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Interactive comment on "Simulation of sub-millimetre atmospheric spectra for characterizing potential ground-based remote sensing observations" *by* Emma C. Turner et al.

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This manuscript investigates the possibility to perform ground-based measurements of HOBr, HBr, HO2 and N2O at frequencies up to 2 THz. Considering the importance (and the expected increase) of bromine and N2O for atmospheric chemistry the aim of the manuscript is justified and it fits very well with the scope of AMT. Exploring the possibilities of ground-based measurements is especially important in the light of the expected lack of limb sounding measurements.

Radio astronomy makes use of recent technology development to obtain low receiver noise temperatures and the same technology can be applied for ground-based atmospheric sounding. The manuscript explores this option, and assess the best frequency

window to use for each species, for different atmospheric conditions.

My main concern with the analysis is that only thermal noise is considered, all other error sources are ignored. This is particularly problematic as some of the measurements require a spectral accuracy of about 10 μK. Is it really possible to maintain a spectral purity of that level over weeks/months? Very small external disturbances could easily ruin the measurements. Could not even interference from astronomical sources be a problem (notice that stronger nearby transitions can be red- or blue-shifted, and end up on top of the target frequencies)? How should various disturbances be handled when averaging spectra?

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The referee comments that some of the calculated sub-millimetre signals for the targeted atmospheric molecules are small, of the order of μK. As such the signals could be at the limit of detection even in the absence of external disturbances such as overlapping transitions from other spectral lines. This is an important point and we have added further discussion. This publication presents a site study of the simulated down-welling radiation received at the surface using averaged atmospheric profiles to represent a range of conditions representative of each site. The profiles are constructed from the best available observations and modelled data where observations are unavailable. The signals presented are unbiased and include those that would be unfavourable to measure due to weak strength. One aim of these results is to help researchers make informed decisions about potential future sub millimetre spectroscopy campaigns, as they not only indicate suitable locations for deploying instruments but also those that are unsuitable for particular species. This has been summarised in the conclusion as follows;

(Page 16, lines 23–30) 'The sample molecules characterised span a range of detectability. The bromine compounds would be particularly challenging to observe. Given the choice of zero zenith angle and non-inclusion of unknown receiver system errors, this essentially presents the upper limit of the detectability suggesting particular combinations of locations and species would be unfavourable for instrument deployment. These results are informative to those considering potential future spectroscopy campaigns. However, promising candidate channels are identified for measuring N2O, HO2 and even HBr which is on the limit of detection, given long integration times and sensitive instruments such as those developed for astronomical applications.'

Potential interference from astronomical sources is not a major problem because they move across the sky rapidly with time, which is why astronomical telescopes have to track the sky during an observation. A source will move in and out of the beam very quickly. The position of strong sources are known and can be carefully screened for by checking catalogues and by pointing towards blank regions out of the galactic plane, such as is done for cosmic microwave background (CMB) observations. This is one of many reasons why working closely with the astronomical community would be mutually beneficial.

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It should be possible to make a rough characterisation of some additional error sources. Maybe most important is to check the interference of species giving stronger spectral features. I don't see anything in the analysis that catches if the target transitions are on top of e.g. ozone isotopologue transitions. If this is the case, variation in both overall ozone concentration and isotopologue fractioning could interfere strongly with the measurement, or even lead to false "detection".

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In order to comment quantitatively on the effect of overlapping species (which was also raised by referee #2) we have added sensitivity tests with perturbed ozone concentrations, and amended Figure 10-13 to include the new analysis. This is discussed in the results as follows;

