

Review-2 of “Impacts of All-Sky Himawari-9 AHI Radiance Assimilation on Cloud and Precipitation Forecasting over the Maritime Continent (JEDI-MPAS 3.0.3)”

General Comments:

This manuscript examines all-sky IR DA over the Maritime Continent and its sensitivity to different DA setups. The manuscript is pleasant to read, and the results are robust (the authors evaluated the performance of all-sky IR DA with a range of metrics and perspectives). I appreciate the authors' efforts to keep their manuscript succinct and their discussion of their observation error modelling. Most of my comments are quite minor. As such, I recommend an editorial decision of minor revisions for this manuscript.

Minor comments:

1) Section 2: Please relocate the description of your MPAS model to the start of Section 2. It is hard to understand your observation error model otherwise.

Reply: Thank you for the helpful suggestion. Following the reviewer's recommendation, we have relocated the original Section 2.3, “MPAS-JEDI Assimilation System,” to the beginning of Section 2, where it is now presented as Section 2.1. Please see the revised manuscript for the corresponding changes.

2) Please state whether you are using the same grid spacing and parameterization schemes for all of your MPAS simulations. For example, do you use $dx = 2.4$ km for your 32-member ensemble, control member, and 6-hour forecasts?

Reply: Thank you for the comment. All MPAS simulations in this study, including the 32-member ensemble, the control member, and the subsequent 6-h forecasts, were conducted using the same model configuration. Specifically, all simulations used a quasi-uniform horizontal grid spacing of approximately 2.6 km and the same set of physical parameterization schemes. To clarify this point, the following sentence has been added to Lines 278–280 of the revised manuscript:

“The same horizontal grid spacing and physical parameterization schemes were used for all MPAS simulations, including the 32-member ensemble, the control member, and the subsequent forecasts.”

3) L237: Are you assimilating GNSS-RO via the local or non-local obs operator?

Reply: Thank you for the question. We assimilated GNSS-RO refractivity using the local observation operator, rather than a non-local bending-angle operator. Specifically, the GnssroRefNCEP operator in JEDI/UFO was used to simulate atmospheric refractivity from the model state. We have clarified this point in Lines 343–344 of the revised manuscript, as follows:

“GNSS-RO observations were assimilated using the local GnssroRefNCEP observation operator in JEDI/UFO, which simulates atmospheric refractivity from the model state.”

4) L254: "vertical localization scales of ... 4 km" -- should this be $4 \ln P$, or something similar?

Reply: Thank you for the comment. MPAS-JEDI supports several choices for the vertical localization coordinate, including model level, geometric height, and scale height $[\log(P)]$. In this study, the localization was configured in geometric height, and therefore the specified vertical localization scale of 4 km is appropriate. We have revised the manuscript to clarify this point in Lines 258–259, as follows:

“ To reduce sampling errors associated with the limited ensemble size, covariance localization was applied with a horizontal localization scale of 300 km and a height-based vertical localization scale of 4 km. ”

5) Fig 1: The y-labels for all of your sub-plots should be $\log(\text{PDF})$ instead of PDF.

Reply: Thank you for pointing this out. Following the reviewer’s suggestion, we have revised the y-axis labels in all subplots of Figure 1 from “PDF” to “Log(PDF)”. The revised Figure 1 is shown below.

