Uncertainty Associated with Modeling the Global Ionosphere

Janelle V. Jenniges  
*Utah State University*

Ariel O. Acebal  
*Air Force Institute of Technology*

Larry Gardner  
*Center for Atmospheric and Space Sciences, Utah State University*

Robert W. Schunk

Lie Zhu  
*Utah State University*

Follow this and additional works at: https://digitalcommons.usu.edu/phys_stures

Part of the Oceanography and Atmospheric Sciences and Meteorology Commons, and the Physics Commons

**Recommended Citation**

A study has been conducted of the effect that different physical assumptions have on global models of the electron density distribution. The study was conducted with the Ionosphere Forecast Model (IFM) and the Ionosphere Plasmasphere Model (IPM) developed by Utah State University. Both physics-based, time-dependent, global models use the same empirical models for the neutral atmosphere (MSIS) and neutral wind (Horizontal Wind Model, HWM), but the altitude range, thermal structure, number of ion species, and magnetic field data are different. The IPM covers the altitude range from 90–1300 km, calculates the densities for four ions (O+, O2−, N+, O−), and is based on a tilted effort dipole magnetic field. The IFM extends from 90–20,000 km, includes six ion species (O+, O2−, N+, N2+, H+, He+), is based on the International Geomagnetic Reference Field (IGRF), and allows for inter-hemisphere flow. Therefore, the comparison of these models will elucidate the quantitative effect of these differences. In addition, simulations were conducted to study the effect of uncertainties in the zonal wind, secondary electron production, O+ / O− collision frequency, tidal structure, and state of plasmasphere refilling. The simulations were conducted for a wide range of solar, seasonal, and geomagnetic activity levels. Quantitative results will be given that establish the importance of the various physical processes.

**ABSTRACT**

A study has been conducted of the effect that different physical assumptions have on global models of the electron density distribution. The study was conducted with the Ionosphere Forecast Model (IFM) and the Ionosphere Plasmasphere Model (IPM) developed by Utah State University. Both physics-based, time-dependent, global models use the same empirical models for the neutral atmosphere (MSIS) and neutral wind (Horizontal Wind Model, HWM), but the altitude range, thermal structure, number of ion species, and magnetic field data are different. The IPM covers the altitude range from 90–1300 km, calculates the densities for four ions (O+, O2−, N+, O−), and is based on a tilted effort dipole magnetic field. The IFM extends from 90–20,000 km, includes six ion species (O+, O2−, N+, N2+, H+, He+), is based on the International Geomagnetic Reference Field (IGRF), and allows for inter-hemisphere flow. Therefore, the comparison of these models will elucidate the quantitative effect of these differences. In addition, simulations were conducted to study the effect of uncertainties in the zonal wind, secondary electron production, O+ / O− collision frequency, tidal structure, and state of plasmasphere refilling. The simulations were conducted for a wide range of solar, seasonal, and geomagnetic activity levels. Quantitative results will be given that establish the importance of the various physical processes.

**Methodology**

All three geophysical cases were run first with the default conditions and then with adjusted physical parameters. Each parameter was examined independently of the other parameters. The model output from the default run was compared to the adjusted run using an absolute difference, percent change, and a cent. The simulations were conducted to study the effect of uncertainties in the zonal wind, secondary electron production, O+ / O− collision frequency, tidal structure, and state of plasmasphere refilling. The simulations were conducted for a wide range of solar, seasonal, and geomagnetic activity levels. Quantitative results will be given that establish the importance of the various physical processes.

