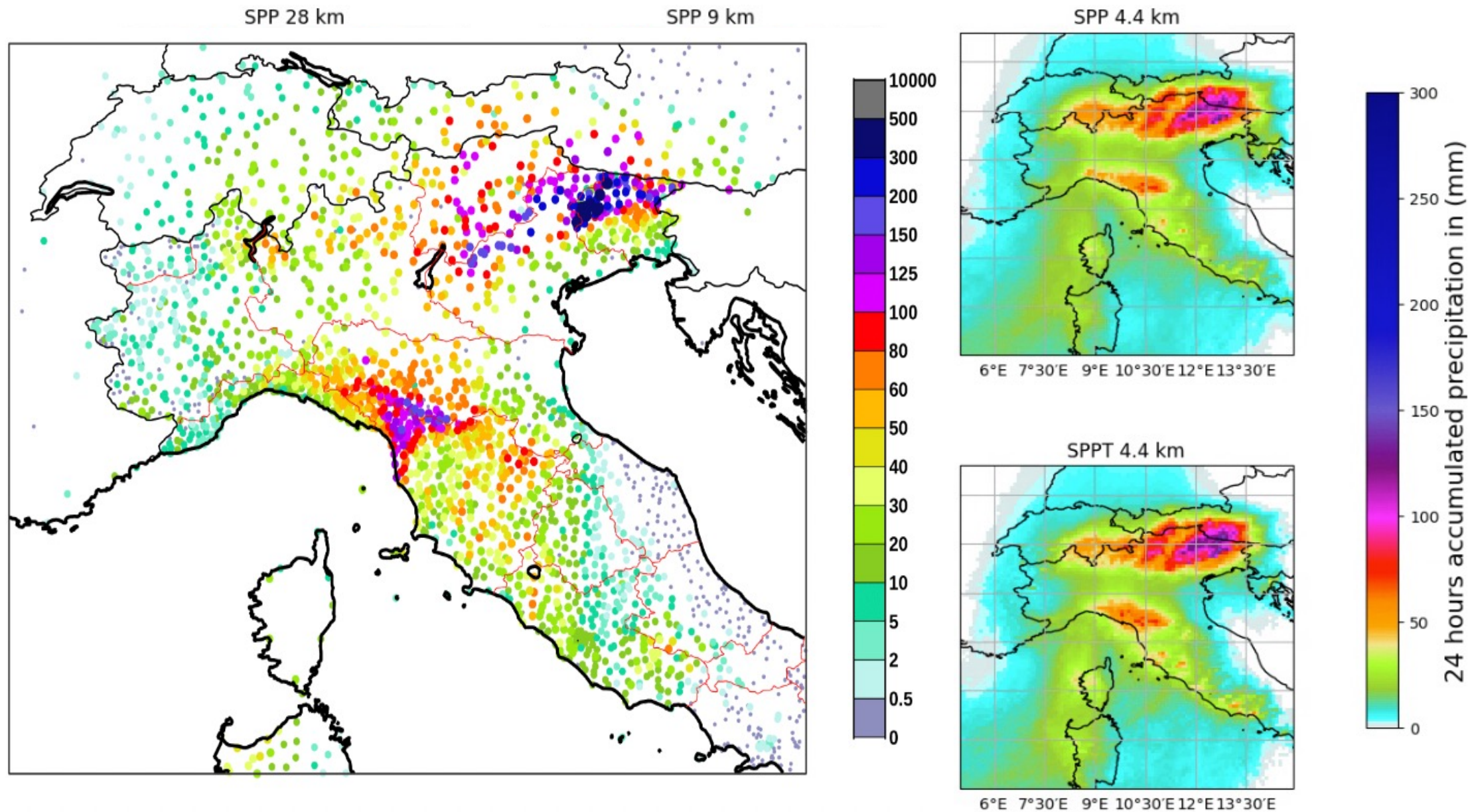
24-hour precipitation valid at 0000 UTC 05 December 2020