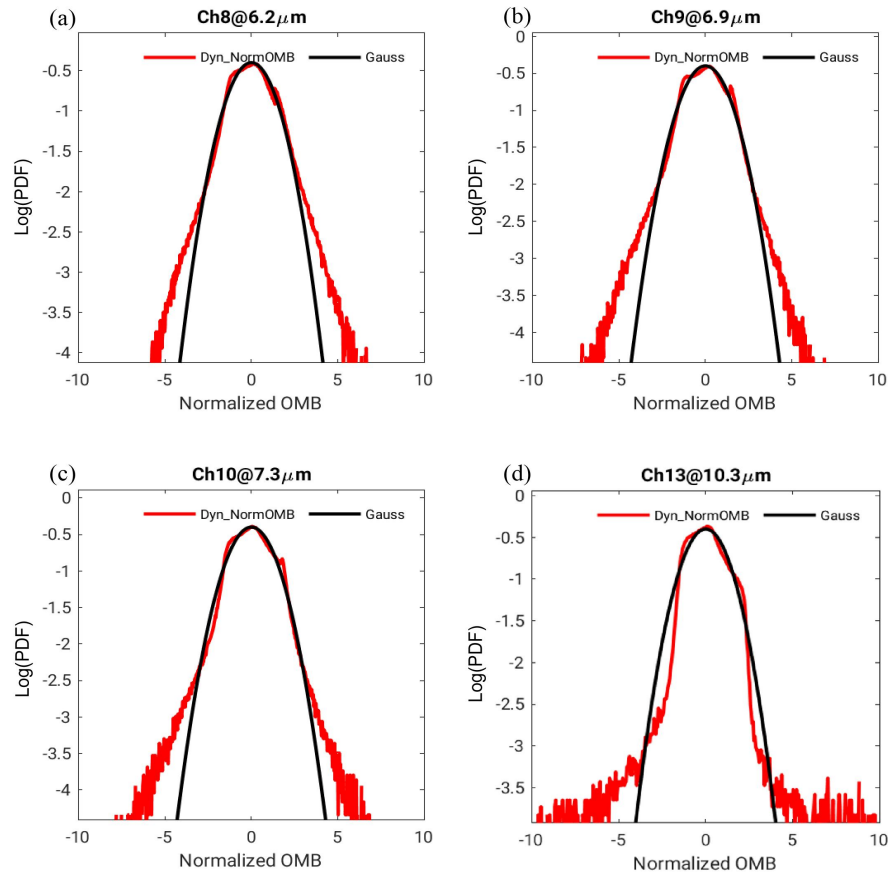


Figure 1. Probability density functions (PDFs) of normalized observation-minus-background brightness temperature (OMB; units: K) for all-sky Himawari-9 AHI (a) Channel 8 (6.2 μm), (b) Channel 9 (6.9 μm), (c) Channel 10 (7.3 μm), and (d) Channel 13 (10.3 μm) brightness temperature (units: K). The black curve denotes the standard Gaussian distribution with $N(0,1)$. The statistics were accumulated at 6 hour intervals from 0000 UTC 13 September 2024 to 1800 UTC 12 October 2024.

6) Fig 2a: Please mention the transect you drew here in the caption, and use a different color to draw your transect line (the dashed line is hard to see for color-blind/weak folks).

Reply: Thank you for the suggestion. We have revised Figure 2a accordingly by adding a description of the transect to the caption and changing the transect line to a more distinguishable color. The revised Figure 2 is shown below.

