CYCLES OF SOLAR FLARES AND WEATHER

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ABSTRACT. Sunspots only constitute potentials of solar activity which are actually released by solar eruptions. Single energetic flares and periods of enhanced eruptional activity seem to be related to weather. This is valid for the quality of weather forecasts (Scherhag, Reiter), atmospheric circulation changes (Schuurmans) , rainfall (Clarkson) , and thunderstorm incidence (Bossolasco et al.). There are models that explain this effect (e.g. Roberts and Olson, Flarkson, Neubauer, and Bucha). This poses the problem of the prediction of solar flares. Such eruptions seem to be distributed in a stochastic manner. But closer examination reveals cycles of solar flares with mean periods of 9 years, 2.25 years, and 3 months. They are accessible to forecasts, because they run parallel with special phases in the Sun's motion about the center of mass of the solar system, and with a cyclic pattern formed by the change in the angular acceleration of the vector of the tidal forces of the planets Venus, Earth, and Jupiter.

RELATIONS BETWEEN SOLAR ERUPTIONS AND WEATHER

A large flare can release energy equivalent to the explosion of more than ten million hydrogen bombs in a few minutes' time. Momentary temperatures exceed twenty million K, hotter than in the dense core of the Sun (Eddy, 1979). The small fraction of the energy of such flares, that the Earth intercepts, is adequate to generate striking effects in the upper atmosphere. These effects are produced by the ultraviolet, x-ray, and energetic particle emissions from flares and other eruptions, and not by an appreciable change in the overall output of the Sun, which at most reaches one thousandth of *1%.* None the less, single energetic eruptions and periods of enhanced flare activity seem to be related to weather. Roberts (1979) stated: "We now have, I venture, pretty solid evidence that there are some bona fide influences of variable solar activity on the troposphere that operate at the weather lead time of a few days". Indirect evidence of this is the observed change in the quality of weather forecasts after flares. Scherhag (1952) observed a sharp degradation of the precision of weather predictions in Great Britain and Germany after the proton flare on February 23, 1952. This connection was corroborated by Reiter (1979a), who investigated a sample of 79 flares observed January 1975 to January 1977. He found a 14$ increase in weather forecasts of poor quality on the key day, marked by stratospheric intrusions of Be7. According to Reiter (1979b) the Be7-concentration in the troposphere is a measure of the intensity of stratospheric-tropospheric exchange caused by flares.

As observed by Reiter (1979c) and Cobb (1967), a sharp increase in air-Earth current density occurs on flare days. The departure from normal lasts three to five days. Accordingly, Bossolasco et al. (1972) and Muir (1979) found a 70^ variation of thunderstorm incidence with the occurrence of solar flares. Harkson (1979) developed a model that shows how flare induced variations in electric fields and ionizing radiation can control cloud electrification, rainfall, and circulation by the redistribution of energy already present within the atmosphere. Schuurmans (1979) could demonstrate that strong flares cause atmospheric circulation changes or variations in mass and temperature distribution at middle and high latitudes, starting within 6 to 12 hours after the flare and lasting approximately one day. Zerefos (1975) obtained similar results. Neubauer (1983) and Bucha (1983) have developed models that connect changes in weather with sudden commencements of geomagnetic storms, generated by solar eruptions. Roberts and Olson (1973) hold that solar particle invasions after flares with increased ionization at stratospheric and probably upper-tropospheric levels could generate increases in high-level cirrus by augmentation of the efficiency or number of sublimation nuclei. An increase in cirrus could affect the latitudinal gradient of the radiation balance and the distribution of wind fields.

9-YEAR AND 2.25-YEAR CYCLES OF ENERGETIC FLARES

The Sun, rotating on its axis, and the Sun, revolving around the center of mass (CM), could be looked at as coupled oscillators capable of internal resonance, resulting in slight positive or negative accelerations in the Sun's spin. Such accelerations are actually observed. Speeding up or slowing down of the Sun's rotation rate is liable to influence the Sun's activity. Slower rotation seems to be linked to enhanced activity and faster rotation to weak activity. According to investigations by Eddy (1977), based on historical observations by Scheiner and Hevelius, the rotation of the Sun's equator sped up just before the Maunder minimum, while its rotation rate about 1620, near a secular maximum of sun-spots, was much the same as it is today. Modern observations confirmed this relation.

