6.28 PREDICTION OF FOG EPISODES AT THE AIRPORT OF MADRID-BARAJAS USING DIFFERENT MODELING APPROACHES

Cecilia Soriano[1], Darío Cano[2] , Enric Terradellas[3] and Bill Physick[4]
[1]Universitat Politècnica de Catalunya. Dept. of Applied Mathematics I. Barcelona, SPAIN
[2]Instituto Nacional de Meteorología, C.M.T. en Madrid y Castilla la Mancha. Madrid, SPAIN.
[3]Instituto Nacional de Meteorología, C.M.T. a Catalunya. Barcelona, SPAIN
[4]CSIRO Atmospheric Research. Aspendale, AUSTRALIA.

INTRODUCTION

The Instituto Nacional de Meteorología (INM) has been investigating for some time the phenomena related to the formation of fog episodes in the airport of Madrid-Barajas and its prediction. Several studies conducted have shown that there is a link between the development of fog and the establishment of katabatic flows in the region, generally under a synoptic pattern involving either Atlantic or Mediterranean advection.

For the prediction of fog, INM is currently using a 1-D version of the model HIRLAM. In this model, terms which are dependent on the horizontal structure of the atmosphere are estimated from the output of the operational run of HIRLAM at a resolution of 0.2º. However, at this resolution, katabatic winds are not always well reproduced by the 3-D model and, consequently, are not reproduced by the 1-D model either. In order to fix this problem, and under some conditions, forcing from the 3-D model are substituted by others of climatologic origin, estimated from a conceptual model of katabatic winds developed for the region.

In order to check the quality of the conceptual model, a simulation has been conducted with a mesoscale model at high resolution. The model used was the Australian model TAPM, and a grid spacing of 2-km was used for the innermost of its nested domains. The simulation was able to reproduce very well the generation of katabatic winds in the region, and has confirmed the main characteristics of the circulatory patterns described in the conceptual model. In particular, the simulation has identified areas of convergent flows, with upward movement of air, close to the airport of Madrid-Barajas.

GEOGRAPHIC FRAMEWORK AND CONCEPTUAL MODEL OF KATABATIC WINDS

The Madrid airport is located in the centre of the Iberian Peninsula. The surrounding region is characterized by the presence of several mountain ranges and river valleys. The main valley corresponds to the Tajo river and has a general orientation NE-SW, channelled by the Central and the Iberian Mountain Ranges. Four tributaries merge in the lower part. Figure 1 shows the complex orography of the region, with mountains well over 2000 m above sea level.

Studies conducted at the INM have shown that the development of mountain breezes is an extended phenomenon in this region. In particular, down slope winds (katabatic winds) due to differential cooling over complex orography.

The conceptual model (represented in Figure 2) has been developed after the climatologic analysis of all available data (Cano *et al*., 2001): ground-based stations, radio sounding and remote-sensing products (radar and satellite). Its main characteristics are the following: 1) Light down slope winds (less that 3 m s^{-1}) start blowing at the end of the afternoon and can last, depending on the season, until well after dawn. Its vertical depth can reach up to 500 m.

Above this level, a return flow in the opposite direction can be sometimes observed; 2) Upward movements are developed in areas with flow convergence with an ascent velocity estimated in the range 0.02 to 0.03 m s^{-1}.

