Surface Heat Balance using Flux Measurement Array during Catch A Plume by SATs (CAPS) IOP

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Abstract

The intensive meteorological observation, CAPS (Catch A Plume by SATs), was carried out twice over postharvest paddy field in northern Shiga prefecture, JAPAN in 2002, 2003. The objective of this project is to understand 1) the distribution of the sensible heat flux over homogeneous surface, and 2) it's influence for surface heat balance; 3) the behavior of the plume, which affects the temporal and spatial distribution of the sensible heat flux. The SATs array and the scintillometers were installed to measure the heterogeneity of the heat flux, with other instruments to complete the surface energy balance. Also surface temperature images were taken by the infrared camera from airplane. And the upper ABL sounding was held using a radio sonde, two SODARs and a lidar. This study is focused on the objective 1) and 2). In CAPS2002, the distance of each SAT was O(100m), and the array was extended 500×1500m horizontally using 16 SATs. The heat balance closure ratio was about 60%. The difference between max. and min. sensible heat flux was almost equal to the random error, and was about 30% of mean flux (77W/m^2) during 9-15 local time in clear condition, and the difference seems to be correspond to the surface temperature distribution. But this difference still does not explain the absence of heat. In CAPS2003, the distance of each SAT was O(10m), and the array was extended 100×200m horizontally using 17 SATs. The difference ratio of the sensible heat flux was smaller than CAPS2002. And the heat balance closure ratio was about 100% by averaging data of the multiple measurement sites.

Keyword: heat balance, imbalance, flux measurement array, CAPS.

1. Introduction

Many projects, such as GAME, have been held and are in progress, to understand the land-atmosphere interaction and the energy and water cycles, meanwhile there have been many problems related to the ABL observation as follows:

The energy (heat) imbalance: the underestimation of the turbulent energy ($H + lE$) flux compared to the forcing energy ($Rn - G$).

Footprint: the source area or the distribution of it's contribution ratio of turbulent flux.

Stationary convection (plume): although over the homogeneous surface, buoyant flow tends to occur in the same area.

Averaging time: if there is long period turbulence, too short averaging time to estimate turbulent flux would provoke underestimation.

The energy imbalance would be caused by the latter three problems.

The *Flux Enthusiasts Party* consists of those who are interested in such problems and the turbulence in ABL (Toda *et al.*, 2000). The intensive integrated ABL observation has been carried out by together with the *Flux Enthusiasts Party* and the *Lake Biwa Project* at the paddy field site of the *Lake Biwa Project*. The *Lake Biwa Project* has been developed and proceeded by a Japanese group for investigating the hydrological cycle near land surface. This observation was called CAPS (Catch A Plume by SATs; SAT is the Sonic Anemometer-Thermometer) because over 16 SATs were used in order to understand the dynamic structure of the plume and the convection in SBL.

The observation has been carried out twice in 2002 (CAPS2002) and 2003 (CAPS2003) autumn. In CAPS2002 and 2003, the distance of each SAT was O(100m) and O(10m) respectively. The footprints of each site in CAPS2002 were independent whereas the ones in CAPS2003 could be overlapped. Thus, the dynamic structure throughout scale from 10m to 1km will be resolved by using the data. In this paper, the distribution of the sensible heat flux and the heat balance is analyzed.

2. Observation

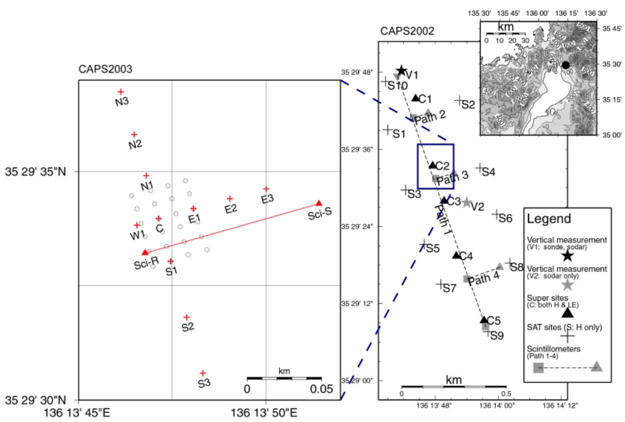

Fig. 1: Turbulent sensors' distribution map of CAPS2002, 2003. (Right) CAPS2002: Legend is indicated in map. (Left) CAPS2003: The line between ▲ shows scintillometer path. +: SAT site (C, S3, N3: 3 heights; C, S1, N1, E1, W1: with water vapor sensor), ○: fine wire thermocouple site.

