Some Characteristics of the Convective Layer

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Abstract

In order to study the planetary boundary layer during dry convective situation, three field experiments were conducted in France. Simultaneous measurements were made using a tethered balloon, an instrumented aircraft and a Doppler sodar. In this study, typical acoustic facsimile records of convective activity and some characteristics of the convective layer are presented.

I. Introduction

This paper presents some of the results of recent experimental studies conducted in 1973, 1974 and 1975 by two French agencies, the Météorologie and the Centre National d'Etudes des Télécommunications. Our aim was to study the lower atmosphere during dry convective situation using a tethered balloon, an instrumented aircraft and a Doppler sodar.

The acoustic sounder used for these experiments was operating in a monostatic mode, transmitting a pulse of sound upward and then receiving the energy which is reflected from small scale temperature fluctuations. The Doppler shift between the frequency of the transmitted signal and the frequency of the reflected signal is a measurement of the radial velocity of the air in the reflecting volume. So, if three Doppler sodars are used together, it is possible to measure three components of wind simultaneously and hence the total wind vector.

II. Description of the experiments

The experiments took place in France over three different sites relatively flat and homogeneous.

The locations of the various instruments, in 1974, are shown in Figure 1. Sodars one, two and three are combined in a three axis acoustic sounder with two tilted antennas and Doppler receivers. The IOPG sodar is independently vertically oriented. The areas seen by the sodars at the altitude of 300 m have been shaded on the figure. In this study, only facsimile records from sodar 3, vertically oriented, are presented. The CNET sodar is described by Aubry et al. (1974). The parameters used during our field experiments are given in table 1. In 1975, the arrangement of these instruments was the same. In 1973, we used no sodar.

Table 1

Frequency	1200 or 2000 Hz
Pulse length	100 or 200 ms
Pulse repetition	period2 or 4 s
Peak power	250 W
Beam width	16° at 1200 Hz 8° at 2000 Hz

Table 2

Parameter	Captor	Accuracy
Temperature	Thermistance Ten mil rod	± 2%
Humidity	Hygristor US ML 473	± 5%
Pressure	Aneroid cell US Bendix	± 0.3 mb
Wind	Cup anemometer	± 0.5 m/s ± 3°

The tethered balloon was instrumented with a radiosonde package developed by the Etablissement d'Etudes et de Recherches Météorologiques. This system allows continuous recording of temperature, humidity, pressure, wind speed and wind direction (Heissat et Gerbier 1973). The sensors capabilities are summarized in Table 2.

In addition, the aeroplane of the Institut National d'Astronomie et de Géophysique was used to make soundings of

