P1.24 Revisiting Albert Defant's (1909) seminal paper "Mountain and valley winds in South Tyrol"

A tribute to a pioneering contribution in mountain meteorology

ICAM 2015
Innsbruck Austria

D. Zardi, M. de Franceschi, L. Laiti, L. Giovannini
Atmospheric Physics Group – Department of Civil, Environmental and Mechanical Engineering – University of Trento (Trento, Italy)
corresponding author address: lavinia.laiti@unitn.it

UNIVERSITY OF TRENTO - Italy
Department of Civil, Environmental and Mechanical Engineering

1 Introduction

After the doctoral degree in meteorology at Innsbruck University in 1906, the scientific interests of Albert Defant (Trento, 1884 – Innsbruck, 1974), best known as a modern oceanography pioneer, focused on the dynamics of lake and valley winds. In particular, he studied the periodic seiches of Lake Garda and the winds developing in the valleys of South Tyrol, blowing between the Po Plain and the inner Alps (Mountain and valley winds in South Tyrol; Defant, 1909).

In the latter work particular attention is paid to the Ora del Garda wind, a coupled lake-valley wind which blows over the northern edge of Lake Garda. In recent years this wind has been the subject of a number of studies, based on both surface and airborne data (Laiti et al., 2013a,b, 2014; Giovannini et al., 2015), as well as on NWP model simulations (oral O4.3).

Defant also proposed a first explanation of the differential heating mechanisms associated with mountain and valley winds including slope winds as a factor determining the diurnal cycles of temperature and pressure gradients observed along the valleys. This theory has been further developed, thanks to results from dedicated field experiments (Rotach and Zardi, 2007) and numerical simulations (Rampanelli et al., 2004; Serafin and Zardi, 2010a,b, 2011).

Here we revisit Defant's seminal work of 1909 in the light of the more recent investigations and results on the subject.

2 Study area and observations

The area of interest is formed by the Adige and the Sarca valleys, connecting the Po Plain and Lake Garda basin with the inner southern Alps, where the city of Bolzano lies (Fig. 1A).

