Impact of horizontal resolution and model uncertainty scheme in ensemble prediction of extreme weather events

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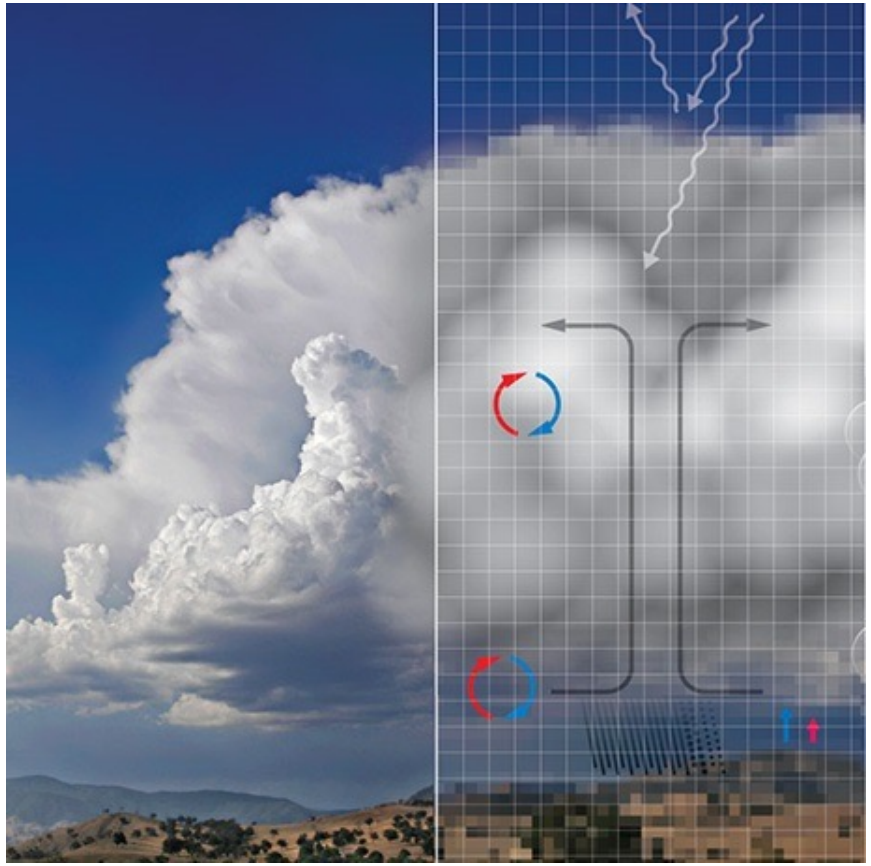
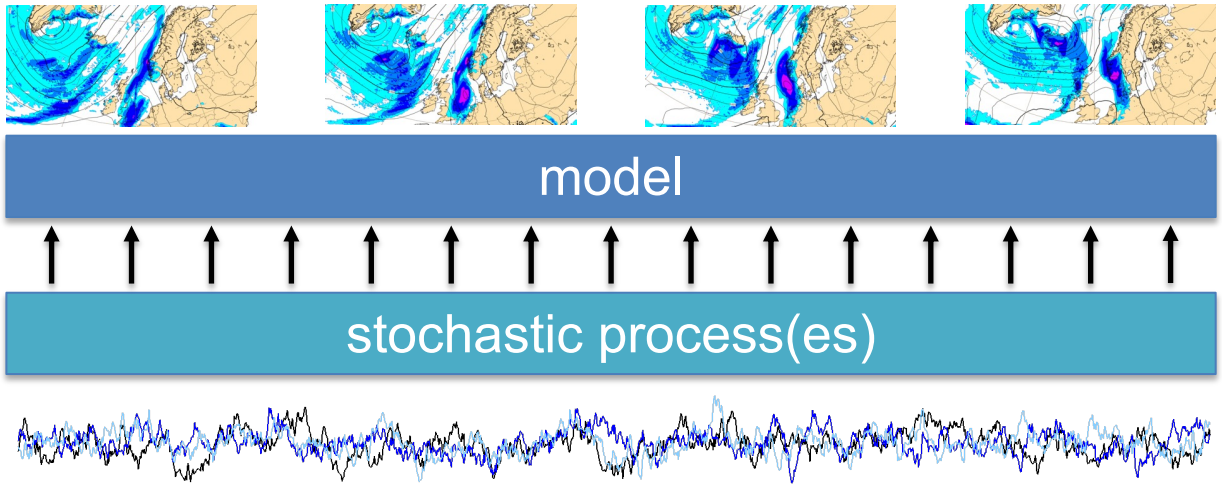
All models are imperfect

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

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



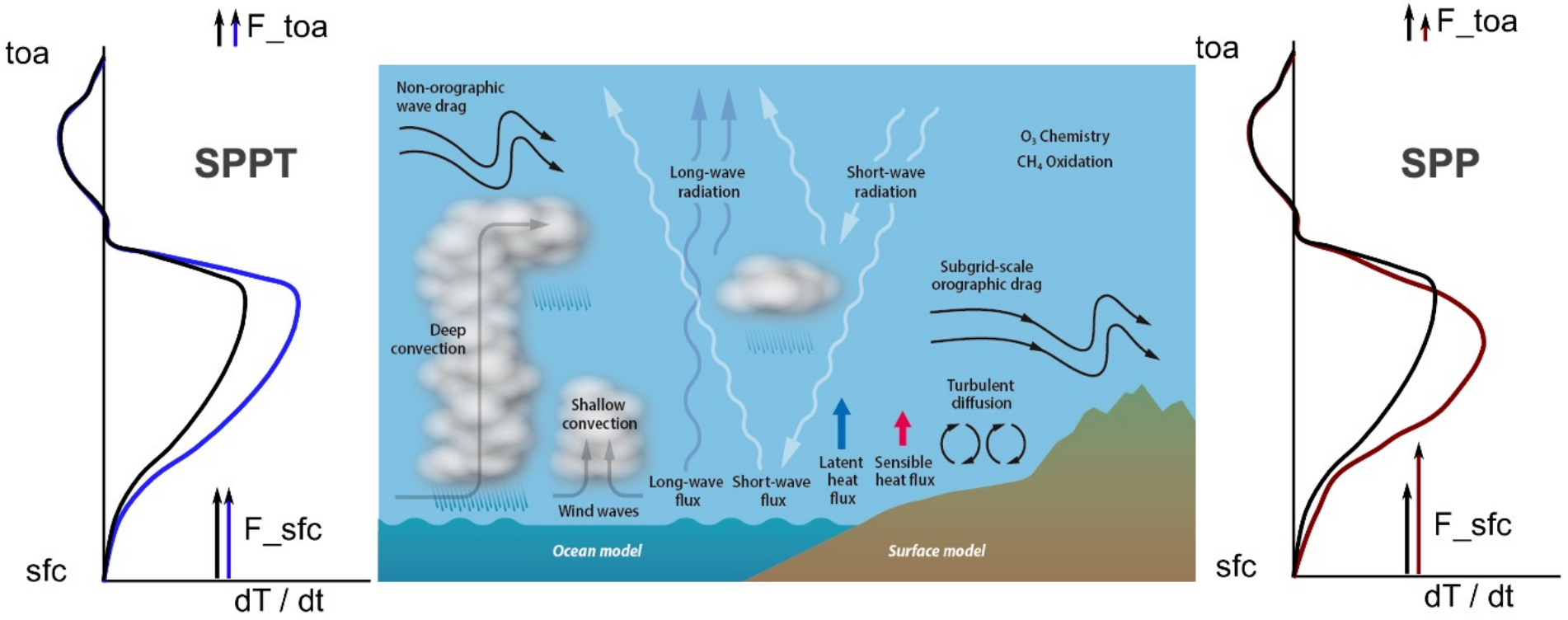
- representing random errors of model improves reliability of ensemble
- Stochastic representation of model uncertainties



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: TCo1279 vs TCo2559

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

- 10 extreme cases (30 forecast days) for both 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), 20-22 January 2023 (Cold spell over Sweden), 28-30 July 2020 (squall line Africa), 03-09 September 2023 (MC Daniel)

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

Experiment Summary Table

Resolution	9 km	9 km	4.4 km	4.4 km
Model version	48R1.0*	48R1.0*	48R1.0*	48R1.0*
Model Uncertainty scheme	SPPT	SPP	SPPT	SPP
Timestep	450s	450s	200s	200s
Member size	10+1	10+1	10+1	10+1

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

What we are going to look at

- Results from 3 case studies (TC Ida, Floods Emilia Romagna, MC Daniel/Floods Greece)
- Differences in precipitation over the tropics between SPP/SPPT and 9 vs 4.4 km
- Scorecard 10+1 ensemble members (SPP, 9 km vs 4.4 km)
- Surface scores for SPP vs SPPT ensemble at different resolutions 4.4 vs 9 km

