

Response to Reviewer #1

We thank Dr. Wang for his extremely thorough and insightful comments, which have been very helpful in the further revision of our manuscript. We have made every effort to address all the concerns raised by this review. Our point-by-point response is given below.

Major comments:

1. *In this manuscript, the authors discussed the mechanism through which the convection (or convective updraft) propagates southeastward from the leeside to the plain area, but not very consistent at different places (for example, in p.27903, L10-13; p.27905, L4-7; also see minor comments #4 and #5). The authors should revise the relevant material, and cite at least a few appropriate references relevant to organization and propagation of convective systems (such as the RKW theory, e.g., in p.27907, near the end of the second paragraph).*

Reply: We believe that there are two mechanisms that contribute to the southeastward propagation of the convective updrafts from the leeside to the plain area. It is primarily induced by the southeastward propagation of the upward branch of the diurnally varying mountain-plains solenoid (He and Zhang 2010). The propagation of the convective systems that is further aided by the cold pool dynamics similar to those proposed in many related studies on mesoscale convective systems (e.g., Rotunno et al., 1988, Weisman and Rotunno, 2004; Bryan et al., 2006, Coniglio et al., 2012; Morrison et al., 2012). We will make relevant changes throughout the manuscript for consistency, and add the following references:

Bao, X., Zhang, F., and Sun, J.: Diurnal variations of warm-season precipitation east of the Tibetan Plateau over China. Mon. Wea. Rev., 139, 2790-2810, 2011.

He, H., and Zhang, F.: Diurnal variations of warm-season precipitation over Northern China. Mon. Wea. Rev., 138, 1017-1025, 2010

Sun, J. and Zhang, F.: Impacts of Mountain-plains solenoid on diurnal variations of rainfalls along the Mei-Yu Front over the East China plains. Mon. Wea. Rev., 140, 379-397, 2012.

Bryan, G. H., Knievel, J. C., and Parker, M. D.: A multimodel assessment of RKW

theory's relevance to squall-line characteristics. *Mon. Wea. Rev.*, 134, 2772–2792, 2006.

Coniglio, M. C., Stephen, F. C., John, S. K.: Views on Applying RKW Theory: An Illustration Using the 8 May 2009 Derecho-Producing Convective System. *Mon. Wea. Rev.*, 140, 1023–1043, 2012.

Morrison, H., Sarah A. T., Kyoko, I., Gregory, T.: Sensitivity of a Simulated Midlatitude Squall Line to Parameterization of Raindrop Breakup. *Mon. Wea. Rev.*, 140, 2437–2460, 2012.

Rotunno, R., Klemp, J. B., and Weisman, M. L.: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, 45, 463-485, 1988.

Weisman, M. L., and Rotunno, R.: "A theory for strong long-lived squall lines" revisited. *J. Atmos. Sci.*, 61, 361-382, 2004.

