

We would like to thank the reviewer for the time spent on the review, prior and during the discussion phase.

Our answers appear in blue below.

Anonymous Referee #1

« A review of sources of systematic errors and uncertainties in observations and simulations at 183 GHz » by Brogniez and co authors.

General comments

This paper nicely reviews the current understanding of an important issue in atmospheric science, namely substantial unexplained discrepancies between spectral observations of the atmospheric water vapor line at 183GHz and predictions of those observations based on independent measures of atmospheric water vapor (and other properties) and established radiative transfer models (driven by laboratory measured and, in some cases, field-validated spectroscopy information).

I am happy to recommend this paper for publication in AMT, though have some suggestions as to how to improve the clarity of these discussions in places. Most of these are detailed in the more specific comments below.

My only major comment is that I feel more discussion could be made of the potential sources of calibration error in the spaceborne instruments. Section 2.4 mainly focuses on field of view and channel shape calibration and gives little discussion of the important role of spectrally-varying radiometric calibration, a potentially important source that instrument teams should be alerted to.

Put briefly, all instruments have a non-linear Brightness Temperature (BT) to counts calibration curve. Naturally, instrument designs are optimized to keep as close as possible to the linear regime (with the the counts vs. BT curve only flattening out at far larger BTs than are expected to be observed). However, the degree of system non-linearity, however small, is dependent on the total brightness temperature seen across the entire receiver pass band, not that in individual channels. In other words, the calibration of an individual channel is dependent on the total signal seen across all channels (and, indeed, in regions in the receiver passband not covered by any measurement channels). It turns out that the approach taken in nearly all microwave instruments of calibrating against spectrally flat hot and cold targets completely masks this effect. In cases (such as the one discussed here) where a strong spectral line is being observed, the spectral shape distortion introduced by the gain compression effect can be a few K, far larger than the non-linearity that would be seen when looking at a spectrally flat black body target (typically 0.1 K or smaller) that is the simplistic test usually undertaken in pre-launch calibration.

While it is beyond the scope of this paper to discuss this issue in detail, I suggest that the authors mention this factor in section 2.3.

In our opinion, even for a strong spectral line such as the 183 GHz water vapor line, we are likely dealing with only a few tenths of a Kelvin across the passband for Earth viewing sensors. The receivers are generally designed to operate well below the beginning of saturation. Further, the dynamic range of the radiometric signal (coldest to hottest scene) is generally less than 3 dB (a factor of two) because the receiver internal noise (especially at 183 GHz) is probably larger than the noise power than comes from the antenna. The major non-linearity (saturation) generally comes from the non-square law characteristic of the diode detector. Because of the small dynamic range of the BT at 183 GHz (a few tenths of K) this would not be a large factor (i.e. 2-5% of the dynamic range).

We added the following brief comment in section 2.4 (instead of 2.3 as suggested by the Referee), which is dedicated to the calibration.

“Finally, the receiver non-linearity (i.e. the BT-to-count calibration curve) has been considered to affect the BT with only a few tenths of a Kelvin across the passband (observed for GMI, D. Draper, Ball Aerospace, pers. comm.)”

In addition, I urge the nadir microwave community to investigate this source of calibration error in more details. Including such a recommendation in section 3 would strengthen the paper.

As answered above, we believe that this source of calibration would contribute only to a small part of the overall biases that we observed. However, we admit that there is not one single source of bias error, which yielded us to add a recommendation.

The recommendation part on the space-borne sounders, in section 3 now reads:

“The possible contribution of biases that could originate from the radiometric calibration and the gain-compression non-linearities, although recognized to be small with respect to the amplitude of the differences, needs to be fully assessed to close the error budget due to calibration.”

In a few places the discussion in the manuscript is a bit garbled and unclear (at least to me). I encourage the authors (including the co-authors) to take the time to ensure that the wording is as clear as possible to the unfamiliar reader to themselves. This is not an issue of English (the standard of which is excellent in this paper), rather one of unclear phraseology. I detail these cases below.

In addition to the specific corrections detailed below, we performed a careful correction of the English grammar and expressions.

