

Modeling Solar UV/EUV Irradiance and Ionosphere Variations with Mt. Wilson Magnetic Indices

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LONG-TERM GOAL

The long term goal for this project is to develop, extend and disseminate new indices of solar outputs based on observations of solar magnetic fields made every clear day at the Mt. Wilson Observatory's 150-foot solar tower. The data reduction is done within hours of at least one observation per day (weather permitting) and the results of the reduction are made available through the worldwide web. The analysis of the past database together with timely dissemination of new data is for the purpose of improving forecasts of the state of the earth's ionosphere in order to better predict the communications environment which relies on radio reflections from the various layers of the upper atmosphere.

SCIENTIFIC OBJECTIVES

The emissivity of the solar atmosphere depends on the strength of the magnetic field on the sun's surface. The solar surface is highly inhomogeneous and contains at least four types of region: quiet sun, chromospheric network, plages and sunspots. Each type of region contributes differently to the total flux of UV, EUV and X-ray output. The solar surface magnetic field is a recognized indicator of the nature and strength of each type of solar region. Our plan is to use the magnetograms obtained at the 150-foot tower on Mt. Wilson to quantitatively divide the solar surface into the different classifications and assign a strength of emission on the basis of the observed magnetic field strength. Previous analysis has shown that the plage regions can be well identified from the magnetic field.

The magnetograph at the 150-foot tower is sensitive to magnetic fields at the 1 gauss level. The fields observed with a 20 arcsec aperture are larger than this over virtually the entire solar surface so that the system has sensitivity to measure the widely distributed weak fields. As described in the next section, a distribution function for the solar fields can be derived and used to identify and define new weak field indices that show promise of giving a measure of the overall strength of magnetic effects outside of the sunspots and plages. Preliminary results for one such index are shown below.

APPROACH

Every clear day the synoptic program at the Mt. Wilson Observatory's 150-foot tower uses the magnetograph system to carry out full solar disk scans which provide measurements of the surface magnetic field strength using the magnetically sensitive spectral line of neutral iron at a wavelength of 525.0 nm. This system has been used in an essentially unchanged configuration since 1967. Important improvements were made in 1982, 1986, 1994 and 1996 and although data

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is available prior to 1986, the modern era of intensive data acquisition begins at that time. The archival record from this program provides a critical resource permitting the retrospective study and validation of prospective indicators of solar UV and EUV output.

The Mt. Wilson 150-foot tower system normally uses a spatial resolution of either 12 or 20 arcseconds squared. Although important magnetic structures are not resolved spatially, the sensitivity to very weak fields permits the detection of the widely distributed quiet sun magnetic field. Observations made with the polarization analyzer inactive provide a means of determining the sensitivity to weak fields. Apparent magnetic fields generated by system noise in these analyzer-off magnetograms have an rms of 1 gauss. With the analyzer on, the magnetic field distribution function can be divided into a core portion which is nearly gaussian and the wings for which the distribution is more complex. The rms parameter for the gaussian core is 2.3 gauss at sunspot minimum in 1996 and 2.8 gauss at the last maximum in 1989. These distribution functions ϕ_B for a sample of phases of the solar cycle and their integrals are shown in figure 1.

