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Spatially Resolved Images and Solar Irradiance Variability

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Abstract. The Sun is the primary source of energy that governs both the terrestrial climate and near-earth space environment. Variations in UV irradiances seen at earth are the sum of global (solar dynamo) to regional (active region, plage, network, bright points and background) solar magnetic activities that can be identified through spatially resolved photospheric, chromospheric and coronal features. In this research, the images of CaII K-line (NSO/Sac Peak) have been analysed to segregate the various chromospheric features. We derived the different indices and estimated their contribution from the time series data to total CaII K emission flux and UV irradiance variability. A part of the important results from this research is discussed in this paper.

Key words. Solar chromosphere: spatially resolved images—chromospheric features—irradiance variability.

1. Introduction

Since the radiative output of the Sun is one of the main driving forces of the terrestrial atmosphere and climate system, the study of the changes in the solar energy flux has become of interest. Although the long-term change in total solar irradiance (the solar energy flux integrated over the entire spectrum) can be considered to be one of the major natural forces of the earth's climate system, the study of UV irradiance variability is an equally important issue in solar physics. The UV irradiance variability has profound influence on the earth's climate and space weather. For more than 2 to 3 decades, the solar irradiance (both bolometric and at various wavelengths) has been monitored as 'Sun as a star' from several satellites. It is known that the solar energy flux changes over a solar cycle. It has been shown that the long-term irradiance variations are attributed to the changing emission of bright magnetic elements (Foukal & Lean 1988; Kariyappa & Pap 1996, 2000; Worden *et al.* 1998), whereas the short-term irradiance variations are directly associated with active regions as they evolve and move across the solar disk (Lean 1987). The difference between the observed and model irradiance variability has not been explained and further investigations are required. The current irradiance models are based on full-disk integrated flux, such as radio flux, CaII K 1 A index, HeI equivalent width, but may not be from spatially resolved features of the Sun. In order to identify and understand the underlying physical mechanisms of solar irradiance variability and to estimate the contribution of various chromospheric features to UV irradiance, a detailed analysis of spatially resolved data both from ground and space are required. The CaII H and K resonance lines are widely used to study the solar chromospheric structures and these lines are very sensitive to the variations in temperature and the magnetic field strength. Therefore they are excellent indicators of the chromospheric structural changes related to solar magnetic activity. The analysis of the CaII H and K spectro-heliograms demonstrate that the main features which are responsible for chromospheric emission are the plages, the network, internetwork and background chromospheric regions. However, separating out these features from the images is one of the biggest problems in image analysis.

2. Observations and data analysis

The CaII K spectro-heliograms have been obtained from NSO/Sac Peak using the spectro-heliograph. We have selected and analyzed the daily images of 6 years (namely 1980, 1985, 1987, 1988, 1989 and 1992) representing the different phases of the solar activity. We derived the full disk indices (spatial K index and Full Width at Half Maximum, FWHM, of the histogram taken for the full disk image), the quiet Sun intensity, the cumulative intensity and area of the individual chromospheric features using the histogram plot taken for the full-disk image of the chromosphere. In this paper, we discuss the variations of these indices and estimate the contribution of the various chromospheric features to CaII K & UV irradiance variability.

3. Results and discussion

We have calculated the histograms for the full-disk images (Kariyappa & Pap 1996, 1999; Kariyappa 2000) to analyze the CaII K spectro-heliograms and to separate out the various chromospheric-magnetic features. We have used the morphology and intensity level of the features as the main criteria to segregate the different features from the images. We are familiar with the morphology of different features:

- the plages are very bright, large, and compact structures,
- the network elements are cellular structures with bright boundaries, and
- the remaining features relate to background + internetwork regions.

We first assumed the intensity levels that might bound the plage pixels in a histogram, and then examined images in which the pixels with greater or lesser intensities than those bounds were masked. The bounding intensities were then adjusted until the masked images mapped the plage regions. We applied similar techniques for the network and internetwork + background features. The intensity and the number of pixels (area) for plages, network, and internetwork + background regions have been derived from these images using their corresponding histogram plots. It has been established that the spatial K index, the FWHM, the intensity of different chromospheric features are well correlated with UV irradiance variability measured in MgII h and k lines and whereas the area of the chromospheric network elements is anticorrelated with solar activity cycle (Kariyappa & Sivaraman 1994; Kariyappa & Pap 1996; Kariyappa 2000). The anticorrelation of the area of the network with solar cycle has also been shown by others (Muller & Roudier 1994; Ermolli *et al.* 1998; Berrilli *et al.* 1998, 1999). The network is fainter during solar minimum, but covers a larger area on the solar disk and hence their contribution should be considered in constructing the irradiance models.

