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Solar activity according to the data of 100-year series of observations

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Digitization of solar activity data over a period of more than 100 years has been performed. The database presents the characteristics of sunspots, sunspot umbras, filaments, plages in $KCaII$ line and prominences. The series of boundary of shapes and photometric properties of the selected objects are created.

The characteristics of individual types of solar activity were determined. An interactive atlas of solar activity has been created, on which daily maps of solar activity, characteristics of individual elements and summary indices of solar activity are presented. The indices of solar activity were reconstructed and the analysis was carried out.

Keywords: Sun, solar activity, long-term variations: general

1 Introduction

We performed the digitization of long-term archives of solar activity observations. The database includes the digitization of photographic archives of daily solar synoptic observations, including: magnetic fields of sunspots on the sketches of Mount Wilson Observatory (MWO) from 1917–2016; sunspots on photographic plates of Greenwich Observatory (RGO) of 1919–1972 and Kislovodsk Observatory of 1954–2016; plages in the spectral line $KCaII$ in the period 1905–2016 according to Kodaikanal, MWO, Sacramento Peak (SP) and Kislovodsk observatories; solar filaments observed in the H_α line, for the period 1915–2016 according to Kodaikanal, Meudon, Sacramento Peak, Kanzelhoe and Kislovodsk observatories; prominences, according to observations in the lines of H_α and $KCaII$, for the period 1910–2017, according to the data of Kodaikanal and Kislovodsk observatories, and sketches of the international observational network of spectrohelioscopes.

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2 Digitization of the long-term white-light archive of RGO Observatory

The RGO archive of solar photographic observations for the interval 1918–1976 contains about 26000 plates obtained during the period of time from 1918 to 1972. The archive was digitized by the Mullard Space Science Laboratory, University College London and converted into a series of FITS-format images with the resolution that corresponds to the sun's image radius having approximately 1600 16-bit pixel.

Special numerical algorithms have been developed for processing these images at Kislovodsk Mountain Astronomical Station of Pulkovo Observatory (Tlatov et al., 2014). Our software also includes the manual screening tool for approving or rejecting the automatically localised sunspots. It is needed for removing photographic artefacts and marks.

The preliminary processing stage of each photographic plate includes the identification of the edge of the solar disc and the overlaying of the heliographic coordinate grid that would correspond to the observation date and time. The second part of image processing consists of building a sequence of calibrated images. For our calibration we assumed that the center-to-limb variation of the quiet Sun corresponds to a standard curve. The intensity local level of the quiet Sun is used for the elimination of non-uniformities across the solar disk, for image calibration and for searching elements of solar activity (active elements). For this purpose, we segmented the solar disc and searched for the maxima of the distribution pixel numbers for different intensities. This distribution corresponds to the level of quiet sun $IQS(\theta, \varphi)$. The calculated areas of these sunspots were compared with the results of manual measurements of the same regions (GRP). The correlation between the automatic

