Climatology of Large-Scale Traveling Ionospheric Disturbances Observed with 14 MHz Amateur Radio Using a Novel Automated Detection Technique

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Abstract

Amateur radio networks provide a powerful, distributed platform for studying ionospheric variability and magnetosphere-atmosphere coupling processes. We present a multi-year climatology of Large Scale Traveling Ionospheric Disturbance (LSTID) period oscillations observed using 14 MHz amateur (ham) radio data. LSTIDs are quasi-periodic electron density perturbations in the F region of the ionosphere that affect radio communications and serve as indicators of energy transfer across the coupled magnetosphere-ionosphere-atmosphere system. These signatures appear during daytime as fluctuations in contact range observed in automated amateur radio reporting systems such as the Weak Signal Propagation Reporting Network (WSPRNet), the Reverse Beacon Network (RBN), and PSKReporter. A new deterministic and fully automated detection method was developed to identify these disturbances by filtering for TID wave periods between 1 and 5 hours and curve-fitting sinusoidal functions to the first-hop skip-distance edges of observed communication ranges. Using this method, we present full-year climatologies of LSTID activity over the continental United States (CONUS) based on RBN, WSPRNet, and PSK observations from 2016 to 2021. Results are organized by wave period, amplitude, and season, showing enhanced LSTID occurrence in winter and reduced activity in fall and spring, with modest increases in summer. In addition to LSTID studies, preliminary efforts are underway to characterize equatorial plasma bubble (EPB) signatures in the amateur radio data, further expanding the scientific potential of citizen-operated observation networks.

Introduction

An amalgamation of amateur radio signals from distributed passive radio receiver networks provides a new tool for investigating characteristics of the complex ionosphere. This tool is voluminous, geographically widespread, and free. This work investigates some of its ambiguities.

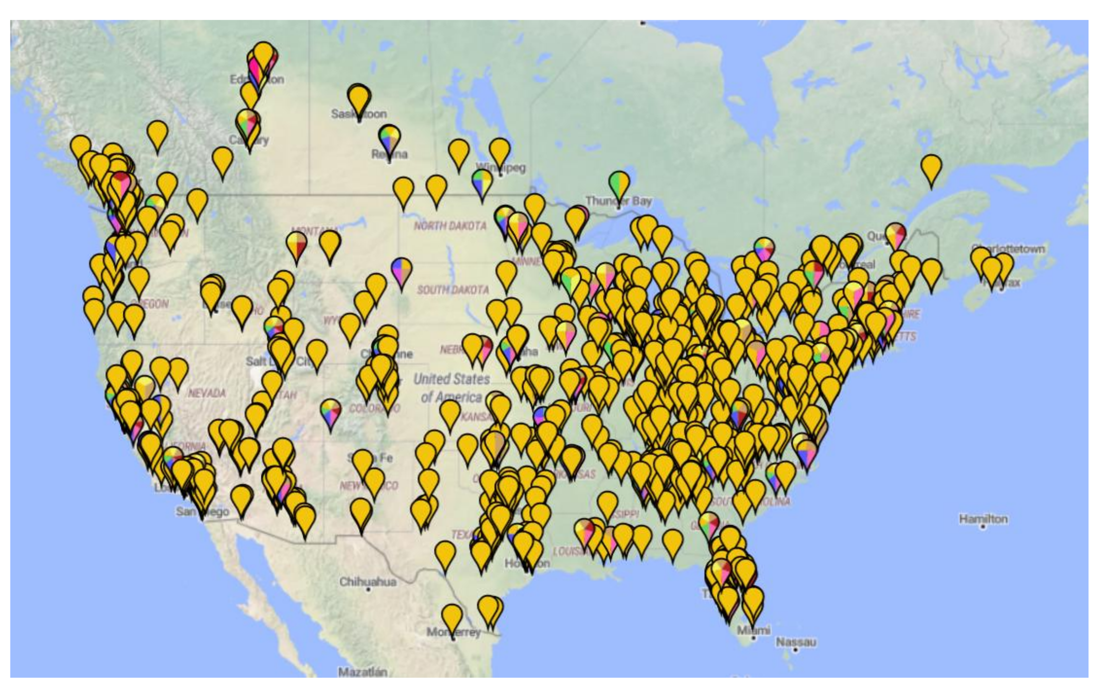


Figure 1: Layers of the Earth's atmosphere including ionosphere layers and altitudes.

