P5.2 MODELLING THE INTERACTIONS BETWEEN SEA BREEZES AND VALLEY BREEZES

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1. INTRODUCTION

A coastal region is influenced by many meteorological phenomena due to the interactions between breezes and large-scale wind systems. Mesoscale air flows in coastal regions are mainly determined by land-sea temperature contrast that drives land-sea breezes, and by the orography that drives mountain-valley breezes while the shape of the coastline has an effect on mesoscale wind flow. All these phenomena strongly influence various scalar fields including moisture and air pollution concentrations.

Over the last decade, sophisticated mesoscale models like RAMS or MM5 were developed. These models are used for purposes ranging from weather forecasting, to air-quality regulatory applications, and to basic research.
The improved capability of these models to reproduce physical complexity nowadays allows accurate simulations. Mesoscale models also help understanding processes by allowing full control over environmental parameters. Hence it is possible to determine the steering factors of a phenomenon and also to test sensitivity against changes in environmental conditions. Scientific goals of mesoscale modelling include accurate numerical simulations of mesoscale processes to understand the role of synoptic scale parameters upon mesoscale phenomena, to find the limits of predictability also by means of sensitivity studies, and to understand the interactions between the mesoscale and the smaller and larger scales.

The aim of this study is to model the mesoscale circulation in a complex coastal region both to improve our understanding of the phenomena and to forecast them. The first step towards the modelling of convective, valley and/or sea breeze circulations for the Esino Valley, in the middle of Italy, was accomplished through the application of RAMS model for several events.

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We have analyzed the relative importance of sea-land and mountain-valley thermal contrasts in governing the interactions between sea breezes and valley breezes. For this study RAMS 4.3 was run with two nested grids with a fine grid of 100m horizontal spacing. The vertical distributions of atmospheric flow and meteorological parameters have been simulated considering the effect of complex terrains.
The input data for initial and lateral boundary conditions have been downloaded from National Center for Environmental Prediction (NCEP) reanalysis products. Mesoscale circulation during two days of the summer of 2001 has been modelled. The main requirement for the selection was the presence of calm conditions with weak synoptic forcing, like the high-pressure system that dominated over the selected area for both days.
It is interesting to examine the effects of sea-land and mountain-valley contrast because of their relevance in determining the local climate.
Three simulations are presented and compared:

1. The sea-land breeze
2. The mountain-valley breeze
3. The interaction between the sea breeze and the valley breeze and their combination.

Results show the importance of orography in determining the interaction between sea breezes and valley breezes and the local climate in a complex region as the Esino Valley.

2. MODEL DESCRIPTION

RAMS is a versatile modelling system capable of simulating flows from the scale of a global hemisphere to the scale of a building (Pielke et al., 1992) with several options including multiple nesting, and several convective and boundary layer parameterisation options. It is assembled around the full set of primitive dynamical equations that govern atmospheric motions, and supplements these equations with optional parameterisations for turbulent diffusion, solar and terrestrial radiation, moist processes -including the formation and interaction of clouds- and sensible and latent heat exchange between the atmosphere and multiple soil layers. Prognostic soil-vegetation relationships are used to calculate the diurnal variation of temperature and moisture at the ground-atmosphere interface. Turbulence sensible heat, latent heat, and momentum fluxes in the surface layer are based on similarity equations.

RAMS is able to handle terrain resolution very well but certain constraints and rules must be observed, however. Most important is that since terrain height is used in defining the model vertical coordinate, compatibility of terrain heights between different model grids is required for proper grid nesting communication. This is equivalent to requiring that terrain heights between grids satisfy the averaging and boundary interpolation operators that are applied to prognostic variables. In facts, the vertical structure of the grid uses the $?_z$ terrain-following coordinate system (Gal-Chen and Sommerville, 1975; Clark, 1977; Tripoli and Cotton, 1982) where the top of the model domain is exactly flat and the bottom follows the terrain.

A second concern is that, in representing terrain on a discrete model grid, terrain main features may be strongly filtered. A common example is a long, narrow mountain chain that acts as a barrier to transverse flow, but which loses much of its effective barrier height when averaged to a coarse model grid using a standard mass-preserving operator.

