P1.20 IDENTIFICATION OF THERMAL STRUCTURE FROM AIRBORNE MEASUREMENTS IN AN ALPINE VALLEY WITH KRIGING TECHNIQUE

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1. INTRODUCTION

Light airplanes provide a suitable platform for detailed investigation of fine scale thermal structures associated with the development of thermally driven flows in alpine valleys, where boundary layer processes display peculiar features due to various constraints like complex orography, valley shape, slope covering and exposition to solar radiation.

A complete view of these structures and related complex dynamics requires detailed information over a whole 3D domain, which are not easily obtained, from available data by means of standard meteorological ground based measurement. Indeed in the case of valley winds, deviations of the variables of interest from an ideal vertical profile, as usually found over flat uniform terrain, are associated with the presence of the valley sidewalls and sloping valley floor.

However suitable mathematical and numerical algorithms are required in order to extract 3D structures captured by measurement flights. Kriging seems to be one of the most suitable tools for mapping of such fields, and an application to the analysis of airborne measurements is shown in the present work.

A suitable 3D mapping of such "anomalies" based on few sampling points where the variable is measured is often required. One of the specific properties of this method is its capability of providing an estimate about the reliability of the estimated variable in the form of an *estimation variance*. On the opposite, other standard interpolation methods - like the well known *inverse squared distance* (ISD) method - cannot provide such information and are usually less accurate, as will be shown later.

2. THE MEASUREMENT FLIGHT

The target area of the present investigation is in the Adige Valley, in the Italian side of the Eastern Alps, a rather long valley connecting the Po plain to the Isarco Valley and then to the Brenner Pass. The valley floor displays an average along-valley slope of around 0.1% and is mainly covered with canopy and cultivated fields (vineyards and apple trees). The valley floor width ranges from 5 to 2.5 km and high sidewalls are present along the whole valley length by compact mountain chains, rarely broken by the inlets of minor tributary valleys.

The target area for measurements is located south the city of Trento near the town of Besenello, the valley floor is about 2.5 Km wide at the bottom and the slopes have an angle of about 30° with the horizontal. A picture of the digital elevation model of the investigated valley section is shown in Figure 1.

The trajectory of the motorglider was carefully planned to obtain the maximum number of data in trhe chosen valley cross-section during a flight whose duration was kept as short as possible in order to give a sort of "snapshot picture" of the atmospheric thermal structure at the time of the flight. The trajectory of the flight is shown in Figure 2. The spiralling pattern allowed exploring the valley section with a detailed and uniform sampling including various measurement points very close to the slopes at turning points.

The motor-glider was equipped with the following instruments:

- Temperature sensor: Fast response PT100,
- Humidity sensor: Rotronic MP101A,
- Pressure sensor: Vaisala PTB101B,
- Positioning system: Ashtech Z12 Surveyor.

3. KRIGING ANALYSIS

The first step in the Kriging procedure is the calculation of the so-called *experimental variogram*, i.e. a function describing the spatial correlation between collected data pairs (cf. Wackernagel, 1995).

For a space dependent variable $Z(\mathbf{x})$, sampled at N locations ($\mathbf{x}$ is the position vector), the so called *dissimilarity* between values at two different points $\mathbf{x}_\alpha$ and $\mathbf{x}_\beta$ is given by:

$$\gamma^*(\mathbf{x}_\alpha, \mathbf{x}_\beta) = \tfrac{1}{2} \left[Z(\mathbf{x}_\alpha) - Z(\mathbf{x}_\beta) \right]^2 \quad . \tag{1}$$

Introducing the separation $\mathbf{h}_{\alpha\beta} = \mathbf{x}_\alpha - \mathbf{x}_\beta$ a plot can be obtained by representing the dependence of Z on $\mathbf{h}_{\alpha\beta}$ over all possible couples of sampling points. Suitable treatment of data can be necessary in order to cope with plot scattering and spurious noise. The method proposed by Li and Lake (1994) for the "moving window" variogram estimator is the best suited for the present purposes. Assuming the existence of an underlying *theoretical variogram* $\gamma(\mathbf{h})$, representing intrinsic spatial correlation of the variable Z, a suitable expression for γ can be obtained by usual best fit methods and on the basis of the physical nature of the variable. In the present case the theoretical model is a Gaussian variogram, as shown in Figure 3.

