Reports

Initial Solar Irradiance Determinations from Nimbus 7 Cavity Radiometer Measurements

Abstract. *Preliminary results from solar radiation measurements from the earth radiation budget experiment on the Nimbus 7 satellite yield a mean value of 1376.0 watts per square meter for the "solar constant" from 16 November 1978 to 15 May 1979. The observed variability (root-mean-square deviation) is ± 0.73 watt per square meter (± 0.05 percent) for the period.*

The climate of the earth depends critically on the radiation received from the sun. Climate models have shown (*1*) that a 1 percent change in "solar constant," defined as the energy per unit time and per unit area at the mean earth-sun distance, would result in a warming or cooling of the global climate of approximately 1°C. A number of experiments are being conducted to monitor solar variability during the solar maximum period. We present here preliminary results from one of these experiments.

Our solar radiation results are derived from a self-calibrating cavity radiometer, which is one of the sensing channels of the earth radiation experiment (ERB) instrument aboard the Nimbus 7 satellite. This device (*2*) is the first of its type to acquire high-precision, nearly continuous data from an earth-orbiting platform over an extended period of time. Earlier measurements, except those reported for Mariner 6 and Mariner 7 (*3*), have been periodic or limited to high-altitude platforms still below part of the atmosphere. Frohlich (*4*) has summarized these earlier measurements. Willson and Hickey updated the review (*5*) through the solar constant rocket experiment (*6*) of 1976. We report here the preliminary results from the latest determination; this analysis covers the period from 16 November 1978 through 15 May 1979. The instrument is still functioning at this time (January 1980). The reason for the qualification "preliminary" is described below.

The basic sensing element of the radiometer is a toroidal plated thermopile to which a cavity receiver is affixed (*7*). The cavity is composed of an inverted cone within a cylinder, the interior of which is coated with a specularly reflecting black paint. The absorptivity of the unit is estimated as 0.999 for the solar spectrum. A precision electrical heater, attached to the cavity assembly, is turned on about once every 2 weeks during calibration sequences while the instrument "views" deep space. The sensor output is sampled once each second when the experiment is in its operational mode, which is 3 out of 4 days as required by the spacecraft on-off schedule.

The radiometer has a 10° field of view which allows the sun to fully irradiate the cavity for about 3 minutes of each 104-minute orbit. The angular response is a cosine function. This has been proved during flight by monitoring the off-axis response relative to the on-axis solar signal. The off-axis angle is sensed by the digital solar aspect sensor, which is part of the satellite's attitude control system. This sensor does not experience the off-axis effects that occurred on Nimbus 6 because of an improved baffle design. Although the adherence to cosine response holds over the entire 10° field, the measurements are generally selected for an off-axis less than 0.5°. The maximum irradiance observed during each orbit should be in error by no more than 0.01 percent as a result of off-axis effects. The zero level irradiance is sensed while viewing space before and after each solar measurement and is subtracted from the solar observation to yield the net thermopile signal. The solar irradiance is calculated by applying the temperature-corrected sensitivity value to the net thermopile signal. The sensitivity values are derived in space by the use of the self-calibration capability described earlier. The small temperature correction adjusts for the difference between calibration and measurement temperatures (*8*). The solar constant value is then computed by applying the earth-sun distance correction to the measured irradiance to normalize the data to mean distance.

The radiometer has been very stable over the first 6 months of operation. The power of the cavity heater has remained stable to within 0.2 percent of the mean value (Table 1). The sensitivity of the device has remained stable to 0.16 percent of the mean value after correction for temperature variations. The sensitivity determinations depend on these quantities during the in-flight calibrations. The three pertinent readings are heater current, heater voltage, and the thermopile signal. During solar measurement the thermopile signal is the single sensed value.

The noise equivalent irradiance is estimated to be 0.024 W m^{-2}, which is well below the resolution capabilities of the Nimbus ERB data system. One digital count of signal is equivalent to 0.77 W m^{-2}. Performance is limited by the analog-to-digital converter to ± 0.5 count. Thus the uncertainty due to this limitation is 0.54 W m^{-2}, which is about ± 0.04 percent of the signal during the solar measurement. During calibration, the same limitation applies to the current and voltage readings, yielding uncertainties of 0.025 percent of their full-scale values.

