Review of Second Revision of "Ice injected into the tropopause by deep convection – Part 2: Over the Maritime Continent" by Dion et al.

Once again, the authors have made extensive revisions in response to referee comments. Many of those comments have been addressed and the manuscript has been improved. In particular, the new approach to and discussion of the quantification of uncertainty in the various ΔIWC estimates is much clearer now. However, the author team's carelessness in manuscript preparation – which has plagued this paper from the start – persists in this latest draft. Not all issues noted previously have been fixed, and new errors (some of which are major) have been introduced. The most serious is a mischaracterization of the accuracy of MLS IWC data (see specific comments below). As a consequence, the authors have not successfully replied to points #1 and #2 raised by Referee #2 in their review of the previous draft.

In addition, the authors' new approach to quantifying the range of variability in ΔIWC estimates means that all of the associated values (in the Abstract and Sections 7, 8, and 9) have changed, and given how many times the quoted numbers have been misstated before, it is difficult for me to have complete faith in them now. Moreover, in some case the values quoted in the response to referees do not match those in the corresponding line in the text, and it is difficult to judge which might be correct. I did a few spot checks on the numbers in the manuscript and found some mistakes (see specific comments below). Thus, I implore the authors to carefully check all of their arithmetic again before submitting a final manuscript for publication.

Finally, I hope that it is clear that I am working hard to be of assistance in improving this manuscript. I am not deliberately being difficult. I believe that this study represents a novel and clever application of MLS data in addressing an important issue. However, the lack of care demonstrated by the authors in writing and revising this manuscript is frustrating. In my opinion, publishing a paper with as many inaccuracies as remain in this draft – the second revision – would undermine their credibility in the community, cast doubt on all aspects of the analysis they have conducted, and ultimately weaken the impact of this work.

Specific comments (both major and minor comments are listed together for each Section):

Abstract:

(1) L6-7: ice injected (ΔIWC) up to the TL by combining ice water content (IWC) measured twice a day in local time in tropical UT and TL by --> ice injected (ΔIWC) up to the tropical UT and TL by combining ice water content (IWC) measured twice a day by
(2) L8: (Prec) measurement --> (Prec) measurements
(3) L12: resolutions --> resolution
(4) L14-21: These sentences are confusing and hard to read. I recommend re-writing as:

> Our study shows that the diurnal cycles of Prec and Flash are consistent with each other in timing and phase over land but different over offshore and coastal areas of the MariCont. The observational ΔIWC range between ΔIWC^{Prec} and ΔIWC^{Flash}, interpreted as the uncertainty of our model in estimating the amount of ice injected, is smaller over land (where the two estimates agree to within –6 to –22 %) than over ocean (where

relative differences are +6 to –71 %) in the UT and TL. The impact of the MLS vertical resolution on the estimation of ΔIWC is greater in the TL (differences between ΔIWC^{ERA5} and $\langle \Delta IWC^{ERA5} \rangle$ of 32 to 139%) than in the UT (difference of 9 to 33%). Considering all the methods, in the UT estimates of ΔIWC span 4.2 to 10.0 mg m^{-3} over land and 0.3 to 4.4 mg m^{-3}over sea, and in the TL estimates of ΔIWC span 0.5 to 3.7 mg m^{-3} over land and 0.1 to 0.7 mg m^{-3} over sea.

(5) In the above, are the values of 0.3 (min of the range in the UT over sea) and 3.7 (max of the range in the TL over land) correct? From Fig. 11, to me these values look more like 0.4 and 3.9, respectively.

(6) L21-23: First, the statement that ΔIWC is smaller than 4 mg m^{-3} over sea directly contradicts the previous sentence, where the top of the range over the sea in the UT is correctly stated to be 4.4 mg m^{-3}. Second, it is not clear that these numbers apply only to the UT, not the TL. I recommend instead using the wording in Section 7.3 (L480): "At both levels, ΔIWC estimated over land is more than twice that estimated over sea."

