Diurnal Variation of LF Transmitter Signals at Many Locations

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Abstract

The United States Coast Guard (USCG) operates a national network of radio transmitters that serve as an enhancement to the Global Positioning System (GPS). This network is termed Differential Global Positioning System (DGPS) and uses fixed reference stations as a method of determining the error in received GPS satellite signals and transmits the correction value using low frequency radio signals between 285 kHz and 385 kHz.

In this presentation, we evaluate whether these transmitters can be used as a diagnostic tool for characterizing the D region of the ionosphere, a region of the ionosphere that is inaccessible to continuous in situ measurement techniques. We utilize data from an array of three LF AWESOME receivers located in the southeastern United States. We present the data and find diurnal trends in the amplitude and phase of these transmitters, suggesting that LF DGPS signals contain a significant sky wave that has been reflected from the ionosphere.

LF Transmitters and Experimental Setup

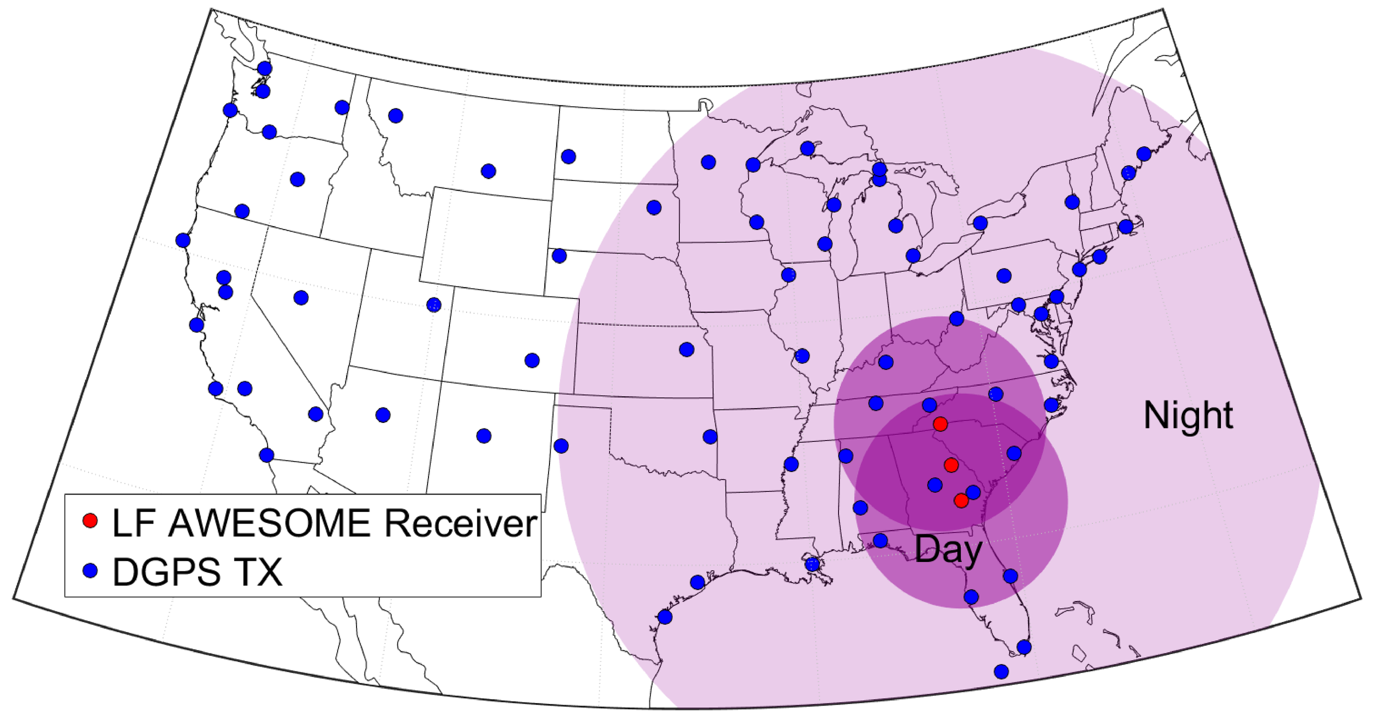


Figure 2: Location of DGPS towers in the continental US and LF AWESOME Receivers.

