3.2 FURTHER INVESTIGATIONS OF THE "ORA DEL GARDA" VALLEY WIND

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1. INTRODUCTION

In the present work the results obtained from recent investigations concerning a local wind system, the so called *"Ora del Garda*", are presented. The latter flows regularly on sunny days during the summer season, when thermal forcing is strong enough to produce an appreciable pressure gradient throughout the valleys connecting the area North of the Garda Lake to the Adige Valley.

The wind originates along the shoreline of Garda Lake (65 m a.m.s.l.) in the late morning, as a typical coast breeze, and then channels along the adjacent Sarca Valley and the Valle dei Laghi till it reaches the Adige Valley (whose floor is about 200 m a.s.l. high) North of Trento, flowing over an elevated saddle (about 600 m a.s.l.). The final stage of the wind results in a strong air mixing connecting the Valle dei Laghi to the Adige Valley.

The particular features of this wind stimulated earlier investigations by Austrian scientists at the beginning of the 20th century, as reported in a well known review by Wagner (1938). The flow structure in the ending part, investigated by means of pilot balloons and double theodolite, appeared as a complex interaction between the upper flow blowing from the Valle dei Laghi and the Adige Valley diurnal wind (Figure 1). After climatological analysis of data collected by meteorological networks operated by different institutions (Baldi *et al.*, 1999) and measurements performed using a light airplane, it appeared clearly that for a deeper understanding of the phenomenon and subsequent modelling further information were needed at a key site, namely at the end of the Valle dei Laghi, very close to the ridge from where the "Ora del Garda" flows down into the Adige Valley.

Therefore an additional fully automated weather station has been located in that area (indicated with a star in Figure 1) where maximum wind speed was expected. The station provided measurement of wind speed and direction at 3 m above ground, air pressure, temperature and humidity, global and net radiation. All these quantities are collected as 10 minutes averages, also storing maximum and minimum value over the averaging period.

In addition to ground based measurements, two flights were performed with an equipped light airplane during a fair weather day when a fully developed diurnal cycle of the "Ora del Garda" was detected. The first flight investigated the whole Valle dei Laghi in the morning, exploring four cross-sections along the valley in order to gain a detailed picture of the evolution of the thermal structure. The second flight started in the early afternoon and explored the high turbulent region of the confluence where strong mixing occurs.

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2. THE DIURNAL CYCLE

The diurnal cycle of the "Ora del Garda", as seen by the weather station located at Monte Terlago, is clearly represented in Figure 2 and Figure 3. By the analysis of collected records it appears that the overall meteorological conditions needed for a full development of the wind are fine weather, associated with high pressure persistence as needed for proper thermal forcing.

The typical observed diurnal cycle shows during the night a wind channelling along the Valle dei Laghi towards the Garda Lake as a quite strong and steady down-valley drainage flow: the wind speed reaches 4 $m\ s^{-1}$ and the direction is constantly from 50° N.

Before sunrise the wind speed decreases and as soon as the sun starts heating the South-East oriented walls of Mt Paganella, the wind begins rotating in clockwise direction with low speed (i.e. 1 $m\ s^{-1}$). At Noon LST (UTC+2) the wind speed increases due to the contribution of the breeze originated at the shoreline of the Garda Lake and reaches its maximum more or less three hours later. The wind direction is around 250° N and remains constant well beyond sunset.

It is also interesting to notice how the wind behaves when it turns from up-valley to down-valley direction. When looking into the wind direction time series, one may notice that this change happens very quickly, i.e. in less than 30 minutes. This feature is well captured by recorded data due to the sampling interval of 10 min, especially when compared to the existent automated stations network whose data are stored as hourly averages.

Furthermore the wind speed time series display another interesting feature: the change in direction is strongly correlated with a wind speed minimum. Due to the vanishing of the thermal forcing advection of warm air from the Valle dei Laghi is no more strong enough and the air masses adjacent to the valley floor and sidewalls rapidly start cooling and flowing as a drainage current reinforcing the nocturnal down valley wind. This diurnal cycle is so regular (as to wind speed and direction) that the superposition of the time series of different events, even when not consecutive, collapse quite well into a single curve. This confirms the "Ora del Garda" as an ideal test case.

