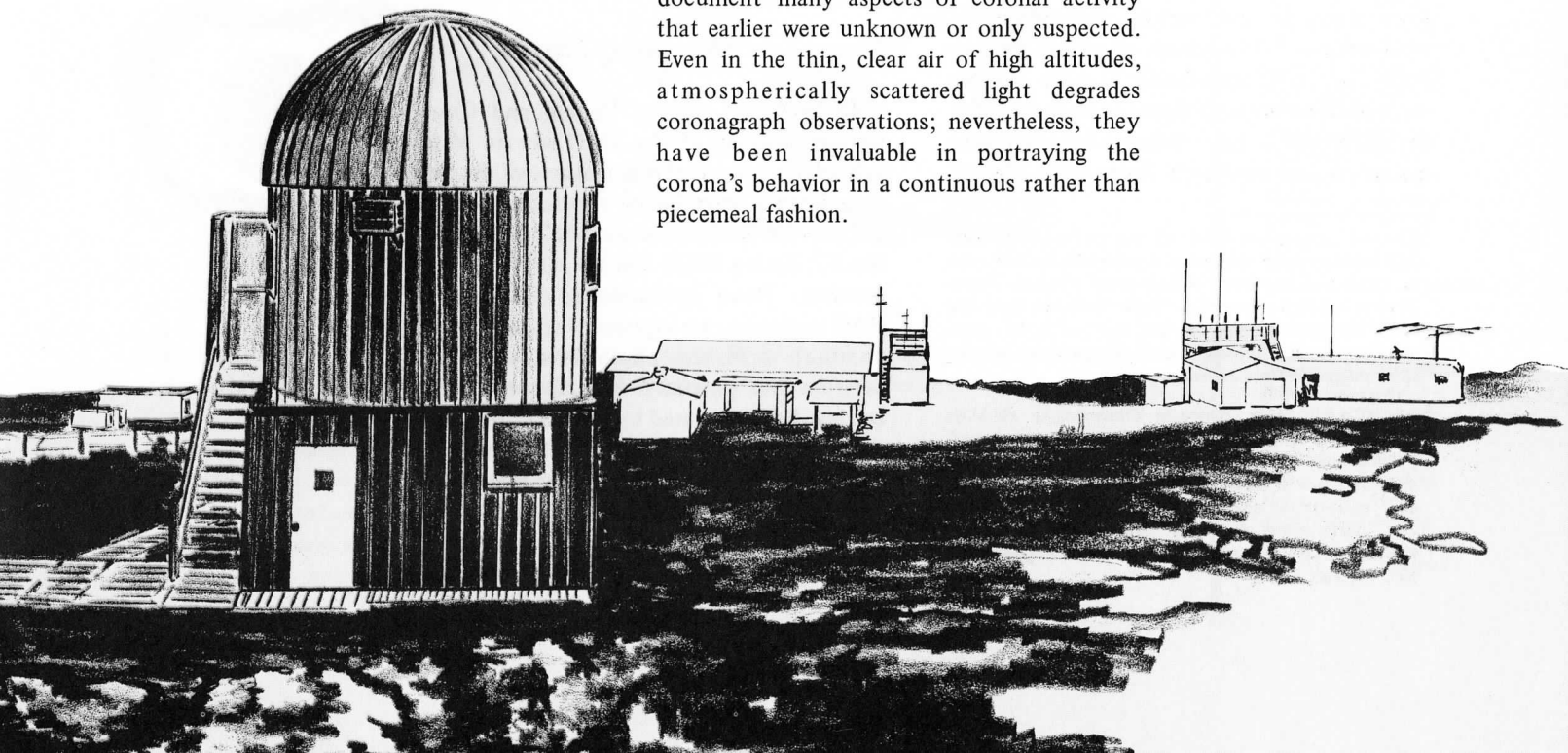


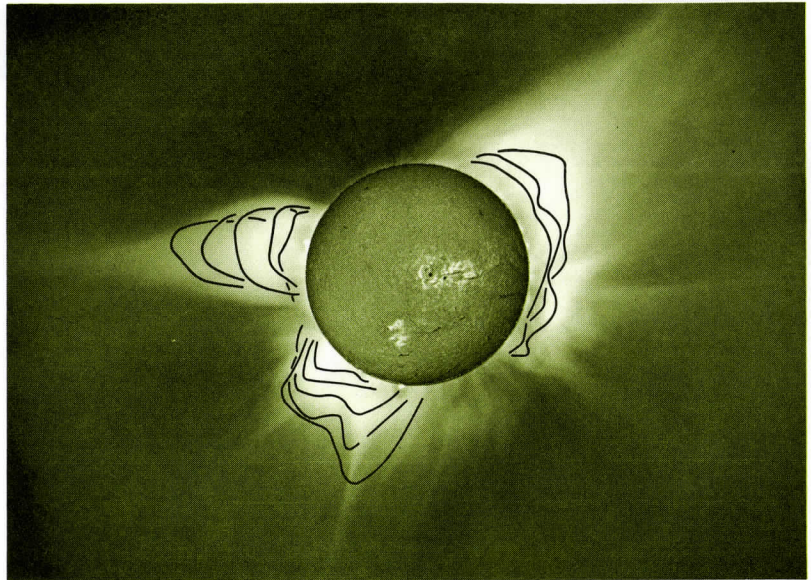
## The Changing Corona

The sun's corona is best observed at times of total eclipse, when the moon, appearing almost identical in diameter with the sun, blots out the overwhelming brilliance of the solar disk (a million times that of the corona), and when the earth's atmosphere along the

eclipse path is also in shadow and interference from scattered sunlight is much reduced. But however breathtaking and however useful to science they may be, total eclipses are so infrequent and of such short duration that they cannot really give us an accurate picture of the long-term behavior of the corona.

