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Article

Continuous measurements of the energy budget components at a pine forest and at a grassland site

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Abstract

Micrometeorological measurement stations have been installed over different characteristic surface types in the vicinity of the Meteorological Observatory Lindenberg (MOL) of the Deutscher Wetterdienst within the frame of the LITFASS project (Lindenberg Inhomogeneous Terrain – Fluxes between the Atmosphere and the Surface – A long-term Study) in order to investigate land surface – atmosphere interaction processes in a heterogeneous landscape. Measurements over forest have been performed since April 2000 at a 30 m meteorological mast installed within a 14 m high pine forest. Results from the measurements at this forest site are compared with data collected at the boundary layer field site Falkenberg of the MOL (grassland). Measurements show over longer time periods (in particular during summer) significantly higher values of the sensible heat flux over the forest when compared to the grassland, while the evapotranspiration is of comparable magnitude or even less. This is attributed both to the vegetation and soil characteristics.

Zusammenfassung

Zur Untersuchung von Wechselwirkungsprozessen zwischen Atmosphäre und Landoberfläche in einer heterogenen Landschaft wurden im Rahmen des LITFASS-Projektes (Lindenberg Inhomogeneous Terrain – Fluxes between the Atmosphere and the Surface – A long-term Study) in der Umgebung des Meteorologischen Observatoriums Lindenberg (MOL) des Deutschen Wetterdienstes über charakteristischen Unterlagentypen mehrere mikrometeorologische Messstationen eingerichtet. Messungen für die Landnutzungsform Wald erfolgen seit dem Frühjahr 2000 an einem 30 m hohen Messmast, der in einem etwa 14 m hohen Kiefernwaldbestand aufgebaut wurde. Ergebnisse der Messungen an diesem Waldstandort werden mit den Daten vom Grenzschichtmessfeld (GM) Falkenberg (Landnutzung Gras) verglichen. Die bisherigen Messungen zeigen, dass über längere Zeit – bevorzugt im Sommerhalbjahr – die Wärmeabgabe des Waldes im Vergleich zum Grasland über einen wesentlich höheren Fluss fühlbarer Wärme erfolgt, während die Verdunstung von vergleichbarer Größenordnung ist oder sogar hinter der des Wiesenstandortes zurückbleibt. Dies wird neben den Vegetationsmerkmalen auch auf die Bodeneigenschaften zurückgeführt (Gras auf Sand über Lehm einerseits, Kiefernforst auf Sand andererseits).

1 Introduction

Forests are the dominating land use in many regions of the world, in Germany they cover about 30 % of the area (Statistisches Bundesamt, 2002), a value which is closely met also in the SE of the federal state of Brandenburg (35 %, Statistisches Bundesamt, 2002). In a 20*20 km^2 area around the Meteorological Observatory Lindenberg (MOL) of the German Meteorological Service (Deutscher Wetterdienst, DWD), forest covers about 43 % of the area, agricultural farmland and grassland about 45 %, 7 % of the surface are lakes while villages and traffic roads cover about 5 %.

Numerical weather prediction (NWP) more and more goes towards the computation of regional and local fields of meteorological variables. Making use of the increasing computer capacities, the horizontal resolution of NWP models is reduced step by step, while the number of layers in the vertical dimension is increased. Grid size reduction makes the grid point model output more sensitive to small-scale heterogeneity in the characteristics of the underlying surface. Proper description of land surface – atmosphere interaction processes in atmospheric models therefore requires an adequate representation of all relevant types of land use within a given model grid cell.

In 1995, the Deutscher Wetterdienst (DWD) had launched the LITFASS project (Lindenberg Inhomogeneous Terrain – Fluxes between the Atmosphere and the Surface – A long-term Study) in order to contribute to the problem of flux averaging over heterogeneous landscapes (BEYRICH et. al., 2002b; NEISSER et. al., 2002). The project was designed in order to develop and to test a strategy for the determination and parametrization of the area-averaged turbulent fluxes of heat, momentum, and water vapour over a heterogeneous landscape.

