SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021
Project Title:	Exploring the predictability limits of severe weather in the western Mediterranean
Computer Project Account:	SPESHOMA
Principal Investigator(s):	Víctor Homar Santaner
Affiliation:	Universitat de les Illes Balears
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Not applicable
Start date of the project:	01/01/2019
Expected end date:	31/12/2021

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	22000000		17000000	17087977.74
Data storage capacity	(Gbytes)	20000	0	20000	0

Summary of project objectives (10 lines max)

This special project is aimed at improving the forecast skill of high-impact meteorological phenomena over the densely populated Western Mediterranean area in order to mitigate their devastating socioeconomic impacts. The specificities of the Mediterranean basin, characterized by extensive maritime bodies with few in-situ observations, pose additional challenges to the weather forecasting process. In this sense, the potential of ensemble data assimilation by means of Ensemble Kalman Filter (EnKF) to advect information from land to maritime areas is investigated. Furthermore, the effects of stochastic parameterization techniques to account for model error are tested. Considering the highly nonlinear processes acting on the development and evolution of convective systems, a great impact in terms of ensemble diversity and skill of short-range probabilistic forecasts is expected from stochastic physics approaches.

Summary of problems encountered (10 lines max)

The focus of this project requires an extremely computationally demanding setup, characterised by convection-permitting simulations (≤ 2.5 km horizontal resolution) and a moderate number of ensemble members (minimum 50) in order to sample a region of phase space including potential risk scenarios. The resources requested (12 million SBU per year) are not enough to conduct multiple ensemble experiments with the above setting. This problem was partially alleviated with the granting of additional resources (5 million SBUs), but are still insufficient to apply the developed techniques to a large set of case studies.

Summary of plans for the continuation of the project (10 lines max)

In case more resources are granted during this year, we would expand the experiments exploring the impact of the diverse ensemble generation strategies based on initial condition perturbation and/or model error sampling to additional case studies.

Furthermore, a new special project application is currently being prepared to continue this research related to Mediterranean extreme events to adapt and extend the methodologies developed and tested for the Weather Reasearch and Forecasting (WRF) model to other atmospheric modelling systems, the Model Prediction Across Scales-Atmosphere and a prototype built up within the meteorology group of the *Universitat de les Illes Balears*, the Triangle-based Regional Atmospheric Modelling.

List of publications/reports from the project with complete references

Amengual, A., Hermoso, A., Carrió, D.S., Homar, V., 2021: The sequence of heavy precipitation and flash flooding of 12 and 13 September 2019 in eastern Spain. Part II: A hydro-meteorological predictability analysis based on convection-permitting ensemble strategies. J. Hydrometeor. (In press)

Carrió, D.S., Jansà, A., Homar, V., Romero, R., Rigo, T., Ramis, C., Hermoso, A., Maimó, A.: Exploring the benefits of a Hi-EnKF system to forecast an extreme weather event. The 9th October 2018 catastrophic flash flood in Mallorca. Atmos. Res. (Under review)

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

The computational resources granted for the last year have been devoted to test the performance of multiple ensemble generation strategies over a set of extreme heavy precipitation episodes over the western Mediterranean.

A collection of these events has been obtained by using precipitation data from the Goddard Earth Sciences Data and Information Services Center (GES DISC) database (Huffman et al. 2019) for the period 2016-2020. These data contain global precipitation data with a spatial resolution of 0.1°x0.1° and a temporal resolution of 30 minutes. A threshold defined by the 99.995 percentile for 30-min and 6-h accumulated rainfall over the selected time period and the domain represented in Fig. 1 is used to select case studies. Days with rainfall accumulations above both thresholds at some land points are selected and ordered according to 6-h accumulations. The days with the highest values of this quantity are selected as case studies.

