The MSFC Solar Activity Future Estimation (MSAFE) Model

Ron Suggs Natural Environments Branch MSFC/NASA

15 May 2017

Solar Cycle Forecasts

- The Natural Environments Branch at Marshall Space Flight Center (MSFC) has been providing solar cycle forecasts for decades to support NASA space flight programs and the aerospace community.

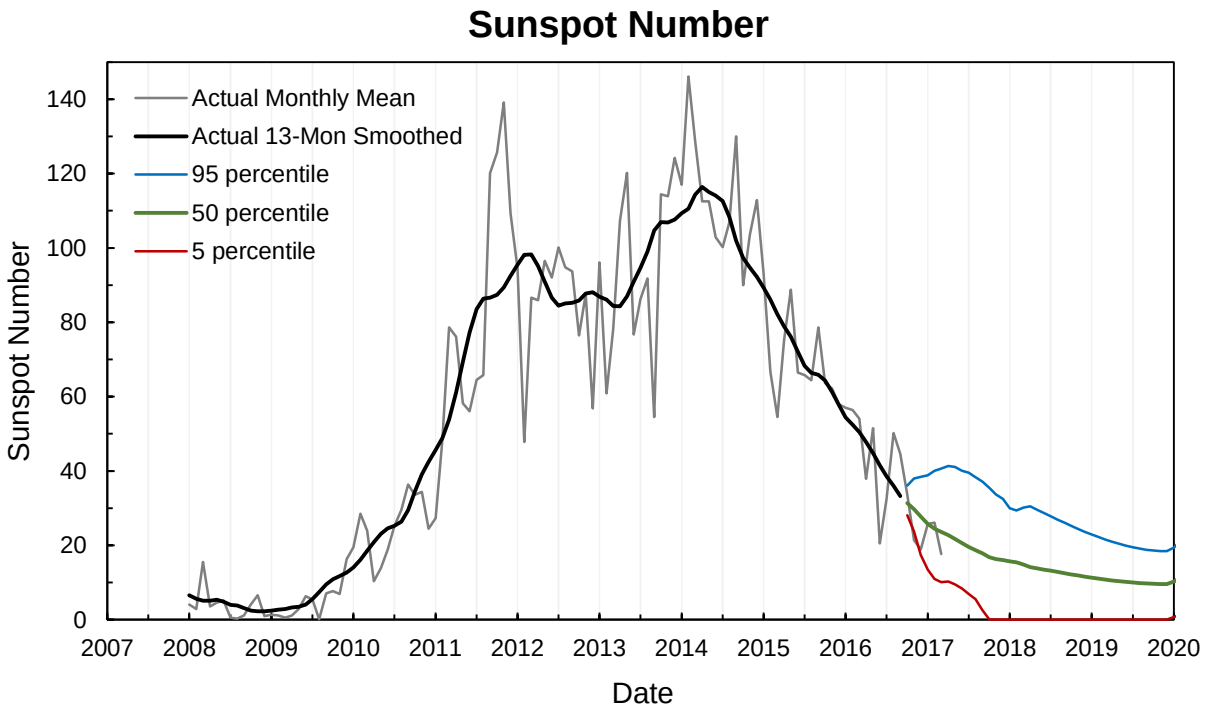
- These forecasts provide future statistical estimates of 13-month smoothed international sunspot number (SSN), solar radio 10.7 cm flux (F10.7), and the geomagnetic planetary daily index, *Ap*.

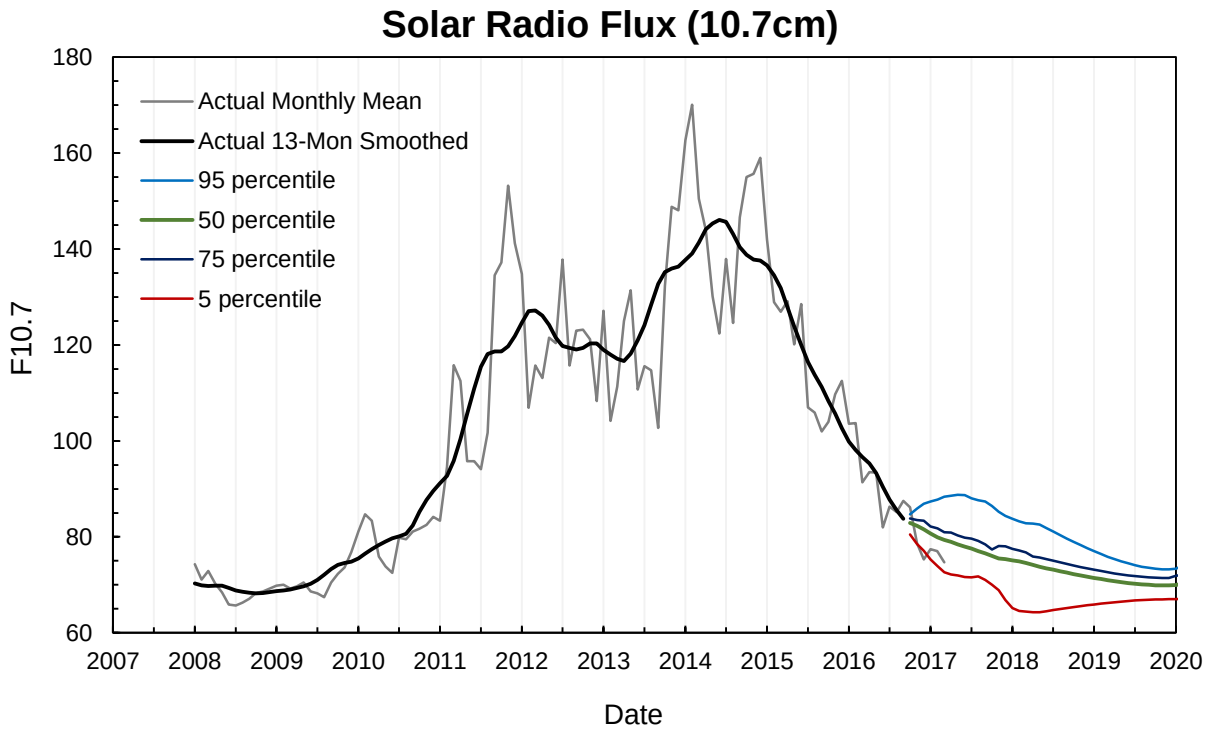
- The purpose of the forecasts is to provide future solar index values for input to various space environment models, mainly the thermosphere density models used for orbital drag calculation.
    - F10.7 – model input as proxy for extreme ultraviolet radiation heating.
    - Ap – model input for solar wind interaction and heating.

- The Solar forecasts are generated each month by executing the branch's solar forecast computer program referred to as the MSFC Solar Activity Future Estimation (MSAFE) model.

- Forecasts are provided on the Natural Environments Branch's solar webpage at https://sail.msfc.nasa.gov/.

