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Solar Activity and Irradiance Studies with Ca II Spectroheliograms: Potential and Problems

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Abstract. Various observatories around the globe carried out synoptic full-disk observations of the Sun since the beginning of the 20th century. The archives created by these observations, especially those including Ca II spectroheliograms, have the potential of providing far more detailed information on solar activity than the indices usually used to study activity variations, solar cycle and irradiance changes. However, these data suffer significantly from various problems including numerous defects in the photographic plates, missing or inaccurate calibration of the blackening curve, changes in the positioning of the exit slit with respect to the spectral line and variable seeing. Here we discuss the quality of images obtained by the digitization of three historic Ca II K time series, specifically those stored by the Arcetri, Kodaikanal and Mt Wilson Observatories. The aim of this work is to evaluate the potential value of these data for studies of solar activity and variability. It also shows the importance of the detailed and accurate image processing technique, in order to obtain uniform and trustable results from images coming from different historic archives.

1. Introduction

The most widely used indicators of solar activity are the number and the area of sunspots observed on the solar surface. This is because they make the longest continuous series of measured activity indicators. However, these numbers alone do not fully characterize the solar variability. In fact, solar activity is driven by the temporally and spatially varying distribution of the magnetic flux in the solar atmosphere. It covers phenomena occurring at all atmosphere levels and at all the time-scales.

High resolution observations show that magnetic features are composed of clusters of flux-tube elements. The density of these elements determines the apparent magnetic field strength measured with magnetographs, as well as the brightness of the magnetic features when observed in the strong resonance Ca II K line. Full-disk synoptic observations in this line were regularly performed at several observatories since the beginning of the last century. The archives of these observations have thus the potential of storing detailed information on solar magnetism, with moderate spatial and temporal resolution.

The analysis of these observations should permit insight to be gained into many topics of solar activity and should prove useful for variability studies. For

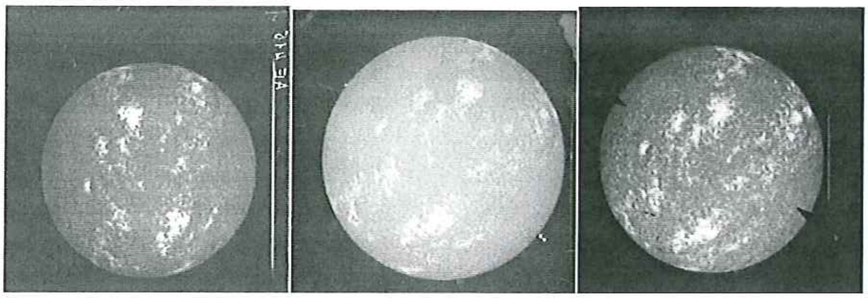

Figure 1. Examples of the Arcetri (left), Kodaikanal (middle) and Mt Wilson (right) analyzed images (January 9, 1958.)

instance, the cyclic evolution of the magnetic field in quiet Sun regions, studied by Harvey (1994) using full-disk magnetograms, would deserve further investigations on longer time-scales (Lockwood et al. 1999). Since such magnetograms are only available for the last three cycles, these investigations can only be addressed with the historic Ca II K observations. Another important application of these data concerns long term irradiance changes. In fact, the success of the recent models (Krivova et al. 2003; Penza et al. 2003; Wenzler et al. 2005) in reproducing the directly measured irradiance variations suggests that also past irradiance changes can be evaluated with significant precision, given accurate distributions of the solar surface magnetic features which may be gathered from these historic observations.

In the last few years the increasing interest in such early observations and the availability of new hardware resources led to the initiation of projects to digitize existing solar photographic archives. For instance, Arcetri, Kodaikanal and Mt Wilson archives have been already fully digitized (Ulrich et al. 2004; Makarov et al. 2004; Marchei et al. 2006). Similar projects are now ongoing at several observatories, for example in Coimbra.

Here we present examples of the three digitized Ca II K archives and describe the main problems affecting these data. This work was carried out in order to evaluate the potential value of these data for solar activity and irradiance studies. It also shows the importance of the accurate image processing technique, in order to obtain uniform and trustable results from images coming from different historic archives.

2. Data

We analyzed images obtained by the digitization of the photographic Ca II K spectroheliograms stored in the archives of the Arcetri, Kodaikanal and Mt Wilson Observatories. The plates stored in these archives have different dimensions and content. They also were digitized using different devices and criteria. Figure 1 shows examples of these data, taken at the three sites on January 9, 1958, although the observing time differs by more than 16 hours due to the site locations. Note that the intensity pattern of both Arcetri and Kodaikanal digitized data was reversed, in order to show the brightness pattern usually observed in the intensity images of the solar disk.

