A new 3D display format relating azimuth-scanning radar data and all-sky images

Ilgin Seker1, Wesley E. Swartz2, John D. Mathews3, and Nestor Aponte4

1Geospace Physics Laboratory, Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA. (ilgin.seker@nasa.gov)

2School of Electrical and Computer Engineering, Cornell University, Ithaca, NY, 14853, USA. (wes.swartz@cornell.edu)

3Radar Space Sciences Laboratory, Electrical Engineering, The Pennsylvania State University, University Park, PA, 16802, USA. (JDMathews@psu.edu)

4Arecibo Observatory, Arecibo, PR, 00612, USA. (naponte@naic.edu)

Abstract

We combine all-sky images of 630 nm airglow with the 3D structure of electron densities in the F-region above Arecibo. The line-of-sight electron densities obtained from the two azimuth-scanning beams of Arecibo incoherent scatter radar (ISR) are plotted in cone-shaped 3D visualizations along with horizontal projections of 630 nm airglow images. Displays of data in this new format from a night with ionospheric plasma irregularities demonstrate the improved perspective of the new format in revealing the 3D structure and evolution of the ionospheric plasma features over that provided by separate 2D plots in latitude and longitude for the all-sky airglow images and in height and time for the ISR electron densities.

1. Introduction

While the azimuth scanning capabilities of the Arecibo incoherent scatter radar have been mostly used to develop velocity vectors of the plasma drifts [1], there also have been a number of classic papers in which the scanning was used to map out horizontal structure in the F-region [2] and sporadic E-layers [3]. Aponte et al. (2000) showed the directionality of the azimuth-scanning ISR data using 2D circular plots [4]. More recently, 3D cone pictorials of electron densities above Arecibo were developed by Swartz et al. (2009) to study medium scale traveling ionospheric disturbances (MSTIDs) [5]. Studies using airglow data describe the key features of these disturbances [6, 7]; namely, that at nighttime in the northern hemisphere, they form bands of enhanced and depleted F-region density bands (hence modulating the intensity of 630 nm airglow) that are typically aligned from northwest to southeast with a horizontal wavelength of ~200 km and travel from northeast to southwest at speeds ~100 m/s. However, it is very difficult to understand the 3D structure of MSTIDs from only all-sky images or ISR profiles.

2. 630 nm airglow from 16-17 June 2004

Nighttime 630 nm airglow is produced by atomic oxygen in the excited 1D state decaying to its ground state. This is a spontaneous emission following the dissociative recombination chemical reaction \(\text{O}_2^+ + e^- \rightarrow \text{O}(^1\text{D}) + \text{O}\) that creates the excited state. Since nighttime molecular oxygen ions are created by the charge exchange reaction \(\text{O}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{O}\), the production rate of excited \(\text{O}(^1\text{D})\), and hence the amount of 630 nm airglow, depends on the densities of both electrons and neutral molecular oxygen, peaking from about 200 to 300 km altitude. Airglow images map large-scale structures in latitude and longitude, thereby complementing the height profiles from the ISR.

The airglow data used in this study was obtained using the Penn State All-Sky Imager (PSASI) located at the Arecibo Observatory (AO) [6]. Seker et al. (2008, 2009) combined the information from the azimuth-scanning ISR and all-sky imager data to learn more about the 3D shape of MSTIDs [7, 8]; however, no directly combined 3D displays of the observations have been shown before. This study expands on this work to relate the flattened projections of all-sky images of 630 nm emissions during the night of 16-17 June 2004, like the one shown in Figure 1, to 3D cone projections of the electron densities, as developed by Swartz et al. (2009) [5]. The MSTIDs aligned in a specific direction are clearly visible in Figure 1 as parallel/periodic depletion bands.

978-1-4244-6051-9/11/$26.00 ©2011 IEEE
The ISR density data for the night of 16-17 June 2004 were obtained in a two-beam mode, with simultaneous profiles being measured with both the line and Gregorian feeds offset from the vertical (zenith) by 15° and with the two feeds offset from each other in azimuth by 180°. Figure 2 shows the plasma density for each beam as a function of height (corrected for range at a zenith angle of 15°) and time covering the period of interest here. The raw range and time resolution of the ISR data is 0.3 km and about 1 min, respectively, but the profiles were smoothed in height for these plots. Corresponding azimuth positions of each feed is also shown. When the line feed is looking at an azimuth of +180° (south), the Gregorian feed is looking at an azimuth of 0° (north). (An azimuth of +90° is east while +270° or -90° is west.) The pseudo periodicities in each plot, and the differences between them, indicate the structure we will examine in more detail. The last hour had the clearest sky and is of prime interest here.