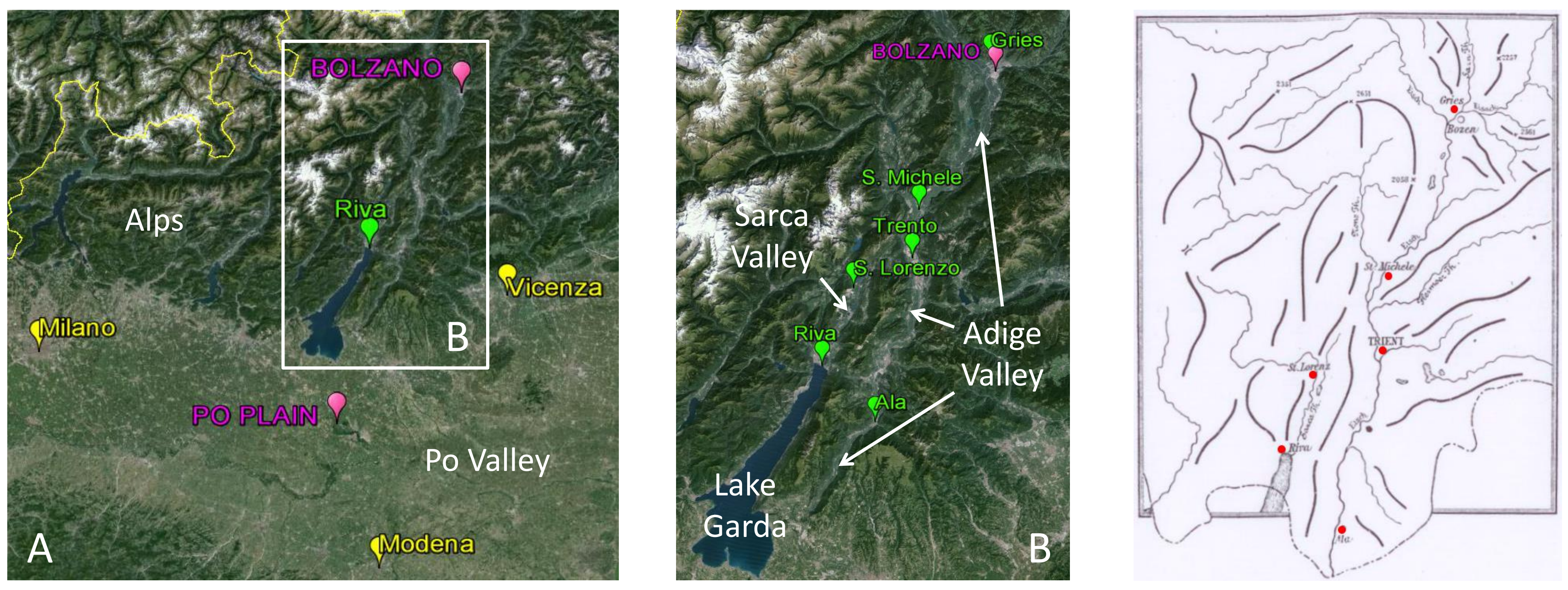

Fig. 1. Left and center: map of the study area and of the weather stations considered in Defant (1909). In yellow and in magenta the stations used for the pressure gradient calculation, in green the stations used for the wind pattern analysis (Google Earth 2015). Right: the original map as reported in Defant (1909).

Defant (1909) calculated the seasonal-average pressure (and temperature) daily cycles for Bolzano (1886-1890) and the Po Plain (based on 1835-1888 data from 3 stations; Fig. 1A), evaluating their amplitude and phase through harmonic analysis. He also analyzed wind direction observations collected at 6 stations (at 7 a.m., 2 p.m. and 9 p.m.) deployed along the Sarca and Adige valleys (1892-1901; Fig. 1B). In addition, lymnograms recorded at Riva, on Lake Garda's northern shore, were also analyzed for the years 1902-1903 (Fig. 1B).

3 Adige Valley pressure gradients

The observed pressure oscillation amplitude is larger at Bolzano than over the Po Plain. Accordingly, positive pressure gradients occurr during the night and early morning hours (down-valley wind phase), while negative gradients characterize the afternoon, in association with up-valley winds. The maximum positive gradient is always slightly smaller than the maximum counter-gradient (especially in spring and fall): indeed, observed down-valley winds are not as intense as up-valley winds. The largest gradients are found in summer (~2 times the winter values; Fig. 2). In summer the average pressure gradient at 4 p.m. is around 1 Hg mm over 150 km (= 0.009 hPa km^{-1}). The time of the gradient (wind direction) reversals (11 a.m. and 9 p.m.) and peaks (5-6 a.m. and 3-4 p.m.) slightly change with the season (see Fig. 2)..

