Investigation of the effect of Terra orbit drift with surface observed flux data

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Terra’s ‘5 Year Mission’ is now going on 17 Years.
Current & Proposed End of Life Plan

- **Current Plan**
  - Final IAM Oct 2017
  - MLT < 10:29 March 2018
  - Constellation Exit January 2020
  - MLT < 10:15 March 2022

- **Proposed Plan**
  - Final IAM October 2020
  - MLT < 10:29 December 2020
  - MLT < 10:15 & Constellation Exit August 2022
  - 9:00 MLT predicted December 2025
“Proposed” - Problem


Within protocol for satellite end of life:
- *De-orbit < 25 years after end of operations*
- “*risk of human casualty from surviving debris*” < 1:10000.

Proposed plan:
- Pushes re-entry from 2055 to 2077.
- Probability of casualty to 1:1410.
Assess Effect On CERES Downward Flux Calculations

In particular the impact on observing trends in surface irradiance if equator crossing time drifts.

- Use long time records of observed surface downward radiative flux measurements and simulate a drift in MLT. (Requires 1 minute time resolution.)

- Construct time series of monthly means at 10:30 AM(PM) local time and at ±5 min, ±15 min, and ±25 min.
Assess Effect On CERES Downward Flux Calculations

- Within 7 time series, replace last three years of the 10:30 time series with the leading and lagging average flux values.

- Use a first-order $\cos(SZA)$ correction for solar irradiance differences between 10:30 AM and other times. Does not account for atmospheric path length differences.

- Deseasonalize the data. (Error propagates back into the record through the canonical monthly mean.)

- Evaluate trend for each time series & compare with that obtained at 10:30 AM or PM over the full time span.
Sites With 16plus Years of Data

- Barrow, AK 18Yr (1992-2009)
- Billings, OK 20Yr (1992-2009)
- Stratus Buoy 10Yr (2001-2012)
- Bermuda 20Yr (1993-2012)
Billings, OK (BIL) (DOE ARM Central Facility) 20 Year Record
Deseasonalized Time Series

Shortwave Down (BIL)

Month/Year

SW Down Anomaly (Wm-2)

-25m, slp: 0.032
-15m, slp: 0.018
-5m, slp: 0.042
10:30, slp: 0.047
Billings, OK SW Surface Flux Down
Trend and Error for Lag/Lead Times w.r.t. 10:30AM

Gray area = 95% confidence interval in trend
Error bars = squared sum of trend error due to MLT change and 95% confidence interval
Billings, OK LW Surface Flux Down
Trend and Error for Lag/Lead Times w.r.t. 10:30

Gray area = 95% confidence interval in trend
Error bars = squared sum of trend error due to MLT change and 95% confidence interval
Tamanrasset, Algeria (TAM) (BSRN Facility)
16 Year Record
Trends at Tamanrasset, Alg

Deseasonalized Shortwave Down (Monthly Mean at 10:30AM)

Trend: 34.5 W/m²/Decade

Deseasonalized Longwave Down (Monthly Mean at 10:30AM)

Trend: 8.8 W/m²/Decade
Tamanrasset, ALG Surface Flux Down Trend and Error for Lag/Lead Times w.r.t. 10:30AM

Gray area = 95% confidence interval in trend
Error bars = squared sum of trend error due to MLT change and 95% confidence interval
Barrow, Alaska (BAR) (BSRN Facility)

18 Year Record

Barrow, AK 18Yr (1992-2009)
Barrow, AK Surface Flux Down
Trend and Error for Lag/Lead Times w.r.t. 10:30AM

Gray area = 95% confidence interval in trend
Error bars = squared sum of trend error due to MLT change and 95% confidence interval
Stratus Buoy (STR) (Woods Hole Ocean. Inst.)
10 Year Record
Stratus Buoy Surface Flux Down
Trend and Error for Lag/Lead Times w.r.t. 10:30AM

Gray area = 95% confidence interval in trend
Error bars = squared sum of trend error due to MLT change and 95% confidence interval
LW Diurnal Cycle STRATUS Buoy

