3.5 STRATIFICATION OF THE LOWER TROPOSPHERE DURING THE ESCOMPTE CAMPAIGN

Clotilde Moppert, Frédérique Saïd*, Aurore Brut, Vincent Puygrenier, Bernard Campistron, Bruno Benech, Fabienne Lohou and Frederic Cousin.

Laboratoire d'Aérologie, UMR CNRS 5560, Université Paul Sabatier, Toulouse, France

1. INTRODUCTION

Implementation of adapted air quality policies and prediction of pollution events require the improvement of our understanding of combined chemical and dynamical processes which lead to high pollutants concentration in the atmospheric boundary layer. The ESCOMPTE program (Cros et al., 2004) was devoted to establish a detailed 3-D database of primary pollutant emissions together with the dynamics and chemical composition of the atmosphere in order to validate and improve chemistry transport models. The ESCOMPTE experiment took place in the early summer of 2001, in the south-eastern part of France where the combination of high urbanization and industrialization with hot and sunny weather enhances photochemical pollution events. Due to the complex terrain of this region (both coastal and moderately mountainous area, channeling effects of the Rhône and Durance valleys,…) (fig. 1), a preliminary effort is necessary to study the atmospheric dynamics in this heterogeneous region in relation with larger scales processes. The main objectives of this paper is to present the vertical structure of the ESCOMPTE area during different meteorological conditions of the second intensive observation period (IOP2) which lasted from June 22 to June 26.

A wide experimental set-up was used over the ESCOMPTE area. It involved turbulence measurements from 2 French aircraft equipped by INSU and Météo-France (Fokker 27 ARAT and Merlin IV) and 1 German aircraft instrumented by IMK (Dornier). A profiler network (Campistron et al., 2004) of UHF radars implemented between Marseille, Saint Chamas, Aix and Marignane provided 3-D fields of horizontal wind components, the mesoscale vertical velocity and the reflectivity which provides us information about the boundary layer height z_i. In addition, radio-soundings performed by IMK and CNRM in Aix, Vinon, Saint Rémy and Marseille were also used to explain the structure of the lower troposphere.

*corresponding author address: Frédérique Saïd, Centre de Recherches Atmosphériques, 8 route de Lannemezan, 65300 Campistrous, France;
e-mail: saif@aero.obs-mip.fr

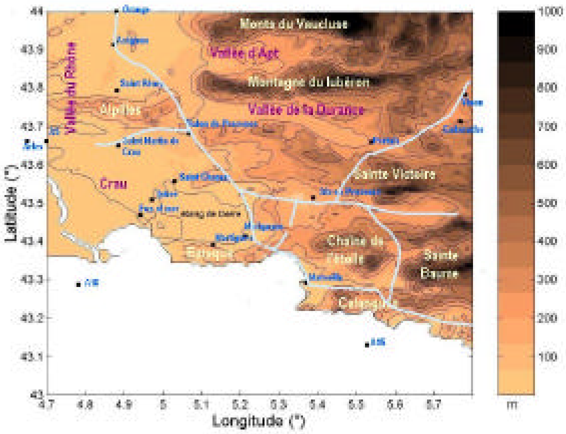

Fig. 1 : Map of the ESCOMPTE area : City names are written in blue, mountains chains are in yellow and the valleys and plains are in magenta. Clear blue lines correspond to the main roads and highways.

2. DESCRIPTION OF THE SECOND IOP

The second IOP of the ESCOMPTE experiment is divided in 2 parts : during IOP 2a (from June 22 to June 23), the Mistral (Guenard et al., 2004) which is a strong northerly low-level, orography-induced wind prevailed whereas IOP 2b (from June 24 to 26) corresponded to sea breeze conditions (Puygrenier et al., 2004).

Fields of potential temperature, specific humidity and horizontal wind over the ESCOMPTE region allow us to characterize the thermodynamic features of these 5 days three times per day. These fields are derived from measurements performed onboard aircraft at 1Hz frequency rate during "exploration" flights. These flights consisted in describing 4 parallel horizontal axes from the Apt valley to Marseille gulf at the constant level of 800 meters a.s.l. Then, data were processed through a kriging algorithm that retrieves the horizontal field accounting for the region heterogeneity.

