Analysis of top-down solar influence using MERRA data

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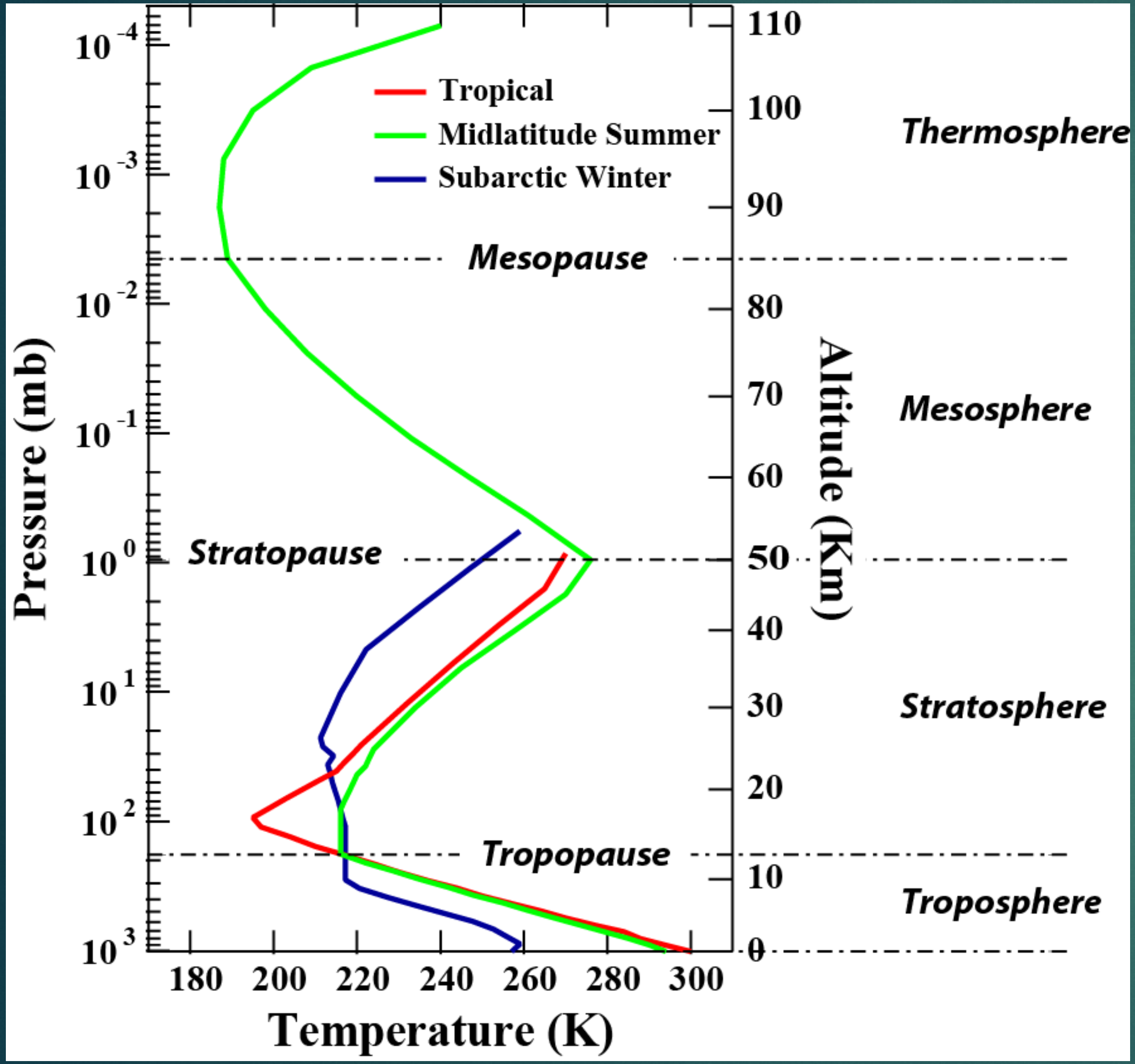
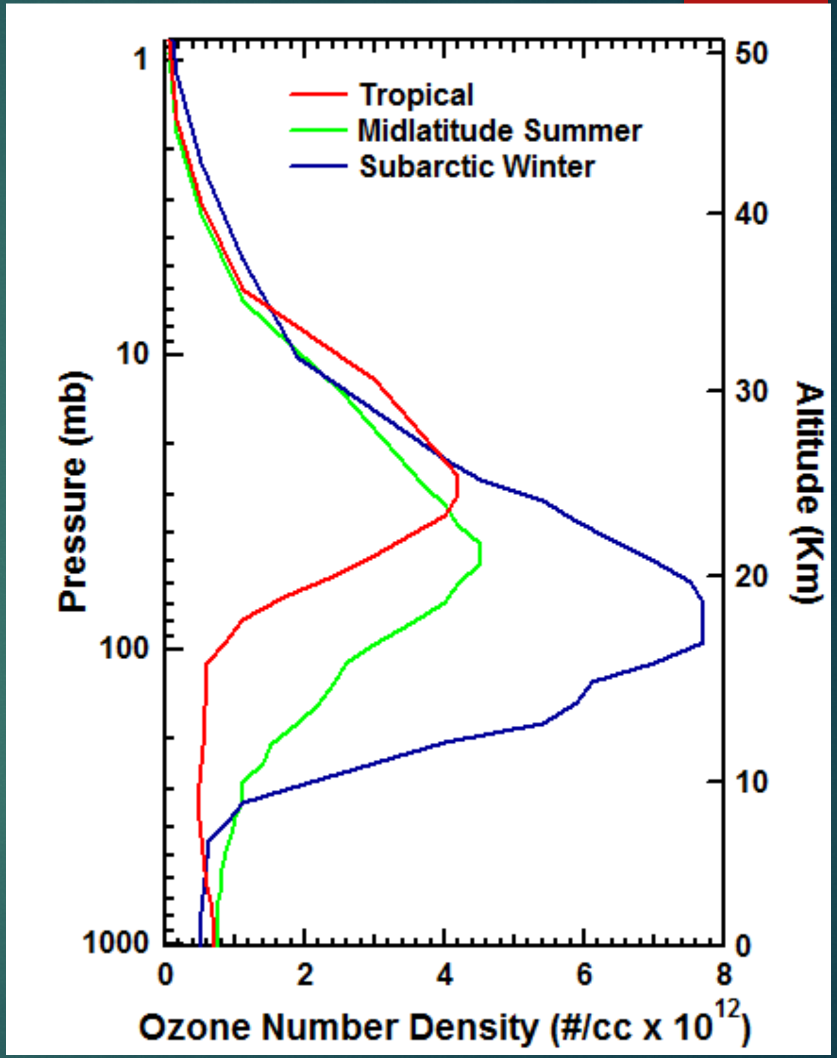
Executive summary