Invention of the coronagraph in 1930 by the French astronomer Bernard Lyot made day-to-day observations of the corona possible, and this instrument has been used to document many aspects of coronal activity that earlier were unknown or only suspected. Even in the thin, clear air of high altitudes, atmospherically scattered light degrades coronagraph observations; nevertheless, they have been invaluable in portraying the corona's behavior in a continuous rather than piecemeal fashion.





### *Solar Cycle Changes in the Corona*

Basic changes occur in the appearance of the corona during the 11 - year solar sunspot cycle.<sup>1</sup> Near solar maximum, when 100 or more sunspots may be visible at one time, the corona appears almost circular, with brilliant streamers radiating from all latitudes. At solar minimum, when few sunspots develop, equatorial streamers predominate, polar features are much reduced, and large rifts often appear near the poles. At this time total coronal radiance is less than half as great as during solar maximum.

Solar cycle changes in the corona were originally discovered by piecing together data from drawings and written descriptions of total eclipses.<sup>2</sup> The advent of eclipse photography in 1851 introduced a more reliable method of recording eclipses and revealed also the difference in total radiance between solar maximum and minimum. Solar cycle changes

*Mauna Loa K-coronameter observations superposed on HAO's 1966 eclipse photograph show that the intensity contours made with this instrument correspond well with the shapes of coronal white-light features. The K-corona is composed of light scattered by free electrons in the sun's atmosphere, and its radiance is a measure of electron density in the corona. This photograph is a composite, with a red-filtered ( $H\alpha$ ) photograph from Sacramento Peak Observatory showing the sun's disk at the time of the eclipse.*

have now been documented photographically and spectroscopically on a continuing basis with coronagraphs at high altitude sites in France, Switzerland, Germany, Czechoslovakia, the USSR, Japan, and the United States.

### *Mauna Loa Observatory Studies*

Richard and Shirley Hansen and Charles Garcia, working at the HAO site on Mauna Loa, Hawaii, are studying features of the inner corona with two highly specialized coronagraphs, the K-coronameter (*NCAR Quarterly* No. 17, Spring 1967) and the coronal activity monitor. These instruments, developed by HAO engineers, are especially adapted to map coronal radiance photoelectrically. They measure the polarized K-component of the corona, light scattered by free electrons in the sun's atmosphere. Both the K-coronameter and the coronal activity monitor measure this radiation by making concentric small-aperture scans around the sun at predetermined distances above the edge, or "limb," of the sun

<sup>1</sup>The 11 - year periodicity of sunspot development and solar activity was recognized by H. H. Schwabe in 1843 and has been documented back to 1610. Studies of solar magnetic fields indicate that the cycle of solar activity is but half of a 22 - year magnetic cycle, during which the polarity of the solar magnetic field reverses twice.

<sup>2</sup>At NCAR's High Altitude Observatory (HAO), John Eddy has collected eclipse drawings and photographs dating back to 1715. Eddy feels that although many early drawings do not provide reliable records of coronal details, they do illustrate the differences between eclipses occurring in various parts of the solar cycle (*NCAR Quarterly* No. 19, Fall 1967).



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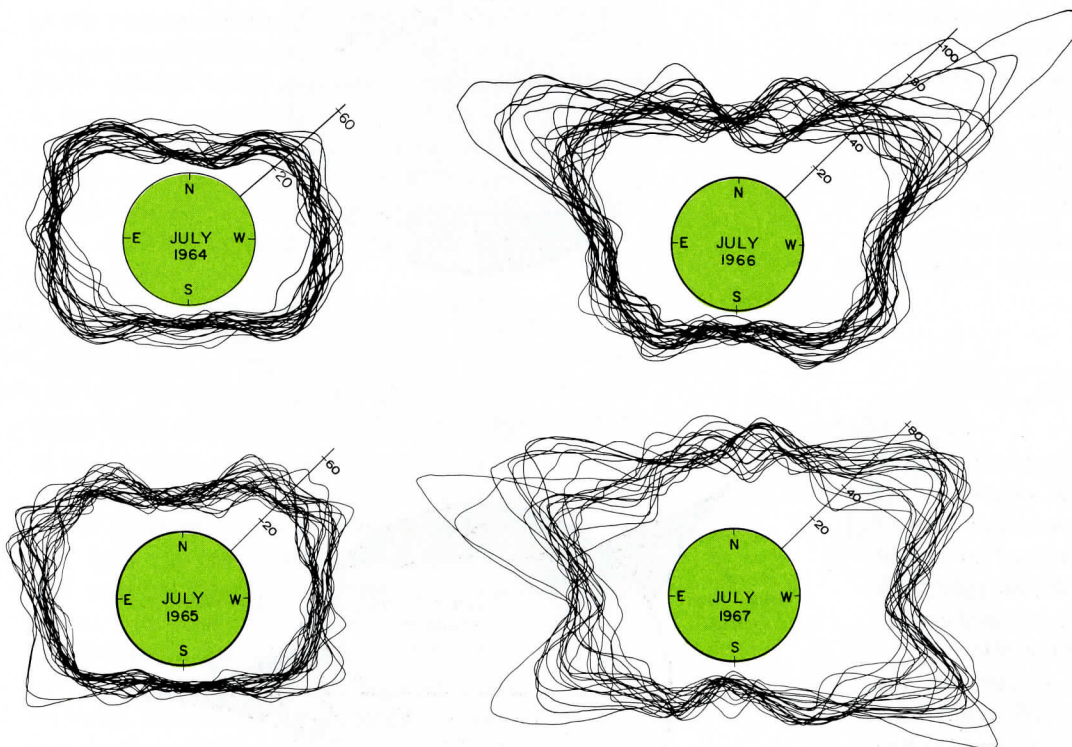
while the solar disk is occulted as in other coronagraphs.

Mauna Loa data verify that pronounced changes occur in the distribution of radiance in the corona during the solar cycle. For example, during the ascending phase (from 1964 to 1967) of the present solar cycle the total radiance of the lower corona doubled and there was a progressive migration of zones of enhanced activity toward the poles, as shown in the accompanying figure.

