SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	High-impact precipitation events prediction with a convection-permitting model nested in the ECMWF ensemble
Computer Project Account:	SPITCAPE
Start Year - End Year :	2016 - 2018
Principal Investigator(s)	Valerio Capecchi
Affiliation/Address:	LaMMA Consortium - Environmental Modelling and Monitoring Laboratory for Sustainable Development Via Madonna del piano, 10, Sesto Fiorentino, Florence, Italy
Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

As stated in the Request Form, the main motivation of the SPITCAPE Special Project is to understand the information content of current numerical ensembles, both at global and regional scales, in re-forecasting past high impact weather events occurred in recent years in Italy.
The goal is achieved by addressing the two following questions:
1) How many days in advance a HPE (High Precipitation Event) can be foreseen by using the global state-of-the-art ensembles?
2) Which is the added value of running a convection-permitting and high-resolution ensemble in terms of QPF (Quantitative Precipitation Forecast)?
The first question is addressed by looking at the ensemble spread of synoptic factors ten to two days in advance, while the second question is addressed by looking at the probability of precipitation occurring in a 24-hour period three to one day before the start of the intense rainfall.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

SBUs indicated in the Request Form were under-estimated, thus it was necessary to request additional resources to for all the three years of the Special Project. The lack of SBUS has been partially by-passed by reducing the length of the IFS forecast (forecast range was initially foreseen up to 15 days and was reduced to 10 days) and by running on the Principal Investigator’s computer facilities part of the WRF simulations.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

No problems were encountered.
As regards the reporting activity, I consider more straightforward to submit interim and final reports by the end of each year of the Special Project (ie in the case of the current project, the first report would be expected by the end of 2016 and the final report by the end of 2018).

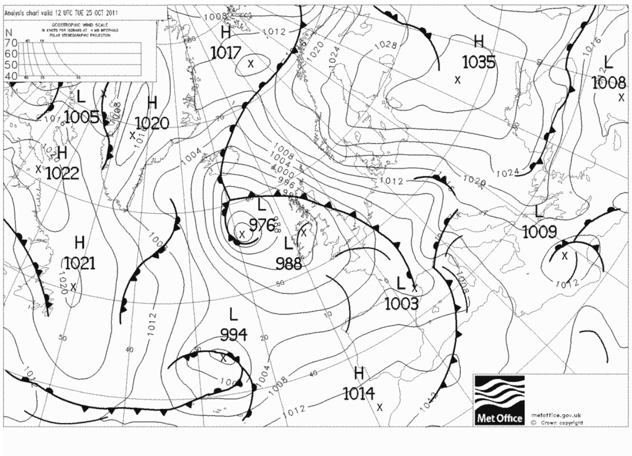
Summary of results of the current year (from July of previous year to June of current year)

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

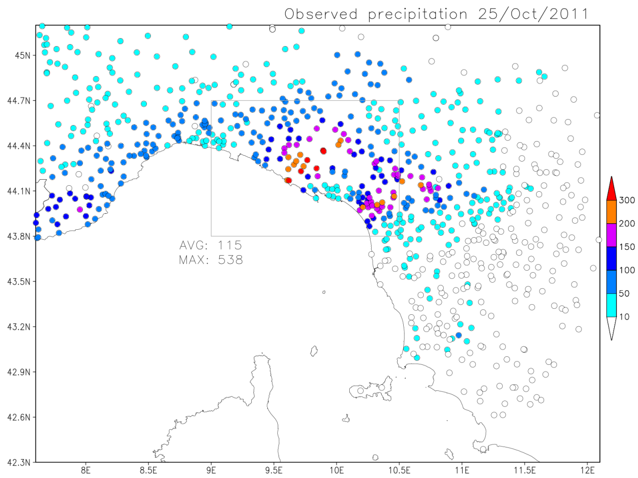
During the third year of the SPITCAPE Special Project (hereafter SPITCAPE-SP), global and limited-area convection-permitting ensemble forecasts (ENS and WRF-ENS respectively) were performed for the last case: the flooding of Genoa due to the Bisagno creek occurred on the 9th of October 2014. This HPE (High Precipitation Event) has been widely analysed in the recent scientific literature, as well as the other cases analysed in the first two years of the SPITCAPE-SP (see the bibliography cited in the Request Form).

To summarize the main differences or common features of the three HPEs, we report in Figures 1, 2 and 3 a synthetic synoptic map, and the 24-hour cumulated precipitation map from data registered by the automatic weather stations in the area of interest (see the gray inset rectangle of panel (b) in each Figure).