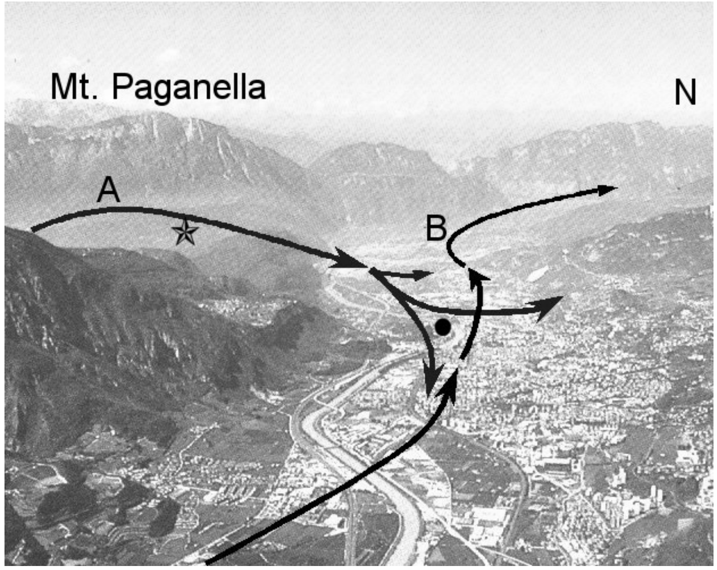

Figure 1: The area North of the city of Trento where the “Ora del Garda”, blowing from the Valle dei Laghi (A), interacts with the up-valley wind flowing in the Adige Valley from South (B). The symbols indicates sites where instruments were located during the experiment: a weather station close to Monte Terlago (★) and a sonic anemometer in the Adige Valley (•), close to an automated weather station of the Hydrological Office.

3. THE CONFLUENCE IN THE ADIGE VALLEY

As previously mentioned, one of the key features of the final stage of the “Ora del Garda” is its interaction with the up-valley wind blowing from South in the Adige Valley during the afternoon. The schematic picture shown in Figure 1 reproduces the flow pattern suggested in earlier investigations by Pollak (1924), Wiener (1929) and Schaller (1936) as reported in Wagner (1938).

This interaction has been variously confirmed by means of recent ground based and airborne measurements, although more comprehensive intensive field measurements would be necessary for a really detailed retrieval of the overall flow features.

Following the “Ora del Garda” outbreak into the Adige Valley in the early afternoon, the wind direction in the middle of the valley rapidly turns from previous 180° N (normal up-valley wind) to 270° N, becoming stronger and persistent till a couple of hours after sunset. Records from meteorological stations located North of this area indicate that this deviation from the “natural” up-valley direction becomes weaker at increasing distance from the area. On the contrary, at the airport of Trento, which is located about 2 km South of the city, the morning up-valley wind rapidly reverses direction and starts blowing from North.

The nearest surface station further South is located about 20 km apart and displays a typical diurnal cycle of up-valley wind. This lack of information in the area between this and the airport station makes it difficult providing any clear picture of the flow field and pattern.

In order to investigate the turbulence structure in the surface layer, an ultrasonic anemometer (Gill Mod. HS Research) was located near the weather station in the middle of the Adige Valley (denoted with a bullet in Figure 1). By means of eddy correlation technique (Druilhet and Durand, 1997) the diurnal cycle of quantities like momentum and sensible heat fluxes have been evaluated

Friction velocity displays, as expected, a significant increase during the “Ora del Garda” events, due to the higher wind speed over the rough ground surface (the valley floor is mainly covered by apple trees). At the same time a clear minimum in the sensible heat flux is observed immediately after 18.00 LST, as shown in Figure 5, where minima up to -150 $W\ m^{-2}$ are reported. This means that the flow at the measurement site in the Adige Valley, already shadowed at that time, is rapidly cooling. However solar heating is still able to maintain the up-slope flow along the Valle dei Laghi for a few hours.