The intensive observations have been performed during November 9 to 22, 2002 and October 1 to 10, 2003. Both periods were after harvest because the homogeneous surface and the greater sensible heat flux conditions were expected during these periods. The site was located near Lake Biwa in northern Shiga prefecture, JAPAN (**Fig. 1**). Prevailing wind direction was parallel to the paths between paddy fields, southerly (lake breeze) in daytime and northerly (land breeze) in nighttime under clear sky conditions. **Fig. 1** shows the distribution of turbulent sensors. These distribution were oriented parallel to the prevailing wind directions.

In CAPS2002, there were 15 SAT sites using 17 SATs in order to measure the heterogeneity of the heat flux. At every site, the installation height of SATs were about 2.5m. 4 of them (C1, C2, C4, C5 site) were with the open-path infrared gas analyzers, and SATs were installed at 3 heights (1.00, 2.45, 5.90m) especially at C4 site. To complete the rest term of the heat balance, other sensors were installed at C sites, only the sensors of C4 site worked well. The measurement area was extended 500×1500m horizontally. Also surface temperature images were taken by the infrared camera from airplane in November 17, 19, 20 under clear sky conditions. And the upper ABL sounding was held using a radio sonde and two SODARs. Details were described in Tamagawa *et al*.(2004).

In CAPS2003, there were 11 SAT sites using 16 SATs to make SAT array. Common SAT installation height was 2.5m the same as CAPS2002. C, S1, N1, E1, W1 sites were with the open-path infrared gas analyzers, and SATs were installed at 3 heights (1.25, 2.50, 5.00m) at C, S3, N3 sites. The most different point from CAPS2002 was that the measurement area was concentrated about 100×200m, centered at C2 site (called intensive paddy field) of CAPS2002. Since each tract of paddy field is about 30m width and 100m length, multiple SATs were in the same tract. Fine wire thermocouples were used to detect the passing plume near the surface. Surface temperature distribution was measured manually by the two infrared thermometer. The upper ABL sounding was held using a radio sonde, two SODARs and a doppler lidar.

The SATs used in CAPS were composed of 10 sets of DA-600 (Kaijo), more than 2 sets of 1210R3 (Gill) and a set of SAT-550 (Kaijo) and other types. Especially, DA-600 and 1210R3 were confirmed that their outputs were almost the same (within 10% difference) sensible heat flux by the eddy correlation method (Ishida *et al*., 2004).

3. Heat Balance

Each term of the heat balance equation:

$$Rn - G = H + lE$$

was measured independently and averaged for each hour. The net radiation Rn was measured by the pyranometers and the infrared radiometers. Since both observations were performed in less than 2km horizontal scale, downward radiation was homogeneous in the area. Upward radiation, however, depended on the surface conditions such as the albedo and the surface temperature. The soil heat flux G was measured by the heat plates. And the sensible and the latent heat flux H, lE was measured by the SATs and the infrared gas analyzers (e.g. LI-7500, Li-Cor). After the simple calibration of the absolute humidity a (Ishida *et al*., 2004) and the double axis rotations ($\overline{w} = 0$), the eddy correlation method ($H = c_p \rho \overline{w'T'}$, $lE = l\overline{w'a'}$) was applied. In this paper, the heat balance closure ratio is defined as the ratio of the left term to the right term of the heat balance equation.

