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Weather Radar Anaprop Conditions at a Mediterranean Coastal Site

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1 Abstract

Many weather radars are affected by some type of anomalous propagation (AP) with a wide variety of frequency and intensity. Some geographical areas have been described to be particularly prone to AP. Even in some sites, AP is not statistically abnormal at all but dominant. Severe AP cases have been reported in coastal areas affected by strong temperature inversions and humidity contrasts such as the Baltic Sea, the Indic Ocean or the Mediterranean. In this paper we present average and extreme propagation conditions in the coastal area of Barcelona (NE Spain) calculated using three years of radiosonde data. Occurrence of different propagation conditions is discussed and related to local prevailing circulations such as the sea breeze with particular interest in the nearby Vallirana weather radar. The effect of some extreme ducting episodes seems to be remarkable in beam blocking correction procedures leading to wrong precipitation estimates when anaprop and rainfall occur at the same time. The use of radiosonde and mesoscale NWP data to derive operationally propagation conditions jointly with other existing techniques based in the analysis of radar data is overviewed.

2 Introduction

In coastal areas the vertical structure of temperature and humidity profiles usually presents much more variability than in inland zones. The sea breeze is an example of local circulation induced by the land-sea interface which causes important modifications in both temperature and moisture.
These variations may be noted in the propagation conditions of electromagnetic radio waves. As pointed by Hsu (1998), coastal areas are easily affected by anomalous propagation (AP) or anaprop, due to both local and synoptic circulations. Typically warm and dry advections over the sea may modify drastically the previous temperature and humidity profiles and, therefore, the electromagnetic propagation environment. In such cases the quality of weather radar observations and also other systems based on microwaves such as communication links, may be seriously affected. Extreme cases of AP effects have been observed in the Mediterranean (Battan, 1973), the Indic Ocean (HMSO, 1994), the US West Coast (Babin, 1995) or the Baltic Sea (Anderson et al., 1997).
A detailed description of the fine-scale structure of the refractive index of the atmosphere requires high resolution measurements taken with refractometers. Examples of such measurements, usually made with instrumented airplanes or helicopters, are given by Brunetti et al. (1983), Babin and Rowland (1992) or Sarma and Reddy (1994).
In spite of their better resolution, the cost and complexity of refractometers has favoured that mean propagation conditions are usually calculated from radiosonde observations. They have much less vertical resolution than refractometers and hence may miss many details of anaprop features. However, as radiosoundings have been traditionally the only source of upper air information available on a routine basis, they have been used for years to calculate long term averages of propagation conditions –see, for example, Gossard (1977) or Low and Huddak (1997)-. Moreover, sophisticated radio refractive models based on the solution of the propagation parabolic equation are usually initialised solely with standard radiosonde data as described by Abdul-Jauwad et al. (1991) and Patterson (1998).
In this study the microwave propagation conditions of the Barcelona area have been characterized using radiosonde data. The main objective was to find average and extreme conditions in order to assess the impact of anomalous propagation in the nearby Vallirana weather radar, in particular regarding a beam blocking correction procedure as mentioned previously by Bech et al (1998).

3 Radiosonde observations

Radiosonde data used in this work was taken with RS-80 Vaisala sondes launched from Barcelona (41.38 ° N, 2.12 ° E). The data were recorded during the period ranging from September 1997 to January 2000 (653 profiles, covering all months). Data was sampled every 10 s as high frequency sampling should provide better results than the standard and more coarse radiosonde standard TEMP coded messages.

Though some previous work about the propagation conditions of the area had been carried out by Lorente and Alonso (1987) with a tethered balloon, results were limited to the first 1000 m above sea level as no upper air data existed before to carry out a study of this type.

4 Methodology

Very small variations in the air refractive index n may be responsible for significant changes in the propagation conditions. Therefore the magnitude known as refractivity, N, defined as one millionth of n-1, is often used in anaprop studies. Bean and Dutton (1968) showed that N can be written as:

$$N = (n-1)10^6 = \frac{77.6}{T}\left(p + \frac{4810 \cdot e}{T}\right), \quad (1)$$

where T is the air temperature (K), p atmospheric pressure (hPa) and e is the water vapour pressure (hPa). Valid range for radio frequencies lies between 1 and 10 GHz.

