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Variations of the apparent solar semidiameter observed with the astrolabe of Santiago

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Abstract. Measurements of the Sun semidiameter made with the Danjon astrolabe at Santiago, Chile, and with the magnetograph of the solar telescope of Mount Wilson Observatory during the period 1990-1995, show similar variations in time and with a similar trend as the variation of sunspot number. The consistency of these results obtained at different sites and with rather different observing techniques could be considered as an empirical evidency that a causal connection may exist between the solar activity and the variations of the apparent solar radius as observed at Santiago and Mount Wilson.

Key words: astrometry – Sun: fundamental parameters – methods: observational

1. Introduction

The existence of long term and specially periodic variations of the solar semidiameter has been a rather controversial issue in astronomy. The research of these eventual variations based on classical observing techniques has given inconclusive results (Newkirk 1983, Parkinson et al. 1980). The classical methods for solar semidiameter measurement are based on timing meridian transits of the borders of the Sun, on observations of the limits of totality of solar eclipses and on transits of Mercury. These last two methods are more accurate than the meridian transits; however, since the interval of data is more or less 9 years, they are not useful to disclose eventual variations of the Sun semidiameter connected with the 11 years period of solar activity (Gilliland 1981). The observation of meridian transits gives individual results of relatively low precision. Nevertheless, its accuracy can be improved by accumulating many observations in a short time making them comparable with more precise techniques such as solar eclipses. However, all these methods are strongly affected by several types of systematic errors (Newkirk 1983).

The Danjon astrolabe, an astrometric instrument which has made important contributions to fundamental astronomy (Guinot et al. 1961; Fricke 1972; Noël 1988), can be also adapted to solar astrometry after prior modifications, and gives accurate semidiameter measurements (Laclare 1983). The astrolabe works according to the method of equal altitudes (Débarbat & Guinot 1970) and the Sun semidiameter is obtained by timing the transit of the solar borders through a fix small circle of altitude.

Concerning Sun semidiameter measurements, the astrolabe has some advantages over the meridian circle. For instance, the meridian transits can give only two measurements during a day (horizontal and vertical radius), but the astrolabe gives a number of measurements which is twice the number of observing zenith distances. Furthermore, the astrolabe provides a rather compact and therefore more stable local reference defined by the mercury mirror and by the angle of the prism which can be considered as the main instrumental constant. The meridian circle is a more complicate instrument and its precision depends on three instrumental parameters which are not easily controlled, specially in the quite critical enviromental conditions which are prevalent during Sun observations (Eichhorn 1974). On the other hand and according to Cullen (1926), the effect of irradiance on meridian observations of the Sun is variable since it depends on the Sun zenith distance. For the astrolabe and for one zenith distance, this effect should be constant.

We present in this paper results of Sun semidiameter measurements made with the Danjon astrolabe at Santiago, Chile, during the period 1990 - 1995. The optical system of our astrolabe was modified for a program of solar astrometry which is in progress since 1990. A detailed description of the instrumental modifications and of the reduction method of the solar observations was given by Chollet & Noël (1993).

2. Observations

The Danjon astrolabe of Santiago is located at the National Astronomical Observatory of Cerro Calán in the eastern outskirts of the city. Since the latitude of the Observatory is $-33\overset{\circ}{.}4$, the Sun can be observed during the whole year at 60° zenith distance and from October 6 until March 7 at 30°. The observing zenith distances are defined by CERVIT reflecting prisms that can be

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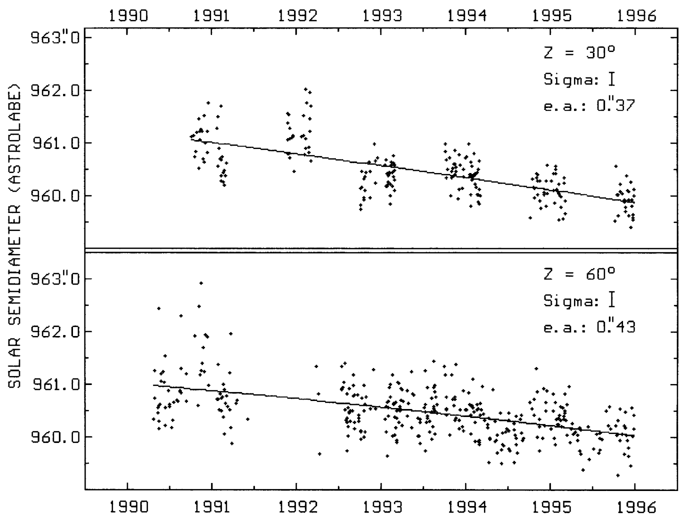

