Proceedings of ERAD (2004): 310–314 © Copernicus GmbH 2004

ERAD 2004

Using mesoscale NWP model data to identify radar anomalous propagation events

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Abstract. The effects of intense anomalous propagation conditions upon weather radar observations may represent a serious problem in some applications because of the increase in quantity and intensity of ground clutter echoes. For example, radar quantitative precipitation estimates in highly complex topographical areas that are corrected for beam blockage might be mistaken under super refractive events. Microwave radar propagation conditions are traditionally obtained from refractivity profiles calculated using radiosonde observations. However, NWP mesoscale output, though have a more limited vertical resolution, may be used to retrieve diagnosed and forecasted refractivity profiles. In this paper, two magnitudes have been considered to monitor the radar propagation environment: the vertical refractivity gradient of the first 1000 m above ground level and a ducting index. The ducting index, which is adimensional, considers the degree of departure from the threshold of the super refractive gradient in the 3 first km of air, examining both surface and surface based microwave ducts and selecting the highest ducting index calculated. The two magnitudes, vertical refractivity gradients and ducting index, have been computed for several months for the Barcelona area, which is often affected by super refractive conditions as many coastal sites in the Mediterranean. NWP output was obtained using the MASS system. Results are compared with observations of the nearby Vallirana weather radar and radiosonde observations.

1 Introduction

Quantitative use of weather radar observations, such as precipitation estimates to be used in hydrological models or assimilation in NWP systems, require an exhaustive quality control system (see for example, Joss and Waldvogel, 1990; Alberoni et al., 2003). Radio propagation conditions of the troposphere may lead to anomalous propagation of the radar beam, so this factor may affect the quality of observations. In this work, done within the EU project CarpeDiem and in the framework of COST 717 WG2 (Frühwald, 2000), NWP mesoscale data is used to forecast the propagation environment in the Barcelona area (NE Spain). Four months of forecasts are compared with radiosonde observations.

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2 Weather radar propagation conditions

Variations of the air refractive index control the propagation conditions of the radar beam (Bean and Dutton, 1968). Standard conditions, i.e. -40 N units/km in the first 1000 m above ground level, are commonly assumed by weather radar processing software. However, departures from this value are not unusual and, in some places, show significant seasonal variations (Bech et al., 2000). For instance, under super refractive conditions the radar energy follows a lower trajectory than expected, increasing the quantity and intensity of spurious ground or sea clutter echoes (anaprop). This may affect post-processing procedures necessary for quantitative estimations such as topographic beam blockage corrections (Bech et al., 2003).

Two magnitudes have been considered to monitor the radar propagation environment: the vertical refractivity gradient (VRG) of the first 1000 m above ground level, and an index to measure the degree of ducting, I_D. VRG is calculated simply as the difference between refractivity values at surface and at 1000 m above ground level, according to ITU standards (ITU, 1997). The ducting index, I_D, considers the degree of departure from the threshold of the super refractive gradient (78 M units/km):

$$I_D = 78\delta z - \delta M \tag{1}$$

where the increment of z is in km and the increment of M is in modified refractivity M units. This magnitude is computed in all layers contained in the 3 first km of air, examining both surface and surface based microwave ducts and selecting the highest I_D calculated. Positive I_D values indicate superrefraction. Johnson et al. (1999) found a high

