Spatial and Temporal Ionospheric Monitoring Using Broadband Sferics

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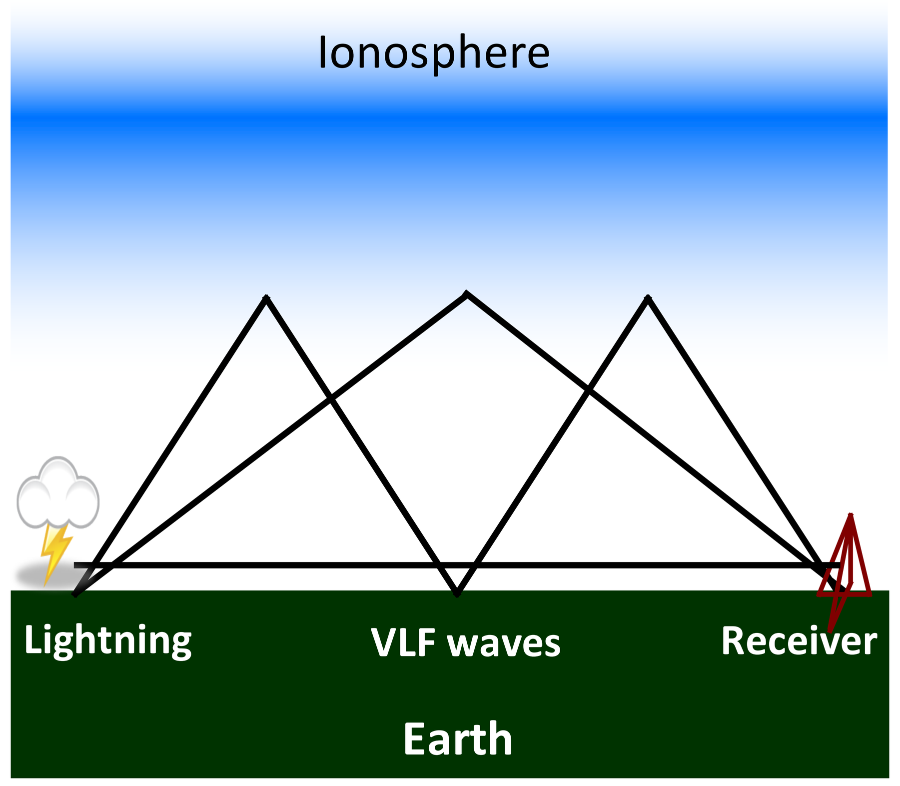
Abstract

