Journal of Mediterranean Ecology **vol. 5, No.1, 2004: 61-68**

Computation of the mixed layer height through a simplified PBL model for small island (ISLA)

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Keywords: Planetary boundary layer, Turbulence modelling, Mixing layer

Abstract

In the present work a simplified model, based on the parameterisation of a growing boundary layer over a coastal discontinuity , has been used to estimate the temporal evolution of the mixed layer height during the PianosaLab experimental campaigns. The bi-dimensional model was applied over the limited surface domain of the Pianosa island. The input parameters of the model derive from the sonic anemometer measurements collected at a ground site (Vaccari et al., same issue).

Introduction

The mixed height, that can be defined as the vertical extension of the atmospheric layer consisting of the surface, mixed and entrainment layers, is an important parameter in the similarity theory parameterisations and in the turbulence planetary boundary layer (PBL) studies. Furthermore, it represents a key parameter in the atmospheric dispersion of chemicals: in fact, it gives an estimation of the maximum height at which the compounds are mixed in the planetary boundary layer.

The experimental in-situ determination of such mixed layer needs the use of vertical soundings methodologies such as the radio-sounding, SODAR and RASS (Seibert et al., 1997) techniques, or instrumented airborne platforms. Such techniques are time- consuming and very expensive, and they may sometimes interfere with the flight-routes of commercial aircrafts. Continuous measurements are consequently not allowed even in remote areas, thus limiting the applicability for the long-term monitoring of ecosystems.

The development of mathematical models able to parameterise the mixed height evolution as a function of meteorological and micrometeorological parameters collected at the surface, can furnish a powerful tools to overcome the highlighted problems. The main question arising in their utilisation is to establish their degree of reliability in presence of changing surface texture and different atmospheric stability conditions.

The continuity solution at the surface represented by the presence of changing roughness, such as the presence of a coastline, strongly limits the utilisation of models that considers an ideal, convective and homogeneous PBL, as the widely utilised Batchvarova and Gryning (1991).

The most dramatic change in the PBL occurs when stable stratified flows encounter warmer surface as happens in the case of coastal discontinuities.

The development of the thermal internal boundary layer (TIBL), starting from the coastline and evolving trough the inland, can be represented by the Arya (1988) parameterisation:

$$\delta_t(x) = a \cdot \left[\frac{H_0 x}{\rho C_p \gamma U} \right]$$

where the constant a is equal to 1.5, ρ is the air density, C_p is the specific heat at constant pressure, U is the wind speed, H_0 is the sensible heat flux, x is the distance from the coastline and γ is the potential thermal gradient. This last parameter, representing the thermodynamic profile of the atmosphere outside the TIBL, can be considered nearly-constant and assumed equal to 0.005 K m^{-1}.

The input parameters of this equation can be directly obtained thought a three axial sonic anemometer measurements.

In this work are reported the results obtained by the utilisation of bi-dimensional ISLA model for data taken during the experimental campaign carried out at the Pianosa island.

Experimental set-up and methodology

The experimental measurement campaign was carried out during the period 17-22 May 2000 in two different positions of the Pianosa island, as reported in Figure 1. The EDDY site (Lat. 42° 35.04' N, Long. 10° 04.82'E) was located in the centre of the island and was instrumented with a ultrasonic anemometer (Mod. USA-1, Metek) positioned at 2.5 m height for the measurement of heat and momentum fluxes. The data acquisition was via a Meteoflux computer system (Servizi e Territorio, Milano) performing real-time measurements of the three wind components and the temperature at 10 Hz frequency. All turbulence parameters are derived together with the sensible heat and momentum flux by post-processing the data with a Fortran code program Sozzi and Favaron (1996).

The PS site (Lat. 42° 34.54' N, Long. 10° 06.11' E) was situated close to the southeast coastline of the island, and was chosen in order to be able to characterize the surface layer at the sea-air-land interface. This station was instrumented with a sonic anemometer (Mod. USA-T1, Metek) positioned at 3.3 m height, and the data were stored into a PC after the electronic processing carried out by a programmable internal board. Two axis rotations and the computation of the 15' averages of the main physical quantities and standard deviations along with the momentum and sensible heat flux determination were done.

The ISLA-model is based on a regular grid, representing the real dimension and the topography of the Pianosa island, nested into this grid through a close polygonal describing the island perimeter and its altitudes above sea level. The grid is constituted by cells of dimensions *dx* (in E-W direction) and *dy* (in N-S direction).. Each cell is represented by a couple of indexes (*i, j*) where *i= 1, nx* and *j=1,ny* and the computation of TIBL height, according to Arya (1988), is made in the middle of each cell.

The input of the model is a file called ISLA.ini, containing all the information useful for the model to run. This file is constituted by the following records:

RK1:
- x_0 and y_0 (geographic coordinate of the apex SW of the grid);
- *nx* and *ny* (grid cells number in *x* and *y* directions);
- *dx* and *dy* (cells dimension in *x* and *y* directions).

RK2:
- Island surface roughness length.

RK3:
- File name of the island topography (max 40 characters).

RK4:
- File name of the micrometeorological file (max 40 characters).

