Intra-Annual Variations in Temperature Lapse Rate Within a Mountainous Basin in Korea – A Case Study of the Punch Bowl, Yanggu

Choi, Gwangyong (1); Lee, Bora (2); Tenhunen, John (2); Kang, Sinkyu (3)

(1) Major of Geography Education, Department of Social Studies Education, Jeju National University, 1, Ara-1 dong, Jeju-si, Jeju Special Self-Governing Province, 690-756, Republic of Korea, tribute@hanmail.net
(2) Department of Plant Ecology, University of Bayreuth, 95440 Bayreuth, Germany, puplebr@gmail.com, john.tenhunen@uni-bayreuth.de
(3) Department of Environmental Science, Kangwon National University, Hyoja-dong, Chuncheon, Kangwon Province, 200-701, Republic of Korea, kangsk@kangwon.ac.kr

Abstract: Spatially and temporally high resolution climatic data between 2009-2011 have been observed at the Automatic Weather Station (AWS) network deployed in Haean basin (called Punch Bowl), Yanggu in the Republic of Korea. In this study, seasonal variations of hourly temperature lapse rate (TLR) in the basin by each synoptic weather condition are examined. Seasonally, lowest daily average TLR is observed in fall (-0.37℃/100m), while the highest value is found in spring (-0.56℃/100m). In most seasons, the lowest daily TLR is observed on sunny days. However in winter, the TLR for partly cloudy days (-0.27℃/100m) is lower than that on sunny days (-0.46℃/100m). In te rms of diurnal progression, the lowest TLR by -0.05℃/100m is observed in the early morning on sunny days, indicating that the calm and clear weather over the mountain basin is a favorable for the formation of cold drainage basin. The difference in TLR amongst different synoptic weather conditions increases during nighttime, while the inter-seasonal TLR differences are considerable in the morning. During the entire study period, extreme temperature inversions of as much as +1℃/100m or more have occurred at dawn after more than 10 consecutive sunny days. These results imply that at regional scales, stagnant high pressure systems associated with East Asian monsoon are a key climatic condition for the formation of cold drainage basin in the mountainous basin in Korea.

Keywords: *mountain climate, temperature lapse rate, synoptic weather patterns, Haean Basin, Punch Bowl*

1. Introduction

More than two thirds of the Korean Peninsula is occupied by mountains. Diurnal temperature variations in mountain valleys and basins such as temperature inversion layer are critical climatic factors to the growth of highland crops. Napa cabbage and radish for Kimchi, which is the main side dish in Korean food cultures, are important crops for agricultural economy in the highland regions in Korea. They have price competitiveness in the market because they are harvested in the off seasons in lowland regions. However, the magnitude of highland crop production varies from one year to another due to inter-annual variations of local climate. Thus, an understanding of mechanisms associated with diurnal and seasonal variations of mountain climate is needed to provide better ecosystem service to farmers in the mountainous areas.

To date, numerous approaches, including high resolution satellite imagery, have been pursued most commonly to reveal characteristics of urban climate. Comparatively, less attention has been paid to the examination of mountain climate. A few studies showed that mountain climate phenomena such as cold drainage are primarily associated with the topography of the basin (Jiang, 1981; Kondo et al., 1989; Kuwagata and Kimura, 1995; Whiteman, 1999; Iijima and Shinoda, 2000), but how closely they are associated with regional, synoptic weather patterns in different climate zones and in different seasons have been not fully understood. Primarily it is attributable to the lack of high resolution observation network in less populous mountain regions. For instance, in the Republic of Korea, the national Automatic Weather Station (AWS) MesoNet has been operated by the Korea Meteorological

Administration (KMA) since the late 1980s. However, the spatial resolution of tens of kilometers is not adequate to understand vertical and horizontal structures of air temperature, especially because these structures change in valleys and basins every few kilometers due to the complex terrains.

To develop a prototype of improved ecosystem service in mountain villages, a Korean-Germany scientist team initiated a collaborative project titled, "complex TERRrain and ECOlogical heterogeneity (TERRECO)" in 2009. As a test-bed, several kinds of observational devices to capture biogeochemical variables have been installed in the Haean basin (also called the Punch Bowl named after its shape by US newspaper reports during the Korean War (1950-1953), Yanggu in the Republic of Korea). Based on the high resolution AWS network established since summer in 2009, preliminary results about diurnal and intra-seasonal progressions of summertime TLR in 2009 were documented (Choi et al., 2010). As a continuing effort, in this study, intra-annual variability of TLR in a mountain basin during a full year are examined using hourly AWS temperature data between June 2009 and November 2010 for the Punch Bowl area.

