Convection permitting EPS on Madeira cases

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Contents

1. Introduction

The Madeira island is a very challenging area for weather forecasting, because it is small (50x20 km) and very steep, with a maximum altitude of 1851 m – Pico do Areeiro (figures 1/2).

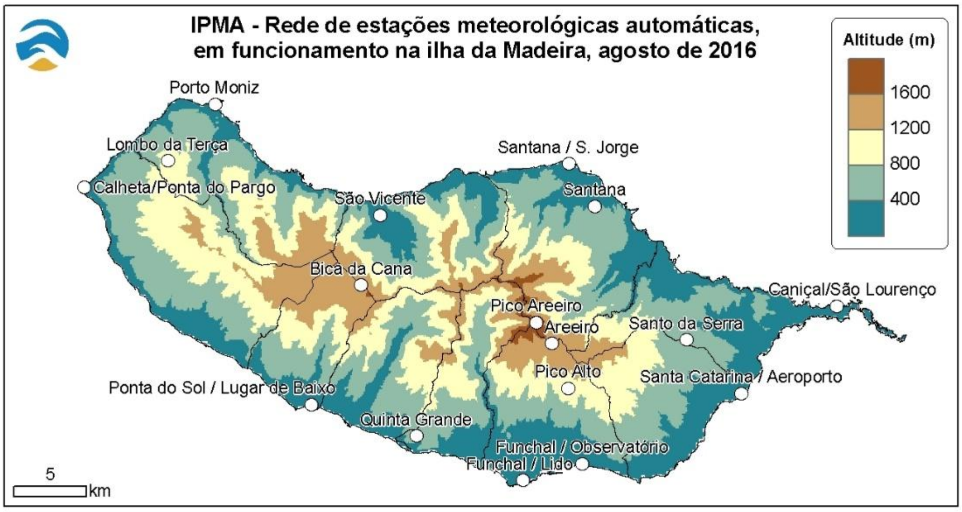


Figure 1 – Orography and weather stations in Madeira, in august 2016.

Figure 2 – Pico do Areeiro (1850 m), at 12 UTC in June 20th, 2017.

Typical issues affecting the Madeira region include:

a) the orographic enhancement of the precipitation, with amounts frequently exceeding 150 mm/24h at altitudes above 1000 m;
b) large amounts of precipitation arising from excessively active convection;
c) incorrect location of active areas of precipitation.

IPMA runs the AROME model operationally (CY38T1) – hereafter AROME-MAD, as a downscaling from ARPEGE, with forecasts up to 48h, twice a day, using the domain shown in figure 3. Figure 4 shows the land sea-mask and model orography, which underestimates the real altitude by around

500 m. Please note that the full archipelago is comprised of the Madeira island, the Porto Santo island (50 km to the northeast), the Deserted islands (30 km to the southeast) and the Wild Islands (290 km to the southeast).

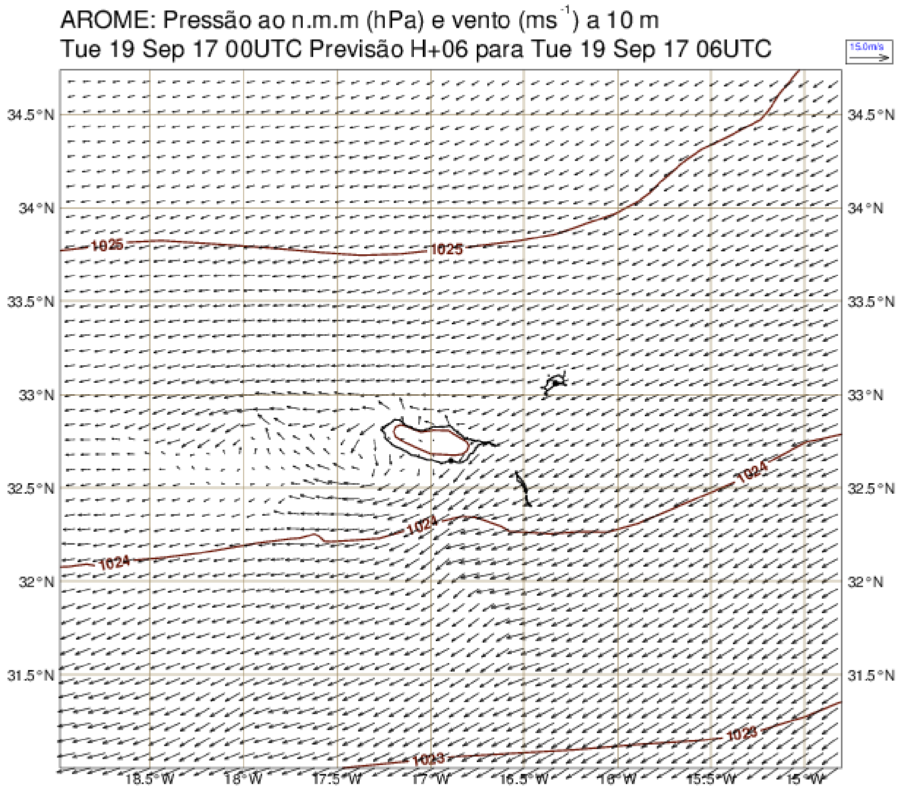


Figure 3 – AROME-MADEIRA: operational domain at IPMA.

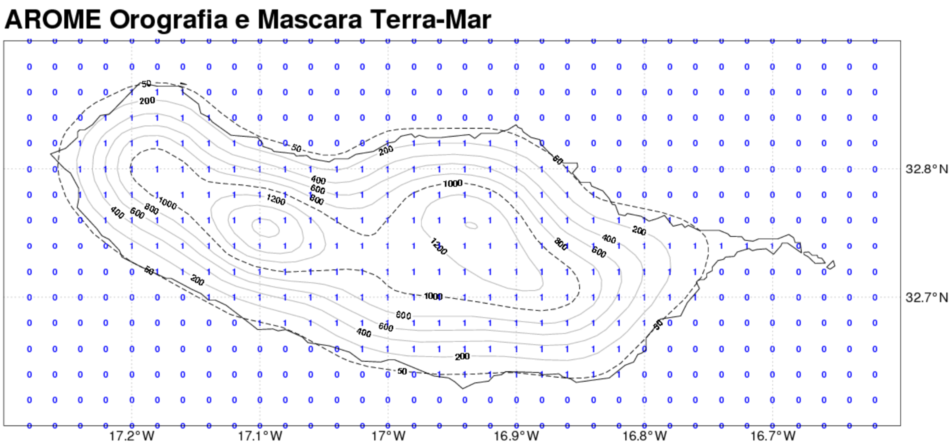


Figure 4 – AROME-MADEIRA (AROME-MAD): land sea mask and model orography.