The Georgia Tech "Southeast Array" consists of three LF 'AWESOME' receivers [4] on the same great circle path in Georgia and North Carolina. The receiver itself consists of two orthogonal air-core loop antennas, which is sensitive to the magnetic field, typically in the North-South and East-West directions.

Currently, there are 72 active DGPS towers in the continental US. **Figure 2** shows the approximate range of each LF AWESOME Receiver based on observations. Broadband data was collected for a three and a half week period, from April 10th to May 4th in 2016.

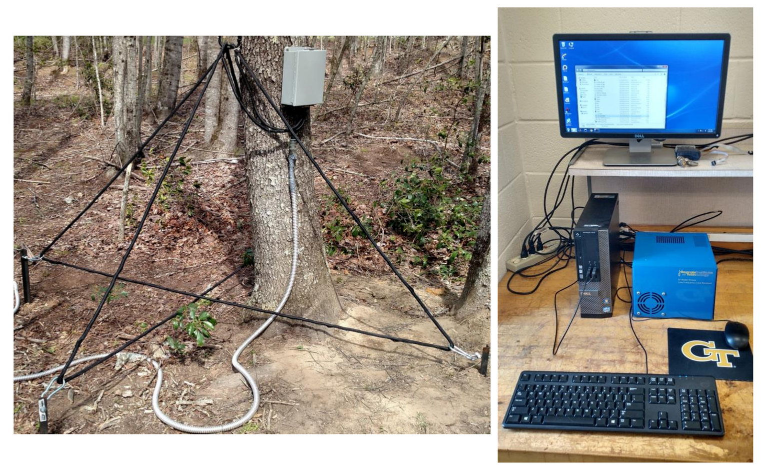


Figure 3: Images of the LF AWESOME Receiver.

VLF/LF Remote Sensing

The D-region of the ionosphere, 60-90 km altitude, is primarily formed by radiation from the Sun, which ionizes the upper atmosphere to form a plasma. The D-region is sensitive to solar radiation (daytime) and from cosmic rays (nighttime). Accurate knowledge of the D-region is valuable for a variety of reasons, since the D-region is perturbed by: (1) lightning, which causes billions of dollars in economic damage, (2) solar flares and geomagnetic storms, which endanger the power grid, (3) and global climate and temperature. As such, accurate D-region monitoring opens a window to monitor a host of geophysical processes.

VLF (Very Low Frequency) radio transmitters are an important means for naval submarine communication because their waves reflect efficiently from the D-region as well as the ground, thereby efficiently propagating to global distances, and penetrate into conducting seawater. These transmitters also serve as a useful diagnostic tool for characterizing the D-region since changes in the D-region affect the propagation conditions and thus the signal at some distant receiver. The D-region is otherwise highly inaccessible because it is too low for satellite measurements and too high for balloon measurements [1]. LF (Low Frequency) signals are largely unexplored as a diagnostic tool for the D-region. In contrast to VLF signals, LF signals propagate over shorter distances due to higher levels of attenuation by the D-region of the ionosphere [2], but have two primary advantages: (1) higher spatial distribution of transmitters and (2) because of the higher ionospheric attenuation, fewer modes propagate in the Earth-ionosphere waveguide, making it a more well posed problem.