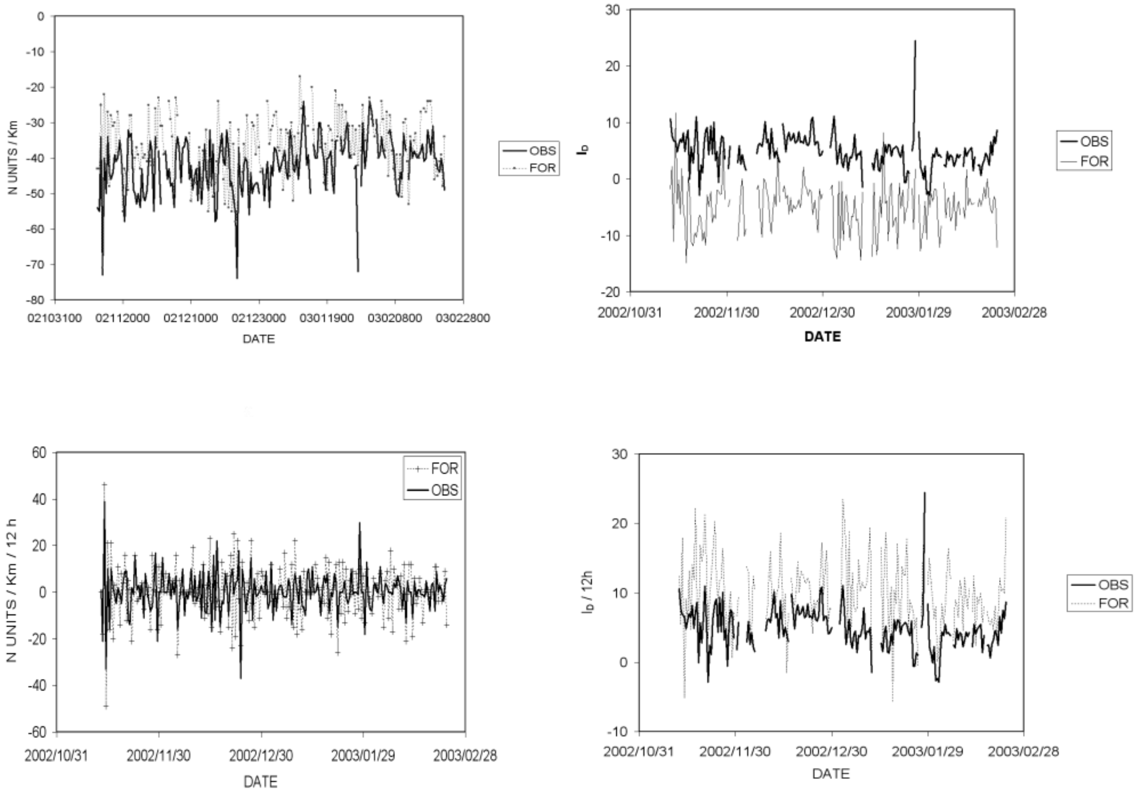

Fig. 1. Time series of VRG (left) and ID (right) forecasts and observations (top) and the corresponding 12 h tendencies (bottom).

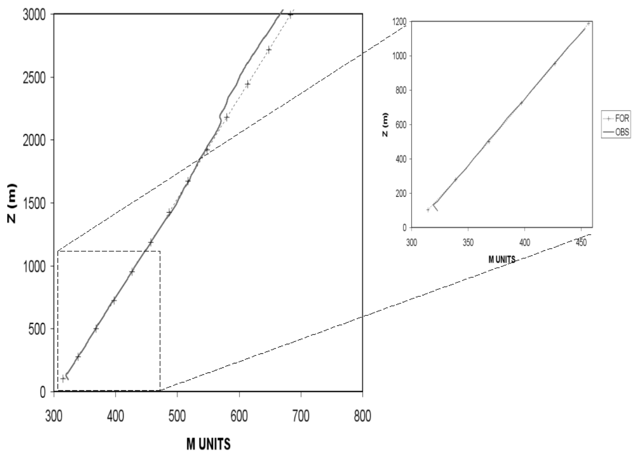

Fig. 2. Vertical profile of modified refractivity on 13 Novembre 2002 at 12 Z over Barcelona: observation (thick solid line) and model forecast (crosses, dotted line). Detail of the first 1000 m are zoomed on the right.

correlation between this index and weather radar anomalous propagation echoes in the UK.

3 NWP forecasts and radiosonde observations

The MASS model (Koch et al., 1985; Codina et al. 1997) was used to obtain vertical refractivity profiles from operational runs at 12 and 24 h. The version of the model was hydrostatic, with a horizontal grid resolution of 15 km and 30 vertical levels. The time period considered ranged from November 2002 to February 2003 allowing the comparison of 183 pairs of model forecasts and radiosonde observations collected in Barcelona (Fig. 1). It may be appreciated that model forecasts tend to underestimate super refraction; both VRG and I_D are biased in this direction (5 N units/km and 10 I_D units, respectively).

Differences in the VRG are usually caused because the surface duct, which is observed frequently, is not correctly simulated by the model. This fact is illustrated in Fig. 2, which shows that in the lower layers the average profile observed and forecasted are very similar. However, as the surface refractivity inversion is not reproduced by the model, VRG values observed (-34 N/km units) and forecasted (-25 N/km units) are different. Differences in the ducting index, apart from the same effect of different surface refractivity value, may be explained by the fact that the index is defined as the maximum value computed over the 3 km layer; radiosonde observations have much vertical resolution allowing to depict sharp refractivity gradients of thinner air layers. For example, in Fig. 2, between 2000 m and 2500 m, a high gradient is observed; this level of detail may not be handled by the coarser model resolution.