A fundamental part of the LITFASS experimental

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program are continuous measurements with a network of micrometeorological (energy budget) stations (the energy-budget measurement network – EBMN) operated over different types of land use (forest, grassland, agricultural farmland, water) in the surroundings of the MOL. These measurements are intended to provide a comprehensive data set on land surface – atmosphere coupling for a wide spectrum of meteorological conditions during all seasons and including weather extremes. A measuring programme projected in this sense requires considerable effort into the quality assurance and quality control (WEISENSEE et al., 2001).

2 Network architecture and facilities

The following locations (for details, see e.g., NEISSER et al., 2002) for energy budget stations have been established taking account the land use distribution and the reference to a model grid element of the DWD NWP models close to the MOL:

– low vegetation (grassland, soil type: sand over loam): continuous measurements at the boundary layer field site (in German: Grenzschichtmessfeld = GM) Falkenberg, 73 m asl, the meadow is mowed up to six times a year to keep the vegetation height below 20 cm,

– high vegetation (pine forest, soil type: sand): continuous measurements in and above a 50 years old stand at 48 m asl near to the village of Kehrigk, about 12 km to the W of GM Falkenberg, vegetation height is 14 m,

– lake (water): seasonal measurements between April and November at the Kossenblatter See, 43 m asl, about 4 km to the S of GM Falkenberg.

Moreover, measurements over different types of agricultural farmland were carried out during the growing season at different sites (depending on the actual crops grown) over several years.

Differences in the soil characteristics and in the topography have additionally to be taken into account when comparing the measurements at the grassland and forest sites. While the former one is situated at an open plain characterised by a soil profile with sand covering loam (which is typical for the moraines of the last ice age), the latter one lies at a lower altitude within a glacial valley where the sand has a depth of several meters. This situation is different to, e.g., FLEMMING (1995) and also to ROST (2004) who described measurements from a comparable pair of stations.

Fluxes of momentum, sensible heat, and water vapour are measured using eddy covariance systems that are located at 2.4 m (grassland) and 30 m (pine forest) above the ground, respectively. The instrumentation includes three-dimensional sonic anemometer (model METEK USA 1) and infrared hygrometer (model LI-COR LI-7500, continuous measurements started in April, 2003). Wind speed, air temperature, and humidity profiles are measured with F460 cup anemometer (Climatronics), Frankenberger psychrometer, and HMP35D (Vaisala) at two levels (grassland) and at 9 levels along the 30 m tower (pine forest), respectively. Net radiation is calculated from separate measurements of the downward / upward short- and longwave radiation components measured separately with both ventilated CM21 pyranometers (Kipp & Zonen) and PIR pyrgeometers (Eppley). The sites are completed by measurements of soil parameters down to a depth of 1.50 m. These include platinum resistance temperature sensors, Trime-EZ (Imko) TDR sondes and HP3 (Rimco) soil heat flux plates. For precipitation a pluviometer (OTT) is installed at 1 m above ground (at the forest site the precipitation is measured at a clearing about 400 m to the S of the 30 m mast). A more detailed description of the site and data collection can be found in BEYRICH (2004).

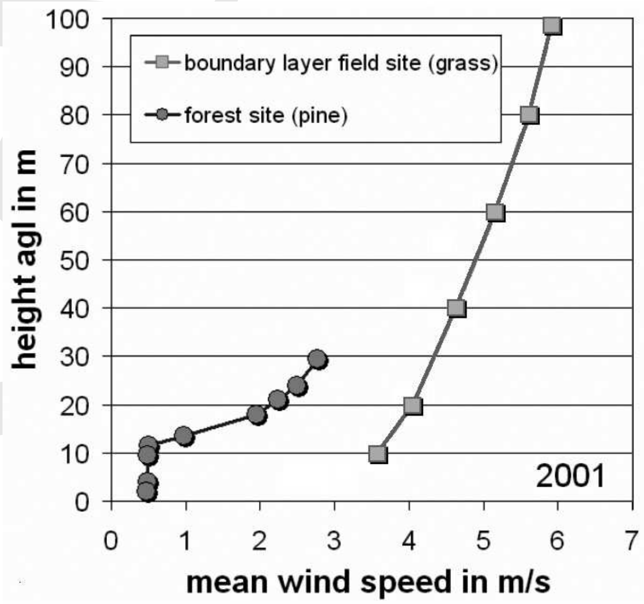

Figure 1: Mean wind speed profiles above ground level along the 99 m tower at GM Falkenberg and along the 30 m mast at the forest site averaged over the year 2001.

