Review 1 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"

Recommendation:
Minor revisions:

General comments:

The reviewer appreciates the authors' efforts to revise the manuscript in response to the previous comments. The authors have compared the two models in physical space by examining OLR and cloud ice water path in Fig. 3 and the vertical profiles of hydrometeors in Fig. 8. They have also analyzed the S1 cross-section normal to Sumatra Island. The different characteristics of upper-level thin clouds between the two schemes may help explain their differing degrees of agreement with the observations.

An important next step would be to improve the representation of high clouds using observational constraints. AHI data may provide useful information for further evaluation; however, as suggested in the previous review, EarthCARE observations can provide more process-oriented information relevant to evaluating and improving cloud schemes. The reviewer hopes that a follow-up study will build on the findings of the present study and further investigate these issues using such observational information.

As described above, the reviewer recommends acceptance of the paper with minor revisions, provided that the authors address the comments below.

Specific comments:

L221-223: The consistency between the schemes in the MPAS simulations and those in the CRTM simulation should be carefully adjusted. Please clarify the inconsistency.

It is unclear what "fixed values are therefore assigned to rain and graupel in the NSSL simulation" means. I assume the effective radii of rain and graupel change in the NSSL scheme because it is a double-momentum scheme. Do the authors mean that these effective radii are assumed to be constant in the CRTM? How about the effective radius of snow and cloud ice?

Reply: Thank you for the comment. As the reviewer correctly pointed out, the NSSL double-moment scheme allows particle size distributions to vary with the predicted hydrometeor mass and number concentrations. The prescribed constant effective radii for rain and graupel are used only in the CRTM radiative transfer calculations, rather than in the NSSL microphysics scheme itself. Specifically, the effective radii of cloud water, cloud ice, and snow used in the CRTM radiative calculations are consistent with those diagnosed by the

NSSL microphysics scheme. In contrast, the inconsistency arises from the use of prescribed constant effective radii for rain and graupel in CRTM, rather than values that vary with the particle size distributions represented by the NSSL microphysics scheme. The NSSL-specific effective-radius diagnostics for rain and graupel have not yet been implemented in the MPAS–JEDI interface.

To further clarify this inconsistency, the relevant sentences in Lines 221-226 have been revised as follows:

" In the current MPAS-JEDI interface, the effective radii of cloud water, cloud ice, and snow used in CRTM are consistent with those diagnosed by the WSM6 and NSSL microphysics schemes. For rain and graupel, the effective radii used in CRTM are diagnosed following the particle-size-distribution assumptions of WSM6, whereas the corresponding NSSL-specific diagnostics have not yet been implemented. Specifically, constant effective radii are prescribed for rain and graupel in the CRTM calculations for the NSSL simulation, rather than values that vary with the particle size distributions represented by the NSSL microphysics. "

L309-310, "but also from an overly moist environment and/or biases in boundary-layer mixing and entrainment–detrainment processes": Does this mean that the simulation is moister than the observations and that mixing is more enhanced? Otherwise, I do not suggest this ambiguous statement because the simulation results do not support it.

Reply: Thank you for pointing this out. As the reviewer suggested, the present results do not provide direct evidence of an overly moist environment or enhanced boundary-layer mixing and entrainment – detrainment processes. Therefore, to avoid overinterpretation, these explanations have been removed, and the relevant sentence in Lines 310-311 has been revised as follows:

"This common high cloud-top bias suggests potential deficiencies in the model's representation of cloud vertical development. "

L372-373, "This relatively greater underprediction in WSM6 may be related to its lower upper-tropospheric cloud-ice and snow contents and reduced cloud fraction (Figure 8)": Please check whether this statement is correct, because Figures 8c and 8d indicate that WSN6 simulates more graupel than NSSL.

Reply: Thanks for the advice. As noted by the reviewer, Figure 8c-d show that WSM6 produces more graupel than NSSL in the middle troposphere. However, Figures 8a-d also

show that WSM6 has lower cloud-ice and snow contents and reduced cloud fraction in the upper troposphere compared with NSSL. To be clear, the relevant sentence has been revised (Lines 372-373) as follows:

"This relatively greater underprediction in WSM6 may be associated with its lower cloud-ice, snow contents and reduced cloud fraction in the upper troposphere, despite its higher graupel content in the middle troposphere (Figure 8)."

L530, "the larger nighttime positive bias in WSM6 is consistent is consistent with the scarcity of cloud cover above 300 hPa": Please remove "is consistent" which is repeated.

Reply: Corrected.