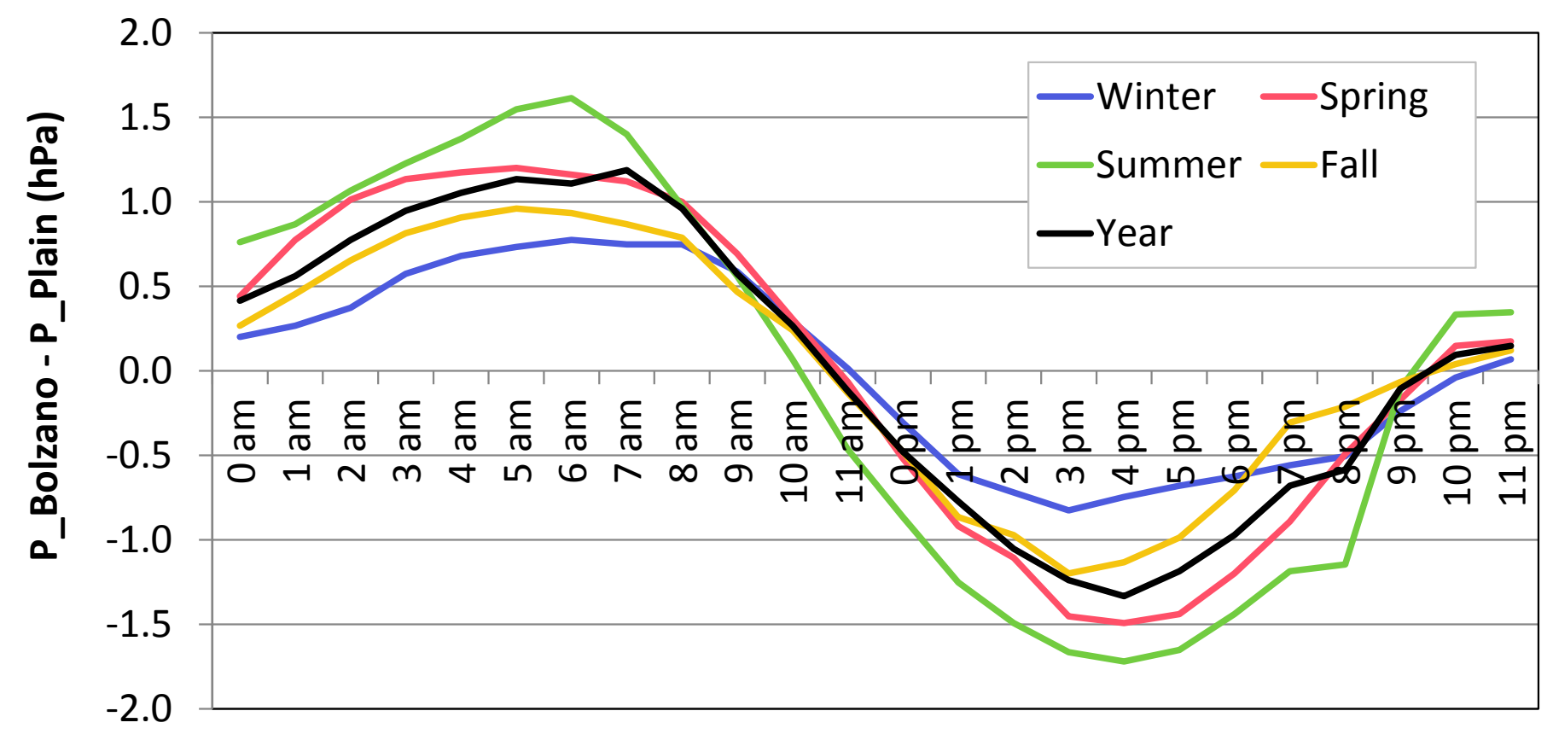

Fig. 2. Seasonal average daily cycles of Bolzano – Po Plain pressure gradients according to Defant (1909).

In the recent study presented by poster P1.25 the pressure gradients along the Adige Valley are calculated over 2012-2014 data from 10 stations, for selected summer days of up-valley wind. An average pressure gradient of 0.022 hPa km^{-1} is found at 4 p.m. The diurnal positive gradient is always larger than the nocturnal negative gradient, and the two correlate well with the corresponding along-valley wind speed. The reversal times are in good accord with Defant (1909), although later onsets are observed in the lower Adige Valley, probably due to local urban effects.

4 Ora del Garda timing and intensity

From the oscillations of the lake water level recorded at Riva by the lymnograph (Fig. 3) the onset, offset and intensity of the local up-valley wind could be retrieved.

