P 6.5 USING THE INVERSE METHOD TO OBTAIN AREA AVERAGED TURBULENT FLUXES FROM AIRBORNE MEASUREMENTS AT ONE LOW ALTITUDE

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1. INTRODUCTION

During LITFASS-98 airborne measurements from the helicopter-borne turbulence probe Helipod and from the research aircraft Do 128 were taken to determine area-averaged vertical turbulent fluxes. For LITFASS-98 a square-shaped relatively small flight pattern of 10 km x 10 km for the Helipod and 15 km x 15 km for the Do 128 aircraft was flown at three altitudes above heterogenous ground. The lowest flight path was at 140 m altitude for the Helipod and at 245 m for the Do 128. The goal of this paper was to determine vertical latent and sensible surface heat fluxes with the inverse method which is a combination of the inverse modeling technique (Tarantola, 1987) and the low-level method (Grunwald *et al.*, 1998) using only measurements from the lowest flight path. In a second step these calculated turbulent surface fluxes were compared to surface fluxes calculated from airborne measurements at three heights and linear extrapolation to the ground (3D-box method) and also to surface fluxes calculated from ground measurements. Using the low-level method has the advantage of not needing the approximation of a linear extrapolation for the complete boundary layer as it is necessary for retrieving surface fluxes from airborne measurements in three heights. Furthermore the inverse modeling method does not require further measurements (e.g., ground or mast measurements). Simply one square in low altitude has to be flown.

2. INVERSE METHOD

In the following the inverse modeling technique uses a measured data set of an atmospheric quantity and an assumed model relationship that describes physical processes of the quantity to reproduce the measured data set as a set of parameters (Wolff and Bange, 2000). In other words the technique uses appropriate model assumptions that are based on theoretical assumptions to fit measured data. The technique is based on the assumption of a linear relationship (linear operator G) between the model parameters $\vec{m}$ and the measurements $\vec{d}_{obs}$:

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$$\begin{aligned}\vec{d}_{obs} &= G(\vec{m}) \\ &= m_0 + m_1\,\vec{x} + m_2\,\vec{y} + m_3\,\vec{z} + m_4\,\vec{t} \qquad (1)\end{aligned}$$

with

$$(m_1, \ldots, m_4) = \left(\frac{\partial \vec{d}_{obs}}{\partial x}, \ldots, \frac{\partial \vec{d}_{obs}}{\partial t}\right). \qquad (2)$$

In this equation, $\vec{x}$, $\vec{y}$, and $\vec{z}$ are cartesian coordinates and $\vec{t}$ is the time. For example, to reproduce the potential temperature, first, realistic model assumptions in the range of the potential temperature gradients and its temporal development has to be made. Additionally measurement errors have to be taken into account. The output of the inverse model then provides the gradient and the temporal development of the mean potential temperature as the parameters $\vec{m}$.

To calculate the surface heat flux, first, the potential temperature gradients from the inverse model output have to be inserted into the budget equation. For the turbulent sensible heat flux H, this is:

$$\frac{\partial H}{\partial z} = -\left(\rho c_p \frac{\partial \bar{\theta}}{\partial t}\right) - \left(\rho c_p \bar{u} \frac{\partial \bar{\theta}}{\partial x} + \rho c_p \bar{v} \frac{\partial \bar{\theta}}{\partial y}\right), \qquad (3)$$

where ρ is the density of air, c_p the specific heat constant of air, $\bar{u}$ and $\bar{v}$ are the mean horizontal wind velocities and $\bar{\theta}$ is the mean potential temperature. The turbulent sensible heat flux H in one height z can be calculated with

$$H = \frac{1}{n} \sum_{i=1}^{n} \rho c_p \langle w' \theta' \rangle, \qquad (4)$$

where $n = 4$ and is the number of legs and w', θ' are the turbulent parts of the vertical wind and potential temperature, respectively. Finally values for the turbulent sensible surface heat flux H_o can be obtained using the linear extrapolation to the ground:

$$H_0 = H - \left(\frac{\partial H}{\partial z}\right) z. \qquad (5)$$

In the following area averaged sensible surface heat fluxes calculated with the inverse method were compared to those obtained from the 3D-box method and from ground measurements.