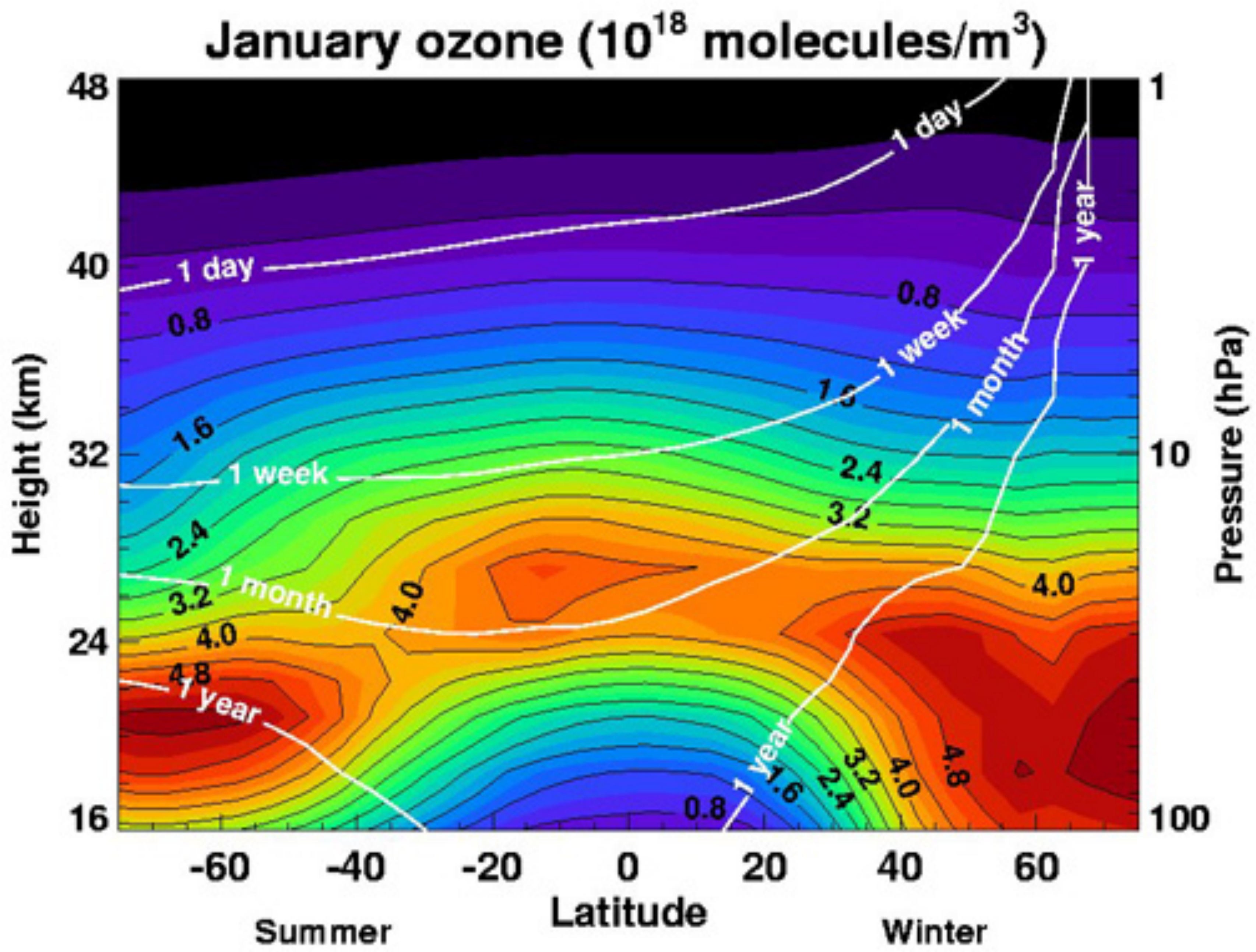
- Short term solar influence can be seen at the upper levels of the atmosphere. Longer term variations are much more difficult to detect and separate from natural variability.
- We employ annual/semiannual fits to remove orbital contributions. This does not introduce discontinuities in the residuals. This provides better information than the standard monthly mean subtraction.
- We employ periodogram analysis to determine statistically meaningful frequency contributions to atmospheric variations.
    - Jeffrey D. Scargle - (1982) Studies in Astronomical Time series Analysis II. Statistical aspects of spectral analysis of unevenly spaced data

Relevant Atmospheric signals





Photochemical Replacement Time

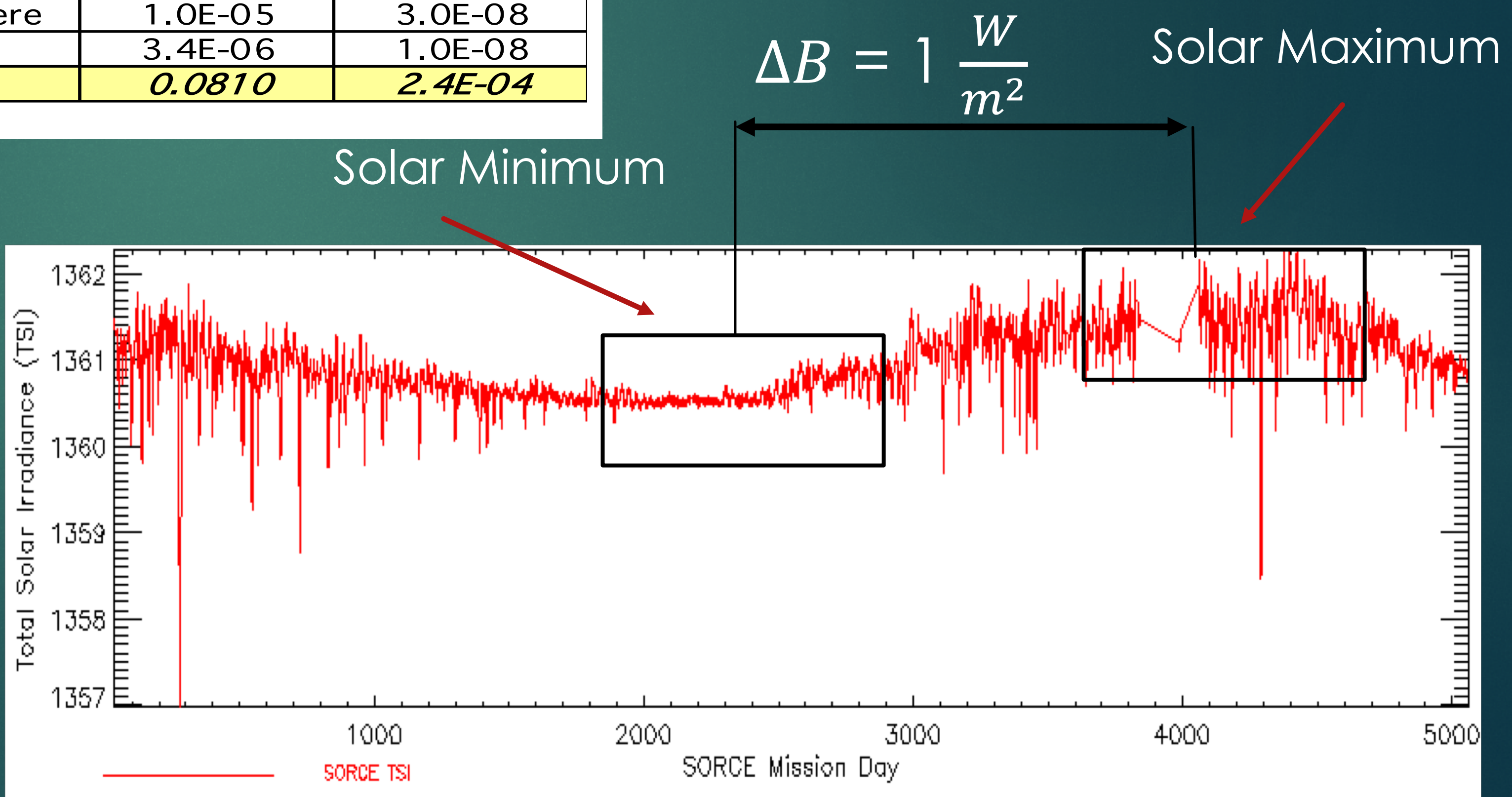


Heat Source	Heat Flux* [W/m²]	Relative Input
Solar Irradiance	**340.25**	**1.000**
Heat Flux from Earth's Interior	0.0612	1.8E-04
Radioactive Decay	0.0480	1.4E-04
Geothermal	0.0132	3.9E-05
Infrared Radiation from the Full Moon	0.0102	3.0E-05
Sun's Radiation Reflected from Moon	0.0034	1.0E-05
Energy Generated by Solar Tidal Forces in the Atmosphere	0.0034	1.0E-05
Combustion of Coal, Oil, and Gas in US (1965)	0.0024	7.0E-06
Energy Dissipated in Lightning Discharges	0.0002	6.0E-07
Dissipation of Magnetic Storm Energy	6.8E-05	2.0E-07
Radiation from Bright Aurora	4.8E-05	1.4E-07
Energy of Cosmic Radiation	3.1E-05	9.0E-08
Dissipation of Mechanical Energy of Micrometeorites	2.0E-05	6.0E-08
Total Radiation from Stars	1.4E-05	4.0E-08
Energy Generated by Lunar Tidal Forces in the Atmosphere	1.0E-05	3.0E-08
Radiation from Zodiacal Light	3.4E-06	1.0E-08
Total of All Non-Solar Energy Sources	***0.0810***	***2.4E-04***

