Where is Ridge A?

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ABSTRACT

First identified in 2009 as the site with the lowest precipitable water and best terahertz transmission on Earth, Ridge A is located approximately 150 km south of Dome A, Antarctica. To further refine this optimum location prior to deployment in 2012 of a robotic THz observatory, we have modelled the atmospheric transmission as a function of location over a 1,000,000 km square grid using three years of data from the Microwave Humidity Sounder on the NOAA-18 satellite. The modelling identifies a broad area of exceptionally low water vapour close to the 4,000 metre elevation contour, reaching below 100 microns for extended periods of time.

Keywords: Ridge A, site testing, Antarctic astronomy, terahertz spectroscopy, precipitable water vapour

1. INTRODUCTION

The terahertz (THz; or sub-millimetre) region of the electromagnetic spectrum remains one of the last truly unexplored spectral areas. The important atmospheric windows in this region contain a host of fine structure and molecular emission lines, providing reliable tracers of interstellar chemistry, star formation rates, and the lifecycle of the interstellar medium.[1,2] Table 1 gives a summary of the dominant terahertz emissions.

Table 1: Summary of THz emission lines.

Species	Frequency (THz)	Wavelength (μm)
[CI]	0.492	609
^{13}CO	0.661	454
^{12}CO	0.806	372
[CI]	0.809	371
NH^+	1.013	296
NH^+	1.019	294
H_2D^+	1.370	219
[NII]	1.461	205
[CII]	1.901	158
[OIII]	3.407	88
[OI]	4.759	63

However, the efficient absorption of terahertz radiation by atmospheric water vapour, oxygen and ozone limits observations to the highest and driest locations. Even in a completely dry atmosphere, the terahertz transmission

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is ultimately limited by the so called "dry-air opacity" (DAO). Caused by collisionally-induced dipole moments in nitrogen and oxygen,[3,4] the DAO depends primarily on atmospheric pressure, and also on temperature.

Terahertz detections have been made from a number of space and sub-orbital observatories, including the Stratospheric Observatory for Infrared Astronomy (SOFIA), the Herschel Space Observatory and the Stratospheric Terahertz Observatory long duration balloon (STO).[5] Ground based observations have been made from the Antarctic plateau (e.g., Pre-HEAT[6]). Observations from Pre-HEAT during 2008 demonstrated that the Antarctic plateau offers exceptional stability and transmission in the terahertz regime.[7]

The suitability of many sites on the Antarctic plateau has previously been evaluated using a variety of criteria,[8] in which Ridge A, putatively defined to be at (81.5S, 73.5E), is expected to have a lower PWV content, and better free-atmosphere seeing than Dome A. In this paper we expand on this previous analysis by examining a 2-dimensional region covering latitudes 75–88°S and longitudes 55–95°E (see Figure 1). We focus specifically on the atmospheric PWV content and DAO to determine the location(s) which boast the highest THz transmission on Earth.

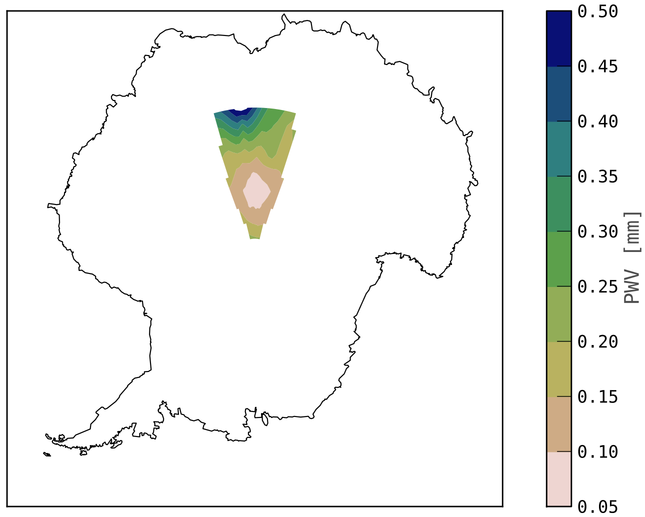
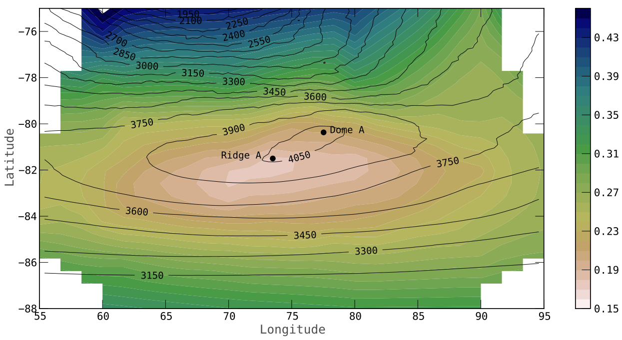