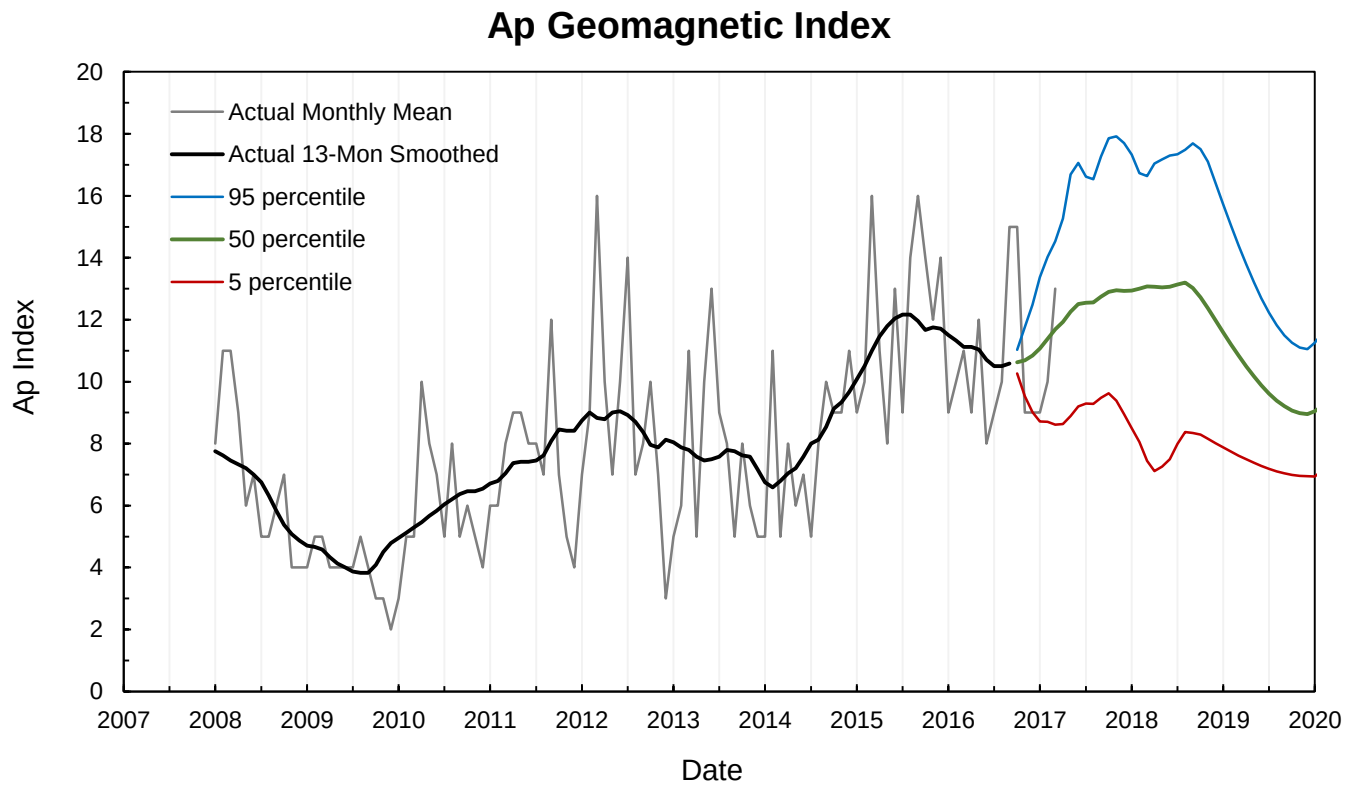
Current Solar Cycle 24 Progression & Forecast





- The forecasted solar indices represent the 13-month smoothed values consisting of a best estimate value stated as a 50 percentile statistical value along with 95 and 5 percentile cumulative frequency bounds or approximately ± 2 standard deviations (SD).
- A 75 percentile bound is also provided for the F10.7 index.
- Although the observed indices are on time scales of days, the MSAFE model is not able to calculate forecasts of the indices on temporal scales such as daily or monthly.

Current Solar Cycle 24 Progression & Forecast



The MSAFE Program

- The MSAFE model employs a statistical method to predict future estimates of solar and geomagnetic indices for the balance of the current solar cycle.

- MSAFE maintains a dataset of historical observed and reconstructed solar indices used by the prediction algorithm and for the calculation of statistical uncertainty bounds of the prediction.

- The prediction algorithm of MSAFE uses a regression method referred to as the MSFC Lagrangian Linear Regression Technique (MLLRT).

- MSAFE is describe in NASA Technical Memorandum 4759, K. O. Niehuss, H. C. Euler, Jr., and W. W. Vaughan.

MSAFE Datasets

Sunspot Number

- Observed since 1600s, regular observations from 1755 begins cycle 1
- MSAFE dataset - International Sunspot number Version 2 from World Data Center, Sunspot Index and Long-term Solar Observations, Royal Observatory of Belgium in Brussels.
- Number of cycles = 23, currently in cycle 24 ; Average length: 11.1 years, 1 SD = 1.8 years

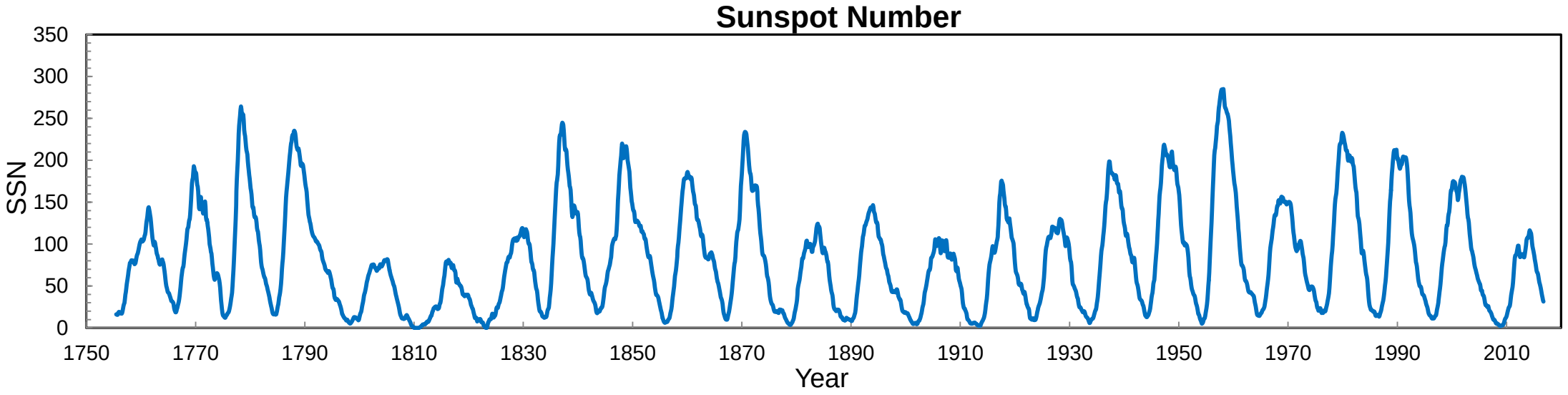
Solar Radio 10.7 cm Flux (F10.7)

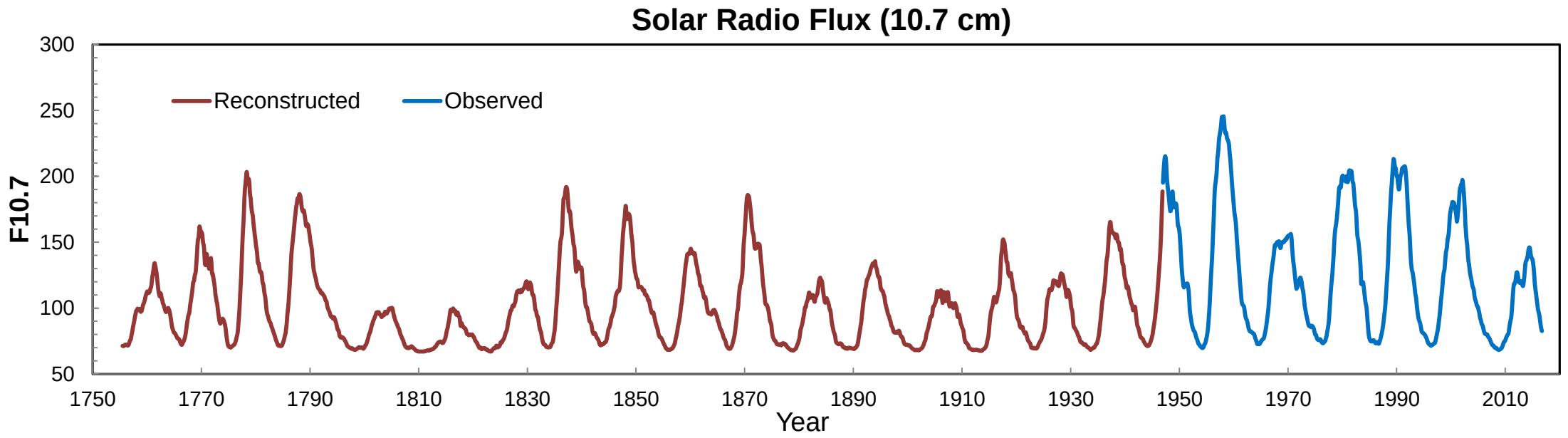
- Observed since 1947
- MSAFE dataset
  - Observed data from Solar Radio Monitoring Program, Space Weather Canada.
  - Plus reconstructed values from 1755 to 1947 using smoothed SSN and F10.7 regression from 1947 to 1980.
- Number of cycles = SSN dataset; Average length = SSN average cycle

