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CHANGE IN THE RADIATIVE OUTPUT OF THE SUN IN 1992 AND ITS EFFECT IN THE THERMOSPHERE

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Abstract. Ground and space measurements of the solar spectral irradiance at radio, visible, UV, and X ray wavelengths show a large decline in the first 6 months of 1992. This sustained drop in the solar output is important in understanding the connection between the emergent magnetic flux on the Sun and the radiative output as well as in understanding the effects of such change in the upper atmosphere of the earth. We present preliminary estimates of the observed changes as the means to spur inquiry into this solar event in the declining phase of solar cycle 22. Typical decreases are 15% in Lyman α and 40% in 10.7-cm radio flux. Mass spectrometer and incoherent scatter model calculations at 600 km in the thermosphere indicate a 30% decrease in the temperature and a 3X decrease in the density of the thermosphere near the altitude where both the Upper Atmosphere Research Satellite (UARS) and Hubble Space Telescope are flying. Decrease of the orbital period of the UARS shows the expected effect of decreasing density at flight altitude. Work in progress indicates that the output change results from the decline in solar magnetic flux to a lower level of activity in the southern hemisphere of the Sun.

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Change in the radiative output of the Sun in 1992 and its effect in the thermosphere

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Abstract. Ground and space measurements of the solar spectral irradiance at radio, visible, UV, and X ray wavelengths show a large decline in the first 6 months of 1992. This sustained drop in the solar output is important in understanding the connection between the emergent magnetic flux on the Sun and the radiative output as well as in understanding the effects of such change in the upper atmosphere of the earth. We present preliminary estimates of the observed changes as the means to spur inquiry into this solar event in the declining phase of solar cycle 22. Typical decreases are 15% in Lyman α and 40% in 10.7-cm radio flux. Mass spectrometer and incoherent scatter model calculations at 600 km in the thermosphere indicate a 30% decrease in the temperature and a 3X decrease in the density of the thermosphere near the altitude where both the Upper Atmosphere Research Satellite (UARS) and Hubble Space Telescope are flying. Decrease of the orbital period of the UARS shows the expected effect of decreasing density at flight altitude. Work in progress indicates that the output change results from the decline in solar magnetic flux to a lower level of activity in the southern hemisphere of the Sun.

1. Introduction

From February to May 1992, the radiative output of the Sun declined from a period of high solar activity to a lower level associated with the change in activity in the southern hemisphere of the Sun. This change occurred during the Upper Atmosphere Research Satellite (UARS) mission which is routinely measuring the total irradiance and the UV spectral irradiance from 117 to 420 nm. Thus we have absolute measurements of the solar output measured together with the traditional indicators of solar activity such as CaII K, 10.7-cm radio flux, and GOES X ray flux, for example. Furthermore, the solar change is large enough and has been sustained long enough to produce changes in the thermosphere that are of diagnostic value in understanding solar-terrestrial coupling. Here we make a preliminary report of the solar change and its effect in the thermosphere as shown by orbital properties of the UARS satellite. Research is now under way to relate this change to variation in solar magnetism and the total radiative output.

2. The Observations

All indices of solar radiative output examined thus far from 1-Å X rays to the 10.7-cm radio flux show the decline is 1992. To place this event in the context of the solar cycle as measured by the CaII K index and 10.7-cm radio flux, we show these two indices for cycles 21 and 22 in Figure 1. These data are from the long-term study of solar variability at the National Solar Observatory [*White et al.*, 1991] and the Dominion Radio Astrophysical Observatory [*Tapping and Charrois*, 1992]. These indices describe variability in the radiation from the solar chromosphere and transition region. Figure 1 shows that similar decreases in radiative output occurred late in cycle 21, but they appear to have been shorter-lived. Of events of this type, the 1992 decline is the best observed in terms of the change in irradiance; therefore its study is potentially the key to understanding those in the past. We note that the solar output has not yet declined to radiation levels characteristic of solar minimum.

The observations from the SOLSTICE instrument on UARS provide new data on variability of the Sun's UV spectrum between 120 and 420 nm beginning on October 3, 1991. These measurements show the rapid decline of solar UV radiations from February 1992 to June 1992 as reported by *White et al.* [1992]. The 170-300 nm band controls ozone chemistry in the Earth's atmosphere, and the solar change will effect the solar input boundary condition for ozone equilibrium during this time.

