Solar and Stellar Variability: Impact on Earth and Planets
Proceedings IAU Symposium No. 264, 2009
A. G. Kosovichev, A. H. Andrei & J.-P. Rozelot, eds.

doi:10.1017/S1743921309992390

Observed variations of the solar photospheric diameter

S. C. Boscardin[1], E. Reis Neto[1], J. Penna[1], A. R. Rodriguez Papa[1,3], A. H. Andrei[1,2] and V. A. d'Ávila[1,3]

[1]Observatório Nacional/MCT, R. Gal. Jose Cristino 77, Rio de Janeiro, Brazil
email: sergio.boscardin@on.br

[2]Obs. do Valongo/UFRJ-BR, Rio de Janeiro, Brazil
[3]UERJ-BR, Rio de Janeiro, Brazil

Abstract. Here we derive a formulation connecting the observed variations of the solar diameter to the heliophysics of the photosphere, in particular in connection to the granulation pattern and morphology. The results from the measurements are next used to correlate the variations of the semi-diameter and of estimators of the solar activity along the solar cycle 23. The values obtained strongly support a broader physical description of the photosphere, intertwining the diameter variations with the irradiance, the sunspots, the 10.7 cm radio emission, and to a lesser degree with the integrated magnetic field and with the flares count.

Keywords. Sun: fundamental parameters, granulation, flares, activity, radio radiation

1. Searching for long time behavior of solar granulation

We have obtained the images of the full solar disc from the Big Bear Solar Observatory. These images cover the beginning, the peak, and the post-peak of the solar cycle 23. They are densely distributed between 2000 to 2006. The images are all of 1364×1035 pxs. The same telescope, the same camera and the same orientation were used. The exposition time varies from 50 to 80 ms. We have examined two kinds of images: **Fl** images - subtracted from dark and from flat field (1261 images), and **Fr** images - subtracted from limb darkening (1341 images)

To avoid limb darkening influences, we took only the central part of the images. Thus, we considered only the central part from each original image up to 0, 35 of the solar radius. In this way only 2% of intensity variation remains even for **Fl** images. The central portion of the Sun was next divided in 10×10 collateral sectors. Each sector has 30×30 pxs. In each sector the statistics described below have been independently applied, and sectors deviating from the average by 3σ or more were removed from all the final analyses. This strategy seeks to discard the presence of sunspots from the solar granulation description.

Three estimators are here used as first assessment to the granulation state. For each estimator the average of the sectors is calculated (after removing the deviating ones).

(a) standard deviation of counts (**S**) as probe of the grains' mean size.

(b) difference between the uppermost and lowest counts tenths (**Q**) as probe of the grains' brightness.

(c) degree of the better adjusted polynomial along lines and columns (**N**) as probe of the grains' number.

The model then assumes a patch of grains formed by bright centers and dark intergrain contours. Through large number statistics the balance between the two structures along the solar cycle is assessed. After all **Fl** and **Fr** images have been treated, and the three statistics obtained for each one, a final filter was applied removing within each year the images for which all three statistics mean value were afar more than 3σ from the yearly average.

The number of used images is 1104 **Fl** and 1245 **Fr**. The average number of subregions used (that is, not suspected of containing spots or faculae) per image is very similar, being 94.1 (σ 2.6) for **Fl** and 94.6 (σ 2.4) for **Fl**.

The autocorrelation **S**, **Q**, and **N** statistics, for both the **Fl** and **Fr** images, extends up to about two months. The exception is **N**(**Fr**), for which it extends beyond half a year (this feature is better understood when of the analysis of the statistics itself). In agreement to the autocorrelation distributions, the Runs test indicates statistically significant presence of signal for all the statistics.

The time series for the **S** and **Q** statistics, for both types of images, shows anti-phase correlation larger than 0.99 to the solar cycle evolution. The position of the minimum of the time series fitted to the **S** and **Q** statistics always. They are: **S**(**Fr**)**min** = 2003.15; **Q**(**Fr**)**min** = 2003.29; **Q**(**Fr**)**min** = 2002.83; **Q**(**Fl**)**min** = 2002.89

On the other hand, there is no significantly variation for the **N** statistics. That is, according to the **N** statistics, there is no significant variation in the number of grains.

In conclusion, the grains sizes are the largest by the solar maximum, in excellent agreement with the maximum of the measured diameter. The grains brightness, on the contrary, is minimum at the solar maximum, and again an excellent agreement is verified with the maximum of the measured diameter. Accordingly, the granulation variation varies the photosphere density, mixing, and eventually its height scale, therefore providing a mechanism to vary the optical depth, and hence the measured diameter.

