

Review-1 of “Impacts of All-Sky Himawari-9 AHI Radiance Assimilation on Cloud and Precipitation Forecasting over the Maritime Continent (JEDI-MPAS 3.0.3)”

This manuscript examined the impact of all-sky Himawari-9 AHI radiance assimilation on the analysis and forecasts over the Maritime Continent using the JEDI data assimilation system and the MPAS model. In addition to the water vapor channels that have previously been widely used by similar studies, this study also explored the impacts of window channel 13. The results suggest that all-sky radiance provides important moisture and hydrometeor information over cloudy regions, with channel 13 observations bringing additional benefits in constraining the distribution of clouds. Using a 4DnVar approach can lead to longer-lasting benefits when assimilating all-sky radiance. This manuscript is overall well prepared. I have a handful of relatively minor suggestions to improve the clarity of the manuscript.

1. Line 129: Are these numbers the mean values of their respective OMBs?

-----

Reply: Yes. These values represent the mean OMBs for the respective AHI channels. This has been clarified in the revised manuscript (Line 147) as follows:

“The corresponding mean OMB values were  $-0.388$ ,  $0.284$ ,  $-0.630$ , and  $-0.660$  K for AHI channels 8, 9, 10, and 13, respectively.”

2. Line 153: How were these three observation errors determined?

-----

Reply: The observation errors for AHI channels 8-10 were estimated from the standard deviations of the clear-sky OMB statistics. For clarity, the relevant sentence in Lines 170–172 has been revised as follows:

“In clear-sky assimilation experiments, constant observation errors of  $1.110$ ,  $1.058$ , and  $0.915$  K were assigned to AHI channels 8-10, respectively, based on the standard deviation of clear-sky OMB statistics.”

3. Table 2: It would be helpful to mark the variable symbols in equations 1 and 2 together with their names in the table.

-----  
 Reply: Thank you for this helpful suggestion. The variable symbols used in Eqs. (1) and (2) have now been added alongside their corresponding parameter names in Table 2 for clarity, as shown in the revised table below.

**Table 2. The observation error parameters of Himawari-9 AHI Channels 8-10 and 13**

|              | <b>Minimum<br/>cloud<br/>amount,<br/><math>C_{a1}</math> (K)</b> | <b>Maximum<br/>cloud<br/>amount,<br/><math>C_{a2}</math> (K)</b> | <b>Minimum<br/>observation<br/>error,<br/><math>SD_{min}</math> (K)</b> | <b>Maximum<br/>observation<br/>error,<br/><math>SD_{max}</math> (K)</b> | <b>Brightness<br/>temperature<br/>threshold,<br/><math>BT_{lim}</math> (K)</b> |
|--------------|------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <b>Ch 8</b>  | 0.50                                                             | 9.50                                                             | 4.00                                                                    | 15.30                                                                   | 230.5                                                                          |
| <b>Ch 9</b>  | 0.50                                                             | 13.50                                                            | 4.60                                                                    | 20.20                                                                   | 240.0                                                                          |
| <b>Ch 10</b> | 0.50                                                             | 17.50                                                            | 3.60                                                                    | 24.00                                                                   | 251.5                                                                          |
| <b>Ch 13</b> | 0.50                                                             | 36.00                                                            | 2.56                                                                    | 40.50                                                                   | 292.0                                                                          |

4. Lines 162-163: "...the corresponding standard deviation estimated for that CA bin": standard deviation of what?

-----  
 Reply: Thank you for this comment. Here, the standard deviation refers to the standard deviation of the OMB departures within the corresponding CA bin. We have clarified the definition in the revised manuscript (Lines 181-182) as follows:

“Where  $OMB(CA_i)$  represents the OMB departures within the  $i^{th}$  CA bin, and  $\sigma(CA_i)$  denotes the standard deviation of the OMB departures within that  $i^{th}$  CA bin.”

5. Figure 2: In panels e and f, why are the OMB values different if this is the first assimilation cycle? I would assume that the observations and the background values are identical between these two panels.

-----  
 Reply: Thank you for this comment. Although the two experiments use the same atmospheric background state in the first assimilation cycle, the simulated background brightness

temperatures are calculated using different CRTM configurations. The all-sky CRTM calculation uses temperature, humidity, and hydrometeor profiles as input, whereas the clear-sky calculation excludes the hydrometeor profiles and therefore does not account for cloud radiative effects. Therefore, the simulated brightness temperatures, and consequently the OMB values, can differ even for the same first-cycle background. In addition, Fig. 2f only includes observations retained after clear-sky screening. To be clear, the relevant sentences in Lines 227–229 have been modified as follows:

“ Although the same atmospheric background state is used, the clear-sky CRTM calculation excludes cloud and hydrometeor profiles from the radiative transfer inputs, resulting in different simulated BTs and OMB departures from those obtained with the all-sky calculation.”

6. Lines 353-363 and Figure 6: Why was V-wind improved, but U-wind was generally neutral? Are they representing or relating to different processes?