(7) L23: present the largest ΔIWC such as the Java Island (7.7 to 9.5 mg m^{-3} in the UT) --> present the largest ΔIWC (e.g., Java Island, with values of 7.7 to 9.5 mg m^{-3} in the UT)

Section 1:

(1) L43: "twice daily in local times" – I do not think that the addition of "in local times" here is helpful, so it should either be deleted or changed to "twice daily (at 01:30 and 13:30 local time)"

(2) L52: center in the tropics with --> centers in the tropics, with

Section 2.1:

(1) The authors have confused accuracy (systematic error) and precision (random noise). Precision is generally improved by averaging; accuracy is not. That is, the precision of an average of N profiles is 1/sqrt(N) times the precision of an individual profile. Since their analysis involves averaging in both space and time, the precision (measurement noise) of the MLS IWC data is of essentially no consequence for this study. But, contrary to what has been written here, such averaging does nothing to mitigate the 100% systematic uncertainty (accuracy) of the IWC measurements. Referee #2 asked what the implications of the large (100%) uncertainty in the MLS IWC data are for this analysis. The authors have failed to address this point correctly in their revised manuscript.

(2) This section was heavily edited in revision, but unfortunately the changes do not represent an improvement. The overall flow is poor, and the repetitiveness and seemingly random arrangement of sentences (with multiple instances of unrelated points being interposed between sentences that should have been connected) make it hard to follow. The wording is also incorrect in places (besides the accuracy issue), and some quoted values are wrong.

(3) To address the above comment (2), I recommend re-ordering / re-writing this paragraph as:

> The Microwave Limb Sounder (MLS) was launched on NASA's Earth Observing System Aura platform in 2004 (Waters et al., 2006). MLS follows a sun-synchronous near-polar orbit, obtaining daily global coverage. Ascending (northbound) portions of the orbit cross the equator at 13:30 local time (LT); descending portions of the orbit cross the equator at 01:30 LT. Among other products, MLS provides

measurements of ice water content (IWC^{MLS}, mg m^{-3}). Although optimal estimation is used to retrieve almost all other MLS products, a cloud-induced radiance technique is used to derive IWC^{MLS} (Wu et al., 2008, 2009). Here we use version 4.2 IWC data, filtered following the recommendations of the MLS team described by Livesey et al. (2018). We select IWC^{MLS} during all austral convective seasons DJF between 2004 and 2017. MLS data processing provides IWC^{MLS} at 6 levels in the UTLS (82, 100, 121, 146, 177 and 215 hPa). We have chosen to study only two levels: an upper and a lower level of the TTL. Because the level at 82 hPa does not provide enough significant measurements of IWC to achieve good signal-to noise, we have selected 100 hPa as the upper level of the TTL (named TL, for tropopause level) and 146 hPa as the lower level of the TTL (named UT, for upper troposphere). The resolution of IWC^{MLS} (horizontal along the path, horizontal perpendicular to the path, vertical) measured at 146 and 100 hPa is 300×7×4 km and 200×7×5 km, respectively. In our study, high horizontal resolution is now possible because we consider 13 years of MLS data, allowing the IWC^{MLS} measurements to be averaged in bins with 2°×2° (~230 km^2) horizontal resolution. Typical single-profile precisions are 0.08–0.18 mg m^{-3} at 146 hPa and 0.20–0.65 mg m^{-3} at 100 hPa, and the accuracy is 100% for values less than 10 mg m^{-3} at both levels. The valid IWC range is 0.1–50.0 mg m^{-3} at 146 hPa and 0.02–50.0 mg m^{-3} at 100 hPa (Livesey et al., 2018).

(4) Note that my suggested re-writing of this section does not address the concern about the accuracy of the MLS IWC measurements raised by Reviewer #2, which I leave to the authors to answer.

Section 2.2

(1) The organization of this section is also awkward, with a sentence about the Prec product not differentiating between stratiform and convective precipitation coming in between two sentences about horizontal resolution and binning, then a couple sentences about averaging in time, followed by a sentence pointing back to the spatial binning methodology. As I stated in previous reviews, the authors should arrange this description in a more logical manner that steps through all related points before moving on to other aspects.

