Semigeostrophic Modeling of Orographic Cyclones

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Introduction

Alpine lee cyclogenesis, triggered by frontal interaction with orography, is frequently associated with episodes of heavy or severe precipitation. Several theories have been proposed in order to explain this phenomenon from different points of view, as the normal mode theory (Speranza et al., 1995), or the numerical model studies (Schär 1990, Gross 1994, Orlanski and Gross 1994). Here, we have developed a semi-geostrophic model of frontal passage over isolated orography to examine a developing orographic perturbation in the presence of a finite amplitude primary wave, in idealized conditions. In the linear formulation of the model an initial state, constituted of a uniform vertical shear and a two dimensional Eady wave of desired amplitude, is perturbed by a small height mountain located ahead of the incoming front. The interior perturbation is assumed of zero potential vorticity and the mountain appears in the bottom boundary condition as a forcing of vertical velocity, so there are no blocking effects. The choice of the semi-geostrophic framework is due to its ability to reproduce the essential frontal features in all stages of development. In fact, the equations of motion in the geostrophic momentum approximation, written in geostrophic coordinates, are formally equivalent to the quasi-geostrophic system, but when the inverse coordinate transformation is applied, it incorporates the well known frontogenetic effects (Hoskins, 1975) by contraction of the areas of positive relative vorticity. The Eady wave, which is finite amplitude solution of the quasi-geostrophic problem, is also solution of the original semi-geostrophic problem; therefore it is possible to express analytically a baroclinic wave with its associated front at any amplitude. However, the fact that the two dimensional Eady wave is a linear wave, i.e. grows exponentially and doesn't exibit any finite amplitude equilibration, makes long integration impossible, because it reaches soon the limits of numerical stability. Even in the linearized model a measure of non-linearity is retained in the coordinate transformation, which includes the perturbation quantities. The model works by time integration of the boundary conditions followed by inversion of the elliptical operator which represents potential vorticity, by a relaxation tecnique. For a detailed description of the model and a discussion of its drawback, as a small inconsistency of the linearized mountain boundary condition, see Fantini and Davolio (1999).

Results

We present here the results of a model run with the following features: wavelenght of the primary wave $L_E = 5 \cdot 10^6 m$; initial amplitude $A_i = 500 Pa$; vertical wind shear $U/H = 2 \cdot 10^{-3} s^{-1}$; top of the model $H = 10^4 m$; Brunt-Väisälä frequency $N = 1.5 \cdot 10^{-2} \mathrm{s}^{-1}$; mountain heigh $h = 1500m$. In the zonal direction the mountain is made of two half gaussians, joined by a flat bottom with a value of 1000 km. In both the zonal and meridional directions, the half width is $L_X = L_Y = 500km$.

