POSTER 09

Field Validation of the Sky-Condition based Lapse Rate Estimation Scheme

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I. Introduction

The model for estimating the weather distribution of complex terrain with high resolution uses the minimum temperature estimation model for the temperature at 0600 LST and the maximum temperature model for the temperature at 1500 LST (Yun, 2015). The two temperature estimations are commonly applied for the correction of elevation above sea level, with the standard weather data from Korea Meteorological Administration (the observed values, ultra-short term forecast, and digital forecast) as the background temperatures, an identical elevation above sea level is assumed as a virtual terrain in order to estimate the temperature lapse rate. This is applied to simulates the temperature variation caused by the difference between the virtual terrain and actual terrain and corrects the background temperature using temperature lapse rate. In previous studies, a single value of average lapse rate for the troposphere (–6.5°C/km) or –9°C/km was used for correcting the elevation above sea level (Kim *et al.*, 2013; Kim and Yun, 2014). However, the environmental temperature lapse rate varies differently in temporal and spatial scales, and using the traditional value can increase estimation errors. In this study, a simple method for estimating temperature lapse rate modulated by the amount of clouds, suggested by Kim and Yun (2016), is used to simulate the temperature at 0600 and 1500 LST, and the improvement of temperature estimation error was compared with the case adopting the existing single temperature lapse rate.

II. Materials and Methods

2.1. Estimation of temperature lapse rate

The estimation of temperature lapse rate suggested by Kim and Yun (2016) shows the day and night periodicity of the temperature lapse rate, with the lapse rate fluctuation curve using the minimum value Γ_{min}, the maximum value Γ_{max} of the temperature lapse rate, and the gradient k (Eq. 1). The change of temperature lapse rate Γ_t at a random time t is similar to

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the sequential change of temperature throughout a day.

The first interval denotes the temperature lapse rate increase (k = 0.95) from the sunrise to the point of maximum temperature, whereas the lapse rate decreases during the second interval (k = –0.95) until 2100 LST, and the third interval (k = –0.45) from 2100 LST to the next sunrise. In Eq. 1, Γ_{min} and Γ_{max} are given as the maximum and minimum temperature lapse rates for each interval, the lapse rate at sunrise (the point of lowest temperature), the lapse rate at the point of highest temperature, or the temperature lapse rate at 2100 (Γ_{21}, –0.0063°C/m) depending on the interval.

$$\Gamma_t = \Gamma_{\min} + \frac{\Gamma_{\max} - \Gamma_{\min}}{1 + \exp\{-k(t - t_m)\}} \tag{1}$$

When Γ_{min}, and Γ_{max} are the respective maximum and minimum temperature lapse rates throughout a day, the standard curve of the temperature lapse rate fluctuates depending on the amount of clouds (Cl) or the weather condition. When the amount of clouds is 0, the amplitude of $\Gamma_{min,max}$ on the standard curve (= Γ_s) becomes maximized, while the difference in the temperature lapse rate becomes 0 when the amount of clouds becomes 10.

Eq. 2 shows the change of Γ_s by the temperature lapse variation per cloud cover V. The parameter V can be divided into V_{max}(= 0.00060°C/m), which is applied at the point of highest temperature, and V_{min} (= –0.000295°C/m), which is applied at sunrise. The Cl_m is the amount of clouds for the standard curve of temperature lapse rate, which is 5.5.

$$\Gamma_{\min,\max} = \Gamma_s + V(Cl - Cl_m) \tag{2}$$

The annual variation of temperature lapse rate was simulated using the 365-day period function (Eq. 3) suggested by Yun *et al.* (2001). The Γ_s, which is calculated by using Eq. 3, is applied to Eq. 2. The parameter d refers to the day of year (DOY, ranging from 1 to 365), and dx is 205. The term $\Gamma_{s,m}$ in Eq. 3 refers to the Γ_{min} and Γ_{max} on the annual average standard curve of the temperature lapse rate and are, respectively, –0.005°C/m, and –0.009°C/m.

$$\Gamma_s = -\left[\,|\Gamma_{s,m}| + 0.0015\cos\{0.0172\,(d - d_x)\}\right] \tag{3}$$

In addition, Γ_{21}, which is not affected by the cloud cover, is reflected by the annual variation of the temperature lapse rate through Eq. 3.

2.2. Application

From May 2007 to March 2008, a meteorological temperature profiler (Model MTP5H, Kipp and Zonen) was installed on the rooftop of the Highland Agriculture Research Institute, located in Daegwallyeong-myeon, Pyeongchang-gun, Gangwon-do province, to measure the hourly vertical distribution of air temperature up to the height of 600 m at intervals of 50 m. Data from 172 days in this period included all the hourly measurements from the MTP5H at 0600 and 1500 LST, except for missing values.