Results for TC Ida

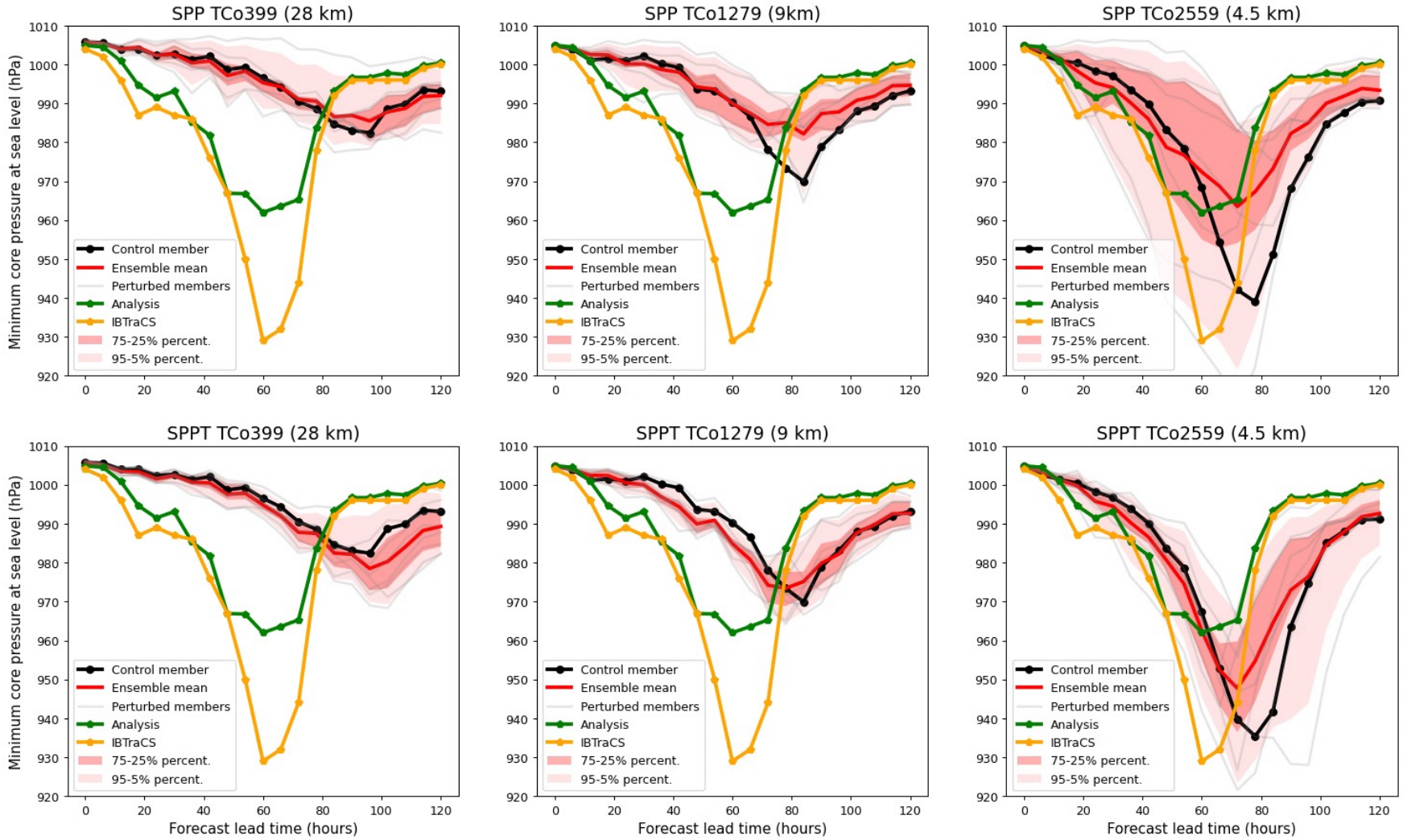
TCo399 and TCo1279 struggle to capture the intensity of Ida

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

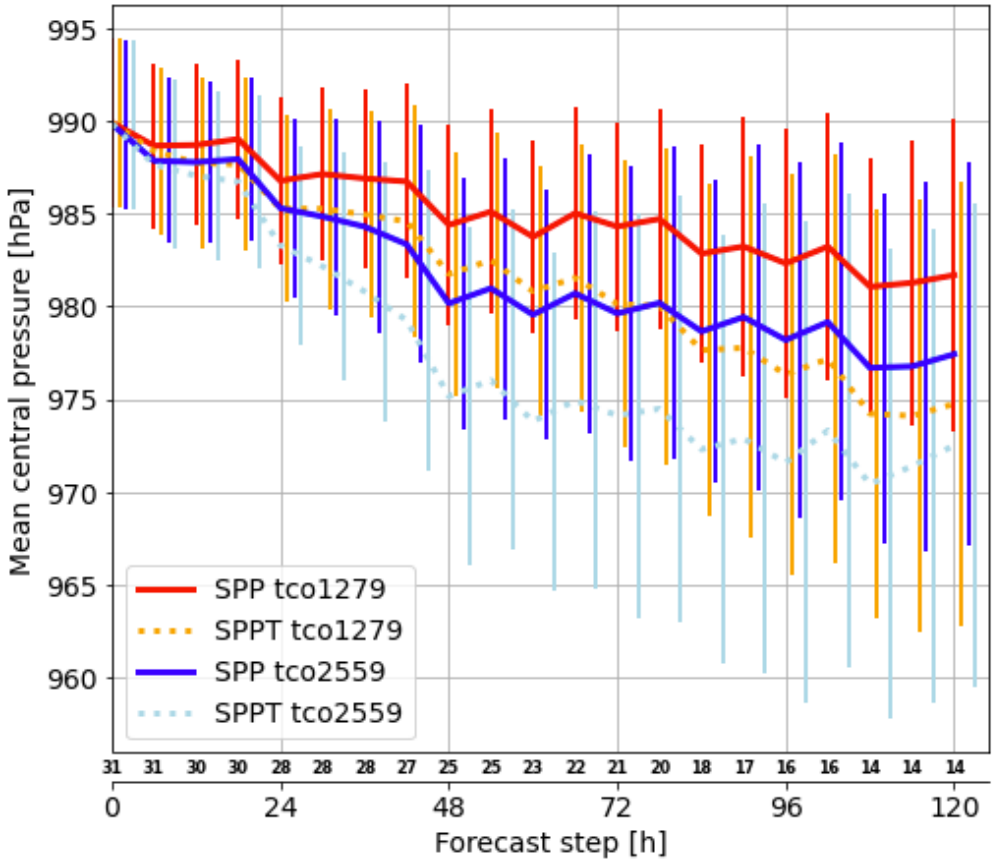
SPP generates more spread than SPPT and has members that exhibit more rapid intensification phase

