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SOLAR PROTON EVENT FORECASTS

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ABSTRACT

The United States operates a space weather service to provide information on space hazards including solar proton events to federal government agencies and other users who operate systems that are affected by disturbances in the upper atmosphere and interplanetary environment. The observation and prediction of solar proton events has been continuous through solar cycle 21 (1976-1986), establishing a base of experience that can be used in providing similar support to space operations in the 1990's. The observations, indices, alerts, and forecasts used in the service are described in this paper. Also provided is a short summary of the experience obtained from making proton event predictions in solar cycle 21 including the years 1976-1986.

1. INTRODUCTION

Forecasts, alerts and summaries of the salient characteristics of solar proton events are available as part of the real time space environment services provided by the National Oceanic and Atmospheric Administration and the U.S.A.F. Air Weather Service. The two agencies jointly operate the Space Environment Services Center (SESC) in Boulder, Colorado to provide space weather information to operations and missions affected by disturbances in the space environment. The solar proton information is part of a larger set of environmental information including solar flares, solar mass ejections and solar coronal holes, the state of the geomagnetic field, and ionospheric information. The following sections describe the observations, reduced data, alerts, and forecasts that are used in providing solar proton event information.

Solar flares are outbursts of energy that occur sporadically on the sun. They usually (but not always) occur in conjunction with the passage of large sunspot groups across the face of the sun. Flares are associated with areas of enhanced solar magnetic field. At the time of solar flares, the background electromagnetic radiation of the sun may be increased by factors of 1000 or more as measured in visible light, radio noise detectors, and x-ray flux sensors. In fact, the most common methods of scaling the intensity of flares use the increase in visible light or x-rays to assign an importance rating to each flare. Sometimes a flare is followed by an enhancement of energetic particles including protons, electrons, and heavier ions in the interplanetary space near the earth. Such enhancements are commonly called solar proton events since the predominance of the monitoring of the particles has been of the protons. The proton events are of interest to space operations because of the increased radiation exposure to both equipment and people in space. One form of the hazard is the degradation of materials due to increased radiation dose. Another hazard is the upset of spacecraft electronics by the passage of heavy ions through the electronic assemblies. Both the solar flare electromagnetic radiation and solar proton events may interfere with communications with interplanetary spacecraft. Sometimes proton events are observed without a solar flare occurrence. Several possibilities account for such events. Flares may occur beyond the visible limb of the sun, and the particles are guided to the earth by the spiral in the interplanetary magnetic field that connects the earth to the sun, and which is distorted from a radial shape by the rotation of the sun about its north-south axis. Other proton events may be produced by other kinds of solar activity, especially by a phenomenon called solar mass ejection which may occur with or independent of solar flares. Larger proton events are all associated with solar flares, so the flares are used as a precursor to predict the proton event since the propagation time of the particles from the sun to the earth is greater than that of the electromagnetic radiation. The following sections describe the experience of the SESC in observing solar flares and solar proton events, and in using simple models.

2. OBSERVATIONS

In lieu of actual measurements of energetic particle fluxes in the solar wind, the space environment services rely on real time data from satellites in locations where the shielding effect of the earth's magnetic field is minimal for protons with energies above approximately 10 MeV. The fluxes measured and reduced from these satellites are representative of the solar produced fluxes in the interplanetary space at heliospheric longitudes in the vicinity of the earth. Energetic particle observations routinely available to the SESC are summarized in table 2.1.

Table 2.1. Particle observations available to the SESC in real time

Satellite or monitor	Location	Particle type	Energy measured (MeV)	Number of of channels
GOES (1)	Geo	Protons	0.6-500	8
		Alpha	3.8-500	6
		Electrons	>2	1
NOAA (1)	Polar	Protons	.03-215	8
		Ions		1
Thule Neutron Monitor	Geomag-	Protons and ions	>500	1

(1) GOES and NOAA Satellites are operated by the NOAA National Environmental Satellite and Data Information Service and include a set of Space Environment Monitors (SEM).

In the past, arrangements have been made with NASA to obtain real time particle fluxes from any of several interplanetary spacecraft, in order to provide information on energetic particle fluxes in other parts of the solar system. When available, these data have been used by the SESC in assessing conditions and making forecasts. Such cooperation began with the Pioneer 6 spacecraft and continued through the period when International Sun Earth Explorer (ISEE) 3 data was provided to NASA, to the SESC, and thence to the Air Force Global Weather Center in real time. Currently, ad hoc arrangements are made with NASA Operations Centers to obtain special reports from satellites such as the currently operating Pioneer spacecraft.

Other data are available in real time and are used to assess the level of solar activity and to make forecasts of individual solar proton events. These observations are summarized in table 2.2.