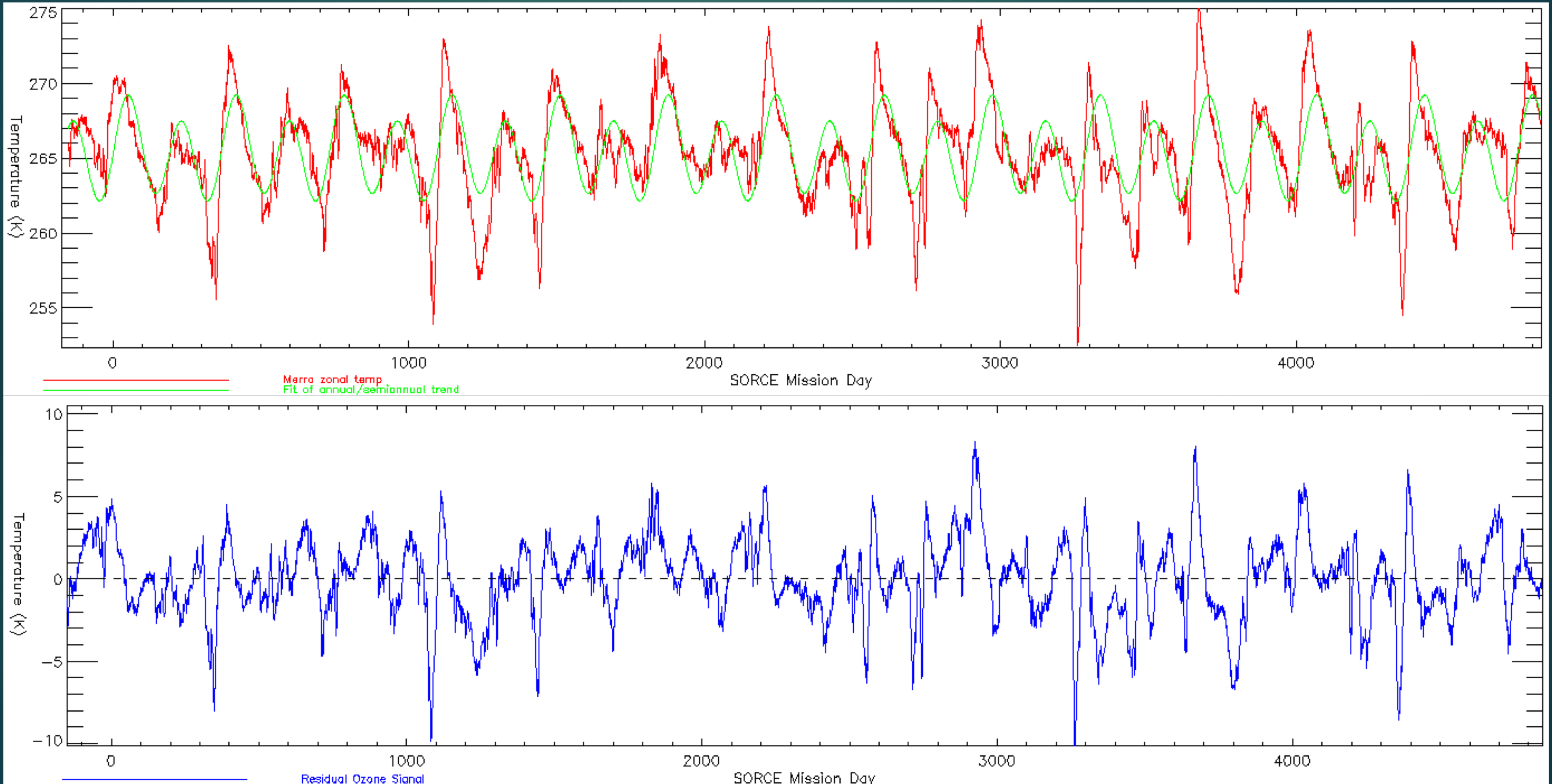
* global average

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

$T \approx 30$ K without Sun

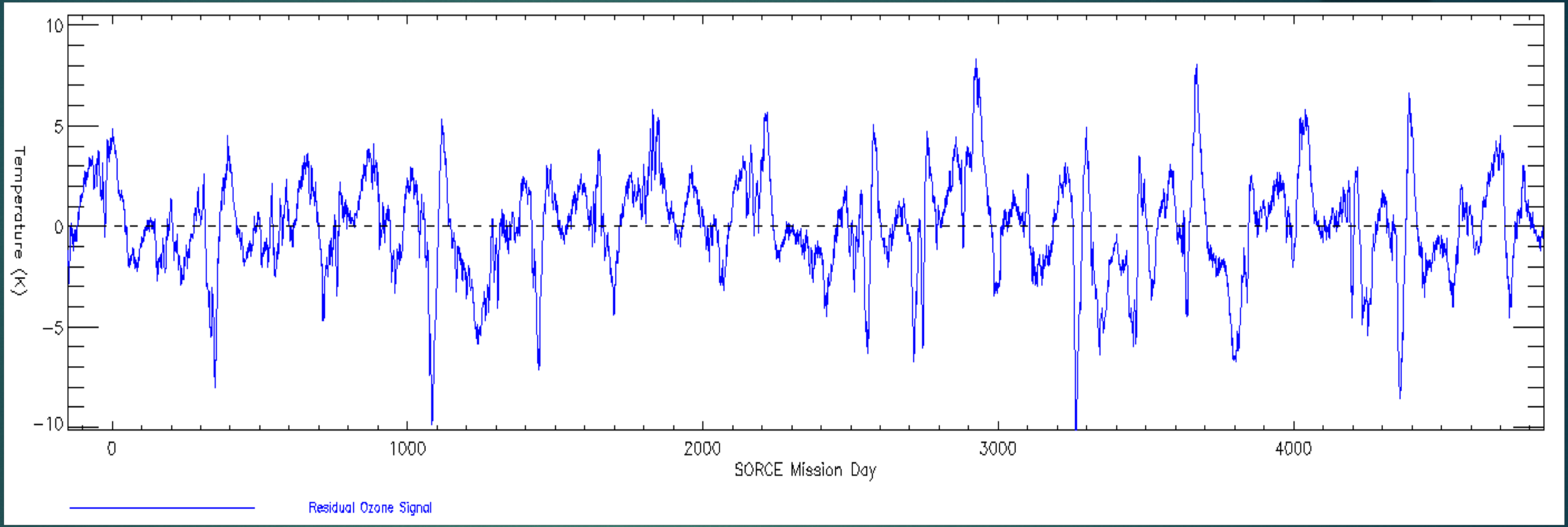


- Temperature and change in temperature at 1 millibar of pressure and at 1 degree of latitude, near the equator
- Obtained with MERRA reanalysis data



Utilizing Stefan–Boltzmann's law..

