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Mesoanalysis of recurrent convergence zones in north-eastern Iberian Peninsula

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Abstract. Combining Doppler radar capabilities with Polar Satellite imagery and another kind of surface data we can detect convergence boundaries/zones which are frequently favorite places to develop shallow or deep convection. At some places, like the north-eastern part of Catalonia (north-eastern corner of Iberian Peninsula), there are some boundary layer convergence zones with a climatology well established. Their ubiquity is determined by some recurrent mesoscale winds, established from interaction between synoptic flux and the main ranges.

The previous knowledge of these convergence boundaries has been obtained mainly from conventional surface data, numerical prediction models and Geostationary Satellite imagery but here we use new tools showing more detailed characteristics and then improving showers and thunderstorm nowcasting.

As a result of our analysis 4 different kinds of planetary boundary layer convergence zones have been recognized in our area of interest: Sea-breeze/coastal ranges interaction, Catalonian-Balearic convergence zone (autoconvective), Tramontane negative vortex (shear vorticity)/land-breeze interaction and prefrontal troughs. All of these can generate stratiform cloudiness as we have seen by Polar Satellite imagery, and also embedded convection, as radar have shown.

1 Introduction

Location and strength of planetary boundary layer (PBL) convergence zones are very important in determining the places of convective clouds formation and associated showers and thunderstorms. We know nowadays that origin of convective phenomena is not randomly distributed as we could think some years ago. There are some different types of convergence zones, depending on their shape, length, movement and origin. Also, their capability in generating convection is not ever the same, and, in consequence, the related phenomena can change significatively from one to another.

There are many detailed studies about detection and characterization of PBL convergence zones, both precipitating and "clear air", utilizing Doppler radar and satellite imagery (e.g., Wilson and Schreiber 1986; Koch and Ray, 1997). In our case, we can not detect easily clear air boundaries because the capabilities of our C-band radar and so, we have identified first some precipitating structures and after we have explained their presence in terms of some convergence at lower levels. We have also utilized Polar Satellite imagery to identify mesoscale areas with radar reflectivity structures embedded. We have worked with Polar imagery because their much greater spatial resolution although their low temporal resolution makes them not very useful to operational forecasters.

The aim of our paper is to show that some of the convective situations affecting coastal areas in the northwestern portion of the Mediterranean Sea, between Catalonian coast and the Balearic Islands, can be explained in terms of triggering from stationary or propagating convergence zones in the PBL. We will do this by means of showing a limited number of examples selected from those cases where precipitation has been detected by our single-Doppler radar. We have needed surface conventional data, satellite imagery and in some cases numerical weather prediction (NWP) model outputs to show the presence of convergence zones in the PBL. Also Catalonia and surrounding areas physical geography must be described to understand the origin and spatial distribution of the main fluxes that define the convergence zones and the places with convection and detectable precipitation.

2 Data and methodology

We provide here some explanations about the main characteristics of the Doppler radar we uses in operational tasks and in our study focusing them in the analysis of the capabilities

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Table 1. Main characteristics of INM Doppler radar used in this study

Band (cm)	C $\lambda = 5.4$
Resolution (km)	Normal:2 $\times$ 2. Doppler:1 $\times$ 1
Range (km)	Normal:240. Doppler:120
Exploration Interval (min.)	10 both modes
Peak Power (kW)	250
Beamwidth (deg.)	0.9°
Pulselenght (m)	Normal: 600 Doppler: 150

of this system to detect convergence zones. The other tools we have used and their role in the identification and characterization of convergence zones are listed in Sect. 2.2.

2.1 Doppler radar

The Spanish National Weather Service (INM) has a 14 C-band Doppler radar network covering almost all the Iberian Peninsula and some maritime areas. The radar of the INM installed in Catalonia is located about 20 km south-west from Barcelona city, and at 654 m above mean sea level (MSL). Table 1 summarizes the principal characteristics of this radar.

The wavelength and the pulselength of the INM-radars are not the better to identify clear air returns, both from Rayleigh scattering caused by birds and insects and from Bragg scattering caused by refractive index inhomogeneities. By this reason, our study search to identify only scattering from precipitation particles and in consequence precipitating boundaries. This is true also for the analysis of the Doppler velocity field. Only when we detect echoes from precipitation we can have some idea about the wind field, and if the reflectivity field is great enough, we will be able to identify some apparent convergent flow. Of course, using a single-Doppler radar only radial component of the wind field is obtained. In two cases with the presence of a cold shallow front we could draw a relatively thin line of apparent convergent flow at low levels, as we explain later in this paper.