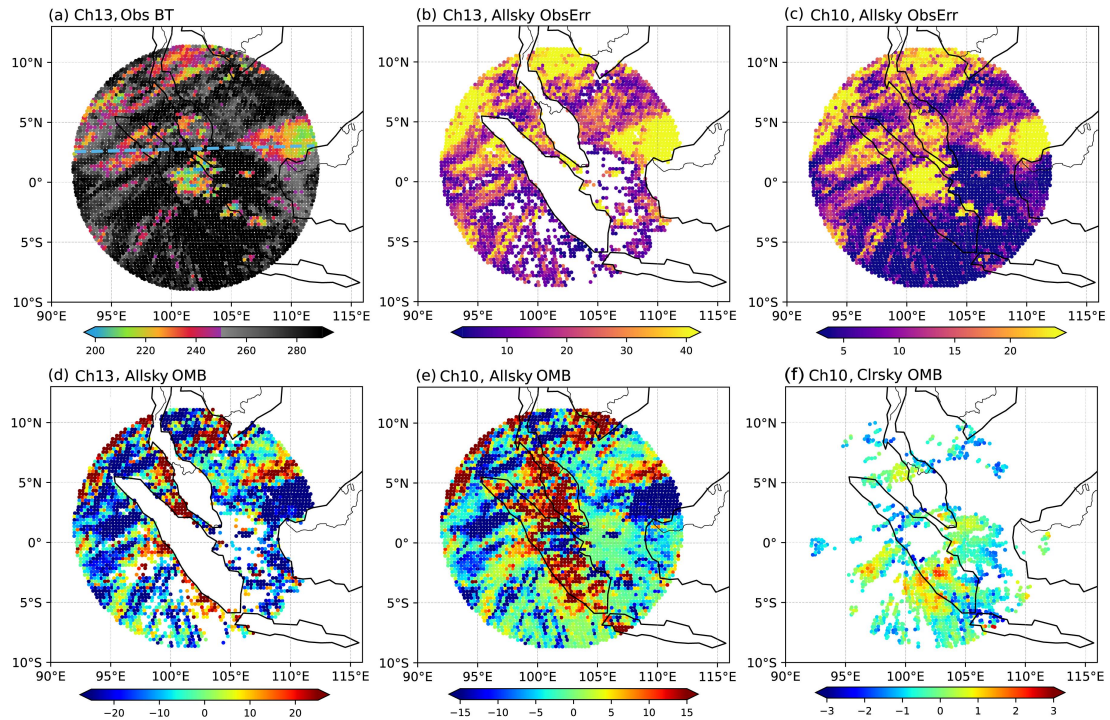


Figure 2. Horizontal distributions of (a) observed brightness temperature (BT; units: K) for AHI channel 13, all-sky observation error (units: K) for (b) channel 13 and (c) channel 10, all-sky observation-minus-background brightness temperature (OMB; units: K) for (d) channel 13 and (e) channel 10, and (f) clear-sky OMB (units: K) for channel 10. The blue dashed line in (a) indicates the location of the vertical cross section analyzed in Figures 3 and 4. All panels are shown for the first assimilation cycle valid at 0600 UTC 23 September 2024.

7) Fig 3e and f: Just to be clear, you obtained these OMA's by running the CRTM on the analysis control member, and then compare against obs? DA systems sometimes spit out an "analysis BT" field, which turns out to be different from what is obtained by running the CRTM on the control member. See Kugler and Weissmann (2025) for an example.

Kugler, L., & Weissmann, M. (2025). Effects of observation-operator nonlinearity on the assimilation of visible and infrared radiances in ensemble data assimilation. *Quarterly Journal of the Royal Meteorological Society*, 151(770), e4970.

Reply: Thank you for this valuable suggestion. Yes, the OMA departures shown in Figs. 3e and 3f were obtained by applying the CRTM observation operator to the analysis control member ' x_a ' through the HofX application. The resulting simulated brightness temperatures, $H(x_a)$, were then compared with the corresponding observations, and the OMA departures were calculated offline as ' $O-H(x_a)$ '. Thus, these OMA values were not taken from an internally generated "analysis BT" field from the DA system. We have clarified this procedure in Lines 315–317 of the revised manuscript, as follows:

“ Specifically, the OMA departures were calculated offline as the differences between the observations and the BTs simulated from the control analysis state using the CRTM observation operator within the HofX application (Kugler and Weissmann, 2025). ”

8) Section 3: please state how your observation time window is set up, particular for ASR4D. For example, does your window go from -3 hour to +3 hour, or 0 hour to 6 hour?

Reply: Thank you for the comment. For ASR4D, the 4DEnVar assimilation window spans -3 h to +3 h relative to the analysis time. Observations within this 6-h window are assimilated according to their actual observation times. To clarify this point, the relevant sentences have been added to Lines 263–265 of the revised manuscript, as follows:

“ In the hybrid-3DEnVar experiment, only ensemble perturbations valid at the analysis time were used. In contrast, the hybrid-4DEnVar experiment employed a 6-hour assimilation window extending from -3 to +3 h relative to the analysis time, with observations grouped into 3-hour time slots and ensemble perturbations sampled at corresponding 3-hour intervals.”

9) Fig 4: Have you taken a look at the relative humidity analysis increments to determine if the hydrometeor analysis increments are physically reasonable? If not, the issues detailed in Chan (2026) may contaminate your findings.

Chan, M. Y. (2026). Improving convection-permitting all-sky infrared radiance ensemble data assimilation through mitigating deleterious non-Gaussian artifacts. *Quarterly Journal of the Royal Meteorological Society*, 152(774), e70039.