The comparative study of potential temperature, specific humidity and wind fields allows us to highlight the following features for the 5 days :

- during the first period (IOP 2a), the wind blows from North-West in the whole area and its magnitude reaches 10 to 14 m/s in the central zone. The wind is decelerated above the eastern mountains (6-8m/s). It starts decreasing in the early afternoon of June 23 : the mean wind is about 7-8m/s from the Luberon mountains to Marseille but it is weaker in the Crau plain (3-6m/s) and above the eastern chains (4-5m/s). Since the Mistral wind brings dry and cold air from the Alps, we observe the coolest potential temperatures during POI 2a associated with low specific humidity. The potential temperature field does not show any tendency in the morning with values from 25°C to 29°C on June 22 and from 30°C to 32°C on June 23. As day goes by, temperatures increase and a gradient appears at 11H UTC with lower temperatures in the western plains. This gradient is stronger on June 23. There is no tendency observed on the specific humidity field : on June 22, mean values vary from 4-6g/kg at 5H UTC to 6-7g/kg at 11H UTC. The field obtained at 5H UTC on June 23 is more heterogeneous with very dry air in the central area (1g/kg). At 11H UTC and 14H UTC, air masses over the ESCOMPTE region are drier than the day before (4-6g/kg).

- Wind direction is still from Northwest at the beginning of IOP2b but its magnitude is weaker (2-5m/s). At 11H UTC, it turns to West and a channeling effect appears along the Durance valley. On June 25, the wind field is very heterogeneous in the morning. An easterly wind blows in the northern part whereas a sea-breeze is observed in the coastal region. At 11H UTC, the sea-breeze invades the whole region. Wind magnitudes are very weak all day long (1-3.5m/s). The wind speed is still low during June 26 (2-4m/s) and the direction is southeasterly. For these 3 days, a potential temperature gradient is observed from West to East, with values rather constant during the day and higher than those of IOP2a. The fundamental difference between the two IOPs appears on the specific humidity fields : no particular organization is found but wetter air masses (9-11g/kg) bring water vapor over the continent in IOP2b.

In conclusion, situations of both intensive observation periods are quite different : during IOP2a, northerly strong wind (Mistral) brings dry and cold air masses, probably enhancing pollution dilution over the region, contrary to IOP2b.

3. BOUNDARY LAYER DEVELOPMENT

The atmospheric boundary layer height is determined using radio-soundings, aircraft soundings and processing of reflectivity from the profilers network. On fig 2 is shown an example of the radio-soundings performed at Saint Remy on June 22. This high frequency of soundings (4 per day) in Saint Remy (and Vinon as well), completed by the UHF radar continuous measurements allow us to analyze the temporal variability of the boundary layer (BL) vertical structure. The overall results concerning its development are summed up in fig. 3 for June 22 and 23 (IOP 2a) and only June 26 to characterize IOP 2b.

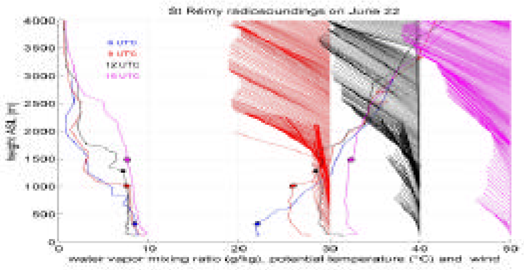

Fig. 2: *radiosoundings performed at Saint Remy on June 22 at 6H UTC (blue), 9H UTC (red), 12H UTC (black) and 15H UTC (magenta).*

The first feature that one can notice is that the boundary layer height z_i is generally higher over all sites during IOP2a than during IOP2b. In addition, another striking feature is the well-marked development of the boundary layer at the entrance of the Durance Valley : in Vinon, z_i usually rises at least up to 1500m at 12H whereas, at the same time, it reaches 1000m in average at the other places.

