SOLAR CONSTANT DATA FROM EARTH RADIATION BUDGET MEASUREMENTS

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ABSTRACT

At present, solar total irradiance measurements are made from four satellites using electrically self calibrating pyrheliometers, as a part of the earth radiation budget measurement programs. The Earth Radiation Budget mission onboard Nimbus-7 spacecraft (Nimbus-7/ERB) started solar total irradiance measurements in November 1978, and is still obtaining irradiance data on every orbit, daily. The Earth Radiation Budget Experiment (ERBE) solar monitors onboard Earth Radiation Budget Satellite (ERBS), NOAA-9 and NOAA-10 started solar total irradiance measurements in October 1984, January 1985, and October 1986, respectively. The ERBE solar monitors are active cavity radiometers of similar design and mode of operation to the Active Cavity Radiometer Irradiance Monitor-1 (ACRIM-1) operated onboard Solar Maximum Mission (SMM) during 1980-1989. In the past, the ERBE missions obtained solar total irradiance measurements biweekly, mainly for the calibration check of earth viewing ERBE sensors. But, after the loss of SMM/ACRIM-1 in December 1989, the solar total irradiance data are taken daily from ERBE onboard NOAA-10, and weekly from NOAA-9. Our knowledge of solar total irradiance and its variability has grown remarkably during the past few years, as a result of the above measurements, and the high precision data obtained from SMM/ACRIM-1. The results from a comparative study of the solar constant data available from the above missions will be presented. The solar constant value derived from the sensors agree within the uncertainty associated with absolute pyrheliometers available at present. An attempt will be made to correlate the solar irradiance variability with other solar parameters. The measurements from Nimbus-7/ERB started November 1978, as the solar cycle 21 was increasing in activity. The solar luminosity reached a maximum in the spring of 1979. The irradiance then decreased slowly to a minimum which lasted from 1984 through 1986. The irradiance is presently increasing towards a new maximum. It appears that the solar constant value follow an eleven year cycle.

INTRODUCTION

The solar constant of radiation, is the most important of all physical quantities because of its influence on the life in the solar system. By the term Solar constant, we infer the intensity of the solar beam, in energy units per unit area normal to the beam, and at earth's mean distance (one Astronomical unit). The Earth's weather and climate are determined by the incoming solar radiation, and its interaction with the atmosphere, land surface and oceans. The radiation balance or the net radiation at the top of the atmosphere, resulting from the radiative exchange between the incoming solar radiation and the outgoing earth emitted thermal radiation, is the central determinant of the earth's climate. The radiation balance (R) can be expressed mathematically as follows.

$$R = S (1 - A) - F \quad \text{-------->} \quad 1$$

where, S is the Solar Constant, A is the planetary albedo, and F is the thermal radiation emitted to space from the earth-atmosphere system. The absolute value of the solar constant, is the key term that determines the Earth's albedo and the radiation budget. The determination of solar constant and its temporal variations is one of the prime goals of climate research.

NIMBUS-7 Earth Radiation Budget Mission

The Earth radiation budget measurement programs determine the Earth Radiation Budget Components: the solar total irradiance, the earth reflected short wave, and the earth emitted thermal radiation. Because of its significance to weather and climate studies, the measurement of the Earth's radiation budget components from spacecraft platforms dates back to the early days of the NASA space program (House et al., 1986). The Nimbus-7/ERB, launched in November 1978, is the first ERB mission to make solar total irradiance measurements using an electrically self calibrating pyrheliometer (H-F or Hickey-Friedan sensor, also known as Channel 10C). The electrical self calibration provided an absolute radiance scale for comparison, while the cavity design reduced the sensitivity to degradation of the solar absorbing surface. The details of the sensor characteristics, data reduction and the results are published by Hickey et al, 1982, 1984, 1987), and by Hoyt and Kyle, 1990 (in this publication). The Nimbus-7 is a sunsynchronous polar orbiter, and the solar total irradiance measurements are made as the satellite crosses the southern terminator. There are 14 orbits in a day and the orbital period is about 104 minutes. The solar disk is completely within the field of view (10 degrees) of the pyrheliometer for about 175 seconds, during each orbit. During the first four years, the Nimbus-7/ERB solar sensor operated on a 3 days on, 1 day off, duty cycle. In later years, the sensor has operated on a full time basis. The solar total irradiance measurements onboard Nimbus-7 continue to the present day, and the data set used in this study cover a period of 11 years and 3 months. The mean value of 1371.89 W m-2 is derived from the Nimbus-7/ERB for the period November 1978 through February 1990.