To assess the benefits of a very high-resolution ensemble system, three cases were selected and the RMI-EPS (based on HarmonEPS cy38h1.1) was run over Madeira by RMI (Geert Smet), using ECMWF-EPS as the parent model. The EPS system runs ALARO and AROME with a horizontal resolution of 2.5 km and 65 vertical levels. The forecast range is 36h. Further details on the RMI-EPS prototype are given in Smet (2017). Figure 5 shows the domain used in this study.

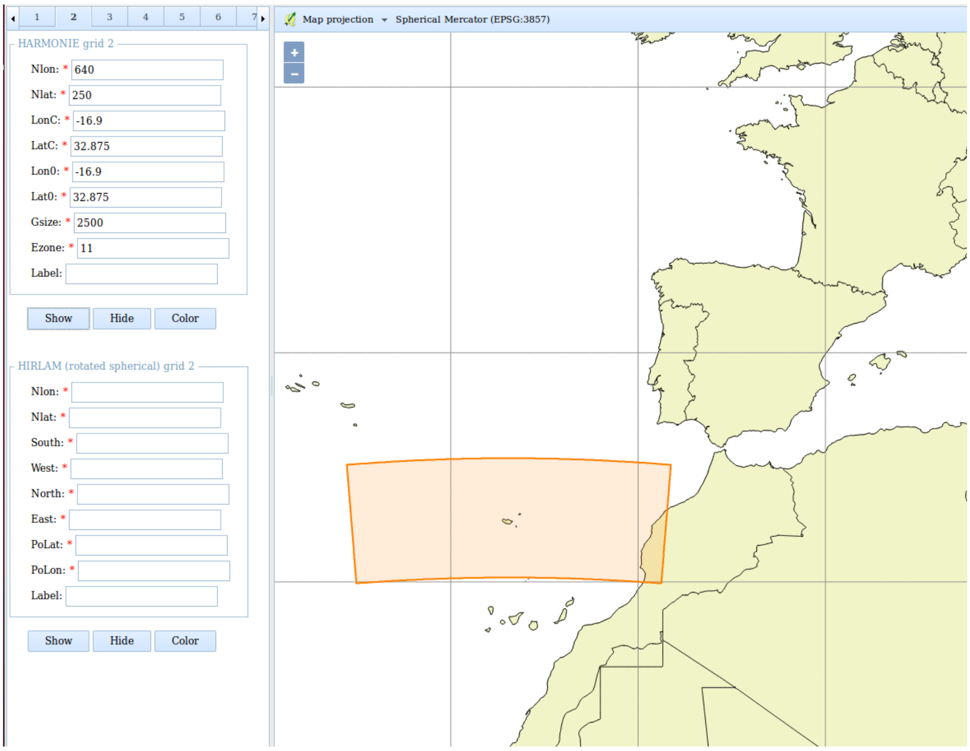


Figure 5 – Madeira domain used in RMI-EPS.

In chapter 2 the results for the three cases are shown and in chapter 3 some final remarks are made.

2. Weather events

2.1 Heavy convective precipitation: 20151016 – 15:30-17:30

On the 16th October 2015, the weather in Madeira was affected by a low pressure system centred to the southwest of the archipelago, which induced a strong, warm and moist south-westerly flow (figure 1.1).

Figure 1.1 – HRV Composite Satellite image, from early afternoon, valid on 16th October 2015 (available at https://worldview.earthdata.nasa.gov).

Figure 1.2 shows the 24h observed precipitation in Madeira on the 16th October 2015. The values show that the orography did not play any significant role in this event, as the precipitation was similar at low level and in the mountains. The observations in Madeira were usually between 15-50 mm/24h without any severe weather reported. However, there were reports, with video available, from employees working for an environmental agency, of severe weather in the Deserted islands (just southeast of Madeira), with heavy precipitation and accumulations around 100 mm/2h.

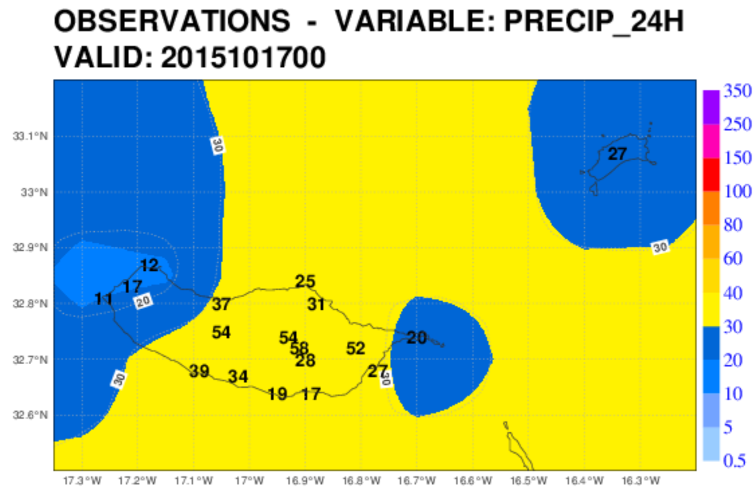


Figure 1.2 – 24h observed precipitation [mm] in Madeira, on the 16th October 2015.

Figure 1.3 shows the timeseries of hourly precipitation in selected locations in the south coast, with rain falling throughout the day, at rates around 5 mm/1h. The maximum precipitation rate was around 15 mm/1h, in a location in the southwest of Madeira.

