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Atmospheric Measurement Techniques
Discussions

# *Interactive comment on* "First Observations of the McMurdo-South Pole Ionospheric HF Channel" *by* Alex T. Chartier et al.

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AMT Response to Reviewer RC-1

Thanks for a thoughtful review of the paper. I will upload a revised manuscript through the website shortly - the website says not to provide the revision as a supplement here. My responses, including important modifications to the text are listed below.

1) Incorrect reference Changed

2) Missing citations Added

3) In section 1.2, the text here requires at least some basic discussion about magnetoionic theory.



We have added the following: "It is important to note that the formulation in Eqs. (1) and (2) is based only on ordinary-mode wave propagation and that mode splitting can occur in the presence of transverse magnetic fields, further adding to the uncertainty of NmF2 retrievals. Budden (1961) provides a comprehensive description of radio wave propagation in the ionosphere."

4) Near line 70, there is mention of a "âĹij14 dB signal processing gain"

We have removed that number to avoid confusion.

5) Near line 95: "Signals above 6dB":

Changed to: "All signals >6dB above the noise floor of the receiver"

6) Either in the "Method" section, or in the "Data processing" section, there needs to be some discussion of how the sounder works: such as how time of flight between the Tx and Rx sites is used to infer the virtual height. Likely this could be done near line 130 in the discussion of equation 3

Added the following explanation: "The virtual height is calculated from the range assuming simple triangular raypath geometry with a single reflection at the midpoint between McMurdo and South Pole. Earth's radius at the midpoint (required to calculate the height of the reflection) is taken from the World Geodetic System 1984 model (WGS84). Note that virtual height is larger than true height because it assumes propagation at the speed of light in free space and ignores signal refraction near the reflection point."

Note that we have made all the code available so interested readers may see how we have implemented these and other calculations. This one occurs in calc_dist() and calc_vht() within plot_rtd.py.

Minor:

1) Near line 40, "5000 km/hour": please meters per second

We prefer to keep the figure and units as stated in the original paper than to introduce a conversion that could potentially be erroneous (at least they are metric. . .)

2) “2x” near line 35 and “10x” near line 90, write these out as “2 times” and “10 times”

changed

3) Written differently, equation 2 is actually an equation for the electron density in terms of the plasma frequency, where all the constants have been approximated by 9. As such, it would be better to either: a. Rewrite this equation using the full equation for plasma frequency, or b. Use the approximately equal symbol, instead of the equals symbol.

Changed (approx. equal sign used)

4) Near line 60, please define “high temporal cadence”? This could be done with a time in brackets, such as (âĹij5 minutes). For example, the CADI ionosondes in Canada produce and ionogram once every âĹij5 minutes.

Added (2-min). Incidentally, 5 minutes might not be enough to catch a supposed typical “patch” (e.g. 200-km diameter travelling at 1 km/s is well within the bounds of the literature, and would pass over a point location in less than four minutes).

5) Near line 60, it might be useful to compare the number of ionosondes in 1957 to the 7 ionosondes maintained by the Canadian High Arctic Ionospheric Network, which are located in the Canadian Arctic (see: http://chain.physics.unb.ca/chain/pages/data_availability)

Added

6) Near line 70: “The number of ionosondes in existence and the availability of their data are restricted by their typically high cost and proprietary status.” How much does an ionosonde typically cost? Can a reference be provided?

Unfortunately we do not have a citation available to include a specific figure in the



manuscript, but $100 000 - $200 000 is typical.

7) Near line 75: “Signals from different transmitters can be separated through post-processing because each one uses a different pseudo-random code on the same frequency.” Some discussion about how this works, or a citation would be beneficial. Some readers will not be familiar with how phase coding and matched filtering techniques work.

Added a reference to Vierinen et al. (2016) where this information came from.

8) Near line 90: “pseudo-random binary phase modulations of 1000 bauds”: It might be clearer to also state the baud length (20 us). This makes it easier to see how one obtains 6000 km unambiguous range.

Added

9) Near line 115, does the “effective transmitted power” mean the RF power leaving the amplifier? This terminology sounds similar to “effective radiated power” which combines antenna gain and RF power into the antenna. Please clarify. Sorry to hear that the amplifier degraded like it did!