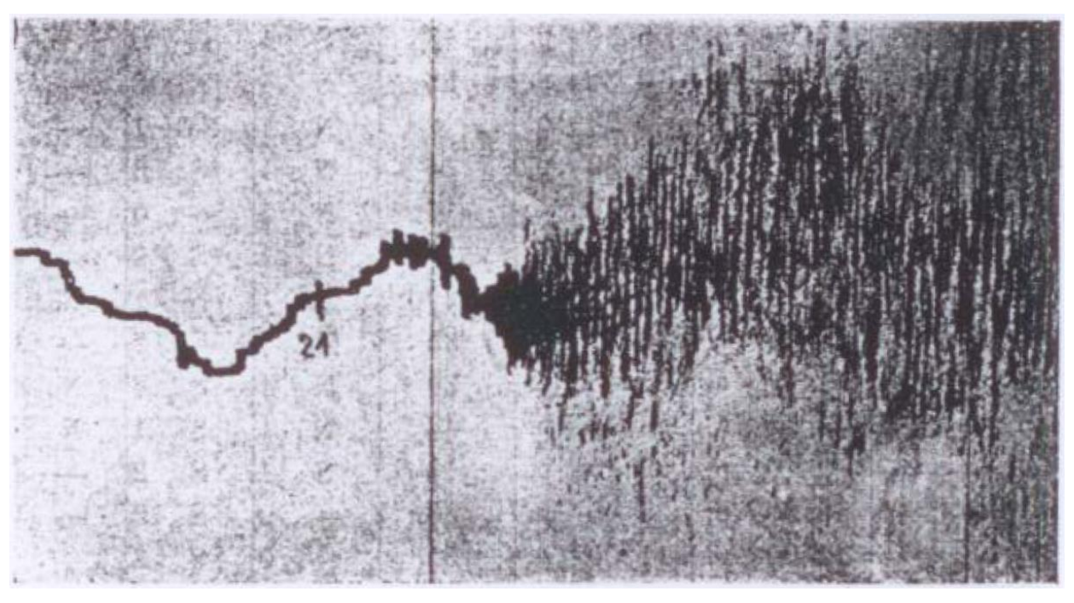

Fig. 3. An example of lymnogram at Riva, showing the effect of the Ora del Garda onset on Garda Lake wave motion. From Defant (1909).

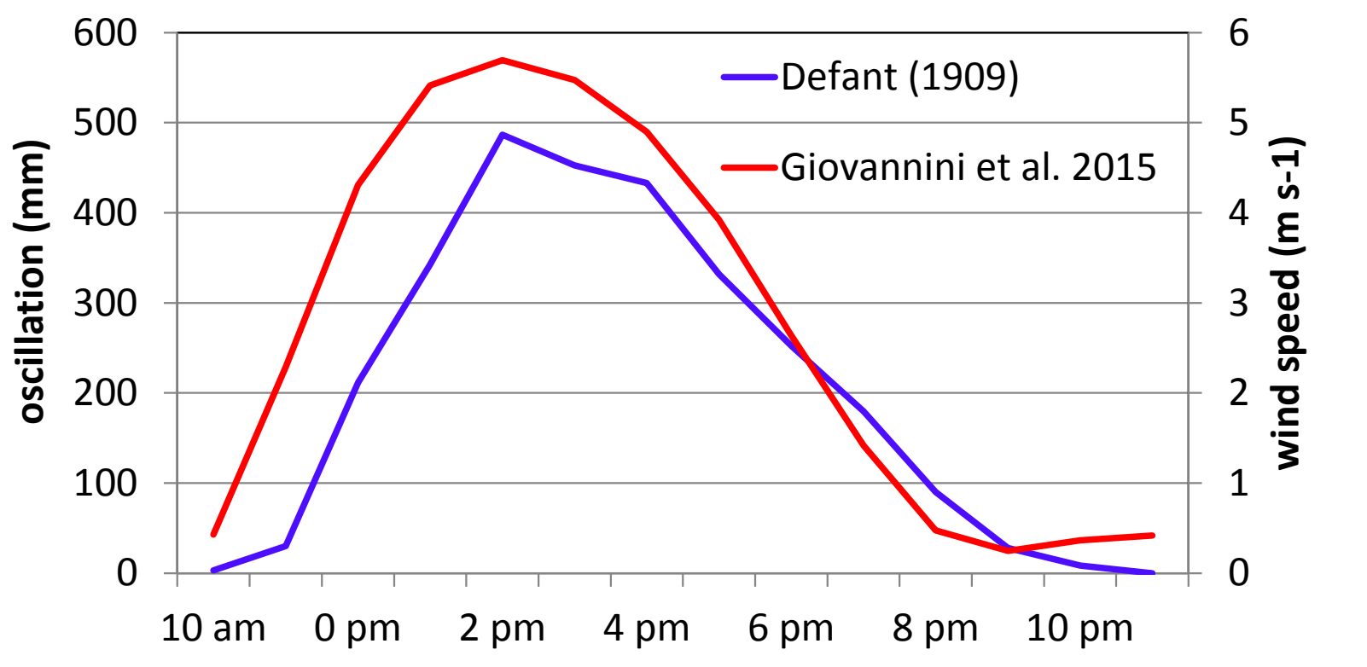

Fig. 4. Diurnal cycle of the wave oscillation amplitude as recorded by the lymnogram at Riva on Ora del Garda days (Defant,1909). The corresponding wind intensity according to Giovannini et al. (2015) is reported for comparison.

	onset	offset	duration (h)	oscillation (mm)
Nov + Dec	12:46	19:12	6.26	31
Jan + Feb	12:26	18:58	6.32	15
Mar + Apr	11:43	20:36	8.53	44
May + Jun	11:06	20:21	9.16	64
Jul	11:10	19:44	8.34	67

Tab. 1. Statistics of the Ora del Garda timing and intensity according to the lymnograms recorded at Riva. From Defant (1909).

