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Interactive comment on "Performance of the line-by-line radiative transfer model (LBLRTM) for temperature and species retrievals: IASI case studies from JAIVEx" by M. W. Shephard et al.

Anonymous Referee #1

General comments:
This paper presents an evaluation of the limits of the Line-By-Line Radiative Transfer Model (LBLRTM) developed by part of the co-authors. This is performed by an intercomparison of the spectral upward radiance measured with the Infrared Atmospheric Sounding Instrument (IASI) and the results of the LBLRTM forward calculations based upon an atmospheric state derived from other atmospheric soundings (aircraft, lidar) performed correlative to IASI. In so doing, significant residuals of the LBLRTM in various spectral regions are found which originate from different error sources. The high quality radiometric calibration of the IASI instrument allows the analysis and determination of these sources, which is done here for different species (CO2, H2O, CH4, and others) and spectral regions. The authors conclude, that the uncertainties in the spectroscopic parameters (line widths, pressure shifts and line coupling) are dominating the errors from the LBLRTM while the measurement errors of the IASI instrument are comparatively small. However, the observed residuals are also impacted by i) errors in correlative measurements of the atmospheric state as an input for LBLRTM, and ii) the spatiotemporal mismatch between IASI and the correlative measurements. This is stated by the authors but the scientific discussion/quantification of these effects is somewhat weak.

Overall the paper gives a good overview of the actual LBLRTM performance. While it is somewhat weak in turning out original scientific results, it highlights possibilities for improvements. Therefore, I recommend publication after revision.

Specific comments:

- The introduction is too long. Some of the species-specific explanations should be moved to the relevant subsections.

We agree. We moved significant sections of the introduction into other sections that we more appropriate. For example, the detailed comparison issue discussion was moved under Section 4 (Model/measurement comparisons: radiance closure) in its own section. The introduction has been reduced by almost half of its previous length.

- Introduction, page 9316: The fact, that airborne in-situ or remote sensing profiling does not sample the atmosphere in the same way as a satellite instrument, is pointed out. However, a quantification (or, at least a rough estimation) of this effect is missing. Currently, the spatiotemporal mismatch always appears as a daemon in the paper, when needed, but escapes from a well-founded quantification, which plays a key role here. This issue should be discussed in a quantitative way in an own section, which should be added.

The Reviewer brings up an excellent point. Quantifying the sampling/variability effect is very desirable, however, this very complex and challenging. We have thought about it in great detail and provide some insight below.

In the paper we quantified spectrally the interpixel variability of the four IASI pixels used for each retrieval in Figures 3(b) and 4(b). This provides a measure of the interpixel variability in terms of brightness temperature across the 4 IASI pixels, but does not account for any sub-pixel variability. Comparing the magnitude of the interpixel variability with the overall residuals (for example in the H2O spectral region) we see a direct positive relationship between the increased variability and increased residuals.

To provide some quantitative values on short-term temporal and spatial variability in terms of geophysical parameters such as the temperatures and water vapor profiles, we quote recent numbers by Tobin et al., 2006. Tobin et al., 2006 performed sonde-to-sonde comparisons of radiosondes launched from the same ARM SGP location one hour apart. This study showed that for nighttime launches the short-term temporal sonde-to-sonde variability at the SGP site had a standard deviation of ~0.5–1K for 1-km averaged thick layers. These same comparisons for water vapor show relative percent standard deviation variability reaching ~25% for 2 km thick layers. In terms of spatial variability, Tobin et al., 2006 also shows the spatial variability of near surface temperature over a 2 deg x 2 deg area based on GOES 4-km product over the ARM-SGP site. The plot shows 5 degree range in temperatures with sharp gradients in the temperature field.

Another point that complicates providing a qualitative value on the variability error is that the retrievals will reduce the impact of match-up. The degree to which the retrieval mitigates these errors depends on the non-linearity of the retrieval inputs, the more non-linear the less effective the retrieval will be at reducing the errors as it assumes linearity.

To provide the reader with a little more insight we added the following text to the paper.