Ensemble mean



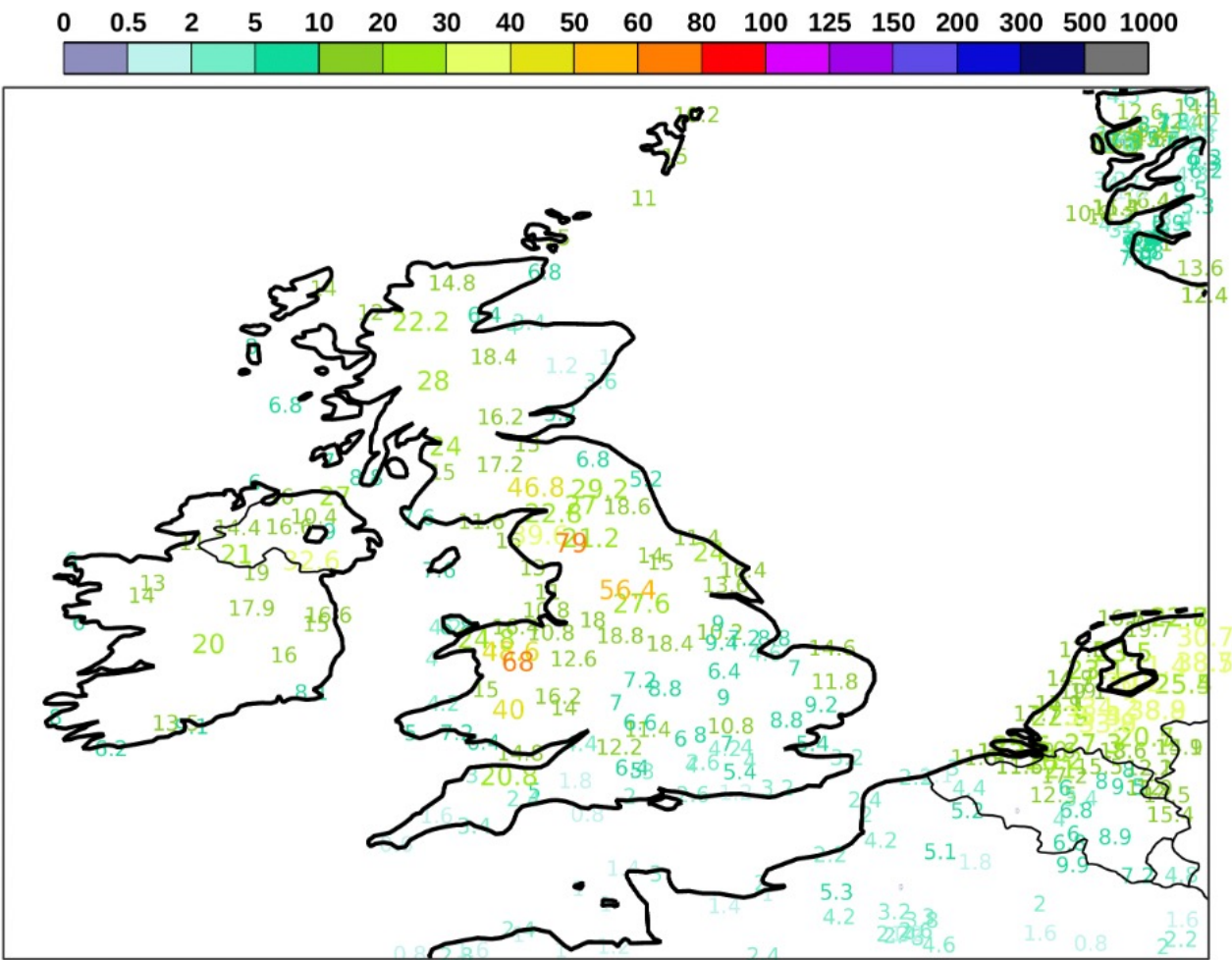
24-hour precipitation valid at 0000 UTC 06 December 2020

