Solar Forecasting using Sunspot Data

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FURMAN COMPUTER SCIENCE

ABSTRACT

Solar Weather has been around as long as time itself and was discovered in the late 1850s. With the rise of technology, solar weather is becoming increasingly important, and imposes operational effects as seen most often in mid latitude regions. These effects include GPS signal scintillation (signal interference & delays) and high frequency radio disturbances from 3 - 30 MHz. Currently, Solar Forecasting with great accuracy is impossible, but machine learning provides hopeful results.

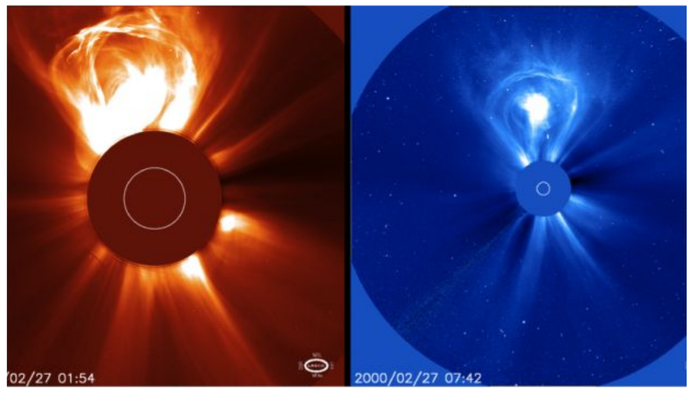
SOLAR WEATHER

Solar Weather refers to Solar Activity that directly or indirectly influences Earth Systems.

Solar Flares:
- Intense bursts of energy emitted from the Sun's surface
- Typically occur in the vicinity of sunspots

Solar Wind:
- The constant flow of charged plasma from the Sun's surface
- Travels at 300-800 km/s

Coronal Mass Ejections(CMEs):
- A large eruption of plasma from the Sun's corona
- Often associated with Solar Flares, but can occur independently
- Billions of tons of solar material at very high speeds



Pictured above is a coronagraph image showing a Coronal Mass Ejection from 27 February 2000.

Sunspots:
- Temporary spots that occur on the Sun's surface
- Associated with increased activity
- Increase and decrease in an approximately 11 year cycle

MODEL

Dep. Variable:	y	No. Observations:	618
Model:	SARIMAX(3, 0, 10)x(1, 1, [], 43)	Log Likelihood	-2699.046
Date:	Tue, 02 Apr 2024	AIC	5428.093
Time:	15:36:35	BIC	5493.408
Sample:	03-31-1818 - 06-30-1972	HQIC	5453.567
Covariance Type:	opg		

$$y_t = \delta_0 + \delta_1 t + \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + \Sigma K_j X_{t,j} + \varepsilon_t$$

The SARIMAX model is a seasonal extension of the well-known ARIMA model. My model uses over 75,000 data points from 1818 through now.

S- Seasonal:
- A pattern or cycle that repeats over a somewhat regular interval of time

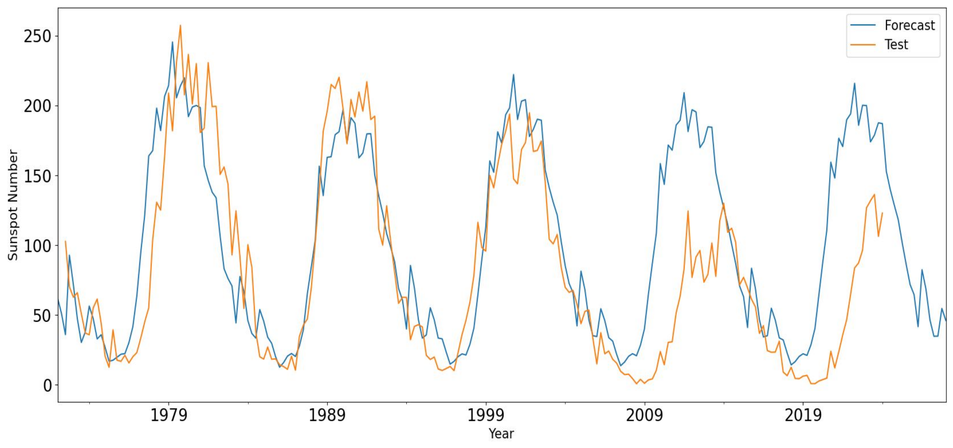
AR- Autoregressive:
- The relationship between the current value and past values