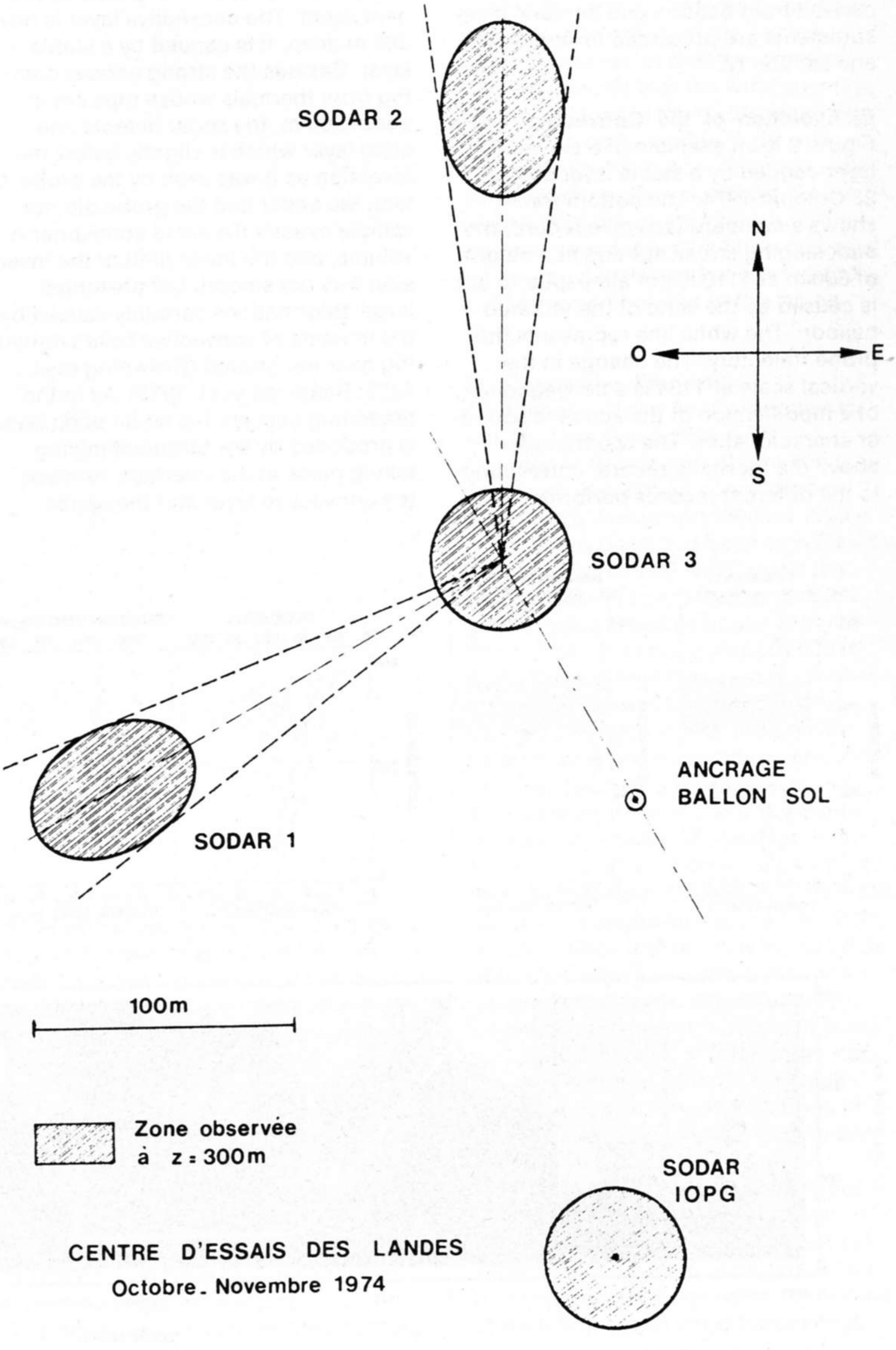


Figure 1. Locations of the sodars and the tethered balloon during the field experiment taking place in the «Centre d'Essais des Landes» in 1974. The shaded areas are the areas seen by the sodars at the altitude of 300 m. Facsimile records from sodar 3 pointed vertically are shown in this study.

the atmosphere both vertically and horizontally. It is an Aerocommander instrumented in a classical way: a Rosemund temperature probe as a far sensor for temperature, Cambridge dew point system, carbon plate and Ly_α for humidity, and normal pitot tubes. The vertical velocity of the air was obtained from an inertial navigation system and from attitude angle vanes. Finally, in addition to the tethered balloon and the plane measurements many free radiosoundings and pilot balloon soundings were performed.

The data obtained during these three field experiments are typical of dry convection in undisturbed conditions. They can be divided in two main sets. The first set describes the evolution of a convective layer capped by a stable layer. The second set describes convective cells. Typical sodar records for these situations and some of the results derived from balloon and airplane measurements are presented in section III and section IV.