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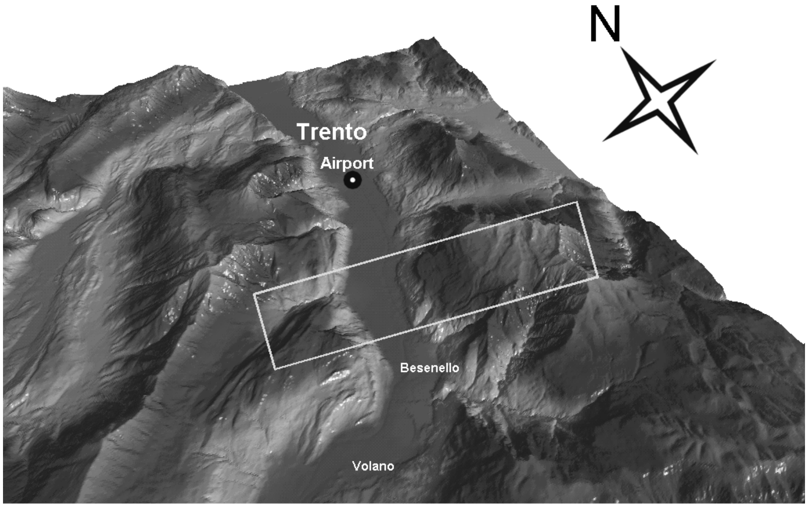

Figure 1: The area of Besenello, South of the city of Trento in the Adige Valley, where the measurement flights were performed on 1 October 1999. The box indicates the valley section explored during the flights. Trento Airport, where all the flights started from, is located South of the City.

An estimate of the unknown value of the variable Z(**x**) at a location $\mathbf{x}_0$, where no measurement is available, can be provided by a linear combination, or rather a weighted average, over available data from measurements performed at N close locations:

$$Z(\mathbf{x}_0) = \sum_\alpha w_\alpha Z(\mathbf{x}_\alpha) , \qquad \alpha = 1, \dots ,N . \qquad (2)$$

A crucial point is how to determine the weights w_α. A procedure often adopted (cf. Hennemuth, 1985) is to make them proportional to the inverse squared distance (ISD) $r_\alpha^{-2}=|\mathbf{x}_\alpha-\mathbf{x}_0|^{-2}$. The Kriging procedure instead allows to take into account the spatial correlation structure available from the variogram.

Requiring the variance of the estimate to be a minimum, weights are given as the solution of a linear nonhomogeneous algebraic system, whose coefficients are defined in terms of the variogram evaluated for couples of positions (for further details on the method, see Wackernagel, 1996).

Then using (2) at various locations (e.g. at regularly spaced points on a grid covering the domain) a mapping of the variable can be obtained. Also the estimation variance can be evaluated at each location to provide an estimate of the associated uncertainty.

