Severe Space Weather and Satellite Vulnerability

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Space Weather

- Solar Wind
- Coronal Holes
- X-rays

Solar Storms

- Coronal Mass Ejections
- Plasma + magnetic field

Cosmic Rays

- Solar Flares
- Energetic Particles

- 8 min. to ~1 hr

- Ionosphere disruption and Healing

Milder Geomagnetic Storms

- 14-hr to 4 days

- No SPEs

- SPEs

Satellite Anomalies

- GPS problems
- Satellite drag

Satellite ESDs

Physical Effects of Space Environment

- Low energy electrons: Surface charging (ESD)
- High energy electrons: Internal charging (IESD)
- Solar flare protons: Solar array degradation
- Ionizing dose: Electronics, materials aging
- Non-ionizing dose: CCD’s, optical couplers
- Heavy ions/cosmic rays: Single event effects
- Ultraviolet Light: Solar panel surface degradation

Satellite Real Estate ca 2005

<table>
<thead>
<tr>
<th>Location</th>
<th>Commercial</th>
<th>Military</th>
<th>Research</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>273</td>
<td>94</td>
<td>70</td>
<td>437</td>
</tr>
<tr>
<td>MEO</td>
<td>19</td>
<td>101</td>
<td>12</td>
<td>132</td>
</tr>
<tr>
<td>GEO</td>
<td>308</td>
<td>51</td>
<td>8</td>
<td>367</td>
</tr>
<tr>
<td>Totals</td>
<td>600</td>
<td>245</td>
<td>91</td>
<td>936</td>
</tr>
</tbody>
</table>

- Total Satellite Fleet (ca Dec, 2004) ........... ~ 936
- Total invested hardware + launch costs ....... ~ $ 230 billion
- GEO Transponder Capacity ..................... ~ 6,800
- GEO industry annual revenue .................. ~ $ 87 billion
- LEO + MEO satellite annual revenue .......... ~ $ 10 billion
- Satellite Industry annual revenue .......... ~ $ 225 billion

Operational GEO satellites ca 2015 = 419
Replacements launched after 2005 = 276

Satellites and solar power loss

Solar Proton Events

2 % per year

Satellite Transponders as Revenue Generators

C and K-band transponders are leased at $1.5 million/yr
Transponders = 16
Leased = 12
Available Power 95%

Satellite has room
but it is either:
1) Too far away or
2) Wrong company

Company A
Can transfer 1 program

Transponders = 9
Leased at new power level - 11
Available Power 65%
11 - 9 = 2 programs to transfer

Company B
No room for 1 additional program

This scenario loses one program of revenue = $1.5 million/yr

Transponders = 20
New leased = 11 + 1 = 12
Available Power 80%

Company A
Can transfer 1 program

Transponders = 16
Leased = 12
Available Power 95%

The good news is that GEO satellites are very robust!

- Plenty of reserve transponders
- Large solar panel power margins
- Satellite Anomalies are rare so MTF>200 yrs vs 10 yrs satellite life
- Lots of well-designed contracts to back up transponder failures
- Solar Cycle 24-25 predicted to be mild

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Simulation transponder revenue versus storm strength

Satellite 'kill' threshold

$25 billion

Storm Strength (pFU)

$50000 $70000 $90000 $110000 $130000 $150000 $170000 $190000

Loss

40,000 pFU = 10/19/1989
43,000 pFU = 3/23/1991
4 x ‘worst case’

$25 billion

Storm Strength (pFU)

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Check out my space weather books on Amazon.com