Urban atmospheric stratification and its dynamics : ABL development above the city of Marseille and in the surroundings

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ESCOMPTE 2001 [1,2] is a field experiment that took place in the south-east of France in order to understand chemical transformation and transport of air pollutants and then to improve numerical models devoted to study and forecasting: http://medias.obs-mip.fr/escompte.
In order to build such 3D database, a large set of ground based, onboard and remote data were collected through several measurement techniques. To be used for model validation, such database needs a reliability that can be obtained by checking the data coherence. For this, we had performed a specialized quality control on altitude ozone measurement, including LIDAR, airplanes and radio-sondes instruments, showing a global coherence within an uncertainty below 15%, which fulfils the European guidelines. Such quality control, which was performed on all chemical and physical measurements, had validated the 3D database and thus all extracted data shall be compared. As an application to the ABL characterization, several flights were devoted to the study of Marseille urban boundary layer where Wind angular LIDAR, Ozone and aerosol angular LIDAR, wind RADAR profilers and Constant Volume Balloon had made continuous characterization of the urban and sub-urban boundary layers. Thus, such combined results [5], which give a global overview of the ABL stratification and its dynamic, might also defined some correlations between chemical vertical stratification, especially on ozone and aerosol, and local or global dynamic effects like for example see breeze development.

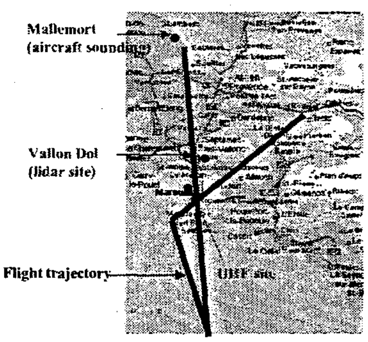

Figure1: trajectory of the Merlin 19 flight

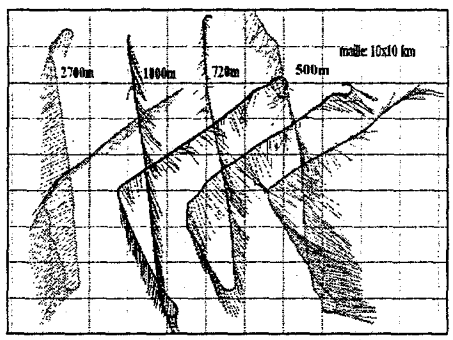

Figure 2: wind vectors along the 4 horizontal legs

ABL dynamic characterization

The "Merlin" aircraft from Meteo-France flew above Marseille at different altitudes in order to obtain a vertical description of the low troposphere. "The Merlin" flight on June 26th, from 9h20 to 12h30 UTC, was divided in first a vertical sounding above Mallemort (40 km, north of Marseille) and then four horizontal legs (2700, 1100, 800 and 500m) along 80 km North-South and 50 km East-West transects over Marseille (figure 1).
The wind speed was strong and easterly at 500m and then turned into a westerly flow at 2700m, which corresponds to sea breeze at low levels and synoptic wind at 2700m (figure 2). This presentation deals with the four North-South legs. The aim is to try to retrieve and analyse the boundary layer topography along a transect that is crossing the coast, south to the city.
Figure 3 shows the water vapour mixing ratio and the potential temperature versus latitude for the four legs, which are spaced vertically according to the height. The highest leg is at 2700m and the lowest at 500m. The aircraft flies over the sea, crosses the Calanques ridge (150m), Marseille town and Etoile mountain (200m under the flight leg). On this graph, we plotted an estimation of the boundary layer height (in red) according to the variation of both potential temperature and humidity mixing ratio.

