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SOLAR EUV FLUX DURING SOLAR CYCLES 21, 22 & 23 AND ITS REALTIME PREDICTION FOR AERONOMICAL STUDIES

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ABSTRACT

Solar EUV flux is an important parameter employed in aeronomical studies of the earth's upper atmosphere & ionosphere and needs real time predictions. For this purpose we examine the solar EUV measurements made by the Electron Temperature Probe (OETP) on Pioneer Venus Orbiter, during solar cycles 21 and 22 and by Solar EUV Monitor (SEM) aboard the SOlar Heliospheric Observatory (SOHO), during solar cycle 23 to study daily as well as their solar cycle variations. We also examine these measurements against several EUV proxy indices and study their correlation coefficient for daily values, as well as for values averaged over one or more solar rotations. We then identify the better of these indices for real time prediction of solar EUV flux.

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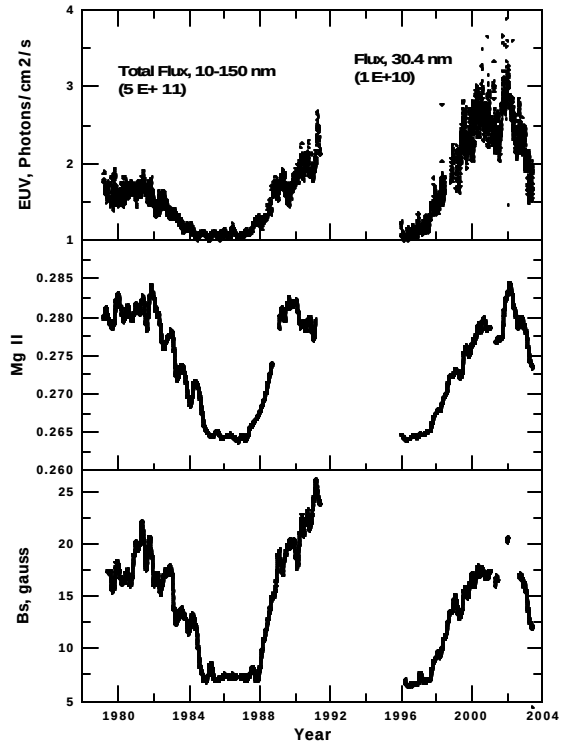
INTRODUCTION

Solar EUV radiation is one of the primary energy source to the thermosphere and ionosphere. Absorption of EUV photons by O, O_2 and N_2 in the atmosphere above 100 km is responsible for most of the heating in the thermosphere. The EUV photons also ionize the neutral atmosphere, forming the ionosphere. The solar EUV flux changes by factors of 2 to 10 across the spectrum from solar minimum to solar maximum. These changes produce large changes in the neutral and electron densities of the upper atmosphere. Thus for aeronomical studies, knowledge of EUV flux is a basic requirement. However, except for some brief periods, there have been very few solar EUV measurements on daily basis. A discussion of the early measurements is given in Lean [1]. Some data for daily values for several months continuously were obtained by the AE-E satellite from 1974-1980. In addition threre were some measurements by OSO4 in the late 1960s, AEROS A in the early 1970s, Prognoz 10 in 1985, and the San Marco satellite in 1988. The period from 1980 onwards was termed as the 'EUV hole', as full spectrum measuring were not expected to occur till the late 1990s. However, from January 1979 to December 1991, the Pioneer Venus Orbiter (PVO), which caried a Langmuir probe to measure the temperature and concentration of electrons in the ionosphere of Venus, also measured integrated EUV flux in the range 10-150 nm when the probe was outside of the Venus ionosphere and was in the solar wind [2] thus filling up the EUV hole to some extent. In recent times, since January 1996, SEM/SOHO has made daily measurements of solar EUV flux at 30.4 nm [3].

Since EUV flux is very important for studying solar-terrestrial effects, several workers in the past have studied the correlation between EUV fluxes and several solar indices, with a view to see whether any index could serve as a 'proxy' for EUV flux [4]. In this paper, we reexamine the relationship of EUV with several well proxy indices during the *Pioneer Venus* interval (1979-1992) covering the solar cycles 21 & 22 and SEM/SOHO interval (January 1996 onwards) covering the solar cycle 23, on long-term (one or more solar rotations) as well as short-term (daily) time scale.

PIONEER-VENUS EUV MEASUREMENTS

During January 1979 to December 1991, the Pioneer Venus Orbiter (PVO) carried a Langmuir probe to measure electron density and electron temperature in the Venus ionosphere, and when the probe was outside the Venus ionosphere and was in the solar wind, it measured integrated EUV flux (called EIpe) in a broad range 10-150 nm, with 55% contribution from Iα, 30% from 30-110 nm continuum, and rest from strong ionizing lines such as He II, He I, C III, etc [2,5].