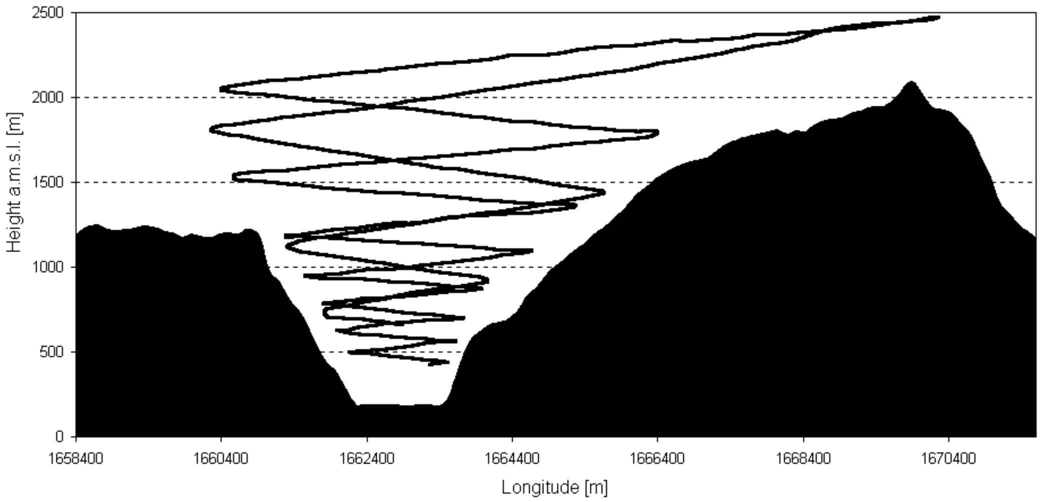

Figure 2: Side view of the trajectory of the second measurement flight, performed 1 October 1999 at 12:30 LST. The spiraling path performed by the motor-glider was specifically planned in order to cover the valley section with the maximum density of sampling points and, at the same time, to have minimum flight duration.

Figure 3: Omnidirectional variogram of data recorded in the flight performed on 1 October 1999 at 12:30 (LST). Dots indicate the experimental variogram obtained with Li and Lake (1994) procedure. Histogram bars indicate the population of the sample used for evaluation of the variogram at that lag distance, i.e. number of pairs of measurement locations displaying reciprocal separation in a neighborhood of that lag distance. The solid line is the best fit theoretical model (Gaussian). Distances between points are normalized using the scales obtained from directional variogram analysis of data (i.e. evaluating variations in different directions).

In figure 4 the potential temperature field obtained from Kriging of data from airborne measurement in a valley cross-section is shown. Data have been estimated over a regular grid with 40m spacing both in vertical and in horizontal direction. The estimation variance turns out to be less than 0.1 K in all the domain. Notice the well mixed boundary layer over the valley floor and the binding of isothermals curves close to the valley sidewalls: the picture is consistent with thermally induced up-slope flows expected to occur there. Indeed further binding would be expected closer to the slope, but for safety reason the flight trajectory could not get so close to the ground as would be needed for capturing this feature. Ground based instruments along the slope could probably provide such information for next measurements.

In Figure 5 the same thermal field is represented in the form of vertical profiles of potential temperature at various locations. Notice the occurrence of a deep inversion layer only in the core region of the valley.

A comparison with interpolation by ISD method can be provided by estimating potential temperature at each location where temperature and pressure have been directly measured, provided the value calculated from data measured at that location has been excluded from the set adopted for use of expression (2).

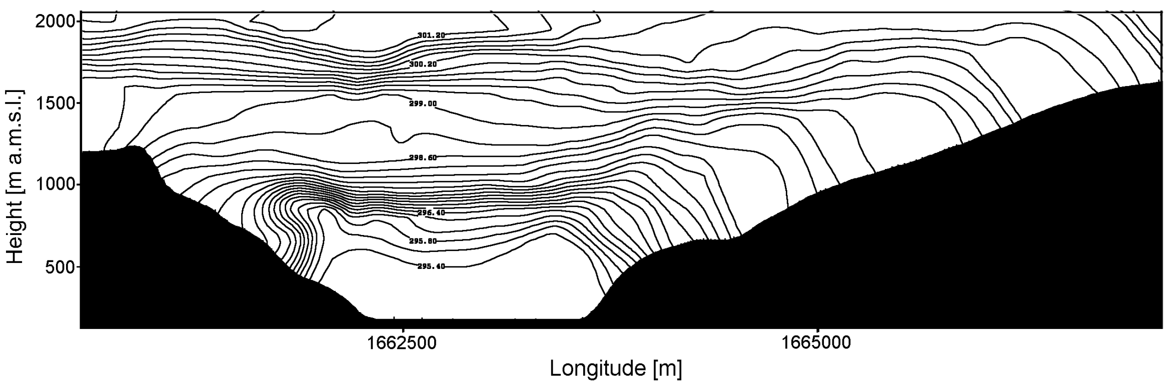

Figure 4: Field of potential temperature for the second flight performed at 12:30 LST in the Adige Valley. Notice the strong and deep inversion layer in the core region of the valley, as reported also by Bader and McKee (1985).

