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Interactive comment

Interactive comment on “ISMAR: an airborne submillimetre radiometer” *by* Stuart Fox et al.

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1 Response to referee 1

We thank the referee for their helpful comments. A revised manuscript will contain significantly more detail on the receiver components. The referee also requests the addition of nadir viewing flight data as more relevant for the future goals of ISMAR. We address this issue in our response to point 9 below.

1.1 Specific comments

1. *The introduction should reference previous submillimetre-wave passive remote sensing instruments of similar design and purpose.*

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Discussion paper

Current satellite submillimetre instruments (e.g EOS-MLS on Aura, Odin SMR) are limb sounders designed for measuring atmospheric composition and have poor horizontal resolution and tropospheric coverage, and their channels are not optimised for cloud ice retrieval. Although other airborne instruments exist (e.g. CoSSIR), the number of measurements is rather limited and the channel selection is not matched to ICI. We will extend the introduction to include references to existing instruments.

2. *In section 2, are all the beam widths the same? Can you be more precise than "less than 4 degrees"?*

   All the beam widths are similar, ranging from 3.37 degrees to 3.79 degrees. We will add measurements of the half-power beam widths to table 1.

3. *Can you be more specific than "Laboratory testing has shown that there are no adverse radiometric effects attributable to the window" (in reference to the heated calibration target)? Is there any measurable loss, which would affect the calibration?*

   Perhaps our statement here was a little strong. We made laboratory measurements of an external liquid-nitrogen cooled black body both with and without the window in place, and at a variety of internal hot target temperatures. Although there was some variation in the measured brightness temperature of the external target between these tests they were within the range that might be expected due to the changes in the hot target temperature gradients between the different configurations and so are not clearly attributable to loss from the window. For flight conditions where there is considerable flow of cold air over the targets we find that the beneficial effects due to the reduction in target thermal gradients with the window outweigh the effects of any window losses.

   We do not have direct measurements of the window loss at ISMAR frequencies. However, the dielectric properties of polypropylene have been measured at the relevant frequencies by various authors, allowing a theoretical calculation of absorption and reflection by the window. The correction due to reflection is small but non-negligible, equivalent to a hot target temperature error of around 0.5K at 664GHz (it is smaller at lower frequencies). We have therefore now added a correction for the window reflectivity in the calibration processing. It is more difficult to characterise the absorption of the window as there are considerable differences between the measurements of the imaginary part of the relative permittivity of polypropylene. We therefore treat the absorption as an additional uncertainty in the hot-target temperature. The equivalent temperature uncertainty due to absorption is less than 0.14K at 664GHz, and smaller for the lower frequency receivers. We will add a new section to the paper describing the correction and uncertainty estimates in detail.

It might also be expected that reflection from the window could exacerbate any standing wave issues. However, as noted in the paper we see similar behaviour on the hot and cold targets when measuring the brightness temperature at different viewing angles so this does not appear to be an issue.

4. *There should be much more description of the front-end (local oscillators, multipliers, and mixers) and IF amplifiers. Obviously, these components are an important part of the ISMAR instrument.*

   We will add more description of the receiver components to section 2

5. *Why is the term "video amplifier" used when it "acts as a low-pass filter with a cut-off frequency of 1kHz"?*

   We used the term "video amplifier" as it is commonly applied to the post-detector amplifiers in total power radiometers. However, since the time-integration of the signal in ISMAR is carried out digitally it is also necessary to low-pass filter the detector output before digitisation to prevent aliasing (each channel is sampled at approximately 2.5kHz). This filtering is carried out within the post-detector amplification circuit. We have modified the wording in section 2 to clarify this.

6. *In section 3, does the 60 second calibration window uniformly weight the calibration looks around the time of the scene view?*

   Yes - we will change to wording to clarify this

7. *In section 4, you might mention that zenith viewing biases due to calibration target temperature extrapolation, though larger, are probably less important than the nadir viewing biases because ISMAR is a demonstrator for the Ice Cloud Imager satellite instrument.*

   We will add wording to this effect

8. *In section 5, equation 14 appears to be incorrect because the units of (NEdT)^2 and Tsys/(tau*DeltaNu) don't match. Considering only the first term on the right hand side, the equation normally would read (NEdT)^2 = Tsys^2/(tau*DeltaNu).*

   This is an error on our behalf - we will correct the equation.