**Evolutionary Changes**

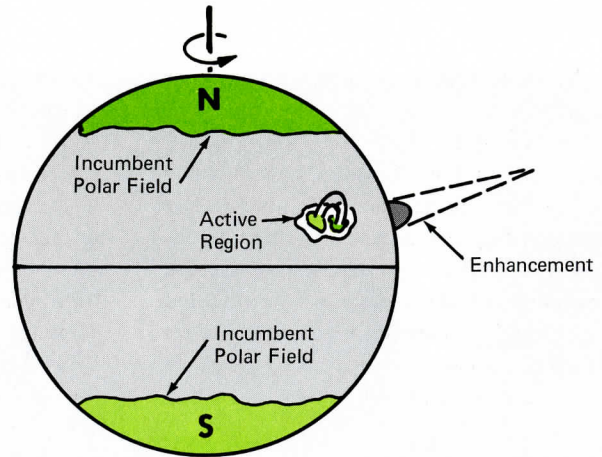
From the wealth of synoptic observations being made at Mauna Loa, the evolution of individual coronal features such as the

streamers seen in eclipse photographs can be related to other solar phenomena. The corona appears to increase in radiance with the emergence of an active center, a localized region containing sunspots and other manifestations of strong magnetic fields. Such an active center, which develops at a low latitude, gradually disperses, and a portion of its magnetic field migrates poleward, trailing behind the equatorward portion because of the differential rotation of the sun. For a time, magnetic field lines connect the two regions, but as the trailing field spreads poleward and eastward, field lines also join this region to the polar field. A filamentary, or "quiescent," prominence typically divides the regions of opposite polarity (NCAR Quarterly No. 29, November 1970).



Superposed daily K-coronameter plots depict solar cycle changes in the corona. Radial distance from the edge of the circle is proportional to radiance at 1.125 solar radii. Note that these are radiance plots and not diagrams of the shape of the corona.

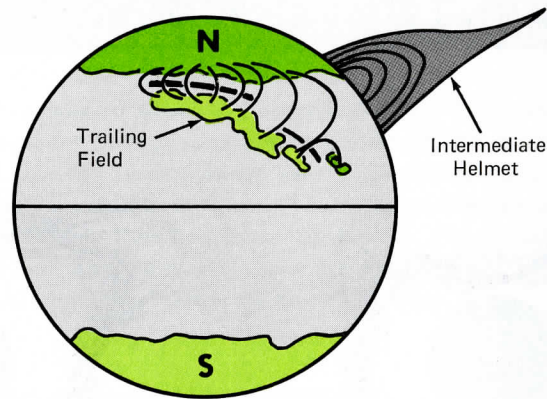
During July of the solar minimum year 1964 the general level of radiance was low and day-to-day changes were slight. By July 1965 activity increased slightly except in polar regions. In 1966, zones of increased activity appeared in the northern hemisphere. The general level of radiance was two to three times as great as that during solar minimum. In 1967 radiance had increased in the southern quadrants also, although a relative void remained over the south pole.



*An active center forms in the equatorial region of the sun. The slender enhancement overlying it is visible against the plane of the sky.*

As the sun's rotation brings active centers near the limb of the sun, the association between active centers and coronal features becomes evident. When seen at the edge of the sun these features are broad helmet-shaped structures; at greater heights above the sun's surface they taper to narrow streamers.

Ultimately, the trailing poleward end of the system appears to break its ties with the equatorward portion and to link up magnetically with the polar field. A long magnetic tunnel arches over the filamentary prominence that separates the trailing field from the polar field, and a helmet streamer extends outward as part of the polar corona. The equatorward end of the original active region, now magnetically unbalanced, may form a transequatorial arch if a similar region of opposite polarity exists at nearby longitudes in the opposite hemisphere.

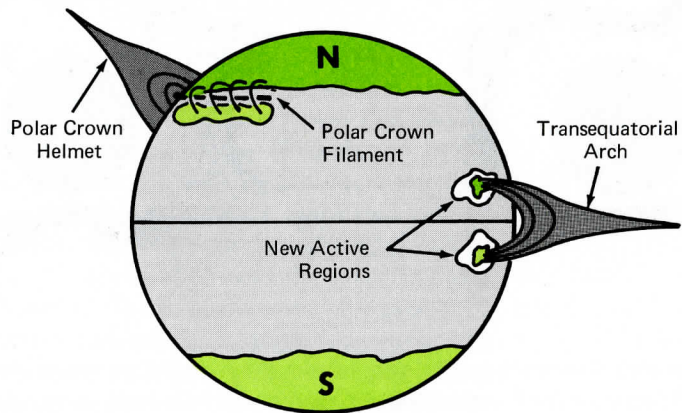


*As part of the active region migrates toward the pole, it diffuses and is strung out by the sun's differential rotation. At high latitudes, field lines join the end of the trailing field to the polar magnetic field. The streamer seen against the plane of the sky becomes helmet shaped.*

### Solar Rotation

The sun's rotation causes systematic and recognizable changes in the appearance of coronal features as they move into and out of the plane of the sky, projecting for several days above the solar limb. Occasionally, very high-latitude features may be followed continuously as they rotate around the pole.

The overall appearance of parts of the corona may be due to the superposition of more than one coronal structure along the line of sight, i.e., several features in the same area of the corona may overlap and blend together. Therefore, analysis of the behavior of any one system is difficult. Martin Altschuler and Michael Perry of HAO are developing a complex numerical technique for calculating the electron densities of coronal structures from K-coronameter observations. By mapping the electron densities in terms of latitude, longitude, and distance above the solar surface,



*The poleward end of the active system breaks free from the equatorward portion, which may connect with an active region of the opposite hemisphere.*

*A model developed by the Hansens and Garcia at Mauna Loa represents the evolution of a coronal system.*



they will be able to identify the boundaries of individual coronal streamers and resolve overlapping features.

