A Holographic Array for Ionospheric Lightning (HAIL) Research

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LONG-TERM GOAL

A better understanding of the processes leading to electromagnetic coupling between the troposphere and lower ionosphere

SCIENTIFIC OBJECTIVES

Recently, VLF remote sensing has emerged as a powerful tool for imaging of ionospheric disturbances. In particular, the strip holography technique [e.g., Chen et al., *Radio Science*, vol. 31, p.335, 1996] is a method by which the relative amplitude and phase changes at a series of VLF receivers are combined to yield a volumetric profile of the scattering region. Previous studies have been done for certain cases where a storm happened to pass through the junction between two transmitter-receiver paths, but the strip holography simulation demonstrated that an array of appropriately spaced receivers would be able to image disturbances over a wider range of land area. With this array now operating in the field, these past techniques and models will be applied towards the new data in the hope of improving the understanding of the occurrence distribution and characteristics of ionospheric disturbances. Interpretation of VLF remotely sensed disturbances has been greatly enhanced through parallel optical recordings of transient heating and ionization events, in particular those named “sprites” and “elves.” Understanding the processes behind these events is crucial to interpreting their distribution and importance for VLF communication, electrical and chemical processes in the lower ionosphere, and the nature of the global electrical cycle. Optical measurements, coupled with VLF broadband recordings, are an integral part of the HAIL campaigns and of a full interpretation of the coupling between lightning and the environmental factors affecting VLF propagation.

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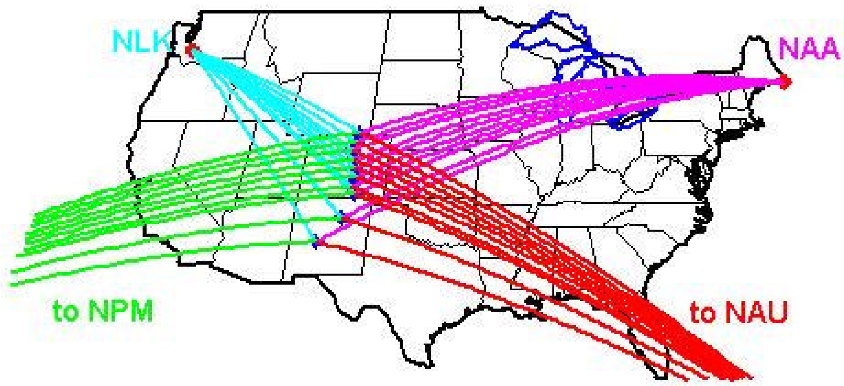