The Earth Radiation Budget Experiment (ERBE)

The Nimbus-7 spacecraft, being a sunsynchronous polar orbiter, the earth radiant exitance measurements are confined to two local times, near noon and midnight; and the earth reflected data are confined to local noon only. This reduces the usefulness of the data for studies of the temporal variability of earth radiation budget components. The ERBE mission of the 1980's is designed to make improved measurements of the radiation budget components at various local times, to study the temporal and spatial variations of these components. In order to achieve this objective, the ERBE sensors make measurements from three spacecraft platforms: the National Aeronautics and Space Administration (NASA) Earth Radiation Budget Satellite (ERBS), and the two National Oceanic and Atmospheric Administration satellites NOAA-9 and NOAA-10, at different equator crossing times and orbital inclinations. The first of the three satellites carrying the ERBE sensors, the NASA ERBS, was launched into a 57 degree inclination orbit by Space Shuttle Challenger in October 1984. The NOAA operational meteorological satellites NOAA-9 and NOAA-10 were launched into near polar orbits in December 1984, and September 1986, respectively (ERBE Science Team, 1986). The ERBE solar monitors are identical electrically self calibrating pyrheliometers of active cavity type; and are similar in design and mode of operation to the SMM/ACRIM-1. In the ERBE measurement approach, the sun is allowed to drift through the field of view (13.6 degrees) of the solar monitors. The sensor characteristics, and mode of operation are given in detail by Lee et al (1987), and Lee (1990) in this publication. The Earth Radiation Budget Experiment (ERBE) sensor package consists of a solar monitor, and the earth viewing radiometers. The solar monitors make direct measurements of solar total irradiance, every two weeks, to provide data for earth radiation budget computations and to serve as a check on the radiometric calibration of earth viewing sensors. A mean value of 1365.15 W m^{-2} for is obtained from ERBS/ERBE for the period October 1984 through December 1989. NOAA-9/ERBE gives a mean value of 1364.75 W m^{-2} for the solar constant for the period January 1985 through August 1989. The solar total irradiance data from NOAA-10/ERBE are processed for a period of six months, October 1986-April 1987, and the mean solar constant value 1363.24 W m^{-2}, is obtained for this period. On April 1, 1987 the shutter mechanism of the solar monitor failed and the solar sensor remain open at all times. However, the solar total irradiance measurements are obtained daily from NOAA-10 spacecraft, from January 19, 1990, and from NOAA-9 every week.

Intercomparison of Solar Constant Data

Figure 1 shows the multiyear data set from the four satellites. The Nimbus-7/ERB solar data set covers a period of 11 years and 3 months (November 16, 1978 through February 1990). The SMM/ACRIM-1 data runs for a period of about 9 years from February 1980 through December 1988. The SMM/ACRIM-1 data is described by Willson et al (1984, 1988)) and Willson (1990) in this publication. The ERBS/ERBE data set is for a period of 5 years and 2 months (October 1984 through December 1989), while the NOAA-9/ERBE data covers the January 1985 through August 1989. It should be remembered that the data points consists of an average of 14 measurements per day for Nimbus-7/ERB; hundred of measurements for SMM/ACRIM-1, while ERBE measurements are the mean of two to three measurements on that particular day. The absolute calibration accuracy of the Nimbus-7/ERB Channel 10C, is quoted as +/- 0.5%, while the other experiments claim accuracy of 0.2% or better. The daily fluctuations in the irradiance values are observed in all the data sets. The maximum in the Nimbus-7/ERB irradiance value 1374.29 W m^{-2} occurs in March 1979, and shows a gradual decrease with time. It reached a minimum during 1984-1986 and then, increases gradually with time up to February 1990, the time the data sets are available at present. SMM/ACRIM-1 data set also shows a decreasing trend in irradiance values during 1985-1986, and then increases from the latter part of 1986. Both the ERBE measurements also show the decrease and increase observed for Nimbus-7/ERB and SMM/ACRIM-1. The increases and decreases are of the order of 0.1-0.2% (2-3 W m^{-2}). The NOAA-9/ERBE data shows more scatter than the other data sets. The results of an earlier intercomparison of the Nimbus-7/ERB, SMM/ACRIM-1, ERBS/ERBE, NOAA-9/ERBE, and NOAA-10/ERBE data sets are available in Mecherikunnel et al (1988).

