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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Telephone: 617-715-5533
Fax: 617-715-0590

To: VSRT Group

From: Rachel Boedicker

Subject: Spectrometers for the Ground Observation of Mesospheric Water and Ozone

Spectrometers for the Ground Observation of Mesospheric Water and Ozone

Rachel Boedicker, Case Western Reserve University
MIT Haystack Summer REU Program

***Abstract*—In order to track the concentrations of molecules such as ozone and water in the atmosphere, spectrometers are used to measure the emission frequencies dictated by the molecules' electronic structure. Observations are often made from above the mesosphere using infrared frequencies. However, ground based measurements can be made less expensively using lower line frequencies, granted the data can be reliably acquired through the atmosphere. The original intent of this project was the observation of the 13 GHz hydroxyl line using a ground-based microwave spectrometer. However, due to lack of significant signal strength in initial observations, the project shifted focus to the 22 GHz water vapor line. Additionally, a previous system for ozone was updated to work with 8 collecting channels.**

***Index Terms*—radar, antenna, radio frequency, waveguides**

I. BACKGROUND

The concentration of certain molecules in the atmosphere can be a valuable tool in understanding the complex chemical interactions that occur there. However, direct measurement is often immensely impractical, and we instead examine the spectral emissions in the atmosphere to determine what molecules are present.

Molecules emit various frequencies depending on their quantum mechanical electronic structures and motion. Thus, the resulting measurement, or spectrum, produced by observing a group of molecules is indicative of their identities.[1]

Since molecules produce a variety of frequencies, which can be adjusted based on their interactions, a higher density of interacting molecules will produce a greater diversity of frequencies. This effect is called 'pressure broadening' and is often seen in lower regions of the atmosphere where there are more molecules. In order to observe a narrower spectrum, which allow molecular frequency lines to be more cleanly distinguished, measurements need to be taken from a lower pressure section of the atmosphere such as the Mesosphere.[2]

The Mesospheric Ozone System for Atmospheric Investigations in the Classroom (MOZAIC) program has been collecting data at MIT Haystack on for years. The goal of the project was to develop inexpensive ozone spectrometers that could be deployed for ground observations. [3]

The microwave spectrometers deployed for this project and other MOSAIC initiatives are built using offset parabolic dish antennas originally designed for television. The receiving element is a low noise block down-converter feed (LNBF), which effectively acts as a heterodyning receiver for microwave frequencies. The signal is then sent to a software defined radio (SDR), which converts the information to usable digital data. See Fig. 2 for the typical geometry of the dish.

Fig. 1. The path through the atmosphere for a spectrometer placed at a low elevation. Note the marked regions for spectral shapes. Not to scale. Image from Rogers 2012. [2]

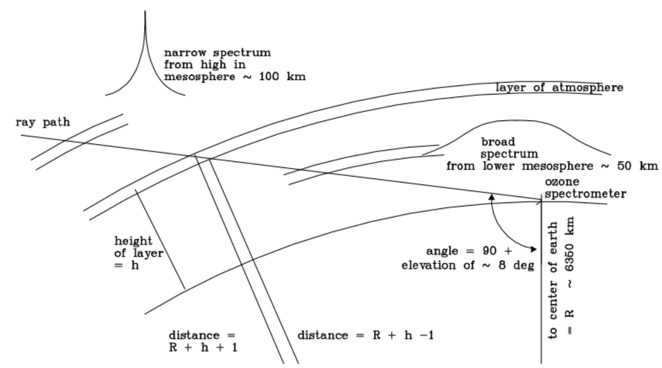
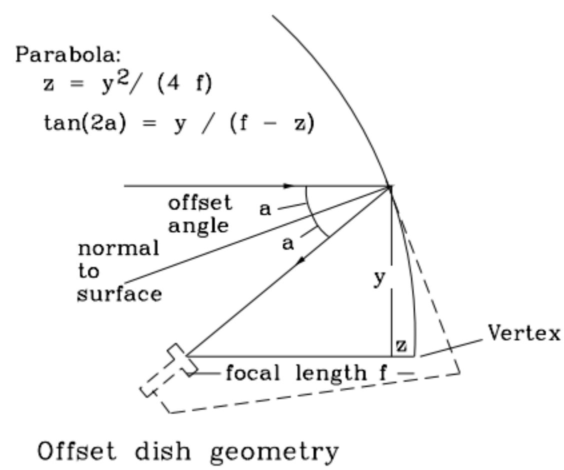


Fig. 2. Image from Rogers 2008. [4]



II. METHODOLOGY

As each spectrometer was designed to observe different emission lines, there was some amount of variation in their use and set-up despite their similar initial architecture.

