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	2020
Project Title:	Exploring the predictability limits of severe weather in the western Mediterranean
Computer Project Account:	SPESHOMA
Principal Investigator(s):	Victor Homar
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)	12000000	12000000	22000000	12430116.14
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 extreme events over the high populated Western Mediterranean area in order to mitigate their devastating effect on society and economy. The specifics of the Mediterranean basin, characterized by extensive areas 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. Given the highly nonlinear processes acting on the development and evolution of convective systems, a great impact in terms of ensemble diversity and skill is expected from stochastic physics approaches. The potential of these cutting-edge ensemble prediction techniques to improve the forecast of socially relevant aspects of extreme events, such as intensity, position and timing is examined.

Summary of problems encountered (10 lines max)

None, except for the limited resource availability with respect to the high computational cost of the high resolution ensemble and data assimilation experiments. The issue is currently solved after the recent acceptance of the request for additional resources.

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

The results obtained for EnKF and stochastic parameterizations ensemble experiments for a flash flood episode occurred in Eastern Spain on 12-13 September 2019 suggest particular strategies to improve their performance.

In addition, testing modifications to the stochastic parameterizations implemented in WRF, such as perturbations to independent physics tendencies or perturbations to parameters within the microphysics scheme is planned.

List of publications/reports from the project with complete references

None to date

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 this special project have been used to study the predictability of two recent flash flood events in Mediterranean Spain by means of cutting-edge ensemble generation strategies.

Predictability of the Flash flood of 9 October 2018 in Sant Llorenç

The first case studied is a flash flood event occurred on 9 October 2018 in Sant Llorenç (Mallorca). The consequences of the torrential precipitation event with accumulations exceeding 400 mm in 6h and the subsequent flash flood were catastrophic including 13 casualties and estimated economic losses of 91 M€ (Lorenzo-Lacruz et al., 2019).

The small scale of the convective system involved in this episode and the remarkably small area of the catchment (23.4 km^2) require high resolution forecasts and advanced ensemble generation strategies in order to produce an accurate representation of the relevant aspects of the convective event. Accurate predictions are crucial to guide civil protection action to mitigate the impacts of such events. In this sense, the evaluation of the performance of high resolution ensemble forecasts applied to this event is key to gain insight on the predictability limit of these events. Indeed, intense nonlinearities associated to small scale mechanisms (Zhang et al., 2015) reduce the predictability horizon to a few hours.

In order to investigate the predictability of this event, 50-member ensemble experiments based on dynamical downscaling of the ECMWF-EPS, multiphysics, stochastic parameterizations using SPPT (Berner et al., 2015) or SPP (Jankov et al., 2017) and EnKF were designed. Owing to the small size of the studied catchment, high resolution was required to be able to obtain accurate precipitation forecasts at catchment scale. Therefore, a 900 m horizontal resolution domain centred over the Balearic Islands was defined.

Ensemble experiments started on 8 October 00 UTC using the different above mentioned techniques showed poor performance as few members produce substantial precipitation amounts over the area of interest (Fig. 1a). Although some ensemble members indicate the potential for a heavy precipitation event, with precipitation accumulations higher than 250 mm in 12 hours (Fig. 1b), at approximately 30 km from the centre of the catchment, these forecasts do not adequately reproduce the location, timing and intensity of the precipitation systems. These results confirm the extraordinary challenges that hydro-meteorological forecasters and civil protection managers currently face to predict Mediterranean flash floods.

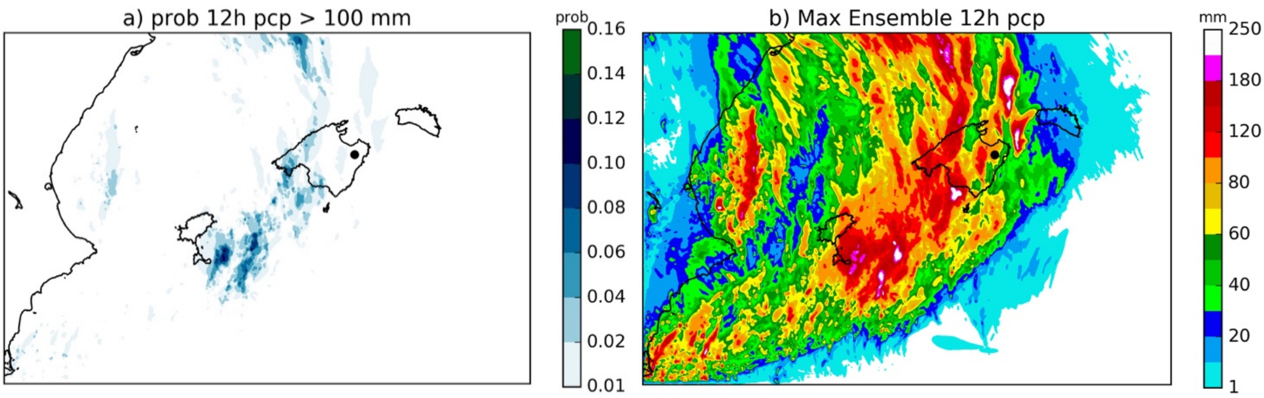

Figure 1. a) Probability of 12h accumulated precipitation (9 Oct 2018 12 UTC - 10 Oct 2018 00 UTC) > 100 mm for an ensemble experiment combining downscaling and SPPT perturbations. b) Maximum ensemble 12h accumulated precipitation.

