Mobile Turbulence Measurements of Heat Fluxes over Tibetan Plateau

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ABSTRACT

During the GAME-Tibet IOP in 1998, an attempt was made to measure turbulence fluxes of the latent heat as well as the sensible heat using an measurement configuration that was designed to be minimum, light and portable. This measurement strategy, called "Mobile Turbulence Measurement", is aimed, 1) to calibrate energy transfer coefficients for each of the Tibetan AWS array located along the North-south Tibetan highway, which would reveal the latitudinal distribution of the surface energy components, and 2) to serve as a reference for the indirect comparison between the measurements at two different flux sites, where the surface energy components were fully measured.

The measurement system, all of which is battery powered, includes an 3D sonic anemometer, capacitance-type humidity sensors, a portable logger and a tripod. All of the data was logged at 10 Hz, and was stored in a specially designed logger. The measurements with this system at four sites, two full flux measurements sites and two AWS sites, yields about 180 hours of turbulence data; two to three days of measurements at each station. Sensible heat flux was computed with the ordinary eddy covariance method applied the sonic measurement data, while latent heat flux was estimated through the indirect methods such as the bandpass covariance technique. The presentation will mainly focus on the result of bandpass covariance technique.

1 Introduction

Methods for measuring turbulent fluxes, such as sensible and latent heat flux or CO_2 flux, on a mast of 1 to few tens meters are available. It is a relatively difficult task, however, to measure these fluxes at a regional scale, say at the scale of 10 to 100 km^2 . One possibility for this is to obtain measurements at the upper surface layer using an aircraft, radiosondes and so on [see e.g. Parlange et al., 1995, for review], or to obtain regional information on the surface using sattelite-based remote sensing. Another possibility is distributing flux sites as many as possible in the target area with a minimum time and labor, as less as possible, on each station. In general, building up and maintaining a flux site takes a lot of labor, time and expense, and reducing these costs is a key to the success in the measurements. On one hand, even if the flux at each site can be measured successfully, there still is an issue of the difference in the observed flux values that can arise from the difference in the sensors used in the measurements which could be at the same order of the magnitude with the real flux distribution. Therefore, the intercomparison of the sensors are always necessary in the this kind of task.

During the GAME-Tibet IOP in the 1998 summer, an attempt was made to measure turbulent fluxes of the sensible and the latent heat flux using an portable measurement system with minimal equipments and sensors. This paper describes the measurements and

the analysis of the acquired data.

2 Mobile Turbulence Measurements

2.1 Strategy

During the GAME-Tibet IOP in 1998 summer, two type of site-fixed surface flux measurements were made. One involves the full measurements of surface heat budget components, including the net radiation measurement with radiometers and measurements of turbulent fluxes with turbulence devices, such as the sonic anemometers. This type of measurements were located at the two super sites, Amdo and Naqu [Choi et al., 2001] flux sites. The other type of the surface flux measurements is with the automatic weather stations (AWSs), which is equipped with the minimal sensors for the air temperature and humidity, the wind speed at the one-level, the solar radiation, and the surface temperature. This AWS was placed at 4 stations along the Tibetan Highway and the array of AWSs combined with he full-measurement type flux stations and the PAM (Portable Automated Mesonet) stations aimed at elucidating the north-south contrast of the surface heat budget over the Tibetan plateau.

In order to produce homogeneous flux data set out of the measurements at the two full-measurement type flux sites, PAM sites and the AWS array, a single portable flux measurement system was employed for a working reference and a validation reference. This measurements strategy called "Mobile turbulence measurements" was designated to interconnect these flux measurements in two ways: 1) As the two full-measurement type flux stations employ different sensors especially for the turbulent flux measurements, an intercomparison is necessary. The mobile flux measurements enable intercomparing these sensors on-site with a single portable sensor as a working reference. 2) As the AWS only has a one-level measurement, a validation reference is needed to compute the drag coefficient and transfer coefficients with which the fluxes are estimated. For these purpose, turbulence data was collected at each stations for at least one day to capture a daily variation using a light-weight and portable measurement system.

