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Flow evolution at a coastal site in the Central Mediterranean

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ABSTRACT

The understanding of the coastal atmospheric processes requires the availability of complete datasets spanning from the surface to the top of the Atmospheric Boundary Layer (ABL) and high resolution modelling to resolve the coastal discontinuity. To study the development of the vertical structure of the coastal flow under different meteorological situations, we carried out an intensive experimental campaign at a site located 600 m inland from the shoreline in the Central Mediterranean area during July 2009 integrating optical and acoustic ground-based remote sensing information and surface standard measurements. In this area, the sea breeze always develops but sometime is overdriven by the synoptic flow that blows from the same direction. LIDAR (LIght Detection And Ranging) and SODAR (SOnic Detection And Ranging) allow deriving the vertical profiles of wind speed and direction and of some turbulence characteristics. Furthermore, the vertical profile of the backscatter intensity of the ceilometer (LIDAR) detects the height of the boundary layer with respect of the aerosol concentration. We observed that when synoptic conditions are favourable to sea breezes development, the air masses with marine aerosols are advected over land in the early morning interacting with the nighttime boundary layer. After the onset of the sea breeze an internal boundary layer develops from the coastal discontinuity, the height of the boundary layerdetected by the ceilometer decreases, likely due to the advection of the marine aerosols above the IBL creating a discontinuity in the aerosol concentration and size distribution. Later in the morning, when the breeze is well developed, convection takes over and mixes marine and continental aerosols creating a homogeneous content of aerosols filling the convective layer. During stationary synoptic flow with wind speed typically larger than 4 ms^{-1}, marine aerosols are mixed with continental aerosols and the height of the boundary layer detected by the ceilometer does not varies. During nigh-time a stable layer develops, both SODAR and Doppler LIDAR reveal the development of a low level jet.

1. INTRODUCTION

To understand atmospheric processes in coastal areas requires the availability of complete datasets to describe the vertical structure of the Atmospheric Boundary Layer (ABL) and its spatial variation. To provide the information of the spatial variation of the ABL high resolution models are necessary to take into consideration the effect of the coastal discontinuity; this requires datasets for improving sub-grid process parameterizations and datasets for their validation. To study the development of the vertical structure of the coastal flow under different meteorological situations, we carried out an intensive experimental summer campaign at a site located 600 m inland from the coastline in the Calabrian region, a mountainous peninsula located at the southern tip of Italy about 50 km wide and elongated 300 km in the north south direction in the Central Mediterranean.(Figure 1). The area of the experiment is.flat and located at the end of the only west-east valley connecting the Tyrrhenian and Ionian seas in complex orography. This location allows studying the land-sea interaction in complex terrain.

The coastal flow regime is characterise by synoptic and sea-breeze winds coming from the same direction i.e. West. Furthermore, sea breeze and land breeze might act in phase with upslope and down-slope winds to determine stronger and more persistent breeze system. [1] [2].

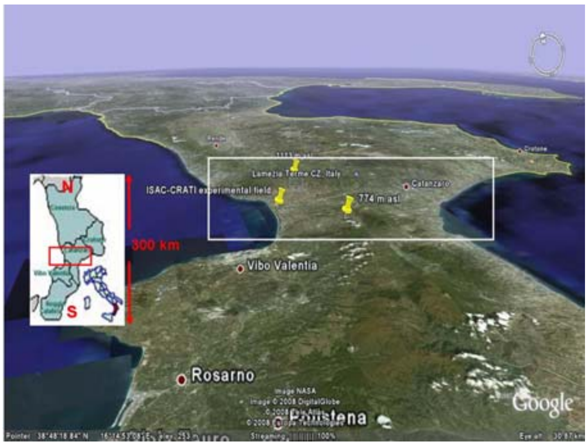

Figure 1. Calabria region in the central Mediterranean. Left: topography (m, gray shading) with topographical features cited into the text. The black dot shows the location of the experimental field.