The extremely low predictability of this event motivated an analysis based on radar data assimilation. The ability of an EnKF ensemble to reproduce the event as a function of lead time was tested. Initial conditions were obtained from the assimilation of radar observations, and simulations were started at different times in order to estimate the predictability horizon for this extreme event. Results obtained showed the capacity of a radar based EnKF to reproduce the event with remarkable accuracy for short lead times (Fig. 2). These encouraging results highlight the potential of data assimilation techniques to overcome the challenges associated to convective scale forecasting.

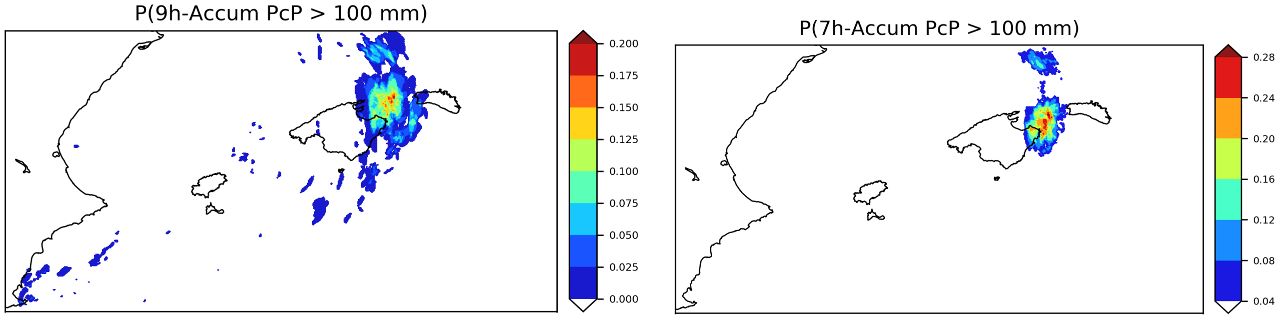

Figure 2. Probability of total accumulated precipitation exceeding 100 mm for experiments started on 9 October 2018 15 UTC (left) and 17 UTC (right).

Application of EnKF and stochastic physics to the 12-13 September 2019 flash flood in Eastern Spain

A long lasting heavy precipitation episode affected Eastern Spain on 12 and 13 September 2019 causing disastrous effects including 7 fatalities and economic losses in excess of 400 M€. The performance of different ensemble generation strategies including initial and boundary condition perturbation (PILB) and model error sampling by means of multiphysics (MPS) and stochastic schemes (STO) was tested. Additionally, an EnKF experiment consisting in the assimilation of conventional observations and atmospheric motion vectors to reduce large scale errors and vertical profiles of humidity and temperature from polar satellites (POES) to reduce convective scale errors. All ensembles consisted of 50 members.

A domain centred over the Western Mediterranean with 2.5 km horizontal resolution was defined. Given the large temporal extension of the episode, ensemble experiments were split to cover the full duration of the episode. Thus, different forecasts were started on 11 and 12 September 2019 at 18 UTC with a lead time of 30 hours.

Results revealed the potential of EnKF to improve the skill of short-range probabilistic forecasts, especially during a phase of the episode which was poorly forecasted by other techniques as displayed by the ROC (Fig. 3a). In addition, the quantitative precipitation forecasts produced by the different ensembles were coupled to a hydrological model in order to provide flash flood forecast assessment. EnKF outperformed other strategies for most of the catchments studied, showing higher exceedance probability thresholds.

On the other hand, ensemble strategies accounting for model error exhibited better performance, particularly for STO during the phase of the episode in which orographic interaction is more important (Fig. 3b). This motivated the design of modifications to the stochastic parameterizations currently implemented in the WRF model which could improve the ensemble performance in extreme events.