Table 1. Cavity radiometer in-flight calibration information.

Orbit	Date	Temperature (°C)	Heater power (mW)	Irradiance sensitivity (count W^{-1} m^{-2})	
				Uncorrected	Corrected to 0°C
323	16 November 1978	20.0	68.316	1.2975	1.2791
630	8 December 1978	21.3	68.228	1.2999	1.2803
947	31 December 1978	23.5	68.210	1.3006	1.2790
1554	13 February 1979	23.7	68.210	1.3022	1.2805
1775	1 March 1979	23.7	68.176	1.3027	1.2809
2374	13 April 1979	21.4	68.280	1.3007	1.2811
2930	24 May 1979	22.3	68.280	1.3007	1.2802
Mean			68.243	1.3006	1.2802
Maximum spread			0.20%	0.25%	0.16%

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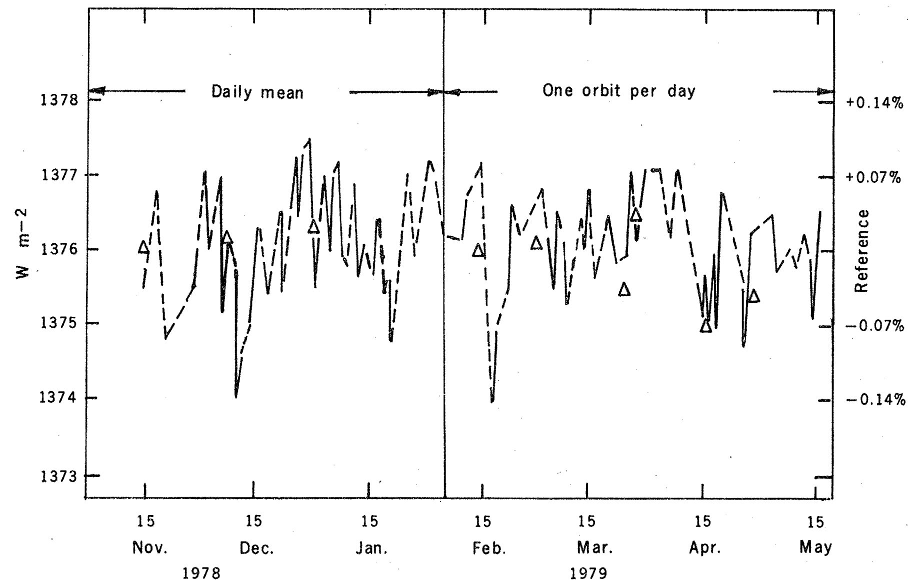

Fig. 1. Daily observations of the solar constant. The right ordinate is the percentage deviation from the mean value of 1376.0 W m^{-2}.

The absolute accuracy of the radiometer has been estimated to be better than 0.5 percent. This estimate includes errors in the heater power measurement and errors associated with the nonequivalence terms, which establish the relationship of the response to the heater to radiative measurements of the solar radiation. The analyses (not presented here) are confirmed at the stated level by intercomparison with other self-calibrating pyrheliometers (*6*) which constitute a basic set. Comparisons traceable to the World Radiation Reference have also been performed. The difficulty in performing such intercomparisons between a spacecraft instrument and a standard pyrheliometer accounts for the conservative estimate of absolute accuracy. The detector may have an accuracy as low as 0.2 percent in this mission.

Cavity radiometer measurements and data from other ERB channels are telemetered to the NASA Goddard Space Flight Center in Greenbelt, Maryland, where they are stored on magnetic tape for future processing into calibrated scientific data tapes. The only data immediately available for analysis were generated by a statistical engineering program and are referred to as the engineering data set. Before 4 February 1979, data were printed out for a number of orbits each day, but thereafter for only one orbit each day. The maximum signal measured by the cavity during each orbit is one of the quantities contained in these data and has been used to investigate the day-to-day variability of the solar constant.