Vertical gradients of N are commonly used to classify the propagation behaviour of microwave beams. Negative values are considered subrefractive: the beam refracts away from the surface more than normal. Normal values are approximately between 0 and –78 km^{-1} and superrefractive layers, bending the beam towards the ground more than normal, are inferior. Ducting occurs when gradients are less than –157 km^{-1} and then the energy may travel trapped in layers for long distances just as in a waveguide before intercepting a surface target.

We have calculated average vertical N gradients in different layers at several heights. The gradients have been obtained by a linear fit of the refractivity measurements of each layer considered. The cumulative frequency distribution of the vertical refractivity gradient for the first 1000 m above sea level is shown in Fig. 1 for the period September 1997 to March 1999.

From a point of view of geometrical optics, treating radar beams as straight lines, a correction that takes into account refraction must be applied. In particular, one may consider a fictitious Earth's radius which converts real curved beams in such straight lines. This is accomplished by means of the so-called effective Earth's model where Earth's radius R is multiplied by a proper correction factor to become R'. As shown by Boithias (1994) for small elevation angles the multiplication factor is:

$$\frac{R'}{R} = \frac{1}{1 + \frac{R}{N}\frac{\partial N}{\partial z}} . \quad (2)$$

Newsome (1992) suggested a series of R'/R factors for different conditions (wet and dry cases) and three different temperature profiles. We have calculated the average value of (2) by inserting the average values of vertical refractivity gradients calculated from (1).

Table 1 shows the mean values of R'/R factors for ten different layers located within the first 4 km above sea level for the period September 1997 to March 1999. The vertical refractivity gradient was calculated using a linear square fit of all measurements along each layer.

Table 2 indicates a summary of 12Z duct height statistics and duct occurrence for the period September 1997 to January 2000.

5 Discussions and Summary

For the first time high resolution radiosonde data sampled every 10 s has been used to characterize microwave propagation conditions at the coastal site of Barcelona (Spain) for the lowest 4000 m above sea level. Extreme cases may be used to identify the worst propagation conditions (both sub and superrefractive cases). Results may be applied to weather radar beam trajectory calculations using beam blocking correction procedures and to enhance the understanding of anomalous propagation phenomena. The analysis of the progation conditions in real time following this approach may be used as a quality control to flag observations collected under anaprop conditions and complement other techniques developed for dealing anaprop weather radar echoes such as those described by Moszkowicz et al. (1994), Pamment and Conway (1998), da Silveira and Holt (1999) or Haddad et al. (2000).

The analysis of the vertical refractivity gradient of the lowest 1000 m above sea level shows that the mean value is –45 km^{-1} , the median value is -40 km-1 and the mode –34 km^{-1}. Therefore, the first kilometre layer considered behaves predominantly as normal. Superrefractive days total less than 10%, though some intense superrefraction events have been detected. The strongest event produced a remarkable –109 km^{-1} gradient in the first kilometre while the largest refractivity gradient value did not produce a subrefractive event.

Many individual ducting and subrefractive layers were observed. In some cases they could be found in operational mesoscale NWP analysis or even in 24-h forecasts. However, the information provided by the NWP data was mostly qualitative though provided a helpful tridimensional perspective which can not be achieved with radiosondes.

Duct occurrence varies during the year, being most frequent in spring. In autumn the minima occurrence was found for this data set; however the highest duct heights appeared in this period. During the year the mode of the duct height does not change significantly and ranges between 140 and 150 m approximately. As the nearby Vallirana weather radar is located at 650 m above sea level, this result indicates that in most cases ducts are well beneath the line of sight of the lowest elevation radar beam. However, the standard deviation of duct height is found to be quite high throughout the year.

Applying an equivalent Earth's radius propagation model, the average ratio R'/R between the new radius R' and the real Earth's radius R has been calculated for ten different layers below the first 4 km above sea level. These results may be compared with Newsome (1992), which presents six sets of R'/R factors for dry and wet atmospheres and three different surface temperature situations obtained assuming wet-adiabatic temperature profiles. It looks that our values correspond to a predominantly dry atmosphere (far from saturation). This result agrees well with the local climatology. It seems to be a far more complex question which surface temperature situation do our results correspond to. The first four layers (0-1, 0-2, 0-3 and 0-4 km) clearly indicate a base temperature around 15°C, which again looks quite plausible climatologically. However, the layers 2-3, 2-4 and 3-4 km seem to indicate a surface temperature between 0 and 10°C while the rest of layers would correspond to a warmer situation.

