9.2 STINHO - STRUCTURE OF TURBULENT TRANSPORT UNDER INHOMOGENEOUS SURFACE CONDITIONS

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1. Introduction

A micrometeorological field experiment within the scope of the STINHO-project (STructure of turbulent transport under INHOmogeneous conditions) was performed at the boundary layer research field of the Meteorological Observatory in Lindenberg (German Weather Service) in the summer of 2002. The aim of this examination was to investigate the interaction of an inhomogeneously heated surface with the turbulent atmosphere. To observe spatially and temporally variable flow and temperature fields above a heterogeneous land surface, acoustic methods (travel time tomography) and optical observation methods (infrared-camera or line-integrated scintillometer-measurements) were used (Arnold et al., 2004). Additional turbulent fluxes and vertical wind and air temperature profiles are observed.

The current set-up of the measurement and analysis technique can provide an image of land surface/atmosphere interaction parameters and processes which corresponds with the grid structure of Large-Eddy Simulation (LES) models. The dataset can therefore directly used for the initialisation and validation of such a numerical model.

The Large-Eddy Simulation (LES) is an accepted technique for predicting properties and flow details of turbulent flows. To drive a LES model (used here: **PALM,** Raasch and Schröter (2001) some meteorological boundary layer data are necessary, and this with an adequate correctness (Weinbrecht et al., 2004).

The LES-Model PALM expect from the observations information for initialization:

- representative values of the aerodynamic roughness of the area of investigation / simulation if possible for the various (two) types of surfaces.

- representative values of the turbulent vertical flux of sensible heat for the various (two) types of the surfaces.

- representative vertical profile of the potential air temperature an wind at sun rise.

The LES-Model calculates flow and temperature field or from them derived values (variances, covariance). These numerical derived data can be compared with observed data. The validation of the numerical calculated data sets are the precondition for the afterwards derivation of parameterized relations to include inhomogeneous surface conditions to explain the vertical heating of the boundary layer-one of the aim of VERTIKO/STINHO.

2. Experimental set-up

To start with a simple case, inhomogeneity of the landscape is considered in STINHO as pronounced thermal contrast of two neighbouring land use types (bare soil, grassland) which are expected to contribute significantly differently to the turbulent heating of the lower ABL.

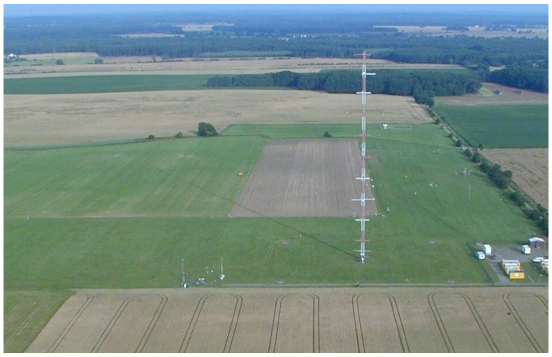

Fig. 1: View of the experimental area at the boundary research site near the Lindenberg Meteorological Observatory of the DWD. The 99m meteorological tower (foreground), the grassland and the ploughed field are visible.

The measurement campaign, STINHO-2, was performed in July 2002 at and around the boundary layer research site of the Deutscher Wetterdienst (DWD, German Meteorological Service) near Lin-

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denberg. The experiment combined local energy balance measurements and area covering measurements over two adjacent different types of surface. The central investigation area had an extension of 300 m × 440 m. One part was a meadow (grass) and the other part was a recently ploughed field (bare soil, Fig. 1, Fig. 2).

Fig. 2: The experimental area for the acoustic air temperature field observations (AT), and for the infrared ground surface temperature observations (black rectangle, IR: position of the infrared camera) during the experiment STINHO-2 at the boundary layer field site of the Lindenberg Meteorological Observatory (DWD). The arrangement of the 12 acoustic receivers (R) and 8 transmitters (S) during the STINHO experiment is shown in the right part. The investigated area is divided into 35 grid cells with an extension of 70 m x 70 m for tomographic inversion calculations.

3. Observational methods

Numerical flow simulation models represent a solution of the hydrodynamic equations over a discrete grid structure. Acoustic travel time tomography (Tetzlaff et al., 2002) is a technique which can be used to observe area-averaged air temperature and wind fields in their horizontal and temporal variability. The acoustic travel-time data can rearranged in a structure which is comparable with the numerical grid structure of the simulation.

