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SOLAR VARIABLITY

INDICATIONS FROM NIMBUS 7 SATELLITE DATA

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ABSTRACT

The cavity pyrheliometer sensor of the Nimbus 7 Earth Radiation Experiment (ERB) has indicated low-level variability of the total solar irradiance. The variability appears to be inversely correlated with common solar activity indicators in an "event" sense. The limitations of the measuring system and available data sets are described.

FOREWORD

The content of this paper is modified from the presentation delivered at the workshop. Some new data and subsequent discussion has been added. Much of the background information has been deleted but is referenced. The figures have been updated to the latest possible available time depending on the data set. The reprocessing effort for the Nimbus 6 data has begun at the time of this writing (early February 1981); however, insufficient information is available to update the Nimbus 6-7 overlap agreement. Only the results from the cavity sensor of Nimbus 7 are presented here.

INTRODUCTION

Solar parameter measurements have been performed since November 1978 by a self-calibrating cavity pyrheliometer on the Nimbus 7 satellite. The results presented here must be considered preliminary because of the nature of the data sets employed. These data sets and their limitations are described in the opening paragraphs of the paper. Correlation with other solar activity indicators are presented as well as a comparison with results from the Solar Maximum Mission.

CALIBRATED DATA (SEFDT)

The orbital values are available for the months of November and December 1978 and January, February, March, June and October of 1979. This data is designated SEFDT data based on the source tape. These data have been processed to the highest degree possible. That is, the correct earth-sun distance, temperature correction, and space-offset have been applied to the data set. The in-flight calibration factors have been applied as obtained from analysis of the heater calibration sequences which are available from an independent data source. The SEFDT set comprises 135 daily mean values for the period. The missing days within the months listed above are not available nor will they be. This is because of the operational schedule of Nimbus 7. The missing months are due to the fact that the processing has not been performed for those periods.

Figure 1 is a plot of the available daily means from this calibrated data set versus time. The solar indicators of sunspots and 2800 MHz flux are plotted on the same time axis for comparison. The mean value is 1374.25 Wm^{-2}. The standard deviation is 0.623 Wm^{-2} or 0.0453% of the mean. The range of irradiance values is from 1372.79 to 1375.45 or 0.19% of the mean. The range is approximately 4.3 times the standard deviation. The minimum value is about 0.11% below the mean while the maximum is about 0.09% above the mean. The slope of the regression shows a small downward trend of -0.9 Wm^{-2}/1000 days. This amounts to -0.065%/1000 days or -0.024%/year.

It is probable that the absolute value of the mean irradiance is too high. Recent investigation of available off-axis flight data indicates that the stray light correction in the calibration equation is underestimated by about 0.2%. While further investigation is required to confirm this effect, it is likely that this correction should be applied. The corrected mean value would then be 1371.5 Wm^{-2}.

ENGINEERING DATA

This data set covers the period from November 16, 1978 through January 5, 1981. The set comprises daily mean values for the period through February 4, 1978 but only one orbit per day for the remainder of the data. The basic sensor output counts are obtained as a peak signal output from the engineering analysis program at the Nimbus ground station. The space-offset value, temperature correction, earth-sun distance adjustment and calibration are applied to the data. A description of the limitations of this data set were presented (1) by the ERB team in describing the early results. While there is additional information available now from the analysis of the calibrated (SEFDT) data set, the engineering data has been continously processed in a consistent manner. The absolute value of irradiance is generally higher for the engineering set because of the method of application of the space-offset term and the temperature correction. The former is because it is either not present in the data or because it is available for the orbit minimum only as a single point value. The latter is because the pre-flight rather than the in-flight derived coefficient is employed.

Since both the space-offset and on-sun signals are single points and since the uncertainty of a single point is $\pm$ 0.5 count of digital output, the uncertainty is $\pm$ 1 digital count for this reason alone. For mean earth-sun distance, this is equivalent to about 0.056 percent or 0.77 Wm^{-2}. There are 463 daily values in the engineering data set for the period of 782 days. The reasons for missing data here are the same as for calibrated data with the additional reason that the engineering analysis program output is not available for every day of ERB operation.

Figure 2 is a plot of the engineering data set for the period. In this plot all of the points have been connected despite the fact that it is not a continuous data set. This figure is included to give the reader a feeling for variability over the entire period. The mean value is designated by the horizontal line at 1375.55 Wm^{-2}. The regression line shows a very small downward trend over the period which can be expressed as -1 Wm^{-2} per 1000 days or 0.073%/1000 days or approximately 0.026%/year. The standard deviation is about 0.071% of the mean value. This is slightly larger than the uncertainty of a single value (0.056%) discussed previously. The range of the data is 0.443% of the mean with the minimum value at -0.27% and the maximum value at +0.17%. Thus, the low value is almost 4 sigma below the mean while the high value is about 2.5 sigma above it. The region of low irradiance values in August of 1979 is the most prominent feature on the plot.