- Visually found quasi-periodic variations in the minimum HF signal distance within WSPRNet, RBN, and PSKReporter ham radio observations, yielding LSTID parameters.
- WSPRNet, RBN, PSKReporter are automated communication observation networks that are voluntarily operated by amateur radio operators that can monitor and log radio signals.
- Each datum ("spot") includes information on the transmitter, receiver, time, and frequency.

The relevant amateur radio operators (transmitter and receiver) were geofenced to be within the continental United States. It is assumed that their transmission was reflected off the ionosphere right above its midpoint. Tallies of these transmissions were gathered from RBN, WSPR, and PSK reporter databases on a one-minute cadence. These data were assembled into pixels 25 km wide. The range of 12 to 24 UTC and 0 to 3000 km resulted in 0 to 720 minutes by 0 to 120 pixels (86, 400 pixels in total). Our data was a plot of these spots, colored by the number of contacts in a pixel.

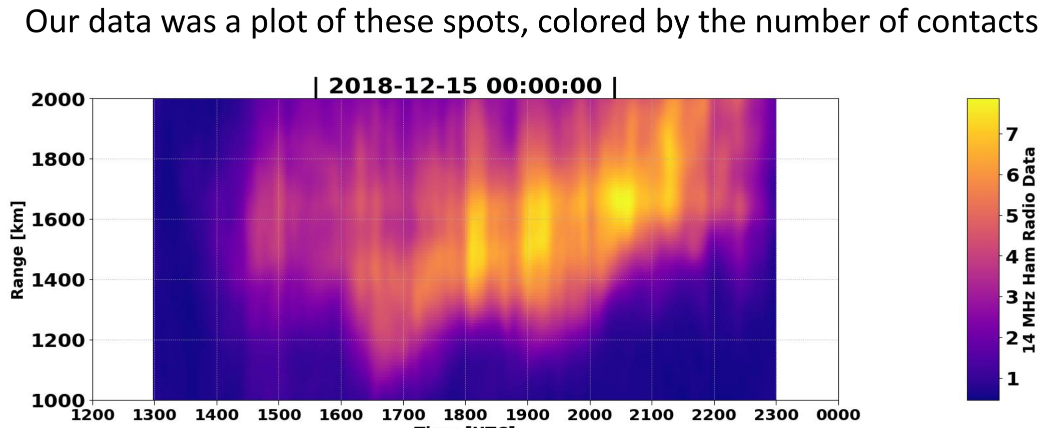


Figure 2: Pre-processed amateur radio histogram.

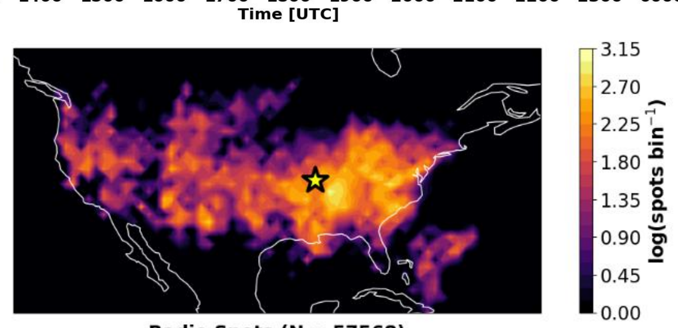
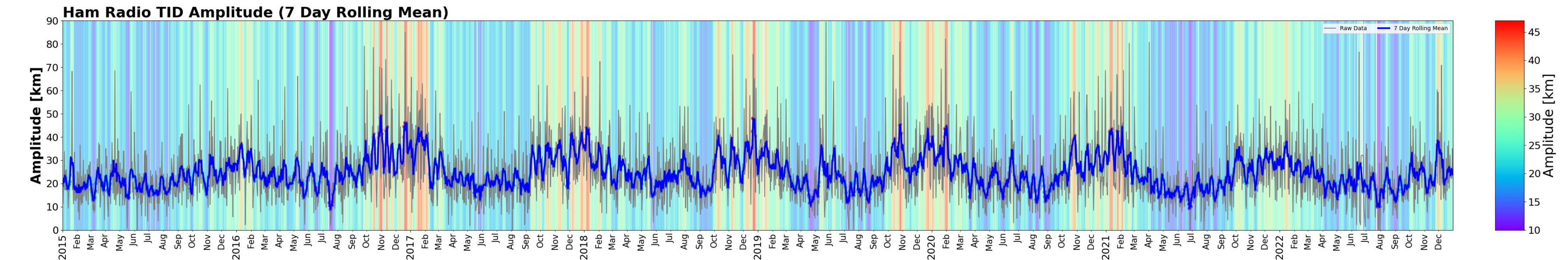