2.2 Other tools of interest

Polar 1.1-km satellite imagery from NOAA-12, 14, 15 and 16, and channels 2, 3 and 4, has been utilized in this study to characterize the cloudiness field coherent with mesoscale humidity convergent fluxes. The cloudiness is usually stratiform but at some small areas inside the regional area there are convection, shallow or deep, depending on the convective available potential energy (CAPE). In this places, precipitation processes can generate radar detectable particles and this is the signal of enhanced convergent zone at low levels.

We have collected surface conventional data from various networks. Specially we have been interested in knowing wind strength and direction at coastal stations and precipitation, if, in some period of the thunderstorm life cycle, the showers have been registered inland. The wind field at coastal areas explains in some cases the enhanced convergence at the PBL and the precipitation echoes. With the purpose of to characterize better the convective phenomena selected we have also collected data from the INM lightning network.

We have classified each case in a synoptic typical situation, with its general fluxes at different levels associated. Only in some event we have analyzed the outputs from the INM-High Resolution Limited Area Model (HIRLAM). From operational experience we know that it has some ability detecting convergence areas or lines but, of course, it can not forecast the exact position of the enhanced convergence and thunderstorm origin.

2.3 Methodology

As we have explained before, clear detection of boundary layer convergence zones is not possible with our Doppler radar and in consequence we have identified radar detectable precipitation cases with one or more of the next special characteristics:

- Night origin and development over the sea of small convective cells.
- Recurrent origin of various convective cells at the same (and small) area.
- Some linear orientation of the real convective elements or an imaginary line joining isolated cells.

We have posed the hypothesis that in these cases the convection is supported by an area of enhanced convergence at low levels and then we define these places as convergence zones or convergence lines. The analysis of all the data and the knowledge of the topographical and climatological background allow to explain the origin of these convergent fluxes. We are not interested in determining the existence of discontinuities in temperature and humidity fields although we know that some of the convergence zones are also airmass boundaries. We have focused our attention over the sea because convection initiation inland is better known among operational staff. Finally, deep synoptic-scale fronts and thunderstorm outflow boundaries have been eliminated from our research because we can identify the first one in geostationary satellite imagery and meteorological analysis and the second type because we are interested essentially in first generation convection (i.e., without any previous thunderstorm).

3 Topography and relevant climatology

Catalonia is located at the north-eastern part of Spain and limited by the Mediterranean Sea (by the east and south), the Pyrenees range at the north, and by the Ebro river at the west. The Pyrenees, reaching more than 3000 m above MSL, and the two ranges extending north-east to south-west and located parallel to the coast, reaching more than 800 m

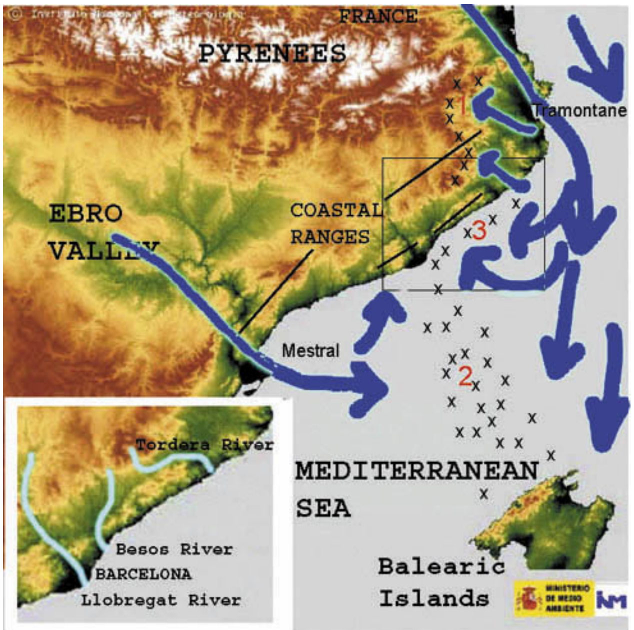

Fig. 1. Orographic map of Catalonia indicating main features, main regional fluxes and convergence areas recognized in the study. 1: Sea- breeze/coastal ranges interaction; 2: Catalonian-Balearic convergence zone 3: Land-breeze/Negative vortex interaction.