Geomagnetic Index Ap

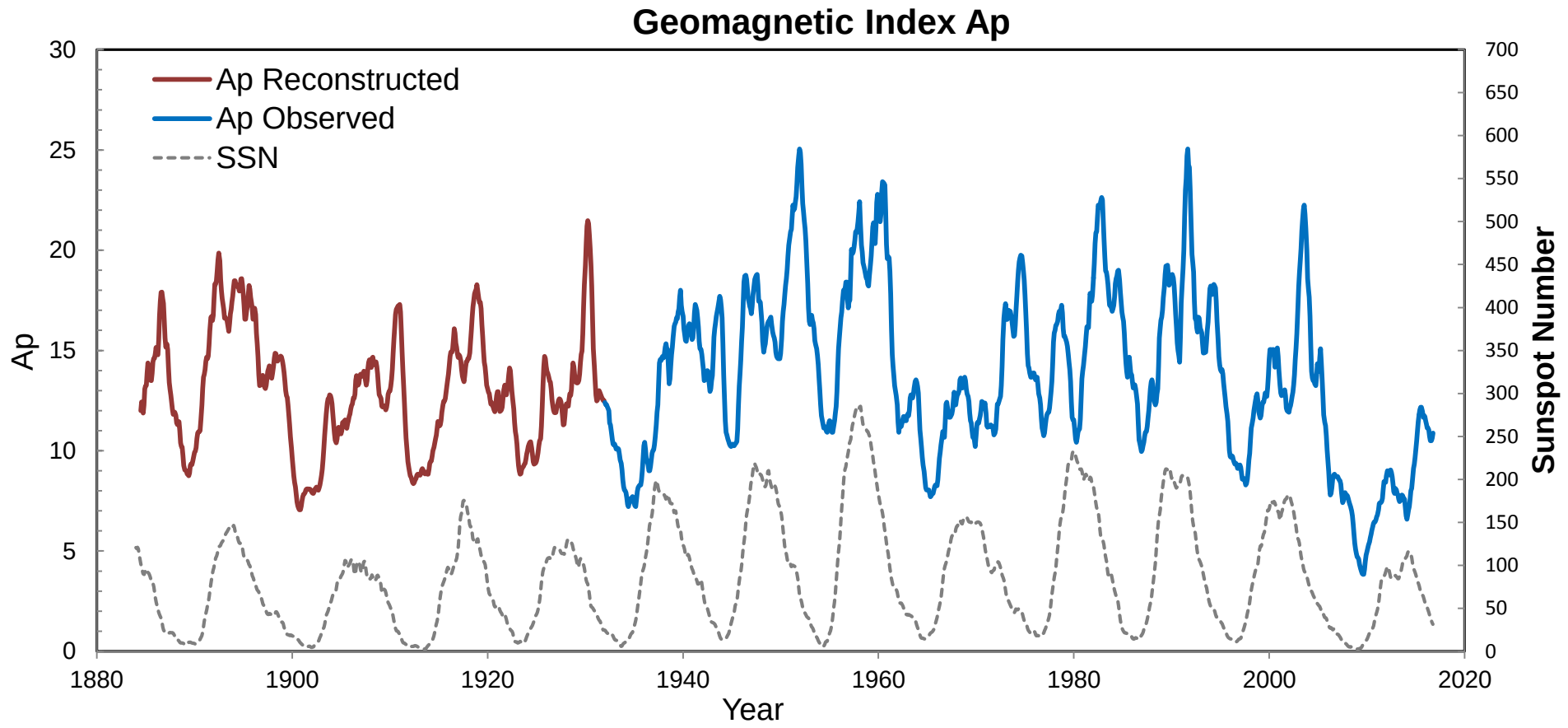
- Observed since 1932
- MSAFE dataset
  - Observed data from Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences
  - Plus reconstructed values 1884 to 1932 using smoothed magnetic character figure (Ci) and Ap regression from 1932 to 1963.
- Number of cycles =11; Average Length: 10.9 years, 1SD = 0.66 years

Historical Solar Cycle Data





Historical Solar Cycle Data



MLLRT Algorithm

- The MLLRT is a modification of the linear regression method applied by McNish and Lincoln (1949). The algorithm uses a mean solar cycle calculated by averaging the previous cycles at each time interval.

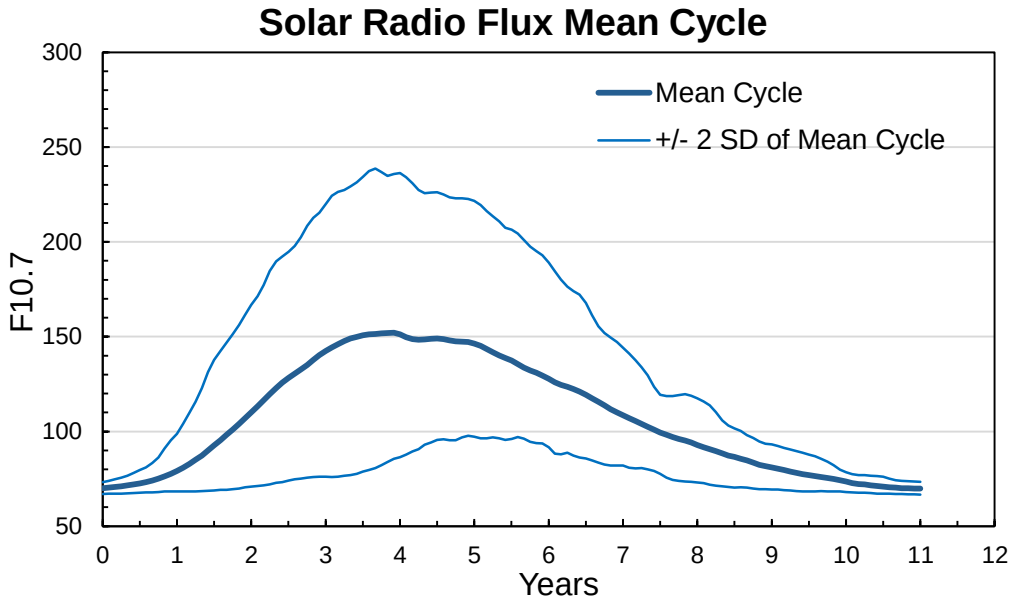
- The mean cycle is used in calculating the deviations between the mean cycle and each of the previous cycle's values at the current month's observation and at the next prediction month.

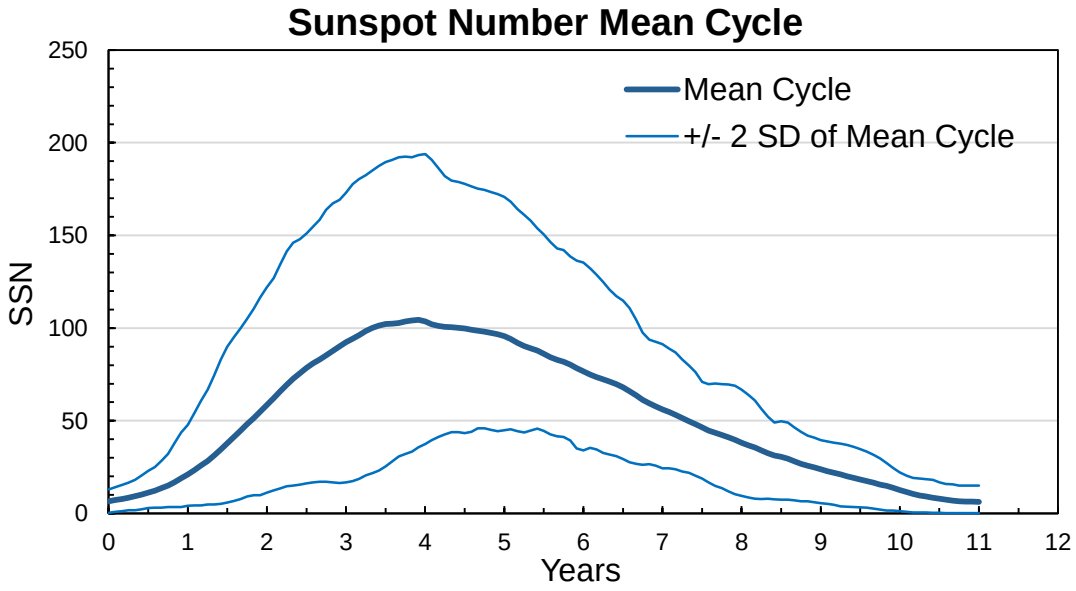
- The deviations are used to find regression coefficients that are used to calculate the next month's observation. The algorithm is applied recursively to each month throughout the cycle.

