AFRL Satellite Drag/Neutral Density Program

Presented to:
Living With a Star Measurement Requirements Workshop
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Presenter:
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Air Force Research Laboratory
Space Vehicles Directorate
• Introduction
• Satellite Drag Variations and Models
• Neutral Density Space Weather Programs
• Future Requirements
• Conclusions
DRIVERS OF NEUTRAL DENSITY VARIABILITY

- Solar EUV Heating
- Auroral Heating
- Upward Propagating Waves

<table>
<thead>
<tr>
<th>Variability (400 Km)</th>
<th>Factor</th>
<th>Time Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar cycle</td>
<td>8.6</td>
<td>Years</td>
</tr>
<tr>
<td>Daily solar flux</td>
<td>1.15</td>
<td>Day</td>
</tr>
<tr>
<td>Geomagnetic storm</td>
<td>3.2</td>
<td>Hours</td>
</tr>
</tbody>
</table>
Empirical Neutral Density Model

- Solar EUV
  - $F_{10.7}$ - daily solar flux measured at 10.7 cm
  - FBAR - 81 day or 162 day mean (centered) of $F_{10.7}$
- Solar Wind Interactions
  - ap - planetary geomagnetic activity index
- Upward Waves
  - Not included in empirical models

a. Nighttime Minimum Exospheric Temperature
   \[ TC = a + bFBAR + c[F_{10.7} - FBAR] \]

b. Diurnal correction
   \[ TL = TC \times f(\text{position}) \]

c. Geomagnetic activity correction
   \[ TG = ap + 100[1 - \exp(0.08ap)] \]

d. Semiannual correction
   \[ TS = f(\text{day of year}) \]

e. Global Exospheric temperature
   \[ TE = TL + TG + TS \]
HISTORICAL TREND OF EMPIRICAL MODEL ERRORS

Marcos et. al. 1997

YEAR

PERCENT STD DEVIATION

Unpredicted neutral density errors degrade capabilities to:

- Catalog all space objects
- Precisely determine orbits
- Provide Collision Avoidance warnings
- Predict satellite reentries
- Estimate satellite lifetimes
- Determine on-board fuel requirements
- Control orbital parameters

Operational density model: 15% error
Goal: 90 - 600 km: 5% error

Major effect of drag is on satellite in-track position
SSN Tracking Data
Operational Drag Errors (15%)

Local operational density model correction

Precision orbit determination with new global density (5%)

Global operational density model correction

Effective solar EUV heating for improved predictions
ERROR REDUCTION USING ATMOSPHERIC CALIBRATION

OPERATIONAL DATA
CALIBRATED DATA

DENSITY ERROR

TIME (DAYS)
RESULTS OF ATMOSPHERIC CALIBRATION TECHNIQUE

<table>
<thead>
<tr>
<th>Inclination</th>
<th>% Std Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.5</td>
<td>Initial</td>
</tr>
<tr>
<td>28.5</td>
<td>After Calibration</td>
</tr>
<tr>
<td>65.9</td>
<td>Initial</td>
</tr>
<tr>
<td>65.9</td>
<td>After Calibration</td>
</tr>
<tr>
<td>97.9</td>
<td>Initial</td>
</tr>
<tr>
<td>97.9</td>
<td>After Calibration</td>
</tr>
<tr>
<td>98.4</td>
<td>Initial</td>
</tr>
<tr>
<td>98.4</td>
<td>After Calibration</td>
</tr>
</tbody>
</table>
Neutral Density
Space Weather Program Summary

• Satellite Drag/Re-entry Atmospheric Calibration Studies

• Data-Driven Models Using Satellite Accelerometer Data
  – CHAMP
  – GRACE

• Atmospheric Density Specification (ADS) Flight Dec 00
  – SSULI calibration
  – Real-time data for models

• Improved Empirical Models
  – Solar EUV proxies
  – Convert EUV into effective F10.7
  – Analyze current models
## REQUIREMENTS MATRIX

