P9.5 ***INFLUENCE OF NONLOCAL ADVECTION ON SURFACE FLUXES OVER A VEGETATED SURFACE: EVIDENCE FROM EBEX 2000 FIELD DATA***

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1 INTRODUCTION

During summer of 2000 an Energy Balance Experiment (EBEX 2000) was conducted in San Joaquin Valley, California over a flood-irrigated flat cotton field with an area of 1.6 km by 0.8 km. The primary purpose of the experiment was to investigate the main reasons of the non-closure of the surface energy balance through taking into account various measurement errors and corrections, different footprints of the energy balance components, vertical and horizontal flux divergences, energy sources in the canopy and the upper soil layer, non steady state conditions and different time constants of the fluxes and meso-scale processes (Foken and Oncley, 1995; Oncley et al., 2002).

Although the site was carefully chosen to be visually homogeneous, flood irrigation patch-by-patch created a step change in soil moisture regime. This heterogeneous property in the soil moisture caused different partitioning of the available energy into sensible and latent heat fluxes, leading to a difference in turbulent structure in the surface layer from patch to patch. Major interest involves the interaction between turbulence fields present in the inner-layer and the outer-layer. Consequently this interaction modifies the downstream profiles of temperature, wind speed, and moisture, and subsequently having great impacts on the development of internal boundary layer (Garratt, 1990). In this paper, we present data to investigate the effects of the outer-layer turbulence on the downstream energy exchanges, profiles and turbulent spectrum.

2 MEASUREMENTS

An array of nine similar stations illustrated by nine numbers in Fig. 1 was setup over a flat cotton field with a size of 1.6 km by 0.8 km.

The canopy height was approximately 0.8 m. Each station consisted of either eddy covariance towers or gradient measurement towers or both. We used the data measured at Station 7 that included two-level eddy covariance systems at 2.7 and 8.7 m above the canopy and a profile measurement system to obtain dry-bulb and wet-bulb air temperatures by aspirated psychrometers at 0.7, 1.2, 1.7, 2.7, 3.7, 4.7, 5.7, 6.7, 7.7, 8.7, 9.7, and 10.7 m above the canopy, and wind speed by cup anemometers at 1.2, 1.7, 2.7, 3.7, 4.7, 5.7, 6.7, 7.7, 8.7, 9.7, and 10.7 m above the canopy.

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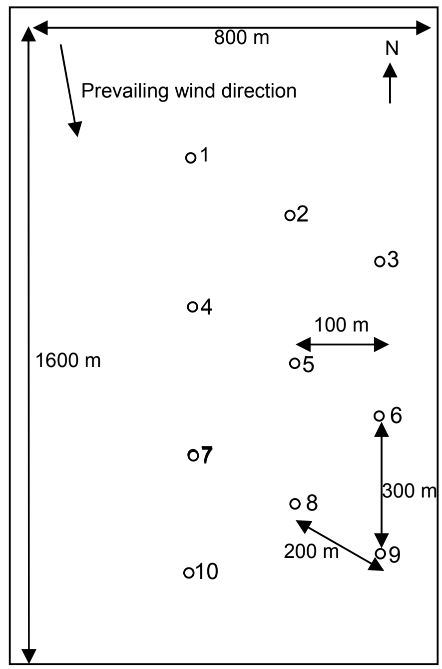

Figure 1. EBEX-2000 experimental site in San Joaquin Valley, California over a flood-irrigated flat cotton field with an area of 1.6 km by 0.8 km

Eddy fluxes of sensible (H) and latent (LE) heat were measured in each level by an eddy covariance system that consisted of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific), a fine-wire fast-response thermocouple (Campbell Scientific), and an open-path hygrometer (KH20, Campbell Scientific). Sonic anemometers measured fluctuations of three components of wind velocity and fluctuations of sonic temperature of the atmosphere. Hygrometers measured fluctuations of densities of water vapor.

