Automated Methods for Studying Long-Scale Ionospheric Disturbances and Climatology

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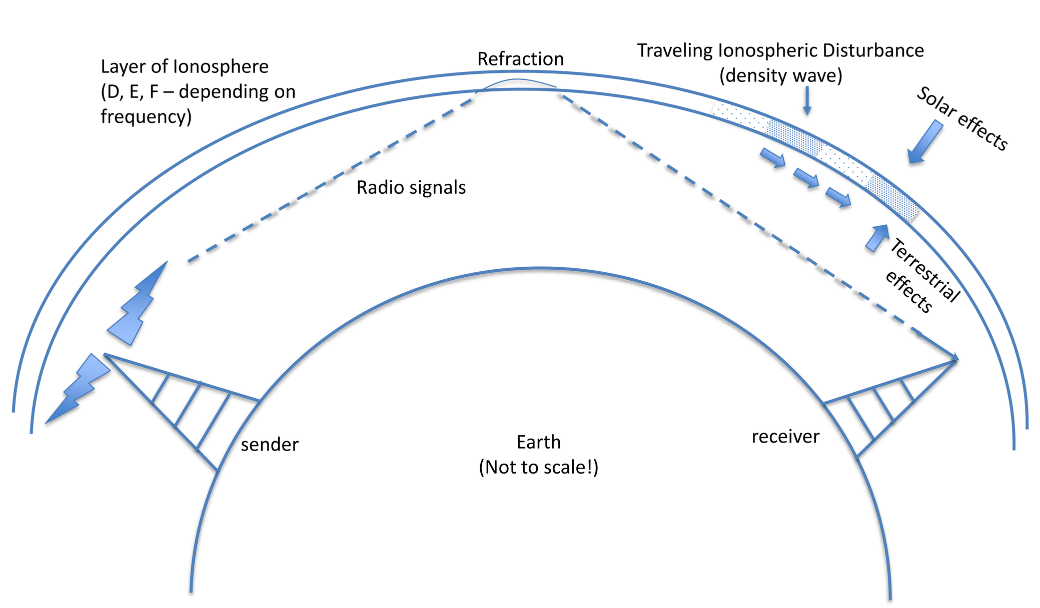
Abstract

Amateur radio operators ("hams") use several digital modes of communication. Signal reports from these contacts (over 30 million per day) are reported to three main databases (RBN, WSPR & PSK). By analyzing these reports, we can infer how HF radio propagation varies throughout the day and use these patterns to detect Large Scale Traveling Ionospheric Disturbances (LSTIDs), and from that study the climatology of the ionosphere. This presentation looks at some automated methods being developed to detect LSTIDs using the amateur radio signal report data.

Introduction

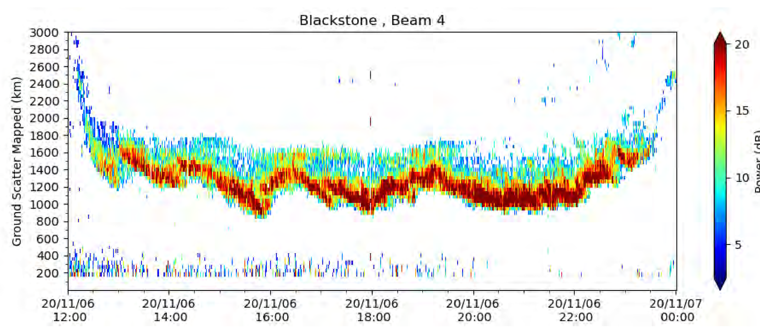
- High frequency radio signals ("HF" – between 3 MHz and 30 MHz) are refracted by the ionosphere, a layer of ionized particles 48 km to 965 km altitude[1]
- This enables long distance and over-the-horizon communication
- Amateur radio operators use this phenomenon to send signals and even compete with each other ("radio sport") to exchange signals with as many different locations (domestically and other countries) as possible
- Digital communication modes (Morse code, or "CW," PSK and WSPR are decodable with a computer connected to the radio) and are usually set up to report signals received to central databases
- The central databases can be processed to analyze signal propagation
- The analyzed signal data can be visualized similarly to the SuperDARN HF Radar system used to study the ionosphere in North America[2] and Europe (where stations have enough density)
- Waves in electron density propagate through the ionosphere; these are called Traveling Ionospheric Disturbances (TIDs).