This inhomogeneity between low and high parts of the layer which extends from 0 to 4 km might be explained by the sea breeze circulation which dominates the wind regime of Barcelona –Redaño et al. (1991)-. Another factor, possibly in combination with the breeze, is the heat island effect of the city. These two factors could produce a significant thermal contrast between lower and upper levels in the first 4000 m.

As well as average refractivity gradients, some extreme values have been examined too. For the first layer, 0-1 km, it was found that gradients ranged from -115 km^{-1} to -16 km^{-1} , while the mean value was -40 km^{-1} well within the standard. If we calculate the difference of the beam height for several ranges assuming the two extreme cases, then the error produced is 125 m at 50 km, 500 m at 100 km and 840 m at 130 km. The effect of such errors in a beam blocking correction procedure seems quite apparent. Therefore it seems reasonable to perform a more detailed analysis of the effects of this error using a larger data set and a digital elevation model in order to assess the impact of extreme anaprop cases in the quality of weather radar observations.

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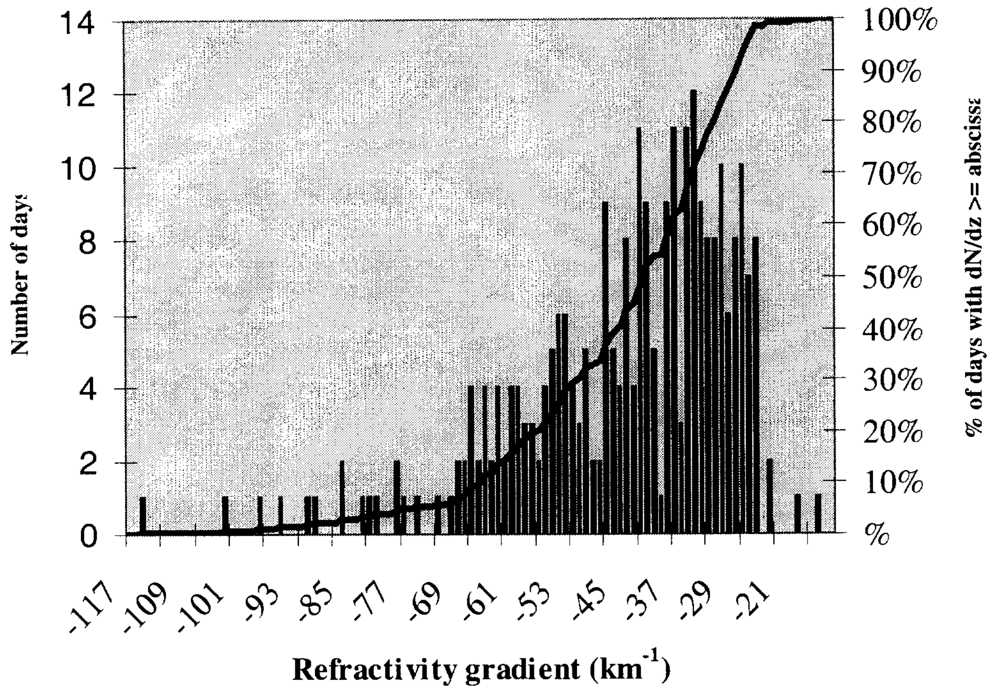

Fig. 1. Cumulative frequency distribution of the vertical refrac2tivity gradient in the first 1000 m above sea level.

Table 1. Mean R'/R factors

Bottom level km asl	1	2	3	4
3				1.20
2			1.24	1.22
1		1.39	1.30	1.25
0	1.39	1.38	1.32	1.28

Top level km asl

Table 2. 12 Z duct height statistics.

Period	Jan - Mar	Apr-Jun	Jul-Sep	Oct-Dic
% daily occurrence	73	79	62	39
Mean duct height (m)	341	399	463	499
Median duct height (m)	159	179	298	157
Mode duct height (m)	146	154	155	137
St. dev. duct height (m)	293	307	329	415