Dynamical interpretation of a banded precipitation event over Italy

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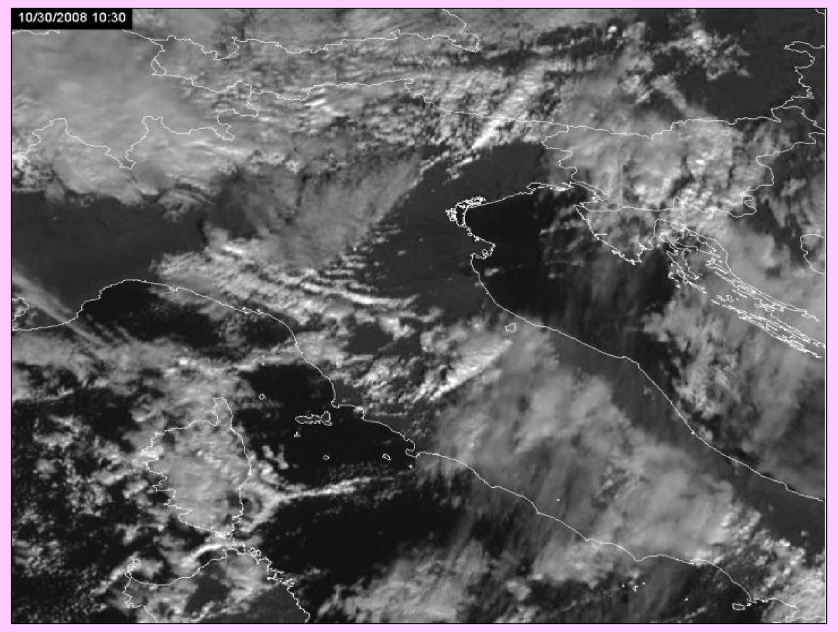
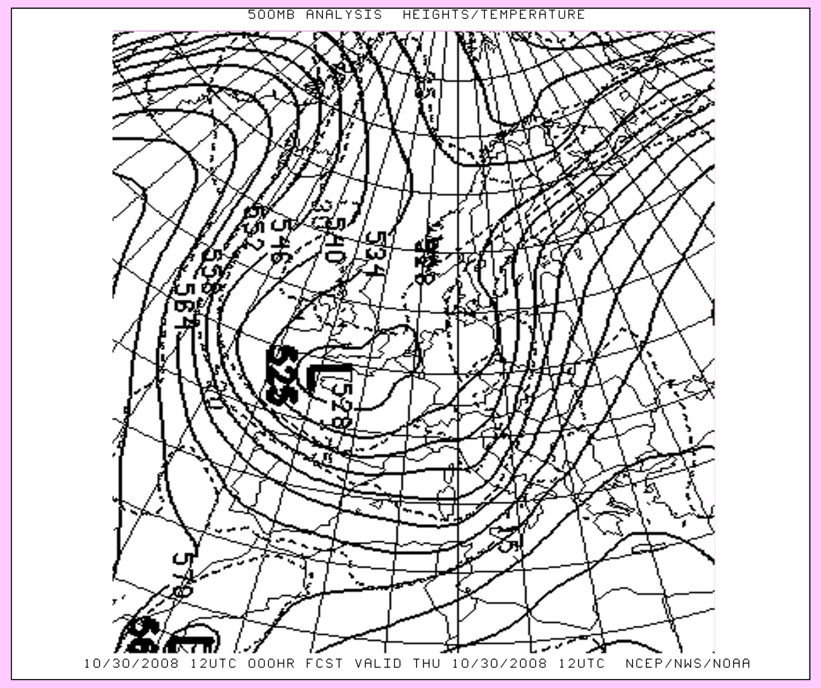


Satellite image at 10:30 UT October 30, 2008 showing wave trains in the lee of the Northern Apennines mountains and several rainbands at various stages of development. (Image Copyright © 2008 EUMETSAT).



500 hPa analysis (height and temperature) at 12:00 UTC 30 Oct 2008

SYMMETRIC INSTABILITY

For a nearly parallel flow one can look at a representative section across the flow and consider the two dimensional problem. Define $M=fx+v$ and let $B=\theta$ in dry conditions, or $B=\theta_e^*$ for saturated flow. Then $M_x<0$ denotes inertial instability and $B_z<0$ denotes convective instability. When the derivatives are positive but the Jacobian is not:

$$Q=\frac{\partial(M,B)}{\partial(x,z)}=M_xB_z-M_zB_x<0$$

then unstable slanted updrafts are still possible. As is the case with ordinary convection, if the air is sub-saturated the instability is "conditional", i. e. external forcing is required to kick-start the motion. Moreover, the consideration of *condensate loading* changes somewhat the above condition (e.g. Fantini and Malguzzi, 2008, JAS).