Reply: Thank you for raising this important point. Following the reviewer’s suggestion, we used the ASR3D-Ch13 experiment as a representative case and examined both the relative-humidity (RH) analysis increments and the corresponding analyzed RH field along the same cross section as that shown in Fig. 4. The results of this additional analysis are shown in Fig. S1. The additional diagnostics indicate a generally consistent spatial relationship among the regions of pronounced hydrometeor increments, relatively large RH increments, and moist to near-saturated analyzed environments. For example, between approximately 99.5° and 104°E, pronounced hydrometeor increments in the mid-to-upper troposphere, mainly between about 200 and 500 hPa, broadly coincide with enhanced RH increments and analyzed RH values of approximately 80–100%. A similar correspondence is also evident near 92°E at around 500 hPa and farther east between approximately 108° and 111°E at 200–450 hPa. In contrast, regions with lower analyzed RHs and weaker RH increments generally exhibit smaller or less coherent hydrometeor adjustments. These spatial relationships suggest

that the major hydrometeor increments are predominantly associated with sufficiently moist environments rather than being systematically introduced into strongly subsaturated air. Therefore, we find no clear evidence of a widespread dry-cloud artifact of the type discussed by Chan (2026), although localized inconsistencies cannot be completely excluded. A brief discussion has also been added to the revised manuscript in Lines 309–311, as follows:

“Further examination shows that these relatively large hydrometeor increments broadly coincide with enhanced RH increments and are primarily located within moist to near-saturated regions, suggesting that the associated cloud adjustments are generally physically consistent (not shown).”

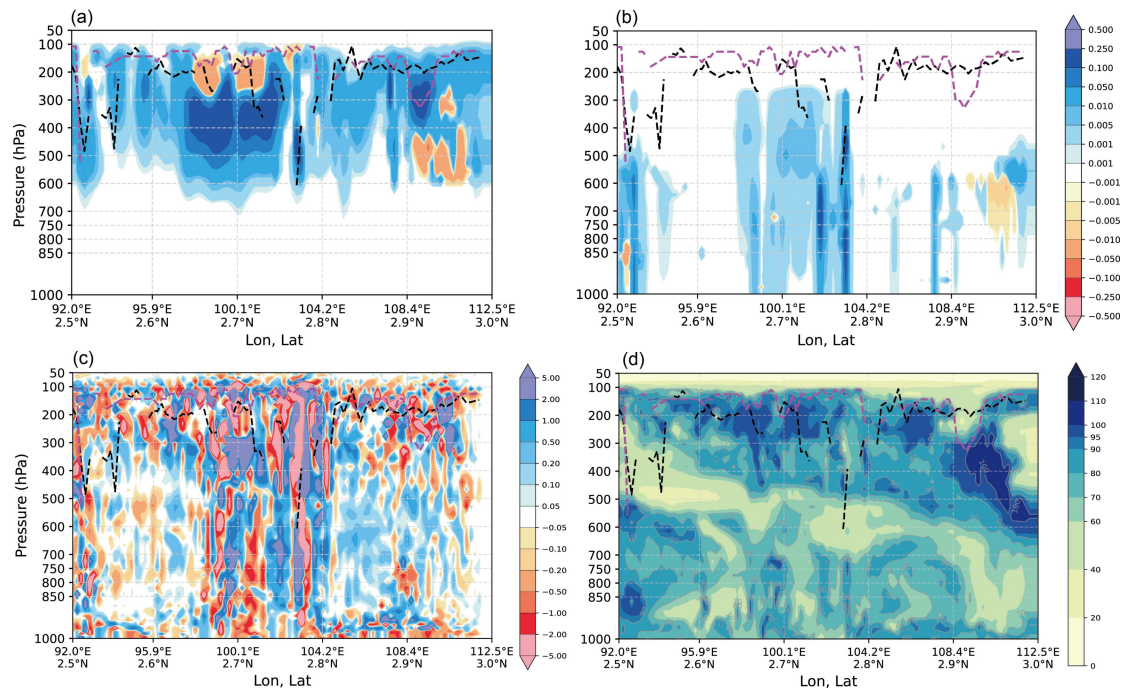


Figure S1. Vertical cross-sections from the ASR3D-Ch13 experiment along the same transect as in Fig. 4, showing the analysis increments of hydrometeor mixing ratio (shading; units: g kg^{-1}), including (a) the combined mixing ratio of cloud ice, snow, and graupel and (b) the combined mixing ratio of cloud water and rain, together with (c) the relative-humidity (RH) analysis increments (shading; %) and (d) the analyzed RH field (shading; %). The black and magenta dashed lines denote the observed and model-simulated cloud-top pressures (units: hPa), respectively. All panels are valid at the first assimilation cycle at 0600 UTC 23 September 2024.