Figures 3a and 3b show the same data set split into two 400 day periods. The points are not connected so that the discontinuities are recognizable. The solar activity indicators of sunspot number and 2800 MHz flux are also plotted on the same time scale for comparison.

COMPARISON OF DATA SETS

There are only 108 points common to the SEFDT and Engineering data sets. It must be remembered that the early engineering data are daily means while only one point per day is available after February 4, 1979. There are 44 points which are daily means for both sets in this discussion. The mean ratio of engineering to SEFDT data is 1.00116 indicating that engineering data is higher on the average by 0.116%. This is equivalent to two counts of input signal as discussed earlier. The nature of the agreement between the sets is shown in Figure 4. The correlation coefficient is only 0.528. The standard deviation is smaller for the SEFDT set (0.046%) than for the engineering data (0.061%) as would be expected. Lines indicating the means of both sets and the regression line are shown on the plot. It should be noted that a number of values fall in the second and fourth quadrants indicating opposite behavior of the data sets about their respective means. Most of these points are close to the quadrant separator lines within the expected uncertainties.

It is noted that the periods which show very low values in the engineering data are generally misssing from the available SEFDT data. Notably, the large August 1979 event and lesser events in September and November of 1979 are not included. Also, two events which were sensed by the SMM ACRIM (discussed later) are not included in the set. The plot is essentially bounded by ± 0.1% deviation on the calibrated data while the engineering data extends from -0.20% to + 0.12%. An analysis on an orbit-by-orbit basis may improve this correlation. The additional information necessary to identify corresponding orbits is not available to us at this time. A preliminary analysis of the SEFDT orbital values has indicated variability at the 0.02% to 0.07% range on a daily basis.

COMMENTS ON SOLAR VARIABILITY

It had been noted early in the project that dips in the engineering data corresponded to peaks in the 2800 MHz and sunspot data in an event sense. However, until higher quality data became available and until the large unambiguous dip occurred in August of 1979, it was not possible to rule out instrumental effects. The identification of a change was reported (2) at the AGU meeting in May 1980 after a confirmation of the engineering data indications by a calibration orbit analysis. An interim set of "preliminary scientific" data obtained from "Master Archive Tapes" (MATS) was, also, employed in confirming the variability (2,3). This set of processed data was found to be improperly corrected for earth-sun distance and had other minor flaws none of which compromised its use in assessing short-term variability. Both the preliminary MAT results and the calibration orbit analysis (3,4) confirmed the short-term variability in the engineering data set although not the magnitude. The higher quality data of the preliminary SEFDT data set became available (4) which led to the previous discussion herein. In August 1980, we were supplied with the results of the ACRIM radiometer aboard the Solar Maximum Mission (SMM) satellite by Dr. R. Willson of JPL. These results have now been published (5) and were discussed at the workshop. A comparison of the SMM results to the ERB engineering data is shown in Figure 5 for 153 days starting in February 1980.

The circles represent the ERB data overlayed on Willson's original plot. The higher resolution of the SMM instrument is obvious from the plot. Both plots are expressed in percent deviation from the mean for the period. The two prominent dips in the SMM data correspond to the two most prominent dips in the ERB data. The larger of the two is about -0.16% for SMM and -0.21% for ERB. The other at day 147 is about -0.09% fro SMM and -0.18% for ERB. Thus, both the ERB deviations are greater than the SMM indications. The remainder of the plot shows correspondence within the engineering data uncertainty with a few notable high values on day 142 and in the period 165 to 180. We must wait for the calibrated ERB data before making conclusions relative to the remainder of the period or for evaluating differences in magnitude or corresponding events. It is noted that the large August 1979 dip was -0.27% below the mean.

From all of the correlative data it appears that the variability of the solar irradiance evident in the engineering data set is confirmed in principle but not necessarily in magnitude. All correlative data indicate lower magnitudes of the deviations. Unfortunately, no correlative data other than calibration orbits cover the periods of the greatest indicated variations.

CORRELATION WITH OTHER INDICATORS

A number of simple correlation analyses have been performed for the ERB data sets versus sunspots and 2800 MHz. These are given below.

data set	correlation coefficient vs	
	sunspot Rz	2800 MHz
SEFDT	- .311	- .321
Engineering	- .284	- .342
Cal. orbit	- .441	- .550