Table 2.2. Other observations available to the SESC (1)

Observation	Source	Wavelength
Whole sun x-ray flux	GOES GOES	1-8 Angstrom 0.5-4 Angstrom
Solar chromospheric real time patrol	SOON (2)	Hydrogen-alpha
Solar Radio Noise Patrol	RSTN (3)	606-8800 MHz 8-80 MHz
Solar white light patrol	SOON	
Solar magnetograms	Various	
Geomagnetic indices	Various	

(1) Real time data in the SESC are handled by the Space Environment Laboratory Data Acquisition and Display System (SELDADS), which receives 1100 data sets on a continuous basis from a variety of sources (Cruickshank, et. al., 1988)

(2) The Solar Optical Observing Network (SOON) is operated by the U.S.A.F. in cooperation with the Australian Department of Science and NOAA.

(3) The Radio Solar Telescope Network (RSTN) is also operated by the U.S.A.F. in cooperation with the Australian Department of Science and NOAA.

3. DEFINITIONS

Solar proton events are most generally defined as any increase in fluxes of protons or ions from the sun as measured in the vicinity of the earth. SESC uses a specific definition for a solar proton event in order to simplify communications with users of the service. Real time data displays are routinely available in the SESC and to users for several particle energy thresholds. Alerts of an increase are available for several of these thresholds. Table 3.1 summarizes these definitions and thresholds that are particularly relevant for proton event observation and prediction as of the beginning of solar cycle 22.

Table 3.1. Definitions and thresholds for proton event observation and prediction

Use	Energy threshold or energy range	Flux threshold
Solar Proton Event (definition)	>10 MeV	10 protons cm^{-2} $s^{-1}st^{-1}$
Standard proton displays	>10 MeV flux >30 MeV flux >60 MeV flux >100 Mev flux @ 50 MeV flux @ 10 MeV flux	No threshold; all data displayed
Class X solar flare (definition)	1-8 Angstrom flux	$>10^{-4}$ W m^{-2}
Class M solar flare (definition)	1-8 Angstrom flux	10^{-5} to 10^{-4} W m^{-2}
Standard x-ray displays	1-8 Angstrom flux 0.5-4 Angstrom flux	No threshold; all data displayed

4. SERVICES AVAILABLE

Table 4.1 summarizes the services available from the SESC relevant to the operation of satellites and experiments in space.

Table 4.1 Summary of real time alerts, data, and forecasts for use in space operations

Service	Types of phenomena included
Alerts	Solar proton events Solar flares Solar proton increases at other energy levels Geomagnetic storms Other phenomena
Plots	Standard proton displays
Indices and summaries	Proton fluences Geomagnetic indices Tabulation of solar flares Tabulation of solar mass ejections
Forecasts	Solar proton events Solar flares Geomagnetic indices

5. SOLAR PROTON EVENT OCCURRENCE IN SOLAR CYCLE 22 (1976-1986)

As expected from the classification system, class X flares occur less frequently than class M flares and proton events are even less frequent. Both M and X flares may produce proton events (as defined here) so that the ratio of proton events to flares is the order of a few percent. The operational problem of proton event prediction then becomes primarily a problem of eliminating false alarms. The immediate question when a flare occurs is whether it, as normal, will not produce a proton event or whether it is one of the rarer flares that are followed by a proton event. In solar cycle 21, there were approximately 3300 class M flares, 550 class X flares and 60 proton events. The exact count of events of each type depend on the separation of new events when an earlier one is still in progress.

6. PREDICTIONS OF PROTON EVENTS IN SOLAR CYCLE 21

6.1 Predictions of proton events after a flare occurs

By using characteristics of a solar flare including its electromagnetic radiation and its location on the sun, a more specific prediction can be made of the time and intensity of the proton event. Algorithms for making such predictions were developed during solar cycle 20 (Smart, 1979). The algorithm used in SESC was developed specifically for making radiation predictions for the Apollo lunar missions. It uses observed characteristics of proton events combined with first order models of energetic protons in the interplanetary space (Burlaga, 1967). It was originally oriented to 30 MeV protons but was adjusted to 10 Mev to meet the standard proton event definition that began to be used in 1976. It incorporated the use of soft x-ray emission that was available from the GOES x-ray ionization chambers (Grubb, 1975). The primary assumptions used in the SESC prediction algorithm are summarized as follows (Heckman, 1979):

a. Occurrence of a soft x-ray event is the basis for predicting a proton event.

b. The algorithm predicts a start time, peak flux, a rise time, and a probability of occurrence.

c. The intensity of the proton event is proportional to the peak x-ray flux and type of rise and decay (slow rise and decay is more productive than an impulsive event).

d. The intensity of the proton event is highest when the earth is well connected magnetically to the flare location.

e. The intensity is scaled downward by a factor e^{-1} for each radian the flare is displaced from a direct connection.

f. A history of energetic flares in the region in the 48 hours prior to the most recent flare will increase the predicted event size.

h. The predicted rise time is a minimum of approximately 2 hours for well connected flares and rises to 50 hours for poorly connected events.

