Comparison of MSIS and Jacchia atmospheric density models for orbit determination and propagation

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Overview

- Background on Density Models
  - Jacchia
  - MSIS-class
- Initial Vector Quality (discussed in detail in paper)
- Test Procedures
  - RMS Test
    - Differential Correction
    - Prediction
  - Orbit-to-orbit Test
- Results
- Conclusions
Two common density model families:

- **Jacchia**
  - Developed 1960’s by Luigi Jacchia
  - Valid above 90 km
  - Fit to densities derived from satellite orbits between 1961-1970
  - Model of choice for astrodynamics community

- **MSIS-class**
  - Mass Spectrometer – Incoherent Scatter
  - Developed 1980’s and 90’s by Alan Hedin and others
  - Valid above ground level
  - Fit to individual species densities and temperatures as measured by ground- and satellite-based sensors mostly from 1960’s-1980’s
  - Model of choice for atmospheric scientists
MSIS-class Density Models

Two widely used MSIS models:

- MSISE-90
- NRLMSISE-00

Improvements in NRLMSISE-00 over MSISE-90

- Includes extensive set of total mass density data, including all of the data used by Jacchia in his model, which was previously absent in MSIS models.
- Also added data from accelerometer analysis.

The Future of MSIS…

- Dynamic scaling of the constituent data in NRLMSISE-00 would allow more real-time representation of the atmosphere.
- UV data has been collected from the LORAAS instrument and is currently being incorporated into NRLMSISE-00.
- An analysis of the effects of this is underway.
Data Sets

- **LowSats**
  - 4587 objects
  - September – October 1999
  - All cataloged objects with perigees below 1000 km
  - Good representation of satellite environment

- **HASDM**
  - 60 “calibration” objects
  - January – February 2001
  - Very high number of observations
Test Procedure – RMS Test
Differential Correction

Observations

Starting Vectors
(at time of catalog)

Final Vectors
(at time last ob before RST)

Fitspan (varies by sat: $1.5 < x < 10$ days)

<table>
<thead>
<tr>
<th>Abbrev</th>
<th>Description</th>
<th>LowSats</th>
<th>HASDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPCD</td>
<td>General Perturbations Catalog Date</td>
<td>30 Sept 1999</td>
<td>13 Feb 2001</td>
</tr>
<tr>
<td>RST</td>
<td>Requested Stop Time</td>
<td>01 Oct 1999</td>
<td>15 Feb 2001</td>
</tr>
</tbody>
</table>
Results – RMS Test – LowSats
Differential Correction

<table>
<thead>
<tr>
<th></th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-0.00189</td>
<td>-0.00298</td>
</tr>
<tr>
<td><strong>Std. Dev.</strong></td>
<td>0.0913</td>
<td>0.0848</td>
</tr>
</tbody>
</table>

![Graph of Fractional Change in RMS from Jacchia 70 RMS](image)

Satellites, sorted by fractional change in RMS
Results – RMS Test – HASDM
Differential Correction

<table>
<thead>
<tr>
<th></th>
<th>MSISE-90</th>
<th></th>
<th>NRLMSISE-00</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0170</td>
<td>0.0139</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.0754</td>
<td>0.169</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Test Procedure – RMS Test

Propagation

RST
(from previous DC)

3 days

Final Vectors
(from previous DC)

Observations
(not used in previous DC)

J70
M90
N00
Results – RMS Test – LowSats

<table>
<thead>
<tr>
<th>Propagation</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>$-0.0451$</td>
<td>$-0.0325$</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>$0.271$</td>
<td>$0.328$</td>
</tr>
</tbody>
</table>

Fractional Change in RMS from Jacchia 70 RMS

Satellites, sorted by fractional change in RMS

- MSISE-90
- NRLMSISE-00
Results – RMS Test – HASDM Proagation

<table>
<thead>
<tr>
<th></th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.282</td>
<td>0.142</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.584</td>
<td>0.456</td>
</tr>
</tbody>
</table>
Results – RMS Test – LowSats

Propagation

Perigee Altitude

Inclination

Eccentricity

B-term
Results – RMS Test – HASDM Propagation

Perigee Altitude

Inclination

Eccentricity

B-term

Fractional Change in RMS from Jacchia 70 RMS vs. Perigee Altitude

Fractional Change in RMS from Jacchia 70 RMS vs. Inclination

Fractional Change in RMS from Jacchia 70 RMS vs. Eccentricity

Fractional Change in RMS from Jacchia 70 RMS vs. B-term
**Test Procedure – Orbit-to-orbit Test**

- **RST** (from previous DC)
- Fitspan
- **DC**
  - Observations
  - **Propagation**
  - **1 day**
  - Difference broken down into NTW coordinate system

- Starting Vectors (from previous DC)

**Repeated for each model:**
- J70, M90 and N00
Results – Orbit-to-orbit Test – LowSats

Intrack Component

<table>
<thead>
<tr>
<th>INTRACK</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>493.5</td>
<td>166.9</td>
<td>172.1</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>16592.0</td>
<td>16588.2</td>
<td>16534.3</td>
</tr>
</tbody>
</table>

Statistical units are meters.
**Results – Orbit-to-orbit Test – LowSats**

**Crosstrack and Normal Components**

**X-TRACK**

<table>
<thead>
<tr>
<th>Model</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.8</td>
<td>-11.8</td>
<td>-11.8</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>748.8</td>
<td>820.0</td>
<td>824.4</td>
</tr>
</tbody>
</table>

**NORMAL**

<table>
<thead>
<tr>
<th>Model</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>29.8</td>
<td>34.1</td>
<td>40.5</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>1902.4</td>
<td>1941.1</td>
<td>1950.5</td>
</tr>
</tbody>
</table>

--Statistical units are meters.

**NOTE:** NRLMSISE-00 did better with Satellite 25228, a spent rocket body that decayed less than 10 days directly following this test. J70 and M90 had errors of 2231km while N00 had only 568km.
### Results – Orbit-to-orbit Test – HASDM

<table>
<thead>
<tr>
<th>INTRACK</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1365.8</td>
<td>-7.4</td>
<td>393.1</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>2552.1</td>
<td>2224.4</td>
<td>2128.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X-TRACK</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.2</td>
<td>8.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>21.6</td>
<td>59.0</td>
<td>42.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NORMAL</th>
<th>Jacchia 70</th>
<th>MSISE-90</th>
<th>NRLMSISE-00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-16.4</td>
<td>-7.4</td>
<td>-12.6</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>34.2</td>
<td>37.8</td>
<td>42.4</td>
</tr>
</tbody>
</table>

– Figures not shown. Statistical units are meters.
Conclusions

- For the majority of the tests performed, MSIS-class models show improvement over Jacchia

- Overall, the improvements are very minimal

- Individual satellites can show wide differences between any of the models

- No specific orbital regime correlations

- There is hope that the dynamic NRLMSISE-00 will be much improved
Questions