Review of 'Assessing Cloud Representation in Two Microphysics Schemes of MPAS-Atmosphere Model (version 8.2.2) over the Maritime Continent with Himawari-9 AHI Observations'

Summary

The paper compares simulated brightness temperatures from MPAS with satellite observations. I do not have much expertise on such observations, so my comments will not address the interpretation of these data. The results seem reasonable to me. It would be more useful if there were some digging into the differences of the scheme processes that could shed light on the different outcomes, if possible. It can be a tall order, however, to figure out why schemes have these differences, and it is often not what we speculate it to be. (Especially in a complex scenario like this one.) Otherwise, I have some (minor) comments for the authors to consider for revisions.

Best Regards, Ted Mansell

Minor Points:

1. It would be worth double-checking whether CRTM is fully consistent with the NSSL microphysics scheme. A colleague of mine did some work with CRTM, and I recall them saying that they had to make some modifications for NSSL-MP. I do not know what needed to be updated or how much difference it made, and I do not know if those updates were ever contributed to the code base.

Reply: Thank you for raising this important point. We have carefully re-examined the coupling between MPAS microphysics and CRTM in our configuration. In this configuration, CRTM does not directly invoke the microphysics routines; instead, the MPAS-JEDI interface converts the hydrometeor fields predicted by MPAS into the cloud variables required by CRTM. For both simulations, the mixing-ratio profiles of cloud water, rain, cloud ice, snow, and graupel are taken directly from the corresponding MPAS forecasts, while the effective radii of cloud water, cloud ice, and snow are also obtained from the model fields. For WSM6, the effective radii of rain and graupel are diagnosed following the particle-size-distribution assumptions of the WSM6 scheme, providing a consistent treatment of these species at the interface level. For NSSL, however, corresponding NSSL-specific formulations for rain and graupel effective radii are not currently implemented in the interface; fixed values are therefore assigned to rain and graupel, respectively. This treatment may represent the inconsistency referred to by the reviewer, rather than an issue with the NSSL microphysics implementation itself.

This inconsistency is not uncommon for the radiative transfer models, and we believe the effects of this inconsistency is much smaller than the cloud prediction errors of the model over this region. Sensitivity experiments for geostationary 10.4-μm infrared radiances have shown that the radiative response in upper-level cloudy regions is primarily associated with ice-phase hydrometeors, particularly cloud ice and snow, while the effects of rain and graupel can be considerably weaker (Yang et al., 2022). In the present study, the main findings for the NSSL simulation likewise focus on high-level ice-cloud structures, particularly cloud ice and snow, for which both hydrometeor contents and effective radii are derived consistently from the model fields. In contrast, the graupel-related discussion is mainly associated with the WSM6 simulation, for which the effective-radius treatment follows the particle-size-distribution assumptions of the WSM6 scheme. Accordingly, this limitation is not expected to materially affect the main conclusions of this study.

We have therefore clarified the treatment of hydrometeor effective radii in the MPAS-JEDI–CRTM interface and explicitly noted this inconsistency for the NSSL simulation in the revised manuscript. The corresponding text in Lines 218-224 has been revised as follows:

“ In this study, CRTM version 2.4.1 is employed to simulate AHI radiances under all-weather conditions using geophysical inputs from MPAS forecasts, including profiles of pressure, temperature, water vapor, and the mixing ratios and effective radii of five hydrometeor species: cloud liquid water, cloud ice, rain, snow, and graupel. In the current MPAS-JEDI interface, the effective radii of cloud water, cloud ice, and snow are obtained from the corresponding model fields. For WSM6, the effective radii of rain and graupel are additionally diagnosed following the particle-size-distribution assumptions of the WSM6 scheme, whereas corresponding NSSL-specific formulations are not currently implemented; fixed values are therefore assigned to rain and graupel in the NSSL simulation. ”

References,

Yang, N., Zhu, K., and Xue, M.: Investigation of the convection-allowing prediction error of an extreme precipitation event of China using CRTM-simulated brightness temperature, *J. Geophys. Res.-Atmos.*, 127, e2022JD036760, https://doi.org/10.1029/2022JD036760, 2022.

2. Line 252: 'Unlike the observed channel 13, which exhibits a distinctly narrower BT range and higher frequency distribution, the simulated BTs from both WSM6 and NSSL fail to reproduce this feature, implying limited skill in representing cloud-top radiative signatures. '

What is this channel particularly sensitive to? Given the frequency is between 11 and 14, would it make sense that the microphysics schemes have more or less continuous values of particle size? Could it indicate something about ice habit that isn't captured by the schemes? (I don't know much about radiances!)

