Systematic Statistical Identification of Lower Region Ionosphere Acoustic Waves through VLF Remote Sensing

Georgia Tech College of Engineering
School of Electrical and Computer Engineering

Matthew Woodward
Faculty Advisor: Morris B. Cohen

Motivation

Many communication systems rely on the lower-region ionosphere to transmit signals [1]. A better understanding is needed of the region's conditions.

In particular, the lowest region of the ionosphere, known as the D-region (60-90 km), is difficult to sense as it is above an elevation suitable for balloons yet below that of satellites.

One method that has been popularized through many studies is using very-low-frequency signals to gather physical and chemical condition information about this region. Case studies have proven it effective in identifying periodic oscillation disturbances known as acoustic waves [2].

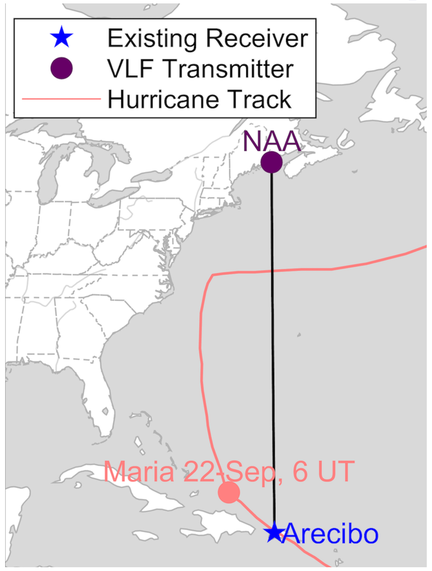
However, VLF remote sensing of the ionosphere has not yet been generalized to provide a systematic method for identifying lower region acoustic wave disturbances.

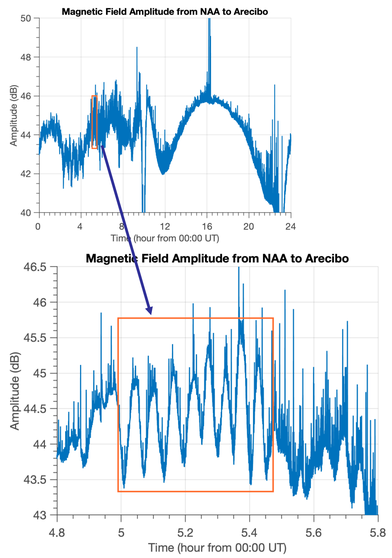
With the development of this methodology, information not previously available on acoustic wave occurrences will be able to be quickly generated on massive datasets, enabling further study of our ionosphere.

Project Goals

Develop a method to automatically statistically characterize ionospheric acoustic wave disturbances (1-5 minute period) propagating through the lower region ionosphere by analyzing magnetic field recordings in the VLF band.

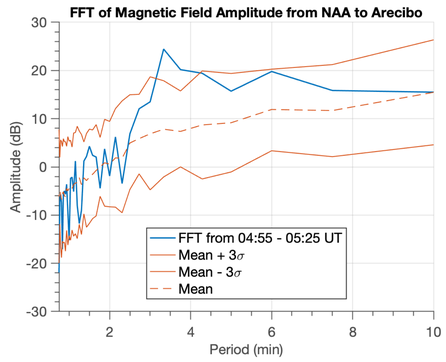
Description of Data

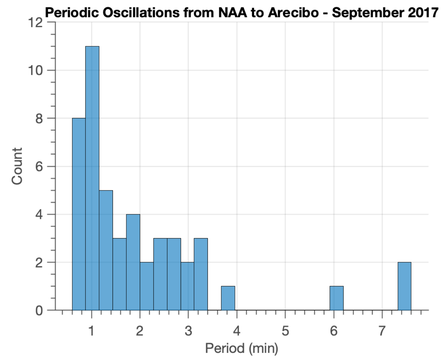




- Data was collected from a transmitter-receiver pair in Maine (NAA) and Arecibo
- This path was chosen for its coverage of the Atlantic Ocean, where acoustic wave-inducing events are likely to occur
- The graphs display the magnetic field amplitude data for September-22-2017
- The orange box is an example of an acoustic wave

Results





- The graph on the left displays the identification of the acoustic wave
- An outlier in the frequency domain data, indicating strong periodicity, is identified through the standard deviation envelope
- The standard deviation bands are 3 standard deviations away from the mean, ensuring strong confidence in identifying the outlier

Conclusion

We present a systematic and statistically confident method for identifying acoustic wave disturbances propagating through the lower region ionosphere.

In running the method over a month of data in September 2017, a few interesting observations surfaced. Firstly, the results of the identified disturbances having 1-3 minute periods aligns with what is expected of acoustic waves. Secondly, and more curiously, the occurrence of acoustic waves seems more frequent than previously thought. Perhaps there are more sources for their generation than is currently believed. In particular, it is possible that hurricanes or severe storms are not a necessity, and that ordinary thunderstorms or other origins should be considered as more prolific sources.

Future Work

Future work can follow three avenues:

1. Incorporate phase data (currently only amplitude)
2. Use information to develop a stronger link between troposphere and ionosphere
3. Analyze the effect lower region ionosphere conditions have on overall ionosphere

Acknowledgment

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References

[1] R. Barr, D. Jones, and C. Rodger, "Elf and vlf radio waves," Journal of Atmospheric and Solar-Terrestrial Physics, vol. 62, no. 17, pp. 1689–1718, 2000. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1364682600001218

[2] A. K. Maurya, M. B. Cohen, K. Niranjan Kumar, D. Phanikumar, R. Singh, P. Vineeth, and K. Kishore Kumar, "Observation of very short period atmospheric gravity waves in the lower ionosphere using very low frequency waves," Journal of Geophysical Research: Space Physics, vol. 124, no. 11, pp. 9448–9461, 2019. [Online]. Available: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JA027360