IN SITU VERTICAL PROFILES OF AEROSOL SIZE DISTRIBUTION MEASURED DURING THE MORE CAMPAIGN

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ABSTRACT

Vertical profiles of particles' number concentration, virtual potential temperature, and absolute humidity measured during the Marine Ozone and Radiation Experiment (MORE) airborne campaign are presented. The relations between boundary layer thermal structures and vertical aerosol size distributions in terms of relative importance of nucleation, accumulation, and coarse mode are discussed. A case of upper tropospheric air intrusion in the coastal boundary layer is observed and described using back-trajectories, lidar, and particles' number concentrations.

1. INTRODUCTION

The MORE airborne campaign was aimed at investigating the vertical distribution of aerosol and ozone in a rural coastal zone of the Mediterranean Sea. The campaign, supported by the EUFAR project, was held in conjunction with the validation campaign of the National Integrated Assessment Modeling system for Policy Making (MINNI, http://www.minni.org) project over the coast of Basilicata (Southern Italy) close to the ENEA Trisaia Center (40.16° N, 16.63° E), were a large set of ground-based and remote sensing instruments were installed less than 2 km from the airfield.

Twelve flights of the KIT ENDURO ultralight [1] were performed from 12 to 26 June 2010, acquiring vertical profiles of several physical and meteorological parameters: ozone concentration, aerosol size distribution, temperature and humidity; for further detail concerning the KIT ENDURO ultralight and its instrumentation see http://www.eufar.net/experiment/aircraft/specaircraft.php?num=43.

The flights were made along two long and two short horizontal legs; the long legs were along the coastline, one close to the coast above the sea, and one about 20 km inland. The flight included several ascents and descents from the ground up to 1000 m. The relatively low speed of the KIT ENDURO and its capability to fly at very low altitude (about 100 m), permitted a detailed investigation of the thermo-dynamical structure of the coastal boundary layer.

The campaign was characterized by two main meteorological situations. During the first part of the campaign (12-16 June) stable conditions led to a well-developed sea breeze regime, which was accompanied by the presence of a considerable amount of desert dust. After 17 June a change in the general circulation induced stronger northerly winds which did not allow flights from 21 to 24 June. The last two days with flights, 25 and 26 June, were both characterized by a continuous air flow from North.

We present and discuss vertical profiles of particles' number concentration measured by a TSI 3010 and a Grimm 1.108 optical counter. The aerosol vertical behavior is analyzed as a function of virtual potential temperature (Tpv) and absolute humidity (Q) profiles, and is interpreted with the support of lidar measurements and of regional scale meteorological model simulations.

2. ANALYSIS AND DISCUSSION

Measurements from four flights are presented; two were made on 16 June (takeoff at 7:25 and 14:40 UT, respectively) and two on 17 June (takeoff at 6:58 and 14:36 UT, respectively). A large variability in the vertical profiles measured at different sites along the flight trajectory is found. This is probably related to the role of the complex orography, with mountains and narrow valleys degrading towards the coast, and to non homogeneous distribution of the aerosol sources (also due to the presence of a city in the North-Eastern portion of the flight path). In this study, only data from the first vertical profile of each flight, obtained over the same location, are discussed.

On 16 June a heavy load of desert dust up to an altitude of 3.5 km (see Fig. 1) was present. During the day the top altitude of the dust layer decreased, and the dust largely penetrated in the boundary layer. The amount of desert dust largely decreased in the first hours of 17 June.

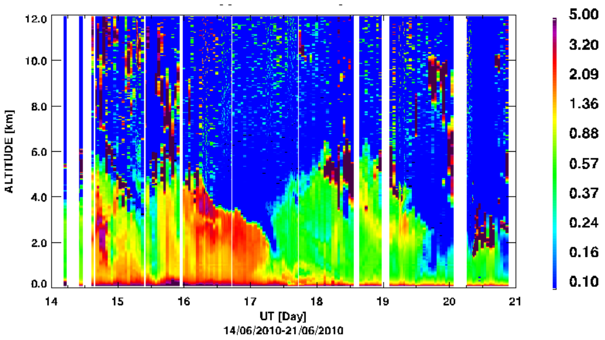

Figure 1. Evolution of the lidar bascatter ratio profile at 532 nm from 14 to 21 June 2010.

Fig. 2 shows the vertical profiles observed during the first ascent of the morning flight on 16 June. The particles' number concentrations measured by the Grimm in the range of diameters from 0.25 to 0.35 μm (G03), and from 0.9 to 1.8 μm (G14) are reported, together with the number concentration of particles with diameters between 0.01 and 3 μm measured by the TSI 3010. The horizontal dashed lines correspond to local maxima of the Tpv gradient.

