Reports

Solar Minimum and the International Years of the Quiet Sun

In January 1964 the International Years of the Quiet Sun (IQSY) officially began. Cooperative national and international studies of the sun and the earth-sun system under circumstances of solar quiet have been planned for the next 24 months. The success of these studies will depend in large measure upon the additional "cooperation" of the sun in providing adequately long intervals in which there are no observable spots, plages, centers of enhanced radio-frequency emission, or coronal condensations to disturb the measurement of needed zero points or to confuse the region between the earth and the sun by emissions and ejecta from flares, active prominences, and "M Regions." IQSY programs designed to determine the nature of solar centers of activity and their terrestrial effects likewise need prior intervals of true solar calm if the characteristics of these phenomena are to be determined unambiguously.

The course of the solar activity cycle is not amenable to exact prediction, and the plans for IQSY had to be made far in advance. Best judgment indicated that sunspot minimum between the 19th and 20th cycles of solar activity would fall in the interval 1964–65. As 1964 begins, there is abundant evidence that the sun has not yet become "quiet." If the anticipated minimum is to resemble the minima of the last 100 years it will occur after 1 January 1964, and the years chosen for the International Years of the Quiet Sun should cover the expected statistical minimum in the solar activity cycle.

How far away is sunspot minimum? The physical circumstances that bring about the cyclic variation in solar activity are so poorly understood that comments upon the probable time of the next minimum in the solar cycle can be made only through comparison of current solar activity with the historical data of past solar cycles. Even though it may turn out that the date of the anticipated minimum in the sunspot cycle is not far in the future (or in the recent past) in our judgment, we cannot estimate (as of December 1963) the probable time of minimum solar activity except within very broad limits. The date and activity level of any specific minimum between adjacent maxima in solar activity depend upon the decline of old cycle centers of activity, the formation of new cycle members, and the level of old cycle activity at which activity in the new cycle becomes significant. Within statistical accuracy certain aspects of these factors may be similar from cycle to cycle, but there still remains much uncertainty in prediction, or even recognition, of solar "minimum." Furthermore, within our physical understanding of the sun it is not clear whether these aspects of solar activity constitute independent or related phenomena. A certain responsibility has been given to those who observe the sun to try to forecast for the IQSY programs the

Table 1. Monthly mean of relative sunspot numbers (Zurich).

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1921	31.5	28.3	26.7	32.4	22.2	33.7	41.9	22.8	17.8	18.2	17.8	20.3
1922	11.8	26.4	54.7	11.0	8.0	5.8	10.9	6.5	4.7	6.2	7.4	17.5
1923	4.5	1.5	3.3	6.1	3.2	9.1	3.5	0.5	13.2	11.6	10.0	2.8
1924	0.5	5.1	1.8	11.3	20.8	24.0	28.1	19.3	25.1	25.6	22.5	16.5
1925	5.5	23.2	18.0	31.7	42.8	47.5	38.5	37.9	60.2	69.2	58.6	98.6
1931	14.6	43.1	30.0	31.2	24.6	15.3	17.4	13.0	19.0	10.0	18.7	17.8
1932	12.1	10.6	11.2	11.2	17.9	22.2	9.6	6.8	4.0	8.9	8.2	11.0
1933	12.3	22.2	10.1	2.9	3.2	5.2	2.8	0.2	5.1	3.0	0.6	0.3
1934	3.4	7.8	4.3	11.3	19.7	6.7	9.3	8.3	4.0	5.7	8.7	15.4
1935	18.6	20.5	23.1	12.2	27.3	45.7	33.9	30.1	42.1	53.2	64.2	61.5
1942	35.6	52.8	54.2	60.7	25.0	11.4	17.7	20.2	17.2	19.2	30.7	22.5
1943	12.4	28.9	27.4	26.1	14.1	7.6	13.2	19.4	10.0	7.8	10.2	18.8
1944	3.7	0.5	11.0	0.3	2.5	5.0	5.0	16.7	14.3	16.9	10.8	28.4
1945	18.5	12.7	21.5	32.0	30.6	36.2	42.6	25.9	34.9	68.8	46.0	27.4
1946	47.6	86.2	76.6	75.7	84.9	73.5	116.2	107.2	94.4	102.3	123.8	121.7
1952	40.7	22.7	22.0	29.1	23.4	36.4	39.3	54.9	28.2	23.8	22.1	34.3
1953	26.5	3.9	10.0	27.8	12.5	21.8	8.6	23.5	19.3	8.2	1.6	2.5
1954	0.2	0.5	10.9	1.8	0.8	0.2	4.8	8.4	1.5	7.0	9.2	7.6
1955	23.1	20.8	4.9	11.3	28.9	31.7	26.7	40.7	42.7	58.5	89.2	76.9
1956	73.6	124.0	118.4	110.7	136.6	116.6	129.1	169.6	173.2	155.3	201.3	192.1
1961	57.9	46.1	53.0	61.4	51.0	77.4	70.2	55.8	63.6	37.7	32.6	39.9
1962	38.7	50.3	45.6	46.4	43.7	42.0	21.8	21.8	51.3	39.5	26.9	23.2
1963	19.3	22.7	16.9	29.7	44.0	36.6	19.0	33.4	40.9	36.	21.4	