Evaluation of the forecasts for cycle 21 has been done in the SESC. For 2180 flares, the forecast was for "no proton event" and no event occurred. In 47 cases, an event was predicted and did occur. In 14 cases, no event was predicted but one did occur. Four of these unpredicted events had a peak flux over 100 protons cm^{-2} s^{-1} st^{-1}, a threshold that would realistically define a proton event for space radiation and spacecraft operational purposes. In the case of a forecast for an event, but where none occurred, 19 times the forecast flux was greater than 100 protons

cm^{-2} s^{-1} st^{-1} but the event did not occur. These numbers indicate the major aspect of proton event occurrence; 96 percent of all flares do not produce a significant proton event at the earth. The first goal of a prediction program is the elimination of these events so they are not treated as false alarms. By using the model, the false alarm rate drops from a 96 percent rate assuming all flares will produce a proton event, to 46 percent false alarms wherein no event occurred when the model had predicted one. The complementary problem is that of missed events (not forecasting one but having one occur anyway). Using the SESC model for solar cycle 21, after a forecast is made for no proton event, less than one percent of the flares actually produced one.

6.2 Forecasts of proton events for one, two, and three days in advance

Since the rise times of proton events are of the order of a few hours, the forecast of an event with longer lead times is more difficult since the responsible flare must also be forecast. SESC does make forecasts of proton events on a longer time scale in the form of a probability of occurrence of a proton event for each 24 hour period in the forecast. The forecasts are analogous to the probability of precipitation in the weather forecasts. Verification of the accuracy of the forecasts indicates they are mostly useful as a guide in identifying periods when proton events may occur, but currently are not of sufficient accuracy for use in specific decision making.

7. ACCESS TO PREDICTIONS AND REAL TIME OBSERVATIONS IN SOLAR CYCLE 22

Mission operators who require support for proton event observations and forecasts can gain access to the SESC services by several methods, depending on the rapidity and level of information that is needed. Table 7.1 summarizes the common methods of accessing the services.

Table 7.1 Access to SESC services for solar proton event information

Services	Method of distribution
Alerts	Telephone call initiated by SESC Receipt of a satellite broadcast from SESC to user's computer system
Proton flux rates	Direct access to SELDADS computer system Receipt of a satellite broadcast
Short term forecasts	Receipt of telephone call from SESC Receipt of a satellite broadcast
Activity summaries	Call to SESC computer bulletin board system Subscription to the "Preliminary Report and Forecast of Solar Geophysical Data" Receipt of daily forecasts and activity summaries distributed over teletype networks
Discussion of current space weather conditions	Call to SESC forecast console and speak to duty forecaster or duty solar technician

To obtain further information, the relevant telephone numbers as of 1988 are given in table 7.2.

Table 7.2 Telephone numbers to call for access to proton event services

Position	Commercial	Federal Telephone Service
Chief Forecaster	(303) 497-3204	320-3204
Duty Forecast	(303) 497-3171	320-3171
SELDADS System Manager	(303) 497-3780	320-3780
Satellite Broadcast Manager	(303) 497-3188	320-3188
Bulletin Board Service	(303) 497-5000	320-5000

8. FUTURE IMPROVEMENTS

As solar cycle 22 progresses into the 1990's, improvements will be added to the SESC proton event services. A new solar patrol instrument that makes images of the sun in x-rays (Solar X-ray Imager (SXI)) will provide improved coverage over present solar flare patrols that currently are blind approximately 20 percent of the time because of bad weather at the ground based observatories. The SXI will also improve observations of events beyond the limbs of the sun and observations of the solar coronal structures that influence the acceleration and release of high energy particles into the solar wind. Particles that contribute to solar proton event fluxes are also accelerated in the solar wind by strong shocks propagating outward from the sun. Instrumentation to detect and measure such shocks would improve the predictions of this aspect of solar proton events. Images obtained by Interplanetary Scintillation telescopes will become available to the SESC in the next few years and may be useful for this detection. Improvements to the prediction routines will also be made which incorporate knowledge gained about energetic particle events over solar cycle 21.

REFERENCES

Burlaga, L.F., Anisotropic diffusion of solar cosmic rays, J. Geophys. Res., 72, 4449.

Cruickshank, C. M., editor, Space Environment Laboratory Data Acquisition and Display System, NOAA Technical Memorandum ERL SEL-76, 1988.

Grubb, R. N., The SMS/GOES Space Environment Monitor Subsystem, NOAA Technical Memorandum, ERL SEL-42, 1975.

Heckman, G. R., Predictions of the Space Environment Services Center, Solar Terrestrial Predictions Proceedings, Boulder, 322-329, 1979.

Hirman, J. W., G.R. Heckman, M. S. Greer, and J. B. Smith, Solar and geomagnetic activity during Solar Cycle 21 and implications for Cycle 22, EOS, 1988, in press.

Smart, D. F., and M.A. Shea, PPS76 - A computerized "event mode" solar proton forecasting technique, Solar Terrestrial Predictions Proceedings, Boulder, 406-427, 1979.

Wagner, W.J., R.N. Grubb, G. R. Heckman, and P. J. Mulligan, The Solar X-ray Imagers (SXI) on NOAA's GOES, Bull. Amer. Astron. Soc., 19, 923.