08/08/08: "the Olympic Storm" event and its implications about Severe Weather

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Abstract

An unusually severe storm hit the Friuli Venezia Giulia region (fig. 1), northeastern Italy, in the late evening of 8 August 2008. Noticeable damages (20 million euros is the estimate) and two casualties resulted from this storm, in particular in the town of Grado (GO), along the shore, mostly due to very strong wind gusts (up to 45.3 ms^{-1}). This work aims to analyze and classify the event through the OSMER-ARPA mesonetwork, C-band Doppler radar data, Udine-Campoformido radiosounding data, Eumetsat MSG images and cloud-to-ground lightning strikes. Moreover a numerical simulations suite (WRF, ALADIN, MOLOCH) has been provided to test the NWP limits in forecast performance.

Introduction and data

This event emerged as a rare occurrence in the climatology of local summer storms; uncertainty in the description and classification immediately arose following the contemporaneous presence of strong linear-wind-compatible land damages in the vicinity of Grado (GO) and funnels and waterspouts which have been reported 15 to 20 km far from Grado during the storm transition,that motivated the media to classify the event as a *tornado*. The results of the present work highlight that the storm structure had many elements in common with the conceptual model of a *bow echo* convective system (Wakimoto et al., 2006). We find that the role of the observed wind gusts can be explained by the hypothesis that a density current sloping downhill from the Alps could act as a high momentum-high static stability flow interacting with a preexisting thunderstorm which can generate a strong low-level outflow by vertical momentum transfer and negative buoyancy acceleration (as a *rear inflow jet*, see Atkins and St. Laurent, 2009 and references therein).