2. Correlations between solar diameter and other solar indexes

At the Observatório Nacional/MCT in Rio de Janeiro ($\phi = -22°$ 53' 42", $\lambda = +$ 2h 52m 53s.5, h = 33m) the series of solar semi-diameter measurements started in 1997, in some way provoked by systematic biases found during several preceding years of astrometric observations of the Sun. For the ensuing semi-diameter long term campaign the instrument underwent several modifications. The most important were the installation of a variable angle front prism enabling the continuous observations between the zenith distance of 26° and 56°, the concurrent installation of a moving density filter, and the installation of a CCD camera, which allowed the observations to become fully freed of personal equations. Here we analyze the period from 1998 up to 2003.

The raw data were corrected from effects related to the observation conditions: the air temperature, its first derivative, the Fried factor and the standard deviation of the adjusted parable to the directly observed solar edge. The instrumental conditions were inspected in order to detect effects caused by any instability of the objective prism and from the lacking of leveling of the astrolabe that could cause errors as function of the observed azimuth. The standard deviation of the data fell to $0''.56$, which showed that all corrections applied were small and did not introduce any spurious long-term modulation upon the series. The very small gain on the standard deviation after the corrections shows that seasonal or annual effects on the raw measurements are very small, coherent with the standard refraction theory.

The final series of solar semi-diameter values was correlated against the series of solar activity parameters in the common period. Although the length of all the series is the same, clearly the number of points is different. It is always much larger for the semi-diameter series, even though it presents a less continuous distribution. In addition, one could hardly expect a physically meaningful variation of the solar diameter, at the level of several milli arcsec within the day, and except for truly exceptional events, within the week. So, in order to deal with significant variations and in order to homogenize the number of points for all the series, those were split into equal sampling intervals.

The series are divided the from 6 up to 72 equal sampling intervals. That is, roughly corresponding to aliasing periods from one month to one year. In this way the correlations cover a range from the more detailed to the broader features. The correlation coefficient is calculated independently for each aliasing period. But, in order to not privilege particular intervals, the beginning date of the sampling intervals is displaced in steps of 10 days. Thus for each aliasing period the doubles of points taken to calculate the correlation follow similarly to a running average with step of 10 days.

All the correlation coefficients have larger values when we consider longer periods. This indicate common trends, suggesting a common set of precursors for the variations of the semi-diameter as well as for the solar activity estimators. The declining of the correlation values towards the smaller aliasing periods, i.e. the recognizing of detailed features, is however quite smooth. This endorses the choice of 1 month as the shortest aliasing period, because it is not dominated by random errors. As it is, the smooth decline is suggestive of a complex interplay between the studied pairs of semi diameter and solar activity estimators variations, and a complex derivation from the set of precursors to the estimators' response.

In general, the allowance of a time delay did not increase the correlation of any given pair beyond one tenth. The noteworthy exception relates the pair of the flare index and the semi-diameter. This can be accounted for by the different photospheric and chromospheric regimens. On the other hand, in many instances statistically significant second peaks do show up.

Also the correlations between the pairs of the estimators of the solar activity were calculated. In the overall, the set of correlation coefficients for pairs including the semi-diameter measured variations fares as statistically significant as the pairs including only the independent estimators of the solar activity. All values though are chiefly representative of the most active half of the solar cycle 23. Their extension to other solar cycles and for the calmer parts of the cycles must made with caution. This is also particularly true for satellite borne experiments that span at most a third of one solar cycle. It emphasizes the need for the support deserved to long series of measurements. Nevertheless the time series covered here also spans some years of calm or moderate solar activity.

Finally, the great number of individual observations from 1998 to 2004 allows us to draw the shape of the Sun and its variations along the solar activity cycle. It transpires that the solar shape has complex features, with distinct features on different heliolatitude zones . They change on the time, and even the solar oblateness results changing according to the values averaged along the solar cycle.

References

Boscardin, S. C. 2005, Análise de Observações do Diâmetro no Contexto da Atividade Solar (Analysis of Observations of the Diameter in the context of the Solar Activity), MsC discertation held at Observatório do Valongo/Universidade Federal do Rio de Janeiro.

Boscardin, S. C., Andrei, A. H., Penna, J. L., Reis Neto, E., & d'Ávila,V. 2009, Solar diameter observed variation: the correlation to activity and the results from different stations, in preparation.

Jilinski, E. G., Puliaev, S. P., Penna, J. L., Andrei, A. H., & Laclare, F. 1998, Solar diameter observations with the astrolabe at Observatório Nacional - Rio de Janeiro, Astronomy and Astrophysics Supplement Series, 130, 317.

https://doi.org/10.1017/S1743921309992390 Published online by Cambridge University Press