Multi-Instrument Observations of an MSTID over Arecibo Observatory

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Abstract

The Penn State All-Sky Imager (PSASI) at Arecibo Observatory provides planar horizontal context to the vertical ionospheric profiles obtained by the Incoherent Scatter Radar (ISR). Electric field measurements from the Communication/Navigation Outage Forecast System (C/NOFS) satellite are mapped down geomagnetic field lines to the height of the airglow layer, allowing multi-instrument studies of field-aligned irregularities with radar, imager, and satellite. A Medium-Scale Traveling Ionospheric Disturbance (MSTID) was observed during such a conjunction near the December solstice of 2009.

1 Introduction

A frequently observed structure in all-sky imager data is the Medium-Scale Traveling Ionospheric Disturbance (MSTID), also referred to in the literature as plasma depletion bands, midlatitude spread-F, and plasma bubbles [1]. These structures have been linked to Midlatitude ionospheric Electric field Fluctuations (MEFs) observed by satellites [2]. These MEFs differ from classic *in situ* plasma bubbles (depletions) and blobs (enhancements) in that they appear without a corresponding change in density or ion temperature. Such electric field structures are frequently observed by the Communication/Navigation Outage Forecast System (C/NOFS) satellite during the recent solar minimum [3]. One of these events is mapped to a corresponding MSTID observed above Arecibo Observatory (AO, 18.3° N, 66.75° W, 29° N geomagnetic).

2 Measurements

The Penn State All-Sky Imager (PSASI) is a CCD-based high-resolution all-sky optical imager that has been collecting ionospheric airglow data at night since May 2003. The imager alternates between a series of filters for the emission lines of O^+, including 630 nm (red), 557.7 nm (green), and 777.4 nm (near-IR). For the purposes of this study, the 630 nm data is used. A fisheye lens on the imager provides a 180° field-of-view. Barriers are placed on the lens cover to block out local sources of light. The images are unwarped and flattened to remove the effects of the fisheye lens. This study uses the 630 nm emission of O^+ due to recombination. The chief responsible reaction is a two-stage process consisting of charge exchange (1) followed by dissociative recombination (2) [4].

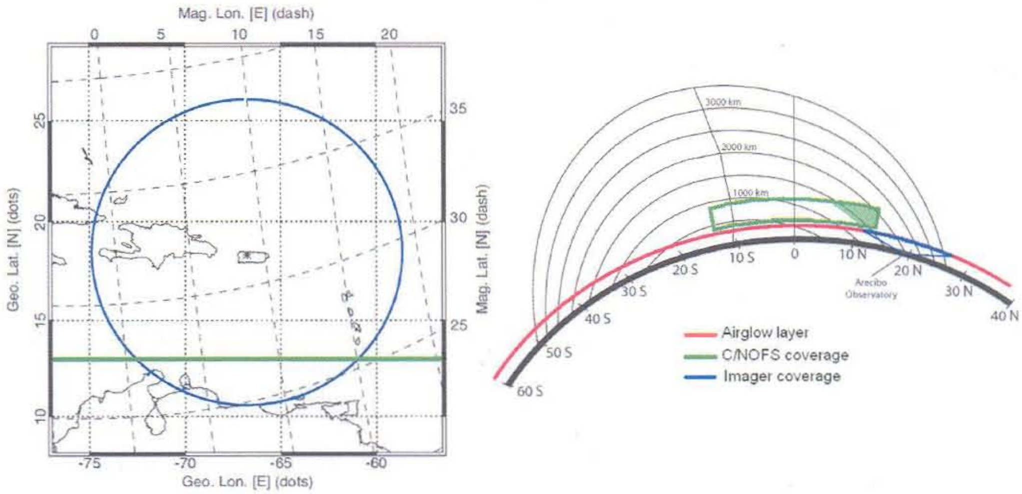
$$O^+ + O_2 \rightarrow O + O_2^+ \tag{1}$$
$$O_2^+ + e^- \rightarrow O^* + O \tag{2}$$

The reaction rate depends both on the height of the plasma layer and the total density. Thus an enhancement in airglow can be due to the F-layer moving downward, a local increase in density, or some combination of a change in height and density. This reaction typically peaks at 250 km.