L619: Please add references to the EarthCARE satellite:

Illingworth, A., Barker, H., Beljaars, A., Ceccaldi, M., Chepfer, H., Delanoe, J., Domenech, C., Donovan, D., Fukuda, S., Hirakata, M., Hogan, R., Huenerbein, A., Kollias, P., Kubota, T., Nakajima, T., Nakajima, T., Nishizawa, T., Ohno, Y., Okamoto, H., Oki, R., Sato, K., Satoh, M., Wandinger, U., Wehr, T. (2015) The EARTHCARE satellite: The next step forward in global measurements of clouds, aerosols, precipitation and radiation. Bull. Amer. Meteorol. Soc., 96, 1311-1332. http://dx.doi.org/10.1175/BAMS-D-12-00227.1

Wehr, T., Kubota, T., Tzeremes, G., Wallace, K., Nakatsuka, H., Ohno, Y., Koopman, R., Rusli, S., Kikuchi, M., Eisinger, M., Tanaka, T., Taga, M., Deghaye, P., Tomita, E., and Bernaerts, D.: The EarthCARE mission – science and system overview, Atmos. Meas. Tech., 16, 3581–3608, https://doi.org/10.5194/amt-16-3581-2023, 2023.

Reply: Thank you for this helpful suggestion. We have added the references to Illingworth et al. (2015) and Wehr et al. (2023) and revised the relevant sentence in the manuscript (Lines 631-634) as follows:

"Future work could additionally incorporate direct observations of cloud-ice fall speeds and vertical cloud structure from the EarthCARE satellite to provide more physically based constraints for evaluating and improving cloud microphysics parameterizations (Illingworth et al., 2015; Wehr et al., 2023)."

Review 2 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
Many thanks to the authors for addressing my comments and questions. I do have a few follow-up questions to consider.

Best Regards, Ted Mansell

Minor Points:
1. Looking back through the manuscript, Fig. 5 raised a question regarding thick ice clouds. Perhaps this is a naive question, but I wonder how model 'thick' ice clouds could have 11.2 brightness temperatures that are above freezing? Panel (c) (Obs) has basically no points for BT (11.2) greater than about 277K, but the models have a lot of points (differences) for BT (11.2) greater than 280K. I realize that frequencies are for the BT differences, but there has to be a BT (11.2) of the given temperature to start with. Are the 'thick' clouds simply vertically thick but not very dense, such that the surface temperature is peeking through? The more basic question is why the model thin and thick cloud patterns look very similar, but the observed ones are very distinct? Is this a generally common issue with models?

Reply: Thank you for this insightful comment.

1) In this study, "thick" and "thin" ice clouds refer to optically thick and optically thin cloud categories defined by their optical properties, rather than their geometric thickness or vertical extent. The anomalously warm simulated brightness temperatures (BTs) under observed thick ice -cloud conditions may arise from two possible factors. First, spatial misplacement of simulated cloud structures relative to observations may lead to insufficient upper-level ice hydrometeors at collocated locations, allowing greater contributions from warmer lower atmospheric layers and the surface to the simulated infrared radiances. Second, as the reviewer suggests, even when ice clouds are present and extend over a considerable vertical depth, their infrared optical thickness may remain relatively small because of insufficient ice condensate. In such cases, radiation from the warmer atmosphere below the clouds and the surface can partially penetrate the cloud layers, resulting in higher simulated BTs.

Following the reviewer ' s suggestion, the following sentences have been added to the manuscript (Lines 373-378):

" In this study, "thick" and "thin" ice clouds refer to optically thick and optically thin categories defined by the AHI L2 cloud-type product based on optical properties, rather than geometric thickness. The anomalously warm simulated BTs (>280 K) under observed thick-ice-cloud conditions in both schemes (Figures 5f and 5i) may reflect spatial mismatches between observed and simulated cloud structures, and/or insufficient ice condensate. These deficiencies may reduce cloud infrared opacity, allowing greater contributions from warmer lower atmospheric layers and the surface to the simulated radiances, thereby increasing BTs. ".

2) Regarding the similar model simulated BT-BTD distributions under optically thin and thick ice-cloud conditions, this discrepancy may reflect limitations of both microphysics schemes in reproducing the distinct radiative characteristics of the two cloud regimes. The NOAA Enterprise cloud-type algorithm distinguishes optically thin and thick ice clouds based on multispectral infrared radiances; therefore, the distinct observed BT-BTD distributions partly reflect the radiative criteria used for classification. Uncertainties in radiative transfer calculations, particularly in the treatment of ice-cloud scattering, may also contribute to this issue (Okamoto, 2017). Without a more comprehensive evaluation across different models and cloud regimes, it remains unclear whether the similarity between the simulated thin- and thick-ice cloud distributions is a common feature of numerical weather prediction models.