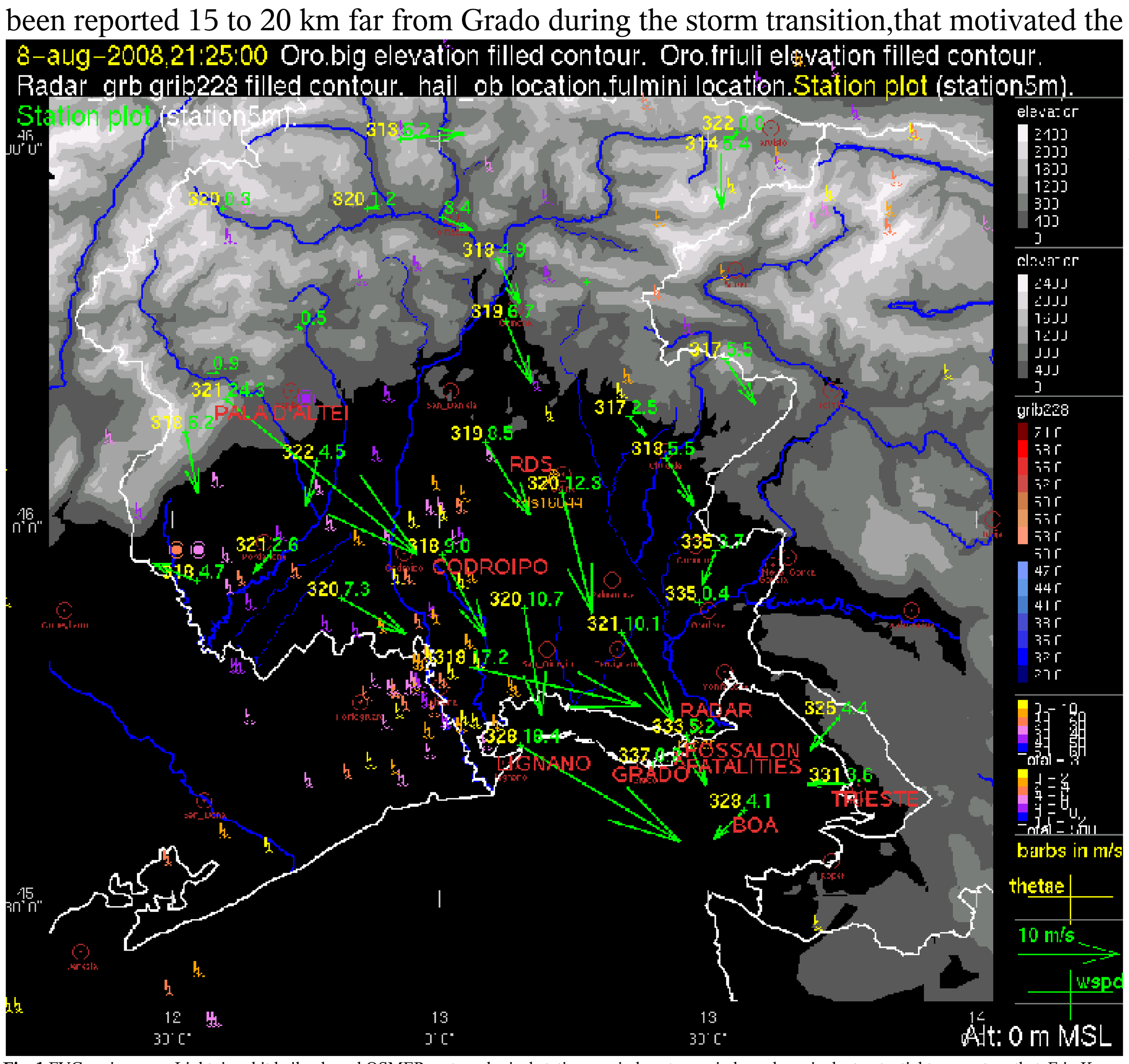

Fig. 1 FVG region map. Lightning, hit hailpads and OSMER meteorological stations - wind vectors, windspeed, equivalent potential temperature thetaE in K - are indicated on the map. The locations of the meteorological stations are reported in capital letters. The "FATALITIES" label indicates the location of the casualties. Position of 16044 radiosounding base of Campoformido (UD) and OSMER rada in Fossalon di Grado (GO) are also reported. Time refers to the meteorological station measure, lightning between the actual time and 12 minutes in advance are shown and hit hailpads refer to a period of 1 hour ending at the actual time.

The analysis has been possible thanks to 39 OSMER ARPA meteorological stations. Data are available every 5' and downloaded once per hour; 5' wind values are computed in the last 10 seconds of each minute, while gust values are the peak registered in one second. Data from the 360 hailpads network managed by OSMER ARPA were used to assess the area hit by hailstorms. VMI and Doppler winds are estimated by the OSMER ARPA Fossalon di Grado (GO) C-band dual Doppler radar (fig. 1), which provides entire volume scan every 5'. The Doppler velocity is affected by folding due to the operational setting of the radar (+/- 16 ms^{-1}) against wind velocities larger than 30 ms^{-1}.

Synoptic and mesoscale analysis

A typical northwestern short baroclinic wave moving from Great Britain towards the Adriatic Sea, in the Mediterranean area, and a cold front passing over the Alps as well, were preceded by warm and moist southwestern wind advection aloft over a potentially unstable low troposphere. This pattern led to continuous convection after an intense 300 hPa wind jet streak divergence. After 20:00 UTC the advection of northwestern cold and dry air behind the trough axis, delayed in the low layers by the presence of the Alps, resulted in a sudden increase of surface northwestern wind that interacted with preexisting convective cells at the bottom of the Alps over FVG plain (fig. 1). That led to a *bow echo* shaped convective system, moving eastward, associated with damaging winds mainly along the downdraft outflow (fig. 2). Nevertheless the short development time (few minutes) is not comparable to what has been found in other studies (e.g. Weisman, 1993), in spite of the presence of some typical features of *bow echo* occurrence. For example, the presence of mesovortexes is noticeable near the leading edge of the convective system at a height of 3000 m in Doppler image (not shown, see Wakimoto et al., 2006, Atkins and St.Laurent, 2009, Weisman and Trapp, 2003). A storm chaser (Marko Korosec, http://www.weather-photos.net) photographed a waterspout between Duino and Grado, that could have been related to a mesovortex occurrence.