2. Data and Method

In this study, TLR defined as the change of temperature per unit increases in elevation (°C/100m) is analyzed as a key climatic variable to understand the dynamics of diurnal and seasonal thermal conditions. The Punch Bowl is a typical oval-shaped mountain basin where the north-south axis and the west-east axis is 7km and 8.5km, respectively (Figure. 1). There are obstacles in finding optimal locations for the AWS in the basin such as private land ownership and safety issues in De-Militarized Zone (DMZ) bordering with North Korea that has random landmines along the mountain slope. Among a dozen of AWSs deployed in Haean basin since 2009 summer, three AWSs (#4, #6, and #9) in the bottom of the basin and one AWS (#1) located on the northern top of high mountain ridge called Ulchi observatory site are selected to calculate TLR with height at every thirty minute interval between June 2009 and November 2010. The average elevation of three sites located in the bottom of the basin is 485m from the mean sea level, while Ulchi observatory site is 1,050m. The detail of observational environments at each site was summarized in Choi et al. (2010).

TLRs on each day are categorized into six groups based on synoptic weather conditions: snowy day, snow-covered day, heavy rainfall day, rainy day, partly cloudy day, and sunny day. There are significant missing records in precipitation data for the study period at the selected sites. Thus, daily precipitation and temperature obtained from an AWS operated by the KMA for the site in Haean municipality building are alternatively used to determine the type of synoptic weather condition on each day.

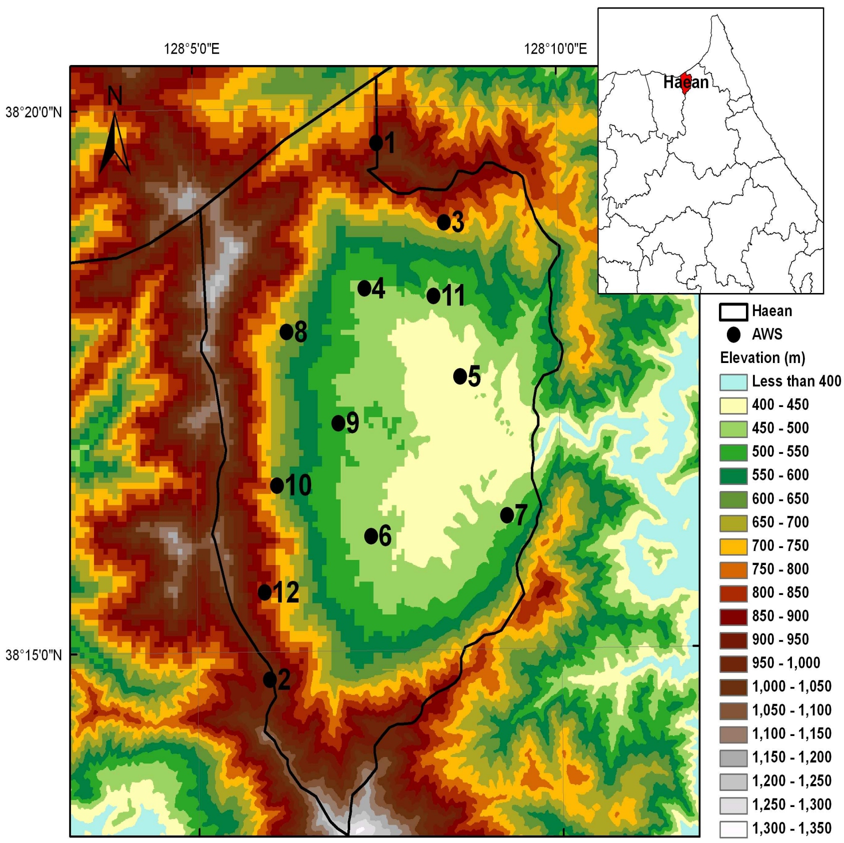


Figure 1. The locations of the AWSs for the TERRECO project in Haean Basin, Yanggu, Republic of Korea.

Days with precipitation are classified into snowy days when daily mean and minimum temperatures are below 5 C and 0 C, and the succeeding no-precipitation day after snow days with 1 mm of precipitation is classified into snow-covered days. Days with precipitation exceeding 30mm is classified into heavy rainfall days, and other days with the less precipitation are classified into rainy days. The preceding and following days based on days with precipitation greater than 0.1mm are defined as partly cloudy days, and other precipitation-free days are defined as sunny days. Table 1 shows the number of days with each synoptic weather condition. Seasonal (each three month interval: e.g. winter between December and February) and annual averages of TLR between the top and bottom sites of the basin at each 30 minute interval during each day are calculated for each synoptic weather category. Synoptic weather cases with less than 5% (5 days) of total days in each meteorological season are excluded in the analyses.

