ACP-2015-687
Authors' Responses to Reviewer 2 (anonymous)
Date: 26 February 2016

Title: A numerical study of back-building process in a quasi-stationary rainband with extreme rainfall over northern Taiwan during 11-12 June 2012
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### 1. General comment:

With a cloud-resolving model, this study investigates a quasi-stationary rainband that caused extreme rainfall over northern Taiwan, in an attempt to understand the processes responsible for the occurrence of severe flooding associated with this particular case. A primary conclusion drawn in this article is that the back-building (BB) processes were suggested to be crucial for contributing to the occurrence of the observed extreme rainfall. Some modeling aspects implicit in the BB processes are also presented and discussed. The central theme of the study is generally interesting. Unfortunately, the reliability of the conclusions learned from the study suffers from a number of fundamental problems, which can be clearly seen based on the current form of the manuscript. The reviewer believe that a significant re-work on writing and analysis will be required to accommodate these serious concerns and the resultant manuscript would be very different from this one.

**Reply:**

The comments from this reviewer (Reviewer 2), as well as those from Reviewer 1, are all appreciated, and the paper has been revised according to all these comments and suggestions. In the revised manuscript (color coded), the changes made in response to Reviewer 1, Reviewer 2, by ourselves (mostly minor changes in wording or to correct mistakes), and during the typesetting stage of ACPD (to comply with the journal format and style) are marked in red, blue, orange, and green, respectively. Thus, words in green are the same as seen by the reviewers earlier, and can be ignored. Our reply to the "general comment" from this reviewer is given in the next paragraph below, while the point-by-point responses to each of the specific comments are listed further below. In each point, how and where the revision is made in the text is indicated.

In response to the overall comment from this review, revision is made mainly to (1) replace Fig. 6 with a new figure, which can more clearly depict the BB process at the end of the convective line and/or to the west of old cells, and (2) to clarify that there are other important processes leading to the formation of the quasi-linear MCS beyond the storm scale (such as frontal and terrain forcings), but we have focused on the BB process west of old cells inside the line on the convective scale (meso-$\gamma$) in the present study. As we know, in extreme events such as the present case, there are often several factors and forcings working in synergy across a wide range of scales to lead to their occurrence. Thus, each of these factors and the interactions among them, in our opinion, is worthwhile to investigate. In the present case, the larger-scale forcings (at meso-$\beta$ scale and larger) provided the background to the problem of our focus, and we have clarified this point in the revision where appropriate (e.g., p.7, L25-27; p.8, L12-15; p.10, L2-11; p.12, L9-10; p.18, L22-23). Please also see our more-detailed reply to each of the specific comments below.

**2. Specific comments:**

1. Various observations and modeling results presented in the paper did support a close relevance of the frontal forcings to the development of heavy rainfall associated with the studied rainband. For example, the CWB surface analysis, the NCEP analysis, and the ASCAT winds shown in Figs. 1 and 2a,c,e all indicate that a slow-moving Meiyu front was oriented NE-SW (roughly along 25 N) and located immediately north of Taiwan. The Mei-yu front coincided very well with the elongated studied rainband, and the orientation and spatial scale for the front and the rainband were consistent with each other, as illustrated by radar maps in Fig. 4. These observations strongly suggest that the convective system causing severe floods over northern Taiwan actually was a frontal rainband rather than a pre-frontal squall line as claimed by the authors. The convective forcings associated with the frontal zone are expected to be one of the primary contributors but were completely ignored in the current context of this study.

**Reply:**

We agree with the reviewer that the forcing associated with the approaching front was an important contributor to the development of the quasi-linear MCSs in the present event, and we do not intent to deny its importance, not even in our previous draft. As suggested by this reviewer, to better place our current study into its context, we have added more material to discuss the role of the approaching mei-yu front (the frontal forcing) and the flow splitting and subsequent channeling, convergence, and acceleration (the topographic forcing) at low levels over the northern Taiwan Strait with appropriate references in the revision (p.1, L14-15; p.4, L10-12; p.7, L20-27; p.10, L1-6; p.12, L18-21). It is stated that such conditions are particularly conducive to quasi-linear MCSs, and both the frontal forcing and the terrain-induced convergence are driving mechanisms at meso-$\alpha$ and meso-$\beta$ scales in the present case (p.7, L25-27; p.8, L12-15; p.10, L8-11; p.12, L9-10; p.16, L20-21; p.18, L22-23;

p.22, L19-21), as suggested. It is also better clarified that the focus of the study is on new cell initiation at convective scale under the frontal and topographic forcings beyond the storm scale (p.4, L10-12; p.10, L12-17; p.18, L24).

2. Further support of the reviewer's point mentioned in the comment #1 is provided by the CReSS model simulations presented in Fig. 7, which shows that the studied rainband formed over northern Taiwan was collocated with a narrow confluent zone in the vicinity of the Mei-yu front between northeasterlies and southwesterlies (cf. Fig. 7f). Note also that an additional wind shift zone was evident offshore over northwestern and northeastern Taiwan (Fig. 7), presumably due to the common occurrence of orographic blocking and/or the leeside effects of topography as prevailing southwesterly flow interacts with Taiwan island during the Mei-yu season (e.g., Sun et al. 1991, MWR; Chen and Li 1995, MWR; Li and Chen 1998, MWR; Yeh and Chen 2002, MWR). This topographically generated convergence may represent another critical mesoscale forcing, favoring the development and organization of deep moist convection associated with the studied rainband.
It is clear that both observations and modeling results provide consistent evidences that the organization and maintenance of the studied rainband are closely related to the frontal and topographic forcings. In fact, the authors have also admitted in the manuscript that the development of the studied precipitation system is closely tied to the low-level convergence associated with the frontal forcing (e.g., L26-29 in P32689). Given this fact, it is not wise to downplay the roles of the frontal forcing in contributing to the occurrence of the observed heavy rainfall.