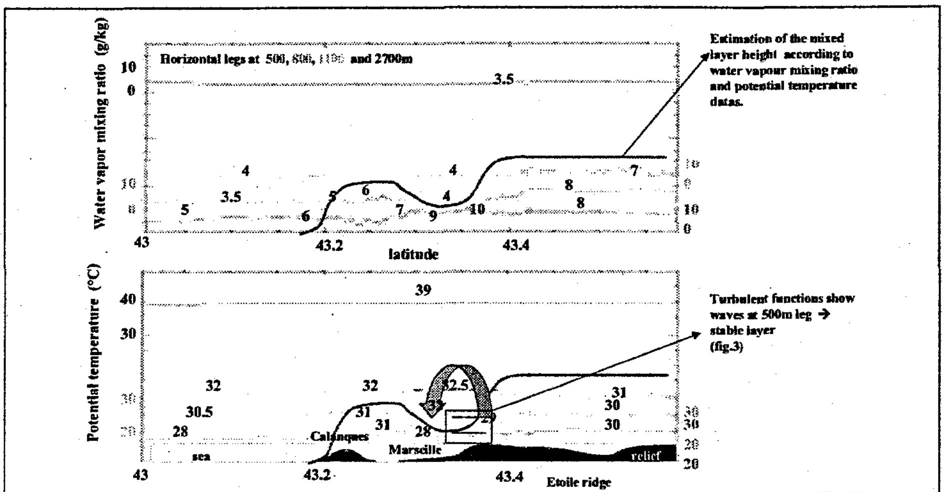

Figure 3: Water vapour mixing ratio and potential temperature versus latitude

We found a sea breeze situation with a stable gradient above the sea between the surface and the free troposphere and unstable above the ground. The height of the ABL increases after the Calanques ridge, mainly due to the relief. Above Marseille, we have lower values of humidity mixing ratio (4g/kg) and higher values of potential temperature (32°C) at the 800m level. So we can estimate the ABL height between the two lowest legs above Marseille. Norther to Marseille, humidity mixing ratio values are high (8g/kg) and potential temperature values low (30°C) at the 1100m legs. So we plotted the height of the ABL over the 1100m leg. It resulted in a boundary layer that is lower above Marseille than above the ground, inland. This height has been confirmed by the Marseille radiosounding information at UTC 12, which indicated 730m. Moreover, the UHF radar data confirm this result (fig 4a.). The boundary layer height that we suppose to be constant north to N 43°4 is consistent with other boundary height measurements at the same distance from the coast such as Avignon (1000m at 10h30 UTC) or Aix-les-Milles (1300m at 12h40).

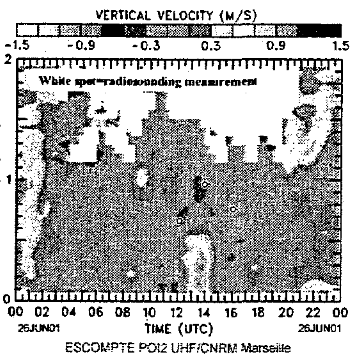

Figure 4a: Vertical velocity, Marseille 26/06/01 (UHF)

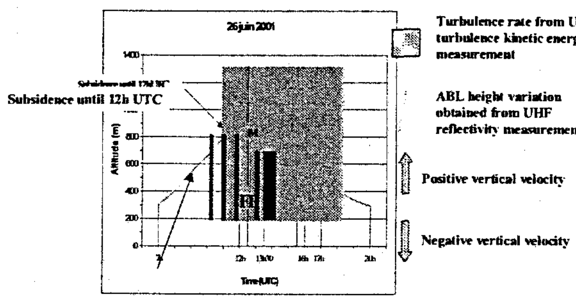

Figure 4b: Turbulence rate, vertical velocity and ABL height in Marseille on June 26th (UHF radar)

Additional information is given by the turbulent functions. We plotted the turbulent functions of the vertical velocity, temperature and humidity (fig.5) for the lowest leg (at 500m). This graph displays some waves above the Etoile ridge, which is quite strange for a flight leg, which is situated in the so-called mixed layer, as indicated in fig.3 where the 500m leg is supposed to be flown in the unstable layer. It's not possible to see waves inside an unstable layer due to turbulence effects. In fact these waves point out a thin stable layer between 500 and 800m. This stable layer seems to be a result of the "Etoile" relief, which generates an ascending flow over the hill colder than the air above. This flow leaps up along the hill and then comes back to the city of Marseille as a return flow, which brings a negative velocity, schematised by pointing down a row on figure3. Later in the afternoon, the differential heating between the hill and downtown vanishes and the UBL climbs up to 1030m agl., as indicated by the UTC 14 h radiosounding in Marseille (figure 4a). Such a capacity to climb up along the mountain is confirmed by the calculation of the Froude number, which was closed to the critical value, as it is show in equation (1).