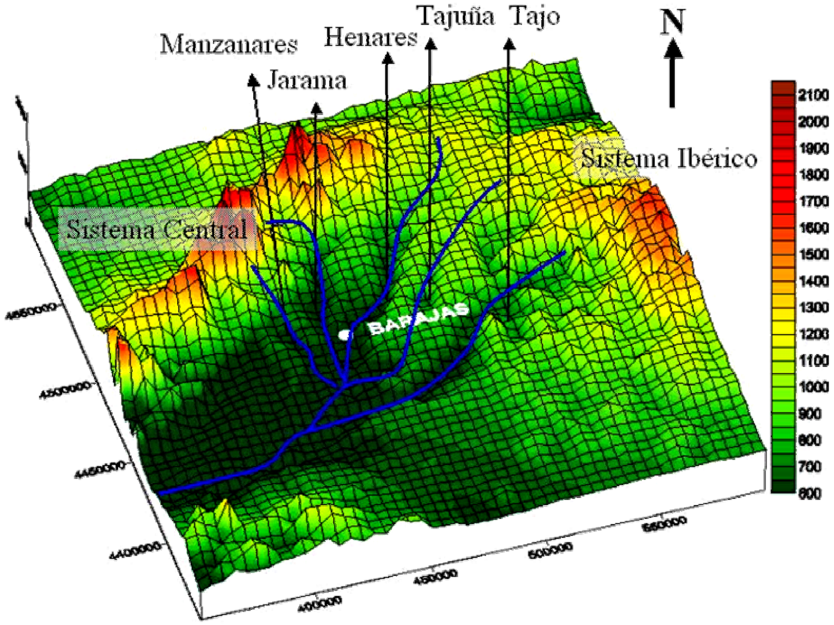

Figure 1. Orography of the region under study and location of Madrid-Barajas Airport.

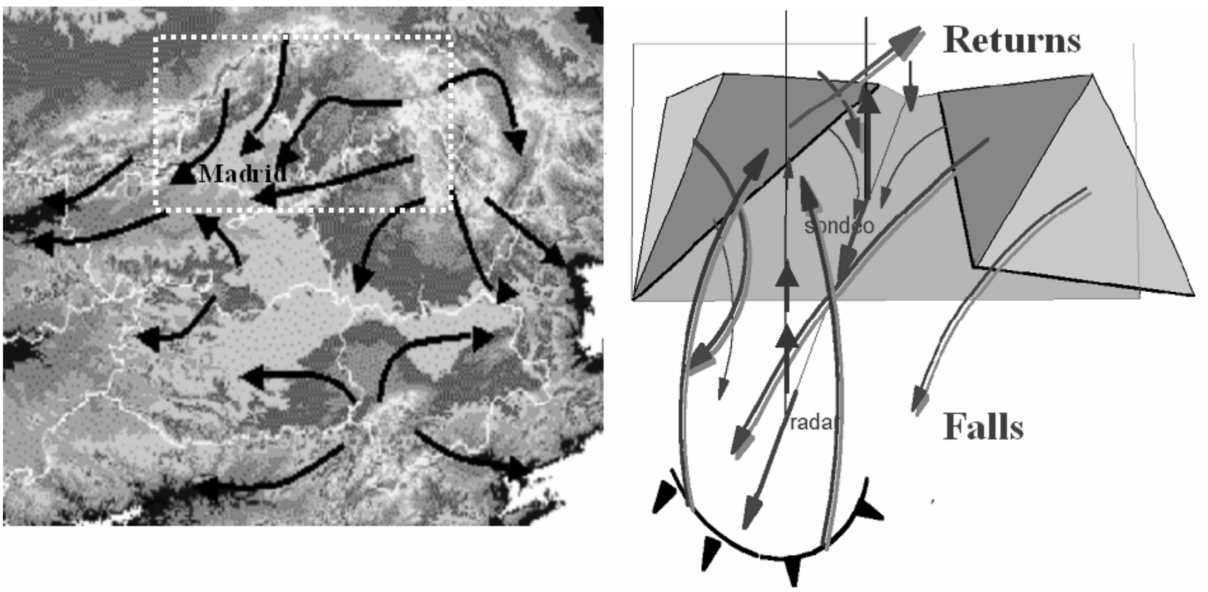

Figure 2. Conceptual Model of the 3-D katabatic flows in the Madrid Area. Left panel shows the model of surface katabatic winds in the Southern Plateau of the Iberian Peninsula. The right panel shows the 3-D model of katabatic wind circulation in the region delimited by a white square in the left figure.

A CASE STUDY: SIMULATION WITH HIRLAM AND TAPM

The night 13-14 November 2003 is characterized by a general high-pressure situation. The central Iberian Peninsula is affected by a light warm and wet south-western advection. Clear skies favoured the development of katabatic winds.

The operational HIRLAM prediction (Figure 3) was not able to reproduce the down slope winds, because of its low resolution.