Figure 1

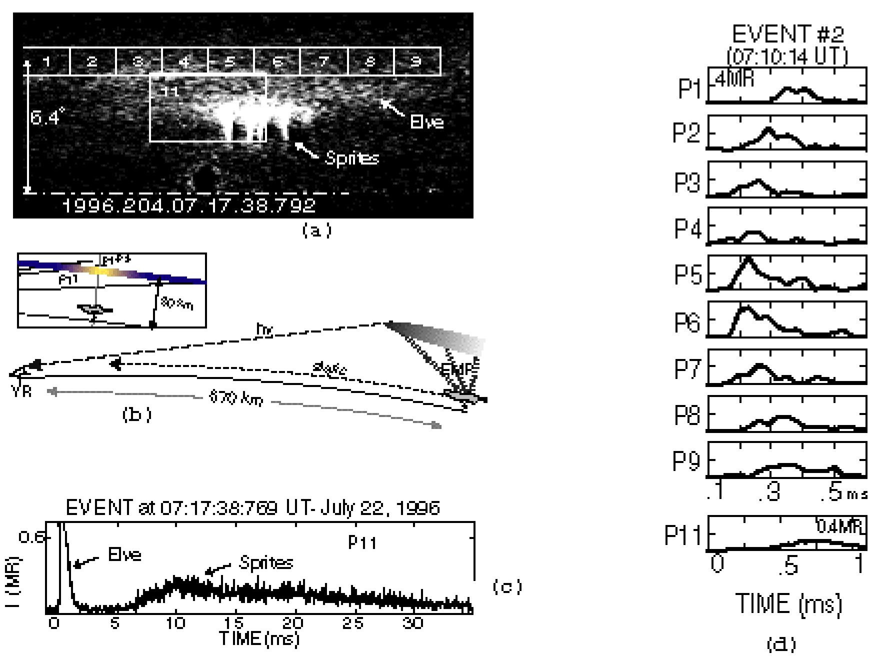

Figure 2

APPROACH

By deploying appropriately spaced VLF receivers (see Figure 1), the area above Midwestern storms is covered with a fine grid to measure the scattered electromagnetic field due to a localized ionospheric disturbance. These scattered field measurements are then compared with model predictions of the magnitude and phase change produced by an ionospheric scattering region. VLF strip holography has been shown to determine the horizontal extent and shape of the D-region disturbance using a three-dimensional numerical model of VLF propagation in the Earth-ionosphere waveguide. The strip holography inversion requires that the receivers be placed approximately 100km apart in order to image the disturbances. Once in place, a robust hardware and software package enables sensitive measurements of amplitude and phase, and then stores these measurements on tape or transmits them back to Stanford over the Internet. At Stanford, data archives on CDROM preserve the high-resolution data while low-resolution data remains available on the HAIL website.

A complementary effort has focused on photometry and optical imaging of two major classes of fast coupling between tropospheric lightning and the lower ionosphere: sprites and elves. Optical remote sensing of these sources of ionospheric ionization changes can help elucidate both the mechanisms involved and the frequency, distribution, and significance of these events. Two instruments are used in these studies. The “Fly’s Eye” photometric array has operated during summer seasons since 1996, and combines a fast triggered data acquisition system with an array of narrowly pointed photometers, along with a broadband VLF receiver to record simultaneous sferics (Figure 2 and Inan et al, 1997).

Figure 3

This year a new instrument has been added to Stanford’s summer campaign in order to extend the optical remote sensing effort (Figure 3). The Dobsonian Sprite Experiment (DSE) is a high-resolution imaging of sprites by means of telescopic measurements. The DSE is consists of a 16” diameter, 72” focal length Dobsonian telescope, two intensified CCD cameras, and monitors. One camera serves as the wide field of view (twelve by nine degrees) and is mounted on top of the telescope. The second camera is attached to the eyepiece of the telescope to give the narrow field of view (.92 by .7 degrees). The DSE provides a resolution of about 10 meters at a range of 500-km. The DSE was successfully deployed for two months Summer 1998 at Langmuir Laboratory in the Magdalena Mountains of central New Mexico. Although zoom lenses have been used previously to observe sprites, the exciting thing about the DSE is its light-gathering ability. Because it has such a wide aperture it is able to clearly see fine streamer structure in sprites where a regular zoom lens would only see the bright central columns. This telescopic imaging conducted with the DSE represents the highest spatial resolution measurement to date of sprites, elves and related phenomena, and complements other ground and aircraft-based measurements being carried out during Summer 1998. Since the fine structure of the sprites gives clues to the breakdown mechanism involved, it is in examining DSE data that the mystery of their formation can begin to be solved.

WORK COMPLETED

During the Spring and summer of 1998, the HAIL group completed the following project tasks:

1. Improved the data acquisition software to make it more robust and contain a broadband envelope detector (“sferic” channel)

2. Completed several new front-end VLF receivers for data acquisition

3. Re-located one receiver at a junior college with an Internet connection

4. Re-located another receiver because of local noise problems

5. Deployed four additional receivers at high schools in Cheyenne, Boulder, Colorado Springs, and Walsenburg

6. Improved the Java Data Browser software to include the new locations and to be easier to use and more robust

7. Improved custom Matlab libraries for data analysis

8. Ongoing data analysis and CDROM archiving

In addition, the optical remote sensing effort led to the following accomplishments:

1. Improved of the Fly’s Eye optical array configuration, including the addition of a wide field of view (~7 x 15 degrees) trigger photometer and a pair of aligned two-color photometers capable of making rough spectral ratio measurements.

2. Improved of both the data acquisition rate (now ~15 microseconds sample period for each of 14 data channels) and the triggering method, allowing autonomous buffered triggering from sferics or photometers.

3. Designed and constructed the new, two-camera telescopic imaging system, the Dobsonian Sprite Experiment (DSE).

4. Deployed the Fly’s Eye array, including its broadband ELF/VLF receiver, and the DSE, at the Langmuir Laboratory for Atmospheric Science in New Mexico for July and August of 1998. These data support the HAIL program as well as providing a rich reservoir of photometry and new high-resolution imagery with which to understand the nature and influence of sprites and elves.

