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RECENT RESULTS ON THE SOLAR DIAMETER

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Abstract. Using optically identical telescopes at different sites, we have measured the solar diameter with a drift-scan technique. In order to investigate the cause of the observed fluctuations, we not only compare observations made simultaneously by different observers at the same telescope, but also observations made simultaneously at two different sites. Our main results are: (a) The mean error of a single drift time measurement is ± 0.08 s (or ± 1.1″) at Izaña and ± 0.11 s (or ± 1.7″) at Locarno; this closely corresponds to the angular resolution at those two sites under normal seeing conditions. (b) We find no correlation between observations at different sites; a significant correlation exists, however, between observations made simultaneously by different observers at the same site: This indicates that most of the observed fluctuations are due to atmospheric effects ('image motion') rather than personality effects. (c) The mean solar semi-diameter derived from a total of 1122 observations made in 1990 (472 at Izaña, 650 at Locarno) is $R = (960.56 \pm 0.03)''$ (Izaña: 960.51″, Locarno: 960.59″); this may be compared with $R = (960.32 \pm 0.02)''$ which is obtained from a re-analysis of 1773 observations made in 1981 (Izaña: 960.16″, Locarno: 960.38″). Although a small residual increase of the solar diameter during the last ten years seems to be indicated, we conclude that most – if not all – of the observed variations are due to variable seeing conditions, and that there is still no conclusive evidence for a genuine solar variation with amplitudes in excess of about ± 0.3″.

1. Introduction

Recent results about a possible cycle-dependency of global solar properties such as irradiation (viz., the solar 'constant') and *p*-mode eigenfrequencies have aroused new interest in possible variations of the solar diameter (e.g., Laclare, 1987; Ribes, Ribes, and Barthalot, 1987; Ribes *et al.*, 1988; Leister and Benevides-Soares, 1990). For a recent summary see Wittmann and Débarbat (1990a, b). Although some authors have presented conclusive evidence for both a cycle-dependence and a long-term variation of the solar diameter (Gilliland, 1981; Sofia *et al.*, 1983; Bachurin, 1984; Delache, Laclare, and Sadsaoud, 1985), this question is not settled yet, and continued observations are needed. In particular, to filter out or exclude terrestrial effects, there is a need for simultaneous observations at different sites. Unfortunately, only few solar observatories are in a position to undertake such measurements, at least on a regular basis. The transfer of our 45-cm Gregory Coudé Telescope from Locarno to Tenerife and the recently completed construction of a very similar telescope at Locarno gave us the unique opportunity to conduct such observations at widely different locations and with almost identical telescopes (and sometimes even identical observers). Here we present our first observations made with these two telescopes ($D = 45$ cm, $f = 25$ m) in 1990. The drift-scan technique was employed which still is the most accurately calibrated

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method for ground-based angular measurements along circles of constant declination (for a detailed description see Wittmann, 1980a, b; Wittmann, Bonet Navarro, and Wöhl, 1981).

2. Observations

The observations at Locarno (latitude: 46° 10′40.6″ N, longitude: 8°47′22.9″ E, altitude: 506 m) were made with IRSOL's recently commissioned 45-cm Gregory Coudé Telescope which utilizes the optical spare parts of the Gregory Coudé Telescope at Izaña/Tenerife (quartz mirrors, $D = 45.0$ cm, $f = 25.00$ m, Dawes-type circular field stop of 2.8 mm = 230″ diameter in the prime focus). The Locarno telescope is therefore optically almost identical to the Tenerife telescope, and it also has very similar stray-light characteristics. A white-light image of the Sun was projected on a white surface (scale: 0.6230″ mm^{-1}): when the hour drive of the telescope is off, the image of the solar disc (diameter 308 cm) will drift across a small black reference point in the image plane with an angular speed of roughly 15″ s^{-1}. As the telescope is at rest during the observations, only refraction itself – but not *differential* refraction – needs to be taken into account (cf. Wittmann, 1980a, b; Wittmann, Bonet Navarro, and Wöhl, 1981). The limb contact times were measured using (a) the internal CPU timer of an 'Atari' laptop computer (resolution 0.01 s), (b) a quartz digital stopwatch 'Citizen' (resolution 0.001 s), and (c) a quartz digital stopwatch 'Heuer' (resolution 0.01 s). The accuracy of our timers was verified against the official time signals emitted by PTB/Mainflingen and PTT/Neuchatel.