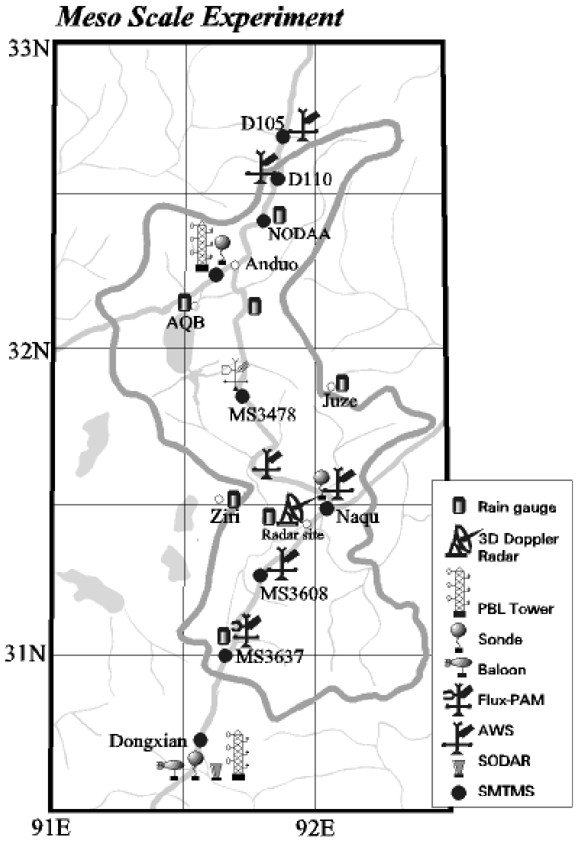

Figure 1: Schematic map of GAME-Tibet mesoscale observation area showing the measurements stations in GAME-Tibet IOP 1998.

2.2 Equipments and Sensors

Measurement system used in the mobile turbulence measurement, here called as "Mobile turbulence system", is composed of the sensors listed in Table 1, a order-made logger, a tripod, and a battery. The sonic anemometer of Kaijo measures the turbulence component of the 3D wind speed, u, v, w, and the temperature, T, while two of the capacitance-type humidity meter, Vaisala Humicap and AIR Humair, gives T and RH, and thereby q, with relatively slow response sensors. Specifically, Humicap was intended to give a mean T, q, whereas Humair, faster in response than Humicap but slower than ordinary turbulent devices, gives a quasi-turbulent component of q, which will be used for the latent flux calculation. The frequency response of the two humidity meters will be investigated later in this paper. All of the sensors are mounted on a tripod at about 1.5 to 2 meter above the ground, and all of the system runs on a battery. Data sampling rate is 10 Hz, and all of the unprocessed data are stored in

Table 1: Sensors used in the mobile turublence system

Sensors			Measured variables
Sonic anemometer thermometer	Kaijo	DA-100	Turbulence (u, v, w, T)
Capacitance-type humidity meter	AIR	HumAir	T, RH
	Vaisala	Humicap	T, RH

Table 2: Measurement site and period of the mobile turbulence measurements.

Site	Period	Length (hrs)
Full flux sites		
Amdo	05/23 11:50 – 05/24 06:50	19.0
	07/31 14:50 – 08/02 13:50	45.8
Naqu	08/05 17:10 – 08/06 10:40	16.6
	08/08 11:40 – 08/09 16:00	27.6
AWS sites		
D110	06/01 12:50 – 06/03 10:40	46.0
MS3608	08/11 16:40 – 08/12 17:10	24.5
Total		179.8

a order-made logger with a 10 minutes segment in one file. Whole measurement system can be transported in a carrier of a single Pajero-type vehicle, and, therefore, it can be moved anywhere to start the measurements.

With these equipments, measurement sequence follows as this. After arriving at the site, the measurement system was set up, which usually took less than two hours with two to three person, and the measurement was started up. The measurement was continued more than one day in order to capture the full diurnal variation, and then one day or two day later, the whole system was again packed and loaded on the vehicle to move to another site. After continuing this sequence, data of about 180 hrs were collected at four sites, two full flux sites and two AWS sites (see Table 2), which is subject to the analysis in this study.

3 Data Analysis

All of the data were first checked in terms of their quality, and then three consecutive data files, each 10 minutes long, were connected to form a 30 minutes data run that is subject to the analysis.