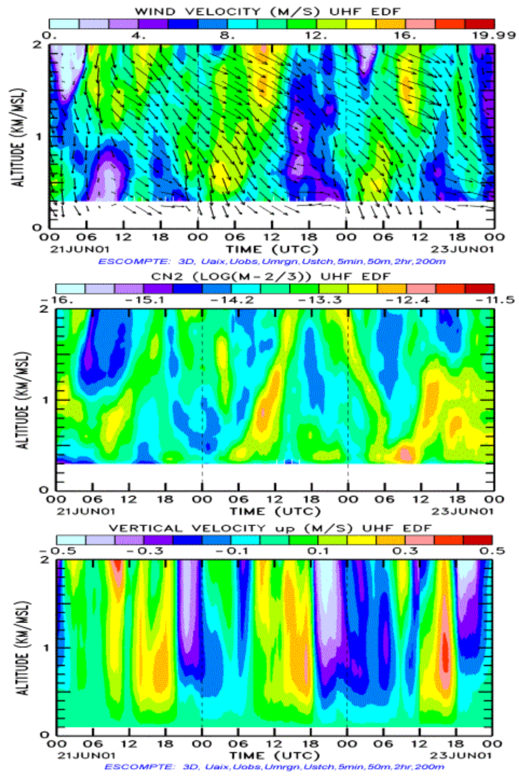

Fig. 4: *height-time sections of the horizontal wind (speed and direction), the structure coefficient C_N^2 from reflectivity and the vertical velocity obtained using the profilers network between 01/06/21 and 01/06/23.*

If we accurately examine the spatial and temporal variability of the vertical structure during IOP2a, we can notice that for similar conditions

(Mistral events), the atmospheric boundary layer does not behave identically on June 22 and on June 23.

Fig. 3 shows that the boundary layer development is rather fast like in usual convective boundary layers. In the morning, it grows up to 1250 –1500m in the West part (Saint Rémy) and slightly decreases in the afternoon. This behavior is related to both the dynamical turbulence generated by the strong wind and the latent heat fluxes due to high humidity gradients between the surface and the air. Although atmospheric conditions are very similar to those of June 22, the development of the boundary layer is rather different on June 23 : z_i only reaches 500-600m around noon at Saint Remy and it keeps rising in the afternoon near the coast (Saint Chamas). In the eastern part, the boundary layer height rises higher than in the West. This difference between these two days can be observed on the height-time section from the profilers network (fig. 4): the boundary layer rises less and later during the second day of IOP2a. In addition, the vertical velocity which is retrieved from the horizontal wind divergence and corresponds to the mesoscale vertical motions, indicates that the boundary layer moves upwards from 6H to 13H UTC on June 22 whereas a general downward motion is observed on June 23. Fig. 4 also highlights a diurnal cycle of the Mistral wind with positive vertical velocities in the deep boundary layer from 8H to 12H, then again, from 14H to 18H UTC. On the contrary, vertical velocities are negative from 18H to 6H UTC. Variations from this cycle induce substantial consequences for the atmospheric boundary layer as noticed on June 23.

Concerning IOP2b, we restrict our abstract to the description of June 26 since this day is rather representative of the period. Since the synoptic flow is weak, the sea-breeze can be properly established. So, the boundary layer heights are lower in the coastal region than in the northern part (typically 650 to 800m in the South and 1000-1100m in the North) due to the cooling effect of the sea-breeze in the lower layer which limits the convection. In addition, in the northern region except in Vinon, the boundary layer also decreases rapidly in the afternoon.

4. VERTICAL STRUCTURE OF THE LOW TROPOSPHERE

The aim of this section is to determine possible transfers between the atmospheric boundary layer and the capping stable layers. We used profiles of ozone concentration which revealed to be a good tracer to evaluate the various staggered layers of the low troposphere as can be seen in fig. 5. This example shows the vertical stratification of ozone on June 24. Three superimposed layers are displayed : the residual layer (from June 23) or boundary layer at low level, capping between 800m and 1100m, an intermediate layer between the latter and 1800m, and finally the upper layer between 2000-2800m. Ozone concentration is highly varying at low level with an increase in the morning and a decrease after 13 UTC in the range 50-75 ppb. The intermediate layer is very steady all the day long with about 55 ppb of O_3.

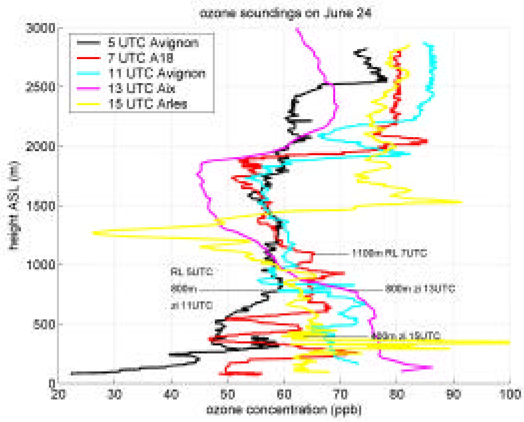

Fig. 5: *Ozone profiles from various soundings during June 24 over the ESCOMPTE area. RL means residual layer.*

The upper part displays a diurnal cycle in the ozone concentration which indicates that the corresponding air mass is not an old one and carries chemically active pollution from another area in contact with surface sources (NO and NO2 are however constant between 1000 and 2800m, with respective values of 0.05 and 0.4 ppb). Backwards trajectories calculated with the Meso-nh non hydrostatic model (Cousin et al, 2004) correctly describe the displacement of the two upper air masses. They are shown on Fig. 6 as a characteristic example for June 24. The final point is Avignon and points are 1h-spaced.