Figure 1: Region of interest, showing typical PWV values.

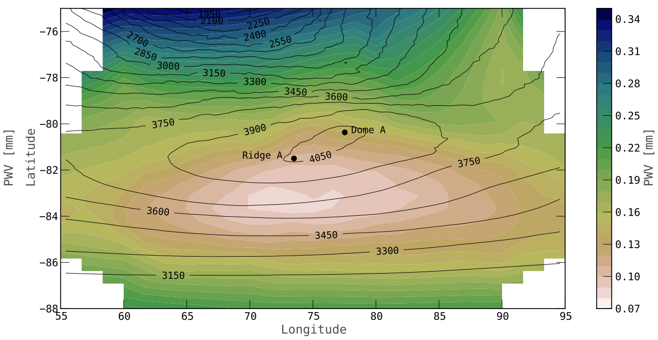
2. SATELLITE PWV EXTRACTIONS

In order to visualise the changes in PWV with position, we use a 253 point grid of level-2 data from the Microwave Humidity Sounder (MHS) on the NOAA-18 satellite. For each point, a PWV calculation was made[9,10] from the brightness temperatures recorded in every satellite pass (approximately 5 per day) during 2008–2010. The PWV amounts were subsequently collapsed into daily averages to reduce noise. Various percentiles were calculated and overlaid on topographic contours.[11] The results are shown in Figure 2.

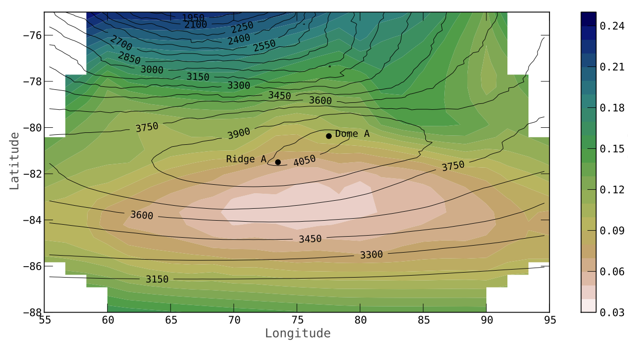
The data suggest that the PWV minimises around 83.5°S which, interestingly, doesn't coincide with the position of maximum elevation (i.e., Dome A).