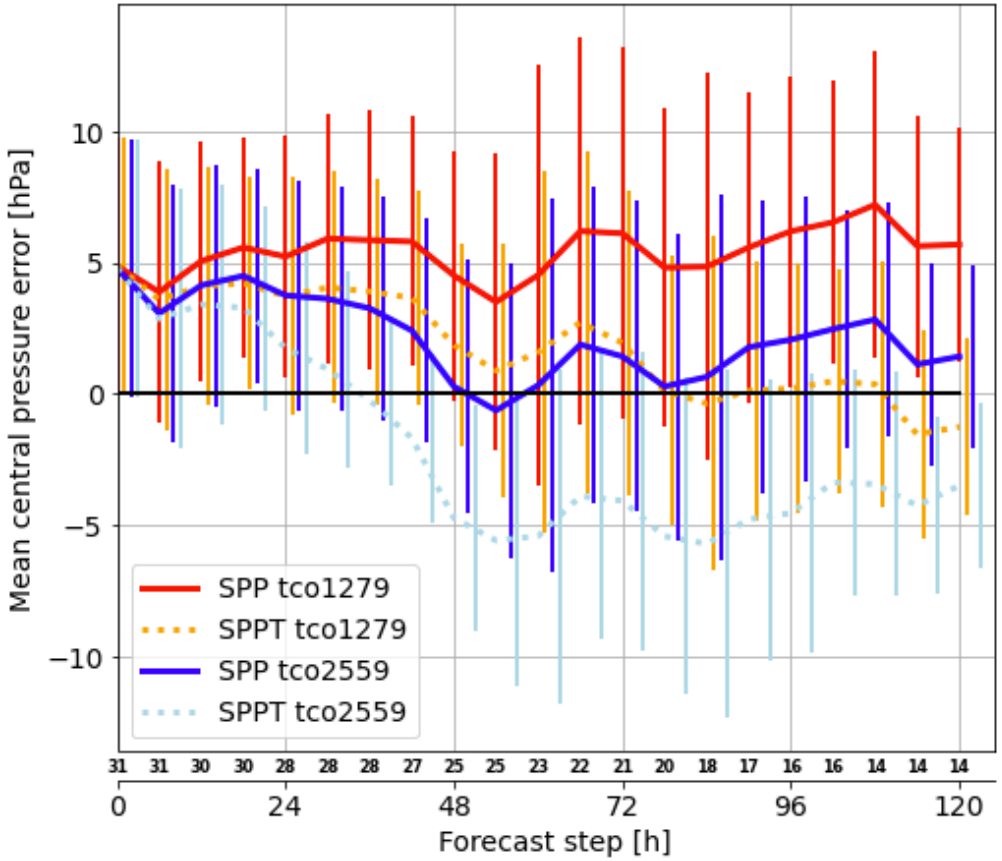
Initialization 27-08-2021 at 0000 UTC



TC intensity

Central Pressure





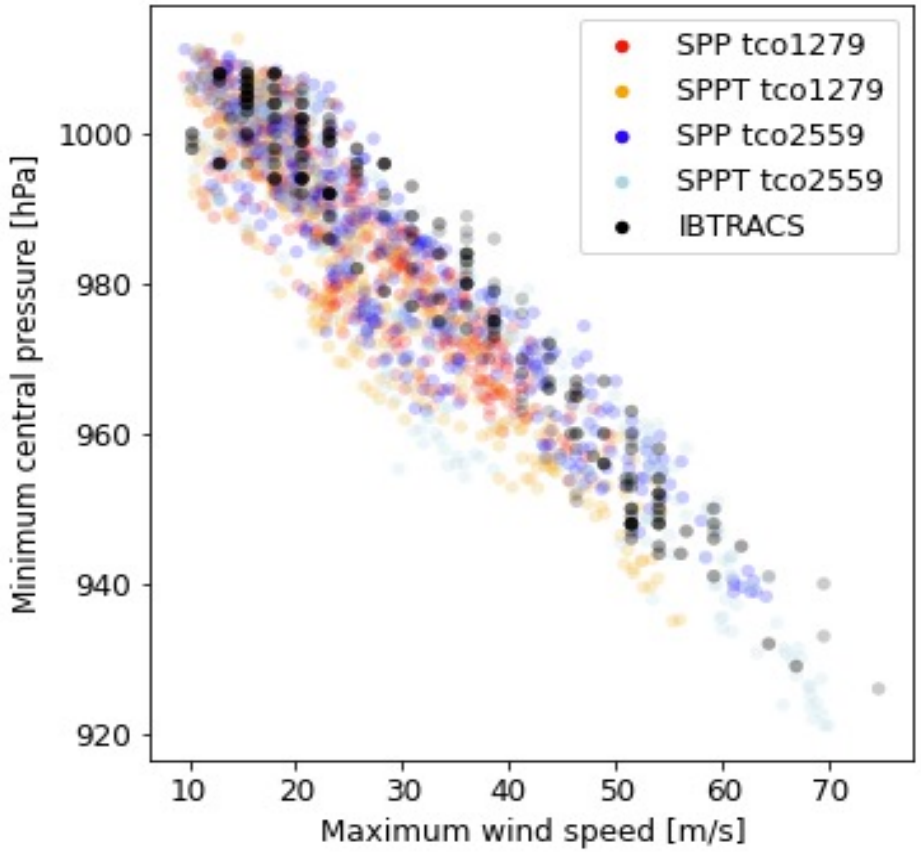
Lower core pressure at 4.4 km resolution → better chances to capture more intense TCs

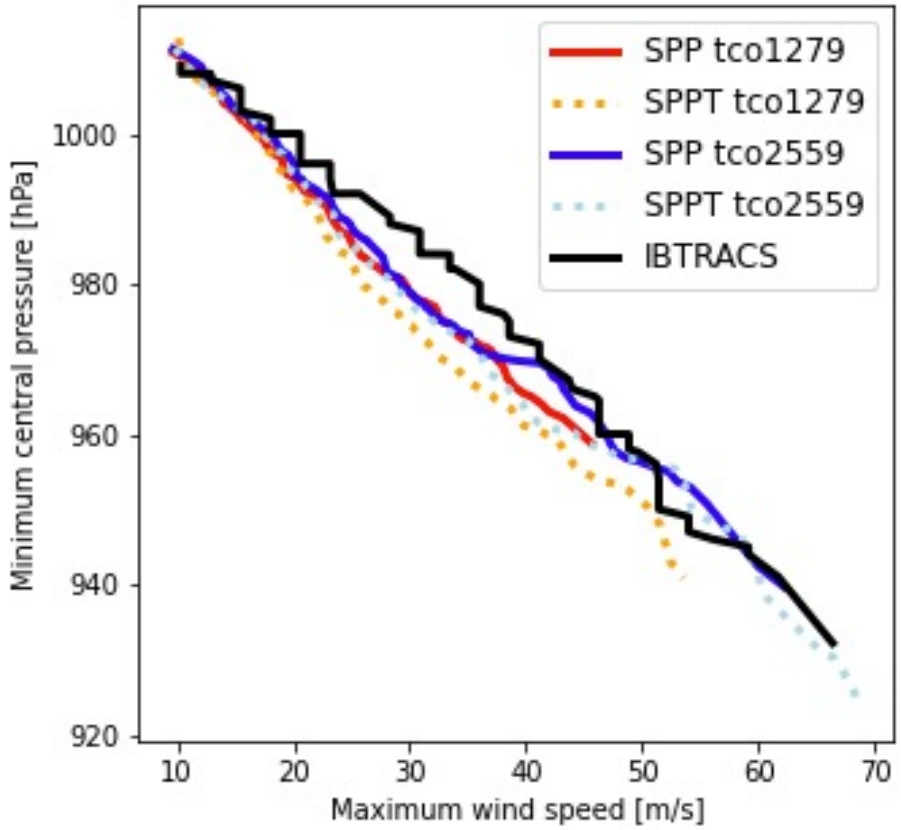
Though our TCs sample is still small to have reliable conclusions

TC intensity

Pressure-wind relationship

Steps 24h-120h are pooled.



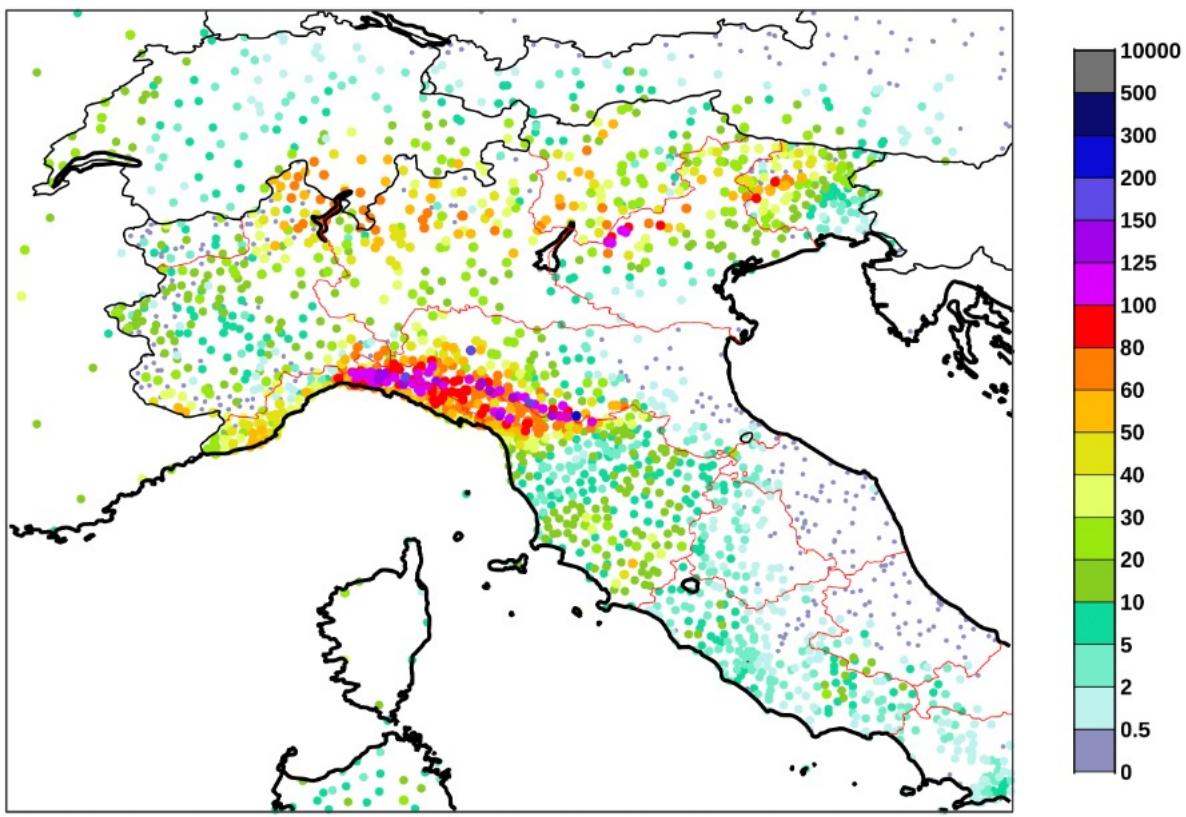


Better match between 4.4 km ensembles and IBTRACS, especially for central pressure below 960 hPa