To monitor the vertical structure of the ABL and estimate vertical profiles of atmospheric parameters such as wind speed U, and turbulent quantities, we used optical (LIDAR) and acoustic (SODAR) ground-based remote sensing [3], [4], [5]. Sound waves are scattered by the thermal structure of the atmosphere. Light waves are scattered at small particles (Mie scattering) or at air molecules (Rayleigh scattering).

In this contribution, we address the dynamics of the vertical structure of the coastal ABL from the ceilometer signal and typical wind profiles from the Windcube.

In a companion contribution in this proceedings [6] we address the performance of the different ground – based remote sensing devices in a coastal site close to the sea, where advection of air of different proprieties i.e. aerosol and thermal might limit their performance.

2. EXPERIMENTAL SET-UP

The intensive campaign ran from 15 July to the 5th of August and we used a combination of ground-based remote sensing devices based on different working principles: two optical instruments Ceilometer (CL31 VAISALA), and a Pulse Doppler LIDAR, Windcube (WLS7-0012-LEOSPHERE) and an acoustic instrument MINI-SODAR (DSDPA.90-24 METEK). Moreover mean standard and turbulent and turbulence parameter where used to monitor the surface meteorological conditions.

The SODAR, the meteorological station and the sonic anemometer are installed and operated routinely within the area of the ISAC-CRATI research coastal center. The ceilometer and pulse Doppler LIDAR were set up for the campaign in our experimental site

Ceilometers incorporate diode laser based LIDAR technology, which allows an active range-resolved optical remote sensing measuring technique. A LIDAR transmits a laser pulses vertically, and measures the backscattered signal that depends on the amount of scattering particles in a volume at a certain distance from the instrument. Recently, ceilometers have been successfully employed for detecting the ABL height (Sempreviva et al 2010). The algorithms for retrieving the height of the inversion are based on the characteristic of the top of the MABL: the entrainment of dry air from the FA, into the moist air below; and the discontinuity in the air properties at the ABL-FA interface (included aerosol contents) [3], [4], [5]. Essentially, the high temporal variability of the entrainment process of warm and dry clean air leads to considerable fluctuations of the aerosols concentration then to a large variance in the optical backscatter. On the other hand, the low content of aerosols in the FA results in a large vertical gradient of the aerosol concentration and then in a minimum scatter of the LIDAR signal. Therefore, the height of the maximum variance, and the height of the largest negative peak of the derivative of the optically attenuated backscatter intensity, can both be assumed as being the height of the ABL (Emeis et al., 2008). The ceilometer Vaisala CL31 operates as follows: it uses infrared light of 910 nm, a height resolution of 20 m, and a maximum range of 7500 m and it is sounded at zero zenith angles. Data are collected every 2 seconds.

The Windcube, is a Doppler LIDAR with a fixed focus, operating at the 1.5 µm wavelength. It has a 30° prism to deflect the beam from the vertical but here the prism does not rotate continuously. Instead, the prism holds still whilst the LIDAR sends a stream of pulses (5000-10000) in a given direction, recording the backscatter in a number of range gates (fixed time delays) triggered by the end of each pulse. Having sent the required number of pulses, the prism rotates to the next azimuth angle to be scanned, each separated by 90°. A full rotation takes about 6s.At each direction step, the Windcube combines the four most recent radial speeds at each height in order to obtain the horizontal and vertical speed and wind direction.

The SODAR is a sounder for wind and turbulence profiles. It can measures wind profiles and turbulence in a vertical resolution and it operates ranging from 45m to 405 m height and has a working frequency at 1280 Hz. Data are averaged over 10 minutes.