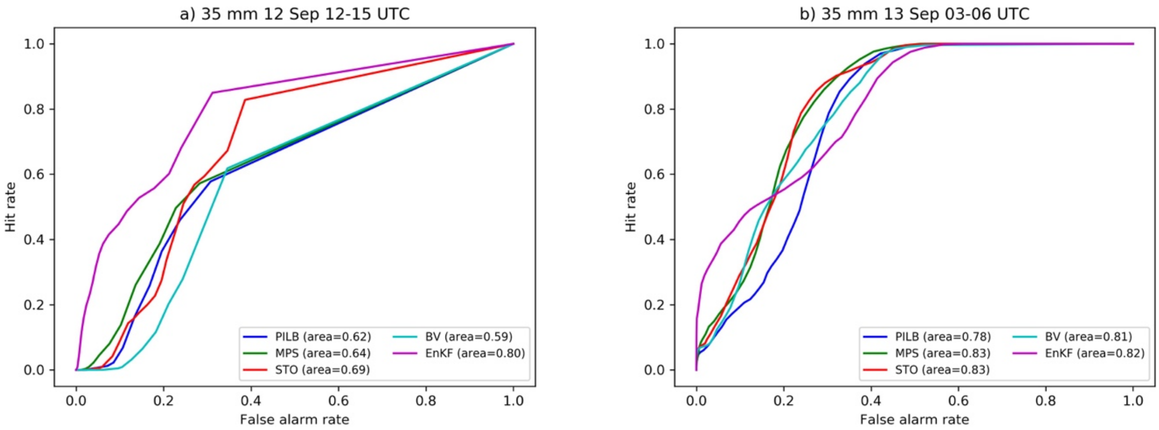

Figure 3. ROC for 3h accumulated precipitation for a) 12 Sep 12-15 UTC, b) 13 Sep 03-06 UTC for a 35 mm threshold.

The modifications proposed include perturbing individual parameterizations tendencies, rather than the full tendency as done in SPPT, and introduce stochastic perturbations to some parameters in the microphysics scheme. Preliminary tests indicated the potential impact that microphysics perturbations can have in heavy precipitation episode as most precipitation vanished when the latent heat release from the microphysics was turned off (Fig. 4). Additional tests are currently being carried out in order to adjust the parameters in stochastic schemes and assess the impact of the new proposed techniques on individual ensemble members before designing the ensemble experiments. These experiments based on modifications on stochastic schemes are part of the activity plan proposed in the resources extension request.

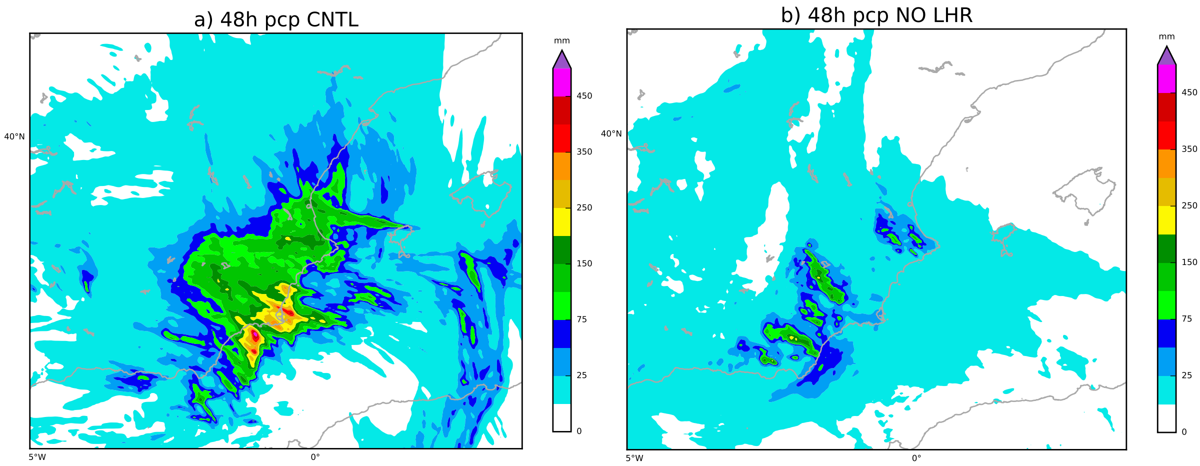

Figure 4. 48h accumulated precipitation (12 Sep 2019 00 UTC - 14 Sep 2019 00 UTC) for a) control simulation and b) simulation with latent heat release from microphysics turned off.

References

Berner, J., Fossell, K. R., Ha, S. Y., Hacker, J. P., and Snyder, C., 2015: Increasing the skill of probabilistic forecasts: Understanding performance improvements from model-error representations. Mon. Wea. Rev., 143, 1295–1320.

Jankov, I., Berner, J., Beck, J., Jiang, H., Olson, J. B., Grell, G., Smirnova, T. G., Benjamin, S. G., Brown, J. M., Jankov, I., Berner, J., Beck, J., Jiang, H., Olson, J. B., Grell, G., Smirnova, T. G., Benjamin, S. G., and Brown, J. M., 2017: A Performance Compar- ison between Multiphysics and Stochastic Approaches within a North American RAP Ensemble, Mon. Wea. Rev., 145, 1161– 1179

Lorenzo-Lacruz, J., Amengual, A., García, C., Morán-Tejeda, E., Homar, V., Maimó-Far, A., Hermoso, A., Ramis, C., and Romero, R., 2019: Hydro-meteorological reconstruction and geomorphological impact assessment of the October 2018 catastrophic flash flood at Sant Llorenç, Mallorca (Spain). NHESS, 19, 2597-2617.

Zhang, Y., Zhang, F., Stensrud, D. J., and Meng, Z., 2015: Practical predictability of the 20 May 2013 Tornadic thunderstorm event in Oklahoma: Sensitivity to synoptic timing and topographical influence. Mon. Wea. Rev., 143, 2973–2997.