The micrometeorological conditions are defined into an input file, containing a number of records equal to the hours of simulation. Each record is represented by the following variables:

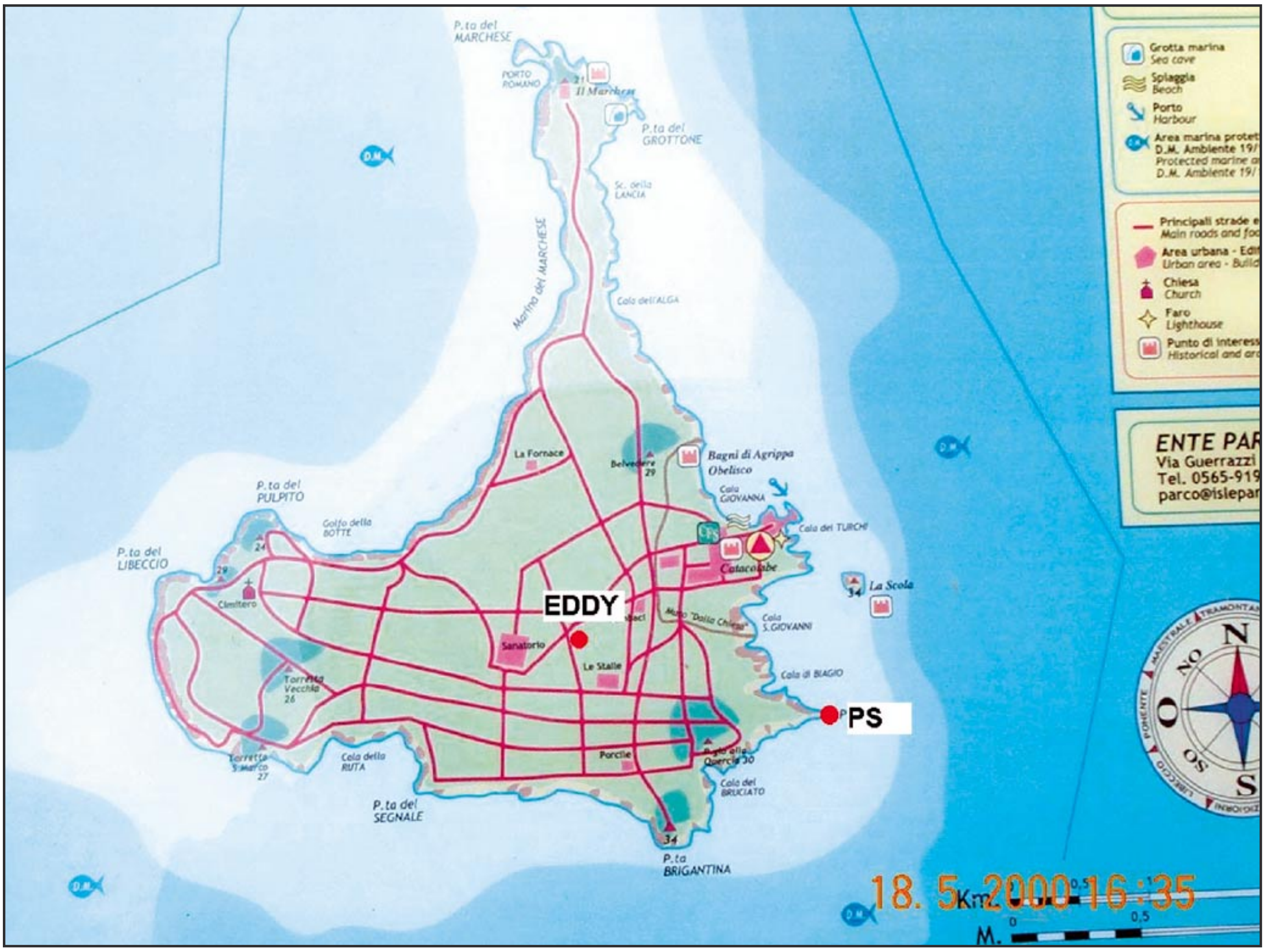

Figure 1. Pianosa island map with the geographical position of the two measurement stations.

- *jday* (Julian day);
- *ih* (simulation hour);
- *dir* (wind direction in degree from Nord);
- *U* (wind speed in m s^{-1});
- *T* (air temperature in K);
- *H0* (Sensible heat flux in W m^{-2});
- *Gamma* (temperature vertical gradient above the TIBL, equal to 0.005 K m^{-1}).

The model output is constituted by a number of files equal to the hours of simulation. Each file, called D*jjjhh*.DAT where *jjj* is the Julian day and *hh* is the simulation hour, contains, for each cell grid, the geographic coordinate of the cell (*x,y*) and the TIBL height value. The cells situated on the sea have a zero value for the TIBL height.