The description has been updated: “Based on the power/SWR meter installed on-site, we estimate that the system produced <50W total transmitted power. Over the course of the experiment, the amplifier developed distortion leading to excessive Standing-Wave Ratio (SWR) and out-of-band emissions, so it is not recommended for future installations.”

Our power meter showed figures between 30 – 100 W and SWR of 1.5 – 3 (both frequency-dependent), so we estimate that the power leaving the antenna never exceeded 50W (50% of power is reflected back towards the amplifier when SWR = 3).

10) Near line 120, is the LNA attached to the receive antenna or is it a pre-amp to between the N210 and RG-6?

The LNA is downstream of the bias tee, inside the vault. New text reads: "At the receiver site, an inexpensive 1m active broadband dipole antenna is mounted around 8' above the ice and connected to the receiver by 600' of RG-6 cable. The antenna receives phantom power from a bias tee located in the vault. Inside the vault, the signal is boosted ∼20dB by a low-noise amplifier and connected to a USRP N210 with BasicRx daughterboard and GPS-disciplined oscillator."

11) Near line 120: suggested "The system has been remotely reconfigured to use different frequencies and changed output power levels at various stages."

Changed to: "At various stages during testing, the system was remotely reconfigured through secure shell connection (SSH) to use different frequencies and output power levels."

12) Near line 120: Since this is a new instrument, it might be beneficial to explain how the data is collected and processed. Voltage samples are saved using DigitalRF? and then post processed how? Here might be a good place to refer readers to specific equations or sections of Vierinen et al. 2016 for parts of the processing that is identical.

Section 2.1 contains most of this information already, but we have added some clarifications to that part. The section now reads:

"We modify the Vierinen et al. (2016) meteor radar approach for ionospheric sounding by adding a frequency-hopping capability. This new code makes the transmitter and receiver step through a pre-defined list of frequencies at specified seconds past each minute. GPS timing signals trigger the oscillators to retune at precisely the same time in both stations. In the present application, this retuning occurs every five seconds, allowing the system to cover 12 frequencies each minute, but up to 60 frequencies could be used without modification of the underlying software. The frequency schedule can be changed simply by editing text files in the transmitter and receiver computers. Aside from that modification, the system is essentially unchanged from that used by Vierinen et al. (2016). The transmitter and receiver bandwidth is effectively 50 kHz



(with 10 times oversampling followed by integration and decimation employed at the receiver to reduce noise). The code consists of pseudo-random binary phase modulations of 1000 bauds in length, each 20 $\mu$s duration, yielding 6000 km unaliased range resolution. Received signals have DC offsets removed, have non-Gaussian components rejected to mitigate radio-frequency interference, and are then autocorrelated with the pseudo-random code to produce range-Doppler-intensity matrices for each analysis period (5-s). All signals >6dB above the noise floor of the receiver are sent back as sparse matrices whenever internet access is available, while the raw I/Q is stored on-site in DigitalRF format for future retrieval and analysis. The result is a remotely-controllable instrument that has a data budget of only a few MB/day and delivers ionospheric soundings at a cadence of one minute. The code for this system is publicly available at github.com/alexchartier/sounder."

13) Near line 130: Are there any plans to model the calibration factor C? One should be able to estimate the factor with an inverse problem where the forward model predicts the time of flight by ray tracing through a model ionosphere. A good candidate model ionosphere that works at high latitude might be E-CHAIM (doi: 10.1002/2017JA024398). At the very least, such a model could provide an apriori from which a perturbation electron density profile could be inferred from the measured time of flight compared to the modeled time of flight.

We are working on raytracing approaches to this and other HF datasets, and will keep E-CHAIM in mind.

14) Near line 160: "which covers more than >2500 km of virtual height and 3000 m/s Doppler velocity". Is this 3000 m/s capability +/- or total? All of this could be discussed together in one section/subsection where a full description of the new sounder is given.

The text has been modified to clarify that this is total resolution: "(>2500 km virtual height and 3000 m/s total Doppler resolution)." The physically-expected Doppler is very small because the system is observing apparent vertical motion for the most part.

The ExB component (observed for example by SuperDARN) is much larger than the vertical component, yet even that is typically below 1000 m/s. We make this point about resolution here in the discussion simply to point out that the system appears to be working correctly.

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