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Sea breeze thunderstorms in the eastern Iberian Peninsula. Neighborhood verification of HIRLAM and HARMONIE precipitation forecasts

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ABSTRACT

In this study we investigated sea breeze thunderstorms with intense convective activity (i.e., heavy rainfall, hail and gusty winds) that occurred over the eastern Iberian Peninsula (Spain) and were missed by the operational HIRLAM model. We used two grid-spacing setups (5.0 km and 2.5 km) of the hydrostatic HIRLAM model, and the non-hydrostatic spectral HARMONIE suite (2.5 km), to simulate isolated convection associated with sea breezes. The overall aim is to estimate the ability of these three experimental setups, in particular the HARMONIE model as the forthcoming operational numerical weather prediction in most European Weather Services, to correctly simulate convective precipitation associated with sea breezes. We evaluated high-resolution gridded precipitation forecasts from HIRLAM and HARMONIE suites for 15 sea breeze thunderstorms against high-density gridded raingauge measurements applying different neighborhood verification techniques. The results indicate that higher horizontal resolutions of HIRLAM and HARMONIE models succeeded in predicting the occurrence of these missed sea breeze thunderstorms, the HARMONIE suite being the most capable of providing good estimates of accumulated precipitation in convective events in terms of space and time. Advances in quantitative precipitation forecasting of locally driven convection could have practical applications for nowcasting dangerous sea breeze convective phenomena.

1. Introduction

The effect of sea breezes in triggering deep convection has been noted in numerous coastal areas around the world (Simpson, 1994). Many numerical modeling and observational studies, particularly for the subtropical Florida Panhandle (e.g., Pielke, 1974; Pielke and Cotton, 1977; Pielke and Mahrer, 1978; Blanchard and Lopez, 1985; Nicholls et al., 1991; Wakimoto and Atkins, 1994), found that low-level sea breeze convergence and consequently sea breeze front (SBF) development enhance planetary boundary layer (PBL) air parcels to lift up to the level of free convection (LFC) (Wilson, 2008; Muppa et al., 2012). Convective initiation can also occur from horizontal convective rolls (HCR) ahead of the advancing SBF (Atkins et al., 1995). Both SBF and HCR updrafts merge, promoting deep convective sea breeze thunderstorms that can sometimes be extraordinarily severe, causing significant rainfall, hail and gusty winds along the frontal boundary (Dailey and Fovell, 1999; Fovell and Dailey, 2001; Fovell, 2005).

Convection resulting from horizontal low-level convergence along SBFs is intensified by several factors (Simpson et al., 2007).

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The most relevant are as follows: (a) anabatic valley wind circulations on heated south-facing mountain slopes play a major role in strengthening uplift processes and developing deep convection by combining with moist sea breezes that transport water vapor to the coastal mountains in the daytime (Millan et al., 2005); (b) convergence and SBF intensification are also enhanced by frictional effects (upslope orographic lifting) produced in coastal areas of complex terrain (Petterssen, 1956; Pérez-Landa et al., 2006; Papanastasiou et al., 2010); (c) strong low-level sea breeze convergence also occurs on convex coastlines (e.g., peninsulas, capes, points, and also islands) contributing to increased upward vertical motion, *Cumulus* (Cu) and *Cumulonimbus* (Cb) activity and thunderstorms along the frontal area (Neumann, 1951; Pielke, 1974; Purdom, 1976; Strickler, 2003); (d) a sharply defined discontinuity and convergence intensification are observed inland along the SBF under offshore large-scale synoptic flows (Bechtold et al., 1991; Atkins and Wakimoto, 1997), and light to moderate winds aloft ($<5.0 \text{ m s}^{-1}$) result in more clouds at the leading edge of sea breezes (Azorin-Molina et al., 2009); and (e) regions of high soil moisture expect heavy precipitation along the SBF (Baker et al., 2001). Most of the aforementioned factors interact over the complex eastern façade of the Iberian Peninsula (Spain), where thermally induced local circulations interact.