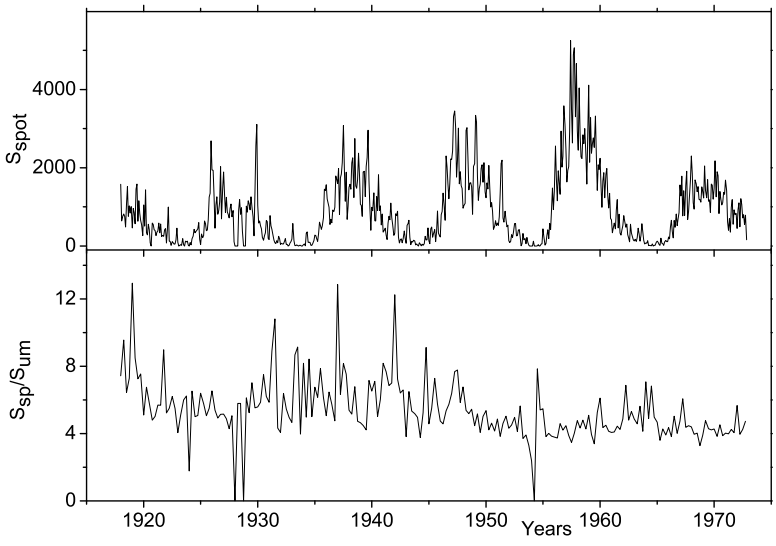


Figure 1 (Upper panel) The new measurements of sunspot areas according to RGO plates in millionths of the solar hemisphere (mhs). (Lower panel) The ratio of the sunspot area to the sunspot umbra area, averaged over a period of 3 months.

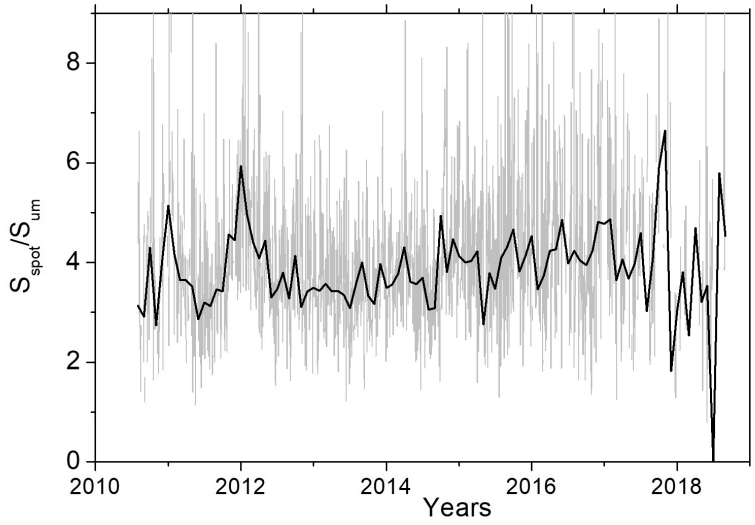


Figure 2 The ratio of the sunspot area to the sunspot umbra according to the synoptic observations in Kislovodsk in the 24-th cycle of activity.

and manual results is quite high ($R \sim 0.97$). The regression equation can be written as $S_{GPR} = 46.7(\pm 15) + 1.05(\pm 0,01)S_{NEW}$.

A new treatment of sunspots allows us to measure the properties of individual sunspots including the measurement of the sunspot umbra area. In Fig. 1, the monthly values of the area of the selected sunspots and the ratio of the sunspot area to the sunspot umbra area are presented for the period 1918–1972. Observations of RGO ended in 1976. These data can be continued with data from the synoptic observations of the Kislovodsk Mountain Astronomical Station. Figure 2 shows the daily and monthly averages of the ratio of the sunspot area to the sunspot umbra area.

3 Database of sunspot umbrae and pores observed at Mount Wilson Observatory from 1917–2016

The longest series of observations of sunspot magnetic fields exists at Mount Wilson Observatory from 1917 until the present. The digitization of the MWO scanned drawings is done in the following steps. In the first step the code identifies and fits the solar limbs to the image. This establishes the transformation between the image and the heliographic coordinates. Next, the operator manually selects the location of individual umbrae and pores to be digitized. The program automatically detects their outer boundaries following the procedure described in Tlatova et al. (2018). Then, the operator manually enters the intensity and polarity of the magnetic field of the respective structure. At each step, the operator verifies the validity of the automatic selection and can make adjustments to the automatic action when necessary.