Figure 2. AO ISR electron densities from line-feed and Gregorian-feed for the early morning of 17 June 2004. The azimuth positions are shown by the black triangular lines.

4. Combining airglow and electron density

A sequence of plots combining the ISR density cones with airglow images is shown in Figure 3. Time, indicated in the upper left, is in Atlantic Standard Time (AST), and the number in the upper right is the frame number of the all-sky images. The ISR cones have been limited to the altitude range of interest (200-450 km) so that the far side of the cone and the center part of the all-sky image are not blocked by the near side of the cone. The all-sky image is projected to ground level instead of being displayed at its height of origin so that it does not block the ISR cone. The same spatial scaling is used for both data sets. Density cone outlines are projected to the two vertical grid planes. The circle on the ground plane corresponds to a horizontal slice through the cone at 300 km altitude. The outline of the island of Puerto Rico is also shown for geographic reference. The projection of the airglow onto the ground has been cropped somewhat to discard the tree-line obscuration at the edges and to allow the density cones to appear larger. The NW to SE alignment of the airglow bands is immediately apparent in plots but should not be confused with the thinner streaks of clouds that are roughly perpendicular to the airglow bands. The clouds are readily distinguished in an animation of the sequence, since the clouds move quite rapidly from west to east during this time period, whereas the airglow bands move toward the southwest. The two halves of each cone
correspond to densities from the two feeds sweeping simultaneously through 180° in azimuth, with the source feed for a given half alternating in the time sequence. This dual beam configuration provides a time resolution of about 8 min, or twice as good as the 16 min that would otherwise be obtained with just one feed rotating in azimuth. Since the time resolution of the all-sky images is about 4 min, usually two consecutive all-sky frames are displayed per each ISR cone in the animation. The entire set of 115 3D images spanning about eight hours is available as a movie.

Figure 3. 630 nm airglow images combined with corresponding ISR electron density cones during 17 June 2004.

The first plot in Figure 3 for 02:55 AST shows a bright airglow band centered on the density cone. There are depletion bands to the southwest and to the northeast of the bright band. F-region densities were relatively high at this time, especially in the southeast quadrant of the cone, which is expected because the transition at the northeastern edge of a bright band is much sharper than the southwestern edge [7]. In other words, the northeastern edge of the depletion band in the southwest is reaching and affecting the western side of the cone. By 03:21 AST, the bright airglow band moved off to the southwest and the densities corresponding to the eastern half of the cone became greatly reduced, whereas the densities to the west increased and then were greater than those to the east. Note that this density change occurred rapidly in about 10 min, revealing the sharp transition at the northeastern
edge of the brightness band. However, the depletion bands do not always correspond to reduced electron densities. For example, even though there is a higher density patch in the south by 03:52 AST, there is little corresponding airglow. It should be noted that the airglow not only depends on electron density, but also on neutral density. The electron density patch is relatively high in altitude and, by this time, the molecular oxygen densities at these altitudes are reduced by the regular nighttime cooling of the thermosphere. Hence, when the electron density is enhanced by an uplifted patch of plasma (resulting in reduced recombination), the intensity of the airglow often decreases because of the smaller neutral densities.

5. Conclusions

The 3D format presented here for combining electron density data with airglow resolves features that are difficult to correlate with just planar views of the data and also makes it easier to see the 3D shape of F-region irregularities. Although the spatial extent of the airglow features is huge, the horizontal extents of the ISR density measurements are large enough to track and resolve edges in the enhancements and depletions. This display format is by no means limited to MSTIDs; it could be applied to other night-time F-region events (e.g., spread-F plumes or brightness waves) as long as both azimuth-scanning ISR and airglow data are available during the event. In theory, this technique can also be used for 3D displays of E-region events (such as gravity waves) using 557.7 nm airglow and scanning lidar data.

Acknowledgments

For this research, W. E. S. was supported under NSF Grant ATM-0737697 to Cornell University, I. S. was supported by an appointment to the NASA Postdoctoral Program at the Goddard Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA, and J. D. M. was supported under NSF Grant ATM-0721613 to The Pennsylvania State University. The Arecibo Observatory is operated by Cornell University under a cooperative agreement with the National Science Foundation.

References