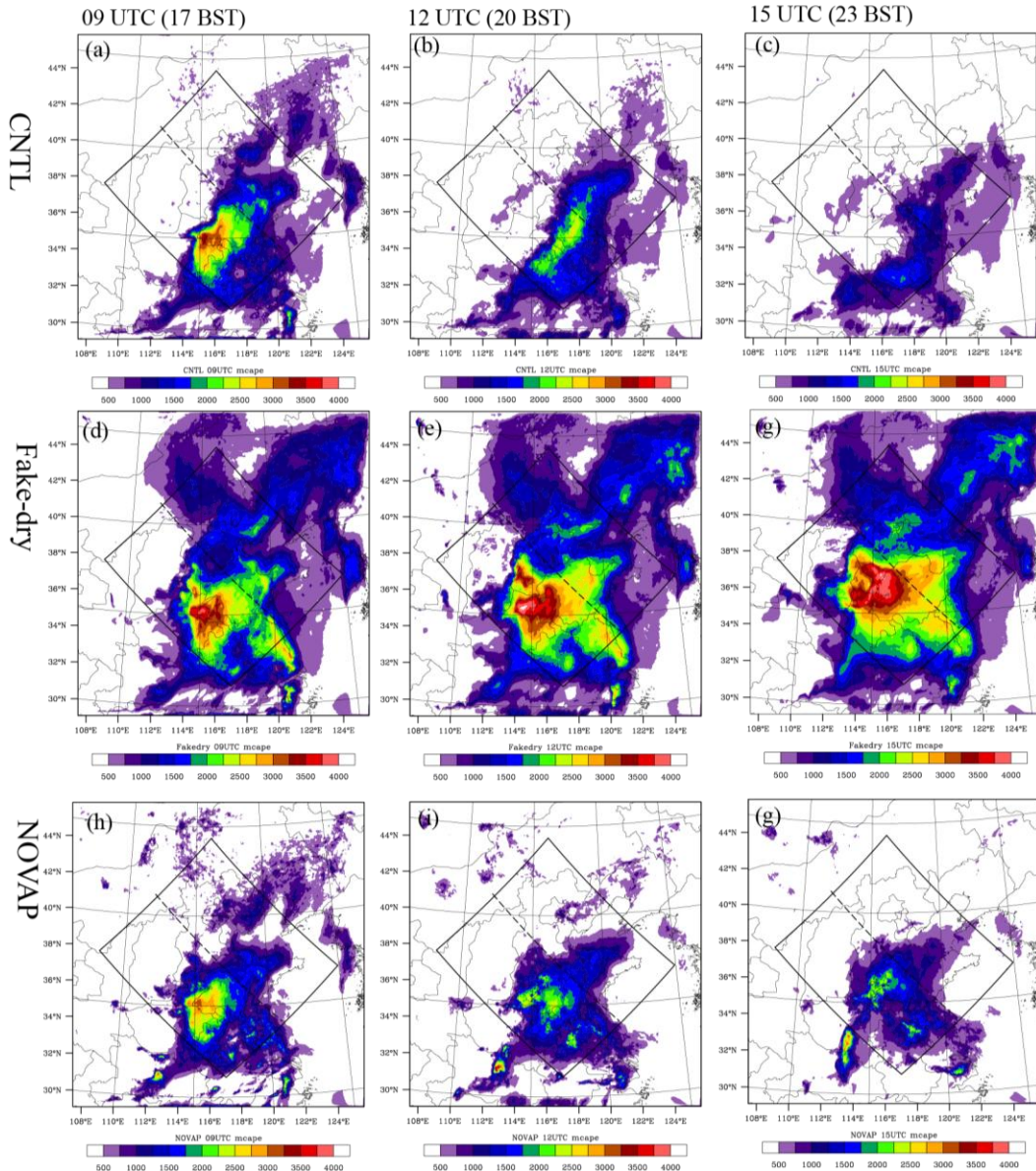
2. P.27903, L6-9: *The issue of stability has never been brought up and discussed by the authors. It would be nice and worthwhile if the authors can examine at least briefly the mean thermodynamic conditions and the stability of the atmosphere over the plain area before the arrival of the nighttime convection. This would also have implication in understanding why the model produces much more rain in NOVAP run compared to CNTL and Fake-dry experiments. Please also see major comment #4 below.*

Reply: We did examine the mean thermodynamic conditions and the stability of the atmosphere over the plain area before the arrival of the nighttime convection. An example of such diagnosis is shown in the following supplemental figure of maximum CAPE distribution plots for all three experiments. From this figure it is unclear such stability analysis suggested by the reviewer will help explain the difference in the amount of precipitation among different experiments. For example, Experiment Fake-Dry has the largest CAPE while produces the least precipitation, CNTL and NOVAP have more or less similar amount of CAPE over the plains before the arrival of the convection. The larger amount of CAPE in Fake-Dry is due to the artificial suppression of the convective potential energy release (and thus more accumulation) by

turning off latent heating release. The updraft has the smallest amplitude in Fake-Dry, which leads to the least amount of precipitation. Although the stability condition (and CAPE) is similar between CNTL and NOVAP, without the cooling due to evaporation, Experiment NOVAP may attain higher amplitude of updrafts that can enhance the precipitation rate, consistent with previous studies of (e.g., Schumacher 2009, Trier et al. 2011). On the other hand, without the cold pool effect due to evaporative cooling in NOVAP, the updraft will move much slower in NOVAP than CNTL. The slower moving speed will further enhance the local accumulated precipitation. The third potential mechanism as suggested by the other reviewer is that excluding evaporation for convection of a given strength may lead to more precipitation reaches the ground when evaporation is withheld. The above discussion will be added to the revised manuscript.

