1. Introduction

Data set of temporal variations of heat and water vapor fluxes (sensible and latent heat fluxes) is necessary to predict precipitation activity over land surface. Behavior of atmospheric boundary layer (ABL) also affects for the precipitation activity through the land-surface processes (exchange processes of sensible and latent heat fluxes) and through the interaction with cloud-layer. In additions, vegetation and/or land-use change will have impacts for the change of ABL structure. Therefore it is necessary to monitor the surface (vegetation) condition, (regional) surface fluxes, ABL structures, and entrainment processes.

LAPS/CREST project focuses on the interaction of land surface processes with precipitation processes. It will carry out ABL observations using with “Flux Tower & Meteorological Observation System”, “Wind (& Temperature) Profiler”, “Microwave Water Vapor Radiometer”, and “Doppler Sodar (Acoustic Wind Profiler)”. Thus in this extended abstract, we will review how to estimate regional surface fluxes and how to evaluate entrainment processes from the one-dimensional profiles of wind speed, temperature, and humidity within the ABL.

2. Estimation of Regional Surface Fluxes

Convective boundary layer (CBL) is generally divided into three layers, i.e., surface sub-layer (SL), mixed layer (ML), and entrainment layer (EL) in turn from above the surface to the free atmosphere. If we have cloud in the entrainment layer partly or completely, EL is also defined as cloud-layer (CL). For the estimation of regional surface fluxes from one-dimensional profiles, we can apply three approaches described below.

2.1. Temporal Scalar Budget Approach

In the absence of subsidence, the conservation equation for a given scalar is classically written as (Lhomme et al., 1997)

$$\frac{dh}{dt} \frac{dC_m}{dt} = F_0 + (C_f - C_m) \frac{dh}{dt}$$

(1)

where \(h\) is the CBL depth, \(C_m\) the scalar concentration of the well-mixed layer, \(t\) the time, \(F_0\) the
surface flux, \( C_f \) the scalar concentration in the undisturbed atmosphere (free atmosphere or just above the capping inversion). By integrating (1) between an initial time \( t_1 \), when \( C_m = C_{m1}, C_f = C_{f1}, \) and \( h = h_1 \), and a time \( t_2 \) \((C_m = C_{m2}, C_f = C_{f2}, h = h_2)\), one obtains the integral form of the CBL budget (McNaughton and Spriggs, 1986)

\[
I_0 = \int_{t_1}^{t_2} F_0(t) dt = h_2 C_{m2} - h_1 C_{m1} - \int_{h_1}^{h_2} C_f(h) dh
\]

where \( I_0 \) is the cumulative surface flux between \( t_1 \) and \( t_2 \). With some parameterization, one can use (2) to evaluate the time-integrated flux of sensible heat and latent heat from mean profile measurements.

2.2. Mixed Layer (Bulk) Similarity Approach

In the steady state ABL, the ratio of inversion flux (entrainment flux; \( H_e \)) to the surface flux \( (H_0) \), \( H_e/H_0 \), is strongly related to \( z_i/L \) (Brutsaert and Sugita, 1991). This means that at least in the case of sensible heat, the incorporation of the entrainment flux \( H_e \) would lead to redundancy and it can therefore be omitted from the analysis. In the light of these considerations, a bulk similarity to the outer region (i.e., mixed layer) can be written as follows

\[
H_0 = (\theta_0 - \theta_m) k u_* \rho c_p \left[ \ln \left( \frac{z_i - d}{z_{0h}} \right) - C \left( \frac{z_i - d}{L} \right) \right]
\]  

(3a)

and

\[
lE_0 = (q_0 - q_m) k u_* \rho \left[ \ln \left( \frac{z_i - d}{z_{0v}} \right) - D \left( \frac{z_i - d}{L} \right) \right]
\]  

(3b)

where \( H_0 \) and \( lE_0 \) are the surface sensible and latent heat fluxes, \( \theta_0 \) and \( q_0 \) the surface potential temperature and specific humidity, \( \theta_m \) and \( q_m \) the characteristic potential temperature and specific humidity in the well-mixed layer, \( k = 0.4 \) von Karman’s constant, \( u_* \) the friction velocity, \( \rho \) the density of the air, \( c_p \) the specific heat at constant pressure, \( l \) the latent heat for vaporization, \( z_i \) the inversion height (height of the mixed layer), \( d \) the zero-plane displacement height, \( z_{0h} \) and \( z_{0v} \) the scalar roughness lengths for sensible and latent heats, \( L \) the Obukhov length, and \( C \) and \( D \) are the similarity functions, which are generally accepted to depend on \( z_i/L \) only (Brutsaert and Sugita, 1991). There are several proposals for the similarity function \( C = C \left( \frac{(z_i - d)}{L} \right) \) and \( D = D \left( \frac{(z_i - d)}{L} \right) \). We should evaluate the \( C \) and \( D \) functions for different ABL conditions but with no subsidence and no horizontal flux divergence.

