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Atmospheric Measurement Techniques Discussions

Interactive comment on "CLIMCAPS Observing Capability for Temperature, Moisture and Trace Gases from AIRS/AMSU and CrIS/ATMS" *by* Nadia Smith and Christopher D. Barnet

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We would like to thank the Reviewer for their generous review of our paper and their comments encouraging us to revisit, clarify and improve a few important sections.

Questions for the authors (all line numbers refer to the manuscript as originally posted):

1. Line 25. The statement from Smith, 2013, appears controversial if it implies we now have adequate data for earth systems analysis. Those of us who have proposed instruments since 2013 might dispute this. I suggest the authors either (a) add some context from the original paper (did they mean we have sufficient but inaccurate data,

or data sufficient for some purposes but not others?) or (b) comment on this statement from the perspective of 2020 and CLIMCAPS.

On re-reading Line 25, we see how our statement misleads. We meant to argue that the existence of high quality satellite measurements across decades from many instruments on multiple platforms does not in itself imply information consistency or the ability to support climate research. In our paper we argue for data processing methods that pay close attention to uncertainty characterization and rigorously account for variability in measurement information content over time and space. The Smith et al. (2013) paper we cite highlighted the challenges in oversimplifying the issue – merely applying the same retrieval method to hyperspectral infrared measurements from different instruments/platforms does not guarantee geophysical consistency. However, this does not mean that the nearly two decades of satellite sounder measurements lack value in climate studies. We argue here that we have a lot to learn yet about constructing long-term satellite sounder records and characterizing the information they can contribute to Earth system research.

The sentence now reads: "While the record of hyperspectral infrared measurements span nearly two decades, changes in technology and instrumentation pose a significant challenge to data continuity (Smith et al., 2013)."

2. Figure 1b. Is the CrIS-NPP noise for NSR or FSR, or does it matter?

The CrIS-NPP instrument noise we depict in Figure 1b is for NSR, while CrIS-NOAA-20 is for FSR. The difference between these two lines, illustrates the difference in instrument noise between the CrIS NSR and FSR. We added a clarification to the Figure caption and thank the Reviewer for highlighting this shortcoming. The difference between CrIS FSR and NSR is part of our argument here.

3. Line 167 and 507. Are any data assimilated by MERRA2 always from a previous orbit? Then data are never absent because of cloudy scenes in this orbit if they would not be considered anyway and the cloudy criterion seems superfluous.

The simple answer to the Reviewer's questions here is, No. Our statement was misleading and more descriptive of forecast models, such as the Global Forecast System (GFS), than of reanalysis models, such as MERRA2. We updated Section 2.1 (previously line 167) with the following text:

"MERRA2 assimilates a small subset of IR channels (i.e., by selecting channels that are primarily sensitive to T but largely insensitive to H2O, clouds and trace gases) only sometimes (i.e., for clear-sky scenes only) and weigh it based on the time of measurement within the reanalysis window and with an assumed representation error across all scenes. This gives us confidence to argue that the IR channels used in CLIMCAPS rarely duplicates the information content of the IR channels used in MERRA2 at a specific scene. Stated differently, the IR information content from AIRS or CrIS in CLIMCAPS is much higher than in MERRA2 because CLIMCAPS retrieves the atmospheric state along line of sight, from a greater selection of cloud cleared IR channels (i.e., all scenes except those with uniform cloud cover) and a full accounting of trace gas absorption. We contrast the CLIMCAPS a-priori approach with those systems that employ a regression first guess such as AIRS V6 (Susskind et al., 2014) that runs a non-linear regression using all IR channels to derive it's a-priori for T, H2O and O3. Unlike AIRS V6, CLIMCAPS does not use the full information content of the available IR channels twice to avoid an aliasing of its retrieval null space error and amplification of instrument uncertainty."

And in Section 3.1 (previously Line 507), we revised the discussion about MERRA2 as follows:

"MERRA2 does assimilate CrIS and AIRS IR radiance channels that are sensitive to temperature. We argue, however, that on a scene-by-scene basis it is highly improbable that CLIMCAPS uses IR measurements twice (first as assimilated information in MERRA2, second as measurement vector in OE retrievals) due to the strong spectral and spatial filters adopted in data assimilation systems. Even where a MERRA2 grid cell does contain IR information at a target CLIMCAPS footprint, we consider the im-

pact of the assimilated IR channels on the OE retrieval to be negligible. CLIMCAPS aggregates an array of 3 x 3 fields of view ($\sim$14 km) during cloud clearing (step 3 in Figure 2) and retrieves all subsequent variables from the cloud cleared radiance that represents the clear portion of partly cloudy atmospheres on a larger field of regard ($\sim$50 km). MERRA2, on the other hand, assimilates single field of view radiances for clear-sky atmospheres. MERRA2 assimilates measurements from many sources, so the contribution made by a single source at a target site is low, especially considering that each source is weighed according to a static, pre-determined representation error. CLIMCAPS, on the other hand, uses cloud cleared IR radiances as one of its primary sources of information that it weighs based on scene-specific information content analysis."

4. Line 171 and 498. Are these climatologies single valued profiles for all space and time, or do they have latitudinal dependence? Is a single CO2 profile used for all time, and does this make retrievals at one time favoured over another? It would be helpful to have a reference to the climatologies used.

We addressed this shortcoming by adding the following text to Section 2.1 (previously Line 171).