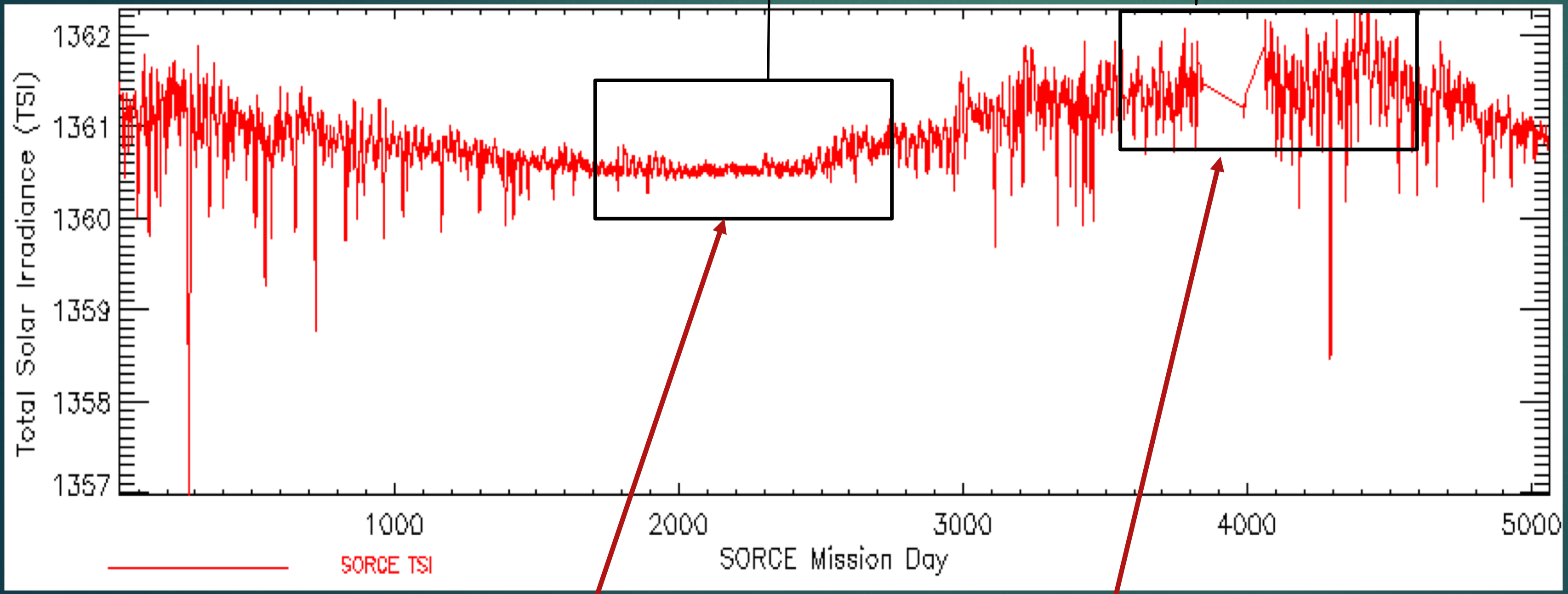
- $B = \sigma T^4$
- $\frac{\Delta B}{B} = \sigma 4 T^3 \Delta T$
- $\frac{\Delta T}{T} = \frac{1}{4}\frac{\Delta B}{B}$
- $\frac{\Delta B}{B} = 8 * 10^{-4}$
- T = 265°K
- ΔT =0.05°K



- Stefan–Boltzmann's law shows radiation released from a black body due to it's 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

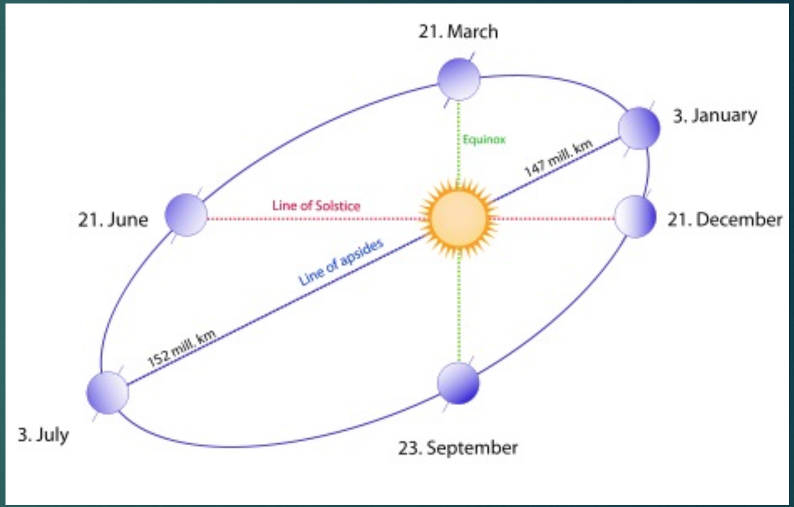
- Elliptical orbit varies +/-1.67% from a circular orbit
- The irradiance follows inverse-square law so varies +/-3.7%
- Annual deviations from 1 AU results in a 45.9 W/m^2 change over just one year
- Annual variation ~42x greater than the change in TSI
- **Question: Can solar cycle variations contribute to the annual cycle??**

