

Multiple Characteristics of Ionospheric Variability Patterns

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LONG-TERM GOALS

Various observational tools are available for the study of F-layer irregularities in the equatorial region. These include optical observations of the depletion of electron density (groundbased and spacebased), GPS phase fluctuations, DMSP and ROCSAT *in situ* observations of ion density depletions, radar observations of coherent backscatter from equatorial irregularities, and ionospheric soundings. Each makes contributions to observational studies and each has its limitations. Our long term goal, using a full set of these measurements, is to study the physics of the equatorial regions, particularly during periods of irregularity development. Subsequent coupling of high latitude observations and equatorial observations will lead to forecasting where and when intense irregularities occur in various world areas and how they affect transmissions from satellites.

OBJECTIVES

Equatorial ionospheric irregularities, particularly in the region 10° to 20° north and south of the magnetic equator, are the cause of radio communications fades of up to 20 dB in episodic occurrence patterns. This latitude region includes regions of DoD/Navy operations in the Middle East, Africa, Indian and Pacific Oceans, and Latin American. Some receivers can deal with fades of this type while others cannot. Field program users of satellite-to-ground or satellite-to-ocean reception links need to know that problems are of natural causation rather than equipment malfunctions. Methods of dealing with the fading can only be designed using knowledge of the geophysical and environmental characteristics of these irregularities (e.g., size and velocity).

APPROACH

Our approach to studying geophysical disturbances as the cause of communications disruptions involves the use of unique (in house) regional data sets funded by ONR, and state-of-the-art models (both empirical and computer simulation codes), in conjunction with global satellite observations available via the internet. Our own optical measurements involve all-sky camera observations of ionospheric structures taken at a site near the Equatorial Ionization Anomaly (EIA) region in the southern hemisphere, i.e., from our ONR-sponsored observing system at the El Leoncito Observatory in Argentina. To assess communications links, we study GPS signal phase fluctuations using an online network of over 60 ground stations throughout the EIA latitude band in both hemispheres. To understand the types of ionospheric structure disturbance responsible for the GPS effects, we use the sensors on board the DMSP and ROCSAT satellites that give direct ionospheric ion density measurements along each orbit.

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The optical all sky measurements also allow us to identify unusual patterns of drift that occur during large-scale, solar-terrestrial disturbances known as geomagnetic storms. Our approach has been to study a number of individual storms and to search for characteristics that are common to all and thus capable of being forecast. Results obtained in the South American region are then tested at other longitudes (where we do not have optical data) using the GPS and DMSP satellites. In this way we are able to examine the longitude consistency and robustness of the forecasting techniques.

Key individuals participating in this work are:

- (1) Michael Mendillo, Professor of Astronomy, serves as PI and directs the overall analysis consistent with current-day theory in space physics.
- (2) Jeffrey Baumgardner, Senior Research Associate in the Center for Space Physics, designs, constructs and repairs all instrumentation; he participates in data analysis and interpretation.
- (3) Joei Wroten, Senior Staff Researcher, is in charge of data analysis and archiving; she maintains our website, conducts image processing, and works with the PI on ionospheric storm studies.
- (4) Carlos Martinis (Post-doctoral Research Associate) conducts the analysis and interpretation of the imaging data from El Leoncito, Argentina.

WORK COMPLETED

The major accomplishment during the third year of this grant was the creation of a three-station, bi-hemispheric observational program for the study of how ionospheric irregularities map along geomagnetic field lines in the American longitude sector. This was accomplished by the award of an ONR-sponsored DURIP grant for the fabrication of two new imaging systems to be placed into service at the new Boston University Observing Station in Mercedes, Argentina. This soon to be operational network will link observations made at Arecibo (Puerto Rico) to those made at the El Leoncito and Mercedes Observatories in Argentina, thereby providing the first comprehensive approach to the specification, prediction and scientific analysis of ionospheric irregularities spanning the Earth's geomagnetic equator.

RESULTS

Background

Boston University's initial ONR-sponsored imager is at the El Leoncito Observatory in the western Andes of Argentina (31.8 S, 69.3 W). This site has relatively high geographic latitude for its location under the southern crest of the EIA region (18 S magnetic latitude). Thus, this location fosters the study of how physical processes originating at the magnetic equator propagate into lower mid-latitudes. Such low-to-high latitude coupling is a frontier area of research in the ionospheric physics community, and our ONR-sponsored efforts offer leadership science in that area (Mendillo et al., 2005, 2006; Martinis et al., 2005, 2006; Martinis and Mendillo, 2007). The imager at El Leoncito records four types of strongly variable phenomena: (1) highly-structured airglow depletions associated with the Rayleigh-Taylor instability [responsible for equatorial spread-F (ESF)]; (2) brightness waves (BW) associated with the midnight temperature maximum (MTM) reported on under previous ONR grants; (3) strong airglow enhancements associated with the positive phase/SED aspects of TEC during

geomagnetic storms, and (4) simple (non-structured) bands of alternating dark and bright airglow emission with characteristics probably related to a coupled Es-layer/F-layer plasma instability. Disturbance types (1) and (4) are the ones most able to cause radio wave scintillations and GPS disruptions, and thus we concentrate on those effects under this grant. As a secondary goal, we study all aspects of solar-terrestrial disturbances, as related to topic (3).