III. Evolution of the Convective Layer

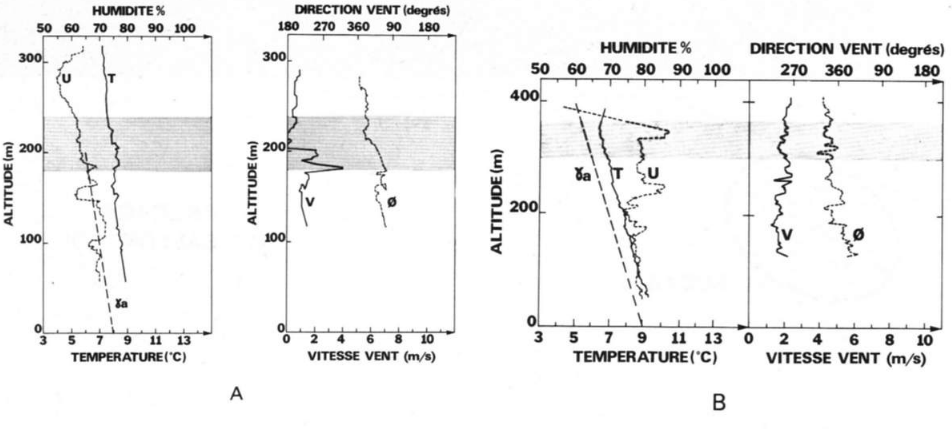
Figure 2 is an example of a convective layer capped by a stable layer on 23 October 1974. The bottom frame shows a standard facsimile record; the dark sloping streak starting at a height of 300 m at 1110 is not atmospheric but is caused by the echo of the tethered balloon. The white line represents the probe trajectory. The change in the vertical scale at 1134 is a consequence of a modification of the acoustic sounder characteristics. The two frames, above the facsimile record, correspond to the different records performed during the descent and the ascent of the probe. The A frame corresponds to the first descent. It shows the corresponding profiles for temperature (T), humidity (U), wind speed (V) and wind direction (Φ). The grey area is the area of strong echo at the time the sounding took place. This echo layer, detected by the sodar, is associated with the top of the convective layer which is marked by a thermally active region and a strong wind shear. The echo layer is related to small scale temperature fluctuations produced by the turbulent mixing between the convective air and the upper stable air (Estival et al. 1976).

Under 150 m the facsimile record shows strong echoes, vertically oriented. These echoes come from convective cells; they are produced by small scale temperature fluctuations generated along the entrainment surfaces of the cells. The B frame corresponds to the next acent. The convective layer is now 360 m deep; it is capped by a stable layer. Besides the strong echoes coming from thermals whose tops are at about 300 m, the sodar detects one echo layer which is slightly below the inversion as it was seen by the probe. In fact, the sodar and the probe did not sample exactly the same atmospheric volume, and the lower limit of the inversion was not smooth but presented large deformations certainly caused by the impacts of convective cells originating near the ground (Browning et al. 1973; Readings et al. 1973). As in the preceding descent the sodar echo layer is produced by the turbulent mixing taking place at the interface between the convective layer and the upper stable layer. This example shows that the sodar continuously monitors the height of the convective layer which is an important parameter to caracterize convective situation. If we want to get information about the average properties of the convective layer, such as the turbulent heat flux, it is necessary to have detailed in situ measurements at the same moment.

The temperature, wind speed and heat flux profiles on 13 August 1973 are shown in figure 3. The vertical profiles of temperature and wind speed, obtained from the balloon, were performed during a descent beginning at 0836 and the next ascent beginning at 1002. In the convective layer, the temperature decreases as the dry adiabatic line. During the descent, the temperature inversion is at 400 m, during the next ascent it is at 500 m. By comparing the two soundings between 400 m and 500 m, we see that the convection has a cooling effect at the top of the convective field. This cooling effect is a consequence of the entrainment of warm air in the cooler boundary layer (when considering potential temperature). In the convective layer, the wind speed is equal to 5 m/s; in the upper stable layer, it is equal to 8 m/s. The dashed line, on the right of figure 3, represents the vertical profile of the turbulent heat flux derived from the evolution of the potential temperature in the mixed layer. The equation describing the conservation of heat was used assuming the average heat flux was zero at 500 m (Lenshow et al. 1968). The heat flux was obtained from:

$$H = [p\ Cp/\Delta t] \int_{Z}^{500} \Delta\Theta dz$$

where $\Delta\Theta$ is the change of potential temperature in the time interval Δt. In such an analysis it is necessary to assume that there is no heat flux due to horizontal temperature gradients or heat flux from radiation. We note an approximatively linear decrease in flux



