Development Mechanisms of Summertime Air Mass Thunderstorms Occurring in the Middle Region of South Korea

K.-E. Kim, B.-H. Heo, H.-R. Lee and K.-D. Min

Department of Astronomy and Atmospheric Sciences.

College of Natural Sciences

Kyungpook National University, Taegu 702-701

(Manuscript received 26 November 1995)

Abstract

A diagnostic study on the summertime air mass thunderstorms occurring in the middle region of South Korea was made by analyzing the data of surface and upper air observations as well as the surface and upper level weather charts. The key parameters used in the present study are the amount of precipitable water below 850 hPa level, the vertical profiles of water vapor content and wind, and both the temperature difference and the equivalent potential temperature difference between 850 hPa and 700 hPa levels.

It is found from this study that the summertime air mass thunderstorms in the middle region of South Korea can be classified into two distinct types, type I and type II. The thunderstorms of type I occur under the atmospheric conditions of high moisture content, low vertical wind shear in low levels, and conditional instability between 850 hPa and 700 hPa levels. On the other hand, the thunderstorms of type II occur under the atmospheric conditions of less moisture content, higher wind shear and conditional instability.

Furthermore, our study suggests that atmospheric instability and the amount of water vapor below 850 hPa level are complementary in the development of air mass thunderstorms. The complementary nature between these two parameters may be an explanation for the thunderstorm development in the areas of low atmospheric water vapor content such as the plains of eastern Colorado.

1. Introduction

Air mass thunderstorms are formed within a relatively homogeneous air mass with little or no synoptic features such as fronts or upper troughs. Many studies have been made on air mass thunderstorms (e.g.,, Keenan et al., 1990; Prezerakos, 1989; Weisman and Klemp, 1982) since the first systematic study on thunderstorms by Byers and Braham (1949). They pointed out that water vapor content, wind shear and atmospheric instability are important factors which determine the nature of thunderstorms.

The role of atmospheric instability is very important in thunderstorm development. An inversion layer, for example, often suppresses atmospheric convection. However, it can also delay strong convection until the lower atmosphere or the atmospheric boundary layer has a sufficient buoyancy to break the inversion lid, and then enhance the severity of thunderstorm.

The vertical wind shear has a strong influence on the type of convection. A close relationship between wind shear and storm type has been clearly demonstrated by Chisholm and Renick (1972).

However, the amount of water vapor needed for thunderstorm formation has not been established from a viewpoint of cumulus or cumulonimbus convection due to a latent heat release from water vapor condensation. The amount of water vapor in the preconvective condition of thunderstorm formation is quite variable in comparable storms in different geographical locations (Djuric, 1994).

Thunderstorm formation in eastern Texas requires at least 25mm of precipitable water. This is quite contrast to the case of the thunderstorm development in the plains of eastern Colorado, where 5 or 10 mm of precipitable water supports the development of severe thunderstorms. This high variation of the observed amount of water vapor in prestorm atmospheric conditions raises a question about how the atmosphere with low water vapor content allows thunderstorm formation.

One of the major problems in characterizing thunderstorm formation is to find how atmospheric water vapor content, vertical wind shear and atmospheric instability are involved in the physical process of thunderstorm formation.

The objective of the present work is to examine how the three factors above are interrelated in thunderstorm formation by a synthetic analysis of prestorm atmospheric conditions. In addition, the synoptic situations which allow air mass thunder formations are also analyzed.

2. Data and anaysis

To study the prestorm atmospheric conditions, the air mass thunderstorms are differentiated from the many types of thunderstorms that occurred in Osan and Kwangju areas during the summers (from June to September) of 1981 to 1990. The following criteria are used for our selection of air mass thunderstorms among the many thunderstorms that occurred during the period. The storm should be developed at the center of high pressure or its nearby area. The cloud coverage at 9 : 00 (LST) in the morning should be less than 50%. The cumulonimbus should be developed in the afternoon.

The surface observation data, the surface and upper level weather maps (850 and 750 hPa), and the atmospheric sounding data at Osan and Kwangju constitute the main data of this study. Several parameters were used to analyze the environmental conditions of thunderstorm development : amount of precipitable water below 850 hPa, vertical wind shear, and both temperature and equivalent potential temperature differences between 850 and 700 hPa levels.

