Characteristics of Rawinsonde Data-Based Storm-Relative Helicity Collected during the Early Summer Monsoon Period in the Southwest Korean Peninsula

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Abstract

The kinetic energy associated with Chang-ma periods was investigated using rawinsonde data from Korea during 2013−2015. Changes in kinetic energy (which is defined in terms of storm relative helicity, SRH) were more pronounced than changes in thermal energy (which is defined in terms of convective available potential energy, CAPE) during precipitation. The median value of SRH increased by 14, 125, and 185 m$^2$ s$^{-1}$ in no-rain, weak-rain (< 5 mm 3 hr$^{-1}$), and strong-rain (≥ 5 mm 3 hr$^{-1}$) time periods, respectively. However, the values of CAPE remained below 100 J kg$^{-1}$ regardless of the rainfall intensity. Moreover, the correlation coefficients (R) between SRH and precipitation amount about 0.4 with 99% confidence level. In addition, we used two vectors constituting the SRH (storm motion vector and horizontal wind vector) to determine the reason for the SRH differences. The change in the y-components of the horizontal wind vector at low levels (850−750 hPa) was determined to be closely related to SRH. The increase in SRH during the precipitation periods was therefore determined to be due to the low-level southerly wind. Based on these results, we conclude that it is possible to forecast precipitation in the early summer monsoon season in Korea. (Citation: Jung, S.-P., T.-Y. Kwon, S.-R. In, S.-J. Kim, G.-T. Kim, J.-K. Shim, C.-G. Park, and B.-C. Choi, 2018: Characteristics of rawinsonde data-based storm-relative helicity collected during the early summer monsoon period in the southwest Korean Peninsula. SOLA, 14, 86−90, doi:10.2151/sola.2018-015.)

1. Introduction

The early summer season in East Asia is constantly raining due to the stationary front, which is called Chang-ma in Korea, Baiu in Japan, and Mei-yu in China, respectively. These rainy season associated with frontal zone are important factor in forecasting rainfall amounts due to its large spatial and temporal scales. Moreover, various precipitation phenomena occurred such as Chang-ma front, low-pressure system, mesoscale convective systems, and typhoon. For this reason, various studies have been conducted on the thermodynamic characteristics and precipitation of this rainy season (Ninomiya and Akiyama 1992; Ninomiya and Shibagaki 2007; You et al. 2009; Zhang et al. 2014). These studies have shown that the low-level southwest flow with moisture into East Asia increased as the North-Pacific High expanded to the westward. This moisture flux into the air mass to form a cloud zone (Chang-ma front) (Ninomiya and Shibagaki 2007; Okada and Yamazaki 2012). Moreover, the low-level southerly winds flows into the mid-latitude westerlies zone and generates strong vertical wind shear (Ninomiya and Akiyama 1992; Ding and Chan 2005; Ninomiya and Shibagaki 2007; You et al. 2009). In addition, Lee and Seo (2013) found that the southerly winds increased the water vapor entering the Korean peninsula using statistical model, and were related to the precipitation associated Chang-ma. The above-mentioned studies have suggested that moisture low-level southerly wind are closely related to precipitation during the Chang-ma season, because it helps to form and maintain convection and vorticity (Ninomiya and Shibagaki 2007; Lee and Seo 2013; Zhang et al. 2014). Therefore, understanding low-level wind is important for predicting precipitation during the Chang-ma season, and it is necessary to quantify the change of the low-level winds.

Several studies using diagnostic factors to indicate atmospheric conditions have been conducted to predict rainfall in the summer (Kerr and Darkow 1996; Thompson et al. 2007; Eom et al. 2008; Lee and Byun 2011; Nomura and Takemi 2011; Jung et al. 2015). These studies can generally be divided into two categories of diagnostic variables. The first aspect relates to thermal instability, such as convective available potential energy (CAPE), Lifted index (LI), K index (KI), and the total totals index (TTI). Another aspect is related to kinematic instability, such as wind shear, helicity, vorticity, and storm-relative helicity (SRH). Among them, SRH is a diagnostic parameter for the characteristics of lower-level winds and it is useful in predicting convection activity (Rasmussen and Blanchard 1998; Bunkers et al. 2006; Schultz and Askelson 2012). Jung et al. (2015) found that SRH and duration of precipitation were positively correlated, with a correlation coefficient of 0.44 or higher. Moreover, SRH has recently been used as a diagnostic parameter for the development of storms (Chen et al. 2015; Bunkers 2018; Ribeiro and Bosart 2018). These studies suggest that high SRH is helpful in increasing vorticity and is correlated with high bulk shear; this is a good environment for storms to develop. In addition, they also compared the SRH associated with thunderstorms and found that most of the differences (or errors) in SRH were due to changes in the low-level winds at 0−1 km.