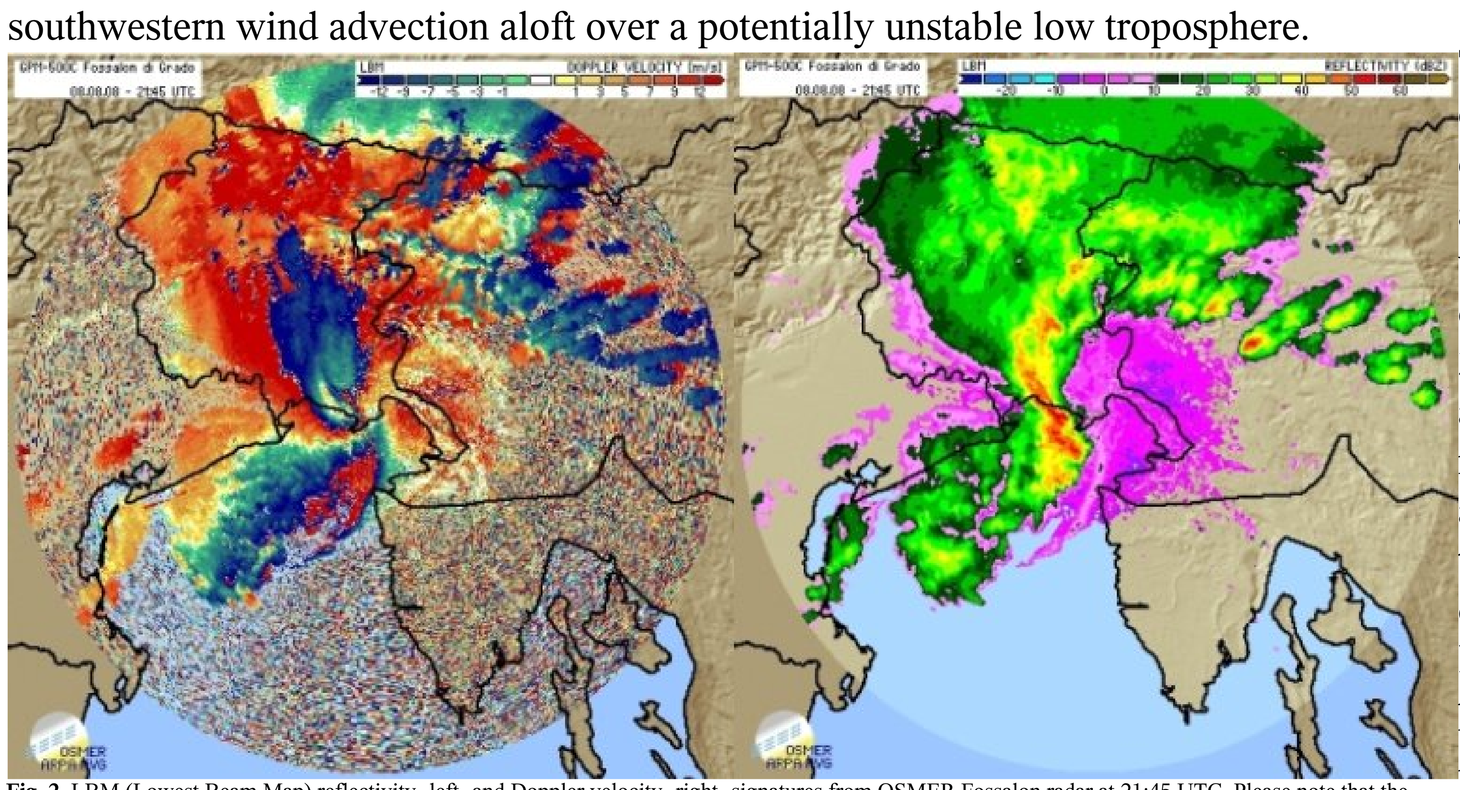

Fig. 2 LBM (Lowest Beam Map) reflectivity -left- and Doppler velocity -right- signatures from OSMER Fossalon radar at 21:45 UTC. Please note that the Doppler signature is affected by multiple folding.

Wind analysis

The Boa Paloma station timeseries (fig 3) is quite interesting because it shows a pressure nose at 21:50 UTC near the thetaE drop, followed by a pressure rise at 22:05 UTC in perfect correspondence to the acceleration of the wind and, 10 minutes later, to the showers. After the pressure rise, a constant and smooth further increase in pressure is associated with synoptic north to northeast winds, whereas another little pressure rise, at 22:45 UTC, is associated with moderate northwestern gust. One could suppose that the first pressure rise is associated with the gust front of the storm and the second pressure rise is associated with the density current coming from behind the storm downhill from the Alps. The role of the cold air carried on by the front and the downdraft in the observed very strong winds is studied through a simple surface wind model (prof. M. Parker, personal communication). The surface measured wind is supposed to be the result of the joint action of the *density current* component, the thunderstorms outflow, the cell motion term and the synoptic environmental wind: the analysis of the role of the *density current* can be addressed through a simplified form of the horizontal momentum equation:

$$du/dt+u\,du/dx+w\,du/dz=-(1/\rho)(dp/dx)+d\tau_{xx}/dx+d\tau_{xz}/dz$$

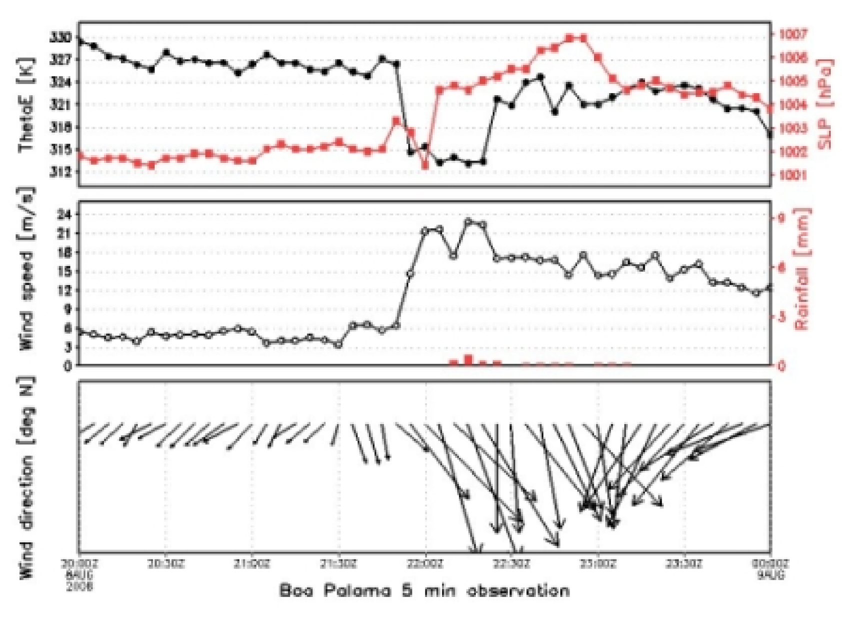

Fig. 3 Time series of the Boa Paloma meteorological station measurements every 5 minutes. The upper pictures shows time series of thetaE in black (unit of measure in K, left axis), surface level pressure in red (unit of measure in hPa, right axis). The center picture shows time series of wind velocity (unit of measure, ms^{-1}. The lower picture shows the time series of wind direction and intensity in vectors.

An approximation of this equation can be made by considering a stationary flow in which *w* and the shearing stress terms are negligible; these approximations bring to:

$u\,du/dx \approx -(1/\rho)(dp/dx)$ and $u \approx \sqrt{2\,\Delta p/\rho_0}$

in Boussinesq approximation. Δp can be interpreted as the total finite pressure perturbation term carried by the *density current*, so that the corresponding wind is to be considered the density current wind component term.

One possible estimate of the downdraft and storm components, considered together, is the gust front leading edge speed (Wakimoto, 1982), computed where VMI and Doppler images (fig.2) were showing it. Looking at the positioning in time of the gust front, a propagation velocity of approximately 25 ms^{-1} can be extrapolated. In the table 1 the Lignano station measured a wind pertaining to the cold front driven *density current*, but the model here considered is not able to properly estimate the wind strength because the pressure rise is affected by several forcing elements. In the other stations the model is able to estimate the gust front wind, considered as *density current* (Wakimoto, 1982), and the much stronger gusts can be addressed to the combined effect of the density current and the convective downbursts, that spread off from the cell and generated the widespread damages. The behavior of the *density current* can be also addressed through a Froude-number analysis (Durran, 2003).

