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Atmospheric Measurement Techniques
Discussions

Interactive comment on "All-sky assimilation of infrared radiances sensitive to mid- and upper-tropospheric moisture and cloud" *by* Alan J. Geer et al.

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Many thanks to the reviewers for their recommendations, and for their constructive and helpful comments. Our responses are interleaved below, with the reviewers comments in italics and our own in normal font.

Anonymous Referee #3

General Comments: The study is very successful to address how the findings relate to previous research in all-sky satellite radiance data assimilation. The authors write the

introduction part very well with the clearly summarization of all relevant work in both research and operational area. The authors also make corresponding explanations and evaluations for the previous work, and tell readers how all-sky radiance data assimilation developed step by step in theory and technique. The language is clear and makes easy to follow. The technical details are sufficient to ensure that readers understand exactly what the researchers studied. Not only the results are clear and have enough experiments to support the conclusion, but also the data selection and quality control have more than enough experiments to explain why the choice made. These details are very valuable for the future researcher to borrow. The very encouraging result of this paper is that it addresses the assimilation of IASI 7 WV channels all-sky radiance achieved a small improvement over clear-sky assimilation in the tropics. All these progress comes from the improved cloud ice optical properties and the ability of increase supercomputing resource to use the full multiple independent column cloud overlap. This is a small but important step towards to assimilate all-sky IR radiance in NWP operational. This manuscript does an excellent job demonstrating significant improvement about assimilation of all-sky IR radiance research in ECMWF. I strongly recommend this paper to be published.

Anonymous Referee #4

This manuscript addresses one of the most highly assessed approaches in field of radiance data assimilation today. It describes in very good details the application and the impact of All-sky approach in data assimilation and on short and medium ranges forecasts. Although the use of infrared data is the focus of this paper, one could get a full overview about the use and performance of the microwave radiances as well. I found this paper very interesting with a lot of details about almost all issues related to clear- and all-sky radiances assimilation. So, I have only few comments, which I believe can further improve the quality of it.

1- Maybe it's not requirement for this journal, but normally the Introduction ends with short description about the structure of the manuscript, which I missed here.

A similar comment was made by reviewer #5 as well. The following outline of the paper will be added to the end of the introduction:

"Section 2 describes how IASI observations are assimilated in clear-sky and all-sky approaches, with attention to the observation operator, observation error and data screening aspects. Section 3 establishes the model's ability to generate cloud fields and to simulate radiances that are consistent with those observed. Section 4 evaluates the results from data assimilation experiments contrasting clear-sky and all-sky assimilation. Section 5 concludes."

2- There are few abbreviations that are not described in the text like for example PDF, ITCZ, TB . . . I think these need to be described either at first use or in a separate part of this paper.

Thanks, we will now spell them out explicitly on first use.

3- You discuss the Figure 5 in page 16 and say that "The simulated brightness temperatures in these five systems are generally warmer than observed, but this is not a general feature of the model." I couldn't identify (well, I can guess, of course) those systems, please highlight these system with circles, arrow or any pointing technique to make it better understood.

We appreciate that these convection systems, and the agreement with the model, may not be totally obvious. Rather than changing the figure we would hope to address the issue with a more detailed discussion around Figure 5. The text now looks like this:

"The coldest brightness temperatures in Fig. 5a and b (200 K and below in the tropics, and down to around 230 K in midlatitudes) tend to indicate high cloud. Taking a synoptic to mesoscale viewpoint, cloud patterns are generally well represented in the background when compared to the real observations. This is true even in the ITCZ,

where low observed brightness temperatures (TBs) of around 200 K indicate convection embedded in the broader high-humidity ITCZ region which has TBs of around 260 K. Around 5 - 10°N between South America and Africa there is a string of around 5 areas of low TB that suggest organised convection (Fig. 5a). The model (Fig. 5b) creates a string of similar features but with TBs closer to 230 K, and with no agreement at the finest scales, but reasonable agreement on the broader location of the convection. The simulated brightness temperatures in these five systems are generally warmer than observed, but this is not a general feature of the model."