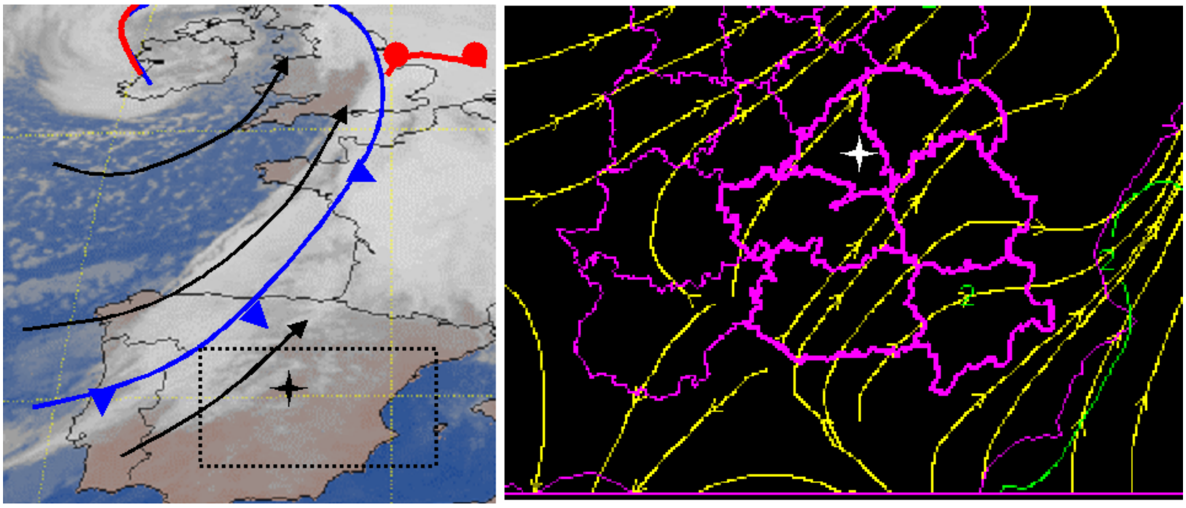

Figure 3. HIRLAM streamlines simulated at 0600 UTC, 14 November 2003. The star marks the location of Madrid Airport, within the region marked with a square in the left panel. Due to the large-scale SW forcing and the low resolution it uses, the operational run did not predict the formation of katabatic winds.

To further investigate the phenomena occurring in the region, a simulation with a high-resolution mesoscale model (TAPM) has been conducted. The TAPM model, developed by the Atmospheric Research Group of CSIRO (Commonwealth Scientific and Industrial Research Organization), in Australia (Hurley et al., 2001; Hurley, 2002) is a complete modeling system for the study of atmospheric transport, although only the meteorological module is used in the current study. It is a non-hydrostatic and full primitive-equation model with an $E-\varepsilon$ turbulence scheme. It works with terrain-following coordinates and allows nesting techniques in order to account for small-scale flows in the inner grid. Non-staggered grids are used in the numerical solution of TAPM's equations.

In the present study, four nested domains have been used, each of them consisting of 50x50x30 cells. The horizontal resolutions are 30, 10, 5 and 2 km. Domains are approximately centred at the Madrid-Barajas airport. Figure 1 represents the domain of the 5-km resolution domain. The simulation is initialized on 13 November at 00 UTC and run for 48 hours. Therefore, the night under study occupies the central hours of the simulation. Analysis and boundary conditions have been provided by the Australian Bureau of Meteorology global analysis model.

Wind fields simulated by TAPM reproduce the main characteristics of the katabatic flow described by the conceptual model mentioned above. The air follows the terrain features, moving downwards and converging in the lowest part of the valley (see left panel of Figure 4). The adaptation of the flow to the subjacent topography is reduced to a thin layer. The flow becomes homogeneous, according to the large-scale forcing, only 500 m above ground level. The flow convergence in the valleys, which forces the elevation of the air masses, is also evident in the simulation. The right panel of Figure 4 represents the vertical velocity computed by the model at 200 m AGL, in a good agreement with the areas of expected convergence or divergence.