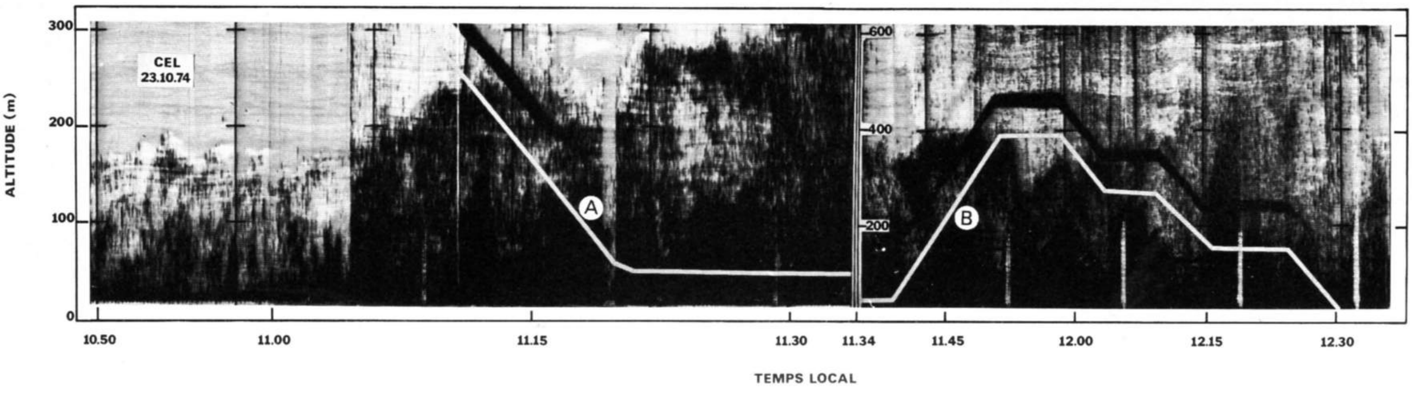


Figure 2. Acoustic sounder record (bottom) compared with tethered balloon measurements made at the same moment (top). The probe trajectory is represented by the white line. On the profiles, the dashed aerea correspond to the echo layer detected by the sodar.

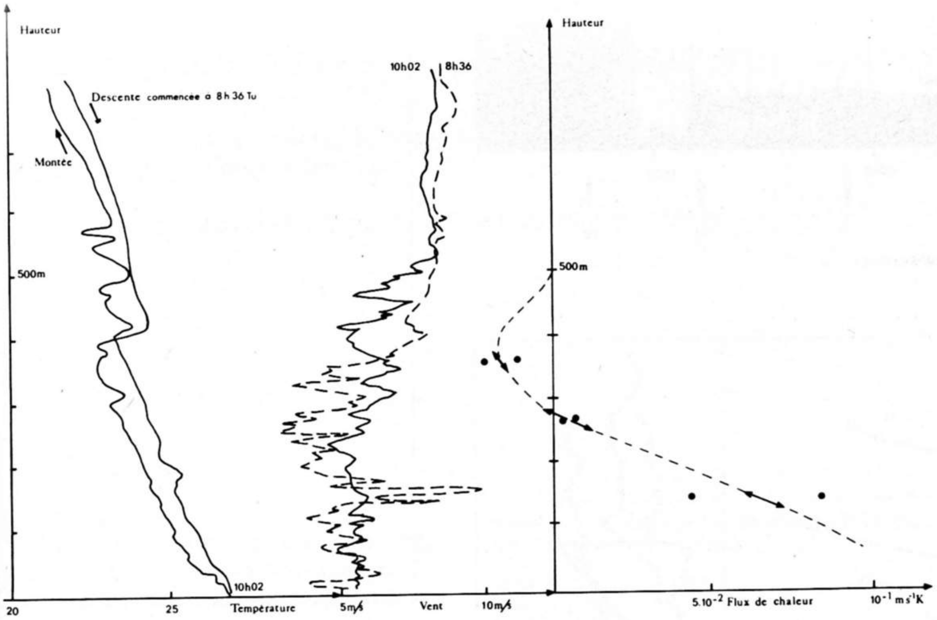


Figure 3. Temperature and wind speed profiles obtained from the tethered balloon on 13 August 1973 (left); heat flux profile (right).

