Analysis of multiple ensemble prediction strategies for Mediterranean high-impact weather forecasting

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1st TRAMPAS meeting 2-3 December 2021

Introduction

- The **Mediterranean** region is frequently impacted by **high-impact phenomena** producing substantial **socioeconomic effects**
- Accurate numerical weather prediction (NWP) is essential to mitigate losses
- Weather **forecasts are uncertain** due to a errors in the estimation of the **initial atmospheric state** and **model formulation**
- **Ensemble prediction** systems are a feasible approach to account for the inherent uncertainties of NWP

Sant Llorenç (Mallorca) October 2018

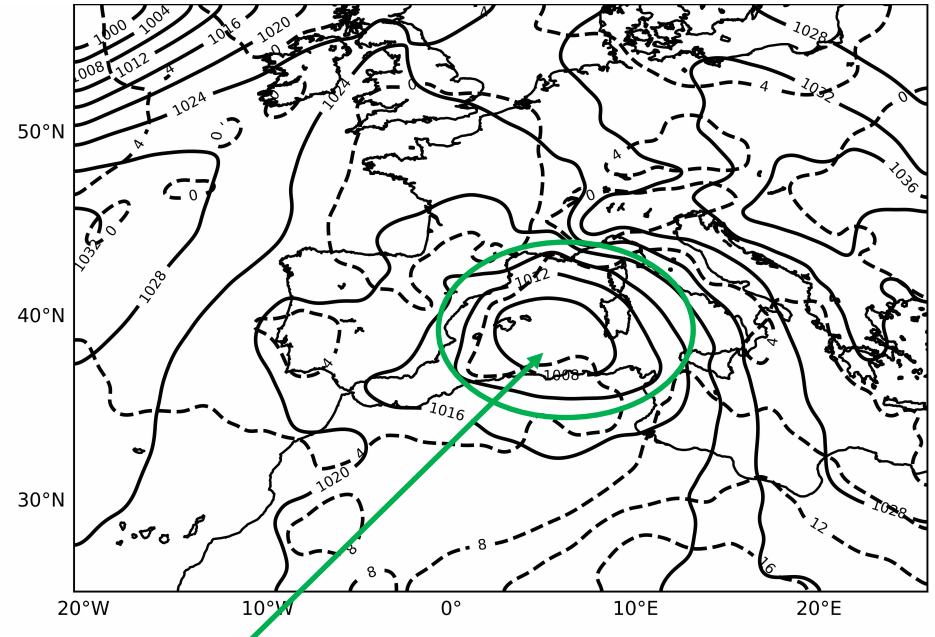
Livorno September 2017

Objectives

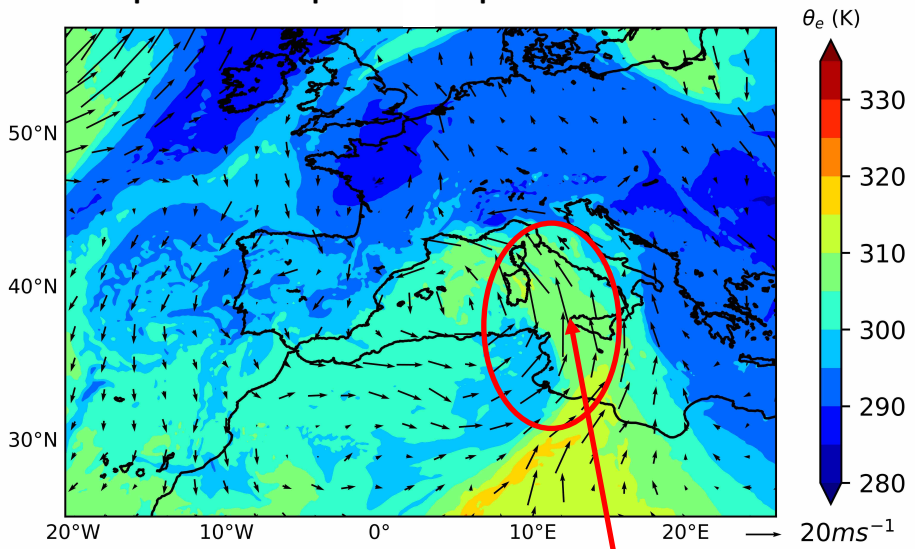
- The main objective is to investigate the **characteristics** of initial/boundary conditions and model perturbations in terms of **ensemble diversity and skill**
- Multiple ensemble generation strategies are tested for three illustrative **extreme heavy precipitation** episodes in a **convection-permitting** framework
- Questions:
  - Small-scale IC perturbations improve these forecasts?
  - The combination of perturbations produces a positive impact?