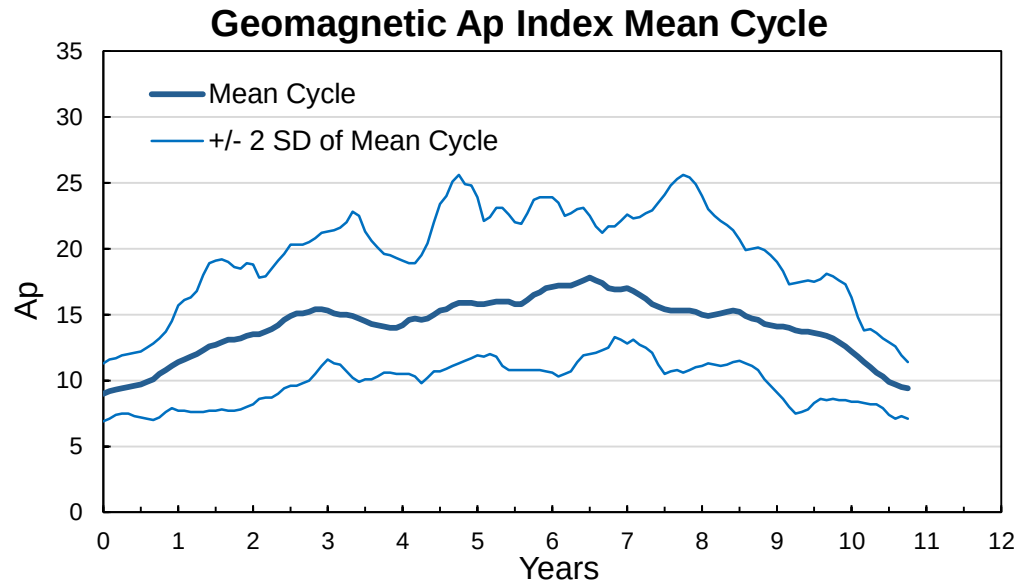
- The prediction uncertainty bounds of 95 and 5 percent are based on cumulative frequency distributions of the differences between the observed and predicted solar index values obtained from applying the MLLRT to the historical solar cycle data (cycles 1-23) in the same manner as in the current cycle prediction.

Mean Cycle Calculation

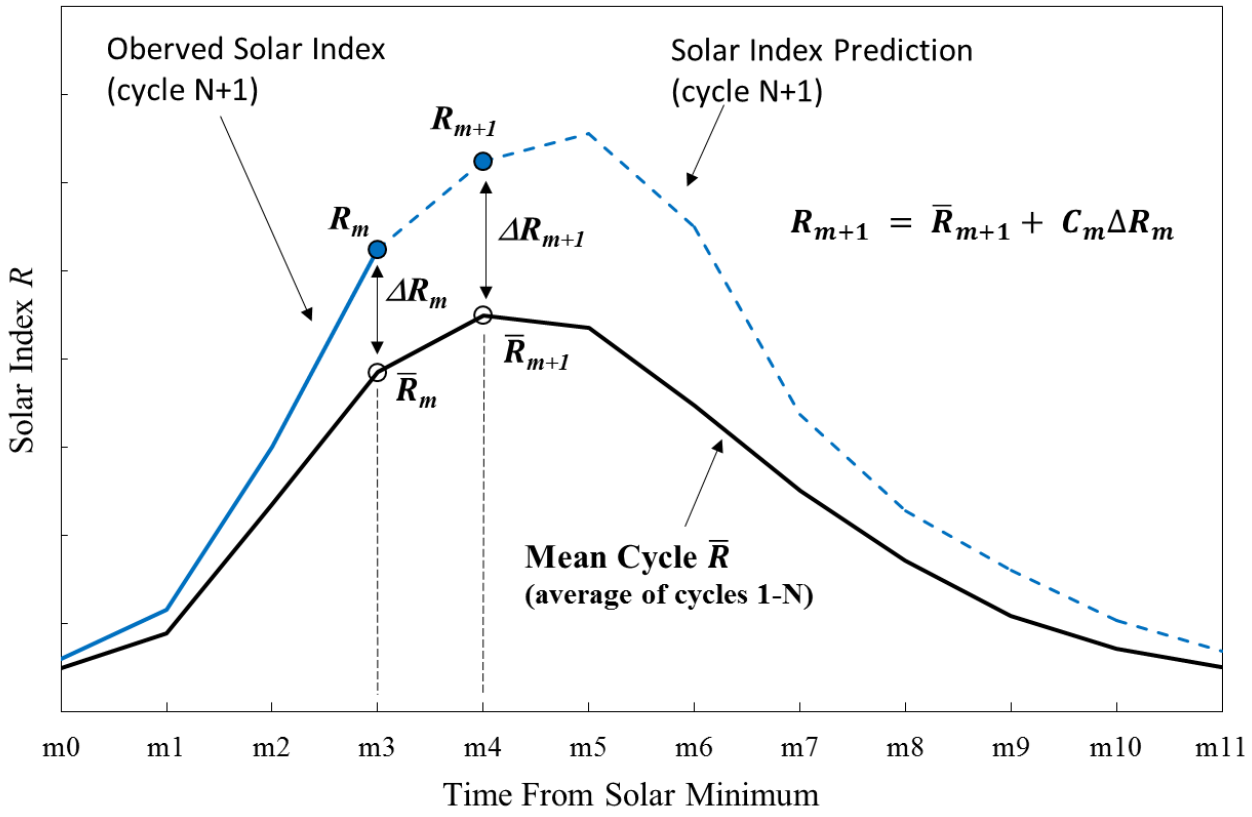
- Each solar index cycle is divided into 132 time intervals.
- At each interval the index value is interpolated using a Lagrangian interpolation technique.
- The effect is to stretch or contract each cycle to the average cycle length of 132 time intervals before averaging.
- The mean cycle is the average at each of the time intervals.