Ensemble mean



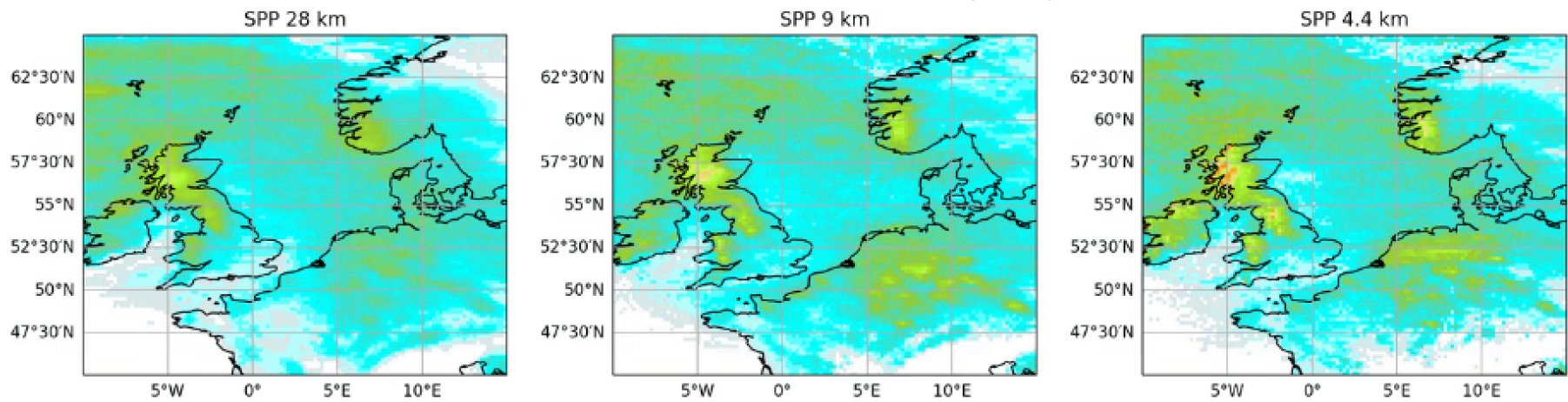
Results for Eunice Franklin

24-hour accumulated precipitation (mm) valid at 0000 UTC 21-02-2022

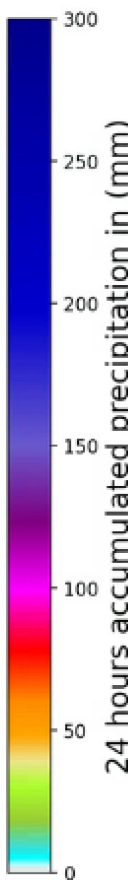
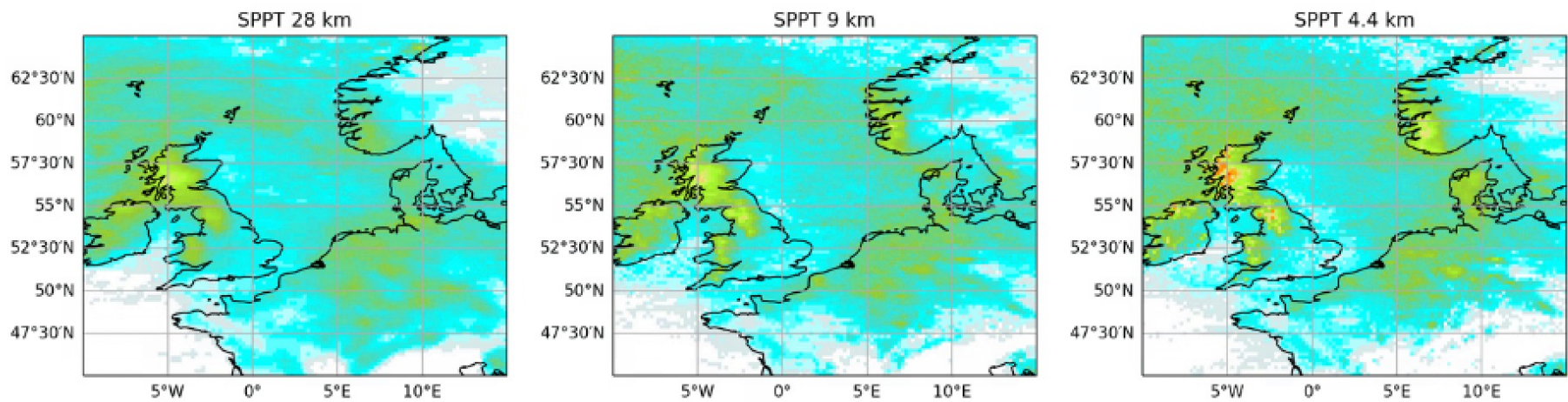


