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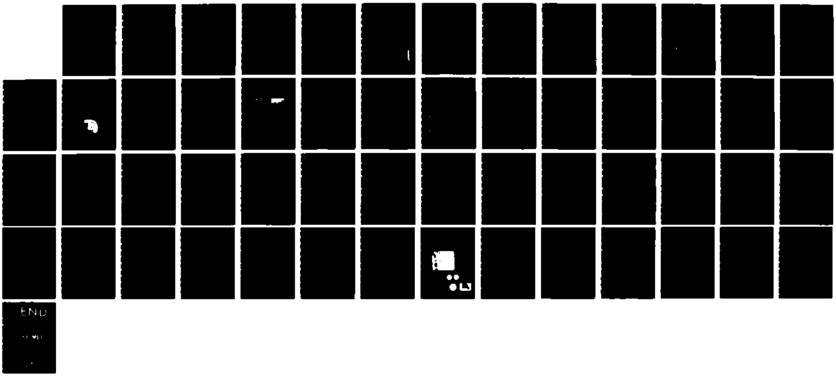

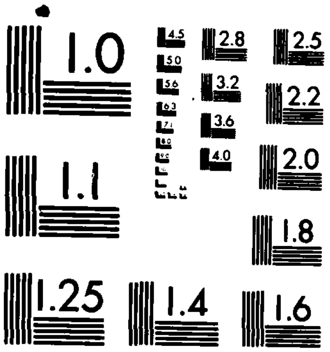

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SUMMARY PROCEEDINGS OF THE STANFORD WORKSHOP ON SOLAR FLARE PREDICTION

February 28 - March 1, 1985

Organizers and Editors

S. K. Antiochos
T. Bai
P. A. Sturrock

Center for Space Science and Astrcphysics
Stanford University

CENTER FOR SPACE SCIENCE AND ASTROPHYSICS
STANFORD UNIVERSITY
Stanford, California

6

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Report No. CSSA-ASTRO-85-22

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Grant NGL 05-020-272

OFFICE OF NAVAL RESEARCH

Contract N00014-85-K-0111

INTRODUCTORY REMARKS

P. A. Sturrock
Center for Space Science and Astrophysics
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Stanford, CA 94305

A workshop on "The Prediction of Solar Activity" was held at the Meudon Observatory in France in June 1984. During that meeting, a number of participants from the United States expressed interest in meeting together to discuss this topic with a view to exploring what actions might be taken to improve our predictive capability. This document contains abstracts of presentations made at the meeting. Keywords: magnetic fields; sunspots;

Following this expression of interest, Spiro Antiochos and I organized a two-day workshop held at Stanford University on February 28 and March 1, 1985. Our aim was to impose as few restrictions as possible on the participants in order to encourage creative thinking. On the other hand, a minimum amount of organization was required, and this led to an agenda and to the agreement of two or three participants to speak in each session.

The participants considered the workshop to be highly successful. There was a valuable exchange of information and viewpoints, and there was keen interest in exploring new approaches to the problem of flare prediction that might yield fruit in a five- or ten- or fifteen-year time scale.

It was generally agreed that some kind of summary of the proceedings would be valuable. As a compromise between the one extreme of having one person try to summarize the whole meeting, and the opposite extreme of having each participant prepare a full-length article, we decided to gather together abstracts of the presentations made at the meeting. These abstracts form the main body of this report.

On behalf of my fellow organizers and editors, S. K. Antiochos and T. Bai, and myself, I wish to thank Miss Jude Costello and Mrs. Louise Meyers for making all the detailed arrangements for the workshop, and for preparing this report.

Maximum [illegible] Forecasting;
Solar [illegible]

SOLAR FORECASTING

Joseph W. Hirman
Space Environment Services Center
National Oceanic & Atmospheric Administration
Boulder, CO 80303

Abstract

This presentation will cover two items:

1. I will describe solar forecasting at SESC.
2. As the only working forecaster here, I will offer some advice. precautions, and reminders.

There are six steps in forecasting operations:

1. Establishment of an observing network
2. Collection of data (observations)
3. Analysis of the data
4. Prognosis, numerical guidance, and prediction models
5. Forecast of solar phenomena and indices. This is a key step. Its success depends upon the professionalism, personal skill, and experience of the forecaster.
6. Preparation and issuance of forecasts. These must be accurate, timely, and effective for user requirements.

This presentation will address only analysis, prediction (prognosis), and forecasting.