According to the present analysis, the total number of thunderstorm occurrence in Osan during the period of 1981 to 1990 is two hundred eighty nine. Of the thunderstorms, thirty six cases are the summertime air mass thunderstorms. The occurrence of air mass thunderstorms is found to be limited from May to September.

The air mass thunderstorms from June to September occupy more than 90 % of the total number of air mass thunderstorms.

The total number of thunderstorms occurrence in Kwangju during the period of 1981 to 1990 is one hundred seventy nine. Of the total number of thunderstorms, thirty eight cases are the summertime air mass thunderstorms, about twenty one percent of the total thunderstorm frequency. The frequency of thunderstorm occurrence from June to September is about 80.4% of the total frequency.

It is found from our analysis that the air mass thunderstorms occurred in Osan and Kwangju areas could be classified into two types : type I and II. The criterion of this classification are based on the vertical profiles of temperature, moisture content, and wind including synoptic patterns. The following discussions are mainly based on the analysis of prestorm atmospheric conditions in Osan area.

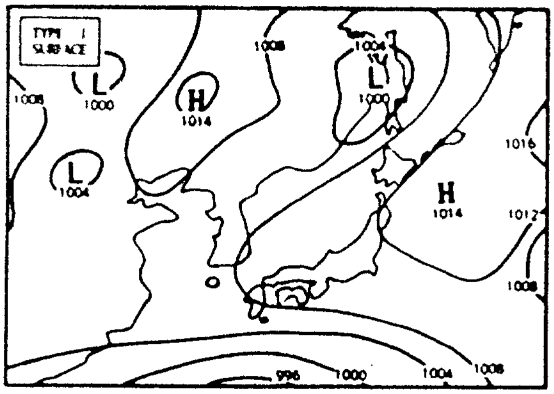

Fig. 1. A tyoical surface weather map for the thunderstorm of type I (0800LST, August 3, 1986).

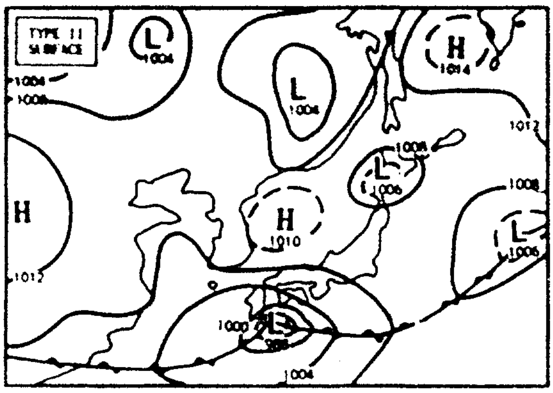

Fig. 2. A typical surface weather map for the thunderstorm of type Ⅱ (0800LST, June 15, 1987).

Figs. 1 and 2 show the typical surface charts of the thunderstorms of type I and II, respectively. In case of the thunderstorm of type I, the weather in South Korea was under the influence of the air mass of North Pacific Ocean. However, the weather in case of the thunderstorms of type II may be considered under a modified continental air mass, which is located above the Bai-u front.

There is a significant difference in the vertical distribution of wind between the two types of thunderstorms as shown in Figs. 3 and 4. According to the relationship between the verical wind distribution and storm type (Chisholm and Renick : 1972), the hodograph patterns in the figures suggest that the thunderstorms of type I are the storms of a single cell while the thunderstorms of type II are the storms of a multicell. In cases of Kwangju, the hodograph patterns for each type of thunderstorm are similar to the patterns analyzed in cases of Osan.