The cloud data at 3-hour intervals were measured while calculating the temperature lapse rate between the intervals of 500 m and 600 m, in order to exclude the influence of the nighttime inversion cap. The measured dates were classified according to their cloud covers, which are classified into ten levels (0-10), measured at 0600 and 1500 LST. Except for the case when the classification of the date was 3 days and less than, the temperature lapse rates from the Daegwallyeong data and the estimated temperature lapse rates were averaged for the each cloud cover classification for comparison.

A catchment of the ‘Hadong 2 watermark,’ which includes Hadong, Gyeongsangnam-do, Gurye, and Gwangyang, Jeollanam-do, was selected as the area for evaluating the practicality of the temperature lapse rate estimation method. The weather data of 0600 and 1500 LST at 12 weather observation sites within the catchment were collected during the entire year of 2015. Also, the ‘sky condition’ of digital forecast products of KMA in 2015 (5 km × 5 km lattice resolution) were collected. According to the method of Yun and Kim (2015), the sky condition values from 1 through 4 were converted into 0 through 10 of the 10-level cloud cover value. After that, the cloud cover data of 0600 and 1500 LST were overlapped with the catchment of the ‘Hadong 2 watermark,’ in order to calculate the spatial average value within the catchment. The spatially averaged cloud cover was used to calculate the 0600 and 1500 LST temperature lapse rate of the catchment in 2015.

2.3. Verification

By using the estimated lapse rate, the temperature distributions for each elevation at 0600 and 1500 LST were simulated. However, at 0600 LST, since the temperature inversion layer is often generated by the surface radiation during the nighttime, the thermal belt's effect and the accumulation of cold air, suggested by Chung *et al*. (2006) and Kim and Yun (2011), were reflected. The background temperature was spatially interpolated with the inverse distance squared weighting (IDSW) method, using the lattice values of the temperature of digital forecast products of KMA on the Automatic Weather System (AWS) locations on Hadong, Gurye, and Gwangyang. The virtual terrain was also spatially interpolated, just like the background temperature, by using the elevation above sea level (based on a 30 m-lattice digital elevation model) for the AWS locations. For the weather sites locations, the simulated temperatures at 0600 and 1500 LST using the cloud cover-based estimated temperature lapse rate, as well as a single value of average lapse rate for the troposphere (–6.5°C/km) or –9°C/km, were compared with the actual measurement values in order to verify if the method in this study shows any improvement in comparison with the existing method.

III. Results

3.1. Relationship between temperature lapse rate and cloud cover

The estimated temperature lapse rate at 0600 LST decreased in a linear manner as the amount of clouds decreased. However, the temperature lapse rate at the elevations between 500 m and 600 m showed little influence from the amount of clouds (Fig. 1, Left). The temperature lapse rate changes by the amount of cloud as shown by V in Eq. 2. This is due to a fluctuation of temperature during the day, according to the weather condition, which is linked to the atmospheric stability (Kim and Yun, 2016). If the changing modes of the temperature lapse rate during the nighttime between the cloudy and clear days are different from that of the temperature, V_{min} will not fully express the fluctuations of temperature lapse rate for each weather condition. During the nighttime, when the atmospheric stability becomes high, the temperature inversion layer is formed. The values derived from the temperature lapse rate estimation are applied to the lapse rate above the temperature inversion layer. Therefore, further studies on the actual temperature lapse rate on the upper layers for each weather condition and on the derivation of parameters in the estimation formula are required. At 1500 LST, the actual values were similar to the estimated values of temperature lapse rate when the cloud cover index was above 3.

However, unlike the linear increase of the estimated temperature lapse rate during the clear days with the cloud cover index below 3, the actual lapse rate at this elevation was similar to the estimated values for cloud cover indexes of 4 through 7 (Fig. 1, Right). Although the atmospheric stability changes by the simple heating and cooling of the air near the surface, the stability is altered by the changes of temperature caused by horizontal and vertical movements of the air. For instance, when the subsidence, a general downward airflow, occurs in high pressure with clear weather conditions, the upper layer of the air mass is heated more than the lower layer near the surface due to compression (Lutgens and Tarbuck, 2007). In addition, since the unstable air rises and generates clouds, it is not quite correct that the degree of atmospheric instability is inversely proportional to the amount of clouds. Therefore, based on the relationship between the actual amount of clouds and the temperature lapse rate at 1500 LST, the cloud conditions covering index values of 0-3 were assumed identical to when the index was above 3. Noting that the KMA sky condition 1 'clear' is the cloud cover index 0, and sky condition 2 'partly cloudy' is 4 (Yun and Kim, 2015), the cases with cloud cover under 4 were all converted to cloud cover 4, since the estimation would be more practical than when using the original values.