The acoustic tomography system consists of several sound transmitters (S1…S8, Fig. 2) and receivers (R1…R12, Fig.2), which are distributed within a landscape (Arnold et al., 2001). In the STINHO-2 experiment, the acoustic tomography covered an area of grassland (300 m × 440 m) including a recently ploughed field of bare soil (90 m × 300 m). This arrangement allowed the area to be divided into 9 grid cells for the calculation of the wind field, and into 35 grid cells for the calculation of the (virtual) air temperature field (s. Fig.2, Fig. 3).

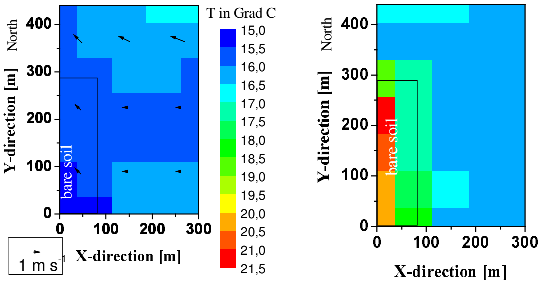

Fig. 3: Snapshot (at 05:20 UTC) of the acoustically determined air temperature and wind field at 2m height (left), the surface temperature field (right) detected with the IR-camera. The area is identical with the AT-array in fig. 1 and 2.

To get information on the horizontal variability of the surface heating, an infrared camera (VARIOSCAN 3021 ST) was used to record the surface temperature within the tomography array and in a surrounding area of 2000 m × 900 m (fig. 2). The infrared camera was mounted on a platform at a height of 16 m. The landscape was scanned every ten minutes during the morning heating phase. The recorded IR-pictures were recombined into grid cells according to the total area of observation of the IR camera, as well as corresponding to grid cells of the tomographic air temperature observations (fig. 3).

This procedure provided the spatial distribution of the surface temperature within the observation area of the IR camera. Examples of the surface temperature distribution (grid cell size: 50 m × 50 m) are shown in fig. 4.

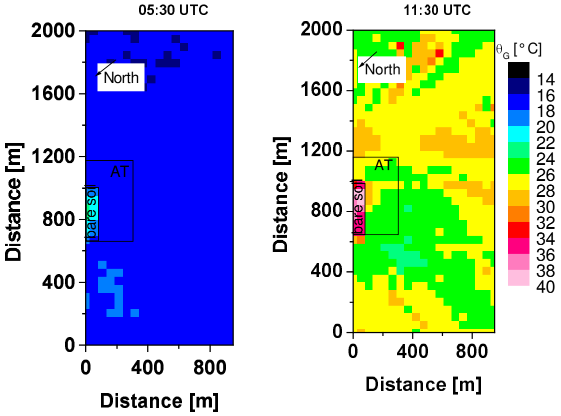

Fig. 4: Examples of a ground temperature snapshots measured by IR camera in the morning and at noon on the July the 06^{th}, 2002 (range: 900 m x 2000 m). The significantly heated area at the left border is the area of the bare soil inside the tomographic area AT (fig. 2).

To provide these initialization data for the LE simulation several turbulence measurements above both surfaces were carried out. The turbulent heat fluxes are observed with eddy correlation technique (sonics) and path integrated technique like Scintillometer which recalculates the vertical heat fluxes observing the fast time dependent extinction of a laser beam. For the observation of the vertical sensible heat flux four laser scintillometer (3 SLS20 and 1 SLS40) and one large aperture scintillometer (LAS) were used (SLS1 …4, fig.2). The eddy covariance measurements were carried out at several positions above the grassland and at one position above the bare soil (fig. 2).

The detailed analysis of the different heat flux observations above grass and bare soil was used to provide a composite of all measurements for the LES initialisation. This composite has been determined as a weighted average of both the sonic and scintillometer measurements where the weights of each individual 10-minute averaged flux value have been fixed taking into account the quality of the data and the footprint contributions to the actual measurement. The diurnal evolution of the averaged heat flux from each of the measurement systems at the grassland and bare soil sites and from the LAS is shown in Fig. 5.

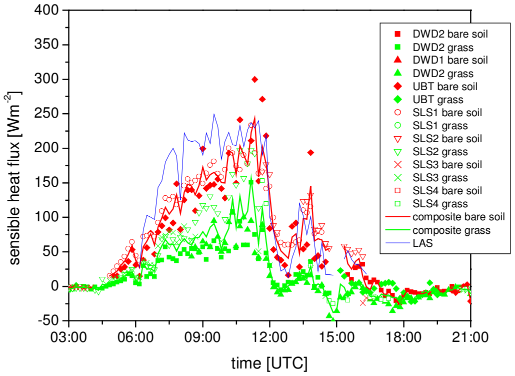

Fig. 5: The evolution of the sensible heat flux on July 06th, 2002 observed with different systems (scintillometer: SLS1 to SLS4 and LAS, sonic anemometer: DWD1, DWD2, UBT) at different positions above grassland and bare soil inside the tomography array. With the change of wind direction around noon the footprint area for the different sensors changes. The solid lines are the composite sensible heat fluxes above grass and bare soil, respectively.