The first set of the spectroheliograms analyzed here was recorded at the G.B. Donati tower of the INAF Arcetri Astrophysical Observatory in Florence from 1931 to 1974. The spectroheliograph used for these observations (Godoli & Righini 1950; Gasperini et al. 2004) had a grating of 600 lines/mm and a ruled area of 100 mm × 110 mm, with a dispersion of 0.33 mm/Å at 3934 Å. The size of the solar disk on most of the plates is ≈ 6.5 cm; the image scale is thus about 0.033 mm/arcsec. The spectral window for these observations was 0.3 Å, centered in the line core. It is worth noting that several instrumental changes occurred during the about fifty years that the spectroheliograph was utilized. These include the use of additional lens and changes of the slits positions, which improved the image definition and monocromaticity, as well as decreased the stray light level. The problem of discontinuities marked by instrumental changes is common among most, if not all, the existing long time series of synoptic observations. The digitization of the Arcetri archive was performed by the CVS project at the Rome Astronomical Observatory (Centrone et al. 2005; Giorgi et al. 2005; Marchei et al. 2006). The work was carried out through a commercial scanner, used with the setting 1200 × 1200 dpi and 16 bit greyscale significant data. From these data, which are saved in the TIF format, 2040 × 2720 pixels 16 bit FITS images for each solar observation were singled out. Information about the plate acquisition noted in the observation logbooks were included in the file headers. The size of the solar disk in these images is about 1550 pixels; the pixel scale due to the digitization is thus 1.2 arcsec/pixel. The digital archive of Ca II K Arcetri observations contains 5976 spectroheliograms obtained on 5042 observing days. The instrumentation used to acquire these observations is no longer available.

The second set of spectroheliograms used here is that recorded at the Kodaikanal Observatory of the Indian Institute of Astrophysics in Bangalore from 1907 to 1999. In brief, the spectrograph used (Evershed 1911; Bappu 1967) is a two prism instrument, with a dispersion of 0.14 mm/Å near 3930 Å. The 70 μm exit slit of the instrument corresponds to a 0.5 Å bandpass, which includes K_{232}. The size of the solar disk on most of the plates is ≈ 6 cm; the image scale is thus about 0.031 mm/arcsec. The full set of Ca II K observations was digitized using a linear array of 900 pixels Makarov et al. (2004). The original observations were stored as ≈ 1.8k × 1.8k, 8 bit greyscale JPEG images. The solar disk in the digitized images has a radius of about 710 pixels; the pixel scale due to the digitization is thus 1.3 arcsec/pixel. The digital archive of Ca II Kodaikanal observations contains 26640 spectroheliograms obtained on 26620 observing days. The instrument used to acquire these observations is still available.

The third set of spectroheliograms studied is that taken at the Mt Wilson Observatory from 1915 to 1985. The spectroheliograph used at the beginning of these observations (Hale 1915) had a grating with 567 lines/mm and a ruled area of 74 × 92 mm. The 80 μm exit slit admits the passage of a band of about 0.2 Å centered on the Ca II K line core at 3933 Å. The size of the solar disk on most of the plates is ≈ 5 cm; the image scale is thus about 0.026 mm/arcsec. The Mt Wilson observations were digitized in the framework of a project (Ulrich et al. 2004; Lefebvre et al. 2005) carried out at UCLA Division of Astronomy, by using a commercial scanner providing images with the setting 1200 × 1200 dpi and 16 bit greyscale significant data. From these data, 2601 × 2601 16 bit TIF images were singled out, in which intensity values are stored as positive integers. The solar disk in these images has a radius of about 1000 pixels, the pixel scale due to the digitization is thus about 1 arcsec/pixel. At present, some information about plate dimensions and content are available on the project webpage. The Mt Wilson Ca II K digital archive contains about 40000 images recorded on over 22000 observing days. The images we analyze are the reduced-size (800 ×800 pixels) science quality FITS files posted for distribution on the project webpage. The solar disk in these images has a radius of about 350 pixels, the pixel scale in these images is thus reduced to 2.7 arcsec/pixel. The file headers contain information about the acquisition of the original plate and its digitization, as well as measurements of the disk horizontal and vertical radii and an evaluation of the plate quality.

Although the Arcetri archive contains a rather small number of plates with respect to the other ones, more than 65% of the plates in the archive contain exposure wedges for the calibration of the non-linear response of the photographic emulsion. By contrast, most of both Mt. Wilson and Kodaikanal plates (75 and 55 %, respectively), do not include wedge calibrations.

3. Data Quality

The analyzed data show some specific artifacts originating from the instrument used at the time of observations, as well as some effects of the observing and storing procedures. For example, sometimes local darkenings due to the passage of clouds during observations are seen on the solar disk. The resolution may also vary over the disk within one image, which is due to changes of the atmospheric turbulence during the observation.

