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THE VARIABILITY OF THE SOLAR OUTPUT *

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ABSTRACT

A review of recent solar constant determinations and measurements of its spectral distribution is presented. For the period from 1966 to 1980 a mean value of 1367 Wm^{-2} is determined. Within the corresponding uncertainty, no significant change of both, the integral value and the spectral distribution can be detected. However, shortterm solar variations and their spectral dependence have been deduced from measurements during four hours on June 20, 1980 from 34 km altitude with amplitudes of ±500 ppm at 368 nm, of ±200 ppm at 500 nm and ±150 ppm at 778 nm. C mparison with simultaneous total irradiance data of the Solar Maximum Mission (SMM) shows a high correlation which indicates the solar origin. The power spectrum shows a weak peak at about 3.2 mHz, which corresponds to the frequency of the 5-minutes solar oscillation.

INTRODUCTION

In the past years, many speculations have been made about the possibility of longterm changes of the solar constant, mainly for the explanation of the Earth's climate during the past 50 to 500 years (ref. 1 and 2). The response of the Earth's temperature, which is one parameter of the global climate to a change in the solar constant, is only of about 1° for a one percent change (ref. 3). Since measured changes in the Earth's temperature are of the order of a few tenths of a degree, the solar constant should be monitored to better than about one or two tenths of a percent in order to establish or prove experimentally this response. Such an accuracy is now achieved by the best radiometers, developed in recent years. Unfortunately, the period, during which such accurate measurements are available is too short to establish such a relationship from measured data.

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Up to now, only energetic considerations have been taken into account. Changes of the solar output are most probably wavelength dependent. This is confirmed by the detected variability of the extreme ultraviolet and the ultraviolet (ref. 4, 5 and 6). However, no evidence of any variability in the blue, the visible and the near infrared part of the spectrum has been found. This is mainly due to the few measurement periods and to the fact that spectral instruments measure much less accurately than total radiometers. Only recently, spectral measurements from stratospheric balloons have shown the wavelength dependence in the energetic bulk part of the spectrum of the solar output, at least during short period variations.

VARIABILITY OF THE SOLAR CONSTANT

Reviews of the solar constant determinations up to the late sixties (ref. 7) and for more recent measurements (ref. 8) have been written. The results are shown in table 1 and figure 1. All results have been reduced to a common radiometric reference, the World Radiometric Reference (WRR), in order to ensure comparability and temporal homogeneity of the record. Usually, the reduction is based on results of direct comparisons between flight instruments and an instrument, directly traceable to WRR. However, it has been found, that the sensitivity of radiometers can be influenced by air pressure and thus may yield different results on ground and in space. Therefore, the results of ground-based comparisons cannot always be used for the reduction of the results to WRR. This is the case for the ACR and ACRIM type instruments of Willson (ref. 9), for SMM results and for the first rocket flight in 1978, when a hard vacuum was maintained during the measurements. These two results are directly based on their individual electrical calibration as indicated in table 1 and figure 1. As the WRR is representing the

Date	Platform	Instrument	Radiometric Reference	Solar constant value (Wm^{-2})
8/1969	Balloon	ACR 111	WRR	1369
6/29/1976	Rocket	ACR 402A	ACR	1368
11/16/1978	Rocket	ACR 402A	WRR	1365
6/14/1979	Balloon	PMO6-9	WRR	1366
5/22/1980	Rocket	ACR 402A	WRR	1365
6/20/1980	Balloon	PMO6-9	WRR	1367
2-7/1980	Satellite	ACRIM A	ACRIM	1368
			mean	1367
			Standard Deviation	1.6

Table 1: Summary of revised solar constant determinations from 1969 to 1980.

SI-units within ± 0.3% and as the absolute accuracy of the ACR and ACRIM is in the order of ± 0.2%, the comparability with WRR values is at least within these limits, although the results indicate that it is probably better. During the other two rocket experiments, no vacuum was present, hence the results of the ground comparisons can be used.