However, several studies (Eom et al. 2008; Lee and Byun 2011; Jung et al. 2015) related to summer rainfall in Korea focused on the thermal instability. Although the seasonal variation of the thermal instability was related to the seasonal march of the Asian monsoon system (Eom et al. 2008), the relationship in June was significant lower than July-August. In other words, the diagnostic factor related to precipitation during the early summer monsoon period is still insufficient. Considering that precipitation in the Chang-ma season is related to low-level southerly wind, these deficiencies can be solved through SRH which represent changes in lower-level winds and useful in predicting convection activity. In this study, SRH is used to understand the characteristics of the early summer monsoon in Korea.

SRH obtained from rawinsonde data were used to investigate and determine whether atmospheric conditions could be used as diagnostic variables for predicting precipitation. In particular, this study analyzed the relationship between SRH and the occurrence and amount of precipitation. Moreover, the two components of SRH (storm motion vector and horizontal wind vector) related to precipitation, which also increase the values of SRH, are discussed. In addition, differences in SRH according to synoptic weather conditions were compared. This paper is subsequently structured as follows: Section 2 describes the data and study methods. Section 3 discusses the characteristics of SRH during
This study used CAPE and SRH to better understand the thermodynamic characteristics during the early summer monsoon. CAPE has been characterized by multiple components (e.g., LFC, EL, θ) in various studies (e.g., Lee and Byun 2011; Nomura and Takemi 2011; Jung et al. 2015):

$$\text{CAPE} = \int_{\text{LFC}}^{\text{EL}} \left[ \nabla \cdot \left( \nabla \times \mathbf{V} \right) \right] \cdot (\mathbf{V} - \mathbf{C}) \, dz. \quad (1)$$

On the other hand, SRH represents the amount of vertical wind shear due to storm motion (Davies-Jones et al. 1990). It is a measurement of the temperature advection; positive and negative values indicate veering winds (warm air advection) and backing winds (cold air advection), respectively (Tuduri and Ramis 1997; You et al. 2009). SRH consists of two implied components: the storm motion vector ($\mathbf{C}$) and the horizontal wind vector ($\mathbf{V}$), shown in Equation (2):

$$\text{SRH} = \int_{0}^{h} \left( \nabla \times \mathbf{V} \right) \cdot (\mathbf{V} - \mathbf{C}) \, dz. \quad (2)$$

Here, an integrated elevation value ($h$) of 3 km has been used in most previous studies (Davies-Jones et al. 1990; Rasmussen and Blanchard 1998; Bunkers et al. 2006; Schultz and Askelson 2012; Jung et al. 2015), while values of 1 or 5 km have been used rarely (Kerr and Darkow 1996; Dupilka and Reuter 2006; Thompson et al. 2007; Bunkers 2018). In this study, the majority of $h$ is 3 km except for SRH0-1 and SRH0-5 in Fig. 6. The storm motion vector ($\mathbf{C}$) is the averaged wind between 0 and 5 km. As shown by the above equation, the change in SRH is due to low-level shear. The following section discusses which of the two vectors increased the SRH as well as the relationship between SRH and precipitation established over the early summer monsoon season.

