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Interactive comment

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 thank the Reviewer for their positive feedback and the interesting questions they raised. Our responses are below.

General questions:

1) Since the damping parameter change for each scene, the AKM also changes. Can it impact the vertical smoothing and therefore alter the effective altitude of the nominal layer in the retrieved profile? Assuming that over time the scene over a particular geographical location might change (i.e. due to climate impact) and it could lead to

changes in the altitude contribution to a particular layer in the retrieved profile. So, effectively the long term trends could be impacted by the change in the altitude where most of the information comes from?

This is a good summary of the challenge we face when constructing long-term records and why we caution against using satellite sounding records in trend analyses without careful consideration (Smith and Barnet, 2019). Retrieved soundings are underdetermined inverse measurements with dependence on prior knowledge about the atmospheric state. This is true not only for CLIMCAPS, but soundings in general. This dependence on the a-priori varies from scene to scene as the information content in the top of atmosphere radiance measurements vary. We can only retrieve as much information as is available in the instrument measurement of a given scene at a specific time.

The instruments we discuss in this paper were not designed for climate trend studies. They were designed for weather monitoring in (near) real-time. This means that the traditional approach to designing retrieval systems is instrument specific and focused on achieving instantaneous tropospheric accuracy. We now have almost two decades of hyperspectral infrared measurements; AIRS on the Aqua (launched 2002) is near the end of its impressive lifetime and we have the CrIS instrument first on SNPP followed by the JPSS series of satellites (one of which was launched in 2017) with planned availability into the 2040s. With CLIMCAPS, we are building a system to help us, as community, address whether these sounding measurements can add value as a long-term record and help us improve our knowledge of retrieval system design for climate science. Every diagnostic metric we used in this paper, together with the various error sources and quality control filters are available in CLIMCAPS product files distributed by NASA GES DISC (earthdata.nasa.gov). With this product now publicly available we wish to explore the questions the Reviewer raised here. We aim to characterize information content for different geographic regions and atmospheric processes so that we can investigate the quality of information available under different conditions. With a baseline now established (as communicated in this paper), we can advance our understanding of the value of these satellite measurements outside of weather forecasting.

2) If AK shapes are very different between instruments located at AIRS and JPSS, how are you proposing to combine records in the long-term time series?

With this paper we are presenting our first information content evaluation of the CLIMCAPS-Aqua (AIRS) and CLIMCAPS-NOAA20 (JPSS) systems. We did not expect their averaging kernels (AK) to show such marked differences. Can we optimize AKs to show similar shapes under similar conditions from different instruments? Are these differences due to our algorithm design or fundamental instrument differences? We will research these questions and adjust the algorithm where necessary/possible in CLIMCAPS Version 3 (due for launch in Summer 2021) so that we can achieve consistency and continuity in information content across decades to promote the usefulness of these products in climate studies. At the very least, such consistency should simplify the interpretation of observed changes over time.

This said, we designed the retrieved soundings from CLIMCAPS Version 2 (as presented in this paper) from Aqua (AIRS/AMSU) and JPSS (CrIS/ATMS) to be continuous as a time-series, irrespective of the shapes of their AK by ingesting MERRA2 as a-priori for temperature and water vapor. In optimal estimation inversion, the a-priori simply fills the null space (Identity matrix minus AK) and thus compensates for lack of information content in the measurements. MERRA2 is a well characterized, accurate representation of atmospheric change over two decades.

3) If uncertainties change over each scene, are these saved for each retrieval and provided for creating the gridded products?

Yes, these are all saved with the retrieved soundings in the product file. NASA GES DISC hosts a range of CLIMCAPS product and application guides that explain the available retrieval and uncertainty fields.

The Reviewer raised a critical issue here and that is the degree of consideration one should give to retrieval (Level 2) uncertainty when gridding them (Level 3). Traditionally, Level 3 methods simply average all retrievals that passed pre-defined quality control filters without consideration for scene-specific uncertainty. This is an area of research we think should get more attention so that we can improve the scientific value of gridded (Level 3) products and promote understanding when comparing against other gridded products (e.g, Smith et al. 2013).