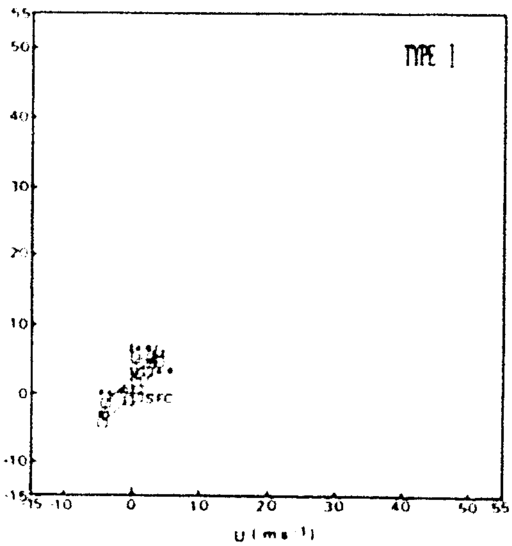

Fig. 3. A typical hodograph of air mass the thunderstorms of type I (0800LST, August 3, 1986). The numbers in the hodograph are the heights(km) above the mean sea level.

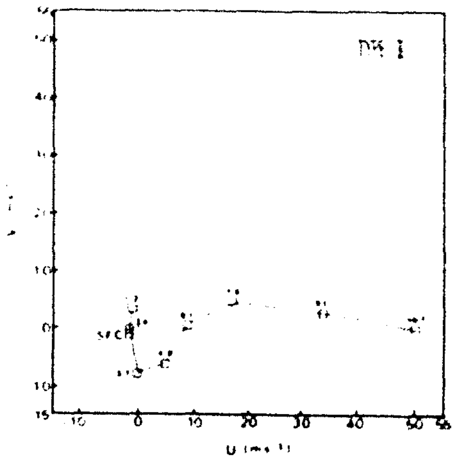

Fig. 4. Same as in Fig. 3 but for the air mass thunderstorms of type II (0800LST, June 15, 1987).

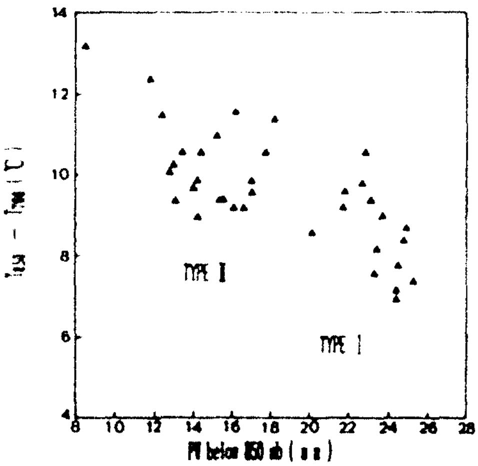

Fig. 5. Plot of the temperature difference (T_{850} - T_{700}) against the precipitable water (PW) from the surface to 850 hpa level.

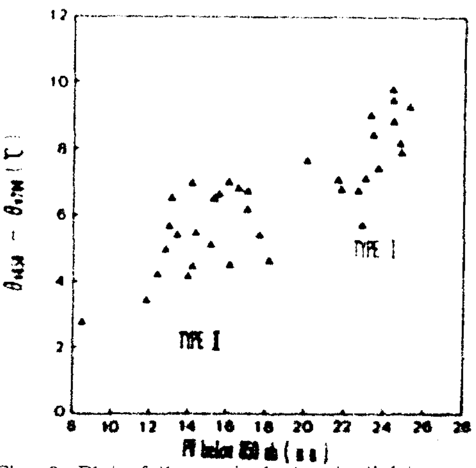

Fig. 6. Plot of the equivalent potential temperature difference (θ_{e850} - θ_{e700}) against precipitable water (PW) from the surface to 850 hpa level.

A significant difference between the two types of the thunderstorms is also found in Figs. 5 and 6, where the amount of precipitable water below 850 hPa level is plotted against both the temperature and the equivalent potential temperature difference between 850 hPa and 700 hPa levels, respectively. A clear distinction between the two thunderstorm types can be made by a critical value of the precipitable water amount in the figure, about 19mm.

In cases of the Kwangju area, the critical value of the precipitable water amount between the two types of thunderstorms is 20 mm as shown in Figs. 7 and 8 although the boundary between type I and II is not very well defined as in cases of Osan.