The mean absolute errors of the whole period tested were 8 N units/km and 10 I_D units for VRG and the ducting index, respectively. The VRG 12 h tendency was generally in

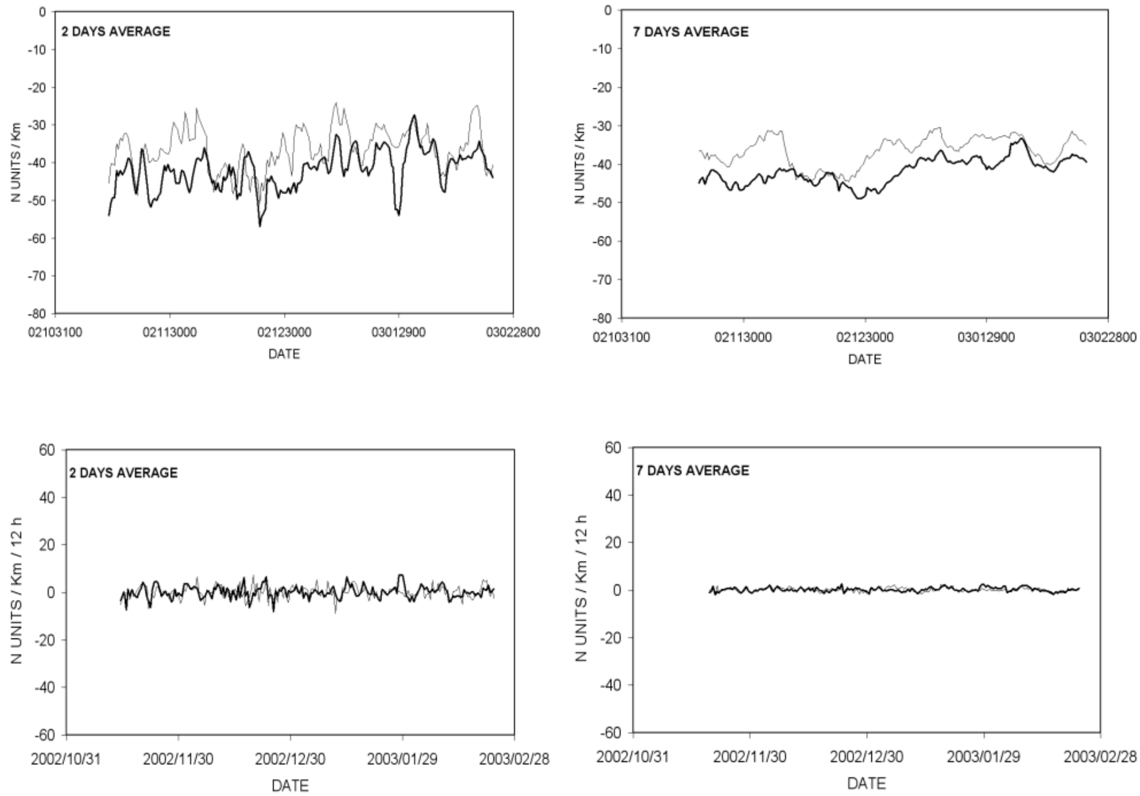

Fig. 3. Two and seven days time averaged plots of VRG (top) and its 12 h tendency (bottom).