Nondimensional standard deviations $\sigma_i / u_* = f(z/L)$, evaluated after suitable mean wind alignment, display peculiar features different from those observed over flat uniform terrain as reported in literature. Nondimensional standard deviations of the vertical velocity component σ_w / u_* is similar to the case of flat and homogeneous terrain over all the stability ranges. The same quantity evaluated for longitudinal and lateral velocity components, σ_u / u_* and σ_v / u_*, display much larger values in the neutral case than the respective *flat* values, and closer to each other. Similar features have been found at other sites in the Adige Valley (Bolzano basin, cf. de Franceschi et al., 2000, 2001).

The picture obtained from ground measurements leaves a question unanswered: does the “Ora del Garda” produce a rotor-like recirculation cell close to the steep slope under the airflow jumping into the Adige Valley and what is the fate of the “normal” up-valley flow in the Adige Valley?

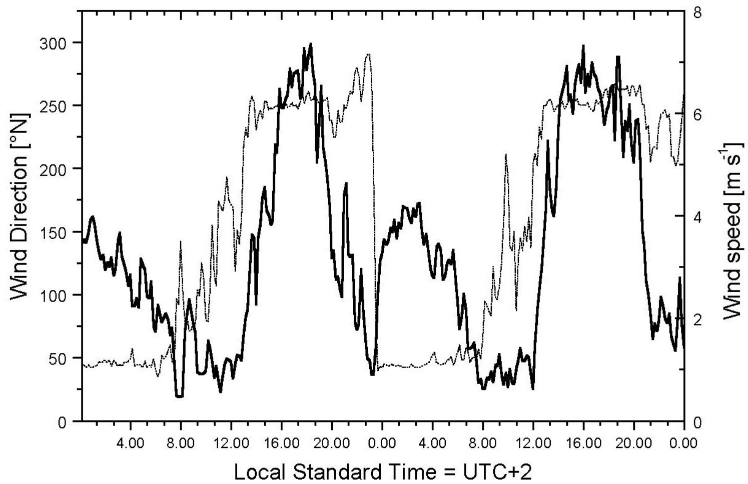

Figure 2: Time series of wind speed (thick line) and wind direction (thin line) for two consecutive days at the end of the Valle dei Laghi, close to the point where the “Ora del Garda” blows down into the Adige Valley interacting with the local valley wind system.

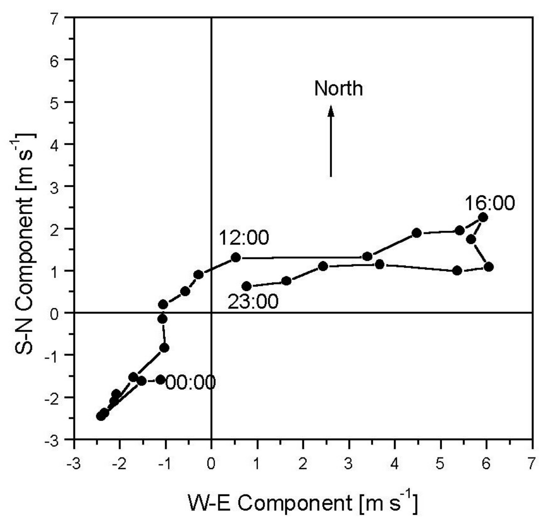

Figure 3: Hourly mean wind odograph for more than 10 days of well developed “Ora del Garda” at the same site reported in Figure 1.

A strong recirculating flow is very likely to occur, and its detection will be the aim of further measurements planned for the next Summer 2002. As to the fate of the up-slope flow in the Adige Valley, the “Ora del Garda” seems to act as an obstruction.

To investigate the latter issue some measurement flights have been performed by means of an equipped motorglider.

The available instruments allowed measurement of scalar quantities (i.e. air pressure, temperature and humidity) along the flight paths, which have planned in order to explore the whole volume of the interacting flows. The vertical profile of potential temperature in the core of the valley atmosphere (Figure 5) shows a well mixed convective boundary layer extending from 500 to 1600 m a.m.s.l., just above the saddle from which the wind jumps down in the Adige Valley. The extent of this layer could represent the thickness of the airflow, dominated by strong mixing and intermittency (the pilot experienced a very strong turbulence with intense up- and down-drafts when flying there!).