References:

- Schumacher, R. S.: Mechanisms for quasi-stationary behavior in simulated heavy-rain-producing convective systems. *J. Atmos. Sci.*, 66, 1543-1568, 2009.
- Trier, S. B., Marsham, J. H., Davis, C. A., and Ahijevych, D. A.: Numerical simulations of the postsunrise reorganization of a nocturnal mesoscale convective system during 13 June IHOP_2002, *J. Atmos. Sci.*, 68, 2988-3011, 2011.



Supplementary Figure 1: The distribution of the average CAPE at 0900 UTC, 1200 UTC, and 1500UTC in CNTL (a)-(c), Fake-dry (d)-(f), and NOVAP (h)-(i).

3. P.27906, L1-4, title and content of section 5: I am confused by the title and L3-7 (i.e., the first two sentences) of section 5. The authors need to make a distinction between the MPS (produced through solenoids from uneven heating/cooling) and the circulation induced by deep convection here. Being induced by topography, the former reverses in its pattern between day and night but stay more-or-less fixed in location, while the latter of course moves (propagates) with the convection. So, I am not sure how latent heating and/or evaporative cooling get the MPS to propagate (which is what the authors state here, see e.g.,

p.27908, L6-10; p.27909, L1-3; p.27910, L13-17). An example is Huang et al. (2010, already in reference list), where the MPS (between the eastern Tibetan Plateau and leeward lowlands) is shown to regulate (or modulate) the propagation of the convection and the convection (at the corresponding phase speed) acts to enhance the MPS locally. In my understanding, the content in section 5 discusses how the development and propagation of convection, not MPS, are affected by latent heating and cooling.

Reply: Contrary to Huang et al. (2012) that suggests the MPS is fixed more or less in location (or purely oscillatory), our past studies found the updrafts of the MPS have the characteristics of propagation over China (He and Zhang, 2010; Bao et al. 2011; Sun and Zhang, 2012). The propagating updrafts of MPS are also found in earlier studies over the lee of the Rockies in the US (Zhang and Koch 2000; Koch et al. 2001). As in the current study, the southeastward movement of the updraft in Fake-Dry also shows that the southeastward propagation of upward branches of the MPS without the cold pool (or without the local enhancement and regulation of convection) albeit slower in speed. As in our response to the first major comment, the propagation of the convection from the leeward to the plains is due to the southeastward movement of the upward branch of the MPS which is further influenced by the cold pool dynamics. Without the cold pool effect due to evaporative cooling, the southeastward speed of convection is substantially slower in NOVAP (as well as in Fake-Dry) than in CNTL.

References:

Bao, X., Zhang, F., and Sun, J.: Diurnal variations of warm-season precipitation east of the Tibetan Plateau over China. Mon. Wea. Rev., 139, 2790-2810, 2011.

He, H., and Zhang, F.: Diurnal variations of warm-season precipitation over Northern China. Mon. Wea. Rev., 138, 1017-1025, 2010

Sun, J. and Zhang, F.: Impacts of Mountain-plains solenoid on diurnal variations of rainfalls along the Mei-Yu Front over the East China plains. Mon. Wea. Rev., 140, 379-397, 2012.

Zhang, F., and Koch, S. E.: Numerical simulation of a gravity wave event observed during CCOPE. Part 2: Wave generation by an orographic density current. Mon.

Wea. Rev., 128, 2777-2796, 2000.

Koch, S. E., Zhang, F., Kaplan, M. L., Lin, Y-L., Weglarz, R., and Trexler, C. M.: Numerical simulations of a gravity wave event over CCOPE. Part III: The role of a mountain-plains solenoid in the generation of the second wave episode. Mon. Wea. Rev., 129, 909-933, 2001.