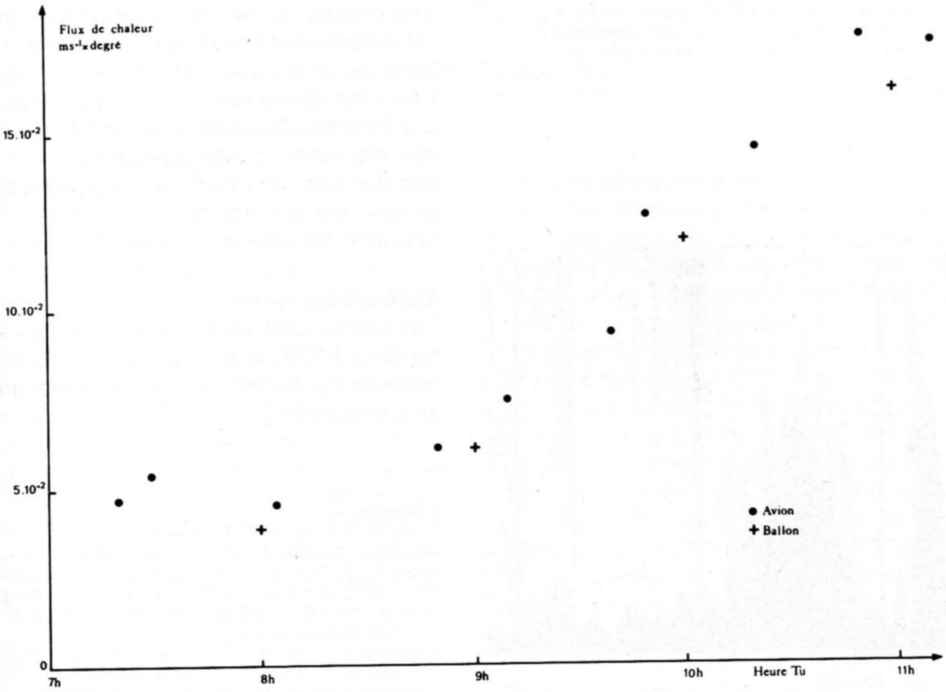


Figure 4. The turbulent heat flux close to the ground as a function of time.

with height. There is a slight negative heat flux at the top of the convective layer. This negative flux corresponds to the entrainment of the upper stable air in the convective air. Close to the ground, the heat flux is equal to 0.13 m s^{-1} K, that is about 10% of the solar constant. The points correspond to the turbulent heat flux obtained from airplane. At a given height, the heat flux is the correlation of the turbulent fluctuations of potential temperature and the turbulent fluctuations of vertical velocity. This day, the plane made two horizontal soundings at the same altitude but at two different times, so we have two values for the flux. The results derived from the plane show fair agreement with those derived from the balloon.

Figure 4 represents the variation of the heat flux close to the ground as a function of time for several days when undisturbed anticyclonic conditions prevailed. The crosses correspond to the heat flux obtained from the balloon. The circle correspond to the heat flux obtained from the aeroplane, for the same days. The heat flux increases as time progresses consistent with an increase in the incoming solar radiation expected during this period. The heat fluxes derived from balloon and aeroplane show fair agreement.

The morning evolution of the structure and the dynamic of the lower atmosphere on 10 Juni 1975 is illustrated by figure 5. The upper part of this figure shows the facsimile record. Until 0740 the sodar detects a strong echo layer between the gound and 200 m; this echo layer comes from the radiation inversion. After 0740, the inversion base is destroyed by the convective activity. Besides the thermals the sodar detects an echo layer of variable altitude whose average level rises. This echo layer comes from the top of the convective layer. After 0945 the sodar detects only thermals. The lower part of figure 5 shows the vertical profiles of the wind speed and the wind direction as measured by the three axis sodar, at various times. Each profile is an average of the wind on 7 minutes. The left frame corresponds to the wind speed. The different profiles are labelled with roman figures. Those figures are associated with those printed on arrows at the bottom of the facsimile. We note that the vertical wind shear decreases as time progresses. Profile IV shows that the wind speed is nearly constant in the mixed layer. The right frame corresponds to the wind direction. Profile I shows that the wind direction changes with height. So we can say that the morning evolution of the lower atmosphere is characterized by the equalization of the wind speed and the wind direction in the mixed layer.

