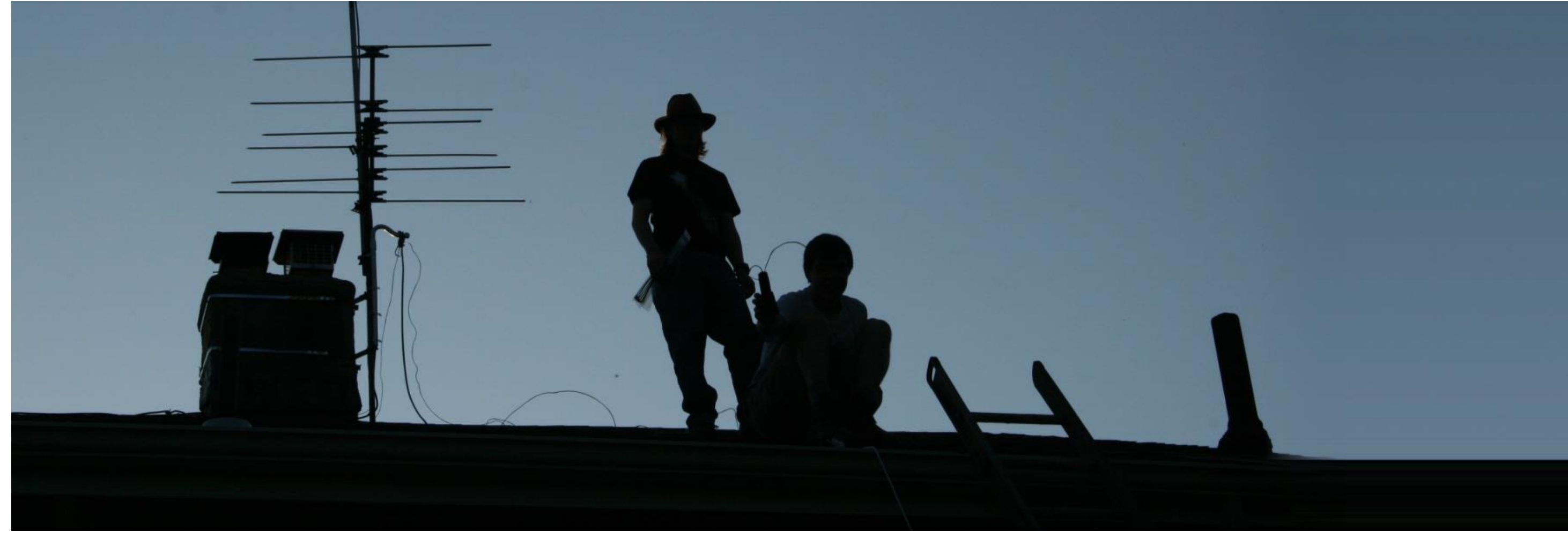

Making Amateur Radio Data Available for Ionospheric Research

Billions of crowd-sourced (citizen science) radio signal reports are now available in Madrigal

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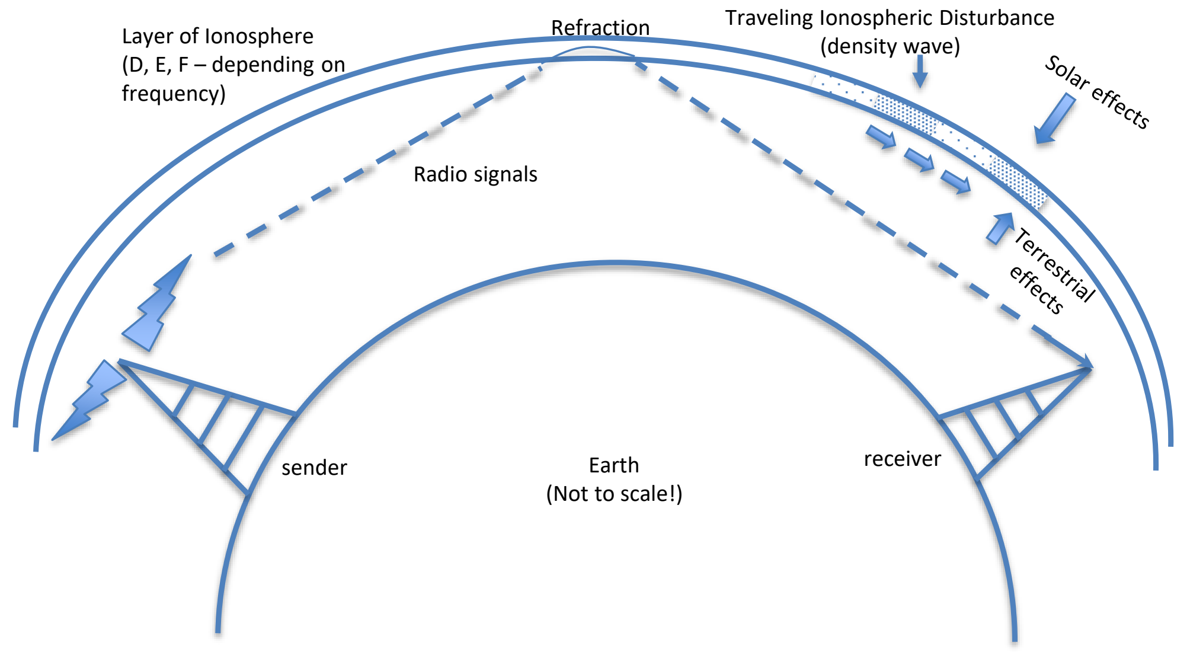
Abstract