Besides the near-surface data, vertical profiles describing as much as possible of the ABL were needed for the initialisation of the LES. In order to provide smooth and representative vertical temperature and wind profiles as initial and boundary conditions for the LES, the temperature and wind profiles measured by the 99 m tower, the radiosondes and the Helipod were used. Helipod is a helicopter based measurement technique (Helipod, Bange, Roth, 1999) which can observe the turbulent structure of the atmosphere in vertical and horizontal direction. These profiles are shown in Fig. 6 and 7. To adapt different observation methods and to provide a smooth profile, an interpolation between these measurements (Helipod profiles between 05:00 and 06:40 UTC) was carried out.

The profile displays a remarkable range between the airborne measurements (Helipod) at different times. This variation can probably be explained by the temporal and spatial displacements between the measurements, which seem to have a larger influence on the wind than on the temperature observations.

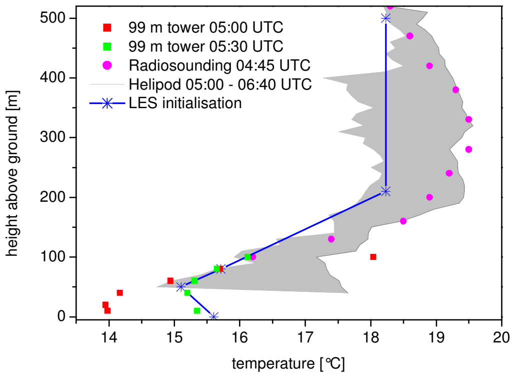

Fig. 6: The temperature profiles on July 06th, 2002. For LES initialisation at 05:30 UTC, an average based on 99 m tower, radio-sounding and Helipod data was used.

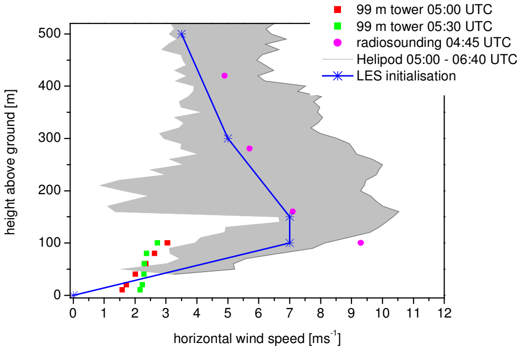

Fig. 7: The horizontal wind speed profiles on July 06th, 2002. For LES initialisation at 05:30 UTC, an average based on 99 m tower, radio-sounding and Helipod data was used.

4. First comparisions between mesurements and LES perdiction

The LES-Model PALM produces a 3 dimensional distribution of the potential air temperature

$\theta(x, y, z, t)$ and the components of the air stream vector $\vec{v}(x, y, z, t)$ within the used numerical grid and time step (Fig. 8). The used grid spacing allow to extract near surface wind and temperature fields in an adequate height like standardized meteorological observations an in the resolution of the acoustic tomography.

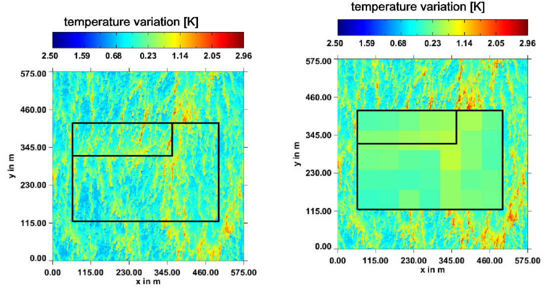

Fig. 8: Comparison of the non-averaged and the tomography grid averaged variability of the potential temperature after 4200 s simulation time on July 06th, 2002.

During the LE-Simulation it was proofed that the energy input into the boundary layer is in accordance to the energy input actually observed during the STINHO-2 experiment. To get the best agreement between analytical model (Deardorff, 1974) and numerical predictions it must be used an energy amount of that observed by the LAS (Fig.9).