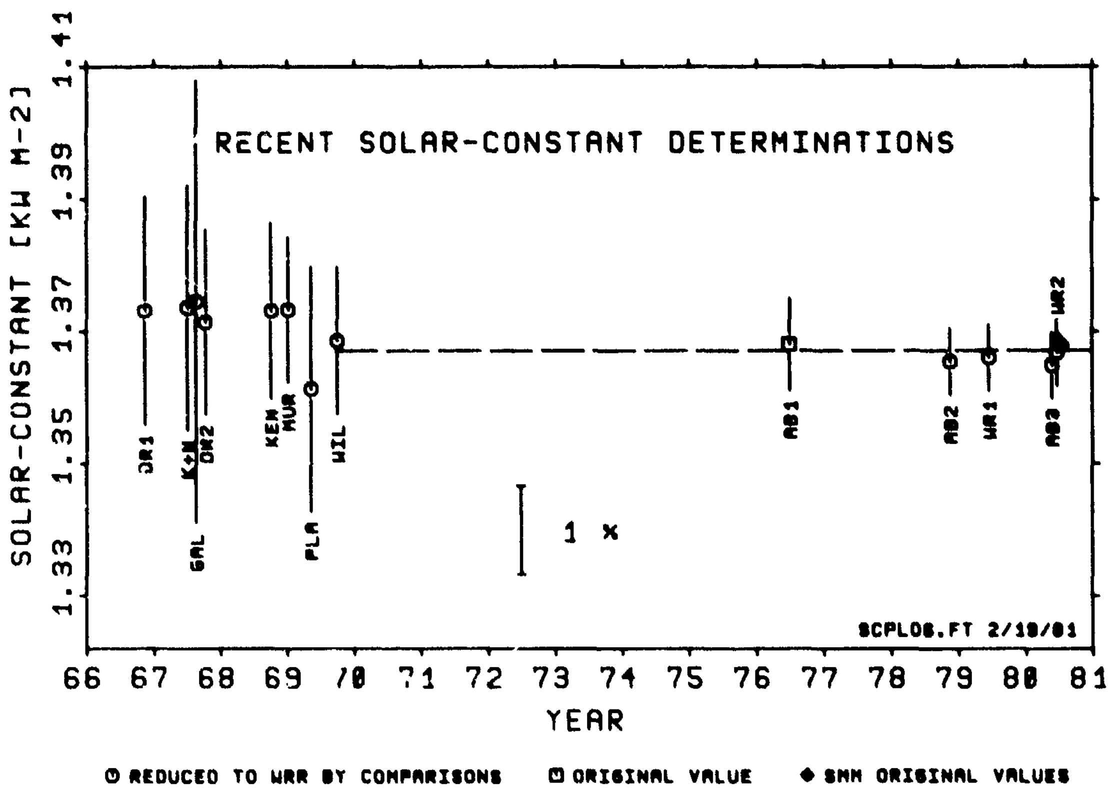

Figure 1: Recent solar constant determinations: DR1: Airplane, Drummond et al (1968); K+N: Balloon, Kondratyev and Nikolsky (1970), GAL: Airplane, Thekaekara et al (1969); DR2: X-15 Rocket aircraft, Drummond et al (1967); KEN: Airplane, Kendall (1973); MUR: Balloon, Murcray et al (1969); PLA: Mariner Satellite, Plamondon (1969); WIL: Balloon, Willson (1973); AB1: Rocket, Duncan et al (1977); AB2: Rocket, Willson (1980); WR1: Balloon, Brusa and Fröhlich (1980); AB3: Rocket, Willson (1980); WR2: Balloon, Brusa and Fröhlich (1981), SMM: Satellite, Willson (1981). (Detailed references can be found in ref. 7 and 8).

No significant change can be detected from the results of the period from 1969 to now: within ± 2 Wm^{-2} or ± 0.15 % the solar constant stayed constant. Although the values for the period before 1969 suggest a slight decrease, the uncertainties of these results are too large to render such a conclusion significant. However, one could speculate and try to explain the decrease of the mean global temperature since the forties with a change of 0.1° per decade, by a decrease of the solar constant of 0.05% per decade, taking the data from 1966 to 1980 of figure 1.

VARIABILITY OF THE SOLAR SPECTRUM

Neckel and Labs (ref. 10) show that the accuracy of their revised spectrum is such that it can be used as a reference or baseline for the sixties, when their measurements were performed. Unfortunately, no other determinations with a similar accuracy and coverage have been made in the meantime. Only some values at a few distinct wavelengths have been determined with sunphotometers from Mauna Loa in 1978 (ref. 11). These sunphotometers have been calibrated either by the laser-radiometer method developed by Geist (ref. 13) or against irradiance standard lamps. Comparisons with the original and revised Neckel and Labs data are shown in figure 2. The agreement is within ±2%. This is excellent, if one takes into account the difficulties of such measurements and their calibration. It demonstrates also the improvement of the Labs and Neckel spectrum by using more accurate limb-darkening data. But due to the uncertainties involved, no conclusions can be drawn about a possible change from 1965 to 1978.