A. Hydroxyl System

The OH system was positioned on the south side of the building since there was no concern of interference from the geostationary satellite belt. The dish elevation was set as close as possible to 8 degrees in order to look through a large slice of

Fig. 3. LNBF Fitted to the expected focus of the dish.

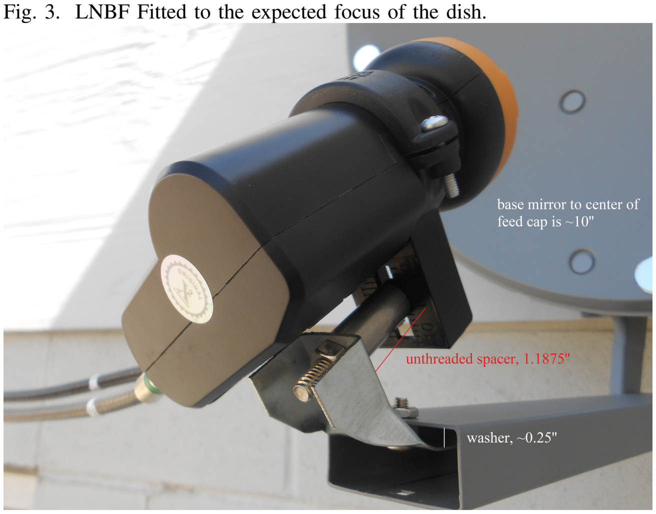


Fig. 4.

the atmosphere. The system was calibrated to observe the 13.4 GHz OH line using an LNBF with a 12 GHz local oscillator.

The potential system noise was also measured by recording data while the LNBF was covered in RF absorbing foam. With all external signals safety attenuated the resulting signal could be attributed to the internal noise of the devices. The system seemed to be within acceptable levels. However, when the un-attenuated signal was observed on a spectrum analyzer we did notice a strange frequency sweep appearing near 13 GHz.

B. Water System

The water vapor system was also positioned on the south side of the building. However, it was placed at a higher elevation (close to zenith) since water is plentiful in the atmosphere; therefore a smaller path distance through the mesosphere is needed to record a good signal.

The local oscillator of the LNBF was 20.25 GHz and the system required a specialized SDR to handle the higher frequencies.

In order to calibrate the water system, a 22.35079 GHz [5] tone was generated with a harmonic generator using the 11.175395 GHz subharmonic. We then observed the frequency placement in the recording software to ensure the frequency was centered.

C. Ozone System

Haystack has a significant amount of recording time on a previous ozone system, however do to interest from collaborators in Sodankyla, Finland, the ozone system was updated to work with eight receiving channels. Theoretically this should reduce the noise in the data by a factor of $\sqrt[2]{8}$.

First, we made measurements of a dish using the intended DirectTV reciever system to get an empirical grasp on the expected focus point. We also attached mirrors to the dish so that a far source, such as the sun, could be reflected to pinpoint the focus. After that we made adjustments to the fit of an LNBF (see Fig. 3).

After that, a plate was made so that two LNBFs could be mounted together. Unlike the three LNBF system that was attempted previously, both LNBFs are equally close to the focus, even if they cannot both be perfectly in focus.

In order to confirm that the twin system would not interfere too much with itself, we tested the signal pointing at a cold patch of sky, just to look for consistency, which would mean consistency in the Y-factor of the antenna. Measurements were made using a microwave analyzer while the secondary LNBF was turned on and off. An absorber was used to attenuate external signals. The results can be seen in Table 1.