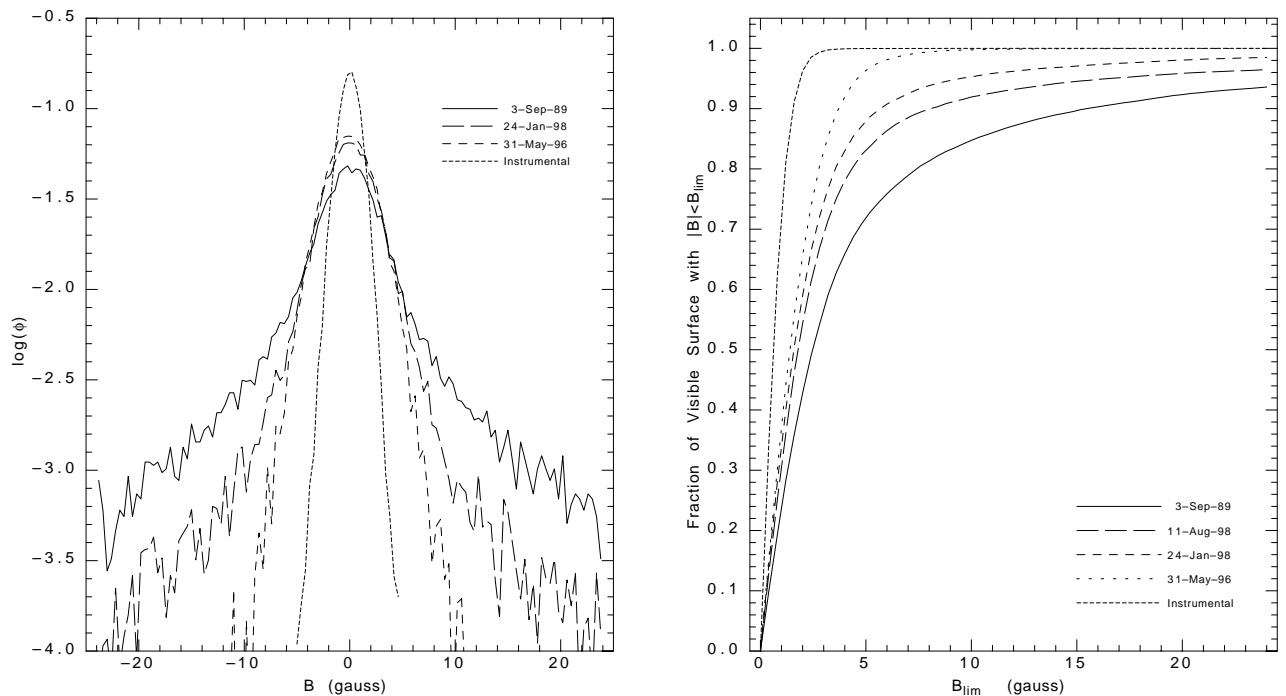


Figure 1: *These figures show the distribution functions ϕ for longitudinal magnetic fields on the solar surface on the left and the integrals of these functions on the right. The distribution function is defined as fraction of the surface with fields between B and $B + dB$ divided by dB normalized to integrate to unity when integrated over all values of B . The gaussian core of ϕ indicates the operation of some mechanism independent of active regions to generate small fields everywhere.*

On the basis of these distribution functions we have taken a measure of the strength of the weak fields to be the ratio between the distribution functions at 0 and 4.6 gauss. Operationally we have evaluated ϕ_B by sorting the spatial pixels according to magnetic field strength bins each of which is 0.4 gauss wide. The value of ϕ_B at $B = 0$ is evaluated by fitting a second order polynomial to ϕ_B over the range $|B| < 3$ gauss while the value of ϕ_B at 4.6 gauss is found by summing the distribution over the six bins with $|B|$ between 4.0 and 5.2 gauss. The Weak Field Index (WFI) is

then the ratio $\sum_{A < |B| < 5.2} \phi_B / \phi_{B=0}$. This index presumably represents the active network area. A second index which represents the area of the plage regions is the Magnetic Plage Strength Index (MPSI) which is the sum $\sum_{10 < |B| < 100} B \phi_B$. This index was introduced by Ulrich (1991, *Adv. Space Res.*, vol 11, no 4, p. 217) and is known to provide a good means of estimating the solar UV flux as measured by the MgII Core/Wing ratio.

WORK COMPLETED

The derivation of the MPSI is now routine and the same-day results are posted most days before 1 PM Pacific Standard Time. Comparison of the MPSI to UV fluxes obtained with UARS satellite show that the MPSI has a 0.98 correlation coefficient with the observed Mg II h & k line core to wing ratio. A comparison of the MPSI and the 10.7 radio flux as proxies for the SUSIM data is shown in figure 2. It is evident that the spread is less using the MPSI as opposed to the F10.7 parameter.

