The FLUXPAT experiment: Integrative characterization of patterns in the atmospheric boundary layer

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Introduction

The exchange of energy, water and carbon dioxide (CO_2) between the earth surface and the atmosphere is determined by the properties of the soil and the plants growing on it, but also by the turbulence and stratification of the atmospheric boundary layer (ABL). The status of the ABL, on the other hand, is strongly influenced by the fluxes of energy and matter from the surface and thus depends on surface properties and their distribution. Due to this coupling patterns in sink and source distribution at the surface play an important role for the organization of fluxes in the ABL. Fluxes from the surface organize in internal boundary layers and differences between them should vanish at the so called blending height (Fig.1). As Monin Obukhov theory assumes horizontal homogeneity it might predict different fluxes than in reality occur.

The Fluxes and Patterns experiment (FLUXPAT) investigates the connection of fluxes and their patterns in the Boundary layer to patterns of sources and sinks at the surface. In spring and late summer 2008 and 2009 in total 5 aircraft campaigns were performed with the Metair-Dimona research aircraft. Simultaneous a multitude of different measurements are performed at the ground (Fig. 2). Mesurement took place in the Jülicher Börde in western Germany (50°52’N 6°27’E, 100m ASL), an area with intense agriculture (Fig. 3).

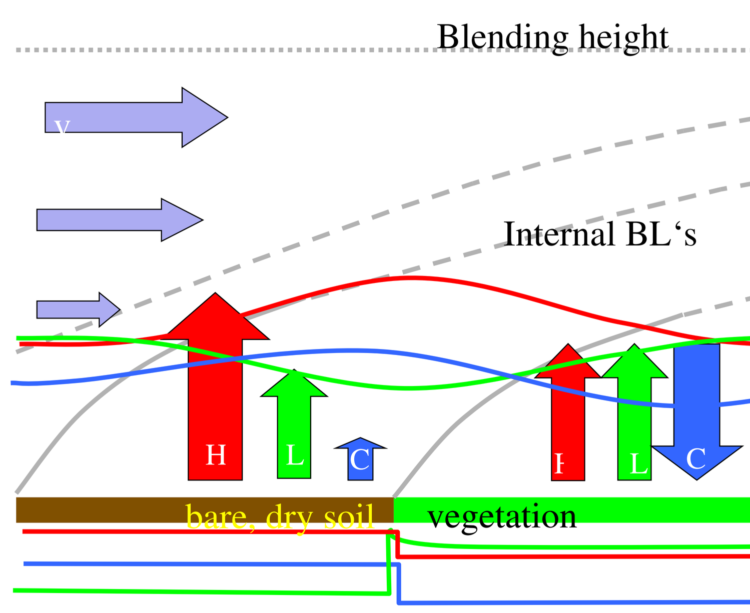

Fig.1: At the border between different surface types associated with different fluxes of latent heat (L, green), sensible heat (H, red) and CO_2 (C, blue) internal boundary layers develop. They are 'tilted' by the mean wind and are diluted by turbulent diffusion across their boundaries (gray solid and dashed lines). The distinct differences between the different layers become smoother with increasing height (solid colored lines). The height where the differences are not detectable any more is the so-called blending height (dotted gray line).