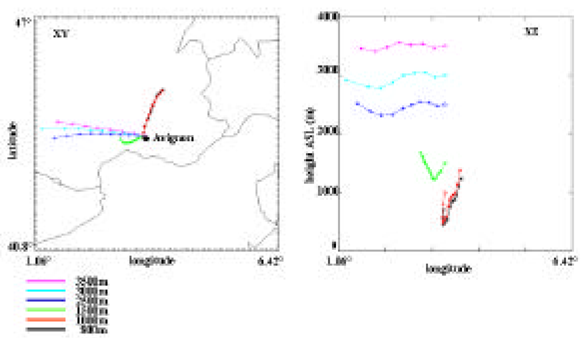

Fig. 6 : *back trajectories at various level in horizontal view (left) and vertical view (right) for June 24. The particle arrived in Avignon and points correspond to every hour position.*

Cross-information from both horizontal view (XY) and vertical view (XZ) indicate that the polluted upper layer comes from the West of Avignon whereas the intermediate layer comes from the North. The former keeps a constant level during the 9 previous hours and is probably fed by higher boundary layers than those of the ESCOMPTE area (higher ozone level). The latter crossed the Alps mountains, which explains both the variability of vertical velocity (the air mass moves downwards and then upwards) and the low ozone concentration (less polluted area).

Our concern is to know whether these two staggered layers are likely to mix with the BL over the ESCOMPTE area. The answer is that the mixing effect is rather weak, in the western part of the domain : in Avignon, the residual layer and BL top reach 800m only at 5H and 11H UTC. Zi is 1100m at 12h in Saint Remy which is close to Avignon. So we can expect that an increase of 300m in the BL development over the Avignon area in a short time interval would induce a mixing between the boundary and the intermediate layer. In Aix, the BL development at 13H UTC is not sufficient (800m) to reach the intermediate layer. Over the sea, the residual layer top is 1100m. Due to the Mistral flow of June 23, this value is characteristic of the BL heights along the coast (St Chamas for instance). But the sea-breeze starts invading the area near the coast on June 24 and the BL will keep low levels (700m in Saint Chamas) at 12H UTC and 550 at 15H UTC.

No ozone sounding is available for the eastern part of the domain where BL heights are higher (1100 m in Vinon at 12 and 15 UTC). There again, a mixing probably occurs between the BL and intermediate layer, leading to a decrease of the ozone concentration in the BL.

The upper layer (free troposphere) never mixes with the BL on this day, whereas it could, on other days such as June 25 or 26 when zi reach such large values as 1900 or 2500m. This study has to be continued.

5. CONCLUSION

This study is a comparison of the atmospheric boundary layer behavior under two main types of conditions : IOP2a corresponds to a Mistral event with dry and rather cold air masses and strong northerly winds whereas IOP2b is representative of sea-breeze conditions with low southerly winds that bring humidity and heat over the continent. The conditions encountered during IOP2a may increase pollution dilution since the boundary layer depth is important and transport is increased by turbulence. Questions are raised on June 23 as the boundary layer seems to have difficulties to develop. In this case, boundary layer development is driven by mesoscale conditions instead of local conditions. This situation may considerably change the conditions of pollution as it will be highlighted in a companion paper (Brut et al., 2004). On June 26, the sea-breeze penetrates far away inland : aircraft measurements show that it reaches the Durance Valley. In this case, due to the weak rising of the boundary layer, we expect that pollutants are accumulated over urban and industrialized areas. This will be further studied in the companion paper.

A specific case is the behavior of the boundary layer at the entrance of the Durance valley : in Vinon, radiosoundings show that the boundary layer is always deep whatever the wind conditions and its development corresponds to an increase in the morning and in early afternoon. Its decrease starts earlier during Mistral events.