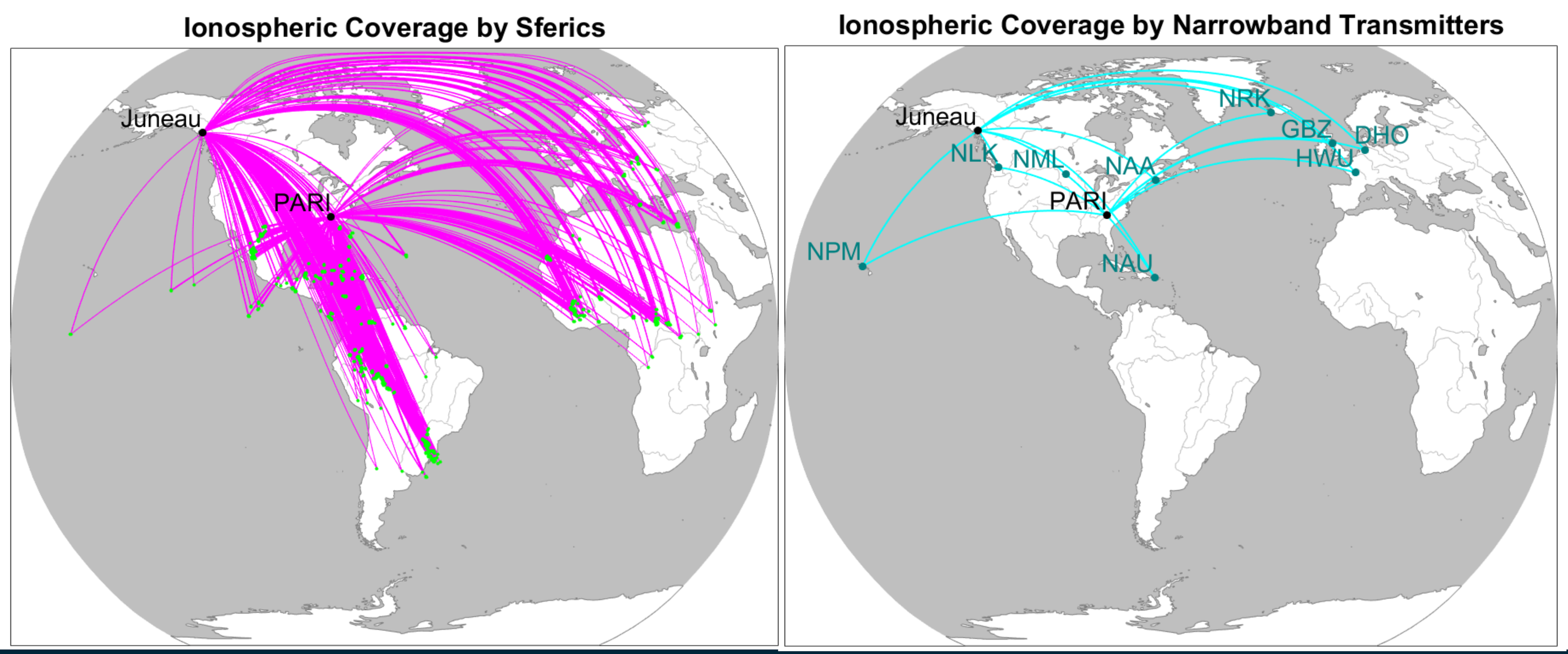
Lightning strokes release intense bursts of Very Low Frequency (VLF, 3-30 kHz) radio energy, known as 'sferics'. Accurate and efficient geolocation of global lightning using sferics and a network of VLF receivers has recently become possible [1]. Sferics propagate through the Earth-ionosphere waveguide. These sferics reflect off of the ionosphere, carrying information about its present state [2]. Lightning occurs frequently and is distributed broadly throughout the world, allowing for constant spatial monitoring of the ionosphere. We utilize global lightning data from the GLD360 and NLDN networks operated by Vaisala [3] combined with VLF sferics observed by the AWESOME instrument [4] to indirectly monitor the ionosphere. We describe a technique to mitigate source variability of sferics and recover stable ionospheric information of current propagation conditions. We demonstrate the coverage potential of sferics compared to common monitoring techniques of by using narrow frequency band navy VLF transmitters.

Sferic Propagation and VLF Remote Sensing

Very low frequency waves (VFL, 3-30 kHz) are trapped between the Earth and the lower ionosphere (60-100 km) forming a waveguide. VLF waves propagate in this waveguide with very low loss (few dB/Mm), to global distances. As the waves propagate, they are sensitive to small disturbances to the ionosphere. A typical sferic may consist of a direct ground wave and ionospherically reflected sky waves, or modes.