Some images also show dark lines across the solar disk, which were produced by dust particles on the optical components of the instrument used to get these observations. Scratches and holes found in the plate emulsion are mostly due to the handling and storage of the plates.

Some of the plates display intensity patterns over the solar disk, which are likely due to chemical effects during the plate development. Large scale intensity patterns, which are clearly seen outside the solar disk but also affect the solar images, are mostly due to scattered light by instrumental components (dispersion grating, entrance slit).

Finally, another frequent problem of these historic observations is the difference in the velocity setting of the driving motors which translate the input solar image and the photographic plate, or the spectrograph slits. This results in geometric distortions on the solar image stored on the plates. In particular, the resulting image is elliptic, the axes of the ellipse being parallel and perpendicular to the slit. Note that the differential refraction of the atmosphere also resulted in an oblateness of the solar disk.

Figures 2 and 3 show some of the artifacts described above. Visual inspection of the analyzed images shows that the Kodaikanal time series is on average less affected by plate defects, such as scratches, rows and geometrical distortions, than both the Arcetri and Mt Wilson series. It might be due to the fact that the digital archive of the Kodaikanal Observatory contains only plates with the best quality. Quantitative measurements of the level of intensity in-

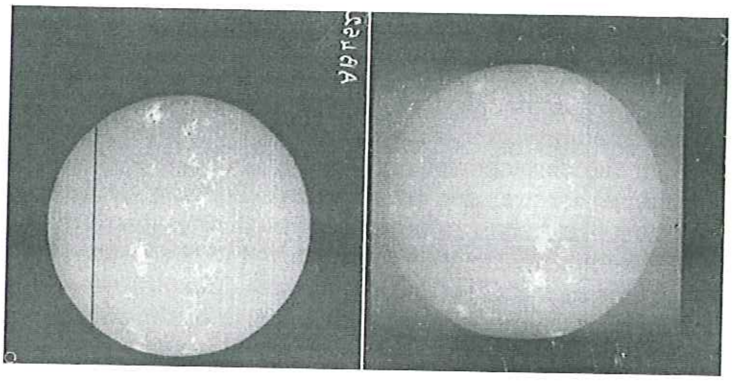

Figure 2. Examples of artifacts affecting the analyzed plates: scratches (left) and holes (right) in the emulsion pattern.

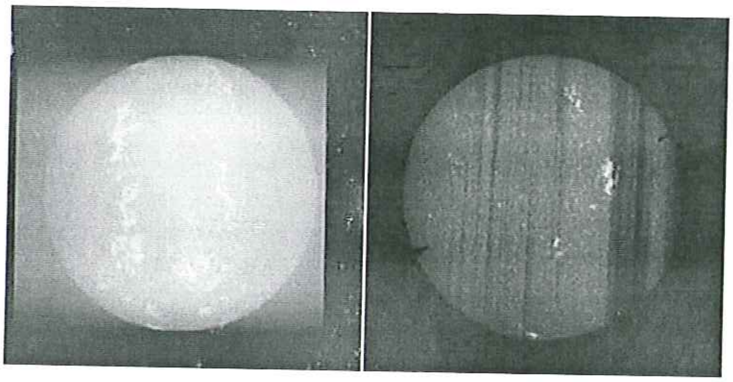

Figure 3. Examples of artifacts affecting the analyzed plates: scattered light by the optical components (left) and intensity in-homogeneities over the solar image (right).

homogeneities over and outside the solar disk, as well as of the spatial resolution on solar images extracted from the three time series confirm the findings of the visual inspection of the data (Ermolli et al. 2006).

It is worth noting that the plate problems listed above affect a rather small portion of the data in the three analyzed time series. Moreover, most of these artifacts can be compensated by applying a proper image processing technique. Finally, the number of images available in two of the three analyzed time series allows the selection and further analysis of only best quality images, without introducing significant losses of the data available for studies focusing on solar variations on daily to multi-decadal time scales.

4. Conclusions

We analyzed images extracted from three digital archives of Ca II K full-disk observations obtained at the Arcetri, Kodaikanal and Mt Wilson Observatories. These images (as also all others coming from similar archives) store detailed spatial and temporal information about solar magnetism during the last century. However, these data suffer significantly from various problems originating from the observational technique, the data storage and the subsequent digitization process. Some of these problems, especially those concerning plate defects, can be solved through the development and further application of a proper image processing technique. For example, the solar disk ellipticity can be compensated by a proper re-sizing of the analyzed images before their processing. On the other hand, effects of the multiple changes that occurred in the instrumentation used during the several decades of observations are more difficult to account for. Such instrumental changes are seen as temporal variation of the results obtained by the analysis of these observations. They can be singled out from solar temporal variations only with the inter-calibration of the data coming from different archives. The main challenge remains the photometric calibration of the data, however.

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