9.1 ENERGY AND WATER VAPOR FLUXES OVER A HETEROGENEOUS LAND SURFACE: THE LITFASS-2003 EXPERIMENT

Frank Beyrich* [1)], Jens Bange [4)], Franz H. Berger [6)], Christian Bernhofer [6)], Thomas Foken [5)], Barbara Hennemuth [2)], Sven Huneke [3)], Wim Kohsiek [7)], Jens-Peter Leps [1)], Horst Lohse [3)], Andreas Lüdi [9)], Matthias Mauder [5)], Wouter Meijninger [8)], Heinz-Theo Mengelkamp [3)]

[1)] Meteorological Observatory Lindenberg, German Meteorological Service (DWD), Germany
[2)] Max-Planck Institute for Meteorology, Hamburg, Germany,
[3)] Institute for Coastal Research - GKSS Research Centre Geesthacht, Germany
[4)] Institute for Aerospace Systems, Technical University of Braunschweig, Germany
[5)] Department of Micrometeorology, University of Bayreuth, Germany
[6)] Institute for Meteorolgy and Hydrology, Technical University of Dresden, Germany
[7)] Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
[8)] Wageningen University, Meteorology and Air Quality Group, Wageningen, The Netherlands
[9)] Institute for Applied Physics, University of Bern, Switzerland

1. Introduction

Land surface - atmosphere interaction processes play an important role in the energy and water cycle over a wide magnitude of scales. An adequate description of these processes in numerical weather prediction and climate models is fundamental for a reliable simulation of near surface weather and climate conditions. However, considerable deficits are still to be noticed concerning our understanding and ability to properly describe these processes consistently over a variety of scales ranging from the local patch scale to the regional landscape scale. This does in particular hold for heterogeneous land surfaces which are typical for most regions in Central Europe. To overcome these deficits, both experimental and modelling activities have to contribute.

2. The LITFASS-2003 Experiment

In 1995, the German Meteorological Service (Deutscher Wetterdienst, DWD) has initiated the LITFASS research project (LITFASS = '**L**indenberg **I**nhomogeneous **T**errain - **F**luxes between **A**tmosphere and **S**urface: a Long-term **S**tudy') in order to develop and to test a strategy for the determination of the area-averaged turbulent fluxes of heat, momentum, and water vapour over a heterogeneous landscape by combining measurements and numerical model simulations. The fluxes shall be representative for a horizontal scale of about 10 km (while the typical patch scale is between 10^2 to 10^3 m) corresponding to the size of a grid cell in the present operational numerical weather prediction model of the DWD (Beyrich et al., 2002a, b).

The operational measurement program established at the Meteorological Observatory Lindenberg (MOL) of the DWD during the LITFASS project includes the following components

- a boundary layer field site equipped with a 99m meteorological tower, a 10m profile mast, a sodar / RASS, and measurement systems for the determination of soil, radiation and turbulence parameters,
- a network of micrometeorological (flux) stations operated over different land use classes in the LITFASS area (grassland, farmland, forest, water),
- networks of automatically recording rain gauges and global radiation sensors to characterise the spatial variability of the main meteorological forcing parameters (insolation, precipitation), and
- a large-aperture scintillometer (LAS) over a path length of 4.7 km for the estimation of area-represen-tative sensible heat fluxes (Beyrich et al., 2002c).

An aerial view across the heterogeneous landscape close to the MOL is shown in Figure 1.