On average the Ora del Garda onset (offset) time occurs earlier (later) in summer, with maximum duration in May and June. The oscillation (i.e. wind intensity) is maximum in May, June and July (Tab. 1). The wave amplitude peaks at 2 p.m. then decreases (Fig. 4), in good correlation with the pressure gradient cycle. Based on 2003-2012 data from a weather station installed at Riva, Giovannini et al. (2015) have also determined monthly-average times of onset, offset and intensity peak for selected Ora del Garda days. Their results are in good accord with Defant's findings (Fig. 4). The influence of the synoptic flow and of the water temperature on breeze timing and intensity has also been investigated in detail by Giovannini et al. (2015), not only at Riva but also at the Sarca Valley end, where the wind overflows into the Adige Valley north of Trento city (cf. Laiti et al., 2013a,b, 2014).

5 The Adige and Sarca valley wind systems

The wind direction frequencies observed at the 6 stations in the Adige and Sarca valleys reflected well the seasonal patterns of the daily cycles of the pressure gradients (Tab. 2). However, observations collected at 2 p.m. (i.e. around the peak of the diurnal winds) revealed an anomaly: while at all stations up-valley winds dominated, at Trento northerly winds were frequently observed.

This fact has been explained only later, as an effect of the Ora del Garda overflowing into the Adige Valley at 2-3 p.m., channeling in both northward and southward direction and displacing the local up-valley wind (see Fig. 5; Schaller, 1936; Laiti et al., 2013b, 2014; Giovannini et al., 2015).

station	N	NE	E	SE	S	SW	W	NW	calms
Riva	1.2	0	0	0	23.8	0	0	0	5.6
Ala	0.2	1.8	0.8	1.4	1.2	19.9	0.6	0.5	4.2
S. Lorenzo	3.1	1	2.6	3.9	10.2	6.4	1.5	1.4	0.5
Trento	0.6	1.3	0.1	3.9	0.5	3.5	0.1	7.4	13.7
S. Michele	4.2	0.8	0.1	1.5	17.2	0.9	0.4	0.3	5.2
Gries	0	0.3	1.3	0.7	0.1	1.7	3.5	0.7	22.4

Tab. 2. Frequencies of wind directions recorded at 2 p.m. in summer at the 6 stations in the Adige and Sarca valleys (Defant, 1909).

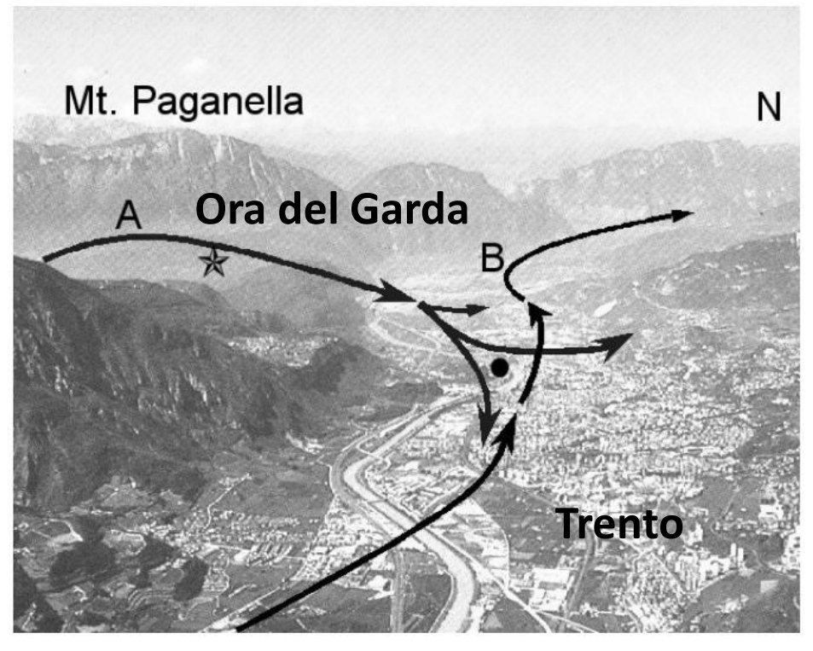

Fig. 5. Overflow of the Ora del Garda in the Adige Valley north of Trento (de Franceschi et al. 2002).