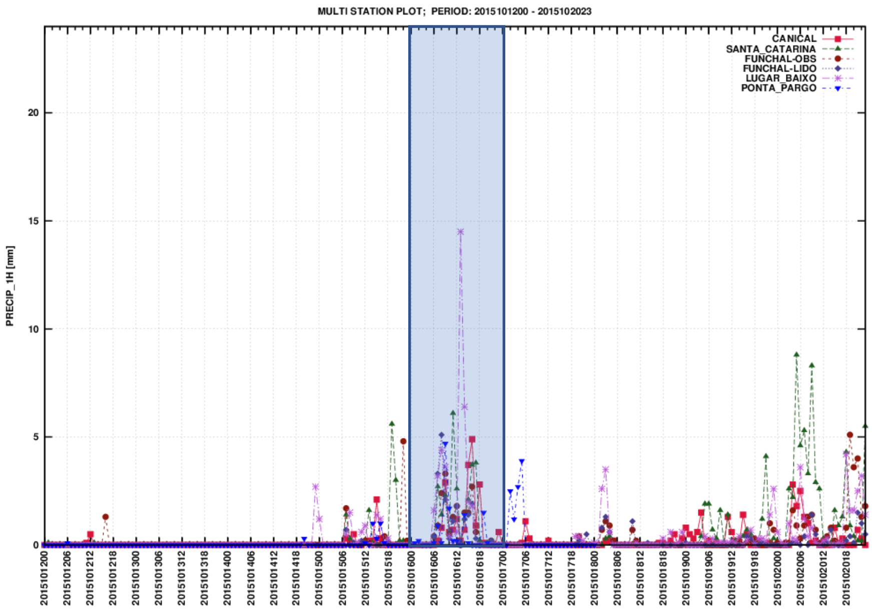


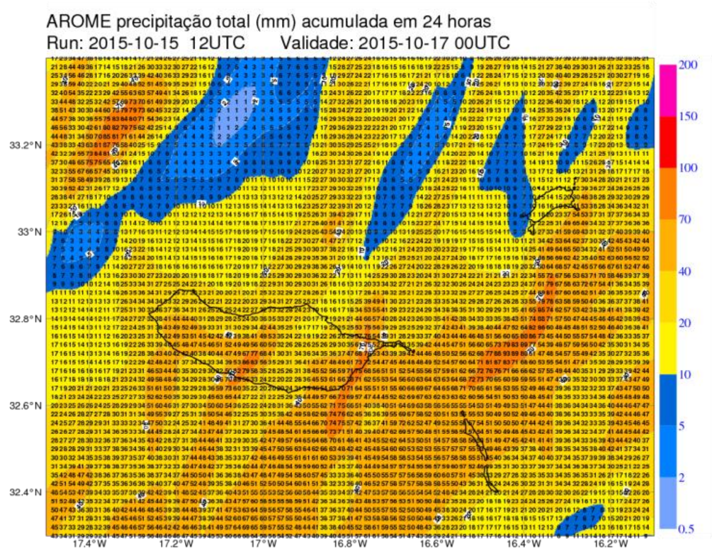
Figure 1.3 – Hourly observed precipitation in weather stations located in the south coast of Madeira, between 00 UTC 12th and 21st October 2015. The 16th October is enhanced in the plot.

The AROME-MAD forecasts suggested heavy precipitation in the area, as summarized and shown in table 1.1, but there was quite a large variability regarding the location of the highest accumulations.

Table 1.1 – Summary of precipitation forecasts from three different AROME-MAD forecasts.

Forecast from	**Madeira Island**	**Deserted islands**
00 UTC 20151015	Heavy precipitation	Almost no precipitation
12 UTC 20151015	Moderate precipitation	Moderate precipitation
00 UTC 20151016	Light precipitation	Heavy precipitation

Figure 1.4 shows the 24h precipitation accumulation from AROME-MAD from the 12 UTC October 15th run (upper panel) and from the 00 UTC run from October 16th, 2015 (lower panel). The 12 UTC forecast suggests widespread heavy precipitation, with large areas having cumulations over 40 mm/24h. In the 00 UTC run, the larger amounts are over the Atlantic, namely to the southeast of the Madeira island and over the Deserted islands. However, because of the variability in the location of the heaviest precipitation and the fact that it was convective, the weather forecast centre issued an orange warning in Madeira.



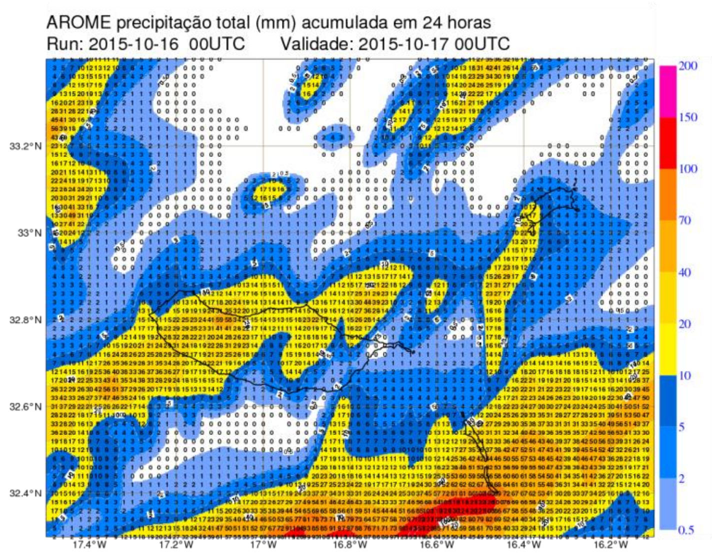


Figure 1.4 – 24h precipitation forecast from the 12 UTC October 15th (upper panel) and the 00 UTC AROME-MAD run from October 16th, 2015 (lower panel).

The RMI-EPS system was run for this case and figure 1.5 shows the probability of precipitation exceeding 60 mm/6h. Figure 1.6 shows the 3h precipitation from the (control) ALARO 00 UTC run from October 16th, 2015. Figure 1.7 is similar, with the model being AROME.

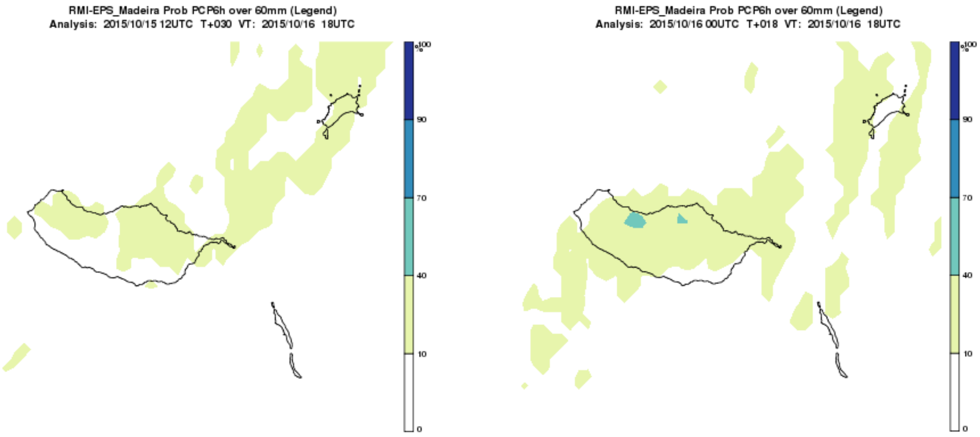


Figure 1.5 – Probability of precipitation equal or above 60mm/6h, from the RMI-EPS 12 UTC (left) run October 15th and the 00 UTC (right) run from October 16th, valid at 18 UTC October 16th.