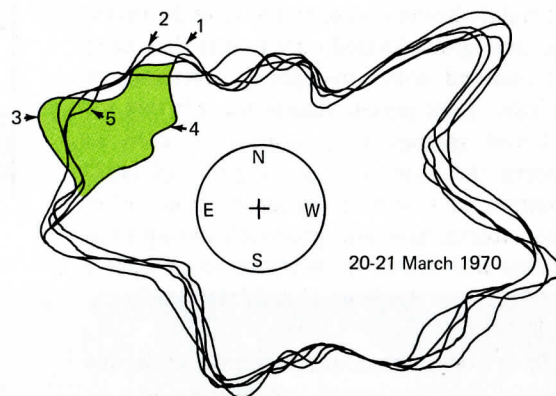
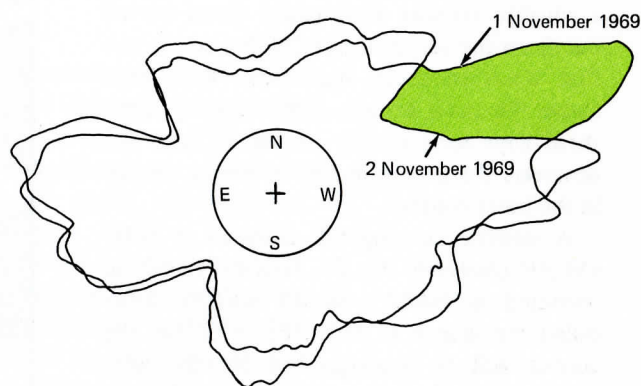
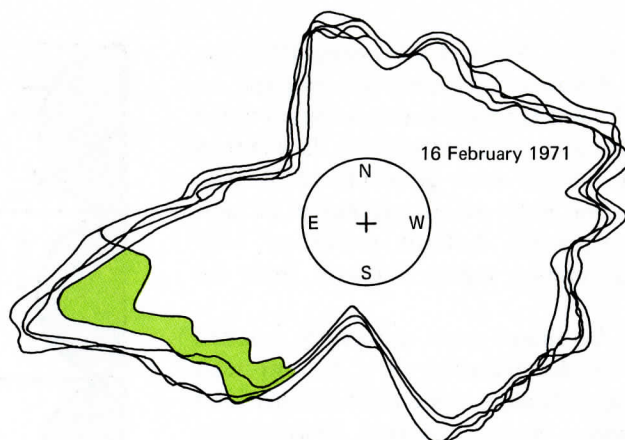
### Coronal Transients

Occasionally, Mauna Loa data show very abrupt, short-lived changes in localized regions of the corona. Although in one case a high-latitude coronal helmet streamer seemed to be blown outward as the prominence underlying it erupted, a more frequent type of coronal transient occurs at lower latitudes and is associated with explosive solar "sprays" (high-speed expulsions moving at 200 - 1,000 km/sec) and with moving sources of radio noise.

Several coronal transients observed at Mauna Loa have also been recorded by the radioheliograph at Culgoora, Australia, operated by the Commonwealth Scientific and Industrial Research Organization (CSIRO). On 21 March 1970, for instance, the radioheliograph recorded three distinct radio sources, one of which moved to a distance of six solar radii from the center of the sun. Mauna Loa data suggest that then, as well as during several other transient events, the loss of material blown out into space depleted part of the corona temporarily, for radiance was markedly reduced in the immediate area of the eruption. Recovery was rapid, however, and by the next observing day the coronal structure had returned to its pre-flare shape and brightness.

### Satellite Observations

Just recently, two remarkable solar transients were observed from OSO - 7, a NASA Orbiting Solar Observatory satellite. On



Three coronal transients are shown in these plots of K-corona intensities at 1.5 solar radii. Green areas indicate rapid changes in radiance over time intervals of a few hours. Depletion of the corona was greatest in the 2 November and 20 - 21 March events. In the latter, the sudden decrease in radiance occurred between scans represented by lines 3 and 4; line 5 indicates that the coronal structure reformed by the next day. Radio sources associated with this coronal transient were recorded by the CSIRO radioheliograph at Culgoora, Australia.

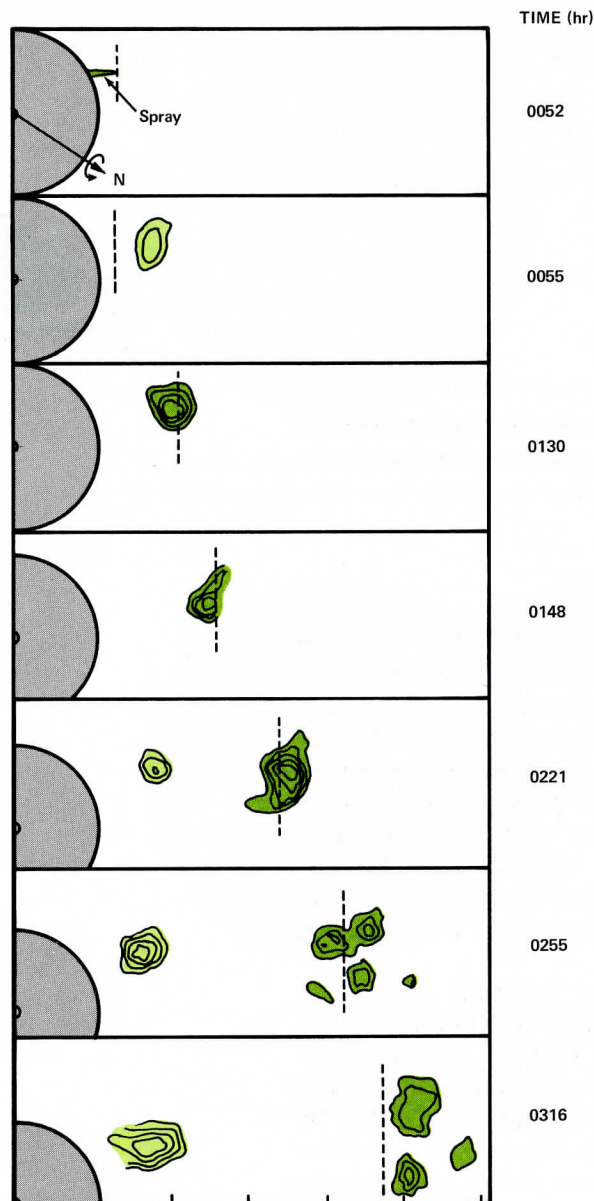
13 December 1971 and 8 February 1972, the Naval Research Laboratory coronagraph on OSO - 7 recorded two massive eruptions in the outer corona, much farther from the sun than can be studied from ground-based observatories. For both events, telemetry pictures show immense brilliant clouds of solar material moving rapidly outward from the sun.