The observations at Izaña (latitude: 28° 17′56.3″, longitude: 16°30′25.3″, altitude: 2409 m) were made with the Gregory Coudé Telescope (Zerodur mirrors, $D = 45.0$ cm, $f = 25.00$ m, Dawes-type circular field stop of 2.8 mm = 230″ in the prime focus; cf. Kneer *et al.*, 1987). A white-light image of the Sun (diameter 225 cm) was projected on a white surface (image scale: 0.8515″ mm^{-1}), and the limb contact times were measured with respect to a small circular reference point in the image plane. At Izaña only the 'Citizen' digital stopwatch was used. The declination of the centre was set using the 'CENTRE' command of the GRECOS operating system (Wittmann and Kroll, 1990) which utilizes the photoelectric Zeiss guider described by Wittmann (1980c). The positional accuracy of each drift-scan – which of course must correspond to the east–west diameter, not to a chord – was verified with respect to sunspots and other surface features. The scan positions at Locarno and Izaña were compared via a telephone link using large-scale drawings made before and after each observational run.

3. Reduction

A detailed discussion of how to reduce drift-scan timing observations has been given elsewhere (Wittmann, 1980a, b; Wittmann, Bonet Navarro, and Wöhl, 1981). To verify our reduction procedure we have not only reduced the present observations but also the observations made by one of us (A.W.) in 1981 at Locarno and Tenerife; the results