6 Explanation of the along-valley pressure gradients

Defant compared the observed along-valley pressure gradients with corresponding estimates based on observed temperature daily cycles only. He concluded that the different heating of the air columns over the plain and over the mountain slopes does not provide a sufficient explanation. Instead, he ascribed the amplification of the afternoon pressure minimum to a greater expansion of the air column at the valley center (with respect to the air columns above the valley slopes), causing air to flow from the valley center towards the valley sides (Fig. 6). The recent developments of the theory of valley winds are based on the clarification of the real structure and their role of the cross-valley circulations in building up the pressure gradients driving the valley winds. In particular, Rampanelli et al. (2004) and Serafin and Zardi (2010a,b, 2011) highlight the role of the subsidence associated with up-slope winds in the daytime heating of the valley atmosphere core and in determining the valley boundary layer structure (Figs. 7-8).

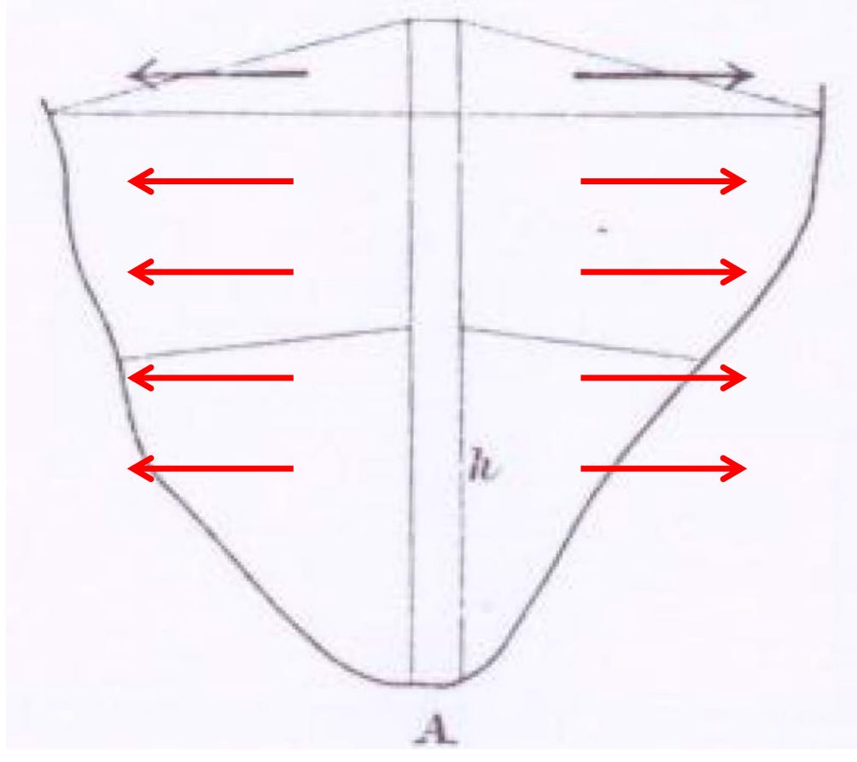

Fig. 6. Scheme of cross-valley flow according to Defant (1909).