Case 1: 19-20 December 2016

Sea level pressure – Temp 850 hPa

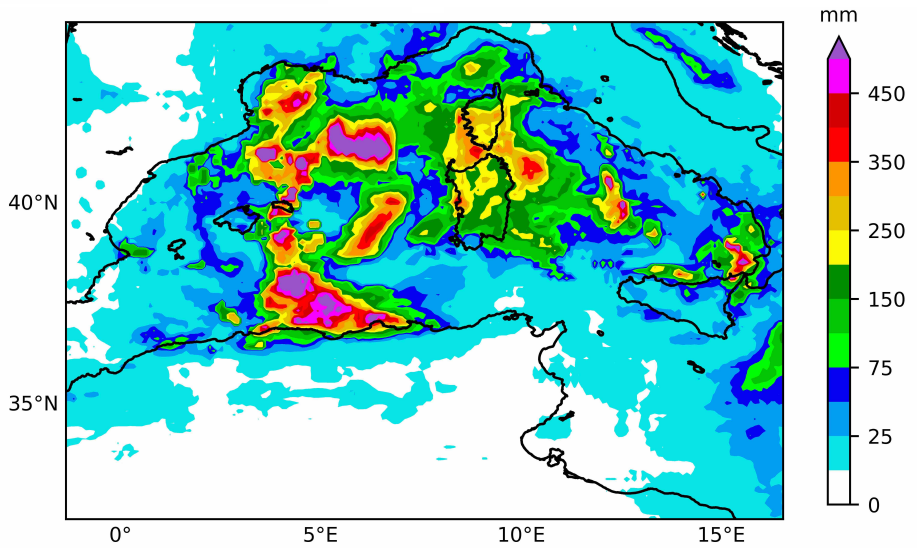


Equivalent pot. temp + wind 850 hPa



Low-level cyclone

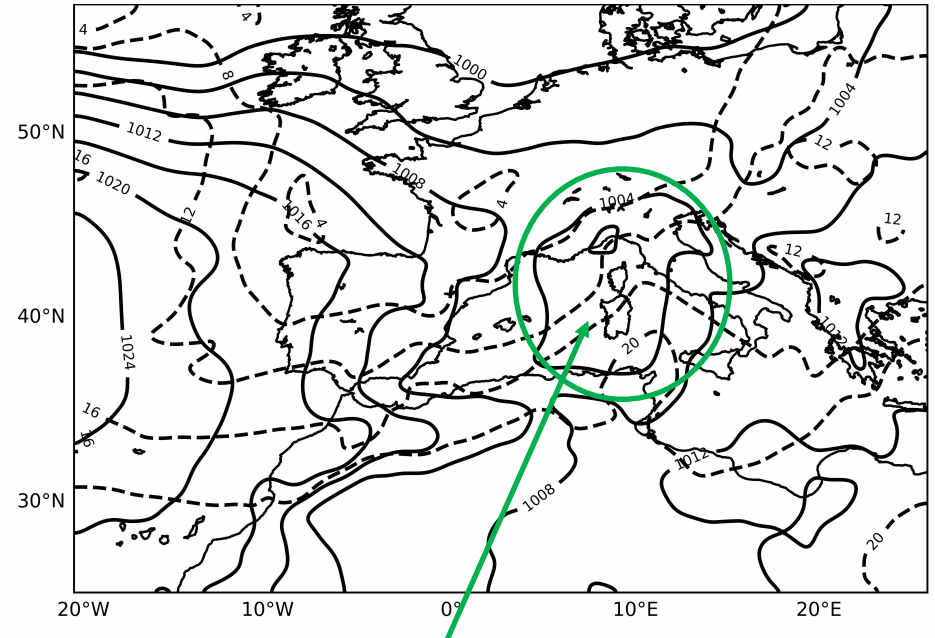
24-h acc pcp



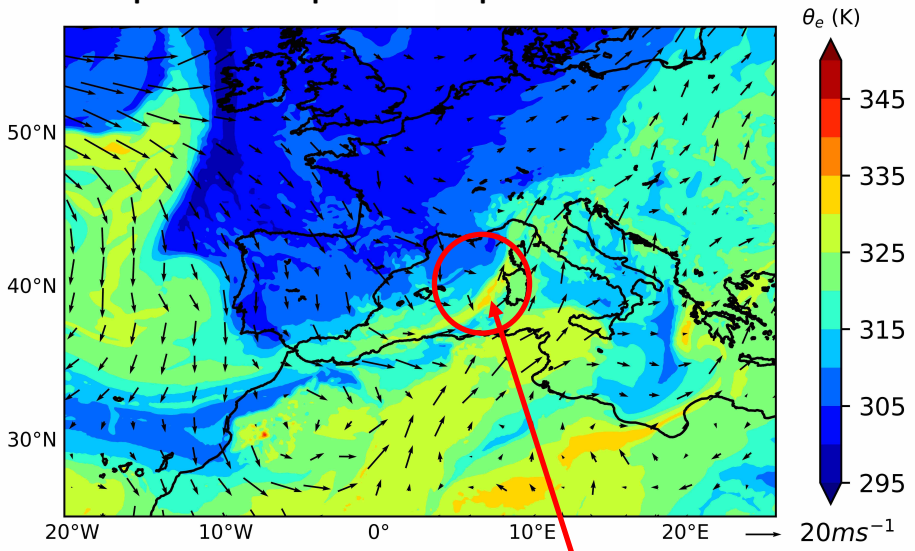
Advection of warm and moist air

Case 2: 9-10 September 2017

Sea level pressure – Temp 850 hPa

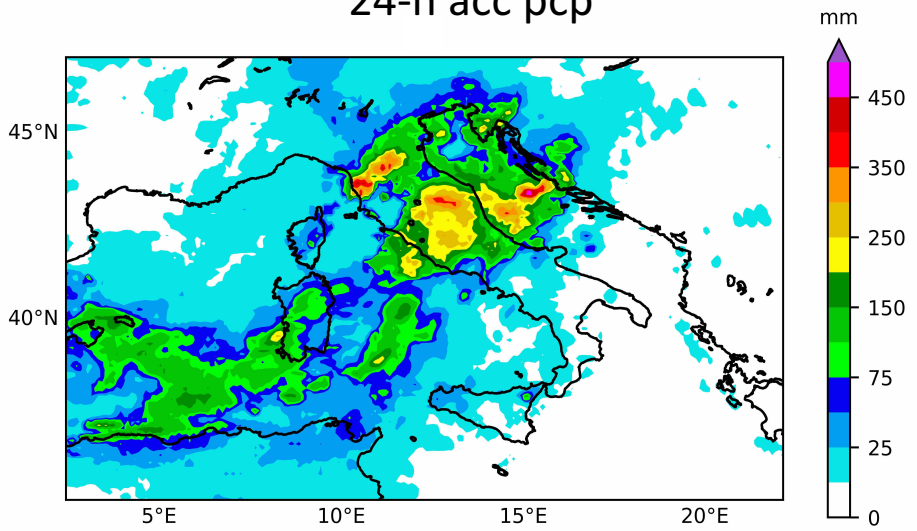


Equivalent pot. temp + wind 850 hPa



Lee cyclone

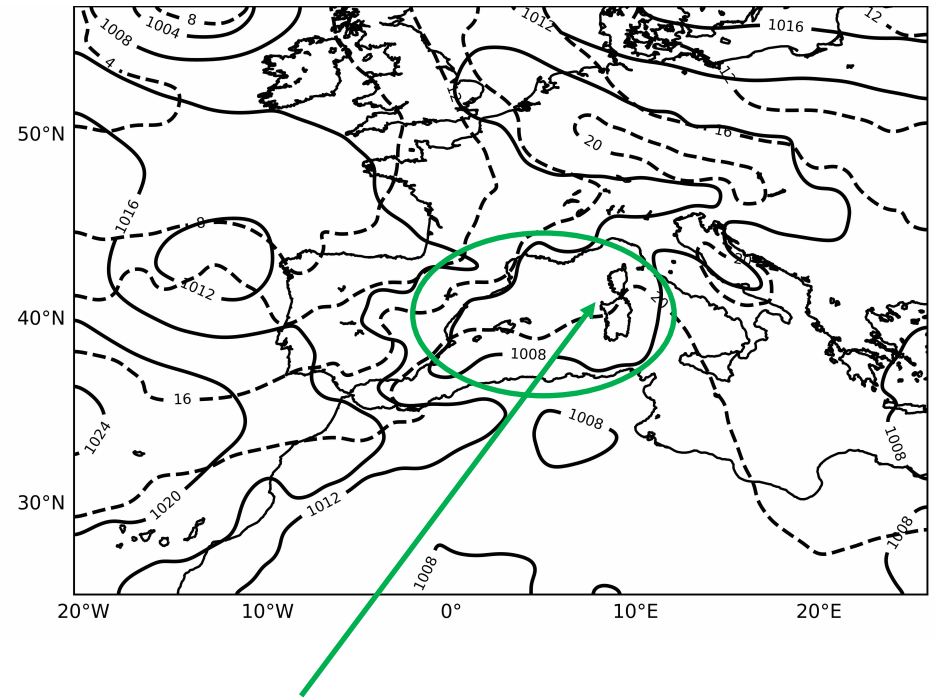
24-h acc pcp



Intense θ_e contrast

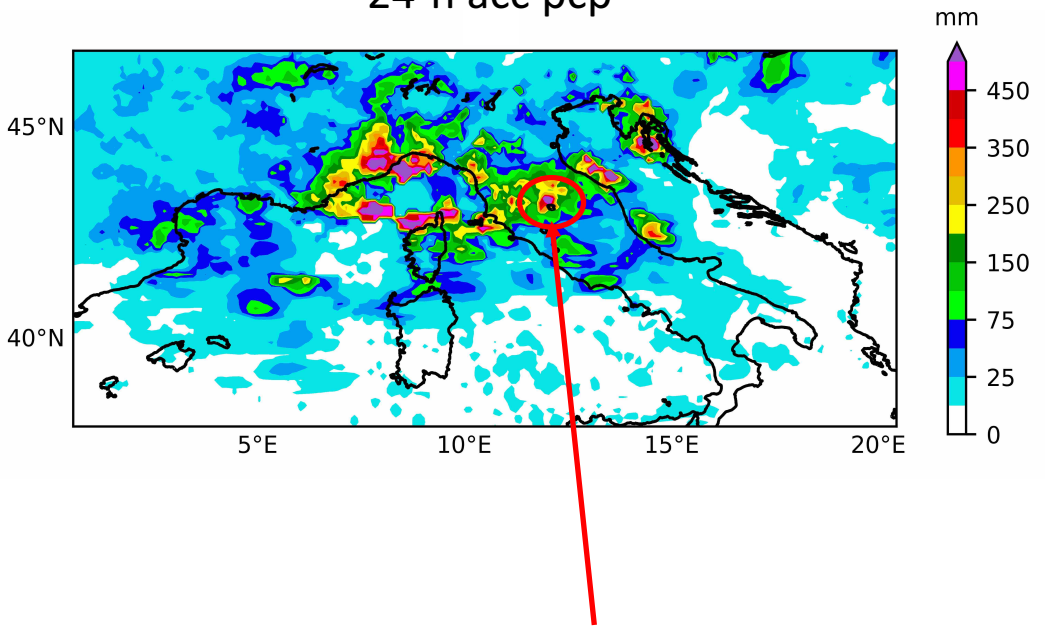
Case 3: 27 July 2019

Sea level pressure – Temp 850 hPa



Low pressure system

24-h acc pcp



Localized convection

General model configuration

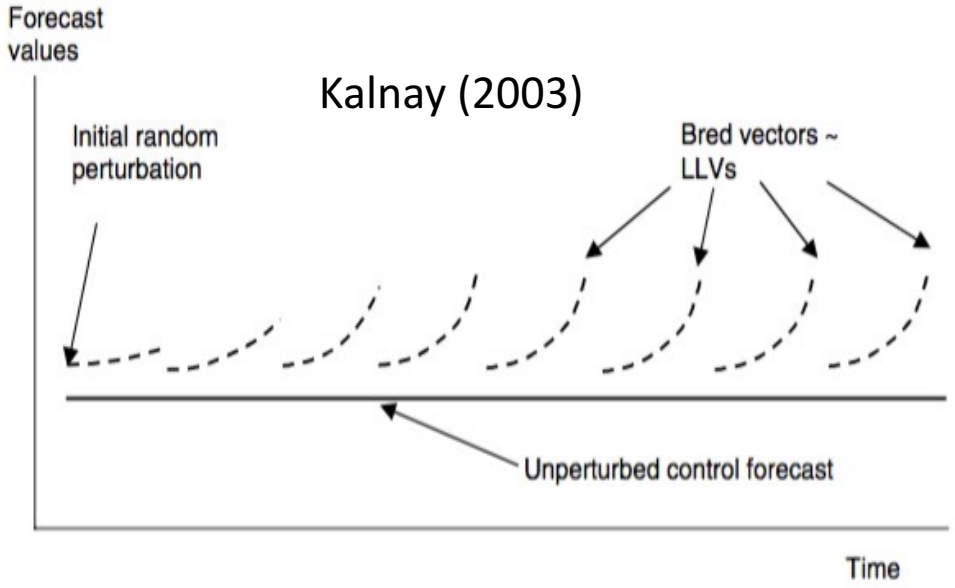
- Experiments performed with **WRF-ARW** version 3.9.1.1
- **2.5-km horizontal resolution** domain (750 x 500 grid points) centred over the region of interest for each case
- **50** vertical levels
- **30 h** lead time (6 h for spin-up)
- **5** configurations of **50-member** ensembles are designed:
  - Initial/boundary condition perturbations. **DOWN** and **BRED**
  - Model perturbations: **STO**
  - Combination of initial/boundary and model perturbations (**DOWN+STO** and **BRED+STO**)
- Same physical parameterizations:
  - NSSL 2-mom microphysics, MYNN boundary layer, RUC land-surface, RRTMG radiation, no convection

Initial condition perturbations: DOWN

- Initial and boundary conditions downscaled from the 50 members of ECMWF ensemble prediction system
- 3-hourly updated boundary conditions
- No model error

Initial condition perturbations: BRED

- Boundary conditions from the ECMWF ensemble prediction system
- Initial condition perturbations generated with the Bred Vector Tailored Ensemble Perturbations (Hermoso et al. 2020)[1]
- 25 breeding cycles started 10 days before forecast initial time
- Difference between control and perturbed simulations rescaled and orthogonalized every 6 hours