Table 1. Seasonal and annual statistics of synoptic weather patterns in Haean basin, Yanggu, Republic of Korea between June 2009 and November 2010

Weather patterns	2009		09/10	2010			09/10
	JJA	SON	DJF	MAM	JJA	SON	Annual (D-N)
Snowy days	0	7	11	13	0	6	30
Snow-covered days	0	3	5	10	0	3	18
Heavy rainfall days	8	0	0	3	10	6	19
Rainy days	30	13	4	13	35	11	63
Partly cloudy days	30	23	11	20	32	16	79
Sunny days	24	45	59	33	15	49	156
Sum	92	91	90	92	92	91	365

3. Results and Discussions

3.1 Seasonal and Annual Variations of Temperature Lapse Rate

The annual average of TLR between December 2009 and November 2010 is -0.47° C/100m (Table 2). Synoptic weather patterns affect the magnitude of annual average TLR. The annual average TLR is greatest for snow covered days, followed by snow or rainy days, heavy rainfall days, partly cloudy days, and sunny days (Figure 2). On snow-covered days, the TLR increases up to -0.62° C/100m, while it decreases as -0.4 ° C/100m on sunny days. At nights on sunny days, outgoing long wavelength energy can freely emit without less atmospheric interruptions. The cooled air along the surface of the mountain slope sinks toward the bottom of basins, forming temperature inversion layer in the cold drainage basin. Thus, the reversed temperature patterns reduce the TLR on sunny days significantly.

The TLR also shows seasonal variations in the range of -0.37° C/100m ~ 0.56° C /100m between June 2009 and November 2010 (Table 2). For instance, the percent of sunny days in 2010 fall are 54% (49 days) (Table 1). On calm and clear days in fall, dry air prevails due to the retreat of humid subtropical high pressure in the Pacific. As the result, the TLR in fall is the smallest and as much as -0.37° C/100m, while the TLRs in spring and summer are greater than -0.5° C/100m. Overall, the TLR is greater in spring, followed by in summer, winter, and fall of 2010. However the TLR in 2009 summer is greater than that in 2010 spring, indicating that the order is variable from one year to another.

The TLR also varies significantly within an identical season by each synoptic weather condition (Table 2). In fall, the smallest TLR is observed in sunny days, while in winter, it is found in partly cloudy days. According to comparisons between 2009 and 2010 summers, the summertime TLR on sunny days varies significantly.

Table 2. Seasonal and annual averages of temperature lapse rate by synoptic weather patterns in Haean basin, Yanggu, Republic of Korea between June in 2009 and November in 2010

Weather patterns	2009		09/10	2010			09/10
	JJA	SON	DJF	MAM	JJA	SON	Annual
Snowy days	-	-0.54	-0.47	-0.62	-	-0.62	-0.57
Snow-covered days	-	-	-0.66	-0.68	-	-	-0.62
Heavy rainfall days	-0.57	-	-	-	-0.55	-0.50	-0.51
Rainy days	-0.63	-0.59	-	-0.38	-0.56	-0.50	-0.56
Partly cloudy days	-0.54	-0.37	-0.27	-0.51	-0.57	-0.41	-0.48
Sunny days	-0.55	-0.25	-0.46	-0.50	-0.20	-0.29	-0.39
Average	-0.58	-0.37	-0.46	-0.56	-0.50	-0.37	-0.47

