Mountain wave episodes using the high-resolution HARMONIE-AROME model in Spain

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Introduction

Turbulence and icing represent a danger for aircrafts as both weather hazards can occur in mountain waves simultaneously (EASA, 2017; Bolgiani et al., 2018). Mountain waves are formed on the downwind and above orographic barriers. Wind is forced to climb up the windward slopes and then down through the leeward slopes. If this air ascends into a stable layer, it is propagated horizontally following a wave-like pattern that can be extended several kilometers downwind (Broutman et al., 2001). Mountain waves turbulence is usual in winter months, when winds are stronger, and the atmosphere is more stable (Wolff and Sharman, 2008). In addition to turbulence, mountain waves can also adversely affect the aircraft security by causing aircraft icing (Fernandez Gonzalez et al., 2014). This phenomenon is more likely to occur between -2 °C and -15 °C temperature (Rogers, 1993; Moran, 1997).

This work has been focused on forecasting mountain wave events using high-resolution simulations with the HARMONIE-AROME model and satellite images from Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI).

Study area and Methodology

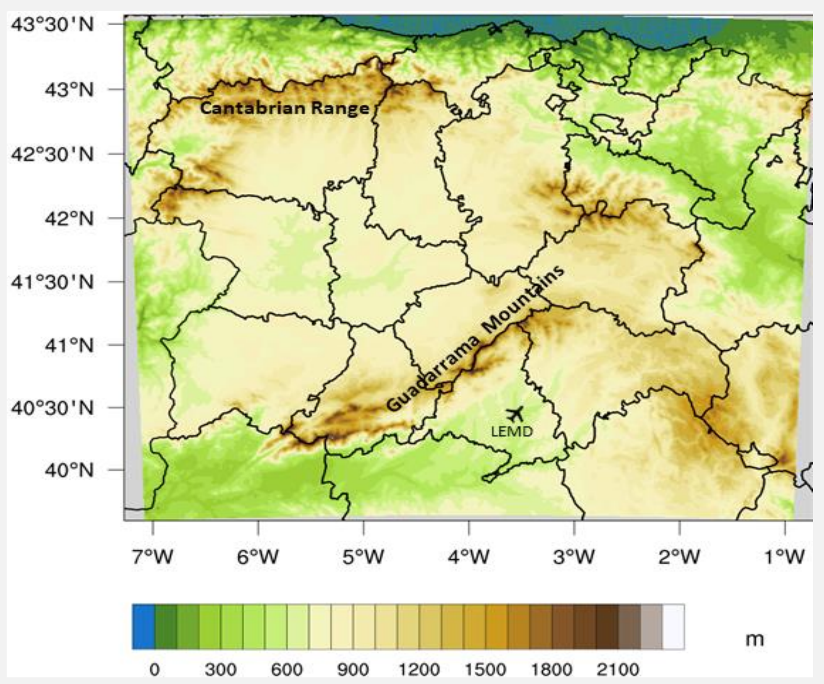

Figure 1. Study area and Harmonie domain.

HARMONIE-AROME model is used in order to analyze mountain wave events in the Guadarrama Mountains and the Cantabrian Range (Spain). This short-range mesoscale numerical weather prediction model is used for operational weather forecasts in many European meteorological organizations with a horizontal resolution of 2.5 km. In this study, a spatial resolution of 1 x 1 km is selected.

The Adolfo Suarez Madrid-Barajas (LEMD) airport is located around 40 km southeast of the Guadarrama Mountains. In the analyzed areas, mountain waves are formed on the leeward side when strong winds, perpendicular to the mountains (usually north or northwest winds), are forced to ascend. Therefore, this airport is highly influenced by the mountain waves episodes. Episodes are selected based on cloud bands which are observed through MSG-SEVIRI over the study area on the leeward side. Due to the melting level being lower in winter, aircraft icing conditions are much more likely - 12 mountain wave episodes were selected during this season.

For each day analyzed, simulated total cloud cover and pseudo satellite image visible channel (cloud water reflectivity) have been analyzed and compared with MSG-SEVIRI satellite images hourly in the diurnal hours (from 9 to 16 UTC).

Mountain waves will be forecasted by the model when it has simulated cloud bands associated with them on the leeward side of the Guadarrama Mountains and/or Cantabrian range.

The verification of dichotomous outcomes was qualitatively carried out, observing the presence/absence of mountain waves and it was developed by using a contingency table (Table 1). Subsequently, several skill scores were calculated: False Alarm Ratio (FAR), Probability of detection (POD), Frequency of Misses (FOM), BIAS, Percent Correct (PC) and Total Error (TE).