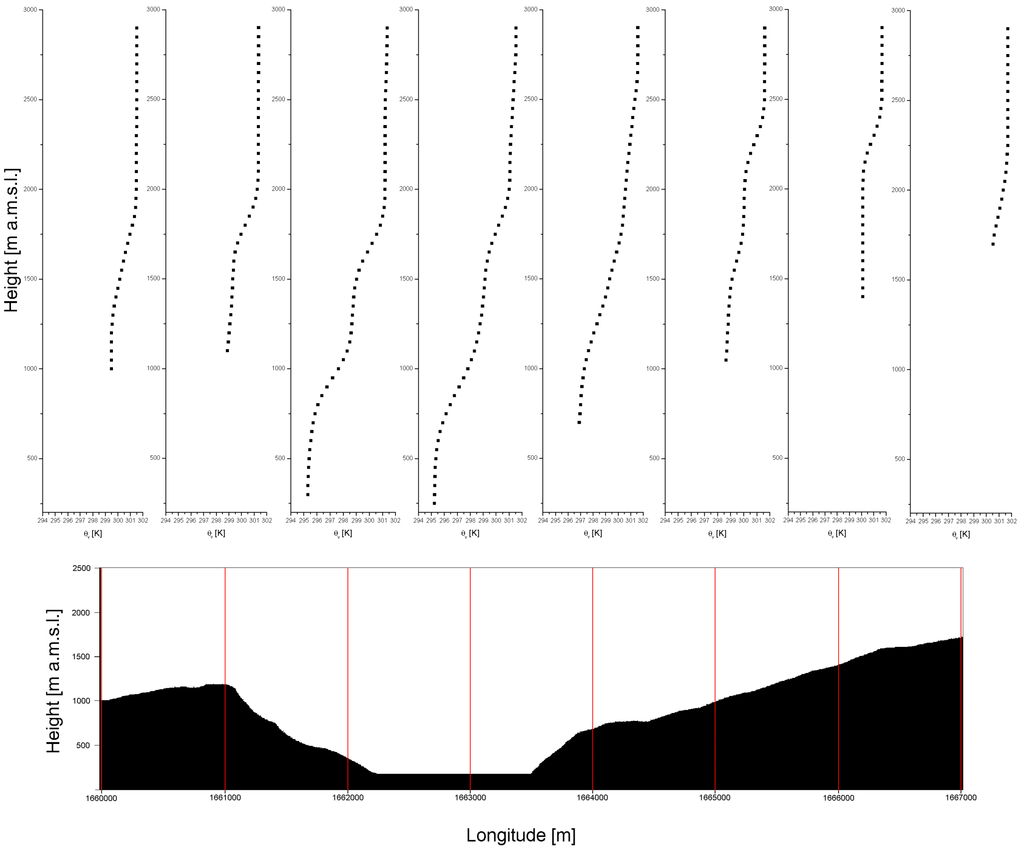

Figure 5: Vertical profiles of potential temperature, obtained through sampling of the field shown in figure 5 along the vertical lines indicated in the lower picture.

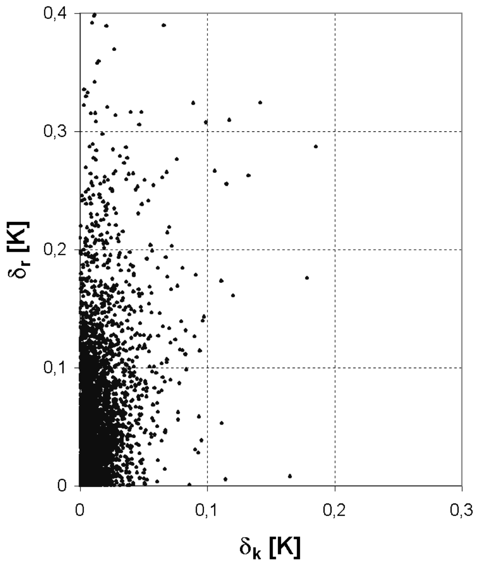

Figure 6: Comparison of (absolute) differences between estimated and measured potential temperature at sampling points using Kriging (δ_k) and ISD (δ_r) interpolation.

Then the two values of the difference between measured and estimated values obtained for the same location using the two methods can be compared. Such a comparison is shown in Figure 6: each point represents one sampled point: *x*-coordinate is the (absolute) difference between the Kriging estimate of potential temperature and the “exact” value calculated from direct measurement of pressure and temperature available form the flight, while *y*-coordinate is the same quantity based on ISD method.

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