Technical report; TR-240

EBEX-2000:
the KNMI/WAU contribution

W. Kohsiek, E.W. Meijer, P.J.B. Versteeg,
O.K. Hartogensis, H.A.R. de Bruin

De Bilt, 2001

Technical Report = Technisch Rapport; TR-240

De Bilt, 2001

PO Box 201, 3730 AE De Bilt
The Netherlands
Wilhelminalaan 10
http://www.knmi.nl
Telephone +31 30 22 06 911
Telefax +31 30 22 10 407

Authors: W. Kohsiek, E.W. Meijer, P.J.B. Versteeg,
O.K. Hartogensis, H.A.R. de Bruin

UDC: 551.511
551.511.33
511.521

ISSN: 0169-1708

ISBN: 90-369-2204-6

● ● ● ●

EBEX-2000: The KNMI/WAU contribution

W. Kohsiek*, E.W. Meijer, P.J.B Versteeg#, O.K. Hartogensis#,
H.A.R. de Bruin#

* Royal Netherlands Meteorological Institute (KNMI), P.O. Box 201, 3730 AE De Bilt, The Netherlands
\# Wageningen University, Meteorology and Air Quality Group, Duivendaal 2, 6701 AP Wageningen, The Netherlands

1. Introduction

EBEX (Energy Balance Experiment) aims to shed more light on the non-closure of the energy balance. In many studies it is found that the net radiation received by the earth's surface exceeds the sum of the turbulent heat fluxes (sensible and latent heat) and the soil heat flux (disregarding for the moment being the energy bound for photo synthesis and the heat stored in the canopy). Broadly speaking, the deficit increases with decreasing wind speed and increasing evaporation.

Although in many experiments a contribution by advection can not be completely excluded, it is not clear why such effect should lead to an energy deficit. An argument could be that the location of the measuring devices often deviates from its surroundings due to treading of the vegetation, the presence of measuring vans or buildings and the like. Much attention has also been devoted to shortcomings of the measuring techniques themselves. In particular is it difficult to measure the soil heat flux with the same relative accuracy as the other components of the energy budget because of the inhomogeneous character of the soil and the difficulty in measuring the flux right at the (often ill defined) surface. If a surface is well covered with vegetation, the soil heat flux is small as compared to the total turbulent flux, and requirements on the precision of its measurement can be relaxed. The vertical fluxes of heat and moisture are commonly measured by the eddy-covariance technique, a method that is nowadays regarded as a standard technique. Radiation instruments have been markedly improved in the last decade, and the net radiation is often considered as the best-known term of the energy budget.

In the EBEX project it is was aimed to measure the components of the energy budget over a large, homogeneous terrain, covered with a well-evaporating, closed vegetation. In EBEX, a multitude of instruments would be employed to assess instrumental accuracies and to investigate horizontal differences across the field of investigation. Groups from several countries participated.

Finding a suitable terrain was not easy because of the high demands put on homogeneity on km scale, the absence of obstructions (trees, farms etc), absence of slope-induced effects (hills), availability of electric power, accessibility etc. A good compromise was found in the San Joaquin valley in California, USA. This is a very wide, flat valley, largely irrigated for agriculture purposes, and offering a good

logistic infrastructure. The site of the experiment was a cotton field of 800m x 1600m at coordinates 36°06' N, 119°56' W, elevation 67 m.
At the time of the experiment the canopy was not completely closed, and this aggravated the problems in measuring the soil heat flux. Turbulence and radiation measurements were made at nine sites in the field (Fig.1), oriented in such a way that advective effects with the mainly NNW winds could be recognized. Soil heat flux was measured at several places and additional measurements of temperature- and humidity profiles were made at a number of sites.