<table>
<thead>
<tr>
<th>CUSTOMER NEEDS</th>
<th>AFRL PLANS/PRODUCTS</th>
<th>HOW NASA CAN HELP</th>
<th>LWS PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Higher Accuracy &amp; Resolution Density Measurements (100 - 600 km altitude range of interest)</td>
<td>1a. Orbital drag &amp; dynamics calculations and reentry performance 1b. Real time data from accelerometers: CHAMP, GRACE 1c. ADS Satellite Experiment (Mass Spectrometers &amp; accelerometer?)</td>
<td>1a. Monitor global neutral atmosphere in the altitude region 100 – 600 km and supply data 1b. Support GRACE data to AFRL 1c. Develop miniature mass spectrometer/ triaxial accelerometer and fly on multiple spacecraft</td>
<td>1a. Global neutral density, composition &amp; winds 1b. Management support and accelerometer data 1c. Simultaneous neutral density and composition measurements from multiple spatial locations</td>
</tr>
<tr>
<td>2. Specify Solar Flux</td>
<td>2. Use data from TIMED, SOHO, and SNOE missions and various proxies</td>
<td>2. Spectral monitoring of solar EUV, and UV</td>
<td>2. Solar EUV inputs to models</td>
</tr>
<tr>
<td>4. Improve Empirical Models</td>
<td>4. Improve indices; convert solar EUV to F10 effective; study latitude, flux, geomagnetic effects</td>
<td>4. Provide supporting measurement data (density, solar EUV, joule heating etc.), analyses and modeling</td>
<td>4. Neutral density, composition &amp; winds; Solar UV &amp; EUV; auroral heating</td>
</tr>
<tr>
<td>5. Forecast Solar Flux</td>
<td>5. Use NOAA products and assess others</td>
<td>5. Develop solar EUV forecast model tailored to density/ ionosphere model input needs</td>
<td>5. Solar Physics sensing (UV, EUV, heliomagnetic field, etc.)</td>
</tr>
<tr>
<td>7. Improve Physical Thermosphere Models</td>
<td>7. Validate with 100 - 600 km altitude data; study ionospheric coupling; examine long-term trends</td>
<td>7. Monitor neutral atmosphere, ionosphere &amp; inputs; support analyses</td>
<td>7. Coordinated studies of thermospheric model inputs &amp; response</td>
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</tbody>
</table>
## ORBITAL DRAG REQUIREMENTS

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<th>AFRL Plans</th>
<th>How NASA Can Help</th>
<th>LWS Products</th>
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<tr>
<td>High-accuracy, High-resolution Neutral Atmosphere Measurements</td>
<td>Orbital Drag, &amp; Re-entry Studies CHAMP &amp; GRACE ADS</td>
<td>Global Neutral Data (100 - 600 km) New Small Sensors Support Grace/ADS</td>
<td>Density, Winds, Composition Multiple Locations</td>
</tr>
<tr>
<td>Improved Models</td>
<td>Improved Indices Thermospheric Response Studies</td>
<td>Provide Supporting Data</td>
<td>Coordinated Studies of Thermosphere</td>
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<tr>
<td>Data-driven, Empirical &amp; Physical</td>
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<tr>
<td>Solar &amp; Geomagnetic Specification &amp; Forecast</td>
<td>Analyze New Measurements &amp; Proxies</td>
<td>Measure Solar EUV /UV, Solar Physics, Fields &amp; Particles</td>
<td>Tailored Solar &amp; Geomagnetic Forecasts</td>
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CONCLUSIONS

• Neutral density errors can be reduced to the 5% level with data assimilation
  – AFRL demonstrated concept with historical orbital drag data

• To meet satellite drag specification/forecast requirements need multi-faceted attack:
  – High accuracy global monitoring of important state variables including density
  – Data assimilation using high-accuracy real-time data
  – Improved understanding of solar EUV and UV fluxes
  – Time-dependent specification of magnetospheric energy, particle and momentum inputs
  – Detailed understanding of thermospheric response to important forcings
    -- Incorporate into data-driven semi-empirical and physical models