After the horizontal interpolation of these data to a temporary grid of comparable resolution to the data and in polar stereographic coordinates, a multi-step averaging process is performed. Averaging process implies conventional and silhouette averages. The conventional average is a simple summation of a fine grid cells contained in a single coarse-grid cell, to obtain the terrain height to be assigned to that coarse grid cell. The silhouette average, on the other hand, finds the mean height of the silhouette as viewed from the East or West of the set of fine-grid terrain heights contained within a single coarse-grid cell, and the silhouette heights together. This becomes the computed silhouette height for that coarse-grid cell. The conventional average, while preserving total terrain volume above the sea level, tends to lower barrier height, even more when the grid is too coarse to resolve the barrier properly. On the other side the silhouette average tends to add mass by filling valleys. The final height values used for computation results from a further weighted average and a final interpolation. The user defines the averaging weights in this last step, and this could be a crucial step in order to obtain a representative terrain model. By the way this was not our issue since after several attempts it became evident that a 1 Km (30'') resolution orography was insufficient to resolve the smooth Esino valley. Minor issues came out about the most inner segments of this valley.

3. METHODS AND DATA

For this study RAMS was run with two degrees of nesting, being fine grids (three along the valley) 100 m horizontally spaced (Fig.1). The vertical distribution of atmospheric flow and the meteorological parameters have been simulated considering the effect of complex terrains.

The input data for initial and lateral boundary conditions have been downloaded from National Center for Environmental Prediction (NCEP) reanalysis products. The NCEP reanalysis data system (hereafter referred to as "data" or "reanalysis data") was chosen as the main data source for the initial and boundary condition files for two reasons:

1) it provides a consistent, easily available dataset for any episode chosen for this study
2) it provides a source for variables such as soil moisture which are not synoptically available over large areas.

Meteorological measurements at four stations were available.

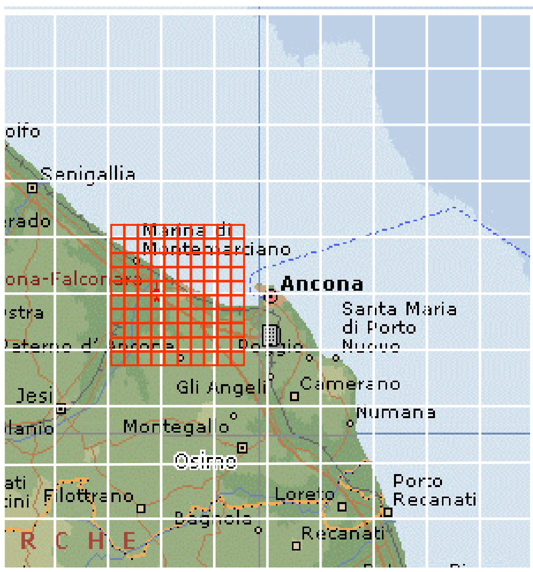

Fig.1 - The first fine grid at the very end of the valley.

3.1 *Case Study*

The Esino Valley (Fig.1) is particularly interesting due to its composite orography (Latini G. et al., 1999) and the presence of an inner city that can complicate small-scale circulation patterns due to its urban heat island effect.

The Valley is surrounded by hillsides sharply rising to mountain height. Its climate is classified under sub coastal where there is an all year round sea breeze. Topography in the Valley area is fairly complex and the proximity to the coast implies a significant interaction between the sea and valley breezes. Topography plays an important role in modifying wind field. But the level of topographical detail in a model is determined by its grid spacing. For this reason a digital elevation model (DEM), covering the selected area with a horizontal resolution of 100 m, was generated.

The climatic conditions for diabatic driven local flows are more favourable in summer, therefore in the next section we report results for July the 16th and July the 17th 2001, under calm large-scale winds and clear sky conditions. Such conditions are often observed in the valley during the summer. In the warm seasons, the local flow is dominated by the sea breeze and by the mountain valley breeze. Observations show that the sea and valley breezes merge in the early afternoon.

In order to examine the relative importance of the sea-land breeze and of the mountain-valley breeze over the Esino Valley several runs have been examined.

