# AN ALTERNATIVE DERIVATION OF THE NIMBUS 7
## TOTAL SOLAR IRRADIANCE VARIATIONS

by

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Abstract.   Nimbus 7 solar irradiance values have been made available to the scientific community through the open literature (e.g., Hickey et al., 1988) and through NASA data centers.   A comparison of these measurements to the SMM/ACRIM time series indicated differences which might be caused in part by the method of converting the Nimbus 7 raw data counts to solar irradiance values.   In an effort to see if the derivation of the solar irradiance could be improved, the raw counts were extracted from the tapes and analyzed to see how a new algorithm could be constructed.  The basic form of the calibration remains the same as in the previous solar irradiance derivations.  However, the input values to the equation differ from what was used before.   In particular, improved values of the Earth-sun distance are incorporated and new temperature sensitivities were derived. Several problems with the instrument were uncovered which previously had not been noticed: 1) The sun did not appear to cross the center of field of the radiometer but was systematically off by 1.5 to 2.5 degrees.  2) The A/D convertor changed its properties in July 1980.  3) The gain of the electronics apparently increased by 0.03% in September 1987.  Applying these and other changes in the processing, the day to day variations appear much more like the SMM observations.  In fact, the Nimbus 7 observations are sufficiently stable that a problem with the SMM observations in the spin mode period of 1981-84 can be detected when the two time series are compared.

# 1. Introduction

The major highlights of the method of reducing the instrument influences upon the measurements are described in section 2. Because of space limitations some of these descriptions will be limited. A paper describing these techniques in more detail is now being prepared for publication in the refereed literature. The third section provides a comparison of some of the newly derived Nimbus 7 solar irradiance values to the SMM/Acrim measurements. The final section sums up our present status in understanding the instrument.

# 2. The Removal of Instrument Influences

The basic equation used to convert counts to irradiance is:

$$S_0 = \frac{0.998}{1.3013} r^2 \frac{(C_{sun} - C_{space})}{\cos(G)} \frac{1}{[1. + A(T-22)]}$$

where 1.3013 is the calibration constant, 0.998 is a correction constant to account for spurious reflections from the baffles into the cavity, $r$ is the Earth-sun distance, $C_{sun}$ is the mean on-sun counts, $C_{space}$ is the mean space look counts, A is the coefficient for the temperature sensitivity of the radiometer, T is the temperature of the radiometer in degrees Celsius, and G is the offset angle between the normal vector to radiometer cavity and the vector to the sun. This equation is an attempt to remove all the portions of the counts signal which arises from the instrument and geometry so that only a pure signal arising from solar behavior remains.

If the Nimbus 7 radiometer had no pointing problems, then each time the sun drifted across its field of view it would pass through the center of the radiometer's field of view. Unfortunately, the sun normally appears to drift through the field of view on an off center cord or path. The angle between the radiometer-sun vector and the normal vector of the plane of the detector is known as the off-axis angle.

The off-axis angle is generally assumed to be measured by taking the difference between the so-called beta and gamma angles. The beta angle is angle between the plane of the satellite's orbit and the plane defined by the ecliptic. The beta angle is measured by the Digital Solar Aspect Sensor (DSAS). The gamma angle, on the other hand, is the angle between the axis of the solar telescope and the orbital plane and it can be varied only in one degree steps. If the two angles are equal, then the radiometer is assumed to be on-axis. In most cases the difference between these two angles is measured as less than one degree. The difference in the two angles provides a measure of the off-axis angle. If these off-axis angles are kept less than 0.5 degrees, then the cosine of

these angles will be very close to one so the pointing correction will be negligible (e.g., 0.05 watts per square meter or less).