-----  
Reply: Thank you for this insightful comment. AHI radiances primarily constrain thermodynamic and cloud-related variables, while their influence on the wind field is introduced indirectly through multivariate background-error covariances and subsequent dynamical adjustment. Over the tropical Maritime Continent, the more consistent improvement in V-wind may be associated with assimilation-induced thermodynamic and cloud adjustments projecting onto the meridional circulation, which is closely linked to cross-equatorial flow and associated moisture transport, convergence, and convective variability (Zhao et al., 2022; Lubis et al., 2023). By contrast, zonal wind variability over the Maritime Continent is more closely related to broader intraseasonal circulation variability, such as MJO-related westerly–easterly anomalies and associated moisture convergence (Lubis et al., 2023). The assimilation-induced adjustments may therefore project differently onto the zonal and meridional wind components, and the contrasting responses of U- and V-wind may reflect their different relationships with regional circulation and convective processes. We have accordingly revised the relevant sentences in Lines 371 – 381 to clarify this possible interpretation, as follows:

“The results suggest that the cycling assimilation of all-sky AHI radiances tends to progressively enhance the background V-wind field, which is likely associated with the propagation of improved thermodynamic and cloud-related analyses into the V-winds via model dynamical adjustment within the Hybrid-EnVar framework. Over the tropical Maritime Continent, this improvement may be linked to adjustments in the meridional circulation associated with cross-equatorial moisture transport, localized convergence, and

convective variability (Zhao et al., 2022). By contrast, the AHI assimilation experiments show an overall neutral impact on the background zonal wind (U-wind) field, with most RMSE differences confined within  $\pm 10\%$  across the troposphere (Figure 6b). More specifically, relative to CTL, CSR3D and ASR3D exhibit comparatively larger RMSE reductions at most levels, whereas ASR3D-Ch13 and ASR4D show larger RMSEs than CTL below 600 hPa. Zonal wind variability over this region may be more closely associated with larger-scale circulation processes, such as MJO-related wind anomalies (Lubis et al., 2023). ”

#### References,

- Zhao, X., Lu, R., Dong, B., Hong, X., Liu, J., and Sun, J.: Tropical anomalies associated with the interannual variability of the cross-equatorial flows over the Maritime Continent in boreal summer, *J. Climate*, 35, 5591–5603, <https://doi.org/10.1175/JCLI-D-21-0764.1>, 2022.
- Lubis, S. W., Hagos, S., Chang, C.-C., Balaguru, K., and Leung, L. R.: Cross-equatorial surges boost MJO's southward detour over the Maritime Continent, *Geophys. Res. Lett.*, 50, e2023GL104770, <https://doi.org/10.1029/2023GL104770>, 2023.

7. Figure 8: There is no need to show "7h" in the x-axis. Additionally, CSR3D and ASR3D have the same color, and their error bars are indistinguishable from each other.

-----  
Reply: Thank you for this helpful suggestion. Following the reviewer's recommendation, we have revised Figure 8 by adjusting the line style of the ASR4D experiment to better distinguish it from CSR3D. We have also removed the unnecessary "7h" label and revised the x-axis time range accordingly. The updated figure is shown below.