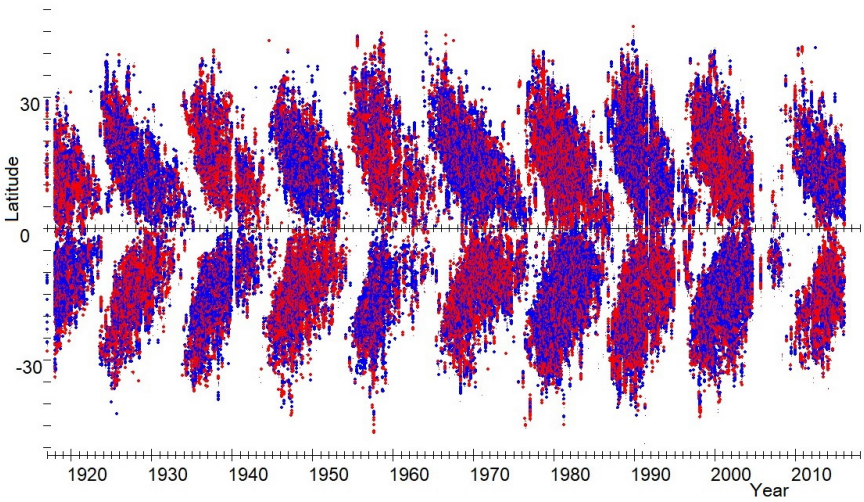


Figure 3 The latitude–time diagram of the measured umbrae and pores with magnetic field polarity indicated in color (red for positive and blue for negative polarity).

Figure 3 depicts the butterfly diagram (latitude–time plot) of the measured umbrae and pores. Each umbra and pore are marked at its position, and colored with its magnetic polarity, using blue for positive and red for negative polarity. Note that each wing of the butterfly is dominated by the color of the leading polarity umbrae due to the larger number of leading polarity umbrae (see later). For example, the northern wing of solar cycle 22 is dominated by red color, which corresponds to a negative polarity field. Note also that, despite the considerably smaller number of measured umbrae from 1917 until 1950, their latitudinal range is not significantly smaller than during the later time intervals with more complete daily coverage. Thus, despite a coarser daily coverage for example in 1930–1940, our data set is still representative of the whole sunspot family.

4 Centenary activity of the Sun from observations in the $KCaII$ line

Arguably, $KCaII$ line observations are the most readily available data from ground-based observatories to characterize long-term solar activity in ultraviolet radiation. Furthermore, in the absence of direct measurements, the $KCaII$ index can serve as a good proxy for solar magnetic flux.

We analyze the synoptic data taken in the KCaII spectral line with spectroheliographs at Kodaikanal Observatory from 1907 to 1999, at Mount Wilson Observatory from 1915 to 1985, and at Sacramento Peak National Solar Observatory from 1963 to 2002 (Tlatov et al., 2009). Photographic data were digitized and calibrated following the same set of procedures developed by Tlatov et al. (2009). Using calibrated data, we have outlined bright plages and have calculated a plage index defined as the fraction of solar hemisphere occupied by the chromospheric plages and enhanced network.

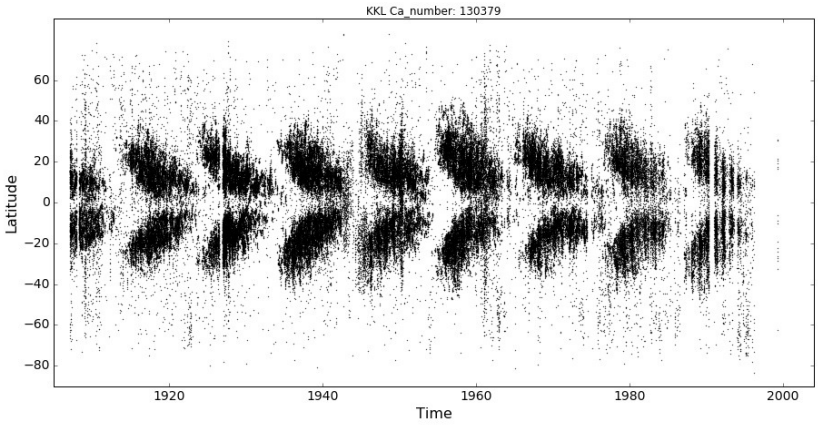


Figure 4 Butterfly diagram plages with ares $S > 1000$ mhm according to $KCaII$ spectroheliograms from the Kodaikanal Solar Observatory.