Figure1
Aerial view across the LITFASS area with the ABL field site Falkenberg marked by an arrow

* *Corresponding author address*: Frank Beyrich, Meteorologisches Observatorium Lindenberg, Am Observatorium 12, D - 15848 Tauche OT Lindenberg
email: frank.beyrich@dwd.de

Based on these operational measurements, a mesoscale boundary layer field experiment (**LITFASS-2003**) was organised within the frame of the **EVA_GRIPS** project (**EVA**poration at **GRI**d / **P**ixel **S**cale) of the German Climate Research Program (DEKLIM) in order to provide a comprehensive data set on land surface and boundary layer processes over a heterogeneous landscape with special focus on evaporation. LITFASS-2003 took place in the area around the MOL between May 19, and June 17, 2003. Energy and water vapor fluxes at different scales were determined from a combination of ground-based in-situ and remote sensing instruments, and airborne measurements. The measurement program comprised, i.a.:

- thirteen micrometeorological stations operated over different surfaces representing the major land use types in the area (forest, water, and different types of agricultural farmland: grass, triticale, rape, maize),
- three large aperture optical scintillometers (LAS) and a microwave scintillometer (MWS) set up along three different paths over distances of 3 to 10 km (see Meijninger et al., this proceedings),
- synchronised high-resolution (10 seconds sampling rate) measurements of water vapour and vertical velocity profiles by a Lidar-/RASS-combination and by a DIAL/Raman Lidar combination (see Hennemuth et al., this proceedings),
- more than 60 flight hours with a turbulence sonde carried by a Helicopter (the Helipod, see Zittel et al., this proceedings).

Several orders of magnitudes of sampling domains and footprint scales were covered by a combination of these measurement systems which is summarised in Table 1. The overall set-up of the measurement systems and the measurement strategy of the LITFASS-2003 field experiment are illustrated in Figure 2.

Table 1 Sampling characteristics of the flux measurements performed during LITFASS-2003

measurement system	sampling scale	sampling domain	footprint scale
sonic / hygrometer	10^{-1} m	10^{-1} m	$10^{1}..10^{2}$ m
(~ at tower)	10^{-1} m	10^{-1} m	$10^{2}..10^{3}$ m
laser scintillometer	10^{2} m	10^{2} m	$10^{2}..10^{3}$ m
remote sensing	10^{2} m	10^{1} m	$10^{3}..10^{4}$ m
LAS	10^{3} m	10^{3} m	$10^{3}..10^{4}$ m
Helipod	10^{0} m	10^{4} m	$10^{3}..10^{4}$ m

3. Results

The analysis of the flux measurements comprised several steps which are illustrated here by using data from May 25, 2003. Time series of the sensible and latent heat fluxes measured with the eddy-covariance systems at each of the 13 surface flux sites are shown in Figure 3. Data from all sites were processed by a uniform flux calculation and correction software (see Foken et al., this proceedings), and the data quality was evaluated

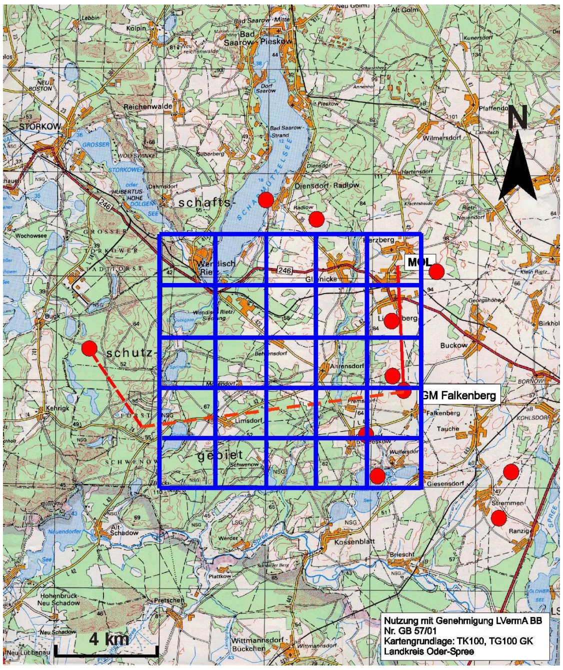

Figure 2
The LITFASS-2003 experimental setup (red circles: surface flux stations, red lines: LAS paths, blue grid: Helipod grid flight pattern)

based on the scheme suggested by Foken and Wichura (1996).

