Stormtime O+ Redistribution: a Connection to Storm Strength?

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A remarkable physical understanding of our space environment was developed solely with ground-based measurements.

Disturbances in Earth’s magnetic field were associated with auroral disturbances and also the appearance of sunspots (Halley 1716).

Improvements in the magnetometer, deployed in expeditions, provided K. Birkeland, here in 1902, enough information to describe electrical currents associated with the aurora.

Egeland and Burke, Hist. of Geo and Space Sci., 2010.
• The global scale of major magnetic disturbances at middle/low latitudes is due to the extraterrestrial disturbance current directed westward around the planet.

• Chapman and Ferraro described the ring current in 1941, supported by these observations, without knowing what its made of.

• Since the 1930s, magnetometer data have been collected with adequate calibration and longitudinal coverage to produce an hourly index of this current.
A Brief History of Space Physics

- Magnetospheric investigations in the 1970s carried mass spectrometers of increasing sophistication.
- AMPTE and CRESS missions of 80s, 90s, further showed that the current carriers of the ring current varies greatly during magnetic storms, and that oxygen is a primary component.

Great storm of March, 1991

![Graph showing the Dst index and O+ abundance in 1991 storm.](attachment:graph.png)
A Brief History of Space Physics

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- All this oxygen has its origin in Earth’s ionosphere, which is primarily O+. Origin is clearly from the auroral oval, about twice as much coming from dayside as nightside.

<table>
<thead>
<tr>
<th>Ion Source and Species</th>
<th>Quiet Time</th>
<th>Small–Medium Storms</th>
<th>Intense Storms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy density, keV cm⁻³</td>
<td>~10</td>
<td>≥50</td>
<td>≥100</td>
</tr>
<tr>
<td>Solar wind H⁺, %</td>
<td>≥60</td>
<td>~50</td>
<td>≤20</td>
</tr>
<tr>
<td>Ionospheric H⁺, %</td>
<td>≥30</td>
<td>~20</td>
<td>≤10</td>
</tr>
<tr>
<td>Ionospheric O⁺, %</td>
<td>≤5</td>
<td>~30</td>
<td>≥60</td>
</tr>
<tr>
<td>Solar wind He⁺⁺, %</td>
<td>~2</td>
<td>≤5</td>
<td>≥10</td>
</tr>
<tr>
<td>Solar wind He⁺, %</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>Ionospheric He⁺, %</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Solar wind, total, %</td>
<td>~65</td>
<td>~50</td>
<td>~30</td>
</tr>
<tr>
<td>Ionosphere, total, %</td>
<td>~35</td>
<td>~50</td>
<td>~70</td>
</tr>
</tbody>
</table>

Yau et al., JASTP, 2007
A Brief History of Aeronomy

- Radio and radar gave scientists the first means of measuring the near-Earth plasma continuously.
- The theory of the ionosphere had been worked to the point that it was clear it was O+ well before anyone flew a rocket into it.
- Globally distributed ionosondes formed a picture of the dynamic storm-time ionosphere: initial positive phases followed by longer negative phases.

Prölls et al., 1991

2012 CEDAR Workshop, Santa Fe, NM
A Brief History of Aeronomy

- The advent of radio occultation techniques allows for imaging of ionospheric total density in day and night.
- Positive phase now clearly seen to be highly structured.
- Global assimilative models provide GPS data on a regular grid, backed by empirical or physics models.
Aeronomy meets Space Physics

- Magnetospheric convection patterns expand during storms to put the ionosphere in motion.
- TEC “Plumes” extending to the auroral oval from middle latitudes transit the cusp.
- The cusp is the “hot spot” for O+ outflow
- The great local enhancement in O+ densities, boosted to higher altitudes & temperatures, is likely a very important factor in the O+ flux outbound.

From Foster et al., *Inner Magnetosphere Interactions: New Perspectives from Imaging*, Geophysical Monograph Series, AGU, 2005

2012 CEDAR Workshop, Santa Fe, NM
Recent investigations describe a longitudinal dependence in the density and latitude of O+ plumes.

If this affects the abundance of O+ in the cusp, then one might naturally expect longitudinal outflow dependence.

Longitudinal dependence in outflow may have interesting consequences for Dst and magnetic storm strength.

Let’s look.

Coster et al., GRL, 2007
Science Investigation Task 1: Quantify TEC Storm Effect

1) Sort all available JPL-TEC maps for the last solar maximum into quiet and active bins and determine the average TEC.

2) Determine the ratio of Active/ Quiet for each UT (2 hour steps) in magnetic coordinates.

3) Track this ratio at middle latitudes (AM, PM) and in the cusp.

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Follow Active/quiet TEC ratio in the cusp in northern, southern hemispheres. Northern Hemisphere shows little variation. Southern Hemisphere shows a remarkable 60% enhancement over lowest ratios.
Science Investigation Task 1: Quantify TEC Storm Effect – Middle Lats

- Compare to middle latitudes, afternoon sector.

Northern Hemisphere shows more variation, about 30% enhancement between European and American sectors.

Southern Hemisphere again a remarkable 60% enhancement over lowest ratios.
• Collect all Dst data for active GPS times (Dst < -100 nT)
• Determine Mean Dst vs. UT: Find Minimum Dst (max Ring Current at 0 UT)
• Anti-correlation of two data sets highest if Dst data are delayed 3 hours.
• A possible relationship between storm enhanced density and storm strength

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• Characteristics, now “classic”, of SED and SAPS plumes are evident in average of stormtime (Dst < -100 nT) JPL TEC maps.
• Storm effects are most prominent in the 18-24 UT timeframe, and in the Southern Hemisphere.
• Question: Why not Northern Hemisphere? SAA connection?
• Another Question: Why the differences in the middle latitude and cusp signature timing?
Mean Storm Dst during the same period shows a ~25 nT variation in anti-correlation with TEC variation.

Delay in Dst minimum vs. TEC maximum is supportive of causative link.

Observed longitudinal dependence in storm-enhanced density clearly a candidate to explain the storm variation.
It gets more interesting for higher levels of Dst, here’s -125 nT

• If this were classic Russell-McPherron type effect, the effect in northern summer should be the weakest.
• Instead, it is the strongest.