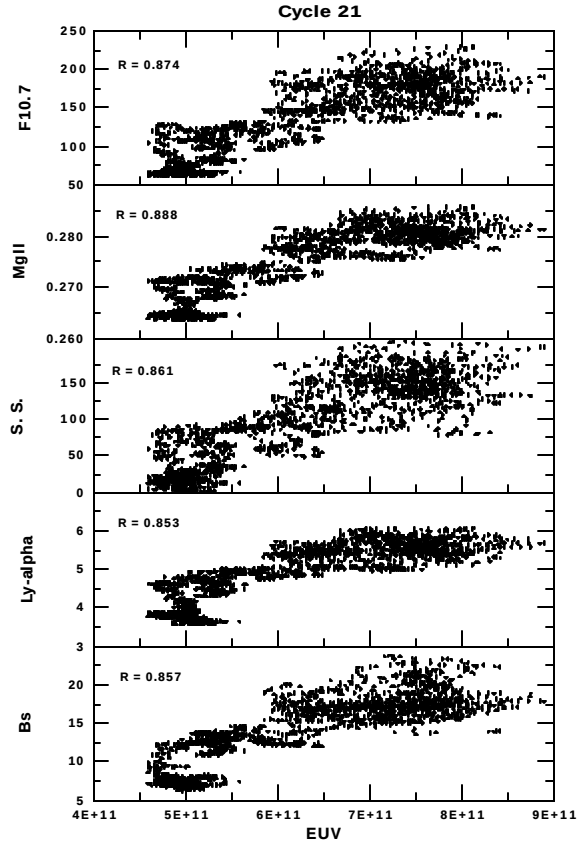


Figure 1: Plot of daily values of EUV flux measured on PVO and on SOHO during solar cycle 21, 22 & 23. Proxy indices Mg II and Bs, averaged over three previous solar rotations are also plotted for the same period. (EUV is in units of photons cm^{-2} s^{-1}

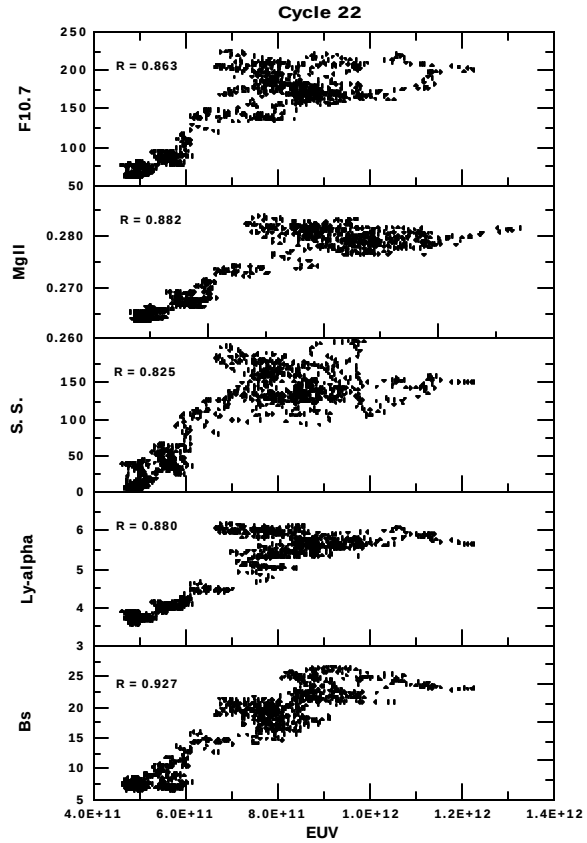
Figure 2: Plots of daily values of EUV flux with various proxy indices for solar cycle 21. ($F_{10.7}$ is in unit of 10^{-22} W m^{-2}; Ly-α is in units of 10^{11} photon cm^{-2} s^{-1})

SEM/SOHO MEASUREMENTS

The SEM/SOHO instrument is a highly stable transmission grating EUV spectrometer [6], and provides the full disk solar irradiance within an eight nm bandpass centered at 30.4 nm. The He II 30.4 lines contributes about 50% of the total signal in the SEM data which is similar to the contribution to atmospheric heating by the He II 30.4 line, especially near solar minimum. Since the launch of SOHO, there have been three sounding rocket calibration under-flight measurements of the 26-34 nm solar flux. Using these rocket flights for cross calibration, the absolute solar EUV flux in the spectral range from 26-34 nm (the 30.4 nm channel) has been determined to an accuracy of ~ 10% and a precision of ~ 1% [7].

