Incoherent Scatter Radar Study of the E-region Ionosphere at Arecibo

The ionospheric E-region lies in the altitude range of 90 to 150 km. This region supports a wide range of waves, including gravity waves, tides, and planetary waves. In this region, the ionized and neutral particles transit from completely coupled in the lower E-region to very weakly coupled at the upper E-region. This is the region where thin ionization layers are formed due to the magnetic field and the rapid altitudinal variation of the neutral wind. Fluid dynamics, electrodynamics and their coupling are fully manifested in this region. The great sensitivity of the Arecibo Incoherent Scatter Radar (ISR) provides the most accurate measurements of electron concentration, ion drift, and ion and electron temperatures, neutral winds and electrical field with very high time and height resolutions. The Arecibo ISR has played a vital role in studying the energetics, dynamics, coupling and compositions in the E-region. With a slew of co-located optical and radio sensors, the Arecibo ISR will continue its pivotal role in the study of the ionosphere and the atmosphere. The following summarizes a few topics that can be best carried out at Arecibo.

Study of Gravity Waves, Tides and Planetary Waves

Gravity waves can have a period of as short as a few minutes. The fact that Arecibo ISR can measure the electron concentration with a time resolution of a few seconds makes it the primary, if not the only, instrument to study E-region gravity waves. Figure 1 shows electron density profiles obtained by Djuth et al. (1997) using the plasma line technique. Djuth et al. have further studied the relationship of the vertical wavelength of the gravity waves as a function of altitude, which is shown in Figure 2. The general trend is that the vertical wavelength increases with altitudes. Subsequent studies reveal that gravity waves are ubiquitous at Arecibo (Djuth et al. 2004).

The Arecibo ISR is an important ground-based tool in studying tides. The tidal waves can be seen in the wind observations as well as in temperature observations, as illustrated in Figure 3 (Zhou et al. 1997). It is generally regarded that diurnal and semidiurnal tides (with a period of 24 and 12 hr respectively) are the dominant tidal modes. A recent study at Arecibo shows that terdiurnal tide (8 hr period) can compete with the diurnal and semidiurnal tides (Gong and Zhou 2011). Figure 4 shows the power spectral analysis of the meridional wind measured at Arecibo. Other than tidal periods, a planetary wave with a period of 2-day can also be seen. Further, spectral peak at 1.5/day may be a result of non-linear interaction between a two-day planetary wave and the diurnal tide. Figure 5 reveals the impact of a 2-day planetary wave on electron concentration. The penetration of electrons to lower altitudes on odd days around 90 km is due to vertical transport of long-lived ions – most likely metallic ions (Zhou 1998).

Scientific questions that can be most effectively pursued by the Arecibo incoherent scatter radar include:

- What are the generation mechanisms and propagation characteristics of the gravity waves, tides and planetary waves?

- How do gravity waves, tides, planetary waves and mean flow interact with each other?
- How do the different waves and their interactions affect the energetics, composition and temperature structures?

Study of Layered Phenomena

One of the most interesting phenomena in the ionosphere is the formation of thin ionization layers, often called sporadic E's or Es layers. While sporadic E's may vary in intensity, their occurrence at Arecibo is quite regular. Its generation is well understood to be due to winds pushing the ions across the geomagnetic field lines in opposite directions. Figure 6 shows ion layers observed at Arecibo (Mathews et al., 1997). Rapid modulation of the Es layers have been shown to be associated with the quasi-periodic echoes observed by VHF coherent scatter radars (Hysell et al., 2004).These thin ionization layers have also been observed to be associated with neutral atom layers, such as Na, Fe, K and Ca (e.g. Zhou et al. 2008). The co-located resonance lidars and optical instruments make Arecibo Observatory a primary site to study not only the Es layers but also the neutral metallic layers in the lower part of the E-region, as well as their connections with meteoric input.

