# The vertical structure of the convective boundary layer from motorglider measurements

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**Abstract**

*Three instrumented powered sailplanes were used to investigate the vertical structure of the convective boundary layer over flat farmland in South Germany. The simultaneous use of several aircraft provides a very good spatial and temporal resolution. Vertical profiles of mean and turbulent quantities and of other characteristic parameters were computed from the data. Some results on the structure of fields of thermals under light wind conditions and on their physical and statistical properties are presented.*

**Introduction**

Convective processes in the atmospheric boundary layer play an important role for the development of cumulus clouds and for the transport of pollutants. Knowledge on the turbulence structure and statistical properties of thermals in the convective boundary layer is also of interest to thermal soaring.

Field experiments were conducted in the convective boundary layer using instrumented powered gliders. The simultaneous use of several research aircraft provides a very good spatial and temporal resolution. The data were analyzed using conditional sampling methods. Similar ways of analysis were pursued e.g. by Lenschow and Stephens (1980) for aircraft measurements over sea (cold air above warm ocean currents) and Milford (1978) for measurements well below the inversion zone over flat land. Hacker (1981) has performed measurements with the same aircraft as described in this paper in a small Alpine valley.

**The observations**

Measurements were taken over flat uniform farmland south of Augsburg in South Germany. The observational period covered ten days in July and August 1983 characterized by high pressure, light to moderate winds, fair weather with varying cloud cover.

Three instrumented powered gliders (Jochum et al., 1984) were flying simultaneously along the same horizontal flight path with fixed vertical spacing (different for both flight directions) in order to measure time series of temperature, humidity and vertical wind velocity along horizontal flight legs. Thus, the temporal evolution from 100m above ground to levels well above the inversion could be covered simultaneously with very good spacetime resolution. A Cessna 207 made spiral ascents and descents to measure temperature and humidity profiles. Wind profiles were obtained by pibal soundings. There was a ground station to measure surface momentum and heat fluxes. An overview of the data and results are given by Jochum et al. (1984) where further references can be found.

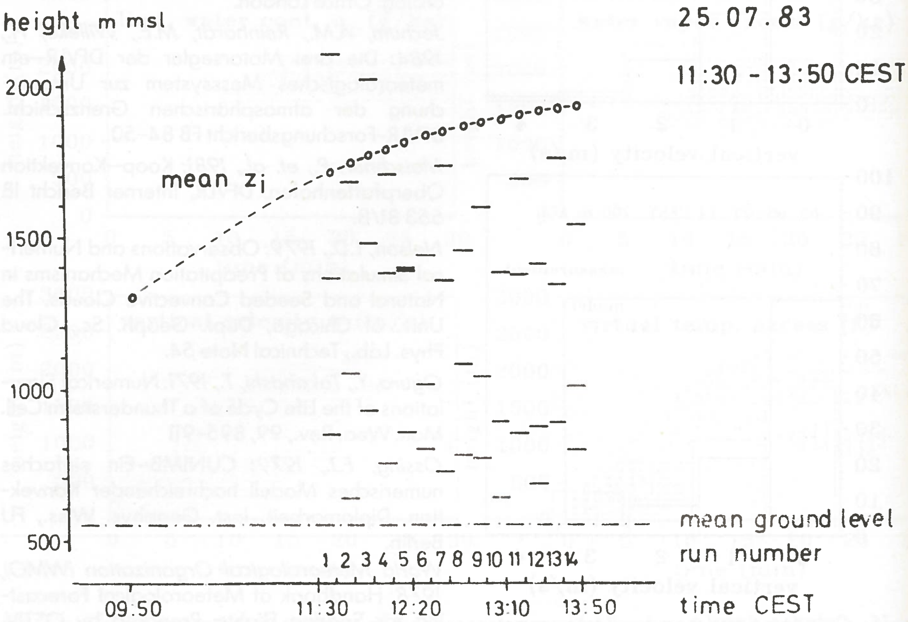


**Figure 1. Measurements taken on 25.07.1983.**

Mean temperature and fluctuations are measured by a platinum resistance sensor, humidity fluctuations by a Lyman-alpha hygrometer, and vertical wind fluctuations are computed by the aerodynamic method described in Hacker (1981). The data are low-pass filtered to eliminate high frequency noise beyond sensor resolution, and high-pass filtered to remove scales larger than the convective scale. The resulting scale range is from 16m to 3.5km.

Results from a midday convective situation (25.07.1983) with weak ambient wind and no clouds are presented here. Figure 1 shows the time and height of the individual measurement runs (42 in total) with respect to the actual inversion height. For analysis all heights are normalized with the inversion height $z_i$ .