The December event apparently resulted from the disintegration of a brilliant solar streamer extending some eight or nine solar radii above the sun's surface. Subsequently, large coronal clouds were seen traveling outward through the corona at an estimated speed of 1,000 km/sec. In the February event, a roughly circular sharp-edged cloud moved out from the sun at about 260 km/sec. It was first observed more than three solar radii above the sun's surface. Unfortunately, both these days were cloudy at Mauna Loa, and observers there were unable to record activity in the inner corona.

A satellite coronagraph designed at HAO (*NCAR Quarterly* No. 31, May 1971) will be mounted in NASA's Skylab satellite, scheduled for launch in 1973. From Skylab the corona will be photographed directly, with film periodically returned to ground stations for processing, so much better resolution can be obtained than with telemetered data.

Satellite-borne coronagraphs have an advantage over ground-based ones in that they need not contend with atmospheric scattering of sunlight. Their present disadvantage is that for technical reasons they cannot be used to observe the inner corona. A group of HAO scientists and several colleagues from other observatories have also proposed an improved satellite instrument to be mounted on OSO-K in 1976, near the beginning of the next solar cycle.

With these instruments, and with the expected increase in solar activity as the solar cycle progresses, many rapid changes in the corona may be observed from space during the next few years. Information may then be available that will relate transient solar events to disturbances in the solar wind (*NCAR Quarterly* No. 34, February 1972) and the upper reaches of the earth's atmosphere. Meantime, observations at Mauna Loa and other ground-based facilities will form the basis for continuing studies of both long-term and short-term changes in the corona.



*On 21 March 1970, soon after the eruption of a flare spray, the Culgoora radioheliograph detected three "Type IV" radio sources in the same region of the corona as the white-light solar transient recorded by the Mauna Loa K-coronameter. (Type IV sources cover a broad range of radio frequencies.) Two of the sources (light green) appeared to be virtually stationary, but one (dark green) moved outward from the sun at 290 km/sec. In this diagram, the dashed lines are advancing at 290 km/sec. Note the ultimate fragmentation of the moving radio source. (After K. V. Sheridan, Proc. Astronom. Soc. of Australia, 1 (8), 376 - 378, 1970.)*



# Solar Activity, Auroras, and Weather

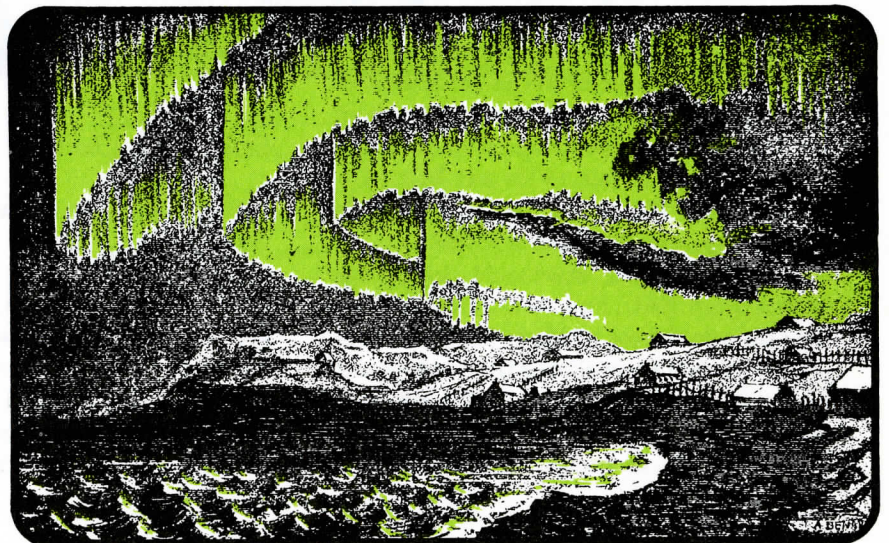
As far as we can tell, the sun's total radiant energy output remains the same from year to year. Measurements show that the amount of solar energy reaching the earth varies less than 0.5%, the limit to which we can measure accurately, except for the annual changes in distance between the earth and the sun. (In January, when the earth is nearest the sun, it receives about 6% more solar energy than in July.) Nevertheless, an impressive body of legend and literature features associations between changes in solar activity and weather phenomena. Through the years, it has become apparent that these associations, however well

“documented,” are generally vague and inconclusive; often they are illustrated only by the cyclic responses of plants—“11-year blooms” and tree-ring cycles—or of animals, or by the seemingly cyclic recurrence of drought.