(2) L115: averaged over a 1-hour interval --> averaged over 1-hour intervals

(3) I still think it will not be clear to all readers how this 1-hr resolution for Prec is achieved. As noted in my previous reviews, the authors are able to take advantage of the precessing orbit of the TRMM satellite and the long (13-yr) study period to bin the data into 1-hr bins. They have now included a sentence to this effect in the LIS description (L132-133), and I think it would be helpful to include something along those lines here as well.

(4) L117: is provided --> are provided

Section 2.3

(1) L119: aboard of --> aboard

(2) L121: pixel representing --> pixel, representing

(3) L123-125: Confusing aspects of the LIS description previously mentioned have not been rectified in the revised manuscript. It is stated that: “The instrument detects lightning with storm-scale resolution of 3-6 km (3 km at nadir, 6 km at limb) over a large region (550×550

km) of the Earth's surface. The LIS horizontal resolution is provided at 0.25°×0.25°." Are these two sentences consistent with one another?

(4) L131: consistent to … we are using --> consistent with … we use

(5) L133-134: "In our study, Flash measured by LIS is binned at 0.25°×0.25° horizontal resolution to be compared to Prec from TRMM-3B42." As stated in L125, 0.25°×0.25° is the LIS native resolution. I assume that 2°×2° is meant here.

Section 4.1

(1) L188: associated to --> associated with

(2) L193: instead of fixing "NewGuinea", it was deleted: (e.g. over) --> (e.g. over New Guinea)

Section 5.2

(1) Once again, the order of the panels in Fig. 7 is mischaracterized. This error had been fixed in the previous revision, but the figure has now been redrawn so it has reappeared in this draft. Consequently, references to Fig. 7 in L290, L307, L315, and L362 are all wrong, as is the figure caption.

(2) L297-299: I still find the wording in these sentences contradictory and confusing. "At the border between the land and the coast areas, a given 0.25°×0.25° pixel can contain information from both land and coastlines. In that case, we can easily discriminate between land and coastlines by applying the land/coastlines filters. Consequently, this particular pixel will be flagged both as land and coastlines." If in fact you could easily discriminate between land and coastlines, then you would not need to "double count" these pixels by placing them in both categories. Isn't it because they cannot be easily differentiated that they need to be flagged as being in both regimes?

(3) L304: Why does this sentence start with "Consequently"? That word does not seem appropriate to me here; perhaps "Nonetheless" might be better, or nothing.

Section 5.3

(1) L335: value --> values

(2) L346: of altitude --> altitude

(3) L348-349: air masses cooled in altitude are transported to the sea favoring the dissipating stage of the convection. Sulawesi is also a small island with high topography as Java --> air masses cooled at higher altitudes are transported to the sea, favoring the dissipating stage of the convection. Like Java, Sulawesi is a small island with high topography.

(4) L356: over tropical land --> over broad tropical land regions

(5) L367: instead of fixing the spelling of "Bismark Sea", it was deleted: NAusSea, Sea and WSumSea --> NAusSea, Bismarck Sea and WSumSea

(6) L373: over the Sea --> over the Bismarck Sea

Section 6

(1) L386-388: This wording is unclear and awkward. I suggest: "In assessing the consistency or lack thereof in the comparisons between ΔIWC^{ERA5} and both ΔIWC^{Prec} and ΔIWC^{Flash}, it should be kept in mind that IWC^{ERA5} data quality has not yet been fully evaluated."