90th percentile of 24-hour accumulated precipitation (mm) valid at 0000 UTC 21-02-2022

SPP

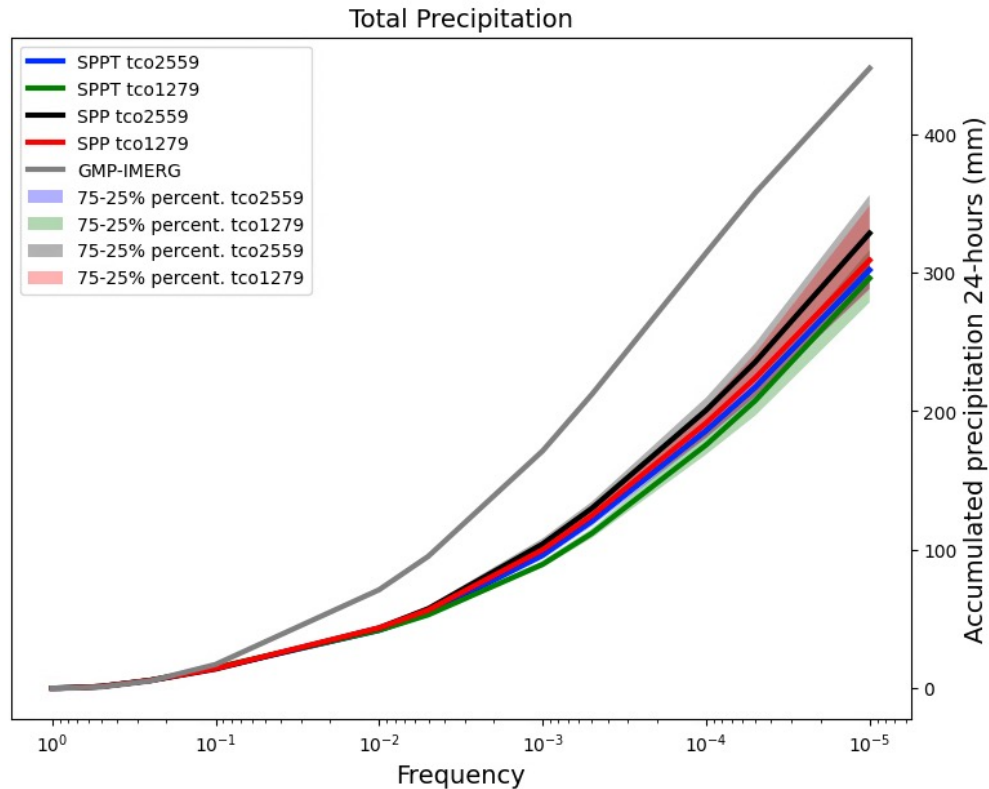


SPPT

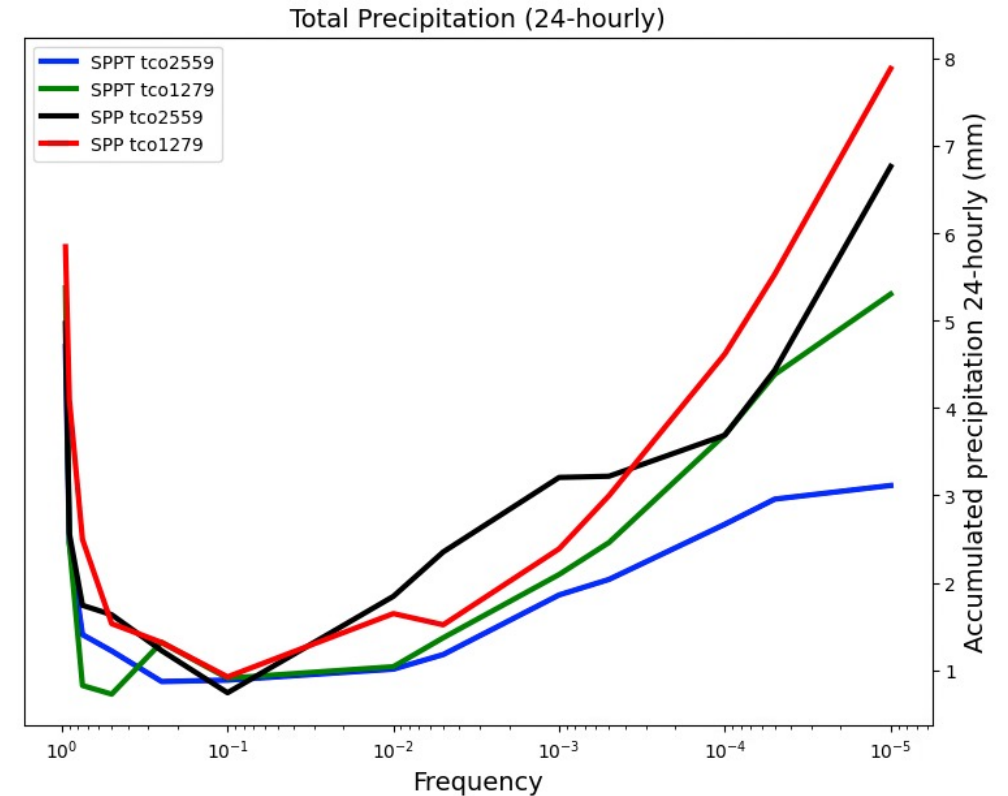


Results for Precipitation over the Tropics

Based on 24-hour accumulated precipitation from 9 initialization days (i.e., 9 * 8 members = 72 runs in total) conservatively interpolated to 0.1 x 0.1 degrees



Normalized standard deviation = standard deviation precipitation frequency (ensemble members) / mean precipitation frequency



More precipitation for percentiles > 99% when resolution increases and when using SPP over SPPT

SPP produces more spread than SPPT for total precipitation

TCo2559 = 4.4 km

TCo1279 = 9 km

Results for TCo2559 vs TCo1279 ensembles (SV + EDA only)

Forecast period 01-01-2022 until 26-02-2022, with 15 forecasts each initialized every 4 days