9. *In section 6, it is disappointing that no nadir viewing flight data from the 17 flights are analyzed. If this is because another manuscript is in preparation, then this should be mentioned. Please give a justification for comparing ISMAR measurements with radiative transfer simulations for zenith views. Comparing ISMAR brightness temperatures with nadir views would be more interesting and relevant and definitely feasible using temperature and water vapor measured by radiosondes or dropsondes.*

   Our aim in this paper is to characterise and validate the performance of the ISMAR instrument. Whilst it is of significant interest to compare measurements with radiative transfer simulations for nadir views, the simulations will depend critically on the temperature and water vapour profiles, as well as assumptions about spectroscopy and surface properties in the sub-mm region which are currently not well validated. Any comparison is therefore as much a test of the simulations as it is of the instrument calibration. In future we plan to use ISMAR to validate nadir-viewing clear-sky radiative transfer simulations as these are an important first step in determining the brightness-temperature depressions induced by cloud ice.

Our use of zenith views is justified by the fact that the atmospheric contribution to the zenith brightness temperature is relatively small (less than 10K in most channels). Errors in the assumptions used for the radiative transfer simulations will only lead to small changes to this atmospheric contribution, so we expect the error in the simulations to be relatively small (perhaps O(1K) or less). As noted previously, this viewing geometry is also the most challenging from a calibration perspective, so if we get good agreement here we can be confident that the calibration is also sufficiently good for nadir views.

We will clarify the wording in section 6 to justify our use of zenith views.

2 Response to referee 2

We thank the referee for their useful comments - our responses are below.

In contrast to the detailed discussion of the calibration process, information on some other instrument aspects is surprisingly sparse. I am here mainly thinking about antenna, sideband and channel characteristics. I understand that the calibration is the most critical aspect, but I expected to find basic data on these instrumental properties in an introduction of a new instrument. Maybe exact measurements are not hand/needed, but best available data should be presented. The only information at hand is that the angular resolution is better than 4 degrees and that the sideband imbalance is max 1 dB. I would suggest to add:

- *The HPBW for each channel in Table 1.*
- *Comments in the text to make clear if the antenna response has been measured or not. If not, can it be expected to roughly Gaussian?*
- *How was the sideband imbalance estimated? Has a 1 dB imbalance any practical impact of the measurements that ISMAR will perform?*
- *What is known about the channel responses (i.e. the relative response as a function of IF)?*

This information is essential for satellite sensors, and I assume the same should be true for airborne measurements.

The antenna responses in the E and H planes have been measured - the HPBW will be added to table 1 as requested and wording added to clarify that these are from measurements.

The sideband imbalance has been measured by using a Martin-Puplett interferometer to create a single-sideband filter for each receiver. However, the measured values are smaller than the estimated error associated with the measurement technique (which is about $\pm$1dB), so we make the assumption that the best estimate for the ratio is 1:1, with a possible error of $\pm$1dB. We will clarify the wording in the text. Since the gaseous absorption lines where the channels are centred are symmetrical and cloud-ice scattering signals are expected to vary slowly with frequency we do not expect a 1dB imbalance to have much practical impact.

The channel responses have been measured. We have added figures for the in-band ripple at 90% bandwidth to table 1.

My second main criticism is that the Introduction lacks a review of older similar measurements. I don't think this can be considered as general knowledge. Most importantly, is ISMAR the first airborne instrument of its kind? And ICI, also first of its kind?

If yes, what are the closest forerunners to these measurements? (On the airborne side a know about some limb sounding instruments operating at similar frequencies, such as ASUR). The lack of such a review makes the overall scientific value vague.

As noted in our response to referee 1, we will discuss other relevant instruments in the introduction.

The manuscript is very well written, and I have only one detailed comment. Is it not possible to find a more direct and easily accessible reference for Eq 4? That is, I suggest to replace/complement Jones (1995).

We have so far been unable to find a suitable replacement reference for Eq 4. Most textbooks on the subject are aimed at lower frequency microwave instruments and make the Rayleigh-Jeans approximation early in the analysis. We will happily change the reference if we are made aware of a suitable alternative!

3 Response to Dong L. Wu

No discussions in the paper are provided on antenna sidelobe and spillover effects, which have a significant contribution to the power measured by these receivers. They can affect the calibration at the targets as well as at the zenith. Simply blaming and correcting biases at PRT may not solve the problem from the root cause, and may create additional artifacts.

We do not expect main beam spillover effects to be significant for ISMAR. The scan mirror, scan drum apertures and calibration targets have been sized to accommodate a (full-width) beam divergence angle of 17, which is greater than the measured main lobe divergence angle for all receivers. We will add this information to section 2.

Antenna sidelobe effects cannot be ruled out. However, since the instrument scan drum is closed apart from the main viewing aperture we expect that the majority of the sidelobes will observe temperatures close to ambient through the whole scan cycle, and will therefore be accounted for in the calibration.

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