- Cinque Terre 25 Oct 2011: this case was characterised by
  - large depression off Ireland's western shore;
  - low-level blocking anticyclone over eastern Europe;
  - Low-level wind shear;
  - Precipitation maxima: 400 mm/12-hour and 150 mm/1-hour



(a)



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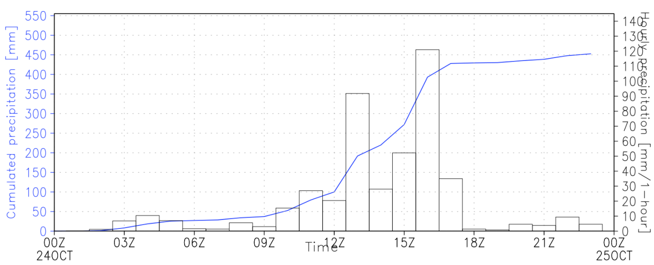
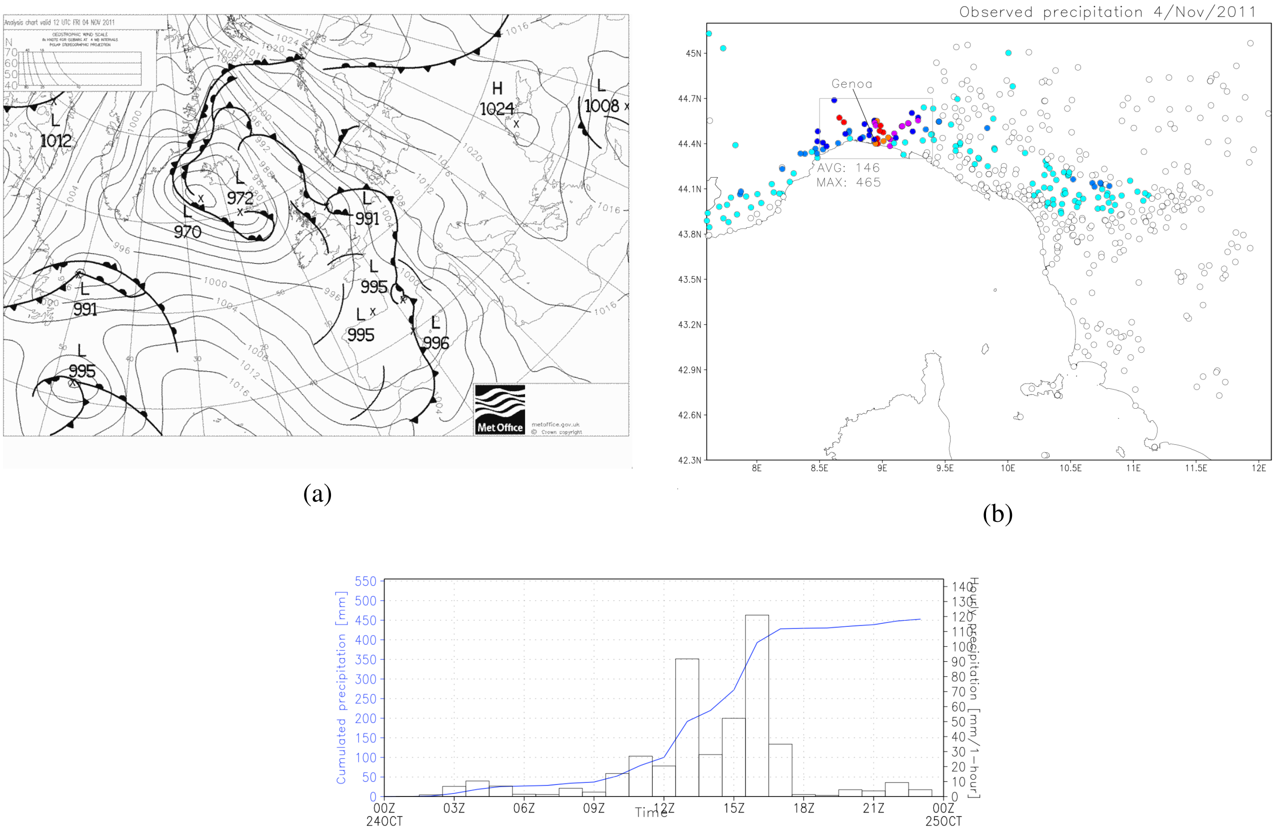


(c)

Figure 1: (a) Synoptic map at 12 UTC 25/October/2011, (b) rainfall cumulated in the 24-hour period ending at 00 UTC 26/October/2011 registered by AWS in the area of interest, (c) single pluviogram of a rain-gauge in the area of interest.

- Genoa 4 Nov 2011: this case has lots of common features with the Cinque Terre Event, but:
  - trough axis orientation is N-S

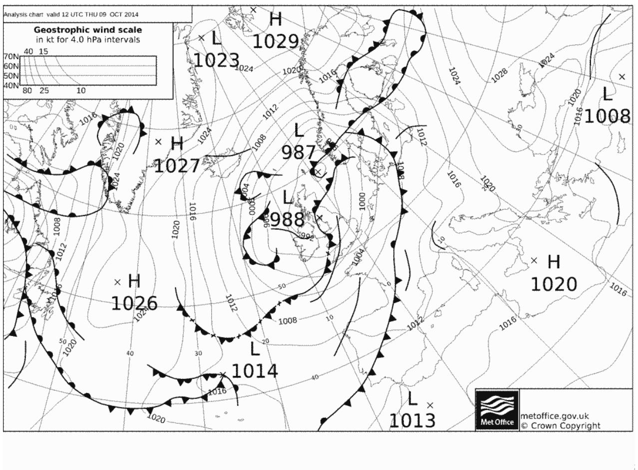
- triggering mechanism is the low-level convergence line
- Precipitation maxima: 450 mm/6-h