above MSL at only 10 km from the coast, are the more relevant topographically features for our research. There are three river valleys (Llobregat, Besós and Tordera) crossing the north half of the coastal range and directed almost perpendicularly to the shore, and many other small gullies with the same direction (Fig. 1). The region has a climate regime with a maximum of precipitation in autumn and a minimum in summer and mild temperatures all over the year. Weak or moderate sea and land breezes are present many days of the year near the coastline. Throughout this paper, the term land breeze include also the katabatic winds from the coastal range directed to the sea (Neumann, 1951). In some occasions, strong winds affect the shore. The north wind (Tramontane) and northwesterly wind (Mestral) affect the north and south extreme of the coastline respectively, almost ever simultaneously, and with their respective shear lines separated 180 km – 200 km one from another. In other occasions very strong easterly winds affect for many days maritime areas.

4 Results

As we have explained before this study is focused in the analysis of the reflectivity field and satellite imagery. We have identified convergence zones and we have categorized them according their spatial pattern and movement. Finally we have tried to associate an origin for each of the boundaries and, in this manner, to show the existence of some preferred areas and synoptic situations for their presence.

4.1 Main characteristics of the selected cases

We have selected 11 situations with the methodology we have explained before. All the convergence areas analyzed have a minimum distance from the radar of no more than about 50 km. Convection have attained in all cases a radar reflectivity of at least 44 dBZ, with a maximum value of 63 dBZ and a mean maximum value of 53 dBZ. In Table 2 we summarize the main features of these. We can observe that 7 of the cases were nocturnal. The surface wind regional system Tramontane-Mestral (T-M) have been found in 8 cases. Lightning have been registered in 6 cases. In one case (14/04/02) heavy rain have been registered, accumulating 48 mm in Barcelona city. In the other cases rainfall inland have not been very important.

The sample that have been analyzed do not allow to obtain statistical conclusions but some regional studies carried out before and the experience accumulated by forecasters staff in Barcelona support the results presented here. We have analyzed time evolution, synoptic situation, observed surface winds, origin location and distance to the coastline, convergence orientation and cloudiness field to categorize convergence zones. Theses categories are based in those proposed by Koch and Ray (1997):

21/09/97: Interaction between the sea-breeze front and coastline-oriented mountain slopes.

29/11/98; 30/12/00; 6/02/02; 4/04/02: Northerly cold shallow front (Tramontane regional wind) following a synoptic frontal passage. Autoconvective boundary (Koch and Ray, 1997).

10/07/00; 1/05/02: Prefrontal trough (lee trough). Land breeze may be play some role enhancing locally convergence off shore.

9/07/00; 30/08/01; 7/06/02: Interaction between land breeze and wind onshore (easterly). This onshore wind may be generated by anticyclonic vorticity center associated with the shear line of Tramontane regional wind (Jansà, 1997). River valleys crossing coastal ranges may play a major role accelerating land breeze locally and enhancing convergence offshore (Fig. 2).

14/04/02: Interaction between onshore wind generated by anticyclonic vortex and local topographic features. Doppler wind field shows a northeasterly low level jet directed to the mouth of Besós River.

4.2 Analysis of the wind Doppler field

At this section we want to identify, describe and analyze the main features of the CBCZ from the point of view of the Doppler velocity. Due to our radar characteristics, as we have seen above, we can only obtain a good image if there is a widespread zone of precipitation particles and the con-

Table 2. Main characteristics of convective structures and convergence zones recognized in this study. Sta.: stationary. Slo.: slow. T-M: Tramontane-Mestral regional wind system. CBCZ: Catalonia-Balearic Convergence Zone