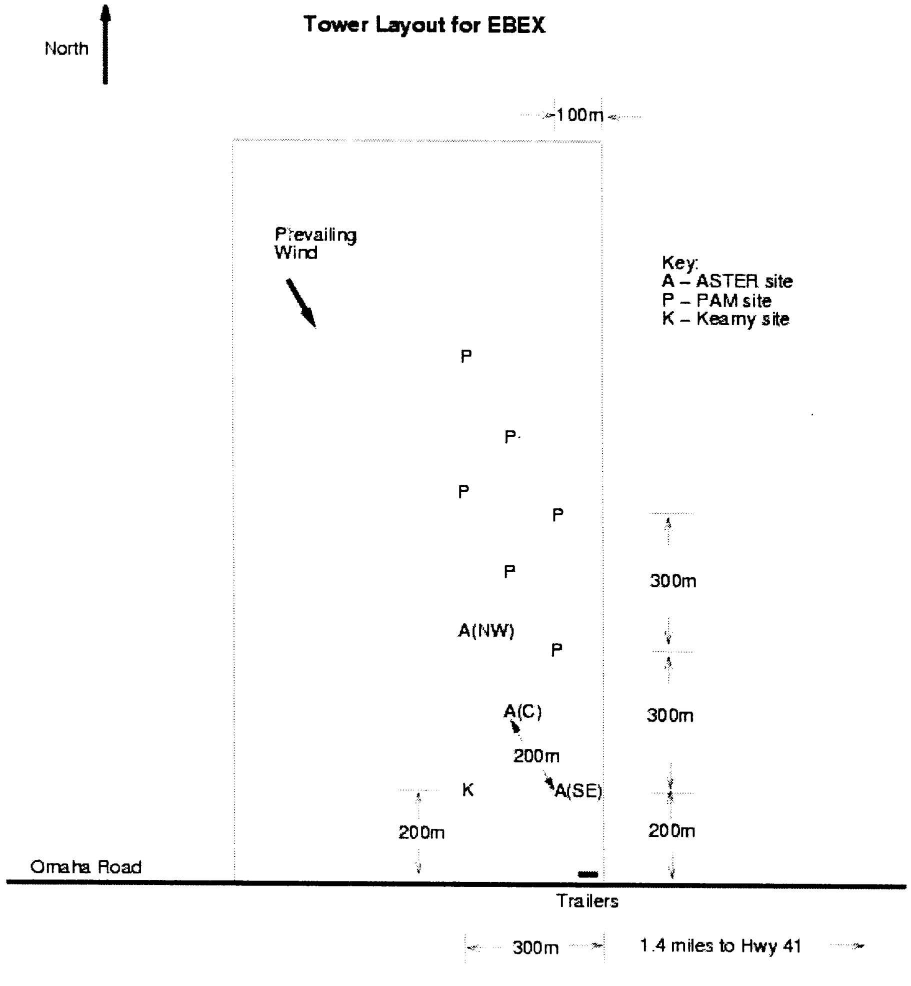

Fig.1 Set-up of the measuring field

2. Description of the KNMI/WAU contribution

KNMI and the Meteorology and Air quality group of the Wageningen University (hereafter called WAU) contributed with two eddy correlation packages, net radiation, screen temperature and humidity and atmospheric pressure. From 25 July till 29 July (DOY 207 till DOY 211) the instruments were positioned at site A(C) (also named site 8) for comparison with the eddy correlation packages of other groups. Thereafter the instruments were transferred to site A(NW) (or site 7) were they remained for the rest of the experiment (ending at 23 August 2000, DOY 236). Table 1 gives details of the instrument set-up at the two sites. Below follows a detailed description of the instruments.

Table 1. Position instruments

	Height site 8 (m)		Orientation site 8 (°)		Height site 7 (m)		Orientation site 7 (°)	
	high	Low	high	Low	High	low	High	low
Turbulence	4.90	1.73	349	349	2.76	1.76	335	335
Net radiometer	1.65		≈180		1.89		195	
Ref. temp&hum.	3.50		≈220		220		≈220	

Note: "high" turbulence had KNMI sonic s/n 09983120 and Krypton #1353
"low" turbulence had WU sonic s/n 01982888 and Krypton #1334