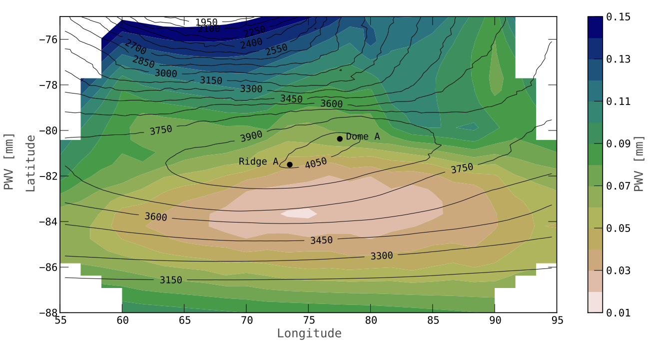
(a) Annual median



(b) Winter median



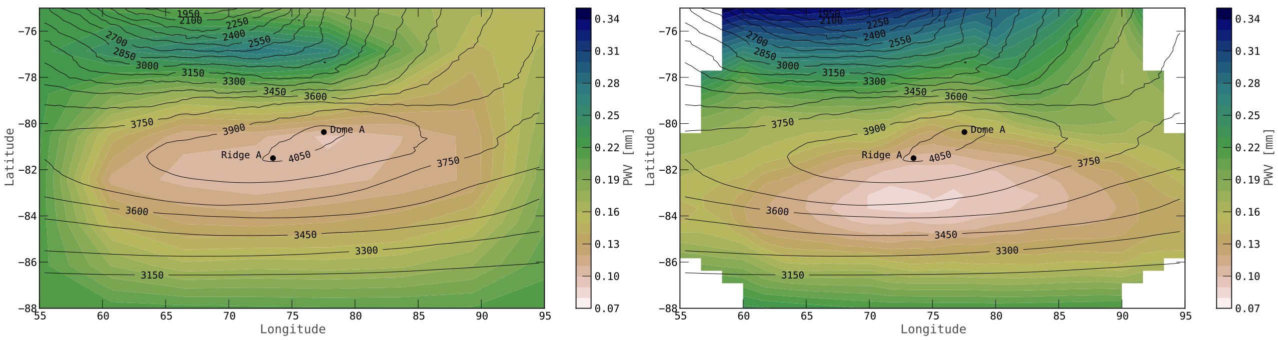
(c) Winter 25%-ile



(d) Winter 10%-ile

Figure 2: Satellite PWV extractions from MHS on NOAA-18 over the 3 year period 2008–2010. The contours show the elevation in metres. The position of Dome A and putative position of Ridge A are indicated. Note the PWV scale changes on each plot and that 'winter' is defined here to be days 120–300.

To further investigate this broad PWV minimum, a similar analysis was performed using level-3 data obtained from the Atmospheric Infrared Sounder (AIRS) on the Aqua satellite over the same 3 year period. After correcting for an observed 0.05 mm overestimation of PWV relative to MHS,[10] the 3 year winter median as obtained from AIRS was compared to that of MHS. The results are shown in Figure 3. In contrast to the MHS data, PWV extraction from AIRS do appear to correlate with topography, with the highest point on the plateau (Dome A) showing the lowest PWV levels.



(a) AIRS/Aqua (b) MHS/NOAA-18

Figure 3: Comparison of winter median PWV extractions from AIRS/Aqua with MHS/NOAA-18. The colour mapping scales are the same in both plots.

As a final check, data from a third satellite instrument, IASI on MetOp-A, were obtained. As the same 3 year data set was not readily available, we simply consider two locations for one year (2009): Dome A and 83.5S, 73.0E. The latter is the approximate position of the PWV minimum inferred from the MHS data (Figure 3b). The winter median PWV at the two positions was found to be 0.22 mm and 0.17 mm respectively, providing further evidence that the PWV does indeed minimise some distance from Dome A. It is worth pointing out that IASI does show consistently larger (0.075 mm) PWV values than the MHS.[10] The time series showing the PWV data for the two locations during 2009 is given in Figure 4.