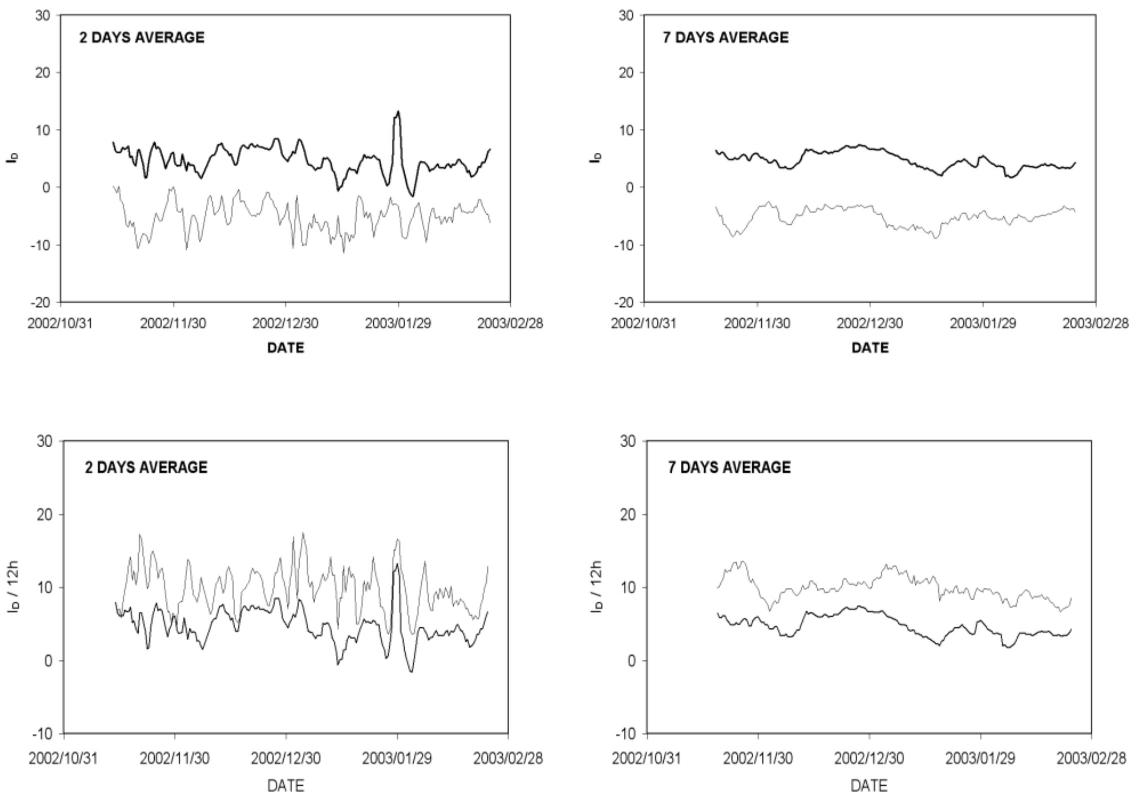

Fig. 4. Two and seven days time averaged plots of I_D (top) and its 12 h tendency (bottom).