To illustrate the general nature of this solar change, we plot several different measures of irradiance and solar activity in Figure 2. After scaling and shifting these data to fit on a single plot, we show the SOLSTICE irradiance observations of the integrated intensity in Lyman α (121.6 nm) together with the 10.7-cm, GOES X ray, MgII core/wing ratio, and geomagnetic A_p records for 1991-1993 [*Donnelly et al.*, 1993; *Tapping and Charrois*, 1992; *White et al.*, 1992]. These data from independent sources illustrate the reality of the decrease in radiation from different parts of the solar atmosphere, while the geomagnetic signal displays typical sporadic behavior without any obvious change corresponding to the radiative change. The quasi-periodic variation in

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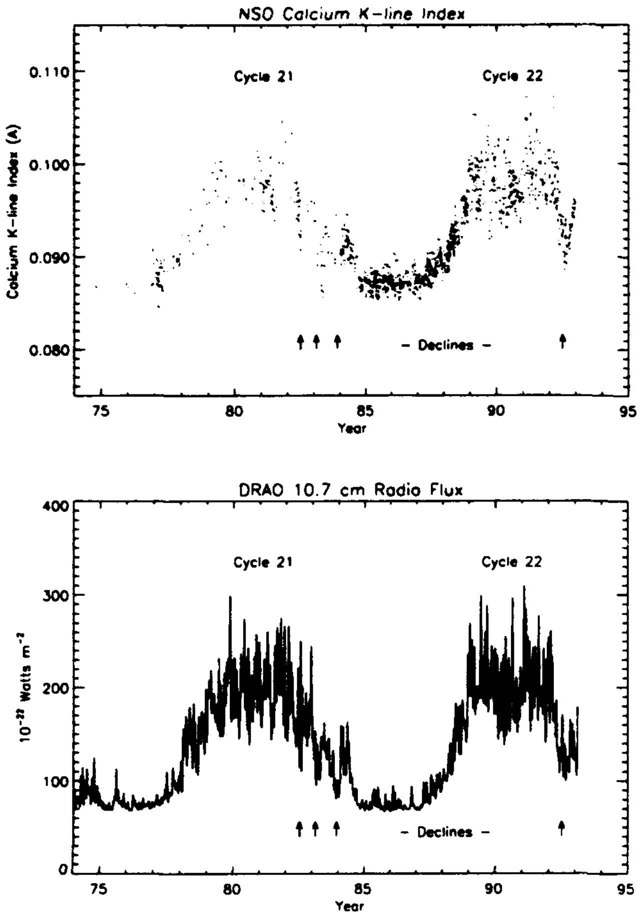

Figure 1. Irradiance history of the sun for cycles 20, 21, and 22 as shown by the 10.7-cm radio flux measurements from the Canadian Dominion Radio Astronomy Observatory [*Tapping and Charrois*, 1992] and the CaII K index data from the U.S. National Solar Observatory [*White et al.*, 1991]. These two indices measure variability of the radiation from the solar chromosphere.

the radiative signals is the solar rotational modulation due to the apparent motion of active regions across the solar disk as the Sun rotates. Superimposed on this oscillatory pattern is the radiative decline, which began after the strong peak in February 1992 and apparently ended in June 1992. The 27-day modulation continues after the decline with a smaller amplitude and a lower mean level. These data suggest that the sun readjusted to a lower level of magnetic activity on perhaps a "global" scale. Work in progress by K. L. Harvey and O. R. White (unpublished data, 1993) shows that the principal cause of the radiative change occurred in the southern solar hemisphere, where the amount of magnetic flux emergent in the photosphere decreased 2X at this time.

To give a more quantitative picture of the degree of change in radiative output, we list in Table 1 the changes in mean levels before and after the decline for the various measures shown in Figure 2 and in addition the CaII K index. We give the mean intensity levels for December 1991 to March 1992 and for June 1992 to January 1993 as well as their ratios for Lyman α, GOES X ray, 10.7 cm, CaII K, MgII core/wing index, and A_p.

3. Thermospheric Effects

With a solar change of the scale observed in 1992, a sustained effect on the temperature and density of the thermosphere is expected. The new Lyman α data from UARS are highly correlated with the EUV emissions below 50 nm that heat the thermosphere. See *Roble* [1987] for data on sensitivity of the thermosphere to EUV radiation. Both UV and EUV emissions follow the degree of solar activity, but the range of variability is much larger for the EUV spectrum [e.g., *Lean*, 1987].

To estimate the thermospheric change, we followed *Prinz et al.* [1992] and used the mass spectrometer and incoherent scatter model (MSISE-90) [*Hedin*, 1991] to estimate temperature and density near the altitude of UARS for the 1992 period of interest. The MSISE-90 model is an empirical model derived from lidar experiments relating the 10.7-cm radio flux and the A_p geomagnetic index to the physical and chemical compositions of the thermosphere. Results of our calculations of modeled global mean temperature and density at 600-km altitude are shown in Figure 3. The estimated mean temperature at this altitude decreased from 1200 to 900 K, while the mean density decreased from 6×10^{-13} to 2×10^{-13} kg/m^3.