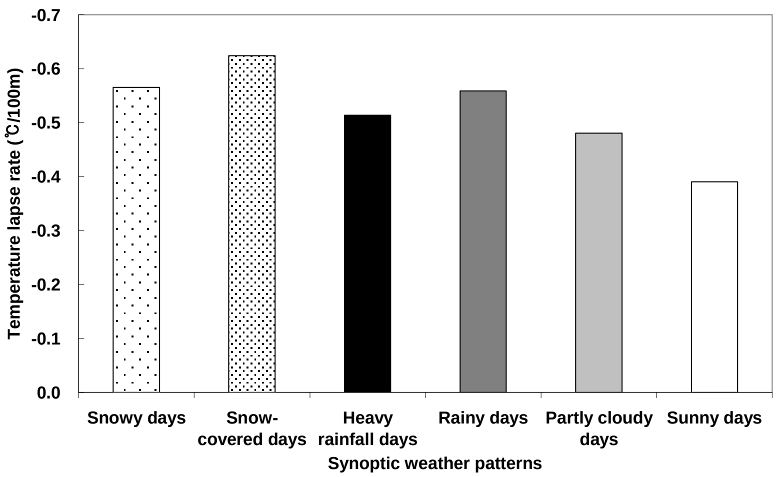


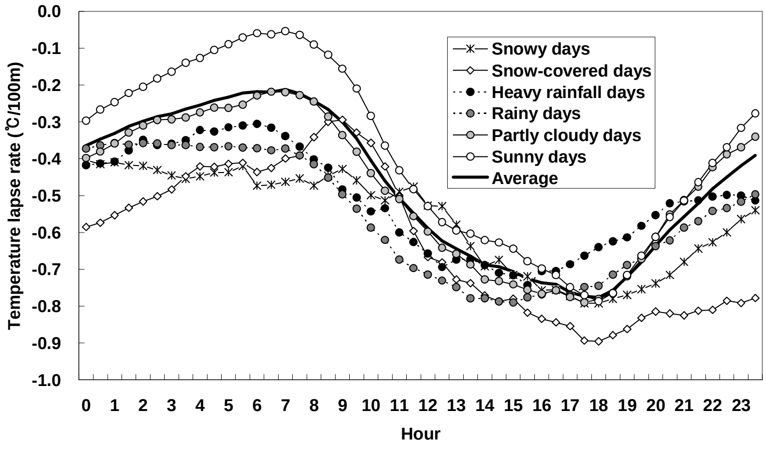
Figure 2. Comparisons of annual average (December 2009-November 2010) temperature lapse rates for each synoptic weather category in Haean basin, Yanggu, Republic of Korea

3.2 Diurnal Variations of Temperature Lapse Rate in the Different Synoptic Weather Conditions

Seasonal and annual average TLR shows noticeable differences between daytime and nighttime (Figure 3a). During a day, annual average TLR is as low as -0.21° C/100m at 7AM, while it increases up to -0.78° C/100m at 6PM. The timing for lowest and highest TLRs also varies seasonally. In winter, the smallest TLR is delayed and is observed at 9AM, while in summer it is advanced to 5AM. The magnitude of the wintertime TLR at 9PM is -0.17 ° C/100m, but the lowest TLR in fall increases up to -0.37° C/100m. The highest TLR in four seasons show less variations in different seasons as the range of -0.78~ -0.84° C/100m. These results indicate that inter-seasonal variations are greater in the TLRs of the early morning than those of early evening. During daytime, the TLRs in winter are smaller than those in summer and fall, while the pattern is reversed during nighttime.

The diurnal progressions of TLR varies by the given synoptic weather conditions (Figure 3b). The TLR increases up to -0.79° C/100m at 6PM in all synoptic weather conditions. Differences in nighttime TLR amongst different synoptic weather types exceed 2° C, while daytime difference is lesser than that. In particular, annual average TLR is smallest by -0.05° C/100m at 7 AM on sunny days. This indicates that the formation of cooling pool in a mountainous basin is common at dawn on calm and clear days. It is because heavy cold air at dawn on sunny days can slide down along the slope of mountain due to gravity, forming a cold drainage basin thermally. Compared to the cases on sunny days, the difference between daytime and nighttime is reduced in the case of heavy rainfall days and snowy days.

a.



b.

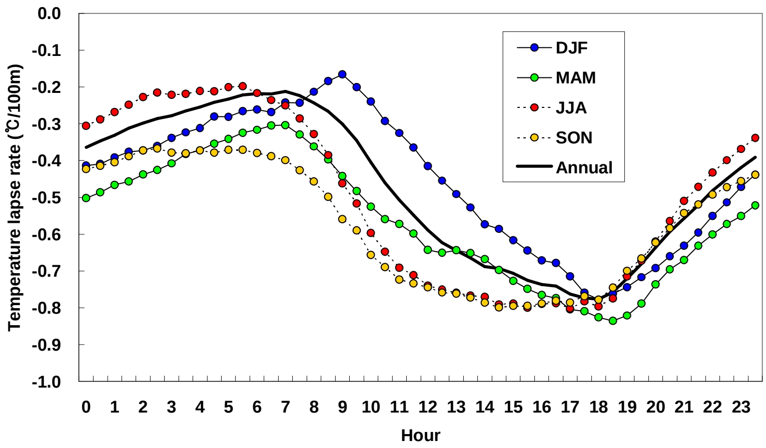


Figure 3. Diurnal progressions of temperature lapse rate for each meteorological season (a) and for each synoptic weather pattern (b) between December 2009 and November 2010 in Haean basin, Yanggu, Republic of Korea.

4. Conclusion

This study shows that the diurnal progression patterns of TLR vary not only between different seasons but also within a season depending on the type of synoptic weather conditions. The lowest TLR as much as -0.05° C/100m is observed in the wintertime morning on sunny days, while the highest TLR as much as -0.9° C/100m is recorded in the springtime evening on snow-covered day. The intensity of cooling pool drainage may be associated with the consecutiveness of sunny days, indicating that water content in the air is a critical factor to the vertical structure of air temperature. Solar radiations and wind patterns should be examined to reveal the mechanisms of diurnal variations of the TLR under different synoptic weather conditions in more detail. Also, both long-term monitoring and spatially extensive monitoring are required to induce climatological characteristics and changes of temperature lapse rate associated with highland crops in the mountain basins in a changing climate.

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