Analysis of Heat Budget for Nocturnal Temperature Inversion in Haean Basin

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Abstract: Nocturnal temperature inversion in the Haean Basin has been analysed using vertical temperature profiles. A tethered balloon sonde was used for observation during good weather conditions. Then the sensible heat flux was obtained as a cumulative heat flux throughout the air column. The observed net radiation was similar to the estimated sensible heat. This can be true if the latent heat flux and ground heat flux are almost equal to zero. After midnight the net radiation increased and latent heat decreased. This can be explained by condensation processes that occur during fog layer development which significantly decrease the long wave radiation cooling during the night-time inversion.

Keywords: *temperature inversion, heat budget, basin*

1. Introduction

The planetary boundary layer is divided into 3 types according to stability; a convective boundary layer in the daytime, stable layer at night, and neutral boundary layer which occurs transiently. During the night when the air in contact with ground is cooled, a nocturnal inversion is formed (Lee, 1985). Kondo et al. (1989) studied the heat budget of nocturnal cooling in the Aizu Basin. His research shows that net radiative flux closely balances with sensible heat flux and ground conduction. The heat budget for nocturnal inversion has been studied by many other researchers including Whitman et al (2004), Andre and Mahrt (1981), and Clements et al (2002). In this research we focused on heat budget estimation using temperature profiles during a night-time inversion event. Our observation site was the Haean Basin located in the northeast part of the Kangwon-do province in South Korea. The basin is characterized by its symmetric features and steep slopes with significant soil erosion. The elevation of the basin floor is approximately 420m MSL. The perimeter of the basin ridge is 31.2km with maximum diameter of 11.7 km. The maximum ridge height is 844.3m over the basin floor (Figure 1). The land is typical rural and mostly used for agriculture especially the cultivation of rice, radish, cabbage and potatoes.

2. Methodology

In this research eddy flux tower data was used. The location of equipment is shown at Figure 1.a. The tethered balloon sounding was performed approximately in the middle of the basin with starting altitude of 430m. The experiments were divided on two parts, spring observation (before monsoon season) and fall season observation. In this research we analyzed only the data from the fall season experiment. The fall season tethered balloon experiment took place from 24th -25th September 2010, and was performed in 1 hour intervals. The sonde consists of a temperature-humidity sensor and air pressure sensor with 1 second logging intervals. The heat divergence Q_z for each layer (Δz thick) at height z was calculated as:

$$Q_z = \rho c_p [(T_{t+\Delta t} - T]_t)$$

Where ρ is the density of air and c_p is the specific heat of air at constant pressure. The T_t is air temperature at time t and at height z, and Δt means time interval between two soundings. The cumulative atmospheric heat throughout air column from ground surface to inversion top (z_{top}) per unit area was then obtained using equation:

$$Q = \sum_{z=0}^{z_{top}} \mathrm{H_z} \qquad (2)$$

The calculated cumulative atmospheric heat using equation (2) was then compared with the data observed by the eddy flux tower.

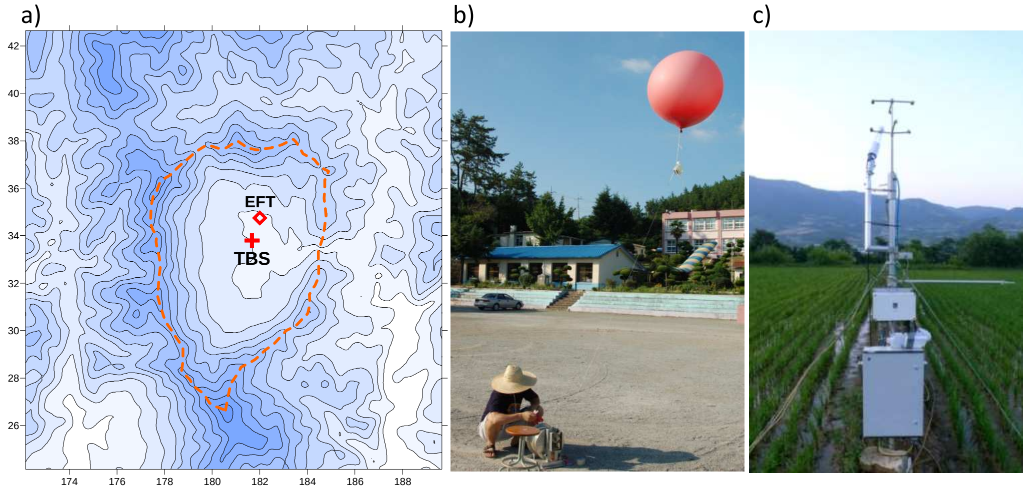

Figure 1. a) Location of tethered balloon sonde experiment (TBS) and eddy flux tower (EFT). b) tethered balloon sonde (photo by Miloslav Belorid) c) eddy flux tower (photo by Zhao Peng)