**Baseline Runs**

- **Figure 1.** Total electron content for all three cases at 00Z and 12Z
- **Figure 2.** Peak electron density for all three cases at 00Z and 12Z

**O+ / O− Collision Frequency Comparison**

<table>
<thead>
<tr>
<th>Case</th>
<th>Pre-Sunrise Peak</th>
<th>P1</th>
<th>Pre-Sunrise Mid</th>
<th>P2</th>
<th>Decor</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>93.26</td>
<td>3.99</td>
<td>6.25</td>
<td>20.4</td>
<td>31.05</td>
<td>2.09</td>
</tr>
<tr>
<td>Case 2</td>
<td>78.2</td>
<td>31.3</td>
<td>13.01</td>
<td>50.72</td>
<td>14.0</td>
<td>2.07</td>
</tr>
<tr>
<td>Case 3</td>
<td>40.6</td>
<td>67.5</td>
<td>14.11</td>
<td>54.9</td>
<td>74.95</td>
<td>2.97</td>
</tr>
</tbody>
</table>

- **Zonal Wind Comparison**
  - Setting the zonal winds to zero causes the enhancement over Madagascar to decrease for both solar minimum and solar medium from 0.15 to 0.3
  - The maximum increase in TEC occurs at 102 for both cases
  - Maximum 12 TEC decrease during solar minimum
  - Maximum 40 TEC decrease during solar medium

- **Daytime Production Comparison**
  - Decreasing the daytime production multiplication factor as a linear function of $F_{10.7}$ resulted in decreased TEC values for all three geophysical cases
  - The maximum decrease in TEC occurs at 124 for all three cases
  - Maximum decrease of 10 TECU decreases during solar minimum
  - Maximum 7 TECU decrease during solar minimum conditions
  - Maximum 30 TECU decrease during solar medium conditions

- **Tidal Structure Comparison**
  - Including tidal forcing causes both enhancements and depletions in TEC and 400 km Ne, as a function of longitude
  - The maximum changes in TEC and 400 km Ne occur at 13L
  - Changes in TEC range from 10% to 23%
  - Changes in Ne range from 25% to 64%
  - The smallest changes occur during case 3 and the largest changes occur during case 1

**Table 1.** Geophysical conditions for the three IMF model runs

<table>
<thead>
<tr>
<th>IMF Model</th>
<th>Solar Minimum</th>
<th>Solar Medium</th>
<th>Solar Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>-20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Case 2</td>
<td>-15</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Case 3</td>
<td>-10</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

- **Table 2.** Adjustments to physical parameters in the IPM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>O+ / O−</td>
<td>1.0</td>
<td>0.99</td>
</tr>
<tr>
<td>zonal wind</td>
<td></td>
<td>adjustment</td>
</tr>
<tr>
<td>secondary</td>
<td>electron production</td>
<td>adjustment</td>
</tr>
<tr>
<td>night time</td>
<td>E x B drifts</td>
<td>adjustment</td>
</tr>
</tbody>
</table>

**Summary and Conclusions**

The combination of empirical model output and robust physics in a physics-based model can lead to erroneous and inconsistent features in the model output. These errors are due to the uncertainty in the model parameters and need to be corrected before the model output can be used. This study examined the effects of the uncertainty in five physical parameters in the IPM. The parameters included the O+ / O− collision frequency, zonal wind, secondary electron production, nighttime E x B drifts, and tidal structure. The uncertainty for each parameter was evaluated by comparing a default run of the IPM to a run with the parameter adjusted for three sets of geophysical conditions. The comparisons showed that the effects of these uncertain physical parameters are significant and can be non-linear across both space and time.

It was found that doubling the O+ / O− collision frequency resulted in increased densities above the F1 peak and decreased densities below the F1 peak.

- **Figure 3.** O+ / O− electron density percent increase for case 1
- **Figure 4.** O+ / O− vs. local time for all three cases

- **Figure 5.** Total electron content for case 2 at 01Z
- **Figure 6.** 45°E electron density for case 2 at 13L

- **Figure 7.** Total electron content for case 2 at 03Z
- **Figure 8.** 270°E electron density for case 2 at 05Z

- **Figure 9.** Total electron content for case 1 at 01Z
- **Figure 10.** Total electron content for case 3 at 01Z

- **Figure 11.** Total electron content for 400 km electron density percent increase for all three cases at 13L