To derive what the off-axis angle really is, it is assumed that the solar constant and radiometer properties remain stable just before and just after the gamma angle change. It follows then that the ratio of the counts, corrected to one astronomical unit, will equal the ratio of the cosine of the off-axis angle prior to the change to the cosine of that angle plus one degree after the change. The only unknown is the off-axis angle, G, which can be solved for, using the following equation:

$$G = atan\left[\frac{-\dfrac{C_1}{C_2} + \cos(1)}{\sin(1)}\right]$$

where $C_1$ is the mean on-sun counts prior to the gamma angle change and $C_2$ is the mean on-sun count after the gamma angle change. In practice, we use 5, 6, 7, 8, or 9 orbits prior and after to form the two means of the counts. These five determinations are averaged together to derive an average off-axis angle. In effect, the observations closest to the gamma angle changes are more heavily weighted.
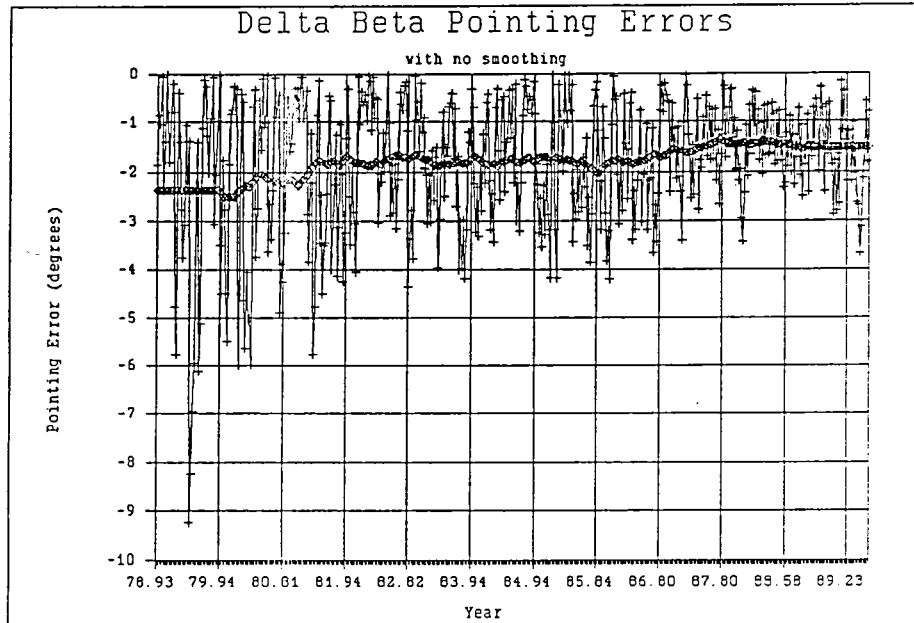


Figure 1. The off-axis angle vs. time using the change in gamma angles and change in counts to calculate the off-axis angle. The individual values show considerable scatter due to the limited resolution of the A/D convertor, the limited number of useful measurements on each side of the gamma angle change, and spurious influences caused by high solar activity. An 81 point running mean is drawn through the points.

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Figure 1 shows the 236 determinations of the off-axis angle. An 81 point running mean is drawn through the points which shows the slow component of the off-axis angle variations. There is considerable scatter in the raw values but a systematic off-axis angle slowly comes closer to the zero as the experiment precedes.

The scatter in Figure 1 is reduced by forming a running mean of values. This procedure is justified since any individual off-axis angle is uncertain due to 1) the limited resolution of the A/D convertor, 2) possible variations in the solar irradiance during each determination, and 3) some small changes in radiometer temperature. Various lengths for the running mean were tried, but a length of 81 points was chosen since there are about 20 gamma angle changes per year and 81 covers 4 years reducing any signal from an annual variation. The radiometer's gamma angle was systematically too low by about 2.5 degrees early in the measurement period, but more recently it is off by only about 1.5 degrees.

Because the A/D convertor provides only a 0.7 watt per square meter resolution for any one measurement, when looking at space to determine the offset of the instrument, a large number of measurements is required to accurately determine the offset. It was decided that large blocks of time, usually one year's worth of data could be used to provide a measure of the offset. This procedure considerably reduces the day to day scatter in the solar irradiance measurements.

On July 20, 1980 the A/D convertor changed its properties such that it tended to round off its count values to the next higher digit more frequently than it would if this bias had not developed. Because both the on sun and zero counts were equally effected, the result is not readily evident in most derivations. However, if we use large blocks of time to measure the zero offset, the zero offset must be determined for the period January 1 to July 20 and from July 21 to December 31, 1980 separately. Otherwise, an artificial trend could be introduced into the solar irradiance values for 1980.