3 Selected results of the land use comparison

3.1 Wind speed and air temperature

The mean wind speed profiles at the forest and grassland sites (averaged over one year) are shown in Figure 1. The wind speed below and within the forest canopy is very

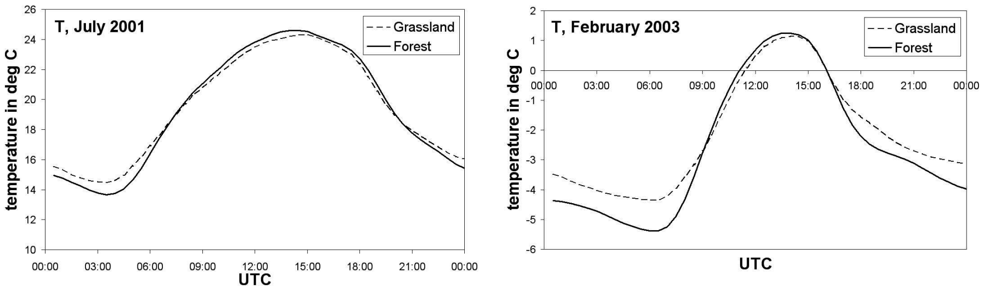

Figure 2: Mean diurnal cycle of air temperature during July, 2001 and February, 2003 at GM Falkenberg and at the forest site.

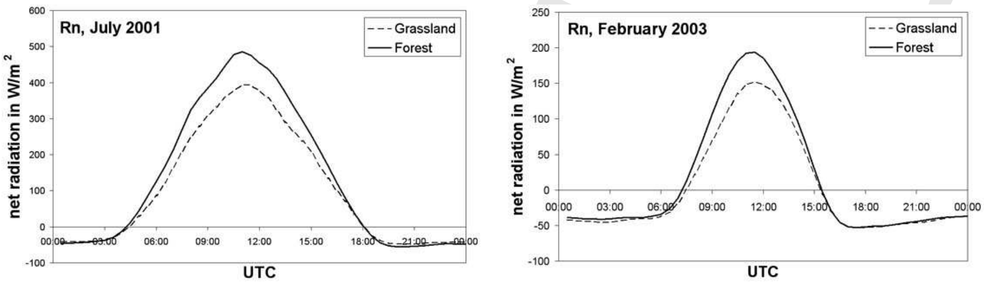

Figure 3: Mean diurnal cycle of net radiation during July, 2001 and February, 2003 at GM Falkenberg and at the forest site.

low. The above-canopy measurements reveal a sharp increase with height, but the wind speed at 15 m above the forest canopy level is still significantly lower than at 10 m height above the grassland at GM Falkenberg. These differences are attributed primarily to the differences in roughness. Moreover, there is some influence of the terrain topography (height above mean sea level), too. Terrain effects are visible in the mean diurnal cycle of air temperature at 2 m (Figure 2) both during winter and summer exhibiting differences up to about 1 K preferably at night due to the pooling of cold air inside the forest at low altitudes.

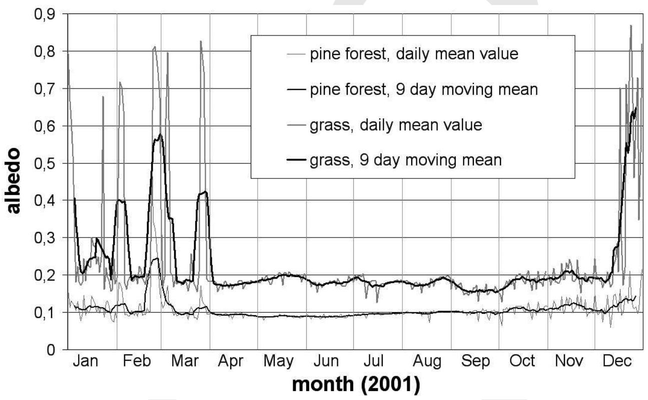

Figure 4: Time series of albedo (daily mean values and a moving average) over pine forest and meadow (grassland) during the year 2001.