First of all, spectra were calculated out of the T and RH measured with the sonic anemometer, HumAir, Humicap to investigate the frequency response of sensors in HumAir and Humicap, and an example of the results are shown in Figure 2. With the vertical axes representing spectrum times frequency, turning points between $fS \sim f^{-2/3}$ and $fS \sim f^1$ clearly divide the turbulent signal and the white noise. These figures shows that the HumAir has a slightly better frequency response than the Humicap, and that both for the HumAir and for the Humicap, the frequency response of the thermometer is more critical than that of humidity meter to the specific humidity computed out of them, which has been experienced by many field observers.

As shown in Figure 2, both of the two humidity meters used in the observation are not fast enough to capture the whole spectral range of the turbulence fluctuation of q. Then, $\overline{w'q'}$ estimated from this q values underestimates the latent heat flux. In order to calculate the latent heat flux, the bandpass covariance method, or the band pass covariance technique [e.g., Hicks and McMillen, 1988; Watanabe et al., 2000; Yasuda and Watanabe, 2001] was used. This method assumes that the similarity holds between T and q in a certain frequency range, and by utilizing this similarity the lost covariance of $\overline{w'q'}$ in the high frequency can be recovered. If we divide the covariance $\overline{w'\theta'}$ and $\overline{w'q'}$ into three frequency range,

$$\overline{w'\theta'} = \overline{w'\theta'}_{lp} + \overline{w'\theta'}_{bp} + \overline{w'\theta'}_{hp} \quad (1)$$

$$\overline{w'q'} = \overline{w'q'}_{lp} + \overline{w'q'}_{bp} + \overline{w'q'}_{hp} \quad (2)$$

where $_{lp}$,$_{bp}$,$_{hp}$ denote lowpass, bandpass, and highpass components of each covariance, respectively. If we set this each frequency ranges such that the measurement of q with slow response sensor does not capture the actual fluctuation in the highpass range, the measured value of $\overline{w'q'}_{hp}$, denoted here as $\overline{w'q'}^{m}_{hp}$, is underesti-

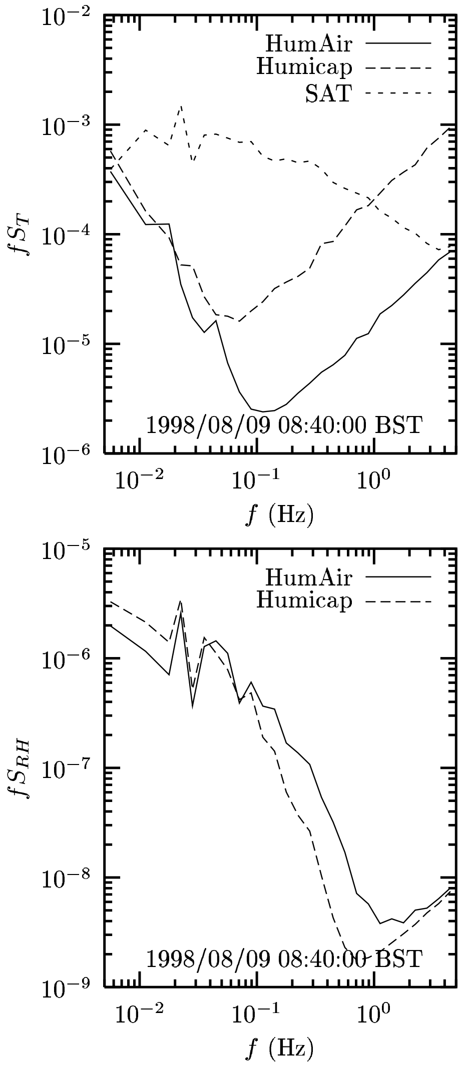

Figure 2: Spectrum of measured T(above) and RH(below).

mated, as

$$\overline{w'q'}^{m}_{hp} < \overline{w'q'}_{hp} \quad (3)$$

If we assume that the similarity between T and q is satisfied in the bandpass range, then

$$\frac{\overline{w'q'}_{bp}}{\overline{w'\theta'}_{bp}} = \frac{\overline{w'q'}_{hp}}{\overline{w'\theta'}_{hp}} \quad (4)$$