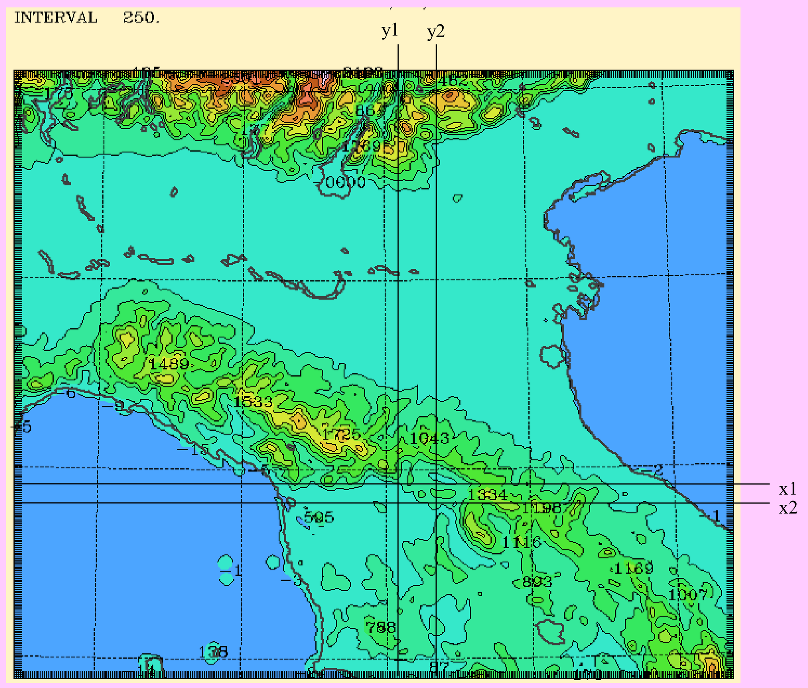
This instability favors structures elongated along the wind and it is therefore generally invoked as a possible explanation for frontal rain-bands (Bennetts and Hoskins, 1979, QJRMS).

The quantity Q above (a two-dimensional potential vorticity) can be interpreted as the gradient of M along the surfaces of constant B, or the gradient of B along M surfaces (with appropriate changes of sign). The state of neutrality Q=0 is easily identified as the two family of isopleths of B and M become parallel, presumably as the final outcome of the instability (usually referred to as "slantwise convective adjustment").

MSG Satellite images of 30 October 2008 show the development over North-Central Italy of several rainbands and multiple wavetrains during a strong south-westerly wind episode associated with a deepening synoptic trough and cold front passage. The nearly two-dimensional structure of the large scale flow and the ubiquitous orographic forcing makes this a nearly ideal setup to test for the occurrence of slanted circulations developing in a symmetrically unstable environment.

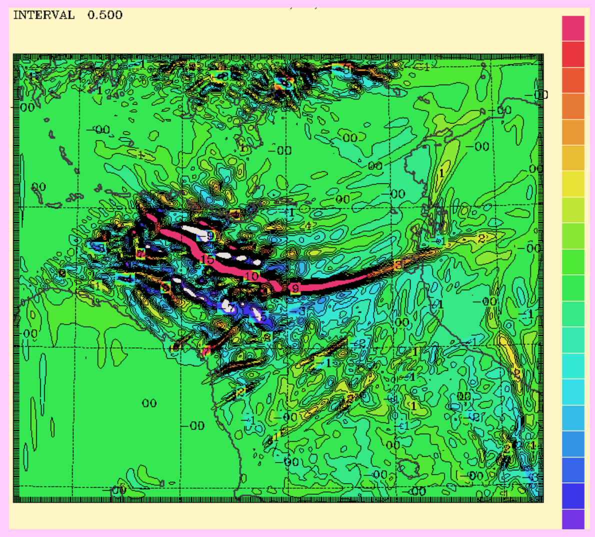
For this purpose we used the ISAC model chain, constituted of the hydrostatic model BOLAM and the non-hydrostatic MOLOCH (see description in the frame below), to simulate the episode, and performed diagnostics that support the hypothesis that symmetric instability was present during the event.