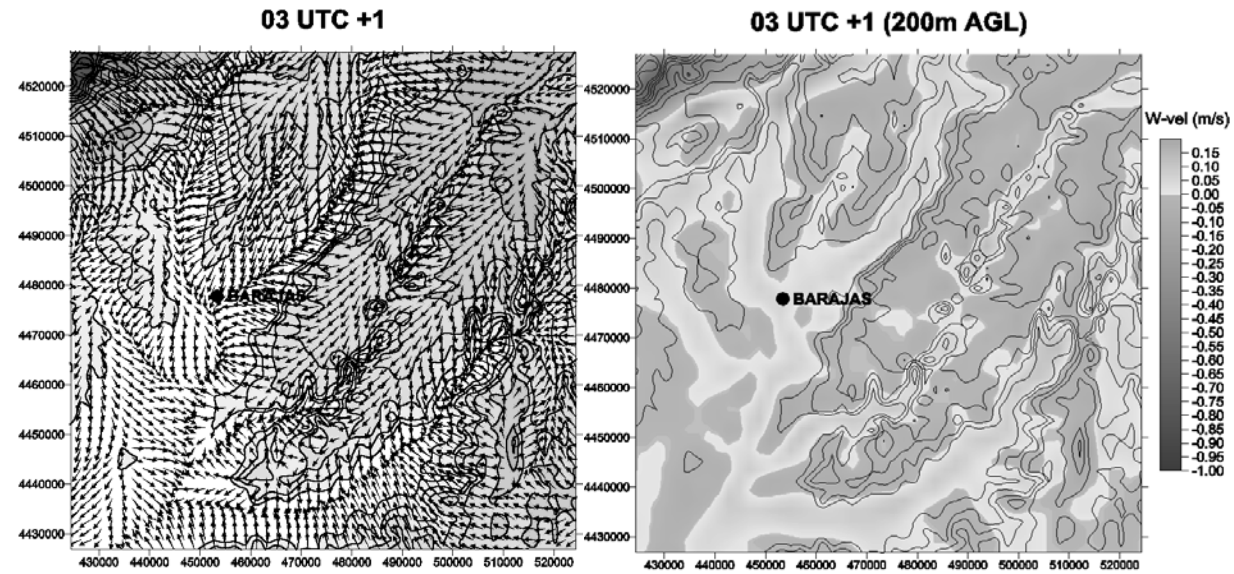

Figure 4. TAPM results at 3 UTC on at 03 UTC of November 14, 2003. Left panel shows wind at the first vertical level (10 m) and right panel shows vertical velocity at 200m AGL.

The model skill in the prediction of the katabatic winds is assessed from the comparison of modelled and measured data. Figure 5 shows the time evolution of wind direction and velocity on 14 November. It is evident that HIRLAM 3D, at its operational resolution is not able to reproduce the katabatic night time winds (northerly), which TAPM does generate at its 2x2 km^2 resolution.

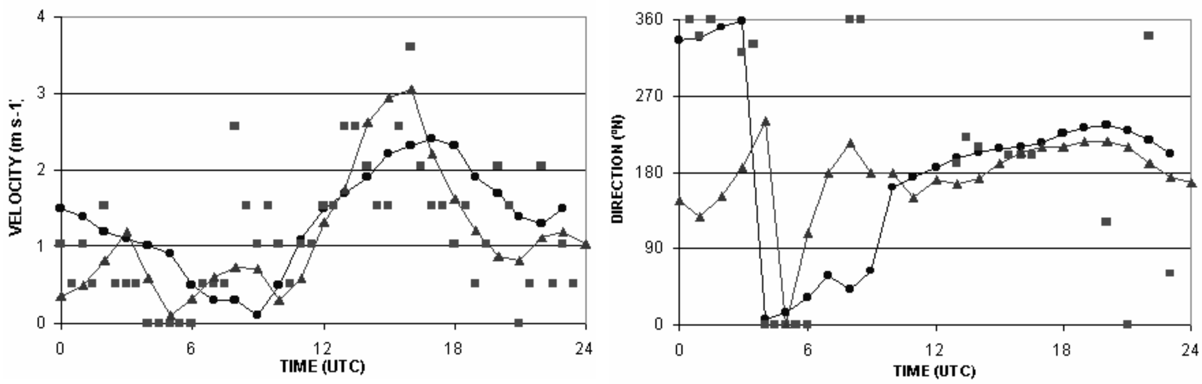

Figure 5. Measured wind speed and direction (squares with no line) for day November14, 2003, and simulated values for HIRLAM 3D (triangles) and TAPM (circles).

THE 1-DIMENSIONAL VERSIÓN OF MODEL HIRLAM (H1D): FOG PREDICTION

The 1-Dimensional version of HIRLAM developed by the INM starts from an initial column of data from the HIRLAM 3D operational run at 0.2º resolution. It incorporates a katabatic module based on the conceptual model described above, which has been confirmed by the high-resolution model. The katabatic flux routine is activated when a surface inversion is detected, modifying some forcing on the model:

- Horizontal advection of the wind: On activation of the module, a horizontal advection is imposed which makes wind zero the next time-step.
- Horizontal pressure gradient: A geostrophic wind is considered with lineal dependence on the value of the temperature inversion.
- Horizontal divergence of mass: It is also taken as linearly dependent on the temperature surface inversion. It will mean a modification of the vertical velocity profile.