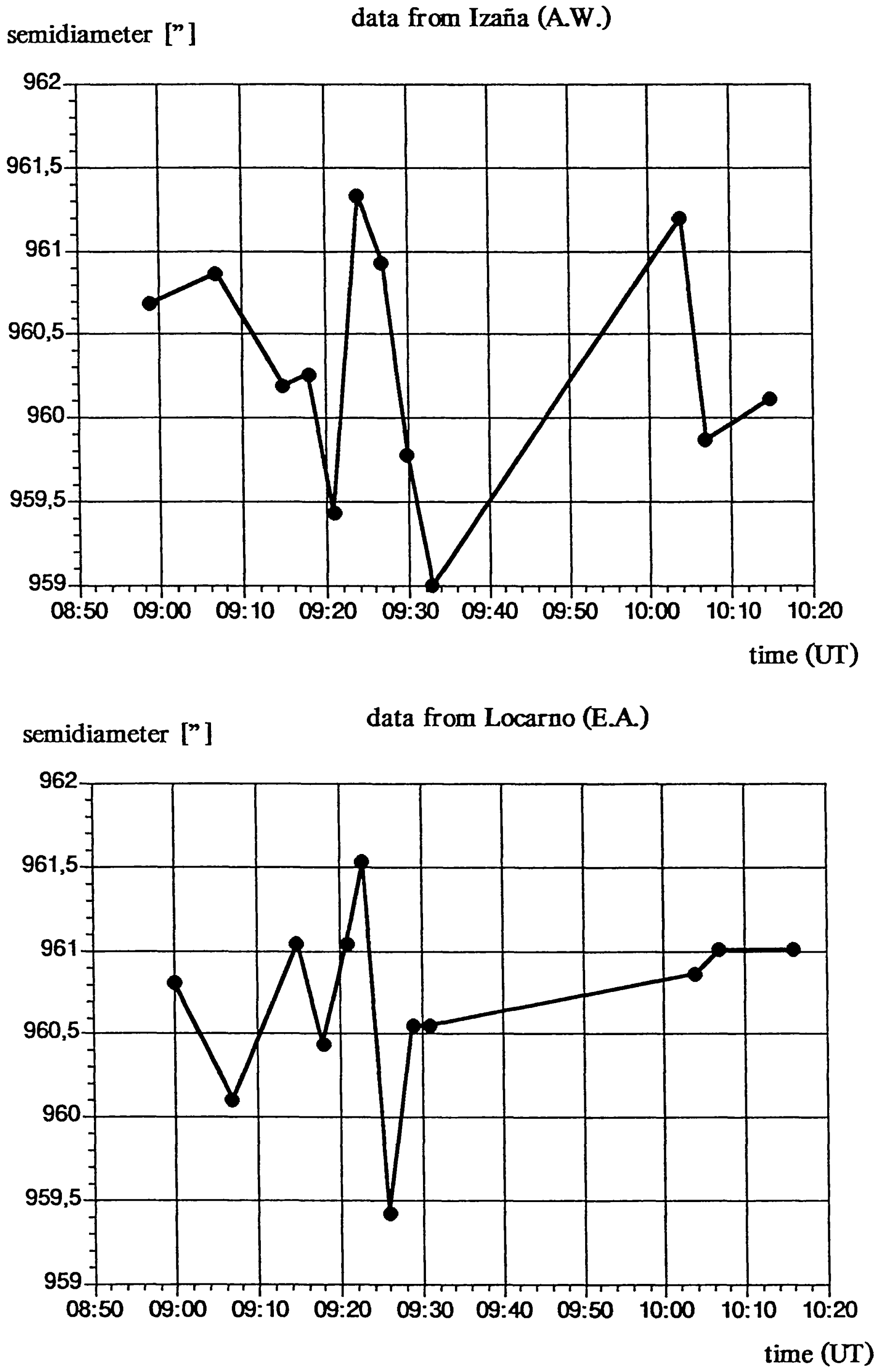

Fig. 1. The solar semi-diameter (reduced to unit distance and expressed in sec of arc) measured simultaneously at two different sites: 12 observations made on 11 September, 1990 between 08 : 59 and 10 : 16 UT are shown for comparison: Izaña is at the top, Locarno at the bottom; the numerical correlation coefficient for the two sets of observations is $r = 0.082$.

do not differ significantly from what has been published previously (Wittmann, Bonet Navarro, and Wöhl, 1981).

The observed drift times T (expressed in mean solar seconds) were reduced according

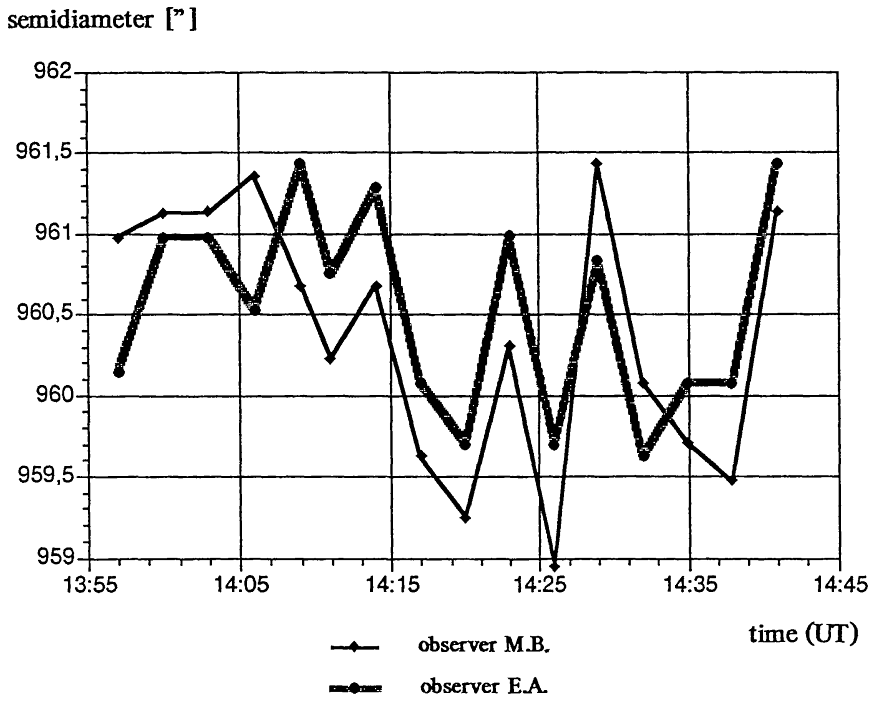

Fig. 2. The solar semi-diameter (reduced to unit distance and expressed in sec of arc) measured simultaneously by two different observers at the same site (Locarno): 16 observations made by E. Alge (grey) and M. Bianda (black) on 14 September, 1990 between 13:57 and 14:41 UT are shown for comparison; the numerical correlation coefficient for the two sets of observations is $r = 0.708$.

to the following formulae:

$$R(r') = 7.52053433(1 - \dot{\alpha}(1 - \dot{\alpha}))T\cos(\delta'), \tag{1}$$

$$R(1) = \arcsin(r' \sin(R(r'))). \tag{2}$$

Here $\dot{\alpha} \approx 0.0027$ is the *geocentric* proper motion in right ascension at the time of observation, δ' is the *topocentric* declination (which includes geocentric parallax and refraction), and r' is the topocentric distance of the Sun (expressed in AU). These quantities were calculated using an ephemeris program developed for the telescope control computer to be installed at Observatorio del Teide in 1992.

4. Results

Seven observational series (comprising 206 measured drift times) could be obtained strictly simultaneously at the two sites (Izaña: A.W., Locarno: E.A.), and three observational series (comprising 96 measured drift times) have been obtained strictly simultaneously at one site (Locarno) by different observers (E.A., M.B.). The computed correlation coefficients confirm the visual impression that there is no significant correlation between different sites, whereas a significant correlation exists between different observers: this is shown in Figures 1 and 2, where examples of both kinds of simultaneous observations are shown.