Date	Time (UTC)	Surface Winds	Convection movement	Origin location and distance to the coastline (km)	Convergence zone orientation	Convergence zone length and width (km)	Cloudiness field
21/09/97	1240-1540	Sea breeze	N/NE to S/SW Slo. propagation	Inland 30-60	N-S	140 35-40	Orographic shallow convection. Locally deep convection.
29/11/98	1700-2350	T-M	N/NW to S/SE Slo. Quasi sta.	Sea/Coastal areas. 20	NW-SE; N-S	250 20-80	Extending from catalonian coast to Balearic islands: Catalonian-Balearic Convergence Zone (CBCZ)
09/07/00	0003-0453	Land breeze Tramontane	SW to NE First sta. After slo.	Sea: < 5	NE-SW	100 30	CBCZ. Locally enhanced.
10/07/00	0523-0753	Weak land breeze	SW to NE Fast.	Sea: < 10	NE-SW	120 10-15	Warm clouds extending over southern Catalonia coastal areas.
30/12/00	0903-1633	T-M	N/NW to S/SE Slo.	Sea: < 20	NE-SW; NW-SE	100 100	CBCZ
30/08/01	0034-0524	Land breeze T-M	W to E First sta. After slo.	Sea: < 15	NE-SW	90 30	CBCZ. Locally deep convection.
06/02/02	0020-0640	T-M	NW to SE First sta. After slo.	Sea/Inland	NW-SE; N-S	90 20-60	CBCZ.
04/04/02	1320-2320	T-M	N/NW to S/SE Slo.	Sea/Coastal areas: < 30	N-S	100 50	CBCZ.
14/04/02	0330-0730	T-M	SW to NE Sta.	Inland: < 15	NE-SW	30 30	Covering all Catalonia. Locally deep convection.
01/05/02	0420-1010	Weak land breeze	SW to NE Fast.	Sea: < 10	NE-SW	100 10-35	Covering all Catalonia. Locally deep convection.
07/06/02	0534-1034	Land breeze T-M	SW to NE First sta. After slo.	Sea: 20	NE-SW	40 10	CBCZ. Locally deep convection.

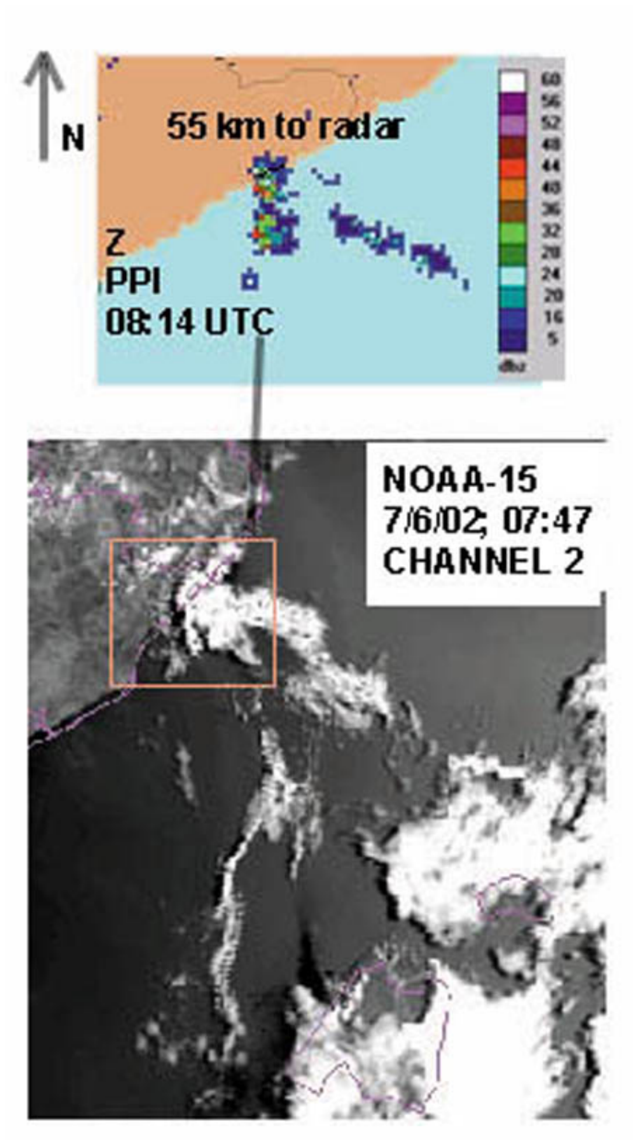

Fig. 2. Example showing cloudiness associated to the Catalonian-Balearic convergence zone and convection related to land breeze/tramontane negative vortex interaction on 7 June 2002. Lower PPI and Polar Satellite image.

vergence boundary is well developed. This restricts the number of cases to two days: 30 December 2000 and 6 February 2002, both analyzed in a distance between 30 km and 80 km easterly from radar. The two cases are different enough to show two common features of the convergence boundary at low levels: a shear line in the direction of the wind, and a cold shallow front (Fig. 3). Lower PPI (Plan Position Indicator) shows a shift in radial wind direction at the usual place of the convergence zone (i.e. WNW-ESE direction from center of Catalonian coast to Balearic Islands). These shear lines are very strong and narrow (less than 10 km width), specially at the second case. In spite of the low vertical resolution of the radar, we have calculated that shear lines spread up to a height between 1 and 3 km, with a northerly slope about 1/13