Figures 2 and 3 present the monthly and yearly mean value of the solar constant respectively, for the same period as shown for the daily mean values. The monthly mean irradiance value shows the same increasing and decreasing trend in all the four data sets. The minimum in solar constant value occurs in 1984-1985 for Nimbus-7/ERB. The SMM/ACRIM-1 and ERBS/ERBE show the minimum during 1985-1986. NOAA-9/ERBE shows a decrease in irradiance with time during 1986 to 1987, and then shows the increase starting 1987. The anomaly observed in the NOAA-9/ERBE data set is caused by factors other than solar, and needs further investigations. (Mecherikunnel et al, 1990).

During the period 1985 through 1989 solar constant data are available from all four satellites for 71 days. It is to be considered that the data samplings vary for the 4 data sets. Table 1 lists the mean solar constant value, the standard deviation and the maximum and minimum observed during the 71 observation days. The solar constant value agree within the uncertainty associated with each solar sensor.

TABLE 1

SOLAR CONSTANT (IN W M^{-2}) FROM N-7ERB, SMM, ERBS AND NOAA-9 ON FOUR WAY MATCHING DAYS 1985-1989

SENSOR	SOLAR CONSTANT (MEAN VALUE)	STD.DEVIATION	MAXIMUM	MINIMUM
NIMBUS-7/ERB	1371.47	0.34	1372.24	1370.72
SMM/ACRIM-1	1367.16	0.40	1369.21	1366.54
ERBS/ERBE	1364.98	0.42	1365.91	1364.00
NOAA-9/ERBE	1364.61	0.85	1366.90	1363.07

Figure 4 presents the Nimbus-7/ERB yearly mean solar constant, and the yearly mean sunspot number. Yearly mean value closely follow the 11 year sunspot cycle, as shown in the figure. The sunspot cycle 21 began in June 1976, reached the maximum in 1979. Nimbus-7/ERB data shows the maximum value of solar constant in 1979 (March), and gradually decrease through the years reaching the minimum in 1984 with a gradual increase to 1990. But, the minimum of sunspot number occurs in 1986. It should be noted that the long term stability of the Nimbus-7/ERB data system is about 0.3 W m^{-2}. This is the first experimental evidence of an 11 year solar constant variability, which several investigators have speculated about for centuries.

Solar Total Irradiance Variability and the Extraterrestrial Solar Spectral Irradiance

The experimental results clearly indicate that there are fluctuations in the daily, monthly, and yearly mean solar total irradiance data. The irradiance variability follow the 11 year sunspot cycle as evidenced from

Figure 4. How do the observed variations in the total irradiance affect the spectral distribution of the total irradiance? The solar spectral irradiance variations in the UV and microwave regions are known and are being extensively studied. But very little is known about the variability in the visible and near infrared solar spectral region that contains more than 92% of the sun's energy. Almost all the radiation effects in the earth and atmosphere are wavelength dependent. Accurate data on solar constant and its spectral distribution in the UV, Visible, IR regions are important in understanding various interactions in the earth-atmosphere system. This is especially significant in the Earth Observation System (EOS) investigations.