The C/NOFS satellite is part of a mission to locate and predict equatorial ionospheric scintillation [5]. It occupies a 13° inclination orbit with perigee near 400 km and apogee near 860 km. The Vector Electric Field Investigation (VEFI) instrument suite consists of multiple sensors, including 3-axis electric field double probe booms and a 3-axis flux-gate magnetometer. While both the DC and AC electric and magnetic fields are measured, this study is primarily concerned with the DC electric fields. The **E** fields are reported in the zonal (positive eastward perpendicular to the meridian plane) and the meridional (positive outward in the plane of the magnetic meridian) directions.

3 Conjunctions

There are a number of considerations in defining a conjunction between C/NOFS and PSASI. To obtain a usable image, PSASI requires a (relatively) clear nighttime sky under "moon down" conditions. Because C/NOFS has a 13.0° inclination, the satellite passes through the field of view of the imager sporadically. Figure 1a shows the range of the imager in blue, while the green line depicts the maximum geographic latitude reached by the satellite. Additionally, the perigee of the C/NOFS satellite is 400 km, far above the peak airglow emission height. However, mapping electric fields down the geomagnetic field lines allows a greater range of comparison, as seen in Figure 1b. The green box represents C/NOFS coverage, and the shaded portion represents potential conjunction locations. All satellite measurements presented in this paper are the local values, but the mapped orbital track will be shown for a more accurate comparison. All geomagnetic field mapping is done using the 11th generation International Geomagnetic Reference Field [6].

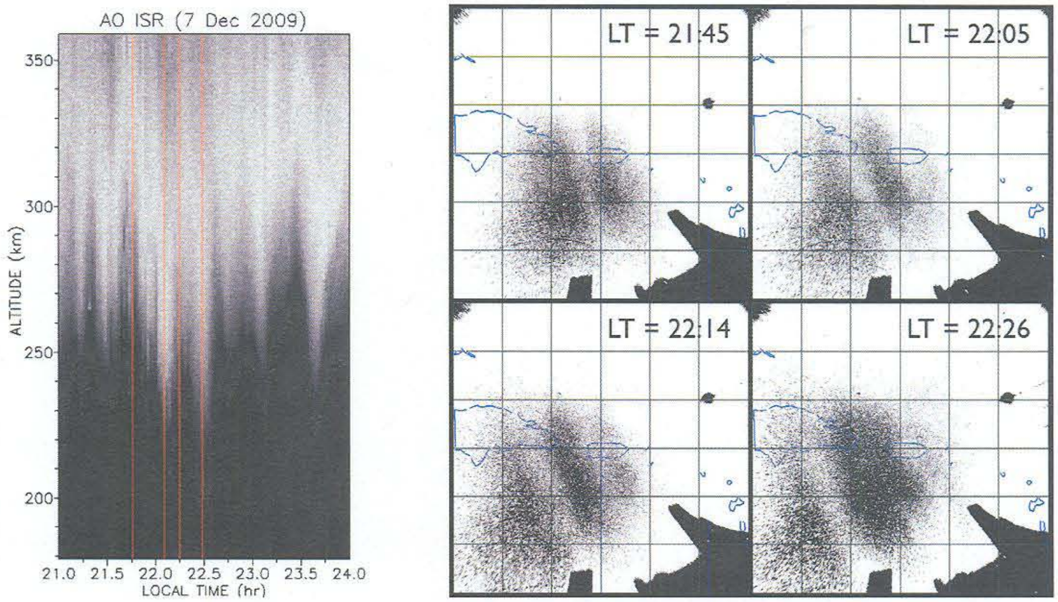


(a) (b)

Figure 1: Possible conjunctions of C/NOFS and PSASI based on the magnetic field geometry. (a) The imager is located at Arecibo Observatory. The blue circle represents the imager coverage, and the green line represents the maximum geographic latitude reached by the satellite. (b) Conjunction criteria using magnetic considerations. For the purposes of this study, the emission layer is assumed to be at 250 km altitude, shown in red. The blue portion of the airglow layer is the coverage of the imager. The green box represents the coverage of the C/NOFS satellite, and the shaded green area represents possible instrument conjunctions.

4 Observation of an MSTID

Figure 2a shows the ISR data for the night of 7 Dec 2009. The F-layer moves up and down periodically. The four orange lines correspond to the four PSASI images in Figure 2b. The grid lines in the image are spaced 200 km apart at the airglow layer. The MSTID can be seen as a series of light and dark bands aligned with the NW direction propagating to the southwest. The bright bands correspond to the F-layer moving downward.