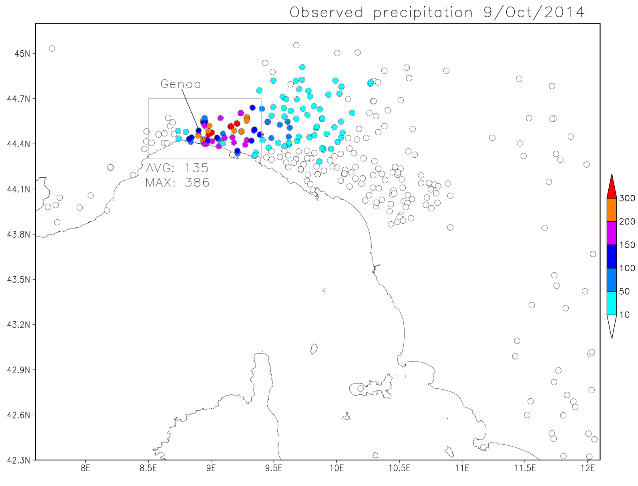
(a) (b) (c)

Figure 2: (a) Synoptic map at 12 UTC 4/November/2011, (b) rainfall cumulated in the 24-hour period ending at 00 UTC 5/November/2011 registered by AWS in the area of interest, (c) single pluviogram of a rain-gauge in the area of interest.

- Genoa 9 Oct 2014: this case was characterised by
  - Upper-level trough over Atlantic Ocean
  - Humid low-level flow over Med
  - V-shaped back-building MCS
  - Two rainfall peaks within the day of 9th of Oct
  - Precipitation maxima: 380 mm/24-hour and 130 mm/1-hour



(a)



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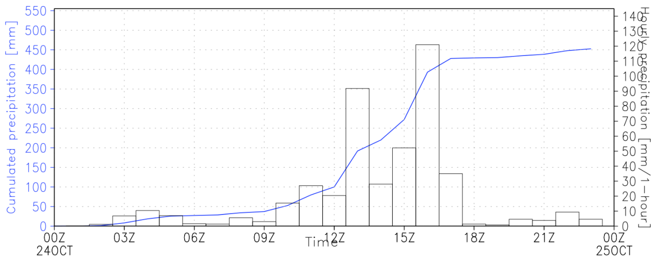
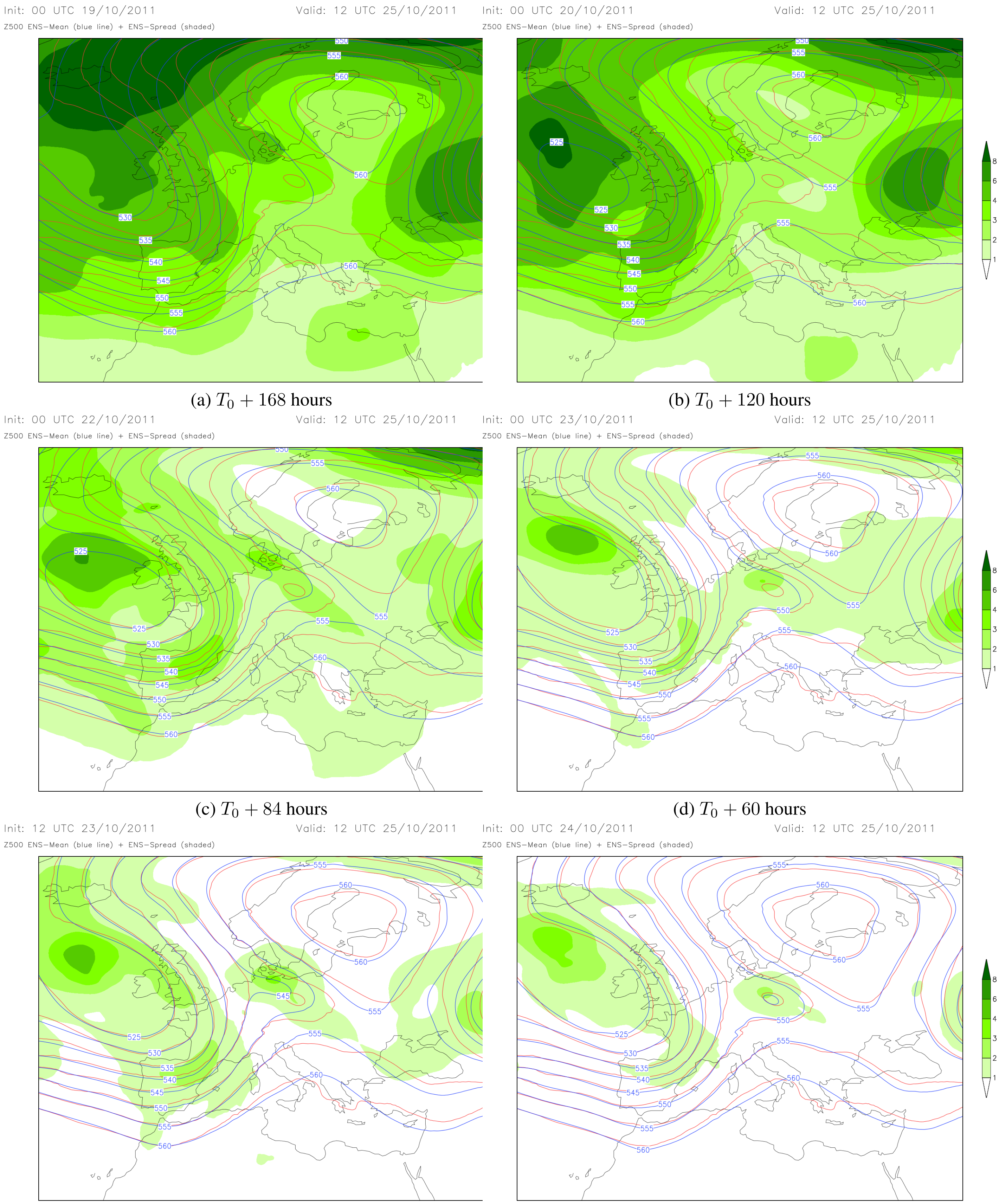