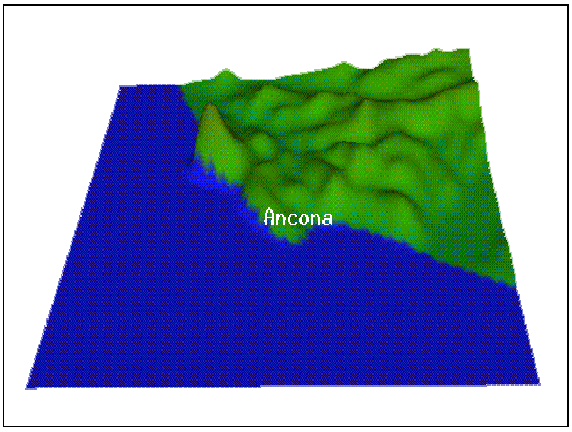

Fig. 2a - The Esino Valley is visualized at 100 m spatial resolution.

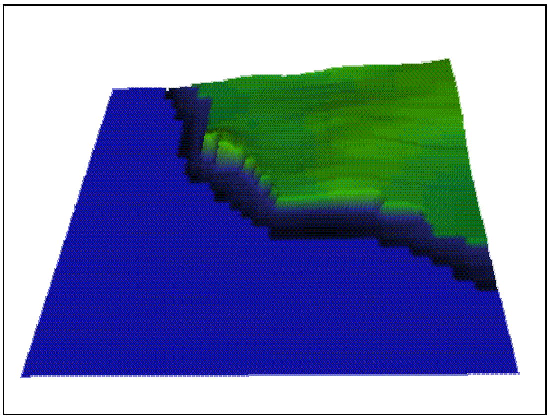

Fig. 2b - The Esino Valley is visualized at 1000 m spatial resolution.

4. WIND FIELD SIMULATION

The effects of dynamic pressure on wind field in the Esino Valley have been analysed.

Some effects are triggered by dynamic pressure differences induced by topography. For simulations in the complex area, two resolution domains have been considered: a coarse resolution of 1 Km (Fig.2a) and a fine resolution of 100 m (Fig.2b) The coarse resolution neglects a lot of topographical detail unlike the resolution of 100 m that accounts for most of the topographical details.

4.1 *Simulation of sea breezes and valley breezes*

In this section we discuss the results for runs in which the sea-land contrast, mountain-valley and sea-valley flows are simulated. In the first case we considered a domain mainly covering the coastal area so that the forcing was essentially due to the sea-land contrast.

A sea breeze event on 16th July 2001 was characteristic of many summer sea breeze events. A slow moving high-pressure cell dominated the synoptic situation. In the morning the sea breeze development along the shores of the Esino Valley had to overcome an initial offshore geostrophic flow. Figures 3 and 4 show the near surface winds in the morning: the limited sea breeze penetration is better represented using the fine resolution.

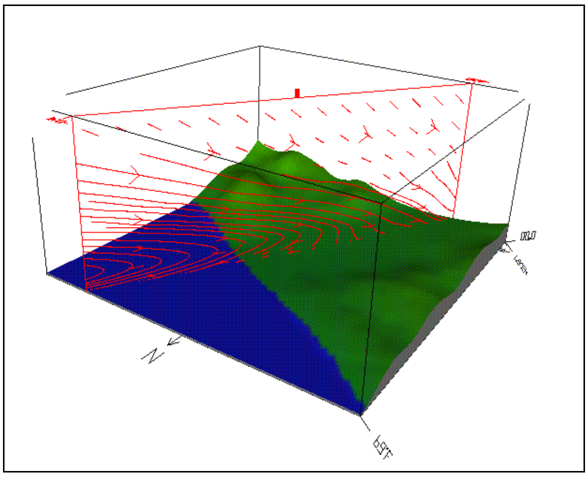

Fig.3 - Sea breeze from RAMS simulation (fine grid).

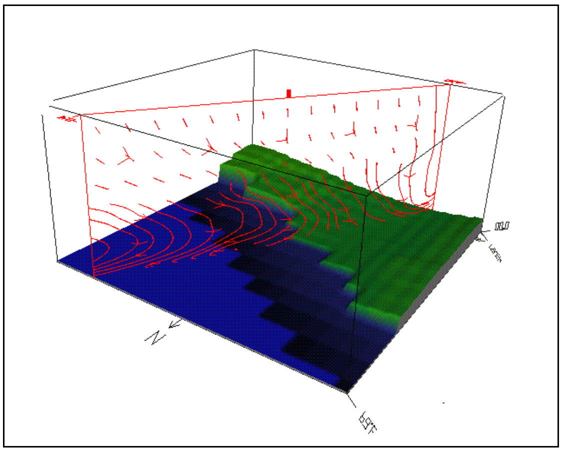

Fig.4 - Sea breeze from RAMS simulation (coarse grid).