I. Who Are We?

The Space Environment and Services Center (SESC) is an office under the joint auspices of the Air Weather Service of the U.S. Air Force and the National Oceanic & Atmospheric Administration (NOAA). The SESC serves both civilian and Department of Defense (DoD) customers on a national and an international basis (see Figure 1). It is a real-time service and operates 24 hours a day. There are five forecasters, who rotate on approximately a solar rotation.

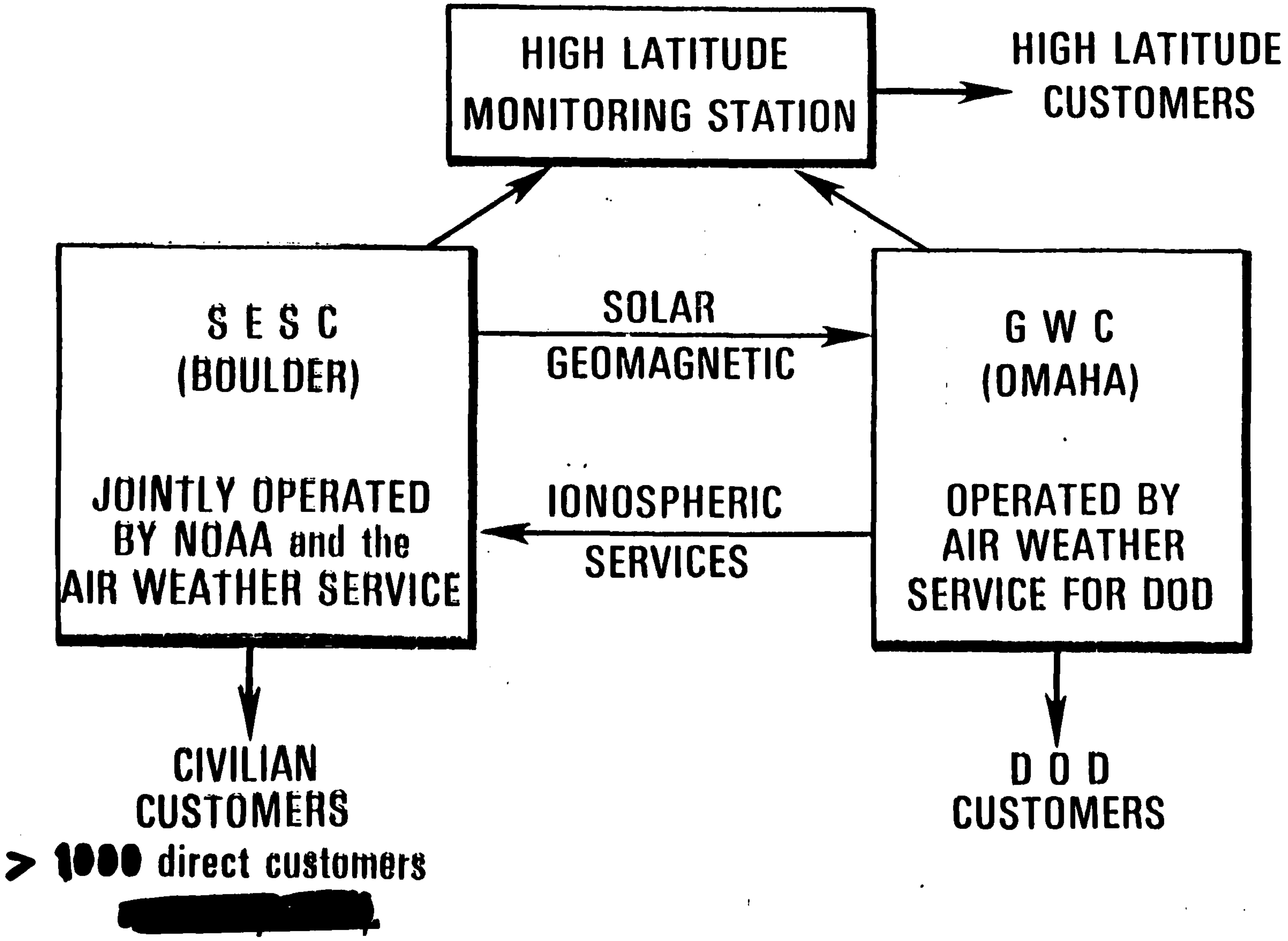


Figure 1. The Space Environment and Services Center is part of a larger network serving civilian and DoD customers.

II. What Do We Do?

SESC's primary mission is to observe and report space weather and to issue forecasts and warnings of geoeffective solar activity for national and public use. Our activities are driven by customer needs.

We have many products, or services, besides solar predictions (as shown in Table I).

