**INTRODUCTION**

The “midnight collapse” of the ionosphere is one of its more interesting dynamic features. It is characterized by a rapid decrease of the altitude of the ionosphere F2 layer peak (hmF2) around midnight and may be accompanied by a decrease, increase or maintenance of the associated F2 layer peak electron density concentration (NmF2). This phenomenon has been studied extensively at Arecibo, Puerto Rico for more than 45 years using various observations and techniques. As shown in Table 1 below, Townsville, Australia has very similar geomagnetic and geographic characteristics as Arecibo, but it is located in the southern hemisphere, so its ionosphere should behave similarly to the ionosphere at Arecibo.

<table>
<thead>
<tr>
<th></th>
<th>GLat</th>
<th>GLon</th>
<th>MLat</th>
<th>MLon</th>
<th>MDecl</th>
<th>Mincl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arecibo</td>
<td>18.4°</td>
<td>66.6°</td>
<td>27.9°</td>
<td>6.48°</td>
<td>-12.8°</td>
<td>48.4°</td>
</tr>
<tr>
<td>Townsville</td>
<td>-19.6°</td>
<td>146.9°</td>
<td>-28.4°</td>
<td>220.5°</td>
<td>7.66°</td>
<td>-49.2°</td>
</tr>
</tbody>
</table>

Table 1. Data for Arecibo and Townsville. Geographic Latitude (GLat), Geographic Longitude (GLon), Magnetic Latitude (MLat), Magnetic Longitude (MLon), Magnetic Declination (MDecl), and Magnetic Inclination (Mincl).

**THEORY**

Ionospheric F2 layer heights (hmF2) are sensitive to the motion of neutral winds along magnetic field lines. Techniques have been developed to derive the magnetic meridional component of neutral winds in the thermosphere using values of hmF2 derived from ionosonde observations. The winds derived from hmF2 are termed ‘Equivalent’ neutral winds because they comprise both neutral wind and electric field contributions to changes in hmF2. This technique, which has been incorporated into the first-principles Field Line Interhemispheric Plasma (FLIP) model has been shown to generate winds that agree well with other observed and modeled winds.

The relationship between the horizontal component of the neutral wind along a magnetic meridian (U) and the resulting change in hmF2 may be described as

\[ U(t + \Delta t) = \frac{h(t)h(t + \Delta t)}{\alpha(t)} + U'(t) \]

where \( h'(t) \) and \( U'(t) \) are the calculated height of the F2 layer and the equivalent wind at time \( t \) and \( \alpha \) is a constant of proportionality. This method is used numerically to estimate neutral wind speeds along meridional field lines using the observed hmF2 layer height, with the assumption that \( h'(t) \) and \( \alpha(t) \) are constant for small time steps.

Ionospheric models require estimates of the local neutral wind velocity and vertical \( \mathcal{E} \times \mathcal{B} \) plasma drift. This technique provides high-resolution winds at a large number of ionosonde sites. Equivalent neutral winds are currently being generated using a global ionosonde database of mid-latitude ionosonde measurements that spans the years 1961-1990 with the goal of developing a new empirical wind model. The database includes nearly 100 ionosonde sites in the mid-latitudes and the wind values being generated have a one-hour time resolution.

**METHOD VALIDATION**

Figure 1. below compares derived Equivalent winds with ground-truth Fabry Perot Interferometer (FPI) night-time optical winds for March 4, 1995. There is very good agreement between the ground truth winds and the hmF2-based Equivalent winds.

**OBSERVATIONS AND MODEL RESULTS AT TOWNSVILLE**

Figure 2 above shows the observed hmF2, modeled hmF2, and modeled winds at Townsville during the equinoxes during several consecutive years. Midnight local time is indicated by a small upward arrow in each UT day. The year and mean F10.7A solar flux are indicated at the top of each plot. A data legend is shown in the plots for Year=1970.

**DATA AND MODEL SUMMARY**

Figure 3 shows summaries of the model data from Figure 2, separately for each season. The annual mean of the F10.7A solar flux is shown in panel (a), the non-directional annual average mean of the wind speed is shown in panel (b), the median F2 layer height just before and after the midnight collapse in panel (c), and the average annual magnitude of the midnight collapse for every year in panel (d).

The annual average wind speeds in (b) increase as the F10.7A decreases, indicating a decrease in ion drag over the 11-year period centered around 1975. The F2 layer heights in (c) vary directly with F10.7A, indicating a direct energy-deposition relationship with F2 altitude. The collapse magnitudes in (d) vary directly with F10.7A with the exception of the years 1972 and 1978. In order to suppress hmF2 outliers due to magnetic activity in Figure 3(c), a median filter was used.

**FOURIER ANALYSIS TRENDS**

Figure 4 shows the Fourier transform of the Equivalent winds from Figure 2, for the spring and fall equinox seasons. Winds with periods of 24, 12, 6, 5 and 4 hours are visible, but the 24, 12, 8, and 6 hour periods are dominant.

In the spring equinox periods, the diurnal (24 hour), semidiurnal (12 hour), and tidal (8 hour) periods are the strongest and show strong year-to-year variability with the annual changes of F10.7A solar flux.

In the fall equinox periods, the year to year variability for the first three periods is different from the spring equinox, and some higher order (6, 5 and 4 hour) terms become statistically significant.

**SUMMARY**

The midnight collapse phenomenon has been shown to occur at almost every night at Townsville, which has consistent with other observations at Arecibo. This suggests that the ionosphere may behave similarly at other sites which have the same geographic latitude and geomagnetic latitudes.

The midnight collapse of hmF2 at Townsville occurred consistently during both the spring and fall equinox seasons over a full solar cycle. The topside F2 layer heights (just before a collapse) decreased more strongly in solar activity than the bottomside F2 layer heights (just after a collapse). This led to a minimum in the magnitude of the midnight collapse when the solar flux was at a minimum. Therefore, solar activity appears to contribute to the characteristics of the midnight collapse phenomena.

The derived Equivalent winds clearly demonstrate wind behavior that is consistent with the hourly and yearly behavior of the observed hmF2 altitudes at Townsville. The HWM14 winds at Townsville exhibit statistical consistence with the observed Equivalent winds at Townsville. The dynamics and strength of the midnight collapse appears to be related to the both strength of the solar activity and some combination of the dominant tidal wind periods. Research into the contribution by the tidal winds is ongoing.