Specific comments

Page 2

Line 32: "quantification of" -> "quantifies"; also "separation of" -> "separates".

Corrected

Line 35: "... from their procedures of calibration" -> "from their calibration procedures".

Corrected

Line 43: "in the" -> "using the".

Corrected

Also, you use the term "183.31 GHz" a lot, sometime to refer to the specific line, which is fine. However, you sometimes say "183.31 GHz channels" when you actually mean channels as much as 4 GHz or more away from 183.31 GHz. Might there be some way to make that clearer? Quoting 5 significant figures seems inappropriate for those cases. How about "channels in the 183 GHz region"? I'll highlight some of these cases later.

We agree and corrected when appropriate.

Line 43/44: "on Megha-Tropiques" -> "on the Megha-Tropiques spacecraft"?

Because all the platforms that are mentioned in the paper are spacecraft, adding this term after “Megha-Tropiques” would logically call for the same addition to all the other platforms (MetOp, Suomi-NPP, ...). However, because this list is heavy to read, we now refer to the table 1 that we modified to add the expansion of the acronyms. An appendix listing all the acronyms has also been added.

The lines 42/46 now reads:

“Recent cross-comparisons between the existing nadir satellite microwave sounders of the tropospheric humidity using the 183.31GHz line, SAPHIR, ATMS, SSMI/S and MHS (instrument details are provided on table 1), show very good agreement (...)”

Line 47: "in a 0.3-0.7K" -> "with a 0.3-0.7K".

Corrected

Lines 48 to 57: Given that you quantify the inter-instrument agreement (line 47), it's better to also quantify in words in the text the biases discussed here that are, after all, the subject of this paper.

We are not sure that we properly understand this comment.

We believe that this refers to absolute biases with respect to the inter-instruments biases that are we discuss. If so, then we can answer: we use the inter-instrument biases as a proxy for the order of magnitude of the absolute biases. As seen in Figure 1, the absolute biases have a spectral-dependence that is not really obvious in the inter-instrument comparisons. This part of the paper discusses the consistency between the various sensors and highlights their strong agreement, within the radiometric sensitivity.

Line 55: Where in the "line wings"? How many GHz away?

The distance from the line center is provided on Figure 1 and on Table 1. The farther channel is located at 11GHz from the line center.

We have added a comment "up to 11GHz from the line center" on line 56.

Line 62: "It" -> "This"; also "which" -> "that"

Corrected

Line 69/70: This sentence is garbled. How about: "Knowledge of absolute errors is important for climate applications such as reanalysis, where the need to detect small changes in the mean state is paramount."

We modified this sentence as suggested.

Line 70: "knowing about" -> "knowledge of"

That was already written this way...

Line 91: "ones" -> "contributions"

Corrected

Page 6

Paragraph from 165 to 177: This discussion might be better placed in section 3 rather than here. This paragraph talks about instrument/model biases in IR that mirror those in the microwave discussed in the paper as a whole. Accordingly, having it in a section called "Radiative transfer modeling and spectroscopy" doesn't feel right to me.

We do not totally agree with the Referee on this point: the parallel with the biases found in the IR is not a recommendation, but rather a statement that needs to be written in this part. Therefore we have decided to keep the IR discussion in this place, rather than in the section 3, dedicated to a recommended list of actions and steps.

Page 7

Line 199: The use of the word "lower" in combination with "confidence" can be confusing (is more better or worse? The same is the case for "resolution", "precision" and "accuracy"). You are saying "confidence limits" which does help, but I wonder if changing "are lower to "have lower values" (or "have smaller values"?) might be even clearer?

We agree with the referee: the sentence might be confusing, and the word "confidence" is misleading. We have modified the text and it now reads:

“(…) the accuracy of these parameters are higher than the above numbers.”

Line 207-214: This discussion is very hard to follow, see some specifics for individual lines below. However, I would urge the authors to work together to make this discussion as clear as possible.

Line 209: ", insensitive to vertical" -> ", and thus insensitive to the vertical"

Corrected as suggested

Line 210: "would provide" confuses the message. Is it "can provide"? If so, does it? Why not simply say "provides"? Perhaps because it doesn't actually agree? How about "can quantify agreement with..."?