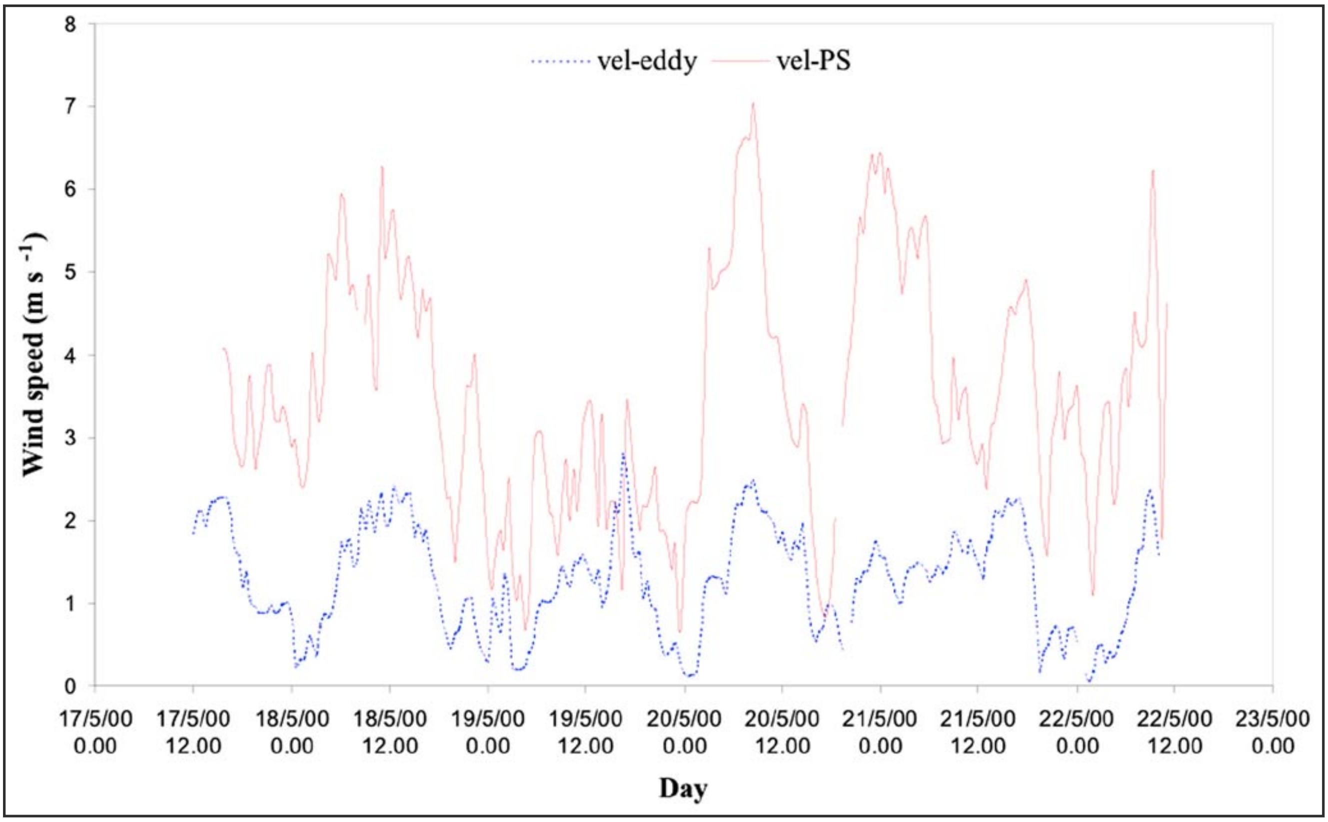

Figure 2. Temporal trends of the wind speed for both sites.