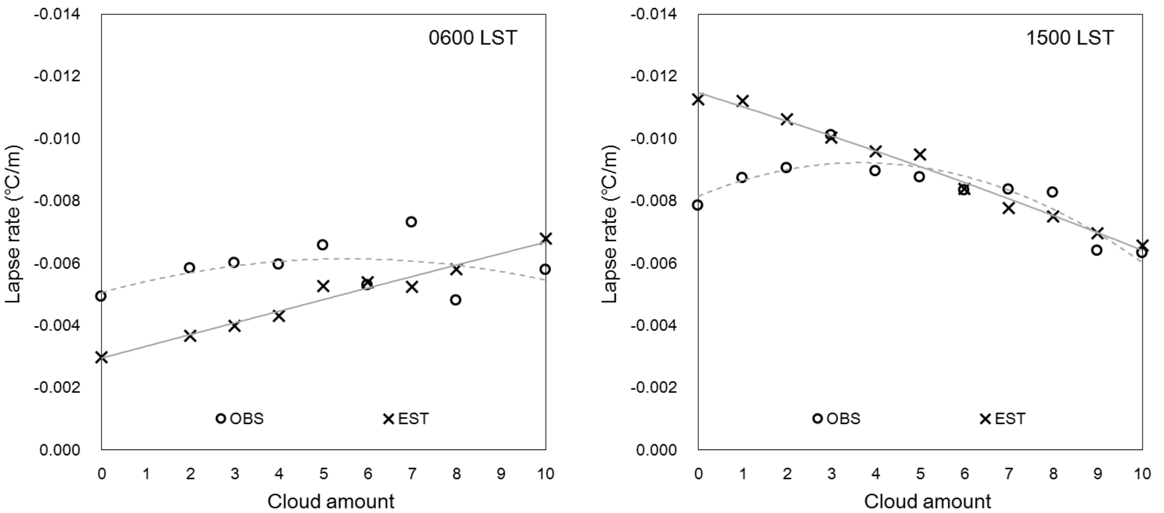

Fig. 1. Comparison of the temperature lapse rate (circle) for elevation 500-600 m measured by MTP5H in Daegwallyeong, at 6:00 and 15:00 LST for 172 days and the estimated temperature lapse rate (X) with the amount of clouds.

3.2. Performance of the cloud cover-based temperature lapse rate

The estimation errors of the temperatures at 12 points within the catchment of 'Hadong 2 watermark' at 0600 LST were ME –0.39°C and RMSE 1.45°C in 2015, when applying the existing temperature lapse rate. Using the new temperature lapse rate, they were somewhat improved to ME –0.19°C and RMSE 1.32°C. For the 71 clear days, except for the missing values and when the amount of clouds was 0, the comparison between the estimation errors of the temperature before and after applying the new temperature lapse rate at 0600 LST changed. The ME changed from

–0.85°C to –0.57°C, and the RMSE changed from 1.72°C to 1.42°C. With regards to the 45 cloudy days when the cloud cover was marked as 10, the ME decreased from –0.17°C to –0.06°C, while the RMSE decreased from 1.16°C to 1.01°C.

At 1500 LST, the effect of the improvements found from the comparison between the existing temperature lapse rate and the estimated temperature lapse rate were minute (ME –1.31°C to –1.28°C and RMSE 1.98°C to 1.93°C, in 2015). This is because the estimated temperature lapse rate of days with fewer clouds is not very different from the existing temperature lapse rate. In contrast, the estimation errors of the temperatures during the 49 cloudy days were ME –0.69°C and RMSE 1.54°C in the case of the existing temperature lapse rate. However, these were improved to ME –0.51°C and RMSE 1.19°C.

Fig. 2 shows the estimation errors (ME) of the temperatures 0600 and 1500 LST for both clear and cloudy days for each point of verification in comparison with the elevation deviation between the actual and virtual terrains. The more elevation deviation increases, the more temperature estimation errors of clear days at 0600 LST decreased in case of using the new temperature lapse rate. When the elevation deviation exceeds 900 m, the existing strong trend of underestimation almost disappears (Fig. 2, upper left). In contrast, the points at which the elevation above sea level is lower than that of the virtual terrain showed a trend of increasing underestimation. This is seemingly because of the cold air accumulation effect, which was reflected in the simulation process of the temperature at 0600 LST and is customized based on the existing temperature lapse rate (–6.5°C/km). The estimation errors of the temperature on cloudy days at 0600 LST generally decreased. In particular, if the elevation deviation is high, the decreasing width of the ME was larger (Fig. 2, upper right). For the temperature at 1500 LST, no improvement was shown on clear days at all points. The overall trend of a significant underestimation seem to be corrected by the effect of solar radiation (Fig. 2, lower left). However, on cloudy days, when the influence of solar radiation is almost zero, the estimated temperature lapse rate derived from the amount of clouds appeared to be effective for improving the estimation errors of the temperature at 1500 LST. The errors of temperature lapse rate at a point with a high elevation deviation were greatly reduced (Fig. 2, lower right).