Anonymous Referee #5

The paper entitled All-sky assimilation of infrared radiances sensitive to mid- and upper-tropospheric moisture and cloud by A. Geer, S. Migliorini and M. Matricardi is a very interesting study dealing with the problem of the all-sky assimilation in the infrared spectrum. This topic is now widely studied, but no operational application is now available. The aim of this paper is to show that all sky infrared assimilation is at least as valuable as clear-sky assimilation in the ECMWF system and could be considered for operational implementation. In order to get a clearer signal from the all- sky assimilation, the chosen approach is to focus on the assimilation of 7 water vapor IASI channels either in the clear-sky stream or the all-sky stream.

The authors first expose the all-sky assimilation with the description of the observation operator, the observation errors described in another paper (Geer, 2018), data selection. The quality of simulated all-sky brightness temperatures is then assessed before presenting the results of data assimilation experiments. This all-sky assimilation is first evaluated with the full observing system and then in the absence of the other observations to increase the impact of the assimilated observations. Finally the weight of the observations due to the use of the variational quality control is discussed. The methodology used in this paper is clear and logical. The authors provide many details *and address a lot of issues while making the comparison throughout the paper with microwave all-sky assimilation. This paper should be published with minor revisions.*

General comments: I am a bit confused with the assimilation of IASI channels. If it is clear that the test of all-sky assimilation is applied only over the 7 water vapour channels, it is unclear to me if temperature and ozone channels are assimilated in the experiments. However, if I understood well subsection 2.2, temperature and ozone channels are assimilated in clear-sky conditions in the 3 experiments. I think it is important to add this information in Table 3, if it is the case, especially for the No WV7 experiment.

Thanks for highlighting this ambiguity in our presentation. In Table 3 we will add to the description of the No WV7 experiment that it is still assimilating all other IASI channels (e.g. temperature and ozone) in clear-sky conditions. A similar message will be added to the text of Section 4.1 with a link back to section 2.2, which describes the used IASI channels in more detail.

Always related to this issue, what is the impact of the clear-sky and the all-sky assimilation of the 7 WV channels on the assimilation of the other T and O3 IASI channels? Is the number of assimilated T, O3 radiances modified by both clear-sky and all-sky water vapor assimilations?

Good question. Figure 1 (similar to Fig. 14 in the paper) shows the standard deviation of FG departures for the other IASI channels. Please note that the automatic "possibly invalid" warning on this plot refers only to the changing usage of the 7 WV channels in the different experiments, and hence can be disregarded. Both clear-sky and all-sky seem to improve fits to the 3 short-wave water vapour channels (right at the top of Fig. 1) and to channels around 760 inverse centimetres, which are lower-tropospheric temperature sounding channels.

Figure 2 shows the IASI observation counts by channel in the three experiments. Clear-sky assimilation of the 7 water vapour channels increases utilisation of other IASI channels by up to around 0.3% whereas all-sky assimilation reduces it by up to 0.5%, with two exceptions – around 712 cm^{-1} and in the 3 shortwave WV channels, where data utilisation is reduced by 2–3%. The channels around 712 cm^{-1} (IASI channels 271, 272 and 273) are a special case where all-sky assimilation seems to have affected the number of observations being identified by a special quality control check as being potentially contaminated by HCN, although the exact mechanism is not obvious. The 3 shortwave water vapour channels have overlapping sensitivities with the 7 channels converted to all-sky in our experiments, and likely all-sky assimilation has affected the background fields in a way that causes more rejections (for example through minor changes in bias). Since these are in any case small changes in data utilisation and they are unlikely to have affected the main results, we do not propose to investigate further. We would hope to add the following sentences in Sec. 4.1:

"Adding the 7 WV sounding channels, whether in clear-sky or all-sky, has a relatively minor effect on the utilisation of the other IASI channels (see additional figures in the interactive discussion). Background fits to lower-tropospheric temperature channels are slightly improved in either case, and the number of observations used remains within around +/-0.5% of the control, except for reductions of 2% - 3% with all-sky assimilation that affect just a few channels. Since these changes are minor, and arise from detailed interactions between quality control, thinning and screening that are hard to untangle, they have not been investigated further."