New Results

(1) Preparations for and implementation of new DURIP observational capabilities.

The central question that is at the focal point of all of our studies is “Do the optical signatures of a structured ionosphere map consistently from one hemisphere to the other?” As explained in our previous reports, to explore this concept in detail we use images taken at the Arecibo Observatory in the northern hemisphere (Puerto Rico) and map each of the pixels along the Earth’s geomagnetic field lines to their corresponding locations in the ionosphere of the southern hemisphere. This “conjugate point” mapping is a complex process in this particular region of the globe because the Earth’s magnetic field is highly distorted near South America (the so-called South Atlantic Anomaly (SAA) in the terrestrial magnetic field). Arecibo’s conjugate point is near, but not coincident with, our optical field-of-view (FOV) from El Leoncito, and the need to have more coherent data sets led to the DURIP proposal and award for new instrumentation at Mercedes, Argentina. Figure 1 gives an example of the overall relationship between the three sites. There are several items to notice in this figure: (1) the circular FOV from Arecibo maps to a distinctly oval-shaped FOV in the southern hemisphere due to the SAA geometry, (2) this southern FOV includes a small portion of that from our imager at El Leoncito, so partial validation of effects can be obtained from the over-lapping area, and they do indeed agree, and (3) a vastly improved set of conjugate point studies can be achieved by installing a second imager at Mercedes. The additional benefit of an all-sky imager at Mercedes is that longitude patterns can be mapped over the full region covered by the joint Mercedes-El Leoncito cameras, a two-FOV system that can test temporal prediction methods for these longitudinally-moving structures.

A significant amount of effort during 2008 was (and will be) devoted to the fabrication of the new optical systems for Mercedes, as well as for their housing and timely installation. Using funds provided by Boston University’s Center for Space Physics to promote studies in equatorial aeronomy, a small “Airglow Observatory” building was added to the existing facilities at Mercedes. The new DURIP all-sky imaging system will be installed there by end of 2008, and additional space (with a second dome to view the sky) has been set aside for the DURIP companion wide-field imaging spectrograph. Space also exists for additional, collaborating instruments to be added in the future.

ONR sponsored Dual-Hemisphere Studies of Ionospheric Disturbances
Imaging Science Laboratory, Center for Space Physics, Boston University

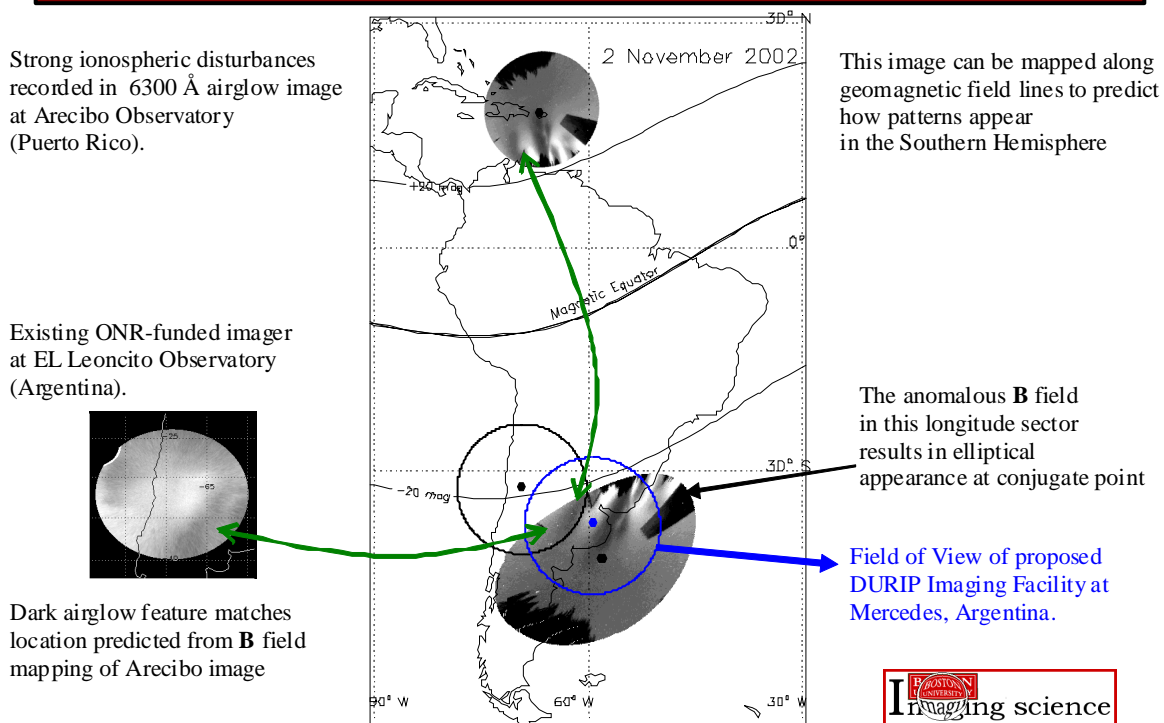


Figure 1. A summary of how airglow images can be mapped along geomagnetic field lines from one hemisphere to another. In this particular example, the validation comes from the ONR sponsored imager at El Leoncito that covers only a small portion of the image mapped from Arecibo. The new instrument location proposed to DURIP is shown with the blue field-of-view, one that covers a far more complete portion of the mapped Arecibo image, thereby allowing for more successful tests of portraying and predicting inter-hemispheric ionospheric disturbances.