Along with the turbulent fluxes, a variety of micrometeorological variables were also measured as 30-min averages of 1 s readings. Net radiation was measured with net radiometer (Model Q-7.1, REBS). Additionally, thermocouples and soil moisture probes (CS615, Campbell Scientific) were buried at several depths to measure the profiles of soil temperature and soil moisture. The soil heat flux (G) at a depth of 10 cm was measured with two soil heat flux plates at each site (Model HFT3, REBS).

During the field campaign from July 20 to August 24, 2000, a very clear sky with few clouds and moderate northerly winds was present.

3 RESULTS

3.1 Characteristics of Turbulent Fluxes

Very smooth change in net radiation is attributed to the clear sky (Fig. 2). However, this smooth radiative forcing does not generate a smooth turbulent exchange (e.g., sensible and latent heat fluxes) even for the daytime (Fig. 2).

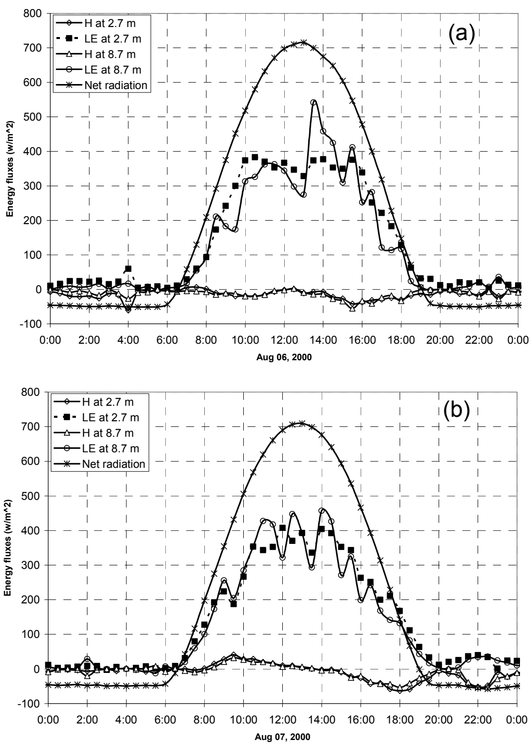

Figure 2. Influence of the outer-layer turbulence field on the inner-layer turbulent fluxes under a dry-to-wet transition on August 6 (a) and August 7 (b), 2000.

It is interesting to notice that latent heat fluxes increase greatly while sensible heat fluxes are fluctuating around zero during the day (Fig. 2a).

Since the irrigation of the whole field was made patch to patch for four or five times from north, the soil moisture availability is different from site to site in the field. This created a dry-to-wet transition from north to south. On August 6 and 7, Station 7 was still muddy as the irrigation had just passed this station. Therefore, this station experienced a warm-dry air advection from upstream areas given the northerly winds for these days.

Under this non-local advection, the entrainment of the dry-warm air with different turbulent structure from above causes an interaction between the locally generated turbulence and the outer layer turbulence (McNaughton and Laubach, 2000). This kind of inactive turbulence could lead to the flux fluctuations especially for latent heat fluxes with larger effects at higher levels. In particular, this outer layer turbulence with warm-dry characteristics can create high water vapor pressure deficit, and cause an enhancement in latent heat flux which can be greater than the net radiation (e.g., at 18:00 LT). On contrary, the locally generated turbulence is decreasing rapidly and become weak in the late afternoon.

It can be seen that the sensible heat flux becomes negative during the daytime given the quite high net radiation. Two causes may be responsible for this phenomenon. One is related to the downward entrainment of the warm-dry air to lead to the heating of the higher level air. The other is due to the large latent heat flux that keeps cooling the surface and the lower level of the surface layer. Combination of the above factors generates a negative air temperature gradient during this period (see Fig. 3).

3.2 Daytime Stable Internal Boundary Layer (Warm-Cool Transition)

Daytime stable internal boundary layer (SIBL) has been found to develop at Station 7 in the EBEX 2000, which may result from this warm-cool transition due to the non-uniform irrigation and the presence of the dry bare surface in the upwind direction under the influence of northerly winds.