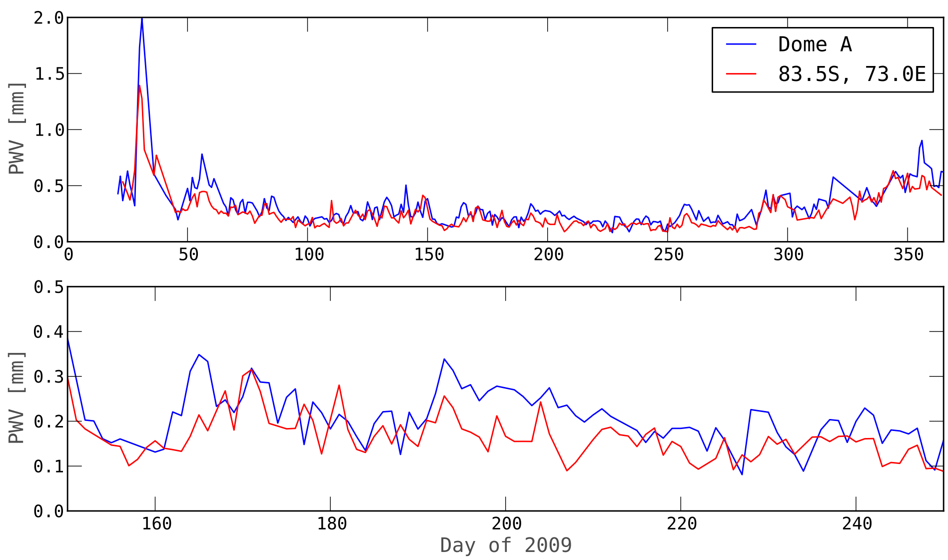
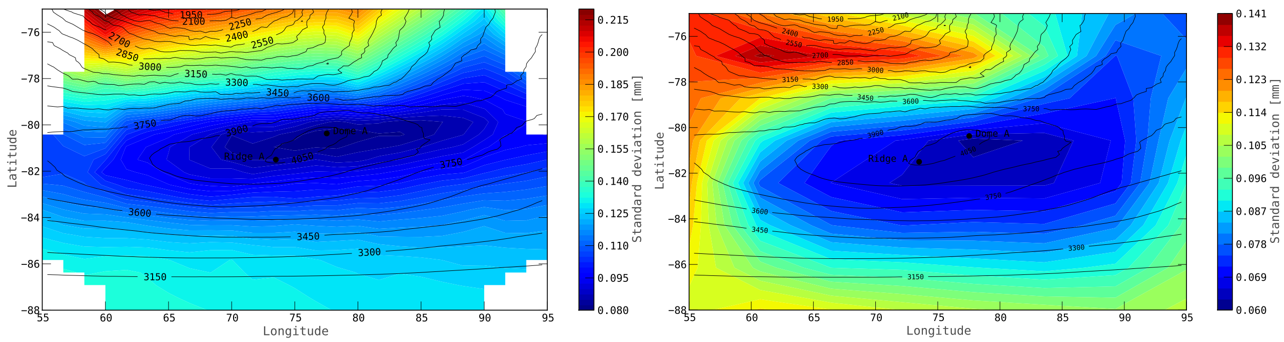


Figure 4: IASI data comparing Dome A and (83.5S, 73.0E) during 2009.

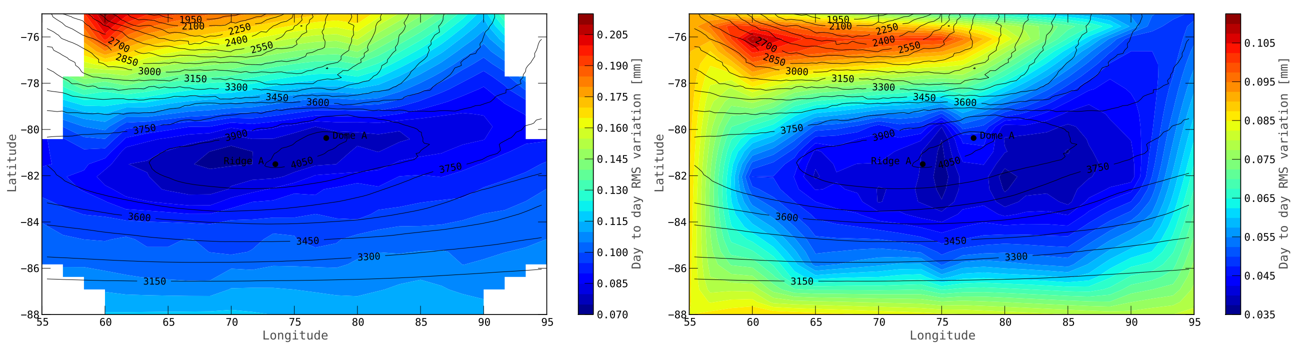
3. PWV STABILITY

Given stability of the atmospheric transmission plays a big role in the success of THz observations, it is worthwhile using the satellite data to examine the PWV variations. Figures 5 and 6 show the 3 year wintertime standard deviation and day to day RMS variation in PWV respectively.



(a) MHS/NOAA-18 (b) AIRS/Aqua

Figure 5: 3 year wintertime standard deviation from MHS and AIRS.



(a) MHS/NOAA-18 (b) AIRS/Aqua

Figure 6: 3 year wintertime day to day RMS from MHS and AIRS.