Table 2. Interval between the first appearance of spots of the new cycle and the time of "minimum" activity.

Cycles	Date of minimum	Smallest smoothed monthly relative sunspot number	Months between first new cycle spot and start of new cycle	Number of new cycle spot groups prior to minimum
15-16	1923 July–Aug.	5.6	14	3
16-17	1933 September	3.4	0	0
17-18	1944 February	7.7	10	10
18-19	1954 April	3.4	9	3

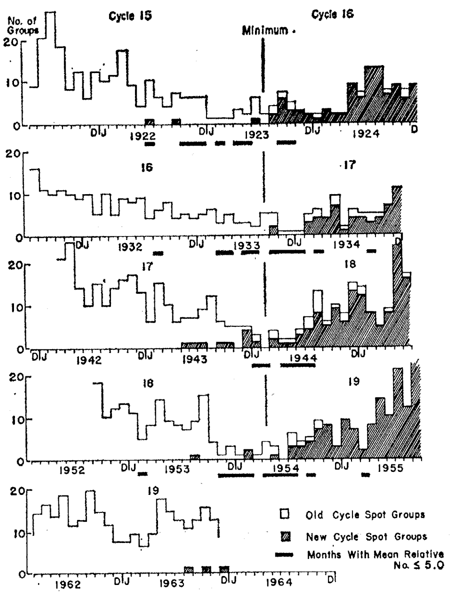

Fig. 1. Number of old-cycle and new-cycle sunspot groups and the months with mean relative Zurich sunspot number ≲ 5.0 for years centered on four preceding solar minima and for 1962 and 1963. The time of "minimum" as indicated by the smoothed monthly means of Zurich relative sunspot numbers is shown by a vertical line.

specific level and course of solar activity. Since we know that we probably cannot do this with much success, we feel it appropriate to summarize the various criteria that serve as guides to the course of the solar cycle so that those who must initiate IQSY programs can judge for themselves the current level of solar activity and can join the solar astronomers in trying to determine the time and the probability of protracted intervals of true solar quiet during the years designated as the International Years of the Quiet Sun.

The most familiar measure of solar activity is the relative sunspot number in one of its various forms. According to the monthly means of Zurich relative sunspot numbers for the last century, each "minimum" has included at least 6 months with this measure of solar activity ≲ 5. Table 1 shows the monthly mean sunspot numbers for the years surrounding the minima of 1933, 1944, 1954 and the decline of cycle 19 through November 1963. The months with values ≲ 5 are enclosed within contour lines. These protracted intervals of lowest solar activity did not happen suddenly but were preceded by 23, 13, and 10 months, respectively, in which the values of the monthly sunspot numbers were consistently < 30. A similar preliminary interval of unbroken relative calm (sunspot number < 30) has not yet been established, although there have been eight months with sunspot numbers < 30. If the next minimum is to resemble its immediate predecessors in these respects, then the intervals of truly low solar activity for which the IQSY programs have been planned may be anywhere from 6 to 18 months ahead.