The Hubble Space Telescope and UARS are flying near 585 km; consequently, this solar-induced change affects these spacecraft by modulating atmospheric drag. Available data on the UARS illustrate the effect of variable solar radiation on the orbit of a large satellite. Figure 4 shows the orbital period, the orbital period decay rate for UARS, and the Lyman α irradiance from launch through the beginning of 1993. Figure 4a is a plot of the measured orbital period showing both the periodic hydrazine burns to reboost the satellite and the steady decline in the orbital period between the reboosts. The circled points in Figure 4a mark the time and orbit period during the reboost, and the arrows mark the

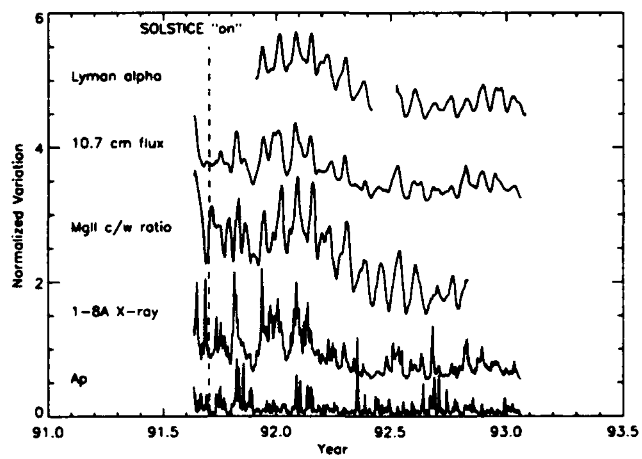

Figure 2. Comparison of the SOLSTICE Lyman α, 10.7-cm radio flux, NOAA (SBUV2) MgII core/wing index, GOES X ray flux, and A_p geomagnetic activity index for the duration of the UARS mission. Data source: UARS project and the World Data Center, NOAA. The radiative indices shown here reflect variability from the solar chromosphere into the corona associated with active regions, while the A_p geomagnetic index refers to variability in the Earth's magnetic field due to changes in the magnetic coupling of the Sun and the Earth.

Table 1. Change in Mean Intensity Levels

Measurement	Mean Before Decline, Dec. 1991 to March 1992	Mean After Decline, June 1992 to Jan. 1993	Ratio, After/Before	Estimated Intensity at Solar Minimum
Ly 121.6 nm, mW/m^2	8.4	7.2	0.86	5
MgII core/wing 280 nm, Å	0.280	0.271	0.97	0.264
CaII K 393 nm, Å	0.098	0.093	0.94	0.086
10.7-cm flux, 10^{-22} W/m^2	202	130	0.654	68
GOES X ray 1–8 Å, W/m^2	1.34×10^{-5}	0.525×10^{-5}	0.392	0
Geomagnetic A_p, 2 nT	24	18	0.765	0

time of the burn. The orbital period decay rate shown in Figure 4b (solid curve) is the negative first derivative of a spline fit to the orbit period data. We superimpose these decay rate variations on a plot of the SOLSTICE Lyman α irradiance time series (dashed line) to show the nature of correlation between orbital decay and chromospheric variability. The UARS orbital decay rate obviously follows the solar irradiance during its 1992 decline as well as some of the rotational modulation in the Lyman α time series. The lack of detailed correspondence results from the difference in variability of Lyman α and the EUV spectrum as well as from the effects of satellite operations, thermosphere response time, and particle injection from the magnetosphere.