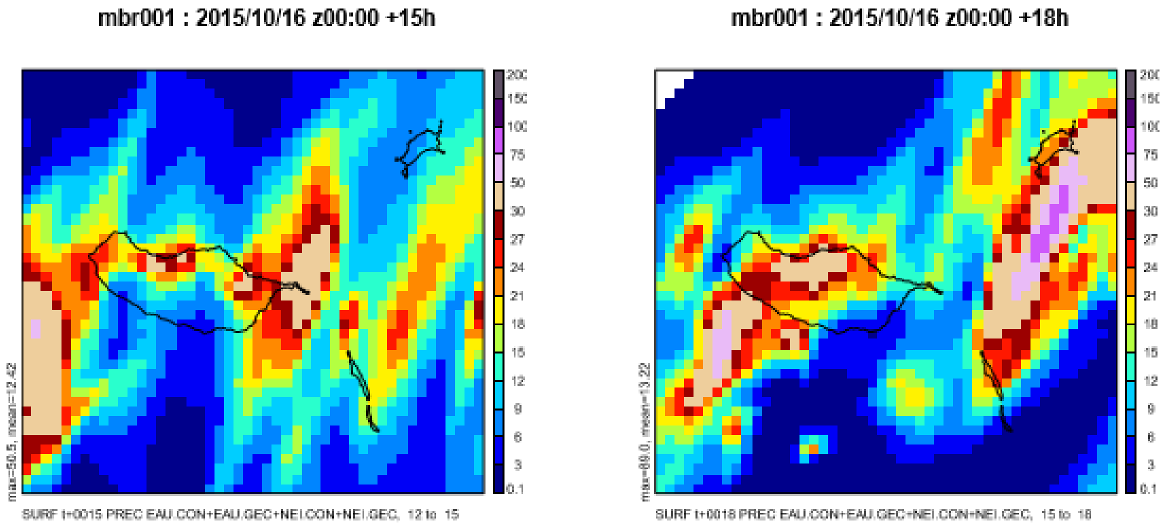


Figure 1.6 – H+15 (left) and H+18 (right) 3h precipitation, from the 00 UTC (control) ALARO run, from October 16th, 2015.

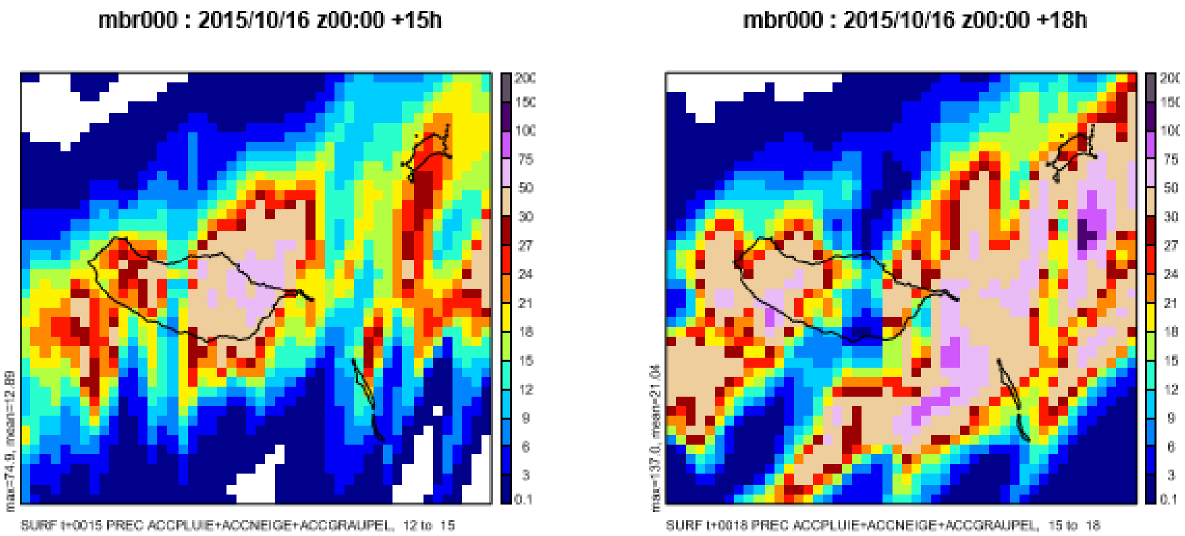


Figure 1.7 – H+15 (left) and H+18 (right) 3h precipitation, from the 00 UTC (control) AROME run, from October 16th, 2015.

Overall, the EPS system suggested that the heavy precipitation could occur anywhere in the area, with somewhat larger probability values over the Madeira island itself. The figures 1.6 and 1.7 show that the control forecasts from ALARO and AROME suggested heavy precipitation, with somewhat larger amounts in the southeast and particularly in AROME. One should also notice that even though the model parent is the same (ECMWF), there is a considerable mismatch between the areas where the models forecast precipitation. The results shown for the EPS are in agreement with the forecasts from AROME-MAD regarding the location and amounts of precipitation.

Regarding the heavy precipitation in Deserted Islands, forecasting this kind of convective events is quite challenging and ultimately depends on the initial conditions provided by the parent model and/or by any improvement coming from satellite data in the assimilation. This case shows that the predictability of convection embedded in a large-scale structure is very limited.

2.2 Enhanced precipitation over mountains: 20160330 – 11:00-16:00

In strong, warm and moist south-westerly flows over Madeira, precipitation is often enhanced by the orography and cumulated values frequently exceed 100 mm/24h at higher elevations. At low level sites precipitation is typically much lower, usually below 20 mm/24h, if convection is not widespread and embedded in a large-scale system.

In March 30th, 2016, Madeira was being affected by such a warm and moist flow, caused by a low pressure system centred north of the archipelago (figures 2.1 and 2.2).

Figure 2.1 – HRV Composite Satellite image, from early afternoon, valid on 30th March 2016 (available at https://worldview.earthdata.nasa.gov).