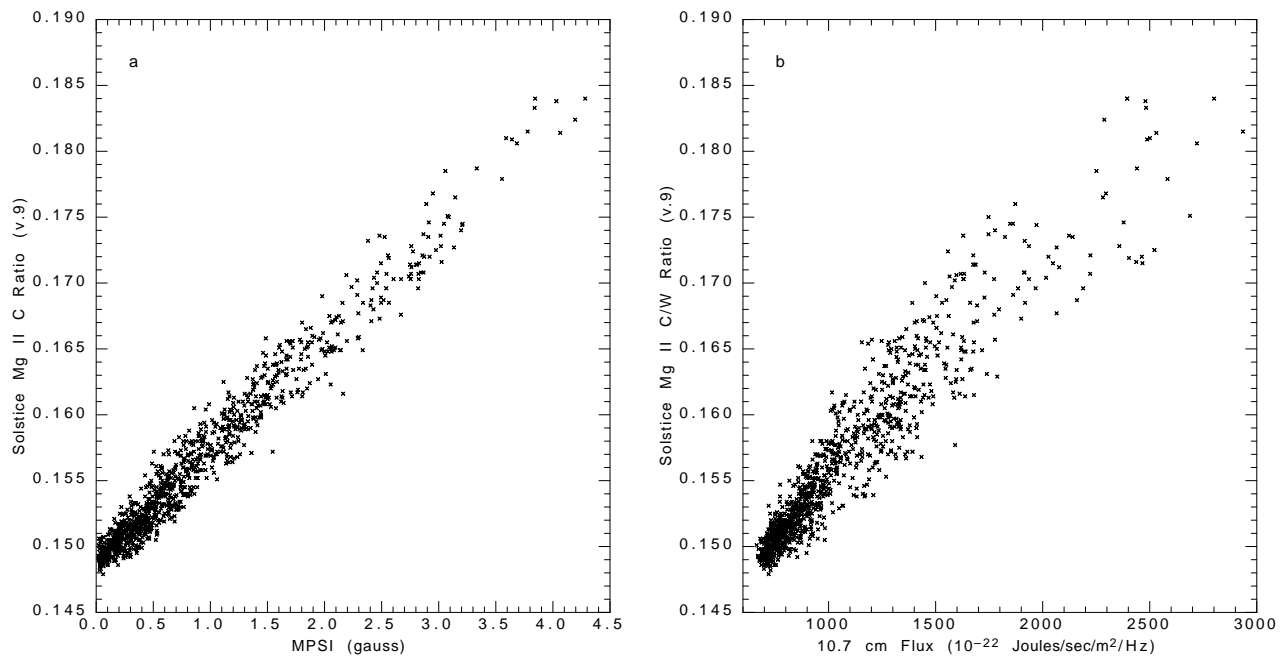


Figure 2: *The relationships between the UV MgII c/w parameter from the SUSIM experiment on UARS and the MPSI and the radio F10.7 flux. Each point represents the daily values of the MgII c/w ratio and either the MPSI or the F10.7 flux interpolated to the nearest daily point reported from the SUSIM experiment. The set of dates shown are those where all three data set values are available. The times of observation range between Oct. 14, 1991 and Jan. 18, 1996.*

RESULTS

The newly defined Weak Field Index has not been computed during previous reductions of the Mt. Wilson data base. For this reason we are not able to illustrate complete results for this index because it is not available without a reanalysis of the raw observational data. The reprocessing of the raw data is a task of moderate scope and has not yet been accomplished. However, in order to validate the provisional definition of the WFI suggested above, we have carried out a reprocessing of one month (near June) each year for the past eight years. In one case (1994 to

1995), the results seemed somewhat unexpected and most of the season between June 1994 and June 1995 were reprocessed. The resulting WFI index values were averaged for each day and are presented in figure 3 along with the monthly averaged sunspot number (SSN). Two aspects of this figure are worth noting: first, the minimum in the WFI occurs later than the minimum in the sunspot number; and second, the decay toward minimum also appears to be delayed relative to the sunspot number although in 1995 the WFI decreased during a period when the sunspot number was slowing its decline. The behavior of the WFI suggests that the weak fields are produced by the breakup of the strong fields and that they can grow in their coverage of the solar surface only after the stronger fields have reappeared.