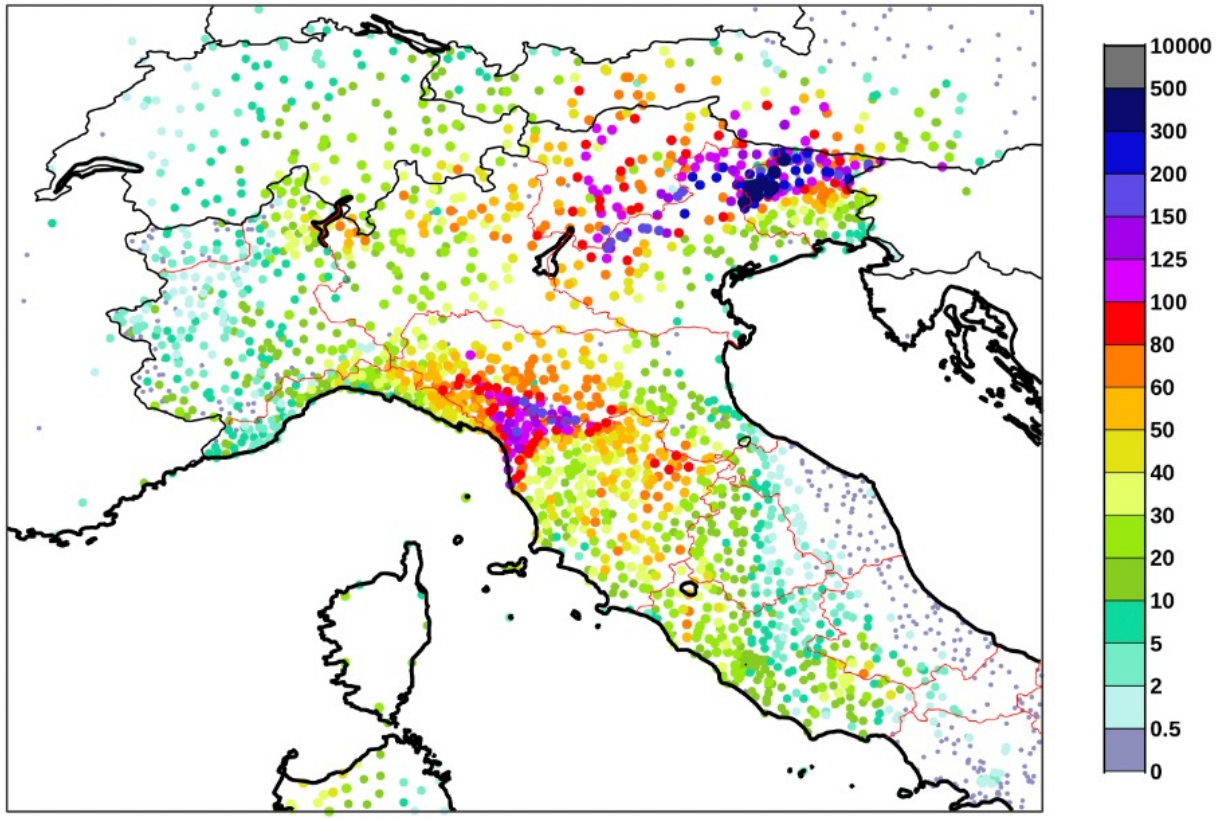
Extreme precipitation at Northern Italy (05-06 Dec 2020)

Observations

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

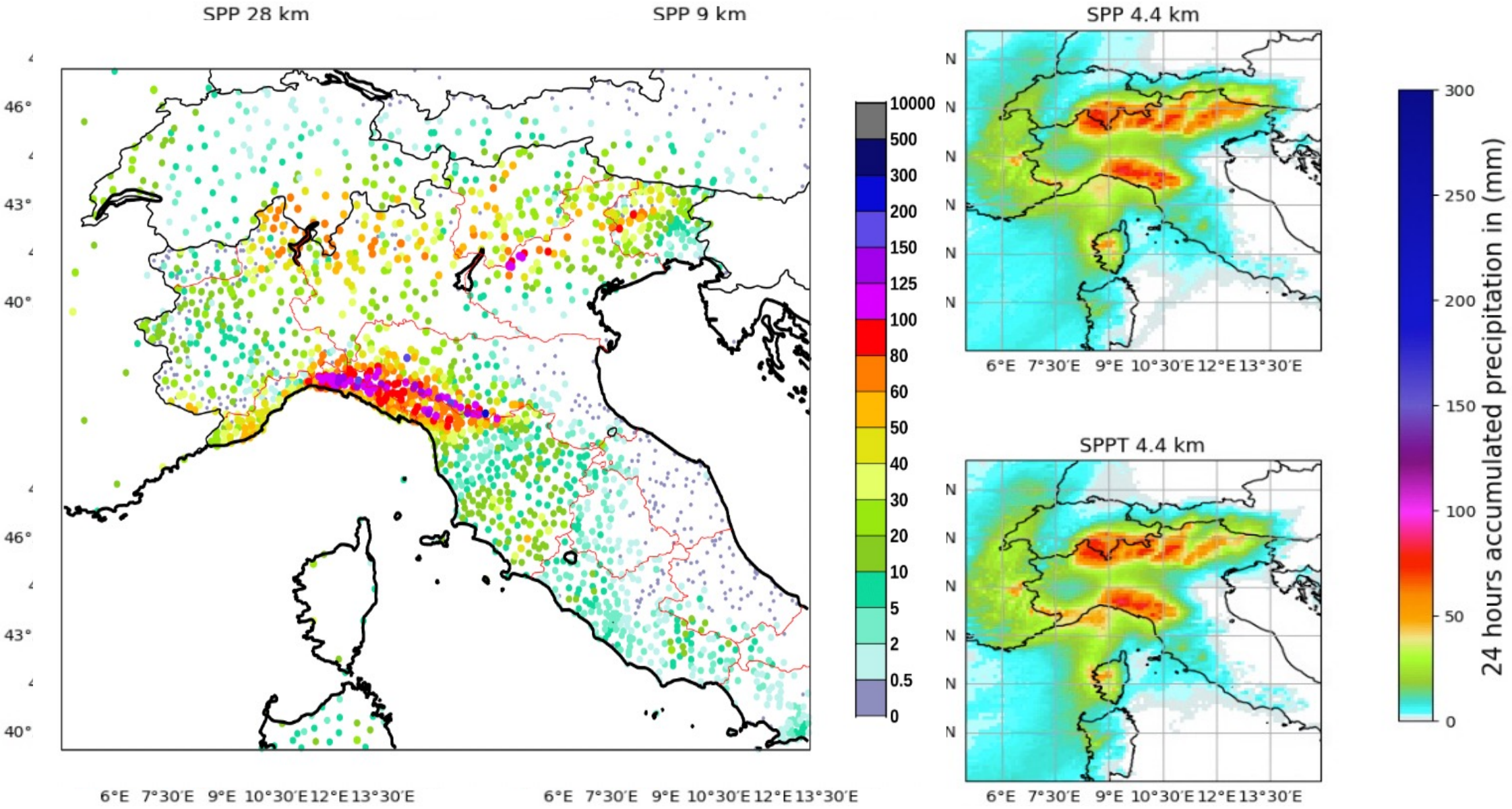


24-hour accumulated precipitation (mm) valid at 0000 UTC 06-12-2020



24-hour precipitation valid at 0000 UTC 05 December 2020

Ensemble mean



Medicane Daniel/Floods in Greece (4-7 September 2023)

The biggest rainfall ever recorded in Greece – 754 mm

Source: https://www.meteo.gr/article_view.cfm?entryID=2913

Accumulated daily rain on the 5th of September 2023 from 00:00 – 20:45 local time

