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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.

Anonymous Referee #1

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Summary

In this manuscript high frequency (HF) ionospheric sounder utilizing modern software defined radio (SDR) techniques is described. The sounder was deployment in Antarctica to provide ionospheric diagnostics in an effort to provide more data coverage for studying the polar cap ionosphere. In contrast to sounders on satellites, this sounder composed of a bi-static ground based system with a single antenna transmitter site nearby the McMurdo Station and the receiver site located at South Pole.

First results from the sounder are presented and compared with data from the VIPIR ionosonde and MIDAS TEC maps. The comparisons show largely good agreement

despite the broad geographical distance between the sounder volume and VIPIR and the significant mismatch in spatial resolution between the sounder and MIDAS. The comparisons seem to validate that the HF sounder is functioning as expected.

While I find the scientific significance of the paper to be excellent, both the scientific quality and the presentation quality require improvement. For example, there are missing references, confused references, and some misuse of terminology that confuses the message of the paper. There is also a need to include some of the theoretical details that enable oblique sounding to function as it does as well as are required for understanding and interpreting the data from an oblique sounder. The instrument is not as well explained as it could be and inclusion of more details with theoretical background information would improve the scientific quality of the paper. For these reasons, I recommend the manuscript be accepted subject to major revision.

Major Comments

Below follows selected major comments. These are structural and/or comments about clarity of ideas and arguments. These are crucial and need to be addressed.

1) Incorrect reference? The citation of Vierinen et al. [2015] near line 70 appears to be incorrect. I believe the authors meant to cite this 2016 publication instead: https://www.atmos-meas-tech.net/9/829/2016/ Please fix this/clarify.

2) Missing citations! A significant number of the citations in the paper are missing from the references section!

a. Vierinen et al. (2015)

b. Vierinen et al. (2016)

c. Lockwood and Carlson (1992)

d. Noja et al. (2013)

e. Chartier et al. (2019)

f. Coley and Heelis (1998)

g. Spicher et al. (2018)

h. David et al. (2019)

i. Breit and Tuve (1925)

Also, I believe that the authors need to cite the Digital RF project, as requested by the developers: https://github.com/MITHaystack/digital_rf#Citation There is an acknowledgement of the use of Digital RF in the acknowledgement section, but a citation needs to be added as well.

3) In section 1.2, the text here requires at least some basic discussion about magnetoionic theory. Fundamentally, the propagation of radio waves through the ionosphere is described by the Appleton-Hartree equation. Fundamentally, this is why the equation relating foF2 and MOF is approximate, because it assumes some things such as spatial uniformity of the vertical ionospheric plasma density profile, which might not hold true. A brief couple of sentences about where equation 1 comes from, the fundamental physical principles underlying it, and the assumptions baked in are needed here. Similarly, equation 2 needs to be explained to be an approximation of the equation relating plasma frequency and electron density. One should also note that this equation is only valid for the ordinary propagation mode, whereas the extraordinary propagation mode includes a gyrofrequency dependence. For oblique propagation nearly perpendicular to the magnetic field (known as Quasi-transverse propagation), there is still mode splitting. Does the new sounder account for mode splitting (via polarization measurements, assuming the splitting is negligible and if so that should be discussed here)?

4) Near line 70, there is mention of a "$\sim$14 dB signal processing gain", but there is absolutely no context for this claim. The closest thing I can find is this sentence directly in Vierenen et al. (2016) [https://www.atmos-meas-tech.net/9/829/2016/]:

"For example, a continuous transmission would result in $\sim$14 dB of increased signal processing gain when compared to a pulsed system with a duty cycle of 4.4 %"

But this isn't actually what is commonly understood as a signal processing gain. The 14 dB gain results from increasing the duty cycle from 4.4% to 100% (10 log(1/0.044) = $\sim$13.6 dB). Of course there will also be a processing gain associated with matched filtering to the pseudo random code, but this gain isn't discussed anywhere in the current manuscript. The lack of context and confusing terminology needs to be addressed, which could be as simple as expanding the discussion to note that increasing the duty cycle provide an effective gain over pulsed systems in addition to the gain provided by coding of the transmission. Processing gain is typically the terminology used in communications, whereas pulse compression is typically the terminology used in radar. Both are the result of using spread spectrum techniques (i.e. effectively what the pulse coding does), not changing duty cycle.

5) Near line 95: "Signals above 6dB": Is this relative to some absolute or relative power measurement? At HF, the noise environment is known to be highly variable with time of day. Please clarify and expand on this.

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. Only a sentence or two is needed. As it is now, there is a lot of inference required from the reader to understand how this works.

Minor Comments/Corrections

Below are selected minor corrections, largely composed of grammar and spelling corrections. Some may be stylistic and can be treated as suggestions.

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

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

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.

4) Near line 60, please define “high temporal cadence”? This could be done with a time in brackets, such as ($\sim$5 minutes). For example, the CADI ionosondes in Canada produce and ionogram once every $\sim$5 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)

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?

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.

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.

9) Near line 115, does the “effective transmitted power” mean the RF power leav-

ing 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!

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?

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

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.

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.

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.

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