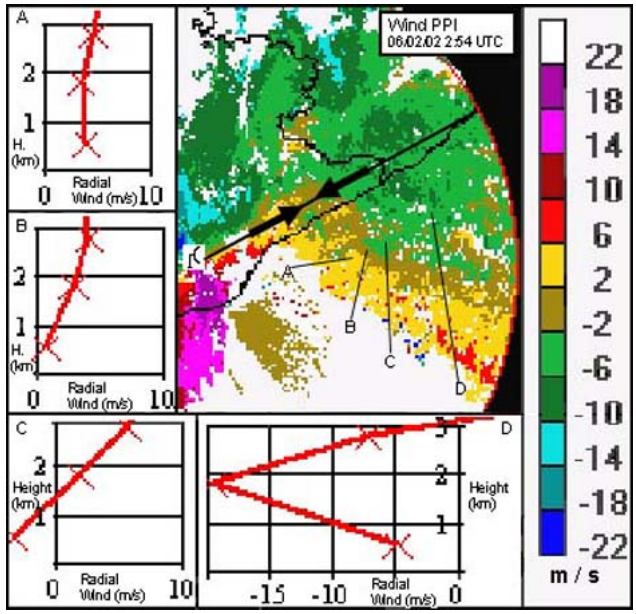

Fig. 3. Example showing the tramontane shallow cold front and its convergence boundary associated (Catalonian-Balearic Convergence Zone) on 6 February 2002. Lower PPI and 4 vertical velocity profiles across the boundary.

(between 1/7 and 1/20).

A cold shallow front has also been identified. This temperature discontinuity has been described, at the context of the PYREX Experiment, as one of the characteristics of the Tramontane wind (Campins et al., 1995). And, of course, it has the same thickness and slope that we have calculated before for the shear line. A diagnosis of the vertical wind profile, shows a veering of northerly winds at lower levels to a uniform field of north-westerly wind over 3 km, indicates the presence of a cold air advection. In fact, a backward ‘s’ shape related as backing vertical wind profile, with cold advection at lower levels, is clearly observed at the first event. On the other hand, it is important to note that cloudiness and precipitation tends to form a few kilometers behind the boundary. Therefore the cold shallow front acts like a synoptic front generating updrafts and clouds.

5 Summary

Planetary boundary layer convergence zones have been identified and analyzed near catalonian maritime areas by using radar and Polar Satellite imagery. INM-radars capabilities are very useful to identify precipitating boundaries but not “clear air” boundaries. By this reason, we must first search radar returns in reflectivity field and then to diagnose if these are related with some enhanced convergence at low levels. From 11 selected events 4 different kinds of convergence zones have been recognized (Fig. 1):

– Sea-breeze/coastal ranges interaction.

– Catalonian-Balearic Convergence Zone (autoconvective).

– Tramontane negative vortex/land-breeze interaction.

– Prefrontal troughs.

Radar and satellite imagery show that all these convergence areas are mesoscale humidity convergent flux zones, with stratiform cloudiness generation but only where convergence at low levels is enhanced it is possible that convection, and eventually deep convection, develop.

Doppler wind field is analyzed in two events, showing that the CBCZ is a consequence of the southward advance of a cold shallow front, known regionally as Tramontane. We have analyzed the horizontal and vertical wind shift at this boundary seeing that these are coherent with a low level cold advection.

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References

Campins, J., A. Jansà, B. Benech, E. Koffi, P. Bessemoulin, 1995. PYREX Observation and Model Diagnosis of the Tramontane Wind. Meteorol. Atmos. Phys., 56, 209-228.

Jansà, A. 1997. A general review about mediterranean meteorology: cyclones and hazardous weather. INM/WMO International Symposium on Cyclones and Hazardous Weather in the Mediterranean. 14-17 April 1997. Palma de Mallorca.

Koch, S.E.; Ray, C.A. 1997. Mesoanalysis of summertime convergence zones in central and eastern North Carolina. Weather and Forecasting, 12, 56-77.

Neumann, J. 1951. Land breezes and nocturnal thunderstorms. Journal of Meteorology, 8, 60-67.

Wilson, J.W.; Schreiber, W.E. 1986. Initiation of convective storms at radar-observed boundary-layer convergence lines. Monthly Weather Review, 114, 2516-2536.