The calibration orbit data represents only 43 points spaced over the period November 1978 through December 8, 1980. While these coefficients are not impressive, they do indicate an inverse correlation. The values of the coefficients are declining as each data set increases in number. In all cases, the 2800 MHz correlation has been higher than the sunspot coefficient. A preliminary event analysis was reported for earlier versions of the data sets (6). There was an indication that 16 of 25 identifiable events were unambiguously anti-correlated. An updated analysis was performed for a 654 day set of engineering data. The nine-day running mean of engineering data, 2800 MHz flux and sunspot number are shown as a function of time in Figure 6. It is easier to visualize the correspondence of events with this smoothed data. All depressions in the ERB data below 1374.5 Wm^{-2} coincide with peaks in the 2800 MHz flux and sunspot plots. This accounts for the 7 major dips in the smoothed data. Of the 13 peaks in the channel 10c which extend above 1376 Wm^{-2} 3 coincide with peaks in the 2800 MHz flux. While correlations can be found in the range of 1374.5 to 1376 Wm^{-2}, they must be interpreted with caution based on the previous discussion of the correlation between the engineering data and the calibrated data. If we consider every identifiable peak in the 9-day 2800 MHz data, there are 26 including many small bumps. Of these, 18 could be considered to coincide with dips in the ERB data. The two dips noted in the SMM data are identified by "x" on the vertical dashed lines.

We will not present further details of the correlation analysis here. We have not attempted to discuss the solar physics implications of these results. We have noted (4) that the large August 1979 dip coincided with the passage of a Coronal hole across the solar disc.

SUMMARY AND CONCLUSIONS

The current status of the ERB/NIMBUS 7 solar constant measurements have indicated that solar variability at the ±0.1 to ±0.2 level. The most probable value of the solar constant derived from the highest quality data and adjusted for under-estimated reflection in the sensor is 1371.5 Wm^{-2}. The major depressions in the solar flux are correlated in an event sense with peaks in the sunspot numbers and 2800 MHz flux. Further detailed analysis awaits availability of a complete high quality data set.

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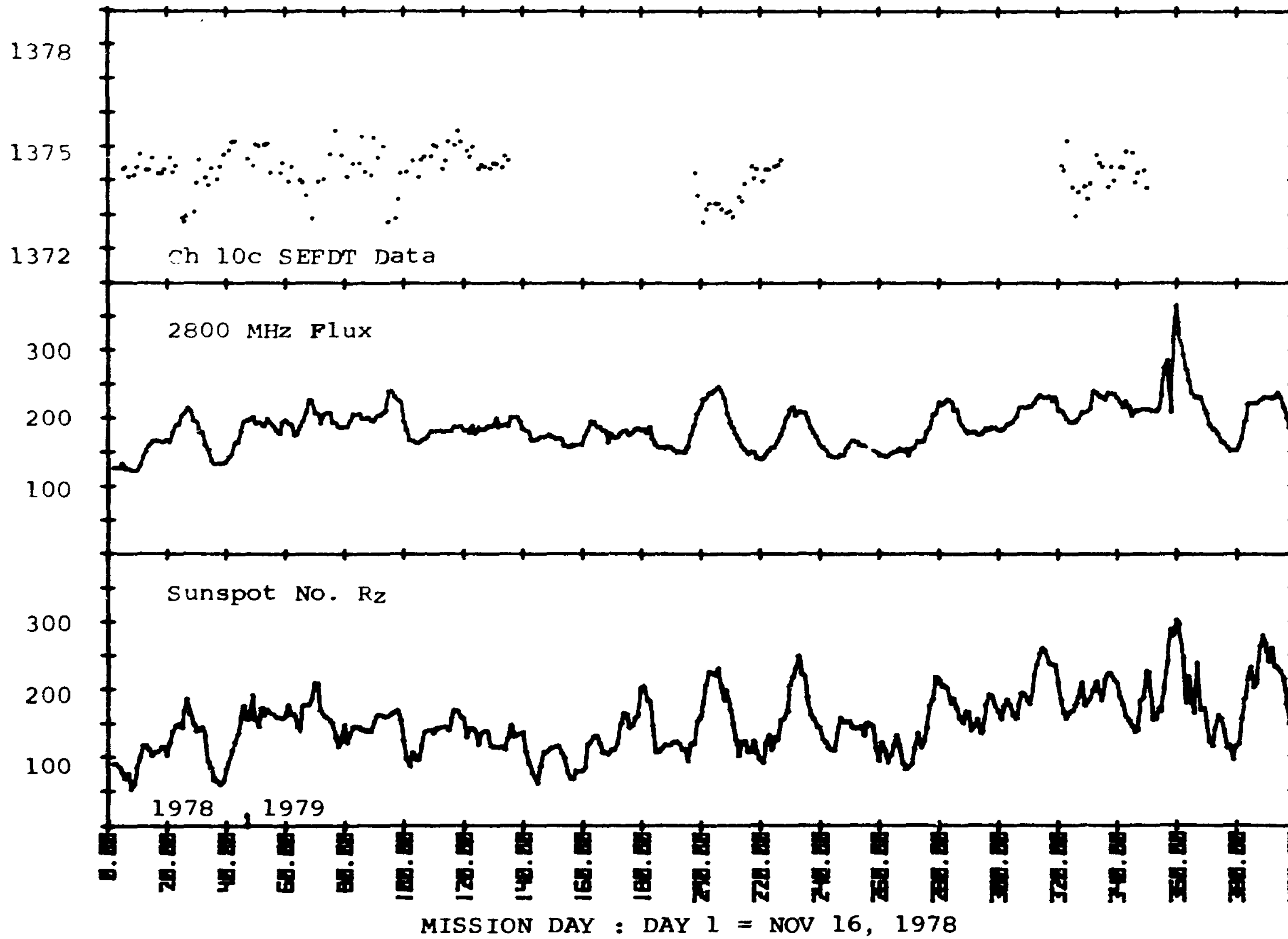

