Research Activities of the ABL Team

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1. Motivations

The motivations of our research team are summarized as follows.

1) How did the synoptic condition and precipitation over the middle part of the Yellow River Basin change in the recent decades?
2) How did the land surface change in China affect for the synoptic condition and precipitation over the region?
3) Did the land surface and atmospheric boundary layer (ABL) actively influence for the precipitation system?
4) What are the primary differences of ABL processes between over the humid and semi-dry regions?
5) How does a sharp topography affect for the atmospheric turbulence within the atmospheric surface layer (ASL)?

2. Objectives

The ABL team established the following four objectives in order to attack the motivations described above.

1) To reveal inter-annual and intra-seasonal changes in precipitation amount and related convective activities over the Loess Plateau and the North China Plain.
2) To find any convective activities and precipitation systems affected by land surface and ABL processes over the Loess Plateau or the North China Plain.
3) To compare the diurnal and seasonal changes in the ABL developments over the humid and semi-arid regions.
4) To investigate topographical effects on the atmospheric turbulence and the local circulations appeared within the ABL over the Loess Plateau in China.

3. Observations and Data

3.1. Observations

We established an ABL observation system on a research field of the "Changwu Agro-Ecological Experimental Station over the Loess Plateau", which is located in southern part of the Loess Plateau in China (35.24 °N and 107.68 °E). The altitude of the station is 1224 m. The observation system consists of the following device (Hiyama et al., 2005):

1) Flux and Radiation Observation System (FROS), manufactured by Climatec, Inc., Japan.
2) Wind Profiler Radar (WPR), manufactured by Sumitomo Electric Industries, Ltd., Japan.
3) Microwave Radiometer (MR), manufactured by Radiometrics Corporation, USA.

The FROS provides turbulent fluctuations of three-dimensional wind speed, air temperature and humidity at the height of 2 m, 12 m, and 32 m. From these turbulent data, we evaluated surface sensible and latent heat fluxes. We selected those fluxes at 12 m and 32 m as regional values over this area. The WPR provides vertical profiles of mean wind velocity and wind direction together with those of echo intensity and Doppler spectral width. The MR provides vertical profiles of air temperature, relative humidity, and liquid water content.

3.2. Data

The following data were also used in this study.

1) NCEP/NCAR re-analysis data set.
2) Outgoing long-wave radiation (OLR) data set obtained from geostationary meteorological satellite (GOES 9).
3) Sounding data observed at Pingliang, which located at around 100 km northwest from Changwu station.

4. Results

4.1. Time-series change in precipitation and water budget over the Loess Plateau

Precipitation has slightly decreased since 1950s both over the Loess Plateau and the North China Plain, but it has no significant trend. On the other hands, the inter-annual variation in precipitation has been very large. This inter-annual variation was mainly caused by the intra-seasonal variation of precipitation during rainy season (July, August and September). Although phase of the intra-seasonal variation was similar both for wet year and dry year, amount of water vapor inflow from southern region was drastically different from each other (see details in the report of Fujinami, 2007; this issue).

The precipitation during rainy season is important for agricultural activities over the Loess Plateau. The available water (P – E), namely, difference in precipitation (P) and evapotranspiration (E), is positive during three months but negative in the others (see details in the report of Takahashi et al., 2007a; this issue). The amount of the available water (P – E) during the rainy season is much affected by that of precipitation (P), because E is conserved effectively by the dry surface layer of the loess.

4.2. Effects of land surface and ABL processes on the large-scale convective activities or precipitation systems

Variations in the latent heat flux over the plateau corresponded to those in precipitation during rainy season. Those dominant frequencies were around 4 or 5 days. This means that the overpass of cyclonic (disturbance) precipitation occur around 4 or 5 days intervals in the region. On the contrary, variations in the sensible heat flux had unclear and the dominant frequency was less than 4 days (see details in the report of Nishikawa et al., 2007a; this issue). This might be correlated with instantaneous formation of the dry surface layer of loess, as described above.

The daily maximum height of ABL was both affected by the surface sensible heat flux and the atmospheric stability in the middle and lower troposphere, which were the product of surface heating as well as intrusion of cold air mass over the region. Thus variations in the daily maximum height of ABL were affected by surface sensible heat flux as well as synoptic conditions (see also section 4.4).