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

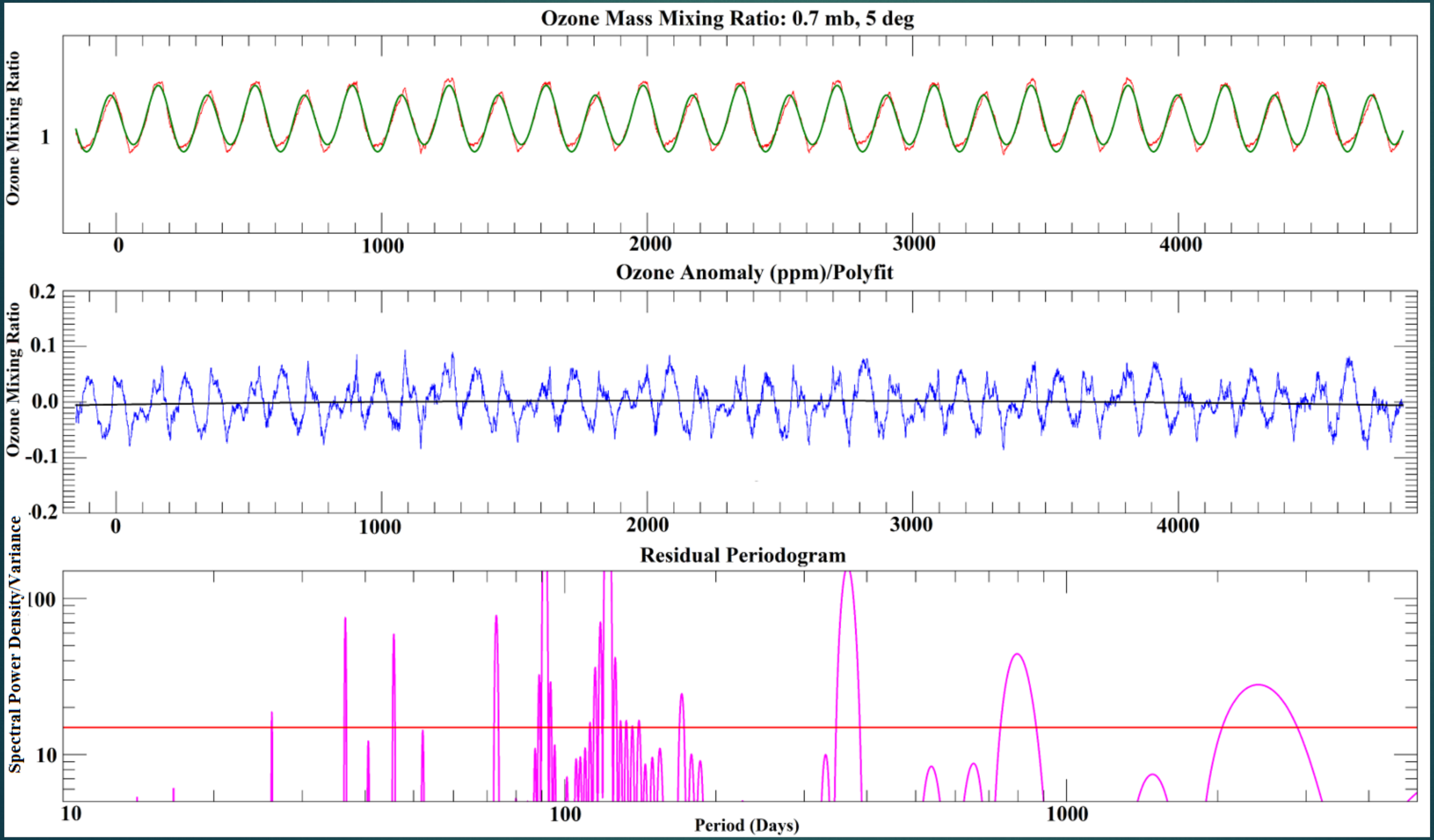


Solar Maximum

Solar Minimum

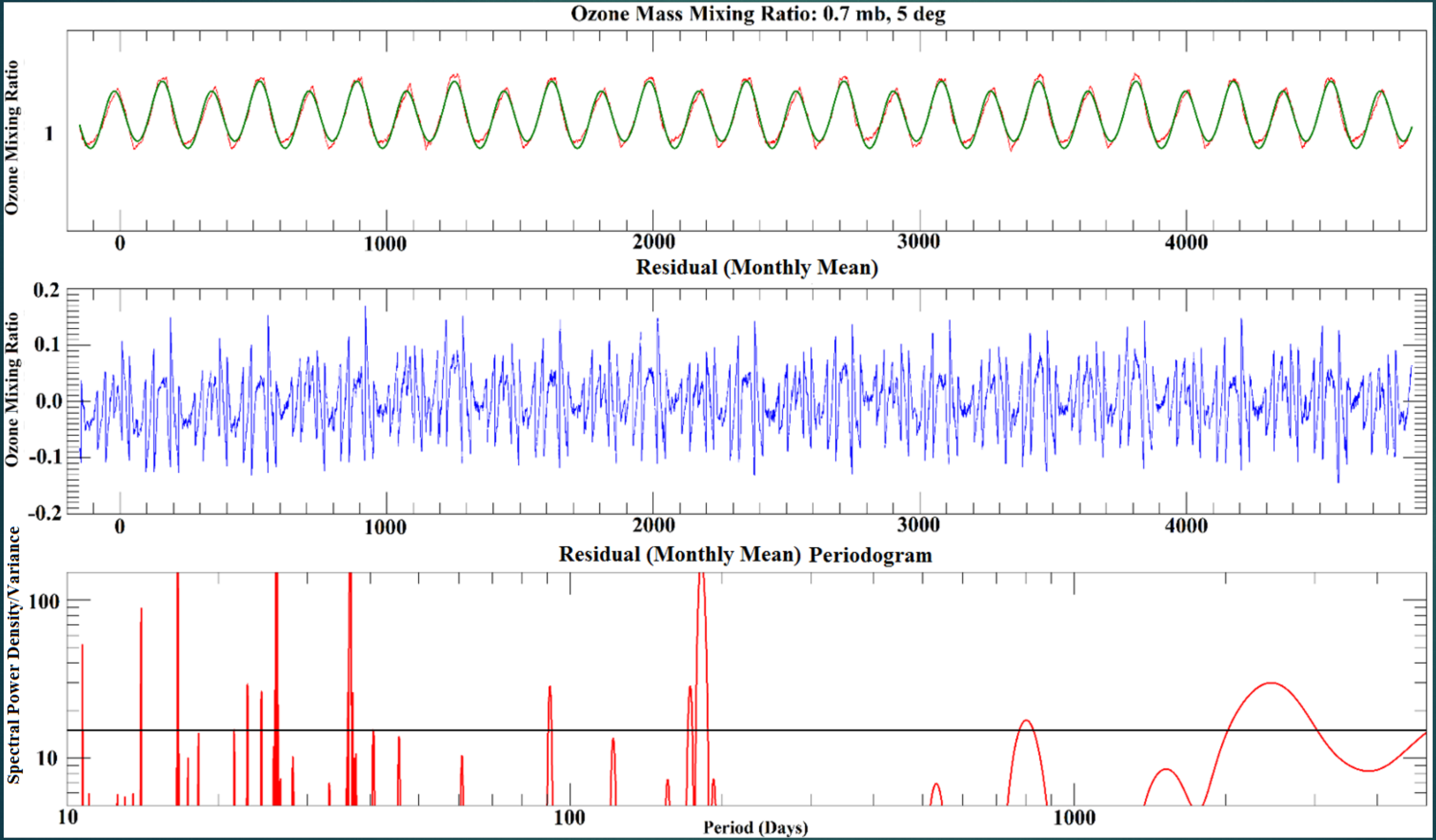


Annual/Semiannual Data Fit



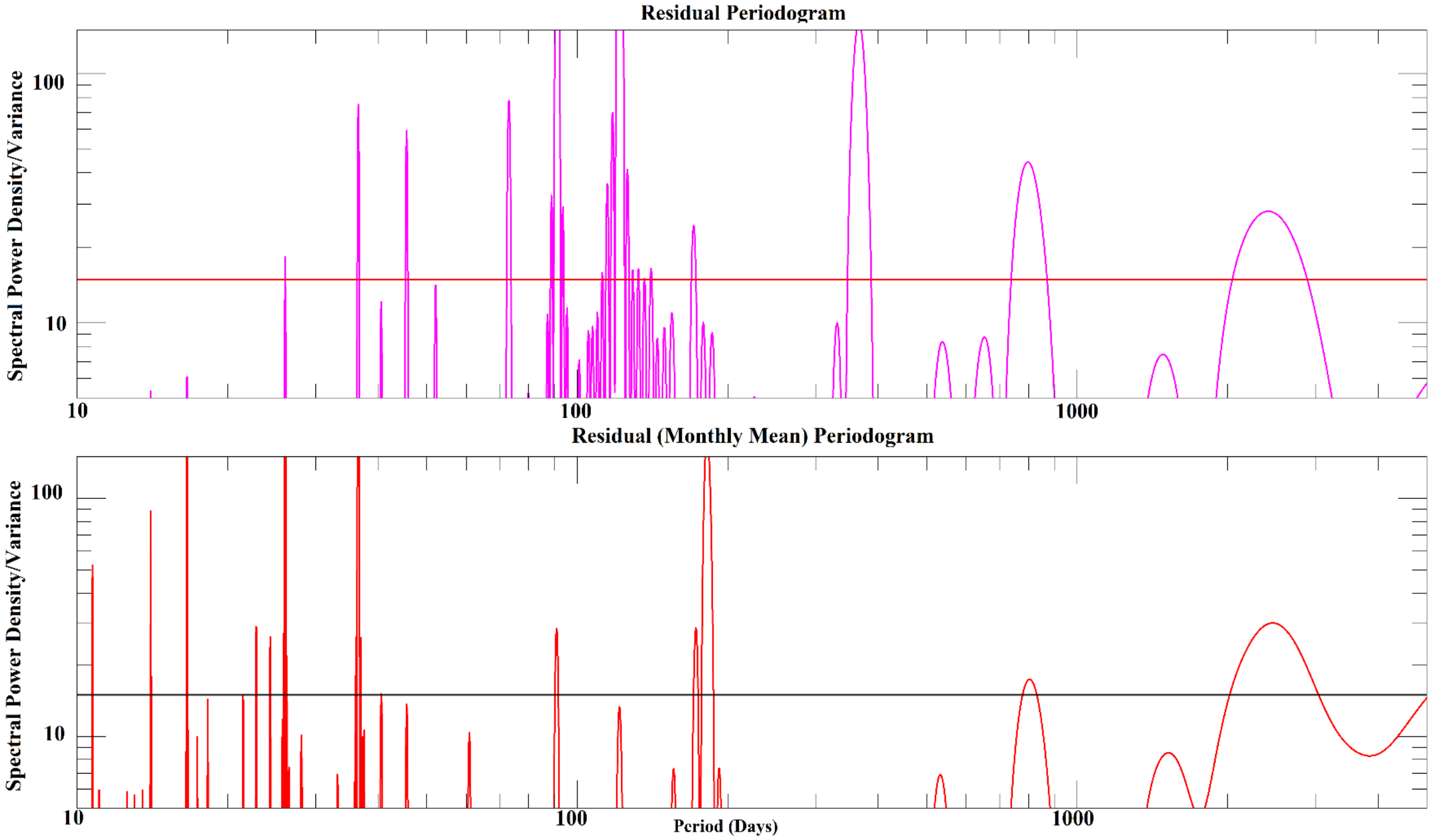
- Top of atmosphere analysis
- Scargle periodograms used to detect periodic signal in noise
- Utilized a constant of 14.9 for the false alarm probability
- Note 27 day contribution from periodogram and overall ozone change.