TABLE I

Drift time observations at Locarno and Izaña: N(total) = 1122, R(total) = (960.558 ± 0.026)″

Date	Site	Obs.	N	T (s)	R (″)
7 July, 1990	Izaña	AW	32	136.444 ± 0.013	960.453 ± 0.094
8 July, 1990	Izaña	AW	32	136.395 ± 0.014	960.873 ± 0.100
9 July, 1990	Izaña	AW	32	136.257 ± 0.011	960.578 ± 0.081
10 July, 1990	Izaña	AW	32	136.184 ± 0.012	961.026 ± 0.087
30 July, 1990	Locarno	AW	3	133.045 ± 0.072	960.429 ± 0.520
2 Aug., 1990	Locarno	AW	16	132.519 ± 0.033	960.585 ± 0.240
5 Aug., 1990	Locarno	EA	16	131.881 ± 0.031	959.703 ± 0.225
7 Aug., 1990	Locarno	EA	40	131.682 ± 0.021	960.649 ± 0.152
8 Aug., 1990	Locarno	EA	63	131.479 ± 0.012	960.421 ± 0.089
9 Aug., 1990	Locarno	AW	16	131.257 ± 0.027	960.123 ± 0.196
9 Aug., 1990	Locarno	EA	32	131.235 ± 0.020	959.995 ± 0.141
10 Aug., 1990	Locarno	EA	80	131.123 ± 0.017	960.244 ± 0.126
6 Sept.,1990	Izaña	AW	16	127.798 ± 0.018	960.168 ± 0.138
7 Sept.,1990	Izaña	AW	48	127.762 ± 0.012	960.313 ± 0.093
7 Sept.,1990	Locarno	EA	32	127.813 ± 0.027	960.753 ± 0.203
8 Sept.,1990	Izaña	AW	48	127.703 ± 0.009	960.279 ± 0.068
8 Sept.,1990	Locarno	EA	32	127.806 ± 0.022	961.053 ± 0.164
9 Sept.,1990	Izaña	AW	48	127.610 ± 0.018	959.945 ± 0.134
9 Sept.,1990	Locarno	EA	32	127.704 ± 0.018	960.658 ± 0.137
10 Sept.,1990	Izaña	AW	48	127.677 ± 0.009	960.789 ± 0.070
10 Sept.,1990	Locarno	EA	32	127.684 ± 0.015	960.853 ± 0.111
11 Sept.,1990	Izaña	AW	37	127.608 ± 0.014	960.605 ± 0.106
11 Sept.,1990	Locarno	EA	32	127.666 ± 0.016	960.982 ± 0.124
12 Sept.,1990	Izaña	AW	99	127.579 ± 0.007	960.589 ± 0.053
12 Sept.,1990	Locarno	EA	32	127.703 ± 0.025	961.505 ± 0.190
12 Sept.,1990	Locarno	MB	16	127.676 ± 0.048	961.311 ± 0.360
14 Sept.,1990	Locarno	EA	32	127.531 ± 0.014	960.592 ± 0.109
14 Sept.,1990	Locarno	MB	48	127.544 ± 0.018	960.692 ± 0.133
16 Sept.,1990	Locarno	EA	16	127.541 ± 0.015	960.848 ± 0.115
7 Oct., 1990	Locarno	EA	16	128.658 ± 0.026	960.041 ± 0.196
7 Oct., 1990	Locarno	TA	16	128.641 ± 0.033	959.915 ± 0.245
11 Oct., 1990	Locarno	EA	48	129.250 ± 0.020	960.701 ± 0.157

Results from all of our observational series are summarized in Table I; they do not show significant variations. The mean value of the semi-diameter (in September 1990) is as follows:

$$R = (960.51 \pm 0.03)'' \quad \text{from 472 observations made at Izaña},$$

$$R = (960.59 \pm 0.04)'' \quad \text{from 650 observations made at Locarno}.$$

This may be compared with $R = (960.32 \pm 0.02)''$, which results from a reanalysis of 1773 observations made (mostly by one of us) in May and June 1981 with the Vacuum Newton Telescope (VNT, $D = 40$ cm, $f = 37.5$ m) at Izaña and the Gregory Coudé Telescope (GCT) at Locarno: although a small residual increase of the solar semi-diameter (of about 0.2″ during the last ten years) seems to be indicated, we think that the evidence for a genuine solar variation with amplitudes in excess of about ± 0.3″ (or ± 0.03%) is still inconclusive.

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