FEATURES OF SOLAR EUV FLUX DURING SOLAR CYCLES 21, 22 AND 23

Daily values of solar EUV flux for the period (1979 to 2004) covering solar cycles 21, 22 and 23 are plotted in Fig. 1. As the 30.4 nm flux is much smaller than the total EUV flux, different multiplication factors have been used for plotting these values in Fig.1. An important feature to be noted in Fig.1 is that while the total solar EUV flux (10-150 nm) measured by the Langmuir probe changed by factors of 1.6 and 2.5 from solar minimum to solar maximum during solar cycles 21 and 22 (1979 to 1992) respectively, this factor was 3 and sometimes more in the 30.4 nm line during solar cycle 23 (1996 onwards). This is an important result which has aeronomical implications in modelling solar cycles changes in thermospheric temperature and composition and thus in the ionospheric behaviour. Most studies in the past have adopted a factor of two change in the EUV flux responsible for thermospheric heating during a solar cycle. Figure 1 also contains plots of important solar EUV proxy indices Mg II and solar magnetic field, averaged over three previous solar rotations. One can note that both these proxy indices very faithfully track the daily flux.



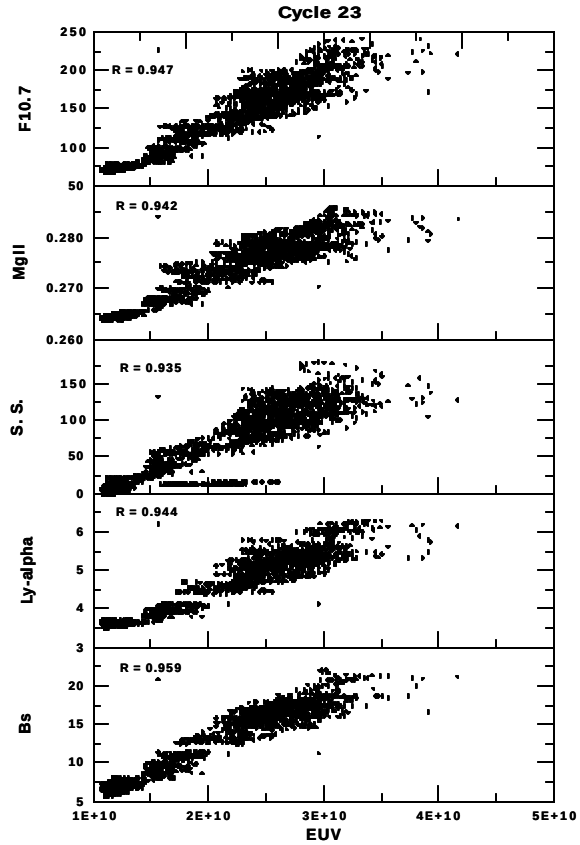


Figure 3: Same as Figure 2, except for solar cycle 22

Figure 4: Same as Figure 2, except for solar cycle 23

REAL TIME PREDICTION OF SOLAR EUV FLUX AND CONCLUSION

In a recent study Viereck et al. [8] found a very high degree of correlation (correlation coefficient 0.981), on daily basis, between SEM/SOHO solar EUV flux measured in the 30.4 nm channel and Mg II index, during the rising phase of solar cycle 23. They, therefore, recommended the use of Mg II as a proxy index for realtime prediction of solar EUV flux. In view of this important result, we have extended this analysis to the total solar EUV measured on PVO during the two previous solar cycles and also to all the SEM/SOHO EUV data available to date.

We have studied the correlation of the daily values of EUV flux with each of the five often used proxy parameters, namely $F_{10.7}$, Lα, Sunspot Number, Mg II and Solar Magnetic field Bs for their daily values as well as values averaged over several solar rotations. In Figs 2-4 are shown the scatter plots of EUV with these proxy parameters averaged over one previous solar rotation. One can note the good relationship, except during the solar maxima where the scatter is rather large. We have found that no single index shows the highest correlation coefficient with the daily values of EUV flux, simultaneously in all the three solar cycles. For example, as can be seen from the Figures 2-4, in cycle 21, all the proxy indices have almost the same correlation coefficient with EUV flux, in cycles 22 and 23 solar magnetic field has higher correlation coefficient than any of the other indices. We found that in cycle 23, although daily values of Mg II have the highest correlation coefficient with daily values of EUV flux, the solar magnetic field is quite close. Daily values for all other indices show generally a poor correlation with EUV flux.

In conclusion, we find that real time prediction of solar EUV flux, and especially the total solar EUV flux, cannot be made on the basis of daily values of any of the proxy indices. We recommend that Bs averaged over one or more previous solar rotation may be used as a proxy index for real time prediction of solar EUV flux.

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