4. P.27906-27909, section 5: *In this section, the authors discuss the impacts of latent heating and/or evaporative cooling on the behavior of convection development and propagation (not MPS, please also see major comment #3 above). In the Fake-dry run where latent heating/cooling is turned off, the rainfall is much reduced and almost out-of-phase from its normal diurnal cycle (Figs. 4c and 6c). However, when only the evaporative cooling is turned off (with latent heating kept on) in NOVAP run, the rainfall is increased dramatically and the convective system propagates at about 2/3 of its normal speed (Figs. 4d and 6d). Notice that in Fig. 6d, there seems to be a second propagation signal at the same phase as the main updraft in CNTL (appearing as light blue, from 07 UTC at 450 km to 14 UTC at 800 km). While I understand the scenario in NOVAP (and in Fake-dry) is hypothetical, the results are a bit surprising since the initial conditions (each 1-day run) are taken from CNTL and are therefore the same. I think that further discussion on why the rainfall increases so much (e.g., reduction in surface cooling and thus less stabilization, and this aspect is related to the major comment #2) and what controls the system propagation (e.g., divergent outflow at surface without enhancement by cooling, or steering flow at certain level?) in this case can shed light on the understanding the behavior of convection at least in the model, and perhaps in the real world as well. To the very least, some plausible explanation needs to be offered. Currently, it is neither clear nor sufficient to me.*

Reply: Please refer to our response to your major comment 2 above. The larger precipitation in NOVAP than CNTL may be due to (1) a stronger updraft due to less energy loss by evaporative cooling despite similar in CAPE, (2) a slowed moving speed without the cold pool by turning off evaporative cooling, and (3) more precipitation

reaching the ground without evaporative cooling.

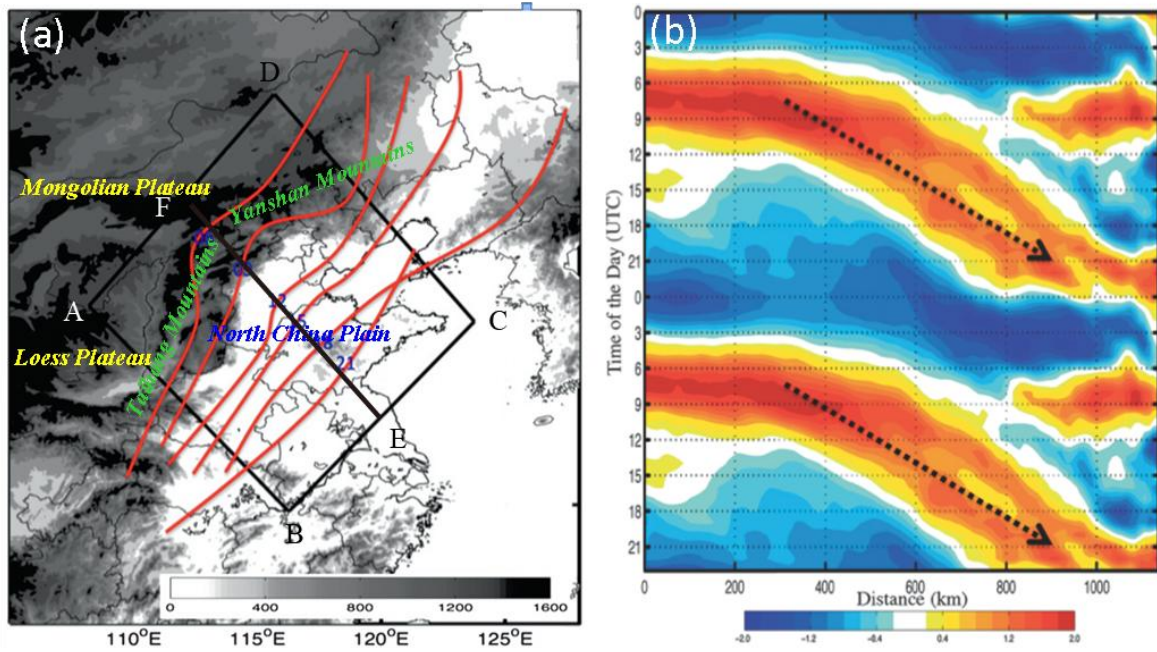
Minor comments:

1. P.27891, title: The data and results of this study are applicable to early summer and perhaps much of the warm season, but not the cold season. Thus, I think it is more appropriate to add "warm season" in the title.