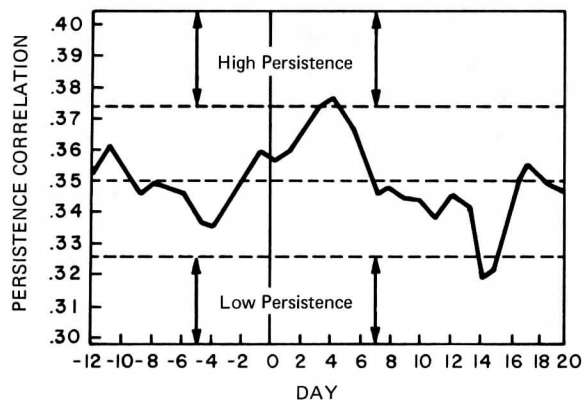
A number of attempts have been made to gather scientific evidence to prove or disprove such associations, particularly in the last few decades as space science has come into sharper and sharper focus. Some of these attempts have zeroed in on the northern part of North America as an area in which outbreaks of solar activity do seem to have an impact on the weather.

*Keoeit, the Northern Lights, flies across the sky. Shimmering bands of white, red, and green spread from horizon to horizon, lighting the long arctic night. Animals venture forth from their winter dens; hunting is good. Hunt well, for when Keoeit lights the sky, a storm will follow.*

*(Nunamint Eskimo legend)*



After a sketch by Bravais, 1837-38, in Störmer, *The Polar Aurora*.



*Shapiro studied 47 years of surface data to show that barometric pressure patterns over North America are more persistent than usual on the third and fourth days after large geomagnetic disturbances and less persistent than usual about ten days later.*

### *Persistent Pressure Patterns*

In 1954 Ralph Shapiro of the Air Force Cambridge Research Laboratories found that the pressure patterns over North America during 1953 appeared to respond to major geomagnetic disturbances, which in turn reflect activity on the face of the sun. Shapiro charted 500 - mb pressure patterns over North America and found that statistically the pressure patterns appeared to be slightly more persistent during the third and fourth days after major geomagnetic storms and slightly less persistent about two weeks after geomagnetic events.

Shapiro's findings led him to examine a larger sample—surface pressure records from 1899 to 1945. In these records also he found that pressure features were more persistent than usual in the third and fourth days after large disturbances, and that persistence declined over the following ten days.

### *Deepening Troughs*

Several later studies strengthened the evidence that geomagnetic storms are related to pressure and circulation patterns in northern North America. Among those who examined the problem in the late 1950s was Walter Orr Roberts, then Director of the High Altitude Observatory, now President of UCAR.

Roberts, Norman Macdonald, other colleagues from HAO, and meteorologists from the Colorado School of Mines devised a more precise method for analyzing the development of pressure patterns associated with geomagnetic storms. For each developing low-pressure system or trough, they calculated a

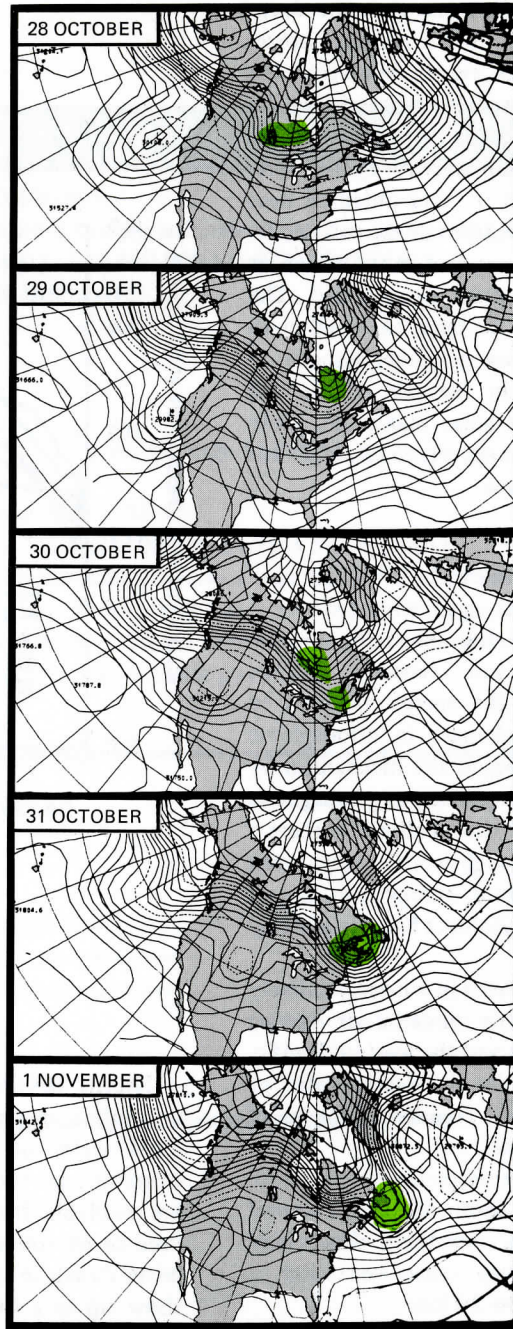
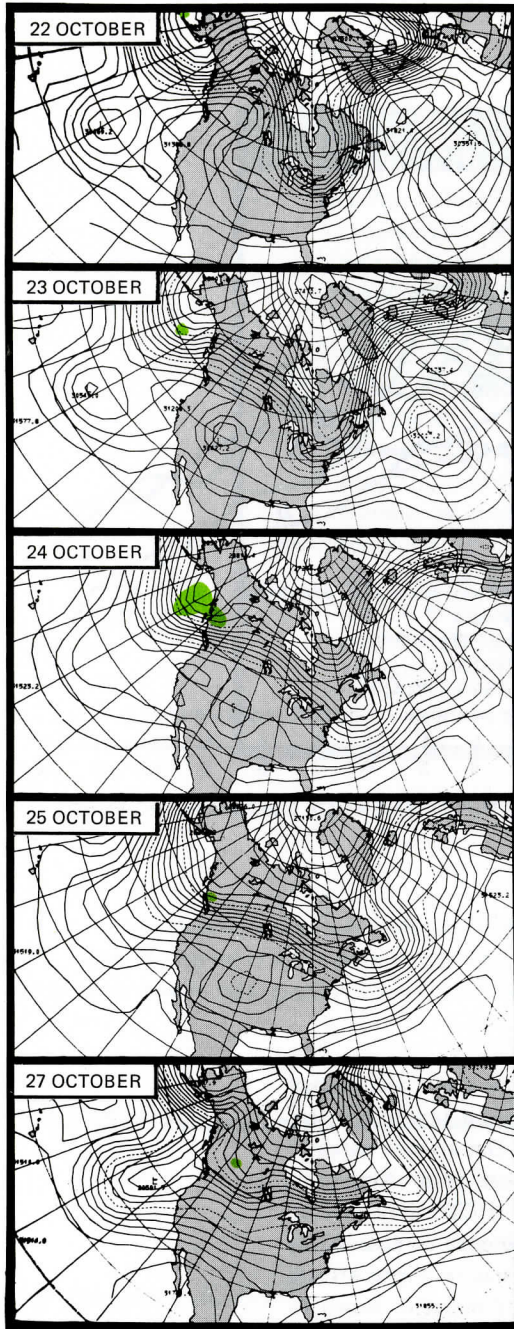
“trough index” showing the depth-to-width ratio of depressions in the 300 - mb pressure surface. They defined “strong geomagnetic disturbances” as isolated sudden-commencement magnetic storms recorded at the geomagnetic observatory at Cheltenham, Maryland, or as strong auroral displays reported from the University of Saskatchewan. They also mapped out a target area in the Gulf of Alaska and considered only troughs which originated in or moved through this area.