Finally we showed that there may be interactions between the BL over the ESCOMPTE domain and the intermediate layer capping the BL : however, with the exception of the Durance valley, this mixing is not frequent due to the weak development of BL.

6. BIBLIOGRAPHY

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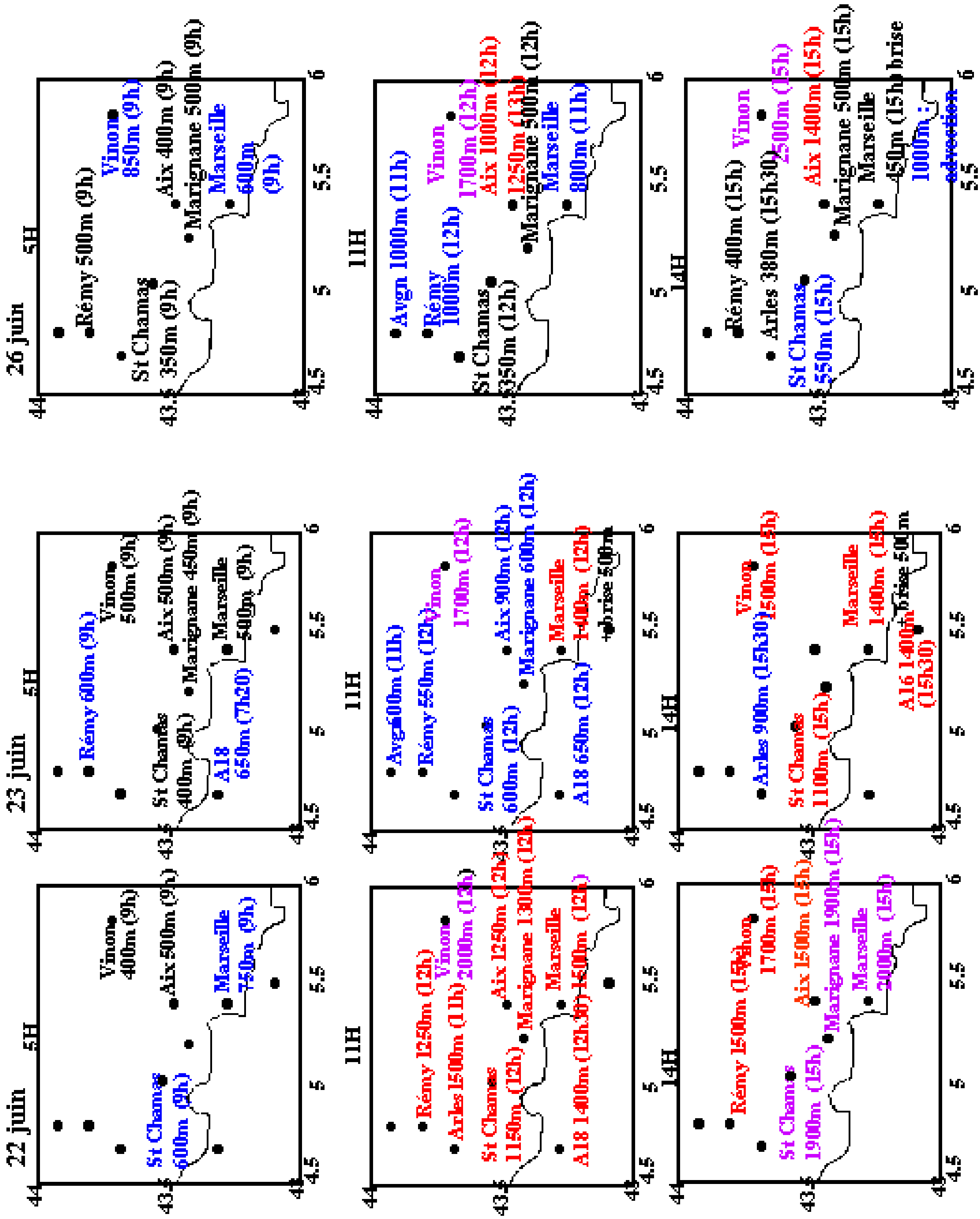

Fig. 3 : *spatial and temporal variations of the boundary layer height during 3 days of IOP2 : Two Mistral events (06/22/01 and 06/23/01) and a sea-breeze event (06/26/01). Black color corresponds to z_i < 500m, blue is for 500< z_i < 1000, red is for 1000< z_i <1500 and pink for 1500< z_i< 2000.*