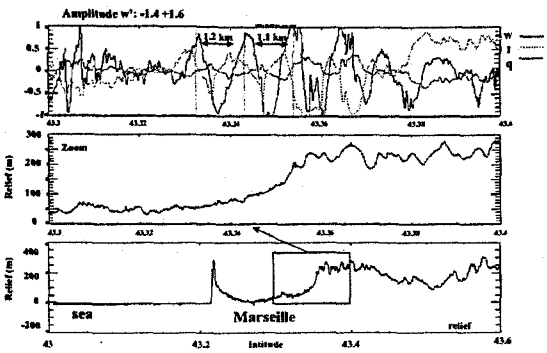

Figure 5: Turbulent functions (W',T',Q') along the south-north leg at 500m : from town to north to Etoile

$$Fr = \frac{\frac{U_o}{N_{BV}}}{H_c} = \frac{U_o}{N_{BV} \cdot H_c}$$

With

$$N_{BV} = \left(-\frac{g}{\rho}\frac{\partial \rho_o}{\partial z} \right) = \left(\frac{g}{\theta_o}\frac{\partial \theta_o}{\partial z} \right)^{1/2}$$

Equation 1

This means that the flow goes over the mountain with a possibility of lee waves formation after the top over-flowing. Finally, whereas the boundary layer development should be more important in an urban area than in a rural area, such description is in our case limited by three different factors such as the sea coast proximity, the return flow above the town due to the slope current and also a mesoscale subsidence which is due to the anticyclonic situation. Last two features are shown in figure 4b, which indicates a descending (blue before UTC 12) and then ascending vertical wind velocity (red between UTC 13 et 15), estimated by the UHF profiler radar, installed in Marseille downtown. This weak height of the boundary layer enhanced the pollution episode because of a less important dilution of the pollutants.

Aerosol vertical stratification within the UBL

Beside this dynamic information, a measurement site in the sub-urban area of Marseille was equipped by 2 angular LIDAR, giving information on the Aerosols spatial distribution, the ozone concentration and the radial wind velocity distribution.

We first obtained the dynamic of the ABL and the angular aerosol load, over several kilometres in North-South direction. Long term angular scan of ozone concentration and atmospheric extinction were made and especially simultaneously to the flights described above.

On this June 26th 2001 (3rd day of IOP 2b) case study, which corresponds to an ozone pollution episode, where the ozone concentration had reached the French public information level, the UV angular lidar provided spatial distribution of the extinction coefficient in order to deduce the development of the ABL in the sub-urban region of Marseille. This lidar was located at Vallon Dol (43.36° N, 5.4° E), 285 m ASL, 5 km from the coast and also about 5 km from Marseille downtown. Extinction measurements were carried out using the off wavelength of the ozone DIAL angular lidar (λ=286.3 nm). These measurements were obtained from several vertical cross section of the atmosphere (angular scan from horizon to zenith in south and north directions) along a North-South axis and an approximately range of 1500m.

Figure 6 represents the temporal evolution of the extinction versus altitude, up to 1800 m (ASL) between 8h00 and 20h00 (UTC). For each lidar beam, the extinction is computed using the slope method. This figure is obtained by vertical projection of angular scans with a 01h00 temporal integration and a 100 m spatial integration. Such representation of the temporal evolution of the atmospheric extinction vertical profile, allows the characterization of the stratification and the dynamics of the ABL, generally recognized by the contrast of the aerosol load between low and high altitude lowers. The height of the ABL, which is at 750m at 11h00 UTC, rises up to 1000m at 13h00 UTC and then stabilizes at 950m at 14h00 UTC. At the end of the see breeze development (17h00 UTC), the 950m layer decreases down to 750 m and then comes back to its morning height. The transition between the different layers, can also be obtained directly and more precisely by the lidar signals, avoiding any interpolation. Figure 7a shows the precise height evolution of the ABL obtained from the log scale of the range corrected lidar signal and thus each point indicates first the top height ABL position from 11h00 to 17h00 (UTC) and then the setting of a layer between 17h00 and 20h00 (UTC). It is then possible to indicate more precisely the transition from a 750m-altitude layer at 11h00 (UTC) to a 950m-altitude layer at 14h00 (UTC). This rising is probably related to the descending and ascending vertical velocity estimated by the UHF radar profiler (figure 4b). The angular vertical cross section (figure 7b) carried out at about 11h00 (UTC), shows the presence of an homogeneous layer characterized by high extinction coefficients (closed to 2 km^{-1}), characteristic of a strong load in aerosols.