3.2 Net radiation

Looking at the energy budget components, significant differences between the two sites have to be noticed as well. The mean diurnal cycle of net radiation for both a summer and a winter month is shown in Figure 3. Differences during daytime amount up to about 25 % nearly independent of the season, and the daytime net radiation at the forest site is always higher. This is basically due to the shortwave radiation budget, since the albedo of a meadow is higher than that one of the pine forest which is illustrated in Figure 4. During the warm season, the albedo of the grassland site varies between about 0.16 and 0.20 in dependence on soil moisture (note that the grass is always kept short). The albedo of the pine forest is around 0.1 during periods without snow cover. The reason for the slightly reduced albedo in May and June is probably the maximum of the noonday sun elevation in the annual cycle.

Very large differences can be noticed during winter periods with (partial) snow cover. While the snow stays at the ground until dewing, it is rapidly removed from the forest canopy by the wind, and the dark canopy of the trees is able to absorb quite an amount of incoming shortwave radiation. This may even result in a completely different behaviour of the heat transfer such that the sensible heat flux is directed into the atmosphere over the forest while a downward sensible heat flux is measured over the snow-covered meadow.

3.3 Sensible heat fluxes

Larger values of net radiation at the forest site provide (neglecting the small values of the ground heat flux and the canopy storage) more energy available to drive the turbulent exchange of heat and water vapour. In comparison with the net radiation the differences in the sensible heat flux are even more pronounced (during daytime up

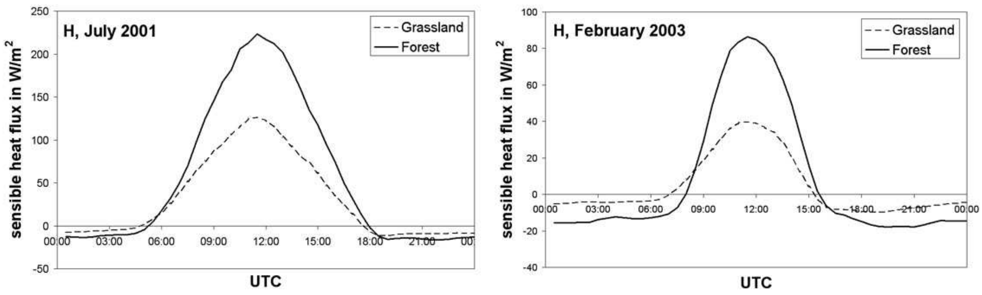

Figure 5: Mean diurnal cycle of sensible heat flux during July, 2001 and February, 2003 at GM Falkenberg and at the forest site.

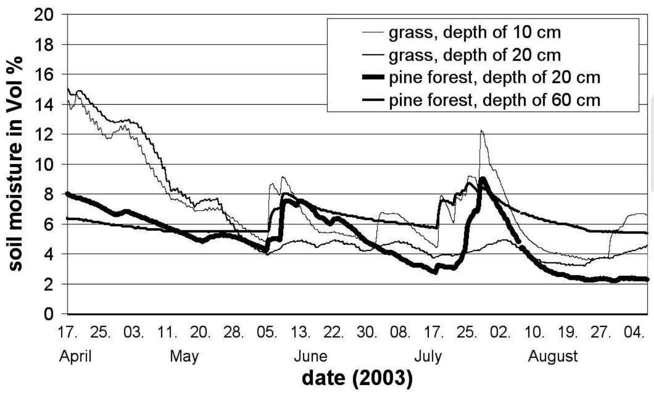

Figure 6: Time series of soil moisture (TDR-measurements) at GM Falkenberg and at the forest site at two levels below the surface in spring and summer 2003.