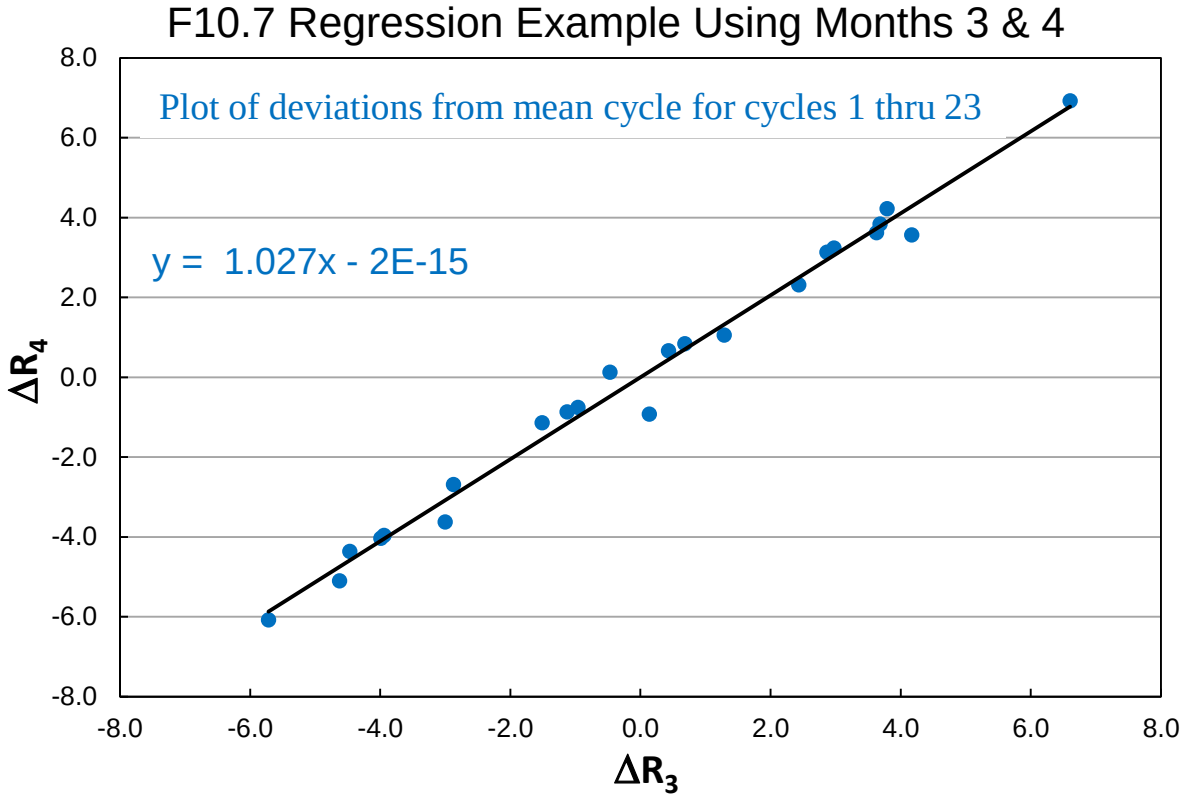






MSAFE Linear Regression Technique





C_m = Slope of Regression Line

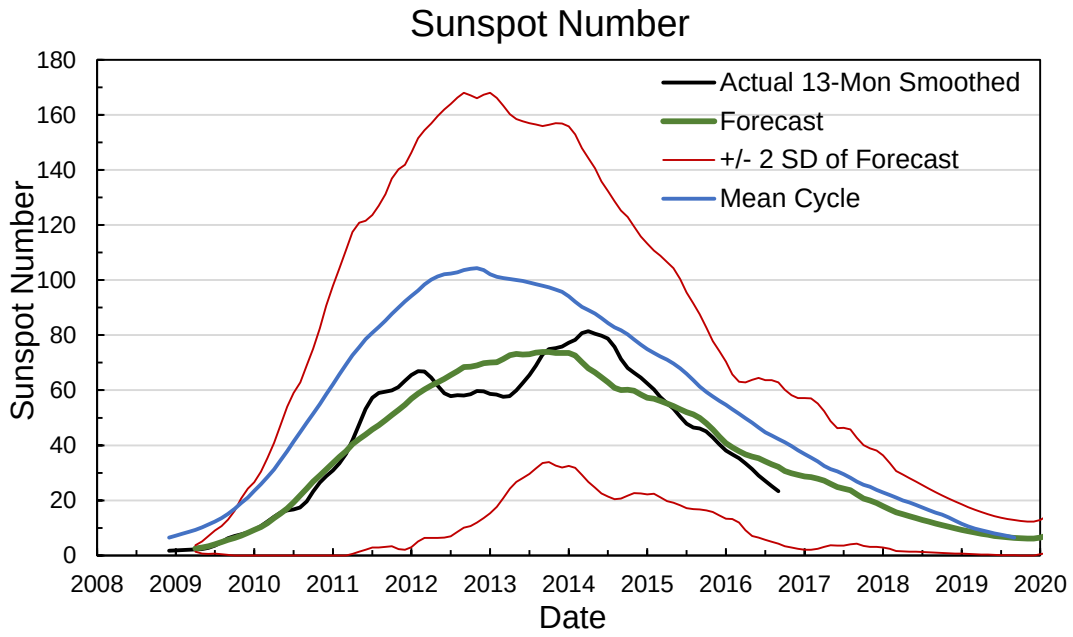
$$C_m = \sum_{i=1}^{N} \Delta R_{m,i}\, \Delta R_{m+1,i} \Big/ \sum_{i=1}^{N} \Delta R_{m,i}^2$$

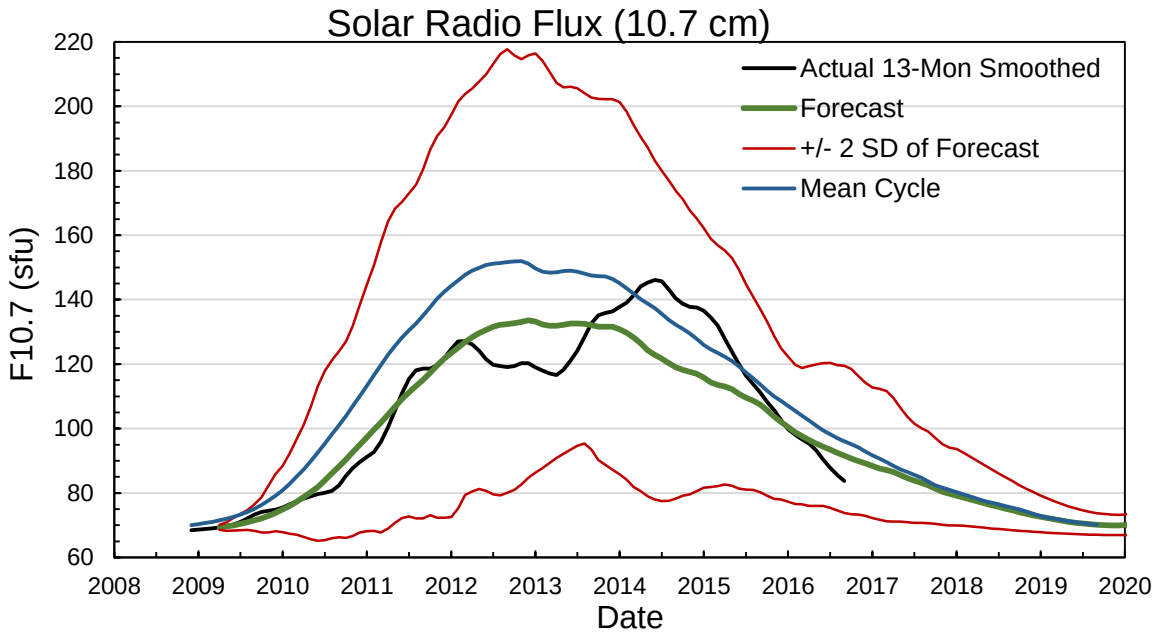
General Equation for Slope and Intercept of Regression Line.

$$m = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2} \qquad b = \bar{y} - m\bar{x}$$

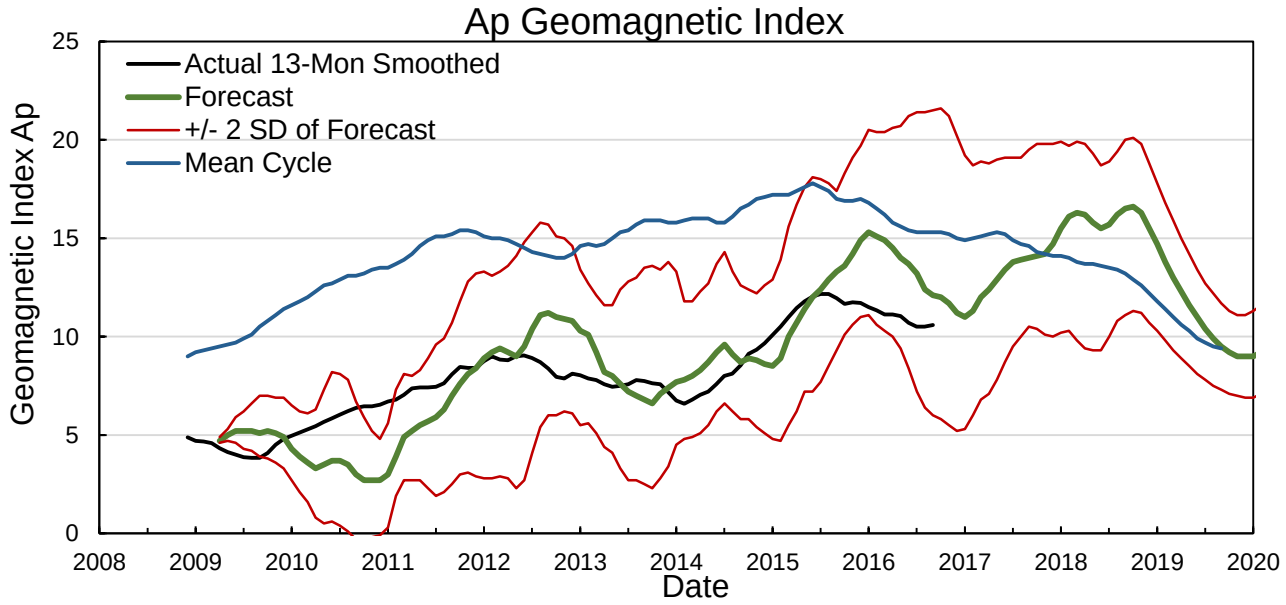
Past Forecasts of the Current Solar Cycle that Began Dec. 2008