Figure 1. Calibrated ERB cavity data and solar indicators versus time

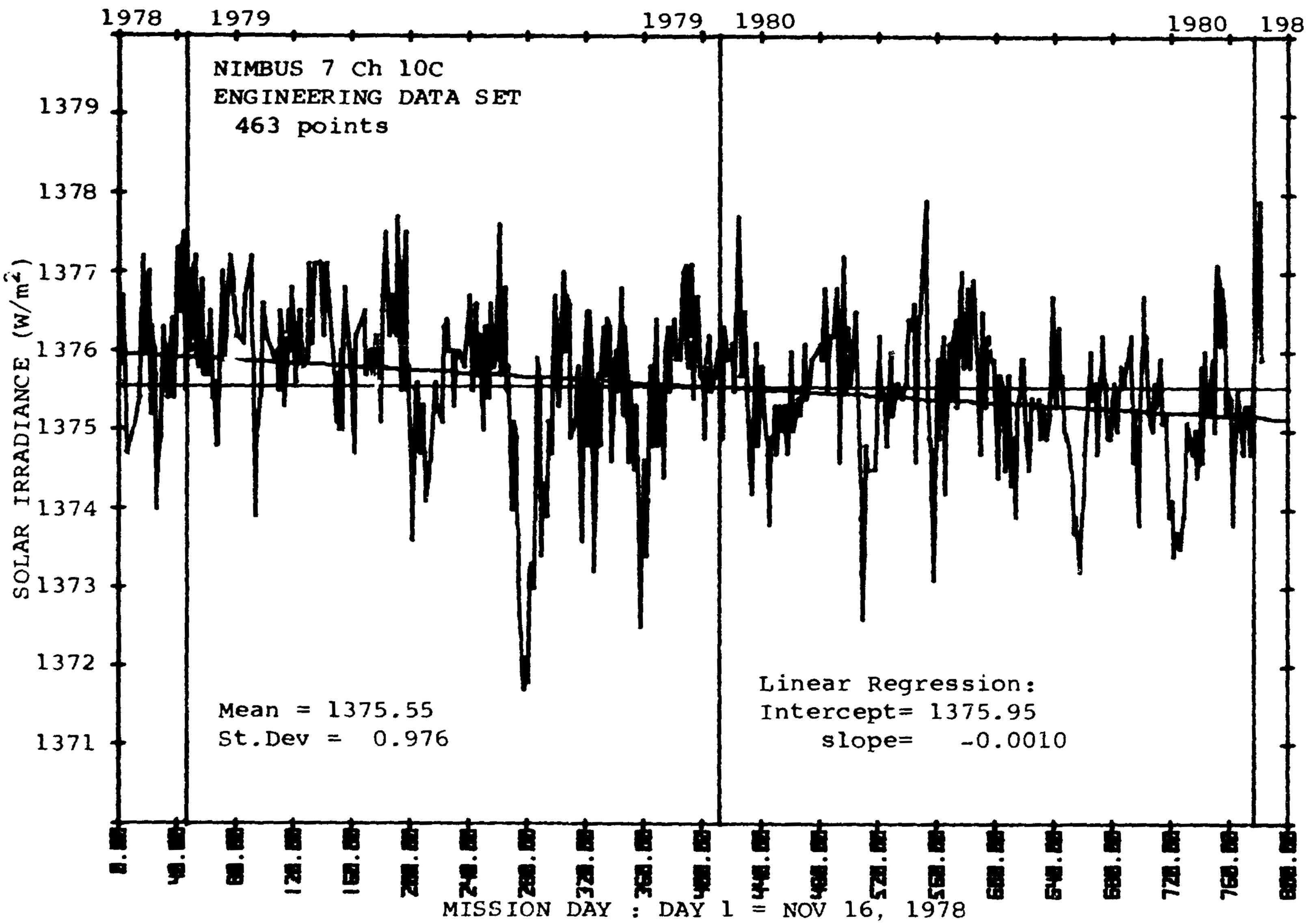

Figure 2. ERB channel 10c Engineering data versus