3.1. CAPS2002

Only at C4 site, all terms of the heat balance equation were measured successfully. But the imbalance heat flux was up to $100\mathrm{Wm}^{-2}$ around the noon (**Fig. 2**), and the closure ratio was 60%. The heat imbalance of CAPS2002 might depend on the distribution of the surface conditions. The surface of C4 site was dark and wet. The albedo of this site was 5∼10% lower than the other sites, that means the net shortwave radiation input was nearly $55\mathrm{Wm}^{-2}$ lower around C4 site because the maximum incoming insolation was $550\mathrm{Wm}^{-2}$. And the maximum difference of the surface temperature was about 2 ℃ in the observation region (**Fig. 3**). It might influence G, H smaller and lE larger. All of these factors could make the local heat imbalance, but they don't explain all of the maximum imbalance ($100\mathrm{Wm}^{-2}$) explicitly.

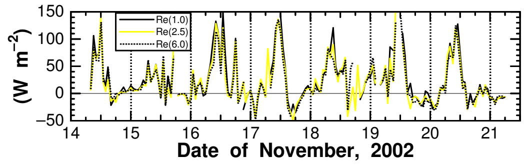

Fig. 2: The residual term of the heat balance of CAPS2002 at C4 site (3 heights; 1.0, 2.5, 6.0m).

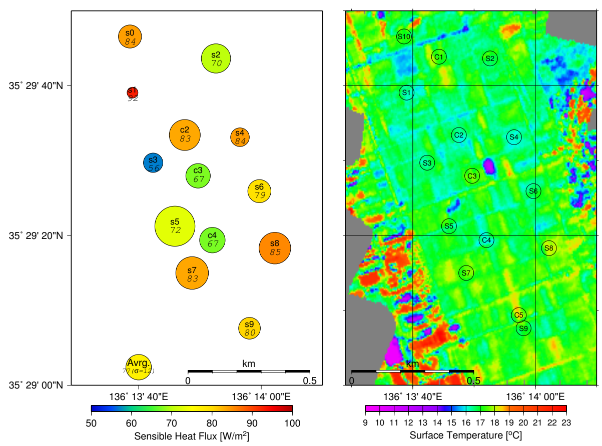

Fig. 3: Distribution map of the average sensible heat flux for 9 to 15JST, Nov. 17, 19, 20, 2002 (right), and the surface temperature for 11:35 to 11:58JST, Nov. 17, 2002(left).

Fig. 3 shows the distribution map of the sensible heat flux and the surface temperature. The surface temperature was measured by the infrared camera (Inframatics, MODEL740), and made calibration and correction of the geometry, the viewing angle and the medium atmosphere, then combined by the multiple shot. The difference of the sensible heat flux between each site was almost equal to the random error, and was about 30% of mean flux ($77\mathrm{W/m}^2$) during 9-15 local time under clear conditions. The difference seems to be correspond to the surface temperature distribution.

Flux footprint analyses of Kormann and Meixner (2001) were applied to CAPS2002. **Fig. 4** shows the footprint areas of each site. The footprint areas were spread northward, because northerly wind was blowing at that time. However each shapes were different by the influence of the local wind distribution. The SATs were installed 3 heights at C4 site, the footprint area of the highest SAT was larger. **Fig. 5** shows the relationship between $U(T_s - T_a)$ and the normalized sensible heat flux. T_s was calculated by the surface temperature in the footprint area. The sensible heat flux was normalized by the bulk coefficient for drag influenced by the roughness length at each site. The normalized sensible heat flux was correlated with the product of the temperature difference between the surface and the air $T_s - T_a$ and the wind speed U. The slope of the data means the bulk coefficient for heat C_{H}, which was almost unity through unstable conditions. These results suggest that local sensible heat flux was determined by the bulk relation of $U(T_s - T_a)$ in the footprint area.

