Thermospheric Density Variations

EUV Solar and Geomagnetic Storm Modeling

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## Density Variations at 400 km

<table>
<thead>
<tr>
<th>Variations</th>
<th>Change</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar cycle</td>
<td>1600 %</td>
<td>11 years</td>
</tr>
<tr>
<td>Semiannual</td>
<td>125 %</td>
<td>12 months</td>
</tr>
<tr>
<td>Solar UV Rotation</td>
<td>250 %</td>
<td>27 days</td>
</tr>
<tr>
<td>Major Geomagnetic Storm</td>
<td>800 %</td>
<td>3 days</td>
</tr>
<tr>
<td>Diurnal effect</td>
<td>250 %</td>
<td>1 day</td>
</tr>
</tbody>
</table>
Solar Flux F10, F10B Indices
UV Absorption Regions

Altitude of Maximum Rate of Absorption of Solar UV Radiation

Wavelength (nm)

Altitude (km)

Hot Corona
EUV Chromosphere
FUV Lower Chromosphere - Photosphere
MUV Cool Corona

S\textsubscript{10} 74%

Y\textsubscript{10} 6%

Ly alpha

Y\textsubscript{10} 6%

M\textsubscript{10} 10%

F\textsubscript{10.7} 10%
New Solar Indices

2005 Solar Flux Indices

Year Day

Solar Flux Units

F10
S10
M10
Y10
2001 Solar Flux Indices

<table>
<thead>
<tr>
<th>Year Day</th>
<th>F10 Flux</th>
<th>F10B</th>
<th>ap</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
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<tr>
<td>150</td>
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<tr>
<td>200</td>
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<tr>
<td>250</td>
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<td>300</td>
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<td></td>
<td></td>
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<tr>
<td>350</td>
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</tr>
</tbody>
</table>

Legend:
- F10
- F10B
- ap
All previous empirical models use the $ap$ geomagnetic index for storm modeling.

The 3-hour $ap$ is a measure of general magnetic activity over the Earth, and responds primarily to currents flowing in the ionosphere and only secondarily to magnetospheric variations.

The $ap$ index is determined by observatories at high latitudes which can be blind to energy input during large storms (Huang and Burke, 2004).

The Disturbance Storm Time (Dst) index is primarily used to indicate the strength of the storm-time ring current in the inner magnetosphere.

During the main phase of magnetic storms, the ring current becomes highly energized and produces a southward-directed magnetic field perturbation at low latitudes on the Earth’s surface.

The Dst index is determined from hourly measurements of the magnetic field made at four points around the Earth’s equator.
2004 Storm Geomagnetic Index Dst

- 1st Storm Start
- 1st Storm End
- 2nd Storm Start
- Recovery Slope Change
- 1st Storm Recovery
- Main Phase
- 2nd Storm Recovery Phase
- 1st Storm Dst Min
- 2nd Storm Dst Min
- 1st Storm Main Phase End
- 2nd Storm Main Phase End
• The thermosphere acts during storm periods as a driven-but-dissipative system whose dynamics can be represented by a differential equation.

• The driver is the magnetospheric electric field. Burke (2008) determined the relationship for the exospheric temperature responses as a function of Dst:

\[ \frac{dT_c}{dt} = (1 - \frac{1}{\tau_1})dT_c_0 + S \left[ \text{Dst}_1 - \left(1 - \frac{1}{\tau_2}\right)\text{Dst}_0 \right] \]

• The above equation must be integrated from storm beginning throughout the entire storm period in-order to compute \( \Delta T_c \) at every point during the storm.

• The above equation was optimized to fit the CHAMP and GRACE accelerometer density data, along with HASDM global densities. The resulting main phase equation, with variable slope \( S \), is shown below:

\[ \frac{dT_c}{dt} = 0.846 \, dT_c_0 + S \left[ \text{Dst}_1 - 0.870 \, \text{Dst}_0 \right] \]
2004 Dst with Orbit Averaged Density Ratios
2003 Dst with Orbit Averaged Density Ratios

Day of Year

-Rho Ratio

-Dst

-50 0 50 100 150 200 250 300 350 400 450

301 302 303 304 305

Dst
3-hr ap
CHAMP
HASDM
JB2008
MSIS
J70
Density Model Accuracies

Orbit Averaged Model Density Errors

Model STD (%) vs Average 3-hour ap

- J70 (JB2006)
- MSIS
- JB2008
- HASDM

Major Storms
Moderate Storms
Minor Storms
Operational, event-driven Dst forecasting requires:

- Flare magnitude – proxy for ejected mass
- Integrated flare irradiance – used for speed computation
- Flare event location – earthward storm effectiveness

GOES hourly X-ray Xhf index used for flare magnitude and integrated flare irradiance (0.1–0.8 nm X-rays with background removed)

NOAA and SDO SAM flare event locations are used

- optical flare observed in H-alpha
- SXI X-ray flare from GOES Solar X-ray Imager (SXI)
- X-ray event from SWPC's Primary or Secondary GOES spacecraft

Standard Dst storm profile assumed
Flare Event Location Analysis

SDO EVE SAM detector with centroid of flare location
Anemomilos Dst size vs. flare size and location

Occurrence of Dst vs $X_{hf}$ and Longitude

- Medium & Large Events
- Small Events
- No Events

Heliocentric longitude

Dst size (nT)

$X_{hf}$

210
180
150
120
90
60
30
0
Anemomilos flare velocity function from integrated Xhf

\[ V_{2001} = -2191 + 4.74 \sum_{0}^{1} Xhf \, dt \]
Anemomilos Dst prediction of start

 DST (nT)

 Day of year

 Jan 22 2012 07:00:00 UT (2012/022)
Anemomilos Dst prediction of event peak
Conclusion

• Operational satellite position predictions greatly improved through:
  • JB2008 atmospheric model implementation
  • HASDM global density corrections
  • Use of new UV solar indices
  • Dst geomagnetic storm modeling
  • Dst storm prediction Anemomilos modeling