**Mean vertical profiles**

The vertical profiles of mean potential temperature and specific humidity shown in Figure 2 give evidence of the well mixed character of the undisturbed boundary layer under investigation. Under such conditions the resulting vertical sensible heat flux is linearly decreasing upward from its surface value to about -20% of this value at the inversion level. In order to understand the physical processes involved in turbulent heat transfer and its relation to the turbulence structure, two different methods of analysis have been pursued.

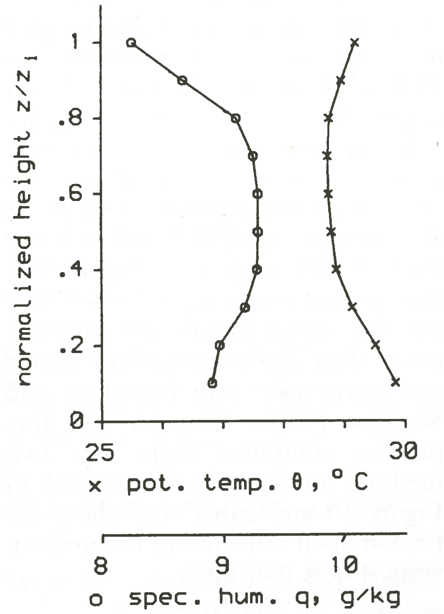


**Figure 2.** **Vertical profiles of mean potential temperature and specific humidity. Height is normalized by inversion height $z_i$.**

## Methods of analysis

Conditional sampling techniques were applied to the data in the following way: First, an indicator series is chosen to distinguish a thermal from its environment. For soaring purposes it is most straightforward to define thermals as updraft events. This approach was pursued in this paper except where mentioned otherwise. Moisture is another possible choice and was used by Lenschow and Stephens (1980) for reasons discussed there. Second, a threshold is defined, usually half the standard deviation of the indicator series to separate 'thermal' (larger than mean plus threshold) from 'non-thermal' (or 'environment') values. Then, a minimum event length is specified in order to prevent very small bursts within larger events from splitting these structures. In this paper the threshold is set to half the standard deviation which for the data used is around 0.5m/s. A minimum event length of 100m, which makes sense for soaring purposes, is used except where otherwise mentioned. Milford (1978) uses a threshold of 0.5m/s for at least 100m, Lenschow and Stephens (1980) use the half standard deviation criterion with a minimum event length of 25m.

Another method of analysis consists of partitioning time series of temperature and vertical wind into the four quadrants of the $\theta' - w'$-plane and of computing fluxes and other quantities for each of these quadrants which represent different physical processes (for details of the method see e.g. Grossman, 1984): Warm updrafts ($\theta' > 0$ and $w' > 0$) are thermal motions, cold updrafts penetrating thermals, warm downdrafts represent entrainment of warm air from aloft, cold downdrafts are compensating sinking motions. Contributions from each of these processes to total transport and area fractions covered by the corresponding motions can be computed this way.

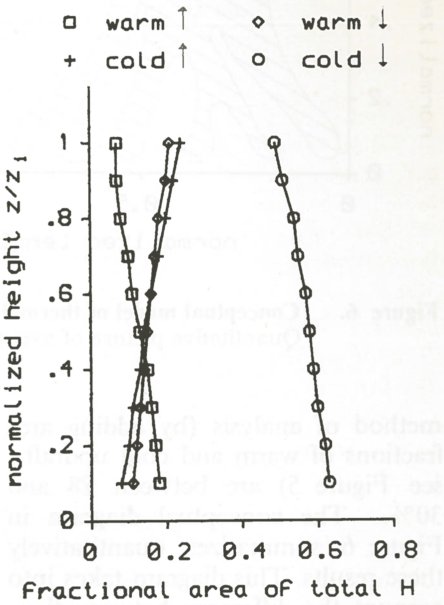


**Figure 5.** **Fractional areas of physical processes contributing to heat transport.**

## Statistics of updrafts

The average thermal intersection length for events larger than 100m is shown in Figure 3. The solid line has been fitted by eye. The results agree with those of Milford (1978), who uses a similar sampling criterion. The average intersection length depends, of course, on the minimum event length chosen. For reasons of using most complete information in designing the conceptual model in Figure 6 the minimum event length of 35m was evaluated additionally and is plotted in Figure 3 as a dashed line. It confirms that smaller events are most important in the lowest part of the boundary layer. Figure 4 shows the average number of thermal intersections per unit length of run (here 10km), which above $0.2z_i$ agrees again with Milford (1978). From these data the average area fraction covered by updrafts can be computed. The resulting values are between 32 and 36%, with a maximum around $0.4z_i$. Fractional areas of updraft regions computed from the second