In figures 5a and 5b an outstanding implication of orographic resolution in local meteorological formation is reported. The image represent morning scenario (10:00 am) at the very end of the valley, along the Adriatic sea shoreline for the same model simulation at two different terrain resolution: 100 m and 1 Km. Light blue lines represent wind streamlines in a vertical slice positioned in center of the valley, while the terrain color mapping, from blue (lower temperatures) to red (higher temperatures) depicts the thermal field on the surface.

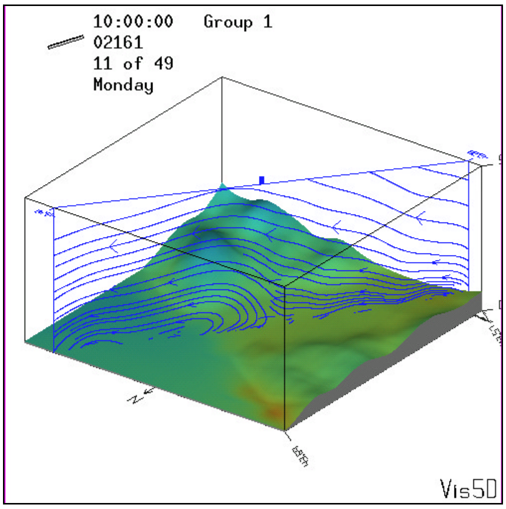

Fig 5a - Vertical slice for streamlines at the end of Esino valley with 100 m resolution terrain. Terrain color mapping (from blue to red) depicts the thermal field on the surface

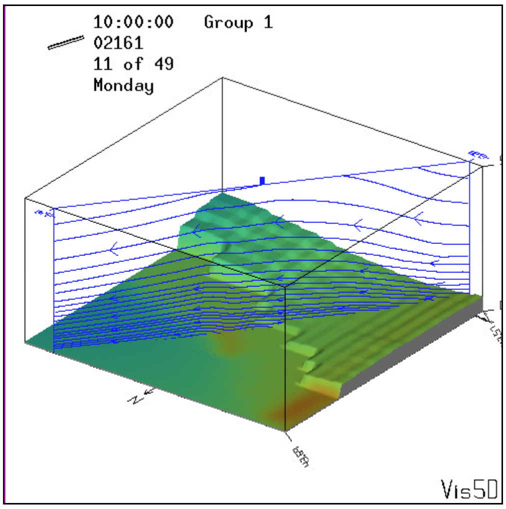

Fig 5b - Vertical slice for streamlines at the end of Esino valley with 1000 m resolution terrain.

It is evident that there is a scarce correspondence between the two temperature fields, due to model averaging, resulting in a smaller temperature gradient along the valley direction. As a consequence, we either have a triggered sea-cell convection process or not. Successive images show that a sea-cell starts in the coarser grid too, but several hours later .

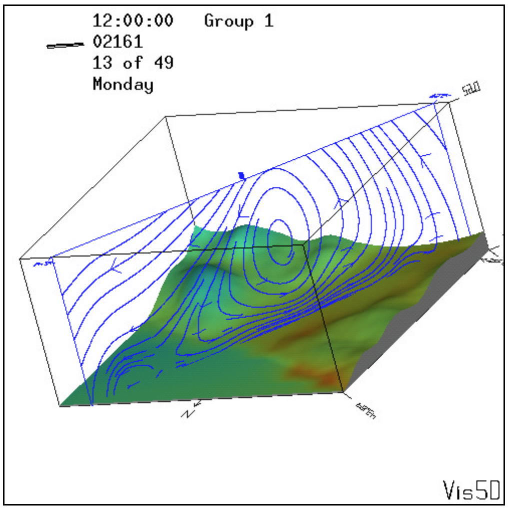

Fig.6a - Vertical slice for streamlines at the end of Esino valley with 100 m resolution. All the same as figure 5a but two hours later.