Mt. Uilson observations (Howard, 1975), presented in Fig. 1, show two striking jumps in the Sun's rate of rotation in 1967 and 1970. These jumps occurred when the Sun'scenter, the center of mass of the solar system, and the planet Jupiter were on a line. These heliocentric constellations are indicated in Fig. 1 by arrows. Jupiter plays a dominant role even among the giant planets, that regulate the Sun's oscillations about CM. Jupiter holds *71%* of the total mass of the planets and *61%* of the total angular momentum of the system, while the Sun governs less than *1%* of the angular momentum. This seems to be indicative of a case of spin-orbit coupling of the spinning Sun and the Sun revolving about CM, involving transfer of angular momentum from Jupiter to the revolving Sun and eventually to the spinning Sun. With respect to the angular momentum conservation law, it makes sense that the observed slowing down in the Sun's spin went along with an increase in its orbital angular momentum.

Conjunctions of Jupiter and CM .relative to the Sun's center constitute a cycle with a mean period of 9 years and a range of variation from 3 to 15 years. Since the spectrohelioscope by Hale was not fully developed until 1931, the 17th 11-yr cycle of the late thirties was the first during which flares were observed systematically. Since that period, conjunctions occurred in 1942, 1951, 1959, 1967, 1970, 1974, and 1982. There was always very

energetic eruptional activity around these events (Landscheidt, 1976). As to the activity in 1982, the reliability of the relation was tested by a long range forecast. X-ray bursts are a good measure of the energy released by flares. They were listed since 1970. Bursts greater than X9 are rare events. Only two of this category occurred 1970 to 1981. According to a forecast issued 3anuary 1982, events greater than X9 were expex-ted 29 April to 5 May, 22 May to 9 June, and 27 September to the middle of December 1982. The observations match the prediction. Bursts X12, X12.9, and X10 occurred on 6 June, 15 December, and 17 December 1982. In addition several X7, X8, and X9-events were observed. The forecast was checked by the Space Environment Services Center, Boulder, and the astronomers Gleissberg, Pfleiderer, and Ub'hl.

If the interval from one conjunction or opposition of Jupiter and CM to the next one, from one jump in the Sun's rotational velocity to the next one, is looked at as a cycle and subjected to Fourier analysis, the fourth, fifth, and sixth harmonic prove to be strong. A superposition of these harmonics forms a neu cycle, the mean period of which is 2.25 years, one fourth of the fundamental. A Pearson-test of x-ray bursts ^ X1, related to this shorter cycle, yields the value 40 for 1 degree of freedom (P< 0.00001) for the years 1970 to 1974. A replication for the fundamental period 1974 to 1982 gives out the value 79 for 1 degree of freedom (P"0 .00001) .

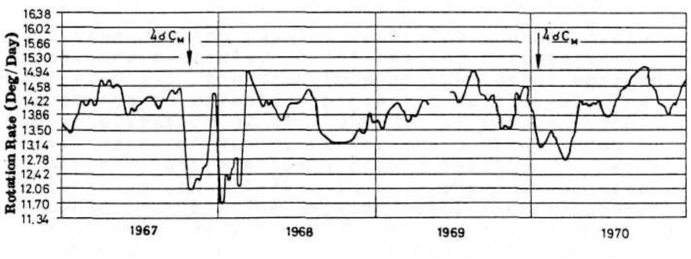

Fig. 1. Sudden decrease in the Sun's rate of rotation (from Howard, 1975) related to heliocentric conjunctions of the planet Jupiter and the center of mass.

ANGULAR ACCELERATION OF THE VECTOR OF TIDAL FORCES AND 4-MONTH CYCLE OF X-RAY BURSTS

The Sun's oscillations around CM are regulated by changing constellations and variations in the distance of the four giant planets. Another cycle is generated by the tidal planets Venus, Earth, and Jupiter. There is a wealth of literature dealing with a presumed influence of tidal planets on sunspots. Critical authors stress that all tidal planets, when conjunct, could only raise a tide of a few millimeters on the Sun. But it should be taken into consideration, that the horizontal component is not negligible, since the Sun's gravity acceleration is 28 times that of the Earth's, flpik (1972) has shown that the mean velocity of tidal currents on the Sun reaches about one third of tidal currents generated by the Moon on Earth. As to relations of tidal planets with flares, there are only few papers (Blizard, 1965; Svest-ka, 1968; Landscheidt, 1976, 1981, 1983). This disproportion is not justified. We know from Skylab observations that flares are set off by initial disruptions in hot coronal loops over active regions (Eddy , 1979). It is easier to imagine that tidal disturbances may trigger such events in an unstable zone of the Sun's atmosphere than to concede that tide generating forces could act on the strong magnetic fields constituting sunspots. Calculations of the relative tidal force of the planets Mercury to Saturn show that the latter is negligible as well as Mars, Venus is sometimes stronger than Jupiter. Comparison of the combined vector of the tidal forces of Venus, Earth, and Jupiter, including or excluding Mercury, shows that the vector including Mercury oscillates around the vector of Venus, Earth, and Jupiter. Therefore, only the latter has been investigated in its relation to energetic flares marked by x-ray bursts.

