Space Weather -- Sunspots
12/04/2025

Sunspots are areas where the sun magnetic fields tangle each other that trigger intense magnetic activities on the surface of the Sun. The activities cause eruptions as solar flares and coronal mass ejections (CMEs) of high energy particles and plasma. These eruptions, when arrive at the Earth, will interact with the earth magnetosphere and cause geomagnetic storms.

Strong geomagnetic storms can induce power grid current surges, overloading transformers and causing electricity outrage (e.g., Quebec's 1989 event). High energy particles (either electrically charged or electrically neutral) can damage airplane and satellite electronics, disrupting communications and navigation. Intense solar flares can also cause earth radio blackouts, particularly affecting the polar regions as a strong ratio interference. Therefore, study of sunspots helps develop mitigating measures that can minimize the impact to human society.

The data are collected by the Royal Observatory of Belgium (https://www.sidc.be/SILSO/datafiles). The daily total sunspot number is computed by the formula:

$$R = N_s + 10 \times N_g$$

where N_s is the number of spots and N_g the number of groups counted over the entire solar disk.

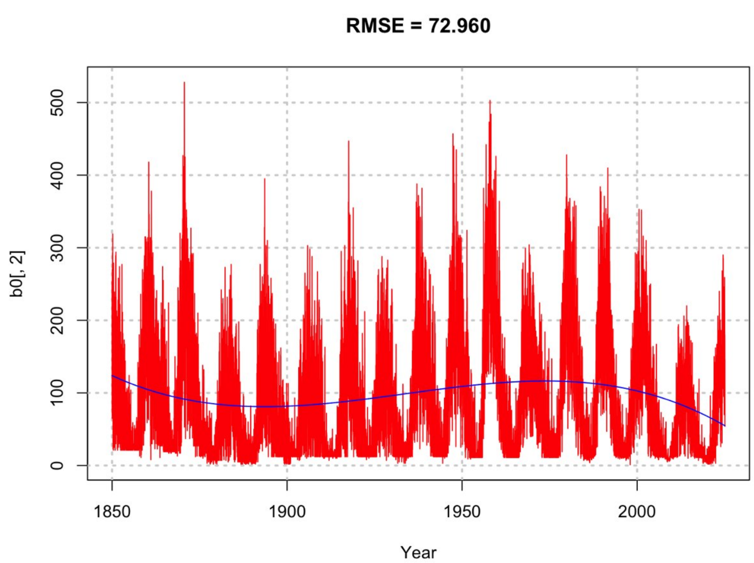

Figure 1, Daily Sunspot Number Measurements (red) and the General Trend Line (blue) using a Cubic Linear Model.

Figure 1 shows cubic linear model fitting the data. A higher order linear model does not improve the root mean square error (RMSE). The seasonality of the data is modeled using the Fourier transformation. Figure 2 shows the spectrogram of the residual term from the trend model.

The center frequency component is located at the frequency index of 16, corresponding to seasonality of 54605/16 = 3413 days, or 8.8 years. The frequency index actually spreads from 14 to 21 (7.1 years to 10.7 years). Therefore, the Fourier transformation includes all the frequency components below 23.

Figure 3 shows the modeling results. The root mean square error (RMSE) of this model reduces from 72.96 for the general trend model to 47.27 when the seasonalities are accounted for.

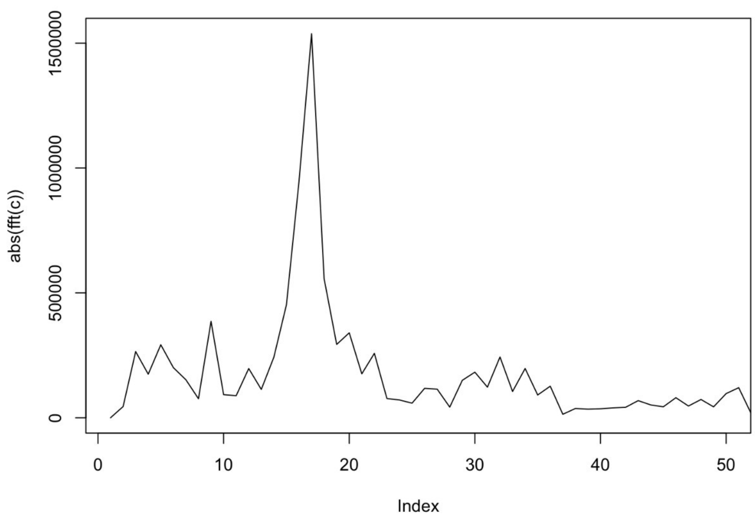

Figure 2, Fourier Transformation of the Residual Term from the Trend Model.