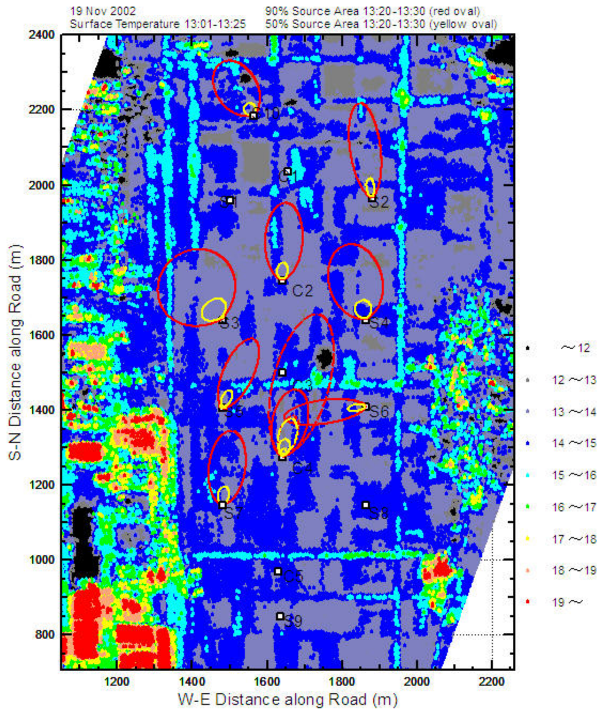

Fig. 4: Footprint areas of the sensible heat flux of each SAT site. 13JST, Nov. 19, CAPS2002.

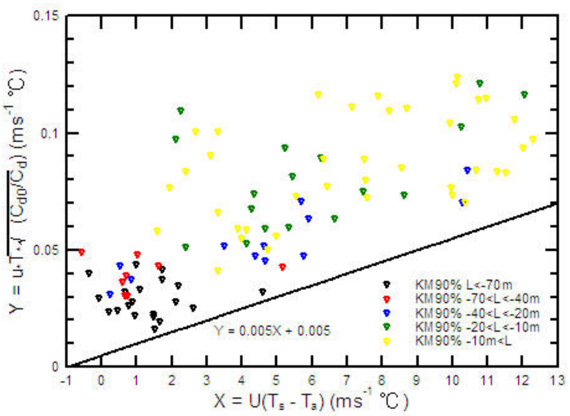

Fig. 5: Relationship between $U(T_s - T_a)$ and the normalized sensible heat flux in CAPS2002.

Large Eddy Simulation (LES/CReSS: Cloud Resolving Storm Simulator) was performed under the same conditions of CAPS2002, except for the homogeneous surface boundary conditions, $z_0 = 0.017$m, albedo $= 0.2$, $\beta = 0.2$. CReSS is non-hydrostatic mesoscale model with cloud physics scheme. LES is adopted for the one-and-a-half order turbulence closure to resolve plumes sufficiently. The modeled domain was 4×4km in horizontal width and 1.6km in height with 40m resolution 100 horizontal grids and 80 vertical grids in which the finest resolution was 10m at the lowest grid. The simulation was started with the initial condition at 9JST, Nov. 17, 2002, and calculated for 3 hours (until 12JST). The sensible heat flux at the lowest grid was calculated by the bulk method. The simulated sensible heat flux was shown in **Fig. 6**. The structure of the plume seems to have a few hundred meters scale, and exists statically. And the amplitude of the sensible heat flux difference was consistent with the observation (**Fig. 3**).

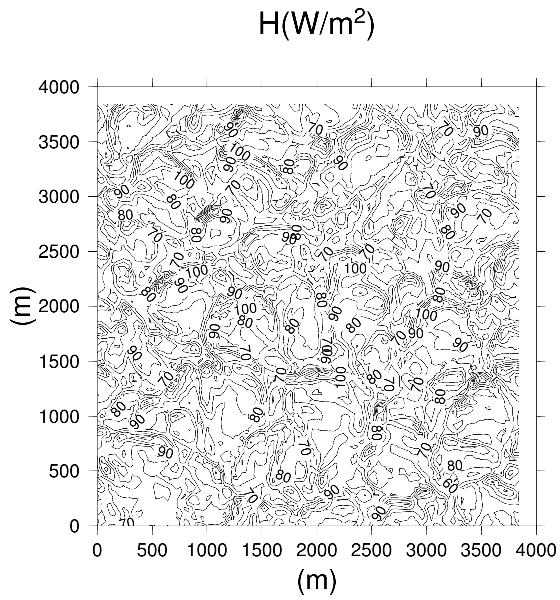

Fig. 6: Distribution map of sensible heat flux simulated by LES using boundary condition of 11-12JST, Nov. 17, CAPS2002.

