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Trace gas fluxes in the convective boundary layer observed with DIAL and Radar-RASS

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Introduction

DIAL (differential absorption lidar) and Radar-RASS (radio acoustic sounding system) have proven to be powerful tools to measure trace gas concentrations and wind speed, respectively. With a combination of these two active remote-sensing systems transport processes of trace gases can be investigated. The high spatial and temporal resolution achieved in boundary layer measurements make DIAL and Radar-RASS suitable instruments to retrieve turbulent trace gas fluxes by using the eddy correlation method. An advantage of using remote sensing systems is that fluxes can be measured simultaneously at different heights.

Experimental setup

This new approach has been used to measure vertical water vapor and ozone fluxes by combining the water vapor as well as the ozone DIAL of the Max-Planck-Institut für Meteorologie with the Radar-RASS system of the Meteorologisches Institut der Universität Hamburg. The Radar-RASS was operated simultaneously with the water vapor and the ozone DIAL, respectively, at a flat site northwest of Hamburg for several days during summer under predominantly convective conditions. The systems pointed vertically and were put closely together to ensure overlap of the different measuring volumes. For these first measurements the height range of the combined DIAL-RASS systems extended from 300 m to 800 m. Typical height and time resolutions are 75 m and 60 s, respectively. The DIAL and Radar-RASS measurements were complemented by a meteorological ground station, which (in case of the ozone DIAL-RASS combination) included fast ozone and temperature sensors for direct ozone flux measurements.

Data analysis

After highpass filtering the water vapor, ozone and vertical wind speed data with a suitable filter length (typically 30-50 min) to suppress flux contributions due to long-term, non-turbulent variations, water vapor and ozone fluxes are calculated for each measurement height using the eddy correlation method. Since the fluxes are retrieved from density measurements of water vapor and ozone, the Webb corection is applied [1].

Direct flux measurements only make sense, if the eddies performing most of the turbulent transport can be resolved by the flux sensors. In a convectively mixed boundary layer these eddies have horizontal scales of about 1.5 z_i (z_i = boundary layer height)[2], which, for a typical mid-latitude, mixed boundary layer(z_i = 1-2 km, horizontal wind speed u = 5-10 m/s), translates to time scales of about 3 to 10 min. Thus, direct detection of fluxes in the convective boundary layer seems to be possible with a time resolution of 60 s that can be achieved with DIAL and Radar-RASS. For each measurement, the variance spectra of water vapor, ozone and vertical wind speed are used to check whether the resolution of DIAL and Radar-RASS was sufficient. A decrease at the high frequency ends of the spectra proportional to $f^{-5/3}$ - as expected for the inertial subrange region - is a strong indication that the eddies that are not resolved fall into the inertial subrange region and, consequently, do not contribute significantly to the flux. In addition to the direct flux measurements, the DIAL and Radar-RASS data are used to estimate the boundary layer fluxes with indirect methods [3] and to get an estimate of the rate and location of the ozone production in the boundary layer.

Results

Water vapor flux profiles have been measured in the convective boundary layer under different meteorological conditions. In the investigated cases the resolution of DIAL and Radar-RASS proved to be sufficient to resolve the major contributions to the flux. A comparison with indirect estimates of the water vapor flux profiles shows reasonable agreement [3,4].

The analysis of the ozone flux measurements has just begun. The first results indicate a downward flux in the lower half of the boundary layer which has about the same magnitude as the ground ozone flux. In the upper half of the boundary layer the downward flux decreases with height. At the conference ozone flux profiles and ozone budget estimates for the convective boundary layer will be presented for some selected cases.

References

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