The start of new cycle activity is related to the time of the subsequent solar minimum. Generally, sunspots and plages of the new cycle appear at high latitudes before activity of the old cycle at low latitudes has ceased. However, according to data for the last four cycles the intervals between the first appearance of spots of the new cycle and the time of "minimum" varied from 0 to 14 months (see Table 2).

Waldmeier, at Zurich, reported observation of the first spot of cycle 20 on 28 August 1963, at latitude 34°N. At least two additional spots of the new cycle were observed in 1963. They were in well-developed regions of relatively long duration and suggest that the new cycle started rather vigorously while the old cycle was still at a relatively high level of activity. Figure 1 shows for the preceding four minima the relationships between the decline of old cycle activity, the onset of new cycle spots, the time of "minimum" according to the smoothed relative sunspot numbers, and the months with mean relative sunspot number ≲ 5.0. Similar data for the present cycle, through November 1963, have been added. Just where they should be placed in the diagram is not obvious. Perhaps the present situation resembles most closely the approach to the 1944 minimum. If so, this suggests that the forthcoming minimum will be in the late spring of 1964, and that the level of residual activity may be high. It should be noted that in the number of spots here plotted, a spot group that endures more than one rotation has been counted each time it traverses the solar disk.

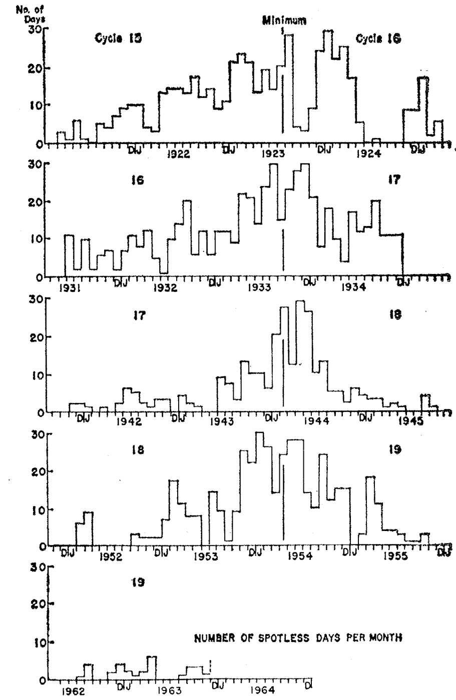

Fig. 2. Number of spotless days per month for the years centered on the four preceding solar minima and for 1962 and 1963. The time of "minimum" as indicated by the smoothed monthly means of Zurich relative sunspot numbers is shown by a vertical line.

Another guide to the probable time and level of the anticipated solar minimum can be found in the number of spotless days each month. Figure 2 summarizes this information for the four preceding minima. Again it is difficult to know where to place data for the current cycle. If the onset of new cycle regions is used as an additional guide, the 1944 minimum again seems most suitable for comparison. In both 1943 and 1963 there were relatively few spotless days before at least three spots of the new cycle had appeared. If this comparison is meaningful for forecasting, the next minimum may be expected to occur in the late summer or early autumn of 1964.

The first spots of a new activity cycle appear at high latitudes (>30°) and as the cycle advances the spots form at lower latitudes. Table 3 sum-

Table 3. Average latitude of spots in years near minimum. Data for 1923–1944 are taken from *Sunspot and Geomagnetic Storm Data . . . 1874–1954* (Royal Greenwich Observatory). Data for 1951–55 are taken from Mount Wilson yearly summaries of sun spots. Data for 1962–63 are taken from sun spot measurements at the McMath-Hulbert Observatory and are complete through 18 Dec. 1963.