2.1 Net radiation (Fig.2)

Net radiation was measured with a Schulze net radiometer. This instrument gives the total downward radiation (shortwave plus longwave) and total upward radiation. The instrument was calibrated before and after the experiment, both by the manufactured (shortwave and longwave) and by the KNMI (shortwave only). Table 2 gives the results. Curiously, the latest calibration of the manufacturer deviates from the other calibrations. We chose to ignore this deviating calibration for the moment being and use a sensitivity of 44 $\mu V/(Wm^{-2})$ for all 4 components. We hope to clarify the cause of the deviating calibration in the future. When using independent measurements of the downward and upward shortwave radiation, it is possible to refine the calculation by taking into account the differences in shortwave and longwave sensitivity, as well as the differences in downward and upward sensitivity. The error made in ignoring such differences is less than 5 Wm^{-2}.

Fig.2 The Schulze net radiometer

The electric output of the instrument was recorded on a Campbell 21X datalogger using a sampling rate of 1 Hz and an averaging interval of 10 minutes. Only average values were retained. In the beginning of EBEX, the datalogger malfunctioned. After its replacement on August, 9 the data were recorded continuously. The domes of the Schulze were cleaned almost every day.

Table 2a. Calibration Schulze net radiometer # 310310 shortwave ($\mu V/(Wm^{-2})$)

date	24.09.96	25.04.97	21.02.01	04.05.94	19.12.00
	KNMI	KNMI	KNMI	Manufact.	Manufact.
upper thermopile	44.2	43.0	43.6	44.1	47.0
lower thermopile	46.3	45.7	46.2	45.9	49.1

Table 2b. Calibration Schulze net radiometer # 310310 longwave ($\mu V/(Wm^{-2})$)

date	04.05.94	19.12.00
	Manufact.	Manufact.
upper thermopile	42.6	47.2
lower thermopile	43.8	47.8

2.2 Turbulence instruments (Fig.3)

Two identical turbulence packages were employed. Each consisted of a sonic anemometer with 5 cm path (Kaijo Denki, probe TR90-AH), a Krypton hygrometer (Campbell Scientific KH2O) and a thermocouple temperature probe with a diameter of 0.025 mm (Campbell Scientific; type K, chromel-alumel). These instruments were mounted in such a way that the distance between the vertical transducer pair of the sonic, the Krypton's measuring volume and the thermocouple was approximately 5 cm. Considering the physical size of the Krypton hygrometer, an effect on the air flow in the sonic's measuring volume was expected. In order to make corrections, the