CONCLUSION

The comparative study of the solar constant data from the recent spacecraft measurements indicate that the results are within the absolute radiometric accuracy of each sensor used in the measurements. The similar trends in solar irradiance variability is observed in all the data sets. The increases and decreases in the total irradiance observed are in step with the 11 year sunspot cycle. The results shows beyond any doubt that the variations observed are solar in nature. The Nimbus-7 ERB solar constant data set gives the first experimental evidence of an 11-year solar cycle in the total irradiance, analogous to the 11-year sunspot cycle.

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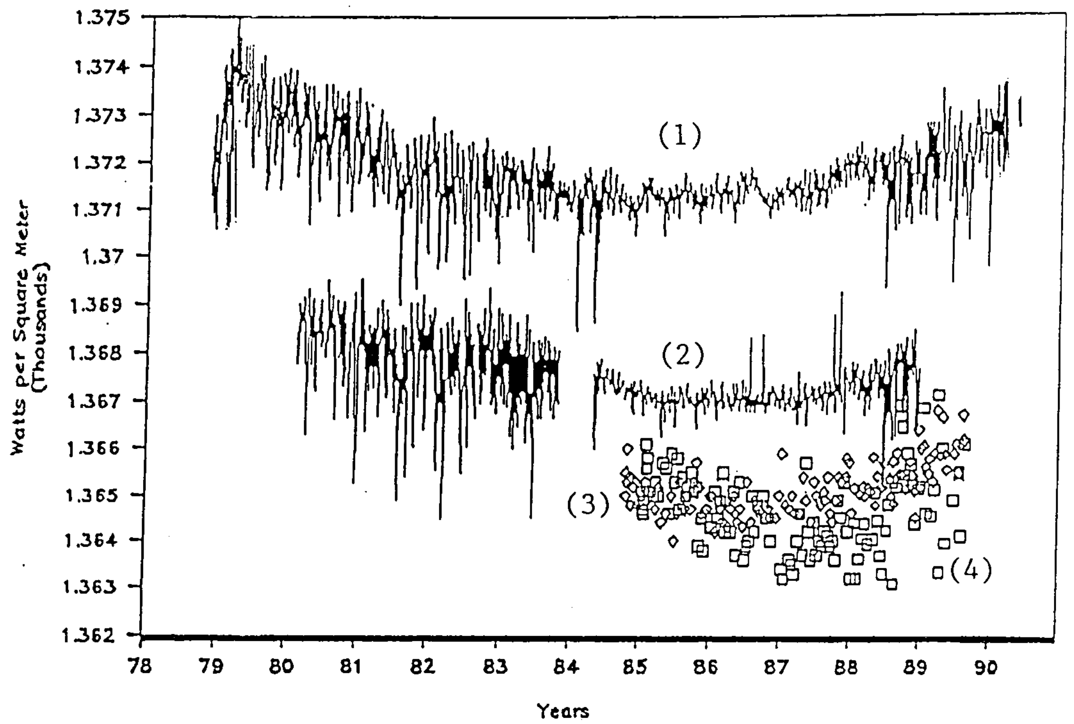

Fig. 1. Daily Mean Solar Constant from: 1) Nimbus-7/ERB Nov. 1978-Feb. 1990; 2) SMM/ACRIM-1 Feb. 1980-Dec. 1988; 3) ERBS/ERBE Oct. 1984-Dec. 1989; and 4) NOAA/ERBE Jan. 1985-Aug. 1989.