During the first 6 months, another program was used to display all telemetered data for nine special calibration orbits. These data are referred to as the scientific data set. A detailed hand computation of the solar constant was carried out for each of the nine orbits. These values are of high quality since spurious signals have been eliminated and averages have been taken over a time interval containing the maximum signal.

The average value of the solar constant for the 6-month period derived from the engineering data was only 0.7 W m^{-2} (approximately one count) higher than the average derived from the scientific data. Consequently, all engineering data values have been lowered by 0.7 W m^{-2} to be consistent with the scientific data. All of the in-flight calibration data (Table 1) were obtained from the scientific data sets which are available for all calibrations. The consistency of the calibration results is within a maximum spread of 0.20 percent. The sensitivity values (Table 1) are calculated from the measured heater power and the thermopile signal. The temperature-corrected values show a maximum spread of 0.16 percent, which is 0.09 percent less than the range of uncorrected values. Since the spread in corrected sensitivity values is less than that of the heater power values, it is evident that thermopile signal contributes little to the uncertainty of the sensitivity.

The solar constant measurements are presented in Fig. 1. Values derived from the scientific data set are plotted as triangles. Daily values from the engineering data are plotted as points for each day that data were available. Solid lines connect data points for consecutive days, and dashed lines connect points separated by days without data. The mean value over the 6-month period is 1376.0 W m^{-2} with a root-mean-square deviation of $\pm$ 0.73 W m^{-2} ($\pm$ 0.05 percent) and a maximum range of less than 3.3 W m^{-2} (0.24 percent). Investigations are currently under way to determine if there are relationships with the indices of solar activity. A more precise and complete analysis will be performed when the scientific data tapes have been processed.

The observed solar constant is 0.66 percent higher than the average value of 1367 W m^{-2} reported for the cavity radiometers of the 1976 rocket flight (*6*). It is 0.15 percent higher than the value reported (*9*) for the 1978 flight. For the latter, R. C. Willson and J. M. Kendall have indicated an increase of 0.4 percent (*10*) from their 1976 results. They indicate a precision of 0.1 percent. Hickey has indicated an increase of from 0.3 to 0.6 percent for the same two flights. His precision was compromised by a minor instrument problem (*11*). This apparent increase is of interest because the comparison interval reaches from the minimum between solar cycles 20 and 21 and the period of increased activity before the peak of cycle 21. This series of rocket measurements made above the atmosphere with cavity radiometers beginning in 1976 indicates an increase in the solar constant with increasing solar activity during cycle 21. The value reported here falls within the range reported by Hickey (*11*) for the most similar instrument on the rocket for the data of the November 1978 flight.

It remains to examine the scientific data from this continuous experiment and the results of the upcoming rocket reflight in order to corroborate the indication.

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12. We are grateful to F. Griffin, R. Frieden, J. Gniady, J. Swedberg, S. A. Cone, L. Manello, and the NASA and General Electric personnel of the Nimbus ground station. We also thank O. R. White for his helpful comments and encouragement.

12 October 1979; revised 21 January 1980

Late Miocene Origin of the Benguela Upswelling System off Northern Namibia

Abstract. *Deep Sea Drilling Project cores collected at site 362/362A suggest the time of initiation of the Benguela upwelling system off northern Namibia. Studies of sediment accumulation rates, diatom abundances, microfossil temperature preferences (for planktic foraminifers, calcareous nannoplankton, and silicoflagellates), productivity (expressed as the organic carbon content), and phosphorus incorporation in calcareous skeletons all suggest that major, sustained upwelling began in the early late Miocene. Upwelling brought cold, nutrient-rich waters to the surface, and the modern Benguela system dates from this time (about 10 million years before the present).*

The Benguela upwelling system ("Benguela Current") is the northward-flowing, cold, upwelled water found within 100 nautical miles (1 nautical mile = 1852 m) of the west coast of South Africa and Namibia (South West Africa) between 15°S and 34°S (*1*) (Fig. 1). These cold, upwelled waters are extremely rich in phosphate, nitrate, and silicate—nutrients which support a vast population of phytoplankton. The abundance of phytoplankton, in turn, provides the basic food stock that makes this one of the world's richest fishing grounds. The purpose of this report is to suggest a time for the origin of the Benguela system.