Reply: We will make title word change from "precipitation" to "warm-season precipitation".

2. P.27894, L2-3 and other places: Throughout the text, specific geographic features, mostly mountains and plains near and over Northern China, are mentioned quite frequently, such as the Great Khingan, Taihangshan Mountain, Wushan Mountain and Xufeng Mountain, as well as the Yanshan-Taihangshan Mountain ranges (e.g., p.27895, L7-8). I think that a figure showing these features early in the paper can assist the unfamiliar readers a great deal and help the authors convey their arguments better.

Reply: We will label some main topography features over North China on the revised map of Fig. 1a (shown below): Mongolian Plateau, Loess Plateau, Taihang Mountains, Yanshan Mountains and North China Plain. The other mountains, such as the Great Khingan, Wushan Mountain and Xufeng Mountain, which don't locate over North China, aren't marked.



3. P.27903, L10 and other places: The cold pools in Fig. 8 and other similar figures (Figs. 10 and 11) are not shown clearly. Please consider some alternatives to enhance the readability, for example, highlight a certain potential temperature value (or plot a certain negative perturbation value) using a different color. Similarly, the reversal of horizontal temperature gradient (p.27903, L27-28) at nighttime is not clear in Fig. 8.

Reply: We will revise Fig. 8 as shown below to enhance the readability as recommended.