Reply: Thank you for this insightful comment. AHI channel 13 is centered at 10.4 μm and is an infrared window channel. Under cloudy conditions, channel-13 BT is primarily sensitive to cloud-top properties and the microphysical, optical characteristics of upper-level ice clouds. We agree that the broader simulated channel-13 BT distributions may partly reflect differences in ice-cloud microphysics, such as particle size and ice habit. However, these effects are generally diagnosed using spectral differences among multiple infrared-window channels, including the 8.6, 10.4, and 12.4 μm bands, rather than channel 13 alone, and their individual contributions would require dedicated sensitivity experiments with systematically varied particle-size and ice-optical-property assumptions, which is beyond the scope of this study.

We have revised the relevant sentences in Lines 258-260 to clarify this interpretation:

"Unlike the observed channel-13 BTs, which exhibits a distinctly narrower BT range and higher frequencies between 230 and 250 K, both WSM6 and NSSL produce broader distributions, indicating greater variability in the simulated cloud-top and upper-level ice-cloud properties. "

3. Line 258: 'Lastly, verification against nighttime channel 7 (3.9 micron) observations indicates that NSSL aligns more closely with the observed BT distribution, implying a more realistic simulation of low-level clouds or fog compared with WSM6. '

Any ideas why the schemes differ here? Is Fig. 2 showing that WSM6 has more warm clouds than NSSL?

Reply: Thank you for this comment. A similar contrast is evident across several cloud-sensitive infrared channels, with WSM6 showing a greater occurrence of relatively warm BTs and NSSL extending more broadly toward colder BTs. This behavior suggests a greater occurrence of high, cold clouds in NSSL. Conversely, the warmer BT distribution in WSM6 may reflect lower and warmer effective emission levels, potentially associated with a greater occurrence of low-level warm clouds. Although nighttime channel 7 (3.9 µm) is useful for identifying low-level clouds and fog, such features are typically inferred from spectral differences with longwave infrared channels rather than from channel-7 BT alone. The relevant sentences have therefore been revised more cautiously:

" Lines 251-252: Verification against nighttime channel 7 (3.9 µm) observations shows that NSSL more closely reproduces the observed cold-end BT distribution below 250 K.

Lines 266-269: A similar contrast is evident across several cloud-sensitive infrared channels, with WSM6 exhibiting a greater occurrence of relatively warm BTs and NSSL extending more prominently toward lower BTs. This contrast suggests that NSSL tends to produce more high-level, cold clouds, whereas the warmer BT distribution in WSM6 may reflect a greater contribution from lower, warmer clouds."

4. Figure 3 is a single cross section snapshot from this entire forecast. Can you say how well it represents the forecasts generally? Also the S0 cross section goes right up to the domain boundary, so it might be showing too much influence from boundary conditions.

Reply: Thank you for this helpful comment. To provide a more representative assessment of the forecasts and avoid potential sensitivity to the domain boundary, Figure 3 has been revised to show mean horizontal distributions rather than a single cross-section snapshot. The corresponding discussion in the manuscript has been removed.