Roberts and Macdonald's statistical studies were based on weather records for the winter half-years (October-March) of 1956 - 57, 1957 - 58, and 1958 - 59. Their results, like Shapiro's, indicated a link between geomagnetism and weather: troughs which formed within or moved into the target area two to four days after the first appearance of a strong geomagnetic disturbance tended subsequently, as they moved eastward across the North American continent, to grow larger than similar troughs that were not preceded by such geomagnetic activity. Maximum trough development in these cases usually occurred five to eight days after the geomagnetic disturbance.

### *Solar Cycle Changes*

Recently Roberts, working with Roger Olson of the National Oceanic and Atmospheric Administration, has obtained new results from data gathered during the last solar cycle. Applying to 1964 - 65, 1965 - 66, and 1970 - 71 data the previous trough-index methods and a new and more objective technique based on computer-calculated “absolute vorticity” of low-pressure systems, Roberts





*In winter, low-pressure regions from the Aleutian area or the Gulf of Alaska move eastward across Canada and the United States. On this series of 300 - mb maps the low-pressure trough identified by its associated center of high vorticity (color) moved into the Aleutian region on 22 October 1964, three days after a major geomagnetic event, and reached the east coast of North America about ten days later. For clarity, other high vorticity areas are not shown.*



and Olson have shown again that the deepening of troughs over North America correlates with geomagnetic events. Moreover, the sum of all data now available suggests that the strength of this correlation may vary, at least slightly, with the solar activity cycle. Previous studies were all of data obtained near solar maximum, the portion of the solar activity cycle when sunspots and other evidences of solar activity are most pronounced. The 1964 - 65 and 1965 - 66 data, obtained close to solar minimum, show a weaker association than data obtained in the late 1950s and 1970 - 71, years near solar maximum. More data will be needed, however, to establish this relation with confidence.

### Mysterious Mechanism

Energy inputs to the atmosphere from geomagnetic events are relatively minute, trivial compared to the energy required to bring about major changes in atmospheric circulation. What, then, is the mechanism by which solar activity, expressed as geomagnetic storms, can influence the weather? Is there a chain of events through which very weak changes in solar-derived energy can trigger trough development? Roberts hazards a highly speculative answer:

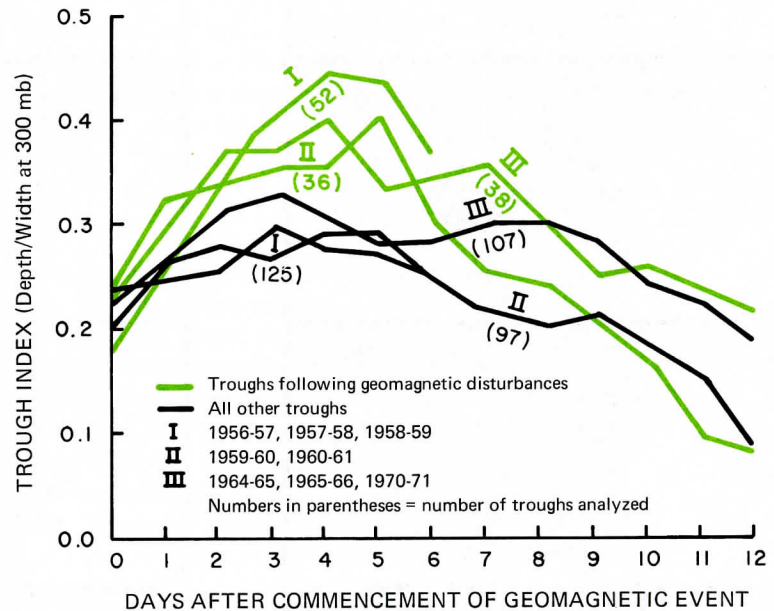
- In the Gulf of Alaska in winter, relatively warm waters frequently underlie air moving eastward from Siberia and the western Pacific. Conditions are ideal for the development of moist, supercooled air, cloudless because of the absence of ice nuclei.

- During severe geomagnetic storms, auroral effects extend far south of normal auroral belts. X rays resulting from these effects high in the atmosphere may cause ionization at levels down to or below 20 km.

- This ionization may stimulate the formation of ice nuclei in the low stratosphere over the Gulf of Alaska, bringing about the development of cirrus clouds.