Following the reviewer's suggestion, the relevant sentences have been added to the manuscript (Lines 379-382):

"Furthermore, the similar model simulated BT-BTD distributions for optically thin and thick ice clouds, in contrast to the distinct observed distributions, suggest that both microphysics schemes may have limitations in reproducing the distinct radiative characteristics of these two cloud regimes. Uncertainties in the treatment of ice-cloud scattering in the radiative transfer calculations may also contribute to these simulation errors (Okamoto, 2017). "

References,

Okamoto, K.: Evaluation of IR radiance simulation for all-sky assimilation of Himawari-8/AHI in a mesoscale NWP system, *Q. J. Roy. Meteor. Soc.*, 143, 1517–1527, https://doi.org/10.1002/qj.3022, 2017.

2. The zenodo link for the MPAS model is an NCAR release version that does not include the NSSL microphysics scheme. This would instead have been an in-progress version that added it.

Reply: Thank you for pointing out this discrepancy. We have updated the code citation to the modified code repository (https://doi.org/10.5281/zenodo.23487937) and revised the Code and Data Availability statement to refer to the modified MPAS-Atmosphere v8.2.2 code used in this study, which incorporates the NSSL two-moment microphysics scheme. The revised statement reads as follows:

"The modified MPAS-Atmosphere v8.2.2 code used in this study and CRTM v2.4.1 are available via Zenodo at https://doi.org/10.5281/zenodo.23487937 (last access: 10 June 2026; Zhang et al. 2026c) and https://doi.org/10.5281/zenodo.7823722 (last access: 10 June 2026; Johnson et al., 2023), respectively."

References,

Zhang, X., Wei, W., Tao, S., Zhiquan, L., and Chen, I.-H.: MPAS-Model v8.2.2 with WSM6 and NSSL Microphysics, Zenodo [code], https://doi.org/10.5281/zenodo.23487937, 2026c.

3. The namelist.atmophere on zenodo for the NSSL forecast does not set a value for config_nssl_hail_on. The default value is true, so if it was not set to false, then the hail category would have been turned on. If this is indeed the case, I suggest simply combining qh with qg in Fig. 8. Depending on the version, the log.atmosphere.0000.out should have a printout of the value of config_nssl_hail_on.

Reply: Thank you for this comment. The hail category was indeed enabled in the NSSL forecast. A comparison of the graupel mixing ratio with and without including hail showed no substantial differences in the overall distribution. Following your suggestion, Fig. 8 has been revised by combining the hail (qh) and graupel (qg) mixing ratios and plotting their sum (qh + qg). The revised Fig. 8 is shown below.