Both in pre-rainy season and in rainy season (from April to July), land surface has occasionally enhanced cyclonic precipitation (or meso-scale convective activities). In 2005, the region has experienced 4 times in heavy rainfall at late afternoon, all of which exceeded 10 mm/hour in rainfall intensity. These heavy rainfalls have been brought by overpass of cold front. The cloud top height (i.e., brightness temperature) of the cold front, derived from a geostationary meteorological satellite (GOES 9), clearly showed diurnal variation (see details in the report of Nishikawa et al., 2007a; this issue).

4.3. Effects of land surface wetness and topography on regional-scale ABL development and cumulus generation

We employed a cloud resolving model (Cloud Resolving Storm Simulator; CReSS) developed in HyARC, Nagoya University, to perform sensitivity analyses of ABL and cumulus developments. In order to reveal effect of surface wetness on the ABL and cloud generation, we referred observed evapotranspiration efficiency using FROS (Li et al., 2008).

Over a virtually homogeneous flat terrain, surface wetness (or evapotranspiration efficiency) as well as relative humidity within the ABL are important for ABL and cloud generations. Lower surface wetness made mature ABL higher but generated cumulus less effective due to shortage of water vapor supply from the land surface. If the relative humidity was higher, cumulus generated more effectively (see details in the report of Takahashi et al., 2007b; this issue).

In contrast to this, over the real topography of the Loess Plateau, topographical effect is much higher than the effect of surface wetness for ABL development and cumulus generation. Topography of this region generates small-scale local circulation, in which vertical and horizontal scales are around a few kilometers (see details in the report of Nishikawa et al., 2007b; this issue). This scale might be correlated to the ABL height scale over the region.

4.4. Comparison of ABL processes between over a humid region and over the Loess Plateau

We compared seasonal ABL processes between over a Chinese humid region (Shouxian, Anhui province) and over the Loess Plateau (Changwu, Shaanxi province). Briefly, seasonal change in daily maximum height of ABL over the Loess Plateau was very unclear. This is mainly due to the following two reasons: 1) Land cover over tablelands of the plateau is very heterogeneous in addition to the existence of steep gullies. These land surface features contribute to complex seasonal march in the surface fluxes of sensible heat and latent heat, and thus to daily maximum height of ABL. 2) Weak subsidence (or capping inversion) appears during summer season over the area. This cooperates with thermals developing up to ABL tops or more (Hiyama et al., 2007). If atmospheric humidity became higher due to vertical or horizontal water vapor supplies, cumulus convection effectively enhanced.

4.5. Effect of topography on turbulence structures in atmospheric surface layer (ASL)

We present the power spectra of wind velocity and the cospectra of momentum and heat fluxes observed for different wind directions over flat terrain and a large valley on the Loess Plateau. The power spectra of vertical (w) wind speed downwind of the valley had similar shape as previous studies. Thus topographical effect for sensible and latent heat fluxes will not be large in the region (Li et al., 2007).

The power spectra of longitudinal (u) and lateral (v) wind speeds satisfy the -5/3 power law in the inertial subrange, but do not vary as observed in previous studies within the low frequency range. The u spectrum measured at 32m height for flow from the valley shows a power deficit at intermediate frequencies, while the v spectrum at 32m downwind of the valley reaches another peak in the low frequency range at the same frequency as the u spectrum. The corresponding peak wavelength is consistent with the observed length scale of the convective ABL at the site. The v spectrum for flat terrain shows a spectral gap at mid frequencies while obeying inner layer scaling in its inertial subrange, suggesting two sources of turbulence in the surface layer.