IV. Convective Plumes

Another aim of our field experiments was to study convective cells.

The record displayed in figure 6 is typical of well-developed convection on 4 Juni 1975. Between 1150 and 1300 a group of thermals has been advected by the mean horizontal wind above the vertical antenna of the sodar. At 1202 we can see a well-developed thermal. The top of the echoes is about 500 m high. The fact that there are no echoes above 500 m does not mean that the thermal is limited to that altitude. In fact, above a few hundred meters, temperature fluctuations become much smaller than close to the ground and the related echoes may well be undetected. At 1157 we observe a one piece thermal; between 1233 and 1237 we can observe a composite thermal. At 1227 we can notice that the downwind edge of the thermal is less sharp than the upwind edge. The sodar echoes are weaker on the downwind side; it is an indication of smaller temperature fluctuations at this location. This result agrees with airborne observations of thermal structure as described by Lenshow in 1970.

The vertical velocity of the air in thermals was measured the aeroplane. Figure 7 shows the maximum vertical velocity as a function of height. To be more specific, it is the mean of maxima at each flight level, for different days

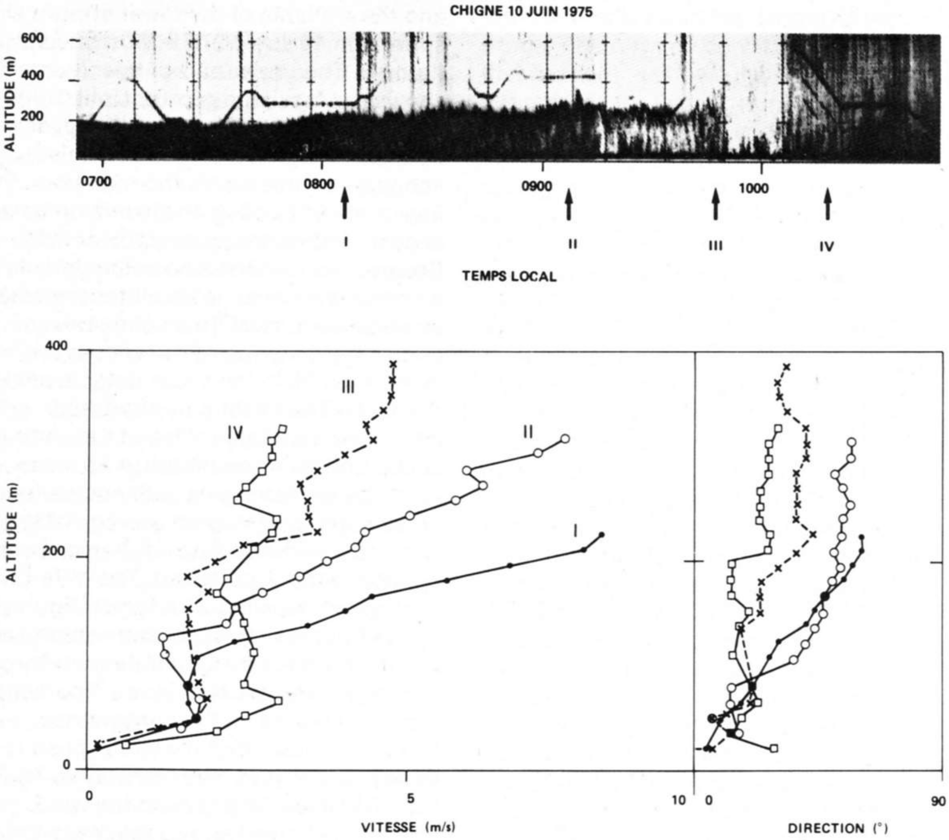


Figure 5. Sodar record (top) compared with wind profiles (bottom) measured by Doppler sodar techniques.

