NHESS-2015-261

Responses to Anonymous Referee#1

Date: 25 January 2016

Authors Response

We revised the manuscript title "Dominant Processes of Extreme Rainfall-Producing Mesoscale Convective System over Southeastern Korea: 7 July 2009 case" that was submitted to *Natural Hazards and Earth System Sciences* on 11 October 2015. We incorporated the corrections and modifications as suggested by the referee#1 in the revised manuscript. We would appreciate any feedback on the revisions.

Major comments

The main reason would be the difficulty to understand the subject of this paper: no coincident among the title, described purposes in abstract, and described purpose in introduction. - Title: dominant processes of extreme rainfall - Abstract: to better understand 1) synoptic/meso-scale environment, and 2) behaviour of MCS - Introduction: 1) mechanism of rainfall, and 2) effect of synoptic/meso-scale environment on MCS - Section 1.2 (Organization of paper): 1) synoptic/thermodynamic environment, and 2) evolution and structure of MCS Authors didn't describe the importance to study on these subjects, and didn't show any results regarding these subjects in deed.

Response

We appreciated very much your constructive comments/suggestions on our manuscript. Based on referee#1's suggestions, we tried to incorporate the corrections and modifications. A point-by-point response to each of your comments/suggestions is given below.

Specific comments

1) In terms of the "to better understand synoptic/meso-scale environment"; first, author have to explain what is previously revealed synoptic/meso-scale environment favoured for the target MCS development by previous studies (e.g. known, and unknown factors) as there are many previous studies already done on this subject. Based on the careful

review of previous studies, then, author can raise the clear subjects of this paper, then, finally author can explain the new finding regarding the subject.

Response

Thank you for this suggestion. We fully agree your opinion. To clarify the purpose of our study, we included the previous studies associated with synoptic and mesoscale environment which lead to extreme rainfall.

We revised and modified the following sentences in introduction section (page 3-4, line 31-48).

- The Changma front affects Korea and other parts of East Asia; it develops during June and July which is called Changma season. Along the Changma front, the synoptic and mesoscale environments are favorable for deep convection. Several studies conducted that the synoptic and mesoscale environments associated with Changma front include (1) different air masses that formed through the meeting of maritime tropical and continental polar air mass; (2) a southwesterly monsoonal flow that is embedded with high equivalent potential temperature (Sun and Lee, 2002). Lee et al. (1998 and 2008), Sohn et al. (2012) examined the influence of strong warm and moist air that transport across Korean Peninsula along the northwestern periphery of the North Pacific high. Under these favorable synoptic conditions, Changma frontal precipitation accounts for a large fraction of the annual rainfall over the Korean Peninsula.

  Even with synoptic conditions being favorable for heavy rainfall during Changma season, the synoptic environment during the Changma season is characterized by strong baroclinicity because the atmosphere over Korea is generally thermodynamically neutral. This contrasts with the large convective available potential energy (CAPE) in the central US (Hong, 2004). Our present work builds upon this previous study and further investigates certain synoptic environment without CAPE, with the purpose to characterize the extreme rainfall-producing MCSs associated with Changma front.

Reference

Sohn, B.J., Ryu, G.-H., Song, H.-J., and Ou, M.-L.: Characteristic features of warm-type rain producing heavy rainfall over the Korean Peninsula inferred from TRMM measurements, Mon. Wea. Rev., 141, 3873–3888, 2013.

Hong, S.-Y.: Comparison of heavy rainfall mechanisms in Korea and the Central US, J. Meteor.

Soc. Japan, 82, 1469–1479, 2004.

2) In terms of the "mechanism of rainfall"; which mechanism author have in mind? For rainfall associated with MCS, e.g. the initiation, development, maintain, etc. could be the one. Please carefully mention it.

Response

This study investigated the reason and mechanisms leading to the extreme rainfall in the Busan, specifically how the heavy rainfall persisted for longer as the result of a slow-moving MCS, or of the sustained regeneration of convection. The main reasons of mechanisms leading to the extreme rainfall was '*back-building process*', which occurred when convective cells repeatedly form upstream of their predecessors and pass over a particular area as '*train effect*'. We examined these effects in section *4(a) characteristics of the quasi-stationary MCS* by using radar observational data. We modified the figure 10 to see clearly.