Late Cretaceous (*2*), Eocene (*3*), or early Oligocene (*4*) have all been suggested or implied as possible times for the establishment of the Benguela system. Recent work on Deep Sea Drilling Project (DSDP) cores (site 362/362A) collected from the continental margin off northern Namibia indicates that strong, persistent upwelling of cold waters (that is, the present Benguela system) began in the early late Miocene. Evidence from sedimentological, micropaleontological, and geochemical studies supports this conclusion.

Site 362/362A (Fig. 1) is today under the influence of the Benguela system (*5*) and has been throughout all later Cenozoic time (*6*). Fossil skeletons of planktic organisms that once lived in the waters of the Benguela system now reside in sea-floor sediment; these sediments, and the fossils of which they are largely composed, record the history of changing conditions in the overlying water masses.

The onset or intensification of upwelling would bring more nutrients to the surface, thus promoting prolific plankton growth and ultimately an increase in plankton skeletons deposited as sediment on the sea floor. A major increase in pelagic-biogenic sediment accumulation may therefore reflect upwelling. Sediment accumulation rates for site 362/362A (Fig. 2) have been corrected for postburial compaction on the basis of measured downhole variations in porosity and gravimetric bulk density (*7*). Two major peaks of rapid sediment accumulation are apparent in Fig. 2: one in the mid-Oligocene and one in the late Miocene.

The very rapid accumulation in mid-Oligocene times reflects the enormous blooms of a single nannoplankter, *Braarudosphaera*. An interval more than 50 m thick is overwhelmingly composed of fragments of this single genus [up to 95 percent in some beds (*7*)]. The *Braarudosphaera* bloom was not a local event occurring solely off northern Namibia. This distinctive chalk also appears during the same time interval in the central and western South Atlantic [on the Mid-Atlantic Ridge and in the Brazil and Argentine basins (*7*)]. The enormous *Braarudosphaera* blooms at this time were probably a response to a regional South Atlantic oceanographic event. The nature and causes of this event are still speculative (*8*). However, we can be cer-

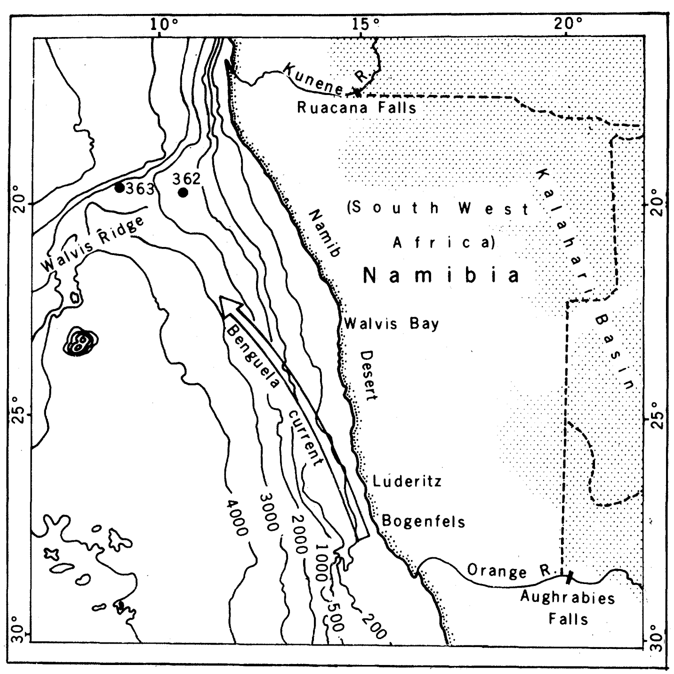

Fig. 1. Location map showing site 362/362A. Isobaths are in meters. The water depth at the site is 1325 m; the subsea-floor drilling depth was 1081 m.