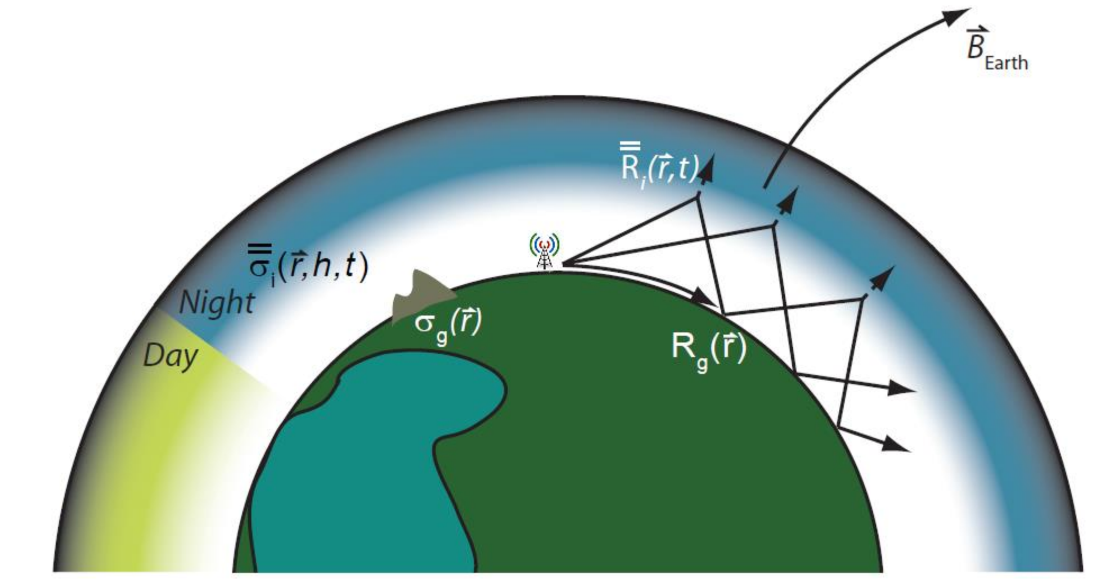
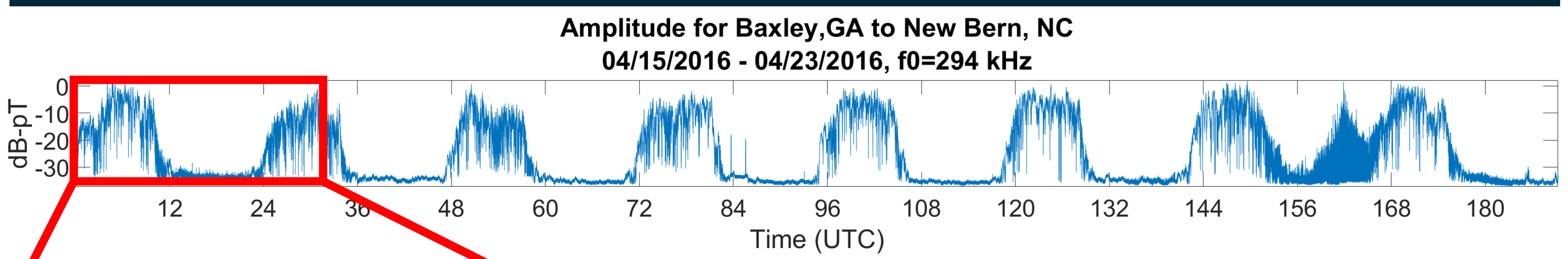
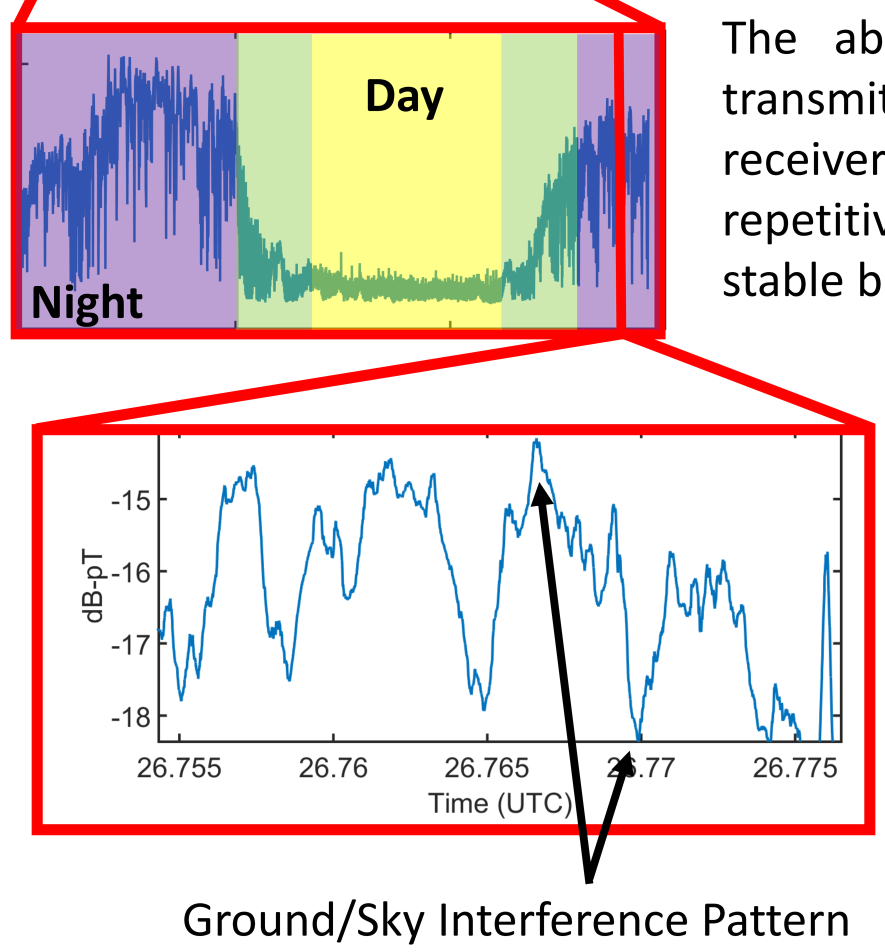