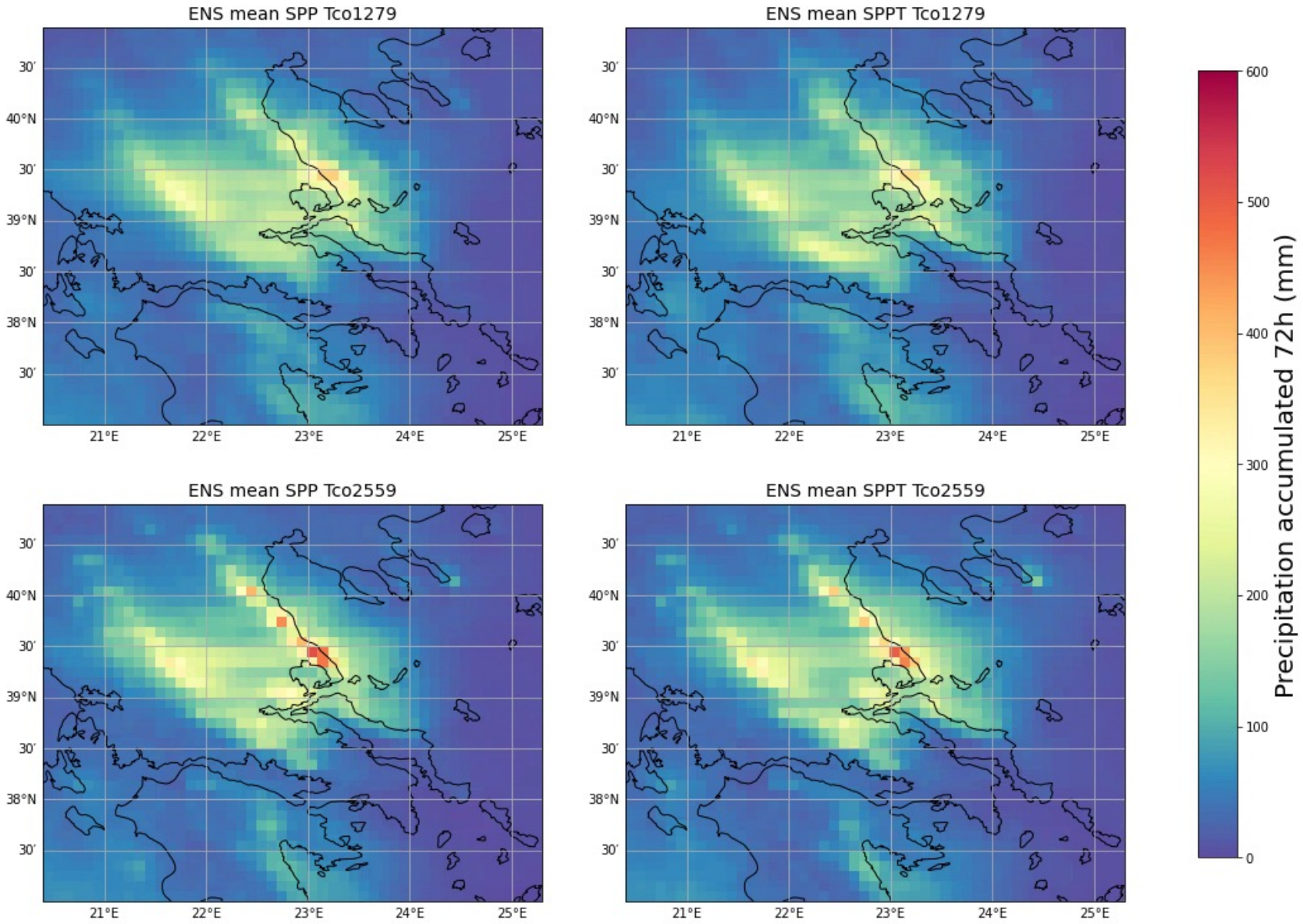
Medicane Daniel/Floods in Greece (4-7 September 2023)

Ensemble mean 72h accum. Precipitation (between 4-7 Sep. 2023)

SPP 4.4 km = 515 mm/72h

SPP 9 km = 381 mm/72h

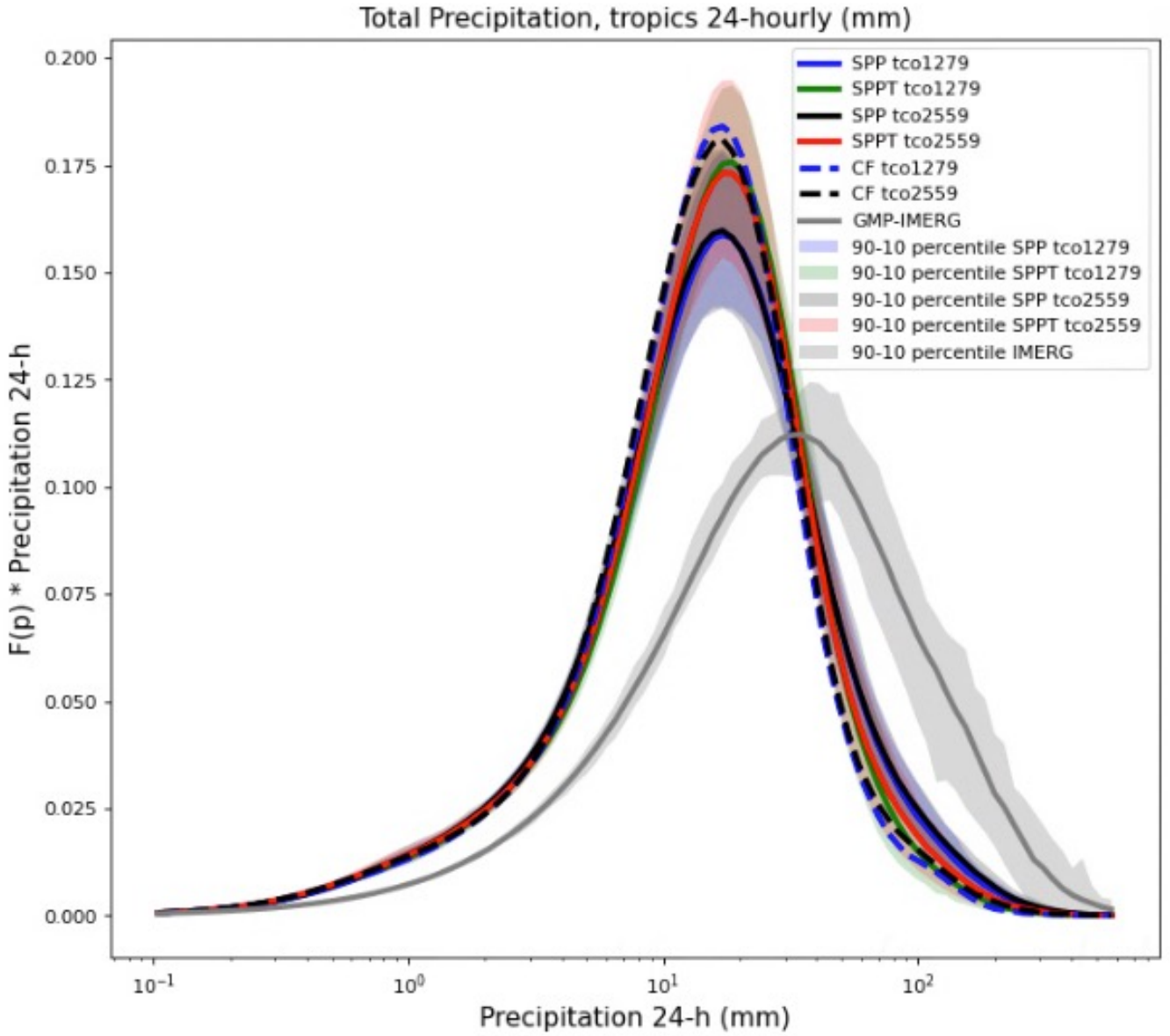
Better prediction of extreme precipitation with increasing resolution



Results for Precipitation over the Tropics

Based on 24-hour accumulated precipitation from 12 initialization days (i.e., 12 * 10 members = 120 runs in total) conservatively interpolated to 0.1 x 0.1 degrees