### 3. Results and discussion

Figure 2 shows the temporal distribution of the CAPE, SRH, and precipitation amounts during the early summer monsoon season at BGSO as well as the synoptic conditions for each case. The pattern of variation seen in the precipitation is more similar to that of the variations in SRH rather than of the variations in CAPE. Moreover, most cases show that the precipitation-associated SRH values exceed the threshold for supercell development (Dupilka and Reuter 2006); that is, SRH > 150 m$^2$s$^{-2}$ and peaks at times similar to those of the precipitation. However, except for in a few cases, the change in CAPE has a weak relationship with precipitation during the early summer monsoon season. In addition, the correlation coefficients (R) between SRH and precip-
into three categories: hours with no rain, weak-rain hours (less intensity (Fig. 3). The data from 332 rawinsondes are divided characteristics of SRH and CAPE according to precipitation conclusions. Because the precipitation characteristics of each case are distinctly different. The majority of cases are affected by the Chang-ma front (C) in the following sequence. Prior to a precipitation event, the SRH is smaller than the threshold value (150 m s$^{-2}$). However, as the precipitation begins, the value increases to not only exceed the threshold but to possibly surpass 400 m s$^{-2}$ or more. After the rainfall rate and SRH values have peaked, both decrease gradually, though the SRH values remain positive throughout the period. Based on these results, the precipitation associated with the Chang-ma front is assumed to be related to positive SRH (warm advection) in the lower atmospheric layers (consistent with previous studies, You et al. 2009). Secondly, the low-pressure system (L) clearly shows both positive and negative SRH values (these can be interpreted as warm and cold advections). In Cases 9 and 10, it can be seen that SRH gradually increases prior to precipitation, reflecting the influence of the slow-moving warm advection (Tuduri and Ramis 1997). On the other hand, SRH sharply decreases and becomes negative following precipitation, reflecting the influence of the cold advection. Finally, the typhoon case values (Cases 7 and 12) differ for each event. In Case 7, the SRH exceeds 500 m s$^{-2}$ for only six hours. In Case 12, the SRH continuously increased to reach 800 m s$^{-2}$ during precipitation events. This difference exists because the precipitation characteristics of each case are distinctly different. Additional case studies are required for more definitive conclusions.

The frequency distribution is exhibited at the 95th, 90th, 75th, 50th (median), 25th, 10th, and 5th percentiles to investigate the characteristics of SRH and CAPE according to precipitation intensity (Fig. 3). The data from 332 rawinsondes are divided into three categories: hours with no rain, weak-rain hours (less than 5 mm 3 h$^{-1}$), and strong-rain hours (more than 5 mm 3 h$^{-1}$). Here, the rainfall intensity is based on the three-hour precipitation, including one hour before and one hour after each of the launch times. As a result, the clear, weak, and strong precipitation times were 232, 71, and 29, respectively.

The distributions of the frequencies of SRH and CAPE are distinctly different. The median values of SRH were 14, 125, and 185 m s$^{-2}$ in no-rain, weak-rain, and strong-rain environments, respectively. However, the median values of CAPE were 19, 33, and 58 J kg$^{-1}$ in the same respective environments. In other words, the SRH value increased with rainfall intensity, but the CAPE value did not change with intensity. When precipitation occurs during the early summer monsoon season in Korea, the kinetic instability (SRH) is strong due to wind shear in the middle and lower parts of the atmosphere (Hong 2004; You et al. 2009; Lee and Seo 2013). However, it is necessary to separately analyze the two components of SRH—the horizontal wind and storm motion vectors—to better understand the reasons behind the increasing SRH.

The distribution of storm motion for the three rainfall intensity levels is shown in Fig. 4. Most (77%) storm motions are directed to the eastward (~45–135 degrees) in cases of no rain and weak rain, while a few are to the northward or to the westward. On the other hand, all storm motions in the strong-rain cases are northward. This means that the direction of the storm motion does not change much (dominant in the eastward direction) except for in strong-rain cases. Moreover, the correlation coefficient between value of SRH and x-component of storm motion was 0.1 (not shown). The coefficient in y-component was 0.3. According to previous research (Duplilka and Reuter 2006), the value of the SRH is critically related to storm motion. But, the storm motion in this study during early summer monsoon season in Korea does not change significantly due to the influence of the regional midlatitude easterlies. In addition, few cases of heavy rain appeared the northward of storm motion. As a result, it is difficult to attribute increased kinetic instability (SRH) solely to storm motion and heavy rain is expected to be related to south wind. Therefore, further analysis of the horizontal wind vector is warranted.

The relationship between the horizontal wind vector and SRH is depicted by the scatter diagram in Fig. 5. Although multiple analyses were conducted between 950 hPa and 300 hPa, the results are presented for only three representative levels in which the x- and y-components of the horizontal wind vectors are separately calculated. The x- and y-component of winds have distinctly different relationships with SRH. The x-component of the wind vector has the significantly weaker relationship with SRH, as evidenced by correlation coefficients of less than 0.2 at most levels, except for at 950 hPa ($R = 0.5368$). Correlation coefficients calculated for the y-component of the wind vector were higher than 0.4 except for at 950 hPa ($R = 0.3739$). In particular, the distributions at 850 hPa, 800 hPa (not shown), and 750 hPa depict linear patterns with the highest correlation coefficients of 0.7682, 0.7595,
and 0.7215, respectively. However, correlation strength decreased gradually from 700 hPa ($R = 0.6917$) to 300 hPa ($R = 0.4071$).