In addition fetch and footprint estimates were performed in order to sort out non-reliable data. As can be seen from Figure 3, the local energy and water vapour flux measurements over the different types of land use showed significant differences which were most pronounced between the major land use classes (forest, low vegetation - farmland, and water). However, significant differences have also been found between the different types of agricultural farmland.

For the different types of agricultural farmland (cereals, rape, maize, and grassland), flux composites have then been determined by averaging the data from all measurements performed over the same type of crops considering the actual data quality. In order to account for site specific differences, a correction factor was derived for each individual site from the measurements during time periods where data from all sites of a given type were available with good quality. This correction factor represents the ratio of the site-specific flux when compared to the mean flux of the relevant crop type. An overall farmland composite was then constructed in the same way taking into account the relative occurrence frequency of the four major crop types in the area. Comparison of the composites shows (Figure 4), that the highest farmland evaporation was measured over the rape fields while the sensible heat flux was highest over the maize fields which consisted of a considerable portion of bare soil especially during the first two weeks of the experiment.

In order to validate this averaging strategy, the farmland composite (as well as the locally measured forest fluxes) were compared to area-representative flux values derived directly from the long-range scintillometer and from the Helipod measurements (Figure 5). For the sensible heat flux, good agreement was found between the scintillometer and the averages from the surface measurements characterising the surface types upwind of the scintillometer paths. Also, the heat flux values derived from the Helipod measurements along low-level flight legs over either forest or farmland fit well into the picture obtained from the surface and scintillometer data. For the latent heat flux, larger differences were found between the different types of measurements. Systematically higher latent heat fluxes have been derived from the microwave scintillometer data when compared to the composite of the eddy covariance measurements, and quite some scatter has to be noticed in the Helipod fluxes. Interpretation of these differences will be the subject of further data analysis.

As a final step, area-averaged fluxes for the whole LITFASS area (20*20 km^2) were computed from the surface flux data by performing a land-use weighted average of the flux values representing the different surface types. Area-averaged surface fluxes were also determined from the Helipod flight data using an inverse modelling algorithm (see Bange et al., this proceedings). These area-averaged flux values will further be analysed in relation to numerical model results and to surface flux estimates from satellite data. A first example is shown in Figure 6. Here, the output of the operational run of the NWP model LM of the DWD and the fluxes estimated from the NOAA-AVHRR image at around noontime are presented indicating considerable overestimation of the latent heat flux both in the model and from the satellite data.

4. Summary and Outlook

A comprehensive and unique data set on land surface / atmosphere interaction processes over a heterogeneous land surface at the meso-γ scale has been collected during the LITFASS-2003 experiment which was embedded in the operational measurement program of the MOL. A hierarchy of instruments and methods was used to derive the fluxes of energy and water vapor from the local to the regional scale including eddy-covariance measurements, scintillometry, ground-based remote sensing systems and airborne measurements using the Helipod, a turbulence probe carried by a helicopter. Analysis of the data revealed a significant variability of the surface layer fluxes across the area in dependence on both the land use and the meteorological forcing conditions. Area-averaged surface fluxes calculated from the local measurements by using the tile approach are in good agreement with area-representative values directly obtained from the scintillometer and Helipod measurements. The data collected during LITFASS-2003 are now used either as boundary conditions and forcing data for different kinds of numerical models or as a verification data set within the EVA_GRIPS project. The modeling activities in EVA_GRIPS comprise 1-dimensional models for off-line simulations of the soil-vegetation-atmosphere exchange processes (see Johnsen et al., this proceedings), 3-dimensional non-hydrostatic mesoscale models and a large-eddy simulation model (see Uhlenbrock et al., this proceedings). Moreover, the data are used to validate retrieval algorithms for the determination of land surface parameters and energy fluxes from satellite data. First comparison with output data from the operational NWP model runs at DWD showed a systematic overestimation of the latent heat flux both in the model and from the satellite data. It should be remarked that in the operational LM, soil moisture is a parameter tuned to optimise the forecast of the temperature at 2m height which of course effects the modelled latent heat fluxes. Further work will also include research versions of the LM. With this, the EVA_GRIPS project will contribute to improve the surface processes parameterisation schemes in NWP and climate models.

