Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Variations in Ca-K line profiles and Ca-K line features as a function of latitude and solar cycle during the 20th century

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Abstract. The analysis of the Ca-K line spectra as a function of latitude and integrated over the visible disk obtained during the period of 1989–2011 at the Kodaikanal Solar Tower Telescope shows that the FWHM of the K1 distribution at different latitudes varies by negligible amount at about 60° latitude whereas it varies significantly at other latitudes. Findings, especially the fewer variations in mid-latitude belts as compared to polar regions and complex variation in the shift in the activity around 60° latitude belt, will have important implications on the modeling of solar dynamos. Further, we have generated a uniform set of digitized Ca-K line images by selecting images considering the intensity distribution of the images corrected for the instrumental vignetting for the data obtained at Kodaikanal during the 20th century. Then, we have determined the percentage of plage and network areas by using the intensity and area threshold values.

1. Introduction

It is important to study the large scale, such as Ca-K plages as well as small scale (networks) variations on the sun as a function of latitude and time for making realistic models for the solar cycle variations. After analyzing the digitized images of the sun in Ca-K line obtained at Mount Wilson Observatory (MWO), Foukal *et al.* (1996) found variations in the plage areas similar to the sunspot numbers with a period of ∼ 11 years. Further, they reported that the area covered by the plages were maximum during the 19th solar cycle as compared to other solar cycles. Number of such studies have been made (e.g., Ermolli *et al.* (2009), Foukal *et al.* (2009), Tlatov *et al.*(2009), Bertello *et al.* (2010), Chatterjee *et al.* (2016)) using MWO, Kodaikanal (KKL) and other data sets to investigate the variation in the plage areas and Ca-K index with time. They showed the correlation between different data sets by averaging the parameters over months and years. Priyal *et al.*(2014, 2017) using the methodology similar to that of Worden *et al.*(1998) computed the fractional areas for the plages, Enhanced Network (EN), Active Network (AN) and Network for the period 1906 -2005 using the images taken at KKL observatory. Pevtsov *et al.* (2013) found weak dependency of intensity in the line core (K3) of basal profiles on solar cycle. Bertello *et al.*(2016, 2016a) studied the correlation between the sunspot numbers and the Ca-K emission index and computed the emission index for the period 1907 - 2015 by combining the data from KKL, Sac Peak and SOLIS (ISS). Here, we describe the new methodology to select images and create a uniform set of data from the long series of Ca-K line images obtained at KKL observatory for the period 1905 -2007 to study the variations in Ca-K features reliably.

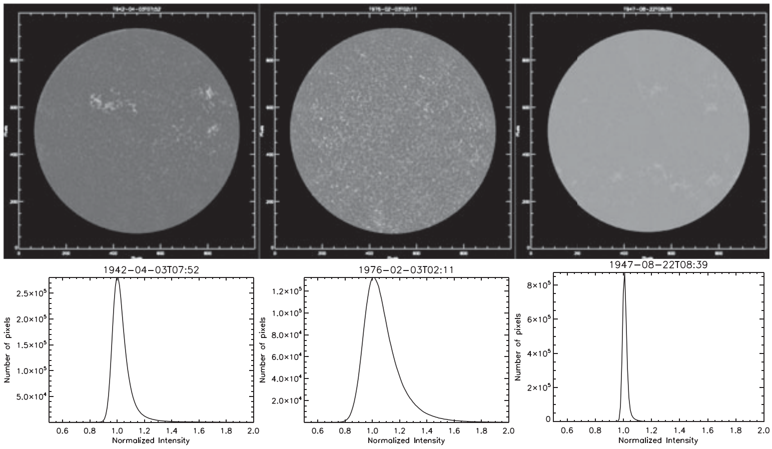

Figure 1. Typical examples of Ca-K line images of 3 type, one with normal contrast at the K3 (left), the second with high contrast at K2V (middle) and third with very low contrast most likely in the off-band (right).

2. Spectroscopic, Imaging Data, and Analysis

We obtained the high resolution Ca-K line profiles as a function of latitude and integrated over the visible solar disk at the KKL solar telescope for the period 1986–2011 (Sindhuja *et al.* (2014). The K1 and K2 widths of the Ca-K line were determined at an interval of 10° latitude for each day of observations. The cross-correlation between the temporal variations in the K1 width at 35° latitude belt with other latitude belts was used to compute the phase difference between the maximum of activity at the latitude belts considered and then determine speed of activity shift from one latitude to other.