Assuming the calibration constant of channel 10c remained unchanged throughout the mission and calculating the solar irradiance, it varies smoothly except for an upward jump of 0.03% in irradiance on September 26, 1987. The change in sensitivity is confirmed by the electrical calibrations, so its effect is removed by having a new calibration constant after this date.

The radiometer is slightly sensitive to temperature since the cavity sees the field-of-view limiters which have different temperatures for each solar irradiance measurement. The temperature sensitivity can be determined by two techniques: 1) Assume the solar irradiance is a constant and the unexplained variations arise from the radiometer temperature variations and 2) use the space look observations and the temperature measurements and derive a fit between the counts and the temperature. Both

techniques were tried and gave nearly the same answers. The coefficient "A" in the calibration is found to be 0.001998 for temperatures above 18 C, 0.0002713 for temperatures between 15 and 18 C, and 0.0003086 for temperatures below 15 C based upon the first technique and using all observations between November, 1978 and December, 1988. Using the second technique, the temperature sensitivity above 18 C for 1988 is 0.000196. The second technique is actually less accurate than the first technique, because of the limited resolution of the A/D convertor. Therefore, the temperature coefficients from the first technique are used.

Previously published solar irradiance measurements assumed a single value of 0.000524 for temperatures of the radiometer. This value was based upon a few determinations in 1978 and 1979. Smith et al. (1983) previously pointed out that a linear relationship of the radiometer is not valid since the transfer of radiation from the field-of-view limiters to the cavity is done radiatively and is thus proportional to the blackbody flux which depends upon temperature raised to the fourth power. By using a linear relationship and splitting it into three ranges, much of this non-linearity is captured. However, there are several methods which may be used to derive the temperature sensitivity of the instrument and the problem continues to be studied. Future studies may improve our understanding of the temperature sensitivity of the instrument.

Finally, the derived solar irradiance measurements were improved by using more precise Earth-sun distance calculations. This distances are now accurate to eight significant figures and are calculated for each orbit rather than for each day as was previously done.

3. A Comparison to the SMM/ACRIM Measurements

Daily solar irradiance values from the SMM are available for the period February 1980 to December 1988 (e.g., Willson and Hudson, 1988). These independent solar irradiance measurements are numerous enough to provide a good comparison to the Nimbus 7 measurements. Figure 2 shows the measurements for 1988. The correlation between these two measurements is 0.87 for this year. Overall these two independent sets of measurements show good agreement. This increases our confidence that the true solar behavior is being tracked.

Figure 3 provides a plot of the Nimbus 7 and SMM monthly mean solar irradiance values. The two curves are quite similar with both instruments indicating a rise in solar irradiance in the latest cycle to a value less than that in the previous cycle. In Figure 4, the differences in monthly means is plotted. These differences are about 4 to 5 watts per square meter when the SMM pointing is known to be correct and slightly less than 4 watts per square meter during the period 1981 to 1984 when the SMM had

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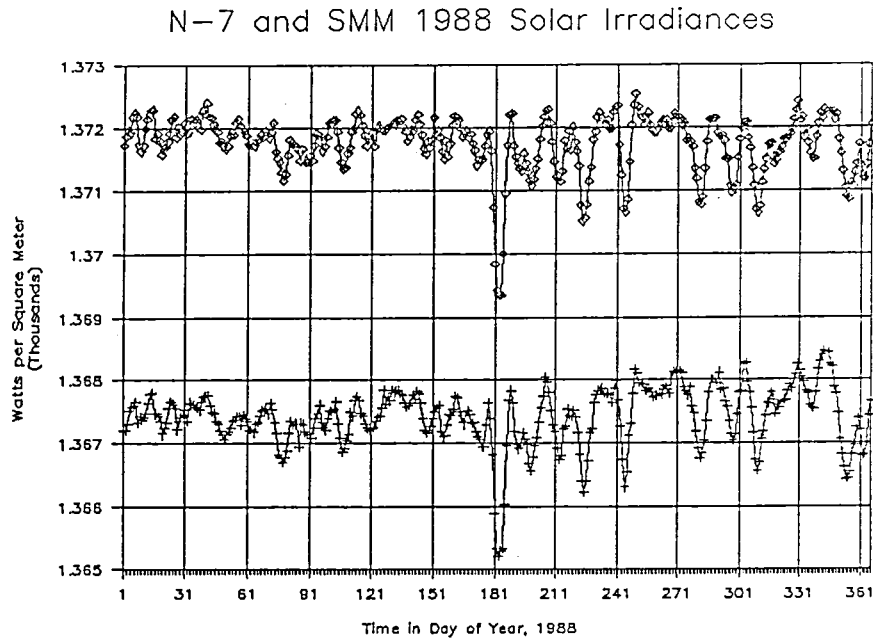## N—7 and SMM 1988 Solar Irradiances