(2) L390: New Guinea where --> New Guinea, where

(3) L410: impact on --> affect

Section 7.1

(1) Unless I missed it, nowhere in this section is it stated that the range between ΔIWC^{Prec} and ΔIWC^{Flash} is quantified as a means of characterizing the uncertainty in their model. Such a statement is made in the Abstract (L15-16), and I think it would be good to explicitly note it here (e.g., in L419, observational upper and lower bounds), as well as in the Conclusions.
(2) L424: (with $r^{Prec–Flash}$ ranges from - 6 to - 22% over the study zone) --> (with $r^{Prec–Flash}$ ranging from –6 to –22% over the study zones)
(3) L425: Of course, I did not check all of the arithmetic in this section, but I recommend that that the authors do so. According to Eqn. (4) and the values given in L423, for Java $r^{Prec–Flash} = 100 \times [(8.7–7.9) / 0.5*(8.7+7.9)] = 9.6\%$, not 7.1% as stated here.
(4) L426: To me it looks as though ΔIWC^{Flash} is greater than ΔIWC^{Prec} by more like 2.3 mg m^{-3} over the NAS, not 2.1 mg m^{-3} (the max difference stated here).
(5) L428: are --> is
(6) L431: UT with --> UT, with
(7) L433-434: What is the statement "Observational ΔIWC over Java island is larger by about 1.0 mg m^{-3} in the UT and about 0.3 mg m^{-3} in the TL than other land study zones" based on? Do these values represent averages of the ΔIWC^{Prec} and ΔIWC^{Flash} estimates for Java vs. averages of the ΔIWC^{Prec} and ΔIWC^{Flash} estimates for all of the other islands? Or are the authors just comparing the bottom end of the estimate range for Java with the top end of the range for all of the other islands? Certainly, the estimates for Java exceed those for some of the other islands (e.g., Sumatra) by much more than 1.0 mg m^{-3} in the UT. A similar question pertains to the value of 0.3 mg m^{-3} in the TL.
(8) L436: largest difference --> larger difference

Section 7.2

(1) L446: The ice injected from ERA5 at z_0 --> The ERA5 amount of ice injected at z_0
(2) L447: we can consider --> we consider
(3) L458: larger than ΔIWC^{ERA5} by less than 2.5 mg m^{-3} --> larger than ΔIWC^{ERA5} by as much as 2.5 mg m^{-3} over some islands
(4) L459: To me it seems that the difference between ΔIWC^{ERA5} and $\langle \Delta IWC^{ERA5} \rangle$ might be as large as 0.3 mg m^{-3} for the Java and North Australian Seas, not 0.2 as stated here.

Section 7.3:

(1) L465: range --> ranges
(2) L467: greater than the reanalysis by ~1.0–2.2 mg m^{-3}, showing a systematic larger estimate derived from observation than derived from reanalysis --> greater than that of the reanalysis by ~1.0–2.2 mg m^{-3}, with systematically larger estimates derived from observations than from the reanalysis
(3) L468-472: The description of the quantification of the "consistency" between the observational and reanalysis ΔIWC estimates remains confusing and poorly written. For one thing, it is presented in such a way that small values (0–25%) indicate that the two are consistent and large values (96%) indicate that they are inconsistent, which seems

counterintuitive. In addition, the wording "the difference between x minus y" is incorrect, and several other wording issues and grammar errors make these sentences hard to understand. I recommend re-writing L468-472 as:

> The consistency between observational and reanalysis ΔIWC ranges is calculated as the minimum value of the higher range minus the maximum value of the lower range divided by the mean of these two values. In the UT, observational and reanalysis ΔIWC estimates are found to be consistent over land, where the relative differences between their ranges are less than 25%, but inconsistent over sea, where differences are 62–96%. In the TL, the relative differences between the observational and reanalysis ΔIWC ranges are 0–49% over land and 0–28% over sea.

(4) L472-476: The description of r^{Total} is also quite unclear and badly written. Moreover, as originally defined, r^{Total} would always be a negative number, but the values quoted for it are not negative. I recommend re-writing as:

> In the following, we define the total range covering the observational and reanalysis ΔIWC estimates, r^{Total}, as the maximum value of the higher range minus the minimum value of the lower range divided by the mean of these two values. In the UT, the observational and reanalysis ΔIWC estimates span 4.2 to 10.0 mg m^{-3} (with r^{Total} values from 8 to 59%) over land and 0.3 to 4.4 mg m^{-3} (with r^{Total} values from 104 to 149%) over sea. In the TL, the observational and reanalysis ΔIWC estimates span 0.5 to 3.7 mg m^{-3} (with r^{Total} values from 85 to 127%) over land and 0.1 to 0.7 mg m^{-3} (with r^{Total} values of 142 to 160%) over sea.