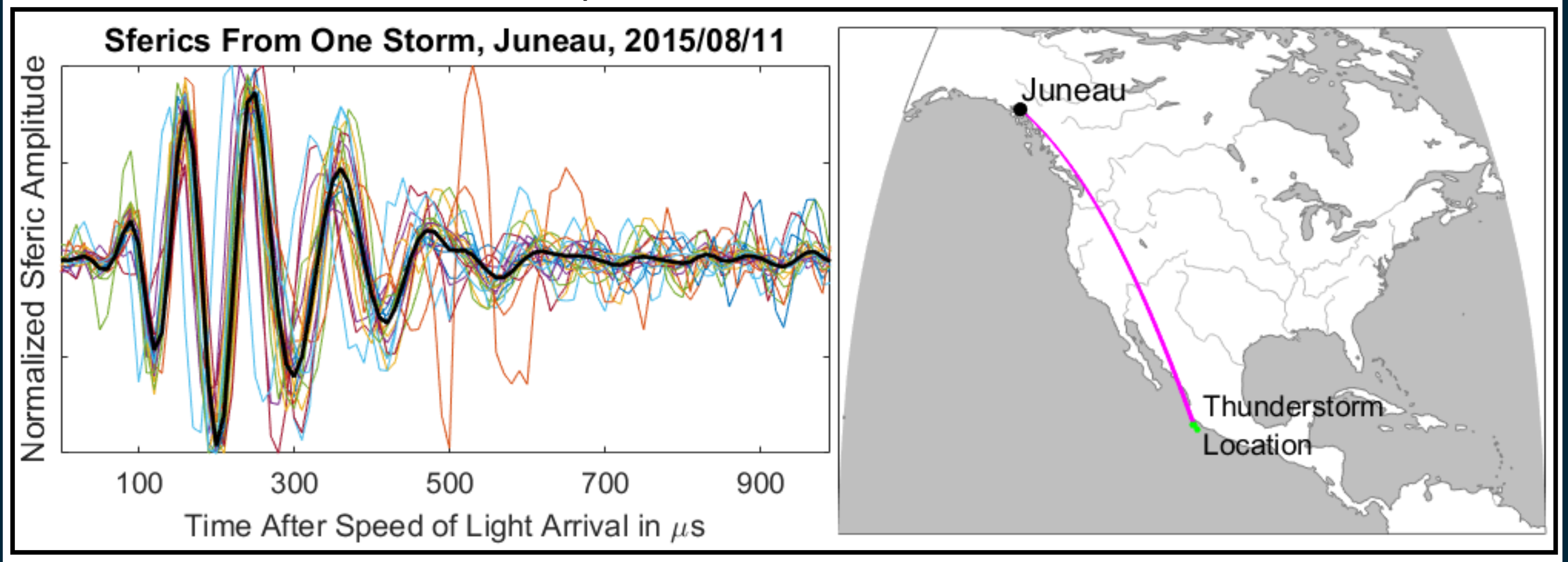


The lower ionosphere varies due to solar diurnal effects and on a seasonal basis. It also varies on small spatial and time scales due to transient perturbations such as solar flares or electromagnetic pulses from lightning. Previous studies have used a small number of transmitter-receiver geometries. Both these navy transmitters (NB) and Lightning strokes are present simultaneously, however, sferics cover a far greater portion of the Earth due to their global distribution. Using sferics will allow remote sensing over a greater geographical region than can be achieved by solely using narrowband transmitters.

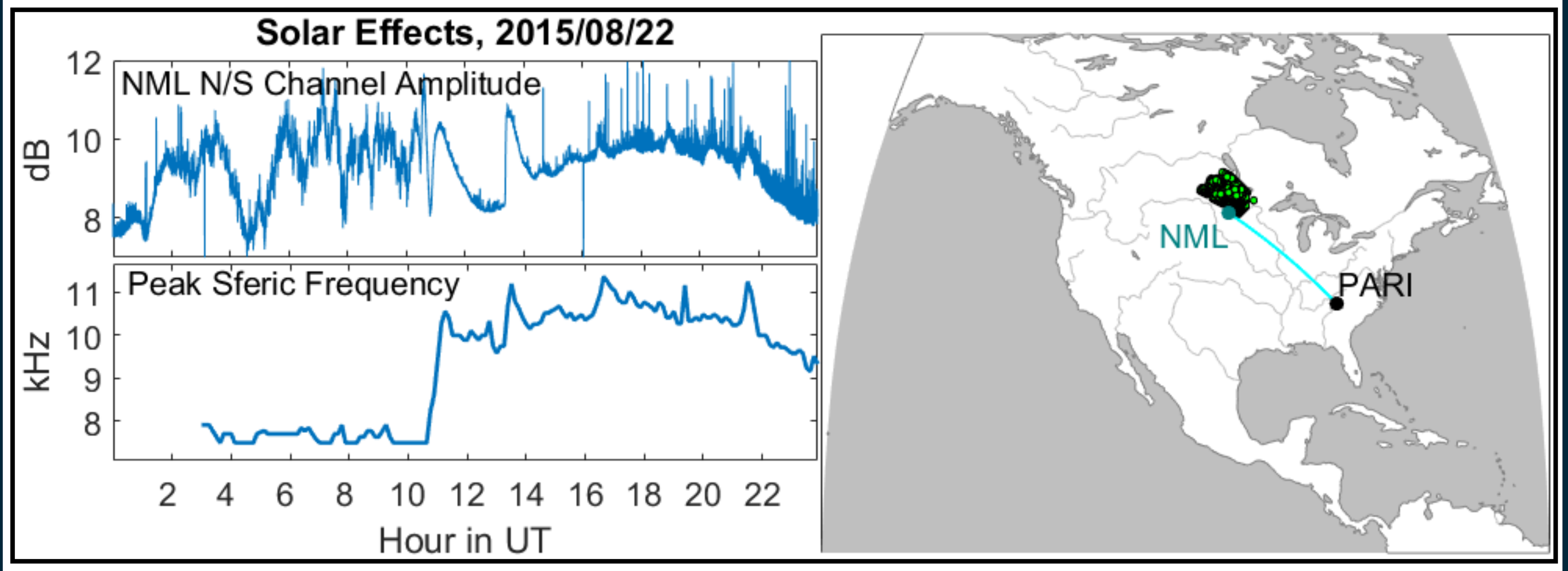


Source Variability and Mitigation

While sferics are plentiful and have far broader spatial coverage, narrowband transmitters are much more stable in frequency. Received sferics vary based on several parameters including propagation conditions (Ground conductivity, permittivity, ionosphere electron density distribution), distance from source to receiver, and the source parameters of the lightning stroke (Peak current, cloud charge structure, type of thundercloud). Even when considering a single storm from an isolated location for a small time period, the received sferic still varies in arrival time and shape.