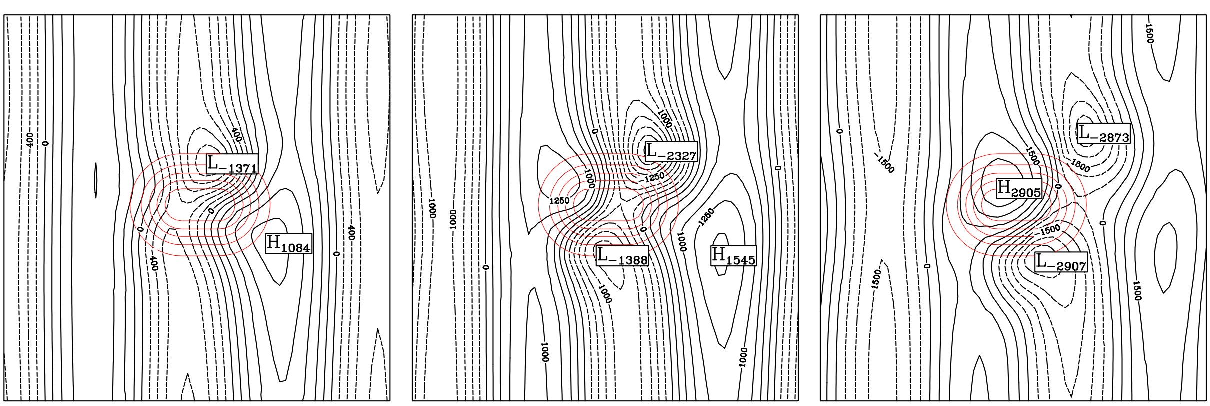

Figure 1: Surface pressure in Pa at times $(a) 12 \cdot 10^4 s$, $(b) 21 \cdot 10^4 s$,$(c) 30 \cdot 10^4 s$

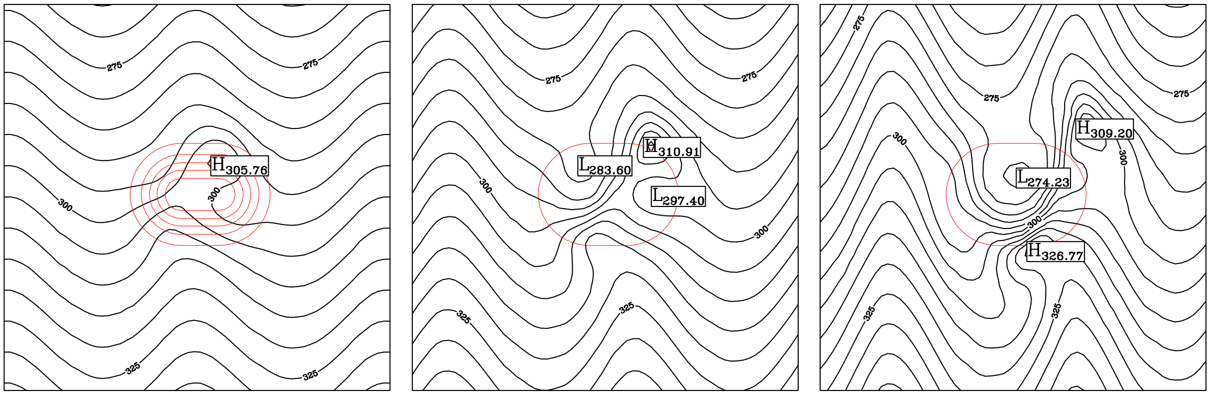

Figure 2: Potential temperature at the surface in K at the same time as in Fig.1

At the beginning the front is oriented along the meridional direction and the phase of the primary wave is chosen so that the front, and the corresponding minimum surface pressure, are co-located over the 500 m western topographic contour. Fig.1 and Fig.2 show respectively the surface pressure and surface potential temperature evolution for the same time. Because of the initial phase of the primary wave, a pressure low appears first on the northern side of the mountain, associated with a warm anomaly; at a later time the perturbation, while moving eastward, develops a minimum surface pressure in the southern side, which grows very rapidly and overtakes in amplitude the northern one when it reaches the south-eastern corner of the orography. At this time the northern low is deatached from the mountain because of the combined effect of the mean wind and the primary wave and the amplitude of the orographic perturbation (not shown) is now bigger in the southern side where it is still growing. While the warm bubble follows the northern pressure low, cold air associated with the primary wave moves across the mountain top, and together with warm advection within the lee-side low, contributes to the creation of a intense cold front on the southern slope. Probably because of the lack of blocking effects, the intensification of the front seems to be due to air flow across the mountain and not around it, so the area of the convergence is located more to the east than expected. It is interesting to note that the deformation of the primary wave can be seen even at 5 km, where a cut-off low develops on the south-est side of the mountain (not shown).

This work shows that the model is able to reproduce resonably an orographic perturbation even if many drawbaks tend to limit its range of application. On the other hand this test has allowed us to find out all the main shortcomings, so that in the future we'll be able to develop the model in order to overcome them, i.e. with a proper rappresentation of the orography by terrain following coordinates.

References

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