Despite the two instruments largely disagreeing as to the driest location, they agree remarkably well that the overall variability of the PWV is minimised around Dome A. Since most of the sky noise is due to variations in PWV, the site with the lowest variation in derived wintertime PWV (or 183 GHz temperatures) is likely also to have the lowest absolute PWV. By latitude 83°S, the wintertime deviations in PWV have risen significantly, and it continues to get worse as you move south.

Perhaps more important than the overall winter variation are the day to day fluctuations as continuously low periods of PWV are highly advantageous for THz measurements. In this regard, it appears the location with the lowest RMS day-to-day fluctuations is indeed *not* Dome A. The MHS sensor predicts this location to be 5°west of Ridge A, while AIRS data implies it is somewhere south of both Dome A and Ridge A (the discontinuity in the AIRS map is a result of interpolation over the sparse grid; the minimum observed data point was 82S, 75E).

4. ATMOSPHERIC MODELS

In order to asses the PWV and DAO/pressure considerations, a number of atmospheric transmission models were produced using the Line-By-Line Radiative Transfer Model (LBLRTM). The transmission between 400 and 2000 GHz was calculated for a number of locations with varying PWV and altitude. The positions chosen were all at 73°E longitude, and varied from 80°S to 86°S, as shown in Figure 7.

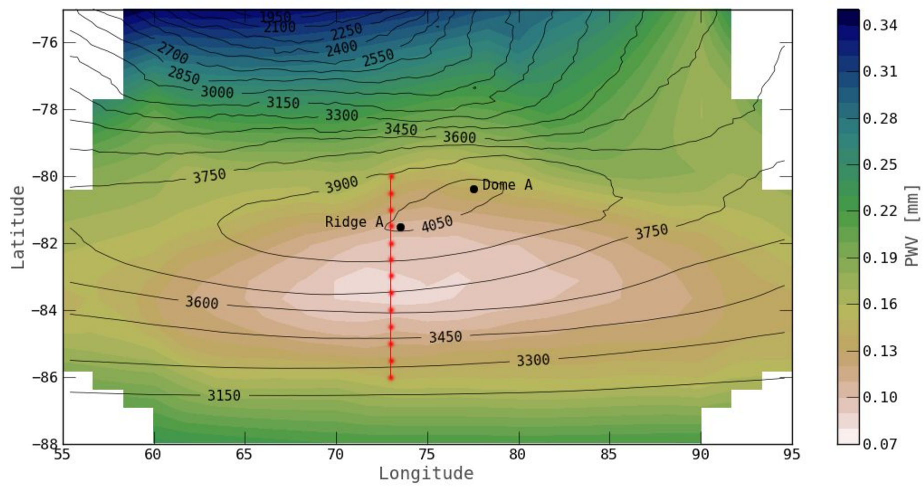


Figure 7: LBLRTM plan.

For each site, a median Dome C atmosphere profile was used,[12] with the altitude set to match the topographic data and the relative humidity scaled to the median winter PWV given by the satellite extractions. The results, presented in Figures 8 and 9, demonstrate that if the satellite PWV extractions are blindly accepted, there is indeed an advantage to moving down the slope toward 83.5°S as the dry air limits do not not vary significantly among the sites. Figure 10 demonstrates how the transmission varies over the median, best 25% and best 10% of days.