In summary, SRH had no significant relation with the x-component of the wind vector but was highly correlated with the y-component of the wind vector in the lower layer of the atmosphere (about 850–750 hPa). It is assumed that these low-level winds were caused by the expansion of the North-Pacific High (Ninomiya and Akiyama 1992; Ninomiya and Shibagaki 2007).

These results are consistent with those of previous studies that indicate that the amount of precipitation measured during the early summer monsoon season is related to the moisture stream present in the middle and lower layers of the atmosphere (Hong 2004; Ninomiya and Shibagaki 2007; Lee and Seo 2013).

Differences in SRH were compared for the three integration altitudes ($h$, refer to Eq. 2) at 1, 3, and 5 km. Figure 6 depicts the temporal distribution of SRH for twelve precipitation cases.
associated with three synoptic conditions: the Chang-ma front (top and middle of Fig. 6), low-pressure systems (bottom left), and typhoons (bottom right). Overall, the SRH measured between 0–1 km is clearly smaller than those of the other integrated altitudes. On the other hand, the SRH values between 0–3 and 0–5 km are virtually the same and are seemingly related to precipitation. These results suggest that SRH increased mostly in the 1–3 km altitude, and this increase was closely related to the increase in the y-component of the horizontal wind vector (Fig. 5) as a low-level southerly wind.

In addition, the low-level southerly wind is shown in Fig. 6. The blue shaded area indicates southerly winds between 1000 and 600 hPa for the considered lower layer. As a result, southerly winds were observed during precipitation in most of the cases, and the high SRH values were associated with deep southerly winds at 950–600 hPa. In the case of the Chang-ma front, the SRH increased steadily during the rain events. The SRH and southerly wind remained positive after the rain event ended. This result is attributed to warm air advection (veering wind) with the expansion of the North-Pacific High (Okada and Yamazaki 2012). In the case of a low-pressure system, the SRH values were positive and maximized prior to and during the precipitation event but decreased (while still remaining positive) after the event. This suggests the influence of cold air advection (backing wind) at the rear of the low-pressure air mass. Finally, the southerly wind appears in the deep layer starting before the precipitation, and the SRH values measured in the lower layer for Case 12 were significantly higher than those in other cases. Thus, the influence of each typhoon is related to its path of movement.

4. Conclusions and recommendations

This study used rawinsonde data to investigate the kinetic instability (SRH) of meteorological conditions during the summer monsoon period in Boseong, Korea, 2013–2015. Precipitation amount associated with the Chang-ma season was found to be more closely related to SRH (R=0.4) than to CAPE (R=0.1), and the kinetic energy was increased by southerly winds in the low-level atmospheric layer (850–750 hPa). In most cases, SRH increased prior to a precipitation event and peaked towards the end of the event. But, there is a time lag of about 6–12 hours between SRH and precipitation. Moreover, SRH increases mostly in the 1–3 km layer, which is the influence of the southerly wind mentioned above. In addition, SRH characteristics differed with synoptic conditions: 1) continuous positive value (warm advection) characterized the Chang-ma front, 2) changes from positive value (warm advection) to negative value (cold advection) characterized a low-pressure system, and 3) unstable air in the lower layer of the atmosphere characterized typhoon cases. Based on these results, it can be concluded that SRH serves as an effective index for predicting precipitation not only for storms but also for frontal systems related with Chang-ma during the early summer monsoon period. However, this study was based on results for a relatively short period of time. Therefore, long-term observations and analyses are recommended for the various conditions proposed herein. In addition, further research is required on small-scale phenomena occurring within the Chang-ma season.

Acknowledgements

The authors wish to thank the two anonymous reviewers for their constructive comments and the editor (Prof. Tetsuya Takemi) for his review of the manuscript. This work was funded by the Korea Meteorological Administration Research and Development Program “Research and Development for KMA Weather, Climate, and Earth system Services-Development and Application of monitoring, Analysis and Prediction Technology for High-impact weather” under Grant (KMA2018-00123).

Edited by: T. Takemi

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Manuscript received 16 April 2018, accepted 15 June 2018.

SOLA: https://www.jstage.jst.go.jp/browse/sola/