The thermal structure on the morning of 16 June is characterized by a strong stability. A small convective layer is observed from the surface to 70 m; the Tpv gradient is about -0.7 K/km up to about 170 m, where an abrupt decrease of Q, typical of the marine boundary layer structure, occurs. From 170 m to 530 m Q slowly decreases, while Tpv increases. The Tpv gradient is about 3.5 K/km up to 500 m, and strongly increases up to 550 m altitude. At 530 m and 790 m maxima of the Tpv gradients are associated with an increase of Tpv by about 2 K and 0.8 K, respectively. Rapid vertical changes of Q are associated with changes of Tpv; a small local minimum of Tpv occurs at 170 m, where the strong decrease of Q is observed.

The CNC vertical distribution presents very clear and sharp transitions in correspondence of each of these four altitudes (the three peaks of the Tpv gradient and the sharp transition of Q at 170 m); also the behaviour of G03 appears connected with the Tpv and Q discontinuities, although the variations are smaller than for CNC. G14 is almost constant over the whole profile, showing a decrease above 950 m. Information on the relative weight of nucleation (ultra fine particle with dimensions between 5 and 50 nm), accumulation (fine particle of dimensions 50-500 nm), and coarse (particle dimensions greater than 500 nm) modes in the aerosol size distribution are derived by comparing the behaviour of the CNC, G03, and G14 measurements. Apparently, coarse particles play a very minor role in the size distribution below 1000 m. Thus, the comparison between CNC and G03 provides information on the nucleation mode, whose vertical profiles have been rarely reported in the literature. It is reasonable to suppose that the accumulation mode plays a major role in the size distribution in those regions where CNC and G03 display a similar behaviour. On the other hand, differences between CNC and G03 measurements suggest a larger role of the nucleation mode.

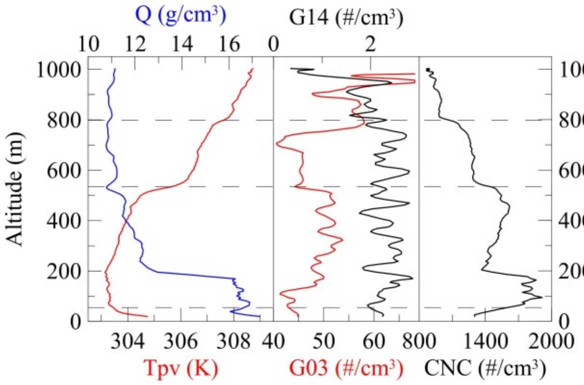

Figure 2. Vertical profiles of the morning ascent flight on 16 June. Profiles of Tpv and Q (left panel, red and blue lines), G03 and G14 (middle panel, red and black lines), and CNC (right panel, black line) are presented (see text for details).

Having in mind this perspective, the lowest layer with high Q values is the richest in ultra fine particles. On the other hand, the discontinuity around 790 m is characterized by a decrease of CNC, and an increase of G03, suggesting a predominance of fine particles and a reduced role of the nucleation mode. This behavior and the constant values shown by G14 suggest the possible presence of an aged polluted aerosol layer.

Vertical profiles measured during the afternoon flight on 16 June are shown in Fig. 3. Values of the Tpv profile show an expected diurnal increase with respect to the morning values.

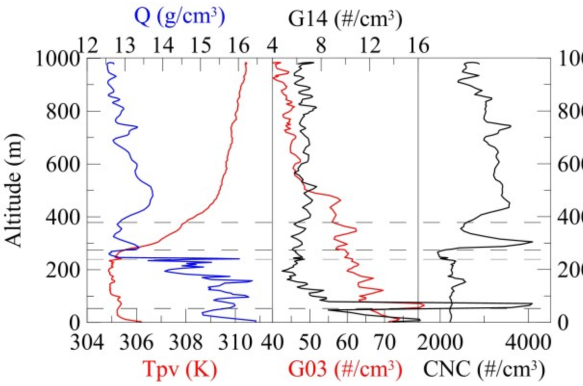

Figure. 3 As fig.2, but for the ascent flight on the afternoon of 16 June.