Using equation (4), $\overline{w'q'}_{hp}$ is compensated and the whole covariance can be estimated as,

$$\overline{w'q'} = \overline{w'q'}_{lp} + \overline{w'q'}_{bp}\left(1 + \frac{\overline{w'\theta'}_{hp}}{\overline{w'\theta'}_{bp}}\right) \quad (5)$$

Equation (5) was applied to the q measurements with HumAir as well Humicap. An example of the results, given in Figure 3, shows the estimated latent flux values with the bandpass covariance technique with the estimation with the complete eddy covariance technique at Naqu[Choi et al., 2001]. The comparison with the complete eddy covariance technique at Naqu[Choi et al., 2001] (denoted as “Tower” in Figure 3) demonstrates that the bandpass covariance technique improves the computed value of the latent heat flux. It is also shown in Figure 3 that not only the q data from HumAir but also that from the Humicap can be used with the bandpass technique. This indicates that even a generally-used humidity meter can capture, though partially, the turbulent flux of water vapor. This can be simply explained by the fact that the time constant of the such a “slow response” humidity meter is at the order of 10 seconds, while the characteristic time of the largest eddy of the turbulence is at the order of 100 seconds. The presentation will discuss more in detail about this topic.

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References

Choi, T., J. Kim, H. Lee, J. Asanuma and J. Wang, 2001: Measuring turbulent exchange of heat and water vapor over a praire site in the central Tiebetan plateau. *Boundary-Layer Meteorol.*, **submitted**.

Hicks, B. and McMillen, 1988: On the measurement of dry deposition using indirect sensors and in nonideal terrain. *Boundary-Layer Meteorol.*, **42**, 79–94.

Parlange, M. B., W. E. Eichinger and J. D. Albertson, 1995: Regional scale evaporation and the atmospheric boundary layer. *Review of Geophysics*, **33**, 99–124.

Watanabe, T., K. Yamanoi and Y. Yasuda, 2000: Testing of the bandpass eddy covariance method for a long-term measurement of water vapor flux over a forest. *Boundary-Layer Meteorol.*, **96**, 473–491.

Yasuda, Y. and T. Watanabe, 2001: Comparative measurements of CO_2 flux over a forest using closed-path

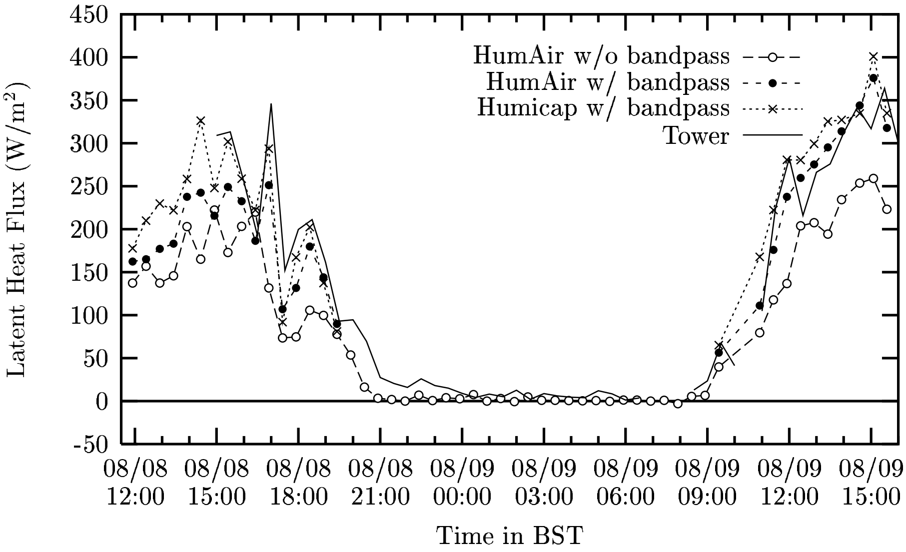

Figure 3: Computed latent heat flux values at Naqu Flux site. Tower denotes the computed values through the eddy covariance from the observation with full flux measurements.

and open-path CO_2 analysis. *Boundary-Layer Meteorol.*, **100**, 191–208.