[1]Hermoso, A., Homar, V., Greybush, S.J. and Stensrud, D.J., 2020: Tailored ensemble prediction systems: Application of seamless scale bred vectors. J. Meteor. Soc. Japan, 98, 1029-1050

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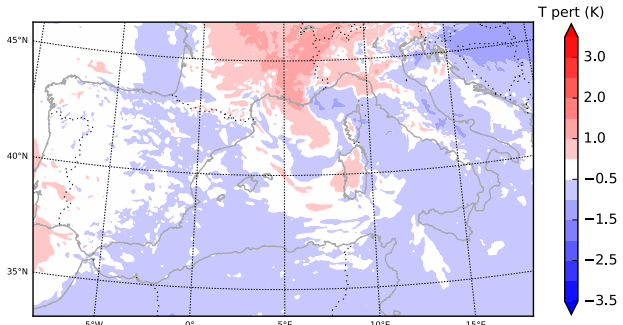
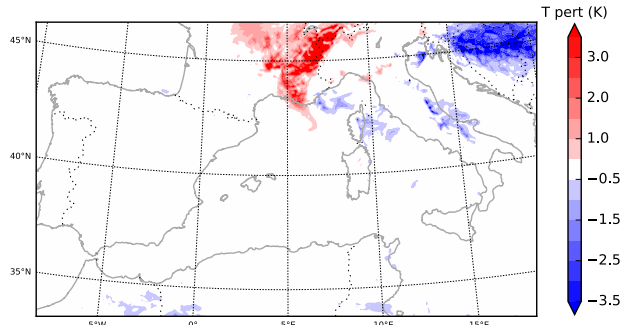
- 25 breeding cycles started 10 days before forecast initial time
- Difference between control and perturbed simulations rescaled and orthogonalized every 6 hours
- Bred vectors at forecast initial time tailored to account for uncertainties at different scales
- 25 twin (anticorrelated) perturbations





[1]Hermoso, A., Homar, V., Greybush, S.J. and Stensrud, D.J., 2020: Tailored ensemble prediction systems: Application of seamless scale bred vectors. J. Meteor. Soc. Japan, 98, 1029-1050

Model perturbations: STO

- Combination of stochastically perturbed physics tendencies (SPPT) and stochastic perturbations to microphysics parameters
- **SPPT**
  - Total physics tendencies (except microphysics) are multiplied by a spatially and temporally correlated random pattern (Berner et al. 2015)[1]:

$$X = X_{dyn} + X_{phys}$$

$$X'_{phys} = X_{phys}(1 + r(x, y, t))$$

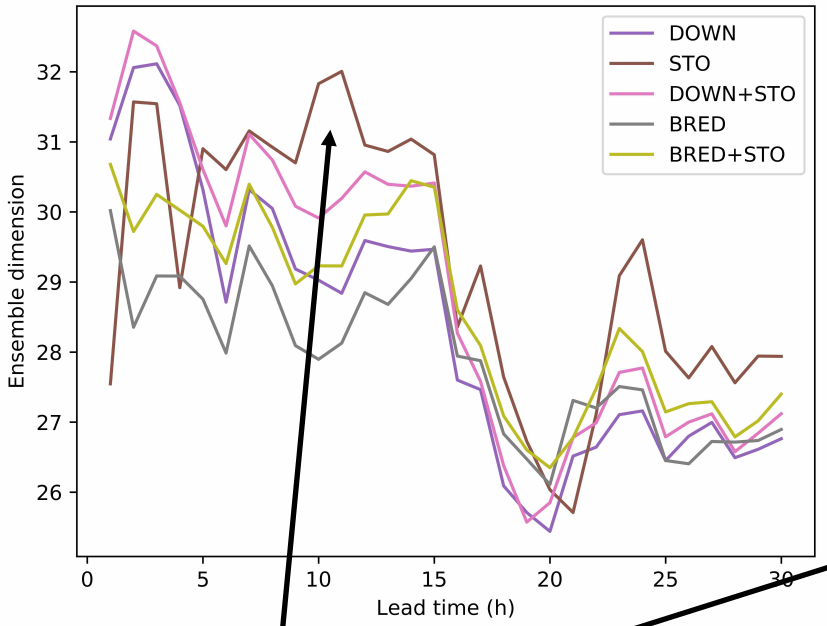
- **Perturbations to microphysics** (Hermoso et al. 2021)[2]
  - Cloud condensation nuclei, graupel and hail fall speed factors and saturation percentage for cloud formation are perturbed
  - Parameters are modified during the forecast lead time. Constant across the domain
- No initial/boundary perturbations

[1]Berner, J., Fossell, K., Ha, S., Hacker, J.P., Snyder, C., 2015. Increasing the skill of probabilistic forecasts: Understanding performance improvements from model-error representations. Mon. Wea.

Rev. 143, 1295–1320

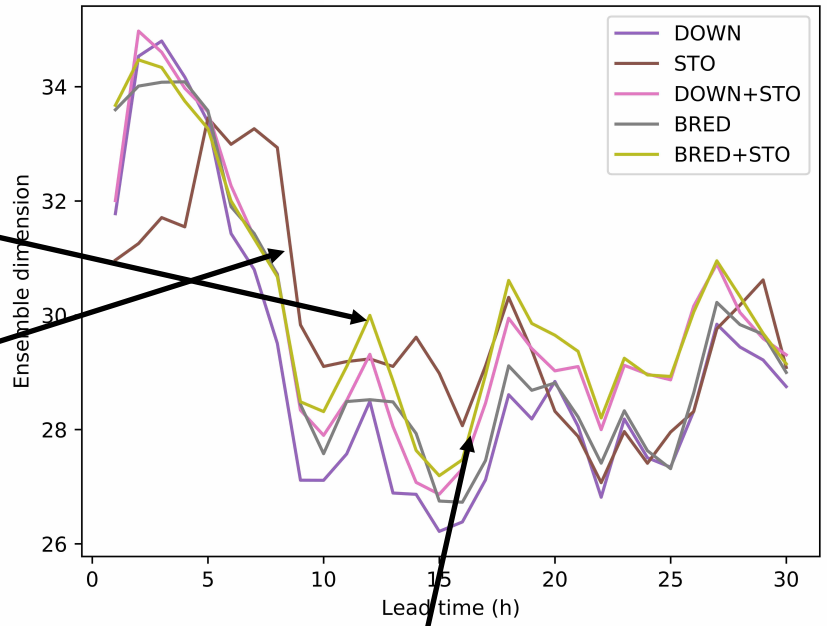
[2]Hermoso, A., Homar, V. and Plant, R.S., 2021: Potential of stochastic methods for improving convection-permitting ensemble forecasts of extreme events over the western Mediterranean. Atmos. Res. 257, 105571

Results: Ensemble dimension (1000 hPa)