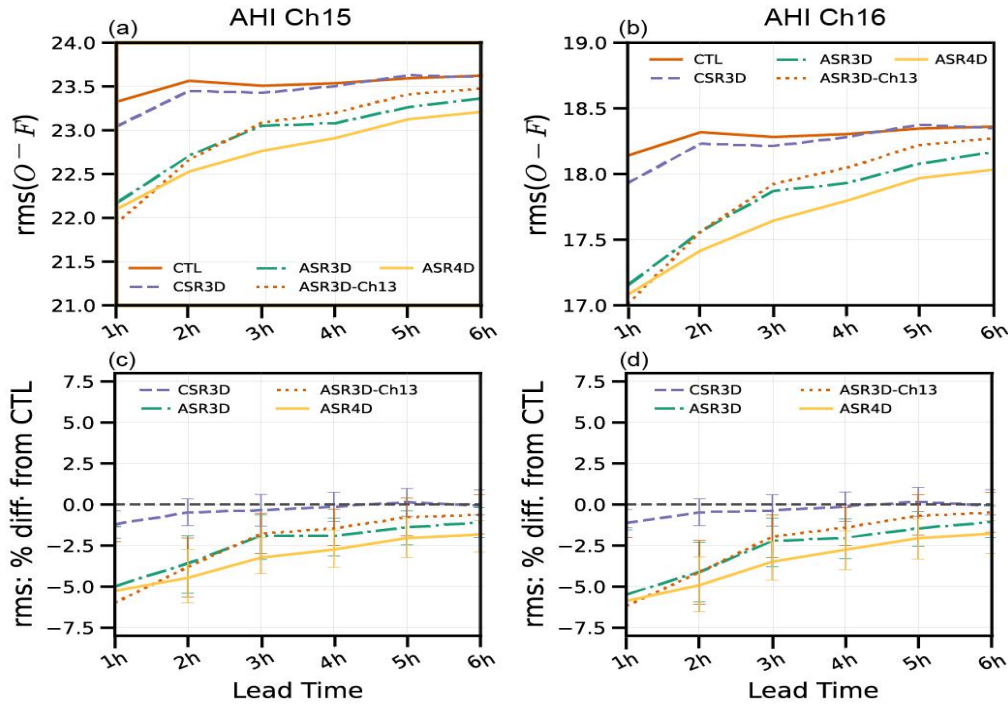


Figure 8. Root-mean-square error (RMSE) of AHI observation-minus-model simulated brightness temperature base on the 1-6 hour forecasts (OMF, units: K) as a function of lead time for (a) channel 15 and (b) channel 16, along with (c, d) the corresponding percentage differences relative to CTL for CSR3D, ASR3D, ASR3D-Ch13, and ASR4D. Statistics are computed from 1200 UTC 23 September to 0000 UTC 29 September 2024 with a 6 hour interval. Error bars denote the 90 % confidence intervals.

8. Line 430: What does "complete distribution" refer to?

Reply: Reply: Thank you for this comment. The phrase "complete distribution" was intended to indicate that the selected case exhibited well-developed convective echoes with a pronounced vertical radar-reflectivity structure. To be clear, the sentences in Lines 457–459 have been revised as follows:

"The independent observations are from a S-band radar over Singapore, with a selected case characterized by well-developed convection and strong vertical echo development."

9. Lines 444-445: Is there any proof of this statement? I would assume that in cloudy regions different infrared channels generally have the same values of radiance and therefore their sensitivities to hydrometeors within the cloud are similar (and result mostly from covariance).

Reply: Thank you for this insightful comment. We agree that the multivariate background-error covariance plays an important role in projecting radiance innovations onto hydrometeor increments, and therefore the differences in hydrometeor analysis increments should not be attributed solely to the direct sensitivity of individual infrared channels. In addition, we would like to clarify that cloudy-sky radiances from different infrared spectral regions do not necessarily provide the same observational information. Although the brightness temperatures of water-vapor and window channels may become similar for very high and optically thick clouds, particularly when the cloud top approaches the tropopause, their spectral and vertical sensitivities can remain different under other cloudy conditions. Under cloudy conditions, the water-vapor channels retain channel-dependent sensitivity to mid- and upper-tropospheric humidity and clouds, whereas the atmospheric-window channels provide complementary information on cloud-top emission and cloud radiative properties (Hirose et al., 2019; Li et al., 2020).

Compared with CSR3D and ASR3D, the better representation of the high-frequency core ( $> 0.8\%$ ) in ASR3D-Ch13 and ASR4D may be associated with different aspects of their assimilation configurations (Fig. 9). Relative to ASR3D, ASR3D-Ch13 retains the same 3DEnVar framework but additionally assimilates the cloud-sensitive window channel 13, thereby introducing complementary observational information on cloud-top emission and cloud properties. By comparison, ASR4D uses the same set of assimilated infrared channels as ASR3D but differs primarily in the temporal treatment of the background-error covariance within the assimilation window, allowing the evolution of flow-dependent error structures to be represented more explicitly. These differences in observational information and background-error treatment may both affect how radiance innovations are projected onto hydrometeor and dynamical fields. To avoid overinterpreting the underlying mechanisms, we have revised the statement in Lines 470–475 accordingly:

“ Among the AHI assimilation experiments, ASR3D-Ch13 and ASR4D tend to better capture the pattern of the high-frequency core ( $> 0.8\%$ ). By contrast, CSR3D and ASR3D show suboptimal performance, characterized by reflectivity values exceeding 25 dBZ that form an unrealistic downward-tilted structure relative to the observations. Compared with CSR3D and ASR3D, the better representation in ASR3D-Ch13 and ASR4D may be associated with different aspects of their assimilation configurations, including the additional cloud-sensitive information provided by channel 13 and the improved temporal representation of flow-dependent background-error covariances in the 4DEnVar framework, respectively. ”

References,

Hirose, H., Shige, S., Yamamoto, M. K., and Higuchi, A.: High temporal rainfall estimations from Himawari-8 multiband observations using the random-forest machine-learning method, *J. Meteorol. Soc. Jpn.*, 97, 689–710, <https://doi.org/10.2151/jmsj.2019-040>, 2019.

Li, X., Zou, X., Zhuge, X., Zeng, M., Wang, N., and Tang, F.: Improved Himawari-8/AHI radiance data assimilation with a double cloud detection scheme, *J. Geophys. Res.-Atmos.*, 125, e2020JD032631, <https://doi.org/10.1029/2020JD032631>, 2020.

10. Figure 10: What is the neighborhood size of FSS?

-----

Reply: Thank you for this comment. The FSS was calculated using a neighborhood size of  $5 \times 5$  grid points. To make this information clearer, the corresponding sentence in Lines 489-490 has been revised as:

“The FSS is calculated using a 5x5 grid-point neighbourhood window, for which a value of 1 indicates a perfect forecast.”