(Pages 15, lines 7 - 24) 'A potential source of error when selecting the optimum signals for each species is the presence of overlapping lines from other gases close to the target peak frequency. This is particularly true if the concentrations of the interfering species are higher than those estimated in the atmospheric profiles used in the radiative transfer calculations. The sensitivities of these strongest signals to changes in ozone concentration are tested, as this species has numerous lines in the submillimetre that can interfere with the target emission lines. We focus on the winter (JJA) scenario as a favourable season for campaigns in Greenland, due to cold, dry conditions producing low atmospheric opacity. The 13 μK HBr signal centred at 500.65 GHz (Figure 10b) is overlapped by the 16O3 line at 500.43 GHz. Doubling stratospheric ozone concentrations, at atmospheric pressures below 200 hPa reduces the peak HBr signal by 1 μK (Figure 10b), i.e. a change of 8% from the unperturbed calculation. Halving the O3 concentration produces no significant change in the peak HBr signal. For HOBr there are no ozone lines in the signal bandwidth (Figures 11b) and for HO2 all overlapping O3 lines are weak with line intensities below 10-26 cm-1 /(molecules cm$-$2) (Figure12b), therefore the target lines for these two molecules show negligible response to changes in ozone concentration. The N2O transition centred at 301.44 GHz (signal strength = 1.7 K) is overlapped at the edge of the FWHM by a 16O3 transition at 301.81 GHz of similar intensity (Figure 13b). Doubling the O3 concentration reduces the edge of the N2O signal by 0.15 K but has negligible effect on the peak signal. Though the calculated sensitivity of these particular signals to O3 are minimal they emphasise the need for accurate profiles of overlapping atmospheric species. Vertical O3 columns are well measured by satellites and ground based receivers, however, other less well-known species with overlapping lines could introduce random errors, particularly ones with comparable line intensities and/or close proximity to the target signal, necessitating prior screening.'

We have also added the following to the conclusion,

(Page 16, lines 20-22) 'Signal selection should also be informed by screening for overlapping spectral lines from other atmospheric species. This is particularly important if the interfering line falls within the bandwidth of the target signal and/or is of comparable intensity, or if the species concentration cannot be well-estimated.'

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Some error sources, such as reflection inside the receiver system, are hard to characterise in a general manner, but they should at least be commented. Could any such error source even be a "showstopper"?

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Agreed that receiver errors are important yet hard to characterise. We now expand upon this in section 3.3.1 Estimation of receiver characteristics, whilst acknowledging that only background noise is included in the present study, to thereby set technical specifications for any instruments built.

(Page 11, lines 4-11) 'To measure a species signal it must be sufficiently distinguishable from the underlying atmospheric spectrum and errors sources within the receiver must be adequately accounted for. For example, standing waves in optical systems, are a central consideration when designing submillimetre-wave spectrometers. These are well known to be problematic in both bolometric and coherent spectrometers. This is usually dealt with by ensuring optical system designs that minimise the effect, but also by fitting baselines. For narrow spectral lines, this is possible, but for broad spectral lines this can be a problem. Switching the receiver against a calibration load is often used as a way of 'subtracting the baseline'. In this study we only consider background noise, which arises due to the inherent natural variation of the flux of photons arriving at the receiver (Benford et al., 1998). This sets the limit of detectability with which to set technical specifications for any instruments built.'

Unknown receiver system errors are commented as an unknown error source in the conclusion,

(Page 16, line 25-26) '..non-inclusion of (unknown) receiver system errors..'

Another source of error is the presence of clouds in the field of view of the sensor, requiring simultaneous detection to either remove them or discard the measurement. This is now noted in the introduction,

(Page 2, lines 23-28)' 'It should be noted that while we can easily eliminate clouds in the model world, these could contaminate signals unless carefully screened for. We focus on polar locations, as these are regions that are particularly vulnerable to climate change (Marshall et al., 2014; Serreze et al., 2011), and have unique atmospheric conditions that present a challenge for instrument deployment. For example, when dealing with a near-horizon view over ice sheets, the air in the first few metres just above the ice surface in winter often has poor visibility and high internal reflectivity because of so-called "diamond dust", a mist of tiny ice crystals in the atmosphere.'

And the 'showstopper' is likely to be the estimated water vapour profile, as opacity strongly modifies the signals received at the ground. This is commented in the discussion of background climatologies;

(Page 7, lines 10-13) 'For example, if the water vapour profile is poorly characterised, e.g. due to local variations in humidity and temperature within clouds, this will produce changes in the signal received at the ground (in the real world this can be modelled by adjusting the tropospheric opacity/water vapour to fit the baseline atmospheric brightness temperature).'

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The manuscript text is very well written. In fact I have no detailed comments worth mention.

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Thank you.