BOLAM was run for 15 hours starting from NCEP analysis at 00:00 UT with boundary conditions every three hours taken from the NCEP global daily forecast, with horizontal resolution 13 km and 40 vertical levels. The non-hydrostatic MOLOCH was then nested in the BOLAM domain, starting at 01:00 UT and boundary conditions updated at 30 minutes interval. MOLOCH was run at 0.01 degrees resolution, corresponding to 1.1 km, and 50 vertical levels.

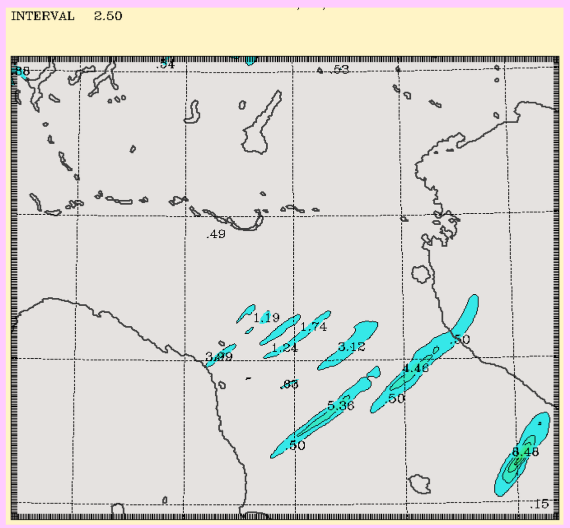


MOLOCH domain of integration, topography and land-sea mask. Contour interval 250 m.The position of the cross-sections is identified by thick lines.

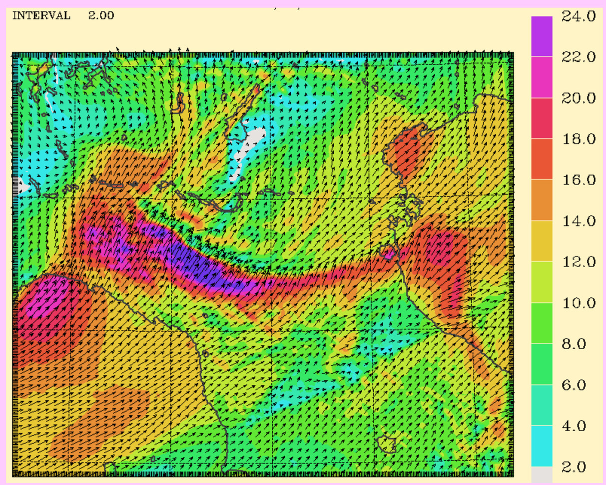
The non-hydrostatic model MOLOCH integrates the fully compressible set of equations, using as prognostic variables pressure, temperature, specific humidity, horizontal and vertical velocity components, and five water species. Model dynamics are integrated in time with an implicit scheme for the vertical propagation of sound waves, while explicit, time-split schemes are implemented for the remaining terms. Advection is computed using the Eulerian WAF scheme (Billet and Toro, 1997). The vertical grid is stretched exponentially with height. Horizontal fourth order diffusion and divergence damping are included to prevent energy accumulation on the shorter space scales. The microphysical scheme is based on the parameterization proposed by Drofa and Malguzzi (2004). The physical processes determining the time tendency of specific humidity, cloud water/ice and precipitating water/ice are divided into "fast" and "slow" ones. Fast processes involve transformations between specific humidity and cloud quantities, while slow ones involve rain/snow/hail production and fall. Temperature is updated by imposing exact enthalpy conservation at constant pressure. Fall of precipitation is computed with the stable and dispersive backward-upstream scheme, with fall velocities depending on concentration.