Another type of thin ionization layers frequently observed at Arecibo is the so-called intermediate layers. This type of layer is formed at the upper part of the E-region and becomes part of the Es system once descending into the lower part of the E-region, as shown in Figure 6. One question regarding the intermediate layer is its composition. Es layers are generally understood to be composed of metallic ions generated through meteoric ablations. Intermediate layers, as shown by Roddy et al. (2004), may contain a large fraction of metallic ions as well. How do metallic ions get up to the altitudes well above meteoric ablation heights is still not well understood.

Study of E-region Electric Field

Electric field in the ionosphere along the geomagnetic field line is generally regarded to be negligible because of the high conductance in this direction. As a result, the electric field perpendicular to the field line is height invariant. This property is thought to apply to both the F- and the E- region where electron density is high enough and ion-neutral collision is low enough for the ionosphere to be highly anisotropic. A recent study by Zhou et al. (2011), however, shows strong evidence that the E-region electric field is not height invariant. Figure 6 shows the deduced electric field at Arecibo. A height variant electric field challenges our fundamental understanding of the physics occurring in the ionosphere. Arecibo Observatory's location (dip angle ~ 45^{o}) and its accurate and high resolution measurements make it best suited for this types of studies.

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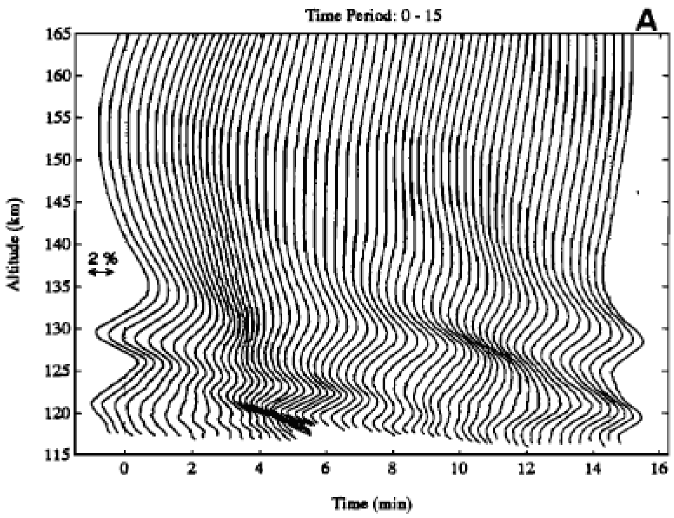

Figure 1. Residual electron density profiles expressed as a percentage of the mean profile. The double arrow indicates the magnitude of a 2% fluctuation. Time periods are in unites of minutes and are referenced to 13:51 LT on July 10, 1992. (From Djuth et al. 1997)