Normalized Avg Oct 2000 to 2009

Local Time

LW Down (Wm-2)
### SW Down Trend (Err) Wm$^{-2}$/Decade

<table>
<thead>
<tr>
<th>Site</th>
<th>-25min</th>
<th>-15min</th>
<th>-5min</th>
<th>10:30AM</th>
<th>+5min</th>
<th>+15min</th>
<th>+25min</th>
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<tbody>
<tr>
<td><strong>BIL</strong> Trend (Err)</td>
<td>3.9 (1.7)</td>
<td>2.1 (3.5)</td>
<td>5.1 (0.5)</td>
<td>5.6 (0.0)</td>
<td>6.6 (1.0)</td>
<td>10.1 (4.5)</td>
<td>10.7 (5.1)</td>
</tr>
<tr>
<td>-95%Conf</td>
<td>-7.6</td>
<td>-9.3</td>
<td>-6.2</td>
<td>-5.7</td>
<td>-4.7</td>
<td>-1.0</td>
<td>-0.6</td>
</tr>
<tr>
<td><strong>TAM</strong> Trend (Err)</td>
<td>32.5 (4.3)</td>
<td>34.9 (1.9)</td>
<td>35.7 (1.1)</td>
<td>36.8 (0.0)</td>
<td>38.7 (1.9)</td>
<td>41.1 (4.3)</td>
<td>41.8 (5.0)</td>
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<tr>
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<td>21.4</td>
<td>23.6</td>
<td>24.1</td>
<td>25.2</td>
<td>27.1</td>
<td>29.6</td>
<td>30.3</td>
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<tr>
<td><strong>BAR</strong> Trend (Err)</td>
<td>7.2 (2.8)</td>
<td>7.5 (2.5)</td>
<td>9.5 (0.5)</td>
<td>10.0 (0.0)</td>
<td>9.3 (0.7)</td>
<td>9.7 (0.3)</td>
<td>9.9 (0.0)</td>
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<tr>
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<td>1.4</td>
<td>3.4</td>
<td>3.8</td>
<td>3.1</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>BER</strong> Trend (Err)</td>
<td>4.2 (2.4)</td>
<td>2.7 (3.9)</td>
<td>5.9 (0.6)</td>
<td>6.5 (0.0)</td>
<td>7.0 (0.5)</td>
<td>9.1 (2.7)</td>
<td>9.5 (3.0)</td>
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<tr>
<td>-95%Conf</td>
<td>-6.7</td>
<td>-8.2</td>
<td>-4.3</td>
<td>-3.6</td>
<td>-3.1</td>
<td>-1.4</td>
<td>-0.7</td>
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<tr>
<td><strong>STR</strong> Trend (Err)</td>
<td>-73.1 (24.5)</td>
<td>-72.0 (23.3)</td>
<td>-56.1 (7.5)</td>
<td>-48.7 (0.0)</td>
<td>-43.7 (5.0)</td>
<td>-36.0 (12.8)</td>
<td>-25.9 (22.8)</td>
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<tr>
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<td>-77.7</td>
<td>-72.9</td>
<td>-63.9</td>
<td>-54.8</td>
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</tbody>
</table>

**Notes:**
- **BIL**: Billings OK (Mid-Latitude)
- **TAM**: Tamanrasset Alg. (Desert)
- **BAR**: Barrow AK (N Polar)
- **BER**: Bermuda (Island)
- **STR**: Stratus Buoy (Tropical Marine StCu)
## LW Down Trend (Err) Wm⁻²/Decade (10:30AM)

<table>
<thead>
<tr>
<th>Site</th>
<th>25min</th>
<th>15min</th>
<th>5min</th>
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<th>5min</th>
<th>15min</th>
<th>25min</th>
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<tbody>
<tr>
<td>+95%Conf</td>
<td>5.4</td>
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<td>5.9</td>
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<td>6.2</td>
<td>6.4</td>
<td>6.7</td>
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<tr>
<td>BIL Trend (Err)</td>
<td>3.1 (0.6)</td>
<td>3.5 (0.3)</td>
<td>3.7 (0.1)</td>
<td>3.8 (0.0)</td>
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<td>1.4</td>
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<td>1.6</td>
<td>1.8</td>
<td>2.2</td>
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<tr>
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<td>12.1</td>
<td>12.2</td>
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<td>13.1</td>
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<td>TAM Trend (Err)</td>
<td>7.7 (1.1)</td>
<td>8.2 (0.6)</td>
<td>8.6 (0.2)</td>
<td>8.8 (0.0)</td>
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<td>BAR Trend (Err)</td>
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<td>3.9 (0.1)</td>
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<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
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<td>0.1</td>
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<td>0.7</td>
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<td>0.8</td>
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<tr>
<td>BER Trend (Err)</td>
<td>-1.0 (0.2)</td>
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<td>-0.8 (0.0)</td>
<td>-0.8 (0.0)</td>
<td>-0.7 (0.1)</td>
<td>-0.4 (0.3)</td>
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</tr>
<tr>
<td>-95%Conf</td>
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<td>1.8</td>
<td>1.7</td>
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<td>STR Trend (Err)</td>
<td>-1.9 (0.1)</td>
<td>-1.4 (0.5)</td>
<td>-1.8 (0.1)</td>
<td>-1.9 (0.0)</td>
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<td>-2.1 (0.2)</td>
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Summary

*Whether changed or not appears that it will remain within +/- 15mins of 10:30 MLT through 2020.

*Resultant error is largely a function of climatology of the site.

*More pronounced with stronger diurnal cycles.

*Worst case scenario (Where clouds change rapidly around 10:30, eg. at Stratus buoy with marine StCu) the error is approaching the 95% confidence band at 15 minutes lag.