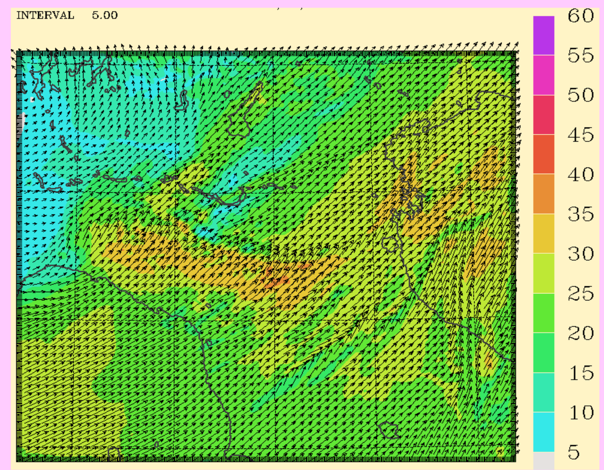


Vertical velocity at 700 hPa, 09:30 UTC from MOLOCH simulation

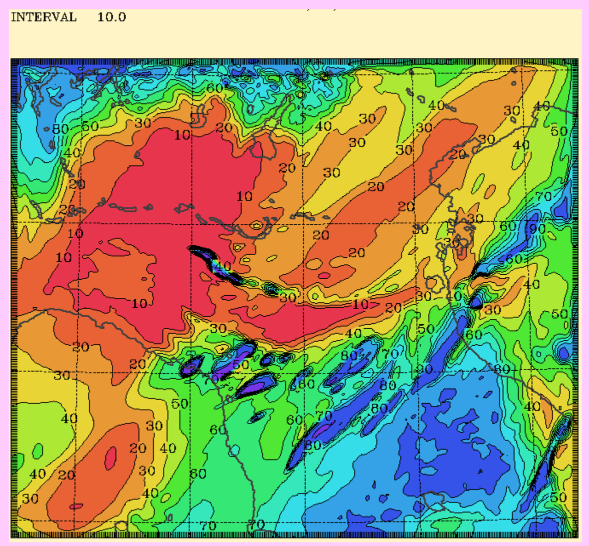


Accumulated precipitation between 09:00 and 09:30 UTC





Wind vectors at 10 metres (above) and at 700 hPa (below)



Relative humidity at 600 hPa, 09:30 UTC

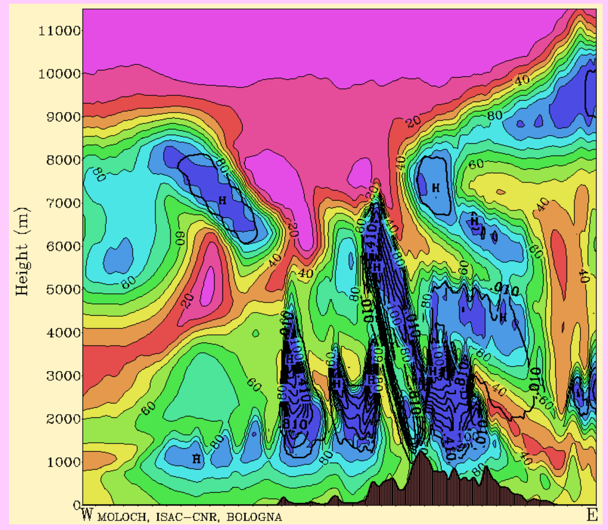
The MOLOCH simulation generates deep convective activity from early morning to about 12:00 UTC, mainly in the south-east part of the domain, in the warm and moist sector ahead of the front.

Between 09:00 and 10:30 slanted convective lines appear over Central Italy, oriented SW to NE. These lines are aligned with the jet, perpendicular to the mountain chain and well distinct from the lee waves that can be seen over the Po Valley. From these simulations we show (left, top to bottom): w at 700 hPa, accumulated precipitation in 30 minutes, and wind vectors at two levels. A foehn wind forms early in the morning in the lee of the Northern Apennines, reaching maximum amplitude at 9:00 UT, when the simulated 10 m wind reaches maxima of 30 m/s. Damages due to strong gustiness were reported in several mountain locations during the late morning hours.

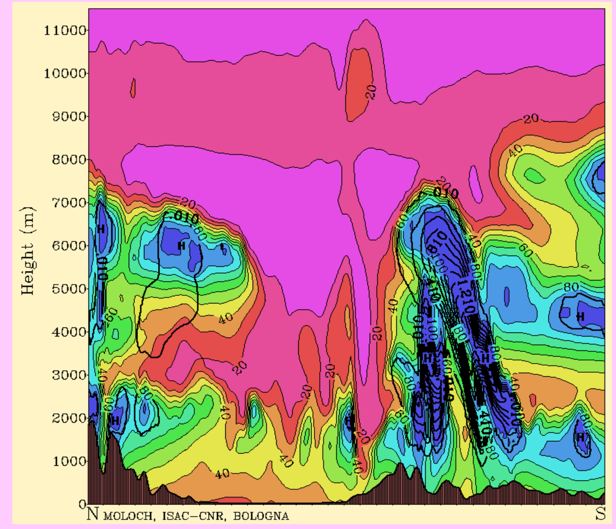
The waves on the Po Valley are orographically generated, have maximum amplitude near the ground and displace too little moisture to form any precipitation. The cloud bands over Central Italy are convectively active, with maximum intensity in the mid troposphere, and are precipitating. We also show (left, bottom) the relative humidity at 600 hPa that shows the rather sharp boundary between the moist warm area ahead of the front and the dryer air behind it.