A deeper understanding of the thermal structure occurring in connection with the airflow, can be gained by means of the kriging technique (see the paper by Rampanelli and Zardi, 2002, Poster P1.20 in this Conference), which allows the mapping of 3D fields of the quantities measured along the flight trajectory on a regular grid over all the valley volume.

Acknowledgments

This work has been supported by the project “Study of atmospheric dynamics in Alpine Valleys” sponsored by the National Institute for Scientific and Technological Research in Mountain Regions (INRM).

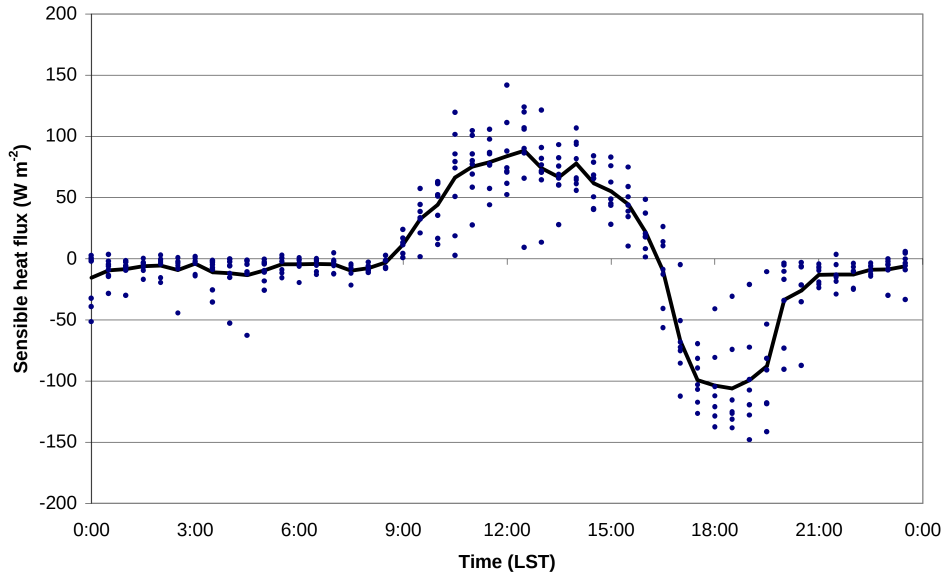

Figure 4: Diurnal cycle of sensible heat flux in the Adige Valley when the “Ora del Garda” occurs. Points denote the flux value from average over 30 min period for different days. The solid line is an average of all the values obtained for different days at the same time.

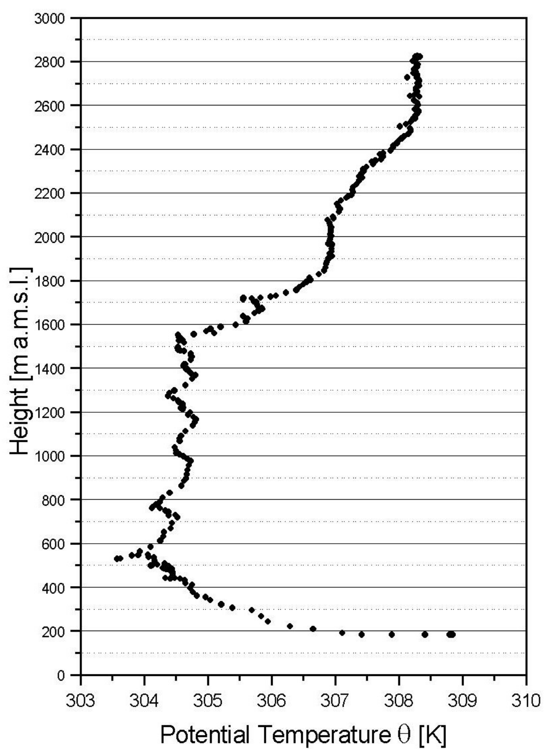

Figure 5: Vertical profile of potential temperature measured in the early afternoon during the “Ora del Garda” event of 23rd of August 2001 in the region where the flow interacts with the up-slope wind which blows from South in the Adige Valley.

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