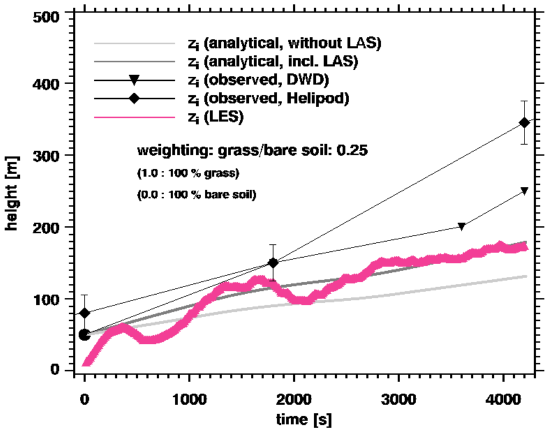

Fig. 9: Comparison of the observed and calculated convective boundary layer heights (Experiment STINHO-2, on July 06th, 2002) between 05:30 UTC (0 s) and 06:40 UTC (4200 s) resulting from the Helipod and operational meteorological measurements (DWD). The analytical values assume a fraction of 25 per cent bare soil. The calculations were performed using the composite values of the heat fluxes (see Fig. 5) (the values before 06:00 UTC were extrapolated).

The analytical model significantly underestimates the boundary layer height even if it is assumed that an unrealistically large proportion of the total area is bare soil (refer to Fig. 1) and even if the maximum of the (meso-scale) observed turbulent heat fluxes (LAS in Fig. 5) is used instead of the composite values of the local heat fluxes (Fig. 5). Using such an time depending increase of the heat flux (Fig. 5) the LE-Simulation can reproduce the development of the near surface air temperature in the time period after sun rise (Fig. 10).

The observed value of the turbulent heat flux is too low to explain the observed time-dependent increase of the boundary layer height using such an analytical model. Hence, it is not easy to decide which near-surface sensible heat flux is necessary in order to reproduce the time-dependent increase of such a boundary layer height, primarily if near-surface flux measurements are available. However, such estimations are the first step towards providing initialisation data for any numerical simulation model which allows recalculation of the boundary layer structure in comparison to the observations in a realistic manner.

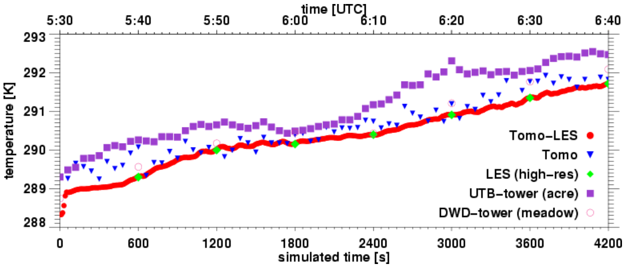

Fig. 10: Comparison of the observed and calculated development of the near surface air temperature (Experiment STINHO-2, on July 06th, 2002) between 05:30 UTC (0 s) and 06:40 UTC (4200 s). resulting from different observations (acoustic tomography and convectional meteorological observations)

5. Discussion

The deliberate focus of attention of the STINHO project is the investigation of the energy transfer within the atmospheric boundary layer under inhomogeneous surface conditions at the micro-α scale. This is achieved by combining experimental methods and highly resolved LE simulations. The measurements within the STINHO-2 experiment comprised both standard micro-meteorological methods (profile and eddy covariance methods) and different techniques which allow the determination of spatially representative meteorological parameters, or even a spatially resolved mapping of surface and atmospheric variables (acoustic tomography, IR-thermometry, scintillometer, low-level flights with the Helipod).

In order to identify the signal from inhomogeneous heating clearly, the observations were performed close to the surface and around the borders between two fields of different surface properties. The resulting differences in the vertical turbulent heat fluxes between neighbouring surface conditions are significant and much larger than measurement errors. Corresponding to this result, the differences in the air temperature field at a height of 2 m over different land uses are negligible.

It has been shown here that the current set-up of the measurement technique can provide an image of land surface / atmosphere interaction parameters and processes which corresponds with the (horizontal) grid structure of LES models.

Therefore, the first aim of the STINHO project, to provide a data set of proven quality to initialise an LES, was realised. However, it was demonstrated which difficulties arise in the use of experimental data. If the observed heating rate as well as the increase of the boundary layer height are correctly reproduced by the simulations, the observed values of the near-surface small-scale sensible heat flux are too small. One possible reason is that the processes occur at different scales: the observations represent the micro-scale processes, whereas the boundary layer growth is dominated by larger-scale phenomena. Another possible reason is a deficiency in the energy balance observations, which can be found in most of the energy balance measurements (e.g., Twine et al., 2000; Wilson et al., 2002).

The further work will deal with the comparison of the LES output with the described observations. In principle, acoustic tomography as well as airborne measurements by the Helipod can provide data with an adequate structure. However, a quantitative comparison of the simulated data with the observed area-representative data is exceedingly difficult (see Weinbrecht et al., 2004) because of the requirements on the accuracy of the measured initial and boundary conditions.

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