TABLE I
SIGNAL STRENGTH

Second LNBF (ON/OFF)	Absorber (ON/OFF)	dB	dB	dB
ON	ON	-47.09	-48.12	-48.22
OFF	ON	-48.20	-48.02	-48.31
ON	OFF	-53.02	-53.07	-53.1
OFF	OFF	-52.81	-53.12	-53.28

The ozone system was placed on the north side of the building facing north, away from the geostationary satellites. It was mounted higher than the original system and a hole was drilled into the wall to run feed lines back into the building.

Since the system has a lot more parts, each of the cables was labeled. The dishes and LNBFs are numbered back to front starting at the door. The Bias Tee stacks are also labeled starting from the wall. Finally, the USB port label is opposite from the channel number. See Table 2 for a summery of the system connections. Fig. 5 and 6 also show the entire layout of the system.

Additionally, after attempts at taping a calibrator antenna into place, we drilled a hole directly into the dishes to place small dipole antennas in the centers (see Fig. 7). This simplified the calibration system and its division between the two dishes.

D. Data Processing

First-off, data is collected using the '*spec' executable C-code. The files are then stored in files organized by the date.

Fig. 5. Inside view of the 8-channel system. The Bias Tees provide power at either 12 or 18 V depending on the intended polarity. The signals are attenuated around 16 dB and fed into SDR dongles. The USB hub shown here was later replaced with an 8-port hub.

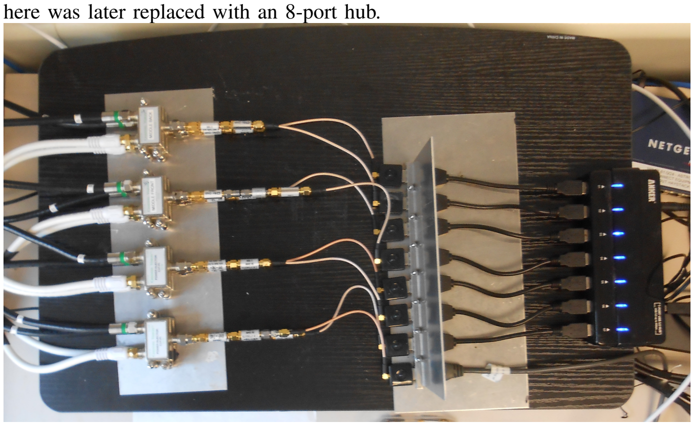


TABLE II
PORT CONNECTIONS

Dish Number	1	1	1	1	2	2	2	2
LNBF Number	2	1	2	1	4	3	4	3
Cable Number	50	48	51	49	blank	46	52	47
Bias Tee Stack	1	1	2	2	3	3	4	4
Supplied Voltage	18	18	12	12	18	18	12	12
Port Number	1	2	3	4	5	6	7	8
Channel Number	8	7	6	5	4	3	2	1

Data is compiled into one temporary file and processed with the correct 'plot' executable through the corresponding do* C-shell script. All 'make' files are bash scripts to compile the plotting C-code into executables.

I added bash scripts to check for errors in the ozone system and restart the collection software in case any were found. I also adjusted a version of the wplot.c and ozoneplot.c file to extract already processed data before the graphing stage. In MATLAB I created functions to process some amount of raw data, as well as programs to make more detailed plots using the extracted data.

Fig. 6. Outside view of 8-channel system.

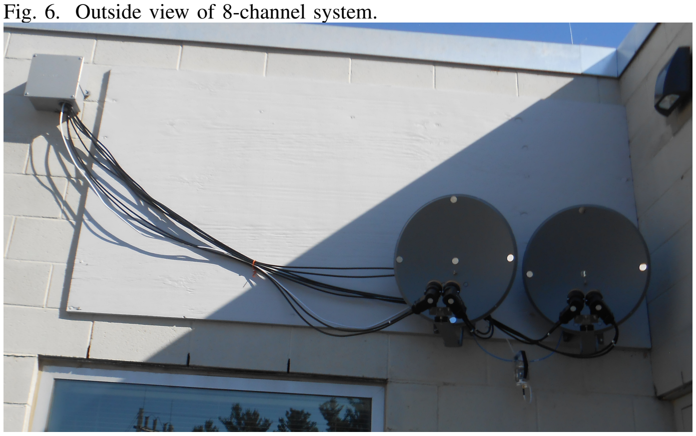
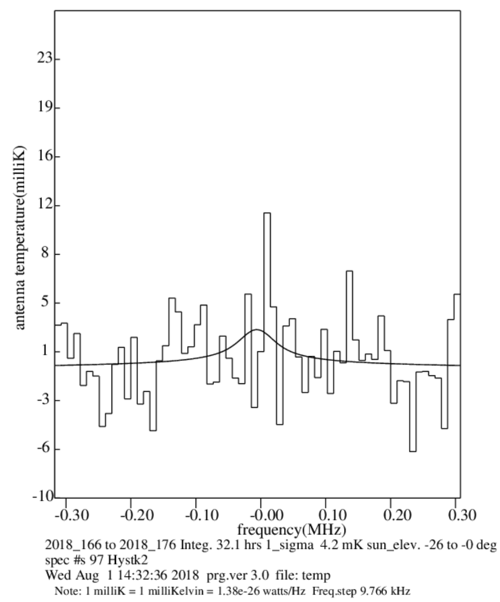