We understand this comment and now use “provides” instead of “would provide”.

Lines 212-214: This sentences is still very unclear to me. The sentence implies two things are being compared, but then uses the phrase "together with" which implies we're still discussing the first one.

We believe that the length of the sentence and its amount of details induces the lack of clarity underlined by the referee. We have simplified it and it now reads:

“There is thus an inconsistency between two large sets of experimental data, namely laboratory (together with surface path measurements) and radiometric measurements.”

Page 8

Line 219: Comma needed after "Finally"

Added

Line 225: Specific example of where quoting 5 significant figures on the frequency is inappropriate.

Simplified

Line 246: "while they naturally" -> "even though they". Again, 183.31 GHz too precisely quoted.

Corrected

Line 250: add "the" between "specifying" and "shape"

Corrected

Page 9

Line 252-255: Again, I don't really follow the logic here. When talking about the "model cloud and precipitation fields" do you mean things like particle shape/size etc. discussed on the previous page, or do you mean (or also mean?) the cloud amount? If you mean all of the above, then a first guess departure would indicate some problem with the first guess itself would it not. Forgive me if I'm missing some obvious point here.

This is indeed a sound comment: this part was lacking logic. So we re-shaped it and dropped the part mentioning the first-guess departure. Indeed it added more confusion than clarification.

This part now reads:

“An issue that affects most comparisons between 183GHz observations and model simulations is cloud detection. Indeed clouds and precipitation are not usually included in MW radiative transfer simulations for NWP. The main reason is the difficulty in specifying the shape, density and particle size distribution of solid precipitation particles [Burns et al., 1997; Doherty et al., 2007; Geer and Baordo, 2014]. Clouds and precipitation tend to reduce the 183GHz BTs, particularly in the lower-peaking channels, either by scattering or by absorption, which shifts upwards the altitude of the weighting function. In situations where the cloud detection is failing to identify and therefore omits some cloud-affected scenes, the observed BTs would be lower than the simulated ones (see for

instance the negative bias in the Inter-Tropical Convergence Zone in Figure 2).”

Line 253: Perhaps insert "(observed minus predicted)" after "departure" just to be clear.

Added

Line 253: "selection" -> "selected"?

Corrected

Line 254: "missing" -> "failing to identify and omit"?

Corrected

Line 260: comma needed after "exist"

Added

Line 261: "and rely" -> "relying"

Corrected

Line 269: by "the biases" you mean the ones using the non-cloud-aware RT model, yes? Please clarify either way.

The Referee is correct: we compare all-sky and clear-sky frameworks.

We chose to replace the term “biases” by “signals due to clouds” in order to clearly stipulate that we are taking about the cloud effect rather than the overall biases that the paper is all about.

Page 10

No specific issues with anything on this page, but I’ll just restate my request for some more discussion of radiometric calibration and gain compression non-linearities.

Page 11

Line 331: Please clarify what is meant by "measurements" here. Is it the ATTOMS measurements or the ATMS etc. measurements? If ATTOMS is it an ATOMMS measurement of something other than opacity then? Again, I’m finding this discussion somewhat unclear.

This part (lines 328-339) only discusses the ATOMMS measurements versus a radiometric model.

Page 12

Lines 347-357: Again, a recommendation to further consider gain compression would be valuable.

We added a sentence on this, as answered for a previous comment:

“The possible contribution of biases that could originate from the radiometric calibration and the gain-compression non-linearities, although recognized to be small with respect to the amplitude of the differences, needs to be fully assessed to close the error budget due to calibration.”

Page 22

Line 582: Period needed after "legend" and start a new sentence with "The horizontal..."

Corrected

Page 23

Line 595: "captions" -> "legend"

Corrected

Page 24

What are the meanings of the different symbols? Either describe them in the caption (or a legend), or make them all the same.

The symbols refer to the different field and laboratory data that have been gathered. The legend now associates the symbols with its reference(s).

Line 603: "... less than the size of the points".

Corrected

Line 604: "for" -> "using the"?

We corrected to "for the" instead of the suggested "using the", because the coefficients are those used for the MPM model.