The reason of a slow-moving MCS examined in section *4(b) Propagation of the quasi-stationary MCS*. Shortly, the present case included: (i) the movement of convective cells opposing the motion from backward propagation; (ii) convective cells moving parallel to the convective line; (iii) the system as a whole moving slowly. This produces a persistent convective event at a given location.

3) In terms of the "effect of synoptic/meso-scale environment on MCS"; author needs to be very careful regarding the "effect" term. As this terms used in subject, readers will expect the quantitative or qualitative effects (of synoptic/meso-scale environments) on MCS (of its initiation, development, maintain) in the result. However, author didn't show any of these related results.

Response

Thank you for this suggestion. We agree your opinion and revised the quantitative analysis (of synoptic environment) associated with MCS.

We revised the following sentences in *3.1 synoptic environment*.

- The deep convection with $T_B \leq 220$ K was compared with a severe MCSs, which classified by Jirak et al. (2003). (page 7, line 133-135)

- The NCEP–NCAR reanalysis at 0900 LST 7 July at the surface indicates relatively strong pressure gradient of about 1.1 hPa (100 km) between the subtropical high and the deepening frontal low (Fig. 4a). (page 8, line 142-144)
- Further aloft at 500 hPa, a main trough was located at 123°E and west-southwesterly winds of 20–25 m s^{-1} ahead of it prevailed near western Korea. (page 8, line 151-152)

Reference

Jirak, I. L., Cotton, W. R. and McAnelly, R. L.: Satellite and radar survey of mesoscale convective system development. Mon. Wea. Rev., 131, 2428–2449, 2003.

4) In terms of the "evolution and structure of MCS"; It seems that author explain this term by description in section 4.1 with figures 9 and 10. For instance, author used important terms e.g. squall line, deep convection, leading-line trailing-stratiform, convective cell, cell initiation, cell merge in this section, however, it's hard to find where these terms are depicted on the figures. What is the definition of squall line, deep convection, convective cell, cell initiation and merge? And how those terms are seen in the figure? Depending on the definition, what we can find could be different. Author have to kindly explain so that readers can learn the interesting features seen in the analyses.

Response

Thanks for pointing it out. The section 4 (structure and evolution of the quasi-stationary MCS) with Figs. 8–10 explained the mechanisms leading to extreme rainfall over Busan. Figure 8 showed overall structure of MCS type (squall line, leading-line trailing-stratiform). And the more detailed description of the characteristics of MCS (e.g. convective cell merging and initiation) was explained by figures 9–10. The relevant structure of MCS leading to extreme rainfall was back-building process, which new convective cell was initiated on the upstream side (rear flank) of convective line. Figures 9–10 revised to improve presentation clarity and paper were revised accordingly.

- At 0710 LST, a new convective cell (reflectivity values ≥ 47 dBZ, marked by D in Fig. 9b) was initiated on the upstream side (rear flank) of the convective line. (page 13, line 251-253)