When describing the potential match-up variability we stated:

"For example, Tobin et al., (2006) showed the short term temporal variability by performing sonde-to-sonde comparisons of radiosondes launched from the same ARM SGP location one hour apart. Their results showed nighttime standard deviations in the temperature profile of 0.5- 1K (1km averaged layers), and variability in the water vapor profile reaching 25% (for 2-km thick layers). This same study provides insight into potential spatial variability of "near surface" atmospheric temperatures and water vapor by showing 4-km GOES products over the SGP site.

Just below this we also added:

"It is often the case that a retrieval step is needed in the radiance closure so that the importance of external data sources in the comparison (such as radiosonde measurements) is significantly reduced, allowing greater freedom from sampling issues. The degree to which the retrieval mitigates the sampling issue depends on the non-linearity (which is a function of the variability) of the retrieval inputs)."

In the results and discussion section we mention:

"It can be seen from Figure 3(b) and Figure 4(b) that there are significant variations in the atmospheric water vapor (1200 to 2000 cm^{-1}), even over the relatively small geographical area covered by the four instrument FOVs. The variation in water vapor for the ocean case is greater than for the land case. It is difficult to quantify impact of the variability based on just these two comparisons, however, comparing the magnitude of the interpixel variability in Figures 3 (b) and Figure 4(b) with the overall residuals (for example in the H2O spectral region) in Figures 3 (d) and Figures 4 (d) we see a positive relationship between the increased variability and increased residuals."

- Introduction, page 9316, line 13: "While such in-situ ..." add "and remote sensing ..."

Added to manuscript as suggested.

Page 9317, line 6: wording does not fit into a scientific paper: "Such issues raise the question, "What is truth?""

Change the sentence:

"Such issues raise the question of 'What is truth?'"

to

"Such issues raise the question of how to define truth sources that can be use to evaluate both forward models and observations utilized in retrievals and data assimilations."

Page 9318, lines 8 – 22: the message of this lengthy passage can and should be said in one sentence.

This is an important message that cannot be put into on sentence, but we agree that it can be reduced. We took out the following four lines referring to AIRS, " "For example, the AIRS team has adopted this approach. In their description of the AIRS operational radiative transfer algorithm (RTA), Strow et al. [2006] state that "some empirical adjustments to the RTA channel-averaged absorption coefficients were required to achieve the stated accuracies"."

We also removed the line ". An example of when this might be an issue is provided later in this study when evaluating potential improvements from new spectroscopic line parameters for water vapor." and merged a few sentences.

- Splitting different species / spectral regions into different sections, in principle, is a good idea, but a synthesis of the basic results and the effects of the different error sources is missing. Also, reading the Summary it becomes not clear what the essential results are. This might be an inherent problem in the type of this study being an "Evaluation" rather than an active improvement of LBLRTM. As a remedy we repeat the recommendation of our ACPD access review to add a Table similar to Table 1 (or extend Table 1) where the wave number intervals of all identified model errors are listed together with a statement on the type/possible reason/recommended remedy.

We will add a table as suggesting by the Reviewer.

- Section "Water vapor": This section is far too long for the relatively weak conclusion, that the "remaining residual features are associated mainly with the atmospheric variability of water vapor and with uncertainties in the line widths, pressure shifts and line coupling."

The water vapor analysis contains one of the most important results in the paper. Showing that the upper tropospheric water vapor is 10 % high when using the standard HITRAN line parameters is a very significant result! There has been a lot of research trying to quantify the upper tropospheric water vapor for weather forecasting and climate (radiosondes themselves are not very accurate in the mid-to-upper troposphere). It appears that we did not highlight this result enough in the paper. After the line "Changing the line strengths has a significant impact on the retrieved water vapor, particularly in the upper troposphere where the differences reach ~10%." in the conclusions we added "This is a very important result, especially in terms of assimilating infrared satellite observations (e.g. AIRS, TES, IASI) in numerical weather prediction and global circulation models."

- Page 9330, lines 24 - 26: For meteorological reasons I would expect a lower water vapor variability in the ocean case compared to the land case. Explain why the opposite

should be true.