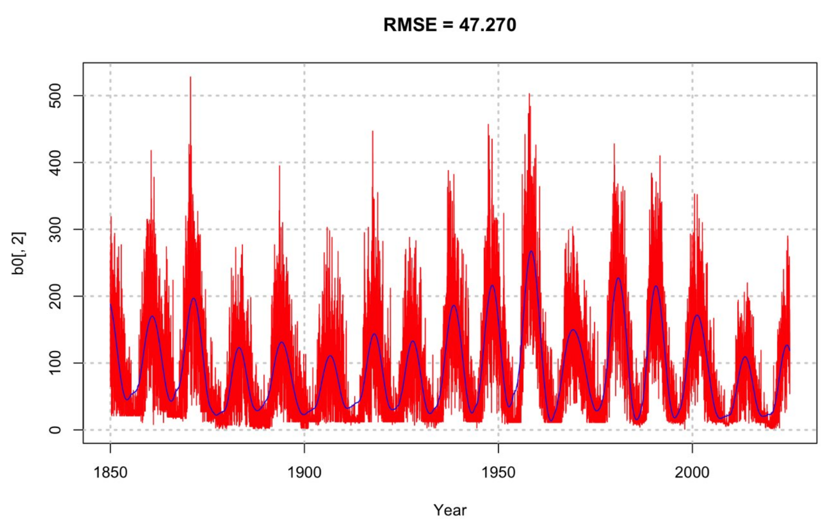

Figure 3, Daily Sunspot Number Measurements (red line, hidden) and Model of both the Trend and Seasonality (blue line).

The partial autocorrelation function (PACF) of the residual terms from the seasonality model is shown in Figure 4. It suggests that the sunspot measurements are correlated to those values six days prior. These measurements are then included into the autoregression model.

The combined model is shown in Figure 5. The RMSE of the combined model is reduced to 21.653 from 47.27, a significant improvement.

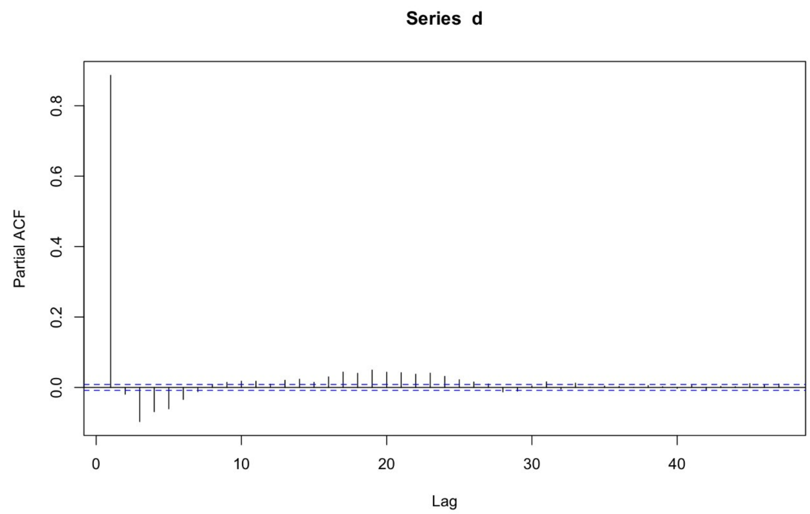

Figure 4, Partial Autocorrelation Function of the Residual Term (d) from the Seasonality Model.