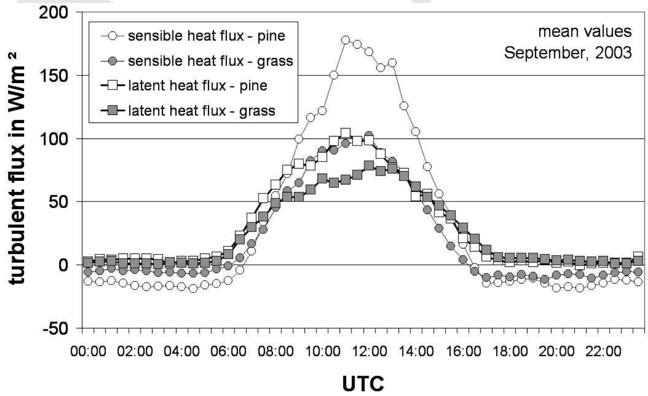

Figure 8: Mean diurnal cycle of the (turbulent) sensible heat flux and of the (turbulent) latent heat flux over grassland and pine forest in September, 2003.

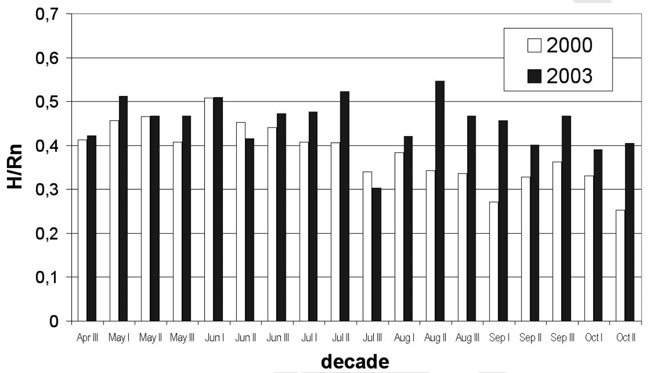

Figure 7: Ratio of the turbulent sensible heat flux H to the net radiation Rn for the forest site in two different years (mean daily values of H/Rn for the condition Rn ¿ 300 W/m, running averages over 10 days).

to about a factor of 2 or 100 %), as can be seen from Figure 5. During summertime the differences of the averaged (!) values of sensible heat flux are a bit smaller. ROST (2004) shows similar results of a higher sensible heat flux over a pine forest in comparison with a grassland site in the Upper Rhine area. Besides the vegetation, also the soil characteristics, and specifically soil moisture providing water for transpiration, determine the partitioning of available energy into the sensible and latent heat fluxes (if there is no evaporation from intercepted water and no evaporation from the ground surface). Higher sensible heat fluxes at the sandy forest site are thus also supported by low values of the soil water content. This is illustrated in Figure 6 showing the time series of soil moisture at the two sites during spring and summer, 2003. Especially during spring, soil water content is considerably higher at the grassland site. Rapid drying was observed during April and May, 2003 due to the very dry weather conditions. During large periods of the summer, soil moisture was below five per cent by volume at both sites.

The year-to-year variability of the energy budget components in dependence on the meteorological forcing conditions is illustrated in Figure 7 showing the ratio between sensible heat flux and net radiation (during noon time) at the forest site. While the differences between the two years are small from April to July, they drastically increase during August which was rather wet in 2000 (monthly precipitation sum 72 mm, 114 % of the 30-years climatological mean value) and very dry in 2003 (monthly precipitation sum 15 mm, 21 % of the long-time average).

3.4 Latent heat fluxes

In Fig. 8, the averaged diurnal cycle of both the sensible and latent heat fluxes over grass and over the pine forest is presented for September, 2003 (monthly precipitation sum 33 mm, 80 % of the 30-years climatological