(c)

Figure 3: (a) Synoptic map at 12 UTC 9/October/2014, (b) rainfall cumulated in the 24-hour period ending at 00 UTC 10/October/2014 registered by AWS in the area of interest, (c) single pluviogram of a rain-gauge in the area of interest.

To evaluate the medium-term predictability of the three HPEs under exam, we report in Figures 4, 5 and 6 the Geopotential 500 hPa Ensemble spread and average for different forecast ranges.

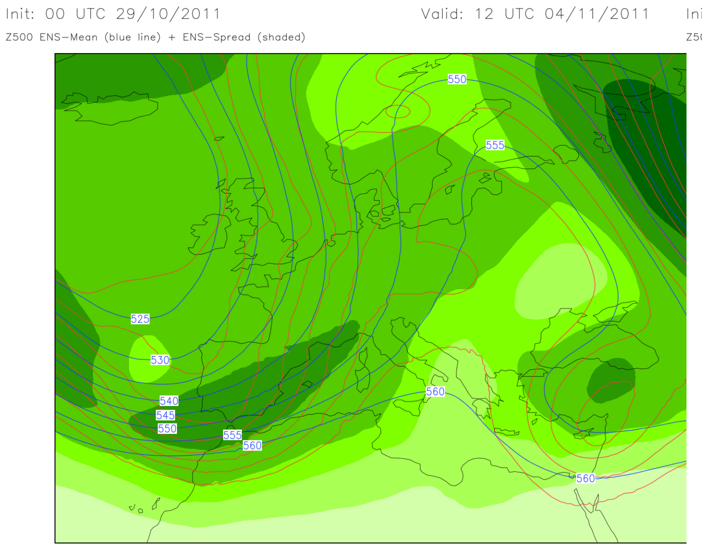


(a) $T_0 + 168$ hours (b) $T_0 + 120$ hours

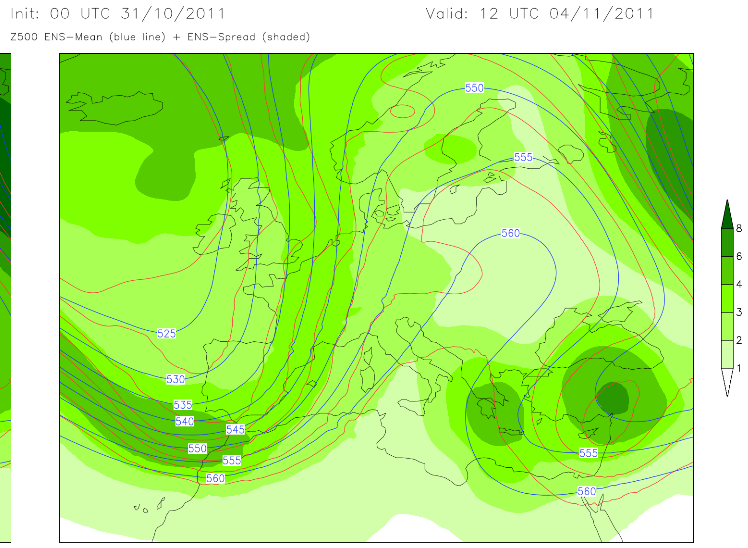
(c) $T_0 + 84$ hours (d) $T_0 + 60$ hours

(e) $T_0 + 48$ hours (f) $T_0 + 36$ hours

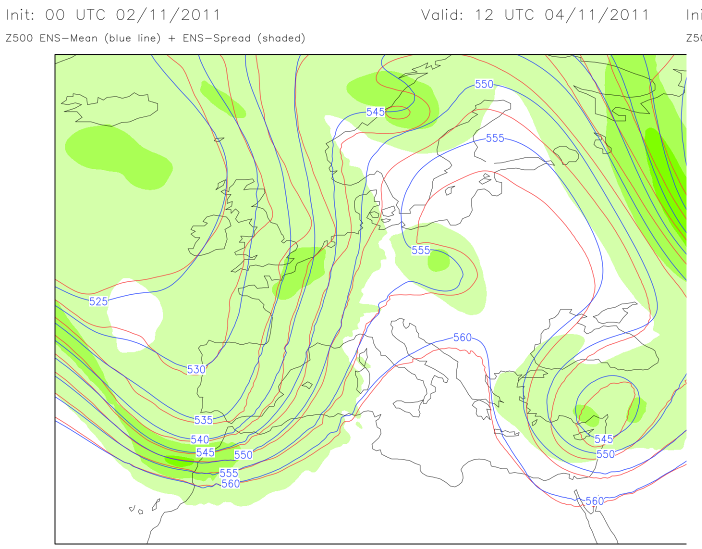
Figure 4: Cinque Terre 25/Oct/2011 case: 500-hPa geopotential height of ENS ensemble mean (blue lines) and spread (green shades) defined as standard deviation. Starting dates range from $T_0 + 168$ hours (panel a) to $T_0 + 36$ hours (panel f). Verification time is 12 UTC on 25 October 2011. Unit is decameter (dam). The red line is the ERA5 analysis. Contour levels of ensemble mean and analysis are from 525 to 560 every 5 dam.