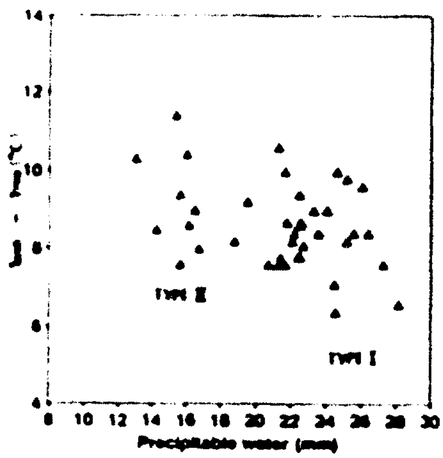

Fig. 7. Plot of the temperature difference (T_{850} - T_{700}) against precipitable water (pw) below 850 hpa level.

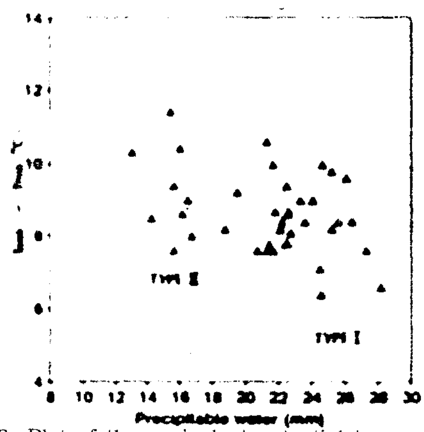

Fig. 8. Plot of the equivalent potential temperature difference (θ_{e850} - θ_{e700}) against the precipitable water (PW) below 850 hpa level.

Figs. 5 and 7 show that there is a close relationship between the amount of precipitable water below 850 hPa level and the temperature difference betwen 850 hPa and 700 hPa levels. The air mass thunderstorms of type I develop under the conditions of high amount of precipitable water and low conditional instability between 850 hPa and 700 hPa levels. On the other hand, the air mass thunderstorms of type ii develop under the conditions of low amount of precipitable water and high conditional instability betwen 850 hPa and 700 hPa levels. Our analysis of Figs. 5 and 7 indicate that the amount of precipitable water below 850 hPa level and the degree of atmospheric instability are complementary in the development of air mass thunderstorms.

According to Figs. 6 and 8, the thunderstorms of type I has a tendency of higher precipitable water and equivalent potential temperature difference between 850 and 700 hPa levels, compared with the thunderstorms of type II. This tendency indicates that the amount of water vapor in the atmospheric boundary layer plays a major role in the development of thunderstorms of type I while the atmospheric thermal instability above the boundary layer plays an important role in the develoment of thunderstorms of type II.

3. Conclusions

The air mass thunderstorms occurring in the middle region of South Korea can be classified into the two distinct types, type I and type II, based on synoptic pattern, vertical profiles of moisture, wind and temperature. The thunderstorms of type I occur when the atmosphere has high moisture content, low vertical wind shear in low levels, and conditional instability between 850 and 700 hPa levels. On the other hand, the thunderstorms of type II occur when the atmosphere has low moisture content, high wind shear and conditional instability.

The present study shows that the atmospheric thermal instability and the amount of water vapor below 850 hPa level are complementary in the development of air mass thunderstorm. The complementary nature between the two parameters provide us with an explanation for the thunderstorm development in the areas with very low atmospheric water vapor content such as tin he plains of eastern Colorado. The analysis of the hodographs (Chisholm and Renick, 1972) suggests further that the thunderstorms of type I have a single cell while the thunderstorms of type II have a multicell.

References

Byers, H. R. and R. R. Brahm Jr., The thunderstorm, U. S. Government Printing Office, Washington D. C., 287pp., 1949.

Chisholm, A. J. and J. H. Renick, The kinematics of multicell and supercell Alberta hailstorms. Alberta Hail Studies, 24-31, 1972.

Djuric, D. WEather analysis, Prentice Hall pp. 304, 1994.

Keenan, T. D., B. R. Morton, X. S. Zhang, and K. Nyguen, Some characteristics of thunderstorms over Bathurst and Melville Islands near Darwin, Australia. Quart. J. Roy. Meteor. Soc., 116, 1153-1172, 1990.

Prezerakos, N. G., An investigation into the conditions in which air mass thunderstorms occur at Athens. Meteor. Mag., 118, 31-36, 1969.

Weisman, M. L. and J. B. Klemp, The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. Mon. Wea.. Rev., 110, 504-520, 1982.