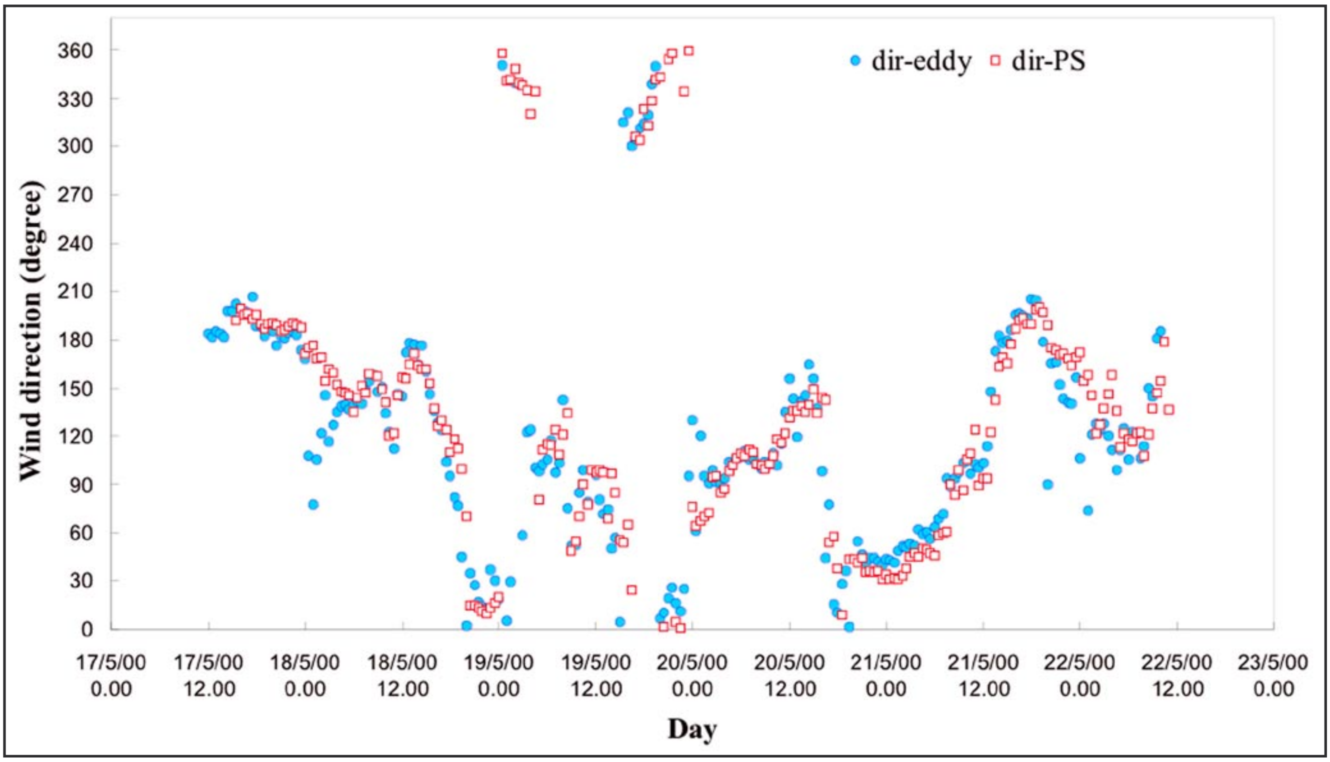

Figure 3. Temporal trends of the wind direction for both sites.

Results and Discussion

The temporal trends of wind speed and direction for both sites are reported in Figures 2 and 3. The wind speed recorded on the cost (PS) is greater than in the centre of island (EDDY). The wind direction is almost the same in the two sites, indicating a decrease in intensity of the coastal flux during its path from the coast to inland principally due to the surface friction.

In Figure 4 is reported the air temperature recorded in the two stations: the coastal temperature varying less than the inland temperature, thus evidencing the mitigating effect

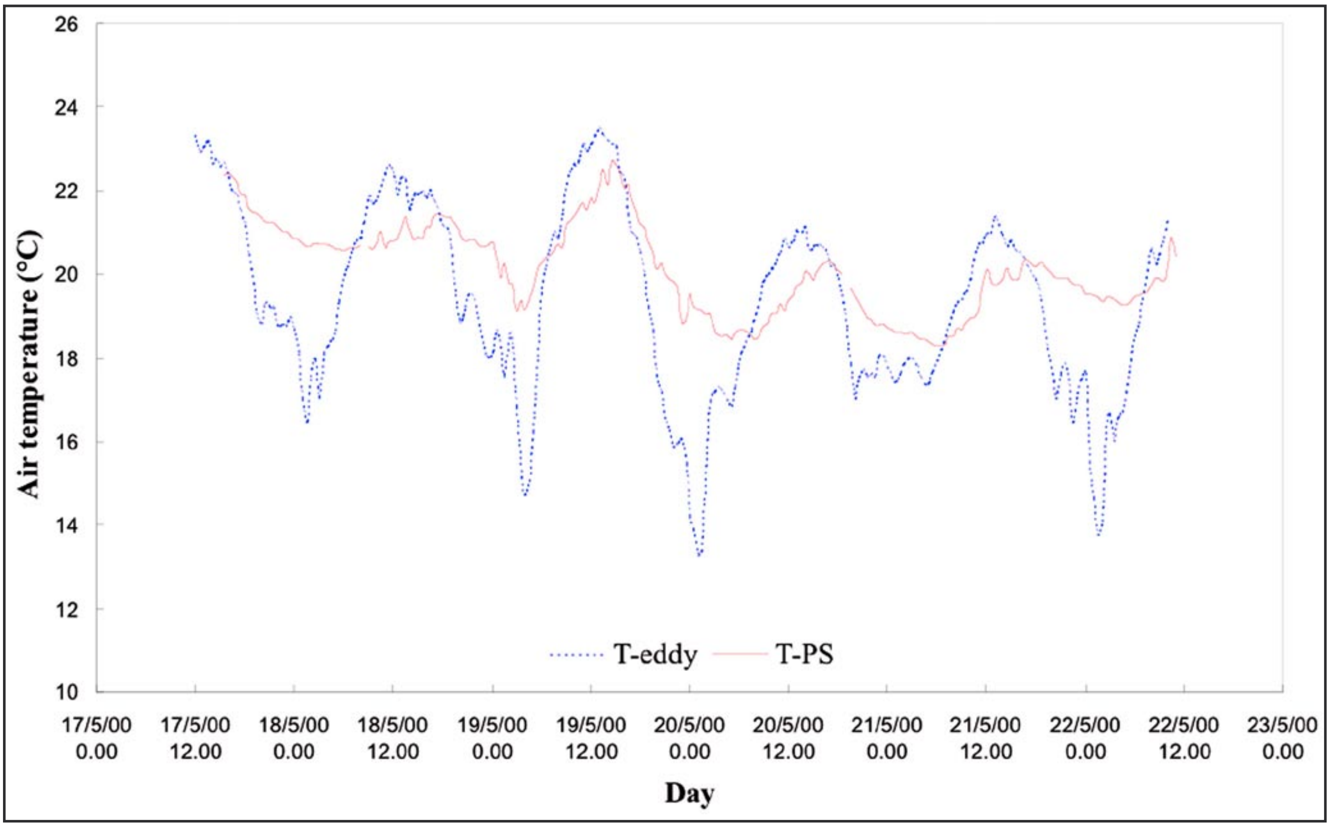

Figure 4. Temporal trends of the air temperature for both sites.