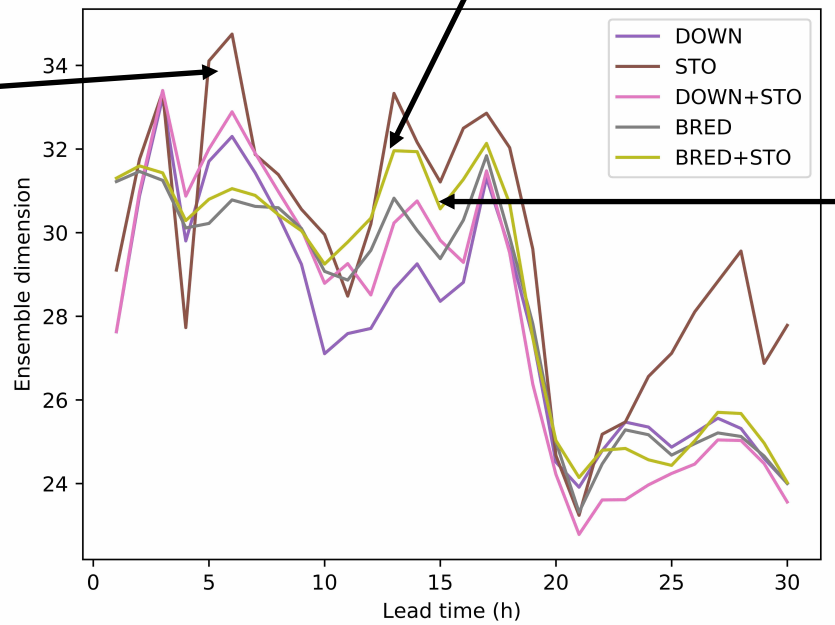
Case 1

BRED perturbations produce larger diversity for Case 2 and 3



Case 2

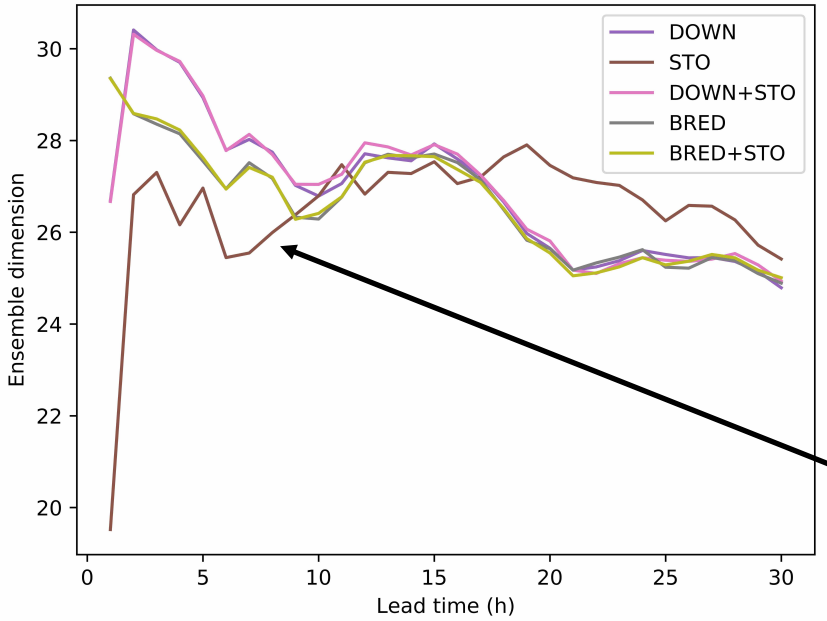
Higher dimension for STO at low levels



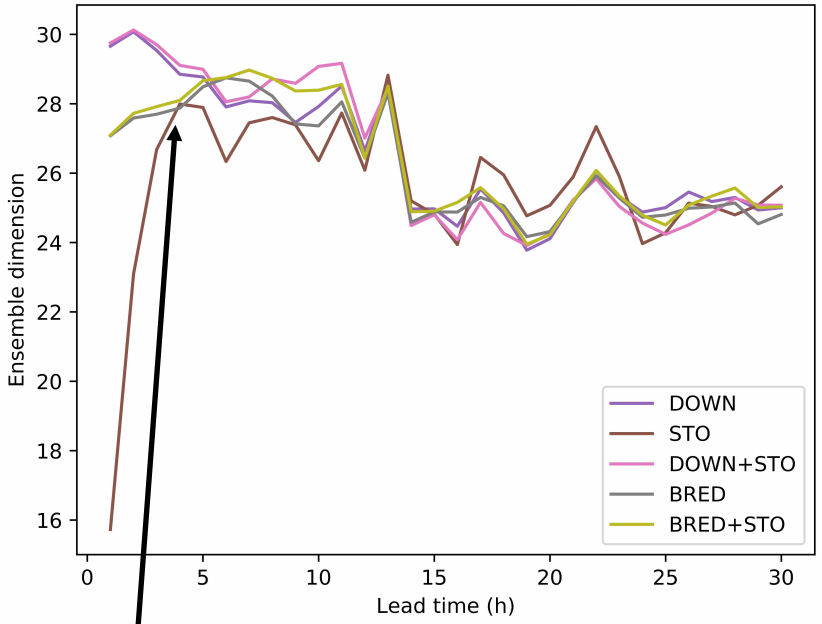
Case 3

Combination of perturbations generally increase diversity

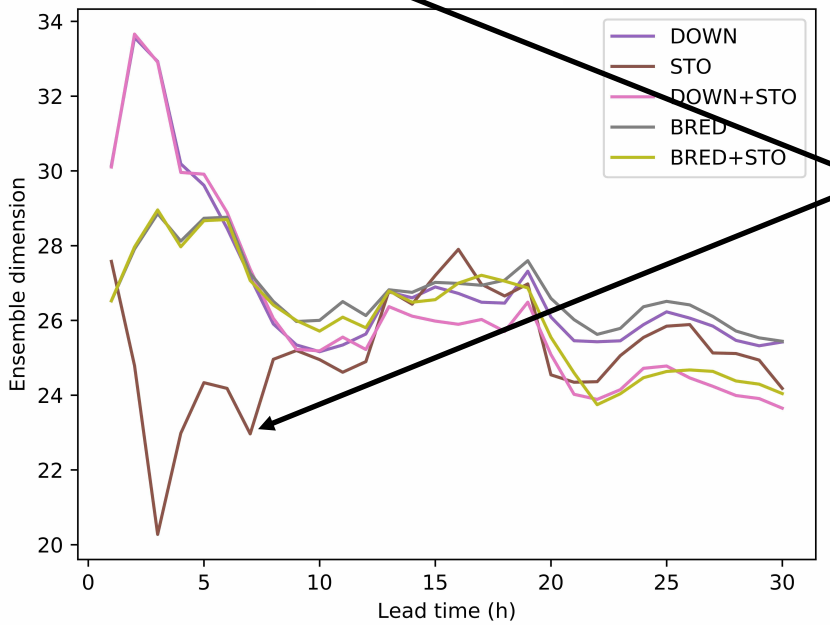
Results: Ensemble dimension (500 hPa)