Acknowledgements

The LITFASS-2003 experiment was designed and performed within the EVA_GRIPS project, funded from the German Federal Ministry for Education and Research (BMBF) within the frame of the German Climate Research Program (DEKLIM) under contract No. 01LD0103. Part of the measurements was carried out within the frame of the VERTIKO project, funded by BMBF within the frame of the Atmospheric Research Programme AFO-2000 under contract No. 07ATF37.

References

Beyrich, F., S.H. Richter, U. Weisensee, H.-J. Herzog, H.A.R. de Bruin, W.M.L. Meijninger, 2002a: Fluxes over a heterogeneous land surface: Results and perspectives of the LITFASS program, in: *AMS: Proc. 15th Symposium on Boundary Layers and Turbulence, Wageningen / The Netherlands,* 653-654

Beyrich, F.; H.-J. Herzog; J. Neisser, 2002b: The LITFASS project of DWD and the LITFASS-98 experiment: The project strategy and the experimental setup. *Theor. Appl. Climatol.* **73**, 3-18

Beyrich, F.; H.A.R. de Bruin; W.M.L. Meijninger; J.W. Schipper; H. Lohse, 2002c: Results from one-year continuous operation of a large-aperture scintillometer over a heterogeneous landscape. *Boundary-Layer Meteorol.* **105**, 85-97

Foken Th., and B. Wichura, 1996: Tools for quality assessment of surface-based flux measurements. *Agricult. Forest Meteorol.* **78** 83-105

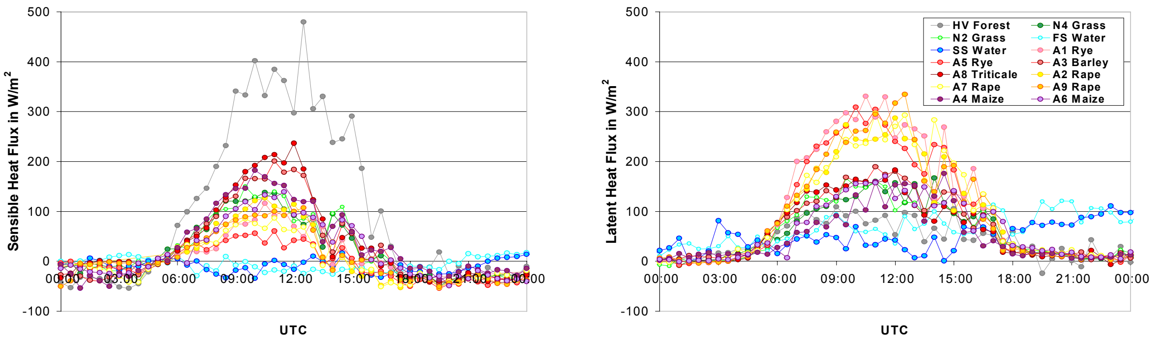

Figure 3
Diurnal cycle of sensible and latent heat fluxes measured at the 13 surface flux sites on May 25, 2003