04 FEB 85 Table I. SESC PRODUCTS

REAL-TIME

ALERTS
PRESTOS
STRATWARMS
SMM SUPPORT
GWC BACK-UP
SATELLITE BROADCAST MESSAGE
GWC DIRECT DATA LINK
NOSC DIRECT DATA LINK
SELDADS CALL-UP USER DISPLAYS

3 HOURLY

BOULDER K-INDEX
ANSAPHONE RECORDING OF SOLAR ACTIVITY
WWV RECORDING OF SOLAR ACTIVITY
NASA SHUTTLE SUPPORT

DAILY

SOLAR & GEOPHYSICAL ACTIVITY REPORT AND FORECAST (SGARF)
SGARF - PROBABILITIES ONLY
BOULDER RWC ADVICE
GEOALERT
SOLAR REGION SUMMARY
SOLAR AND GEOPHYSICAL ACTIVITY SUMMARY
1800Z FORECAST (Kp & preliminary 10cm Flux)
BOULDER SPOTS REPORT
BOULDER NEUTRAL LINE MAP
BOULDER CORONAL HOLE MESSAGE
DATA ACQUISITION REQUEST
ANCHORAGE ADVISORY REPORT 2100Z
SST RADIATION FORECAST
H-ALPHA PRINTS
DAILY RGON STACK PLOTS
Retransmission of ATN messages
    SMM Observing Schedule
    ANCHORAGE URALS DATA MESSAGE
    BOULDER UFOFH MESSAGE
    Fredericksburg UMAGE MESSAGE
    CULGOORA MORNING/AFTERNOON/EVENING REPORTS
    GEOALERTS - DARMSTADT, PARIS, MOSCOW, TOKYO, SYDNEY
    STANFORD SOLAR MEAN FIELD
    IUWDS DATA INTERCHANGE
    IUWDS QUALITY CONTROL LISTINGS

WEEKLY

PRELIMINARY REPORT OF SOLAR GEOPHYSICAL DATA
    SYNOPTIC MAP
    GEOSYNCHRONOUS SATELLITE ENVIRONMENT GOES-5
27 DAY AP & 10CM FORECAST
GEOALERT ADVICE SUMMARY - RWC'S

MONTHLY

MONTHLY SUMMARY OF GEOALERTS & PRESTOS FOR SGD
LISTINGS / MAPS / DRAWINGS FOR SGD/NESDIS
NAVAL RESEARCH LABORATORY DATA TAPE
NESDIS DATA LISTINGS
NESDIS DATA TAPE
USAF DATA LISTINGS
Retransmission of the
    SIDC PROVISIONAL INTERNATIONAL MEAN MONTHLY SUNSPOT NUMBER

3 TO 12 MONTHS

IUWDS CODE BOOK
QUARTERLY MAGPRAG AND 7 DAY FORECAST VERIFICATION
FORECAST VERIFICATION
SUN-SATELLITE PROXIMITY AND ECLIPSE TIMES
SMOOTHED SUNSPOT NUMBER PREDICTIONS
NASA SHUTTLE SUPPORT SIMULATIONS

ARCHIVED & SENT ON REQUEST

REAL-TIME DATA & PRODUCT ARCHIVES
DAILY SOLAR INDICES; MONTHLY & YEARLY SUMMARIES
LIST OF M & X FLARES
LIST OF MAJOR EVENTS
GOES RAW ARCHIVE TAPES
TIROS RAW DATA ARCHIVE TAPES
NOVA2 1-5 MINUTE DATA BASE ARCHIVE TAPES
SELDADS PROCESSED DATA TAPES
MONTHLY SESC VERIFICATION

USER INFORMATION

SESC GLOSSARY OF SOLAR TERRESTRIAL TERMS
SESC PRODUCTS AND SERVICES BROCHURE
REPRINTS
SELDADS OPERATORS DESCRIPTION & USERS MANUAL

At SESC. flare forecasting translates into:

1. Forecasts for flares of 1-8 A X-ray emission (not H-alpha, radio, or gamma rays). See Figure 2.
2. The probability for C, M, or X class flares (levels of the largest event)
3. Forecasts for one, two, and three days (greater than three days is general)