The stable layer between 170 and 530 m has disappeared, substituted by a transition zone connecting the stable and humid layer below 245 m (0.2 K/km Tpv gradient between 100 and 240 m) with an upper layer

which displays a constant Tpv gradient of 2.2 K/km from 500 m to the top flight altitude. Compared to the morning flight, Q is smaller in the lowest layer, and larger in the upper layer.
G03 and G14 are both larger than in the morning flight, and display a smaller variability, in agreement with the Tpv and Q profiles. Coherently with the lidar measurements (Fig.1), the high G14 values (the highest measured during the campaign) suggest that the altitude of the desert dust layer decreased during the day, probably stabilizing the atmosphere above 500 m.
The decrease of G14 from surface to 180 m is probably connected to the contribution of surface sources. A remarkable peak is observed around 50 m altitude, with a 100% increase of G14, and a 23% increase of G03, whereas CNC measurements do not evidence any variation. These characteristics suggest that this peak is probably due to local agricultural activities.
G03 particles regularly decrease form surface to 500 m, where the upper stable zone begins. Also in this case the CNC vertical distribution appears strictly related with the maximum variation of Tpv values (dashed lines). The CNC number of particles is roughly constant up to the first maximum of the Tpv gradient at at 240 m, followed by a sudden decrease in the small layer from 240 to 290 m. In the transition zone between the 290 and 400 m CNC reaches the maximum concentration (about 4000 particle/cm^3); this maximum does not correspond with an increase in G03, indicating the importance of the nucleation mode in this thin layer.

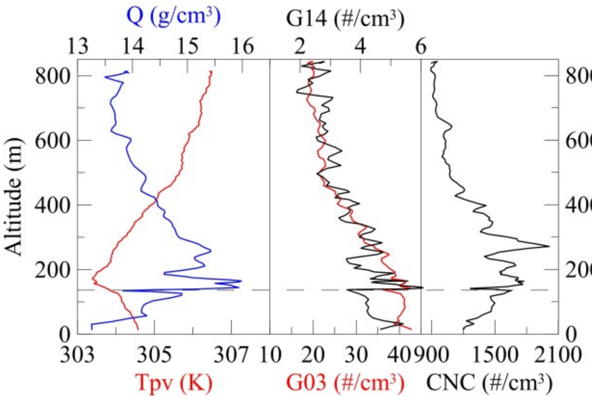

Figure. 4 As fig.2, but for the ascent flight on the morning of 17June morning.

The morning flight on 17 June (Fig. 4) is characterized by very different profiles compared to the previous day, according to the lidar measurements (Fig.1), which show a strong decrease of the aerosol amount during the night between 16 and 17 June. An evident discontinuity of the Tpv gradient occurs at 160 m, where the Tpv gradient changes from -8 K/km (between the surface and 160 m) to 6.3 K/km (from 160 to 400 m), indicating the base of a stable layer extending up to about 500 m. The Q profile shows interesting features: low values in the first 160 m, an abrupt increase just above the 160 m discontinuity, and relatively high values at higher altitudes, larger than the Q values observed in the 16 June flights. Above the discontinuity at 160 m, CNC, G03, and G14 present a decreasing behavior, with CNC number concentrations reduced by about 50% compared to the 16 June afternoon.

During the afternoon flight on 17 June (Fig. 5) the minimum aerosol number concentration (G03, G14 and CNC) is measured between the surface and 160 m; this is the only case in which a similar vertical aerosol distribution was observed throughout the MORE campaign.
Tpv and Q profiles are similar to those measured during the morning flight, with a Tpv gradient of -3.0 K/km from the surface to 160 m, and an almost constant gradient of 6.3 K/km at higher altitudes.

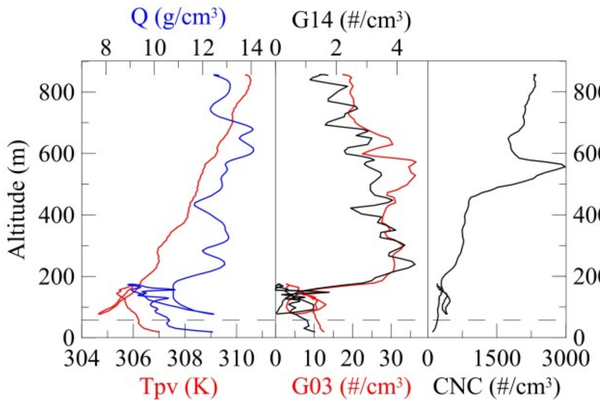

Figure 5. As fig.2, but for the ascent flight on17June afternoon.