3. Results

The observed temperature profiles are shown in Figure 2.a. The surface temperature change varies with the time. The difference of temperature between soundings is plotted on Figure 2 b. Significant surface temperature change of -1.78 C/h was found during first measurements between 18:00 and 20:00. Then the cooling process was slowed down and the surface temperature change reached less than -1 C/h. Figure 3 shows potential temperature profiles. From the plot an average inversion depth can be estimated and in this case it was approximately equal to the average basin mountains height (500m). The strength of the inversion can be estimated as the difference of potential temperature at the top of inversion and the potential temperature at the surface. Strength of -6.5 K was observed at 1:00 AM which is the maximum for the studied period.

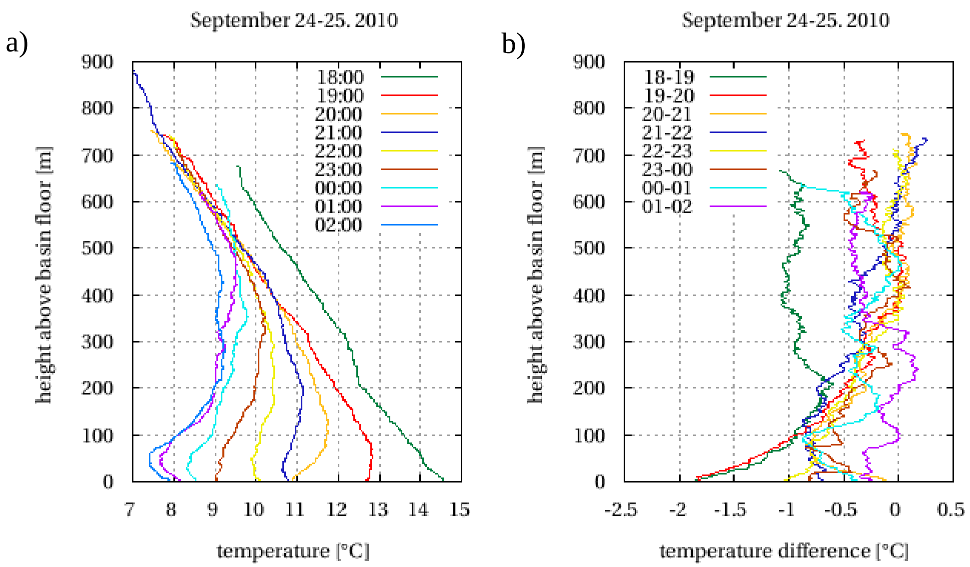

Figure 2. a) Temperature profiles from tethered balloon soundings, b) vertical profiles of temperature change for 1 hour interval

Using equation (1) a heat divergence was calculated. The vertical profiles of heat divergence are shown in Figure 4. An obvious cooling process can be seen in lower layer (up to 200m). Conversely, a warming can be seen in upper layers especially between 00:00 and 02:00 soundings. This warming can be explained by an advective flow which was probably present above the basin ridge. The energy balance equation for the ground surface is given by:

$$RN = H + LE + G \qquad (3)$$

Where *RN* is net radiation, *H* is sensible heat flux, *LE* latent heat flux, and *G* is the ground heat flux. Figure 5 shows the heat budget for whole observation period. *Q* represents sensible heat estimated from cumulative atmospheric heat, obtained using equation (2). Note, that the vertical profiles used in the analysis are only until 02:00 AM. After that time a fog layer appeared which negatively affects the cooling process during the inversion event. As shown in Figure 5 the latent heat rapidly decreased between 2:00 AM and 4:00 AM which agrees with the condensation process during the fog formation. If we assumed that the ground heat is so small that we can ignore it, and the latent heat is close to zero (19:00-00:00AM) then value of the sensible heat should be close to the net radiation. This agrees with our estimation shown in Figure 5.