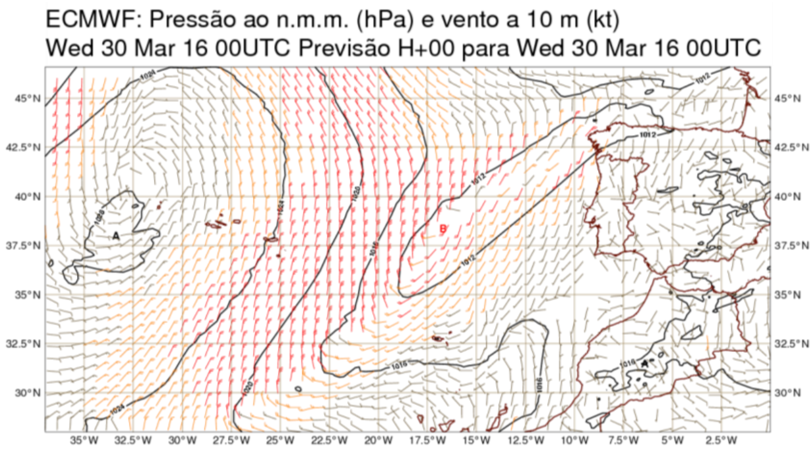


Figure 2.2 – ECMWF analysis of mean sea level pressure and 10 m wind, valid at 00 UTC in March 30th, 2016.

Figure 2.3 shows the 24h observed precipitation in Madeira and figure 2.4 is the hourly timeseries of precipitation in the weather stations located in the mountains. The observed precipitation reached a maximum value of 179 mm/24h, with hourly values around 15-20 mm/1h, for several hours in the afternoon. The precipitation at low level sites was quite low in the southern coast, as is often the case in this kind of events, with values around 5 mm/24h. In the northern coast the values were larger, probably due to the strong south-westerly advection during the event.

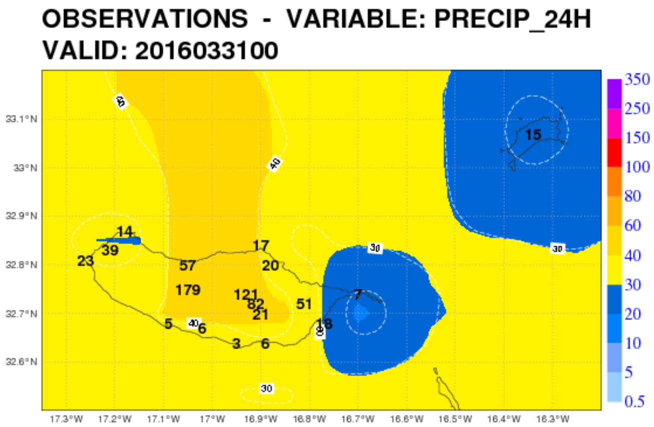


Figure 2.3 – 24h observed precipitation [mm] in Madeira, valid at 00 UTC in March 31st, 2016.

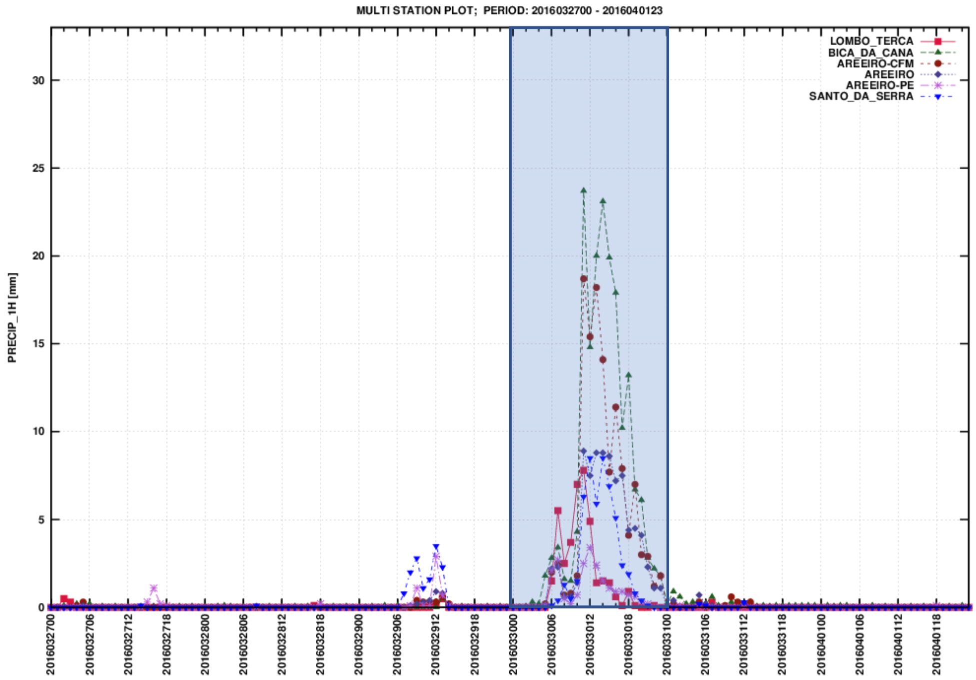


Figure 2.4 – Hourly observed precipitation in weather stations located in the mountains, between 00 UTC 27th March and 2nd April 2016. The 30th March is enhanced in the plot.

Figure 2.5 shows the cumulated precipitation in 24h from the AROME-MAD runs from the 12 UTC March 29th (upper panel) and from March 30th, 2016 (lower panel). Figures 2.6 and 2.7 show the probability of precipitation exceeding, respectively, 50 and 100 mm/24h from the RMI-EPS system.

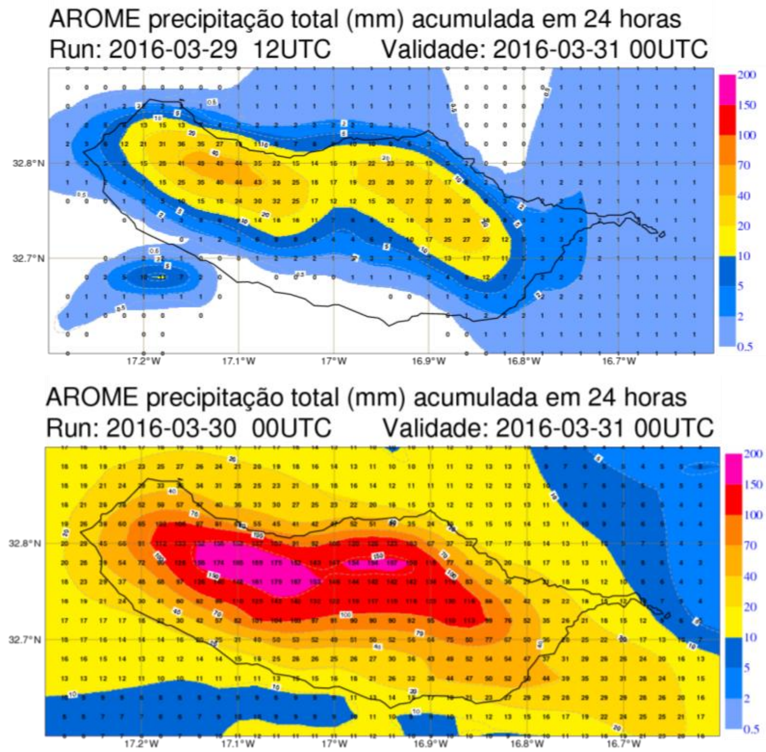


Figure 2.5 – 24h precipitation from the 12 UTC run from March 29th (upper panel) and the 00 UTC run of March 30th (lower panel) of AROME-MAD.