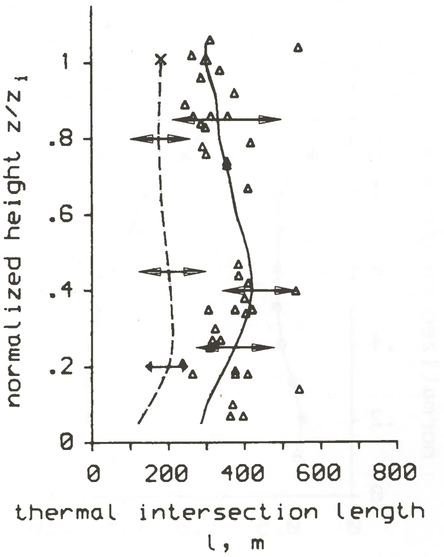


**Figure 3.** Vertical profile of mean thermal intersection length. Horizontal bars give standard deviation.

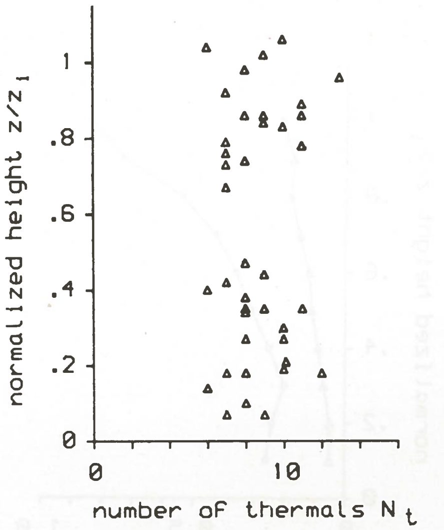


**Figure 4.** **Average number of thermal intersections per 10km.**

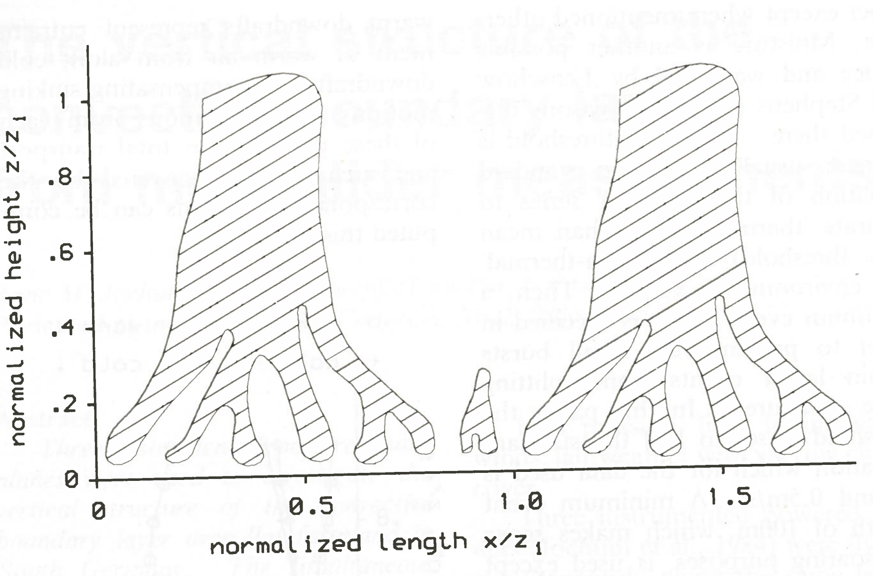


**Figure 6.** **Conceptual model of thermal field: Quantitative picture of average x-z-plane.**

method of analysis (by adding area fractions of warm and cold updrafts, see Figure 5) are between 28 and 30%. The conceptual diagram in Figure 6 summarizes quantitatively these results. This diagram takes into account the difference between thermal intersection length and actual thermal diameter which can be estimated statistically (see e.g. Lenschow and Stephens, 1980).

