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A study of the 21 March 2012 tornadic quasi linear convective system in Catalonia

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ABSTRACT

This study presents a description of a quasi linear convective system that took place in Catalonia (NE Spain) on 21 March 2012 producing heavy rainfall, moderate lightning activity and a weak tornado in the village of Ivars d'Urgell around 19 UTC after local sunset. A post-event survey indicated EF0 and EF1 damage in houses of the village – roofs and ceilings, broken windows, fences and walls and trees knocked down – along a track approximately 4 km long and about 20 m wide. Doppler radar observations show that the parent thunderstorm that spawned the tornado was one of a series that developed along a convective line that moved from S to N, initiating convective activity in terms of precipitation and lightning in the Mediterranean Sea and moving inland in S Catalonia (Tarragona and Salou coastal areas, producing local flash floods). Convective activity remained several hours with series of thunderstorms developing along the same paths. The synoptic situation was dominated by a high pressure ridge extending from northern Africa to central Europe, with a closed maximum sea level pressure area around 1036 hPa over northern France, southern Germany and Austria. On the other hand a relative low pressure area seen on 850 hPa and upper levels was present over the Iberian Peninsula, favouring a southern maritime flow from the Mediterranean between the forward part of the low pressure area and the high pressure system which blocked the advance of the low to the east. In the study we examine both the synoptic environment and storm scale observations with Doppler radar and total lightning data (cloud to ground and intracloud flashes) that lead to this cool-season severe convective event which is remarkable given the fact that, unlike in this case, most reported tornadoes in the region occur during the warm season (with peaks in August and September) and during daylight hours (6 to 18 UTC).

1. Introduction

On 21 March 2012 a series of thunderstorms developed along a convergence line from SW to NW Catalonia (NE Spain) for several hours producing heavy rainfall, local flooding and an EF1 tornado a few minutes before 19Z, after local sunset. Daily precipitation amounts exceeded 100 mm in several stations and produced local flooding. The tornado was spawned by a thunderstorm embedded in a quasi linear convective system (QLCS) and affected a small village, Ivars d'Urgell, located in a flat, rural area with low population density.

Previous studies of tornadoes from QLCSs such as squall lines and bow echoes have shown substantial differences in their characteristics compared to those associated to isolated supercell (SPC) thunderstorms; in essence SPC mesocyclonic tornadoes may be stronger and present clearer signatures both in weather radar and lightning data. Weisman and Davis (1998) and Trapp and Weisman (2003) studied numerically the mechanisms responsible for the generation of low-level

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mesovortices in QLCSs, at times associated with tornadoes, and found that environmental vertical wind shear controlled largely their formation and evolution. A preliminary climatology of QLCS tornadoes was presented by Tessendorf and Trapp (2000) and later Trapp et al. (2005) using a 3-yr data set of US tornadoes found that QLCSs tornadoes accounted for 18% of the total but in some regions, such as the state of Indiana, represented 50% of all tornadoes recorded. Other remarkable QLCS tornado characteristics were that they were predominantly weak (F1), and more frequent in winter and in late night or early morning hours which made them suggest that many of these, mostly weak tornadoes might be undetected and therefore under-reported in the databases. Other recent studies confirm that, given their characteristics, QLCS tornadoes are generally more difficult to detect and predict than mesocyclonic tornadoes from isolated SPC, and also indicate that the convective mode of the parent storm is more complex than the simple distinction between isolated SPC and QLCS, such as non-isolated SPC in lines ore embedded in QLCS (Brotzge et al., 2013; Smith et al., 2012; Thompson et al., 2012).

In Europe Gatzen (2011) studied a 10-year data set of cold season linear convective systems in Germany and found that they were mostly associated with weak convective instability (average lowest 50 hPa mixed-layer CAPE values of 13 J kg^{-1}) and strong low-level vertical wind shear; 20% of the cases produced either strong gusts above 25 m s^{-1} or a tornado. Similarly Clark (2013) examined seven years of cool-season convective storms in the UK and found that 27% of the lines produced at least one tornado. In some cases, cold season QLCS can also present embedded SPCs that spawn strong tornadoes or damaging winds such as in the two cold season derechoes described in Gatzen et al. (2011).