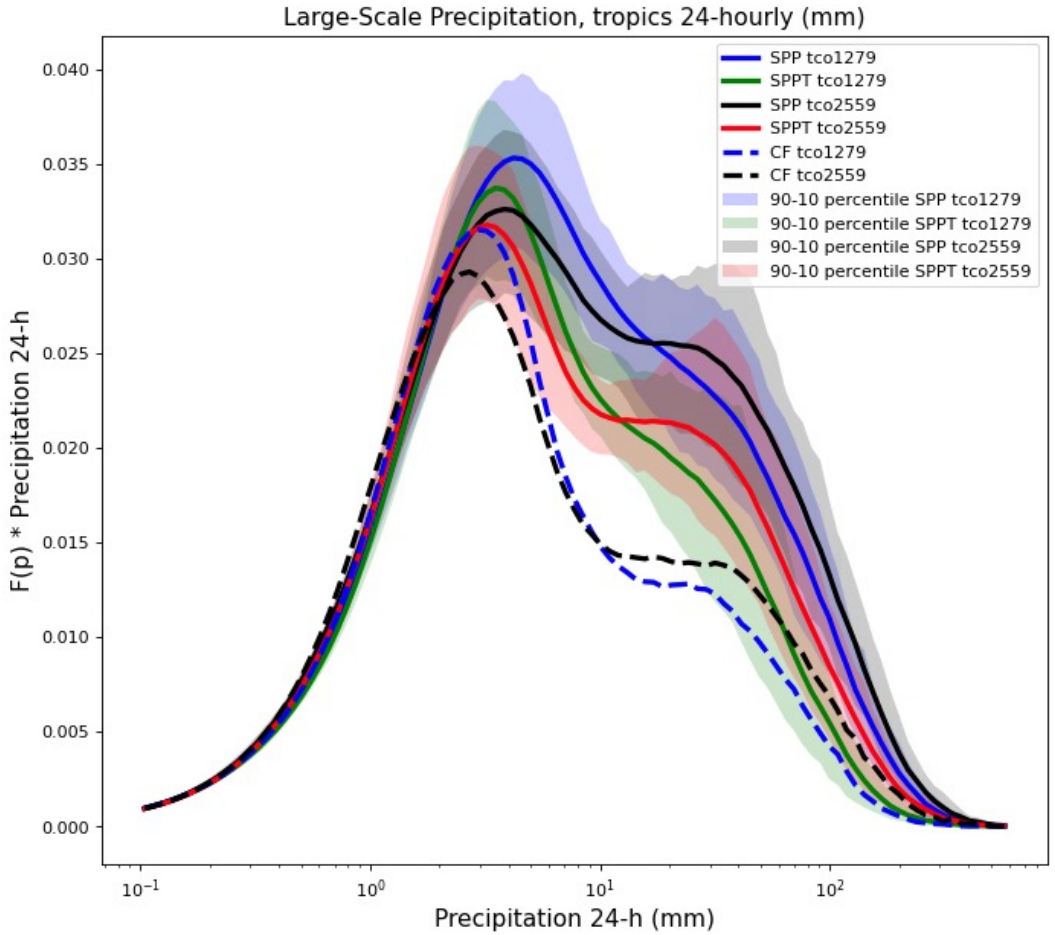
- Decrease of moderate intensity precipitation at both 4.4 and 9 km
- Increase of more intense precipitation rates
- SPP ensembles closer to the observed distribution from GMP-IMERG

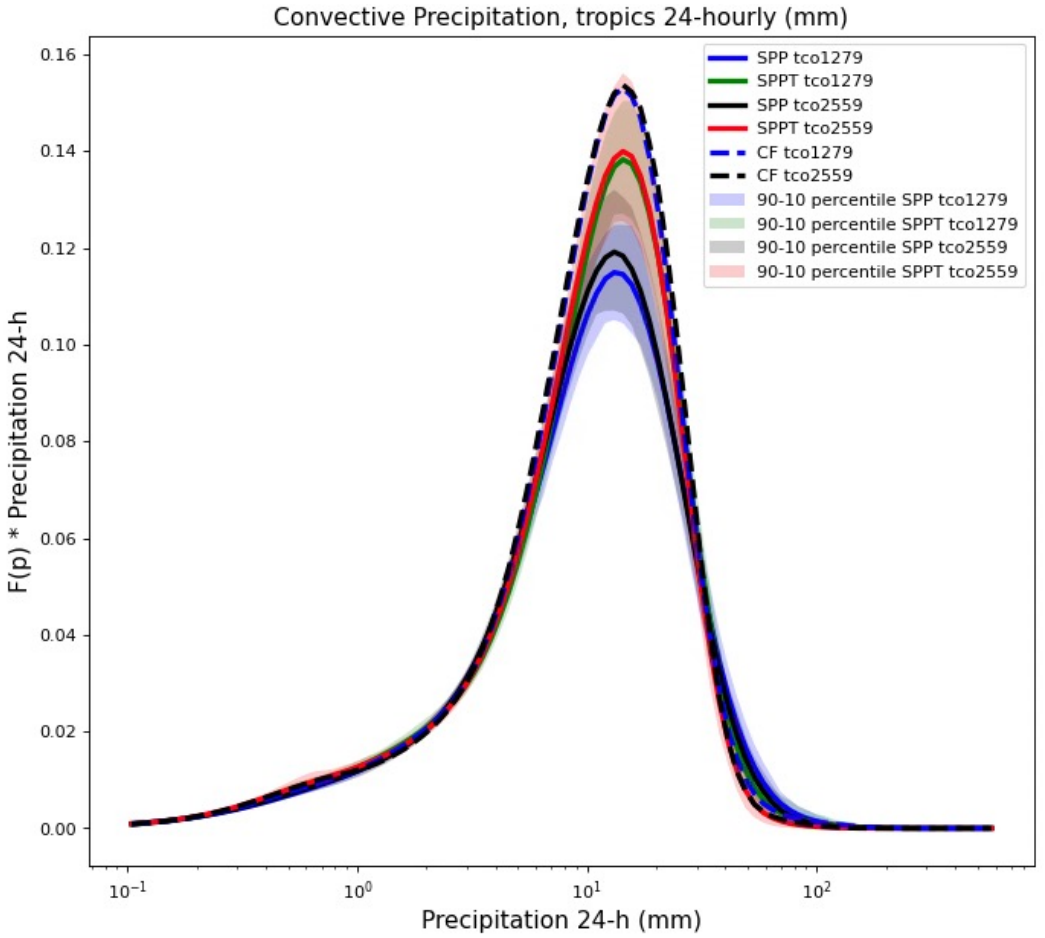


Results for Precipitation over the Tropics

Effects of SPP : more large-scale precipitation, less convective precipitation

Increasing resolution : increase in large-scale precipitation for daily rates > 20 mm /day





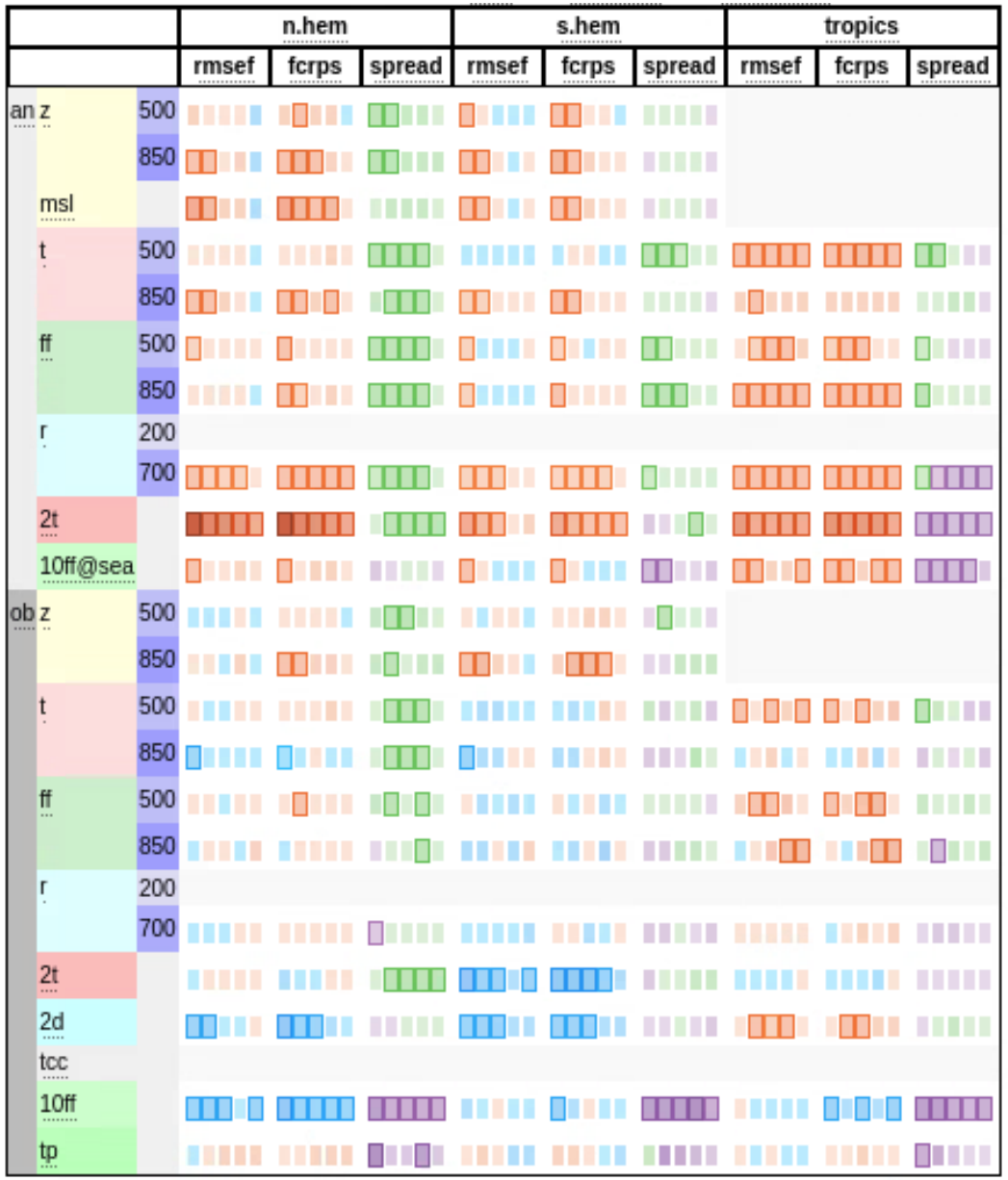
Results for TCo2559 vs TCo1279 ensembles (SPP)