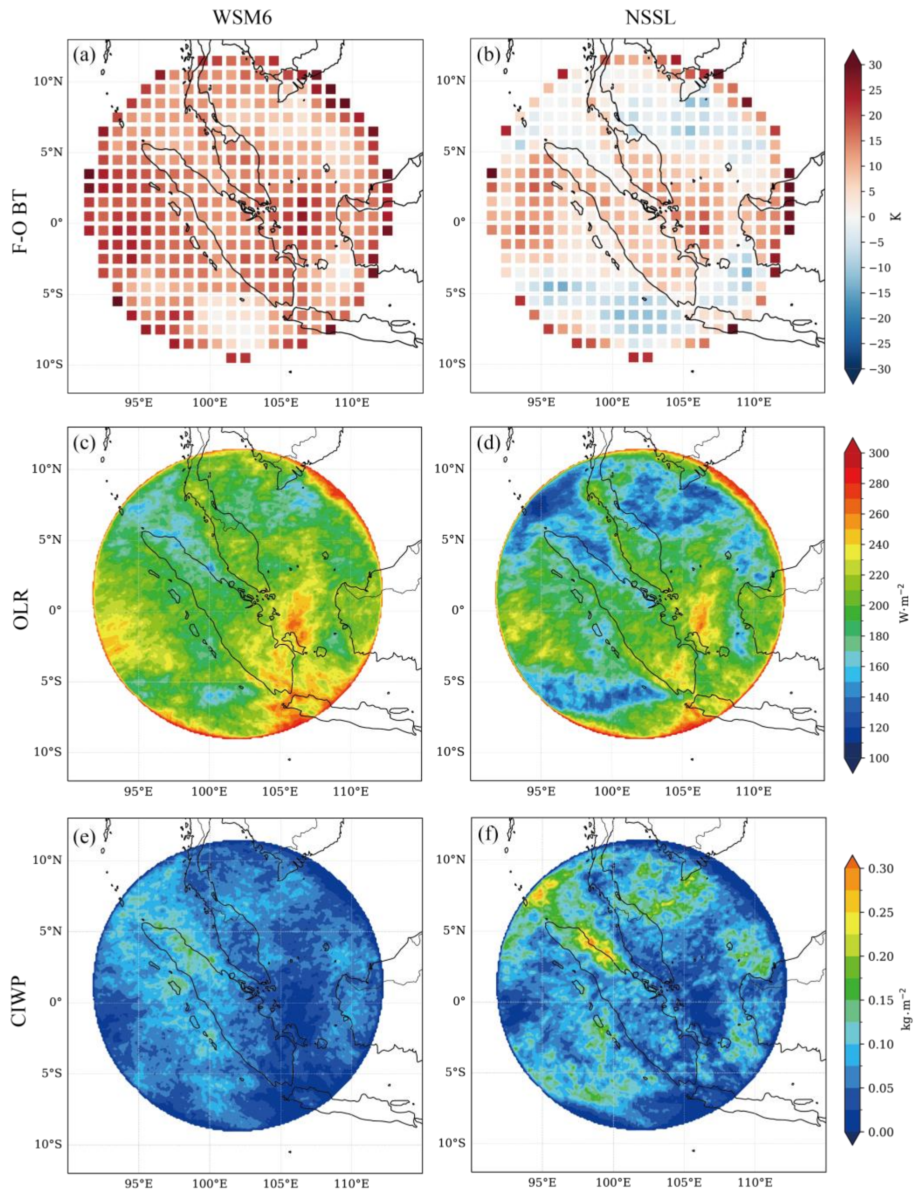

Figure 3. Daily-mean horizontal distributions of (a, b) AHI channel-13 forecast-minus-observation (F−O) brightness-temperature differences, (c, d) simulated outgoing longwave radiation (OLR), and (e, f) simulated cloud ice water path (CIWP) for WSM6 (left column) and NSSL (right column). Statistics are computed from 24-48 h forecasts at 6 h intervals using cloudy samples.

5. Line 285: 'In WSM6, the core of upward motion is generally confined to lower altitudes near the melting layer (Figure 3e) '

Any ideas why this might be? Perhaps less freezing? Or maybe the mass loading is distributed differently, perhaps related to the coupled fall speeds of graupel and snow? I can only speculate.

Reply: Thank you for this comment. Conrick et al. (2018) found that weaker vertical motion in WSM6 coincided with increased graupel mixing ratios and interpreted this relationship as being consistent with reduced updraft speeds associated with hydrometeor loading and graupel generation. A similar pattern is evident in our Figures 8 and 10, where WSM6 exhibits enhanced graupel content above the melting level, together with weaker upper-tropospheric vertical motion relative to NSSL. The enhanced graupel content may increase hydrometeor loading and reduce buoyancy, potentially limiting the vertical penetration of the updraft into the upper troposphere.

In the revised manuscript, this statement has been removed, and the corresponding analysis has been replaced with mean horizontal distributions based on a larger sample for a more representative comparison of the two microphysics schemes. The associated physical interpretation has instead been added to the discussion of Figure 10 (Lines 523-525):

"The weaker upper-tropospheric ascent in WSM6 compared with NSSL may be partly related to its enhanced graupel content shown in Figure 8, as increased hydrometeor loading can reduce net buoyancy and thereby suppress updraft development (Conrick et al., 2018). "

References,

Conrick, R., C. F. Mass, and Q. Zhong, 2018: Simulated Kelvin–Helmholtz waves over terrain and their microphysical implications. *Journal of the Atmospheric Sciences*, 75, 2787–2800. https://doi.org/10.1175/JAS-D-18-0073.1

6. Line 310: 'It is noted that both schemes tend to overpredict cloudy pixels and underpredict clear-sky pixels relative to the observations. '

Could this also indicate excessive moisture in the environment? Or the boundary layer scheme is mixing too deeply? It could be that both microphysics schemes are somehow biased in similar ways in this regard, but it could also point to a separate cause (bias) that the schemes are responding to.