Time in Nimbus-7 mission days

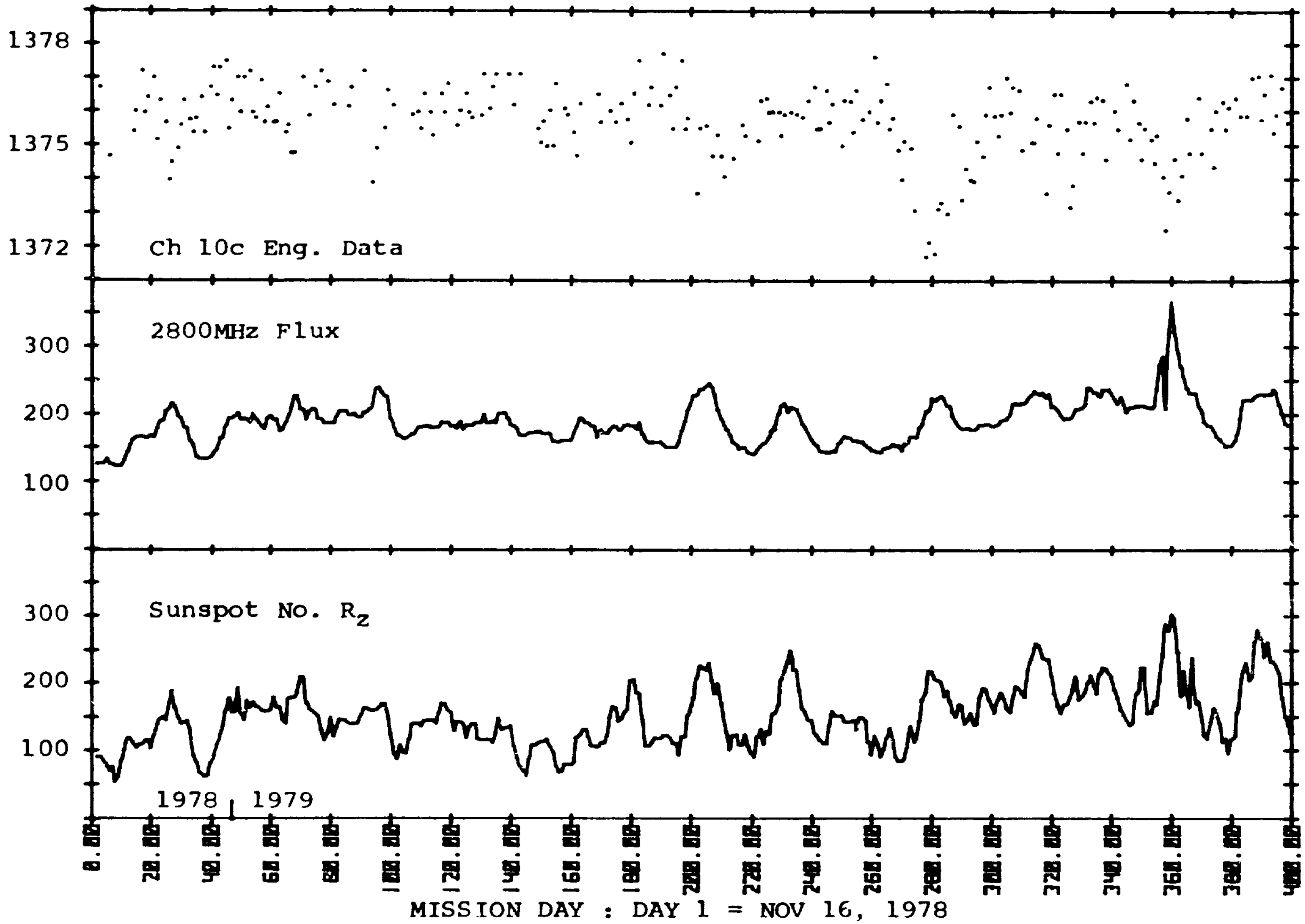

Figure 3a. ERB channel 10c engineering data and solar indicators versus time
First 400 days