Scorecard generated for 20 forecast initialization dates (concatenated from extreme case studies)

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

Substantial improvement in near-surface variables with increased resolution, when evaluated against observations

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



Comparison of 4.4 km vs 9 km ensemble with SPP

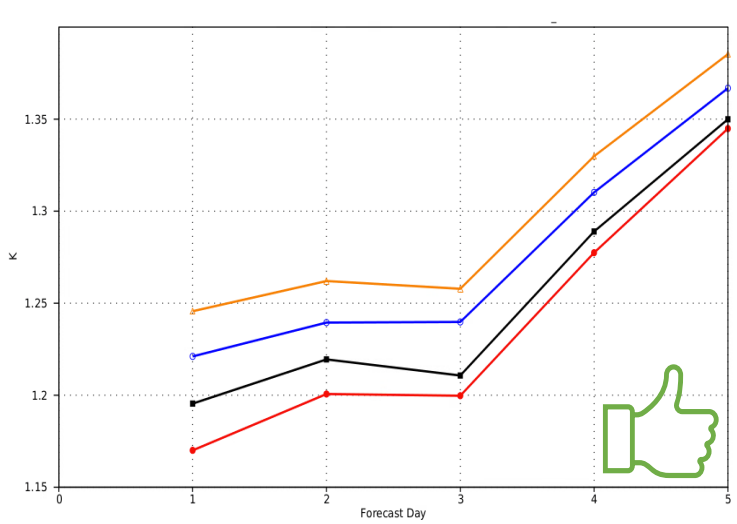
Metric : fCRPS

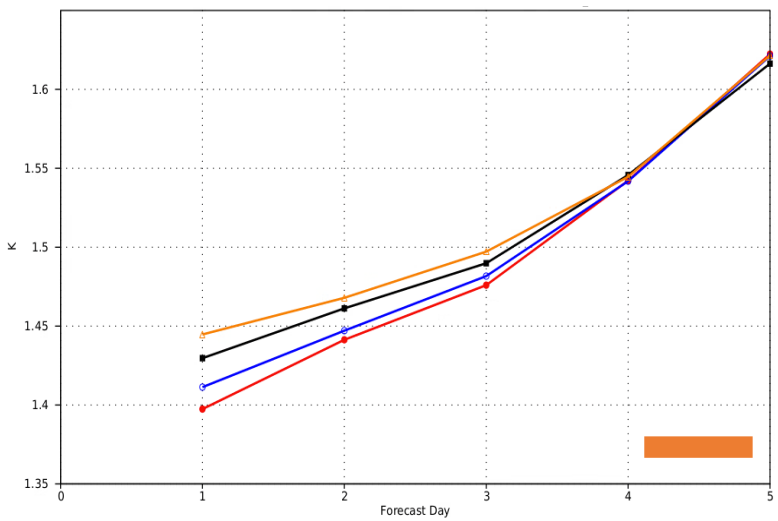
TCo2559 : SPPT SPP

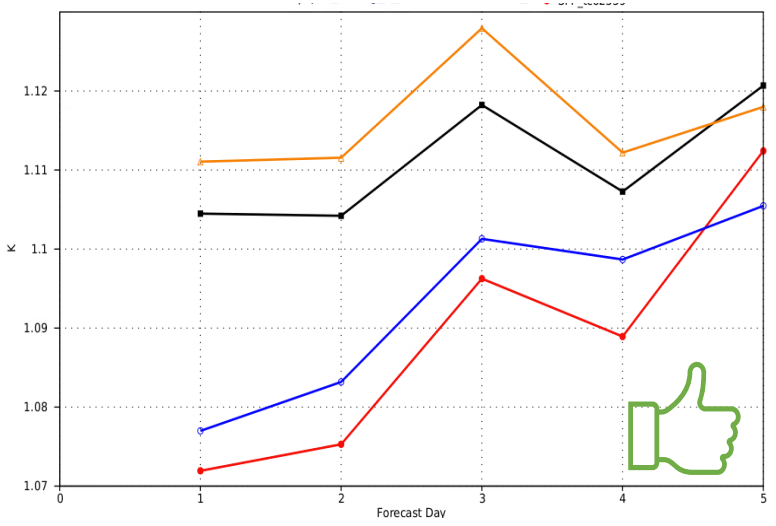
TCo1279 : SPPT SPP

Southern Hemisphere | Northern Hemisphere | Tropics

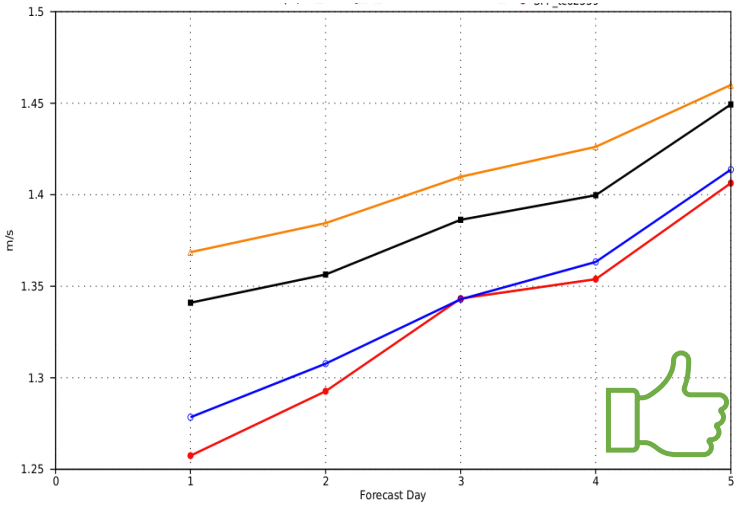
2-m temperature (K)

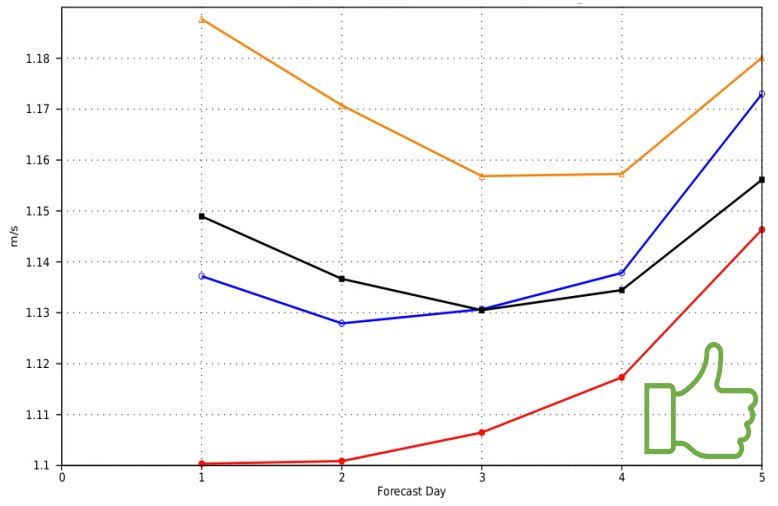


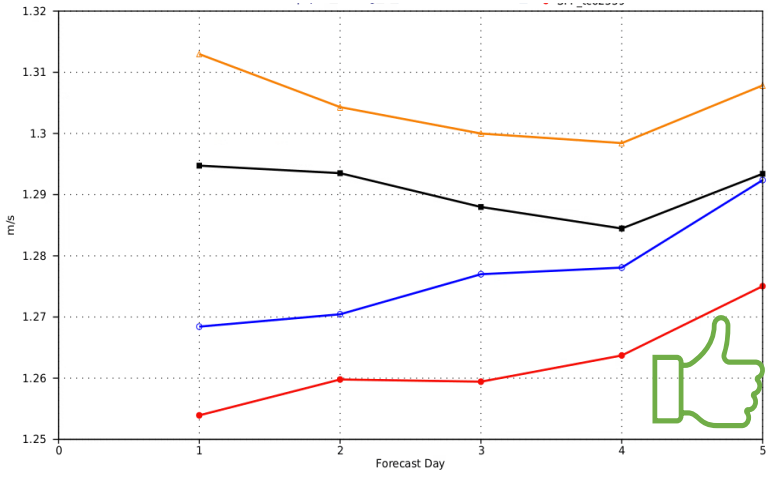




10-m wind speed (ms-1)







better similar

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 (10+1 members) with 5 day forecast lead time costs **0.58** mil. SBUs per initialization day

- TCo2559 ensemble (10+1 members) with 5 day forecast lead time costs **4.7** 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 (TCs central pressure, 10m wind speed and extreme precipitation) compared to TCo1279 and have more ensemble spread – albeit limited number of extreme events

- Upper atmosphere score seem to be degraded against analysis (neutral against observations) with TCo2559, but scores for near-surface variables (evaluated against observations) are better and the ensemble spread is higher (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 are moving forward mainly with the SPP scheme for high-resolutions experiments, but we still will look to make improvements in the scheme

Thank you very much!!