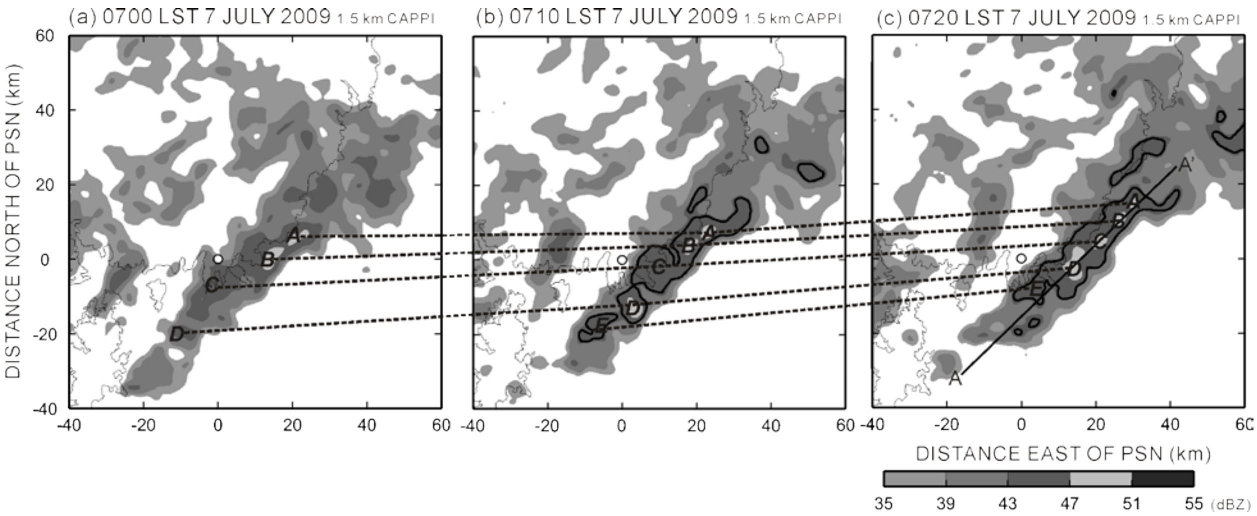

Fig. 9

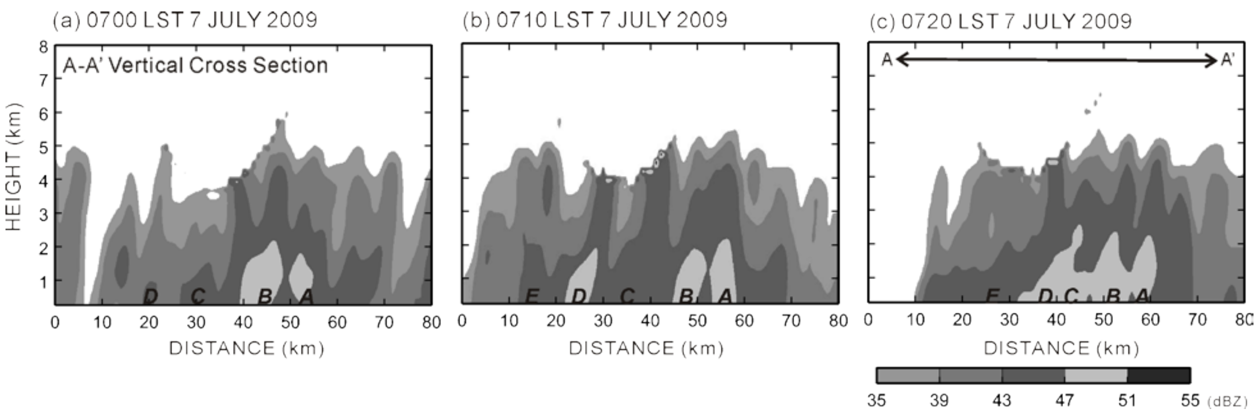

Fig. 10

5) How the TS could be explained without showing stratiform region (reflectivity less than 30 dBZ)? The trailing stratiform region is characterised by large horizontal area, notch like concavity at rear edge, secondary dBZ maximum, separated from convective cloud and etc. And the convective region has arc-shape, rapid movement, solid appearance, strong dBZ gradient at leading edge, elongated cell and etc. Please kindly describe these TS characteristics.

Response

The figure 9 could not explain stratifrom region because the reflectivity was shown less than 35 dBZ. The characteristics of trailing-stratiform (TS) could explain and examined through Fig. 8. In this study, the trailing stratiform region has 1) relatively large area of precipitation region in Busan; 2) behind the leading convective line. The convective region has 1) bowlike feature; 2) organized into a linear shape; 3) relatively strong gradient of leading convective line. These features mentioned in section 4.1 characteristics of the quasi-stationary MCS. Interestingly, TS-MCS are often associated with a synoptic cold front, but in this case developed north of a stationary warm front. The environment in the present case obviously differs from that in previous studies (page 12, line 243-247).