Amateur radio operators ("hams") use several digital modes of communication. These include CW (Continuous Wave, or Morse Code), WSPR (Weak Signal Reporting Network, used for monitoring and studying HF propagation), and noise-tolerant/low-signal modes such as FT4, FT8, MSK144 etc.) Signal reports from these contacts (over 150 million per day) are reported to three main databases (Reverse Beacon Network or RBN, Weak Signal Reporting Network or WSPR, and PSK Reporter). 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 explains how the data we collect is being prepared and made available for scientific study.

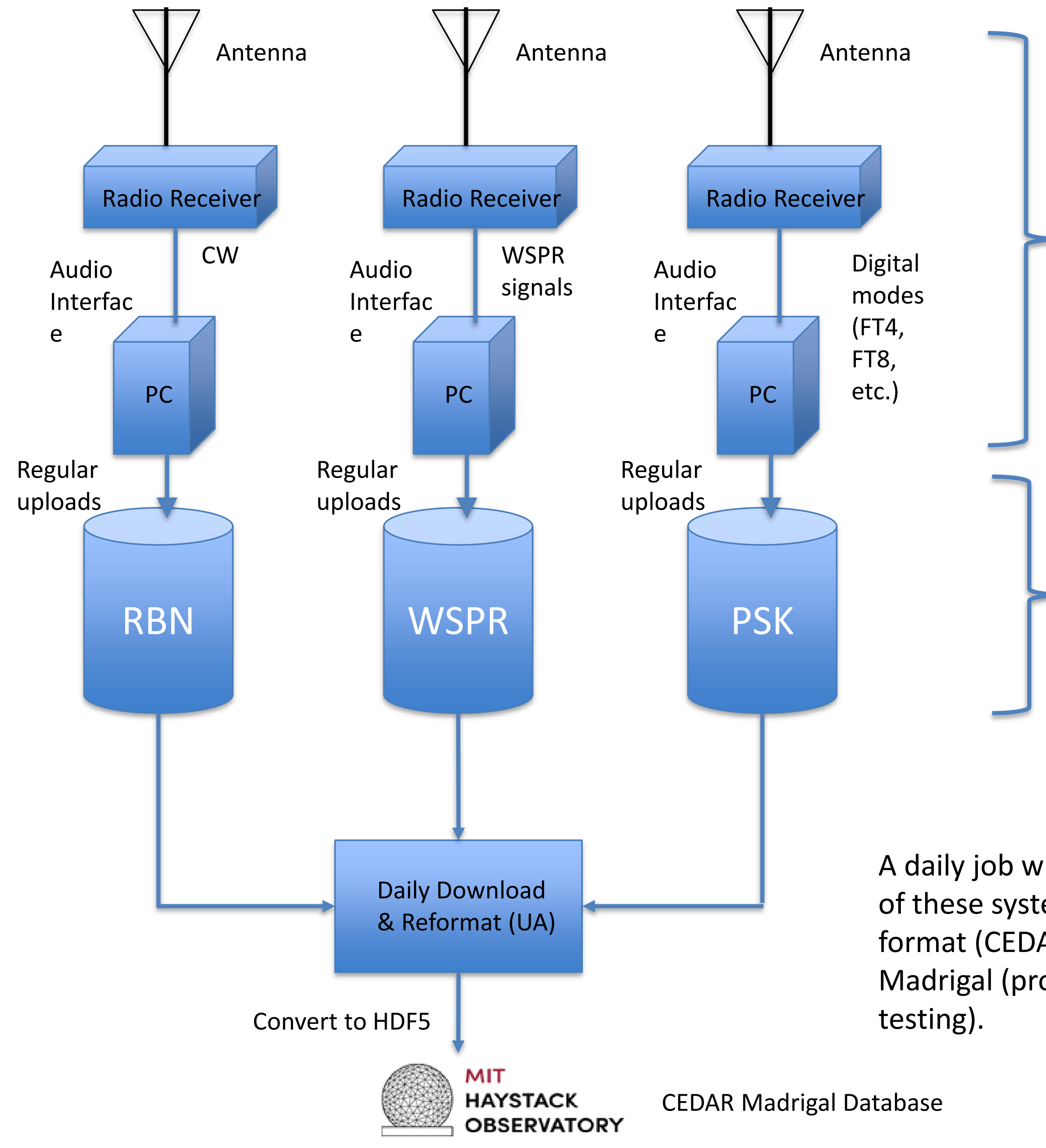
Introduction

- 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]



- 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

Data Collection



About 125,000 hams worldwide are collecting and reporting these signals 24 hours per day.

Volunteers run these systems, collecting signal reports using automated systems.

A daily job will collect data from each of these systems, put into a common format (CEDAR) and upload to Madrigal (process currently in final testing).

