CHANGE IN THE SOLAR CONSTANT BETWEEN 1968 and 1978*

John J. Kosters and David G. Murcray
University of Denver, Denver, Colorado, 80208

ABSTRACT

Solar irradiance measurements made from a balloon on January 27, 1978 and February 10, 1980 show a change of 0.4% over similar measurements made in 1968. This change is greater than the uncertainty of the measurement and is felt to be the result of a change in the solar constant.

INTRODUCTION

The question of the extent of variability of the solar "constant" is one that has been of interest for many years. Early attempts to assess the possible variability were limited by the large and variable atmospheric correction that had to be made to the ground-based observations used as a data base. During the 1960's several investigations were undertaken with the objective of obtaining a better measurement of the solar constant by making the observations from a high-altitude platform, i.e., aircraft or balloon (ref. 1-4). At that time we constructed a system for measuring the total solar irradiance from high altitudes using large balloons. This system was flown several times during 1967 and 1968. Once state-of-the-art measurements had been made, interest in the solar constant declined. It has been revived recently due to the current interest in climate and man's possible impact on climate. As a result of this renewed interest, we repeated measurements of the solar constant on January 27, 1978 and February 10, 1980. We used the same instrumentation for these measurements that was used in the 1967-68 measurements. The use of the same instrumentation for both series of measurements allows a direct comparison to be made of the results down to the level of repeatability of the instruments. This has been shown to be better than 0.1%. The recent measurements indicate that the solar irradiance above 30 km has increased by 0.4% over the value observed in 1967-68. In view of the measurement precision, it is felt that this change in irradiance is real and greater than can be expected due to a change in atmospheric transmission above the balloon. It is our opinion that the observed change is due to an increase in the solar constant.

INSTRUMENTATION

At the time our balloon-borne system was constructed two units were in common use for pyrheliometric measurements. These were the Eppley NIP thermopile unit and the Ångstrom-designed pyrheliometric unit. The Ångstrom unit

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was designed as an absolute unit; however, it was general practice at that time to calibrate all units against secondary standards. Because the thermopile units offered a significant number of advantages from the standpoint of unattended operation, they were chosen as the units to be used in our system.

Preliminary tests with the units as supplied by Eppley indicated that, to achieve the desired precision, extensive modifications would be required. Since the units were quite susceptible to any temperature gradients, it was necessary to place them in an isothermal enclosure in order to get stable outputs. The sensitivity of the units was also temperature dependent and, although some temperature compensation circuitry was included, it was not adequate for the precision sought in the measurement.

Rather than trying to control the temperature, we calibrated the units over the range of temperature in which they would be operated during the balloon flight. Thus, the final system consisted of the pyrheliometers, a voltage reference, a low-noise amplifier system, a digital magnetic tape recording system, and a biaxial pointing system capable of orienting the two thermopile normal incidence pyrheliometers toward the sun.

The gondola housing the various units also carried the balloon control instrumentation along with a silver-cadmium 28 vdc battery supply and an antifreeze solution, with pumps for circulating the solution through the isothermal enclosure. The output of the pyrheliometers, zero reference, and the standard cell voltages were sequentially fed to a low-noise amplifier by means of geneva gear movement which operated a low noise switch. Thus all voltages were processed by the same electronics. The instrumentation is described in detail in a previous report (ref. 5).

CALIBRATION

At the time this program started, all pyrheliometric measurements were being made using the IPS 56 scale. During the late 1960's, the active cavity radiometer system was being developed at JPL and, during the last decade, these units have been used to establish a new pyrheliometric scale which is slightly more than 2% higher than the IPS 56 scale. A discussion of these scales and the relations between them is given by Frohlich (ref. 6).

Since the measurements reported here are relative, all values quoted are in IPS 56 units. The units were calibrated using an Epply Ångstrom pyrheliometer (s/n 7010). All calibrations were performed either at Echo Lake on Mt. Evans, Colorado, or at Denver. The calibration at the two locations agreed to within the precision of the measurements for similar solar intensity values. The upper range of the calibration was performed at Echo Lake since the solar irradiance levels on a good day were higher than those measured at Denver. Over the range of solar irradiance values encountered during calibration, all units agreed to within ±0.10%.

When we proposed flying the system again, we were concerned that any change which we might measure would be attributed to a shift in calibration of the units during the time they had been in storage. When the units were compared, all units agreed to within the ±0.10% using the calibration factors as determined during the earlier calibration. There was no indication of any shift in any of the units.