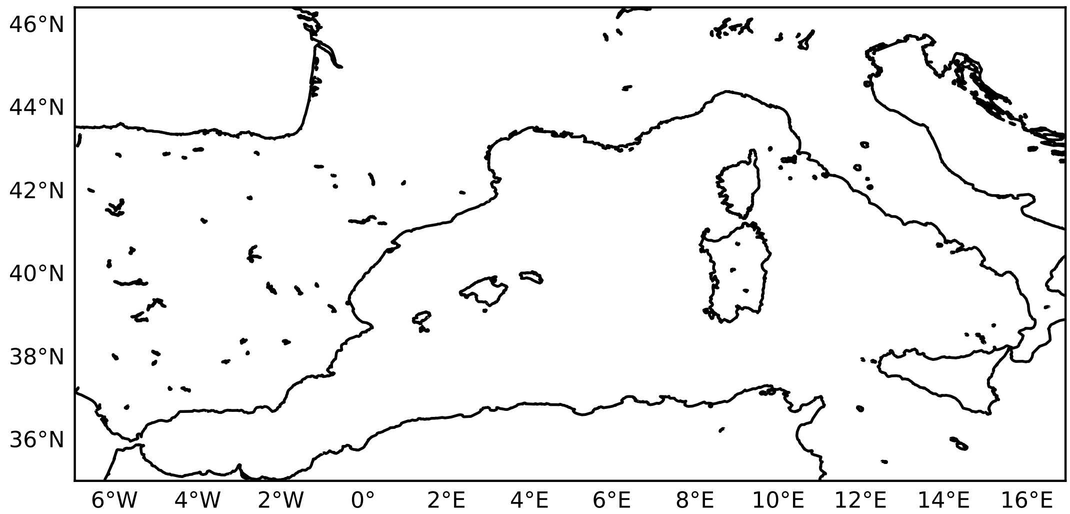

Figure 1. Domain centred over the western Mediterranean used to select case studies. See text for details.

For the selected cases, 5 different 50-member ensemble configurations were tested, including downscaling from the ECMWF ensemble prediction system, tailored bred vector perturbations (Hermoso et al. 2020) and stochastic perturbations to physics parameterisations. In particular, the version of stochastically perturbed physics tendencies (SPPT) implemented in WRF (Berner et al. 2015), which does not include perturbations to microphysics processes, together with additional perturbations to the National Severe Storms Laboratory (NSSL) 2-moment microphysics scheme (Mansell et al. 2010) as presented in Hermoso et al. (2021). In addition, combination of these methodologies were also tested. For each case study, a domain centred over the region of interest for each event and forecast are run for a lead time of 30 h, leaving the first 6 h for a spin-up period.

Results were analysed in terms of diversity by means of ensemble diversity (Bretherton et al. 1999). This value of this metric is comprised in the range [1,*N*], being *N*, the number of ensemble members and allows us to effectively quantify the degree of diversity of the ensemble because modifications to perturbation amplitude do not alter ensemble dimension. Results for this quantity reveal a substantial impact of stochastic perturbations at low levels that decreases for upper levels (Fig. 2). The larger impact of stochastic perturbations at lower levels can be related to the fact that these perturbations affect boundary layer and microphysics process, which have a greater influence at lower levels. By contrast, all other ensembles, which include initial and boundary conditions present more constant evolution of ensemble throughout the troposphere. However, only minor differences among the different ensemble are detected (Fig. 2).

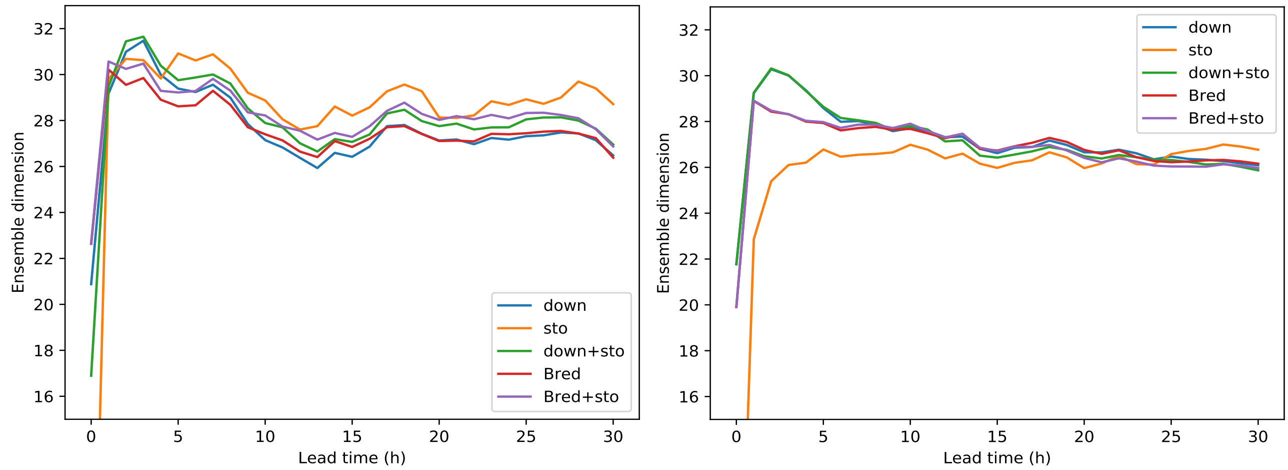

Figure 2. Ensemble dimension for the 5 ensemble configurations tested as a function of lead time: downscaling (blue), stochastic perturbations (orange), tailored bred perturbations (red), combination of dowscaling and stochastic perturbations (green) and combination of bred and stochastic (purple) for 1000 hPa (left) and 700 hPa (right).

Regarding verification, Fractions Skill Score (FSS; Roberts and Lean 2008) was used to assess the skill of the different ensemble strategies considering multiple spatial scales defined by squares of certain side length centred at each grid point (Fig. 3). GES DISC data were used as observation given its uniform coverage for all the study are and time period considered. A slight improvement is found for ensembles including model or small-scale (bred) perturbations at intermediate lead times for moderate precipitation accumulations (20 mm in 3 h). The lack of boundary conditions for the stochastic perturbations experiments is reflected in the decrease of FSS at the end of the forecast. However, for higher rainfall thresholds, perturbations downscaled from the ECMWF ensemble offer similar or even better skill than tailored bred perturbations.