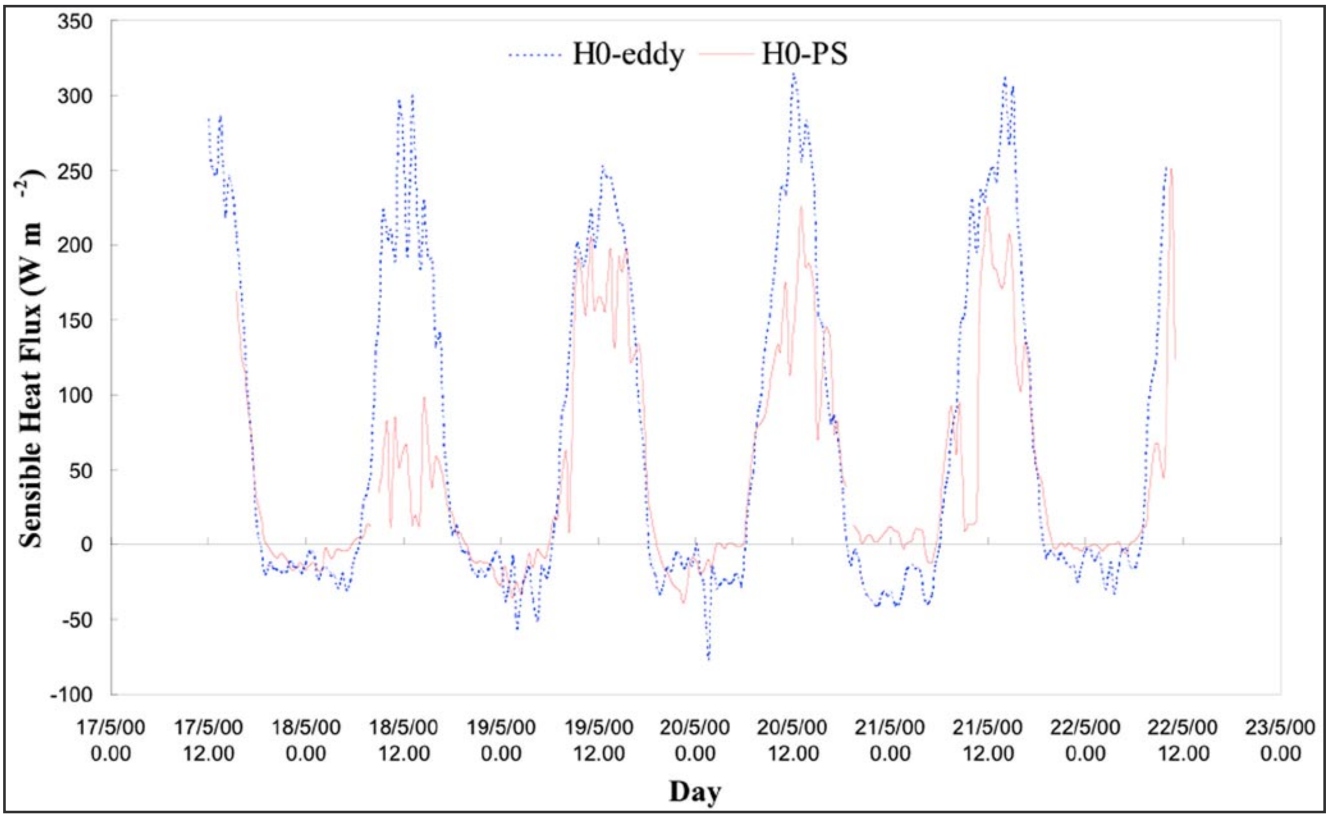

Figure 5. Temporal trends of the sensible heat flux for both sites.

of the sea. During the diurnal hours, the EDDY temperature is greater than the PS, while during the night it drastically decreases reaching values of 13 °C. The thermal excursion is about 10 °C for the inland station and 5 °C for coastal site.

An other quantity basic in to characterising the surface micrometeorological conditions is the sensible heat flux, that was computed in the two different locations from the raw data of the sonic anemometers through the eddy covariance techni-