3. RESULTS

3.1 Meteorological condition from surface measurements.

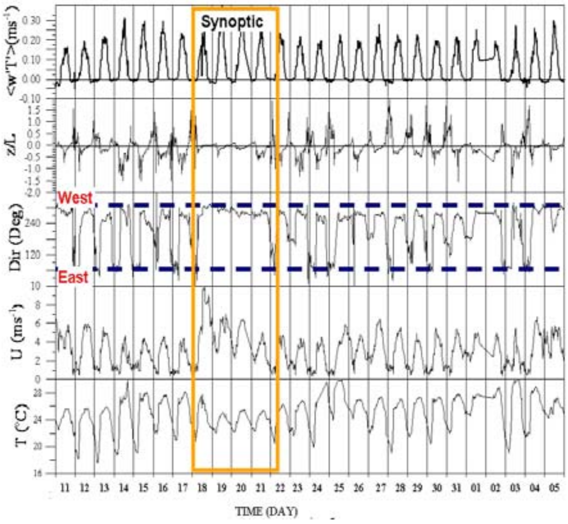

Figure 2. From top to bottom, time series of turbulent heat flux <w'T'> (note that positive values indicate downward fluxes), the Monin-Obukov stability parameter z/L where z is the height above the ground, wind direction DIR, wind speed U, air temperature T, the area in the orange box corresponds to synoptic flows; dashed line delimits the cycle of the complete sea/land breeze in West-East directions.

The main characteristics of the atmospheric flow regimes in the area is that the sea breeze has the same direction as the synoptic winds i.e. from the West. [1]. During sunny daytime, sea breeze is always starting and overimposes on the synoptic winds, conversely, during night the land breeze from the east is suppressed. An example is shown in Figure 1 during 18 to 21 June 2010 where we note that westerly winds are predominant all day long but the wind speed shows a daily cycle because the sea-breeze.

From the analysis of the surface meteorological data, shown in figure 2, we note periods with 1) well developed sea-breeze regimes with wind direction shifting between west and east during daytime and nigh time respectively, 2) not complete sea-breeze i.e. where wind direction during night comes from South and 3) synoptic wind.

During synoptic winds, the stability conditions are near neutral - likely due to the higher wind speed than during sea breeze - whereas during the sea-land breeze regimes there the typical unstable-stable daily cycle day and night respectively.

3.2 Vertical structure of the boundary layer.

To study the evolution of the vertical structure of the boundary layer and its height H during the different regimes, we used ceilometer. We had do deal with three problems:

- The ceilometer raw signal at 10 s resulted very noisy therefore, we tested three averaging periods, i.e. 1 minute, 5 and 10 minutes. The best signal average time resulted to be 5 minutes. The difference with and without averaging is showed in figure 3.

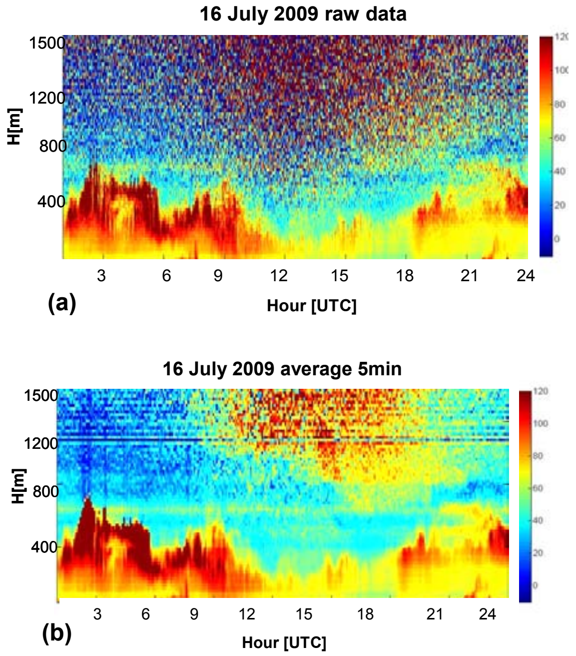

Figure 3. 2a) shows the raw data signal; 2b) shows the 5- minute averaged signal in which atmospheric structures are more distinguishable. The colour scale is in arbitrary unit.