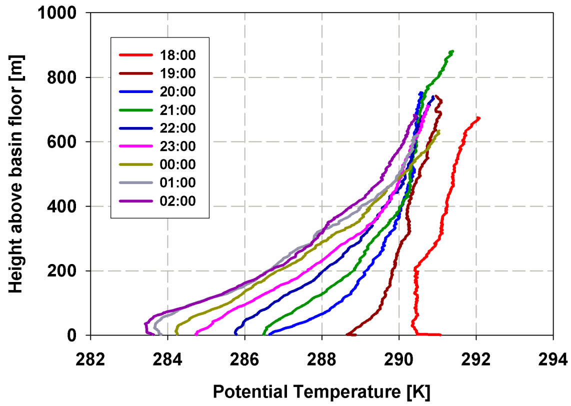

Figure 3. Change of potential temperature profiles

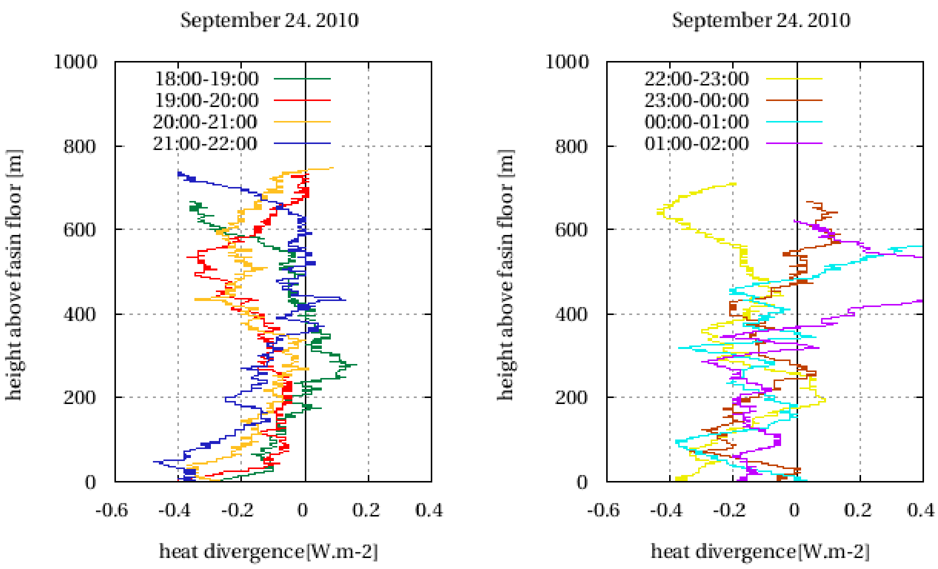

Figure 4. Time variation of heat divergence [W.m-2] for studied period

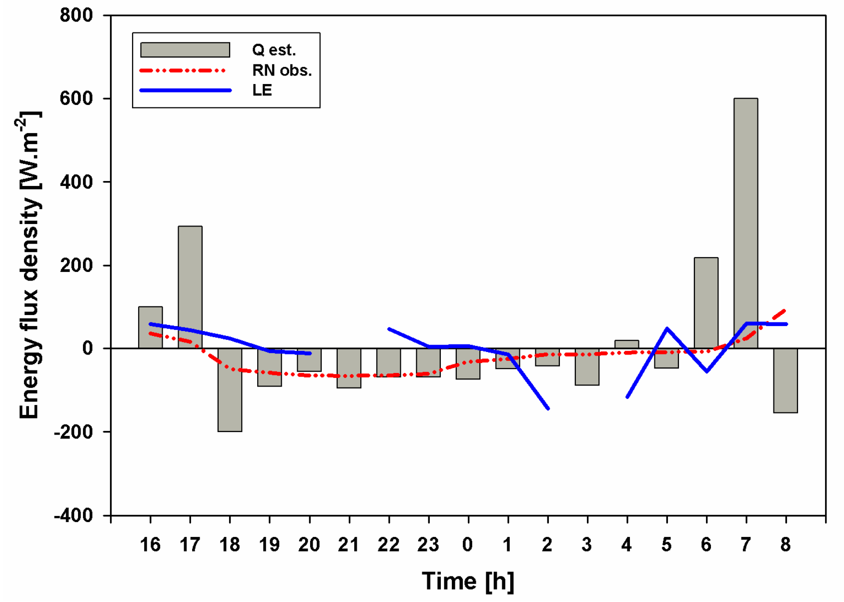

Figure 5. Heat budget for observation period. Red line is the measured net radiation, grey bars are estimated sensible heat flux, and blue line is latent heat flux obtained from TK2 based on flux tower measurement. Note that the gaps in data are filtered low quality data.

4. Conclusion

Data from tethered balloon soundings has been used to compute the heat divergence. Then the sensible heat flux was obtained as a cumulative air heat flux. The observed net radiation was closed to estimated sensible heat which can be true if the latent heat flux and ground heat flux are almost equal to zero. After midnight the net radiation increased and latent heat decreased. This can be explained by condensation process during the fog layer development which was also evidenced during the tethered balloon soundings. Thus, the radiation cooling is significantly lower if the fog layer appears in the basin. In this research we calculated cumulative heat flux throughout the air column of unit area. For more accurate estimation of cumulative heat flux for the Haean Basin the drainage area should be considered. In future research we have plan to use GIS data to compute the drainage area of the basin and include the data in our calculations.

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