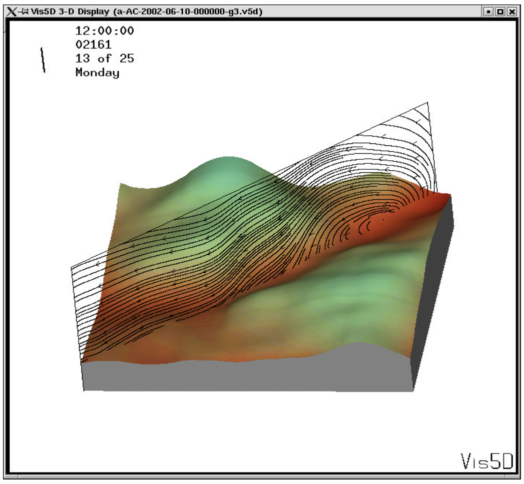

Fig.7a - Vertical slice of wind streamlines and surface temperature field for an inner segment (high segment) of the Esino valley.

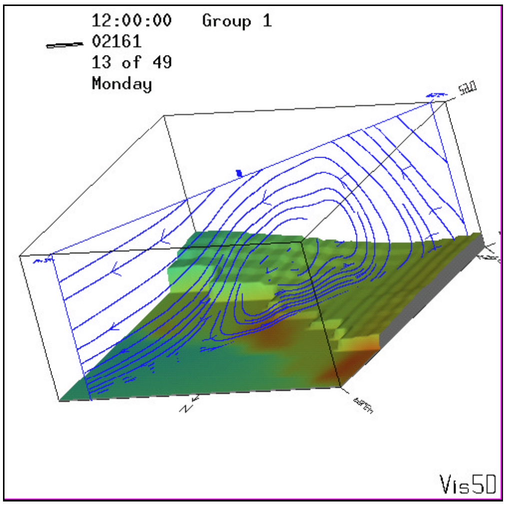

Fig.6a - Vertical slice for streamlines at the end of Esino valley with 1000 m resolution. All the same as figure 5a but two hours later.

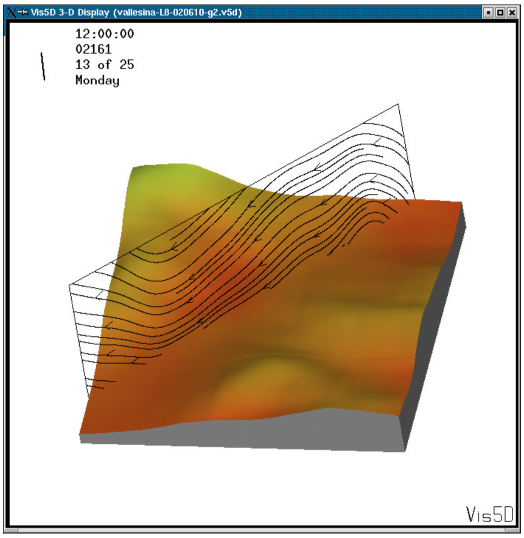

Fig.7b - Vertical slice of wind streamlines and surface temperature field for an inner segment (middle segment) of the Esino valley.

Moreover, the averaging process, when coarse grids are used, may result in excessive terrain smoothing eliminating a barrier effect. This is the case of Conero promontory on the right side of the valley (in the sea direction). A dominant southward wind field (not visible in the figure) tends to blow away every local eddy and this increases the delay in the convection-cell formation.

Figures 7a and 7b show that convective phenomena along the inner valley are very weak, especially in the central segment where the valley is large and scarcely sloping (figure 7b). On the contrary the steep sides of higher segments of the valley allow the development of a small convection cell. Again, surface temperature field is represented by colors (from blue to red) of terrain.

5. CONCLUSIONS

The present study has investigated the relative role of the sea-land contrast and of the mountain-valley contrast in determining the local thermal convergence pattern over a complex coastal area such as the Esino Valley.

We have used a mesoscale meteorological model (RAMS) to study the problem. Our results have shown that the topography plays a fundamental role in determining the mesoscale flows. In particular, for the Esino Valley, the mountain-valley contrast is of the same order of magnitude with respect to the sea-land contrast. Therefore the local climate is both due to the presence of the sea and to its sharp topography in the inner valley.

This paper demonstrates that even the most sophisticated models, namely RAMS, will fail to simulate flows in the complex topography of a complex area, as long as they are restricted to smaller resolutions. This study suggests the necessity to use fine grids: the relative contributions to the flow, i.e. the sea breeze, mountain-valley breeze and the combination of the sea breeze with the mountain-valley breeze in the simulated cases, using fine resolution, are well reproduced.

6. REFERENCES

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