Figure 2.  A comparison of the Nimbus 7 and SMM solar irradiance values for 1988 on the same plot.  Day to day variations have a correlation of 0.87 for this year.

## Nimbus—7 and SMM Solar Irradiance
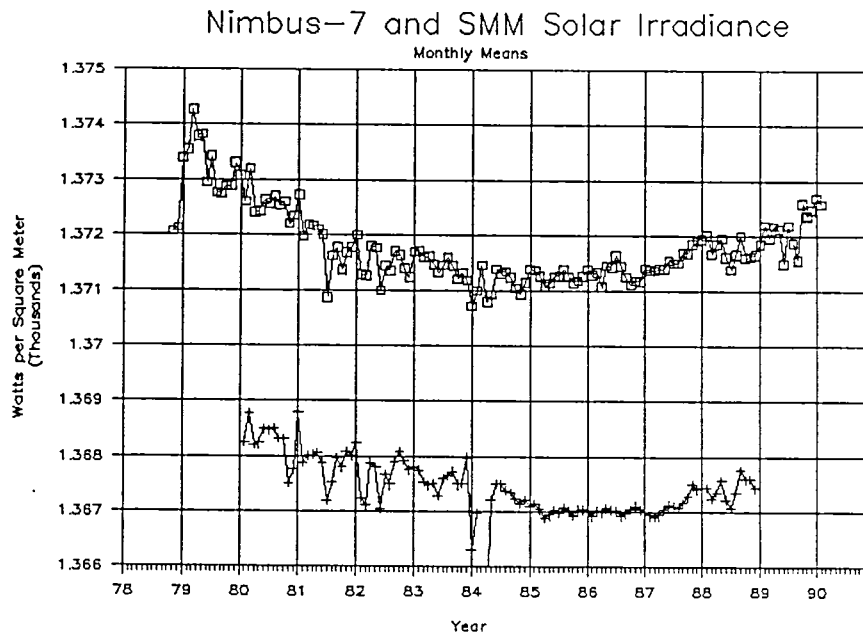### Monthly Means



Figure 3.  The Nimbus 7 and SMM monthly means for 1978 to 1989. Both instruments are indicating similar solar behavior except for a few periods such as early 1980, late 1983, mid-1986, and late 1988.

pointing problems. During the quiet sun, the SMM radiometer has smaller month to month variations than does the Nimbus 7 radiometer. This may indicate that some residual pointing errors still exist in the Nimbus 7 measurements. The rise in Nimbus 7 measurements in August 1987, which does not occur in the SMM measurements, could be caused by an undetected 0.1 degree error in the Nimbus 7 pointing. Alternatively, since this rise was evident just after a special operations period, the Nimbus 7 radiometer's thermal properties may have changed for a time and relaxed back to normal after several months. In late 1988 there is a small divergence between the two measurements for as yet unknown reasons.