Figure 4 shows the latitude-time diagram of the distribution of plages according to the analysis of observations made at Kodaikanal Observatory.

5 Reconstruction of a hundred years series of solar filaments from daily observational data

The preliminary results of solar filaments distinguished in daily H_α observations at Kodaikanal (1912–2002) are presented. To mark the boundaries of solar filaments, methods based on automated procedures of marking low-contrast objects on the solar disk, as well as editing of the marked boundaries in a semiautomated manner, were developed.

The new data set of characteristics of solar filaments makes it possible to perform a thorough analysis of solar activity at different latitudes of the solar atmosphere. Figure 5 shows the latitude–time plot of filaments center locations in the Kodaikanal observatory data. Annual variation in the filament number, which is apparently associated with weather conditions and quality of the original photographic plates, may also be noted. The plot also features an equatorward migration, which is associated with the distribution of sunspot activity, and a poleward drift associated with the polarity reversal of the large-scale magnetic field during the activity cycle. In contrast to the data from Tlatov et al. (2016), where the sketches were processed on the Meudon Observatory synoptic maps, here we present the results of the analysis of daily observations.

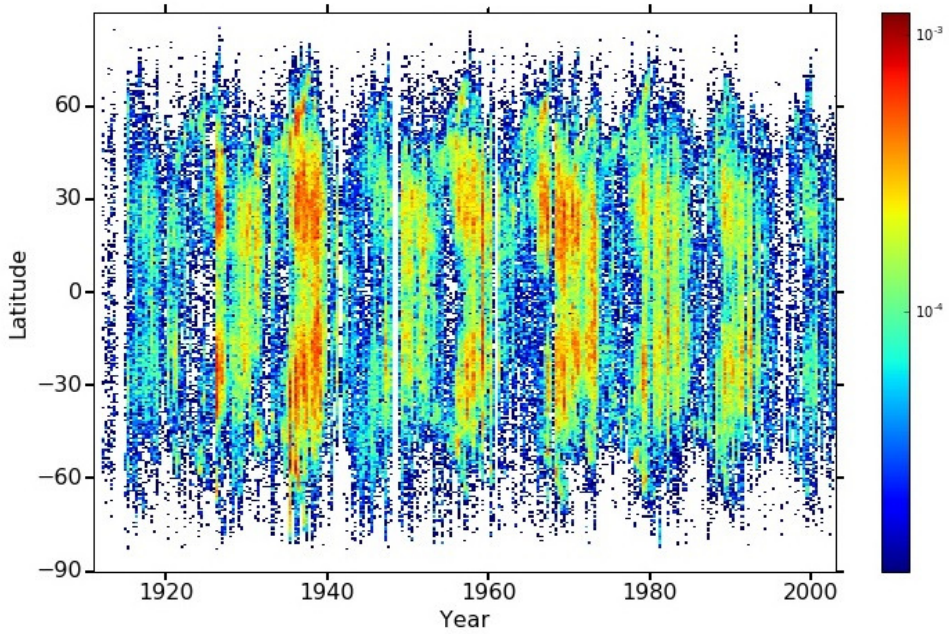


Figure 5 Latitude–time plot of the distribution density of numbers filament center locations for 1912–2002 in Kodaikanal observatory data.