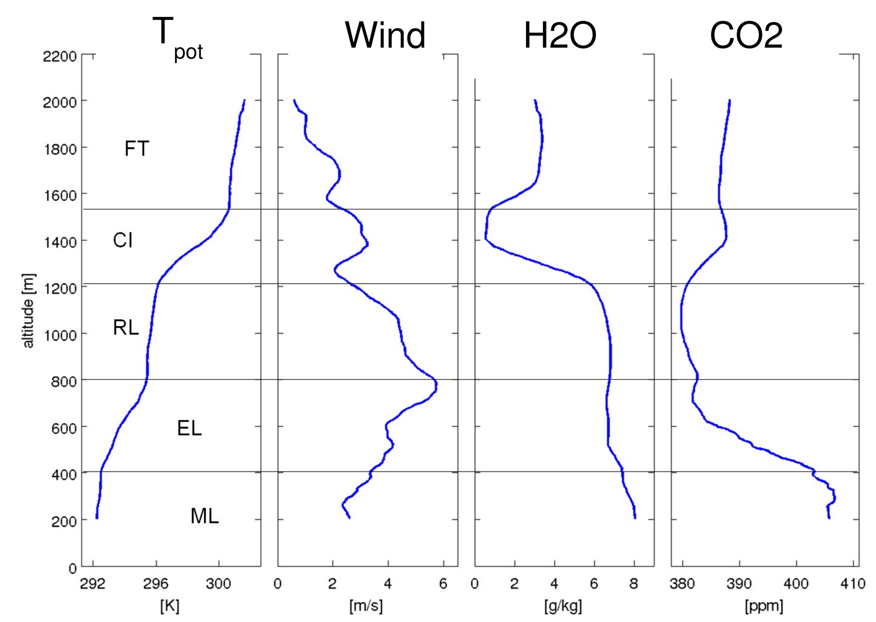

Fig.4: Vertical profiles measured by the aircraft on the morning of July 1, 2008 7:50 UTC. The profiles indicate the complex situation in the morning: Letters on the left panel and horizontal lines indicate the mixed layer (ML) i.e. the growing boundary layer, an entrainment layer (EL) above, separating it from the residual layer (RL) from the day before, capping inversion (CI) and free troposphere (FT) above.
The elevated CO2 values of 405ppm in the ML are a common feature. They are remainders of the polluted and enriched atmosphere of the nocturnal boundary layer and will be mixed into the boundary layer during the hours till noon.

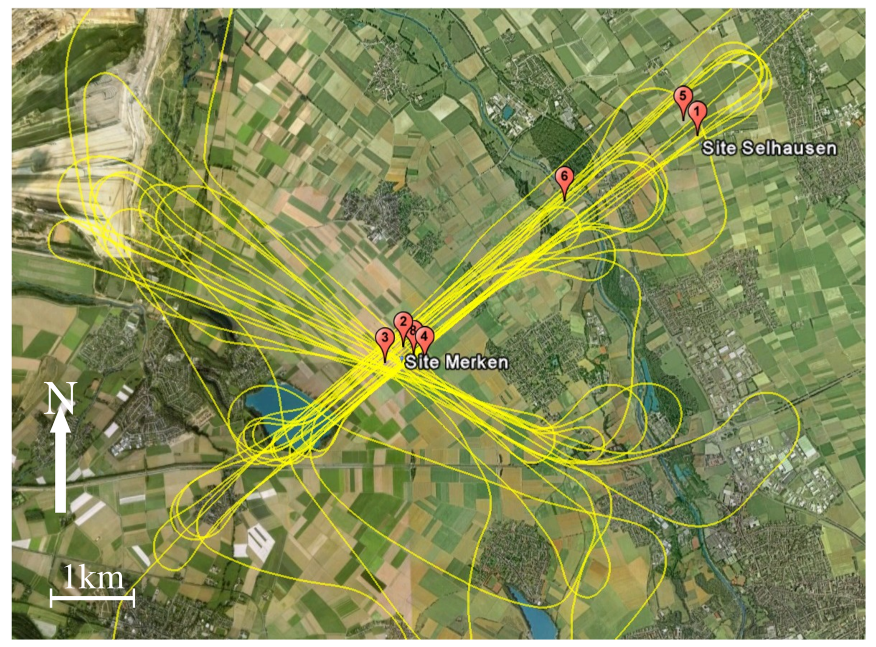

Fig.3: Flight pattern above the surface stations (2-8) on July 1, 2008. As far as flight regulations permit Legs are oriented parallel and perpendicular to the prevailing wind (SE). Surface stations were in 2008 located on fields with winter wheat (1, 2) and sugar beet (3, 5). In 2009 the distribution was, following the crop rotation of the farmers: winter wheat (1, 3), winter barley (2, 8), sugar beet (4), meadow (6). Station number 7 (3km NW from 1, not visible,) is the 120m Tower of the research center Jülich representing an average of the region.