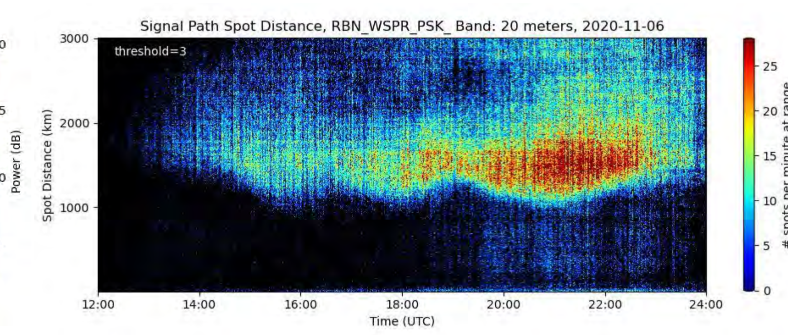


- TIDs can affect HF propagation and GPS accuracy
- We can detect and study TIDs by a variety of means, including analyzing amateur radio signal reception data
- This project focuses on using automated techniques to detect and characterize TIDs using data from amateur radio databases
- The causes of TIDs are still being investigated, but are thought to include solar effects, the polar vortex[3] and possibly even thunderstorms[4] ; much research remains to be done in this area

Method/Experiment

- Daily, we download files of signal reports from the three databases and put them in a common format. For analysis, we select signals starting and ending in a given continent; to visualize, we show the reports by time and signal distance, creating an image directly comparable to a SuperDARN plot.