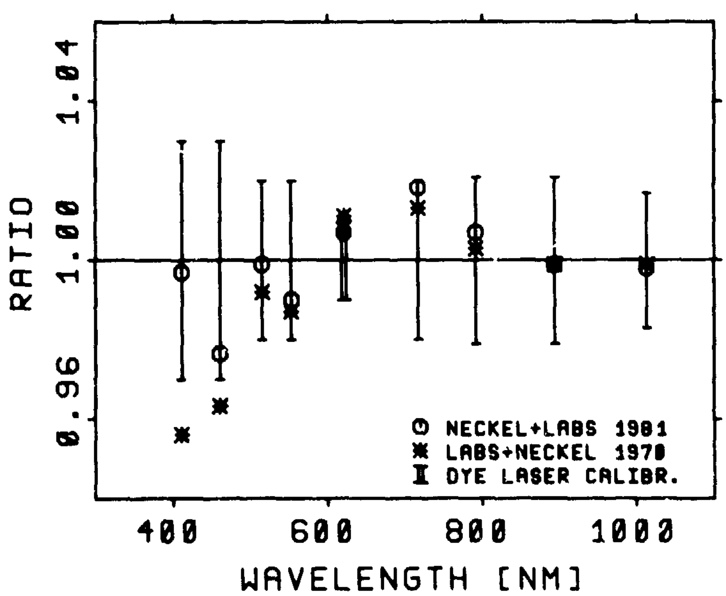

Figure 2: Comparison of Labs and Neckel (ref. 12), Neckel and Labs (ref.10) and Shaw and Fröhlich (Ref. 11) spectral irradiance data.

During the balloon experiment in June 1980, Ch. Wehrli of our institute has flown sunphotometers with centerwavelengths at 368, 500 and 778 nm and bandwidths of 5 nm. Preliminary results of the dye laser calibration of the 500 nm instrument yield a value of about 2% lower than the corresponding Neckel and Labs value. The value is just within the limits of the stated uncertainties and no conclusion about any longterm change can be drawn. On the other hand, the precision of the sunphotometers is so good that they can be used to monitor the solar output with a very high resolution during the few hours of the balloon flight. The result for the shortterm variability is shown in figure 3. Most important is the high correlation between the three wavelengths, which indicates the solar origin of the variability, because the three instruments are operated separately. To further exclude the possibility