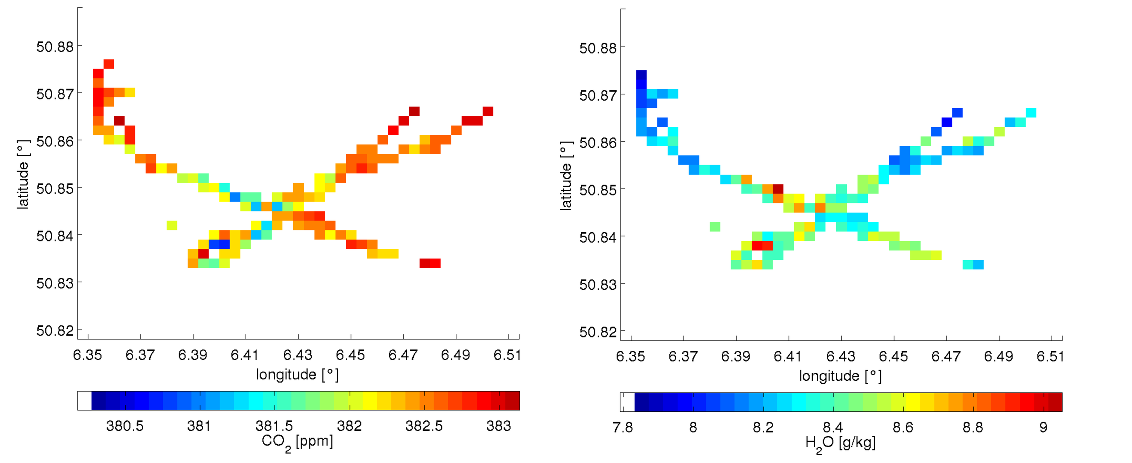

Fig.8: The aircraft measures several trace gases. We show here the spatial distribution of mass mixing ratios of CO2 (left) and water vapor (right) measured on July 1, 2008, 13:30-14:00 UTC. Data are time averages gridded into 200 m x 200 m boxes for flight levels of 100 m±25 m. Both quantities show a clear anti correlation indicating that their origin are either the plants at the surface (+H2O and -CO2) or entrainment from the free troposphere (-H2O and +CO2). Although the averaging interval is rather short and most boxes where passed only one time by the aircraft the plot gives an impression of the variability in the ABL.

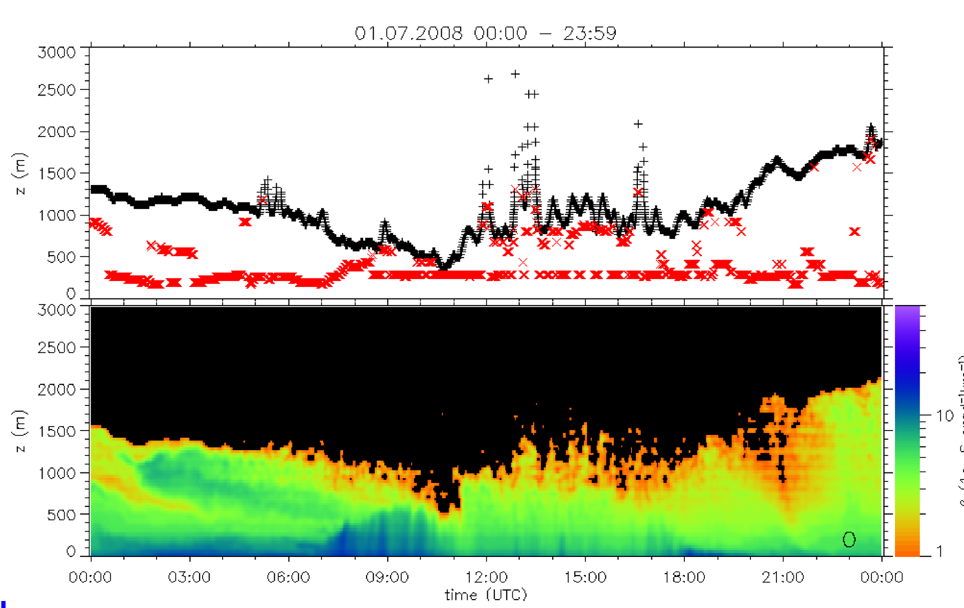

Fig.9: A ceilometer is used to monitor the development of the boundary layer. The graph shows smoothed backscatter coefficients (bottom) and derived boundary layer heights (top) on July 1, 2008. Black plus signs indicate the height of the residual layer (night) and the mixed boundary layer (day). Red crosses mark the height of strongest gradient in the BL and are an indicator for the top of the mixed layer. Main features are a descent of the BL top to a minimum below 500m at 10:30 UTC, a constant height around 1000m till the evening and a rise after 18 UTC. Both, decrease and rise are indicators for large scale synoptic processes and show that the boundary layer may develop in a complex way.