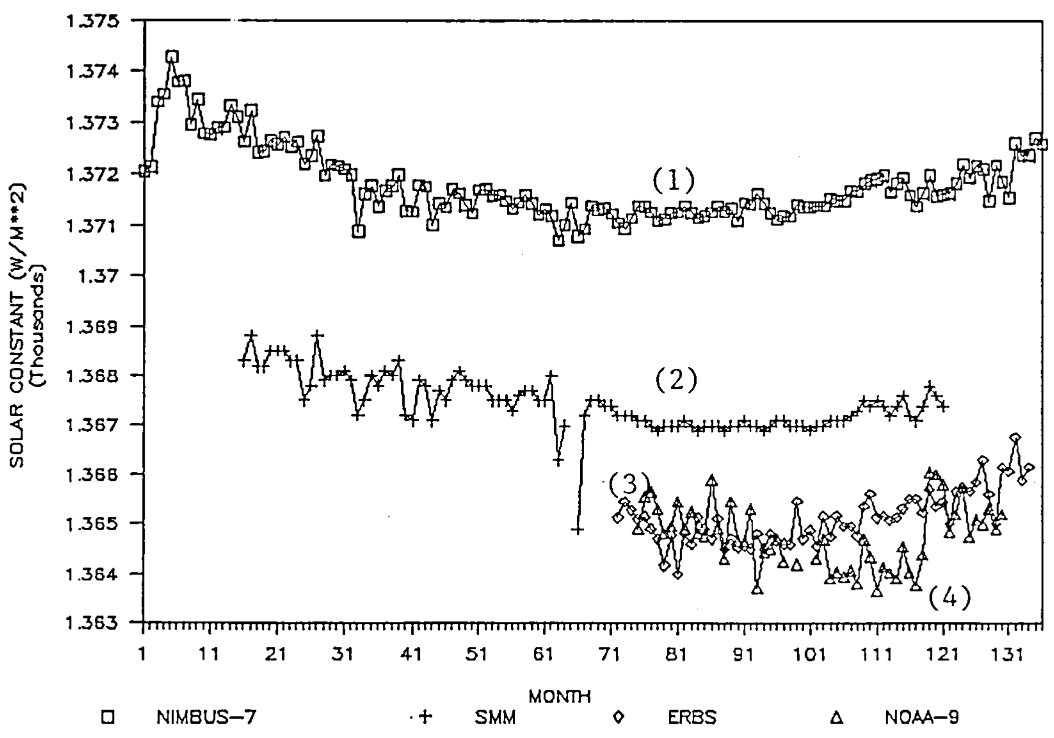

Fig. 2. Monthly Mean Solar Constant from: 1) Nimbus-7/ERB Nov. 1978-Feb. 1990; 2) SMM/ACRIM-1 Feb. 1980-Dec. 1988; 3) ERBS/ERBE Oct. 1984-Dec. 1989; and 4) NOAA/ERBE Jan. 1985-Aug. 1989.