Specific comments P 3, line 31: Could you please explain more why water vapour channels are not affected by the zero gradient problem?

As well as outer loops (relinearisation) and specific fixes that are mentioned in the paragraph immediately preceding, we could have explicitly mentioned the advantage of using WV channels for all-sky assimilation, but the problem is this is specifically a paragraph on surface-sensitive channels, so it does not fit. Instead we will add this information in the following paragraph on water vapour sounding channels, more explicitly mentioning the zero gradient problem:

"A main benefit of water vapour sounding radiances is that even when the data assimilation system cannot generate a gradient with respect to cloud (the zero-gradient problem) these channels retain a sensitivity to relative humidity that acts in the same direction. So a data assimilation system can still adjust relative humidity to try to fit the observations and this will likely influence the cloud in the right direction too."

P5 line 30. The paper structure is not announced at the end of the introduction, as usually done.

We will add this, as described in response to reviewer #4, who made a similar comment.

P6, line 24: Could you please explain more which impact (or not) could have the reduced horizontal model resolution on your results as you said p2 l21 before that increased model resolution allows for cloud simulation to be closer to observation clouds.

This is a good point but in practice we have never noticed much difference, except for at very coarse scales (e.g. worse than 50 km). We will add a sentence or two roughly as follows:

"Most testing at ECMWF is done at reduced resolution, but experience shows that results from the lower-resolution testing tend to be replicated at higher-resolution. This is true even in the case of all-sky developments, suggesting that changing scales of cloud represented by the model (at least between 25 km and 9 km grid resolutions) does not have a great effect on the use of all-sky observations."

Typos: P13, Fig2c: Should title of the panel be FG eigendeparture check?

Yes, thanks, this will be changed.

Fig2: it is very difficult to distinguish something in this blue color with this color palette.

The idea was to retain the same colour palette and scale for all panels in figure 2, so that the relative data volumes can be easily compared. This does have the effect of making panel f a fairly uniform blue. However, that is why Figure 3c exists, which uses a more appropriate colour scale to plot the same data as in 2f.

P14 line 5: What is the difference range between values of blue over Europe and darker blue over Africa in the area contaminated by aerosols?

To best address this comment, the reader can be told at this point that data from panel 2f have been re-plotted on a more appropriate colour scale in Figure 3c.

P 19, caption Fig. 6: As Fig 5 but . . .

Thanks, this will be fixed.

A number of other small modifications have been made in the manuscript, mainly to improve readability or for additional clarification, particularly in section 4.3. Further, there was a small mistake in section 2.2.3 in describing the IASI thinning that actually uses the smallest background departure, not the warmest observation as originally stated, when selecting IASI observations that are least likely to be affected by cloud. This mistake does no affect anything else.