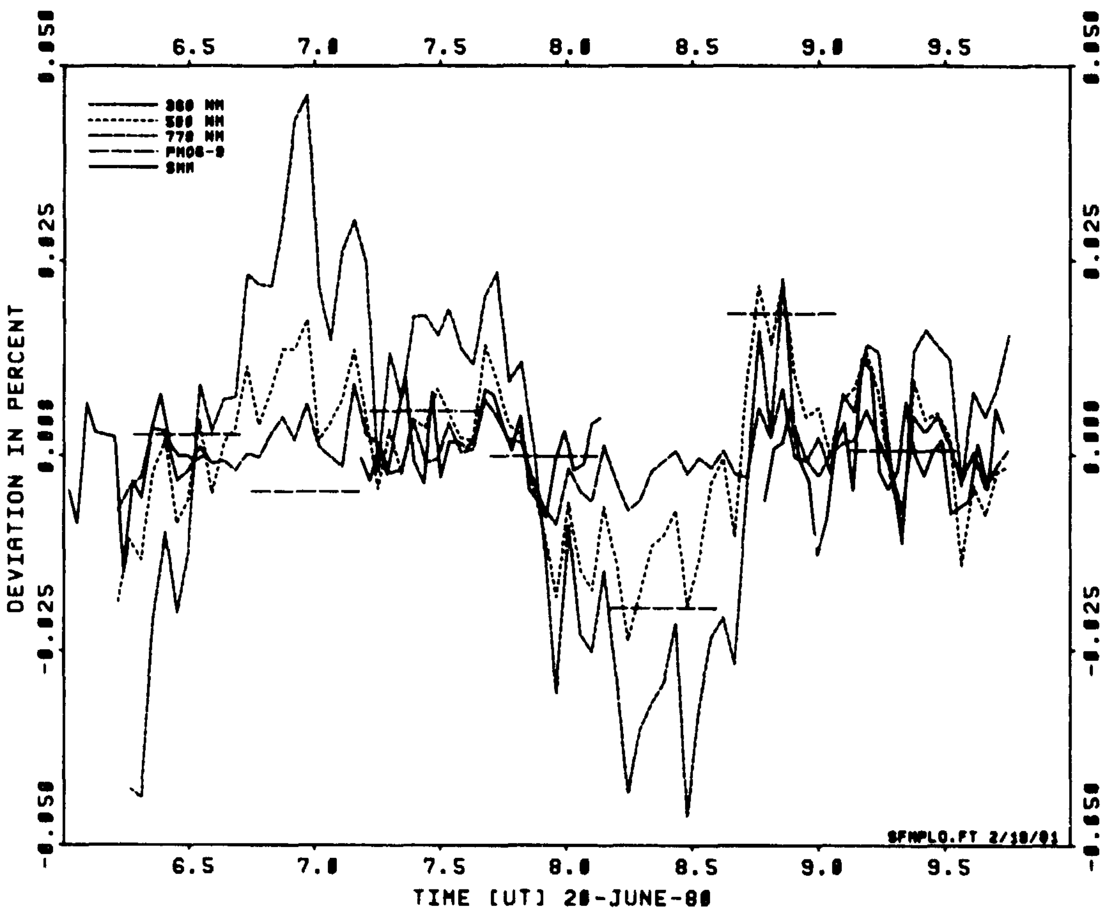

Figure 3: Shortterm variations of the solar output measured from a balloon at an altitude of 34 km with sunphotometers at 368, 500 and 778 nm and an absolute radiometer PMO6-9, compared to ACRIM radiometer data of SMM satellite.

of an instrumental, tracking or atmospheric influence, these results are compared with simultaneous measurements from the Solar Maximum Mission (SMM) total irradiance sensor ACRIM (*). Due to orbital restrictions, the SMM results cover only part of our records and unfortunately, only those with the least variation. But they do correlate very well, so that the solar origin of the variations is highly probable. Also the amplitudes compare well: as the solar spectrum is divided into two energetically equal parts at a wavelength of about 725 nm, the ACRIM amplitude is expected to lie somewhere between the amplitude of the 500 and the 778 nm record, which it does. Further analysis of these results are in course, but already these preliminary data reveal with a high degree of confidence for the first time the spectral dependence of the solar variability: the amplitude at 368 nm is more than double the amplitude at 500 nm, which in turn is about 1.5 times the amplitude at 778 nm or about 1.2 times the amplitude of the total irradiance variation measured from SMM.

The power spectrum analysis of the data show three major peaks for all three wavelengths at periods of 19, 6.5 and 5.2 minutes (figure 4). The last

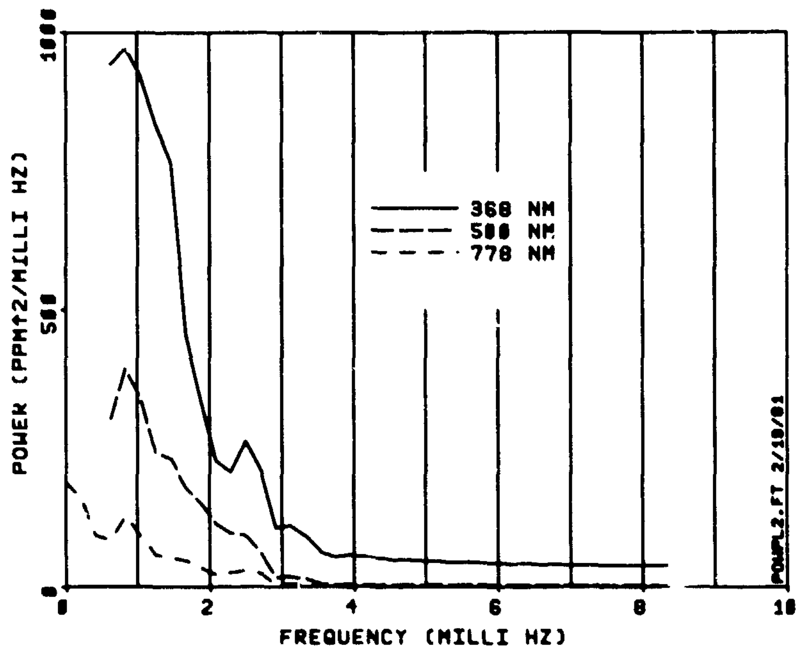

Figure 4: Powerspectrum of the shortterm variation of the solar output at 368, 500 and 778 nm.

(*) Willson, R.C.: Preliminary data of SMM ACRIM, private communication, 1980.

peak, although very weak, may indicate the intensity variation due to the 5-minutes solar oscillation. However, the sampling of two minutes is just marginal to detect this kind of variation. At least some of the variability could be due to the high activity of the sun during this period and thus bury more or less the amplitude of the 5-minutes oscillation.

CONCLUSIONS

The results of the analysis of the solar constant determinations reveal no indication for any significant change from 1966 to 1980. Unfortunately no data exist for the period from 1969 to the solar minimum. Hence, the question still remains, whether the total solar irradiance is changing with the solar activity cycle. The analysis of the available spectral data yields the same result but with less confidence, due to larger uncertainties.

A shortterm solar variability has been detected with amplitudes in the order of 100 - 500 ppm, which show a strong wavelength dependence, with an increase of a factor of three from 778 to 368 nm. Thus the measurement of these shortterm variations and their spectral distribution is capable to yield important information about solar variability and its spectral behaviour.

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