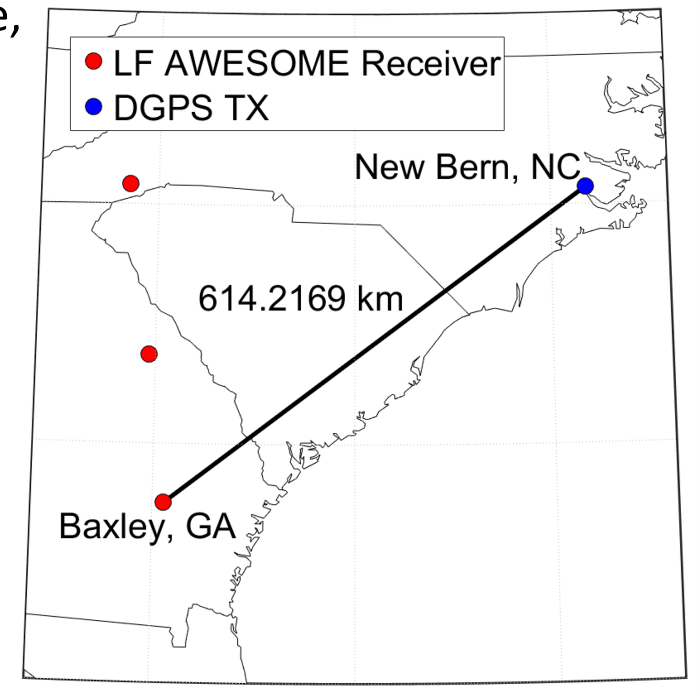
Figure 1: Depiction of VLF/LF propagation in the Earth-ionosphere waveguide [3].