- We also observed that the backscatter signal resulted attenuated during the central hours of the day likely due to the high solar radiation and the presence of a high albedo due to site location near the sea. We then tilted the ceilometer with an angle of 12°, we obtained and improved signal. In figure 4, we show the effect of the tilting on the signal.

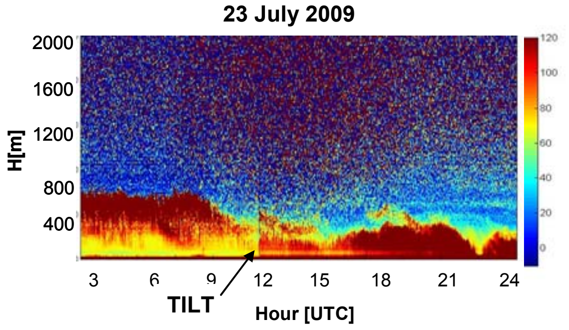

Figure 4 Ceilometer CL31 tilting on 23th July 2009, the tilting effect on signal is visible. The colour scale is in arbitrary unit.

- Finally, the bottom 80 m of the ceilometer data is characterised by persistent erroneous signals, of which, the bottom 50 m of the ceilometer data was deemed unusable; data between 50 m and 80 m required significant vertical averaging in order to remove erroneous vertical fluctuations.

Taking into account the above information, we estimated the height of the boundary layer, using two different algorithms [Munken] [Emeis]:

MINIMUM GRADIENT METHOD (**GM**): the method looks for the minimum gradient $\partial\beta/\partial z$, where β is the volume backscatter coefficient and z is the height above the ground. The steepest decreases with the backscatter profiles;

THE IDEALIZED BACKSCATTER METHOD (**IBM**): an idealized backscatter profile, B(z) the fitted to the measured attenuated backscatter profile $\beta(z)$.

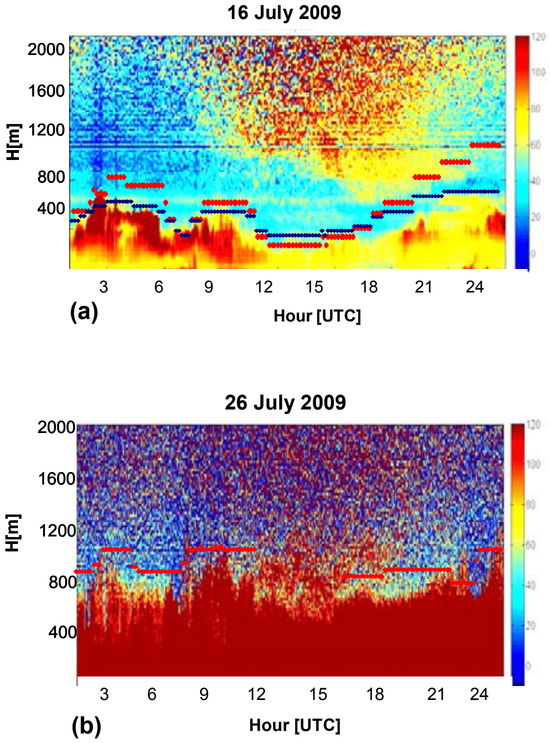

Figure 5. Backscatter signal of the ceilometer in case of (a) Sea-breeze regime i.e. 16 June and (b) synoptic regime i.e. 26 June and the estimated height of the boundary layer using the GM method (blue) and the IBM method (red), in complete breeze development – considered days 16th -26th July 2009. The colour scale is in arbitrary unit.

In Figure 5, we visualised then the evolution of the vertical structure of the coastal ABL i.e. the height of the well mixed aerosol layer, during two days representative of the two regimes typical of the area [1]. In Figure 5a we present a sea breeze day. We note a daily cycle of H. The height of the boundary layer detected after the onset of the sea breeze, (typically after 9 UTC) decreases compared to the night-time height, and increases after noon. During the night, a stable surface layer develops with low winds. In Figure 5b, we present a typical day with synoptic conditions where H remains constant at about 800 m all day long.