On the other hand previous tornadic case studies in the region of Catalonia (Aran et al., 2009; Bech et al., 2007, 2011; Mateo et al., 2009; Ramis et al., 1997) described that tornadoes were spawned mostly by multicell storms, squall lines or, in a few cases, single cell thunderstorms, some of them exhibiting classical supercell characteristics. Gayà (2011) studied a 33-year database of tornadoes recorded in Spain and found that Catalonia and the Balearic Islands were the two most tornado-prone regions. In a second study focused specifically on the tornado climatology of Catalonia, Gayà et al. (2011) determined that tornadoes have been reported in all seasons and at any time of the day but there is a seasonal maximum of tornadoes in August and September and a minimum in February and March, and also that 80% of the tornadoes occur from 6 to 18 UTC.

For all the above, the interest of this case study is twofold. Firstly, it is relevant because it represents a good example of tornadic storm associated to a cool season QLCS occurring in the late evening when weak tornadoes may be undetected in sparsely populated areas. Secondly, the date and hour of occurrence of this event were rather unusual compared to the existing regional tornado climatology, which is also a good reason for further analysis. Therefore, the objective of this paper is to document this case study from three points of view: synoptic and mesoscale meteorological conditions for forecasting purposes, operationally available observations – in particular from remote sensing systems – for surveillance tasks, and finally the damage description and analysis for completion and future reference.

The rest of this paper is organized similarly as the tornadic case study of the 2 November 2008 in S Catalonia (Bech et al., 2011), which has some similarities with this one as will be discussed later. In Section 2 a description of the synoptic and mesoscale setting, remote sensing and relevant regional observations is provided. An analysis of the damage survey and intensity rating process is given in Section 3 followed by a thunderstorm analysis based on weather radar and total lightning data in Section 4. Finally, Section 5 concludes with a summary and final remarks.

2. Synoptic and mesoscale framework

2.1. General setting

An account of the general synoptic setting is presented here using 0.5° resolution model forecasts of the Global Forecast System (GFS) run by the US NOAA Environmental Modeling Center (EMC, 2003). The forecasts were from the 21 March 2012 00 UTC run and were valid at 15 UTC that day. This set of maps is produced daily to support the activity of the European Storm Forecast Experiment (ESTOFEX, http://estofex.org) and is available at http://www.lightningwizard.com/maps; for further information see van der Velde (2007). A first introduction is provided in terms of basic ingredients for convective storm development (Doswell et al., 1996), in terms of moisture, atmospheric instability and lift, and later, in Section 2.2, more specific parameters are examined.

On 21 March 2012 the synoptic situation was dominated by a high pressure ridge extending from northern Africa to central Europe, with a closed maximum sea level pressure area around 1036 hPa over northern France, southern Germany and Austria, as shown by the model output (Fig. 1a). A relatively low pressure area at surface level, 850 hPa and upper levels was present over the Iberian Peninsula and moved slowly to the NE, favouring over Catalonia a southern maritime flow from the Mediterranean between the forward part of the low pressure area and the high pressure system which blocked the advance of the low to the east. Moreover, as shown in Fig. 1a, some instability was present over the southern and central coasts of Catalonia and offshore, as indicated by the mixed layer convective available potential energy (MLCAPE) field, with values below 250 J kg^{-1} at 15Z. Mixing ratio at low level (0 to 1 km above ground level) was over Catalonia about 6.5 g kg^{-1} with higher values in front of the coast (Fig. 1b). Lapse rates in the 2 to 4 km layer were 6.5 °C km^{-1} and again higher values (7 to 8 K km^{-1}) were present in front of the coast as depicted in Fig. 1c. A source of lift is provided by surface wind convergence (1000 to 800 hPa layer deep convergence shown in Fig. 1d), with a local maximum in NE Spain extending to NW Catalonia and decreasing towards the sea. So there is moisture, some instability and some, but limited, lift caused by surface convergence over the area of interest. In the following section more details are given regarding upper level features providing more lift and also wind shear favouring organized convection.

2.2. GFS-derived convective environment

Synoptic scale dynamics provided favourable conditions for organized convection. The movement of the cut-off low over the Iberian Peninsula produced large areas of positive vertical velocities over NE Spain (Fig. 2a), which remained stationary for several hours. Moreover, differential cyclonic vorticity