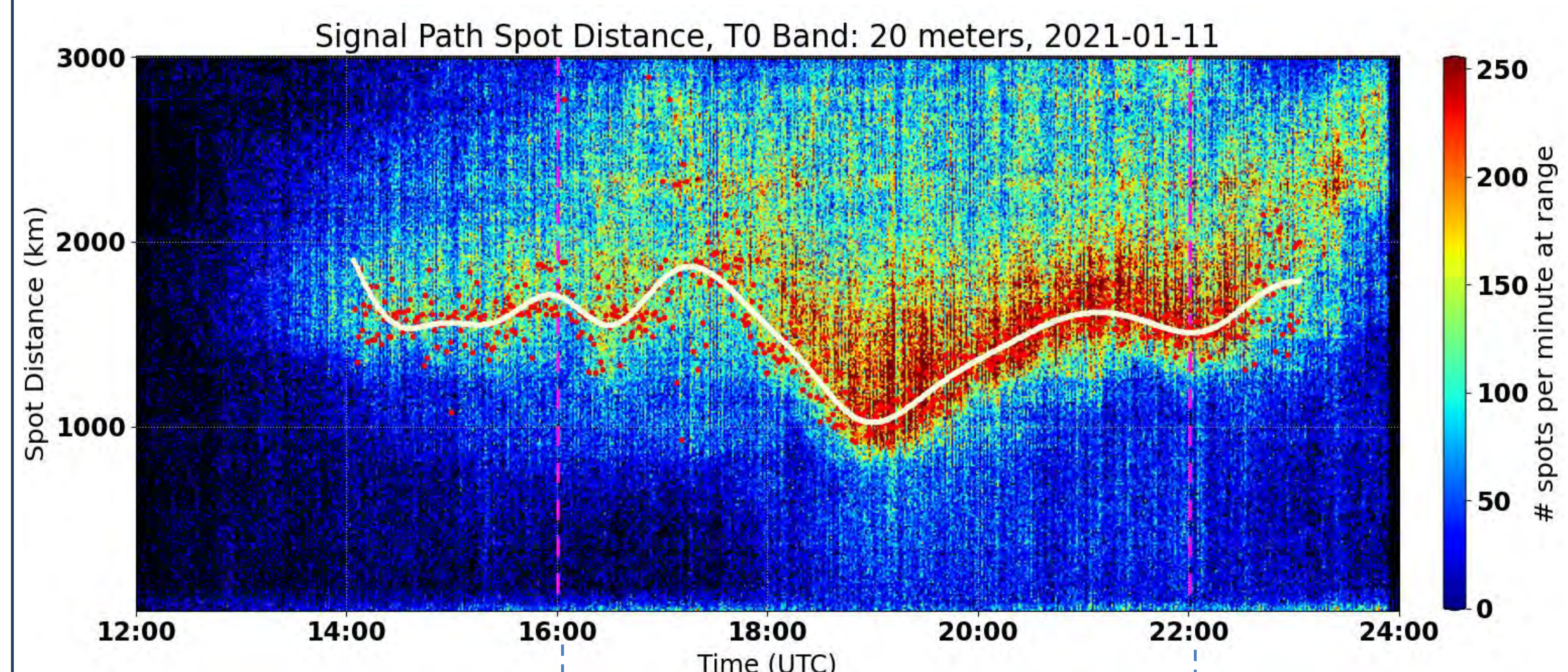




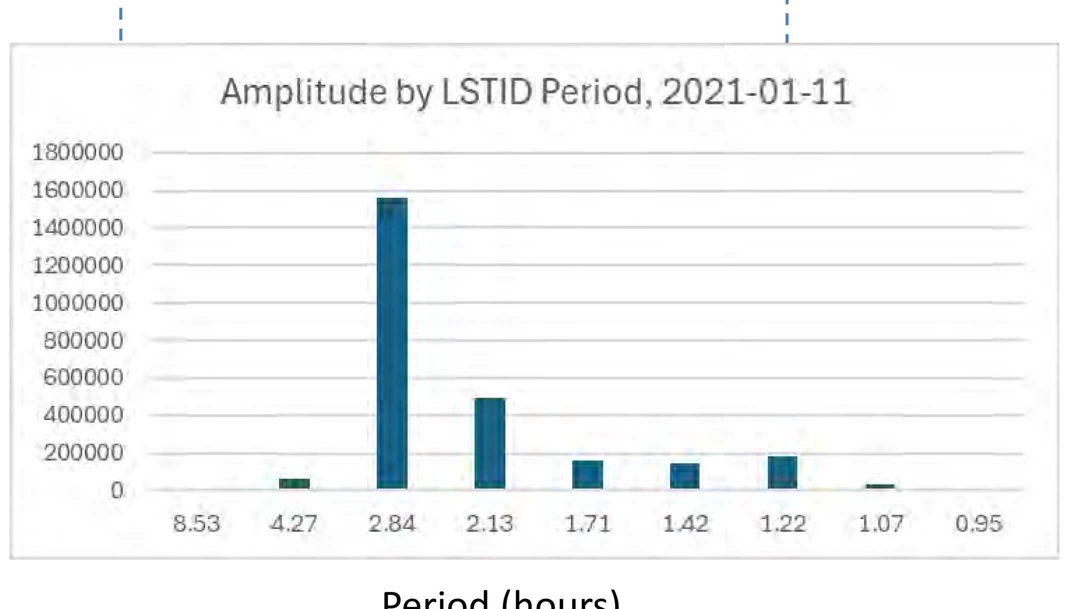
- Above left is a SuperDARN plot showing HF ground scatter from the Blackstone HF radar site (which covers much of North America). On the right is an image of radio reports similarly plotted by time and range. We see the same sine-wave-shaped features in both for the same day.
- This method was originally described by Frissell et al. (2022)[2].

Data and Analysis

- For automated LSTID detection, we developed a minute-by-minute gradient detection algorithm to find the main lower edge of the distance plot, finding the Minimum Useful Range (MUR). The changing of the MUR over time shows how HF signal propagation distance for a given frequency (14 MHz, or 20 meters wavelength) changes as the ionospheric electron density changes due to TID activity.

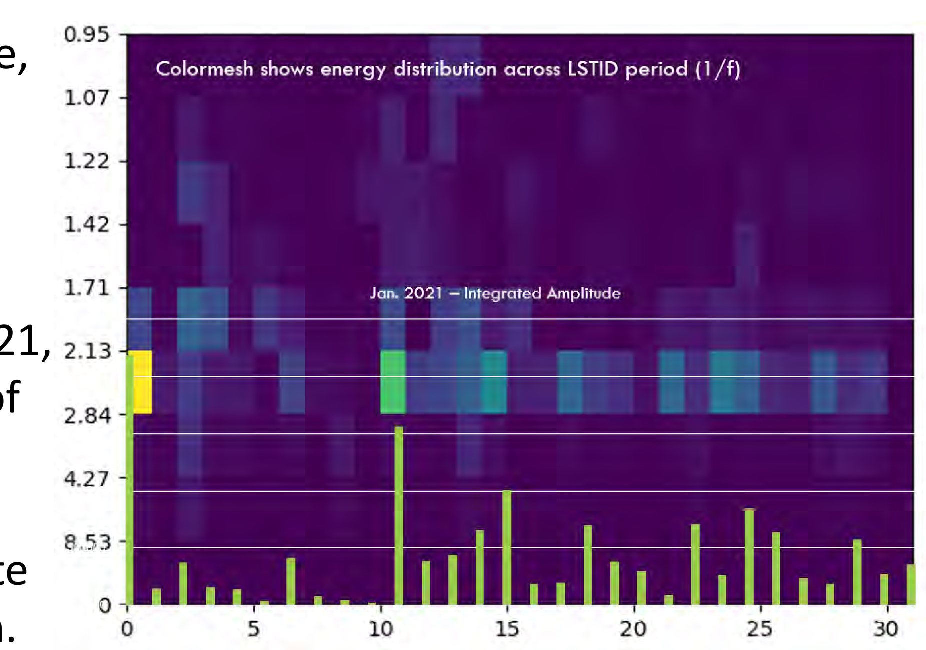


An FFT analysis detected a strong TID on 2021-01-11. The integrated spectral power on that day was very high.