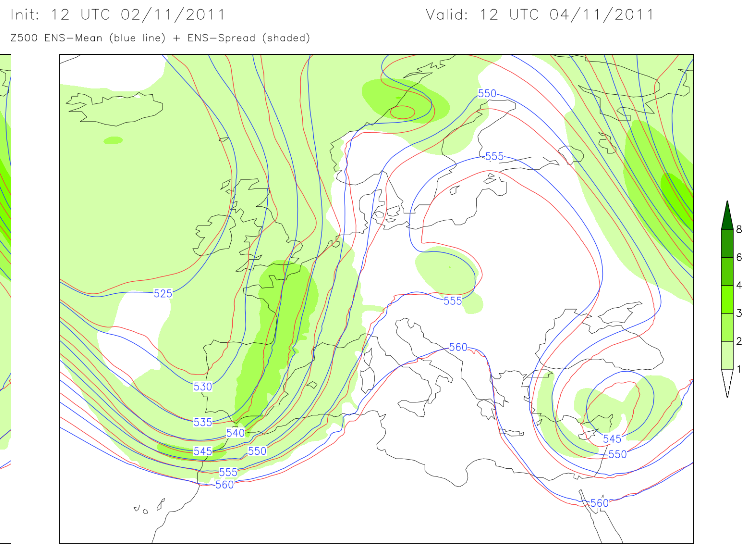
(a) $T_0 + 156$ hours



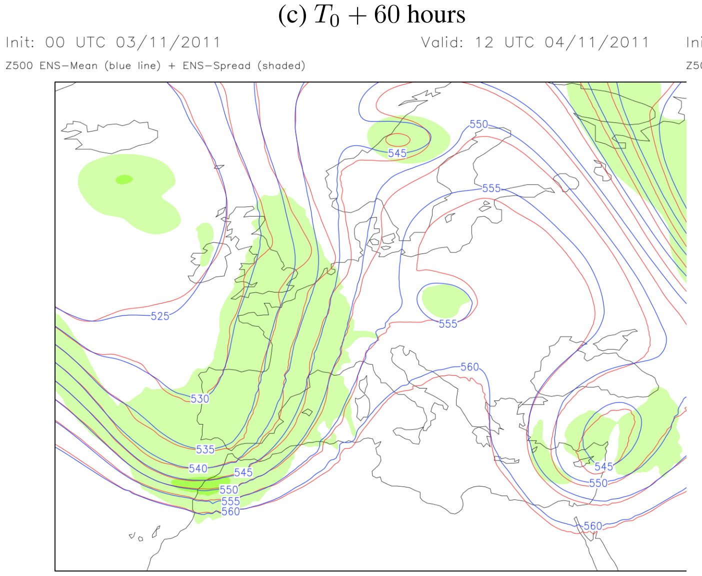
(b) $T_0 + 108$ hours



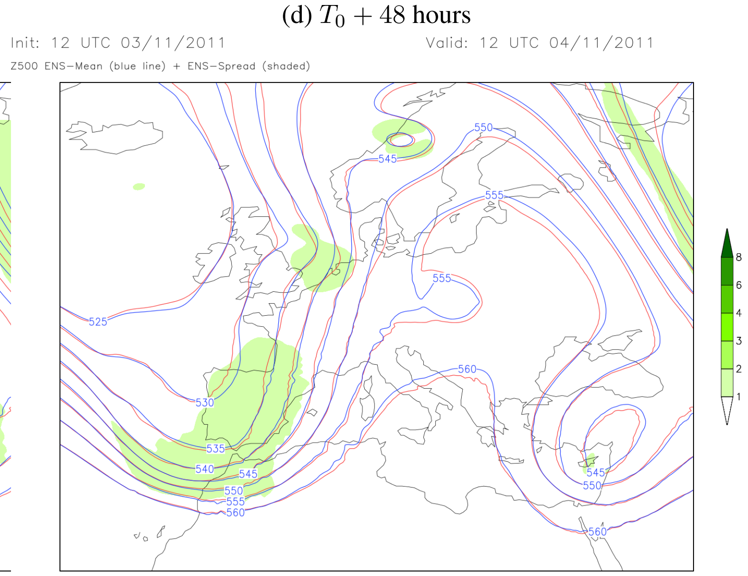
(c) $T_0 + 60$ hours



(d) $T_0 + 48$ hours

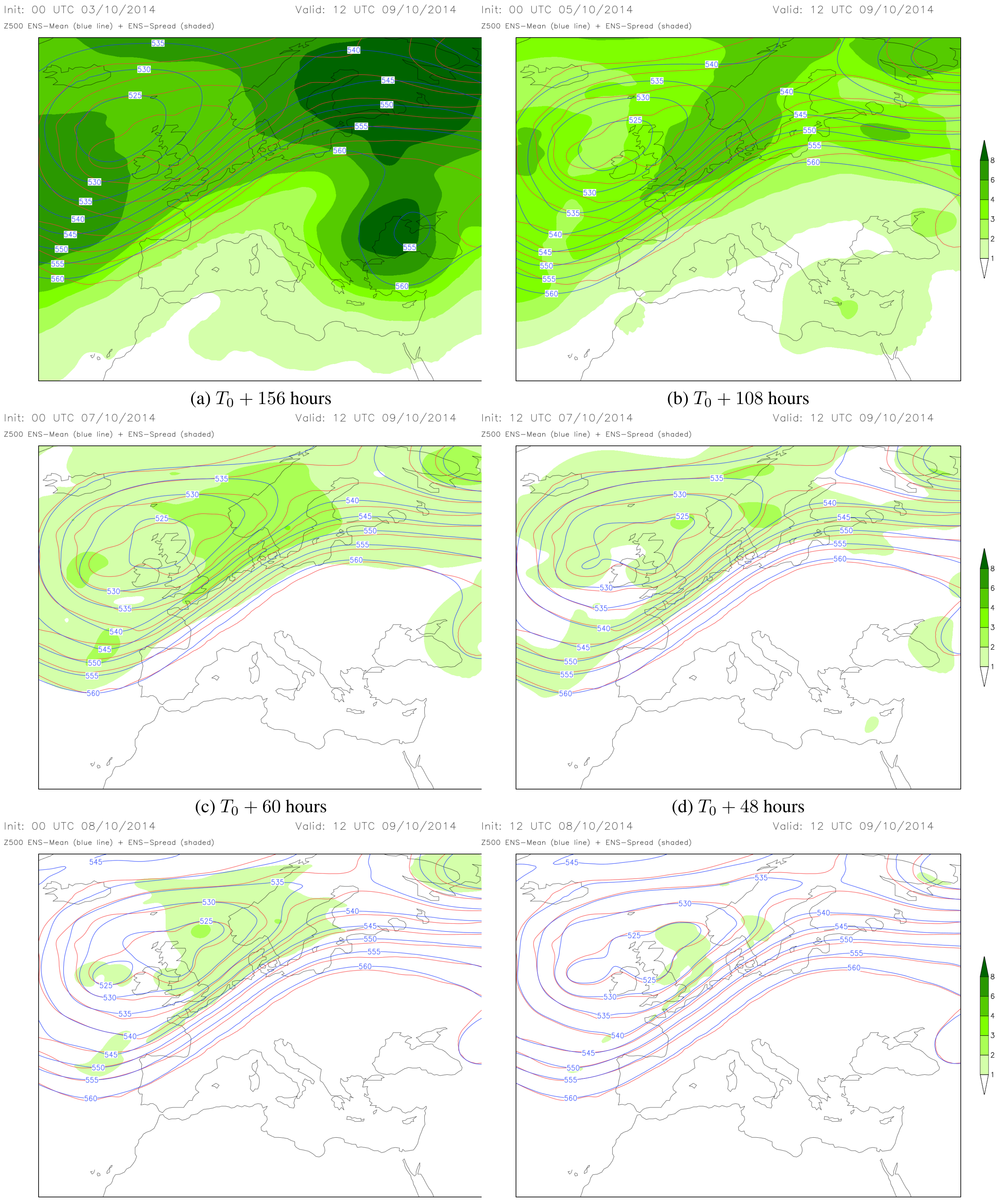


(e) $T_0 + 36$ hours



(f) $T_0 + 24$ hours

Figure 5: Genoa 4/Nov/2011 case: 500-hPa geopotential height of ENS ensemble mean (blue lines) and spread (green shades) defined as standard deviation. Starting dates range from $T_0 + 156$ hours (panel a) to $T_0 + 24$ hours (panel f). Verification time is 12 UTC on 4 November 2011. Unit is decameter (dam). The red line is the ERA5 analysis. Contour levels of ensemble mean and analysis are from 525 to 560 every 5 dam.