The multi-valued structures observed between 80 and 160 m are due to the aircraft altitude changes during the ascent, and reflect the crossing of the sea-land interface. The boundary layer over the sea is characterized by a positive Tpv gradient between 60 and 170 m, while a negative gradient is measured over the land. The differential heating of the lowest layers induced by the sea and land surfaces, at different temperatures, probably play a central role.
The values of G03 and G14 below 160 m were very low, as evidenced comparing the afternoon and morning profiles. The progressive decrease of G03 and G14 with altitude above 250 m, with values of particle number concentration higher than in the morning flight, is also surprising. Also CNC shows very low values below 160 m, an increase from 160 to 450 m, and a nearly constant value of 750 particle/cm^3 between 300 m and 450 m. A pronounced increase of CNC appears at higher altitudes (up to a maximum of 3000 particle/cm^3 at 620 m), in correspondence with a smaller increase (about 15%) of G03. This behavior indicates a possible dominant role of the nucleation mode, and the coexistence of an accumulation mode. This may suggest that the nucleation processes within the air mass have had time

to produce fine particles. It is also interesting the opposite behavior of GR3 and CNC above the 650 m, indicating the possible presence of nucleation processes.

In order to investigate the possible causes for the decrease of aerosol particles in the lowest layer, a back-trajectory analysis was performed with the HYSLIPT model [2].

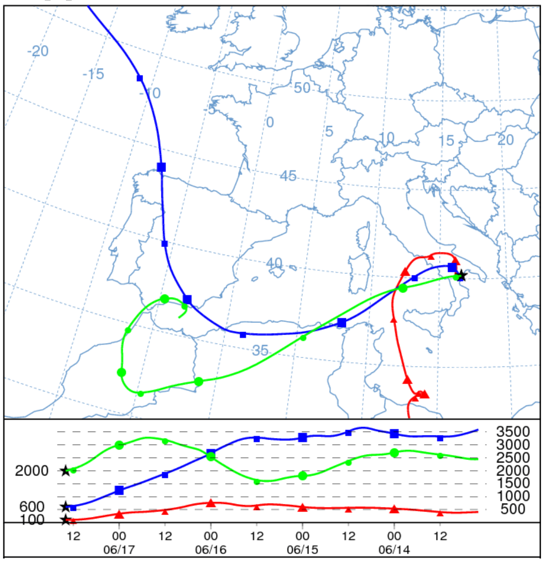

Figure 6. HYSPLIT backward trajectories ending at 100, 600, and 2000 m on17th June at 14 UT.

Back-trajectories ending at Trisaia Center at 14 UT at altitudes of 100, 600 and 2000 m were computed using the NCEP reanalysis data with an horizontal resolution of 2.5 degree and a 6 hour temporal step. Trajectories at different final altitudes show very different origins. The air masses arriving at 600 m originate from an altitude of 3-3.5 km in the North Atlantic, while those arriving at 2000 m from altitudes of 2-2.5 km over Northern Africa.
Due to the complex orography of the coastal region where the MORE campaign took place, the accuracy of back-trajectories based on low resolution meteorological data, especially in proximity of the surface, is limited. Thus, a 24 hour back-trajectory ending at 80 m altitude was calculated using an *ad hoc* module fed by 3D MINNI atmospheric fields, produced with the prognostic, non-hydrostatic Regional Atmospheric Modeling System (RAMS, [3]). For the purpose of the MINNI validation campaign, RAMS was run using 4 nested domains with horizontal resolutions of 48, 12, 4, and 1 km, respectively, and 35 irregularly spaced vertical levels, from 40 m up to about 20000 m. Data were produced at hourly intervals. These 3D atmospheric fields are expected to provide a reasonable description taking into account the orography and time evolution.

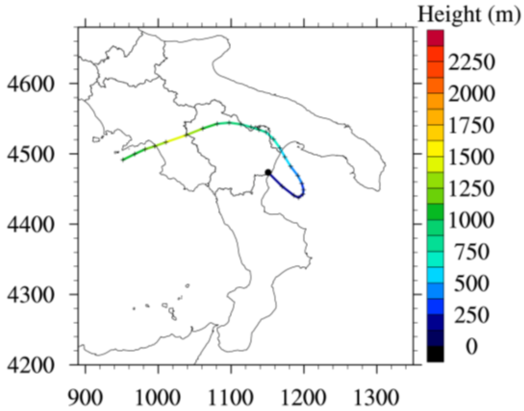

Figure 7. 24 hour back-trajectory ending at 80 m altitude on 17 June at 14 UT calculated using the RAMS model dynamical field.

The trajectory at high resolution shown in Fig. 7 confirms the presence of descending air masses which were at about 1200 m over the Tyrrhenian Sea during the previous day, in agreement with the large scale trajectories shown in fig. 6. The good agreement between the high and low resolution trajectories suggests that the low aerosol concentration observed during 17 June was due to a descending "clean" air masses of mid-tropospheric origin. The relatively low concentration of Q as well as the intrusion of clean air shown by the lidar data (Fig. 1) during the night between 16 and 17 June also support this explanation.

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3. REFERENCE

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