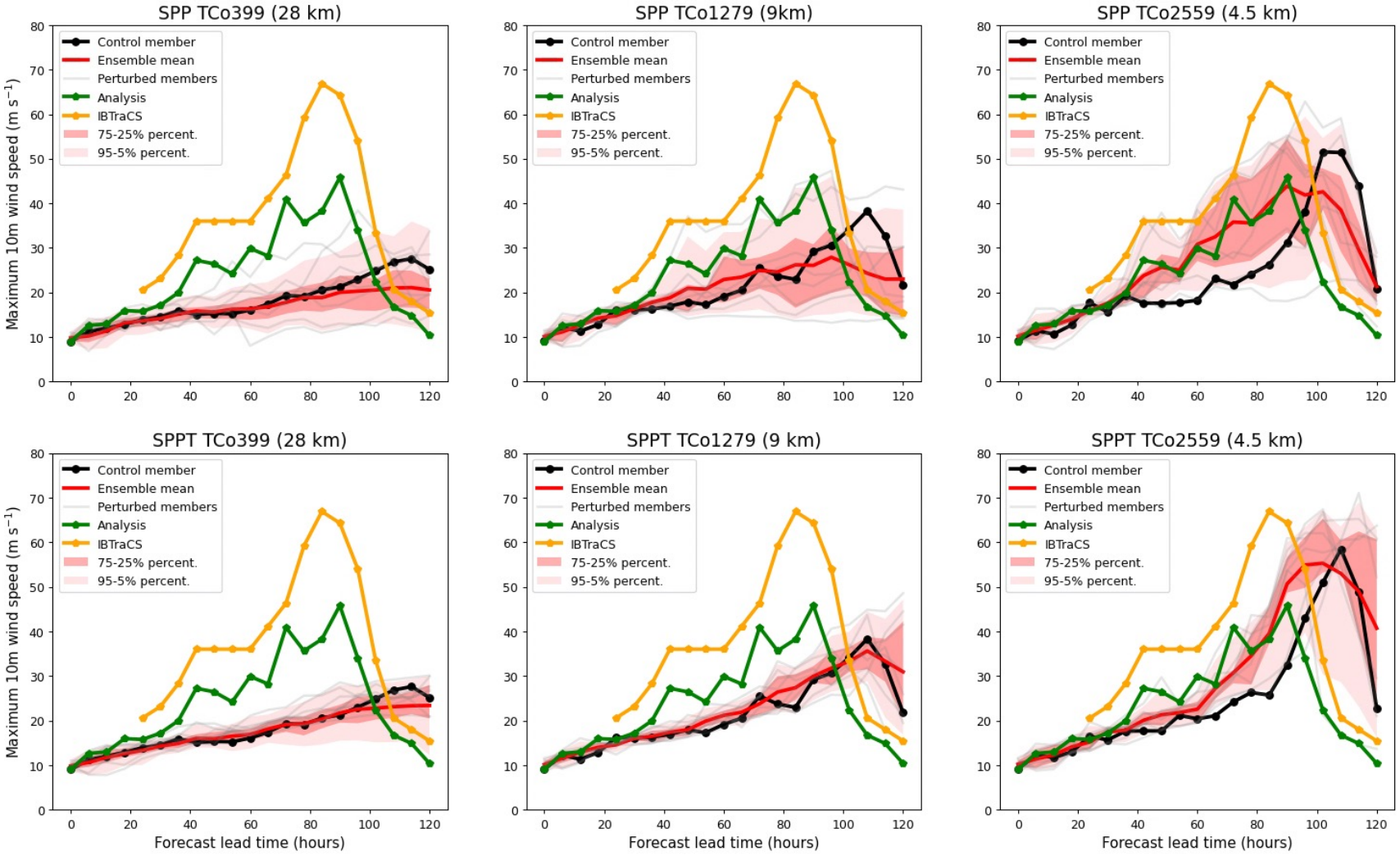
Results for TC Ida

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 weaking phase

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

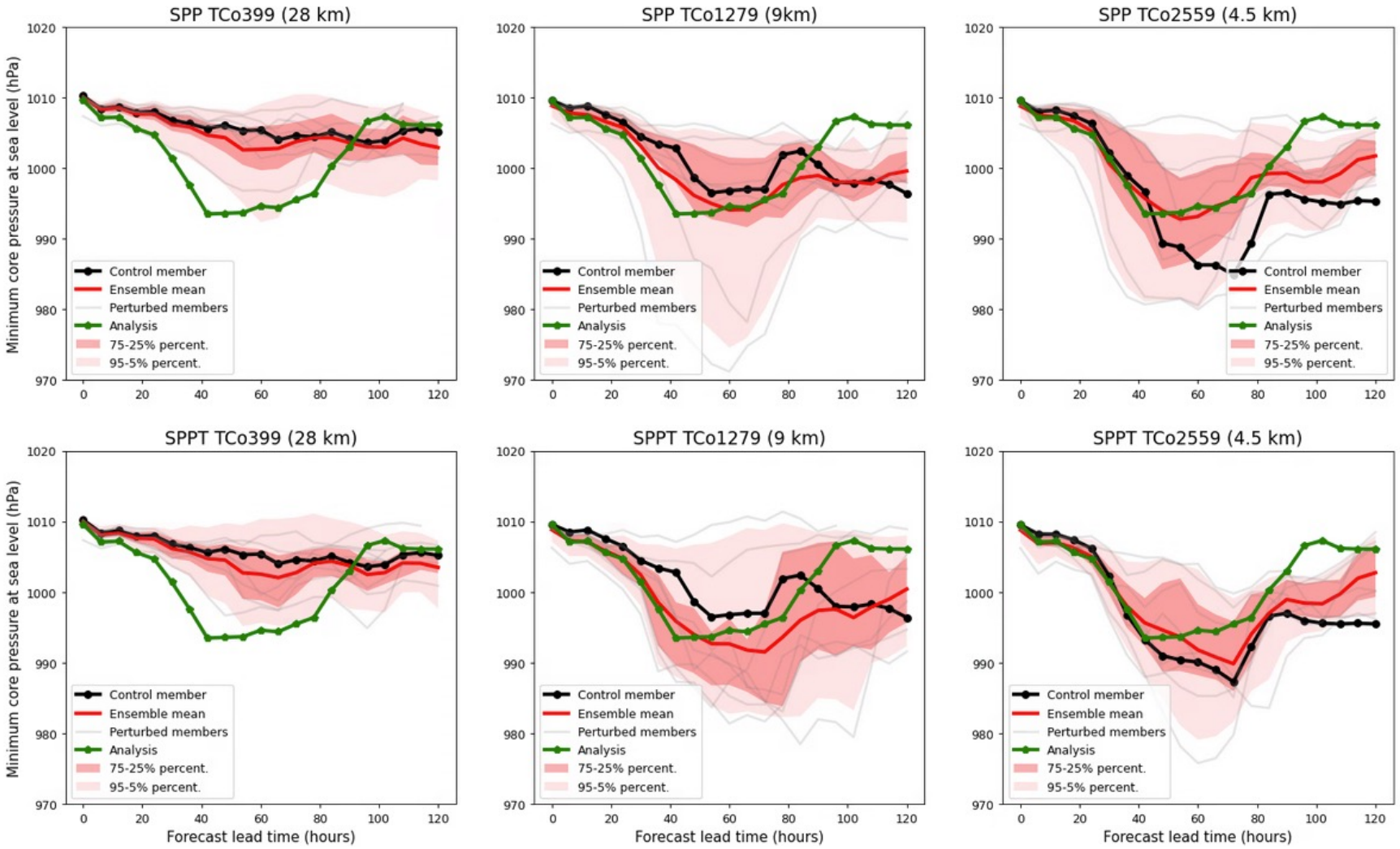


Results for MC Ianos

Initialization 15-09-2020 at 0000 UTC

TCo399 struggles to capture Ianos intensity

TCo1279 and TCo2559 do a much better job



24-hour precipitation valid at 0000 UTC 06 December 2020

Ensemble mean