(a) $T_0 + 156$ hours

(b) $T_0 + 108$ hours

(c) $T_0 + 60$ hours

(d) $T_0 + 48$ hours

(e) $T_0 + 36$ hours

(f) $T_0 + 24$ hours

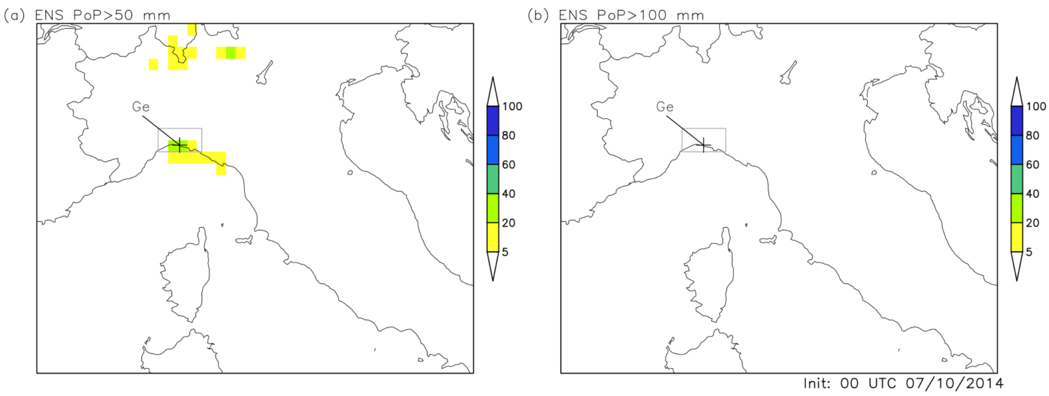
Figure 6: Genoa 4/Nov/2011 case: 500-hPa geopotential height of ENS ensemble mean (blue lines) and spread (green shades) defined as standard deviation. Starting dates range from $T_0 + 156$ hours (panel a) to $T_0 + 24$ hours (panel f). Verification time is 12 UTC on 9 October 2014. Unit is decameter (dam). The red line is the ERA5 analysis. Contour levels of ensemble mean and analysis are from 525 to 560 every 5 dam.

To evaluate the added value of running higher-resolution convective-permitting ensembles nested in global ensembles, we computed standard verification statistics. Table 1 reports the RMSE (root-mean-square error; the lower the better) of the ensemble QPF (quantitative precipitation forecast) given by the ensemble mean of both ENS and WRF-ENS, evaluated over the rain-gauges belonging to the inset gray rectangles displayed in panel (b) of Figures 1, 2 and 3. To compare observed data and model data, we picked the nearest-neighbor grid value.

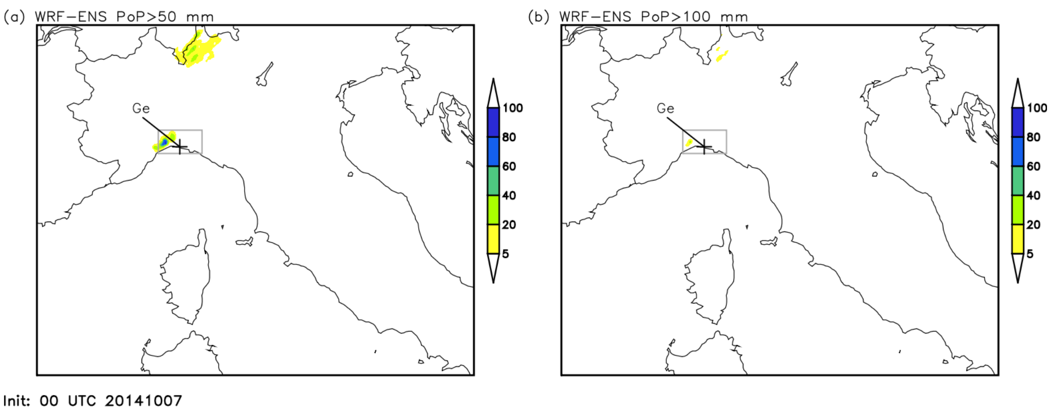
	Cinque Terre 25 Oct 2011		**Genoa 4 Nov 2011**		**Genoa 9 Oct 2014**	
Forecast range	**ENS**	**WRF-ENS**	**ENS**	**WRF-ENS**	**ENS**	**WRF-ENS**
T_0 +36 hours	106	107	133	156	164	176
T_0 +48 hours	114	127	130	151	165	169
T_0 +60 hours	112	113	138	159	169	189
T_0 +72 hours	121	112	135	146	171	153

Table 1: RMSE of QPF ensemble mean of both ENS and WRF-ENS evaluated for the rain-gauges in the area of interest. The cell highlighted with the green color indicates the best skill score for each event and for each forecast range.

To evaluate and compare the probabilistic skills of ENS and WRF-ENS, we calculated for all the three HPEs under exam, the probability of precipitation (PoP) exceeding predefined thresholds in a 24-hour period and by varying the starting dates. For sake of brevity and to have an idea of the differences that might arise between the ENS PoP values and the WRF-ENS ones, we show in Figure 7 the PoP maps for the 50-mm and 100-mm precipitation thresholds and for the last case analysed (that is Genoa 9 Oct 2014).



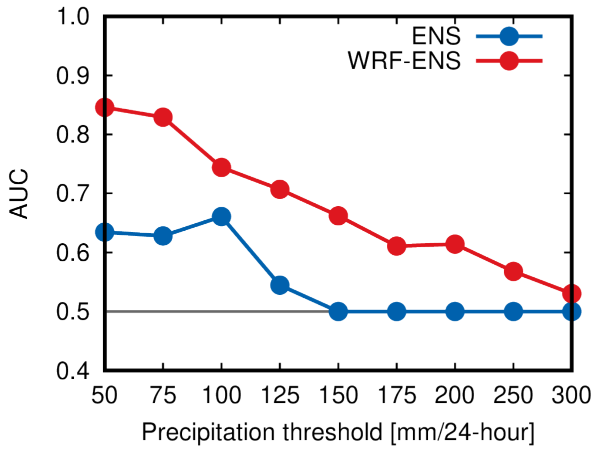
(a) ENS PoP for forecasts at $T_0 + 48$ hours