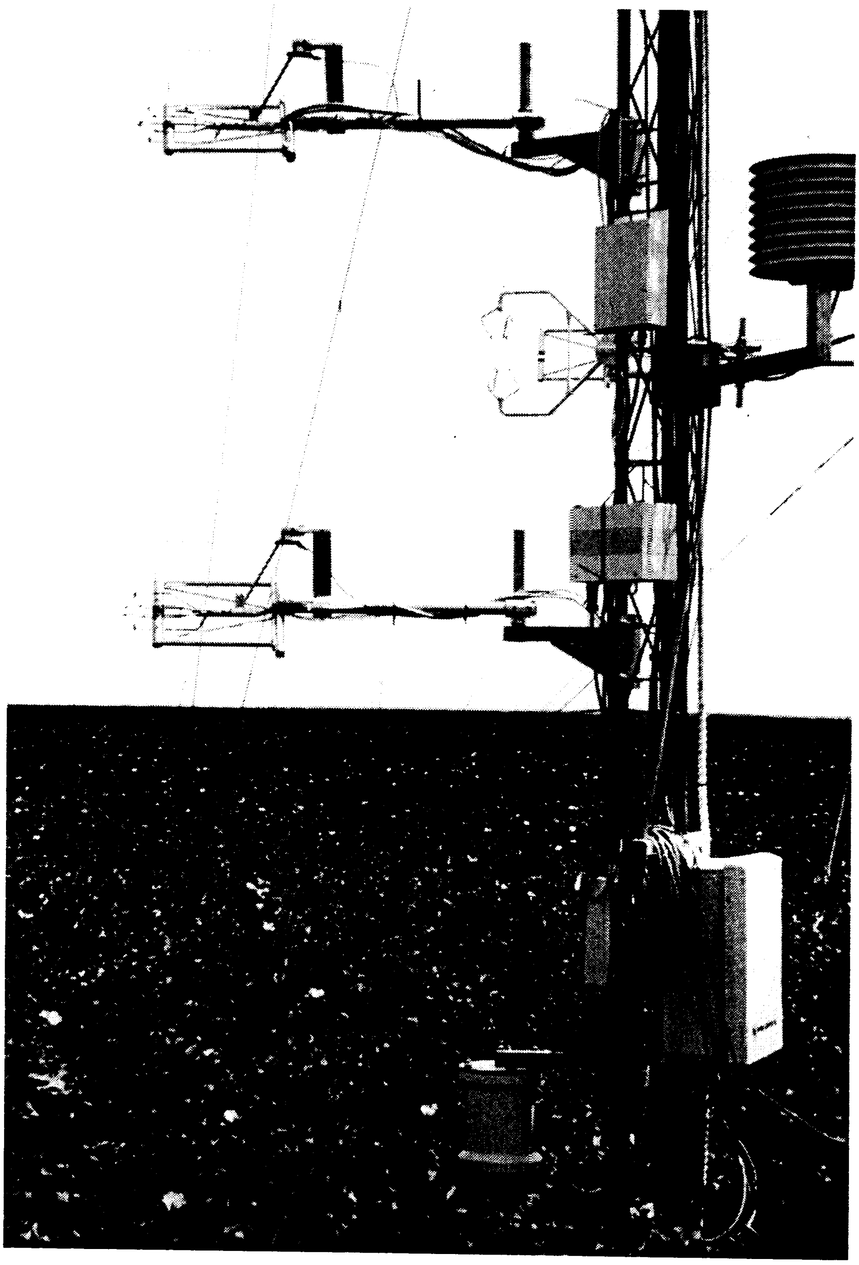

Fig.3 The set-up of the two turbulence packages (left) and the slow temperature and relative humidity beehive screen. The third sonic left from the beehive is in a different tower

package (without the tiny temperature probe) was tested in a wind tunnel. An example of the w (vertical) response as a function of azimuth and elevation is given in Fig.4. In this figure, the vertical wind component as measured by the sonic is divided by the calculated vertical wind component, that is the wind tunnel wind speed times the sine of the elevation angle. It is seen that the response is a-symmetric in azimuth and depends on elevation. The asymmetry is caused by the asymmetric position of the Krypton. It is further noted that the response deviates significantly from ideal (=1). Deviations of 20% are present at certain azimuth angles. A way to apply the wind tunnel results to the field measurements is to correct every sample by interpolation in the wind tunnel response tables. There are two concerns here, however. First, the set up in the wind tunnel was not symmetric regarding positive and negative elevation because the instruments were.mounted on a pole that turned on an axis under the base of the tunnel. At positive elevation the pole is slanting backwards in the wind and may induce a vertical wind component. Secondly, it is questionable to what extend the results found in a wind tunnel were the flow has little turbulence are applicable in a highly turbulent atmosphere. In view of the wind tunnel results, and these considerations we decided to apply a correction of –15% to the sensible and latent heat flux, independent of azimuth and elevation angle and wind speed.