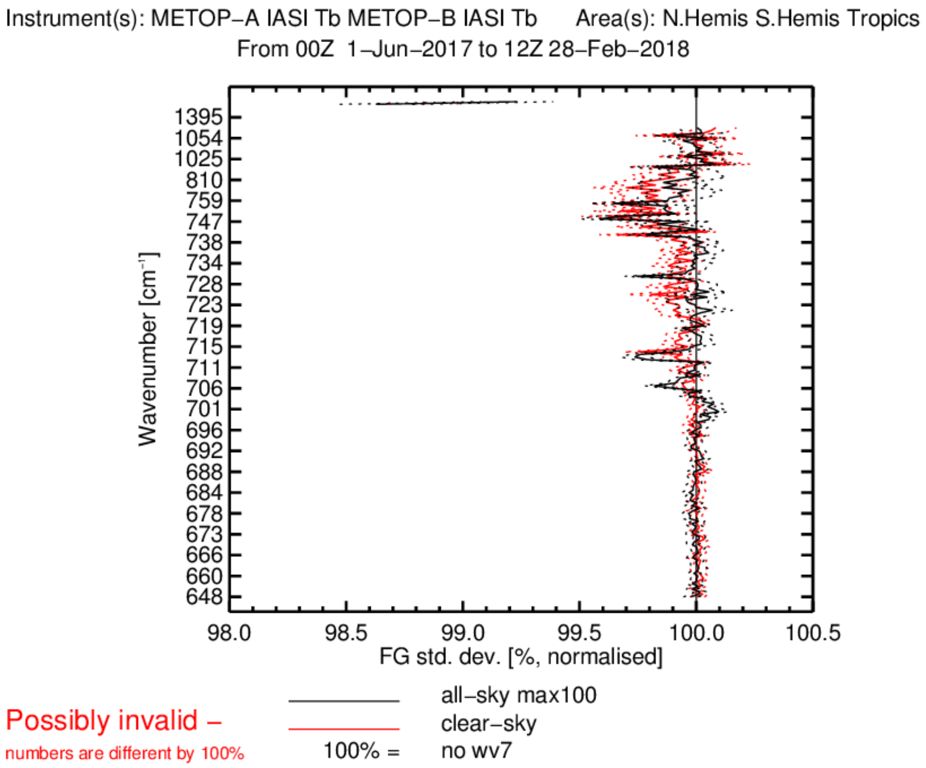

Fig. 1. Normalised standard deviation of IASI background departures with the No WV7 experiment as 100%. See text, which explains why the "Possibly Invalid" warning message can be disregarded.

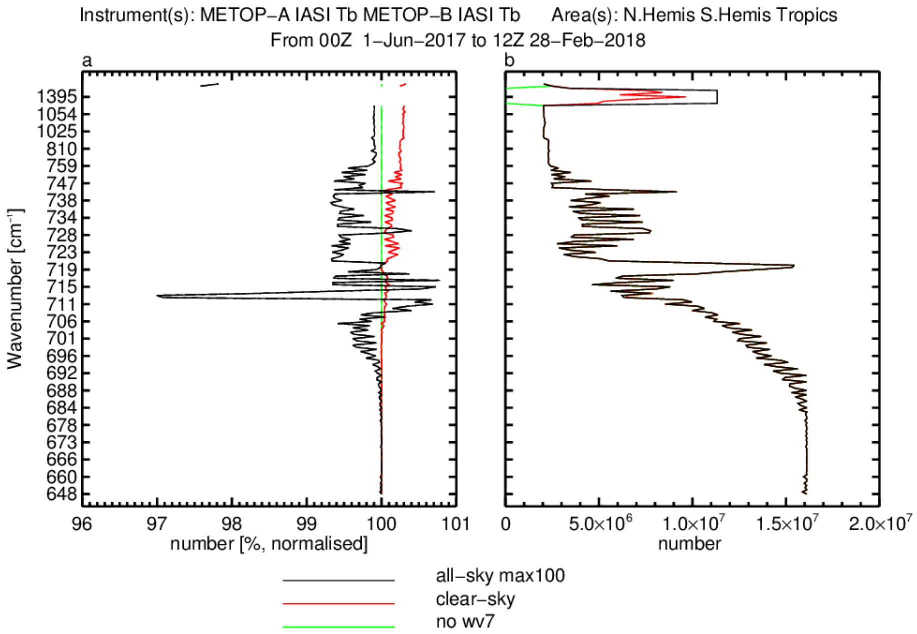

Fig. 2. Number of IASI observations (right) and relative number of observations (left) actively assimilated.