Case 1



Case 2



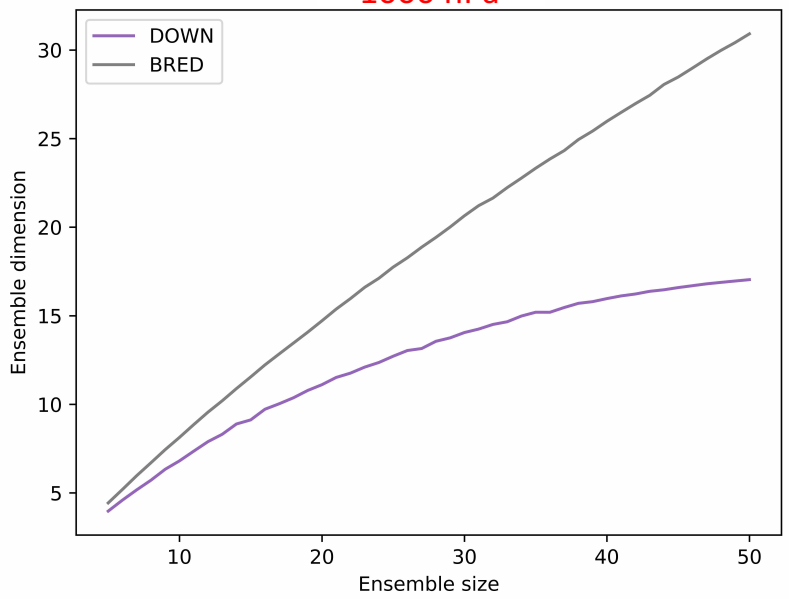
Case 3

Smaller differences among perturbations

Smaller effect of model perturbations

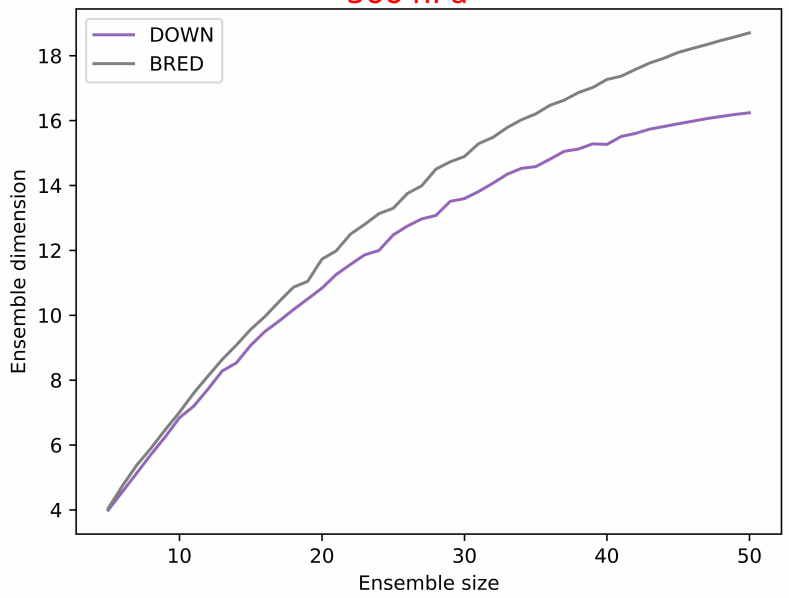
Results: Ensemble dimension vs size

1000 hPa

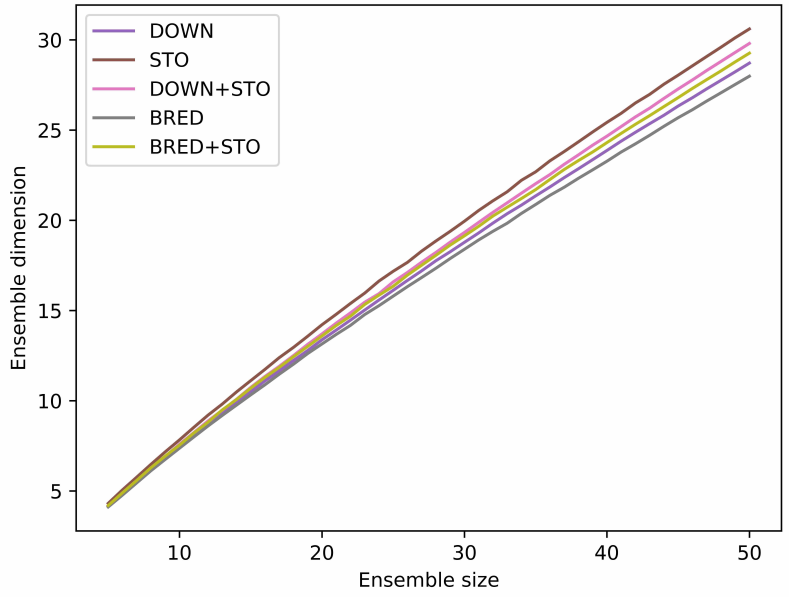


Saturation for DOWN at t=0

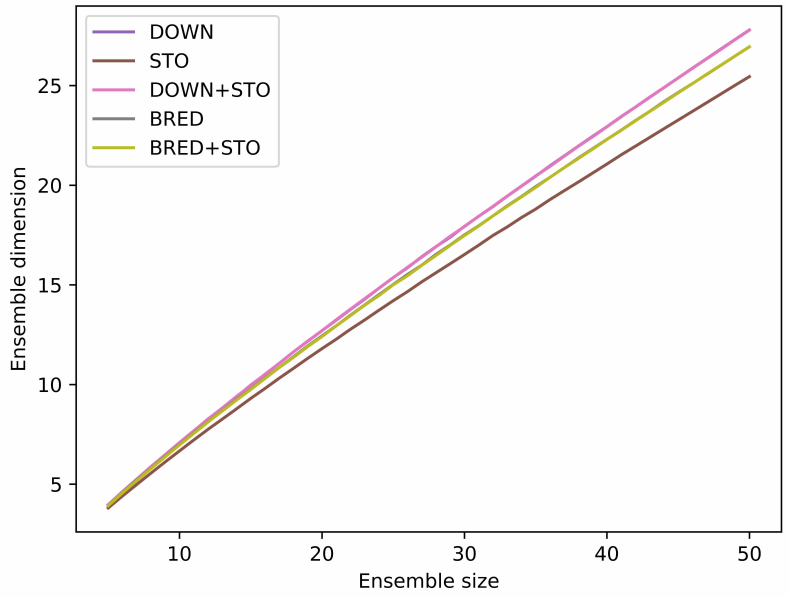
500 hPa



Initial time



Ensemble dimension could be increased by adding more ensemble members



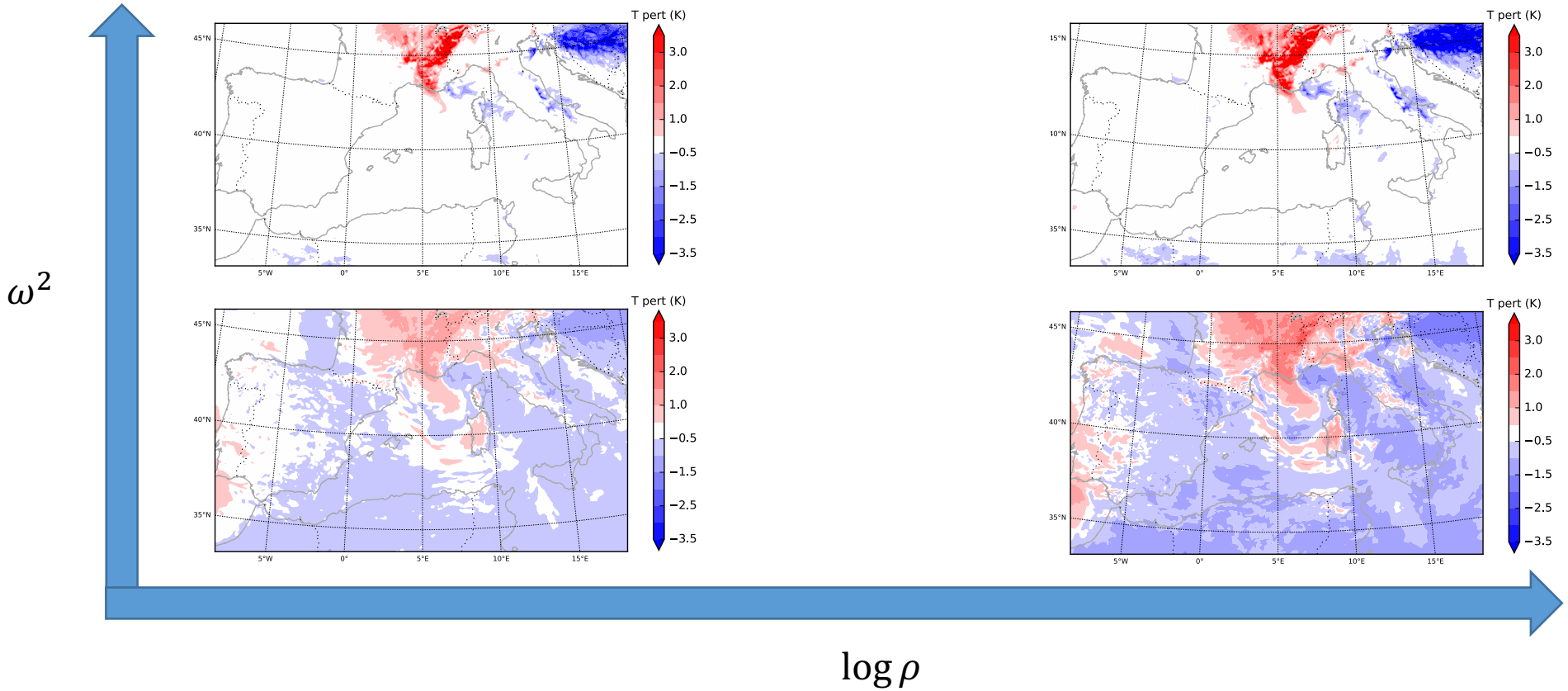
6-h lead time

Amplitude and localization of perturbations

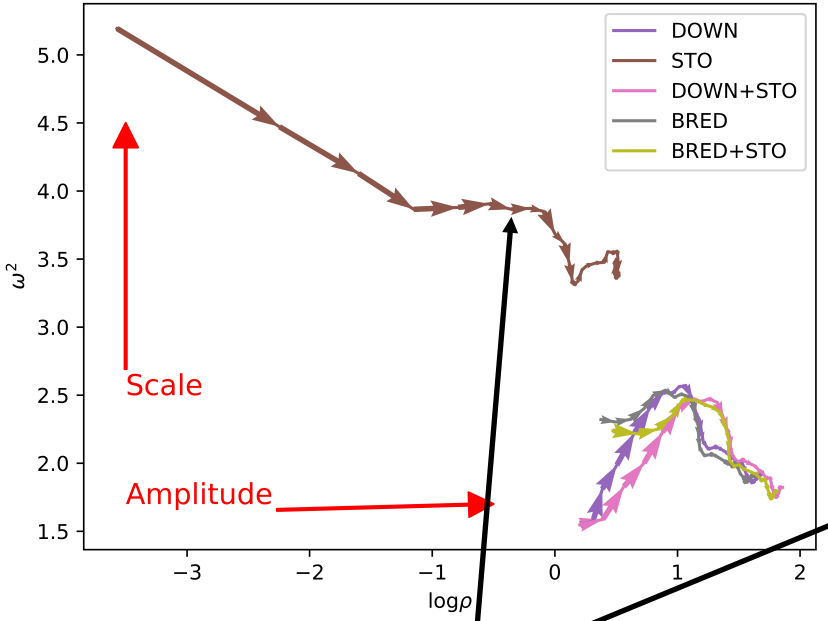
The amplitude and scale of the perturbations can be defined with the following parameters:

$$\log \rho = \log \prod_{i=1}^{N} |\delta x_i|^{1/N} \quad \text{(Amplitude)}$$

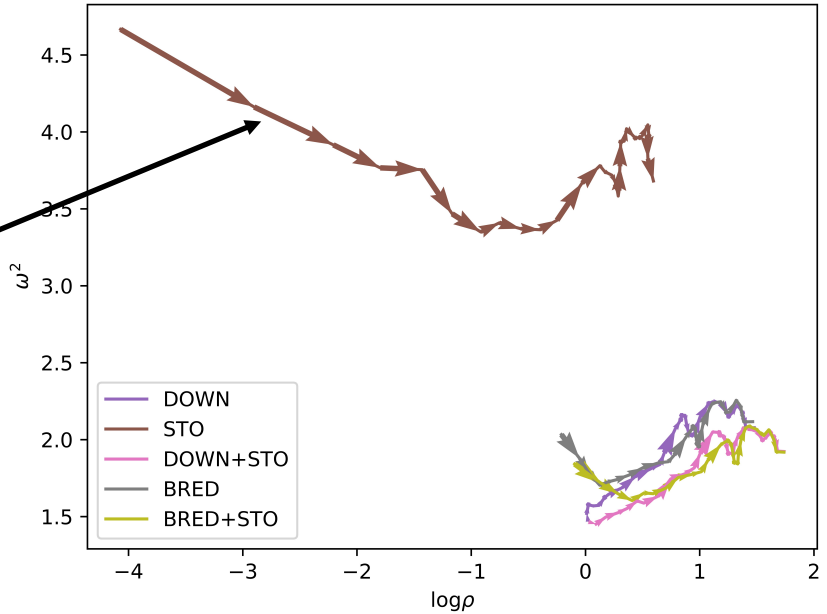
$$\omega^2 = \overline{(\log \delta x_i - \log \rho)^2} \quad \text{(Localization)}$$



Results: log ρ - ω^2 (1000 hPa)