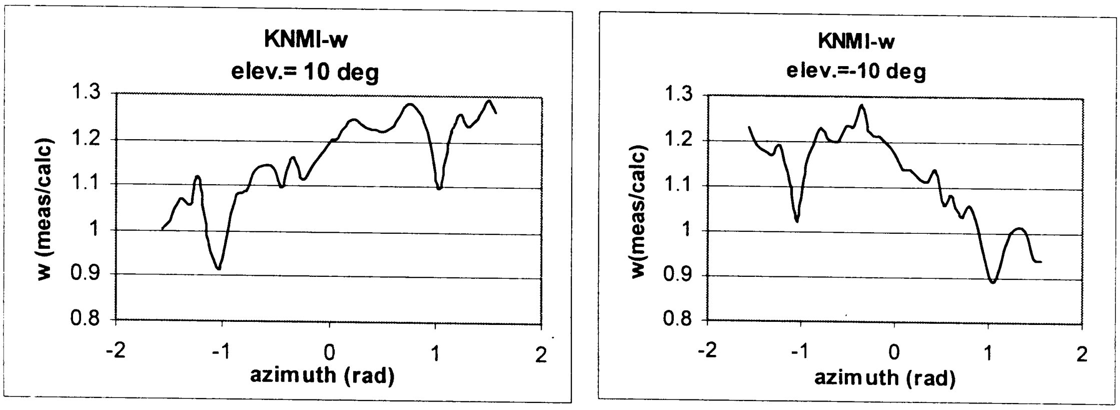

Fig.4 Response of the sonic's vertical wind component (measured/calculated) as function of azimuth angle (rad) and for two elevation angles

The Krypton hygrometer was laboratory calibrated just before and just after the experiment. In the first calibration, performed by WAU, the path length was kept fixed and the humidity was changed. In the second calibration, after the experiment, the path length was varied and the humidity was constant (procedure applied by the Bayreuth group). Table 3 gives the results. Also the manufacturer's calibration (who followed the first procedure) and a calibration performed by WAU a year after EBEX is given there. With respect to the w'q' covariance, only the slope $1/xK_w$ is of importance. It is seen that the calibrations just before and just after EBEX agree well and that the manufacturer's values of xK_w are somewhat smaller than the other values, in particular for instrument #1353. The calibration a year after EBEX is almost identical with the calibration just before, showing that the slope is stable. The calibration just before EBEX was used in later calculations.

Table 3. Calibration Krypton hygrometers: $\rho(g/m^3) = -1/(xK_w)(\ln V - \ln V_0)$, V and V_0 in mV

# 1334			# 1353		
ref (month/year)	xK	$-\ln V_0$	ref (month/year)	xK	$-\ln V_0$
Campbell(9/1998)	0.1859	8.6205	Campbell (1/1999)	0.1833	8.5493
WAU (6/2000)	0.1911	8.2218	WAU (6/2000)	0.206	7.8469
Foken (8/2000)	0.1944	10.7705	Foken (8/2000)	0.2127	10.5658
WAU (7/2001)	0.1915	8.0389	WAU (8/2001)	0.2096	7.9250

The thermocouple probe was calibrated by WAU in a thermostatted bath. A fourth order polynomial described its response adequately.
The turbulence data were recorded on a Campbell 23X data logger at a rate of 20 Hz. The data were automatically downloaded on a small-sized laptop every minute. Each package had its own data logger and laptop. About every day the data from the two laptops were transferred to another laptop that could hold all data. During the data transfer the measurements were interrupted (typically, a half-hour was lost).

2.3 Screen temperature and humidity (Fig.3)

A Vaisala type HMP233 relative humidity sensor, placed in a KNMI screen (no forced ventilation) was employed. This sensor incorporates a Pt100 temperature probe for internal purposes, but the signal from the Pt100 is also externally available for independent registration. The sensor was calibrated in the KNMI climate chamber for humidity and temperature. Data collection was on the same Campbell 21X logger as for the net radiometer.

3. Data processing

First, the turbulence data were transferred from the Campbell binary format (.dat) to NetCDF (.nc) format. Thereafter average quantities, (co)variances, standard deviations and fluxes together with their errors are calculated with a computer program developed at WAU. In this program several corrections can be set, such as for trend, the sonic temperature, oxygen sensitivity of the Krypton hygrometer, co-ordinate rotation, time response, sensor separation etc. At the moment of this writing we have calculated half-hour averages.