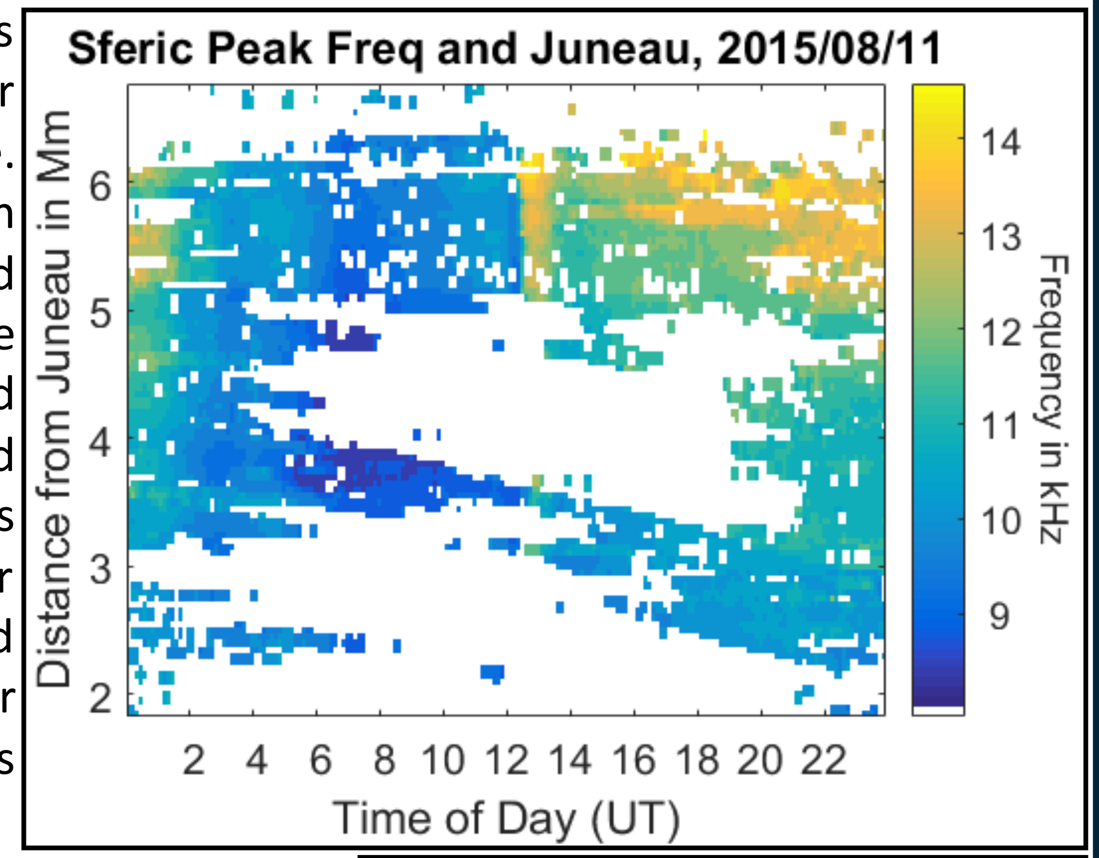
The remaining variability is likely due to lightning stroke source parameters and source estimation error. With careful processing, these variabilities can be mitigated and a stable information-rich sferic will result. We time-align sferics from similar locations over small time windows, then average all of the received sferics from that 'bin'. With stable sferics, we can now consider changing ionospheric conditions. The primary factor determining current large-scale ionospheric conditions is the sun's position and radiation. The ionosphere varies during the day because of changing solar zenith angle as well as due to solar events such as solar flares.