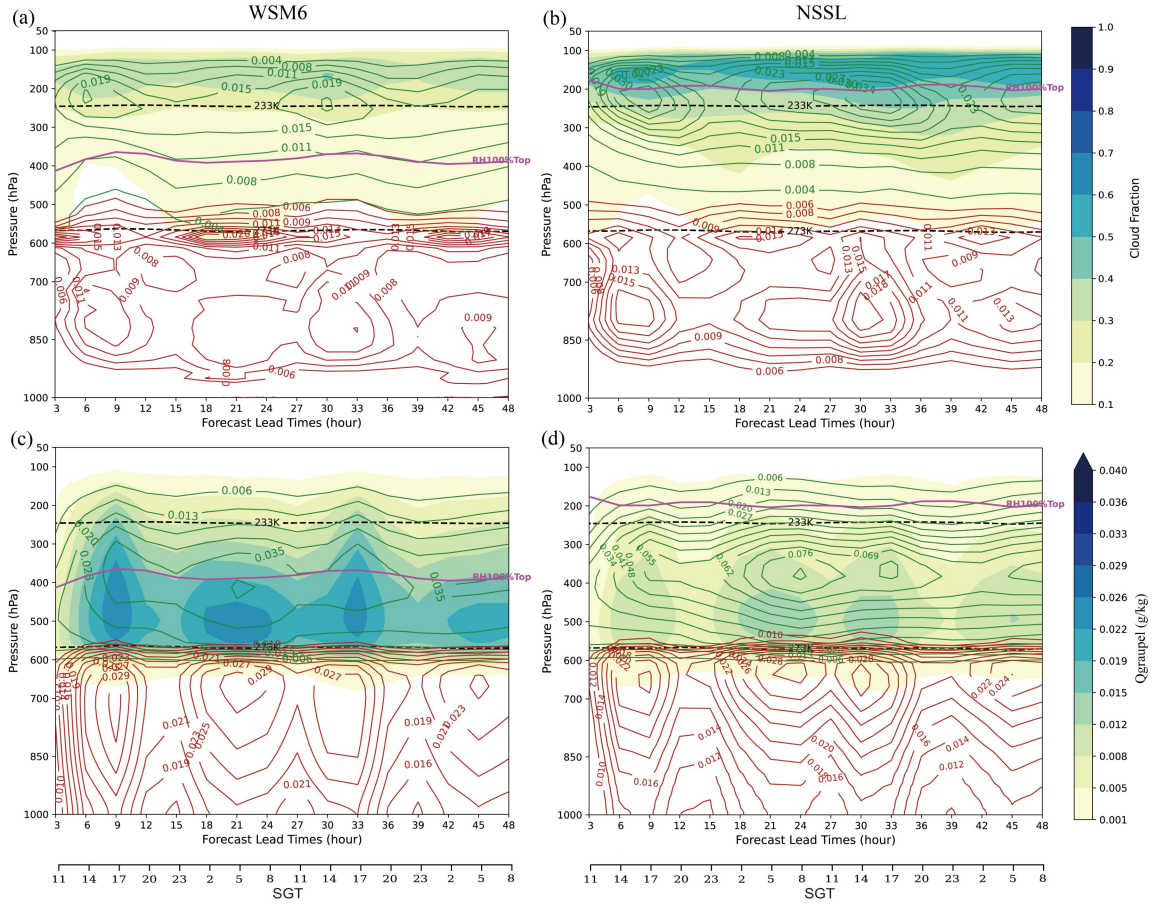


Figure 8. Domain-averaged (a, b) cloud fraction (shading), the mixing ratio (units: g/kg) of Qc (red contours) and Qi (green contours), and (c, d) Qg (shading), Qs (green contours) and Qr (red contours) as a function of forecast lead time and pressure for the WSM6 (first column) and NSSL (second column) microphysics schemes. The dashed black lines mark the 273 K and 233 K isotherms, and the magenta line indicates the uppermost level where the relative humidity reaches 100%.

4. WSM6 probably has a lower graupel fall speed than in NSSL, which would keep mass aloft longer (Fig. 8) and contribute to loading. WSM6 uses the same weighted fall speed for both snow and graupel: vt = (vts*qs + vtg*qg)/(qs + qg).

Reply: Thank you for this insightful comment. As noted, WSM6 applies a mass-weighted fall speed to both snow and graupel, which may reduce the effective sedimentation velocity of graupel when snow is present. This could prolong the residence time of graupel in the

atmosphere and partly contribute to the higher graupel mixing ratios simulated by WSM6 compared with NSSL (Figure 8).

Following this suggestion, the relevant sentences have been added in Lines 464-466 as: "Moreover, the higher Qg in WSM6 may be partly attributed to its use of a shared mass-weighted fall speed for snow and graupel (Dudhia et al., 2008), which may allow graupel to remain aloft longer and contribute to the greater graupel mass loading shown in Figure 8c."

References,

Dudhia, J., Hong, S.-Y., and Lim, K.-S.: A new method for representing mixed-phase particle fall speeds in bulk microphysics parameterizations, J. *Meteorol. Soc. Jpn.*, 86A, 33-44, https://doi.org/10.2151/jmsj.86A.33, 2008.

5. If I am looking at the correct version (or close enough), the default config_nssl_cccn value was 0.8e9, which is moderate-high continental. (Check the core_atmosphere/Registry.xml to see the actual value for the simulations.) If the authors wish, they could change that to something like 0.25e9 for a maritime-dominant environment and see if there is a substantial difference. If there are large differences, that would be informative.

Reply: Thank you for this valuable suggestion. Following the reviewer's recommendation, a preliminary sensitivity test was conducted using two forecast samples, with the NSSL namelist parameter config_nssl_cccn reduced from its default value of 0.8×10^9 to 0.25×10^9 m^{-3}, a value more representative of maritime conditions.

The comparison results in Figure S1 shows that reducing the CCN concentration decreases Qc while increasing Qr, consistent with more efficient warm-rain conversion. The increases in Qg and Qh further suggest that the CCN concentration also influences the distribution of mixed-phase hydrometeors. Moreover, the upper-tropospheric cloud fraction exhibits little overall change, with a slight decrease at 100-200 hPa during 42-48 forecast hours.