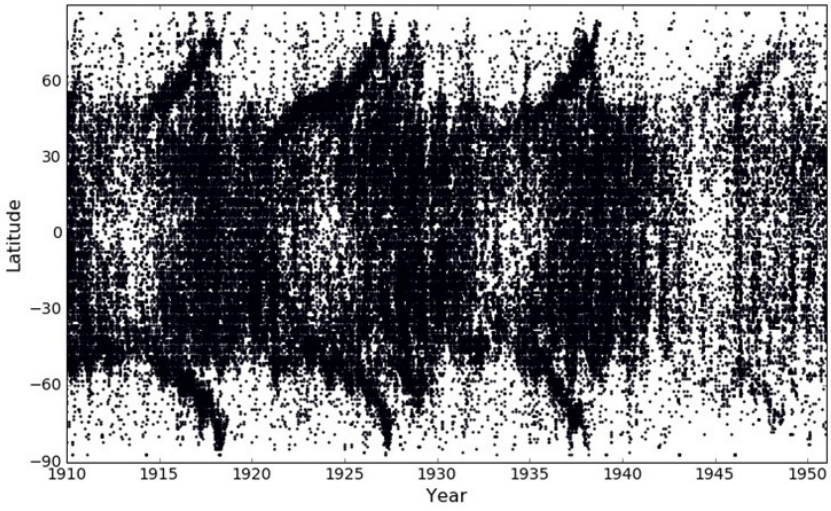


Figure 6 The latitude-time data of the position of prominences from the digitization of observations of Kodaikanal observatory in the CaIIK line.

6 Digitization of long-term series of observations of prominences

Regular observations of the solar chromosphere in the $KCaII$ line at Kodaikanal Observatory provide the possibility of allocating prominences on photographic plates. According to observations in the $KCaII$ line of Kodaikanal observatory for the period 1904–1954 we performed digitization of images (Fig. 6). In total, more than 90 thousand prominences were allocated. These data were supplemented by data on the digitization of prominences on Wolfer atlases (Wolfer, 1897) for the period 1887–1900 and observations of Kislovodsk Observatory in the period 1957–2017 (Fig. 7).

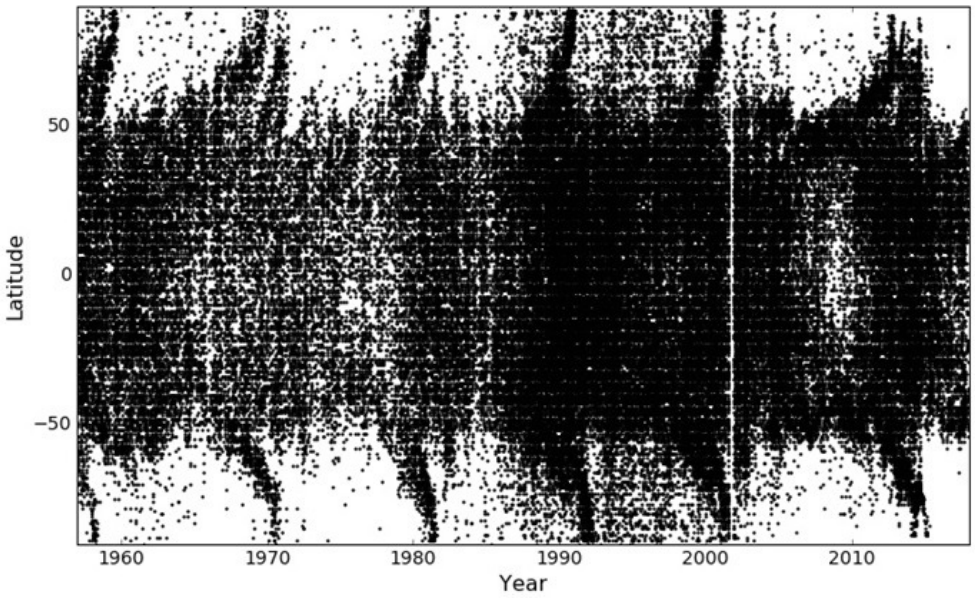


Figure 7 The latitude–time data of the position of prominences from the digitization of observations at Kislovodsk Observatory in the H_α line.

Conclusions

Several research groups are presently working on a reconstruction of the long-term indexes of solar activity based on the processing of long-term archive data. 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.

Currently, these activity data are partially loaded onto the interactive atlas of solar activity (www.observethesun.com).

Acknowledgements

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