Monthly Mean Fit



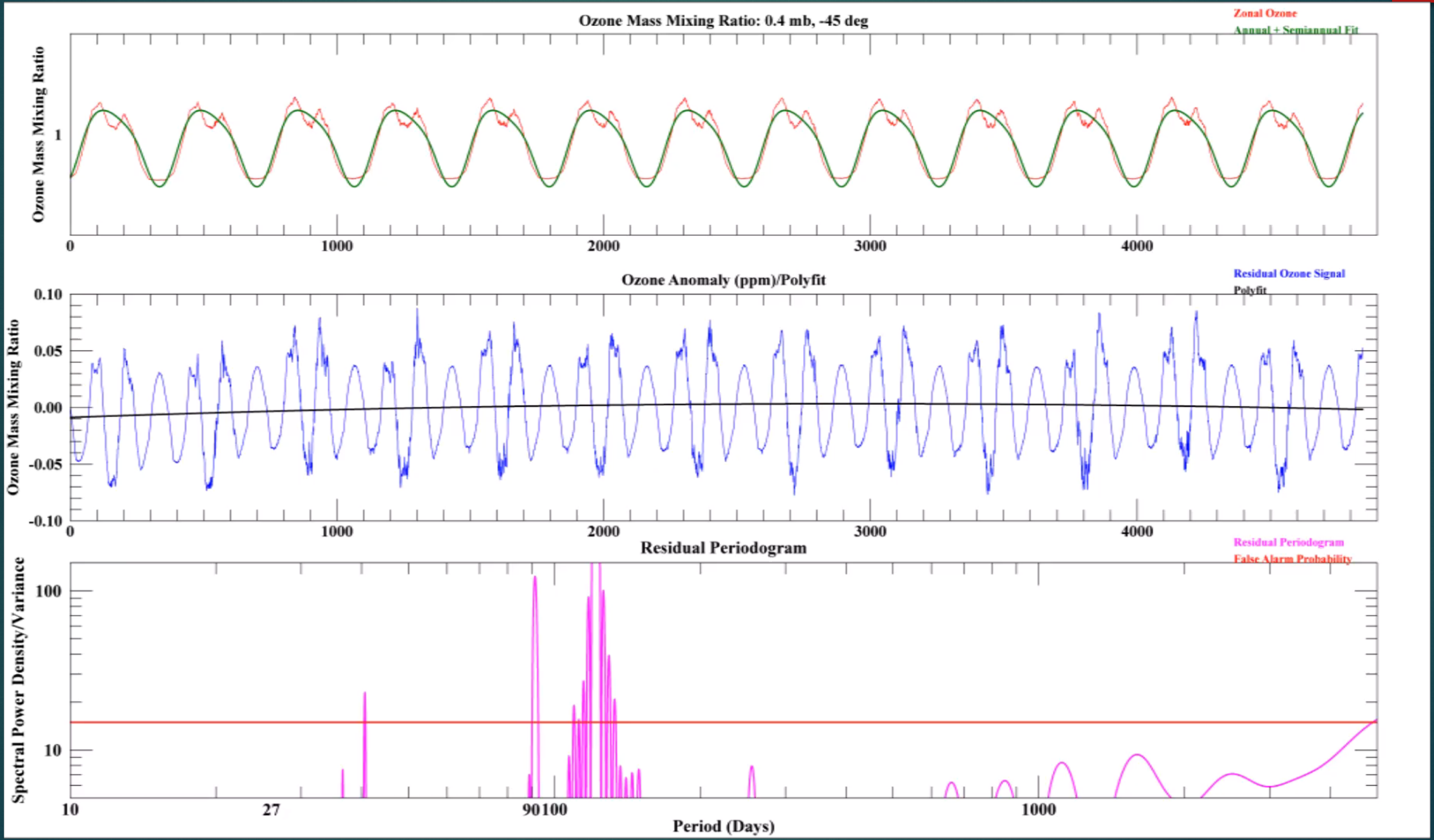
- Similar to previous slide
- Uses monthly mean climatology for the anomalies
- Provides more periods throughout