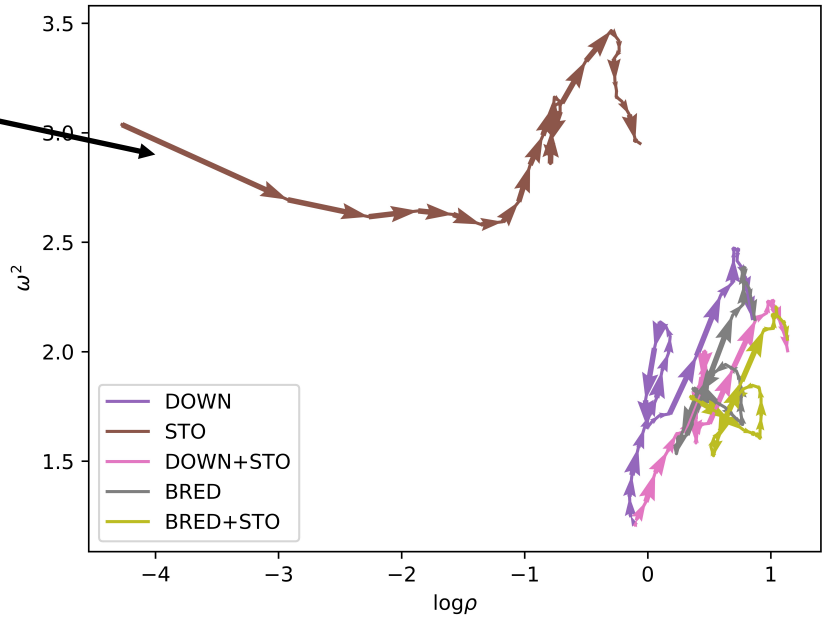


Case 1



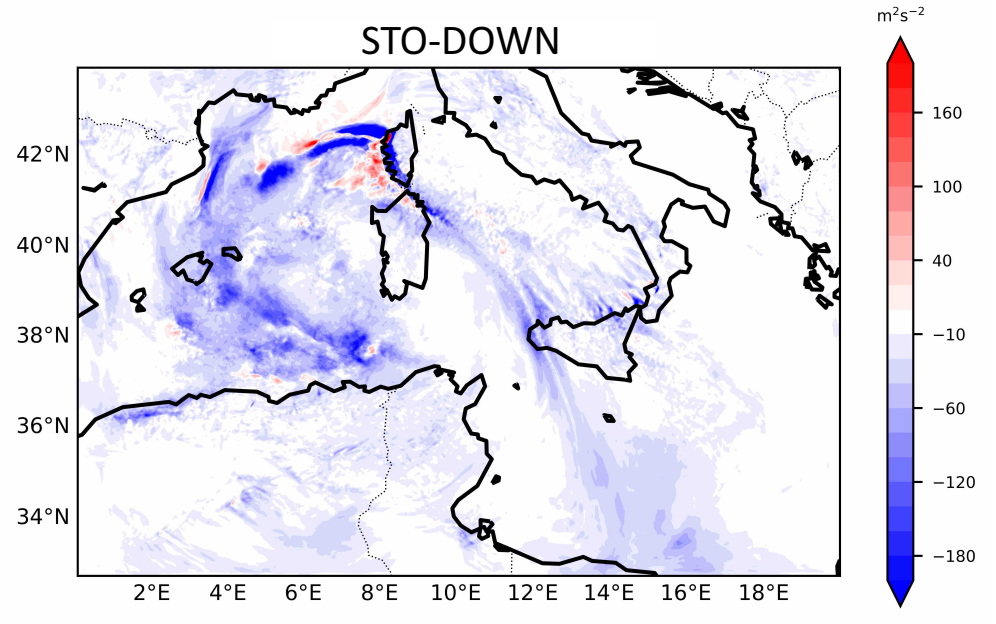
Case 2

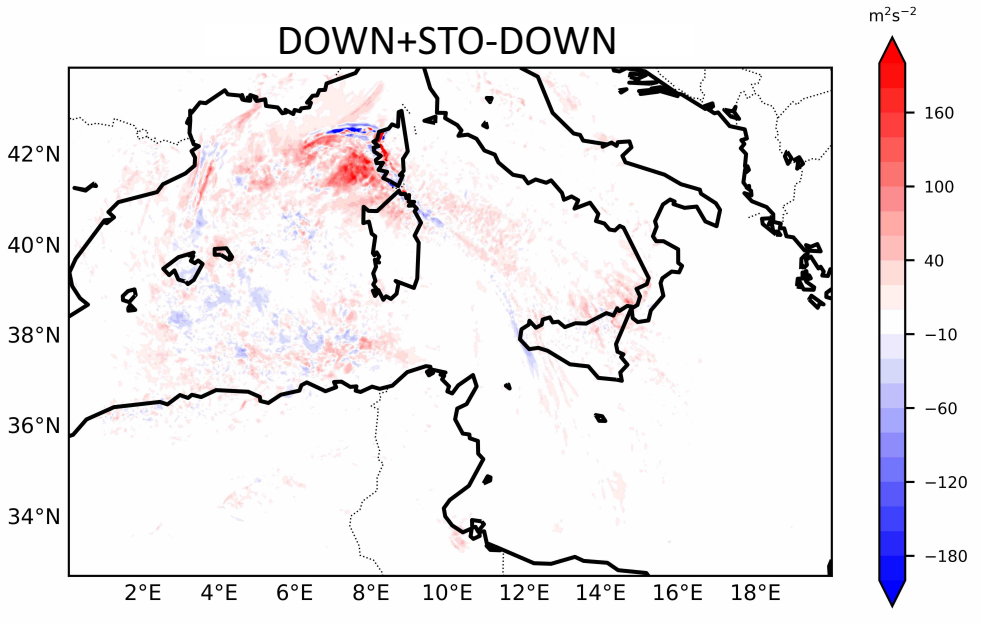
STO: Small amplitude
high localization

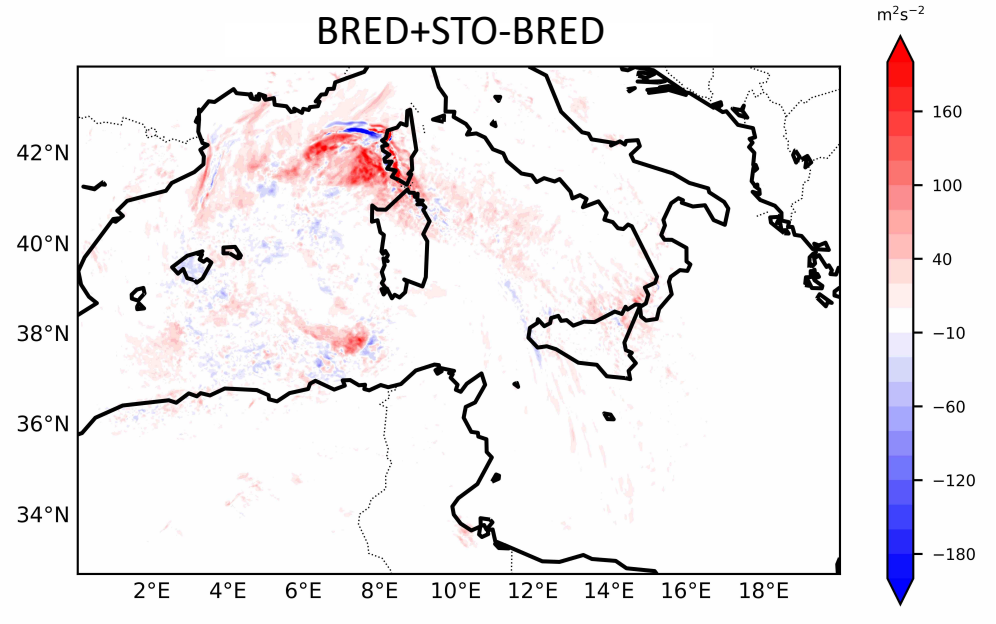


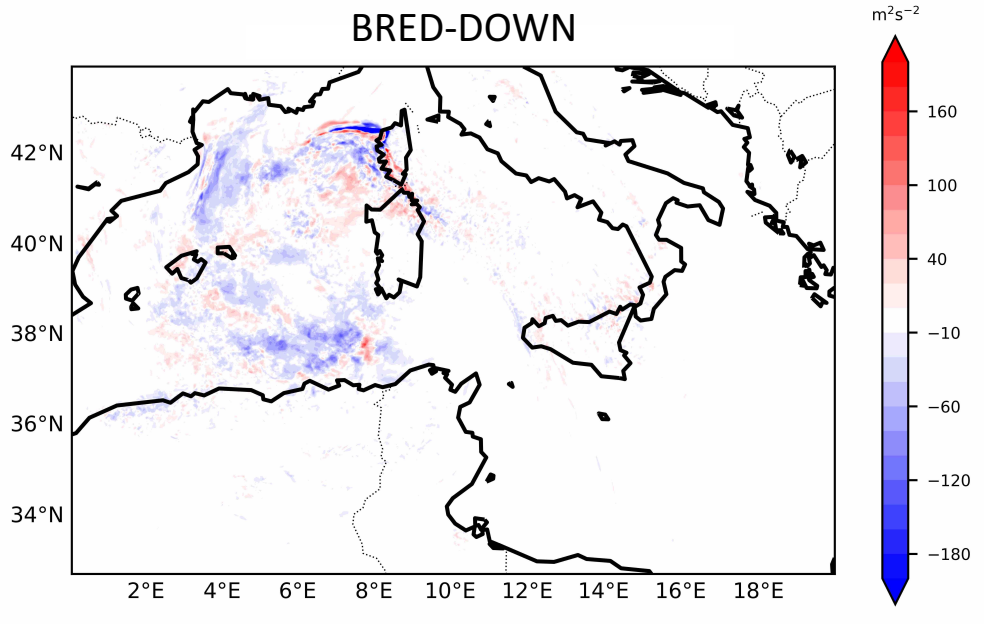
Case 3

Differences among perturbations (Case 1)