Reply: Thank you for this insightful comment. Previous studies have shown that excessive environmental moisture can favor deeper convective development (Qian et al., 2016), while boundary-layer mixing and entrainment – detrainment processes can modulate the vertical transport of heat and moisture and thereby influence convective depth and cloud-top height (Lamraoui et al., 2019). These processes may therefore represent additional sources of the common high cloud-top bias in both simulations. The discussion in Lines 308–311 has been revised accordingly:

" It is noted that both schemes tend to overpredict cloudy pixels and underpredict clear-sky pixels relative to the observations. This common high cloud-top bias may arise not only from deficiencies in the microphysical representation but also from an overly moist environment and/or biases in boundary-layer mixing and entrainment–detrainment processes, which may favor deeper convective development (Qian et al., 2016; Lamraoui et al., 2019)."

References,

Qian, Y., Yan, H., Berg, L. K., Hagos, S. M., Feng, Z., Yang, B., and Huang, M.: Assessing impacts of PBL and surface layer schemes in simulating the surface–atmosphere interactions and precipitation over the tropical ocean using observations from AMIE/DYNAMO, *J. Climate*, 29, 8191–8210, https://doi.org/10.1175/JCLI-D-16-0040.1, 2016.

Lamraoui, F., Booth, J. F., Naud, C. M., Jensen, M. P., and Johnson, K. L.: The interaction between boundary layer and convection schemes in a WRF simulation of post-cold-frontal clouds over the ARM East North Atlantic site, *J. Geophys. Res.-Atmos.*, 124, 4699–4721, https://doi.org/10.1029/2018JD029370, 2019.

7. Line 324: '(WSM6) CSI score remains lower than that of NSSL.'

This does not seem like a significant difference, however (0.02), and the scores are pretty high as it is (greater than 0.7).

Reply: Thank you for this comment. The discussion has therefore been revised to avoid overstating the advantage of NSSL. The corresponding sentences in Lines 324-326 have been revised as: "At later forecast times beyond 24 h, both schemes maintain relatively high CSI values (>0.7, Figure 4c), indicating good agreement between the simulated and observed spatial distributions of cloudy pixels.”.

8. Line 394: ‘However, it also exhibits an expanded high-frequency occurrence of BTs near 220 K above 150 hPa (Figure 6c), suggesting an overprediction of optically thick high-level ice clouds. ’

Could you explain how this works, physically? A higher BT (warmer) at low pressure (low temperature)? Does a thicker cloud average its temperature depth?

Reply: Thank you for this comment. For an infrared window channel, a higher cloud top generally shifts the effective emission level to colder atmospheric layers, resulting in a lower BT. Thus, the enhanced occurrence of low CTPs is physically consistent with the increased frequency of low BTs, rather than representing an average temperature over the cloud depth. The discrepancy is more pronounced in NSSL, which shows a substantially higher frequency of cloud tops near 100 hPa and BTs below 220 K, consistent with the greater occurrence of cold thin-ice clouds (BTs < 220 K) than in both the observations and WSM6 (Figure 5h). Meanwhile, the vertical hydrometeor distributions in NSSL show enhanced frozen hydrometeor content and larger cloud fractions in the upper troposphere (Figure 8). These results suggest that NSSL tends to overpredict high cloud tops and upper-level ice clouds, which may contribute to the greater frequency of low-BT/low-CTP occurrences.

To more clearly explain the potential physical mechanisms underlying this feature, we have revised the discussion in Lines 393-399, as follows:

“ In both schemes, the simulated CTP frequencies are concentrated primarily between 100 and 200 hPa, with substantially fewer occurrences at 300–400 hPa than observed, indicating an overall bias toward higher cloud tops. For an infrared window channel, a higher cloud top generally shifts the effective emission level to colder atmospheric layers, resulting in a lower BT. The discrepancy is more pronounced in NSSL, which shows a higher frequency of cloud tops near 100 hPa and BTs below 220 K, consistent with its greater occurrence of thin ice clouds in the cold-BT regime (BTs < 220 K) relative to observations (Figures 5h and 5i). Meanwhile, the vertical hydrometeor distribution in NSSL shows enhanced frozen hydrometeor content and larger cloud fractions above 200 hPa (Figure 8). ”

9. 444: ‘The enhanced efficiency of riming and accretion in WSM6 is likely associated with the lower altitude of the saturation-layer top (RH = 100%) near 400 hPa, which facilitates supersaturation and intensified liquid–ice interactions. ’

A little more explanation here would be helpful. Enhanced efficiency relative to NSSL? I’m not sure that I follow the last phrase (‘which facilitates....’) With the default CCN concentration for NSSL, it may have a slower warm rain process than WSM6. That default setting is more appropriate for continental clouds (or over land generally), and may be too high for the maritime portions of the domain.

