The asymmetry of the solar cycle: Analysis of the cycle #24 forecast.

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Introduction

- Different numerical analysis models for fitting the shape of Wolf number evolution – not satisfactory

- Few attempts to base the forecast on a physical basis

- The paper presents the progress we made in analysis of the Wolf sunspot numbers with a special attention on the asymmetry exhibited for each cycle based on our previous findings:
  - Periodicity of approximately 11 years of maxima
  - Variability of the “amplitude” of these maxima
  - Asymmetry of the variation: a quick increase and a much slower decrease of the sunspot numbers (maxima present asymmetry)
  - Many of them the presence of two maxima
The pattern of the time series of wolf numbers for a log period
The pattern of the time series of wolf numbers for a log period

Mean monthly number
The pattern of the time series of wolf numbers for a log period

(http://www.sidc.be, Feb 1, 2012)

Mean monthly number
General models – smoothed

Sunspot number Ri:
- Monthly
- Smoothed
- Kalman filter corrections for SM
- Kalman filter corrections for CM

http://www.sidc.be, Feb 2012
Pattern for the mean values – sliding mean

SUNSPOT NUMBER Ri
- Monthly
- Smoothed
Our procedure for finding the minima & maxima of the wolf number series
(O. Tesileanu, Z. Mouradian, M. Rusu – 2002)
The asymmetry
Nonlinear van der Pol model
(J.M. Polyagiannakis, X. Moussas, C.P. Sonett - 1996)

Time series and space phase plot for van der Pol oscillator
A detailed analysis of each cycle – samples
(M.V.Rusu – 2004 - 2006)

Eqn: $a \exp\left(\frac{-(x-b)^2}{c}\right) + b \exp\left(\frac{-(x-a)^2}{c}\right)$
$a = 126.697$, $b = 0.0022238$, $c = 60.053$
Search for the best fit symmetrical curve: Gauss, Lorenz, Dyson
De-convolution

The idea: the asymmetry is due to presence of superposition of two peaks

eqn: \( y = a \exp\left(-\frac{(x-1758.5)^2}{2}\right) \)
\( a = 23.2101, b = 69.0712, c = 1 \)
De-convolution
Gaussian functions - describe the normal distributions (statistics)
- solve heat equations and diffusion equations (math);

Mean \( \mu = b \), Variance \( \sigma^2 = c^2 \) : Area \( a \cdot c \cdot \sqrt{2\pi} \)

The product of two Gaussian functions is a Gaussian,
The convolution of two Gaussian functions is a Gaussian, with \( \Delta = \sqrt{c^2 + g^2} \)
Peaks position and their amplitude
Correlation $r$ versus $\Delta$

$y = +0.676x - 0.582$, $R:0.484$, max dev:0.961
\[ \Delta = f - b \]

1749 - 2006
Forecast of NOAA and ours

Solar Cycle 23 (observed)

Solar Cycle 24 (predicted)

Updated 2009 May 8

NOAA/SWPC Boulder, CO USA
Prediction and correction for cycle #24
An international panel of experts led by NOAA and sponsored by NASA has released a new prediction for the next solar cycle. Solar Cycle 24 will peak, they say, in May 2013 with a below-average number of sunspots.
The area under the picks - constant

cycle
The position of the superposed picks × equal heights
The position of the superposed picks – the shift
The position of the superposed picks unequal heights
The position of the third possible pick
SMOOTHED SUNSPOT NUMBERS

- Blue: Excess North vs South
- Red: Excess South vs North

Time (years): 1960 to 2010
Figure 17

Monthly averages of the sunspot numbers, for the northern and southern hemispheres, derived from Fraunhofer Institut daily maps of the sun during the period 1956-1964. $R_N$ and $R_S$ refer to the sunspot numbers for the northern and southern hemispheres respectively. The $g$'s refer to the number of groups and the $f$'s refer to the number of spots.
Conclusions

- New model for sunspot cycle variation having also a physically interpretation besides the statistical one
- Nonlinearly coupled oscillators could be assimilated to a parametric self sustained oscillator
- The periodicity of 11 year becomes more conventional, being difficult to assume the “distance’ between two peak activities
- The “elementary” Gaussian peaks
  - correspond physically to a combination of normal errors distribution
  - are bound to the Green function solution of the nonlinear partial differential equation of the diffusion phenomena that govern surface phenomena of the Sun
- Statistically it is shown that the two peaks are not related to the North- South asymmetry
- The model of two peaks give us analytical function, inferred form the statistically and physically correlated characteristics, that permit forecast of the next cycle, we did for the cycle #24
- Equal area means constant energy in the sunspot systems
Thanks for your attention!
References

- Sello, S., ”Wavlet analysis of solar activity”, Topic Note Nr. UGS/12012000 (V1.1).
• Baranovski A., Clette F., Nollau V., Nonlinear solar cycles forecasting: theory and perspectives,
• Kilcik A., Andreson C.N., Rozelot J.P., Ye H., Sugihara G., Osguc A. Nonlinear Prediction of Solar Cycle 24,
• Maris G., Oncica A. 2006, *Sun Geosph.*, 1, 8
• Hiremath K.M., Preiction of solar cycle 24 and beyond, 2008,
Early sunspot observations. This figure, from Scheiner's Rosa Ursina, completed in 1630, shows several sunspots on successive days, as they are carried round by the Sun's rotation. The distinction between the umbra and penumbra of a sunspot had already been recognized. (Courtesy of the RAS.)
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Abstract

• In an early paper we analyzed the asymmetry of the sunspot cycles from the point of view of its non-linearity. There are many attempts to predict the features of the future evolution of the solar activity which are based on different models for fitting the shape of Wolf number evolution. None of them are fully satisfying and the recent delay of the solar cycle #24 is one example. Unfortunately the majority of the predictions are based on the numerical analysis, and just a few attempts to base the forecast on a physical basis. We try to go closer to a solution of the prediction problem, using some physical evidences we found presented in the early article and now we made a critical analysis of our prediction based on the accumulated data that from 2007.
The pattern of the time series of wolf numbers for a log period
\[
\frac{d^2}{dt^2} v(t) - \frac{d}{dt} \left[ \alpha v(t) - \beta v^3(t) \right] + \omega_0^2 v(t) = 0
\]

\[
\frac{1}{2} (\omega_0^2 - \omega^2) V(t) - i \omega \dot{V}(t) + i \omega \frac{1}{2} \left[ \alpha - \beta |V(t)|^2 \right] V(t) = i \frac{\omega^2 V_0}{2}
\]


\[y'' - \mu (1 - y^2) y' + y = 0.\]
Parametric oscillator

\[ \frac{d^2 x}{dt^2} + \beta(t) \frac{dx}{dt} + \omega^2(t) x = 0 \]
Full set of monthly mean Wolf number

Year
The pattern of the time series of wolf numbers for a log period
$\Delta = f-b$

mean: 2.603e+000
sdev: 6.855e-001
var: 4.699e-001
# pts in +/- n devs:
0-1: 17
1-2: 6
2-3: 1
3+: 0