Scorch marks from the sky

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Accepted Version

Re-submitted to *Weather*, 5 July 2010

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Abstract

Daily sunshine duration is commonly reported at weather stations. Beyond the basic duration report, more information is available from scorched cards of Campbell-Stokes sunshine recorders, such as the estimation of direct-beam solar irradiance. Sunshine cards therefore potentially provide information on sky state, as inferred from solar-radiation data. Some sites have been operational since the late 19th century, hence sunshine cards potentially provide underexploited historical data on sky state. Sunshine cards provide an example of an archive source yielding data beyond the measurements originally sought.

Keywords: proxy methods, cloud data, Campbell-Stokes sunshine recorder, solar irradiance

Long duration series of atmospheric variables are useful for providing a basis for comparison with modern measurements. These can be obtained from proxy measurements, or by re-examining existing data sources for additional information.

An example of a meteorological data-source in widespread use that has probably only been partially exploited is the Campbell-Stokes sunshine recorder: invented in the late 19th century to provide a measurement of the duration of bright sunlight by making a burn mark on a treated 'burn card'. Each burn provides a continuous record of the state of the sky during daylight hours, by recording the absence or the presence (and indeed burning power) of the Sun's rays. Beyond just the length of the burn, which was routinely converted to the daily total sunshine duration as the primary quantity sought, the detailed properties of the burn would also have been influenced by the sky through which the solar radiation passed. Therefore the burn marks contain, to some extent, additional embedded information on the state of the sky.

Analogue sunshine recorders are now increasingly being replaced by modern electronic sunshine sensors which measure the sunshine duration in a different way. Because the electronic measurement is solely that of sunshine duration, there is likely to be a temptation to regard the transcription of the sunshine duration from the burn cards as sufficient data with which to form a combined long data series; and as a presumed safe basis on which to destroy the original burn cards. Our purpose here is to emphasize that the original burn cards probably contain additional sky state information—beyond that of just sunshine duration—for which, in common with other original geophysical archive sources, they may be irreplaceable. There are good reasons to seek new information on past cloud properties quantitatively, not least because of the importance of clouds in Earth's radiation balance (Solomon *et al.*, 2007).

The burn card of the Campbell-Stokes sunshine recorder

The Campbell-Stokes sunshine recorder (CSSR) records sunlight without a mechanical tracking system, through use of a spherical glass lens (Figure 1) to focus the Sun's rays from the variety of possible solar positions. The lens focuses the direct beam onto a treated card placed in a metal holder at the base of the recorder (Meteorological Office, 1982; Strangeways, 2003; Stanhill, 2003).

On cloud-free days, as the relative positions of the Sun and Earth change, a continuous burn mark is scorched across the length of the card. There is an onset threshold of solar radiation to initiate the burn, which varies slightly and is affected by the state of the card (such as its moisture content; Painter, 1981) and the quality and physical state of the lens (Curtis, 1898). At the onset of the burn—as the solar beam brightens—the card initially begins to mark, then to scorch more substantially, only burning through the card completely in strong sunlight.

The length of the burn(s) provides an estimate of the daily summed 'bright sunshine' duration, following a standard procedure which allows for intermittent burns (Meteorological Office, 1982). This variable has been the primary measurement, as for example used by seaside resorts in holiday advertisements (e.g. in a 1957 tourism brochure: Fraser, 2009)[1].

Extra information from the burn card

Because the focussing of sunlight by a CSSR scorches a permanent mark on the burn card, information beyond just the primary measurement of sunshine duration—concerning the sky state—is also, in principle, recorded. To retrieve this information, many procedures have had to be devised. For example, empirical relationships have been derived to estimate the direct-beam irradiant energy I (J m^{-2}) from the number of sunshine hours (Wright, 1935; Stanhill, 1998). In one novel approach, the total post-exposure mass of 100 burn-cards from Mexico City was shown to correlate well (correlation coefficient r=+0.93) with direct-beam irradiant energy (Galindo Estrada and Fournier D'Albe, 1960). Information has also been obtained about the composition of the atmosphere that the sunlight passes through: such as the number of sunshine hours 'lost' due to

[1] The record sunniest month is 383.9 hours at Eastbourne (East Sussex) in July 1911 (Met Office, 2007).