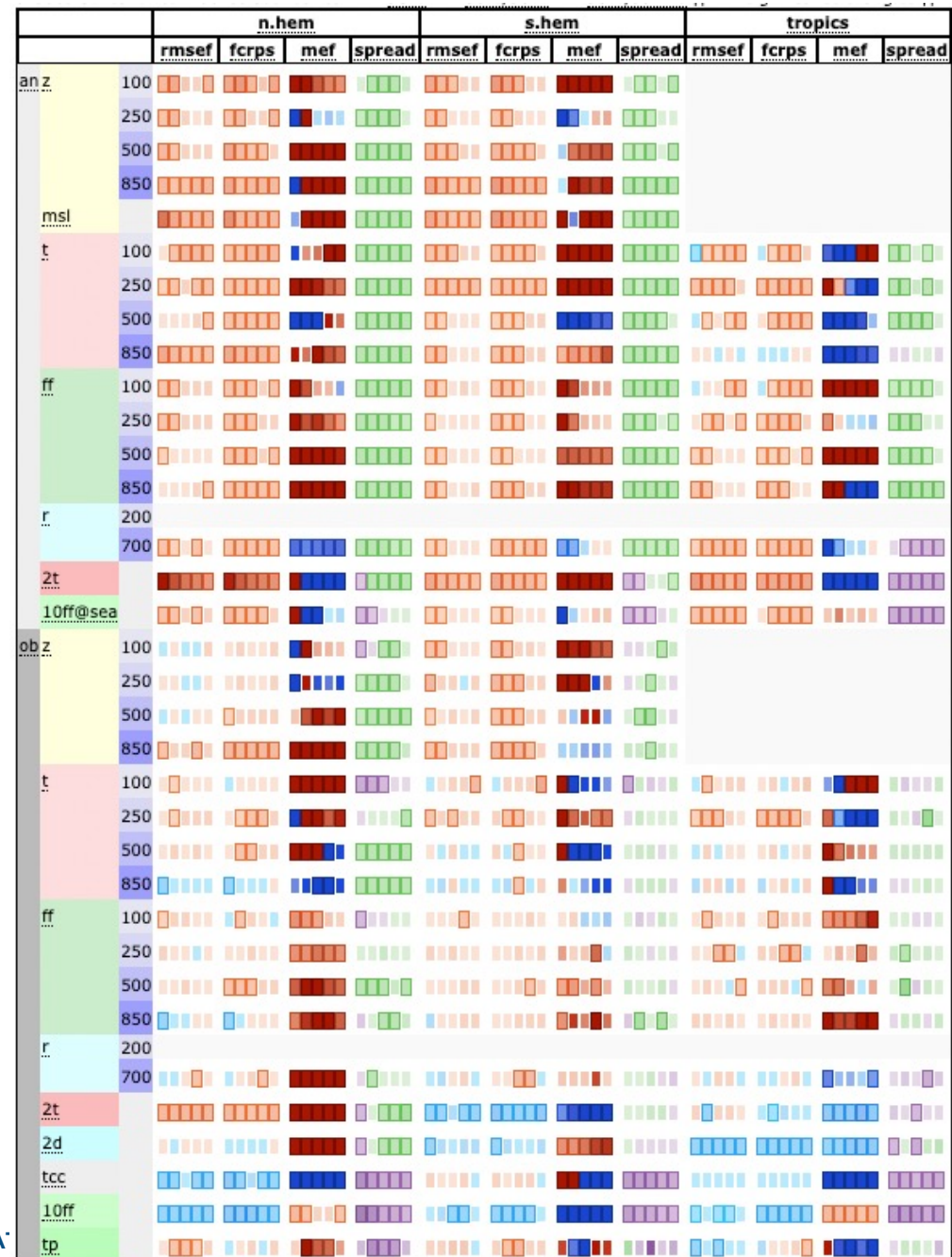
TCo1279 better than TCo2559 against the 9 km analysis, less negative results when evaluated against observations

Large mean bias differences between TCo2559 and TCo1279

Small decrease (1-2 %) in ensemble spread at pressure levels, but increase near the surface