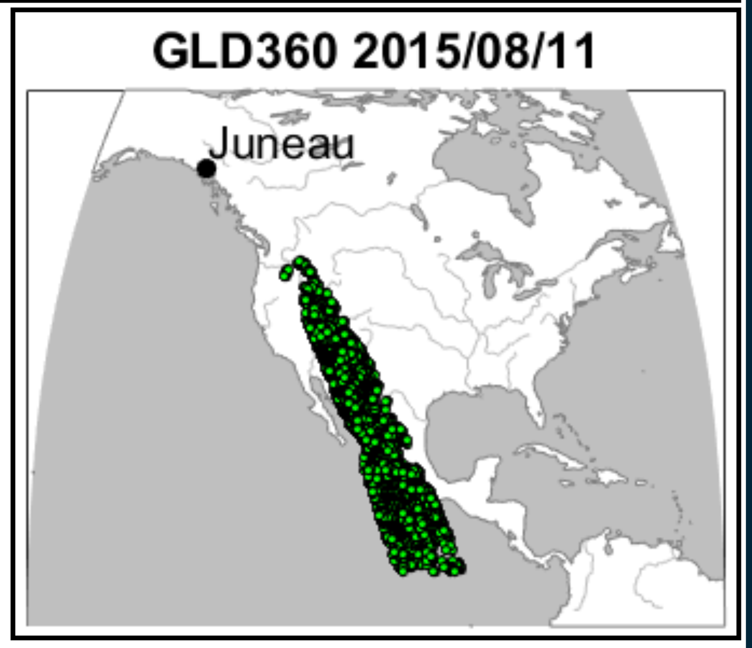
Daytime effects are seen in the Navy transmitters clearly as the amplitude peaks at local noontime (~18 UT at PARI). The amplitude is also modulated due to solar flares. These same effects are observed in peak sferic frequency.

Spatial and Temporal Monitoring

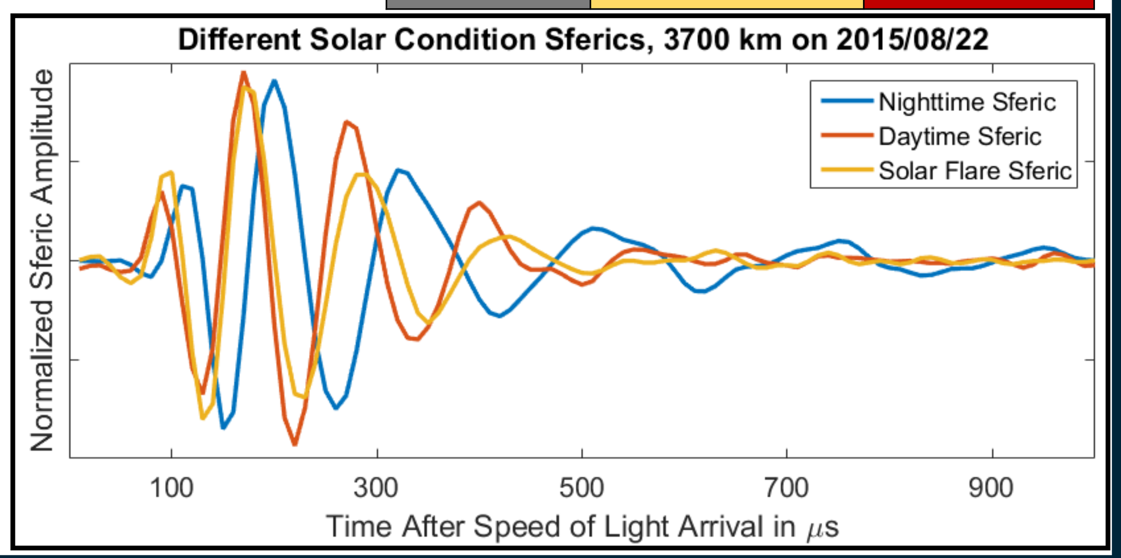
Peak sferic frequency is affected by current solar state, as well as distance. This feature change with respect to distance and solar conditions can be immediately observed with the processed binned sferics. Sferics propagating from similar paths see a marked sunrise effect at further distances which is reduced closer to Juneau.



The peak sferic frequency varies with solar zenith angle at all distances, but to a varying extent. In nighttime sferics, lower frequencies dominate and are significantly more stable than narrowband signals. In attempt to model the ionosphere, many have parametrized the ionosphere using the Wait parameters [5] h' or effective VLF reflection height, and β, or ionospheric electron density gradient ('sharpness'). Some have used features of a received sferic to infer these wait parameters [2], but the majority of sferic information has not yet been utilized. Qualitatively, certain solar conditions cause a relatively high or low h', β. Since sferics are strongly affected by current ionospheric conditions, these large changes are reflected by large impacts to sferic shape, propagation velocity, and amplitude.



	High β	Low β
High h'	Nighttime Sferic	???
Low h'	Solar Flare Sferic	Daytime Sferic



References and Contact

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Conclusions

- Sferics can be used to monitor the D-region of the ionosphere.
- With careful processing, sferics can become stable and comparable with traditional navy VLF transmitter remote sensing techniques.
- Analysis of sferics allows monitoring the ionosphere both spatially in addition to temporally, allowing for greater coverage than previous studies using single transmitter-receiver paths.
- These methods can be used to monitor the ionosphere for long-term trends, as well as short-time transient perturbations.