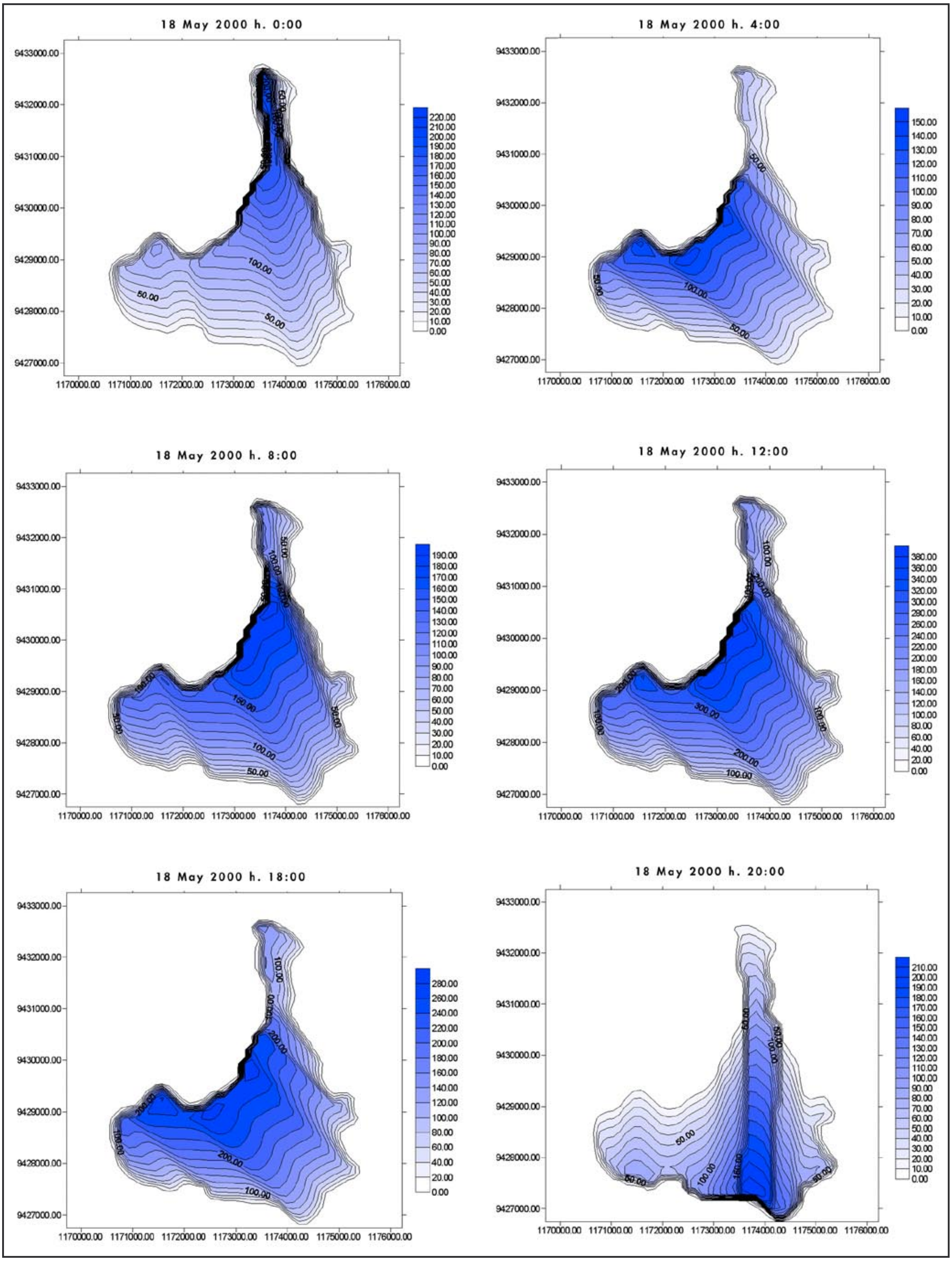

Figure 6. Results of 6 hours of ISLA model simulation for Pianosa island during 18th May 2000.

que. A typical diurnal trend was evidenced in both sites, with maximum values recorded around 13:00 (solar time, GMT+1 (Fig.5). As expected, the inland values are greater than the one recorded at the cost o, due to a greater surface warming and a higher thermal internal boundary layer height, as we will evidence in this paper. During the night the cooling of the EDDY site is more marked than PS site, leading to sensible heat flux values of about –50 W m^{-2}.