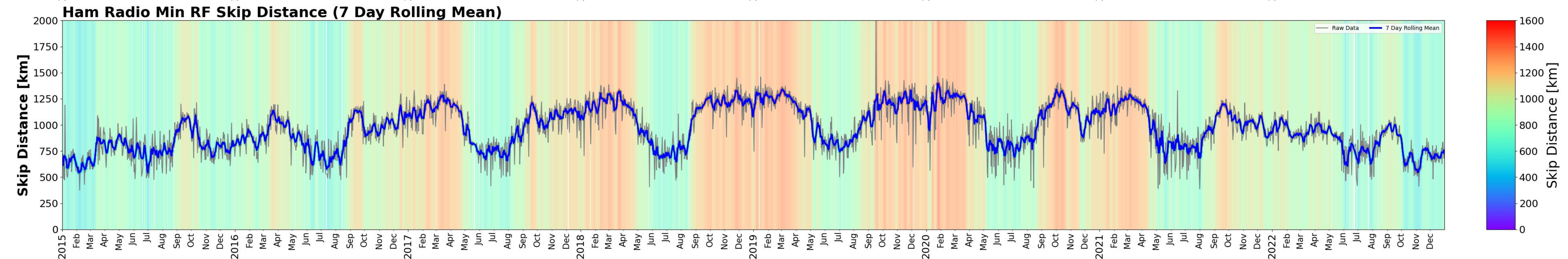
Figure 3: 2D Ham radio histograms generated from RBN and WSPRNet with geographic location of midpoints between transmitters and receivers.

Results



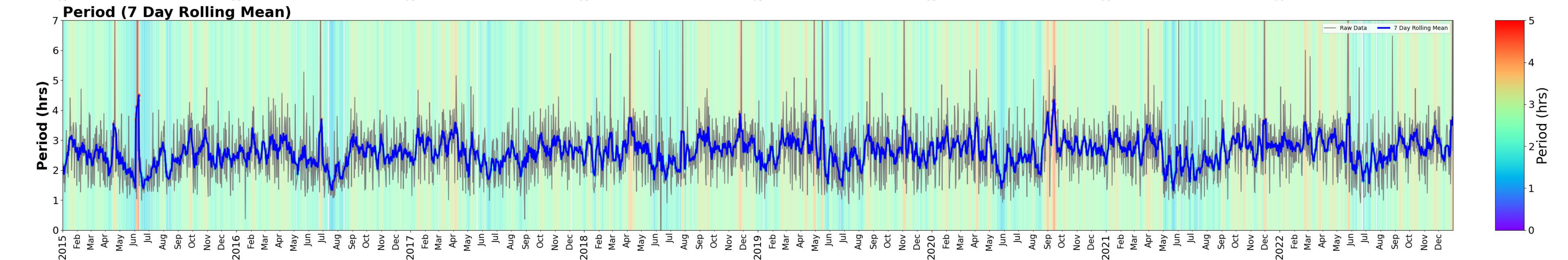
Key parameters like amplitude, period, and skip distance are extracted from the generated sinusoid fits and used to create two climatology's.

Figure 7 Daily disturbance amplitude in kilometers.



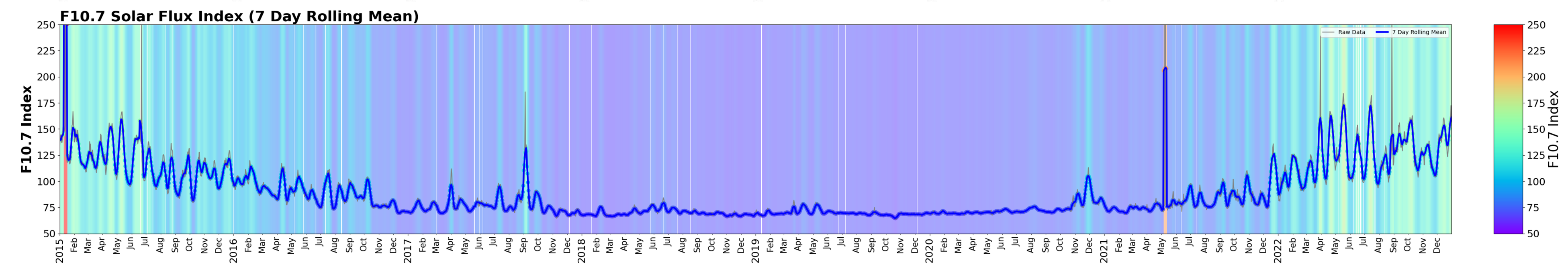
Daily values of each parameter were visualized along with a rolling average, that was applied to help smooth short-term noise and highlight trends and seasonal variations. Extra color-coding of the data points was used to provide additional insights into how these parameters vary with time. Amplitude and minimum skip distance were chosen as the two main parameters to observe.