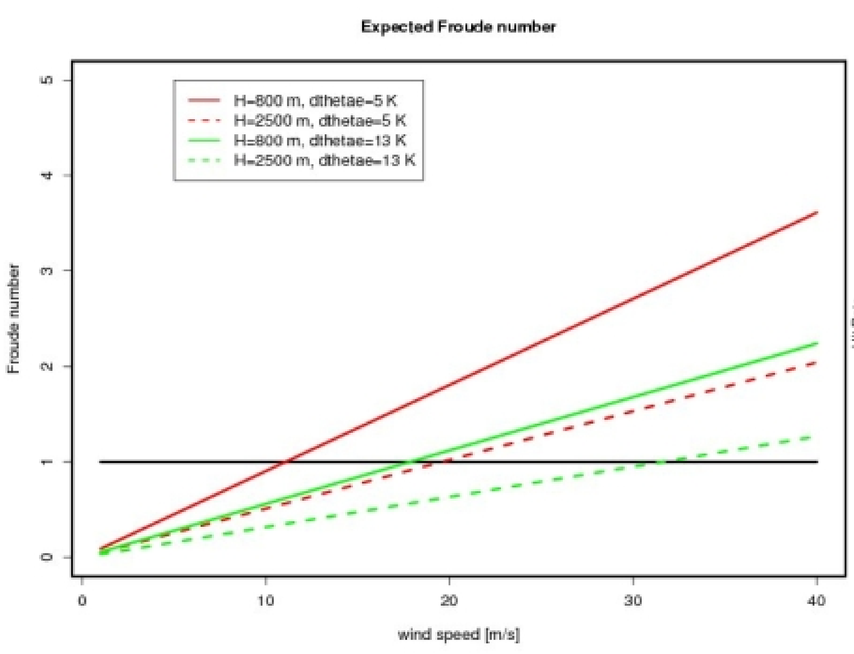

Fig. 4 Expected Froude number analysis. Red lines refer to an hypothetical thetaE perturbation of 5K, green lines refer to an hypothetical thetaE perturbation of 13 K.

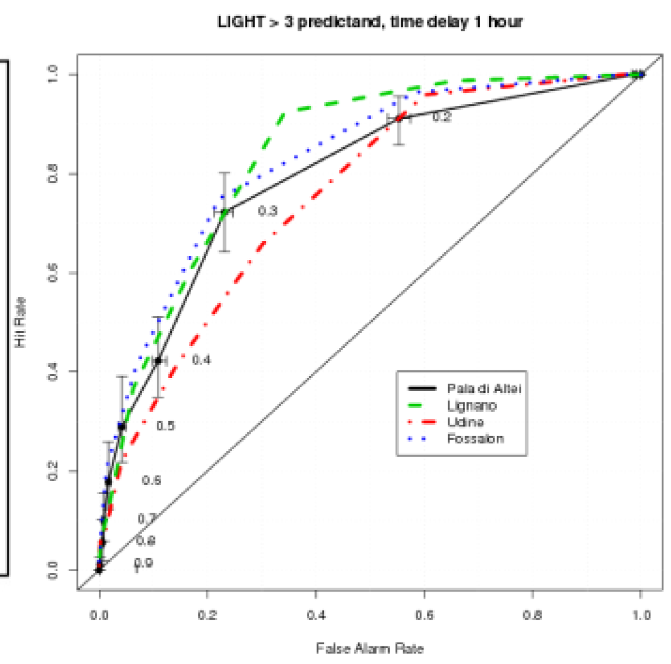

Fig. 5 ROC curves of 4 stations (see the legend in figure). The predictor is the maximum wind gust measured at each station; the predictand is the occurrence of more than 3 lightnings over the FVG area.

Considering an estimated range of the density current depth between 800 and 2500 m and a thetaE drop ranging from 5 to 13 K with respect to the environment, as measured from different stations, the results are shown in fig. 4. Supercritical flow (F>1), as expected from a cold front driven density current overcoming an orographic barrier as the Alps, is an evaluation compatible with the measured surface winds.

	Gust front propagation	Density current estimate	Density current derived measure	Real measured wind	Maximum gust
Codroipo	--	31	6	9	17
Lignano	--	25	32	31	35
Fossalon	--	17	23	22	33
Grado	25	19	16	15	29
Boa Paloma	25	25	22	23	45
Trieste	--	27	28	25	34

Table 1. The table of the density current winds. The first column reports the name of the meteorological stations involved in the evaluations. The colum 2 reports the simple wind model computation; column 3 reports the measured wind without synoptic component; column 4 is the total measured wind; column 5 reports the maximum measured gust. Unit is ms^{-1}.

A further step towards a statistical analysis is to consider all the measured gusts in the database of 4 meteorological stations over a period 5 years long. In particular the wind has been taken as predictor of convection activity and the occurrence of more than 3 lightnings over FVG plain and coast 2 hours after the time of the wind gust measurement has been taken as predictand. The resulting ROC, obtained by considering a normalized logarithm of the wind-speed, shows that the coastal stations Lignano and Fossalon have unexpectedly better performances than Pala di Altei upwind mountain station as predictor of convection (ROC area 0.85 vs 0.81).