TCo2559 = 4.4 km

TCo1279 = 9 km



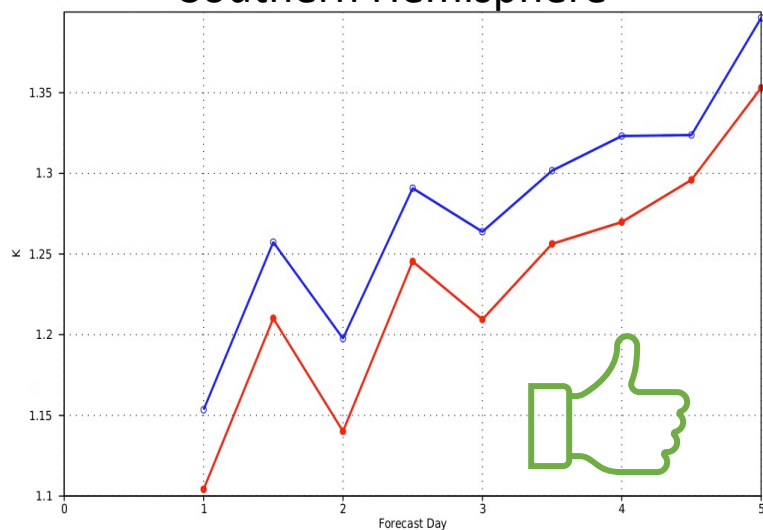
Metric : fCRPS

Comparison of 4.4 km vs 9 km ensembles with SPP

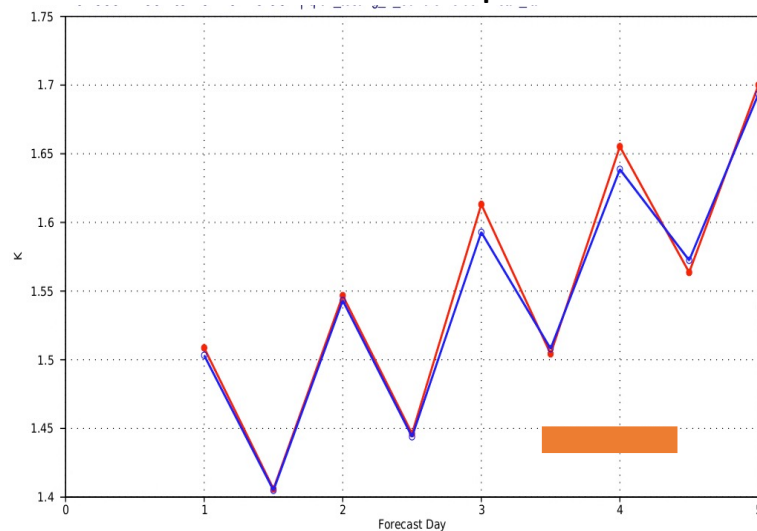
— TCo2559
— TCo1279

2-m temperature (K)