(5) L476: Are the values of 0.3 mg m^{-3} for the bottom of the ΔIWC range over sea in the UT and 3.7 mg m^{-3} for the top of the ΔIWC range over land in the TL correct? To me, they look more like 0.4 and 3.9 mg m^{-3}, respectively (as also noted in connection with the abstract).

(6) L478-479: Amounts of ice injected deduced from observations and reanalysis are consistent to each other over land in the UT and over land and sea in the TL (to within 0 to 49%) but inconsistent over sea in the UT (up to 96%) --> Amounts of ice injected deduced from observations and reanalysis are consistent (i.e., the relative differences between their respective ranges are less than 49%) over land in the UT and over land and sea in the TL but inconsistent over sea in the UT (where differences are as large as 96%)

(7) L478-479: This is backwards! the impact of the vertical resolution on the estimation of ΔIWC is much larger in the UT than in the TL --> the impact of the vertical resolution on the estimation of ΔIWC is much larger in the TL than in the UT

(8) L481: The statement that "Java island presents the highest observational and reanalysis ΔIWC range in the UT (between 7.7 and 9.5 mg m^{-3} daily mean)" is misleading – at first I interpreted it to be saying that Java shows the largest *range* of observational and reanalysis ΔIWC estimates (which, according to Fig. 11, is not true: that would be New Guinea, with values from ~5.6 to 10.0 mg m^{-3}). I think the authors mean that the estimated ΔIWC *values* for Java are larger than for other islands, but that is the case only for the observational estimates, not ΔIWC^{ERA5}. Also, what is meant by "daily mean" here?

(9) L482-484: The statement "assuming that ERA5 IWC data have not yet been evaluated" makes no sense in this context. I suggest instead:

> Whatever the level considered, although Java has shown particularly high values in the observational ΔIWC range compared to other study zones, the reanalysis ΔIWC range

shows that Sulawesi and New Guinea may also reach high values of ΔIWC similar to those seen over Java. However, as the ERA5 IWC data have yet to be extensively validated, it is also possible that the reanalysis overestimates IWC in these regions.

Section 8.1

(1) L494: impacts on the diurnal cycle of Prec and on the IWC --> impacts the diurnal cycle of Prec and the IWC
(2) L495: delete "and" at the end of this line
(3) L498-499: cumulus merging processes which are processes more important --> cumulus merging processes, which are more important
(4) L501: IWC is increasing proportionally with Prec consistent --> IWC increases proportionally with Prec, consistent
(5) L502-503: add commas after "(2019)" and "(Fig. 3)"

Section 8.2

(1) L508: precipitations --> precipitation
(2) L515-516: the calculation of ΔIWC estimated from Prec is possibly overestimated because Prec include --> ΔIWC calculated from Prec is possibly overestimated because Prec includes

Section 8.3

(1) L522: ~71% --> ~–71%
(2) L523: large highlighting the difficulty to estimate --> large, highlighting the difficulty of estimating

Section 9

(1) L537: binned at a 1-hour diurnal cycle --> binned at 1-hour resolution over the diurnal cycle
(2) L538: selected among --> during
(3) L555-556: (a) I think that "disagree" or "deviate from one another" would be better than "depart". (b) "from" and "to" should be "by". (c) –6% over sea should be +6%. (d) If the sign of these relative differences is specified, then the fact that Prec is usually smaller needs to be made clear. (e) largest --> larger. Thus, taking these issues into account, I recommend that these lines be re-written as: "ΔIWC^{Prec} is typically smaller than ΔIWC^{Flash}, with the two estimates disagreeing by –6 to –22% over land and +6 to –71% over sea. The larger …"
(4) L561: inconsistent to within 96 % over sea in the UT. Thus, thanks to the combination --> inconsistent over sea in the UT, where relative differences are as large as 96%. Thus, considering the combination
(5) L563: 0.3 might be 0.4 and 3.7 might be 3.9, as mentioned earlier
(6) L564: found higher --> found to be greater
(7) L567-568: Java with … the Java Island --> Java, with … Java Island
(8) L568-569: See comment #6 in Section 7.1.
(9) L570: than the Java Island keeping in mind --> than Java Island, although it must be kept in mind