Comparison of periodograms

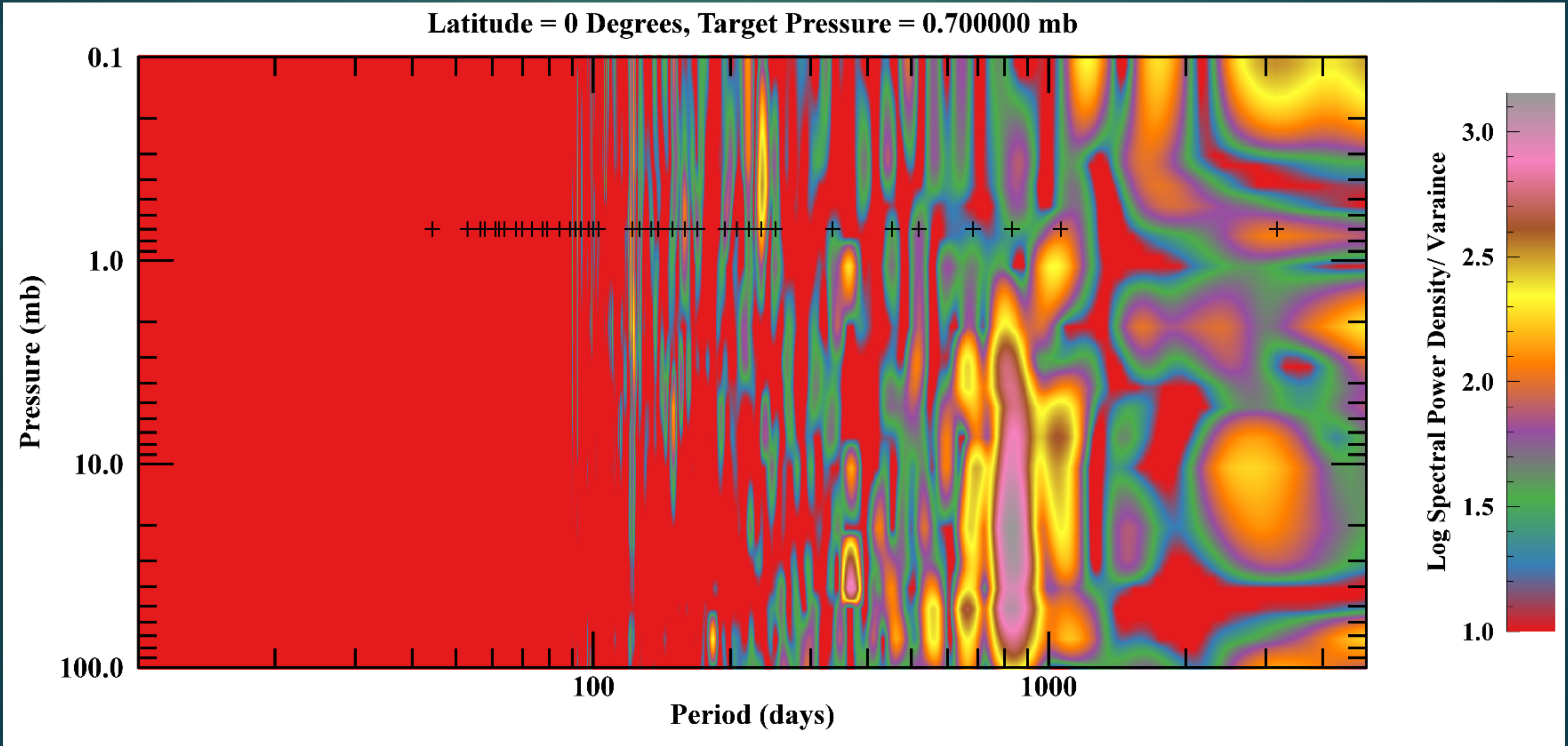


- Ozone residual periodogram versus difference mean periodogram
- Subtraction distorts anomalies
- Note similarities

Variation throughout change in latitude at constant pressure



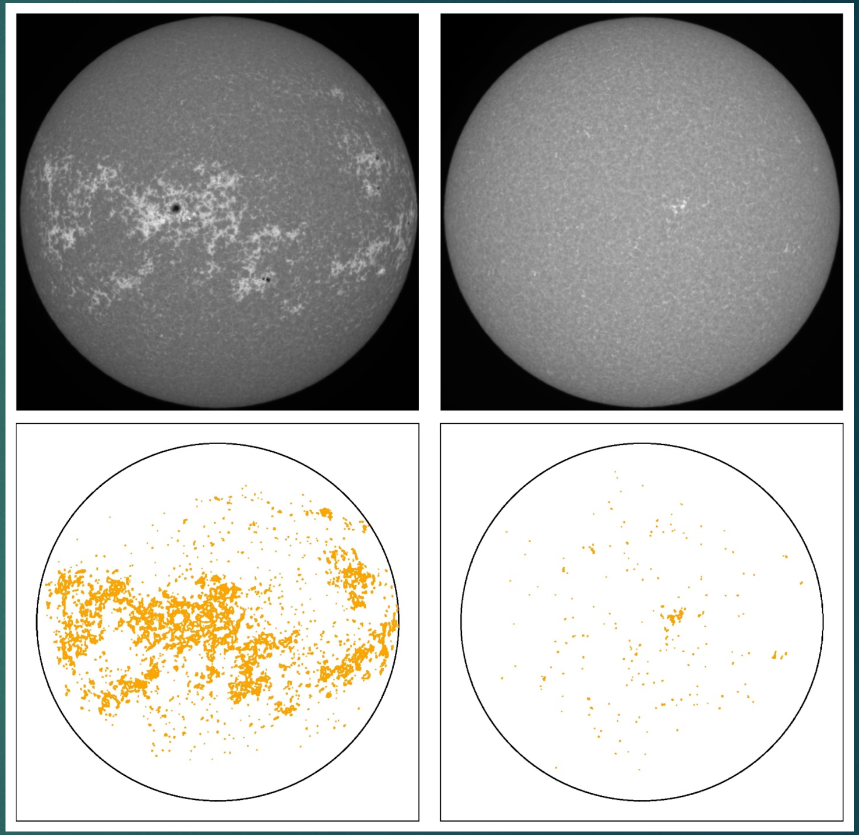
Vertical cross section through atmosphere