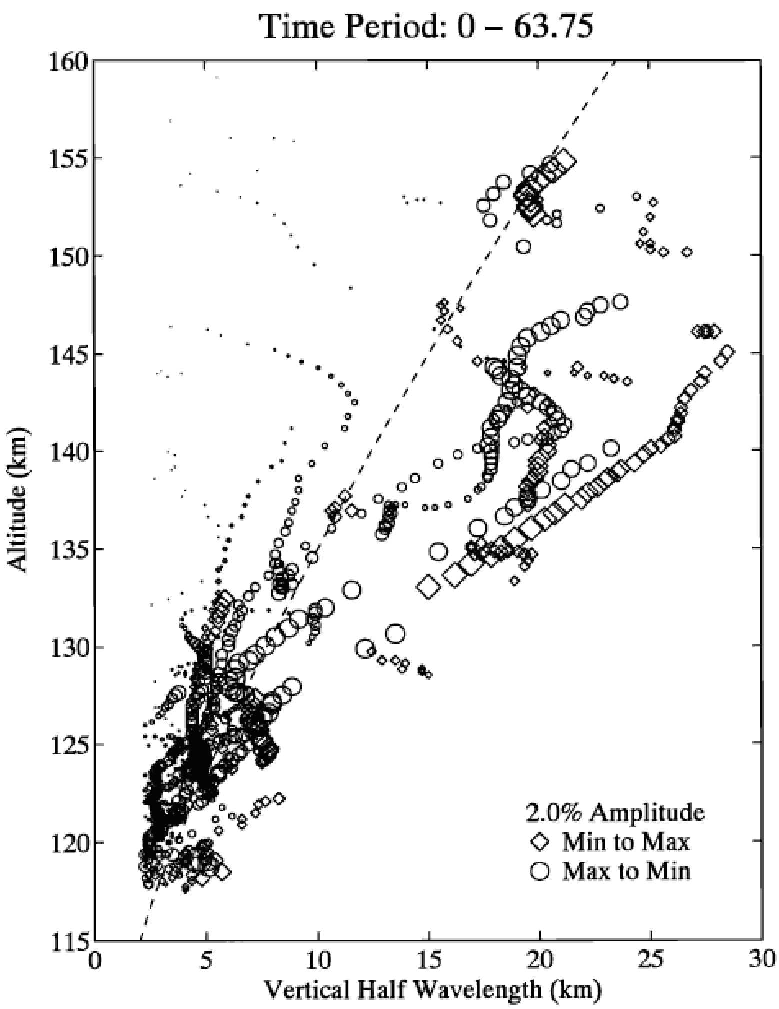

Figure 2. Vertical half-wavelength as a function of altitude observed above Arecibo (Djuth et al., 1997).