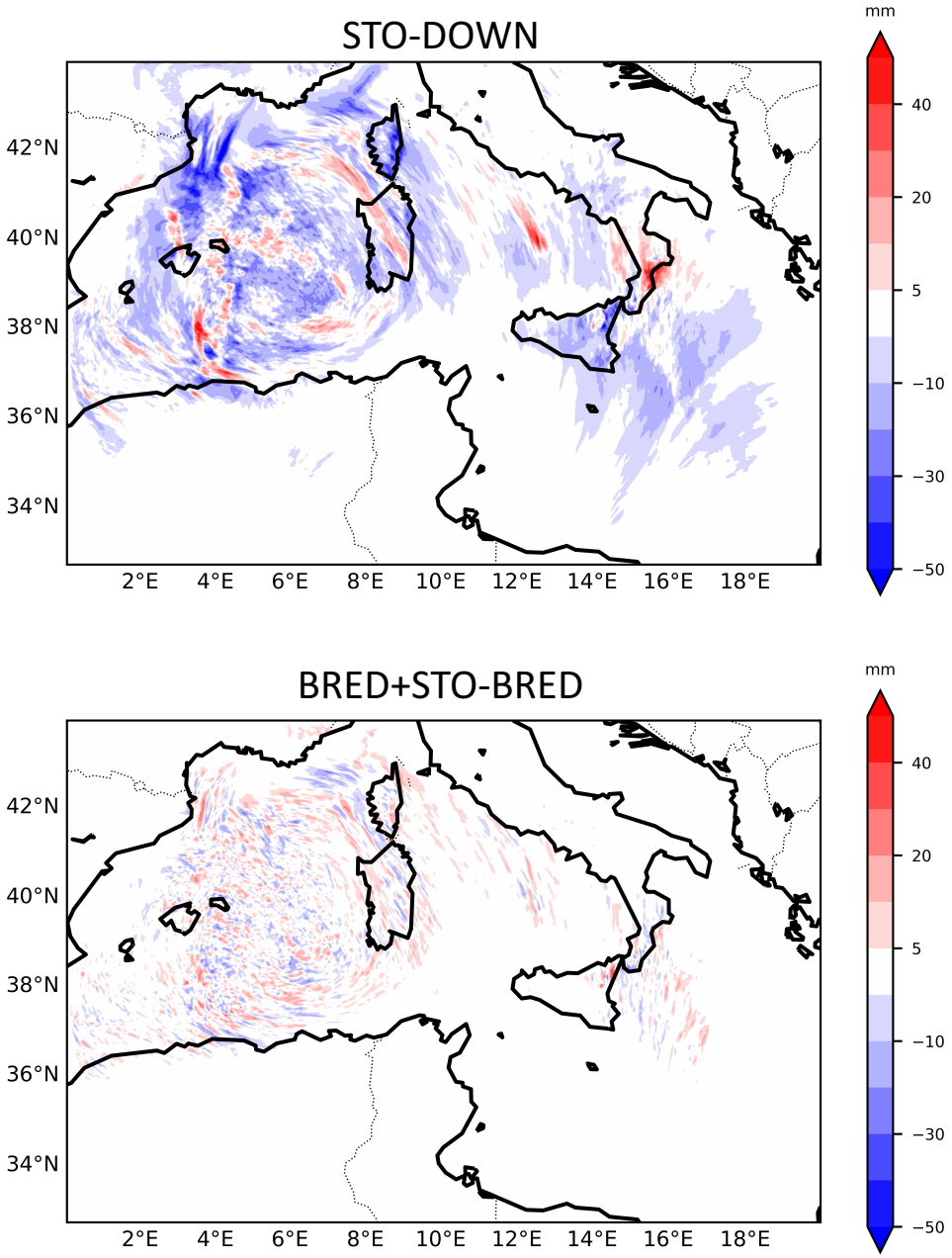


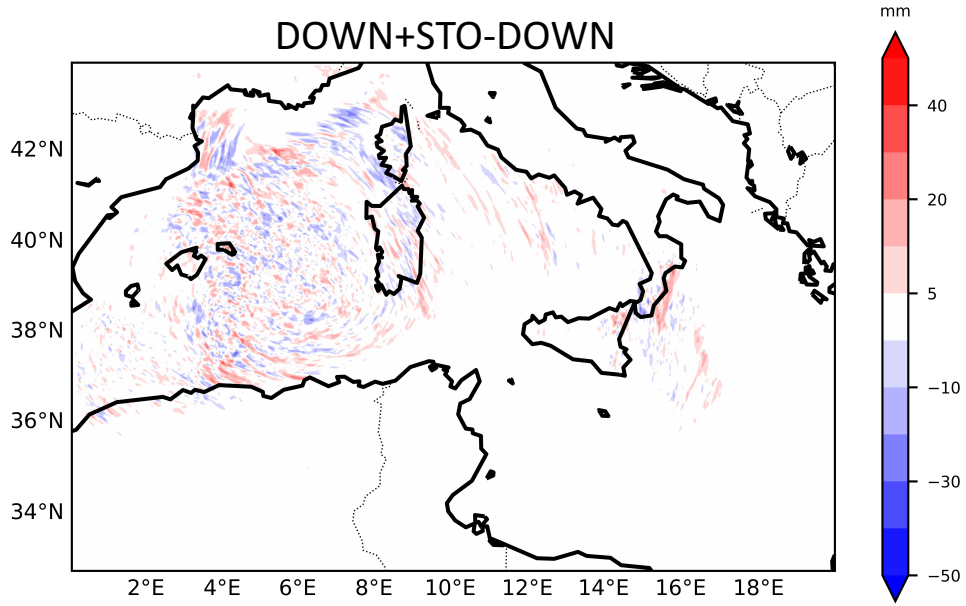


Total energy perturbations
Mean of top decile difference

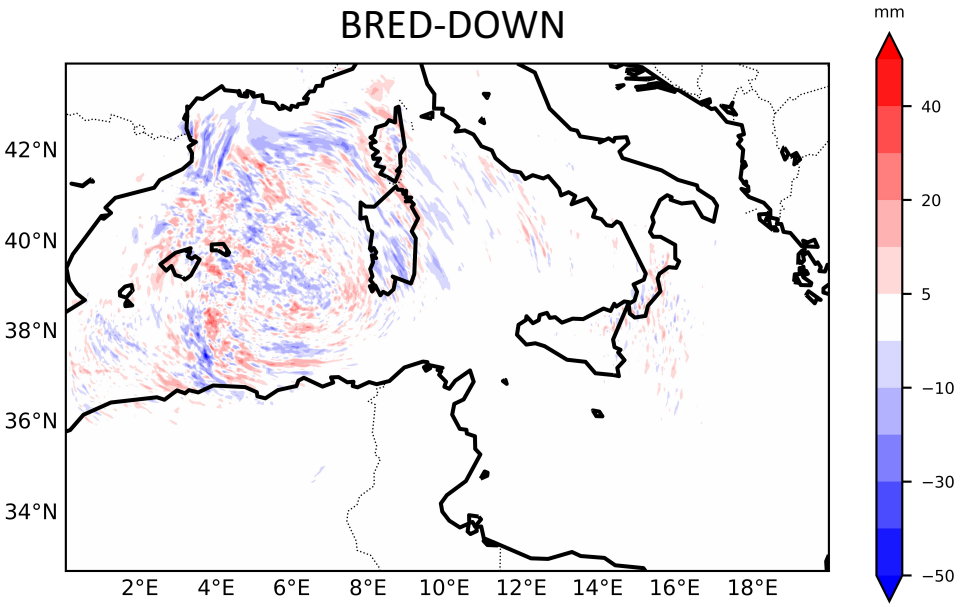
Model level 4
≈ 950 hPa

Differences in accumulated precipitation (Case 1)





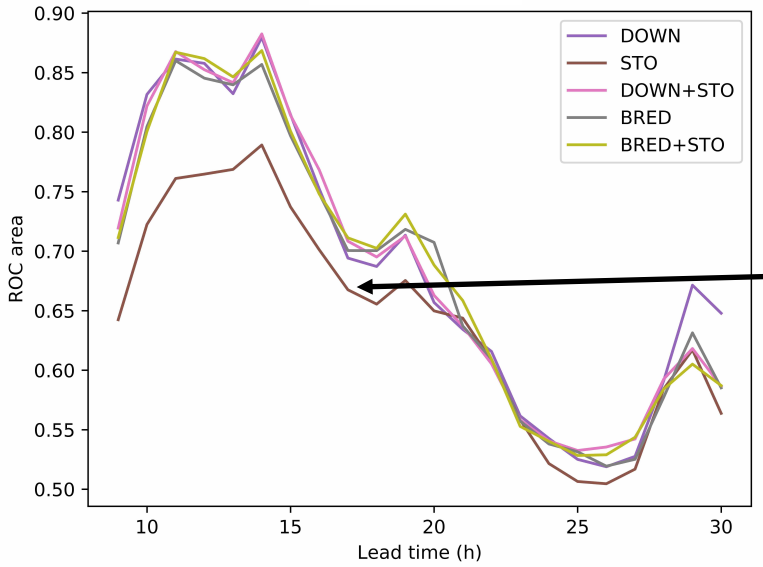
Mean of top decile difference



Results: Ensemble verification

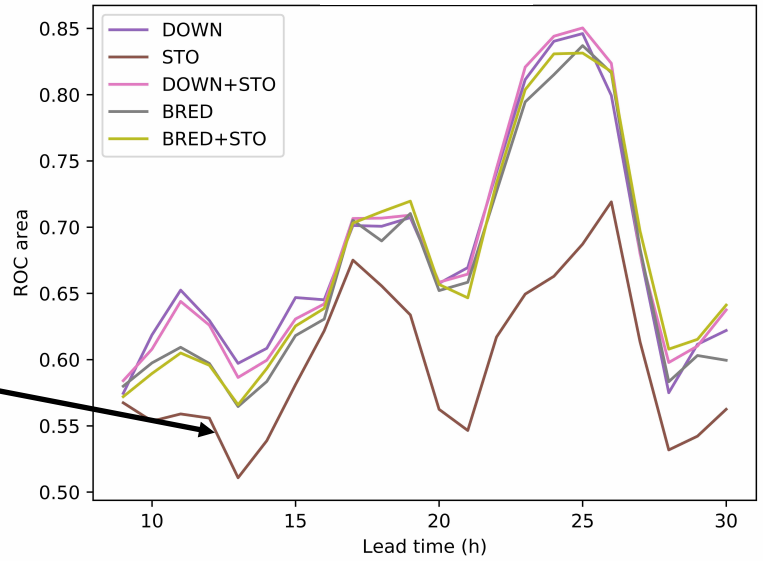
- Variable: 3-h accumulated precipitation
- Metric: ROC area
- Observation: GPM-IMERG precipitation product
  - Global dataset
  - 0.1° x 0.1° spatial resolution
  - 30-min temporal resolution