London smoke pollution in the mid-twentieth century (Cowley, 1976; Hatch, 1981), and estimating turbidity and aerosol properties (Helmes and Jaenicke, 1984; Horseman *et al.*, 2008).

A different technique has been investigated to obtain temporal variations in the direct beam during the day, which utilises the width of the burn. Strong sunshine (e.g. at the daily maximum) gives a wide burn; the burn width is reduced when the direct-beam intensity is less, such as near dawn and dusk (Figure 2). The arc marked out by the burn mark is smooth on clear days, but can show irregularities, such as on 10th May 2008 (Figure 2). The burn starts to become thin (and sometimes disappears) when a cloud covers the Sun, but when the Sun is exposed again then the burn widens again. This variation of the burn width forms the basis for an estimation of the direct-beam irradiance S_b (W m^{-2}): a procedure originally investigated by Wright (1935). The results originally reported (Figure 3a) show the positive relationship between burn width and S_b.

Since Wright's (1935) work is perhaps not sufficiently-widely appreciated, the effectiveness of the method was evaluated using a modern suite of automatic solar radiation instruments at the University of Reading's Atmospheric Observatory (http://www.met.reading.ac.uk/weatherdata/). Burn widths were obtained at 5-minute intervals by making manual measurements on an enlarged copy of the sunshine card from 11th May 2008, and compared with the 5-minute-average S_b measurements made by the Observatory's pyrheliometer (Kipp and Zonen). Figure 3b again shows a positive relationship between direct-beam S_b and burn width w. A relationship is included based on 12 burn cards from Reading during January–May 2008, at 15-minute resolution (Lally, 2008). Interestingly, the data from Reading showed a similar relationship to that originally found at Kew by Wright (1935), although the burns at Kew were slightly thinner than those at Reading.

The temporal variations in S_b and the measured burn widths match well (Figure 4): the qualitative agreement is clear, and the evidence for the quantitative relationship apparent. Availability of such solar radiation data is potentially useful because surface solar radiation measurements can be used to infer cloud properties (Duchon and Malley, 1999; Harrison *et al.*, 2008), implying in turn the possibility of retrieving cloud information from burn cards. The interpretation of data from partly-cloudy skies thus requires further detailed investigation (Campbell, 1879; Pallé and Butler, 2002; Stanhill, 2003), notwithstanding the fact that some basic statistics can be readily obtained from the daily sunshine totals: such as totally overcast or clear days. Finally, observations of burn cards suggest that clouds that are optically thin lead to a surface scorch mark rather than burning fully through the card, implying the possibility of retrieving limited cloud type and/or thickness information.

Protection issues

The burn cards of the CSSR provide an illustration of the importance of not only conserving the data originally intended, but also conserving the core geophysical material from which currently-unforeseen data may yet be obtained. The extent of this is clearly difficult to estimate in general, but there is no reason not to expect further future serendipity in extracting additional scientific information from existing archive material.

Utilising historical records ever more effectively can arise through improvements in theoretical models providing new proxy methods, such as those used in determining information on the solar position in Monet's "London Series" of paintings (Baker and Thornes, 2006) or deriving the diurnal cycle of 18^{th} century air pollution in London from primitive electrostatics measurements (Harrison, 2009). Even sources previously mined extensively for one variable might still yield new information about other variables. An illustrative case is that of a weather diary used as a source for part of the Central England Temperature data series, which also contained indirect solar activity information in the form of auroral observations (Harrison, 2005). A further example is presented by ships' logs made for navigational purposes, but now providing datasets for climatology (Wheeler & García-Herrera, 2008) and paleomagnetism (Jackson *et al.*, 2000).