Date	Old cycle spots		New cycle spots	
	North	South	North	South
1924*	6°.6	11°.6	27°.1	27°.5
1933*	4°.1	4°.4	25°.4	28°.3
1943	9°.0	0°.3	—	26°.1
1944*	4°.2	7°.6	22°.2	24°.0
1951	11°.6	11°.3		
1952	10°.7	10°.4		
1953	9°.9	8°.6	52°.0	—
1954*	7°.1	4°.3	27°.7	26°.5
1955			26°.6	25°.1
1962	11°.1	10°.7	—	—
1963	9°.7	10°.7	32°.0	—

* Minimum.

marizes mean values of spot latitudes for the years at or before solar minimum for the four preceding cycles. In 1963 the average latitude (McMath-Hulbert spot records through 18 December) of the old cycle spots was 9°.7 in the Northern Hemisphere and 10°.7 in the Southern Hemisphere. These values are considerably higher than those for the years of the four preceding minima and suggest at least another 12 months before the old cycle activity will have reached the latitudes that are usually associated with solar minimum.

Solar radiation at 2800 Mcy/sec follows so closely the variations in sunspot area and sunspot number that it is considered to provide an excellent measure of overall solar activity. For only one solar minimum has solar radiation at this frequency been observed, so it is not possible to do more than compare current 2800 Mcy/sec data with similar measurements in 1952–54.

Figure 3 brings this information together and indicates either that the sun is still a year or more from solar minimum or that the forthcoming minimum is going to be at a significantly higher level of activity than that of 1954.

Is there any evidence that the anticipated minimum may be markedly different from the minimum of 1954? It may be of significance that the highest smoothed monthly relative sunspot number during the recent solar maximum, 201.3, was the highest ever recorded, and was 28 percent higher than any similar measurement in the preceding 200 years. It is possible that an abnormal maximum will be followed by an abnormal minimum, but history does not make clear whether the abnormality would be expressed through unusual calm or unusual lack of calm (see Fig. 4). High maxima were followed by the unusually high minima of cycles 4, 9, and 18, but the low minima of cycles 5, 10, 12, and 19 took place after abnormally high maxima.

Over the centuries the level of activity at maximum has shown great variation. During the maxima of 1685, 1805, and 1816 extended intervals of truly great solar activity apparently did not take place. It is probable that there have been similarly great variations in the "quietness" of minimum. In May 1963, d'Azambuja, the distinguished French observer of solar activity, was asked whether, in his judgment and long experience, solar minima tended to be more alike or different. He re-

Table 4. Summary of circumstances during the 1954 solar minimum.

Circumstance	1953	1954	1955
Months with mean monthly relative sunspot number $\lesssim$ 5	3	7	1
Days with no calcium plage $\lesssim$ 500 millionths of solar hemisphere	33	56	0
Days with no calcium plage $\lesssim$ 100 millionths of solar hemisphere	17	29	0
Days with 2800 Mcy/sec flux $\lesssim$ 68 $\times$ 10^{-22} watt/m²/cy/sec	63	137	0
Months without reported geomagnetic storms	0	2	0
Days with $k_p \lesssim 8$	32	34	54
Days with $A_p \lesssim 3$	18	17	26

Table 5. Intervals between flares in various importance categories. The number of flares of importance $\lesssim$ 1, 1954: 16; prior to the minimum (April), there were 7 flares; after the minimum, there were 9.

Category	Dates	Interval (mo)
3	22 Nov. 1952 – 15 Jan. 1955	26
2	15 Oct. 1953 – 5 Jan. 1955	14
1	16 Oct. 1953 – 28 Feb. 1954	4
	17 March 1954 – 5 Aug. 1954	4