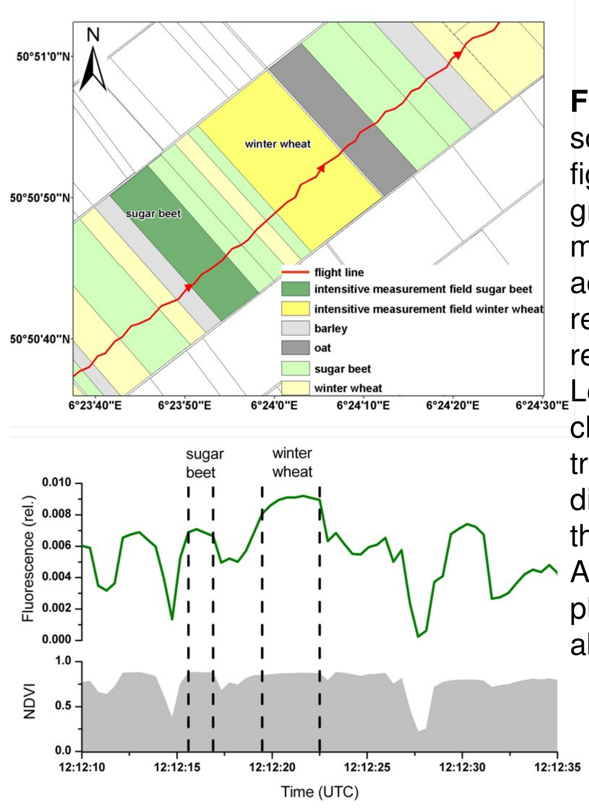

Fig.5: The aircraft carries a hyper- spectral scanner to map patterns of plant activity. The figure shows an exemplary transect. Upper graph: map of two of the intensive measurement fields (site 2 and 3 in Fig.3) and adjacent fields, red line indicates the geo-referenced trajectory of the hyperspectral reflectance measurements.
Lower graph: NDVI and sun-induced chlorophyll fluorescence at 760 nm along this transect. The fluorescence signal shows distinct differences between the vegetated fields while the NDVI does not.
As the fluorescence signal is a measure for the photosynthetic activity it contains information about the fluxes connected to plant activity.