4. Weather and field conditions

A very stable weather pattern was met during EBEX, with many cloudless days and light winds from the NW to N. No precipitation was recorded. The temperature in the cotton field showed a strong daily variation with a maximum of typically 30-35 °C and a low of 15-20 °C, and the relative humidity ranged typically from 30% to 90%. The cotton was planted on ridges that ran E-W across the field with a separation of about 1 m. These ridges lay about 0.3 m above the interspersed furrows. The furrows provided the natural pathways to the measuring sites. The cotton field was irrigated at an interval of approximately 2 weeks by means of siphoning water into the furrows from a canal that ran parallel to western edge of the field. Irrigation started at the north and it took 4-5 days to complete. During the first 2-3 days after furrows were filled with water, they were very muddy and virtually inaccessible. The cotton canopy was not closed, the degree of closure increasing during the experiment.

5. Some results

We present here some results of the KNMI/WAU equipment. Emphasis is on the fluxes of heat and moisture and the net radiation. Since our group did not measure the soil heat flux, it is not possible to make-up the energy budget here.

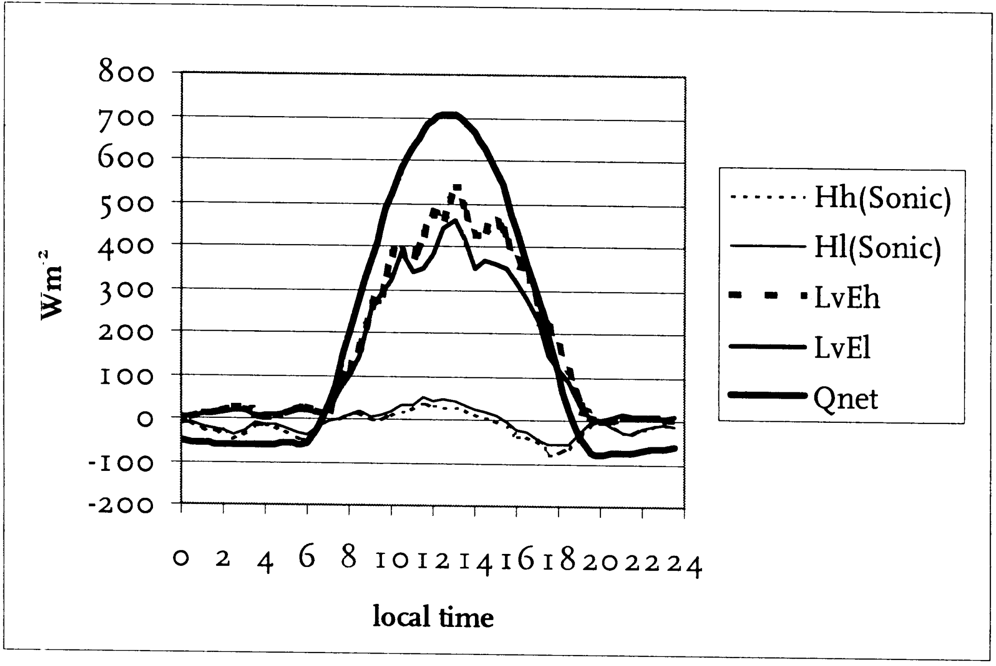

Fig.5 Daily course of the net radiation (Qnet), the sensible (H) and latent (LvE) heat flux on two levels (high and low) on DOY 226 (13 August 2000).

Fig.5 presents the daily courses of the net radiation, the sensible and the latent heat flux on two levels for a particular day. It is noted that the sensible heat flux is small as compared to the other fluxes. In the early afternoon it changes sign and the atmosphere has a near-neutral stratification. The latent heat flux is large, leading to a moisture loss of about 6 mm per day. Remarkably, the latent heat flux at the upper (2.76 m) level is larger than the one at the lower (1.76 m) level. This situation was met throughout the experiment as shown by Fig.6, a scatterplot of the latent heat flux at the two levels. Fig.7 shows that the standard deviation of the vertical wind and Fig.8 that the standard deviation of moisture is equal at the two levels, on the average. This suggests that the w-q correlation at the lower level is smaller than that at the upper level. Such may have to do with the close presence of the plants at the lower level, leading to extra turbulence that does not carry away moisture. This hypothesis does not explain the divergence, however. The sensible heat flux did not show a divergence (Fig.9). Sensible heat fluxes obtained from the thermocouple wire compared well with those from the sonic temperature, except for very stable (large negative H values) conditions (Fig.10).