Despite these divergences the agreement is still rather good. The correlation of the monthly means is 0.867 for 1980 to 1983, 0.014 from 1984 to 1986 after the SMM pointing was restored but the sun remained quiet, and 0.816 in 1987-88 when solar activity resumed. The low correlation in 1984-86 arises because the variability in the solar irradiance became less than the noise in the measurements, particularly in the Nimbus 7 measurements. As a comparison, the older published Nimbus 7 irradiances had correlations with SMM of 0.863, 0.000, and 0.836 respectively for the three periods. Much of these correlations are arising from common long-term trends. Using daily values for 1988, the new algorithm has a 0.87 correlation with SMM whereas the old algorithm has a 0.75 correlation.
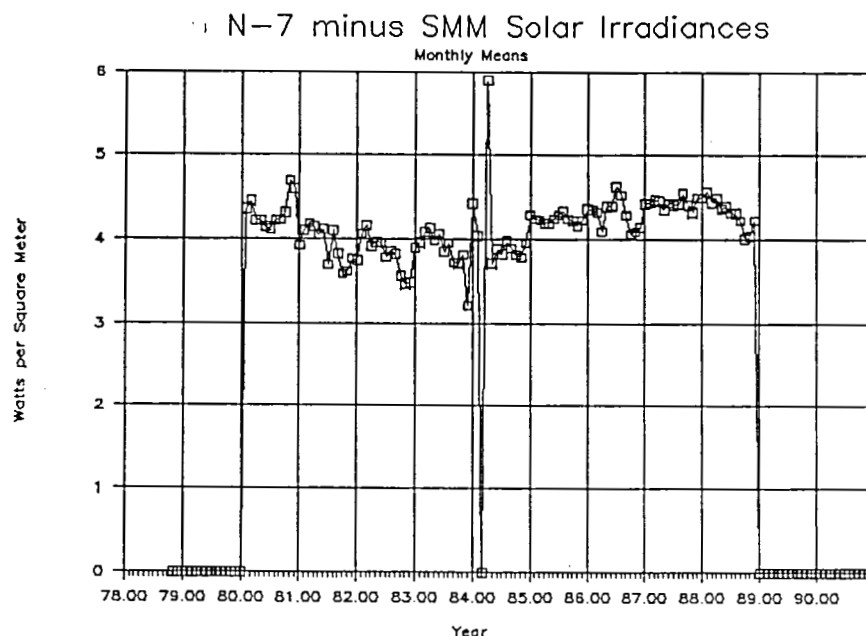


Figure 4. The Nimbus 7 monthly mean solar irradiance minus the monthly mean SMM solar irradiance. Most differences are between 4 and 5 watts per square meter except for 1981 to 1984 when the SMM had pointing problems.

## 4. Concluding Remarks

A new algorithm to derive the solar irradiance from the Nimbus 7 raw data is reported upon here. The algorithm removes more of the instrumental and geometrical influences upon the measurements than did the old algorithm so that the true solar behavior becomes more apparent. Changes in the analysis include: 1) better Earth-sun distance determinations, 2) improved temperature sensitivity coefficients, and 3) re-calculated off-axis angles. These algorithm changes give substantially smoother day to day variations in the solar irradiance and a greater correlation with the SMM observations. The Nimbus 7 long-term trends in solar irradiance are different then previously calculated and now generally closer to the SMM observations. These changes increase our confidence that both satellites are measuring a real solar signal. Despite nearly equal solar activity for the last two solar cycles based upon Wolf sunspot numbers, the solar irradiance for the two cycles are not equal. Both the Nimbus 7 and SMM satellites appear to confirm this behavior.

Considering that the SMM measurements suffered from pointing problems between 1981 and 1983, it is reasonable to suggest that the Nimbus 7 solar irradiances derived for this time period are a better measure of true solar behavior. Most of the differences between the two measurements in the 1981-83 time period may be arising from random errors in the SMM measurements which has a greater day to day variability than the Nimbus 7 measurements.

Although some of the problems with the Nimbus 7 measurements are removed in this analysis, insufficient information exists to remove all the instrument influences on the solar irradiance determinations. In particular, the off-axis angle corrections remove the short-term and long-term variations in the off-axis angle, but the intermediate variations (months to two years) may not be fully removed. With the limited number of independent measurements of the off-axis angle (236) and the limited accuracy of each off-axis angle determination, it does not appear that these intermediate term variations can be removed completely.

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