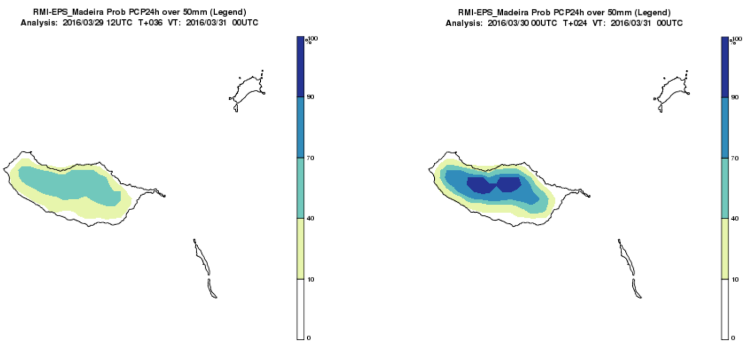


Figure 2.6 – Probability of precipitation equal or above 50 mm/24h, as given by the RMI-EPS, valid at 00 UTC in March 31st, 2016. The left panel is from the 12 UTC forecast from March 29th and the right panel is from the 00 UTC forecast from March 30th.

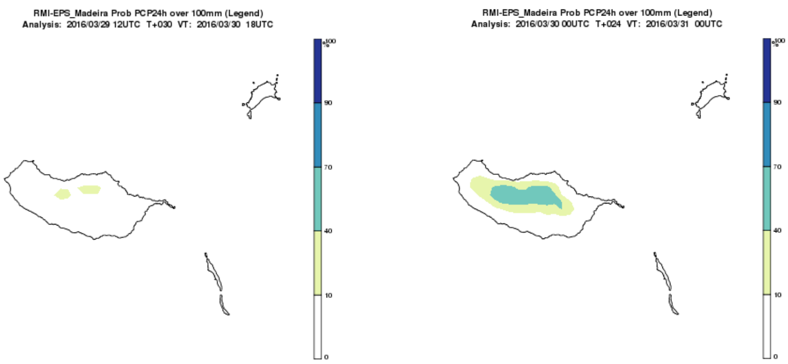


Figure 2.7 – Probability of precipitation equal or above 100 mm/24h, as given by the RMI-EPS, valid at 00 UTC in March 31st, 2016. The left panel is from the 12 UTC forecast from March 29th and the right panel is from the 00 UTC forecast from March 30th.

In this case there was a clear difference in the guidance of the two consecutive AROME-MAD forecasts, with the 12 UTC run suggesting values around 50 mm/24h. The 00 UTC AROME-MAD provided a good guidance as it suggested a clear enhancement of the precipitation over mountainous regions. In this event, the AROME-MAD forecast even provided a good estimate of the total precipitation in the mountainous regions, with values of 150 to 200 mm/24h.

The EPS system also provided a good guidance for the likelihood of an event with large amounts of precipitation in the mountains. In the forecasts from the 12 UTC 29th March, the probability of at least 50 and 100 mm/24h was, respectively, 40-70% and 10-40%. In the 00 UTC forecast from 30th March, the values for the same thresholds went up to 90-100% and 40-70%. These results show that despite the EPS provided a very useful guidance, the probability figures still show that issuing red warnings can only be done in the short-term, if one wants to avoid a large number of false alarms.

The ALARO and AROME models, running with a horizontal resolution of 2.5 km, are able to simulate the enhancement of the precipitation caused by the mountains. On the other hand, their guidance of much lower values of precipitation is also valuable, as can be seen using the probability of precipitation over 10 mm/24h (figure 2.8), as it drops remarkably from inland towards the low-level areas and the Atlantic. If this was a convection case, like the previous, the probability over the Atlantic would have been much higher and there would not have been such a large difference between the mountains and the ocean.

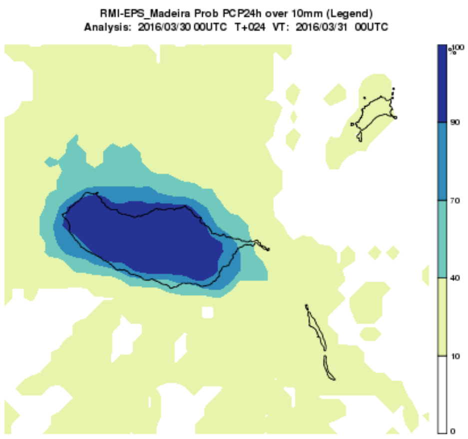


Figure 2.8 – Probability of precipitation equal or above 10 mm/24h, as given by the RMI-EPS, valid at 00 UTC in March 31st, 2016.

2.3 Over-active convection: 20161028 – 15:30-17:30

In late October 2016 Madeira was being affected by a strong south-easterly flow, caused by a low pressure system centred to the northwest of the archipelago. Because of a return flow that induced low-level convergence in the northern coast of Madeira, AROME-MAD forecasts suggested local precipitation. Although this forecast may seem unlikely at first sight, this feature appeared in three different runs (albeit with a large variability in the amounts) and was physically compatible with the weather pattern at the time. Additionally, this kind of localized and stationary convective structures occur in mountainous regions (*e.g.* as is the case of Madeira and Azores) are often too small to be seen in satellite images (a radar in the region will be operational only in 2018) and can lead to severe flash-flooding.

Figure 3.1 shows the satellite image in the early afternoon of October 28th, 2016, with Madeira having clear skies, between two large cloudy areas, with clear convective activity to the west. Figure 3.2 shows the mean sea level pressure and the 10 m wind valid at 21 UTC on the 28th October 2016. These pictures show a clear south-easterly flow in the area, with a much weaker return flow in the north/northwest of the island.