For the case of the CSSR, which was adopted operationally from the 1880s, measurements exist at some sites for over a century. During 1992, for example, an estimated 303 global stations outside the UK had CSSRs recording data (Stanhill, 2003). There are therefore potentially tens of thousands of station-years of data on the state of the sky which remain under exploited, and on which future cloud retrieval techniques may depend.

Protection of the core geophysical material in perpetuity, to allow for development of better data retrieval techniques, clearly presents a completely unrestricted commitment. In this respect practicality will necessarily force some compromises, but there is a sense in which the necessary small amount of continued investment—archiving and conservation—is about maximising the initial investment and effort in the staffing and infrastructure required for the original data acquisition. In a rather humble way, sunshine recorder burn cards offer an atmospheric parallel with space missions which have generated science results well beyond those originally planned because the original data have remained available. At the least therefore, the protection (or destruction) of an irreplaceable geophysical archive—such as that of sunshine recorder burn cards—brings an obligation to consider its potential use beyond that for which it was originally intended.

Acknowledgements

Ken Spiers provided the sunshine recorder burn cards. Techniques for the digitization of burn cards have been extensively investigated by John Lally (Lally, 2008), who also provided the burn width measurements.

References

Baker J, Thornes JE. 2006. Solar position within Monet's Houses of Parliament. *Proc. R. Soc. A* **462**: 3775–3788.

Campbell JF. 1879. Twenty-nine Gleams of Sunshine, August 7, 8, 9, in Nine Hours. *Nature* **20:** 403–403.

Cowley JP. 1976. Variations in global solar radiation at Kew. *Meteorol. Mag.* **105**, 329–343.

Curtis RH. 1898. Sunshine recorders and their indications. *Q. J. Roy. Meteorol. Soc.* **24:** 1–30.

Duchon CE, Malley MS. 1999. Estimating cloud type from pyranometer observations. *J. Appl. Meteorol.* **38:** 132–141.

Fraser J. 2009. Sunny Worthing slogan to boost tourism. *Worthing Herald.* 28 May 2009. http://www.worthingherald.co.uk/worthing/VOTE-Sunny-Worthing-slogan-to.5310440.jp, accessed 18 May 2010.

Galindo Estrada IG, Fournier D'Albe EM. 1960. The use of the Campbell-Stokes sunshine recorder as an integrating actinometer. *Q. J. Roy. Meteorol. Soc.* **86:** 270–272.

Harrison RG. 2005. Aurora Diaries. *Astron. Geophys.* **46:** 31–34.

Harrison RG. 2009. Two daily smoke maxima in eighteenth century London air. *Atmos. Environ.* **43:** 1364–1366.

Harrison RG, Chalmers N, Hogan RJ. 2008. Retrospective cloud determinations from surface solar radiation measurements. *Atmos. Res.* **90:** 54–62.

Hatch DJ. 1981. Sunshine at Kew Observatory, 1881–1980. *J. Meteorol.* **6:** 101–113.

Helmes L, Jaenicke R. 1985. Hidden information within series of measurements—four examples from atmospheric science. *J. Atmos. Chem.* **3:** 171–185.

Horseman A, MacKenzie AR, Timmis R. 2008. Using bright sunshine at low-elevation angles to compile an historical record of the effect of aerosol on incoming solar radiation. *Atmos. Environ.* **42:** 7600–7610.

Jackson A, Jonkers AR, Walker MR. 2000. Four centuries of geomagnetic secular variation from historical records. *Phil. Trans. R. Soc. London A* **358:** 957–990.

Lally MJ. 2008. *Solar beam intensity inferred from Campbell Stokes Sunshine Records.* BSc dissertation, University of Reading, UK. 24 pp.

Met Office. 2007. Fact sheet no. 9: weather extremes. National Meteorological Library and Archive. September 2007. 13 pp. http://www.metoffice.gov.uk/corporate/library/factsheets.html, accessed 18 May 2010.