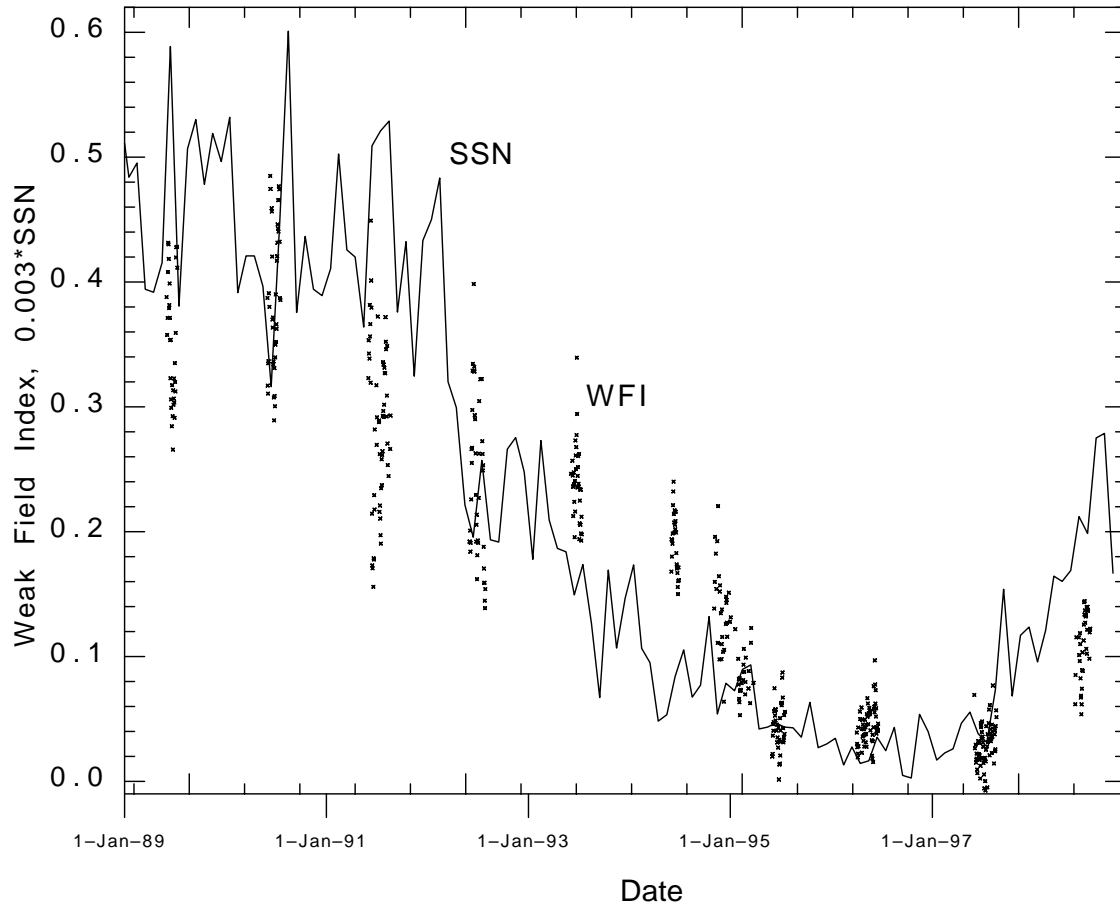


Figure 3: *The time dependence of the new Weak Field Index (WFI) compared to the Sunspot Number (SSN) where the SSN has been rescaled to match the minimum and maximum of the WFI. New reductions of the raw archival data have been carried out to make this index available. Additional indices can now be studied since the new reductions include as output the full distribution functions in addition to the particular combination which has been used to define the WFI.*

IMPACT/APPLICATION

We believe the combination of the WFI and the MPSI will permit us to better model solar outputs which depend on all components of the solar surface: widely distributed network, plages and sunspots. We now have indices which provide a measure of the nature and strength of each

component (the sunspots can be modelled either with the sunspot number or the Mt. Wilson Sunspot Index, MWSI).

TRANSITIONS

We will continue to provide the current and near term predictions of the Mt. Wilson indices. These will be distributed through the world-wide web as they have been for the past two years. We are close to beginning the formal full re-reduction of the archival data base. In addition to the provision of new data for the WFI and related indices, this new reduction will make available a new data base of solar apparent diameters defined on 18 sectors around the solar circumference using an algorithm which reduces the sensitivity to transparency fluctuations.

RELATED PROJECTS

The magnetograms are utilized by Sheeley in a model which predicts the heliosphere magnetic structure in the near-earth environment.

The ground-based indices are being used by Pap et al. (1997) to study the long-term variations in the total solar and UV irradiances. The historical data from this project extends back to 1967 and this database can be used to address questions concerning the solar output at successive solar minima and maxima. The above paper finds that the variations were similar at minimum and maximum for solar cycles 21 and 22. The ground-based indices are among the few tools available for comparison to direct flux measurements which cover more than one solar cycle. The minimum levels of both the MPSI and the Mg II h & k c/w ratio were about the same for cycles 21 and 22.

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