3.2. CAPS2003

In order to measure greater spatial difference of the sensible heat, CAPS2003 was carried out 1 month earlier than CAPS2002. So the maximum net insolation was 50Wm^{-2} larger, and the surface temperature was 10℃ higher than CAPS2002. Since the observation region was smaller, the difference of the upward shortwave and longwave radiation was smaller. The maximum difference of the soil heat flux G was 50Wm^{-2}. Thus the surface conditions must have been more homogeneous than CAPS2002. The difference ratio of the sensible heat flux was a little smaller than CAPS2002 (**Fig. 7**), and was almost equal to the random error. The footprint analysis should be applied to CAPS2003 in future to understand what influences the difference of the sensible heat flux.

The heat balance was roughly closed in CAPS2002; the average closure ratio was 100% whereas the deviation was up to 100Wm^{-2} (**Fig. 8**). These results suggests that the heat balance would be closed using the data measured at multiple points under thermally homogeneous surface conditions.

4. Conclusion

The heat imbalance is likely occurred by the one point observation. Followings are possible reasons:

- There are slight heterogeneity of the thermal surface conditions; albedo, the surface wetness and temperature, even on *apparently* homogeneous surface.
- The spatial difference of the turbulent heat flux is deter-

mined by the local difference of the surface temperature and wind speed caused by the plume in a few hundred meter scale.

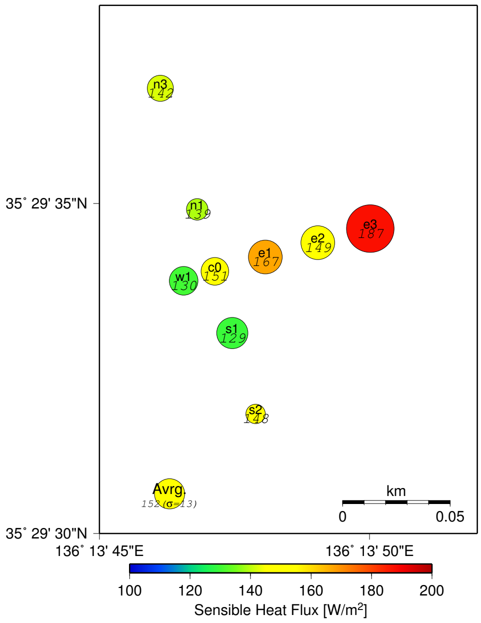

Fig. 7: Distribution map of daytime average sensible heat flux. 9 to 15JST, Oct. 10, 11, 12, CAPS2003.

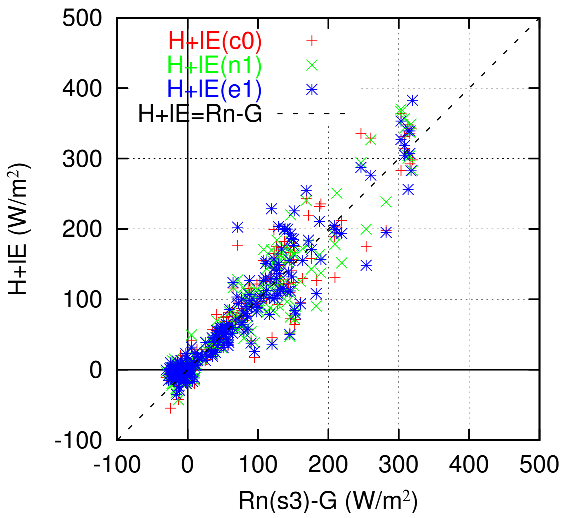

Fig. 8: Heat balance of C, N1, E1 site in CAPS2003. The data of net radiation at S3 site was used.

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