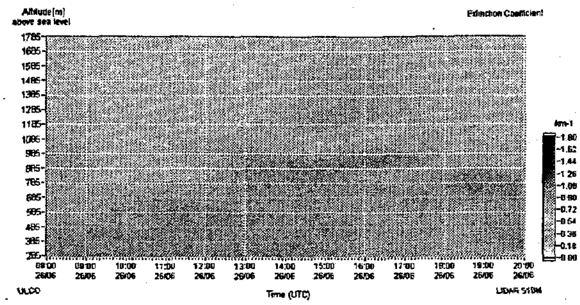

Figure 6 : Extinction measured with the Lidar UV at Vallon Dol on 26th june 2001 (IOP 2b)

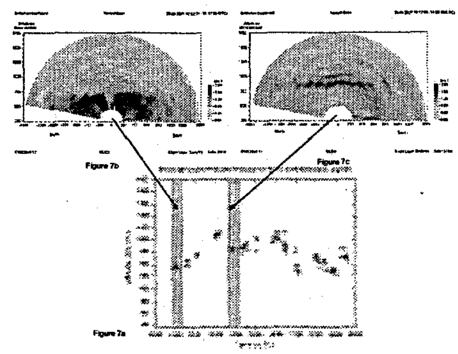

Figure 7 : lidar angular prfofiles of the atmospheric extinction showing ABL stratification

After the rising of the ABL, mainly when convection processes take place, the aerosols load is definitely lower due to dilution processes (about 1.2 km^{-1}) but still increases at the top of the ABL (about 950m) as shown on figure 7c. Such aerosol load at the top of the ABL and thus in the see breeze development layer, might correspond to a transport effect of maritime aerosols. In order to confirm this hypothesis and then be able to quantify the see breeze effect, dynamically but also in the atmospheric aerosol load, it is then important to evaluate the vertical profile of the size distribution.

Vertical distribution of the aerosol size distribution as ABL parameter

As it is difficult to use onboard instruments due to the fast ABL rising processes, remote sensing technique might be an alternative method. But, as remote sensing instrument is of common use for gaseous pollutants, it is still under development regarding aerosols characterization and especially for concentration and size distribution evaluation. In particular, UV and IR lidar profiles obtained during the ESCOMPTE campaign with temporal and spatial correlation (co localized in the same measurement site), had shown different atmospheric stratification.
As it is well known, beside molecular absorption, all aerosols and molecules along the beam affect UV lidar signal; Oppositely, mid-IR lidar signal is affected by coarse particles.
Using the spectral dependency of the aerosol scattering, one can then obtained the response on coarse or fine particles by selecting the lidar wavelength. As it was seen above, ozone lidar profiles were made in the UV range. In the same measurement site, the radial wind was also evaluated simultaneously using the Wind angular Doppler lidar, which works in the IR region. Using lidar signals in the UV range (off ozone dial wavelength) and in the IR range (10.2µm Doppler lidar wavelength), we will then try to obtain the 2 principles modes of the aerosol size distribution. To achieve such result, beside lidar profiles in the UV and IR regions, we will also use first a new lidar algorithm based on fractal, Mie and Rayleigh theory, a non-linear Kernel procedure and finally, as we need to reduce the uncertainty associated to this result, we will use physical parameters like the aerosol index, pressure and humidity instead of the common fit parameters usually employed. We finally expect to retrieve the vertical profile of the size distribution dynamic, which might characterize the transport effect of maritime aerosol under sea breeze development.

References

1. Cros B et al, 2002 : « ESCOMPTE program : an overview ». accepted in Atmos. Res.
2. Cros B et al, 2002 : « The ESCOMPTE experiment. », AMS, Norfolk,USA
3. Saïd F et al 2002 : « Vertical Structure of the Polluted Low Troposphere », XXVII EGS, France
4. Puygrenier et al, 2002 : « Comparison of Urban and Rural Atmospheric Boundary Layers During Sea Breezes ». 7th Conférence IGAC, Créte, Gréce
5. A. Thomasson et al, 2002 : « LIDAR mapping of ozone-episode dynamics in Paris and intercomparison with spot analyzers », App. Phys. B 74 pp 453.