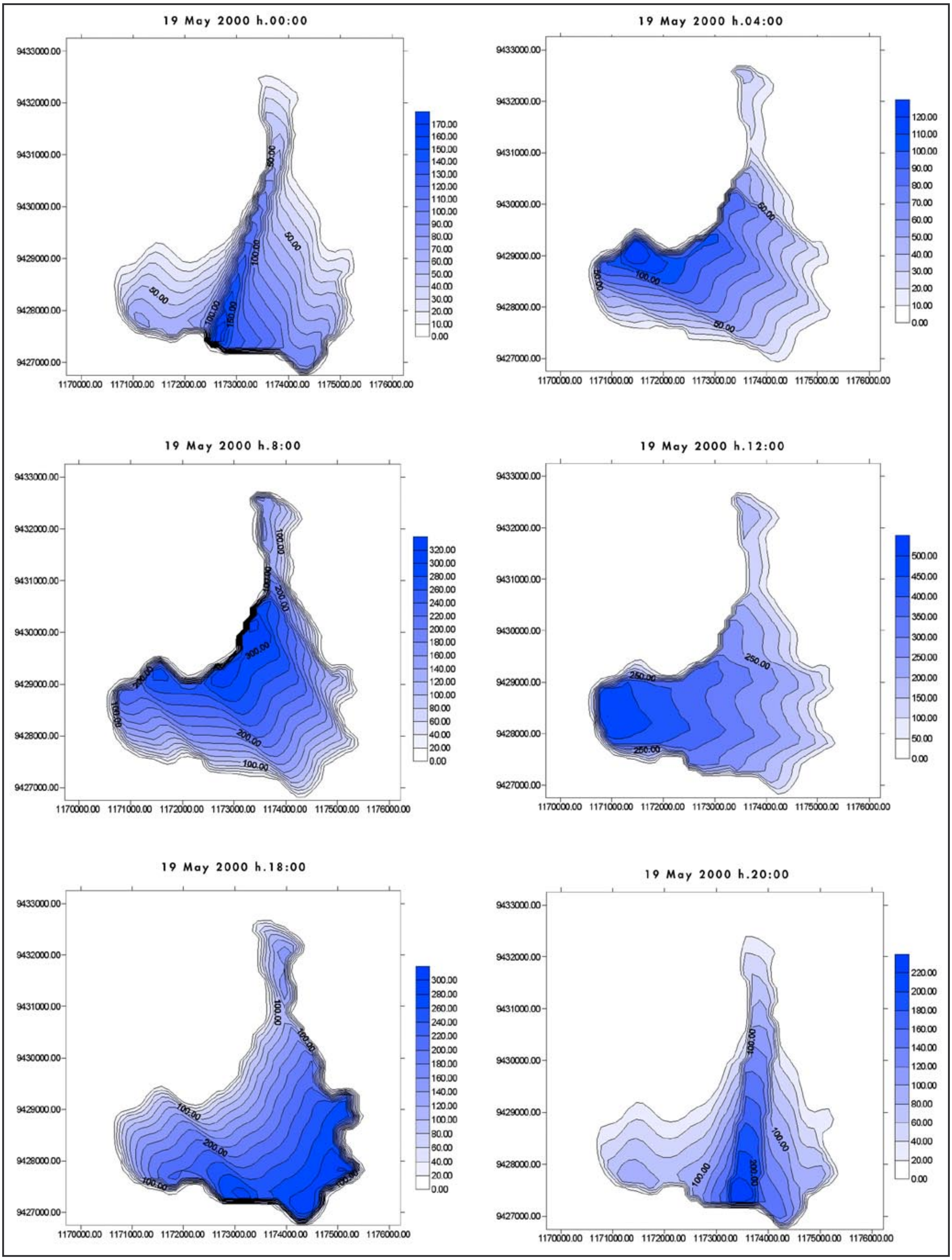

Figure 7. Results of 6 hours of ISLA model simulation for Pianosa island during 19th May 2000.

The micrometeorological data recorded through the sonic anemometer situated in the middle of the island (see Figure 1) have been utilized as inputs for the ISLA model. In Figures 6, 7 and 8, the obtained results for some hours of three days simulations are reported. It appears evident that during the night the TIBL height is lower than during the day, when also the convective part is present. On May 19th and 20th , at around midday, the TIBL height reaches

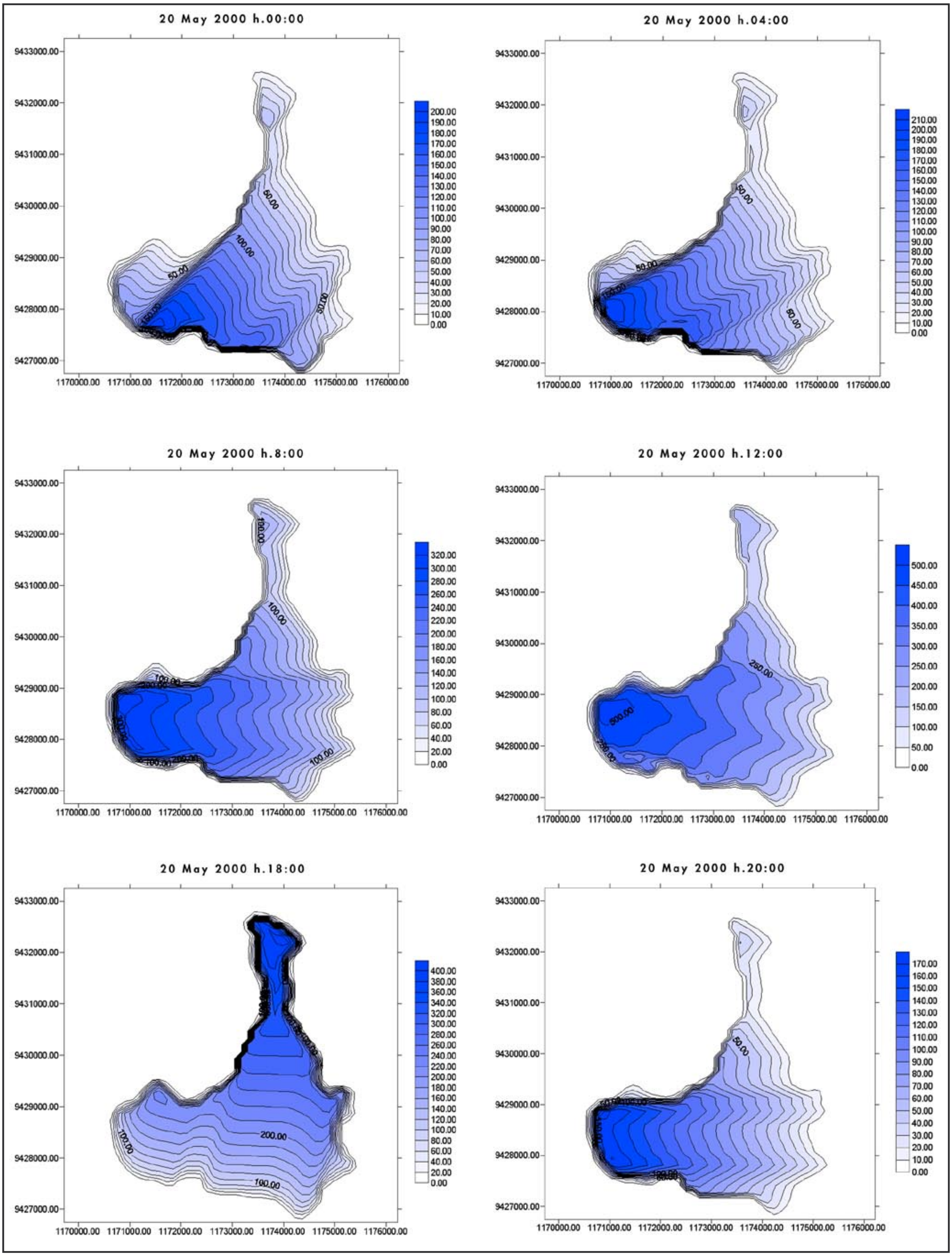

Figure 8. Results of 6 hours of ISLA model simulation for Pianosa island during 20th May 2000.