What's in the data?

We receive over **150 million signal reports per day** from all over the world, on bands LF through SHF. These reports are called "spots." There are about 125,000 unique stations transmitting.

Each spot contains (among other things):

- Sender's amateur callsign and latitude/longitude
- Receiver's amateur callsign and latitude/longitude
- Frequency, Date and Time
- Signal strength (when available)
- We can estimate the signal's path length and centerpoint using the Haversine formula.

This system and SuperDARN complement each other. While HF signal analysis does not have the resolution of SuperDARN, it covers all continents that have a significant number of amateur radio operators and runs "24 by 7." Path length estimates assume short path.

References

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5 JAXA/NASA/Hinode/SAO/MSU/Joy Ng

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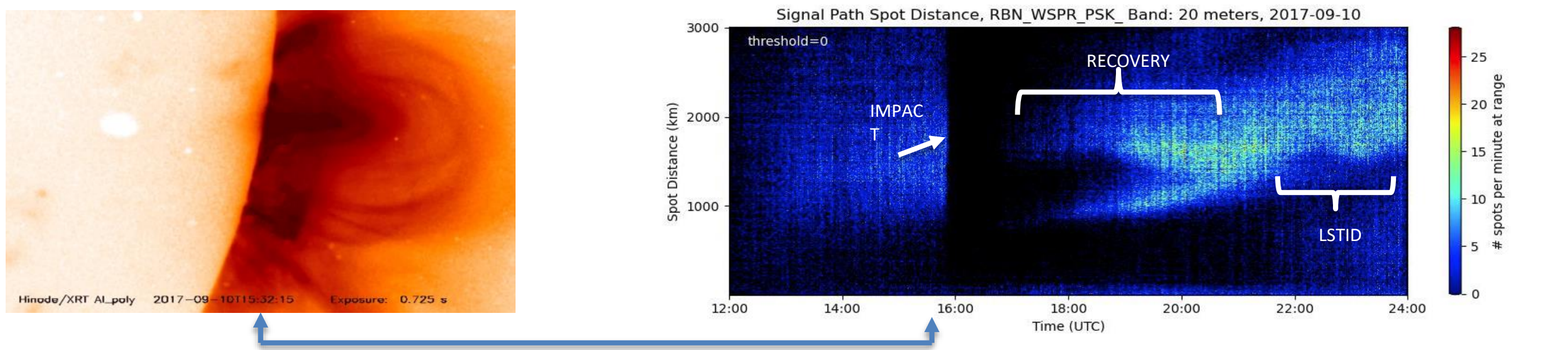
- We acknowledge the use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and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