Figure 3.1 – HRV Composite Satellite image, from early afternoon, valid in October 28th, 2016 (available at https://worldview.earthdata.nasa.gov).

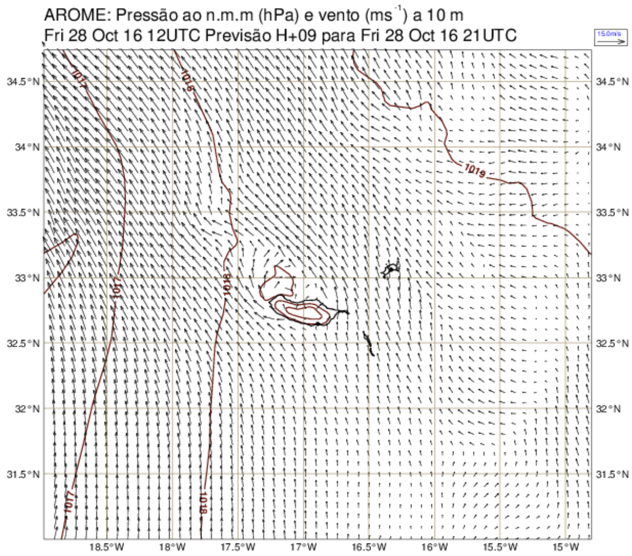


Figure 3.2 – AROME-MAD H+09 forecast of mean sea level pressure and 10 m wind, valid at 21 UTC on the 28th October.

Figure 3.3 shows the AROME-MAD 3h precipitation, valid at 21UTC on the 28th October 2016 from the 00 UTC and 12 UTC of October 27th, 2016. Figure 3.4 is valid at the same time, but is a forecast from the 00 UTC of October, 28th. These three forecasts suggested localized convection, with precipitation typically in 20 mm/3h for the forecasts started on the 27th. The 00UTC from the 28th provided higher figures, over 60 mm/3h.

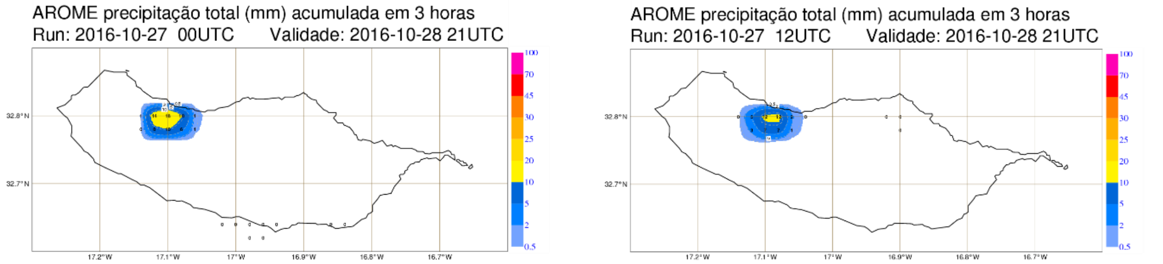


Figure 3.3 – AROME-MAD 3h precipitation, valid at 21 UTC in October 28th, 2016. Results are from the 00 UTC (left) and 12 UTC (right) run from October 27th, 2016.

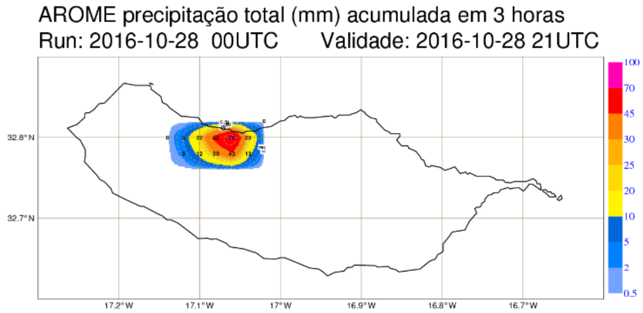


Figure 3.4 – AROME-MAD 3h precipitation,
valid at 21 UTC in October 28th, 2016, from the 00 UTC run of October 28th, 2016.

Figure 3.5 shows the observed 24h precipitation and figure 3.6 shows the timeseries of hourly precipitation in selected stations located in the north of the island.

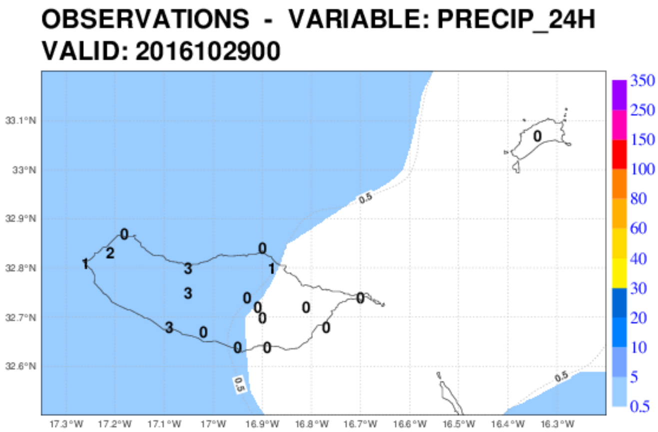


Figure 3.5 – 24h observed precipitation [mm], valid at 00 UTC on the 29th October 2016.

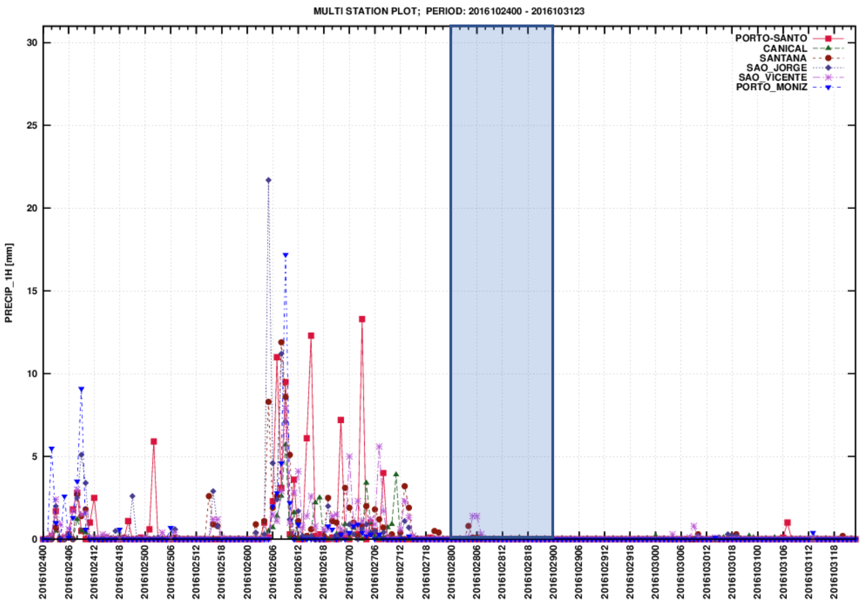


Figure 3.6 – Hourly observed precipitation in weather stations located in the north of Madeira, between 00 UTC 24th October and 1st November 2016. The 28th October is enhanced in the plot.