**Physical properties of thermals**

The average temperature excess of updrafts compared to their environment is shown in Figure 7 which confirms the well known fact that near the inversion updrafts become negatively buoyant and thus colder than the environment. Except for the layer around $0.5z_i$ the values are lower than those of Milford (1978) which might be due to the stronger convective activity predominant there. The average temperature excess computed for moist events (specific humidity series chosen as indicator) is also shown in Figure 7. Thermals defined this way have a much lower level of neutral buoyancy than updrafts. The values agree closely with Lenschow and Stephens (1980). The vertical profile of the average moisture excess as plotted in Figure 8 shows that moisture is indeed a good criterion as well for defining a thermal: At all heights there is a marked humidity difference between thermal and environment. The most interesting property for soaring purposes certainly is the average vertical wind velocity excess which is shown in Figure 9 to have its maximum around $0.4z_i$. Values for moist events are generally lower than those for updraft events and agree again with Lenschow and Stephens (1980). Sensible heat flux profiles computed from the two methods of analysis are plotted in Figure 10 and either way show the predominant influence of thermals on vertical heat transport.

**Conclusions and outlook**

A conceptual model of the structure of a field of thermals and physical properties of an 'average' thermal were derived from aircraft measurements in the fair weather convective boundary layer over uniform flat terrain. The different ways to define a thermal - updraft, moist event or other - and resulting questions are subject of ongoing work.

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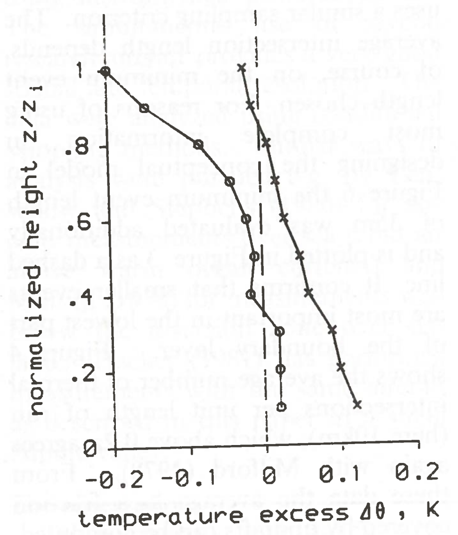


**Figure 7.** **Mean temperature excess of updrafts (×) and moist events (o) over environment.**

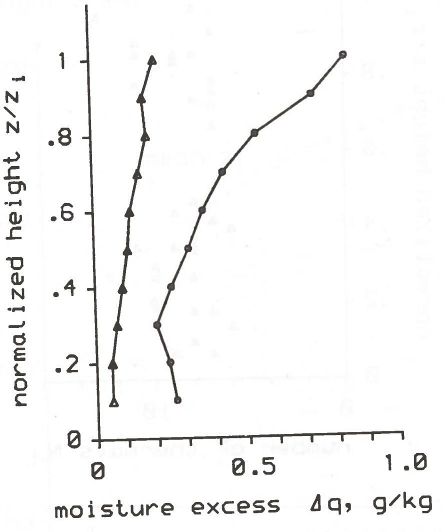


**Figure 8.** **Mean moisture excess of thermal over environment.**

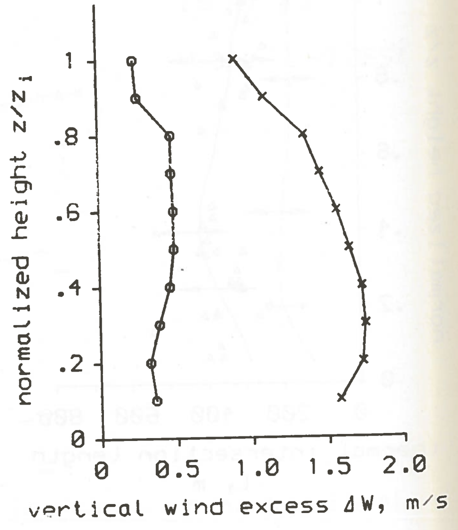


**Figure 9.** **Mean vertical wind velocity excess of thermal over environment.**

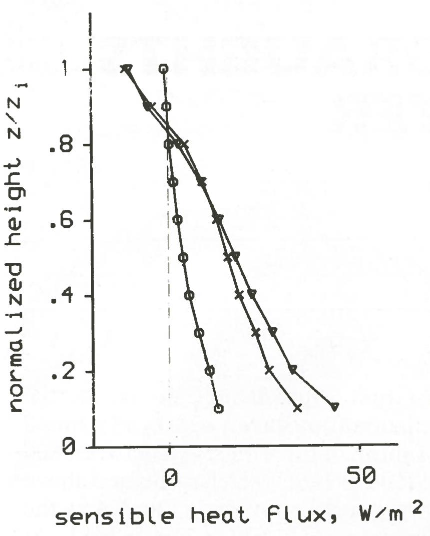


**Figure 10.** **Vertical heat flux profiles from conditional sampling (× updrafts, o environment) and quadrant analysis (∇ sum of warm and cold updrafts) methods.**

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