	Forecast YES	Forecast NO
Observed YES	X	Y
Observed NO	Z	W

Table 1. Contingency table: number of hits (x), false alarms (Z), misses (Y) and correct non-events (W).

Results

An example of mountain wave events (26 November 2018) is shown in Figure 2. As seen in HRVIS channel (Figure 2a) several cloud bands associated to mountain waves can be observed on the leeward side of Guadarrama Mountains and Cantabrian range. In Figure 2b the pseudo satellite image simulates the cloud bands in the study area with high accuracy. However, orographic clouds on the windward side are simulated with highest precision in the total cloud cover simulations (Figure 2c)

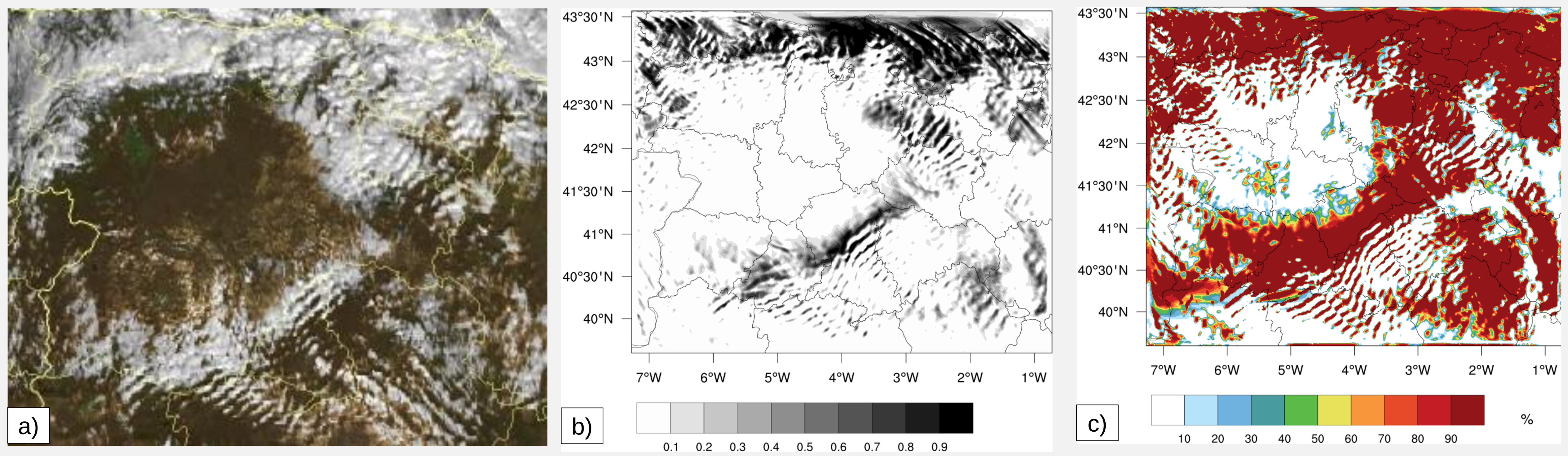

Figure 2. Images at 1200 UTC on 26 November 2018: **a)** HRVIS channel from MSG-SEVIRI **b)** Pseudo satellite image visible channel simulated. **c)** Total cloud cover simulated.

	CANTABRIAN	GUADARRAMA
FAR=Z/(X+Z)	0.097	0.054
POD=X/(X+Y)	0.992	0.927
FOM=Y/(X+Y)	0.008	0.073
BIAS=(X+Z)/(X+Y)	1.153	0.987
PC=(X+W)/n	0.885	0.895
TE=|(1-BIAS)|+(1-PC)+FAR+FOM	0.373	0.244

Table 2. Skill scores for the detection of cloud bands associated to mountain waves in Cantabrian range and Guadarrama Mountains.

Conclusions

- Both areas (Cantabrian and Guadarrama) showed good POD and PC values (near 90%).
- FAR score is under 10% in both study areas.
- Concerning BIAS scores, the detection of cloud bands associated to mountain waves were overestimated (BIAS > 1) in Cantabrian range, while in Guadarrama Mountains were underestimated (BIAS < 1). For aircraft security reasons, a slightly overestimation is desirable because on contrary case, more misses can appear carrying an increased risk of accident. In spite of an overestimation involves an increased economic spending, it will be positive because the misses tend to decrease.
- The most notable differences in both areas among them lie in the formation and dissipation hours of the mountain waves.
- Orographic clouds on the windward side in both study areas, were simulated with more precision in the total cloud cover simulations than the pseudo satellite image visible channel simulations.
- Based on Total error (TE), the cloud bands associated to mountain waves were simulated more accurately in Guadarrama than Cantabrian.

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