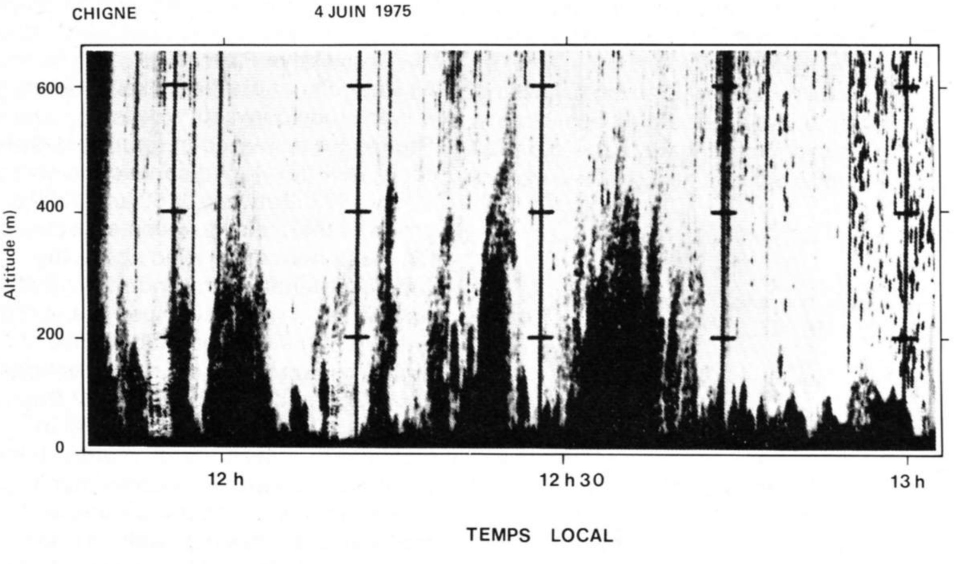


Figure 6. A typical facsimile record of thermal plume structure on 4 June 1975.

typical of well-developed convection. The maximum vertical velocity is non-dimentionalized by the convective velocity defined by Deardorff in 1970; the altitude is non-dimentionalized by the height of the convective layer. W_{max} is the mean velocity of the thermals crossed by the plane.

We can see that the velocity of ascending columns is maximum, about z/h equal to 0.3; we have W_{max} / W. equal to 1.8. It is likely that this coefficient of proportionality is related to the convective activity.

V. Conclusion

The combination of acoustic remote sensing technique with detailed in situ measurements provides new information on convective phenomena. A three axis doppler sodar can provide real time information on the structure and the dynamic of the lower atmosphere. The various probing methods used during our field experiments have also shown that the height of the convective layer and the turbulent heat flux close to the ground are important parameters to characterize convective situations.

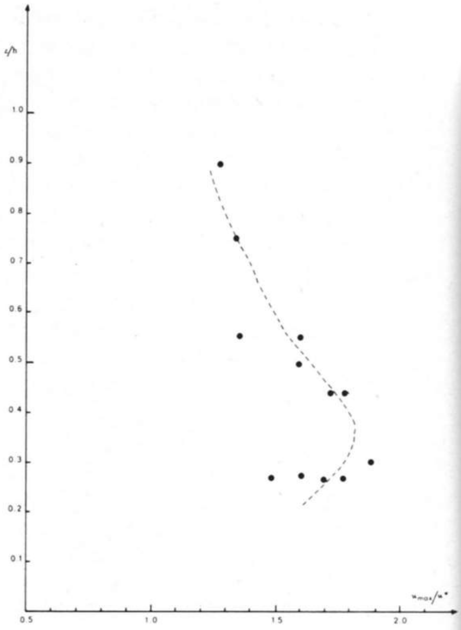


Figure 7. Maximum vertical velocities in thermals as a function of height.

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