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Properties of sunspot umbrae of leading and trailing polarity in 1917–2013

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Abstract

Using the software developed by us, we produced a digitized (tabulated) database of sunspot umbrae and pores observed at Mount Wilson Observatory (MWO) in 1917–2013. The database includes the heliographic coordinates, areas and the polarity and strength of magnetic fields of umbrae and pores in the MWO sunspot drawings. Using this database we study here the properties and long-term variation of sunspot umbrae and pores, separately for leading and trailing polarity spots. We find that the leading sunspots have tendency for larger umbrae and stronger magnetic field strength than the trailing spots. The average field strength and area of sunspot umbrae vary with sunspot cycle. Furthermore, the mean magnetic field strength in sunspot umbrae exhibits a gradual increase from early 1960s to 1990s. The nature of this increase is discussed.

Keywords: Solar cycle; Sunspot; Magnetic field

1. Introduction

The magnetic field is the main characteristic of sunspots, and as the magnetic field changes in time, the intrinsic properties of sunspots may also change. Synoptic measurements of sunspot magnetic fields using the Zeeman effect began in the early 20th century, and have continued until the present time. Studying the long-term variation of the magnetic fields of sunspots can provide unique information about the nature of the solar dynamo and the solar cycle. The longest series of observations of sunspot magnetic fields exists at Mount Wilson Observatory (MWO) from 1917 until the present. (Due to funding shortage, the daily sunspot measurements were stopped on 16 September 2004, but restarted on January 25, 2007). These are the very same observations based on which the fundamental laws of the solar magnetic cycle were originally established. For example, these observations were used to demonstrate that sunspots are regions of strong magnetic fields, that they often appear in the form of a bipolar magnetic field structure (Hale, 1908), and that the magnetic polarity of these bipoles changes for every 11-year sunspot cycle (Hale et al., 1919). It is now known that the magnetic fields have both cyclical and long-term variations. Several recent studies of sunspot field strengths speculate on a possible decline in their average field strength over the declining phase of cycle 23 (e.g., Livingston et al., 2012, and references therein), while some other question the origin of such a decline (e.g., Pevtsov et al., 2011, 2014). The long-term measurements such as those made at MWO allow to glean into a history of long-term changes in sunspot properties

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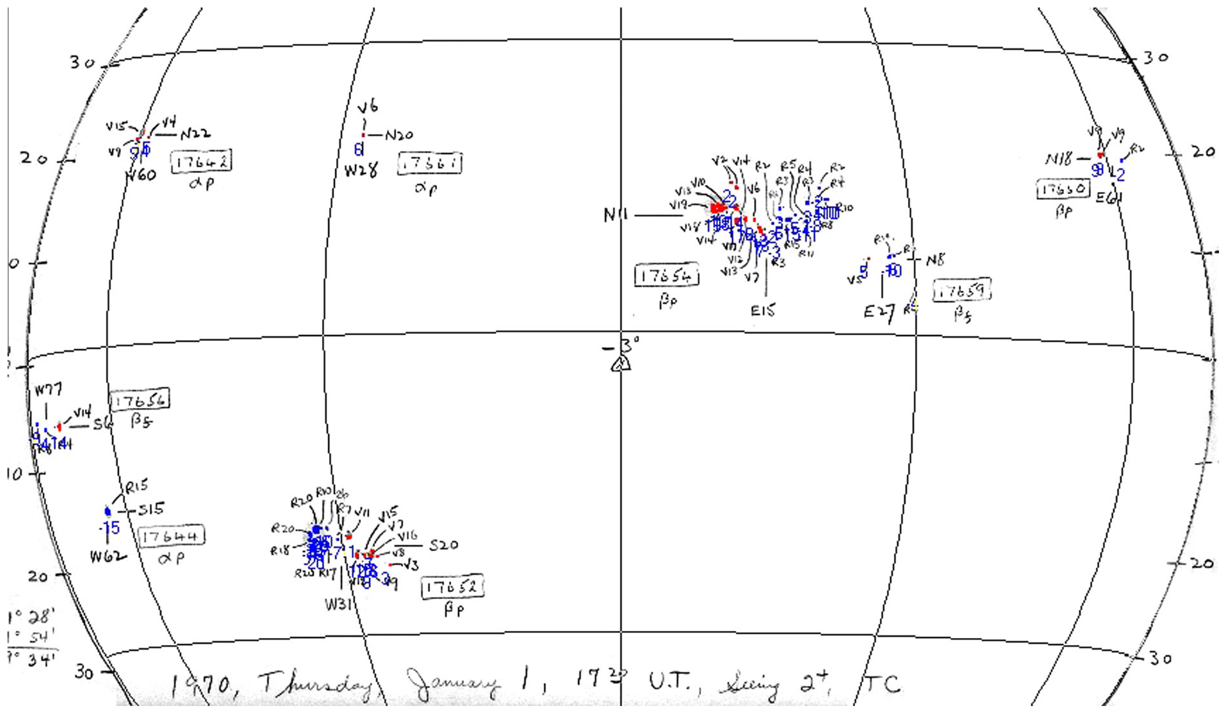