- Horizontal advection of humidity: Proportional to wind velocity.
- Horizontal advection of temperature: Different schemes are available. In this case, it is taken constant.

Figure 6 shows the application of the H1D model to the night we are studying. The upper plots show results when the katabatic module was activated and the lower plots when no katabatic forcing was introduced. The introduction of the katabatic forcing reproduced the northerly winds during the night hours (central panels), which where not present if only HIRLAM 3D data was used. The fact lead to the prediction of fog that night (right upper panel), shown by the presence of clouds at surface level.

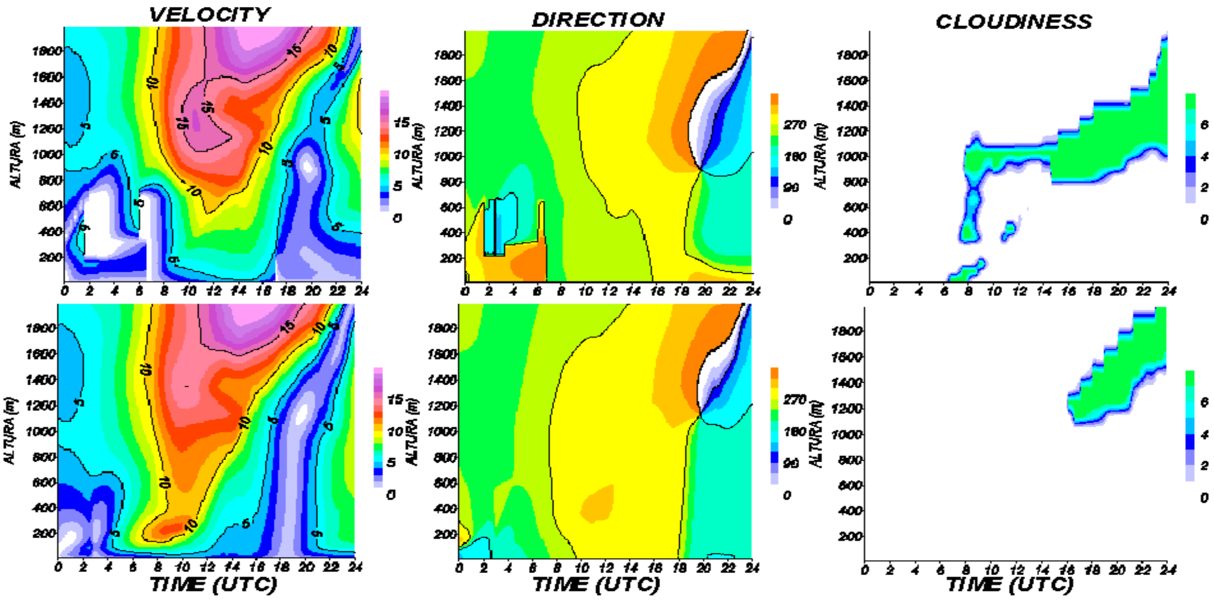

Figure 6. H1D results (velocity, direction and cloudiness) for November 14, 2003 when the katabatic module is activated (above) and when it is not (below).

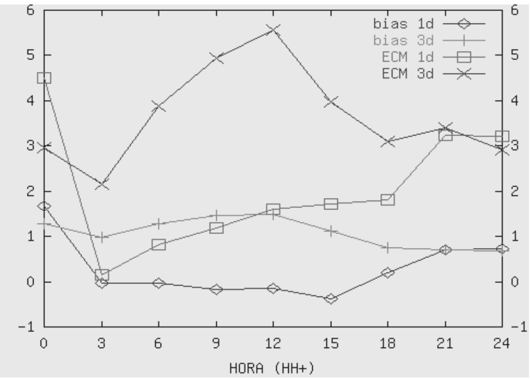

Figure 7. H1D vs. H3D evaluation

Finally, Figure 7 shows verification of the model for specific humidity after a period of operational application of 5 months. The graph shows improvement of the prediction of this quantity by the H1D model, as Bias (diamonds) and Squared Mean Error (ECM, squares) are lower than those statistics for H3D (crosses and X respectively) . H1D also shows a better evolution of the prediction with time after the initialization of the model.

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