Fig. 7. Dipole antenna for calibration signal.

Fig. 8. OH measurements.



III. RESULTS AND DISCUSSION

A. *Hydroxyl*

The OH system did not observe any particularly strong signals (see Fig. 8) which could have to do with the lack of atmospheric events that would raise the OH levels. For instance, both sudden stratospheric warming (SSW) events and solar proton events tend to increase hydroxyl concentrations in the mesosphere.[6] If the system were to take data throughout the first three months of the year, where SSW are extremely likely to occur, more significant signal might be observed.

B. *Water*

The first thing of note about the water system is that it has quite a broad spectrum compared to the other spectrometer results. The water spectrum has quite a diversity of frequencies. As seen in Fig. 15, the rotational line we are interested in has 6 hyperfine transition lines.[7] The strongest of those lines are the 7-6 and 6-5 lines, which have 39 and 33 Zeeman lines respectively.[8] The water system is also looking at a frequency effectively double that of the ozone or hydroxyl system, so Doppler spreading of the spectrum

Fig. 9.

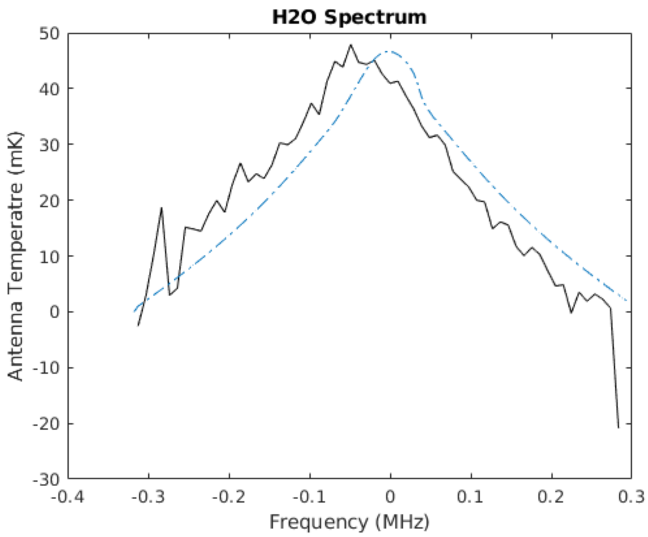


Fig. 10.

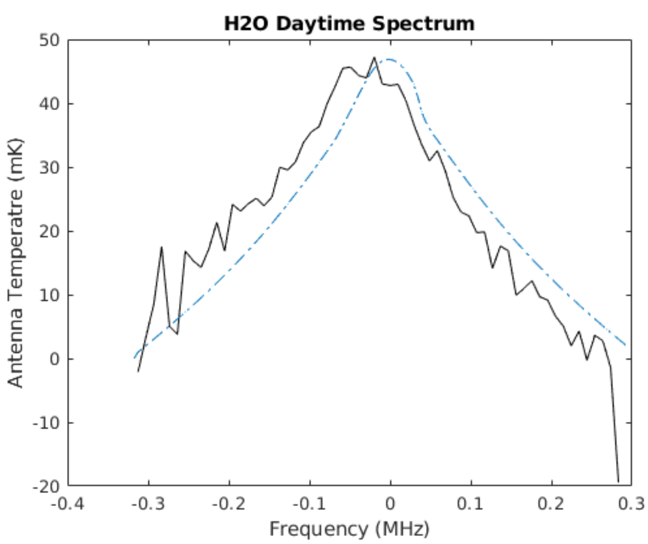


Fig. 11.