(a) (b)

Figure 2: MSTID observed on 7 Dec 2009 over Arecibo Observatory. (a) Incoherent Scatter Radar data. The MSTID appears as a variation in the height of the layer. (b) Four images from PSASI. The MSTID appears as alternating light and dark bands and propagates to the southwest. Each of the images corresponds to one of the orange lines in panel (a).

Figure 3 compares the *in situ* data from C/NOFS at 840 km to the PSASI image during a flyby. The green line is the orbital track of C/NOFS mapped along field lines to the image altitude. The red lines represent the coastlines of the local geography. Panels (b) and (c) shows the **E** fields as measured by VEFI. The zonal field is defined as the direction perpendicular to the meridional plane and points roughly eastward. The meridional field is the outward (upward) direction perpendicular to the field line in the magnetic meridional plane. All data in the two lower panels are the local values measured by C/NOFS plotted as a function of the mapped geographic longitude. The actual location of the C/NOFS satellite and the associated measurement times are printed below the graph. At this high altitude, there is no significant variation in ion density or composition related to the electric field structure. The two bright bands in the image correspond to the two westward-pointing zonal fields (*ie*, downward $\mathbf{E}\times\mathbf{B}$ drifts). This is consistent with the bright bands being a result of the F layer moving downward. The meridional field is outward for the entire pass, corresponding to a westward $\mathbf{E}\times\mathbf{B}$ drift. This is also consistent with the propagation of the MSTID structure as observed by PSASI.

The C/NOFS satellite provides a new tool for investigating the effects of MSTIDs along a flux tube. Work is ongoing as more conjunction events are catalogued, including other locations.

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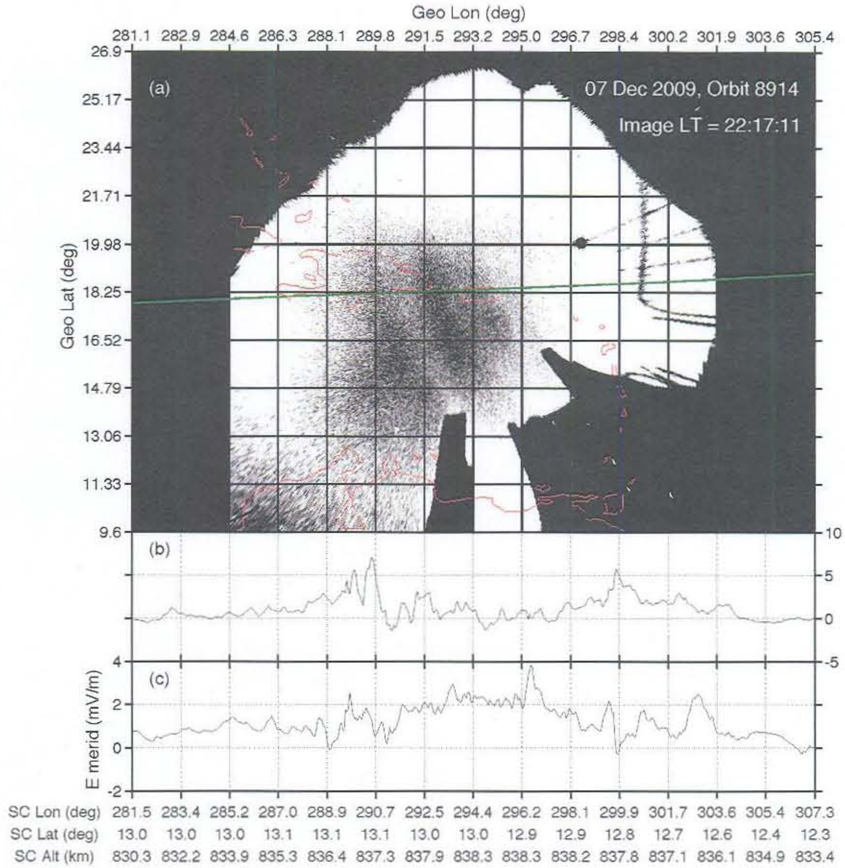

Figure 3: MSTID observed on 7 Dec 2009. The coordinates below the graph are the local values for the C/NOFS spacecraft, which are plotted as a function of the mapped longitude.

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