(2) An Experiment of Opportunity.

As part of our continuing efforts to study the larger-scale ionospheric disturbances that occur in total electron content (TEC) during geomagnetic storms, a second project was completed during year 3 of this grant. When large rockets are launched into the upper atmosphere, if their engines continue to burn above ~200 km, a dramatic depletion of TEC occurs simultaneously with a strong burst in airglow. The first use of the GPS network of TEC observing sites in the American sector, together with an all-sky imager to record 6300 Å emission, was conducted during the past year to document such a case. The strong gradient in TEC produced by a rocket-exhaust-depletion (RED) of TEC was compared to cases of similar gradients associated with the end of the positive phase of ionospheric storms (now called SED events). This study showed that such disturbances can be monitored by routine radio and optical systems, perhaps offering another way to detect rocket plume effects from any space vehicle. This study was published in the journal *Space Weather* (Mendillo et al., 2008).

IMPACT/APPLICATIONS

Much of current understanding of the morphology patterns of communications-disruptive ionospheric irregularities comes from data taken at sites at or near the magnetic equator, such as Huancayo and Jicamarca (Peru) and Manila (Philippines). However, the very strongest amplitude and phase fluctuations of GPS signals come from stations in the Equatorial Ionization Anomaly (EIA) region, a latitude band in each hemisphere located between about 10° to 20° from the geomagnetic equator. In these regions, amplitude fluctuations to 20 dB have been noted, even at the high frequencies of GPS. Forecasting the timing and extent of communications dropouts due to ionospheric disturbances are the central applications products of the studies we are conducting.

TRANSITIONS

In order to move towards the goal of forecasting the effects of ionospheric irregularities on communication system, we must understand the patterns of occurrence during both quiet and disturbed periods. The former is well in hand for ESF-related effects (“airglow depletions”) in that the seasonal-longitude patterns already determined are essentially regional forecasts of *ionospheric disruptive climate*. The day-to-day variability during those seasons remains the elusive topic. This type of *ionospheric weather* is under active study, and forecast techniques are within reach. Progress has been made on the major challenge of understanding *the regional role* of geomagnetic storms in enhancing or inhibiting the occurrence of equatorial and low-latitude irregularities (Martinis et al., 2005). That aspect of our study dealt with the determination of effects caused by *severe ionospheric weather*, and at a very localized level within several world regions. The analogy to tropospheric disturbances would be to tornadoes, i.e., very severe and highly localized micro-climate.

The more demanding problem is day-to-day disturbances, and their consistency in both hemispheres within specific longitude sectors. While we have taken a major first step in understanding this topic under this grant, it is not ready for a transition to operational, reliable use. Similarly, the separate type of “airglow bands” and the irregularities associated with them have not been studied sufficiently (during both quiet and storm conditions) to warrant realistic transitions to operational use. Our prior studies of the ionosphere’s total electron content (TEC) storm effects, on the other hand, have achieved a level of closure between observations, theory and modeling, and forecasting methods are within operational reach (Mendillo et al., 2006). Similarly, the prediction of rocket exhaust depletions of the ionosphere were once again validated using new GPS methods under this grant and reliable forecasts can be made if prior knowledge is available of launch time and vehicle characteristics (Mendillo et al., 2008).

REFERENCES

- Martinis, C., M. Mendillo, and J. Aarons, Toward a synthesis of equatorial spread F onset and suppression during geomagnetic storms, J. Geophys. Res., 110, A07306, doi:10.1029/2003JA010362, 2005.
- Martinis, C., J. Baumgardner, S. Smith, M. Colerico, and M. Mendillo, Imaging science at El Leoncito, Argentina, Ann. Geophys., 24, 1375-1385, 2006.
- Martinis, C., and M. Mendillo, Equatorial spread F related airglow depletions at Arecibo and conjugate observations, J. Geophys. Res., 112, doi:10.1029/2007JA012403, 2007.

Mendillo, M., E. Zesta, S. Shodham, P. Sultan, R. Doe, Y. Sahai, and J. Baumgardner, Observations and modeling of the coupled latitude-altitude patterns of equatorial plasma bubbles, *J. Geophys. Res.*, 110, A09303, doi:10.1029/2005JA011157, 2005.

Mendillo, M., Storms in the ionosphere: Patterns and processes for total electron content, *Rev. Geophys.*, 47, RG4001, doi:10.1029/2005RG000193, 2006.

Mendillo, M., S. Smith, A. Coster, P. Erickson, J. Baumgardner, and C. Martinis, Man-made space weather, *Space Weather*, 6, S09001, doi:10.1029/2008SW000406, 2008

RELATED PROJECTS

None.

PUBLICATIONS

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