We would agree that in general one might expect lower water vapor variability of the ocean. However, water vapor can be very variable. Figure 2 provides some insight on the subject as one can see that even through the region we pick is cloud-free (marked by the 1,2,3,4 box) there is a lot of atmospheric variability in terms of clouds etc. Therefore, the observations over the ocean during this IASI validation campaign are not the more typical mundane conditions.

- Section "Carbon dioxide", first paragraph: Lengthy unclear wording about mathematical issues: add appropriate mathematical formulae and shorten wording.

This is an excellent point. When writing the paper we debated how much, or if any, details about the CO2 formulation were needed in this paper. For this evaluation type paper the decision was made that we should only provide the reader with a qualitative description, as the more quantitative details significantly increased this section and would be better provided one-on-one to the users of LBLRTM that would specifically need this information.

- Page 9325, line 3-6: What is the significance of this statement? Because of the very homogeneous distribution of CO2 I would not expect this. Please quantify your statement.

It this statement we are not referring to the CO2 profile, rather we are referring to the CO2 residuals caused by the radiosonde temperature profile. The authors were making the assumption that the reader assumed that the CO2 was homogeneous and that the CO2 residuals are due to the radiosonde temperature errors. The sentences referred to by the Reviewer are, "The residuals from the initial radiosonde temperature and humidity profiles (plus US Standard atmosphere trace gas profiles) are shown in Figs. 3c and 4c. It is clear from the magnitude of these residuals in the carbon dioxide and water vapor regions that the radiosonde profiles do not sample exactly the same atmosphere and surface state measured by the IASI FOVs."

Since this was not evident to the Reviewer, it also might not be evident to other readers so we made it more explicit to the reader in to ways:

(i) We modified the sentence:
From : "It is clear from the magnitude of these residuals in the carbon dioxide and water vapor regions that the radiosonde profiles do not sample exactly the same atmosphere and surface state measured by the IASI FOVs."

To: It is clear from the magnitude of these residuals in the carbon dioxide and water vapor regions that the radiosonde temperature and water vapor profiles do not sample exactly the same atmosphere and surface state measured by the IASI FOVs."

(ii) We added in the retrieval description (above this section) the following: "Note the spectral regions used for the temperature retrievals include spectral regions in the CO_2 ν_2 that profile the troposphere and CO_2 ν_3 region that senses the stratosphere; the Q-branch at 667 cm^{-1} was excluded as the modeling for this region is under investigation (see following discussion)."

- References: The reference list is still far too long. Reduce to key papers in the respective field.

This is a little tough as Reviewer 1 wants us to add more references (especially European ones) and here Reviewer 2 wants us to reduce the references.

Technical remarks:
- Some references do not show up in the reference list, e.g. P9331 Tobin et al. 2006a and Tobin 2006b. Only one Tobin reference shows up in the reference list. Please check for other errors like this.

Corrected.

- Page 9317, line 17: error in hyphenation

We agree. This is in the ACPD PDF, but not in our supplied Word document so this will need to be changed by ACPD editors. We will look for it in the final proofs.

- Page 9327, lines 1-3: verb is missing in the first part of the sentence.

We agree and changed the sentence from:

"Since the inclusion of Pand
R-branch line coupling coefficients in the line parameter database, the chi factor in LBLRTM has been set to unity."

To:

"Since the P and R-branch line coupling coefficients are now included in the line parameter database, the chi factor in LBLRTM has been set to unity"

- Page 9329, line 6 and page 9330, line5: "v3"

Changed "ν_3" to "ν_3"

- Page 9355, Fig. 9: legend / explanation missing

The legend is in the middle of the plot. With solid line being the retrieval and the dotted line being the a priori profile. We are assuming that the Reviewer just missed the legend, and that since it is similar to Figures 5-8 that it is fine.

- Page 9356, Fig. 10: legend / explanation missing

See comment above.

- Page 9362, Fig. 16: legend / explanation missing

We agree. We added to the caption: "The dotted line is the difference from the radiosonde using the HITRAN2004 water vapor line parameters in the retrieval, and the solid line is the difference from the radiosonde profile using Coudert water vapor lines in the retrieval (note the ~10% difference in the upper troposphere)."