10) Section 4: you did a great job with comparing the results of the various experiments. To take this a step further, please add some deeper discussion about why different DA setups behaved differently. For example, why did ASR3D-Ch13 perform worse than ASR3D with respect to GNSS-RO the upper troposphere (Fig 5b, 8-10 km), and with respect to U from 850 hPa to 350 hPa (Fig 6b)? I am specifically asking for deeper discussions relating to the characteristics of the observation system (e.g., ch13) and DA fundamentals.

Reply: Thank you for this important comment. The main difference between ASR3D-Ch13 and ASR3D is the additional assimilation of the cloud-sensitive AHI channel 13 (10.4 μm). In the present configuration, only cloudy observations from channel 13 are assimilated. Unlike the water-vapor channels 8–10, which are directly sensitive to moisture in the middle and upper troposphere, channel 13 under cloudy conditions is primarily sensitive to cloud-top emission and therefore provides additional information on cloud-top temperature, cloud height, and hydrometeor distributions. However, channel 13 provides no direct observational constraint on upper-tropospheric moisture or winds. Its influence on these variables is therefore exerted primarily through the multivariate, flow-dependent background-error covariances.

Because ASR3D-Ch13 assimilates the same water-vapor channels as ASR3D, the differences between the two experiments primarily reflect the additional impact of cloudy channel-13 observations. Channel 13 is strongly sensitive to cloud emission and cloud-top properties, while the relationship between cloudy radiances and cloud hydrometeors is highly nonlinear and state dependent. The additional channel-13 information can produce substantial cloud and thermodynamic adjustments, whereas its influence on upper-tropospheric moisture and winds is transmitted more indirectly through multivariate background-error cross-covariances and subsequent cloud-microphysical and dynamical adjustment. Previous work has shown that the multivariate forecast statistics linking all-sky infrared radiances and model variables can deviate substantially from Gaussianity under cloudy conditions, potentially leading to physically inconsistent analysis increments (Chan, 2026). In the present hybrid system, this complexity, together with sampling uncertainty in the flow-dependent covariance estimated from the finite 32-member ensemble, may lead to less optimal projections of the additional channel-13 information onto indirectly constrained variables. This may provide a plausible common explanation for both the somewhat poorer GNSS-RO verification at 8–10 km and the degraded zonal-wind verification between 850 and 350 hPa in ASR3D-Ch13 relative to ASR3D.

The corresponding discussion has been expanded in Section 4, Lines 381–391, accordingly:

“ Moreover, in the mid- to upper troposphere, ASR3D-Ch13 shows weaker improvements than ASR3D, as indicated by the U-wind verification between 850 and 350 hPa (Figure 6b) and the GNSS-RO verification at 8–10 km (Figure 5b). Since both experiments assimilate the same water-vapor channels, the differences primarily reflect the additional contribution of cloudy channel-13 observations. Unlike water-vapor channels, cloudy channel-13 radiances provide no direct constraint on upper-tropospheric moisture or winds; instead, their impact is transmitted more indirectly through multivariate, flow-dependent background-error covariances. Previous work has shown that departures from Gaussianity in the multivariate forecast statistics under cloudy conditions may affect the accuracy of covariance-based cross

-variable adjustments, potentially leading to physical inconsistencies between hydrometeor and thermodynamic increments (Chan, 2026). In the present hybrid system, this complexity, together with sampling uncertainty in the flow-dependent component of the background-error covariance estimated from the finite 32-member ensemble, may reduce the effectiveness of multivariate adjustments for those variables that are indirectly constrained by the window channel-13 observations. ”

References,

Chan, M.-Y.: Improving convection-permitting all-sky infrared radiance ensemble data assimilation through mitigating deleterious non-Gaussian artifacts, *Q. J. Roy. Meteor. Soc.*, 152, e70039, <https://doi.org/10.1002/qj.70039>, 2026.