

Review of “LIMA (v2.0): A full two-moment cloud microphysical scheme for the mesoscale non-hydrostatic model Meso-NH v5-6” by Tanfour et al.”

This study developed LIMA v2.0 worked by newly predicting the number concentration of precipitating ice hydrometeors of snow aggregates, graupel, and hail. In addition, the 2<sup>nd</sup> version of LIMA was tested in the case of mid-latitude supercell to examine the differences in the representation of ice particle growth in comparison to the 1<sup>st</sup> version of LIMA. The authors successfully presented the advantage of the full 2 moment framework with the focus on well-known issue on the number diagnosis in the 1 moment framework. The manuscript is well organized and the conclusion is well supported by the figures. However, readability is not a bit good. In addition, there exist some confusing descriptions. These points will be fixed soon with no additional analysis. Therefore, my recommendation is minor revision rather than major revision although the author needs to fix a lot of points.

#### Major points on readability

1. In section 4.2, it is not clear whether the authors explain about LIMA or LIMA2. The authors should clarify “in LIMA2” or “in LIMA” after the explanation.
  - 1.1. Line#378, “whereas LIMA2” would be “whereas LIMA”. Is it right?
  - 1.2. Line#397, this sentence is about “LIMA2”
  - 1.3. Line #418, “The onset is 6min later ...” would be the explanation for LIMA2. Is its right? In addition, what do you mean with the words “6 min later”? What occurs before the onset?
  - 1.4. Line#427, the sentence begins with “However, the mixing ratios ...” may be description about LIMA2. Is it right?
  - 1.5. Line#446-447, Which do you mention after the “leading to a reduction in ..”? LIMA or LIMA2? Regarding the conjunction, it would be LIMA. However, in the context, it may be LIMA2. In addition, this sentence is confusing. Please rewrite the sentence.
  - 1.6. Line#447-449. This sentence is also confusing. Which process in LIMA2 do you indicate? I think aggregation of cloud ice by snow is “not” efficient in LIMA2 as was shown in Figure 8e. Therefore, large amount of cloud ice exists in LIMA2. What do you mean with the words of “the process is more efficient in the LIMA2”? Is it LIMA?
2. Readability of figures is not good.
  - 2.1. Regarding Figure 2 and Figure 4, I don’t understand what the stipple in the legend means. What is  $x$  and what is the unit of  $x$ ? Please describe them in the caption.
  - 2.2. Regarding the figure caption in Figure 4, “between 0 and 4 km” is to be clarified as “at altitudes from 0 to 4 km”.
  - 2.3. Regarding Figure 5, it is difficult to distinguish the cloud ice color from the snow color in the

pie charts. Please use different color tone for snow to explain the differences in cloud ice and snow distribution in the main text.

- 2.4. Regarding Figure 8, I may miss the description of some processes. Where is HONC in (a)? In addition, it is difficult to distinguish the colors between SEDI and CNVI in (a) and between SEDI and HMLT in (d). In general, this panel is too busy to follow the important differences between LIMA and LIMA2. I suggest to pick up only the upper most 3 processes in each figure (a-h) and other minor processes to be omitted or shown in supporting information.
- 2.5. Regarding Figure 8 and table 1, CNVS is sublimation of aggregates. Thus, CNVS should be negative. However, CNVS is positive in (b). In addition, I don't know why sublimation of aggregates is shown in (a) although sublimation of snow does not affect cloud ice. I guess the description of CNVS is wrong. Please fixed table 1.
- 2.6. Regarding Figure 9, what is the unit of diameter isolines indicated by dashed grey lines. Is it mm?
- 2.7. In Table 2, HIND and SEDI are not included. CNVS may be wrong. In addition, I do not distinguish between CNVI and CNVS. What is the difference in the physical processes dividing CNVI and CNVS?

#### Specific comments.

1. In Abstract, the difference in the mechanisms between LIMA and LIMA2 were not described at all. Therefore, I suggest to emphasize the unreasonable diagnosis of number concentration of snow, graupel, and hail in the one moment framework and then briefly describe that the prediction of number concentration reasonably slow down the growing processes based on physics.
2. Line#386-8, How do you determine “advection is dominant”? I think this is the result and is not the cause. In LIMA2, the number concentration of snow and graupel significantly decrease by reasonable representation. Based on Section 3.1, the riming terms are proportional to the particle number concentration. This results in significant reduction in the removal of rain droplets by riming. In addition, prediction of rain droplets selectively removes larger rain droplets faster through riming and sedimentation. As a result, smaller rain droplets are likely to be transported upward due to smaller terminal velocity.
3. Equation (23), I require the documentation of the  $\lambda_{min}$  and  $\lambda_{max}$  for each hydrometeor in a table to hold the reproducibility of the model description. In addition, the number of cells used for the two-dimensional look up table is required too in the same table. One may follow your article to develop their own full 2-moment cloud microphysics scheme. The perfect way

is also documenting the accuracy of the look up table because the accuracy depends on the number of cells, but I don't require this level of documentation.