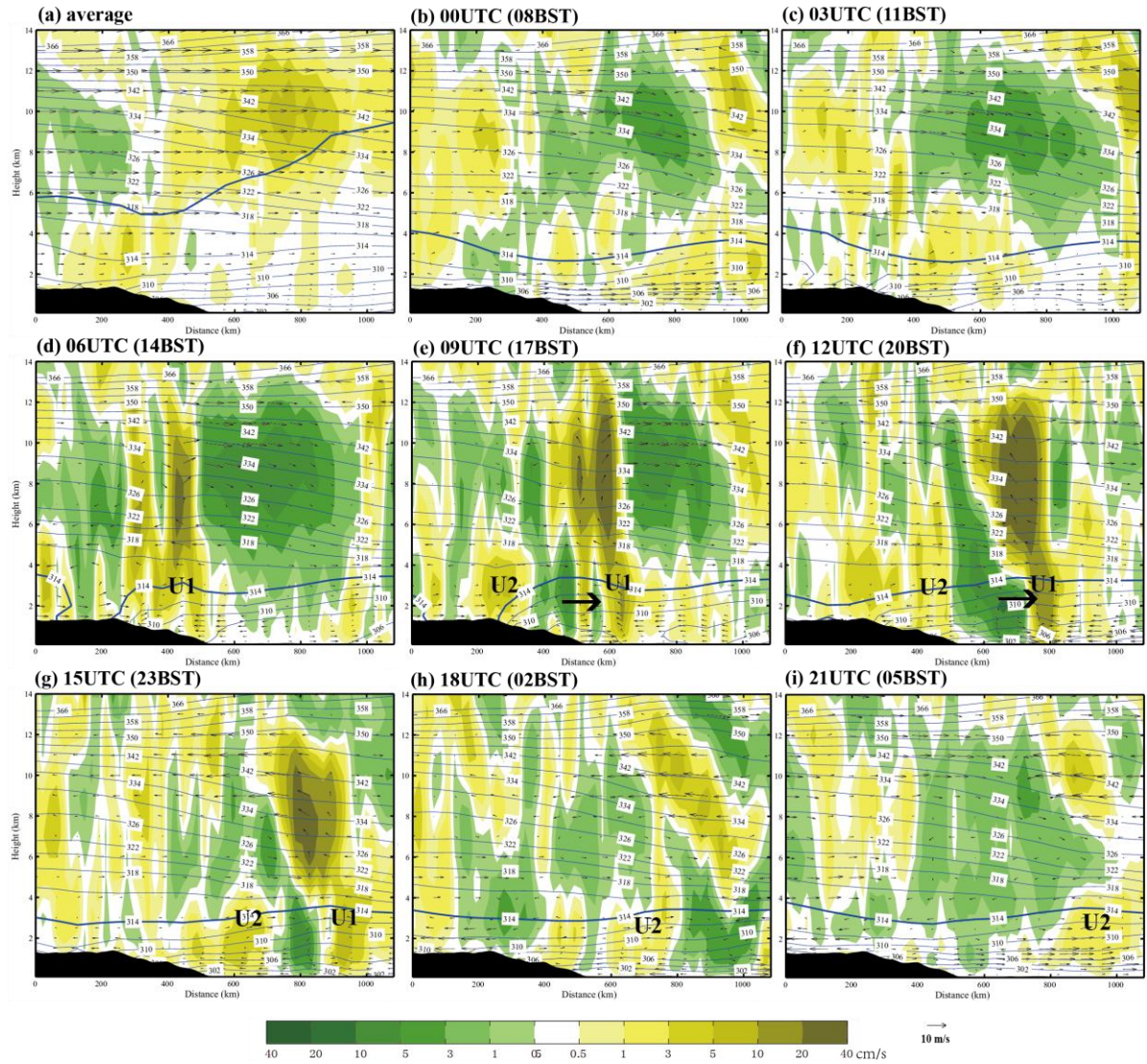


Fig. 8. (a) Height-distance cross section of daily mean potential temperature (solid lines, K), vertical velocity (shaded, cm s^{-1}) and the mean circulation vectors (horizontal wind component along the northwest-southeast cross section and 100 times the vertical velocity) averaged over ABEF from CNTL. The thick blue line shows where the northwesterly wind is equal to 12 m s^{-1} . (b)-(i) As in (a), except the vertical velocity and circulation vectors are the diurnal perturbations from the daily mean (potential temperature contours are of their full values). The black shading represents topography. The thick blue lines show the potential temperature value is equal to 314K in (b)-(i). The arrows show the pressure gradient force.

4. P.27903, L10-13: While reasonable and likely so, the existence of forward-directed horizontal pressure gradient force (PGF) is not demonstrated in Fig. 8, and I am not convinced that this is the primary mechanism by which the updraft propagated forward. An example of case study can be found in Wang et al. (2011), where the PGF caused

acceleration further downstream near the surface and triggered new convection remotely, away from the old convection.

Reply: Please refer to our response to your major comments #2 and #4. The southeastward movement of the convection is primarily due to the southeastward propagation of the upward branch of the MPS, not purely by the PGF induced by the cold pool. We agree with the reviewer and thus will add to the revised manuscript that the PGF may cause acceleration further downstream near the surface and triggered new convection remotely, away from the old convection, as in Wang et al. (2011), and also suggested in our earlier studies of He and Zhang (2010).

5. P.27904, L13-15 (also p.27905, L1-2): If the environment is conditionally or convectively unstable, the (convective) updrafts, once developed, are bound to produce precipitation, so I don't think that they can be considered the "triggering mechanism" of rainfall (as they are associated with one another). Based on the authors' discussion, the cold pools of the propagating MCSs act as the triggering mechanism of new convection. If the authors meant the upward branch of the MPS, the convection would be locally triggered. This is different from the propagating component and requires further clarification.

Reply: As in our response to the major comments #2 and #4, the up branch of the MPS can indeed propagate southeastward and induce new convection. In the meantime, as in your minor comment #4 (as well as in our response), the cold pool can trigger new convection remotely. The manuscript will be revised accordingly for clarity.

7. P.27907, L11-21: Note that the system in Fake-dry propagates (at about 1/2 speed) from about 250 to 600 km (Fig. 9c), where significant sloping terrain exists (cf. Fig. 3c). The authors may want to stress this.

Reply: It is unclear what the reviewer means but stressing the sloping terrain from 250 to 600km since the southeastward movement of the up branch of the MPS is due to

diurnally varying differential heating between the mountains and plains. This part of the sloping contributes to the MPS though the contribution is likely to be small comparing to the overall elevation difference between the mountain tops and the plains. Nevertheless, we will point this synergy in the revised manuscript.