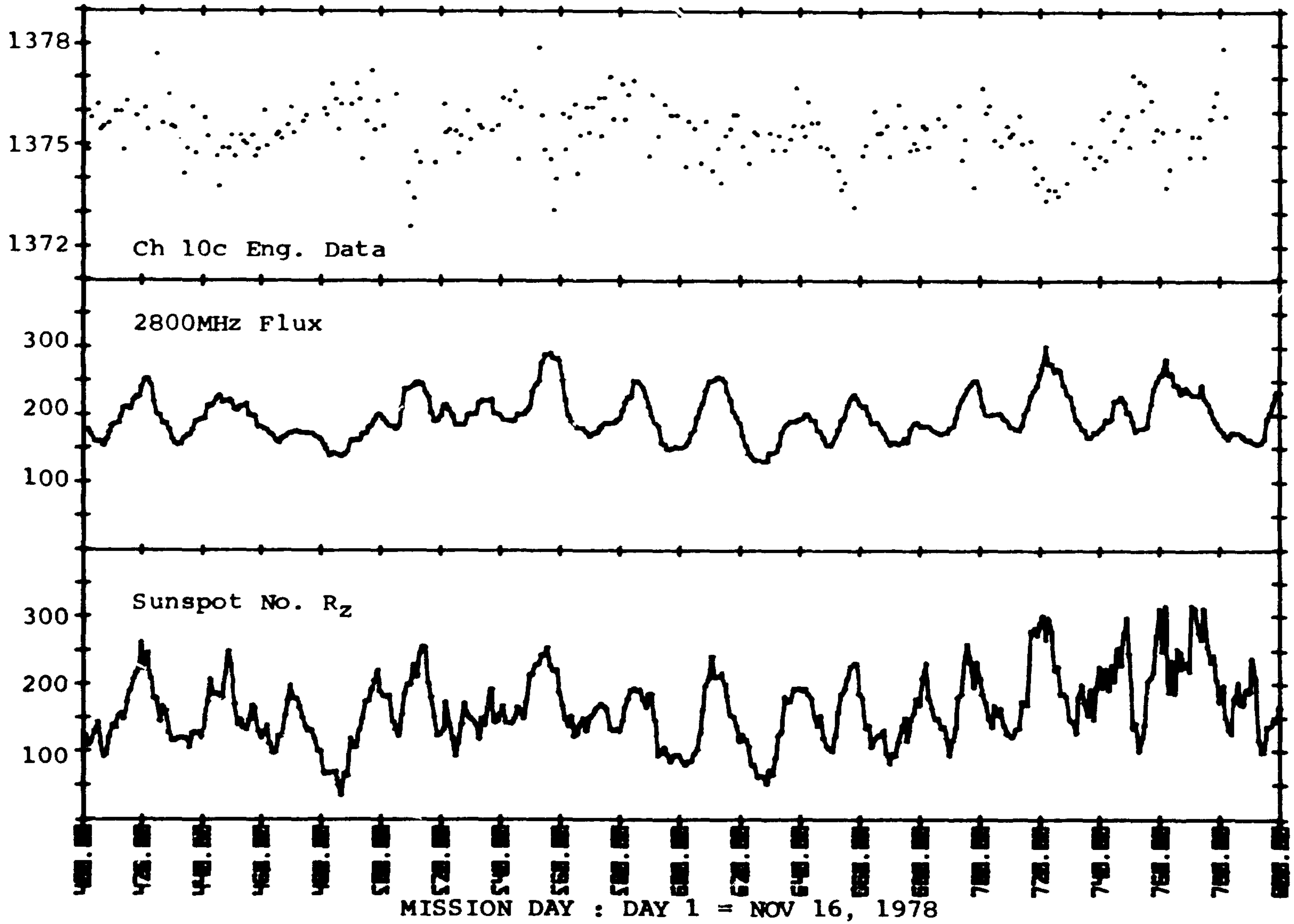

Figure 3b. Same as 3a. for days 401 through 782

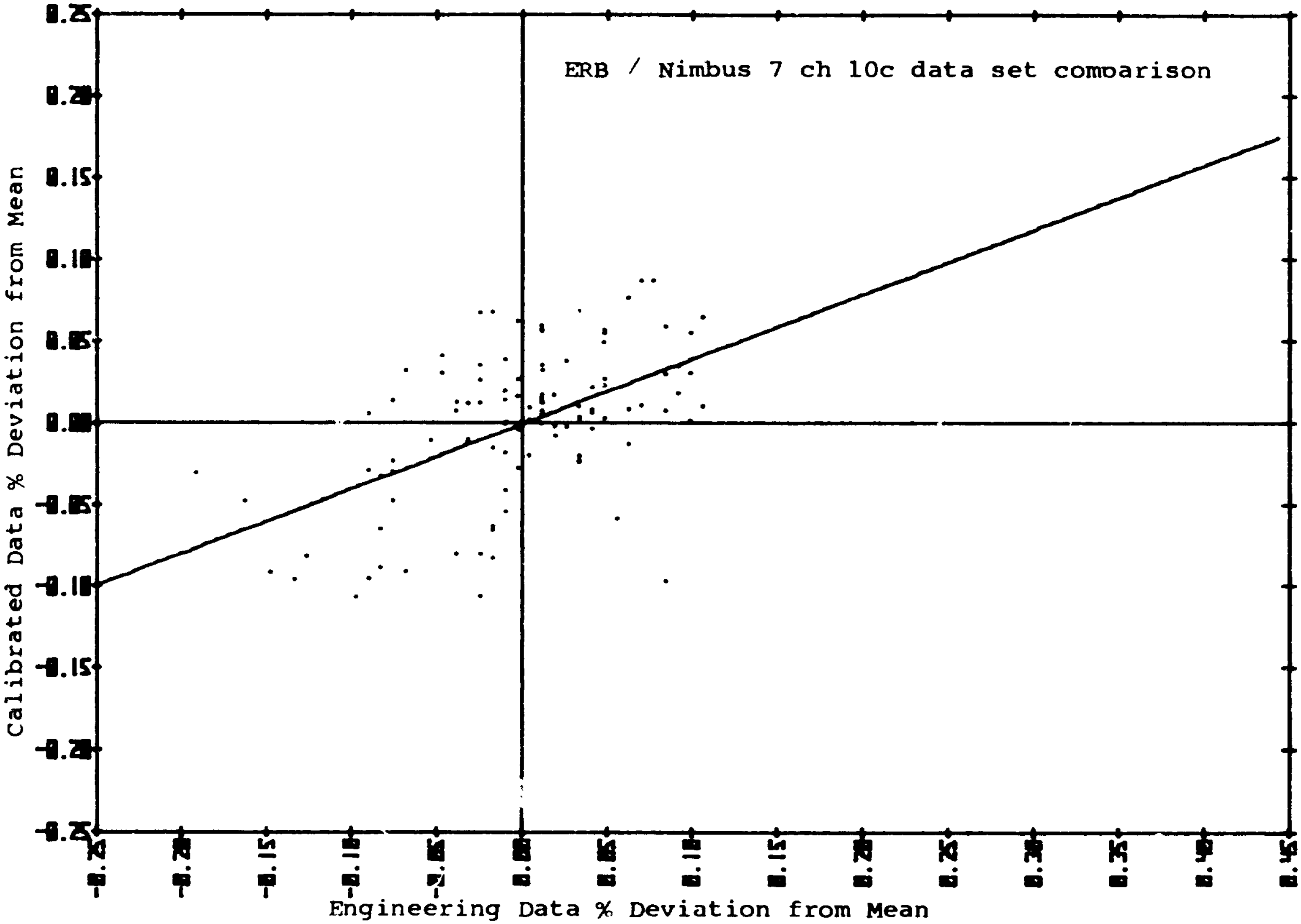

Figure 4. Comparison of