Figure 8: Minimum daily value in kilometers of the superimposed curve fit from figure 4.



Results show that the automated detection see increases LSTID activity during the winter months, with a decline during the spring and fall, with occasional enhancements during the summer. Each year appear relatively consistent with each other. Figure 7 also shows that there is an overall increase in the minimum skip distance from one year to another. Data from 2015 and 2016 show much lower overall minimum skip distances.

Figure 9: Daily disturbance period in hours.



Minimum RF skip distance over multiple years also shows a clear pattern that aligns with the solar cycle. As the average yearly minimum skip distance increases, the solar flux values decrease, indicating a transition toward solar minimum. This inverse relationship highlights how ionospheric conditions, reflected in RF propagation, are strongly influenced by solar activity.

Figure 10: Solar Flux Index showing yearly solar cycle patterns.

Method

A deterministic and fully automated detection method was then developed to find these LSTID structures in the amateur ham radio spot data. Images are first trimmed to where LSTIDs are regularly observed. A function for median absolute deviation rescaling and gaussian blurring is then applied to help with edge detecting. For each discrete bin represented in the image, values lower than the bin are removed. This results in a minimum line tracking the edge for that threshold, the vertical values of minimum height measured data are stored in the corresponding bin.

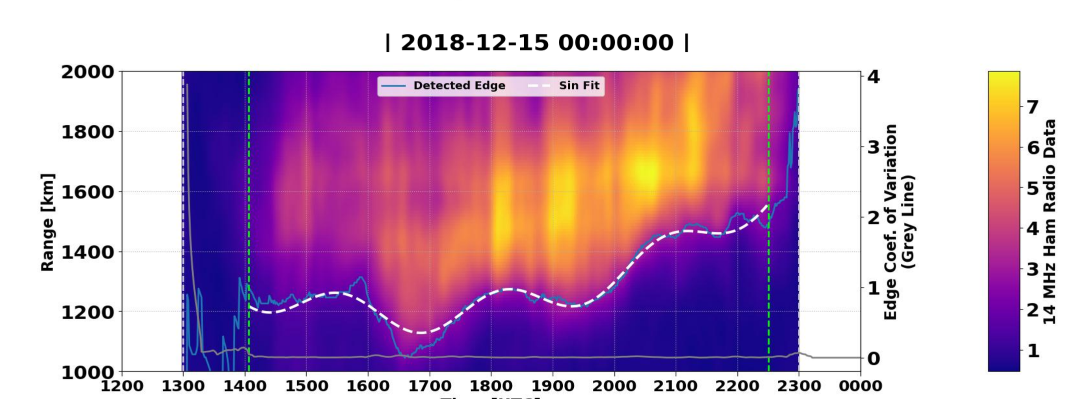


Figure 4: Preprocessed amateur radio histogram with detected edge, coefficient of variation, and curve fitting superimposed.

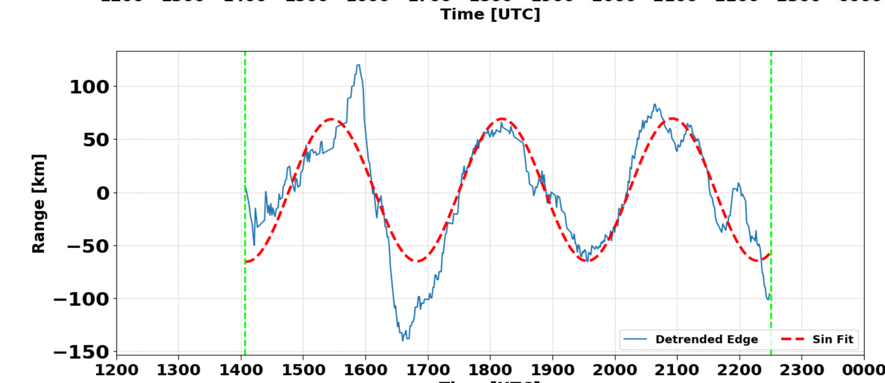


Figure 5: Detrended detected edge and sinusoid curve fit.