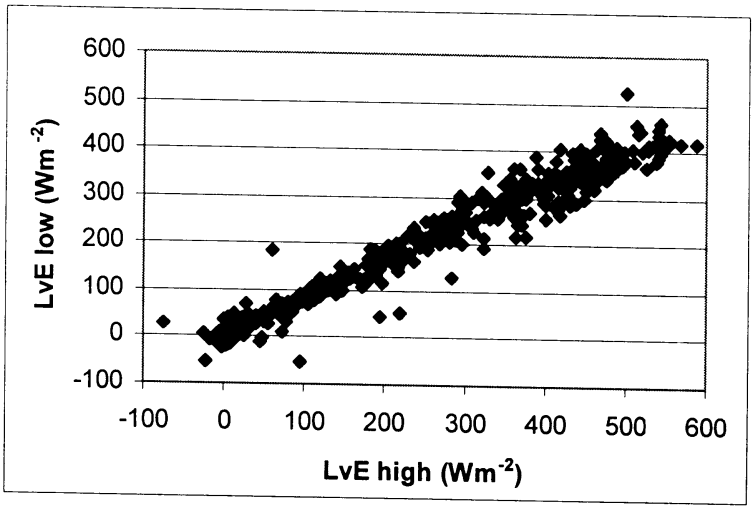

Fig.6 Scatterplot of the latent heat flux at the lower and the upper level. Half-hour averages

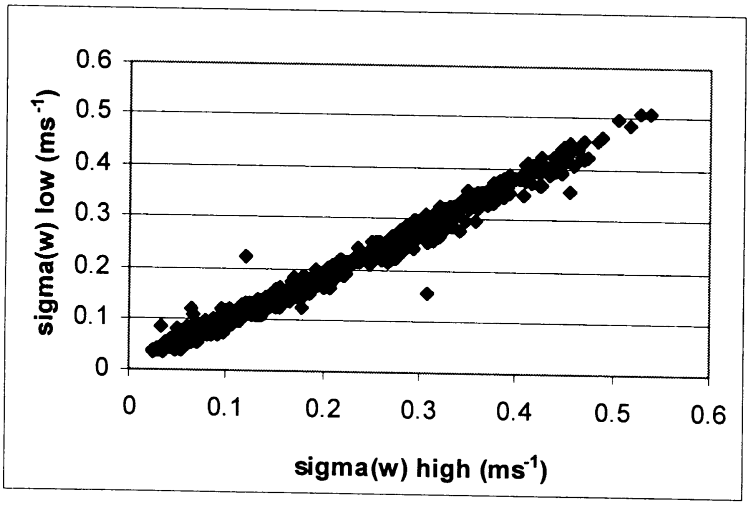

Fig.7 Scatterplot of the standard deviation of the vertical wind speed at the lower and upper level. Half-hour averages

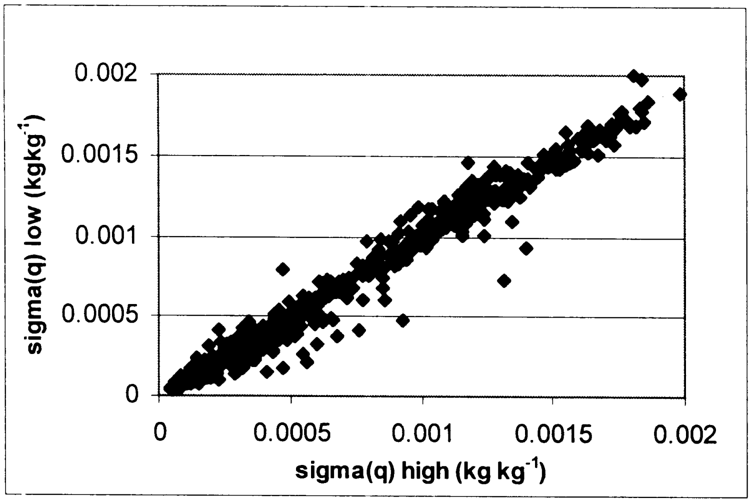

Fig.8 Scatterplot of the standard deviation of the specific humidity at the lower and upper level. Half-hour averages