4. Line#415-432, The authors should mention the rationality of 2-moment schemes and evident errors in 1-moment schemes based on Figure 7.

For example, graupel is produced by freezing of rain droplets or riming of snow. Therefore,  $N_g$  should be equal to or smaller than  $N_s$  or  $N_r$ . However,  $N_g$  is significantly larger than  $N_s$  and  $N_r$  based on Figures 7b,c, and f. In addition, assuming a binary collision,  $N_s$  values is to be close to half of  $N_i$  when much snow is initiated by self-aggregation of cloud ice at  $t=20$  min in Figures 6b and 7b. However,  $N_s$  is significantly smaller than  $N_i$  by four to five digits. Therefore, diagnoses of  $N_s$  and  $N_g$  are clearly wrong.

In addition, please show the references articles of the number diagnoses of  $N_r$ ,  $N_s$ ,  $N_g$ , and  $N_h$ . I guess that individual diagnosis was obtained in different types of rainfall systems. When  $N_r$  and  $N_g$  diagnoses are obtained in the same case,  $N_g$  would be smaller than  $N_r$  as was represented by LIMA2. However, if  $N_r$  diagnosis was obtained in maritime rain systems and  $N_g$  diagnosis was obtained in the continental supercells,  $N_g$  could be significantly larger than  $N_r$ . In this way, consistency among the diagnoses is important for one-moment schemes. Please discuss these points to emphasize the rationality of 2-moment schemes and deficiency in 1-moment schemes.

5. Line#462, I don't understand the context. Why is "nevertheless" used here? When different cases were observed, different diagnoses were obtained. In this manuscript, the objective rainfall system is provided by Klemp and Wilhelmson (1978) and is different from the system observed by Taufour et al. (2018). Therefore, it is obvious that the black line on Figure 9a does not exactly follows the major portion of the LIMA2 simulations.

Instead, the most important point of the figure is the similarity of the major relationships between mixing ratio and number concentration. LIMA2 simulations show that number concentration increases as the mixing ratio increases. This feature is also observed in Taufour's observations. In LIMA2, the mean volume diameter gradually increases from 3.0 to 8.0 as the mixing ratio increases from  $10^{-3}$  to  $10^0$  g kg<sup>-1</sup>, whereas the mean volume diameter increases from 0.9 to 2.0 in the same mixing ratio range. This indicates that Taufour's case is relatively moderate rainfall systems compared to Klemp and Wilhelmson's case based on the differences in the mean volume diameter.

6. The paragraph line#468 to #475 is to be put on conclusion section. Similarly, the paragraph from line#477 to #481 is described for the future work. Thus, that is not to be described in the

result section. I suggest to delete the paragraph. The sentences from line#501 to #506 should be modified as the future prospects based on this study. I guess the context as that full-2moment scheme can be utilized as a reference of the number diagnoses used in 1-moment schemes. The paragraph from line#507 to #512 should be moved to introduction section because this is not a summary nor a conclusion

#### Technical comments

1. Line#35, the sentence begins with “This type of scheme for...” is confusing. Please rewrite the sentence.
2. Line#55-57, the sentence begins with “Comparisons of these studies...” is confusing. please rewrite the sentence.
3. Line#59, what does “multi-moment diagram” mean?
4. Line#59, the word “shape parameters” is generally used for the parameter characterizes the shape of the particle size distribution as was used by the authors at line#121 with Eq. (1). I suggest to use “shape of nonspherical ice hydrometeors” or something.
5. Line#60, what does the sentence “the impact of ...” means? Please rewrite the sentence.
6. Line#62, what do “the different schemes” indicate?
7. Line#65, what does the sentence “It is very likely ...” means? Please rewrite the sentence.
8. Line#79, Please replace “Conversely” with “In contrast”,
9. Eq.(4), the dimension of righthand side is wrong. I think  $\bar{D}^p$  should be added because the r.h.s should be equal to  $N\bar{D}$  with  $p=1$ .
10. Line#140, does “CND or EVP” mean the saturation adjustment based on this description? It is known to be better to solve condensation and evaporation explicitly as was solved for ice particles because the timescale of condensation/evaporation is sometimes larger than model timestep, particularly in regional simulations. You can easily find the discussion about aerosol condensation effect of something. This is just a comment.
11. Line#159-160, Doesn't homogeneous freezing of rain droplets turn into hail? I think hail is a dense frozen particle. Thus, frozen rain would be a kind of hail.
12. Section 3. Please show the difference in the calculation costs. I'd like to know an increase in the calculation cost of microphysics and increase in the total calculation cost.
13. Section 3.1.1, In addition to (I)-(III), (IV) self-aggregation of snow, graupel are necessary. In this case, mixing ratio does not change but number concentration reduces. This point is important particularly for the prediction of snow.
14. Eq. (13)-(15) in Section 3.1.2, why is  $E_{xy}$  excluded from the integration? Does the term depend on size or mass as was proposed by Böhm (1999)? Please clarify the formulation of  $E_{xy}$  here.