Fig. 1. Sun semidiameters mesured with the astrolabe of Santiago at 30° and 60° zenith distances

interchanged rather easily in a few minutes without further adjustment of the telescope. Therefore, the Sun can be observed at both zenith distances in the east and west transits during the same day.

The observations consist in timing the transit of the upper and lower border of the Sun through the corresponding almucantar. According to the method of observation (Chollet & Noël 1993), the precision of the results depends on the stability of the instrumental zenith distance, on the stability of the reference clock and on the precise knowledge of the variation of the atmospheric refraction during the short interval which takes the observation of the first and second border of the Sun. For the latitude of Santiago and according to the Sun declination, this interval is comprised between 2.5 and 7 minutes. Considering that the instrumental zenith distance is defined by a prism made of a zero-expansion material like CERVIT, and the reference clock is a Cesium atomic standard, we think that spurious or systematic effects on the results produced by instabilities in the prism angle or in the time reference should be negligible.

Another source of accidental and/or systematic effects are the variations of the instrumental zenith distance induced by minute variations of the residual angle of the solar filter faces during the lapse between the transits of both solar borders. These variations may be produced by temperature gradients inside the filter material. However, since the solar filter is made of a transparent type of CERVIT, such effects must be considered also as negligible.

The parameters to compute the atmospheric refraction are measured before, between and after the observation of both borders of the Sun. The value of the refraction for the instant of each transit is obtained by a curvilinear interpolation using Lagrange polynomials (Whitakker & Robinson 1960).

All the observations were made visually by the author and were reduced using the ephemeris of the Sun given by The American Ephemeris. The results presented in this paper are based on the observations made since the beginning of the solar program in May, 1990 until December 1995.

Table 1. Yearly mean values of solar semidiameter and their mean errors, derived from astrolabe observations at 30° and 60° zenith distances

Year	z = 30°		n	z = 60°		n
1990	961″.071 ±	0″.077	18	961″.049 ±	0″.100	44
1991	960.857	0.080	29	960.683	0.091	23
1992	960.722	0.110	33	960.557	0.061	47
1993	960.424	0.035	50	960.527	0.039	96
1994	960.230	0.045	45	960.249	0.044	79
1995	959.976	0.044	46	960.146	0.041	69
Mean	960″.446 ±	0″.034	221	960″.470 ±	0″.027	358

3. Results

Individual results of Sun semidiameter measurements obtained at Santiago and reduced to the geocenter and to the astronomical unit, were published elsewhere and are available in electronic form (Noël 1993, 1994, 1995). These results, for the period 1990-1995 and for 30° and 60° zenith distances, are plotted in Fig. 1. The smoothing curves were obtained by the method of Vondrak (1969) with a smoothing parameter equal to cero. In Fig. 1 'e.a.' is the precision of the smoothing curves, and the bar errors labeled by 'Sigma', represent the average mean square error of each point which is ±0″.26 and ±0″.30 for 30° and 60° respectively.

In Table 1 are given the annual mean values of the solar semidiameter obtained at both zenith distances, with their mean errors and the number (n) of measurements involved. The mean values for the whole period and their mean errors, labeled by 'Mean' in Table 1, show that there are no significative systematic differences in the semidiameter as measured at 30° or 60°. However, they differ significantly with respect to other results obtained during the last decades (Laclare 1996). It is necessary to point out that there are also appreciable differences between the semidiameters obtained with different observing techniques. According to Laclare (1996) these differences reflect the difficulties of measuring the solar diameter. They arise mainly from the definition of the solar border, from systematic effects introduced by the instruments and/or the atmosphere, and by the observers in case of visual observations. The personal bias in the visual observations can be eliminated by automatic techniques, and a standard definition of the solar border could improve the consistency of the results obtained with different observing techniques.