Sept. 2009 Forecast

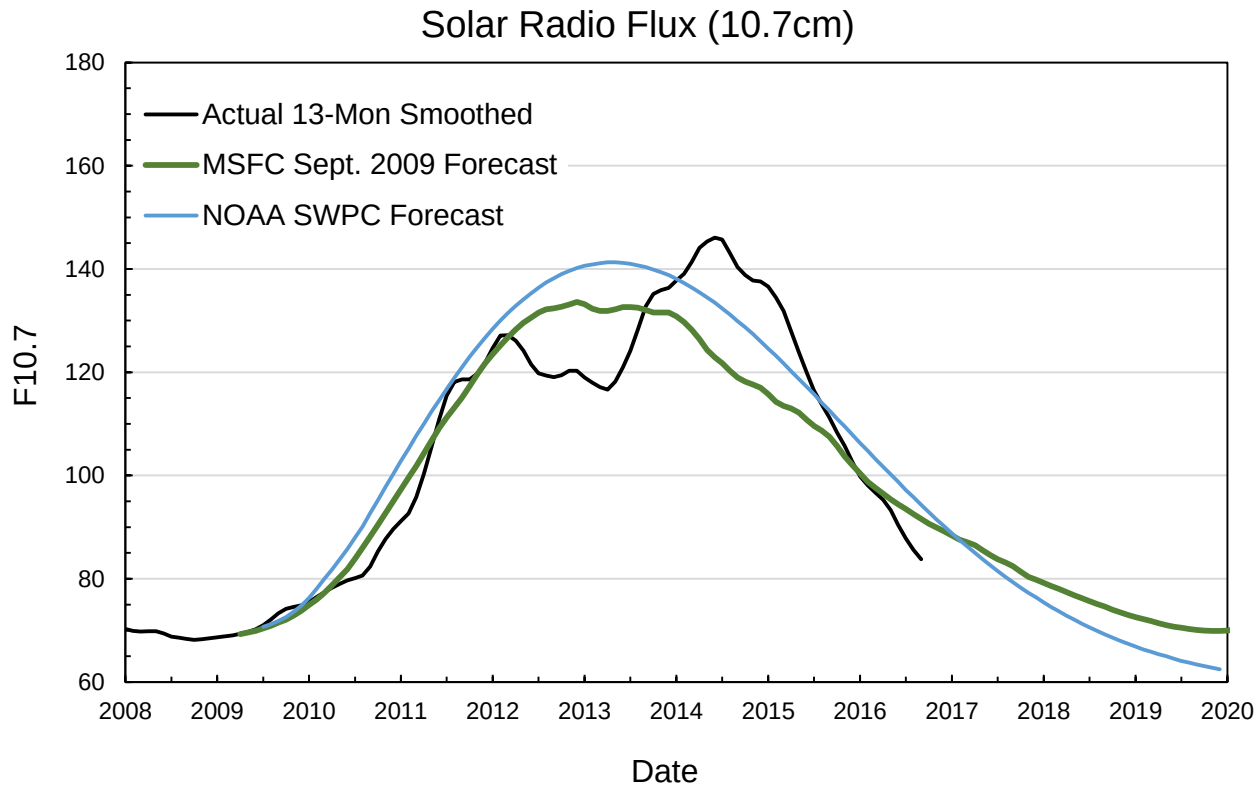




- Forecast used last observed smoothed value on March 2009

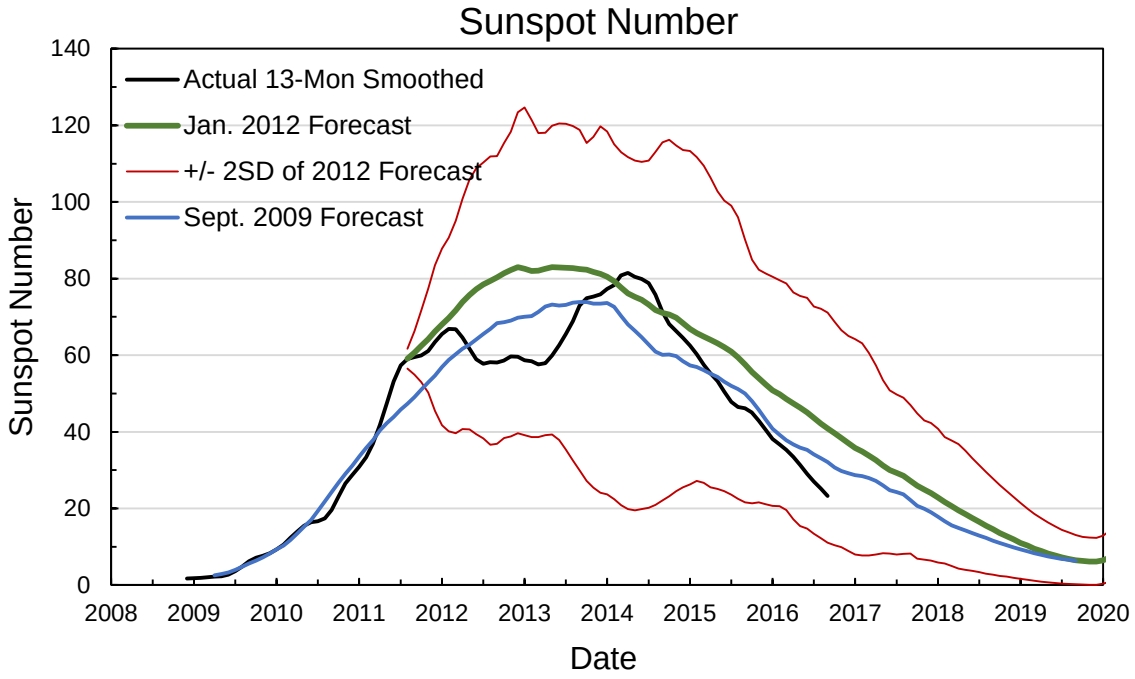


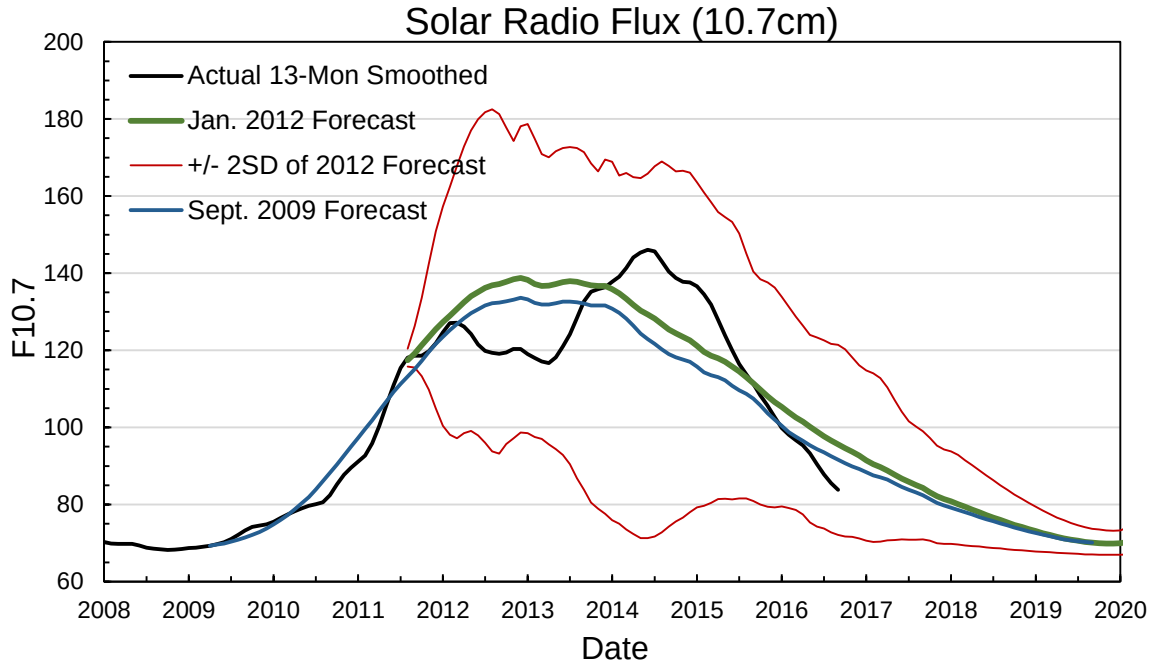
Comparison with NOAA Space Weather Prediction Center Forecast