Results: Ensemble verification (3h pcp > 20 mm)

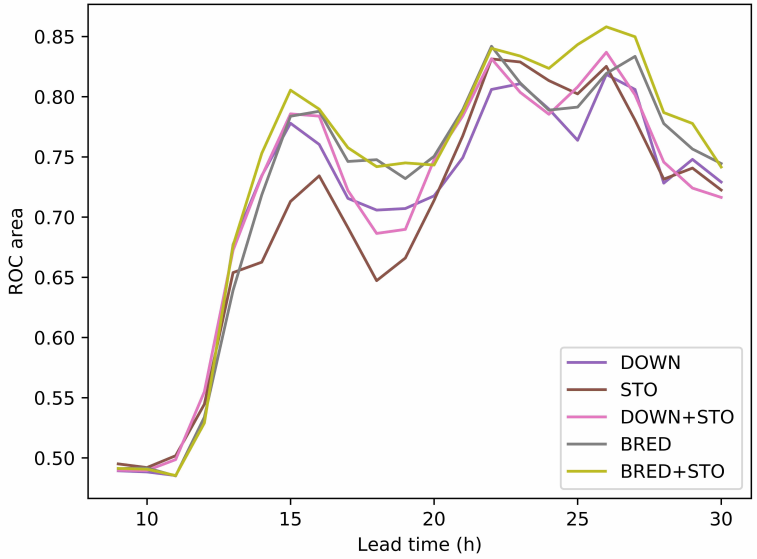


Case 1

Poor performance of STO for Case 1 and 2



Case 2

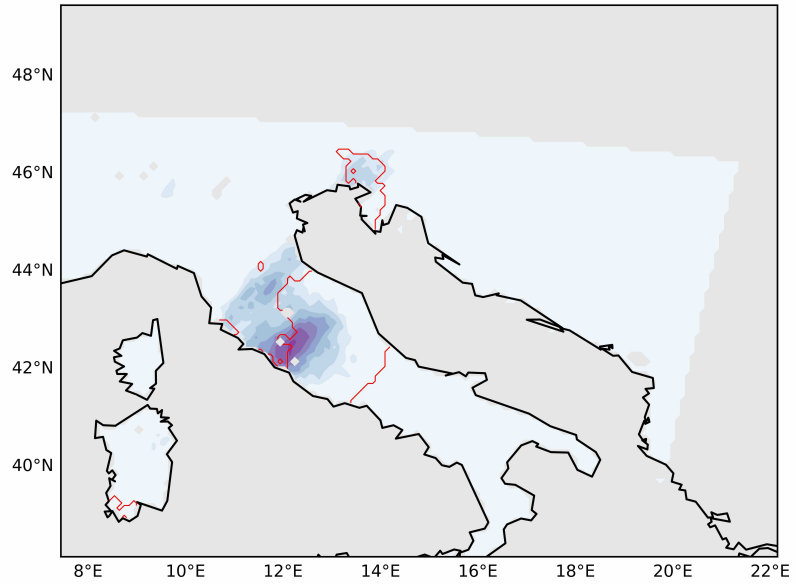


Case 3

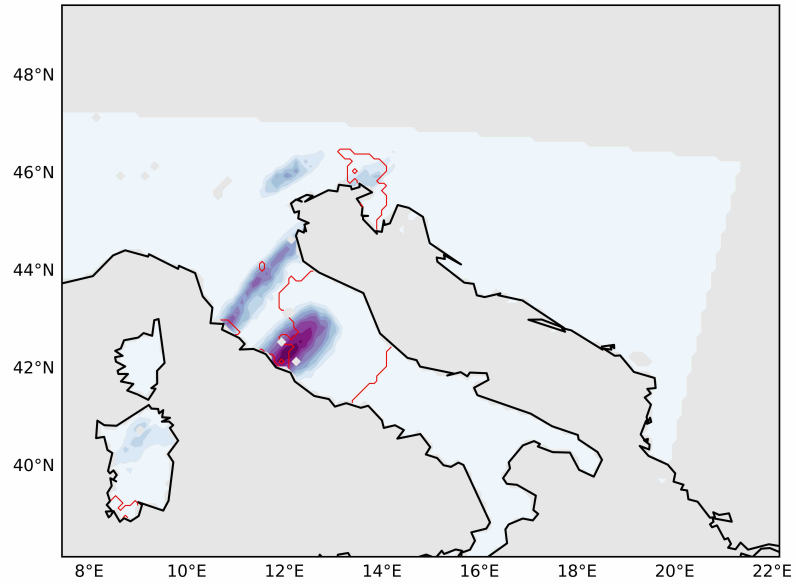
Similar skill for other strategies

Probability 3-h pcp > 20 mm

DOWN Case 2

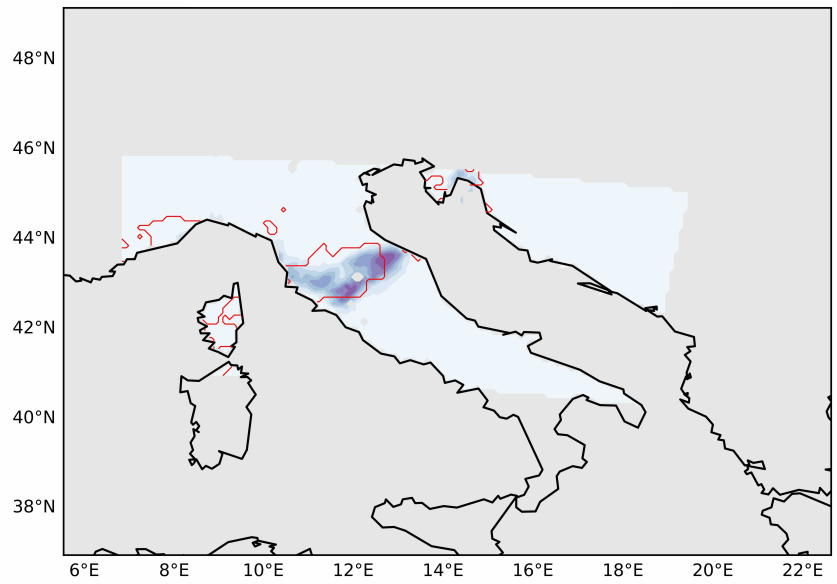


STO Case 2



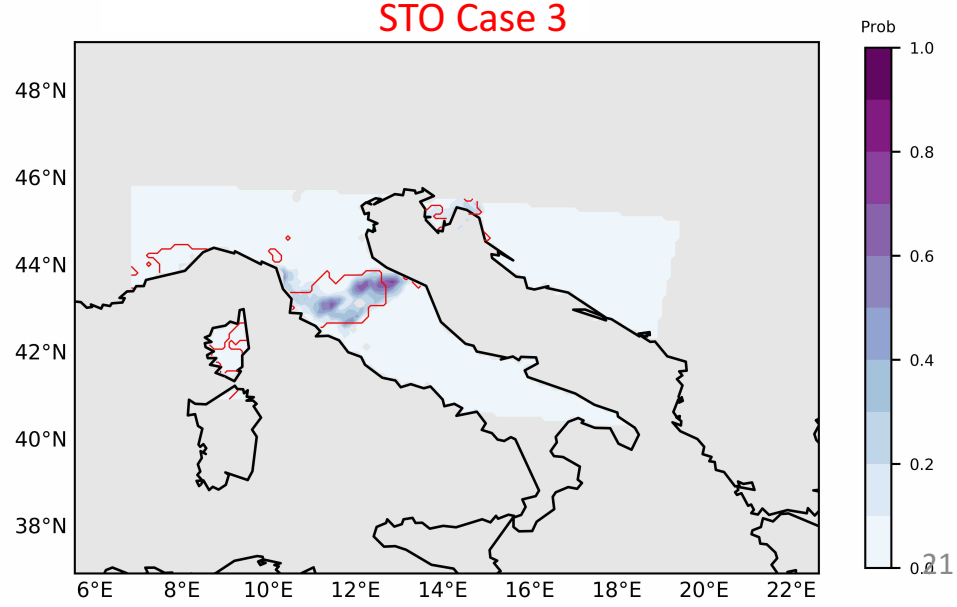
More concentrated probability for STO

DOWN Case 3



Different behaviour when local factors are more relevant

STO Case 3



Conclusions

- The characteristics of multiple ensemble prediction strategies have been investigated for three heavy precipitation events occurred in over the western Mediterranean
- The introduction of perturbations sampling multiple scales generally increases diversity, especially at low levels
- Stochastic model perturbations yield large ensemble dimension at low levels, but are typically insufficient to capture extreme scenarios
- Adding model perturbations to initial condition sampling generally increases diversity and perturbation intensity
- The analysis of ensemble dimension reveals that ensemble dimension can be effectively enlarged by adding more members

Acknowledgments

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