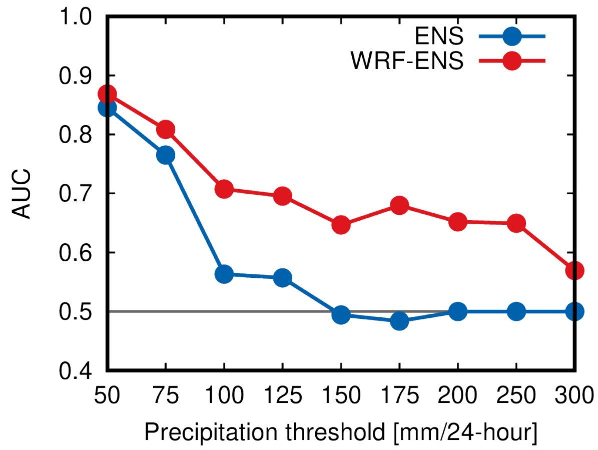
(b) WRF-ENS PoP for forecasts at $T_0 + 48$ hours

Figure 7: (a) Probability of precipitation (PoP) exceeding the 50-mm threshold (top left) and 100-mm threshold (top rigth) in the period 00 UTC on 9 October 2014 to 00 UTC on 10 October 2014 for ENS. (b) As in panel (a) but for WRF-ENS. Starting time of the forecasts is at 00 UTC on 7 October 2014.

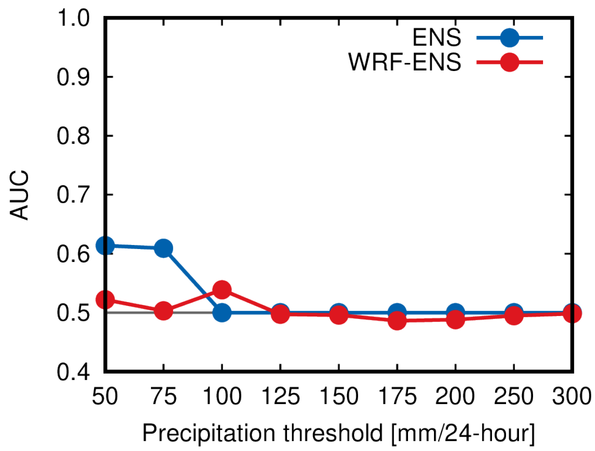
To further evaluate the probabilistic skills of ENS and WRF-ENS, in Figure 8, we show the ROC (relative operating characteristic) area. The ROC curve contrasts the hit rate (POD) versus false alarm rate (POFD), using a set of increasing probability thresholds to make the yes/no decision. The area under the ROC curve is frequently used as an index of the accuracy of an ensemble system to be able to discriminate between the occurrence and nonoccurrence of weather events; the higher the better, 1 is the upper limit and values below 0.5 indicate no skill. The values shown in Figure 8 are averaged over forecast ranges from $T_0 + 72$ hours to $T_0 + 36$ hours.



(a) ROC Area values - Cinque Terre 25 Oct 2011 case



(b) ROC Area values - Genoa 4 Nov 2011 case



(c) ROC Area values - Genoa 9 Oct 2014 case

Figure 8: Area under the relative operating characteristic curve (AUC) for ENS (blue lines) and WRF-ENS (red lines) for the Cinque Terre 25 Oct 2011 case (panel a), Genoa 4 Nov 2011 case (panel b) and Genoa 9 Oct 2014 case (panel c). On the X axis we report a set of increasing precipitation thresholds.

Looking at the plots and table shown above (in particular Table 1 and Figure 8), the main conclusions we can draw so far are:

- **ENS outperforms WRF-ENS** when considering ensemble mean precipitation prediction for forecast ranges ≤ 72 hours;
- **WRF-ENS is better than ENS** when looking at the ROC area for thresholds up to 250 mm (Cinque Terre 25 Oct 2011 and Genoa 4 Nov 2011 cases);
- **no skill** is found for the **Genoa 9 Oct 2014** case both for ENS and WRF-ENS (missing/misplacement of the triggering mechanism?). Further investigations are needed to understand the low ability of the ensembles to predict intense rainfall amounts for this HPE.

List of publications/reports from the project with complete references

No publication or report was published so far.
A poster containing the main results of the SPITCAPE Special Project 2016-2018 was presented at the “Using ECMWF's Forecasts” (UEF2019) Meeting held in June 2019 at ECMWF.
An article is currently under preparation.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

A continuation of the SPITCAPE Special Project 2016-2018 has been granted of additional SBUs. The purpose for the years 2019-2021 (SPITCAPE Phase 2) is to revisit the study cases addressed in the framework of the SPITCAPE Phase 1, by using two additional numerical models (the MOLOCH and Meso-NH models) for the convection-permitting simulations. The comparison between results obtained with these two models and those obtained previously with the WRF model will contribute to the debate regarding the reliability of these regional models and their strengths and weaknesses with respect to: (I) the accuracy of the results for the three events considered, (II) the integration with ECMWF products, (III) the ease of implementation considering the ensemble approach and (IV) the computational costs in view of a potential use for operational forecasting activities.