Meteorological Office. 1982. *Observers' Handbook.* HMSO, London.

Painter HE. 1981. The performance of a Campbell–Stokes sunshine recorder compared with a simultaneous record of the normal incidence irradiance. *Meteorol. Mag.* **110:** 102–109.

Pallé E, Butler CJ. 2002. Comparison of sunshine records and synoptic cloud observations: a case study for Ireland. *Phys. Chem. Earth* **27:** 405–414.

Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996 pp.

Stanhill G. 1998. Estimation of direct solar beam irradiance from measurements of the duration of bright sunshine. *Int. J. Clim.* **18:** 347–354.

Stanhill G. 2003. Through a glass brightly: some new light on the Campbell-Stokes sunshine recorder. *Weather* **58:** 3–11.

Strangeways IC. 2003. *Measuring the Natural Environment*, 2nd edn. Cambridge University Press. 548 pp.

Wheeler D, García-Herrera R. 2008. Ships' logbooks in climatological research: reflections and prospects. *Ann. NY Acad. Sci.* **1146:** 1–15.

Wright HL. 1935. Some notes on readings at Kew Observatory of the Gorczynski pyrheliometer, the sunshine recorder and the black bulb thermometer, *Professional Notes* No. **68**, Volume V. Meteorological Office, HMSO. 7 pp.

Figures

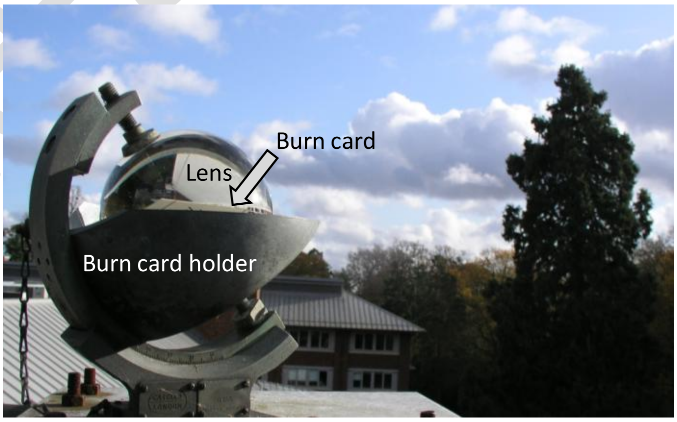

Figure 1. Campbell-Stokes sunshine recorder on the roof of the Meteorology Building at the University of Reading; the lens is about 10 cm in diameter

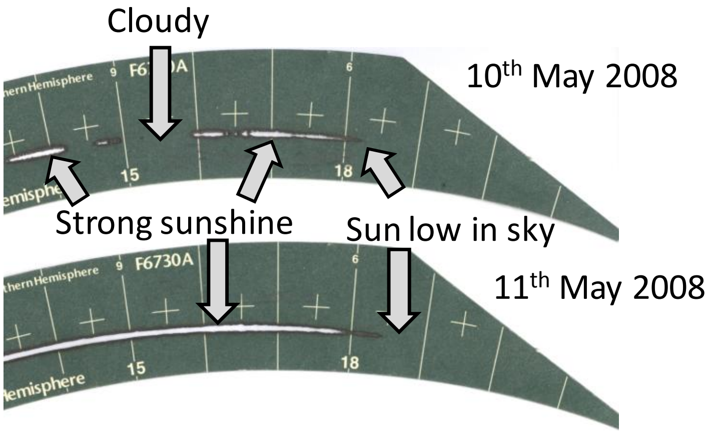

Figure 2. Examples of scorched burn cards with time (hours UTC) marked along the bottom of the cards (Department of Meteorology, University of Reading, UK), from which the sunshine duration is routinely measured and recorded; but burn variability and width is not