Fig. 1. A sample daily drawing of sunspots measured at MWO on January 1, 1970. On the drawing West is at the left. Sunspot umbrae are semi-automatically selected and colored according to their polarity (blue for positive and red for negative). Sunspot group numbers and coordinates, as well as the magnetic fields of umbrae are denoted in the drawing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and to investigate how unique (or typical) the current solar activity is.

Pevtsov et al. (2011) studied the magnetic field strengths taken in Fe I 630.15-630.25 nm line in 1957–2010 at seven stations of the solar observatory network covering eleven time zones in the former USSR. In order to mitigate the differences in atmospheric seeing and in the level of observer experience, they included only the strongest magnetic field observations for each day. Sunspot field strengths were found to vary strongly with the solar cycle, while no definite long-term decline was noted over this time.

Pevtsov et al. (2014) digitized and studied the MWO summary tables published in the Publications of the Astronomical Society of the Pacific (PASP). These data were also made publicly available to the research community at http://www.nso.edu/node/310 for period of 1920–1958. However, these summary tables only give information on the maximum field strength measured in each active region, their mean latitude, and the date of the central meridian crossing. More detailed data are available in MWO hand-drawings only. A sample of such a map (a hand-drawing) is presented in Fig. 1. Software to digitize these MWO drawings has recently been developed (see Tlatova et al., 2013, for a discussion), and is applied to the existing digital images of drawings. This effort produced a database of solar features including the magnetic fields, areas and positions of the nuclei (umbrae of sunspots and pores) as observed at MWO in 1917–2013. In this paper, we analyze this database.

2. Data and processing method

The daily observations at Mount Wilson Observatory are carried out at the 150-foot (45.7 m) Solar Tower (http://obs.astro.ucla.edu/150_tele.html). Solar images are constructed using a coelostat and a lens, and have a diameter of about 42 cm. When taking a measurement, the observer marks the boundary of the solar disk, and draws the position and configuration of sunspots. Magnetic field measurements are then carried out by measuring the splitting of the Zeeman components. The intensity of the magnetic field at the center of the sunspot was measured visually using the iron line λ 617.3 nm in 1917–1961, and thereafter using the λ 525.0 nm line. The spot whose field is to be measured is placed at the spectrograph entrance slit, and the observer judges its polarity and magnetic field strength using micrometer with the tipping plate placed at the focal plane of the 75-foot (22.9 m) spectrograph. With this setup, sunspot polarities and field strengths can be obtained at the accuracy of a few hundred Gauss. The measured value of the magnetic field is then denoted on the drawing of the respective sunspot umbra. As a rule, all spots, umbrae and pores visible on the Sun during the day are drawn. However, in some days the field strengths were measured in only few (not all) sunspots (see, Pevtsov et al., 2014, for selected examples). Sketches of umbrae, penumbra and other magnetic structures used pencils of varying hardness that distinguished these structures by brightness. The archive of these drawings begins