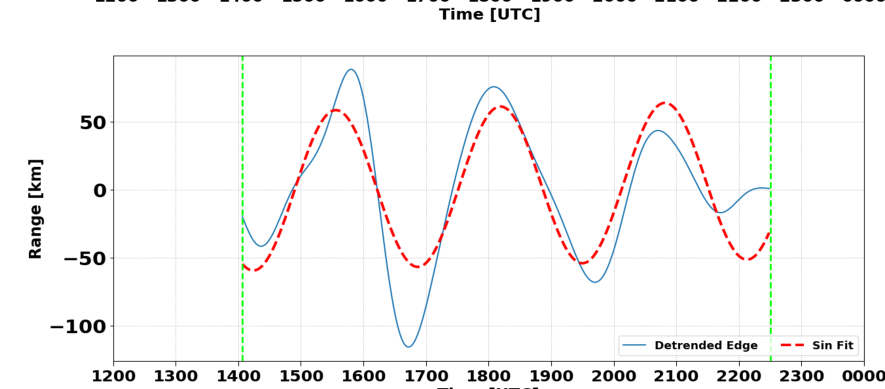
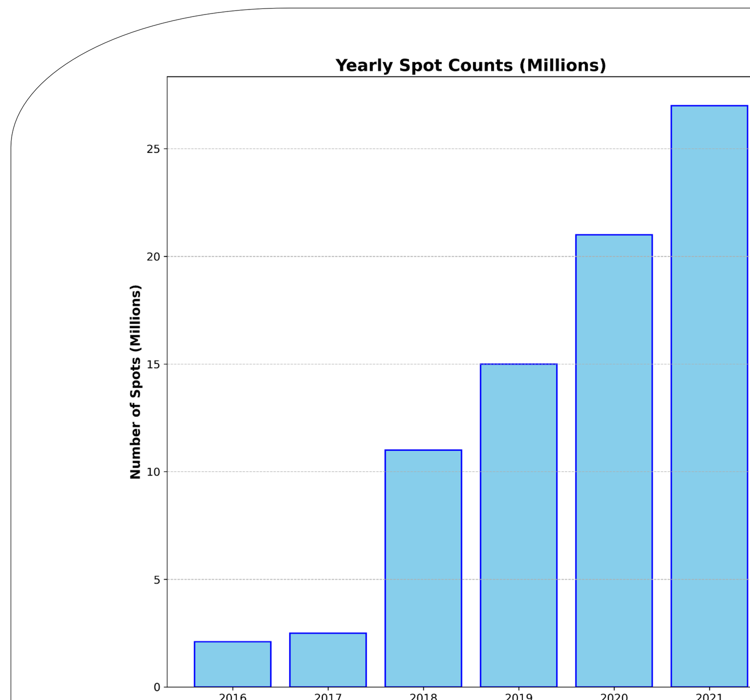


Figure 6: Detrended detected edge and sinusoid curve fit with band-pass filter..



Over the years, the volume of spot data from RBN (Reverse Beacon Network), WSPRNet (Weak Signal Propagation Reporter Network), and PSK Reporter has grown substantially. For example, the number of spots reported annually increased from around 2.5 million in 2016 to over 27 million by 2021. As a result, these platforms now provide increasingly dense and high-resolution datasets, offering valuable insights into real-time propagation conditions and long-term ionospheric trends.

Figure 11: Number of available spot data from 2016 to 2021.

Conclusions

- LSTIDs were mostly observed during the winter months, with a decline during the spring and fall, and occasional enhancements during the summer
- Overall increase in the minimum skip distance from 2015 to 2022
- Automated detection method is consistent each year when observing seasonal patterns.
- Minimum RF skip distance over multiple years shows a clear inverse relationship with solar flux, increasing as solar activity declines toward solar minimum.
- Further development of the automated technique is required to help with curve fitting accuracy.

References and Acknowledgements

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