The average of each pair of annual values at both zenith distances listed in Table 1 are plotted in Fig. 2 with the curve of sunspots based on the annual sunspot numbers published by the National Geophysical Data Center at Boulder, Colorado, U.S.A.

Results of solar semidiameter measurements in the spectral line of neutral iron at 525nm with the magnetograph of the solar

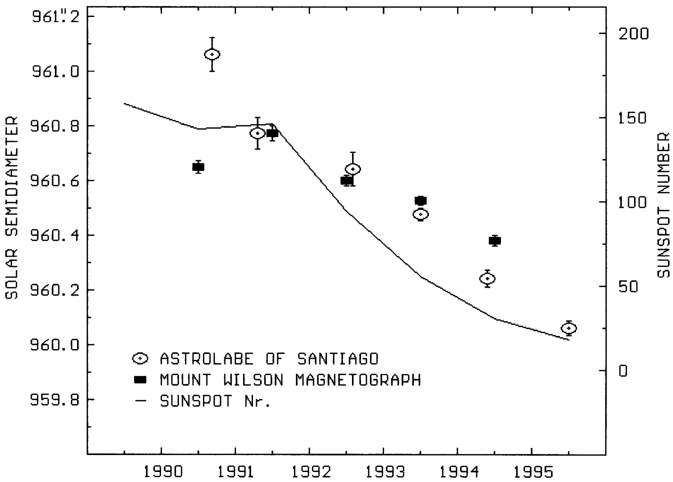

Fig. 2. Yearly mean values of Sun semidiameter as obtained at Santiago and Mount Wilson, and annual values of sunspot numbers

telescope at Mount Wilson Observatory were published by Ulrich and Bertello (1995) for the period 1982-1994. The Mount Wilson results for the common period with the solar observations of the astrolabe at Santiago, i.e. 1990-1994, are plotted in Fig. 2. The points for Mount Wilson were deduced by this author from the figure given in the paper of Ulrich and Bertello (1995). A detailed description of the instrumentation and the measuring technique at Mount Wilson for the Sun semidiameter measurements, has been given by LaBonte and Howard (1981).

It is necessary to point out that the points of Fig. 1 represent all the observations made with the astrolabe during the corresponding period and that no observation has been eliminated to compute the results of Table 1 and Fig. 2.

4. Conclusions

From Figs. 1 and 2 and Table 1, it is quite clear that exists a steady variation in time of the apparent Sun semidiameter observed at 30° and 60°. Practically the same drift is observed in the results obtained at both zenith distances. Since the instrumental system of the astrolabe is defined mainly by the angle of the prism which determine the observing almucantar, the results obtained at different zenith distances can be considered as obtained with different instruments. Therefore, we think that it is rather improbable that the drift observed in the results of the astrolabe can be an artifact of the instrument. On the other hand and considering that the results obtained at Mount Wilson with a rather different observing technique, show a similar variation of the Sun semidiameter, it is also difficult to explain these variations as produced by the observing technique, by personal equation or by local effects. Furthermore, since the trend of these variations according to Fig. 2, is similar as the variation of the sunspots number, one could conclude that there is a high probability that a causal connection may exist between the solar activity and the results of the astrolabe of Santiago and those obtained with the solar magnetograph at Mount Wilson. However, it is fair to say that at the present time we can not discard at all the existency of some yet unknown systematic effect that could be affecting the results of the astrolabe. Only the continuation of the solar program at Santiago will provide the necessary information to obtain a definitive conclusion about the origin of the observed semidiameter variations. In this concern, the improvement of the data acquisition system of the astrolabe in order to make impersonal the results, looks as a rather important point of the solar project at Cerro Calán Observatory. This improvement is in progress through the installation of a CCD camera.

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