4.6. Studies on satellite remote sensing over the Loess Plateau

Surface heterogeneity induces uncertainty in pixel-wise land surface temperature (LST). Spatial scaling may account for the uncertainty, however, different approaches lead to differences in scaled values. Satellite-retrieved LST may be representative of the pixel-wise LST and useful for scaling analysis, but the limited accuracy of retrieved values adds uncertainty into the scaled values. Based on the Stefan-Boltzmann law, we proposed scaling approaches for LST over the Loess Plateau including flat and relief areas to explore the combined uncertainties in scaling using satellite-retrieved data. To take advantage of simultaneous, multi-resolution observations at coincident nadirs by the Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) and the MODerate-resolution Imaging Spectroradiometer (MODIS), LST products from these two sensors were examined for part of the Loess Plateau. 90-m ASTER LST data were scaled up to 1 km using the proposed approaches, and variation in the LST was generally reduced after scaling. Amongst the sources of uncertainties, surface heterogeneity (emissivity) and different scaling approaches resulted in very minor differences. Terrain features, taken as an areal weighting factor, had negligible effects on the upscaled value. Limited accuracy of the retrieved LST was the major uncertainty. The overall LST increased 0.6 K on average with correction for terrain-induced angular effect and 0.4 K for both angular and adjacency effects over the study area. Accounting for terrain correction in scaling is necessary for rugged areas (Liu et al., 2006).

The ratio of latent heat flux to available energy, termed the evaporative fraction (EF), and the ratio of latent heat flux to downward shortwave radiation (ES), are two useful evaporative flux ratios (EFR) for estimating daily evaporation. Both EF and ES remain relatively constant during daytime, but their value varies from day to day. It is yet unclear if long-term change signals are detectable given the uncertainty associated with the diurnal variations. Using EF and ES data obtained during the major rainy seasons on a tableland of the Loess Plateau, we showed that day-to-day variability in the EF or ES was detectable given diurnal variation. The EF and ES showed slight increasing trends from midmorning to afternoon, but the ES was superior to the EF for satellite-based monitoring of

long-term evaporation trends (Liu and Hiyama, 2007) (Fig.1).

5. Unresolved issues

The effect of land surface change on the precipitation trend over the region could not be resolved in this study. This is mainly because of difficulty on separation of land surface effect from the other meteorological factors such as synoptic-scale influences and effects of meso-scale convective activities.

Use of AGCMs (Atmospheric General Circulation Models) has been employed to reveal the land surface effect on the precipitation feedbacks. However such previous studies mainly conducted numerical simulation virtually changing the whole (continental) land surface into the bare soil surface or deserts. Thus the scale issue should be governed in such land-atmosphere interactions. Additionally, previous AGCMs studies have ignored feedback processes of land-atmosphere interaction. Future studies will be encouraged involving such feedback processes of land-atmosphere interaction.

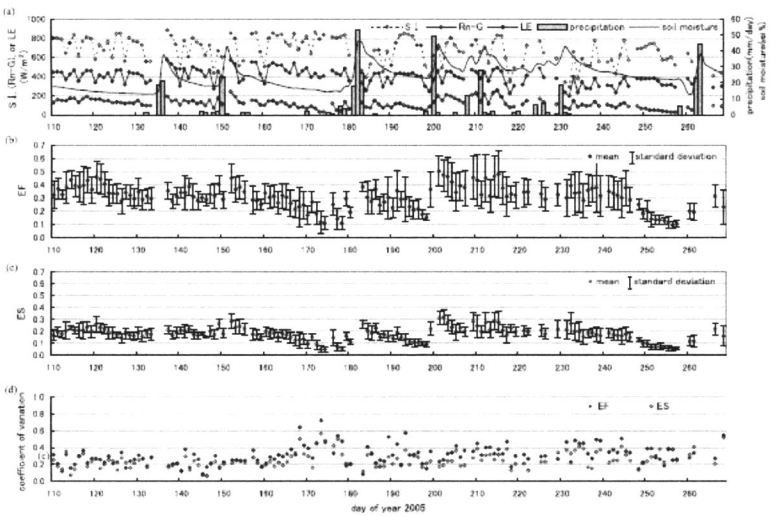

Fig. 1 Seasonal changes in a) downward short-wave radiation (S ↓), available energy (Rn – G), daily precipitation, surface soil moisture, b) EF, c) ES, and d) coefficient of variations of EF and ES, observed at the "Changwu Agro-Ecological Experimental Station over the Loess Plateau" from DOY (day of year) 110 to 270 in 2005. All of the values were daily-bases (Liu and Hiyama, 2007).

6. Publication list

The published papers obtained from the ABL team were listed below.