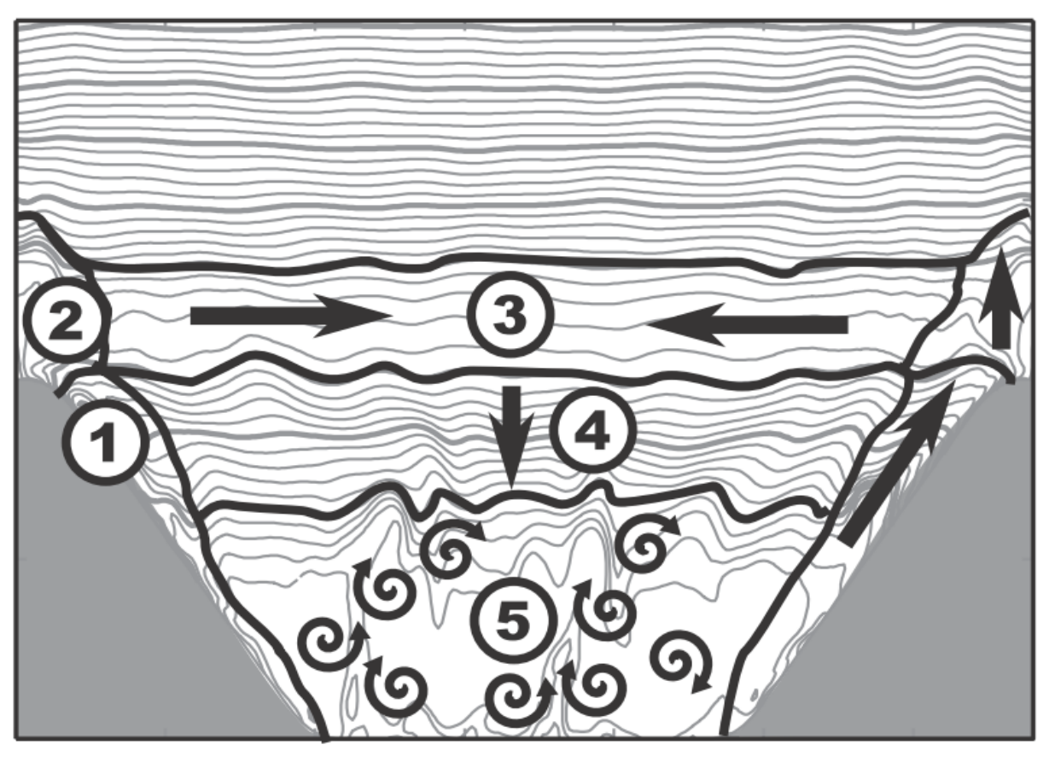

Fig. 7. Scheme of idealized cross-valley flow according to Serafin and Zardi (2010a).