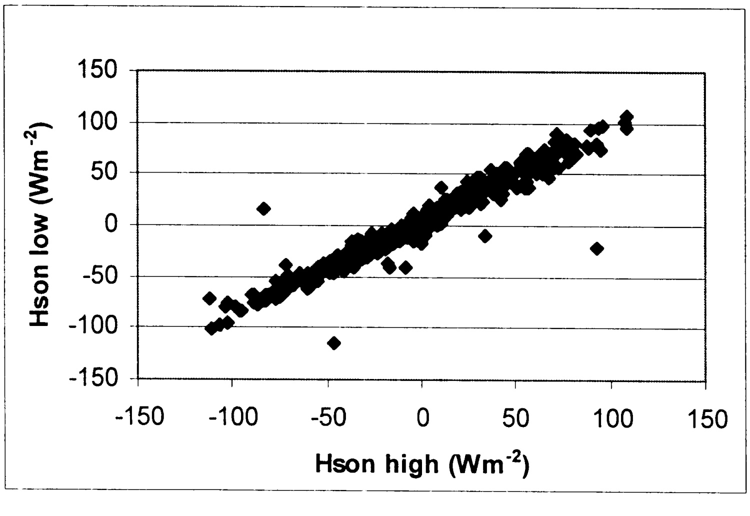

Fig.9 Scatterplot of the sensible heat flux at the lower and the upper level. Half-hour averages

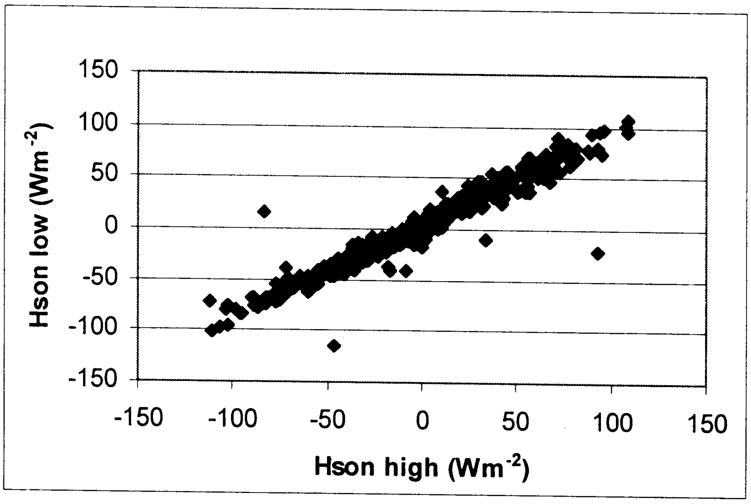

Fig. 10 Scatterplot of the sensible heat flux at the upper level as measured with the sonic anemometer temperature signal and the thermocouple sensor

6. Outlook

In the near future the analysis of all EBEX data will take place. This includes comparison of turbulence instruments (during the first week of EBEX several turbulence packages were mounted on near-by masts at the same level; one of our packages was included), comparison of incoming and outgoing shortwave and longwave radiation, the distribution of soil heat flux between furrows and ridges, the energy balance, boundary-layer characteristics, photo-synthesis etc. In March 2002 the second workshop will be held.

7. Literature

Foken, T., and Oncley, S.P. (1995): A report on the workshop "Instrumental and methodical problems of land-surface flux measurements". *Bull. Am. Soc.*, **76**: 1191-1193.

Oncley, S.P., Vogt, R., Liu, H., Pitacco, A., Ribero, L., Foken, Th., Bernhofer, Ch., Sorbjan, Z., and Grantz, D. (2000): The EBEX 2000 field experiment. 14th Symposium on Boundary Layer and Turbulence, Aspen CO (USA), 7-11 Aug. 2000, Am. Meteorol. Soc., Boston, 322-324.