deviations between calibrated and engineering data

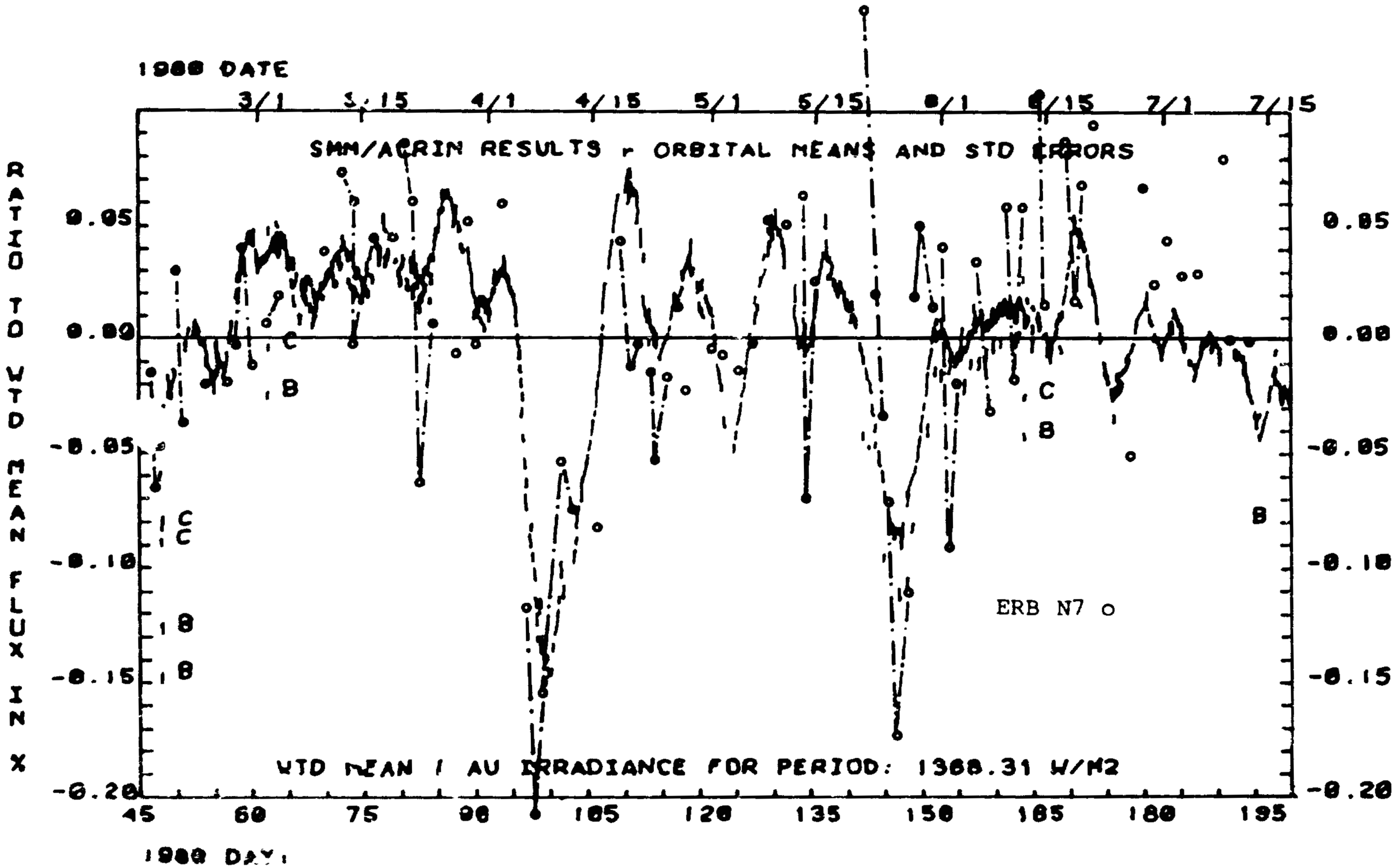

Figure 5. ERB channel 10c Engineering Data overlayed on SMM plot of Reference 5