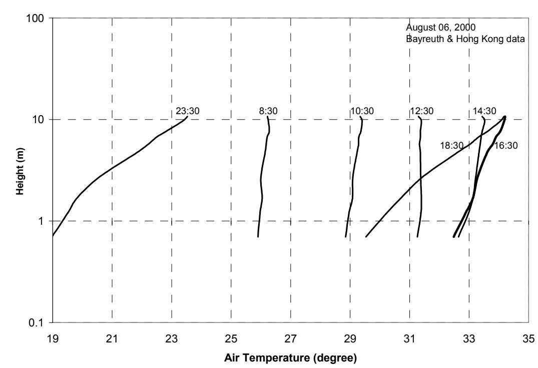

Figure 3. Stable internal boundary layer development during the day on August 06, 2000.

The profile data at Station 7 during the period from August 3 to 8 and from August 17 to 20 can be used for extracting the information about SIBL development. In this case, latent heat fluxes increase at the expense of sensible heat flux. The extra energy for evaporation should be supplied by a downward sensible heat flux, which is maintained in turn by horizontal advection (Kaimal and Finnigan 1994).

The air temperature profiles on Aug 06, 2000 are present here to show the formation about the SIBL (Fig. 3). The SIBL developed below 9 m during the daytime (e.g., 8:30, 10:30, 14:30, 16:30 LT and etc.) while a convective boundary layer may be present in the higher levels that are strongly affected by the upwind dry-warm air.

Moreover, the stable internal boundary layer may develop in multiple layers and the interaction between different layers with different turbulence characteristics may occur due to the highly inhomogeneous surfaces in soil moisture from patch to patch.

3.3 Spectrum

The variations of the latent heat fluxes during the daytime suggest the strong influence of the possible non-local advective processes. The analyses from the daytime spectrum suggest the presence of non-local advection with different scales. Also, the features can be explained well by the interaction of active and inactive turbulence (McNaughton & Laubach, 2000).

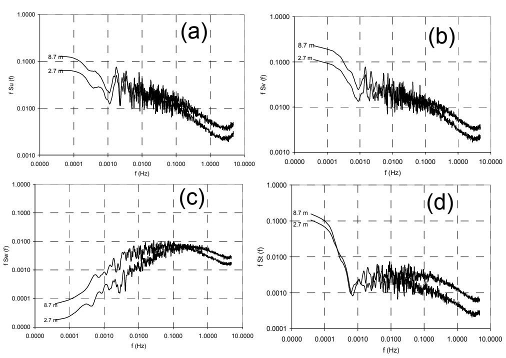

Figure 4. Power spectra of wind velocity for streamwise (a), lateral (b) and vertical (c) directions, and temperature (d) at both 2.7 and 8.7 m

4 CONCLUSIONS

The negative Bowen ratio during the daytime and nighttime suggests presence of advection processes although the oasis effect due to strong evapotranspiration might be another possibility. The interaction between the locally generated turbulence and the outer layer turbulence should be taken into account in explaining the turbulent structure and flux exchange.

The non-local processes mentioned above have great influences on the closure of the surface energy balance. For example, the dry-warm advection during the daytime can cause the strong additional evaporation. Consequently latent heat fluxes can be greater than net radiation (e.g., at around 1800 LT August 5, after 1700 LT on August 7)

The strength of these non-local processes varies with the soil moisture availability during the experiment period. This can be seen from day-to-day variations of partitioning of the available energy into sensible and latent heat fluxes.

All these features can be related to the investigation of the stable internal boundary layer (e.g., Aug. 03-08, and Aug. 17-20 for the site 7) and convective internal boundary layer development (e.g., Aug 14-16 for the site 7).

We should be careful in our analyses when using the one-dimensional formula or Monin-Obukhov similarity due to the non-local effect.

5 ACKNOWLEDGMENT

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