These results suggest that the default CCN concentration may suppress warm-rain development in the maritime-dominant domain and that CCN concentration influences the simulated hydrometeor distributions. The corresponding sensitivity results and discussion have been added to the revised manuscript (Lines 460-464), as follows:

"This contrast may also reflect a relatively high default CCN concentration in NSSL for the maritime domain, favoring more numerous but smaller cloud droplets and suppressing collision-coalescence and the associated cloud-water autoconversion. A preliminary sensitivity test was conducted with 'config_nssl_cccn' reduced from its default value of 0.8 × 10^9 to 0.25 × 10^9 m^{-3}. The results suggested more efficient warm-rain conversion, as indicated by decreased Qc and increased Qr and Qg (not shown). "

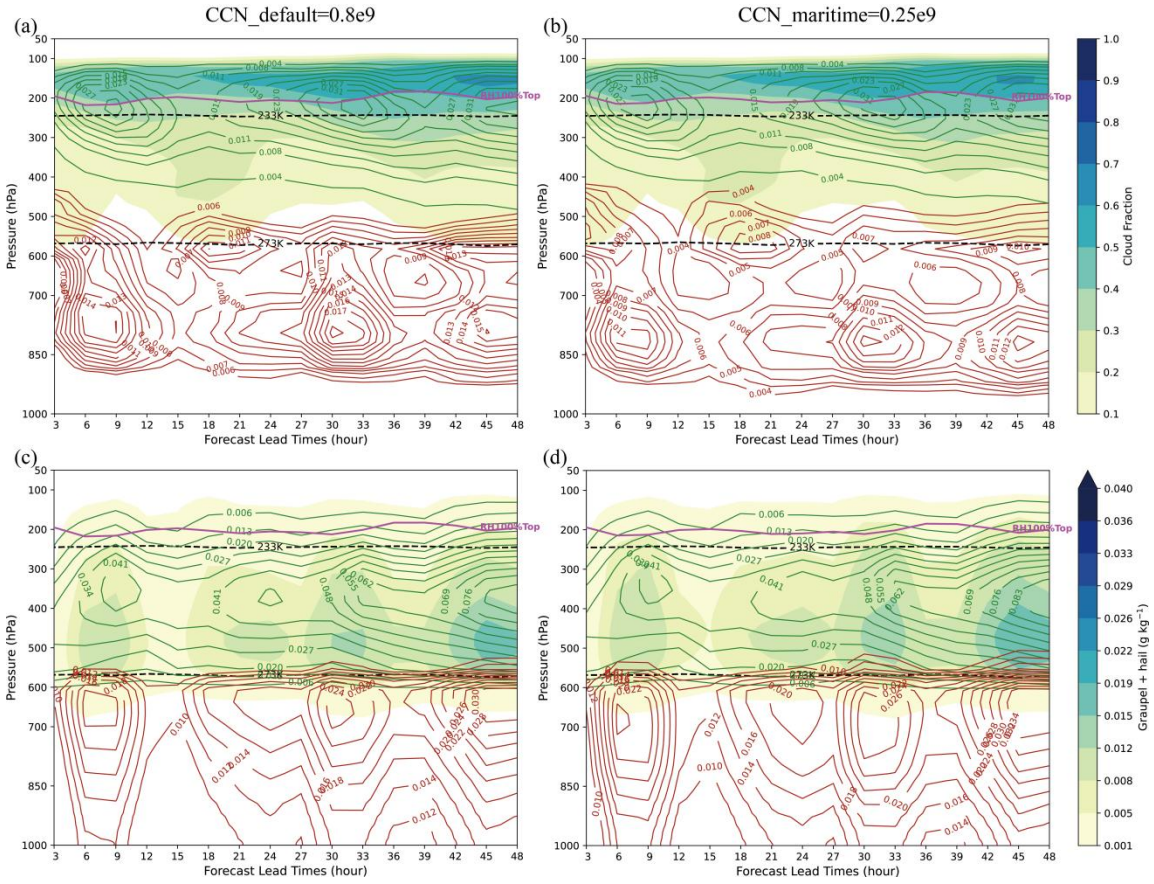


Figure S1. Domain-averaged (a, b) cloud fraction (shading), the mixing ratio (units: g/kg) of Qc (red contours) and Qi (green contours), and (c, d) Qg+Qh (shading), Qs (green contours) and Qr (red contours) as a function of forecast lead time and pressure for two forecast cases initialized at 0000 UTC on 26 September and 3 October 2024, respectively. Panels (a, c) use the default NSSL CCN concentration (0.8 × 10^9 m^{-3}), and (b, d) use the reduced concentration (0.25 × 10^9 m^{-3}). The dashed black lines mark the 273 K and 233 K isotherms, and the magenta line indicates the uppermost level where the relative humidity reaches 100%.Figure S1.