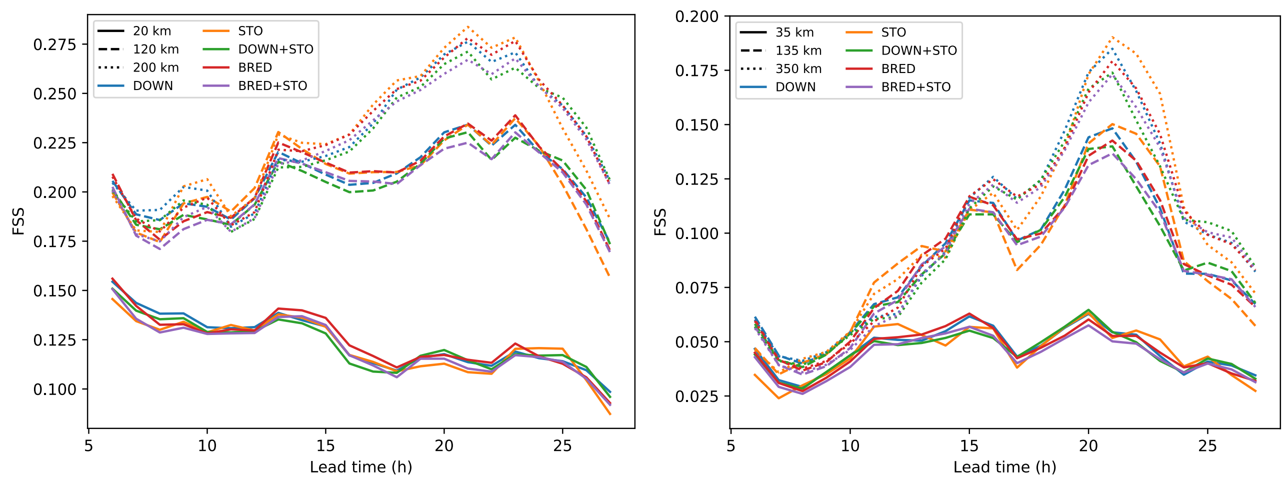

Figure 3. Fractions Skill Score for 3-h accumulated precipitation for the 5 ensemble experiments and different spatial scales: 20 km (solid), 120 km (dashed) and 200 km (dotted) as a function of lead time for 20 mm (left) and 35 mm (right) thresholds.

Results discussed in this report are still preliminary and an in-depth analysis of their statistical significance needs to be made. Furthermore, if more computational resources are available, the study will be expanded to increase the number of case studies and improve the statistical significance of the results.

References

Berner, J., Fossell, K. R., Ha, S.-Y., Hacker, J. P., & Snyder, C. (2015). Increasing the Skill of Probabilistic Forecasts: Understanding Performance Improvements from Model-Error Representations. *Monthly Weather Review*, *143*(4), 1295–1320. https://doi.org/10.1175/MWR-D-14-00091.1

Bretherton, C. S., Widmann, M., Dymnikov, V. P., Wallace, J. M., & Bladé, I. (1999). The effective number of spatial degrees of freedom of a time-varying field. *Journal of Climate*, *12*(7), 1990–2009. https://doi.org/10.1175/1520-0442(1999)012<1990:TENOSD>2.0.CO;2

Hermoso, A., Homar, V., Greybush, S. J., & Stensrud, D. J. (2020). Tailored Ensemble Prediction Systems: Application of Seamless Scale Bred Vectors. *Journal of the Meteorological Society of Japan. Ser. II*, *98*(5). https://doi.org/10.2151/jmsj.2020-053

Hermoso, A., Homar, V., & Plant, R. S. (2021). Potential of stochastic methods for improving convection-permitting ensemble forecasts of extreme events over the Western Mediterranean. *Atmospheric Research*, *257*, 105571. https://doi.org/10.1016/j.atmosres.2021.105571

Huffman, G. J., Stocker, E. F., Bolvin, D. T., Nelkkin, E. J., Tan, J. (2019). GPM IMERG Early precipitation L3 half hourly 0.1 degree x 0.1 degree V06, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC). 10.5067/GPM/IMERG/3B-HH-E/06

Mansell, E. R., Ziegler, C. L., & Bruning, E. C. (2010). Simulated electrification of a small thunderstorm with two-moment bulk microphysics. *Journal of the Atmospheric Sciences*, *67*(1), 171–194. https://doi.org/10.1175/2009JAS2965.1

Roberts, N. M., & Lean, H. W. (2008). Scale-selective verification of rainfall accumulations from high-resolution forecasts of convective events. Monthly Weather Review, 136(1), 78-97. https://doi.org/10.1175/2007MWR2123.1