**Reply:**

Similar to our reply to the specific comment #1 above, we agree with the reviewer that the forcing induced by the blocking effect of Taiwan topography (upstream flow splitting and subsequent channeling, convergence, and acceleration and the LLJ) at low levels over the northern Taiwan Strait was also an important factor and is responsible for the formation of the second quasi-linear MCS during 1800-2400 UTC in our model simulation (according to Figs. 4 and 7, with surface frontal positions marked when available, see the text in 2nd paragraph, p.11, p.36-37, p.40-41). In the revision, the role of topographic forcing is also discussed with appropriate references, as suggested (p.7, L20-27; p.8, L4-6; p.8, L12-15; p.12, L18-21), as we have no intention to downplay its possible role. Again, it is also better clarified that the focus of the study is aimed at the new cell initiation at convective scale, under the frontal and topographic forcings at larger scales beyond the storm scale (p.4, L10-12; p.10, L1-6 and L8-17; p.12, L9-10; p.18, L22-24).

3. The authors strongly argue that the BB processes are a key mechanism for the generation of the convective system that caused severe floods over northern Taiwan. However, this is obviously not the case, as indicated in the sequence of radar maps presented in Fig. 6. Based on these radar-observed precipitation signatures, severe floods over northern Taiwan could be mostly attributed to the presence of an approximately W-E elongated, quasi-stationary rainband. Several precipitation cells (Fig. 6) were formed near the western end of the studied rainband, as claimed by the authors, but they were quite transient and were generally located well offshore, far away from the target area of heaviest rainfall over northern Taiwan. In contrast, most of new precipitation cells conducive to the maintenance of the rainband's convection over land were evidently produced immediately ahead (south) of the entire length of the rainband (i.e., the inflow side), particularly for the inland region of northern Taiwan (cf. Figs. 6i-m). These cells were oriented (organized) roughly parallel to the preexisting rainband. In addition, the enhanced precipitation of the rainband tended to exhibit a quasi-steady signature (Fig. 6), which is in turn consistent with the influence of a persistent convective forcing associated with the slow-moving Mei-yu front as described in the comment#1 and #2. These observational evidences regarding the rainband's evolution did not support the likelihood that the BB processes are a reasonable scenario considering the extreme rainfall observed over northern Taiwan.

**Reply:**

In the revision, Fig. 6 in the previous draft is replaced by a new set of panels using a different color scale, which can better depict the convective elements embedded inside the line and thus their evolution (e.g., new initiation and merging), and this new figure can more clearly show the BB process do take place at the end of the convective line as well as to the west of old cells in the present event (p.18, L13 and L28; p.29, L25-28; p.39). In the text, it is also better conveyed that (1) the were clear westward extension of the linear MCS (as shown in Figs. 4 and 6; p.36, p.39), i.e., the back-building behavior clearly significantly lengthened the heavy-rainfall period (since most cells at/near the western end of the line, transient or otherwise, eventually moves onshore to cause rainfall over land) (evident in Fig. 6; p.8, L27-30; p.9, L29-32; p.10, L11-12; p.39), and (2) some of the new cells just west of old cells in Fig. 6 formed close to the land, and as their counterpart in the model, the studied new cell does merge with the old cell and produce rainfall at high intensity over northern Taiwan (cf. Figs. 7f and 9, p.9, L24, L27; p.11, L26-30). So, as one of the factors, the BB process at the cloud scale indeed contributed to the heavy rainfall in northern Taiwan in the present case (as in many other cases throughout the world), whereas the frontal and topographic forcings are also important factors acting at larger scale, as clarified above and in the revision (p.1, L14-15;

p.4, L10; p.8, L12-15; p.10, 1-6 and L8-11; p.12, L9-10; p.18, L7). In addition, the structure of multiple lines, as mentioned by this reviewer, is noted with appropriate references on its possible mechanism cited in the revision (p.10, L6-8; p.22, L1-2; p.26, L25-26).

4. Suggestion: Because the scientific objective of the study is to understand the processes leading to the extreme rainfall for this particular event, the reviewer strongly feel that the authors should consider focusing on other observational aspects that are more relevant to the occurrence of heavy rainfall, instead of sticking to the unsupported mechanism (i.e., the BB process). For example, relative importance of frontal and topographic forcings and their roles in triggering and organizing the precipitation rainbands observed over northern Taiwan may be worth pursuing further to provide more solid and convincible descriptions.

**Reply:**

In our previous as well as the revised draft, it is explicitly stated that the BB process, and more specifically, why the location about 15-30 km upstream from old cells is more favorable for the initiation of new BB cells (as seen in observations and our model simulation) are the objective, or the scientific question that we wish to address in this study (p.3, L32 to p.4, L2; p.4, L10-12; p.10, L11-17). Thus, the problem to be studied is at convective scale and our goal is not to identify or study the "most important" factor or process leading to the heavy rainfall in northern Taiwan (e.g., p.10, L11-17), which seems to be the purpose interpreted by this reviewer. In the revision, as mentioned above, we have clarified this point and also noted the importance of the processes identified by this reviewer (i.e., the frontal and topographic forcings at scales beyond the storm scale) in the text where appropriate (p.1, L14-15; p.4, L10; p.10, L1-6 and L8-11; p.12, L9-10; p.16, L20-21; p.17, L13-15; p.18, L22-24). As for the suggestion, one of our current studies with a graduate student is focused on the synoptic evolution leading to the event throughout 10-12 June 2012, and this study will most likely touch upon those aspects mentioned by this reviewer that are also important to the occurrence of heavy rainfall. However, that study will indeed be very different from the present one due to their different focuses.