The observed precipitation was light on the 28th October, with values not exceeding 3 mm/24h and noticeable was that it occurred during the 00-06 UTC period.

The RMI-EPS system was run for this event and figure 3.7 shows the probability of precipitation above or equal to 10 mm/3h. Figure 3.8 shows the 3h precipitation from the (control) ALARO 00 UTC run from October 28th, 2016. Figure 3.9 is similar, with the model being AROME. Both forecasts do not show any pattern like the one available in AROME-MAD, which shows that the coupling with ECMWF was beneficial. Any precipitation above 10 mm/3h in RMI-EPS is located to the west of Madeira, as expected from the weather situation (not shown).

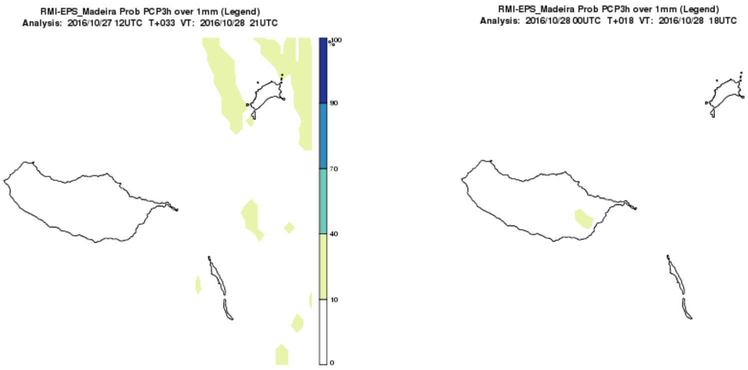


Figure 3.7 – Probability of precipitation equal or above 1 mm/3h, as given by the RMI-EPS. The left panel is a H+33 forecast from the 12 UTC run from the 27th October. The right panel is a H+21 forecast from the 00 UTC run of the 28th October.

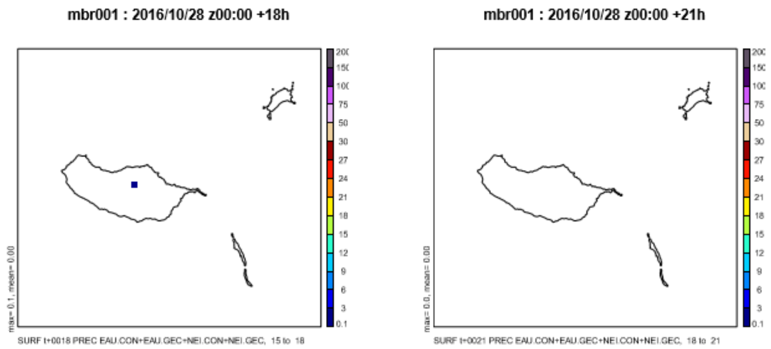


Figure 3.8 – H+18 (left) and H+21 (right) 3h precipitation, from the 00 UTC (control) ALARO run, from October 28th, 2016.

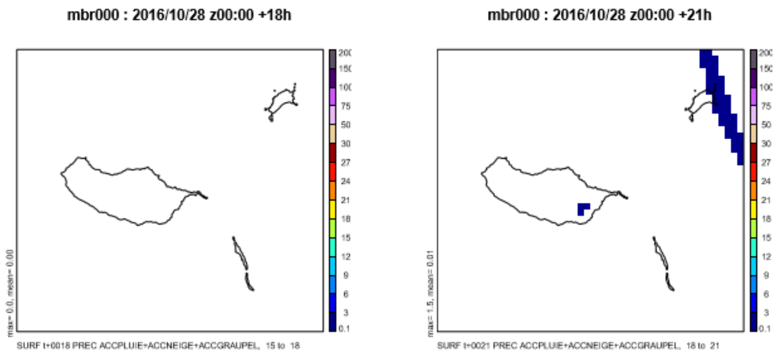


Figure 3.9 – H+18 (left) and H+21 (right) 3h precipitation, from the 00 UTC (control) AROME run, from October 28th, 2016.

In this case there was a clear advantage in running the RMI-EPS system, because it provided evidence that the structure suggested by AROME-MAD was very unlikely to happen. At the time, the operational forecaster disregarded the structure in the AROME-MAD, but nevertheless monitored more closely the weather in the region.

3. Final Remarks

The RMI-EPS was run for three selected weather events in the Madeira archipelago to check if there was an improvement in the guidance provided to operational weather forecasting. The high resolution ensemble system, which is comprised of a total of 22 forecasts with ALARO and AROME physics, does offer a better guidance, although it ultimately depends on the weather event itself. A few general comments are:

1. The models behave differently and as a result the location of selected structures as well as precipitation amounts will vary. For example, on average AROME forecasts give higher amounts of precipitation, at least when convection is dominant. If the ensemble size is small, in some events/areas the probability values may ultimately be affected by this;
2. The EPS offers improved guidance for a given event, but this does not necessarily imply that that a given event can be forecasted sooner, for example 24h in advance. This is most likely caused by issues in the initial conditions as well as the fact that small scales features are inherently far more difficult to forecast;
3. Severe weather caused by convection embedded in large scale systems or convection triggered by dynamical convergence is very difficult to forecast because of errors in the initial conditions. Even with satellite and radar assimilation, as highly non-linear sub-scale processes dominate the forecast, one question that arises is for how long would any improvement of the initial conditions hold;
4. As the EPS provides an ensemble of possible outcomes of the weather conditions, it increases the confidence the weather centre has when issuing a given forecast or warning. However, it should be noticed that the EPS does not necessarily identify individual severe events;
5. Running the EPS with ECMWF as the parent model was beneficial in removing an artificial structure (over-active convection) that was present in the operational AROME-MAD forecast, which is coupled with ARPEGE.

4. References

Smet, Geert, 2017. RMI-EPS: a prototype convection-permitting EPS for Belgium. ALADIN-HIRLAM Newsletter nº8, January.