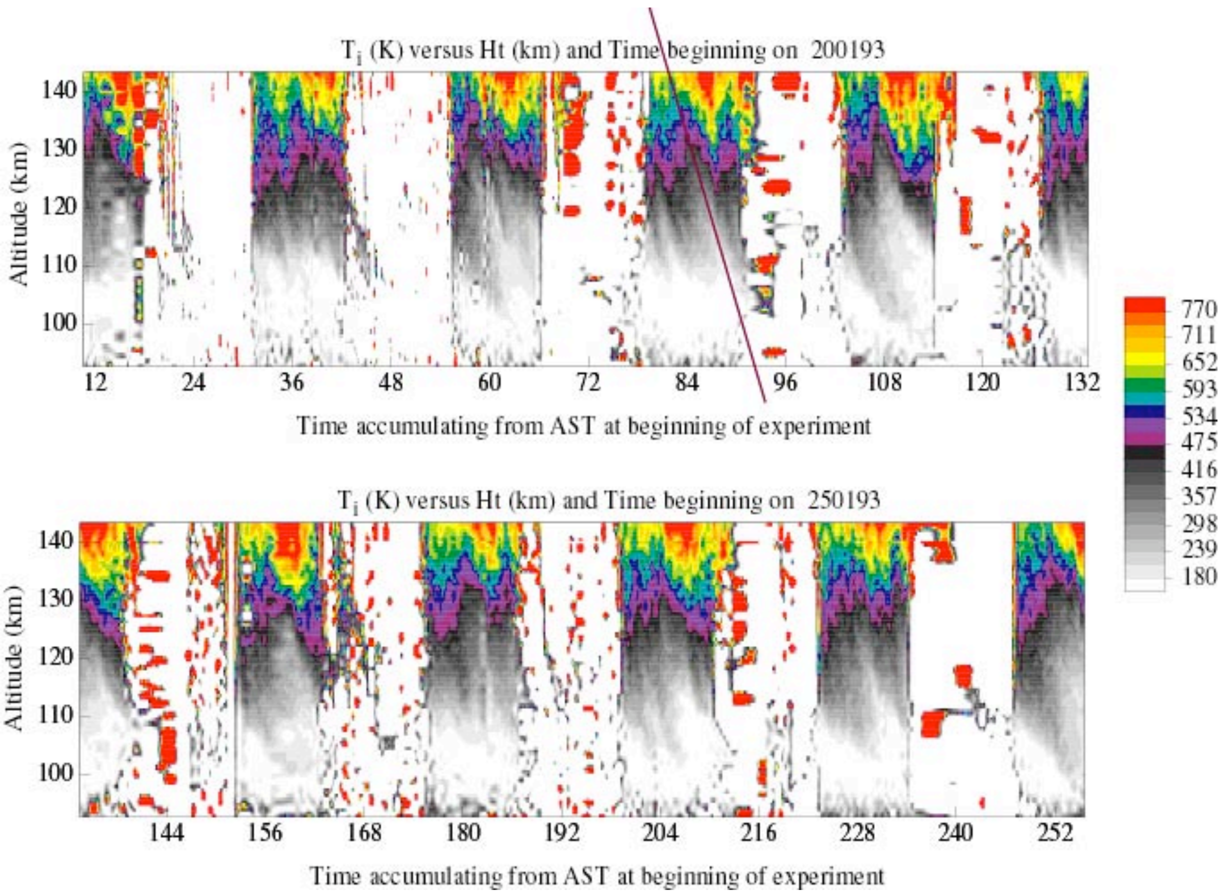

Figure 3. Ion temperature as a function of time and altitude above in January 1993. The red line indicates the general phase progression resulted from tides. (From Zhou et al., 1997)

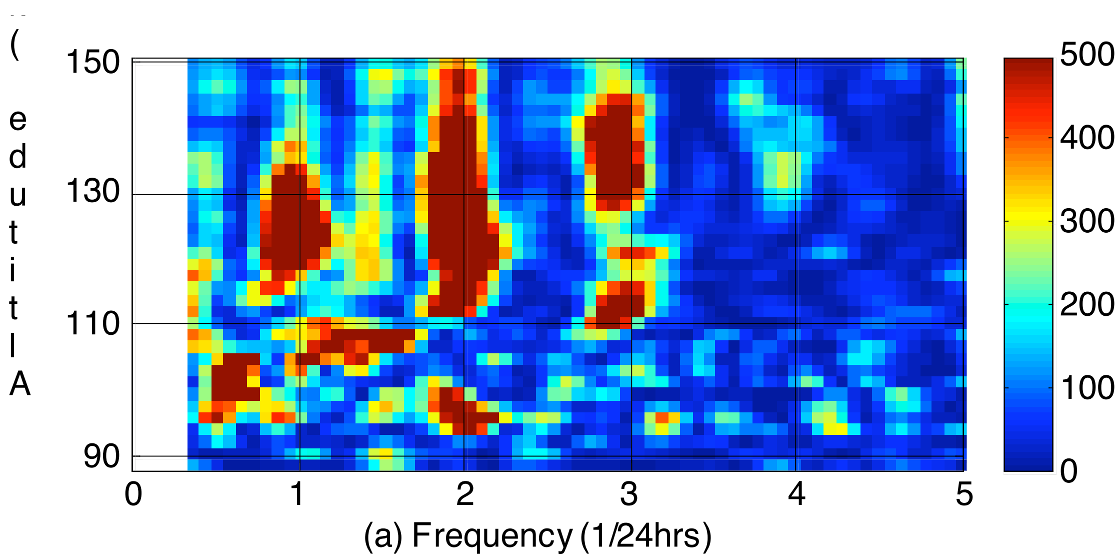

Figure 4. Power spectral analysis of meridional wind measure at Arecibo during Jan. 14-23, 2010. Tidal and planetary wave periods dominate the spectra. (From Gong and Zhou, 2011)