Observed Diurnal Variation

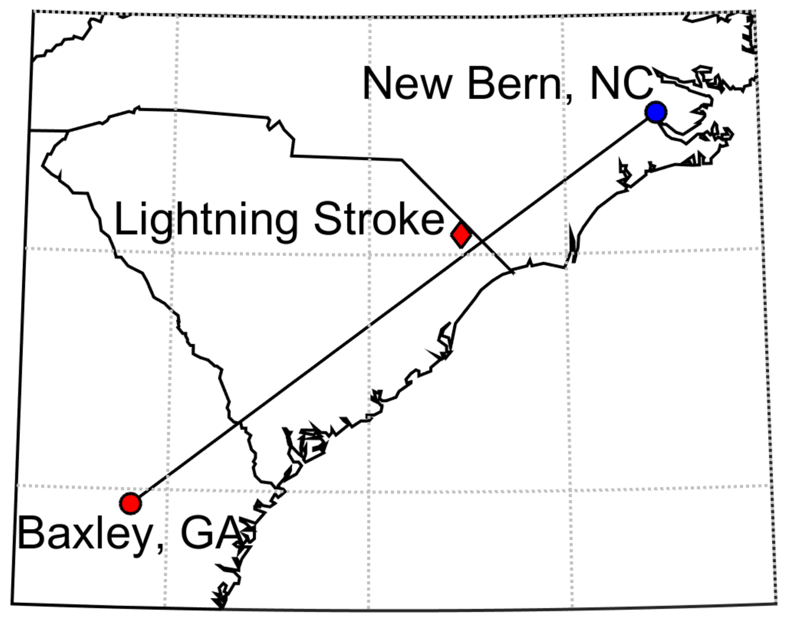


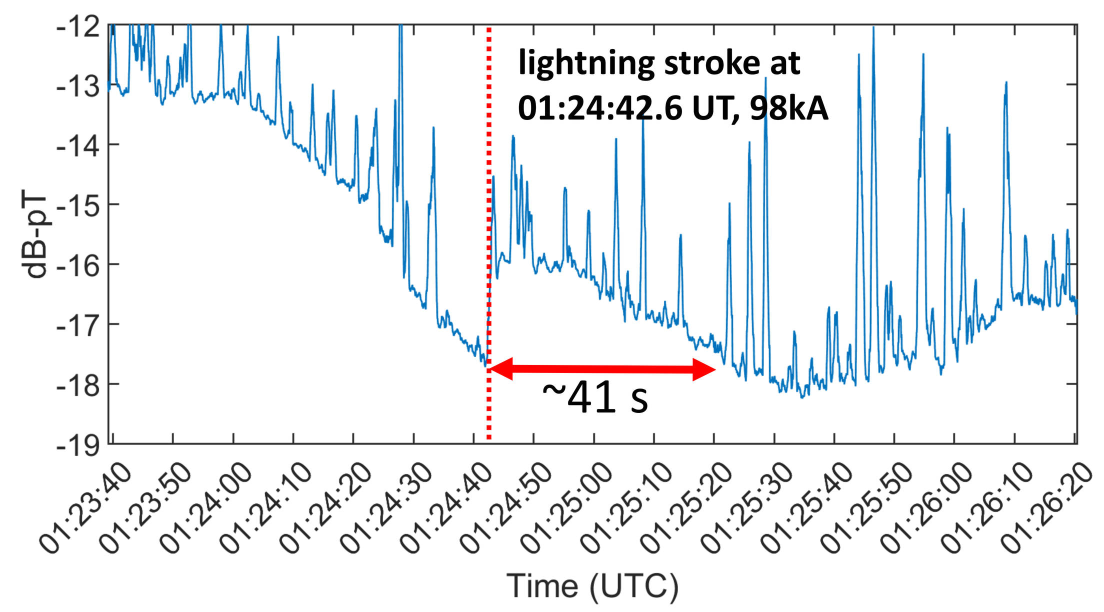


The above figure shows amplitude data from a DGPS transmitter in New Bern, NC, received at the LF AWESOME receiver in Baxley, GA. Over the 8-day period there is a clear repetitive diurnal pattern. Daytime amplitude is relatively stable because the ground wave, or the wave that travels along the earth's surface, is dominate. At night, an interference pattern can be seen because of the stronger presence of the sky-waves, or waves that reflect off the ionosphere. [2]



Ionospheric Disturbance





Summary

- The LF AWESOME receiver has significant range and can detect DGPS towers at ~1800 km at night and ~500 km at day based on observed received signals.
- The LF signal has a clear diurnal and day/night variation, suggesting interaction with the D-region.
- Some observations were made that suggest that it may be possible to detect Early/Fast events and other geophysical phenomena using DGPS LF signals.

References and Contact

[1] Barr, R., Jones, D., & Rodger, C., 'ELF and VLF radio waves', *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 62, no. 17-18, pp. 1689-1718, 2000.
[2] Belrose, J. S., et al. "The engineering of communication systems for low radio frequencies." *Proceedings of the IRE* 47.5 (1959): 661-680.
[3] Said, R. K. (2009). *Accurate and Efficient Long-Range Lightning Geo-Location using a VLF Radio Atmospheric Waveform Bank* (doctoral dissertation). Stanford University, Stanford, CA.
[4] M. Cohen, U. Inan and E. Paschal, 'Sensitive Broadband ELF/VLF Radio Reception With the AWESOME Instrument', *IEEE Trans. Geosci. Remote Sensing*, vol. 48, no. 1, pp. 3-17, 2010.

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