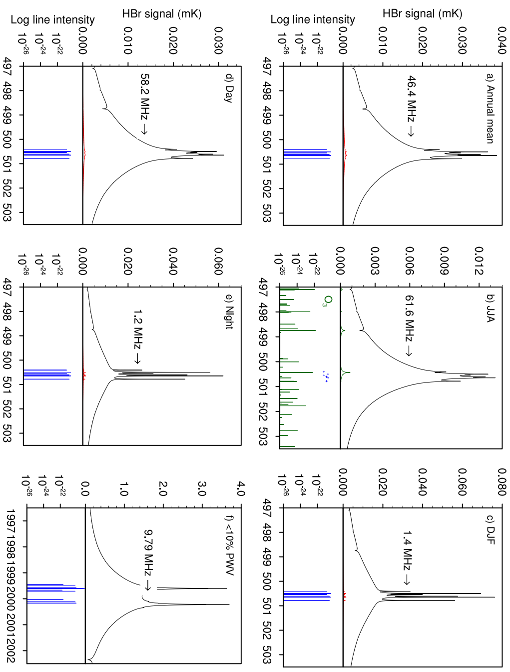
a) Annual mean
46.4 MHz →
b) JJA
61.6 MHz →
O3
c) DJF
1.4 MHz →
d) Day
58.2 MHz →
e) Night
1.2 MHz →
f) <10% PWV
9.79 MHz →
HBr signal (mK)
Log line intensity
Frequency (GHz)

Fig. 1.

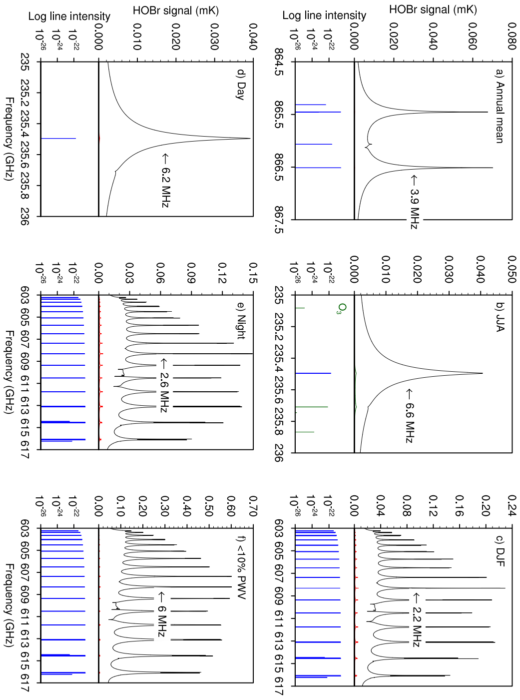
a) Annual mean
b) JJA
c) DJF
d) Day
e) Night
f) <10% PWV
HOBr signal (mK)
Log line intensity
Frequency (GHz)
← 3.9 MHz
← 6.6 MHz
← 2.2 MHz
← 6.2 MHz
← 2.6 MHz
← 6 MHz
O_3

Fig. 2.

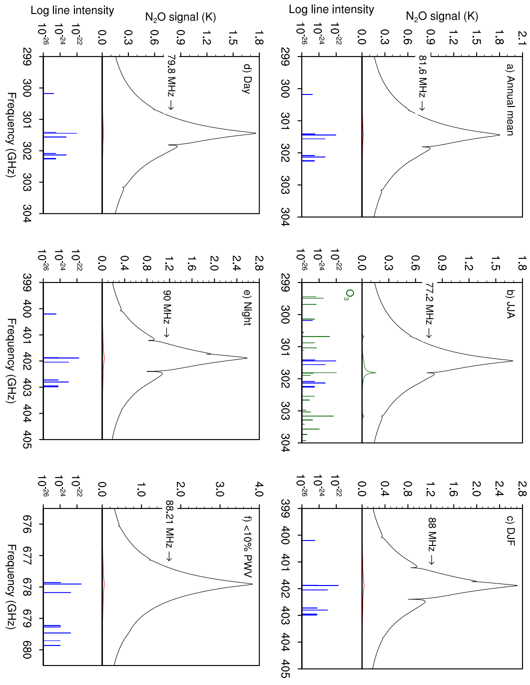
a) Annual mean
b) JJA
c) DJF
d) Day
e) Night
f) <10% PWV
N_2O signal (K)
Log line intensity
Frequency (GHz)
81.6 MHz →
77.2 MHz →
88 MHz →
79.8 MHz →
90 MHz →
88.21 MHz →
O_3

Fig. 3.