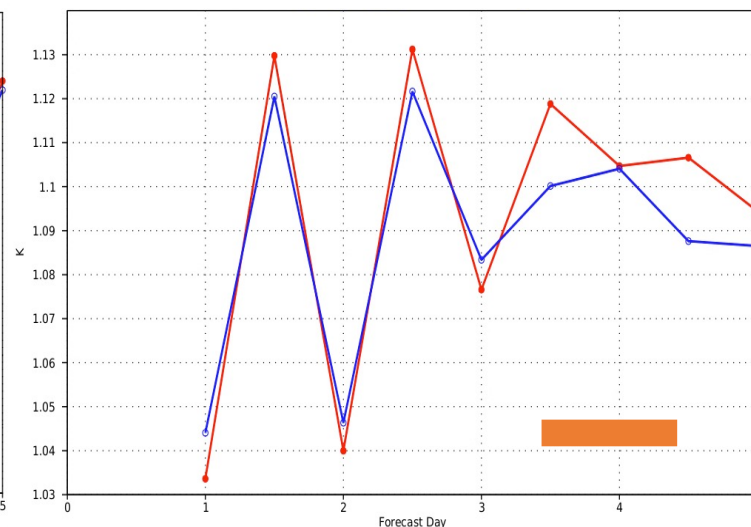
Southern Hemisphere



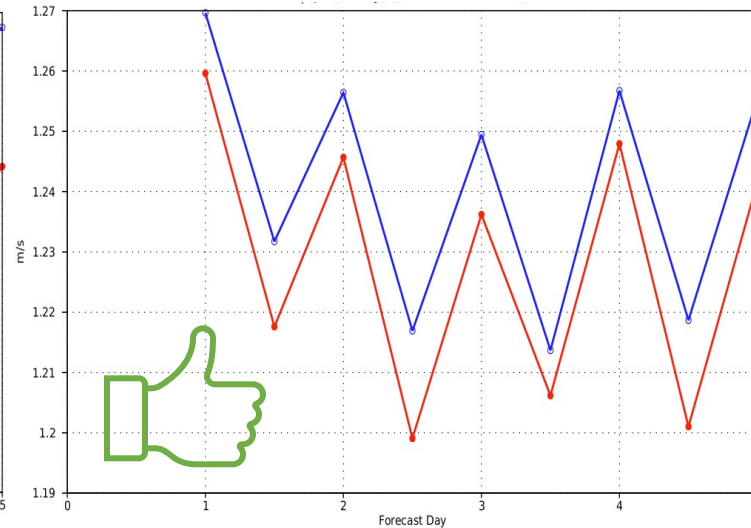
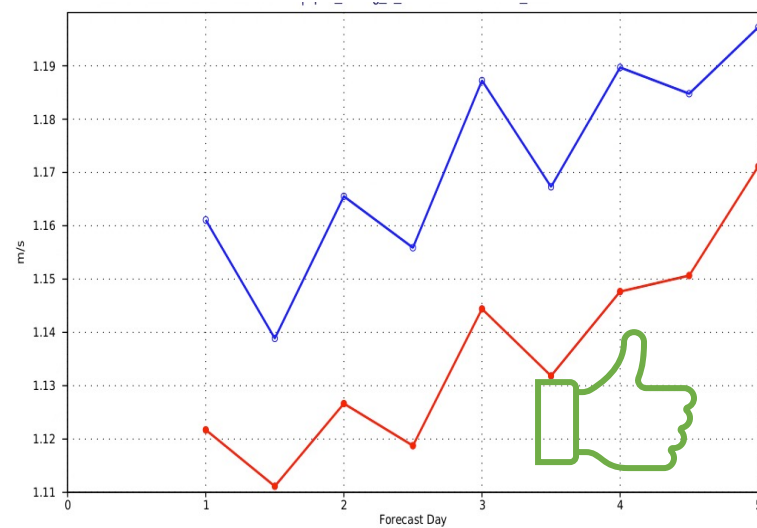
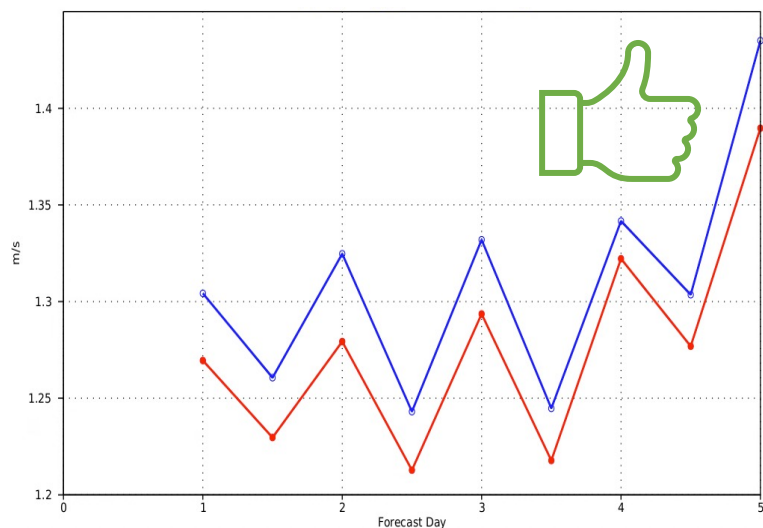
Northern Hemisphere



Tropics



10-m wind speed (ms-1)



Costs in mil. SBUs

- TCo399 ensemble (50+1 members) with 5 day forecast lead time costs **0.18** mil. SBUs per initialization day
- TCo1279 ensemble (8+1 members) with 5 day forecast lead time costs **0.48** mil. SBUs per initialization day
- TCo2559 ensemble (8+1 members) with 5 day forecast lead time costs **3.8** mil. SBUs per initialization day

~ 8 times more expensive!

If we want to fit a TCo2559 ensemble that runs at a similar costs with our new TCo1279 operational ensemble we would need to run:

- 10 + 1 members at TCo2559 for 8 days forecast lead time
- 15 + 1 members at TCo2559 for 5 days forecast lead time

Main Summary Points

- Ensembles at TCo2559 seem to provide better scores for extremes events (especially TCs core pressure, 10m wind speed and intense precipitation) compared to TCo1279 and have more ensemble spread – albeit we have a small number of extreme events to be confident on these conclusions – **to be expanded**
- Global scores seem to be degraded (more vs analysis, less vs observations) with TCo2559, but scores for near-surface variables vs observation are better and the ensemble has higher spread (i.e., is less under-dispersive)
- The SPP scheme shows generally larger spread for TC core pressure, 10m wind speed and precipitation than SPPT, which can be an advantage in quantifying uncertainty for extreme events.
- We plan to move forward mainly with the SPP scheme, but it may need some adjustments for TCo2559

Thank you very much!!