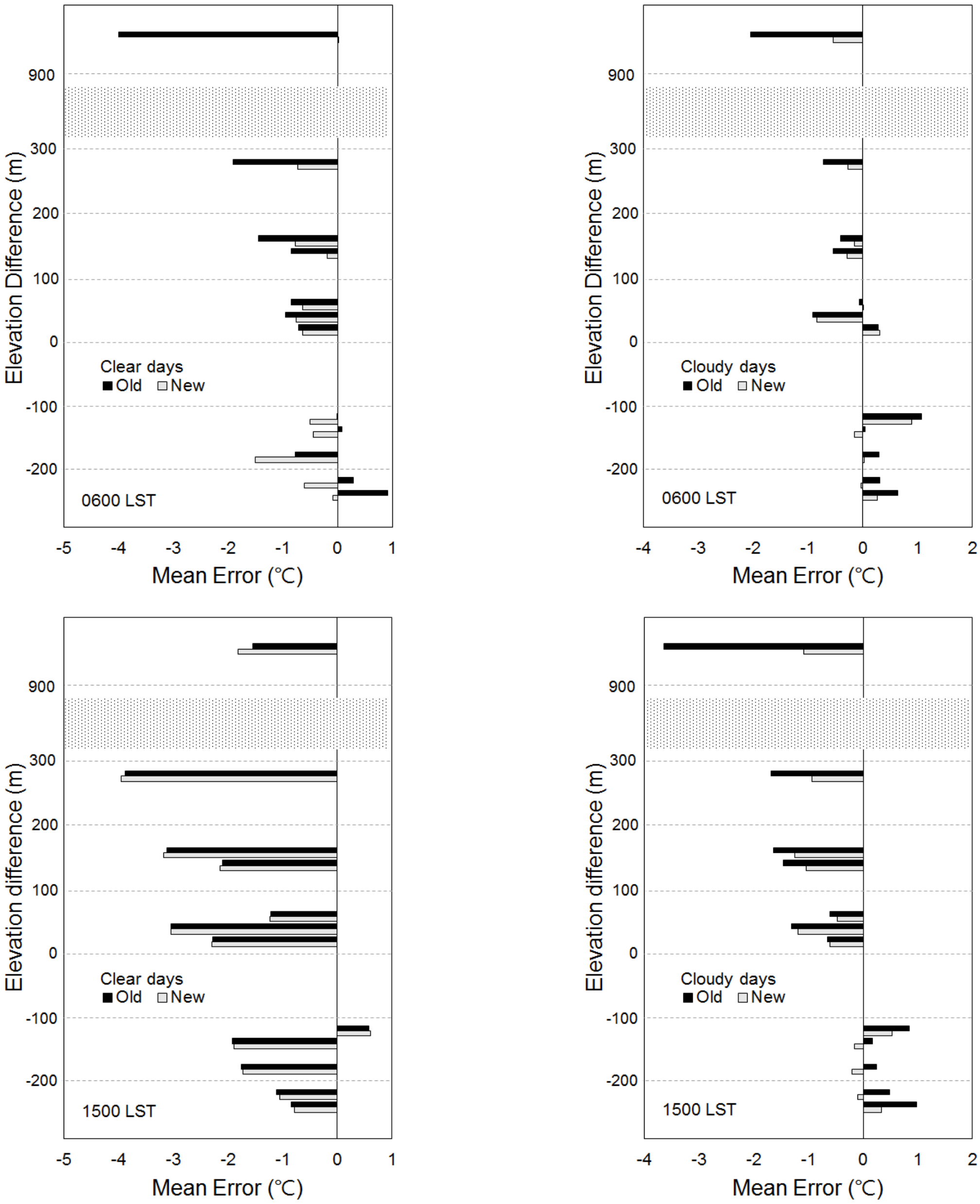

Fig. 2. Comparison of estimation error (ME) between 0600 (above), and 1500 (below), regarding the single value of existing temperature lapse rate and cloud cover-based estimated temperature lapse rate. The left refers to the ME of clear days, while the right refers to the ME of cloudy days

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