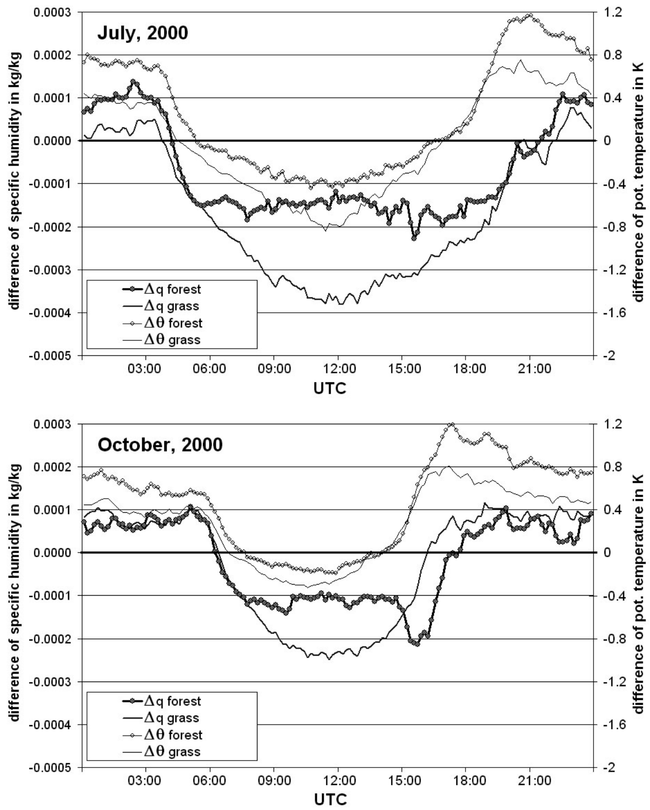

Figure 9: Mean diurnal cycle of the specific humidity difference and potential temperature difference between two levels over different surfaces (forest site: 13.5 m and 29.5 m; grassland site: 0.5 m and 2.4 m) for July and October, 2000 .

mean value). The differences between the evapotranspiration of pine and grass are not that pronounced. Due to the higher net radiation of pine forest the sensible heat flux over the forest is considerably higher again. Furthermore, it can be seen from Figure 8 that there are only small differences between the two sites in the time of the beginning (between 05 and 06 UT) and ending (between 17 and 18 UT) of significant evapotranspiration in the daily cycle.

The beginning of an upward sensible heat flux is slightly later then the beginning of evapotranspiration at both sites, and the onset of an upward sensible heat flux at the forest site is later then at the grassland site. In the evening, there is a small delay, too. Figure 9 again illustrates this dependence of the near-surface profile characteristics on the ”radiation forcing”. The delay in the begin of evapotranspiration (negative gradient of specific humidity) between the sites is very small in summer and in autumn. The beginning of evapotranspiration in autumn is later than in summer, as expected. The delay of ending of evapotranspiration (negative gradient of specific humidity) between the sites is longer, but different in sign between July and October. We think, it depends on the meteorological forcing (e. g. precipitation, wind speed) and the different energy storage. Thus, the bulge in the humidity difference at about 15 UTC in October over the forest has been identified to be associated with the rapid decrease of the turbulent exchange due to increasing stability (temperature difference) and decreasing wind speed. The reduced removal of water vapour results temporarily in the increase of absolute (specific) humidity close to the canopy.

4 Final remarks

Continuous measurements of micrometeorological state variables and energy fluxes have been performed in parallel at a forest and at a grassland site in the heterogeneous landscape around the Meteorological Observatory Lindenberg of the Deutscher Wetterdienst over a period of several years starting in April, 2000. First data analysis has shown that differences in the thermo-dynamic variables measured at the two sites are basically due to vegetation and terrain effects. Significant differences were found in the energy budget components, namely in net radiation and sensible heat flux, during different seasons. These are attributed to both vegetation (including the radiative properties) and soil characteristics. Sensible heat flux between the two sites differs by up to 100 %. This underlines the necessity of energy flux measurements over all relevant types of land use when providing validation data for grid averaged fluxes from mesoscale numerical models or for energy fluxes estimated at pixel resolution from satellite data. A special field campaign has been performed in the LITFASS area during May and June, 2003, in order to study the variability and averaging of fluxes from the local to the regional scale (BEYRICH 2004). In the meantime, data are available from more then three years of simultaneous measurements allowing to study the interannual variability of the energy budget over both forest and grassland in dependence on the meteorological forcing conditions for a wide variety of weather situations.

Acknowledgements

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