Analysis of top-down solar influence using MERRA data

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Executive summary

- Short term solar influence can be seen at the upper levels of the atmosphere. Longer term variations are much more difficult to detect and separate from natural variability.

- We employ annual/semiannual fits to remove orbital contributions. This does not introduce discontinuities in the residuals. This provides better information than the standard monthly mean subtraction.

- We employ periodogram analysis to determine statistically meaningful frequency contributions to atmospheric variations.

Relevant Atmospheric signals
Photochemical Replacement Time

January ozone ($10^{18}$ molecules/m$^3$)

- Height (km): 16, 24, 32, 40, 48
- Pressure (hPa): 100, 10, 1
- Latitude: Summer, 0, Winter
- Time: 1 day, 1 week, 1 month, 1 year
<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Heat Flux* [W/m²]</th>
<th>Relative Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Irradiance</td>
<td>340.25</td>
<td>1.000</td>
</tr>
<tr>
<td>Heat Flux from Earth's Interior</td>
<td>0.0612</td>
<td>1.8E-04</td>
</tr>
<tr>
<td>Radioactive Decay</td>
<td>0.0480</td>
<td>1.4E-04</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.0132</td>
<td>3.9E-05</td>
</tr>
<tr>
<td>Infrared Radiation from the Full Moon</td>
<td>0.0102</td>
<td>3.0E-05</td>
</tr>
<tr>
<td>Sun's Radiation Reflected from Moon</td>
<td>0.0034</td>
<td>1.0E-05</td>
</tr>
<tr>
<td>Energy Generated by Solar Tidal Forces in the Atmosphere</td>
<td>0.0034</td>
<td>1.0E-05</td>
</tr>
<tr>
<td>Combustion of Coal, Oil, and Gas in US (1965)</td>
<td>0.0024</td>
<td>7.0E-06</td>
</tr>
<tr>
<td>Energy Dissipated in Lightning Discharges</td>
<td>0.0002</td>
<td>6.0E-07</td>
</tr>
<tr>
<td>Dissipation of Magnetic Storm Energy</td>
<td>6.8E-05</td>
<td>2.0E-07</td>
</tr>
<tr>
<td>Radiation from Bright Aurora</td>
<td>4.8E-05</td>
<td>1.4E-07</td>
</tr>
<tr>
<td>Energy of Cosmic Radiation</td>
<td>3.1E-05</td>
<td>9.0E-08</td>
</tr>
<tr>
<td>Dissipation of Mechanical Energy of Micrometeorites</td>
<td>2.0E-05</td>
<td>6.0E-08</td>
</tr>
<tr>
<td>Total Radiation from Stars</td>
<td>1.4E-05</td>
<td>4.0E-08</td>
</tr>
<tr>
<td>Energy Generated by Lunar Tidal Forces in the Atmosphere</td>
<td>1.0E-05</td>
<td>3.0E-08</td>
</tr>
<tr>
<td>Radiation from Zodiacal Light</td>
<td>3.4E-06</td>
<td>1.0E-08</td>
</tr>
<tr>
<td><strong>Total of All Non-Solar Energy Sources</strong></td>
<td><strong>0.0810</strong></td>
<td><strong>2.4E-04</strong></td>
</tr>
</tbody>
</table>

* global average

The change in the TSI from this graph is 3 times larger than the sum of all of the other contributions.

$\Delta B = 1 \frac{W}{m^2}$

$T \approx 30 \text{ K without Sun}$
Temperature and change in temperature at 1 millibar of pressure and at 1 degree of latitude, near the equator

Obtained with MERRA reanalysis data
Utilizing Stefan–Boltzmann’s law..

- $B = \sigma T^4$
- $\frac{\Delta B}{B} = \sigma 4T^3 \Delta T$
- $\frac{\Delta T}{T} = \frac{1}{4} \frac{\Delta B}{B}$
- $\Delta B = 8 \times 10^{-4}$
- $T = 265^\circ K$
- $\Delta T = 0.05^\circ K$

Stefan–Boltzmann’s law shows radiation released from a black body due to its temperature, in this case the temperature is given from a pressure of 1 mb and a latitude of 1 degree, near the equator.

The graph shows the residual from the zonal temperature and the fit of annual/semiannual trends. Otherwise known as the change in temperature at various SORCE Mission Days.
- Elliptical orbit varies +/-1.67% from a circular orbit
- The irradiance follows inverse-square law so varies +/-3.7%
- Annual deviations from 1 AU results in a 45.9 W/m^2 change over just one year
- Annual variation ~42x greater than the change in TSI
- **Question:** Can solar cycle variations contribute to the annual cycle??

\[
\Delta B = 1 \frac{W}{m^2}
\]
Top of atmosphere analysis

Scargle periodograms used to detect periodic signal in noise

Utilized a constant of 14.9 for the false alarm probability

Note 27 day contribution from periodogram and overall ozone change.
Monthly Mean Fit

- Similar to previous slide
- Uses monthly mean climatology for the anomalies
- Provides more periods throughout
Comparison of periodograms

- Ozone residual periodogram versus difference mean periodogram
- Subtraction distorts anomalies
- Note similarities
Variation throughout change in latitude at constant pressure
Vertical cross section through atmosphere

Latitude = 0 Degrees, Target Pressure = 0.700000 mb
Continued analysis using solar models and solar indices

- Furthering our analysis using solar models
- (SRPM) Model H + Model P, the facula + plage, or the brightest parts of the calcium image
- Essentially, to see if the Scargle periodogram of each model matches the residual and difference mean of the ozone mass mixing ratio
- Are there common resonances between the periodograms of solar indices and Earth-atmospheric data?
- Utilizing geomagnetic AP index and F10.7
Solar indices, Earth-atmospheric values
Time Series

- Time series of ozone, Geomagnetic ap Index, SPRM Model H +P, and F10.7
Solar indices, Earth-atmospheric values

Periodogram – Short time periods

- Periodograms from 10 days to 100 days
- Note 27 day contribution from the residual periodogram compared to the other periodograms
Solar indices, Earth-atmospheric values
Periodogram – Long time periods

- Periodograms from 125 days to 5000 days
- Note significance of periods past 1000 days
Summary

- More realistic contributions from annual/semiannual fit.
- Lower mesospheric/equatorial region can 27 day contributions be seen.
- Clear atmospheric contribution from the Earth’s orbital dynamics
Further Work

- Requires more sophisticated analysis, beyond the Scargle periodograms (D. J. Thomson, 1982, Proc. IEEE, 70, pp1055) which addresses coherence between different power spectra.

- Longer time period MERRA data is absolutely necessary for refining the longer term solar influence.

- Studying trends in the phase shifts in the annual/semiannual fit as a function of altitude and latitude. Include solar zenith angle.