1) Hiyama, T., Takahashi, A., Higuchi, A., Nishikawa, M., Li, W., Liu, W. and Fukushima, Y. (2005): Atmospheric Boundary Layer (ABL) observations on the "Changwu Agro-Ecological Experimental Station" over the Loess Plateau, China. *AsiaFlux Newsletter*, **16**, 5-9.

2) Liu, Y., Hiyama, T. and Yamaguchi, Y. (2006): Scaling of land surface temperature using satellite data: A case examination on ASTER and MODIS products over a heterogeneous terrain area. *Remote Sensing of Environment*, **105**, 115-128.

3) Kobayashi, N., Hiyama, T., Fukushima, Y., Lopez, M.L., Hirano, T. and Fujinuma, Y. (2007): Nighttime transpiration observed over a larch forest in Hokkaido, Japan. *Water Resources Research*, **43**, W03407, doi:10.1029/2006WR005556.

4) Higuchi, A., Hiyama, T., Fukuta, Y., Suzuki, R. and Fukushima, Y. (2007): The behaviour of a surface temperature / vegetation index (TVX) matrix derived from 10-day composite AVHRR images over monsoon Asia. *Hydrological Processes*, **21**, 1157-1166.

5) Li, W., Hiyama, T. and Kobayashi, N. (2007): Turbulence spectra in the near-neutral surface layer over the Loess Plateau in China. *Boundary-Layer Meteorology*, **124**, 449-463.

6) Liu, Y. and Hiyama, T. (2007): Detectability of day-to-day variability in the evaporative flux ratio: A field examination in the Loess Plateau of China. *Water Resources Research*, **43**, W08503, doi:10.1029/2006WR005726.

7) Li, W., Hiyama, T., Takahashi, A., Nishikawa, M., Kobayashi, N., Higuchi, A., Liu W. and Fukushima, Y. (2008): Seasonal variations in the surface fluxes and surface parameters over the Loess Plateau in China. *Hydrological Processes*, (revised).

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Hiyama, T., Takahashi, A., Nishikawa, M., Liu, Y., Tanaka, H., Higuchi, A., Liu, W. and Fukushima, Y. (2007): Progress in hydro-meteorological studies in Changwu, the Loess Plateau of China. Proceedings of third International Workshop on Yellow River Studies, Research Institute for Humanity and Nature, 61-64.

Li, W., Hiyama, T. and Kobayashi, N. (2007): Turbulence spectra in the near-neutral surface layer over the Loess Plateau in China. *Boundary-Layer Meteorology*, **124**, 449-463.

Li, W., Hiyama, T., Takahashi, A., Nishikawa, M., Kobayashi, N., Higuchi, A., Liu W. and Fukushima, Y. (2008): Seasonal variations in the surface fluxes and surface parameters over the Loess Plateau in China. *Hydrological Processes*, (revised).

Liu, Y., Hiyama, T. and Yamaguchi, Y. (2006): Scaling of land surface temperature using satellite data: A case examination on ASTER and MODIS products over a heterogeneous terrain area. *Remote Sensing of Environment*, **105**, 115-128.

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Nishikawa, M., Hiyama, T., Takahashi, A., Li, W., Fujinami, H., Higuchi, A. and Fukushima, Y. (2007a): Seasonal changes in the conditions of atmospheric boundary layer, land surface, and synoptic field over the Loess Plateau in China. Proceedings of YRiS meeting October 2007 (Ishikawa), (this issue).

Nishikawa, M., Hiyama, T., Tsuboki, K. and Fukushima, Y. (2007b): Numerical simulations on local circulation and cumulus generation over the Loess Plateau in China. Proceedings of YRiS meeting October 2007 (Ishikawa), (this issue).

Takahashi, A., Hiyama, T., Nishikawa, M., Higuchi, A. and Fukushima, Y. (2007a): Vertical transport of water vapor and the atmospheric water budget over the Loess Plateau in China - Comparison of the cases in 2005 and 2006 -. Proceedings of YRiS meeting October 2007 (Ishikawa), (this issue).

Takahashi, A., Hiyama, T., Nishikawa, M. and Fukushima, Y. (2007b): Impact of change in land surface condition on the development of the atmospheric boundary layer and cumulus clouds over the Loess Plateau in China - Numerical experiment -. Proceedings of YRiS meeting October 2007 (Ishikawa), (this issue).