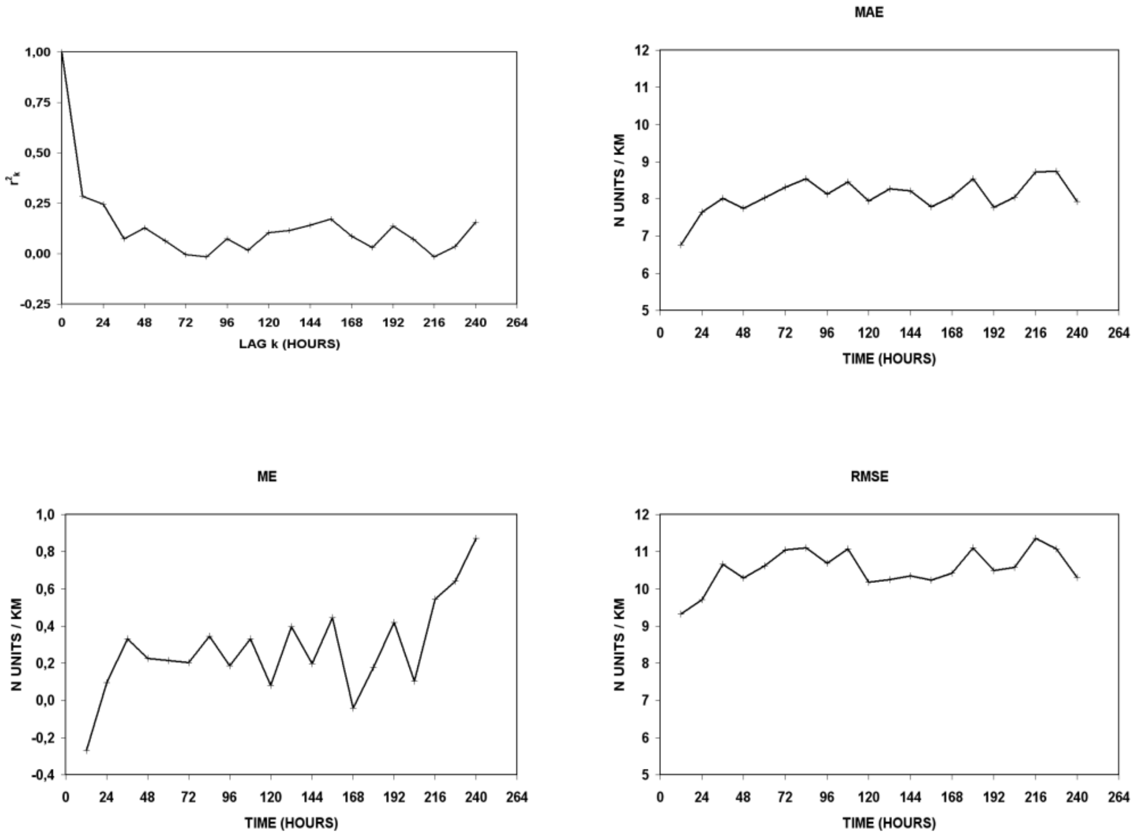

Fig. 5. Autocorrelation function (top left), MAE, ME, RMSE of VRG observations.

good agreement with the observations, particularly its sign, while I_D tendencies were sistematically greater than those observed. Time averaging with moving windows of 2 and 7 days indicated that average conditions and tendencies were reasonably well simulated by the model for VRG (Fig. 3) and, to a lesser extent, for ID, (Fig. 4), which presented more variability. Time averaged plots show clearly that differences in the tendencies converge faster than VRG or I_D values.

To compare these results with the persistence of the observations, their autocorrelation function, mean error (ME), mean absolute error (MAE) and root mean squared error (RMSE) up to 10 days were examined (Fig. 5). For example, the lowest MAE for the VRG observations was achieved with the 12 h persitence (6,77 N units/km) and the ME with the 24 h persistence (0,09 N units/km). Similar results were obtained for the I_D persistence: 12 h ($-0.02\, I_D$ units) and 36 h (2.31 I_D units) for the MAE and ME respectively. These values are better than those obtained with the model forecasts described earlier. So, taking into account these results, new modified forecasts were considered using both forecasts and previous observations.

The modified forecasts, P_i', were built considering simply an initial value P'$_{i0}$ and an increment $\Delta P_i'$:

$$P_i' = P_{i0}' + \Delta P_i'. \quad (2)$$

Ten different P_i', defined as a set of linear combinations of past observations (O_{i-1},O_{i-2}, ... 12, 24 h old, etc) in the initial value $P_{i0}'$and forecasts (P_i,P_{i-1},...) in the increment $\Delta P_i'$, were considered to introduce both the average state of the magnitude and the tendency. In this way, improved ME of 0.01 N units/km were achieved for the VRG. However the MAE did not decrease significantly respect the original VRG forecast. Similar improvements were obtained for the I_D forecasts.

On the other hand, a number of skill scores (Wilson, 2001) were considered to evaluate the ability of new I_D forecasts to predict a positive value of $I_{D,}$ (i.e. detection of super refraction) and were also compared with persistence of the observations 12 and 24 h. The result of the comparison pointed out that new forecasts improved significantly the original model forecasts (for example a POD of 0.89 in front of 0.84 for the unbiased model forecasts). However, the best scores for I_D predictions were obtained using persistence at 12 h (POD: 0.96; FAR: 0.04).

4 Summary and conclusions

NWP model data were used to derive refractivity profiles in order to estimate weather radar anomalous propagation conditions in the Barcelona area (NE Spain). In particular, the vertical refractivity gradient of the first km above ground level and a ducting index were calculated. Four months of model forecasts were verified with radiosonde observations. From this first comparison, and after examining the persistence of the observations, modified forecasts were tested. The new forecasts were built as linear combinations of previous observations and forecasts to improve both the average value and the tendency of original forecasts. Significant improvements were found with the new forecasts, in particular for the vertical refractivity gradient. However, radiosonde observations persistence at 12 h produced better skill scores when used to calculate the ducting index though both mean and mean absolute errors of new forecasts were better than those obtained with the original model output. Future work includes extending the data time period to cover all seasons and refining the modified forecasts by adjusting the average and tendency terms coefficients.

Acknowledgement. Part of this research was funded by the EU project CARPE-DIEM (Contract EVG1-2001-00031) and was done within the framework of the EU COST-717 action "Use of weather radar observations in numerical weather prediction and hydrological models".

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