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

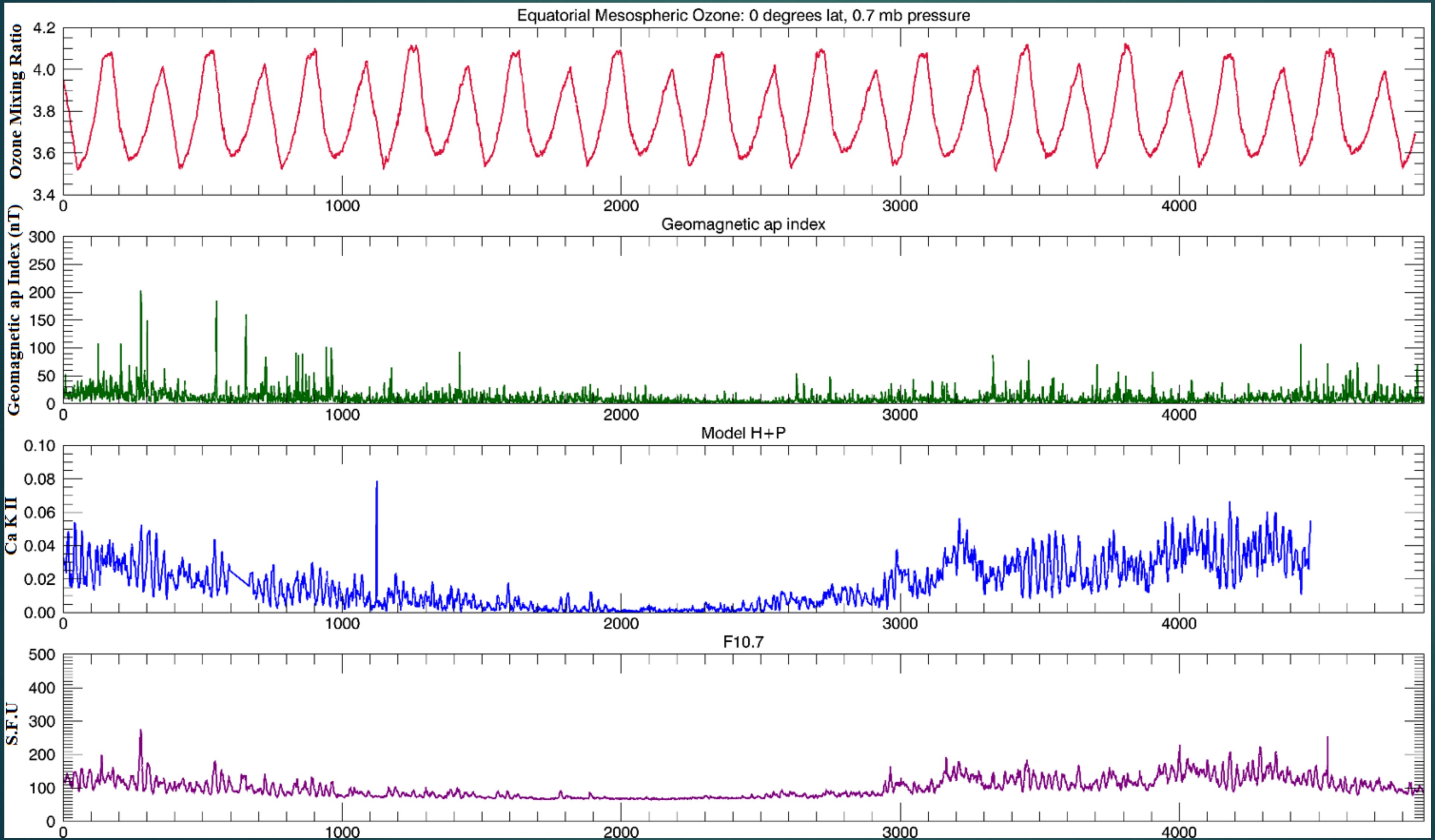
PSPT Ca K II images



Model H + P i.e. Facula & plage

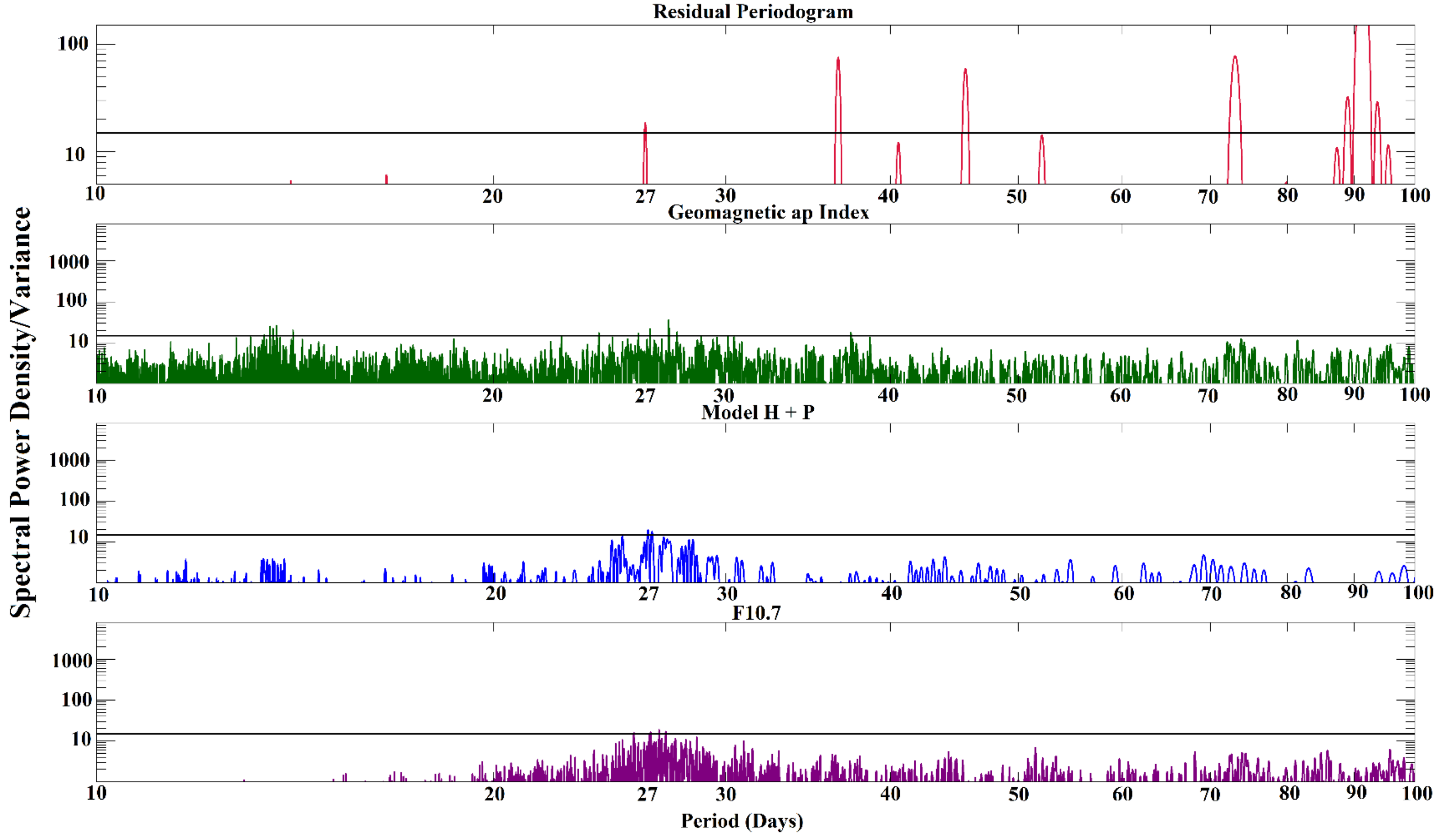
Bright active region component

Solar indices, Earth-atmospheric values Time Series



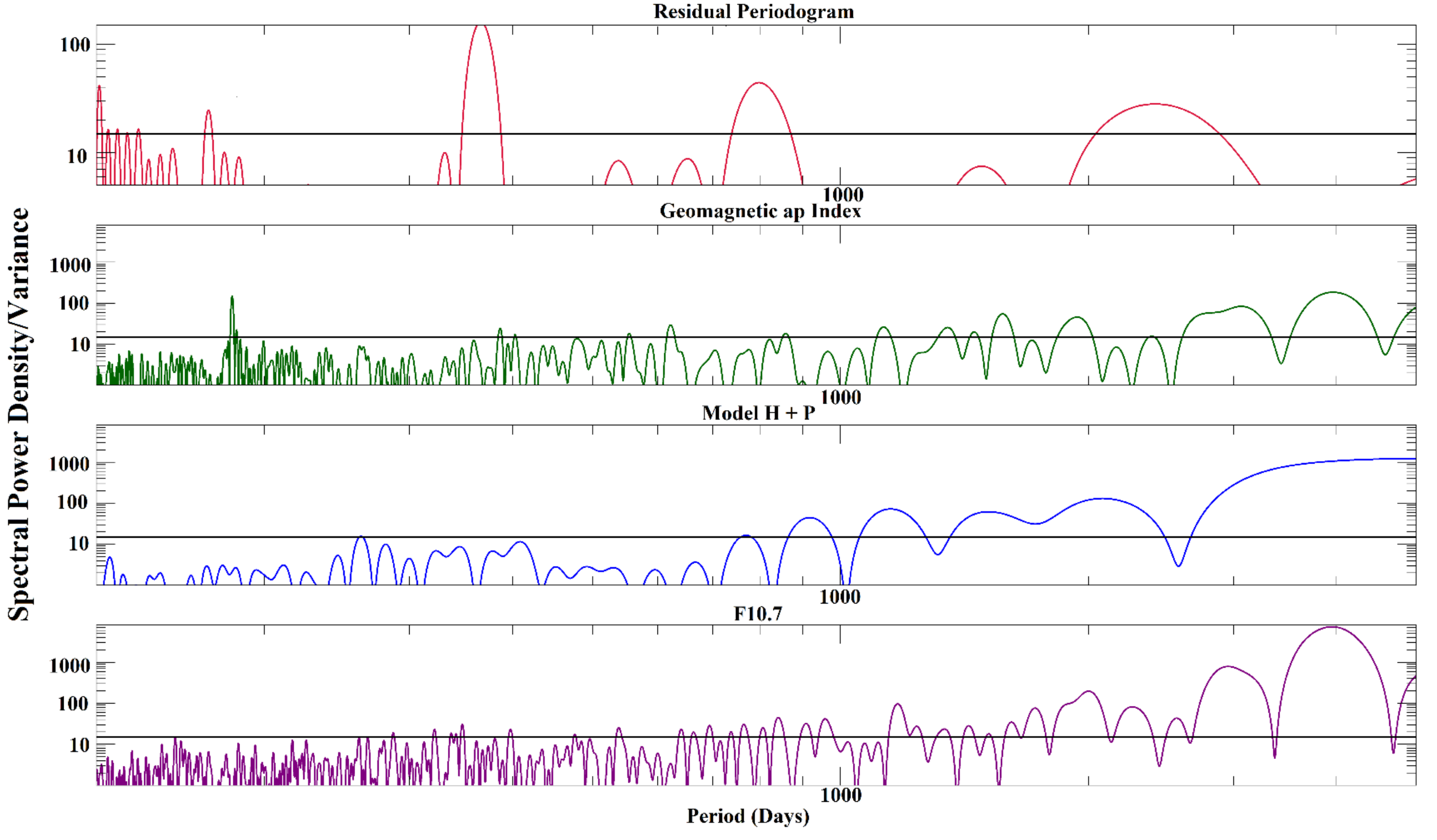
- Time series of ozone, Geomagnetic ap Index, SPRM Model H +P, and F10.7

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.