2.3. Surface Sub-layer (Monin-Obukhov) Similarity Approach

If we could get mean profiles only within the surface sub-layer, the following Monin-Obukhov similarity theory could be applied for the determination of surface fluxes.
\[ H_0 = (\theta_0 - \theta_s) k u_* \rho c_p \left[ \ln \left( \frac{z - d}{z_{0h}} \right) - \Psi_h \left( \frac{z - d}{L} \right) \right] \] (4a)

and

\[ lE_0 = (q_0 - q_s) k u_* \rho \left[ \ln \left( \frac{z - d}{z_{0v}} \right) - \Psi_v \left( \frac{z - d}{L} \right) \right] \] (4b)

Where \( \theta_s \) and \( q_s \) are the potential temperature and specific humidity within the surface sub-layer, \( z \) the height above the ground, and \( \Psi_h \) and \( \Psi_v \) are the stability function of temperature and humidity profiles. This approach should be out of application if the surface is statistically inhomogeneous (e.g., Brutsaert, 1998). For the application of (3) and (4), surface parameter \( z_{0h}, z_{0v}, \) and \( d \) are necessary.

There is possibility to combine the bulk similarity approach with the Monin-Obukhov similarity approach. We have already proposed the combined similarity approach (CSA) for the evaluation of momentum flux using soundings of wind speed (Hiyama et al., 1999). If we succeeded to combine two approaches for the temperature and humidity profiles, surface parameters \( z_{0h} \) and \( z_{0v} \) could be omitted from the equation. The consideration of this possibility is one of the research topics in this LAPS/CREST.

3. Importance of Entrainment processes for Derivations of Surface Fluxes

If we can apply three-dimensional approach and assume no horizontal eddy flux divergences, mass and heat budgets within the convective boundary layer are derived as follows (Betts and Ball, 1994).

\[ \rho w' \xi' = - \frac{1}{g} \int_{p_0}^{p_t} \frac{\partial \xi'}{\partial t} dp - \frac{1}{g} \int_{p_0}^{p_t} \left( - \frac{\partial \xi'}{\partial x} u + \frac{\partial \xi'}{\partial y} v \right) dp - \frac{1}{g} \int_{p_0}^{p_t} w \frac{\partial \xi'}{\partial p} dp + \rho w' \xi', \] (5)

Where \( \xi \) is scalar variables, \( w \) the vertical wind speed, \( g \) the acceleration of gravity, \( p \) the air pressure, \( u \) and \( v \) are the longitudinal (x axis) and latitudinal (y axis) wind components. Subscript \( 0 \) and \( t \) indicate surface and top of the ABL, respectively. Left-hand side of (5) is the surface flux density. Fourth term in the right-hand side of (5) is the eddy flux density at \( p_t \). We can also refer to the non-surface terms in right-hand side of (5) as the budget contributions from local change (term 1), horizontal advection (term 2), and vertical advection (term 3).

Entrainment parameter \( (A_R) \) is convenient parameter for the estimation of heat and water vapor fluxes on the boundary of ML and EL. \( A_R \) is defined as follows (Betts, 1992).

\[ H_e = -A_R \frac{1 + (0.07/\beta_0)}{1 + (0.07/\beta_e)} H_0 \] (6a)

and

\[ lE_e = \frac{H_e}{\beta_e} \] (6b)
$A_R$ is an empirical constant (Stull, 1988), $H_e$ and $lE_e$ are the entrainment flux of sensible heat and latent heat, $\beta_0$ the surface Bowen ratio, and $\beta_e$ the inversion-level (entrainment) Bowen ratio. Equation (6) assumes that the entrainment virtual heat flux density is a constant fraction ($-A_R$) of the surface virtual heat flux density. The value for $\beta_e$ is possible to estimate from soundings immediately above the ABL, using a layer in which $\partial \theta / \partial q$ is relatively constant (Betts and Ball, 1994). Barr and Strong (1996) pointed out importance of vertical wind speed (vertical advection; third term of right-hand side in equation (5)) for the estimation of surface fluxes and $A_R$.

Grant (2001) implied that $A_R$ is changeable in different kinds of cloud ($Cu$, $Cb$, $Sc$, $St$, etc.). Thus the determination of $A_R$ in different cloud conditions is necessary for the derivation of heat and water vapor fluxes on the surface as well as entrainment fluxes.

4. Summary

We reviewed methods how to estimate regional surface fluxes using mean profiles within the ABL. We also suggested importance of entrainment parameter ($A_R$) and vertical wind speed (vertical advection) for the estimation of surface fluxes. If we can assume no meso-scale horizontal advection and no horizontal flux divergences, the regional surface fluxes could be estimated with the mean profiles measured with “Wind (& Temperature) Profiler” and “Microwave Water Vapor Radiometer”. Those precise time-series of profiles will be capable for the detection of meso-scale disturbance, thus we have great opportunity for the evaluations of cloud-capped boundary layer processes (e.g. entrainment process) for various kinds of cloud type as well as precipitation process and land-atmosphere processes.

References