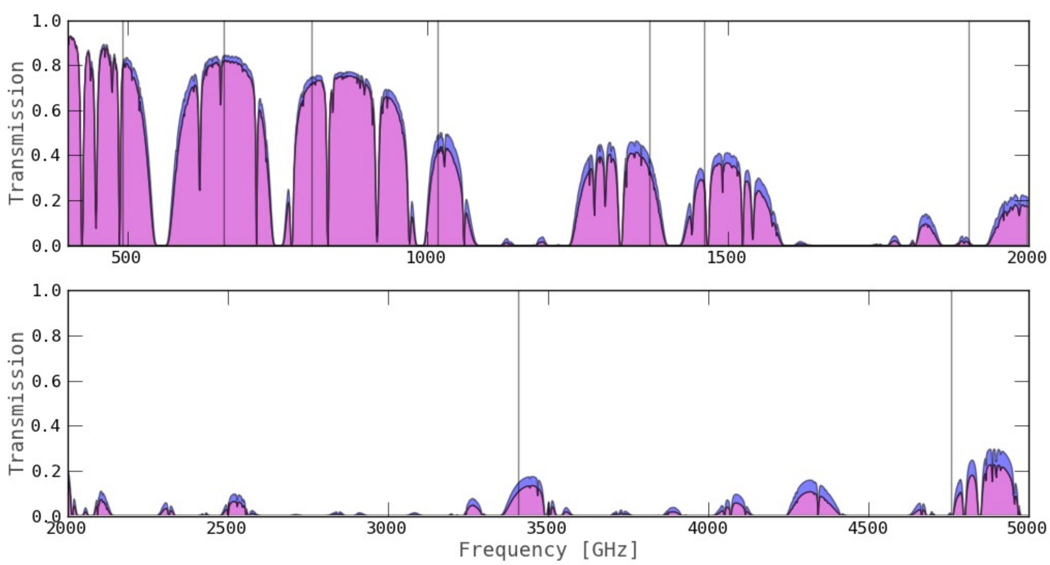


Figure 8: LBLRTM output using winter median PWV values. For clarity, only the driest and highest locations are shown, and are indicated by the upper (blue) and lower (magenta) shaded regions respectively. The vertical lines indicate the THz emission lines from Table 1.

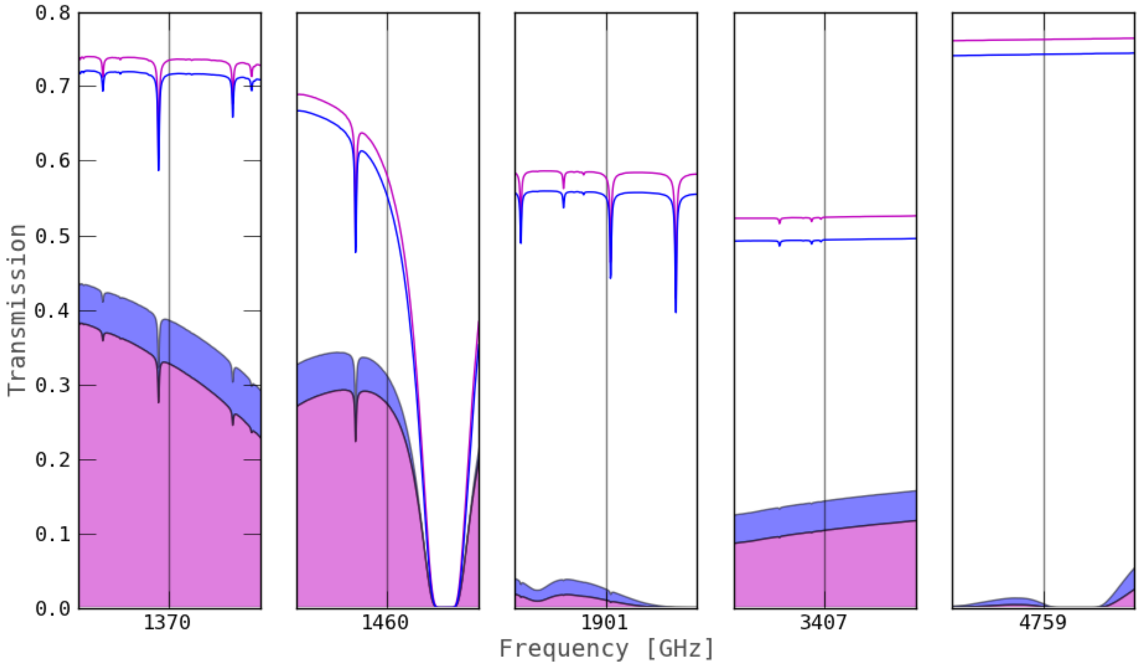


Figure 9: Same as Figure 8, but zoomed in around the THz emission lines. The dry limits (solid lines) represent the transmission at each site when the PWV is set to zero.