Reply: Thank you for this insightful suggestion. The study domain is predominantly maritime, whereas the default CCN concentration used in NSSL is more representative of continental conditions and may be too high for maritime environments. A higher CCN concentration generally favors more numerous but smaller cloud droplets, which can suppress collision–coalescence and reduce the efficiency of cloud-water autoconversion, potentially leading to slower warm-rain production in NSSL. In addition, WSM6 exhibits saturated conditions (RH = 100%) surrounding mixed-phase hydrometeors near 400 hPa, which may provide a more favorable environment for supercooled liquid–ice interactions.

To provide a clearer and more physically consistent interpretation, we have revised the corresponding text in Lines 448-453 as follows:

“ Compared with NSSL, the hydrometeor distributions in WSM6 suggest more active riming and accretion, which may be partly associated with the saturated environment (RH = 100%) surrounding mixed-phase hydrometeors near 400 hPa and the maintenance of supercooled liquid water. In addition, the default CCN concentration in NSSL may be relatively high for the maritime portions of the domain, favoring more numerous but smaller cloud droplets and thereby suppressing collision–coalescence and the associated cloud-water autoconversion. ”

10. Line 449: ‘The lower saturation height in WSM6 likely suppresses depositional ice growth, resulting in thinner ice layers in the upper troposphere. ’

It is possible, but this seems speculative. I think it could also be related to updraft magnitudes at these altitudes.

Reply: Thank you for this helpful comment. The discussion has been revised to also account for differences in upper-tropospheric vertical motion. As shown in Figures 11-12, NSSL produces stronger upper-level ascent than WSM6. Previous studies have demonstrated a close relationship between convective updraft strength and ice-phase microphysical production, with vapor deposition and freezing occurring predominantly within updraft regions (Grant et al., 2022; Tao et al., 2022). The thinner upper-tropospheric ice layer in WSM6 may therefore reflect the combined effects of its lower relative humidity and weaker updrafts in the upper troposphere. The original sentence in Lines 457-458 has been revised as follows:

“ The thinner upper-tropospheric ice layers in WSM6 may be associated with its lower relative humidity and weaker updrafts in the upper troposphere (Figures 8 and 11-12), which can limit depositional ice growth (Tao et al., 2022). ”

References,

Tao, W.-K., Iguchi, T., Lang, S., Li, X., Mohr, K., Matsui, T., van den Heever, S. C., and Braun, S.: Relating vertical velocity and cloud/precipitation properties: A numerical cloud ensemble modeling study of tropical convection, *J. Adv. Model. Earth Syst.*, 14, e2021MS002677, https://doi.org/10.1029/2021MS002677, 2022.

11. Line 582: ‘both schemes tend to overpredict cloud-top heights for high-level clouds, while underpredicting mid- and low-level clouds. ’

Grid spacing might play a role here. 3km makes updrafts too wide for these conditions and may underestimate entrainment.

Reply: Thank you for this helpful suggestion. Previous studies have shown that kilometer-scale simulations can produce larger convective cells with reduced entrainment of midlevel environmental air, contributing to higher cloud tops. (Bryan and Morrison, 2012). This possible explanation has been added in Lines 594-596 to the revised manuscript:

“ The cloud-top biases may also be partly related to the 3-km grid spacing, as relatively coarse kilometer-scale grids can produce larger convective cells with reduced entrainment of midlevel environmental air, thereby favoring higher cloud tops (Bryan and Morrison, 2012). ”

Reference,

Bryan, G. H. and Morrison, H.: Sensitivity of a simulated squall line to horizontal resolution and parameterization of microphysics, *Mon. Weather Rev*., 140, 202–225, https://doi.org/10.1175/MWR-D-11-00046.1, 2012.

Technical/Editorial Notes:

1. Line 143: 'NSSL scheme is a bulk microphysics parameterization that predicts the same five hydrometeor species'

This could be updated to say that NSSL-MP predicts 6 hydrometeor species but that the hail species was deactivated.

Reply: Thank you for pointing this out. We have revised the sentence in Lines 142-144 accordingly:

" Although NSSL-MP includes six hydrometeor species, the hail category was deactivated in this study; thus, the five active species are the same as in WSM6—cloud water (Qc), rain (Qr), cloud ice (Qi), snow (Qs), and graupel (Qg). "