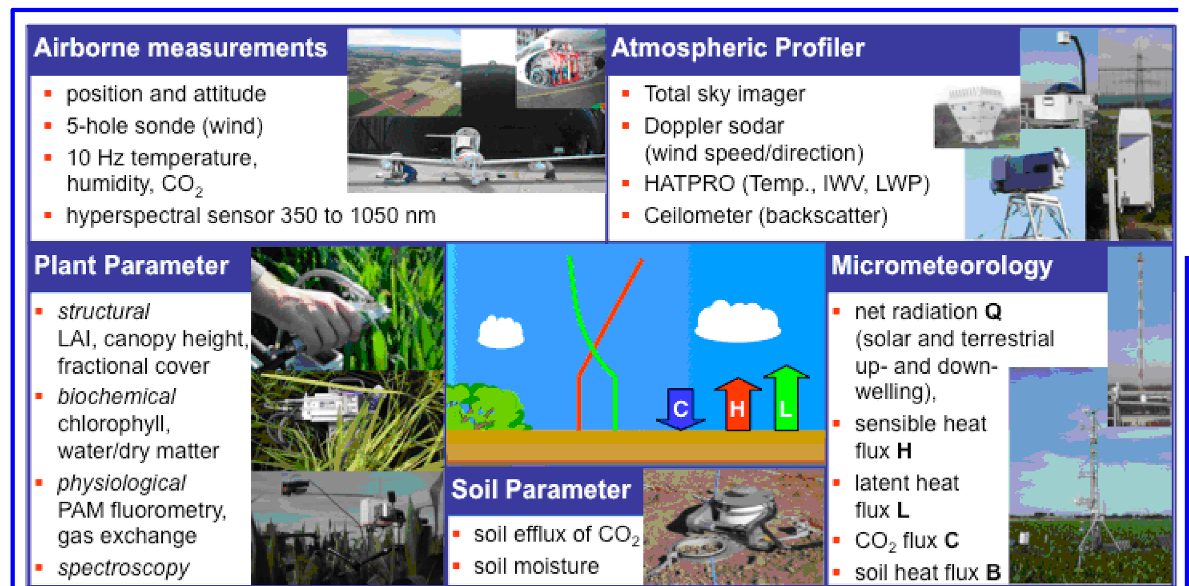

Fig. 2: Overview of the various measurements and instrumentation at different levels of the soil-vegetation-atmosphere system. Profilers are located in Selhausen and the Research center Jülich (4km NW of the site Selhausen). Surface measurements were performed on wheat, barley and sugar beet fields, the main crops of the region. Campaigns were performed in spring and late summer when sugar beet and winter wheat were bare fields respectively. Thus we had strong contrast in fluxes between the different crops.

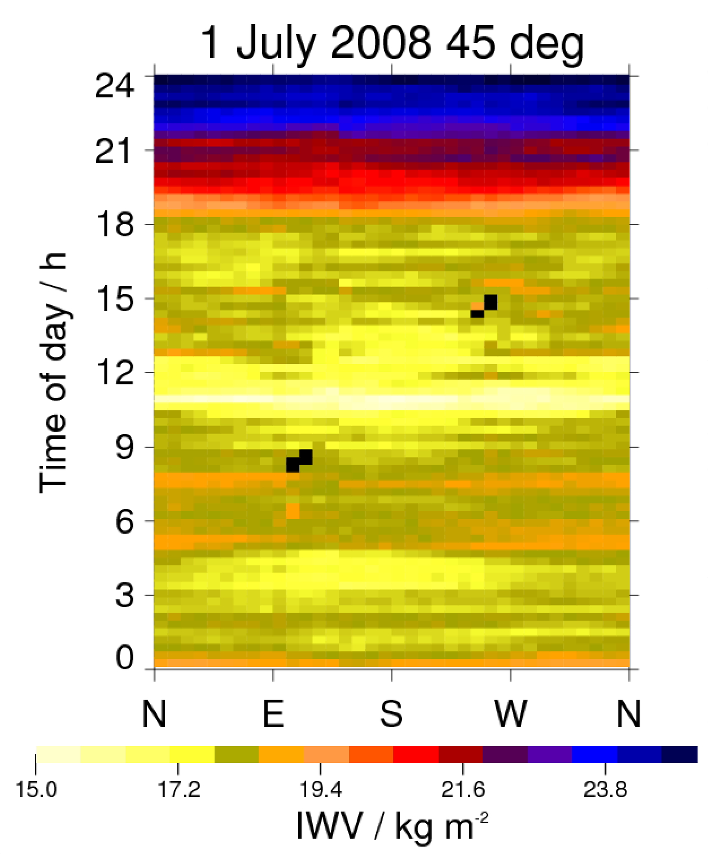

Fig.10: A HATPRO microwave radiometer is used to measure integrated water vapor (IWV). It scans the upper hemisphere and gives information about the spatial distribution of water vapor in the atmosphere. The graph shows IWV as a function of azimuth angle (abscissa) and time (ordinate) for an elevation angle of 45°. The retrieved IWV values for the slanted column are divided by the cosine of the elevation angle to get the equivalent water content of the vertical column. Black squares around 8:45 and 14:45 UTC are contaminated by the sun in the radiometers field of view at these times. Main features are the minimum around 10UTC and the strong increase in the late evening after 18UTC. The minimum at 10UTC coincides with the minimum of BL-height visible in the ceilometer data. The IWV raise in the evening is connected to the increasing BL-height which thus is related to the advection of more humid air. Also visible is a greater spatial variability from 9 to 18UTC indicating active convection during daytime.