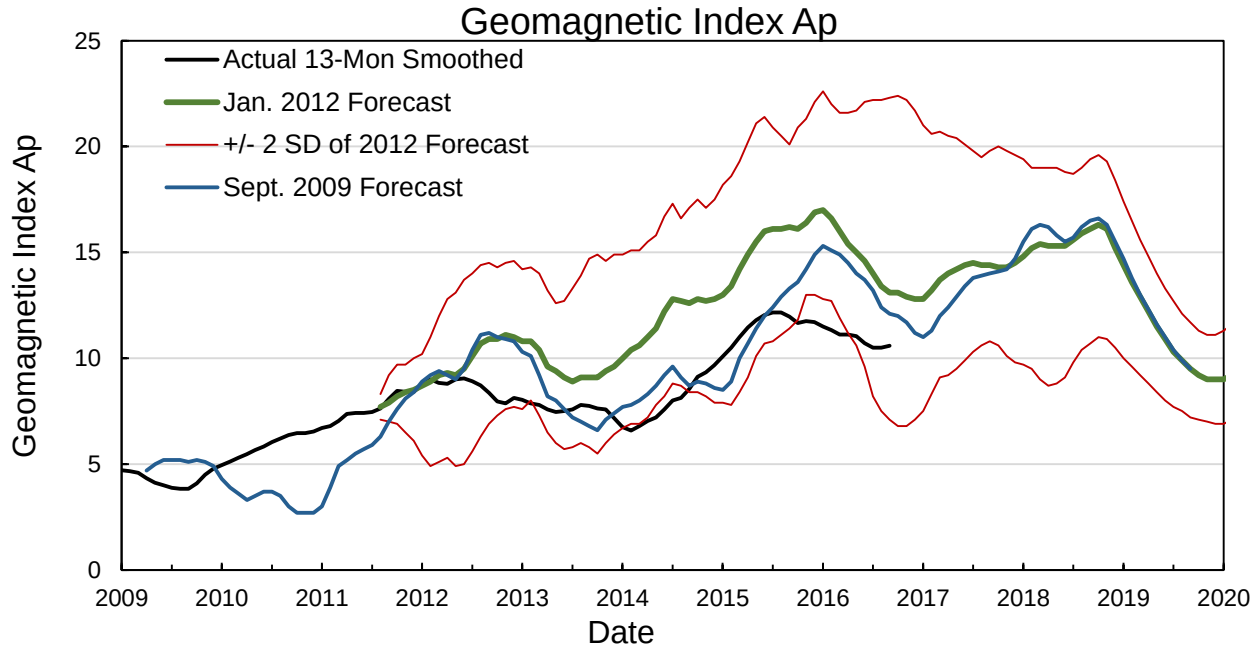
NOAA's forecast is static, made at the start of the cycle and not updated.