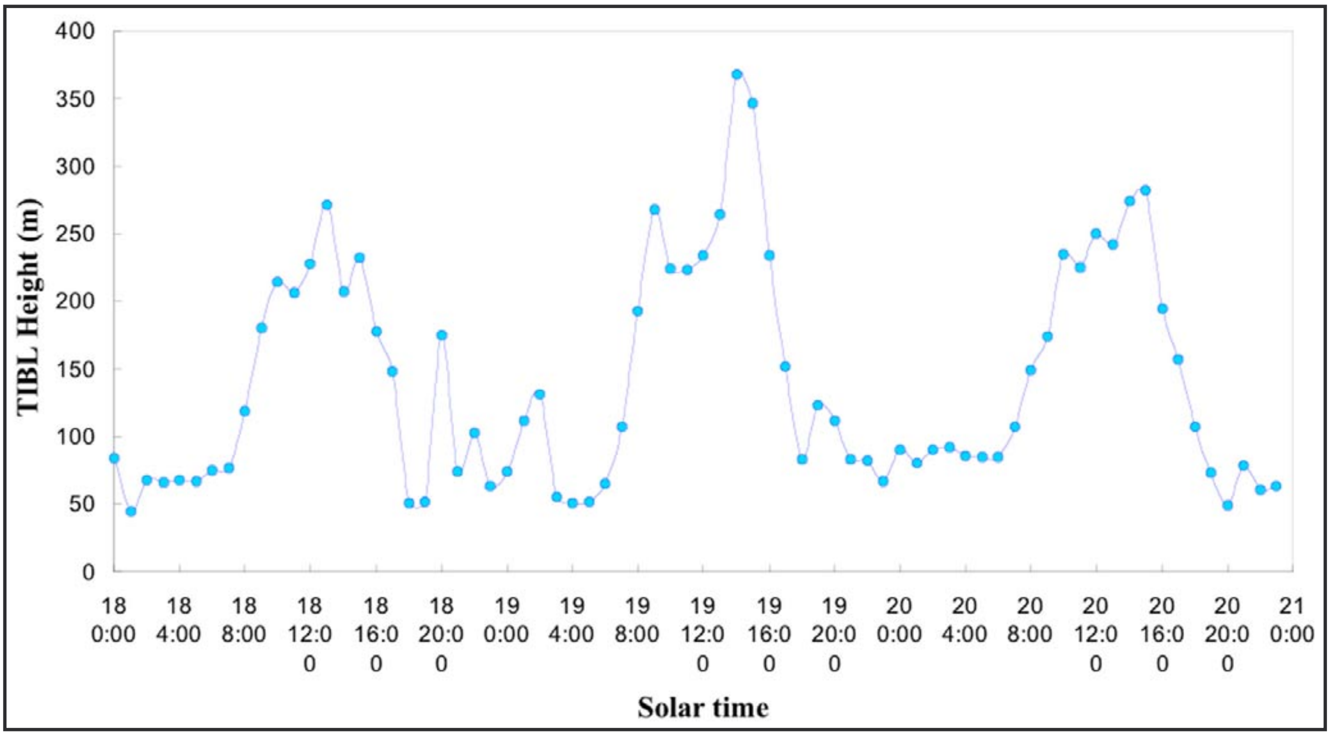

Figure 9. Temporal trend of TIBL height obtained with ISLA model for the grid point corresponding to EDDY station.

its maximum around 500 m, with an increment that can be ascribed to the increase of sensible heat flux recorded on the coast (see Figure 5). The equal height lines evolve as function of wind direction because the TIBL evolves in downwind direction.

The values of TIBL height at the grid point correspondent to EDDY coordinates were considered in order to study its temporal evolution The results are reported in Figure 9, where appears evident the diurnal trend, with a maximum reached at around 14:00-15:00, in correspondence of the maximum mixing. On 19th May the maximum height is reached at about 350 m.

Conclusions

The results obtained allowed to characterize the Pianosa island boundary layer, and to evidence from the principal meteorological variables the wind and the temperature evolution from the coast to the inland.

The ISLA bi-dimensional model, utilized for the computation of TIBL height, showed to be a useful method to give a modelling support to the measurements conducted for the determination of the total CO_2 budget.

Because of the very short duration of the measurements, these results must anyway to be considered preliminary, and other studies on the TIBL evolution during a larger period and relative to different meteorological and climate conditions are necessary.

Acknowledgements

Measurement campaigns and data processing were funded by Consiglio Nazionale delle Ricerche (CNR), AGENZIA 2000 Project 'An advanced ground based network for the study of gas exchange between the terrestrial vegetation and the atmosphere (Pianosa-Lab)

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