Simulations

Simulation aspects of this event have been inspected thanks to: ARSO (Agency of Environmental Protection of the Republic of Slovenia) that provided the outputs of ALADIN model, a hydrostatic LAM with horizontal resolution of 4.4 km, convection partially explicit and initialization on the ARPEGE global model; ISAC – CNR of Bologna (Italy) that provided the output of MOLOCH model, a non-hydrostatic LAM with explicit convection, horizontal resolution of 2.2 km, initialized on the ECMWF global models (Malguzzi et al.,2006); CREST s.r.l. of Trieste (Italy) that provided the output of NCAR WRF-ARW version 2, a non hydrostatic LAM with explicit convection, horizontal resolution of 2.3 km, initialized on the GFS global model. Model outputs are not shown. ALADIN model shows an underestimation of the evening storm due to the the lack of preexisting convection over the plain: the model failed to simulate the interaction between the well developed convection and the *density current*. MOLOCH simulations properly captured the evening convection but 2 hours in advance, with underestimation of the wind. A better simulation of the storm has been obtained by ISAC – CNR Bologna team by inserting finite perturbations that represent developing convective structures during the afternoon. The WRF model simulated the evening storm with good agreement in the timing and slight underestimation of winds. The *density current* is simulated to reach the ground with a north-south pattern, whereas in the reality the direction was northwest-southeast.

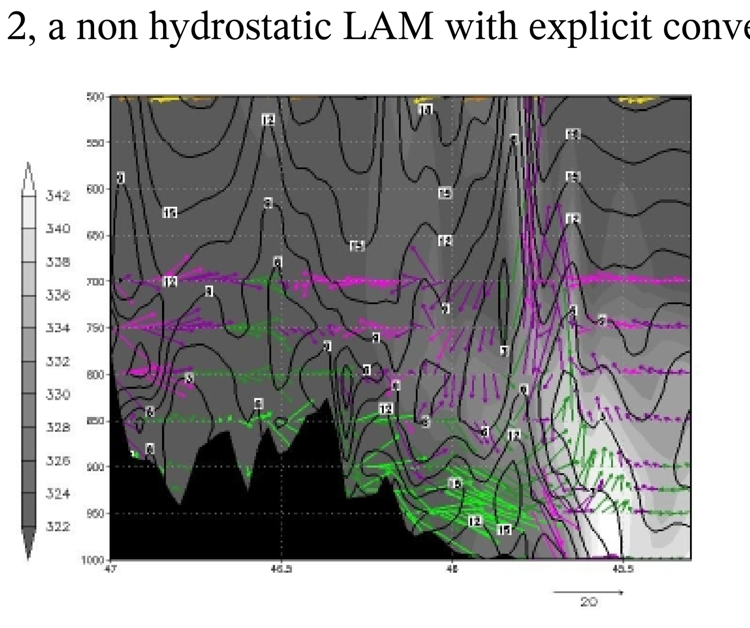

Fig. 6. WRF model cross section along density current direction (north-south). Shaded grey is thetaE (scale in K on the left); isotachs in black contours (ms^{-1}), green vectors are exiting winds (horizontal westward component), violet vectors are sheet-parallel winds. Black shapes at the bottom are Alps.

The cross section of figure 6 shows the cold front driven *density current* sloping down the Alps. The surface wind associated with the storm can be seen as the sum of cold front *density current* component and the downdraft outflow component.

Conclusion

Concerning the classification of this event, we can conclude that it was a *bow echo* occurrence according to the VMI shape and the wind intensity along the leading edge. The associated *rear inflow jet* seems to have a mesoscale guidance rather than a dynamic trigger internal to the convective cell core. This flow is described as a *density current* (Haertel et al., 2001) sloping down from the Alps. The application of a simple wind model indicates that the theory is quite in agreement with the measured winds, while the ground damages were probably due to strong linear downbursts. A preliminary study on the relationship between winds sloping down from the Alps and their role in enhancing convective activity over plain and coast shows that coastal stations are better predictors than mountain station. Lastly, a review of some simulations provided by different LAMs showed that they tend to underestimate the main evening storm intensity, in particular its gust speed.

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