Figure 2 presents the result, revealing another cycle of flares. Unexpectedly, no interesting correlations with variations in the magnitude of the vector emerged. But the change in direction proved to be crucial. The angular acceleration d"j/dt = d^2~//dt^i of the vector of the tidal forces of Venus, Earth, and Jupiter forms a cyclic pattern, which shows a strong relation to x-ray bursts observed'since 1970.- Figure 2 shows the course of the cycle in 1982. The axis of abscissae designates the days of this year. The ordinates represent the time rate of change of the angular velocity of the vector. The active phase of a flare cycle begins when the curve crosses the time axis. This occurs when dw/dt changes from positive to negative or from negative to positive

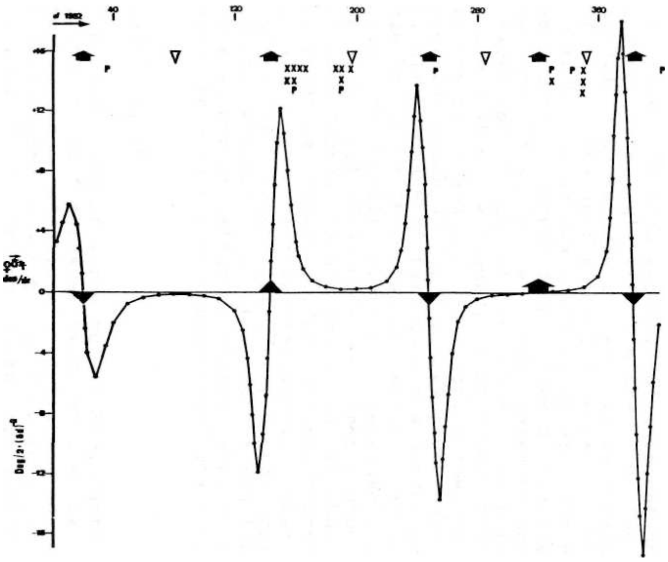

Fig. 2. The change in the direction of the vector of the tidal forces of Venus, Earth, and Jupiter, measured by the angular acceleration d(0/dt, forms a cyclic pattern which correlates with energetic solar eruptions. The plot shows the course of dw/dt and the distribution of energetic x-ray bursts in 1982.

values. These zero phases are indicated in Fig. 2 by fat triangles, and in one case by a fat arrow. The effect is stronger when the curve ascends than when it descends. The strength of the effect on flares is inversely proportional to the steepness of the ascent. Slow ascent releases prolonged flare activity reaching a high level of energy display. The fat arrow in Fig. 2 marks such a situation. In 1982 the ascent, marked by a triangle pointing upwards, had as strong effects as the second case with slow ascent. But this category showed a stronger overall effect since 1970. The lull begins always in the middle between two zero values. On top of Fig. 2 the active and lull phases of the flare cycle are marked by arrows pointing upwards and open triangles painting downwards. Observed proton events (P) and x-ray bursts ^ X3 (x) match the phases of activity without exception. If all of those 106 x-ray bursts = X2 observed since 1970 are tested, 91 of them fit active phases in the cycle and .only 15 inactive ones. A Pearson test yields the value 52 for 1 degree of freedom ($P< 0.00001$). All events ^ X6 fell into the active periods. As the sample covers 36 cycles and shows a homogeneous distribution, the result points to a dependable relation. The high level of significance breaks down when less energetic flares are analysed, even if they belong to an upper optical category. Such optical flares are no reliable indicator of solar-terrestrial relations. Unfortunately, many interdisciplinary papers dealing with solar-terrestrial interaction do not consider this, even if the author investigates flares because he knows that flares are a better criterion than sunspots.

EXPERIMENTUM CRUCIS

Beside the prediction of x-ray bursts >X9, mentioned already, long range forecasts, based on the flare cycles presented and on additional experience, shouied significant reliability. Predictions of periods of energetic x-ray bursts and proton events were published one year in advance and checked by the Space Environment Services Center, Boulder, and the astronomers Gleissberg, Pfleiderer, and Uohl. Out of 29 events observed 1979 to 1981, 27 hit the predicted periods of activity (Land-scheidt, 19831. A Pearson-test yields the value 20.9 for 1 degree-of freedom ($P<0.00001$). A neu forecast, issued January 1983, covers the period 1983 to 1990. In 1983 all events ^ X1 observed match the predicted periods of activity.

These results, when judged with respect to the relations between energetic flares and weather discussed above, should encourage interdisciplinary research, which could lead to an improved understanding of the phenomena involved.

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