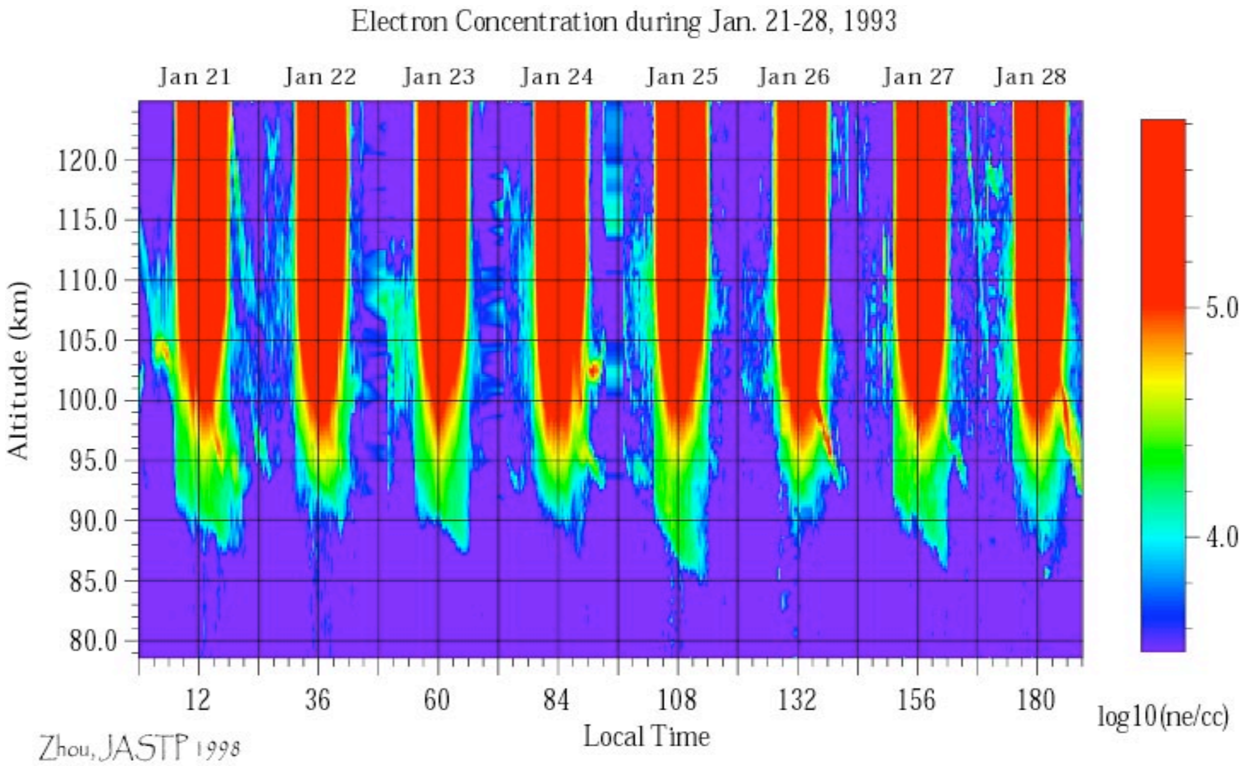

Figure 5. Electron concentration at Arecibo during Jan. 21 to Jan. 28, 1993. Penetration of electrons to lower altitudes on odd days is a result of a 2-day planetary wave. (From Zhou, 1998)