Böhm, J. P., 1999: Revision and clarification of “A general hydrodynamic theory for mixed-phase microphysics.” *Atmospheric Research*, 52, 167–176, [https://doi.org/10.1016/S0169-8095\(99\)00033-2](https://doi.org/10.1016/S0169-8095(99)00033-2).

15. Eq. (13)-(15) in Section 3.1.2, what is  $\rho_{dref}$ ? Based on Eq. (3), that is to be  $\rho_a$ .
16. Eq. (16) contains undefined terms of  $\Delta_{DRYG}r_c$ ,  $\Delta_{DRYG}r_r$ ,  $\Delta_{DRYG}r_i$ , and  $\Delta_{DRYG}r_g$ . I suppose the terms as  $\Delta_{COL}r_c(c - g)$ ,  $\Delta_{COL}r_r(r - g)$ ,  $\Delta_{COL}r_i(r - i)$ , and  $\Delta_{COL}r_s(g - s)$  as was defined in the case (II) in Section 3.1.1. Is it right?
17. Title of Section 3.1.3., the word “significant” would be replaced with “non-negligible”. Similarly, significant at line#247 would be done.
18. Line#247, please close the sentence before “and” to increase readability. Then, please start the sentence with “Therefore” instead of using “therefore” in the middle part of the sentence. In addition, it would better to insert “in this study” at the end of the sentence.
19. Line#265-273 (Rain accretion on aggregates ACC), do the diameters mean the diameter of individual particles or PSD mean diameter? If it means the diameter of individual particles, how do you integrate the collection kernel? Could you clarify this point?
20. Line#285, what is “a threshold”? Please clarify that.
21. Line#292, “primary ice crystal” would be a typo of “pristine ice crystal”.
22. Line#292,  $\Delta_{CNV}r_i$  has not been documented. Please document the equation of the growth term or please refer to the original article in which the term is documented.
23. Line#299, water formed “on” the surface
24. Line#302, here the authors assumed melting graupel particles are larger than 0.72 mm. Do you use something of a criterion for shedding graupel diameter?
25. Line#303-304, please refer to the articles, which document the wind-tunnel experiments.
26. Line#361, At first glance, I don’t understand what do “30 (3.5 mm/h)” means. To increase readability, it is better to modify as “30 min (3.5 mm/h), 34 min (4.5mm/hr) ...”.
27. Line#398, this sentence is not necessary.
28. Line#412, you should remove “it seems to be” because this point is evident from the figure. In addition, it is better to mention the difference in snow amount. Since snow is produced by aggregation of cloud ice, large amount of snow indicates the rapid consumption of cloud ice. This point is clearly shown by Figure 8e.
29. Line#420, after “30 minutes” would be “40 minutes”.
30. Line#423, what hypothesis do you mention here. I guess that is an issue in the number diagnosis. Please clarify that.
31. Line#452, In general, “not shown” is used when it is not important and it does not change

conclusion. When the authors did not show the figure, the results were not verified. Thus, please do not use “verified” here. I suggest to remove the sentence or add the figure. I think that point was found in Figures 8a-d, so you can refer to the figure in this sentence.

32. Line#462, I don't understand the wording “for the benefit” here. Isn't it deficient? Wrong diagnosis of the number concentrations results in wrong estimation of radiative properties. I think this is the deficient in 1-moment schemes.
33. Line#502, the wording “decoupling” does not match the context because the number concentration and mixing ratio should be coupled through the physical processes as was represented by LIMA2. Please change the wording.