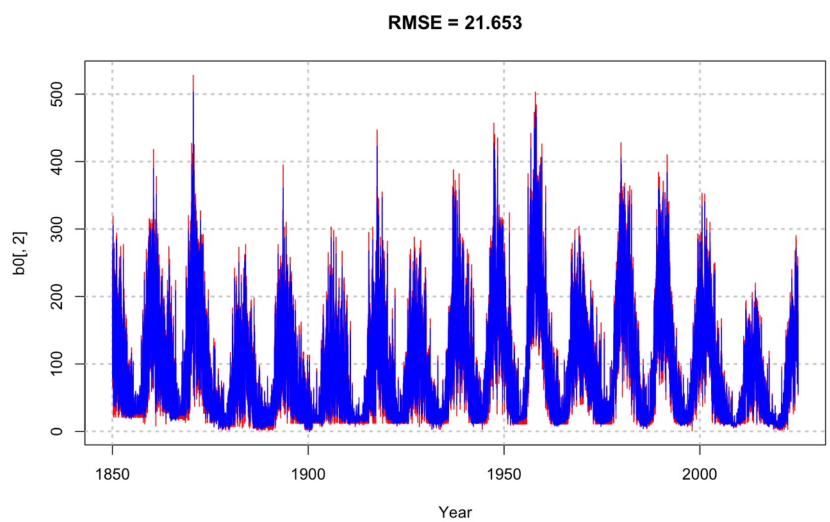

Figure 5, Combined Model with Trend, Seasonality, and Autoregression Components.

A closeup view of the model for the last six years is also shown in Figure 6 where the model data is almost overlapping on top of the actual measurements from the Royal Observatory of Belgium. It shows that 2025 is a peak year of sunspots and the consequential solar flare-induced disruptions to power girds, ratio communications, avionics and satellite electronics. Indeed, the Northern Light this year has reached to southern states like Texas and Airbus recalled a large number of A320 planes due to avionic malfunctions caused by “high energy particles”. Fortunately, the solar activities are on the way to a much reduced level onward because of its cyclic nature.

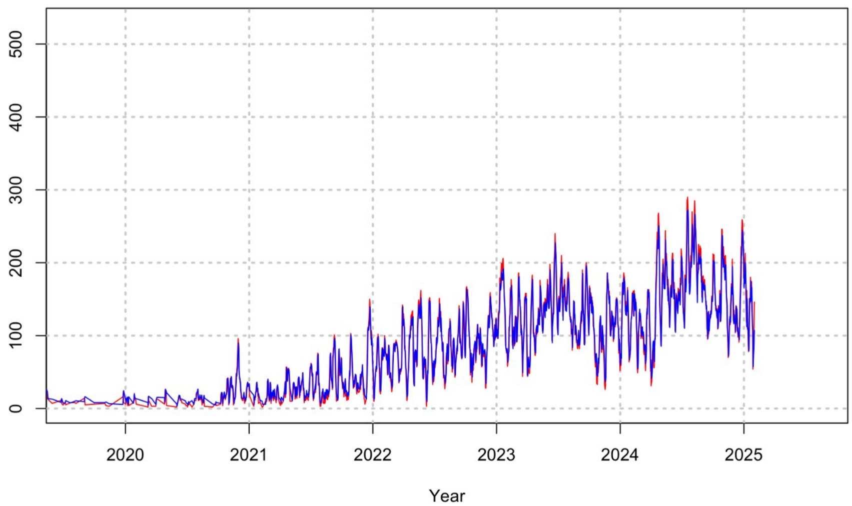

Figure 6, A Closeup View of Figure 5 of Actual Measurements (red line, hidden) and Model Prediction (blue line)

<u>Concluding Remarks</u>

The sunspot events appear to be extremely chaotic (see Figure 1). The observations nonetheless can be approximated reasonably well by the methodological approach with trend, seasonality and autoregression. The root mean square error of the approximation can be as accurate as 21.7 for the average daily value of 200, or 10%. This is quite remarkable given the highly disorganized appearance of the data. Indeed, the estimations are almost on top of the actual measurements (see Figure 6).

One finding of this study is that the dominant seasonality of the data clearly shows an 8.8 year cycles of the phenomenon; yet the number of peaks in Figure 1 suggests an eleven year cycle. The latter time period has been broadly accepted by the scientific community. Therefore, the eleven year cycle perhaps is a combined effect of all the frequency components as shown in Figure 2.

The other finding is that the number of sunspots "exploded" on a day is only connected to the "explosions" occurred during the last six days (see Figure 4), suggesting that the system has a relatively short "memory" given the long overall eleven year cycle of the phenomenon.