Jan. 2012 Forecast

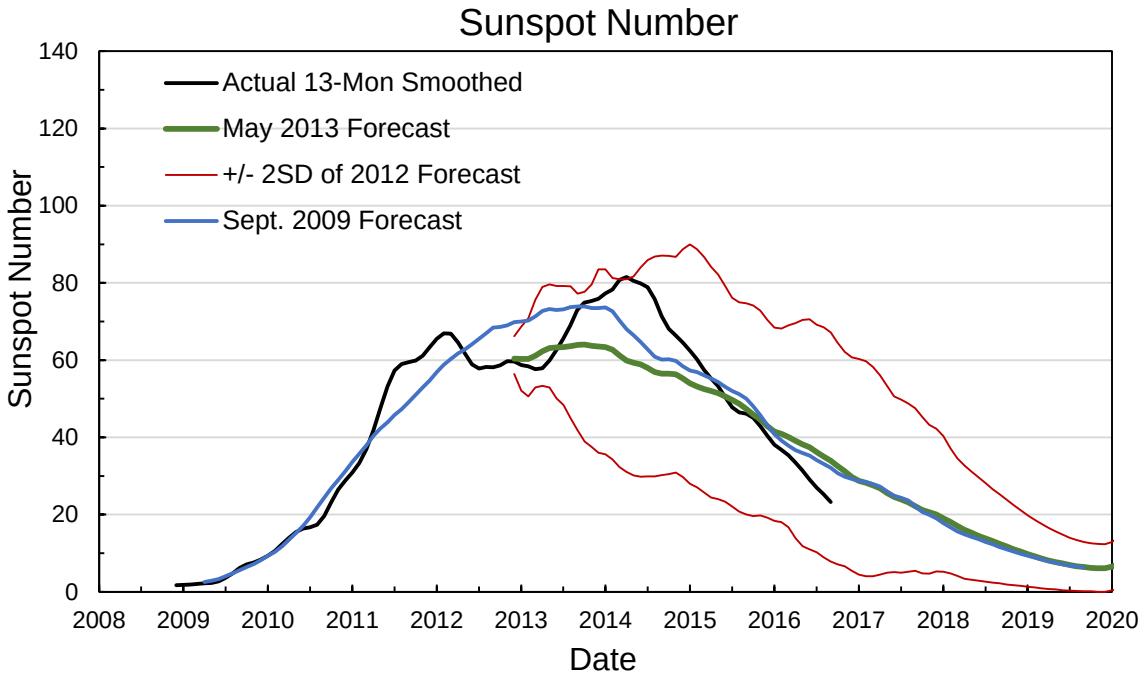


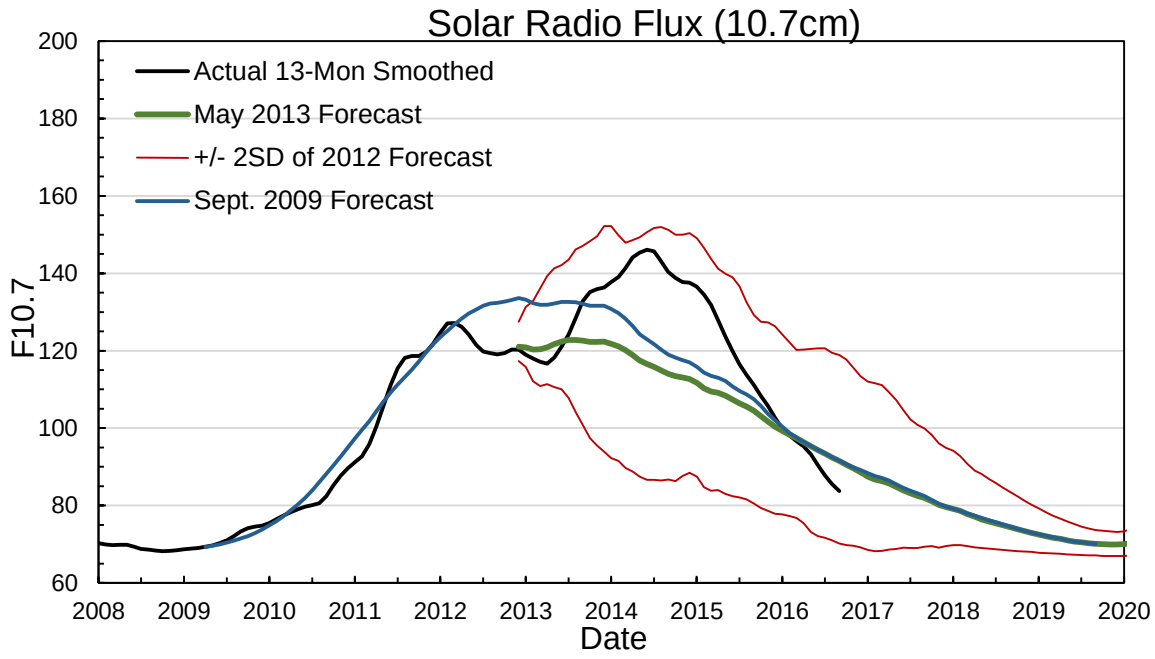


- Forecast used last observed smoothed value on July 2011

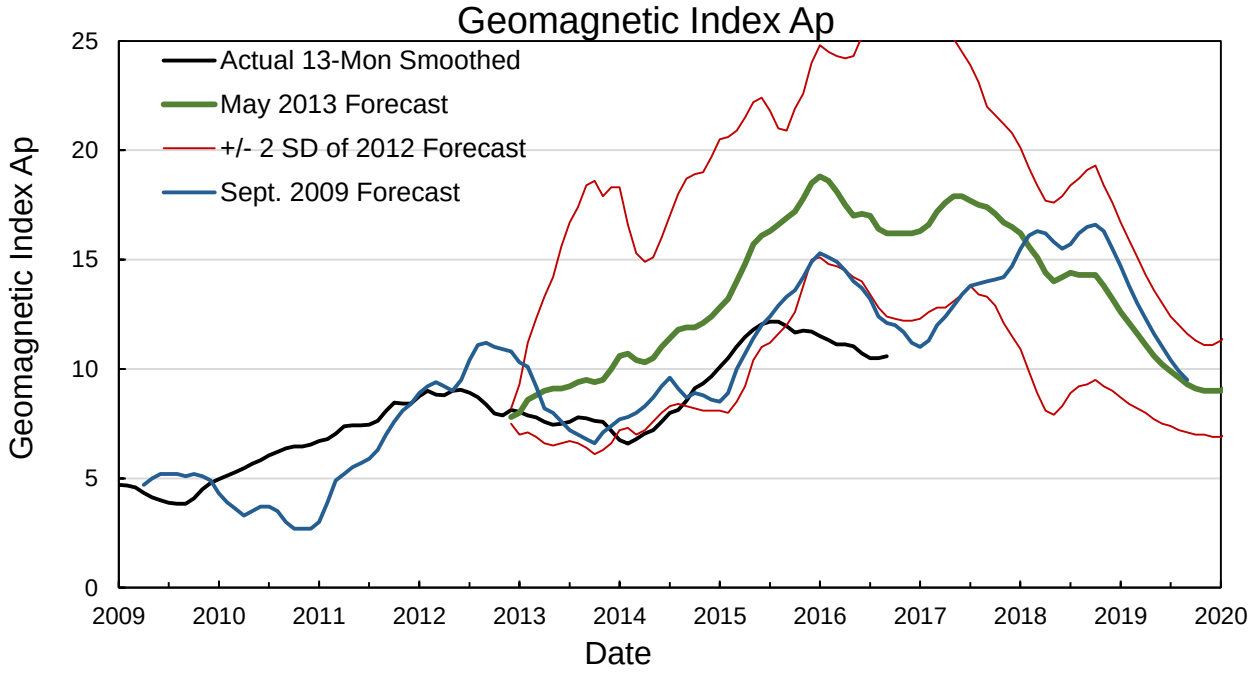


May 2013 Forecast

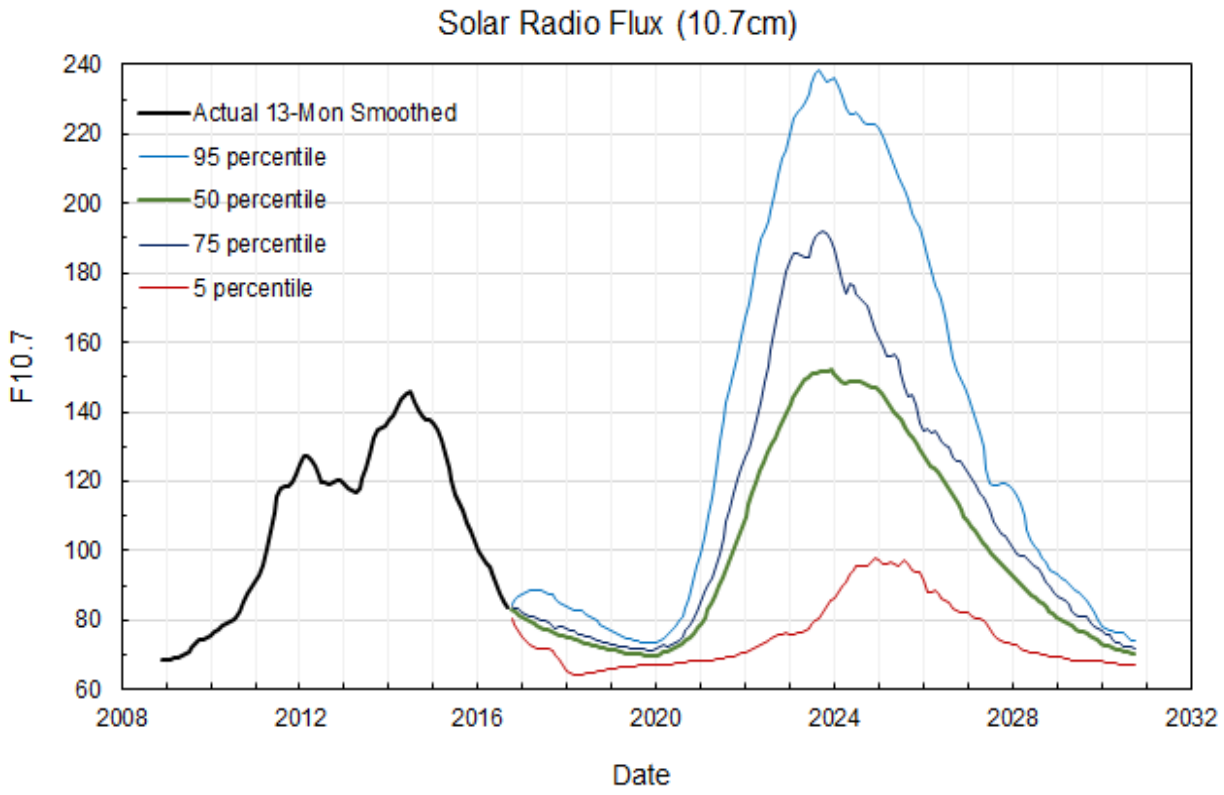


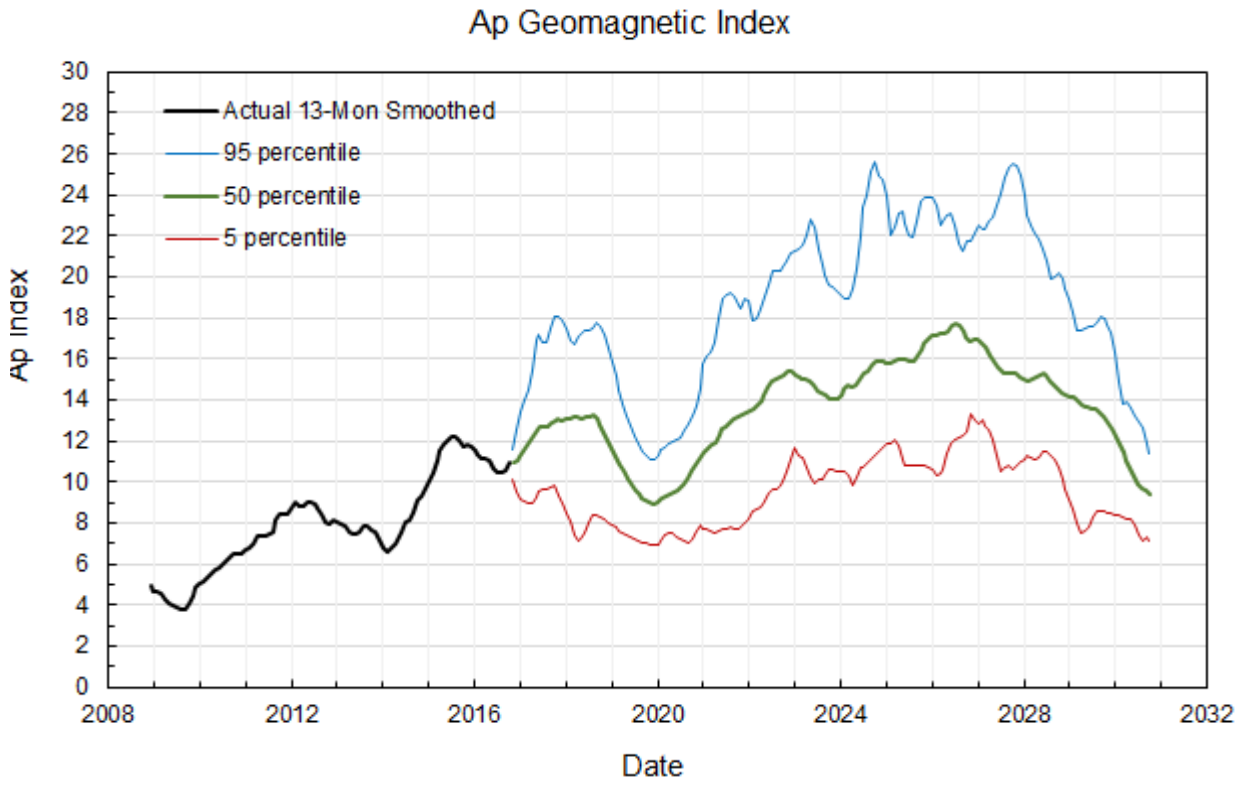


- Forecast used last observed smoothed value on November 2012



Extended Forecast





- The MLLRT algorithm is only applied to the current solar cycle.
- The forecast for the next cycle uses the mean cycle as the forecast.
- MSAFE will allow the cycle to be define from solar minimum to minimum or from solar maximum to maximum.

Summary

- The MSAFE model provides forecasts for the solar indices SSN, F10.7, and *Ap*. These solar indices are used as inputs to space environment models used in orbital spacecraft operations and space mission analysis.

- Forecasts from the MSAFE model are provided on the MSFC Natural Environments Branch's solar webpage and are updated as new monthly observations come available.

- The MSAFE prediction routine employs a statistical technique that calculates deviations of past solar cycles from the mean cycle and performs a regression analysis to calculate the deviation from the mean cycle of the solar index at the next future time interval.

- The forecasts are initiated for a given cycle after about 8 to 9 monthly observations from the start of the cycle are collected.

- A forecast made at the beginning of cycle 24 using the MSAFE program captured the cycle fairly well with some difficulty in discerning the double peak that occurred at solar cycle maximum.