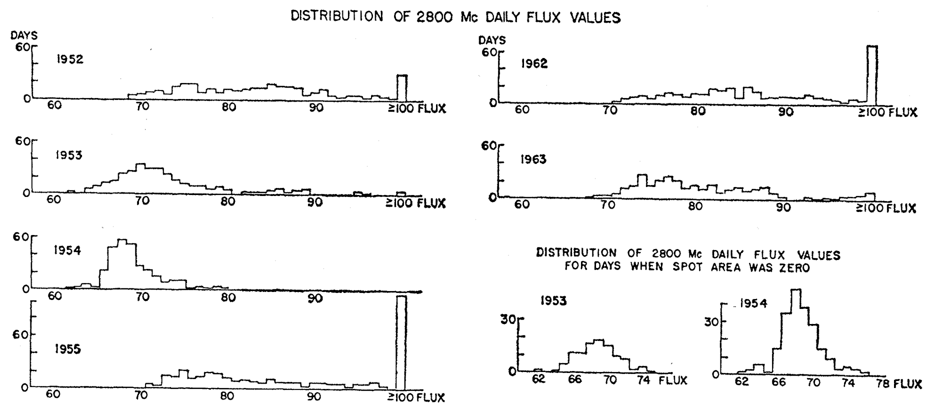

Fig. 3. Comparison of distributions of values of daily solar flux at 2800 Mcy/sec as measured by National Research Council, Ottawa, for the 4 years centered on the last solar minimum and for 1962 and 1963, and similar data for the days in 1953 and 1954 when there were no spots on the visible solar hemisphere. The flux is measured in units of watt per square meter per cycle of band width ($\times 10^{-22}$).

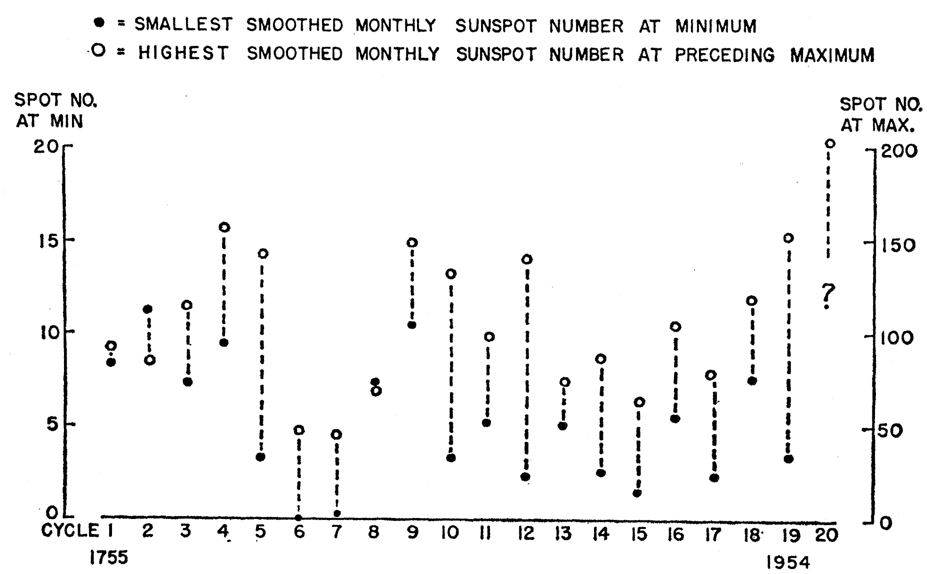

Fig. 4. Comparison of level of residual activity at minimum with activity of preceding maximum (smoothed monthly means of Zurich sunspot numbers), 1755 to 1958. The ordinates at left refer to sunspot number at minimum and those at right to sunspot number at maximum. The horizontal scale gives the cycle number of the respective minima. The maxima, plotted vertically above or below, are those of the preceding cycles.

plied that they tended to be different. The statistics of Fig. 4 confirm his comment.

Many of us who are now observing the sun are most familiar with the minimum of 1954. In spite of the high preceding and subsequent maxima, the years 1953 and 1954 provided relatively long intervals of solar calm. Details of the 1954 minimum are summarized in Tables 4 and 5.

Intervals of true solar quiet similar to those of 1954 are what solar astronomers would like to recognize in advance for geophysicists during the IQSY. However, it seems possible that the sun, during the coming minimum, may not be truly quiet for extended intervals of time. The high values of sunspot numbers at the minima in cycles 1, 2, 3, 4, 8, 9, and 18 give warning that solar minimum can take place without true solar calm.