Short-term forecasting of the timing, location and intensity of isolated sea breeze thunderstorms represents a challenging task in numerical weather prediction (NWP), mainly due to the uncertainties in the initial conditions, limited knowledge about the cloud microphysical processes, and difficulties in resolving low-level sea breeze convergence and convection with fairly coarse horizontal resolution operational NWP models (Mazarakis et al., 2009). Furthermore, isolated sea breeze thunderstorm cells with severe weather can develop unexpectedly under weakly defined synoptic-scale or mesoscale precursor disturbances (Wilson, 2008), and may be missed by forecasts. Strong low-level sea breeze boundaries can deliver enough energy to overcome the stable cap of the PBL and generate local showers and thunderstorms unexpectedly. For instance, deep convection associated with sea breezes can occur even when sounding indices indicate stable weather conditions. This is because sounding indices do not consider layers below 850 hPa, where strong low level convergence may accumulate lower tropospheric moisture (Pielke et al., 1971) or capping of inversions can occur, enhancing or weakening lifting mechanisms, respectively.

Low-level sea breeze convergence occurs preferentially during the warm season (May–September), but also in the transition months of April and October, over the complex eastern façade of the IP. Its time of occurrence is nearly always in the mid-afternoon. Despite the high level of occurrence of thermally-driven winds (sea breezes blow two out of three days of the year, Azorin-Molina and Martin-Vide, 2007) and also that sea breeze convection brings an average of 100–125 mm yearly to inland areas during the summer dry season (Millan et al., 2005), there is little knowledge concerning the important role that sea breezes play in convection initiation in the eastern coast of Spain. A review of these few investigations was presented by Azorin-Molina et al. (2009), who used high-resolution cloud frequency composites derived from NOAA-AVHRR data to identify the location of five preferential sea breeze convergence zones (SBCZ; hot spots) in the Iberian Mediterranean area and the Isle of Mallorca. The current study is focused on two of them, i.e., the SBCZ2 (eastern region of the Iberian system mountains; 1000–1900 m) and the SBCZ3 (Prebetic mountain ranges; 1000–1600 m). These regions correspond to the east of the Iberian Peninsula, an orographically highly complex area (Fig. 1a).

The main goal of this study is to estimate the ability of NWP to correctly simulate convective precipitation associated with sea breezes. Two different setups (5.0 km and 2.5 km horizontal grid-spacing) of the operational HIRLAM model and the non-hydrostatic spectral HARMONIE suite (2.5 km horizontal grid-spacing; Hirlam Aladin Regional/Meso-scale Operational NWP In Europe) are evaluated. Three different neighborhood (also known as 'fuzzy') verification techniques are applied here in order to measure the strength of the HIRLAM and HARMONIE agreements with the observations. The article is structured as follows. In Section 2, we summarize the model description, set-up and initialization of HIRLAM and HARMONIE suites, present the sea breeze thunderstorms simulated and observed precipitation data, and briefly describe the neighborhood verification methods applied in this study. In Section 3, the performance of HIRLAM and HARMONIE gridded precipitation forecasts is evaluated against gridded precipitation observations. In Section 4, the sea breeze thunderstorm that occurred on 7 August 2008 is analyzed. Finally, a summary and discussion of the findings from this study are presented in Section 5.

2. Data and methods

2.1. HIRLAM and HARMONIE model descriptions, set-ups and initialization

The NWP systems used here are the three-dimensional hydrostatic grid-point model version 7.2.2 of HIRLAM (Undén et al., 2002), and the non-hydrostatic spectral model version 36h1.2 of HARMONIE (Seity et al., 2011). The HIRLAM short-range forecasting model was chosen for this research because it is currently employed as one of the most important operational NWP systems at the AEMET, and by eight other European Weather Services: Denmark, Estonia, Finland, Iceland, Ireland, The Netherlands, Norway and Sweden. The HARMONIE limited area model is also used in this study because it will be implemented shortly as the operational NWP in most of the European Weather Services. Actually, it is currently being evaluated as a next-generation replacement for HIRLAM (van der Plas et al., 2012; de Brujin and de Rooy, 2012).

The dynamical core of HIRLAM model is based on a semi-implicit semi-Lagrangian discretization of the multi-level primitive equations, employing a hybrid coordinate in the vertical. The comprehensive sets of physical parameterization schemes selected in the HIRLAM model suite in order to take into account a variety of sub-gridscale physical processes include: (a) a radiation scheme (Savijärvi, 1990), (b) an adapted Rasch–Kristjansson condensation (Zhang et al., 2003; Ivarsson, 2007) and a Kain–Fritsch mass-flux convection scheme with CAPE closure (Kain, 2004; Calvo, 2007), (c) a prognostic moist turbulent kinetic energy (TKE) parameterization (Tijm and Lenderink, 2003), (d) a tiled surface approach distinguishing seven surface types (Interaction Soil–Biosphere–Atmosphere, ISBA surface scheme, Noilhan and