.3.3 Vertical wind profiles with the Wind Cube

In Figure 6a, we show the hourly vertical profiles of wind speed for a day of synoptic flow (20 June). In Figure 6a, we show the wind speed vertical profiles for a day of complete sea breeze (16 June) where a low level jet develops during the night.

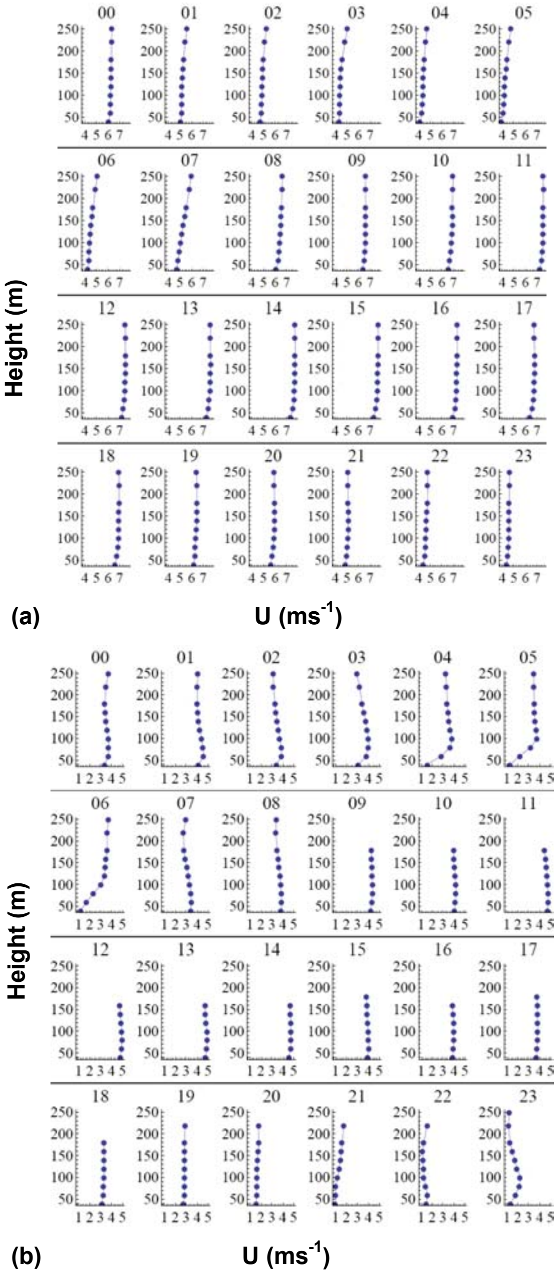

Figure 6. Wind speed vertical profiles for (a) a day of synoptic flow (20 June) and (b) a sea breeze day (16 June) where a low level jet develops during nighttime.

4. FINAL REMARKS

We have addressed the development of a coastal flow in different meteorological situations using ground-based remote sensing devices and surface measurements located at a coastal site 600 m from the shoreline during an experiment carried out in summer 2009. In this area, both synoptic and sea breeze regimes result in westerly winds advecting marine aerosols inland. However, the effect of the advection of the aerosols on the structure of the inland coastal ABL is different in the two meteorological situations.

From the ceilometer, we find that, during synoptic conditions the typical ABL height H is at about 800 m. During sea breeze, H show a daily cycle and its value is typically below 400 m.

The ceilometer is able to detect the height of the ABL with respect to particles but it does not allow us to distinguish between marine and continental aerosols. This could be addressed in the case of polarized lens in order to distinguish the particle size and precisely attribute their origin.

A low level jet develops during nighttime in absence of synoptic flows; in a companion contribution in this conference [(Wagner et al)] the implication of the change in the vertical structure of the ABL on the Windcube and the SODAR signal is discussed.

During the day the breeze is always present and seems to modulate the synoptic winds.

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