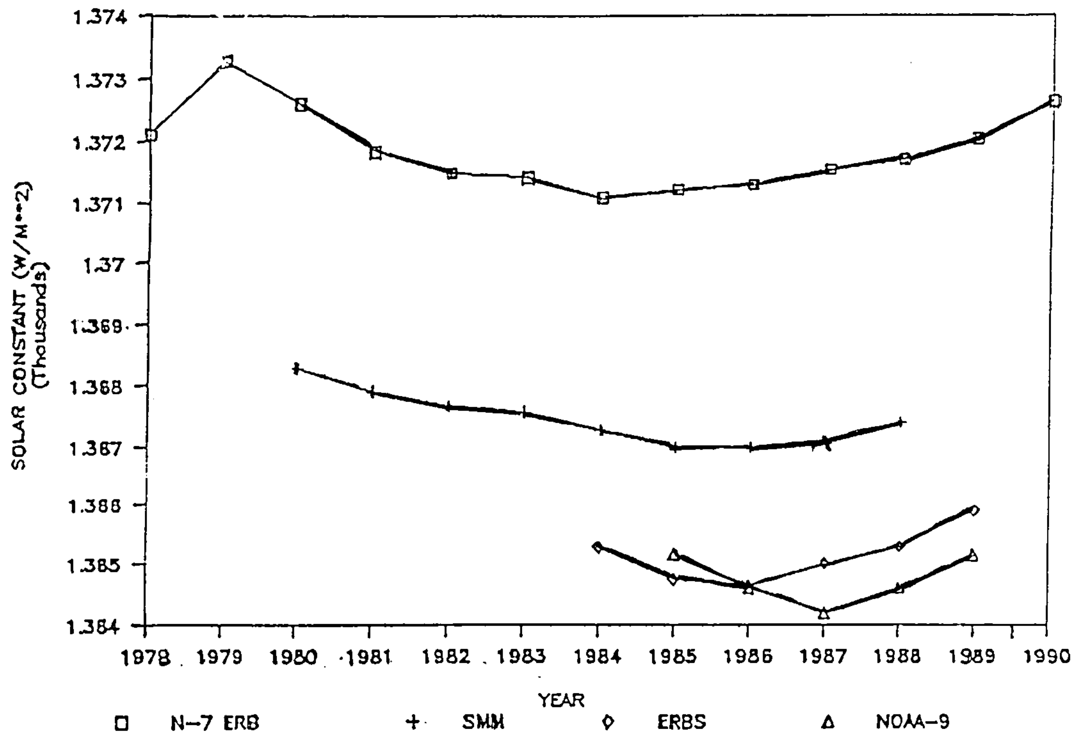

Fig. 3. Yearly Mean Solar Constant from: 1) Nimbus-7/ERB Nov. 1978-Feb. 1990; 2) SMM/ACRIM-1 Feb. 1980-Dec. 1988; 3) ERBS/ERBE Oct. 1984-Dec. 1989; and 4) NOAA/ERBE Jan. 1985-Aug. 1989.

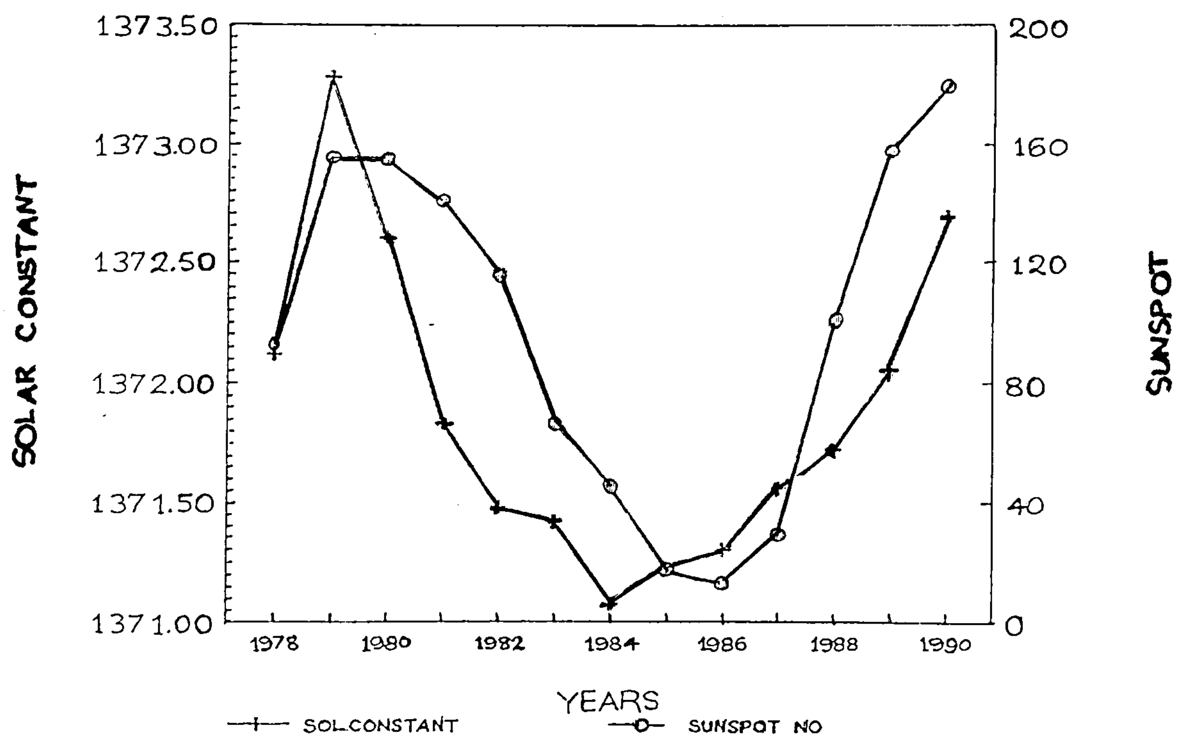

Fig. 4. 11-year Solar Constant Data from Nimbus-7/ERB and the 11-year Sunspot Cycle.