RESULTS

As indicated above, the units were flown four times during 1967 and 1968. All flights were successful; however, one of the pyrheliometers had a poor pressure seal and the sensitivity changed with altitude. This caused considerable difficulty in interpreting the results until after the second flight, when the problem was located and corrected.

In addition, on all flights, as the units ascend and the solar irradiance exceeds the values for which the calibrations have been performed, the two units yield slightly different results. This is due to the slight nonlinearity in the thermopile outputs. Extrapolation of the calibrations using a linear extrapolation introduces a slight error. The error is different for the two units. Thus, the irradiance values measured with P2 at float altitude are 0.4% higher than those obtained with P1.

This divergence of the values obtained with the two units - when the solar irradiance exceeds the ground calibration - can be followed throughout the ascent, and the peak difference of 0.4% occurs at float. The 1968 values of the solar irradiance as measured by the two units were P1 = 1295 w/m^2 and P2 = 1301 w/m^2.

During the 1978 flight the two units again measured slightly different values since the same nonlinear effect was present. The solar irradiance as measured by P1 was 1300 w/m^2 and by P2 was 1306 w/m^2. The same values were measured on the 1980 flight. Thus both pyrheliometers show an increase of 0.4% in the solar irradiance between 1968 and 1978, with the value remaining the same between 1978 and 1980.

DISCUSSION

The measurements of solar irradiance made with these instruments can be interpreted in three ways:

1. The change between 1968 and 1978 reflects the precision of the measurement, possibly reflecting a shift in calibration between 1968 and 1978.
2. The change reflects a real change in the solar irradiance above 30 km, the change being due to an increase in the atmospheric transparency between 1968 and 1978.

3. The change reflects a real change in the solar irradiance above 30 km with the change being due to a change in the solar constant.

As noted in the discussion above, there is no indication of a change in calibration between 1968 and 1978. All ground calibrations indicate a precision of at least 0.1%. The flights made in 1967-1968 all yielded the same solar irradiance, the two flights made since 1978 yield the same solar irradiance which is 0.4% higher than the previous results. We feel that the first interpretation is not valid, and the data indicate a real change in solar irradiance above 30 km. The question of whether this change can be due to a change in atmospheric transmission above the balloon is not an easy one to answer. We argue against it on the following basis: at balloon altitudes and high sun, the residual atmospheric absorption reduces the solar irradiance by at most 2.5%. The majority of this absorption is due to ozone with smaller amounts due to Rayleigh scattering and infrared absorption by CO_2 and H_2O. Thus, in attempting to account for the 0.4% change in the solar irradiance by a change in atmospheric transmission, a change in ozone above the balloon appears to offer the only possibility. Calculations were performed using 0.065 atm cm of ozone, a secant factor of 1.4 and the solar spectral distribution curve of Thekaekara (ref. 7). The value used for the ozone amount is typical of the amount above 30 km in the average curves given by De Luisi (ref.8).

These calculations show that 1.7% of the extraterrestrial solar radiation would be absorbed by ozone before it reached the balloon. If the amount of ozone is halved only 1.4% of the radiation would be absorbed resulting in a 0.3% increase in the solar irradiance as observed at the balloon. The fact that such a large change in ozone results in only a 0.3% change in solar irradiance tends to eliminate a change in atmospheric transparency as the cause for the observed increase in solar irradiance.

Further evidence concerning the atmospheric transmission above the balloon is available from the flight performed on February 10, 1980. For this flight the instrument complement also included a cavity radiometer system supplied by John Hickey of Eppley Laboratories. This unit yielded a solar irradiance of 1338 w/m^2 (SI units). There appears to be some disagreement among the satellite data available for the 1980 time period; the values, however, appear to fall in the range 1365 - 1370 w/m^2. This implies an atmospheric transmission-correction in the range 2.0% to 2.4%. These values are consistent with a 1.7% correction for ozone and 0.3 to 0.5% correction for residual infrared absorptions. They are difficult to explain with any lower absorption due to ozone. The 1338 value is also consistent with the values one obtains by converting our pyrheliometer to SI units. A recent comparison of our Eppley Ångstrom unit with an active cavity radiometer indicated that our values should be multiplied by a factor of 1.024 to convert them to SI units. Using this factor, a factor of 1.7% to correct for ozone absorption and 0.7% for an infrared correction (the pyrheliometers are equipped with windows which do not transmit beyond 4 μm) yields extraterrestrial irradiance in the range 1364 w/m^2 (P1) to 1369 w/m^2 (P2). Again any lower correction for the atmospheric correction yields too low a value for the extraterrestrial flux. The higher irradiance values are best explained by a change in the solar irradiance.

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