As of December 1963 there is evidence that at least another year will be required before old cycle activity will have diminished to the level associated with the truly calm solar circumstances of 1954. This evidence includes the current relatively high values of monthly mean sunspot numbers, mean latitude of old cycle spots, and 2800 Mcy/sec flux. The small number of spotless days and the unusually great solar activity of September and October 1963 indicate that if the anticipated minimum is to be at a truly low level, it will probably not be reached prior to January 1965. If new cycle activity does not develop rapidly this indeed may be the course of the activity cycle. On the other hand, two of the three new cycle centers of activity already observed have been well developed and relatively long-enduring. If these regions indicate that the new cycle is on the threshold of rapid development, then the statistical minimum between cycles 19 and 20 can be near at hand, with the mean level of residual activity unusually high.

It is possible that many of the programs planned for the Years of the Quiet Sun will not be vitiated by the existence of a certain residual solar activity. Nevertheless, it should be noted that on 26 and 27 August 1954 high resolution radio frequency instruments at Nagoya, Ottawa, and Sydney detected radiation from a new-cycle region with a small spot for which the calcium plage was of only moderate intensity and for which the area was no greater than 200 millionths of the solar hemisphere. After the almost complete absence of geomagnetic storms and plages and spots in May and June 1954, geomagnetic stations began reporting storms (albeit minor ones) in July and August, the same months that saw the formation of the first enduring new-cycle calcium plages and spots. Apparently solar measurements and the earth-sun system are exceedingly sensitive to the existence of even minor forms of solar activity.

In the months ahead, the guidance or comments of solar astronomers on the expected specific course of solar activity should be looked upon with uncertainty and perhaps even with skepticism. At the present time there is so little true understanding of why spots and plages form when and where they do, or why they endure or die, that attempts to forecast solar activity are undertaken only in the spirit of trying to evaluate, as best one can, the day-to-day situations in the light of past solar cycles. Let us hope that the activity of the new cycle remains low, and that the activity of the old cycle diminishes quickly, so that 1964–65 will provide the long intervals of solar quiet desired by the geophysicists during IQSY.

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Basaltic Cone Suggests Constructional Origin of Some Guyots

Abstract. *A basaltic cinder cone was built beneath the waters of Mono Lake in Pleistocene time. This cone is now exposed. Its internal structure, external form, and petrography suggest that it was constructed with a flat top.*

A flat-topped, conical accumulation of more or less horizontally stratified basaltic cinders and tuff-breccia occurs in the desert of eastern California within the area once occupied by Pleistocene Mono Lake. It stands on the northern shore of the present lake, well below the late Pleistocene high-water level, and is known simply as Black Point. The basaltic debris consists largely of perfectly clear, pale-brownish-green glass having a refractive index of about 1.57. Such glass, in contrast to the dark brown semiopaque variety clouded by iron oxides, has heretofore been considered evidence of subaqueous eruption (*1*). The peculiar form and structure of Black Point also seem to have resulted from subaqueous pyroclastic eruption and accumulation. The characteristics of this cone may, therefore, provide evidence regarding the internal structure and origin of some guyots and seamounts.

Interpretation of submarine volcanic forms has been based of necessity on comparison with forms of subaerial volcanoes. Except for the "table mountains" of Iceland and the "tuyas" of northern British Columbia which were built within lakes in ice sheets (*2*), volcanoes with primary flat tops have not been recognized. Hence, the flat tops of guyots have been considered "anomalous," requiring special explanation (*3*). The flat tops of guyots are generally considered to have been produced by erosional truncation of volcanoes by wave action at or near sea level (*4*). The presence of basaltic debris on the tops and flanks of guyots has seemed to support this hypothesis. The basaltic cone at Black Point indicates, however, that flat tops and basaltic debris alone do not prove the erosional origin of guyots. It suggests, on the other hand, that these features may result from subaqueous pyroclastic eruptions, providing support for Nayudu's suggestion (*5*) that some guyots may be primary constructional features of submarine vulcanism.

The region surrounding Mono Lake has been characterized by vulcanism almost continuously since the Miocene epoch (*6*), and the structural basin containing the lake has been the site of both Pleistocene and Recent vulcanism. Indeed, the waters of Mono Lake are reported to have boiled and emitted puffs of steam in 1889, presumably as a result of subaqueous eruptions (*7*),