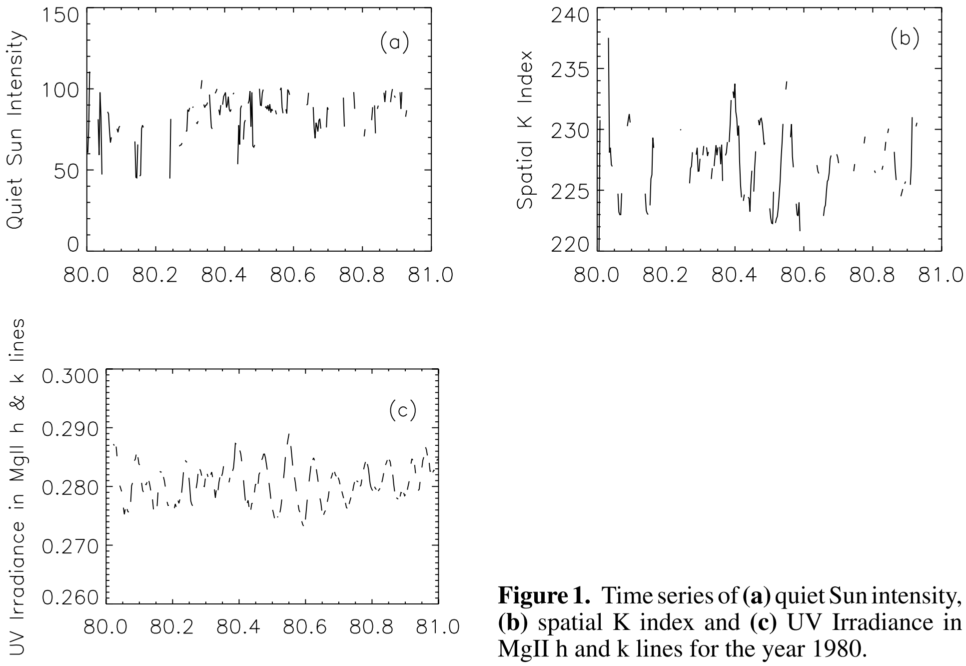

Figure 1. Time series of **(a)** quiet Sun intensity, **(b)** spatial K index and **(c)** UV Irradiance in MgII h and k lines for the year 1980.

In addition to full-disk indices and intensity and area of plages, network and internetwork + background regions, we derived the quiet Sun intensity in a very quiet region at the center of the solar disk and plotted them as a function of time. In Fig. 1, we have compared the variation of quiet Sun intensity with spatial K index and UV irradiance measured in MgII h and k lines for the year 1980 and found that they are well correlated with each other. This represents that quiet Sun intensity will vary in phase with the solar activity and will contribute to the variation of UV irradiance and its contribution should be considered in irradiance models. The results show that the intensity of the quiet Sun will be varying with the solar cycle and is very dynamic and is crucial for the understanding of the chromosphere itself.

From the intensity time series of individual features, we estimated the contribution of various chromospheric features to CaII K irradiance variability using the following expression:

$$\text{Contribution (in \%)} = (\text{Intensity of chromospheric feature/spatial K index}) \times 100,$$

where the spatial K index is the full-disk intensity.

We derived the average contribution for the whole year and found that about 50% of the CaII K solar cycle variability results from plage, about 32% from the network, and about 18% combined from internetwork + background regions. The percentage of contributions of the three features will also explain the UV irradiance variability measured in MgII h and k lines, since it has been established that there is a good correlation between the variability of CaII K emission and UV irradiance. We can conclude from these results that besides the plages, a significant portion of the variations observed in UV irradiance are related to the changing emission of the network and internetwork + background regions. They will play a significant role in their contribution to the variation in UV irradiance and are not constant as assumed in the irradiance models.

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