12-13-2010

Uncertainty Associated with Modeling the Global Ionosphere

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Recommended Citation
ABS# SA51C-1643
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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 (MIS) and neutral wind (Horizontal Wind Model, HWM), but the altitude range, thermal structure, number of ion species, and magnetic field lines are different. The IFM covers the altitude range from 90-1400 km, calculates the densities for four ions (NO+, O2+, N2+, O+), has a simple prescription for calculating H+, and is based on a tilted earth dipole magnetic field. The IPM extends from 90-20,000 km, includes six ion species (NO+, O2+, N2+, O+, H+, H2O), is based on the International Geomagnetic Reference Field (IGRF), and allows for inter-hemispheric 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, tidal forcing, 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

Baseline Runs

Figure 1. Total electron content for all three cases at 02Z and 12Z

Figure 2. Peak electron density for all three cases at 02Z and 12Z

Zonal Wind Comparison

Figure 3. Peak electron density percent increase for case 1

Figure 4. Np/e vs. local time for all three cases

O+/O Collision Frequency Comparison

Table 1. Percent increase in Np/e due to doubling the O+/O collision frequency

<table>
<thead>
<tr>
<th>Case</th>
<th>Pre-Sunrise Peak</th>
<th>12L</th>
<th>Daytime Min</th>
<th>05L</th>
<th>Pre-Sunrise Peak</th>
<th>12L</th>
<th>Daytime Min</th>
<th>05L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>93.26</td>
<td>9.39</td>
<td>6.25</td>
<td>20.4</td>
<td>31.95</td>
<td>21.99</td>
<td>5.86</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td>78.22</td>
<td>15.11</td>
<td>13.03</td>
<td>15.77</td>
<td>140.99</td>
<td>5.97</td>
<td>3.13</td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>96.91</td>
<td>34.72</td>
<td>6.97</td>
<td>14.11</td>
<td>18.44</td>
<td>74.96</td>
<td>0.98</td>
<td>6.99</td>
</tr>
<tr>
<td>Case 4</td>
<td>38.65</td>
<td>8.68</td>
<td>12.37</td>
<td>128.73</td>
<td>5.97</td>
<td>5.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 5</td>
<td>38.99</td>
<td>11.35</td>
<td>19.92</td>
<td>36.38</td>
<td>38.4</td>
<td>7.95</td>
<td>7.95</td>
<td></td>
</tr>
</tbody>
</table>

Zonal WInds

Figure 5. Total electron content for case 2 at 02Z

Figure 6. 45° electron density for case 2 at 13L

• Setting the zonal winds to zero causes the enhancement over Madagascar to decrease for both solar minimum and solar medium from 60—142
• The maximum increase in TEC occurs at 102 for both cases
• Maximum 12 TEC decrease during solar minimum
• Maximum 60 TEC decrease during solar medium

Daytime Production Comparison

Figure 7. Total electron content for case 2 at 03Z

Figure 8. 270° electron density for case 2 at 03Z

• Decreasing the downward E X B drift resulted in increased nighttime low latitude TEC for all three geophysical cases
• The maximum increase in TEC occurs at 03L for all three cases
• Greatest increase of 40 TEC (63%) occurred during solar minimum
• 8 TEC increase (10%) during minimum
• 30 TEC increase (50%) during solar maximum

Tidal Structure Comparison

Figure 9. Total electron content for case 1 at 02Z

Figure 10. Total electron content for case 3 at 02Z

• Including tidal forcing causes both enhancements and depletions in TEC and 400km N, as a function of longitude
• The maximum changes in TEC and 400km N, occurs at 13L
• Changes in TEC range from -10% to +23%
• Maximum 400km N range from -28% to +44%
• The smallest changes occur during case 3 and the largest changes occur during case 1

Tidal Forcing

Baseline Runs

Table 2. Adjustments to physical parameters in the IPM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Tidal Forcing</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>O+/O ratio</td>
<td>Normal</td>
<td>Halved</td>
<td>100% decrease in O+/O collisions</td>
</tr>
<tr>
<td>Zonal winds</td>
<td>Set to zero</td>
<td>Tidal forcing</td>
<td>Tidal forcing included by modulating E X B drift</td>
</tr>
<tr>
<td>Electron density</td>
<td>10% increase</td>
<td>Tidal forcing</td>
<td>Electron density increased as a function of tidal forcing</td>
</tr>
<tr>
<td>Magnetic field</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Geophysical conditions for the three IPM model runs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.7</td>
<td>88.9</td>
<td>101.14</td>
<td>135.16</td>
</tr>
<tr>
<td>F10.7</td>
<td>87.0</td>
<td>102.71</td>
<td>36.99</td>
</tr>
<tr>
<td>Solar activity</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Solar activity</td>
<td>10</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Solar activity</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Solar activity</td>
<td>10</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Solar activity</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Solar activity</td>
<td>10</td>
<td>12</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 4. Maximum percent change in TEC and 400km N, for all three cases at 13L

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>20%</td>
<td>18%</td>
<td>44%</td>
</tr>
<tr>
<td>Increase</td>
<td>15%</td>
<td>10%</td>
<td>24%</td>
</tr>
<tr>
<td>Maximum</td>
<td>15%</td>
<td>10%</td>
<td>24%</td>
</tr>
<tr>
<td>Increase</td>
<td>15%</td>
<td>10%</td>
<td>24%</td>
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<tr>
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<td>10%</td>
<td>24%</td>
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<td>15%</td>
<td>10%</td>
<td>24%</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. These 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 different 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 increases the peak electron density 30—140% in the equatorial anomalies. The most significant results of setting the zonal winds to zero was a 50% decrease during solar medium equinox near Madagascar. It was found that changes in electron density and TEC are directly proportional to how daytime production is scaled to account for secondary electron production. The result of decreasing the nighttime downward E X B drift was an increase in TEC from 60%—130% at low latitudes depending on season and solar cycle. Finally, tidal forcing was included by modulating the E X B drift and was found to reproduce the four-wave pattern of enhanced TEC at low latitudes. Low latitude TEC increased 15—20% at longitudes centered at 15°E, 110°E, 208°E, and 29°E while decreasing 15—20% at longitudes centered at 60°E, 155°E, 245°E, and 335°E.

Methodology
All three geophysical cases were run first with the default conditions and then with the 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 crust.