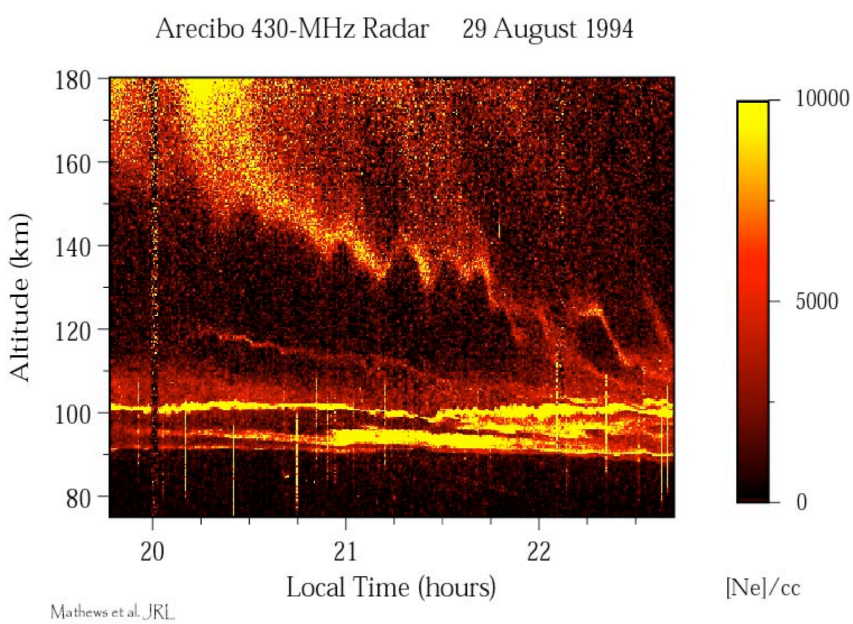

Figure 6. Sporadic E and intermediate layers observed at Arecibo. (From Mathews et al., 1997)

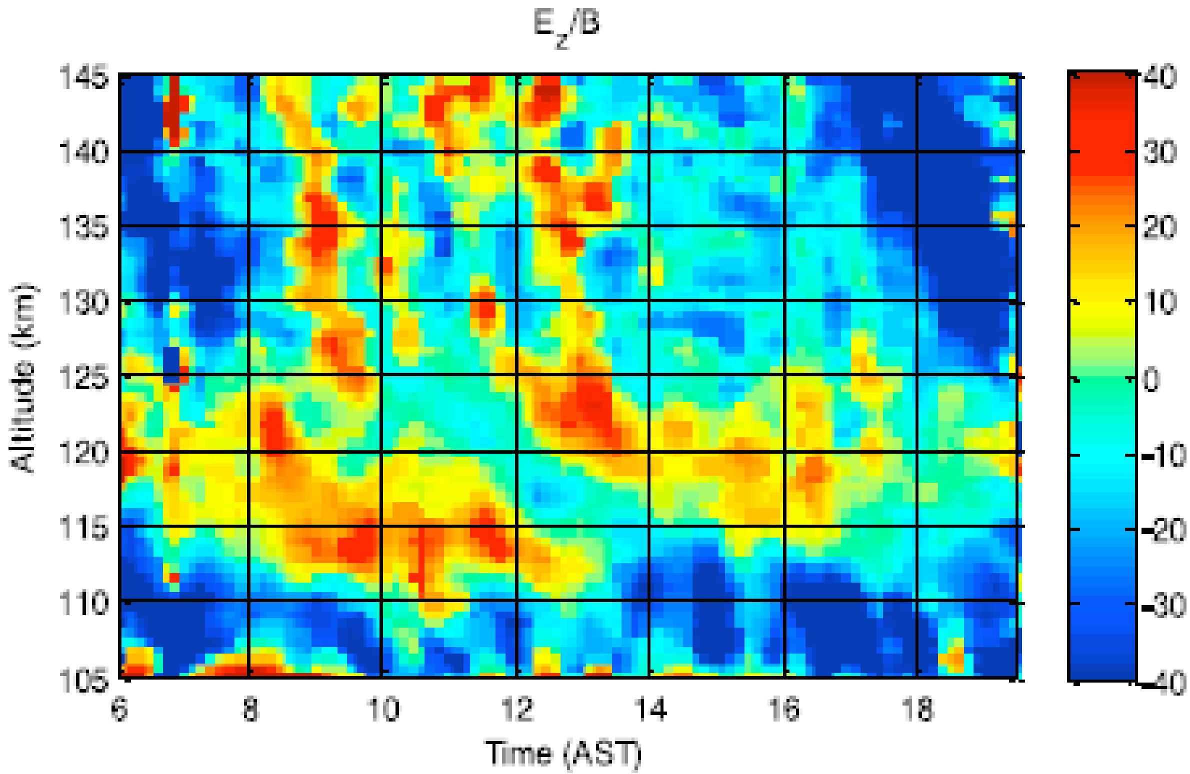

Figure 7. Derived vertical electric field at Arecibo (Zhou et al. 2011). The height varying electric field is not well understood.