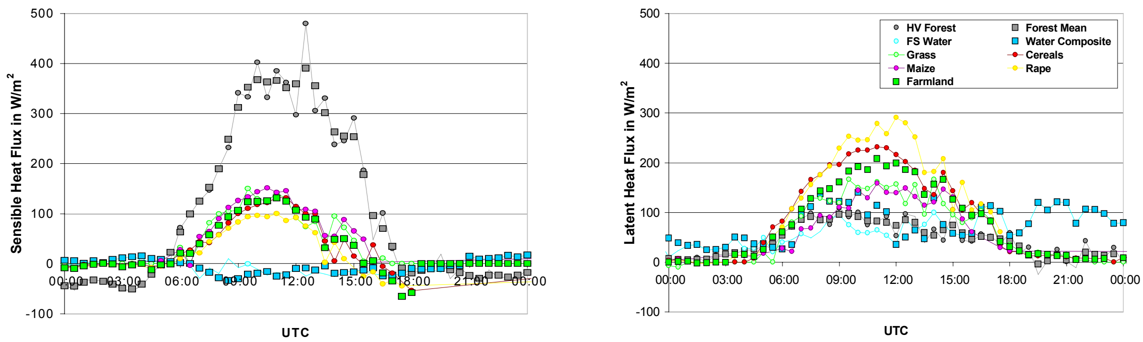

Figure 4
Diurnal cycle of the composite sensible and latent heat fluxes for the major land use types on May 25, 2003

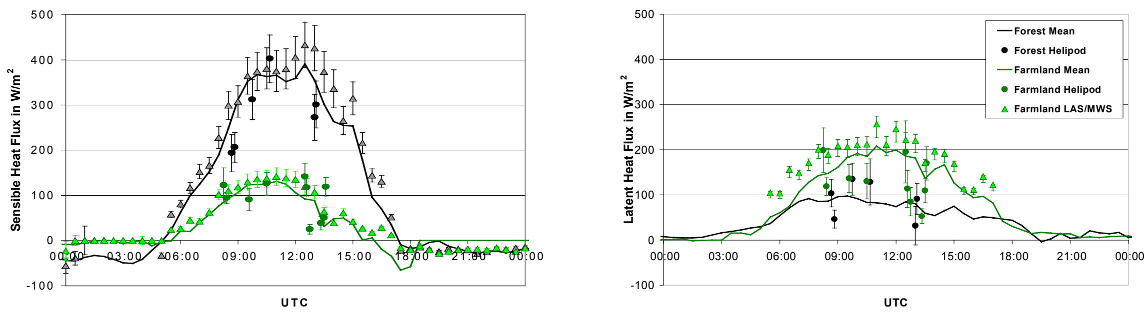

Figure 5
Diurnal cycle of the sensible and latent heat fluxes over farmland and over forest on May 25, 2003 based on surface eddy covariance ~, large-aperture scintillometer ~ and Helipod measurements

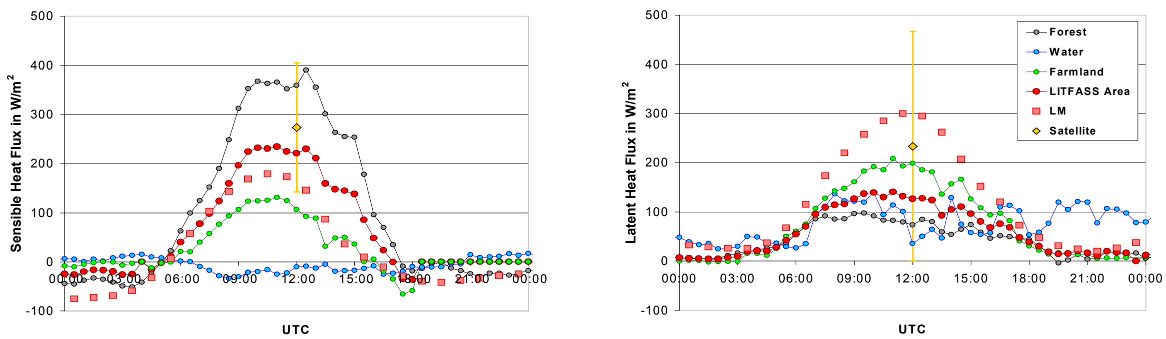

Figure 6
Diurnal cycle of the sensible and latent heat fluxes over farmland, forest and water and as an average over the LITFASS area on May 25, 2003 compared to the operational LM output and to a noontime estimate from satellite data