3. RESULTS

Sensible surface heat fluxes calculated with the inverse method using measurements from the Helipod and the Do 128 were around 105 and 116 $\mathrm{Wm^{-2}}$ respectively and are in good agreement with surface heat fluxes obtained from the 3D-box method for the Helipod data (92 $\mathrm{Wm^{-2}}$) and from ground measurements (108 $\mathrm{Wm^{-2}}$) when measurement errors were considered. The surface heat flux obtained from the Do 128 data with the 3D-box method is 68 $\mathrm{Wm^{-2}}$. Calculated sensible heat fluxes are shown in Fig. 1.

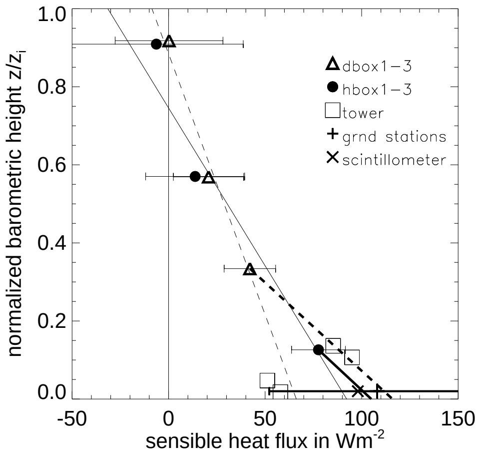

Fig. 1: *Sensible surface heat fluxes.*

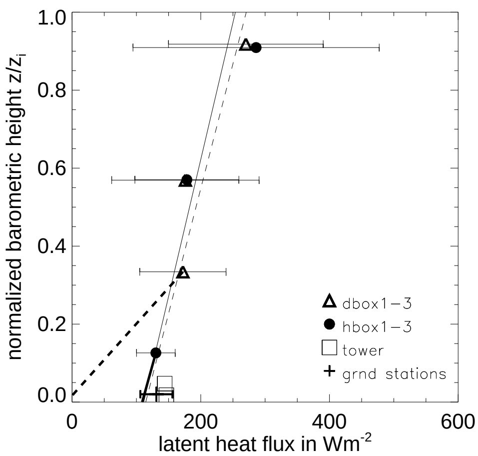

Fig. 2: *Latent surface heat fluxes.*

The dashed lines show Do 128 data, solid lines show Helipod data (Bange *et al.*, 2002). Additionally, thinner lines indicate heat fluxes that were calculated with the 3D-box method and thicker lines show the heat fluxes obtained through the inverse method. The plus sign and squares in the figure represent data from ground stations and from tower measurements, respectively.

As it can be seen in Fig. 2, the calculation of the latent surface heat flux revealed that the measurements from the Helipod led to a good agreement between the 3D-box method (110 $\mathrm{Wm^{-2}}$), the inverse modeling method (109 $\mathrm{Wm^{-2}}$), and ground measurements (108 $\mathrm{Wm^{-2}}$). For the Do 128 measurements the 3D-box method led to a similar surface heat flux (111 $\mathrm{Wm^{-2}}$). The inverse method led to a very different one (-9 $\mathrm{Wm^{-2}}$) for the Do 128 measurements. A reason is the relative large measurement error of the humidity sensors of about 4% which is an input of the inverse model.

Note that, when using the 3D-box method the calculations of the surface fluxes are dependent on the development of the boundary-layer height because atmospheric quantities are scaled with it (Deardorff scaling). The determination of the boundary-layer height has an uncertainty leading to an uncertainty of the surface fluxes. The low-level method has the advantage of not requiring the knowledge of the boundary layer height.

4. OUTLOOK

In future the inverse modeling approach will be extended and improved on further airborne measurements. The next aim is to determine criteria to judge the quality of the calculations. Future aims include the possibility to obtain fluxes of momentum as well as horizontal fluxes of latent and sensible heat. To improve the model assumptions, a nonlinear approach for the inverse modeling technique will be developed.

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