5. Submitted to GRL for publication a manuscript entitled “Spatial Extent and Spectral Characteristics of Elves Triggered by Positive and Negative Lightning Discharges,” showing for the first time the ubiquity of transient heating of the lower ionosphere due to the electromagnetic pulse from lightning.

RESULTS

Numerous VLF events are now measured weekly, in both amplitude and phase, at all the deployed sites. The data indicates that lightning discharges from multiple storms disturb both the distant and overhead ionospheric regions in a complex manner of ways, both directly (early/fast) and by precipitating bursts of energetic radiation belt particles (LEP). The configuration of the HAIL array provides the capability to simultaneously observe ionospheric disturbances occurring in large distributed region. The data analyzed further provides a direct measurement of the VLF scattering pattern of an ionospheric disturbance associated with early/fast events. These disturbances are found to be largely forward scatters, consistent with previous inferences based on measurements from a single receiver site. Figure 4 shows VLF events seen at only two of the nine receiving stations, corresponding to strong forward scattering (bottom five receivers not shown to save space).

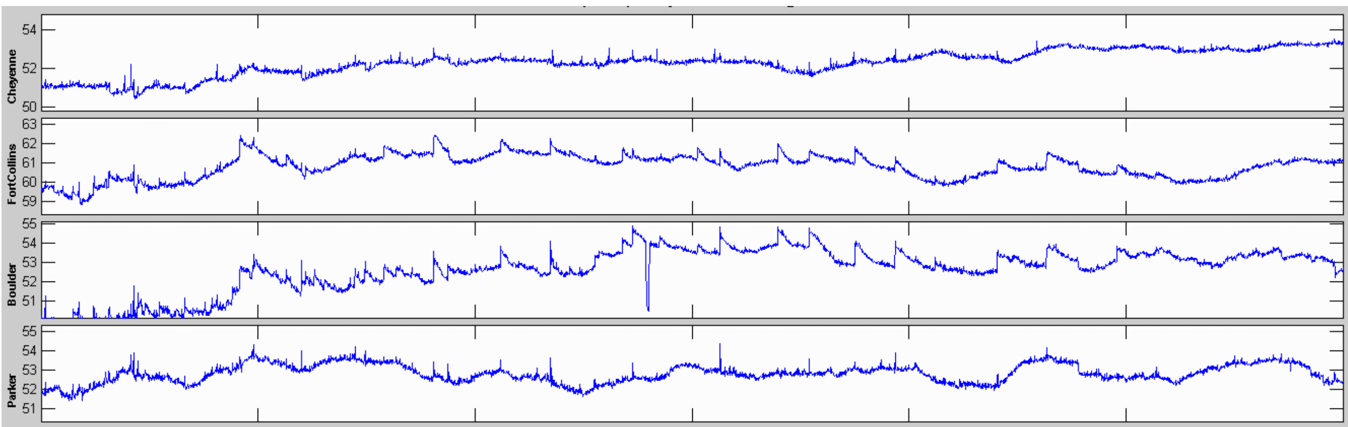

Figure 4

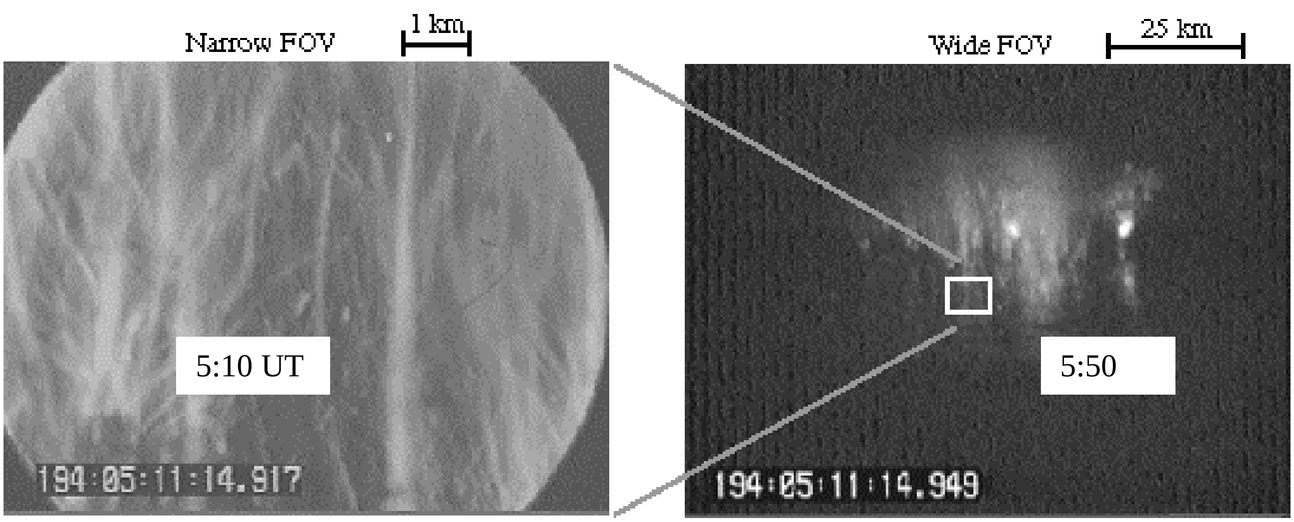

Figure 5

Hundreds of sprites and elves were optically measured during the two-month campaign during the summer of 1998. Most notably, the DSE captured unprecedented high-resolution imagery of the fine structure of dozens of sprites (Figure 5). These images show ionization breakdown in the form of quasidendritic streamers on the order of 10 m wide or less. Analysis of these data, where possible in conjunction with high-time-resolution photometry, promises to provide key new insights into which theoretical descriptions best describe sprite development processes.

Analysis of hundreds of discharges from one storm in 1997 has provided the first proof that elves are produced by both positive and negative cloud-to-ground lightning, and that virtually all large-current (> 50 kA) lightning discharges produce such heating and ionization in the lower ionosphere (80-100 km). In addition the spatial extent of this heating is shown to be often in the range of 200-650 km laterally. The cumulative effect of such frequent and widespread heating over a single storm is predicted to have considerable impact on local electron densities.

IMPACT/APPLICATION