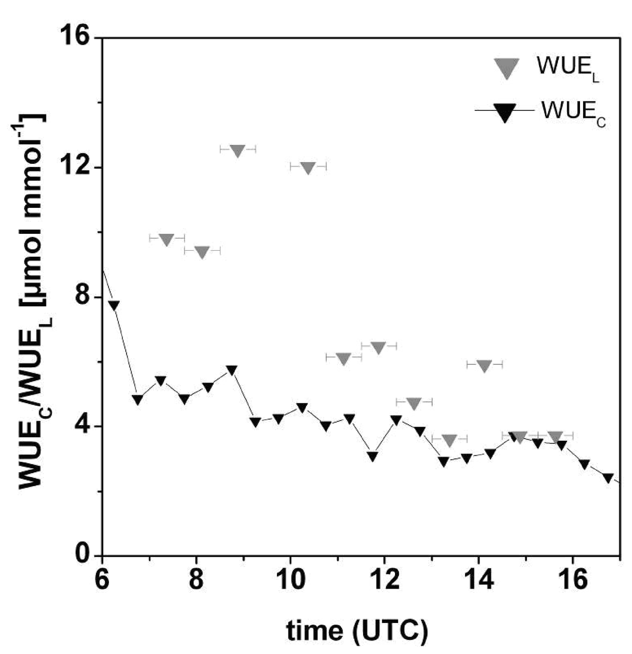

Fig.6: Plant chamber gas exchange measurements are used to determine potential CO2 and water vapor fluxes at the leaf level. The ratio is the potential water use efficiency of the leaf (WUE_L). The same ratio can be derived from Eddy covariance fluxes measured above the canopy (WUE_C).
The graph shows both quantities for July 1, 2008 in the sugar beet stand. As WUE_C contains the non stomatal components of these fluxes it must be smaller. The relation of both quantities may give insight in the vertical distribution of fluxes in the canopy.

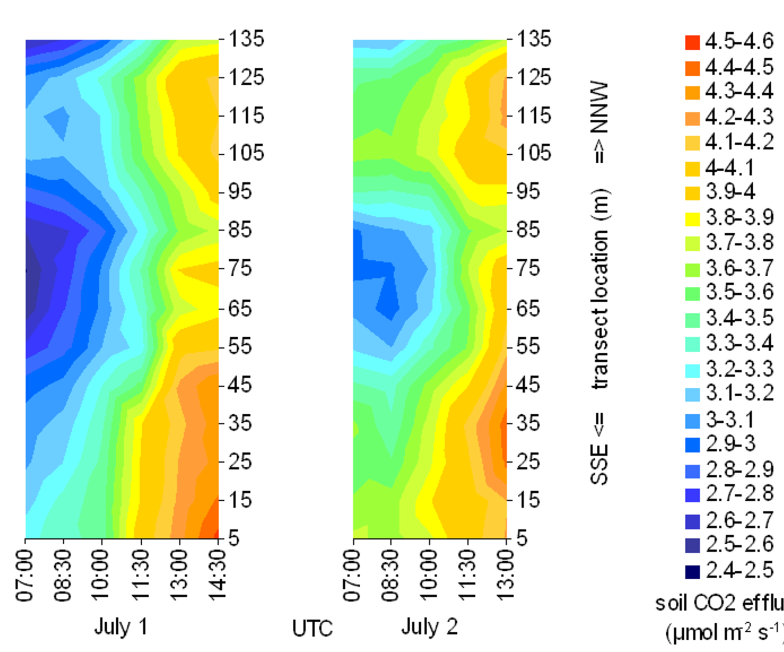

Fig.7: Soil CO2 efflux was measured with dynamic chambers at 30 soil collars in several fields. The graph shows spatial and temporal variability in the sugar beet stand (3 in Fig.3) on July 1, 2008 and the following day. Both days show the same basic temporal and spatial pattern. Air tempe-ratures on the second day were by about 5K higher, morning effluxes are larger, the minimum around 75m is less pronounced, noon values reach the same level as the day before, but the maximum is shifted by about 25m to the north.

Outlook

- Comparison of flux data from eddy covariance measuements, generation of a surface flux map under the assumtion that same crops generate the same flux.
- Generation of a surface flux map based on the airborne flourescence data, in combination with the ground based flourescence measurements and eddy covaraince flux data.
- Try to generate a flux map in 100m from the aircraft data
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