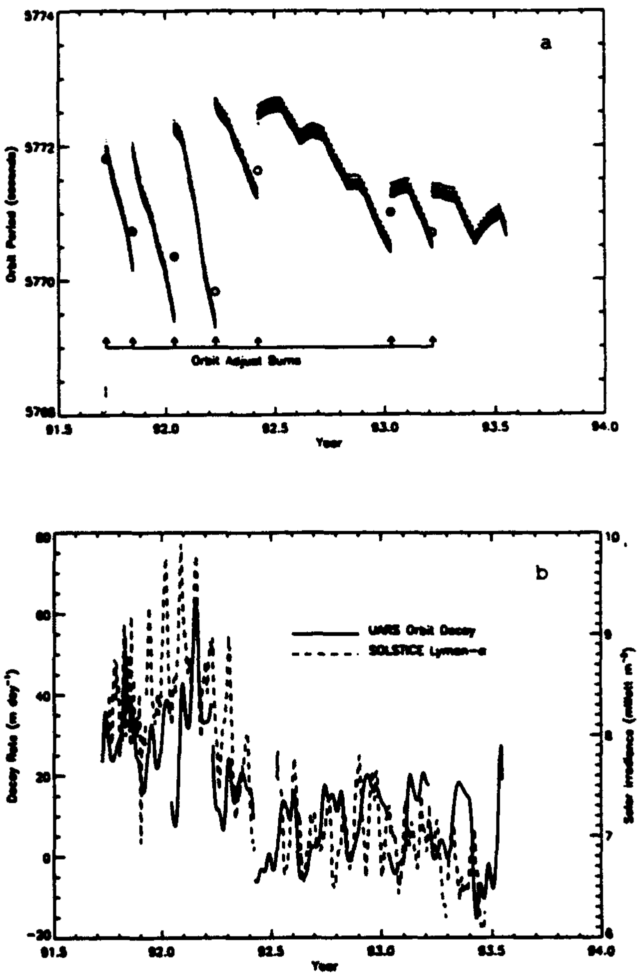

Figure 4. (a) Observed orbital period and (b) computed decay rate of the UARS for 1991–1993 together with the Lyman α irradiance from SOLSTICE. In Figure 4a we plot the measured UARS orbital period with its ± 1 sigma bounds together with indicators of the orbital "reboosts" (circled points). The feature of interest is the decrease in slope of the segments between reboosts. This decrease is due to the decrease in thermospheric density accompanying the decline in solar radiation. Figure 4b shows the decay of the orbital period as computed from the negative first derivative of a spline fit to the orbital period measurements plotted together with Lyman α measurements from SOLSTICE.

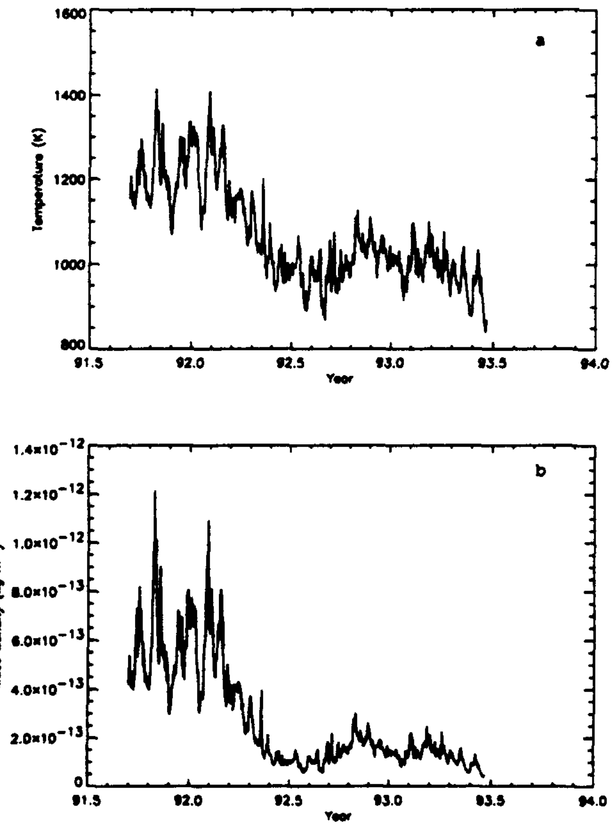

Figure 3. Variability of the global mean (a) thermospheric temperature and (b) density at 600-km altitude for 1991 to 1993 as computed from the MSISE-90 model [*Hedin*, 1991].

4. Discussion

From the solar physics perspective, we ask whether this decline is due strictly to a decrease in the number of active regions during this period or whether a more global change occurred on the Sun. Images in the HeI line at 1083 nm from the National Solar Observatory certainly suggest a decrease in the amount of absorbing plasma outside active regions, which incidentally also appear to be smaller and more compact. At the same time, the total emergent magnetic flux on the Sun decreased by a factor of 2 and has remained at such low values (K. L. Harvey and O. R. White, unpublished data, 1993). This demonstrates the close relationship between radiative energy losses in the outer solar atmosphere and the presence of photospheric magnetic fields linking the solar interior to the chromosphere. One important question is, What is the effect in the total irradiance? This question is under study using data from the Earth radiation budget experiment on Nimbus 7, the active cavity radiometer irradiance measurement on UARS, and the SA-VOS experiment on the European Recoverable Carrier satellite. All that can be said at this point is that an effect is present in the total irradiance and is on the order of 0.4 W/m^2.

A second question is the relationship between this change in solar output and similar ones occurring in the declining phases of solar cycles in the past. Do they mark a point in the solar cycle when a large-scale change in the topology of the Sun's magnetic field occurs during each cycle? [*McIntosh*, 1992].

For the thermospheric physicist, this change in the solar input to the Earth's atmosphere offers an opportunity to improve our grasp of the sensitivity of the upper atmosphere to solar forcing as solar activity declines in cycle 22. The size of the decline plus the persistence of the lower level of irradiance after June 1992 perhaps gives us the signature of a change between two equilibrium states in both the solar and terrestrial atmospheres.

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