8. P.27908, L9: *Producing much more rain, I am not convinced that the mean convective updraft (not that of MPS, again, see major comment #3) in NOVAP is “much weaker” than that in CNTL (cf. Figs. 8 and 11). Please revise.*

Reply: This is a typo. It should be "much stronger" instead. Revised.

Other comments:

1. P.27896, last paragraph, and p.27915, Table 1: *Based on the description, CNTL is a 15-day simulation using mean diurnal cycle over 17-24 Jun 2004 as IC/BCs, while Fake-dry and NOVAP runs are 10 consecutive 1-day simulations initialized using the 0000 UTC forecasts for each of the last 10 days of CNTL. So, only in model physics are Fake-dry and NOVAP configured the same as CNTL (except of course in latent heating and evaporation of liquid water, respectively), and currently the relevant descriptions in the text are not very clear and a bit confusing. Also, the information for forecast lengths and number of runs (one 15-day continuous run for CNTL; but ten consecutive 1-day runs for Fake-dry and NOVAP) should be added in Table 1 to better clarify the differences among the experiments.*

Reply: Table 1 is revised as shown below according to this reviewer’s comment.

Expt	Objectives	Forecast lengths and number runs	Initial condition of	Lateral boundary condition	Description
REAL	Real data simulation for 8 days	One continous run	8-day	0000 UTC 17 Jun 2004	Full physics through 0000 UTC 25 Jun

					2004	
CNTL	Sensitivity to diurnal cycle and initial conditions	One 15-day continuous run	The mean of 0000 UTC from 17-24 Jun 2004		The means of 0000, 0600, 1200, and 1800 UTC between 17-24 Jun 2004	As in REAL
Fake-dry	Sensitivity to both latent heating and latent cooling	Ten consecutive 1-day runs	The 0000 UTC forecasts of the last 10 days of CNTL		As in CNTL	No latent heating or latent cooling; sensible heating allowed
NOVA P	Sensitivity to evaporative cooling <i>only</i>	As in Fake-dry	As Fake-dry	in	As in CNTL	Latent heating is allowed; only cooling from the evaporation of <i>liquid water</i> is turned off.

2. P.27897, L3: *FNL should be defined near the beginning of section 2.*

Reply: We change "The NOAA Global Forecast System (GFS)" to " The National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) final (FNL)".

3. P.27897, L4-7: *The author may want to elaborate a little more about how long the NECV dominated during the 8-day period, and how common such NW flow pattern is over the region during the warm season. This may have implication on the applicability of the results from this study on diurnal cycle of the precipitation in northern China.*

Reply: We believe it is no so much the dominance of the NECV circulation but the persistence and prevalence of the northwesterly flow across the mountains and plains

over North China. Our 7-year observational study in He and Zhang (2010) with CMORPH and FNL analysis showed that southeastward propagation of diurnal precipitation is quite common in warm seasons under cross-mountain northwesterlies, with and without the NECV. Some discussions are added.

4. P.27897, L14: It is a bit awkward toward the end of this sentence. Please revise.

Reply: A word “and” missed here. We inserted “and” between “daily” and “nocturnal”.

5. P.27901, L18-19 (and p.27905, L1): If the propagation speeds of the primary and secondary updraft are both about 12 m/s, the 300 km distance will require at least 6 h to reach. In Fig. 9a, it is indeed the case at 700 hPa (see p.27904, L12) and the two exhibit the same speed. So, the authors may want to revise this and be consistent throughout the text.

Reply: It should be “6h”. Changed accordingly.

6. P.27902, L5-6 and likely other places: I suggest that either “northern China” or “North China” should be used in a consistent manner throughout the text.

Reply: We use “North China” throughout the revised text.

7. P.27904, L24: It is probably better to clarify that the authors mean the “strongest solar heating” within the diurnal cycle.

Reply: For this areas, the strongest solar heating usually happens around 06:00 UT (14:00 BST) in the afternoon. Clarification made in the revised manuscript.

Technical points:

All technical and editorial minor points are well taken off in the revised manuscript according to the suggestions of the reviewer.

We again thank Dr. Wang for his thorough and insightful comments that help greatly in our revision of the manuscript.