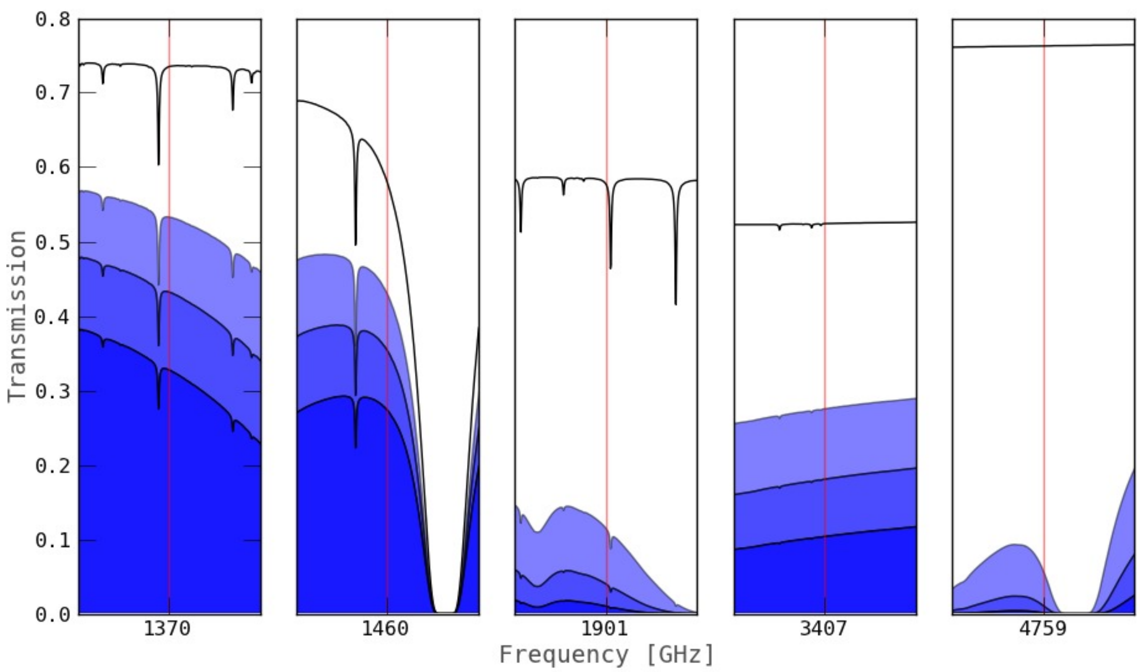


Figure 10: Same as Figure 9, this time using the highest location to demonstrate transmission gained during the driest days of winter. The plot shows median (0.11 mm), best 25%-ile (0.07 mm) and best 10%-ile (0.04 mm) transmission from 4055 m elevation. The dry limit for this altitude is also indicated by the solid line.

5. CONCLUSION

Satellite data from three instruments all identify a broad area of extremely low PWV around the highest point on the Antarctic plateau; Dome A. Two of the three instruments (MHS and IASI) indicate the PWV minimises away from the highest point on the plateau, while the third instrument (AIRS) tends to disagree. It is not entirely clear whether this is a physical or instrumental effect, or a combination of the two. In terms of stability, MHS and AIRS do agree that the day-to-day variation of PWV occurs closer to Ridge A than Dome A.

With respect to the THz atmospheric transmission, dry air opacity limits were investigated and show that a site's elevation is less important than the actual PWV levels. For some of the THz emission lines (e.g., 1.901 and 4.759 THz), a small gain in PWV corresponds to a significant increase in transmission.

It is important to appreciate that this paper is discussing a region with extraordinarily good THz transmission and stability. Every location examined here offers greatly superior conditions to those elsewhere on Earth such as Chajnantor or even the South Pole itself.

Over a three day period beginning on 20 January 2012, PLATO-R was deployed at Ridge A by members of the University of Arizona and University of New South Wales. The PLATO-R observatory and Ridge A are located at 81°40′24.8″ S, 72°42′58.0″ E, at an elevation of 4,035 m.

Figure 11: The PLATO-R observatory at Ridge A in January 2012.

6. ACKNOWLEDGEMENTS

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