Panels to the right report cross-sections of relative humidity (colours) and cloud condensate (water+ice, contours) taken along the lines indicated above. Several episodes of slantwise convection at various stages of evolution can be seen, with cloud top reaching 7000 m at most. Cells arising from more traditional convective instability, due to moist unstable conditions at low levels, are also present in the simulation. These cells tend to develop into mainly shallow convection which tends to coexist with slantwise convection. The last figure shows a typical cross-section of saturated equivalent potential temperature (colour) taken across the main south-westerly jet. Unstable conditions are indeed observed in the layer below 2000 m. Solid contours in the same figure are pseudo angular momentum (M) iso-surfaces computed with the wind across the section. Where slanted convection originates and develops, isolines of equivalent potential temperature and M tend to be, on average, aligned, realizing the condition for marginal symmetric instability.

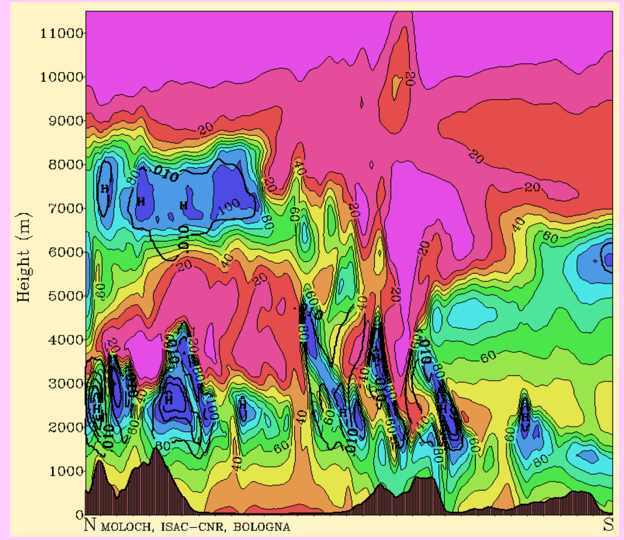
We do not consider this evidence conclusive. However, the growth and permanence, for times of the order of 1 hour, of narrow regions of saturated, precipitating, slanted ascent across the wind (NOT differential advection) and in a direction consistent with the wedge of symmetric instability, and the formation of persistent neutral channels as the end result of the slanted ascent (slantwise convective adjustment) are strong indications that symmetric instability may have taken place in this event. The coexistence of conditions leading to moist convection and symmetric instability, as well as the complexity introduced by orography, the three-dimensionality and non-stationarity of the large scale flow make it difficult to draw firm conclusions. Numerical simulations in more idealized and controllable conditions should be the next step in the process to understand the role played by symmetric instability in determining frontal structure.



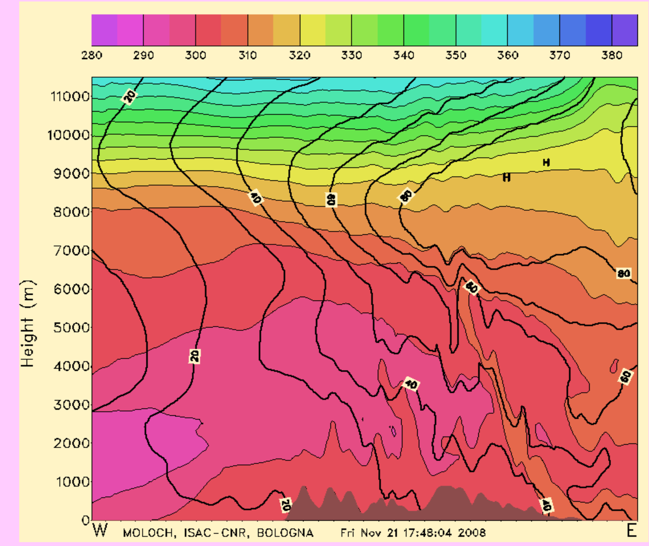
Relative humidity (color) and water condensate (thick contours) at 09:30 UTC on section x1 (see map)



Same as above on section y1 at 09:30



Same as above on section y2 at 10:30 UTC



Saturated equivalent potential temperature (color) and pseudo angular momentum $M=v+fx$ (thick contours) at 09:00 UTC section x2

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