The spectro-heliograms in Ca-K line have been obtained at KKL observatory since 1905 till 2007 with the exit slit of the spectroheliograph isolating 0.5 Å centred around K3 of Ca-K line. All the images during this period have been taken using the same optical setup and there by expected to provide uniform data series to study variations on the sun. Singh *et al.* (2007) designed and developed digitizer units to digitize all the data obtained at KKL observatory keeping in view the scientific requirements to study the small scale features at the chromosphere and photosphere. The pixel resolution for the digitized Ca-K line images is 0.86 arc-sec with 16-bit read out. Singh trained 6-members to digitize the photographic plates by working in shifts to complete the process in short time. The software was developed to identify chromospheric features, such as Ca-K plages, enhanced network (EN), Active network (AN) and network using intensity and area threshold values (Priyal *et al.*, 2014). A close investigation of the analyzed images indicated that there still exists non-uniformity in the data set.

A new methodology to create reliable uniform data series developed is described here. Jagdev Singh displayed all the images one by one on the computer screen along with the intensity distribution of that image. He found three types of images, one taken at the Ca-K line centre which showed normal contrast and intensity distribution as seen in the first column of Figure 1. Other type of images showed very high contrast and broad intensity distribution as seen in second column of Figure 1, most likely taken in the blue wing near K2V emission peak of Ca-K line. Third type of images have very low contrast and very narrow intensity distribution as seen in the third column of the Figure 1, taken at off band or during high clouds. All the images were divided in two groups. First type of

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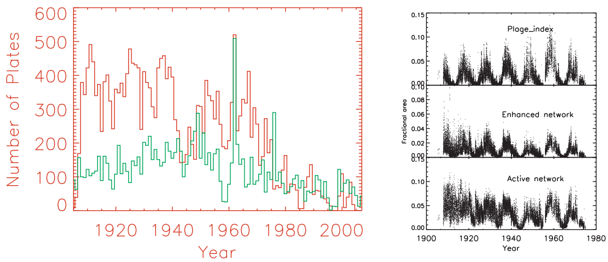

Figure 2. Left: Histograms of the images per year selected as 'Good' for the present study is shown in red and the images as 'Okay' not considered for the present study is shown in Green color. Right: Plots showing the variation of plages, Enhanced Network (EN) and Active Network (AN) with time for the period of 1907 – 76.

images were considered to determine the Ca-K parameters such as plages and networks. Second and third type of images were analysed separately and not reported here. In this article we describe the results obtained using this methodology.

3. Results and Discussions

We have two types of data, one the spectroscopic Ca-K line profiles for the period of 1986–2011 and other the spectroheliograms obtained at KKL observatory for 1905–2007. We have analysed the spectra taken during the period of 1989–2011 that indicates that the K1 width attains maximum amplitude at various latitude belts at different times during a solar cycle. Here we summarise the results of this analysis, details are given in articles by Sindhuja *et al.*(2014, 2015, 2015a). The FWHM of the K1 width distribution at different latitudes shows that its width varies by about 30% for the equatorial belts (<30°) and 11% for the polar region (>70°) latitudes. Interestingly, the K1 width varies by ∼6% only around (60°) latitude belt during the solar cycle. The phase difference between the variations of K1 width of various latitudes with that at 35° latitude belt indicates that solar activity representing toroidal field shifted with a velocity 5.1 m s^{-1} (North) and 7.5 m s^{-1} (South). The phase difference between the maximum activity at polar regions and equatorial belts is ∼5.5 years. Less variation in the Ca-K activity (poloidal field) at ∼60° latitude belt as compared to those for the polar regions during the solar cycle is unexpected and reason for this need to be explored. We speculate three types of cells, one those transports toroidal flux from mid latitudes to equatorial belts, second those transport poloidal flux from mid latitude to high latitude belts up to 60° and the third those exist in the polar regions.