- The cirrus, acting like a blanket, prevents or reduces the escape of infrared (heat) radiation from the ocean, thereby causing a net warming of the lower atmosphere.

- Such warming intensifies the development of the large-scale low-pressure and high-pressure waves, called Rossby waves, that dominate wintertime circulation in this region.



*Three sets of data for winter half-years show that troughs forming in or moving into the Gulf of Alaska three or four days after major geomagnetic events became more pronounced than those forming at other times in the same region.*

Recent developments in space technology now offer an opportunity to test this postulated series of events. Day-to-day satellite observations, such as those from Nimbus 4, are available from April 1970; they can be used to determine the presence or absence of cirrus clouds in the stratosphere. Cirrus effects show up as a lowering of radiative losses to space, that is, as a lowering of infrared radiation measured by instruments on the earth-facing side of the satellite.

Roberts and Olson are studying satellite data for the winter of 1970 - 71, comparing measurements made over the Gulf of Alaska with geomagnetic and auroral records and with the results of their trough analyses for the same winter period. Possibly their study will verify Roberts's speculations concerning the mechanisms by which very weak changes in solar-derived energy can influence weather here on earth.



### *Some Facts About the Sun*

*Radius:* 696,500 km (432,500 mi)

*Composition:* Mostly ionized hydrogen and helium, with no permanent surface

*Distance from Earth (average):* 149,660,000 km (92,960,000 mi)

*Period of Rotation (as seen from earth):*

Equatorial: 26.9 days

Mid-latitude: 28.3 days

Polar: 30+ days

*Solar Cycle:*

Activity (sunspot) cycle: 7 - 17 years (average 11 years)

Magnetic cycle: 22 years

Number of observed sunspots: 0 - 154

*Magnetism:* Polar magnetic fields (extending to about 55° latitude)

are relatively weak, and the sun does not have a true dipole field like the earth's; north and south polar fields may at times have the same magnetic polarity. Strong magnetic fields are related to sunspots and active regions, which tend to occur in pairs having opposite polarity.

## Notes

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### *Key Project at St. Louis*

The UCAR Board of Trustees, at their January meeting, endorsed NCAR's Fate of Atmospheric Pollutants Study (FAPS) as a key project. This study, part of a large-scale cooperative program centered at St. Louis, Missouri, will involve an analysis of the metropolitan pollution that remains in the atmosphere 80 - 120 km downwind from the city. The program will be directed by James Lodge; John Pate will be field manager. Intensive surface and aircraft sampling during short periods in the summer of 1973 and the winter

of 1973 - 74 will be coordinated with data obtained in and near the city by research groups from the University of Chicago, the University of Wyoming, NOAA, and other agencies.

Other NCAR key projects are the Global Atmospheric Research Program and the National Hail Research Experiment. Key project status is assigned to intensive, long-term, multiorganizational programs related to man's needs.

## Notes

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### *NCAR Research Described*

NCAR is featured in a major article in the 1972 *Britannica Yearbook of Science and the Future*, published by the Encyclopaedia Britannica. The article, entitled "Challenging the Restless Atmosphere," was written by John Firor, Director of NCAR, and William Kellogg, Director of the NCAR Laboratory of Atmospheric Science. Written for the general reader, it describes a number of NCAR research programs. The *Yearbook* also includes a review article on atmospheric science by Henry Lansford, NCAR's Public Information Officer.

### *Atlas to Head NCAR Facilities Laboratory*

David Atlas has been appointed Director of NCAR's Facilities Laboratory, and will assume his new duties on 1 September 1972. He succeeds Daniel F. Rex, now chairman of the NCAR GARP Task Group. The Facilities Laboratory, established as a division of NCAR in 1963, provides aircraft, computing, field observing, ballooning, and other capabilities for NCAR and university scientists.

Atlas has been Professor of Meteorology in the Department of Geophysical Sciences at the University of Chicago since 1966; earlier he was associated with the Weather Radar Branch of the Air Force Cambridge Research Laboratories and with the U.S. Air Force. He is a Fellow and Councillor of the American Meteorological Society and a member of a number of other scientific societies.

Atlas received his training in meteorology at New York University and the Massachusetts Institute of Technology. His scientific work, concentrated mainly in radar meteorology, and his inventions of weather radar devices have brought him the AMS Meisinger Award, the AFCRL Guenter Loeser Award, and other honors and citations.

### *Two Solar Eclipses*

During the next two summers, teams from NCAR's High Altitude Observatory will have opportunities to observe two total eclipses. On 10 July 1972 Gordon Newkirk, Carl Lilliequist, and Lee Lacey will photograph an eclipse whose path of totality will cross Alaska, Canada, and the North Atlantic. Their observations will be made from the Gaspé Peninsula in Quebec. Newkirk and Lacey will photograph the solar corona with the same telescope, white-light camera, and radially graded filter that were used successfully in 1966 in Bolivia and in 1970 in southern Mexico. Lilliequist will photograph the outer corona from 2.5 to 20 solar radii in the near infrared (at wavelengths of 8000 - 8500Å).

In 1973, eight or more HAO staff members will participate in an international expedition to Africa to observe the total eclipse of 30 June. About 120 U.S. and foreign observers will record the eclipse from two sites in Niger, Mali, or Mauritania. Totality in portions of this region will exceed 7 min, unusually long for a solar eclipse. The eclipse shadow will cross the area near noon, when observations can be made with minimal atmospheric interference. Weather conditions are expected to be good in this Saharan region, although temperatures are extreme (along the Saharan portion of the eclipse path the mean daily maximum temperature exceeds 100°F in June and July) and there will be the constant risk of dust and sandstorms.

The U.S. portion of the African expedition will be coordinated by the National Science Foundation and carried out under NCAR Facilities Laboratory field management. In the fall of 1971 an NCAR survey team inspected possible sites on the eclipse path; additional advance trips will be made in the coming year to select the final sites and make appropriate arrangements with the African nations involved.