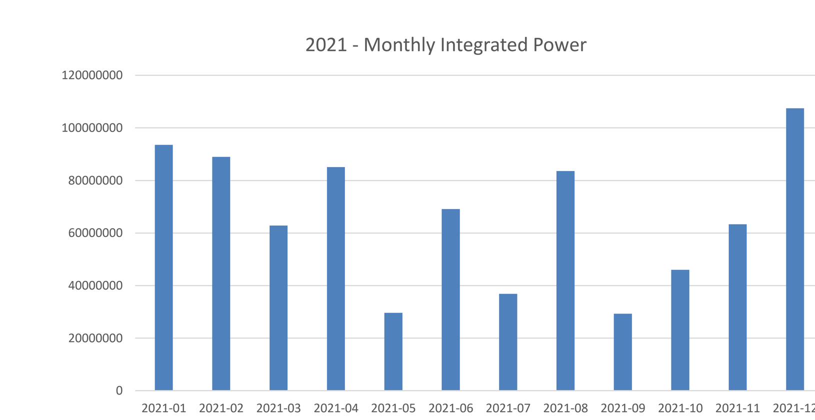


Conclusion

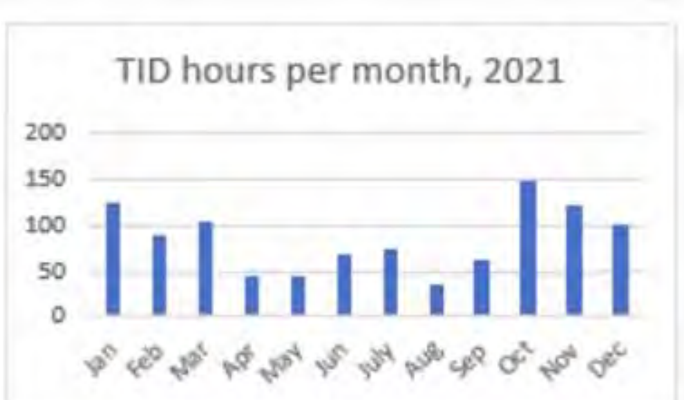
- We have a way to detect TIDs in the amateur radio data, with the ability to estimate the intensity of the TID as expressed by integrated spectral power. **Note that these are interim results, which still need to be further examined for accuracy**.
- By calculating this over time, we can study the climatology of the ionosphere. For example, on the right is a plot of integrated spectral power over the month of January 2021, Plotted over the distribution of LSTID periods as estimated by FFT. Here we see two LSTID events (Jan. 1 and Jan 11); note the possible repeating pattern.



- For all of 2021, we have the following:



Automated Climatology



Manual Climatology

- This shows strong TID activity in the winter, a dip in activity around the equinoxes, and a summer peak. This is generally consistent with a manual climatology generated by this group.
- Possibly this suggests more than one driving factor behind TID activity.
- Polar vortex forcing during the winter is likely based on this and other ongoing research by this team.
- Thunderstorm or Sporadic E activity is a possible source during the summer but is still under investigation. Both thunderstorms and Sporadic E are known to have higher occurrence rates in summer.
- Auroral forcing is also a likely contributor to observed LSTIDs.

References

1 Poole, Ian, "Radio Waves and the Ionosphere", QST, American Radio Relay League, Nov. 1999 - https://www.arrl.org/files/file/Technology/pdf/119962.pdf

2 Frissell, N. A., Kaeppler, S. R., Sanchez, D. F., Perry, G. W., Engelke, W. D., Erickson, P. J., et al. (2022). First observations of large scale traveling ionospheric disturbances using automated amateur radio receiving networks. Geophysical Research Letters, 49, e2022GL097879. https://doi.org/10.1029/2022GL097879

3 Frissell, et al, "Sources and characteristics of medium-scale traveling ionospheric disturbances observed by high-frequency radars in the North American sector, JGR Space Physics, 20 March 2016 - https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022GL097879

4 Los Alamos National Lab., "Lightning strokes can probe the ionosphere," Phys.Org., April, 2013 - https://phys.org/news/2013-04-lightning-probe-ionosphere.html

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- We acknowledge the use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and others (e.g., Millman & Aivazis, 2011).

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