Examples of Data Analysis

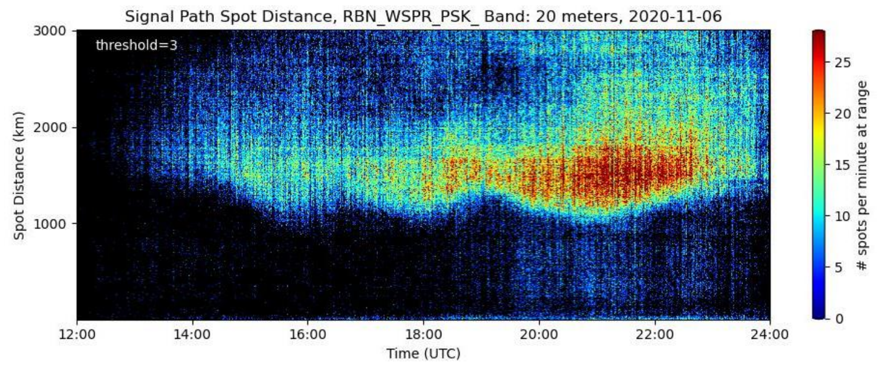
Here are some examples of the types of scientific analyses you can do with amateur radio signal report data:

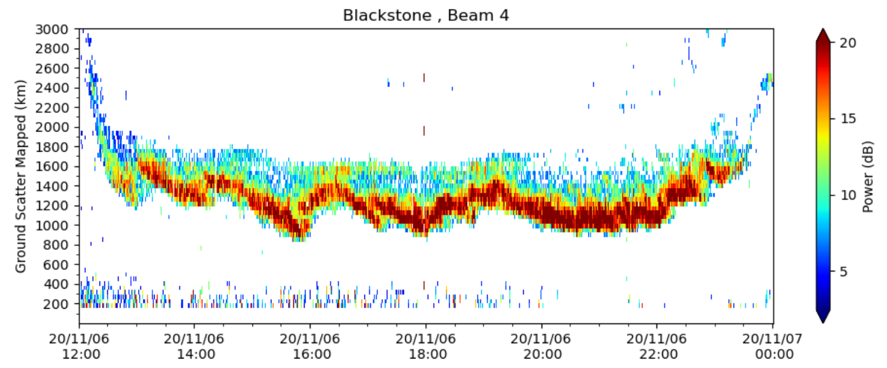
- Observing the effects of solar flares and solar/geomagnetic storms. Here we see how the flare of 10 Sep 2017 wiped out propagation on 14 MHz:



JAXA/NASA's Hinode caught this image of an X8.2 flare on Sept. 10, 2017, the second largest flare of this solar cycle, with its X-ray Telescope(left)[5]. Ham radio spot data (right) shows how radiation from the flare reached earth 8 minutes later, and we see how the band recovered over 3-4 hours(right).

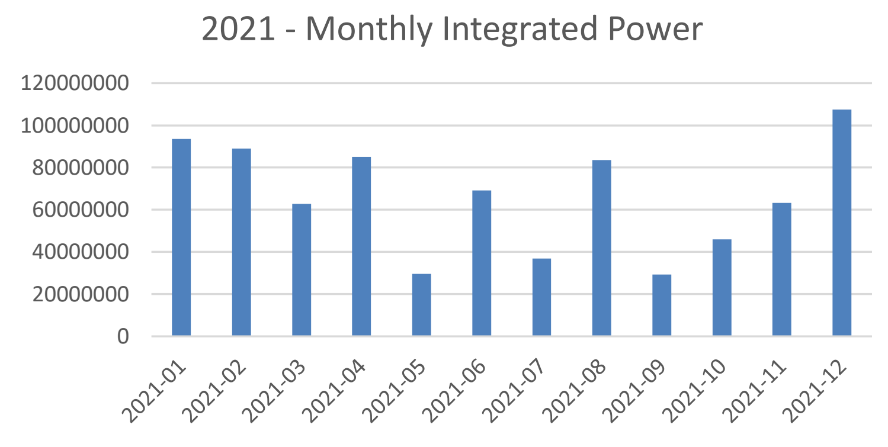
- Detecting Large Scale Traveling Ionospheric Disturbances with the ability to estimate the intensity of the TID. If we plot the data with time on the x-axis, signal range (distance) on the y-axis, and color proportional to the number of signal reports, we can observe Large Scale TIDs (1 to 4 hours in period)(below, left). This maps well to SuperDARN(below, right). Sine-wave shapes in the lower edge (Minimum Useful Range) indicate an LSTID, and be analyzed using FFT and Machine Learning techniques.





- Studying the climatology of the ionosphere. For example, here is a plot of integrated spectral power over the month of January 2021:

(Automated)



(Manual)

Here we see 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(right).

- 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.
- The wide bandwidth of collected data (135 kHz through microwaves) can facilitate study of a wide range of other phenomena, ranging from thunderstorm effects to Sporadic E, GPS accuracy and the solar cycle.

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