"For the trace gas species, we adopted the same approach in CLIMCAPS as that used in AIRS V6 for CO, CO2, HNO3, N2O and SO2 (AIRS Science Team/Joao Texeira, 2013). The CO climatology has no intra-annual variation but does vary seasonally and latitudinally, while the COÂň2 climatology is a static value across all latitudes but increases annually according to the linear fit developed by (Maddy, 2007). The climatologies for the remaining trace gas species, HNO3, N2O and SO2, are static over time and space. The CLIMCAPS climatology for CH4 is derived from a set of coefficients developed by (Xiong et al., 2008, 2013) that is also used in the NOAA-Unique Combined Atmospheric Processing System (NUCAPS)."

In Section 3.1 (previously Line 498) we added this: "All other gases – CO, CO2, CH4, N2O and HNO3 – use climatologies as discussed in Section 2.1"

5. Fig 2 caption. Likewise it would be helpful to have a reference to the Masuda model as there may be multiple versions thereof.

In CLIMCAPS we adopted the ocean emissivity model as implemented in AIRS V6 (AIRS Science Team/Joao Texeira, 2013) which the Masuda, et al., (1988) model as modified by Wu and Smith (1997). We added these references to the caption.

6. Line 199 and Table 1. The text implies that N2ÂňO and SO2 will be in the table and they are not.

Thanks for pointing this out. We added N2O and SO2 to the table for the sake of completion.

7. Line 410. This seems the key point of the continuity mission. The authors have been admirably frank (line 441) in discussing some minor shortcomings of the present version. How would this re-evaluation be done? What will you look at? In particular are there theoretical criteria which can be used? What would be a success criterion for a continuity product?

These are great questions that raise interesting and important issues. There is no simple answer and we think it would be insufficient to rely on the methods traditionally used in data validation with point-source comparisons. We are concerned here with evaluating continuity at much larger scales. The conundrum, of course, is that there is no 'truth' dataset at such scales and the only option being comparison with other datasets that have comparable limitations. This paper by (Gaudel et al., 2018) is a classic example of how data comparison can lead to a 'now what?' moment. What if no two sources agree?

The other challenging aspect is that satellite soundings are inverse measurements with dependence on prior knowledge about the atmospheric state. What if a sounding system uses a model specifically designed for continuity across the AIRS/CrIS era as

a-priori, strongly damps the measurement contribution during the OE retrieval step, thus reproducing the model, and call it a continuity record? Without access to the system's averaging kernels, the retrieval record will be misinterpreted and may even be compared against the very model it used as a-priori. With CLIMCAPS, we make a concerted effort to be transparent about the nature of its inverse measurements (retrievals) to encourage meaningful data comparisons especially across different instruments/platforms.

What would we consider a success criterion for a continuity product? Consistency in information content, and specifically the averaging kernels. The differences we observe in averaging kernels between CLIMCAPS-Aqua and CLIMCAPS-NOAA20 (Figure 5) give us pause. It tells us the two systems apply different weighting to the radiance measurements and thus vary in their dependence on the a-priori. With our next release, we would like to see consistency in vertical sensitivity between CLIMCAPS soundings from the different satellite platforms, not on a scene-by-scene basis, but systematically across latitude zones and seasons. This would tell us that we achieved consistency in observing capability across satellites, with continuity in their sensitivity to the true atmospheric state under similar types of conditions. So, in answering this question, averaging kernels would be our metric and consistency in their shape and magnitude under similar conditions across instruments would be our success criterion. Testing for continuity in retrieval accuracy would require different methods that, for now, falls outside the scope of our efforts.

We expanded on this issue in Section 3.1 (previously Line 410):

"In future, we will experiment with these threshold values to test if we can achieve consistency in averaging kernels across CLIMCAPS-Aqua, -NOAA20 and -SNPP. We are interested in addressing the question whether we can achieve continuity in information content despite instrument differences. The disparity in information content we currently observe between CLIMCAPS-Aqua and CLIMCAPS-NOAA20 (Figure 5) tell us that the two systems apply different weighting to the radiance measurements and thus vary in their dependence on the a-priori. This can introduce inconsistencies in the data record and hamper continuity. In using averaging kernels as metric, we can evaluate information content under similar conditions across CLIMCAPS-Aqua, -NOAA20 and -SNPP and thus test for continuity in their observing capability."

8. Figure 6(d). The low DOF for ozone over Canada is an interesting feature not discussed in the text. Is it due to low ozone values, low temperatures, stratospheric warming, or something else? A sentence about the physical state would demonstrate the utility of the DOF analysis.

This is an interesting feature, especially since none of the other variables have it. O3 DOF could be low over Canada for any of the reasons the Reviewer listed. Analyzing DOF features from specific variables is beyond the scope of this paper, but we added the following sentence to the discussion of Figure 6 to suggest that it is possible to analyze the physical state alongside the DOF to better understand observing capability:

"Where DOF patterns do have distinct features, such as the low O3 DOF feature over Canada (Figure 6d), we can understand them by evaluating the physical state to determine if it is due to conditions such as low O3 concentrations, low lapse rates or stratospheric warming. All retrieval variables and their uncertainty metrics are coincident in space and time in the CLIMCAPS product files."

9. Technical corrections:

We thank the reviewer for their careful read of our paper. We corrected all the mistakes they listed.

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