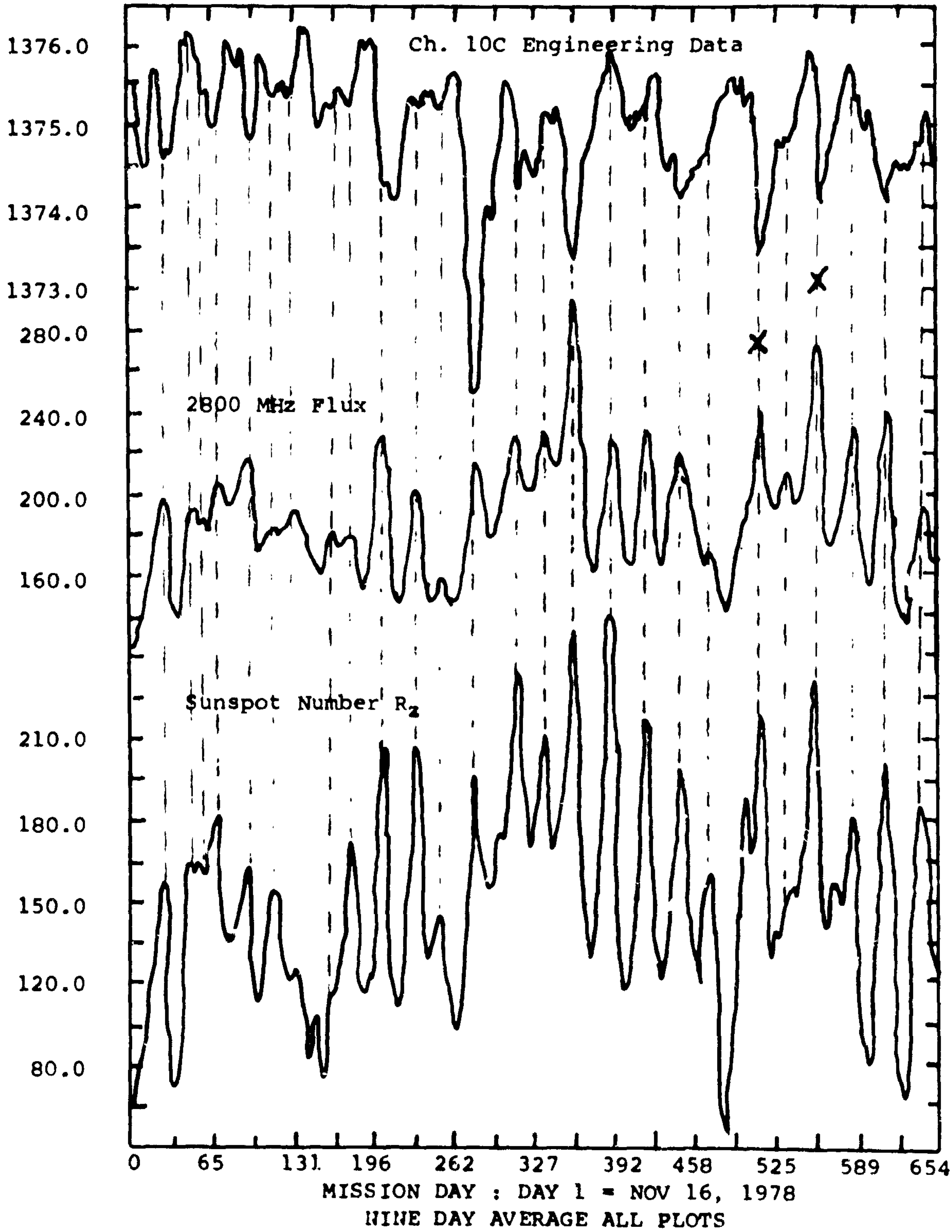

Figure 6. Plot of nine-day running means of 10c Engineering data and solar indicators for event recognition