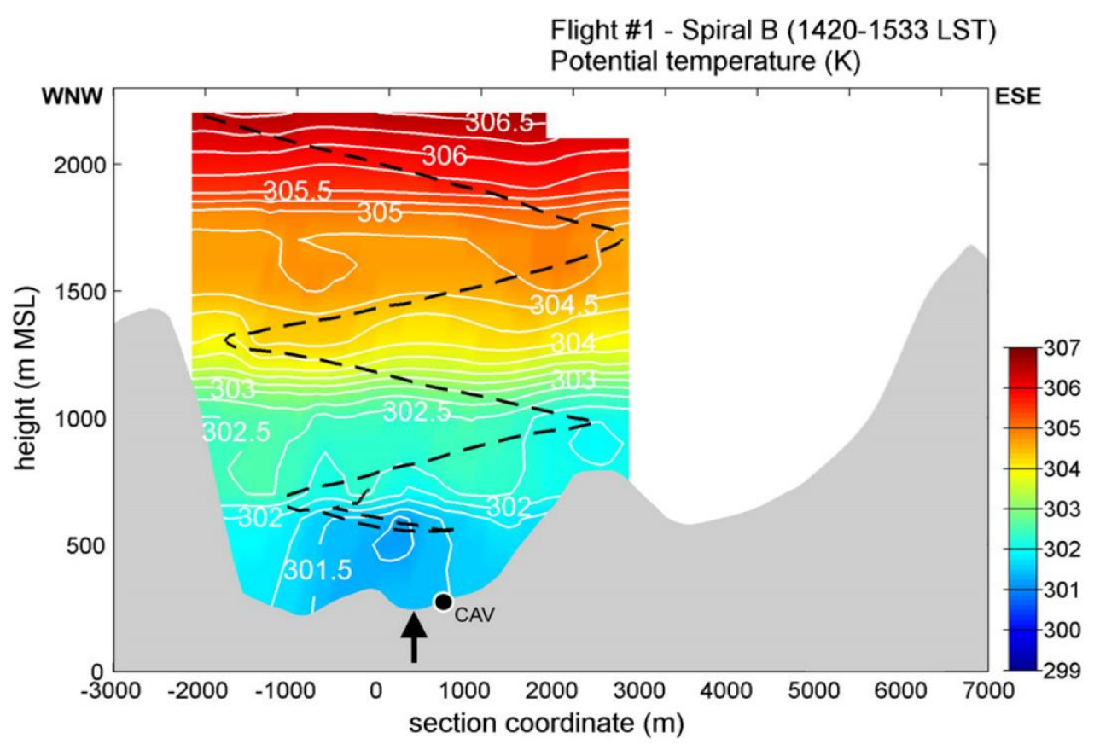

Fig. 8. Cross-valley potential temperature field from airborne data (Laiti et al. 2013b).

7 Conclusions and outlook

- Defant (1909) first analyzed the daily cycles of the average pressure gradients observed between Bolzano and the Po Plain and the associated winds developing in the Adige and Sarca valleys. He focused in particular on the Ora del Garda circulation, thanks to lymnograms taken at the Lake Garda northern shore.
- Recent studies have tackled in more detail the subject and found substantially good accord with Defant's results. They provided explanations for specific aspects and small-scale phenomena that were not solved or even approached by Defant (Laiti et al., 2013a,b, 2014; Giovannini et al., 2015).
- Defant (1909) first included cross-valley circulations in the explanation of the formation of the along-valley pressure gradients driving the valley winds. However, his hypothesis was not very accurate. Only very recently, investigations based on modern approaches (e.g. high-resolution airborne datasets, NWP model simulations, etc.) clarified the role of the cross-valley circulations in building up the above-cited temperature and pressure gradients (Rampanelli et al., 2004; Serafin and Zardi, 2010a,b, 2011).
- Investigations based on both surface observations and high-resolution NWP model simulations (LES) are being carried out at present, to perform a conclusive characterization of the valley wind systems developing in the study area. Among the investigated aspects are: synoptic flow influence, urban effects, interactions between different valley circulations, small-scale features (like lake breeze front structures) (see oral O4.3 and poster P1.25 at this conference).

References

Defant A., 1909: Mountain and valley winds in South Tyrol, Proceedings of the Academy of Sciences in Vienna, 118, 553-604

Giovannini L., Laiti L., Zardi D., de FranceschiM., 2015:Climatological characteristics of the Ora del Garda wind in the Alps. Int. J. Climatol. (online).

Laiti, L., Zardi, D., de Franceschi, M., Rampanelli, G., 2013a. Residual kriging analysis of airborne measurements: application to the mapping of Atmospheric Boundary-Layer thermal structures in a mountain valley. Atmos. Sci. Lett. 14, 79–85.

Laiti L, Zardi D, de Franceschi M, Rampanelli G. 2013b. Atmospheric boundary layer structures associated with the Ora del Garda wind in the Alps as revealed from airborne and surface measurements. Atmos. Res. 132–133: 473–489.

Laiti L, Zardi D, de Franceschi M, Rampanelli G, Giovannini L. 2014a. Analysis of the diurnal development of a lake-valley circulation in the Alps based on airborne and surface measurements. Atmos. Chem. Phys. 14: 9771–9786.

Rampanelli, G., Zardi, D., Rotunno, R., 2004. Mechanisms of up-valley winds. J. Atmos. Sci. 61, 3097–3111.

Rotach, M.W., Zardi, D., 2007. On the Boundary Layer structure over highly complex terrain: key findings from MAP. Q. J. R. Meteorol. Soc. 133, 937–948.

Schaller E., 1936: Aerologische Untersuchung des periodischen Talwindsystems von Trient (Aerologic investigation of the periodic valley wind system of Trento). Dissertation, Innsbruck.

Serafin, S., Zardi, D., 2010a. Structure of the atmospheric boundary layer in the vicinity of a developing upslope flow system: a numerical model study. J. Atmos. Sci. 67, 1171–1185.

Serafin, S., Zardi, D., 2010b. Daytime heat transfer processes related to slope flows and turbulent convection in an idealized mountain valley. J. Atmos. Sci. 67, 3739–3756.

Serafin, S., Zardi, D., 2011. Daytime development of the Boundary Layer over a plain and in a valley under fair weather conditions: a comparison by means of idealized numerical simulations. J. Atmos. Sci. 68, 2128–2141.