The lightning induced D-region disturbances studied with the HAIL array and photometric sensors affect VLF communications, particularly during periods of increased solar activity. Also, remote sensing of these disturbances is contributing to the understanding of D-region chemical and electrical processes.

TRANSITIONS

Each day, a networked PC at each of the HAIL stations automatically sends 20 Megabytes of data back to Stanford using ftp. This data is then available on Stanford's web server, in both high and low resolution form, as Matlab files. Twice a week, the high-resolution data is archived onto CDROM, however the low-resolution data is permanently stored on a server. To improve accessibility of this data set, a data browser (http://hail.stanford.edu) has been written in Java to access the low-resolution Matlab data from Stanford with only a web browser. This allows extraordinary flexibility in viewing HAIL data. People from different geographical locations running vastly different systems can all access the data. In addition, help files show how to view and interpret the data, and contain links to HAIL's science page (http://www-star.stanford.edu/~hail). Although this data browser was written to promote educational outreach at our participating receiver school locations, other high school students, interested adults, and even HAIL project scientists have also used the utility. Since its introduction, the Data Browser has been extended for use on a different VLF remote sensing project involving movement of the Auroral Electrojet in Northern Canada. While the Browser's Java source code is specifically tailored for this type of data, there are a number of general plotting methods that are freely available to other developers.

Each HAIL receiver operates at a high school or college and thus presents a unique opportunity for a cooperative relationship between science oriented students and researchers. In the past two years, Stanford graduate students have combined field site installations and maintenance visits with class lectures and one-on-one discussions about Sun-Earth connection physics. With these visits and with an extensive online tutorial and data viewing software, high school students actively participate in the data acquisition and analysis. By utilizing the synergistic relationship with a host school, the HAIL program gains a field site location as well as an army of enthusiastic young volunteers to help comb over the large quantity of acquired data.

RELATED PROJECTS

"Characterization of the Auroral Electrojet and the Ambient and Modified D-Region for HAARP Using Long-Path VLF Diagnostics"

"Global Thunderstorm Activity and Its Effects on the Radiation Belts and the Lower Ionosphere"

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