Specific questions:

1) Lines 248-260 – does reduction in the vertical resolution of the retrieved profiles lead to the issues with the interpolation of profiles for the iterations in the forward model that has 100 layers? Was this error investigated?

No, because all forward model calculations in CLIMCAPS are performed on 100 layers. The CIMCAPS Jacobians are calculated with brute force perturbation of the a-priori profile, and these are done not as single-layer perturbations but multiple layers as defined by the trapezoid hinge points. The result is a Jacobian (K) matrix with reduced dimension along the state axis. This greatly speeds up the OE retrieval, which is an important consideration for global and decadal data (re)processing. It does introduce an additional factor of smoothing, which was thoroughly documented by (Maddy et al., 2009; Maddy and Barnet, 2008; Susskind et al., 2003). CLIMCAPS builds on the methods developed by the AIRS Science Team from the past three decades, so we did not deem it necessary to investigate the effect of this smoothing on the V2 retrievals. We could revisit it in future if it becomes relevant in a specific application.

2) Lines 454-508, Section 3.2 discusses the interpretation of the informational content of profiles from adjacent scenes. The MERRA-2 is used as a priori and sometimes the RT returns the a priori. Ozone, H2O, and temperature RTs are the only ones that use MERRA2 a priori that changes with time and space (other species are retrieved with static a priori climatology). How much could it impact on the derived ozone and H2O

trends?

MERRA2 will strongly impact trends in CLIMCAPS temperature, H2O and O3 retrievals since MERRA2 fills in the retrieval null space by design.

3) AK could be the same, but a priori could change with time...

Exactly. But this is true for all sounding systems, not just CLIMCAPS.

4) Have you assessed the trends in MERRA2 ozone a priori, particularly in the troposphere where ozone variability is limited to the differential column between assimilated stratospheric ozone from MLS and OMI total column? Is H2O a priori changing in the upper troposphere since 2002 and how it might be related to the tropopause variability?

We have periodic conversations with the MERRA2 team and are aware of the jumps in the record when MLS was introduced and we have had discussions for the plans when MLS data is no longer available. We argue that it is better to have a well characterized a-priori, even if it changes with time, than to have an a-priori that is not well characterized.

The first full record of CLIMCAPS-SNPP and -NOAA20 is now publicly available. The product files contain the CLIMCAPS retrieval, space-time-pressure interpolated MERRA2 a-priori for temperature, H2O and O3, together with the averaging kernels, uncertainty, error and quality control estimates at each retrieval scene. We, as community, can now address the questions the Reviewer posed.

5) Lines 517-528 – Discussion and Table 3 present a summary of the quality of retrieval results for one day. The Figure 10 shows four examples at different latitudes. A number of profiles that have high observing capability are significantly higher than for low sensitivity cases. For the profile to differ from a priori significantly or not depends on the a priori (as you mentioned). In the case of H2O the a priori is climatology and thus the retrieval wit high observing capability should have a larger departure from a priori. Can you please provide information if this result is common for any other day, and how

it changes by scene, location, or time? Also, it would be good to see a priori profiles and AKD for temperature retrievals matching the H_2O examples shown in Figure 10.

We are encouraged that our discussion in this paper generates these ideas for experiments worth investigating in future. We are cautious, however, to add more figures and expand the discussion in the paper too much beyond what we have for the sake of efficiency. We are eager to explore and demonstrate all the issues the Reviewer lists here in future work.

Just a side note: the CLIMCAPS a-priori for H_2O is MERRA2, not a climatology.

6) Lines 575-577 – Figures 11 and 12 show daytime and nighttime retrievals, but not over the same geographical area. Why not? IT would be of interest for the reader to learn about differences between daytime and night time observational sensitivities. Many air quality studies rely on the contrast in ozone and WV levels between nighttime and daytime.

Our goal in this paper was to introduce CLIMCAPS V2 (the first public release) and additionally illustrate how its retrievals can be diagnosed using the available information content and uncertainty metrics. It will be very interesting to evaluate diurnal effects using the technique presented in Figures 11 and 12, and we will explore this in future work.

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