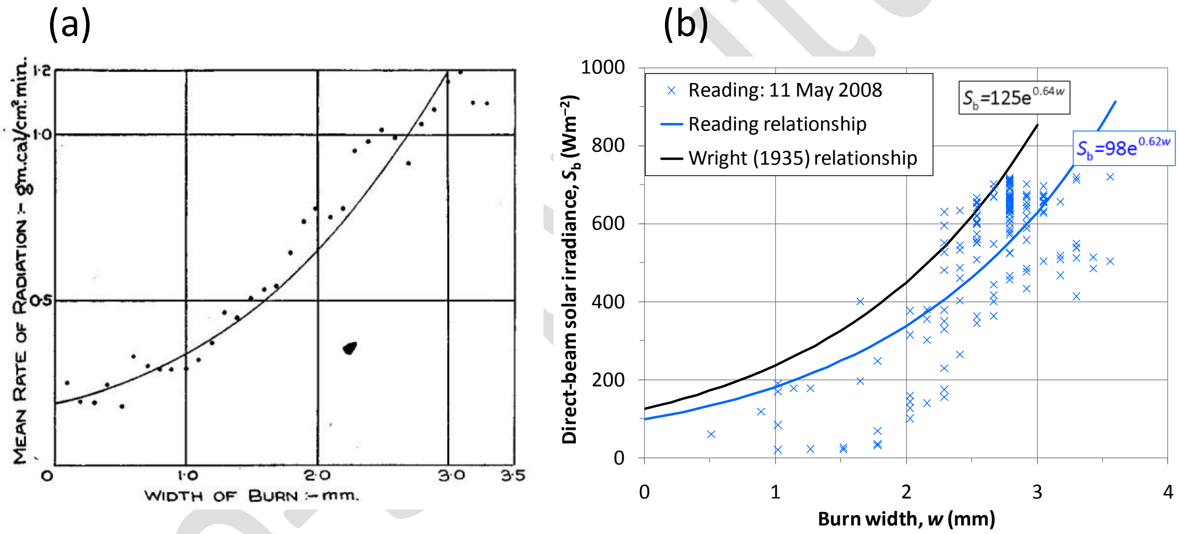

Figure 3. (a) Wright's (1935) results for the relationship between burn width w on the Campbell-Stokes sunshine card and direct-beam solar irradiance S_b at Kew Observatory (unknown number of days' data used during July–November 1927); (b) 5-minute values obtained at the University of Reading's Atmospheric Observatory on 11th May 2008 (with Reading relationship (Lally, 2008) plotted, see text)

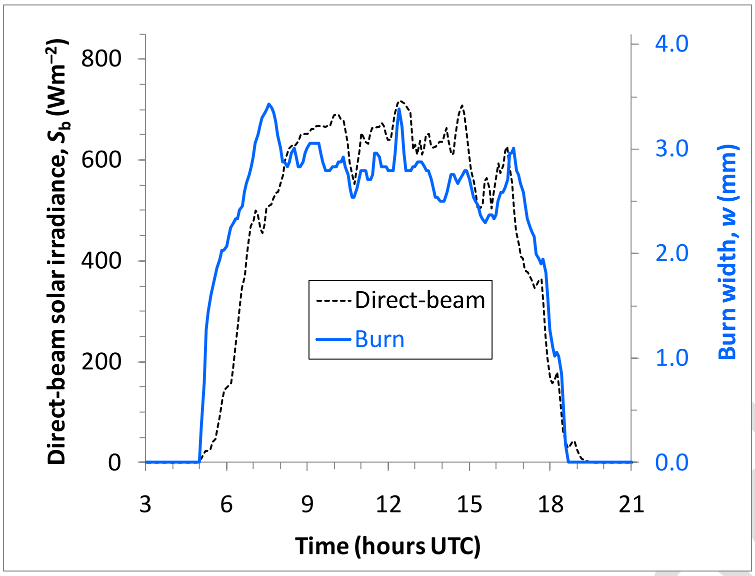

Figure 4. Evolution of 15-minute direct-beam solar irradiance and burn width on 11th May 2008 (Department of Meteorology, University of Reading, UK)