About the imaging data, Jagdev Singh displayed about 37000 images one by one along with the intensity distribution of that image. About 24500 images were found to be good to generate a uniform series of the images taken around K3 and the remaining about one third of the total images were of very high or low contrast. It may also be noted that in some years more images have been taken around K2V and in some other years more images have been taken off band (away from K3). Thus it affects the derived Ca-K line parameters even when monthly or yearly averages are obtained. It is not clear if the observers in the past, obtained the images around K2V with some particular objective. It appears that the observers took images around K3 and off band for some time, probably to make corrections for the intensity vignetting due to the instrument. These possibilities, Jagdev Singh thought while inspecting all the images one by one. The histogram in the red in Figure 2(left) shows the number of images selected per year considered (here after called 'Good images') for determining the plage and network parameters. Whereas the

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histogram in green shows the number of images (here after called 'Okay images') not considered for this article. The histograms in the Figure 2(left) shows that total number of images per year are > 600 for the period 1906–1976 except for the period 1942–48 and Good images are considerably more than the Okay images during this period. The number of images per year after 1976 reduced gradually because of less number of clear days per year and also due to non-availability of proper photographic film. It may also be noted that after 1980, number of dark lines started appearing in the images and these lines increased with time. In December 1986, Singh (1988) cleaned all the optical components on which dust and fungus had deposited. After the re-alignment the image quality improved appreciably as number 'Good images' increased during the year 1987–88 as compared to 'Okay images'. But, soon the image quality degraded due to use of old photographic plates as the supplier stopped the production of such emulsions.

After normalizing the background intensity we have used intensity threshold >1.30 and area threshold >1 arcmin^2 for the plages, intensity >1.30 and area >25 arcsec^2 for EN and intensity <1.3 and >1.2 as AN. In Figure 2(right), we show the variation of plages, EN and AN in fractional area of the visible disk as function of time for the period 1907–76. The short term variations in these parameters are due to rotational modulation and of solar origin. Further, the study of plage and networks, as a function of latitude and time indicates that small scale activity also varies with solar cycle. The detailed analysis of these data are in progress to study the long and short term variations.

4. Conclusions

We can say that variations in the Ca-K line features (plages, EN and AN) can be investigated reliably if the images are corrected for the instrumental vignetting effectively and selected to maintain the uniformity of the data as done here. Short term variation in the occurrence of plages and solar activity can also be investigated accurately. Further. we believe that correlation can be improved in different data sets on much shorter time scale (couple of days) by using this methodology as compared to months or years as done presently.

References

Bertello, L., Ulrich, R. K., & Boyden, J. E. 2010, *Sol. Phys.*, 264, 31.
Bertello, L., Pevtsov, A. A., Tlatov, A. G., & Singh, J. 2016 , *Sol. Phys.*, 291, 2967.
Bertello, L., Pevtsov, A. A., Tlatov, A. G., & Singh, J. 2016a, *AsJPh*, 25, 295.
Chatterjee, S., Banerjee, D., & Ravindra, B. 2016, *ApJ.*, 827, 87.
Ermolli, I., Solanki, S. K., Tlatov, A. G., Krivova, N. A., Ulrich, R. K., & Singh, J. 2009, *ApJ.*, 698, 1000.
Foukal, P. 1996, *GRL*, 23, 2169.
Foukal, P., Bertello,L., Livingston, W. C., Pevtsov, A. A., Singh,J., Tlatov, A. G., & Ulrich, R. K. 2009, *Sol. Phys.*, 255, 229.
Pevtsov, A. A., Bertello,L., Uitenbroek, H. 2013, *ApJ.*, 767, 56.
Priyal, M., Singh, J., & Ravindra, B.,Priya, T. G., Amareswari,K., 2014, *Sol. Phys.*, 289, 137.
Priyal, M., Singh,J., Ravindra, B., & Rathina, S. K., 2017, *Sol. Phys.*, 292, 87.
Sindhuja, G., Singh, J., & Ravindra, B. 2014, *ApJ.*, 792, 22.
Sindhuja, G. & Singh, J. 2015, *JApA*, 36, 81.
Sindhuja, G., Singh, J., & Priyal, M. 2015a, *MNRAS*, 448, 2798.
Singh, J., Aleem, P. S. M., & Nagabhushana, B. S. 1988, *Kodaikanal Observatory Bull., Tech. Report, No. 2.*
Singh, J. 2007, *Annual Report, Indian Institute of Astrophys.*
Tlatov, A. G., Pevtsov, A. A., & Singh, J. 2009, *Sol. Phys.*, 255, 239.
Worden, J. R., White, O. R., & Woods, T. N. 1998, *ApJ.*, 496, 998.