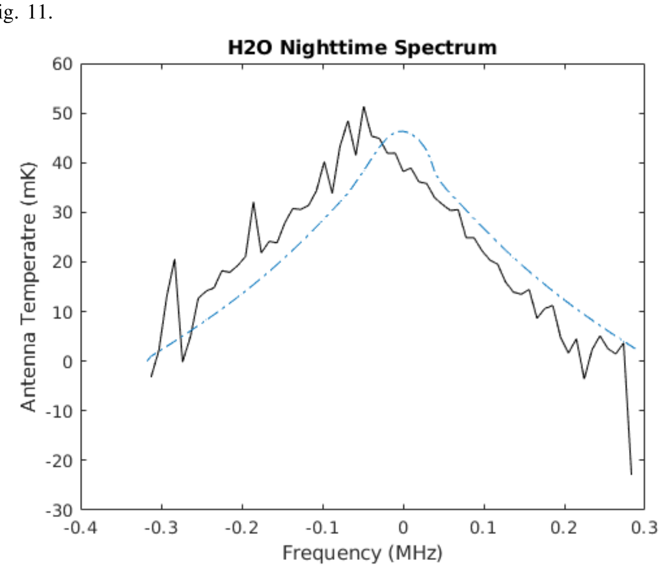


Fig. 12. Rotational states of water from Varshalovich 2006 [7]

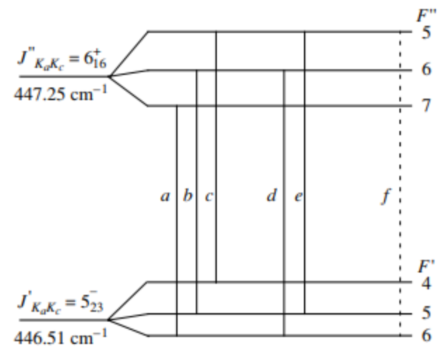
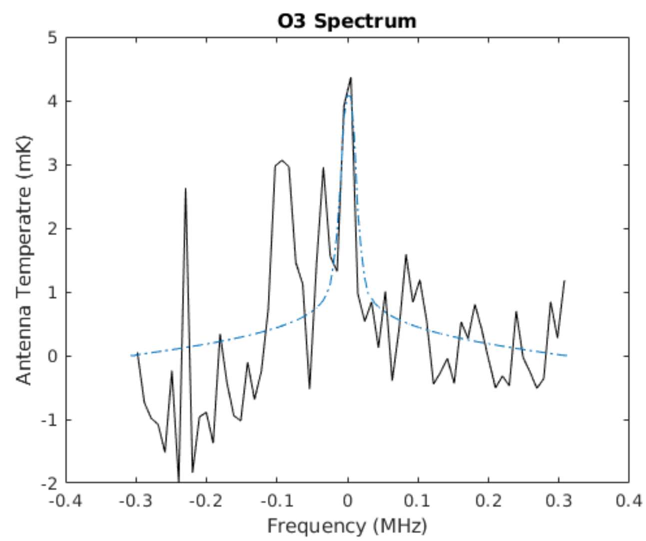


Fig. 13.



is more noticeable. It is typical for the spectrum to be quite broad, and other results also confirm this. [9]

What is less typical is the frequency offset between the weighted average [5] and the measured peak of the water data (see Fig. 9-11). Interestingly, there is a 0.048 MHz during the nighttime and a 0.02 MHz offset during the day, as well as a small difference in signal strength. This could mean that the water is being influenced by solar radiation, as the shift occurs towards the stronger hyperfine lines. The maximum offset possible from weighting completely to the 7-6 line, however, is only 0.03 GHz. This means that there may be more atmospheric or magnetic effects influencing the data to produce the full shift.

C. Ozone

The ozone spectra (see Fig. 13-15) produce the expected diurnal variation caused by solar radiation. However, the spectra also seem to show RFI sources, with a particular peak just left of center and one very strong peak at the left edge of the data (removed here for graphing purposes).