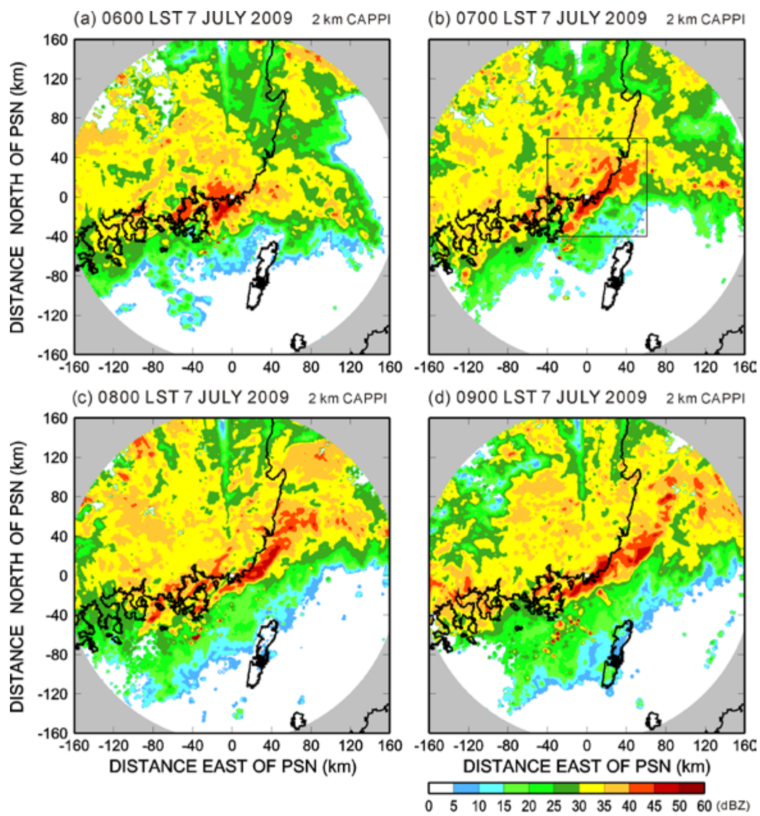

Fig. 8

6) Another reason would be the mixed description of analyses results of the present study and results of previous studies. In sections of 3 and 4 which is the "result" sections, authors have to describe carefully the analyses results, explaining kindly the analyses methods in section 2, so that readers can follow. For instance, descriptions of analyses methods for Figures 11 and 12 ("area average" analyses) are missing. As the interesting region is in baroclinic environment, the analyses results are dramatically changed, depending on the designed analyses area, especially for wind and temperature parameters.

Response

Thank you for this suggestion. However, following suggestion of Referee #1, the descriptions of analyses methods for Figures 11 and 12 ("area average" analyses) included in section 2 (Data and methodology) as 'Thus, some alternative sounding and domain-averaged information for this event was taken from the JMA-MSM analysis.' (page 6, line 103-105) And the paper added to more clearly express this method. 'The domain-averaged was to be used for particular region within the quasi-stationary MCS.' (page 6, line 105-106)

7) It's difficult to find any of new finding in the described contents in summary and conclusion. The described important factors e.g. frontal slope, trough, upper-level jet, LLJ, and upstream initiation of MCS on rainfall in the section of summary and conclusions are already very well-known factors in meteorological field. In conclusion section, author should focus the new finding and the worth of the results.

Response

Thank you for this suggestion. The described important factors were well-known factors in meteorological field. However, these factors were not be favorable for extreme rainfall. This manuscript mainly focus on a development mechanism of MCS leading to extreme rainfall which was relevant rain-induced natural hazards in Korea. This paper is first reported in this rare event. We hope this is a new founded meaningful works in Korea.

8) author mentioned the important roles of cold pool and downdraft in inducing long lasting MCS, however the corresponding results are not clearly shown in results section; this term should be carefully described showing the proper evidences, e.g. the vertical wind cross-section along the low-level wind direction, horizontal vertical wind distribution and its temporal evolution. The cold pool was briefly explain using Figure 13. However, these following terms are necessary to be described kindly: 1) how the offshore wind could be captured by surface observation data? 2) what is data error? 3) how the "outflow boundary" was identified? 4) what is the cold pool boundary? 5) normally the inland temperature is lower than those temperatures observed on coastal region or offshore. Keeping this on min, how author explain the generated cold pool?

Response

Thank you for this suggestion. The paper revised and modified as following:

(1) The paper revised to more clearly express method how to derive offshore winds and temperature.

- The surface observational data was interpolated from the measured points within neighborhoods, which was analyzed larger spatial areas near MCSs. (page 7, line 121-123)

(3) The outflow boundary was identified sudden change in surface wind direction and speed using surface observation data. And surface wind was confluence between southwasterly and northeasterly flows. The paper revised to more clearly understand.

- a sudden change in surface wind direction and speed which identified outflow boundary was observed in southern Busan at 0600 LST (marked by the box in Fig. 13b). (page 16, line 336-337)

(4) The cold pool boundary was identified surface temperature depression approximately 3–5°C.

- With the arrival of the cold pools at the coastline, the surface temperature depression was approximately 3–5°C (Figs. 13c,d). (page 16, line 329-330)

(5) In general, the inland temperature is lower than those temperatures observed on coastal region or offshore. In this study, the cool surface temperature (≤20°C) gradually expanded where previous precipitation progressed northeastward in the direction of convective system movement. This pattern should be different compared with normal.