I- Integrated:
- Used to make the series stationary

MA- Moving Average
- Dependance between an observation and residual error

X- eXogenous Regressors
- Allows for the inclusion of external factors that may influence the time series

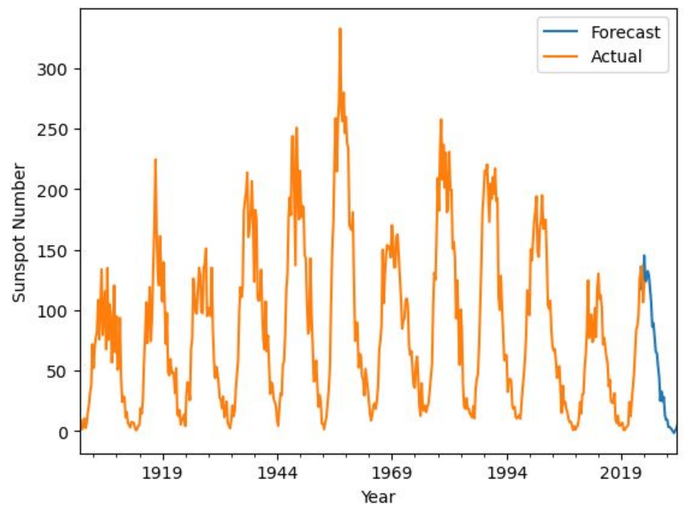
TRAINING & FITTING

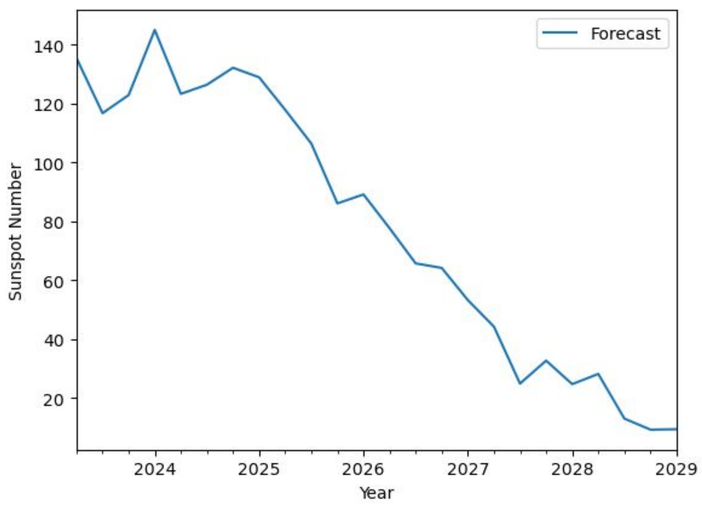


Initial Results:
Pictured is the SARIMAX (3, 0, 10) X (1, 1, 0, 43) model, which fits decently. In order to perform a better accuracy score, first I identified potential values for each of the order (p, d, q) values and seasonal order (P, D, Q, s) values.

Performing a Grid Search:
After identified, I made every possible combination of these parameters. Next, based on the accuracy score, I chose the models which fit the best. After this, I protected values for the remainder of Solar Cycle 25, expecting a peak in July of this year with a relatively weak cycle and solar minimum in 2029.

RESULTS





These 2 graphs display the same results. The first graph shows the prediction plotted with the historical data, while the second focuses on just the prediction.

CONCLUSION

While Solar Forecasting is a historical phenomena, it has proved difficult to predict very accurately. I think with the rapid improvement of technology in the recent years, machine learning will provide valuable insights that will allow NASA and NOAA to meet forecasting goals nearing 2030, and reach some level of accuracy predicting when a CME will hit further than 72 hours out by the late 2020s.

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https://github.com/Jack-brewster/arctic-forecasting