The dishes are much closer to the edge of the roof than the original system which almost touched the ground. This means they may be seeing a diffracted signal from the Anik

Fig. 14.

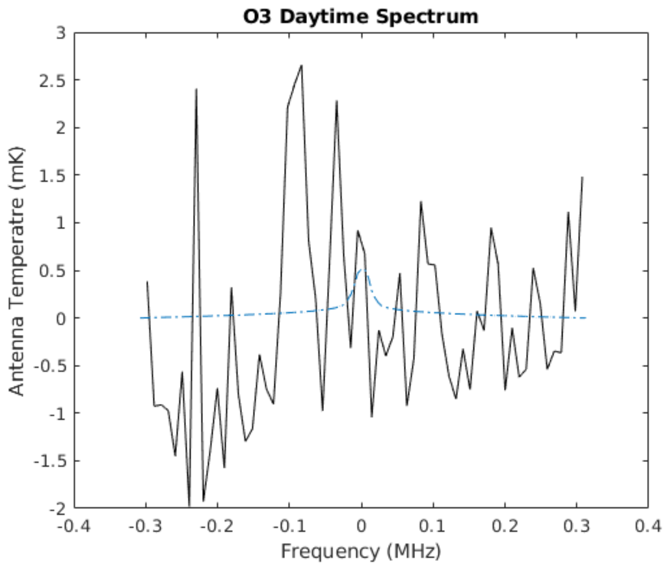
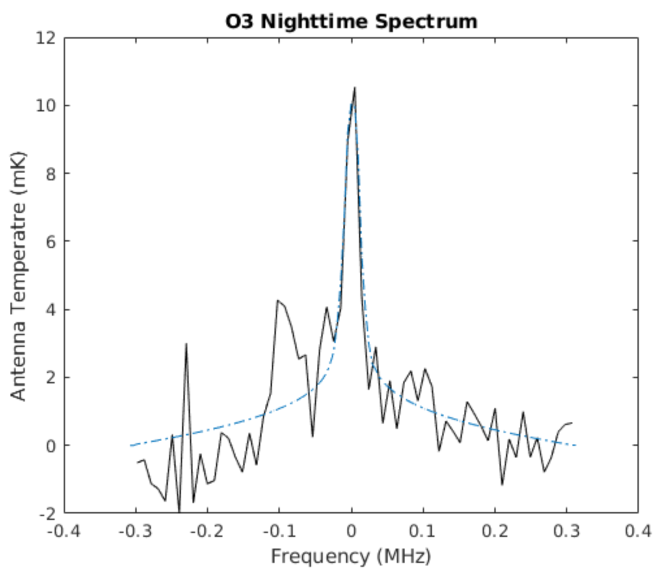


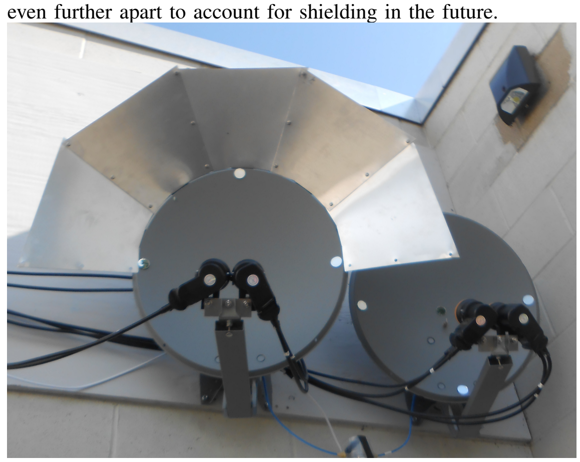
Fig. 15.



G1 satellite. [10]. The LNBFs also have a direct line of sight to the Haystack Radome, which happens to operate in 11 GHz.

A potential option is to add shielding to the dishes (see Fig. 16) to see if that reduces both spillover and RFI. After that, a better determination can be made on whether the noise has been reduced by a factor of $\sqrt[2]{8}$.

Fig. 16. The start of shielding on on of the dishes. The will need to be spaced even further apart to account for shielding in the future.



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