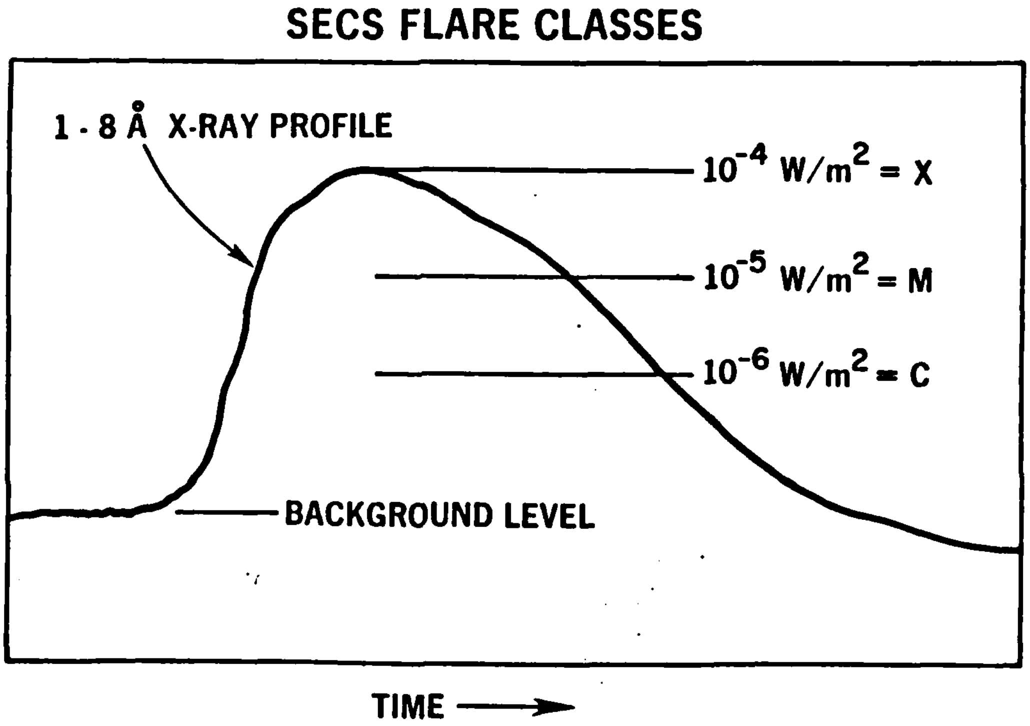


Figure 2. Flare Classes.

III. Why? Customer Needs

SESC's customers are primarily concerned with four aspects (consequences) of solar flares (see Table IIa):

1. X-rays - ionospheric effects, space systems
2. Radio bursts - noise on telemetry and tracking
3. Energetic particles - radiation hazards and ionospheric effects
4. Geomagnetic storms - HF, drag, induction (a concern of two-thirds of SESC's customers)

Table IIa. TERRESTRIAL EFFECTS OF FLARE RADIATION

SOFT X-RAYS

IONOSPHERIC DISTRUBANCE: HF/VLF
RADIATION EFFECTS ON SPACE SYSTEMS

RADIO BURSTS

EXTRANEOUS NOISE IN TELEMETRY AND
TRACKING SYSTEMS

ENERGETIC PROTONS

RADIATION HAZARD TO SPACE OPERATIONS--
SENSORS, POWER SUPPLIES,
CIRCUITRY, PROCESSORS, PERSONNEL
IONOSPHERIC EFFECTS IN POLAR REGIONS:
HF/VLF STRATOSPHERIC CHEMISTRY

GEOMAGNETIC STORMS

IONOSPHERIC STORMS—HF PROPAGATION, VLF
PHASE, SATELLITE SIGNAL SCINTILLATION
SATELLITE DRAG VARIATION
POWER LINES AND PIPE LINES
GLOBAL ATMOSPHERIC ELECTRIC FIELD
GEOPHYSICAL EXPLORATION

Table IIb. Translate to Solar Flare

1. Soft (1-8 Å) X-rays*
2. Radio emission
3. Proton acceleration**
4. Mass ejection

*only prediction
**after flare

As shown in Table IIb, we translate these into solar-flare phenomena (and we predict):

1. Soft 1-8 Å X-rays - a forecasting problem
2. Radio emission (S band) - don't
3. Proton acceleration - flare mode
4. Mass ejection - ?

IV. How Do We Forecast?

The forecast process consists of:

1. Inputs
2. Analysis
3. Output

Inputs

There are approximately 800 data sets available (many are not solar but rather terrestrial-effect measurements).

1. SEL Data Acquisition and Display System (SELDADS) and Observatories (see Figures 3 and 4, respectively)
2. Data sets (as shown in Table III)
3. Availability (shown in Table IV)

Analysis

When a forecast is made, the following items must be taken into consideration:

1. Flares appear only in areas of strong magnetic field. One must look at the character of the active region (A.R.) and look at the features of the evolution of the A.R.
2. Flares are not random; 80 percent of the A.R. produce no flares, and 80 percent of flares occur in a few A.R. Magnetic complexity appears to be a significant factor.
3. Flares occur in regions with: (a) growth and decay, and (b) differential development.

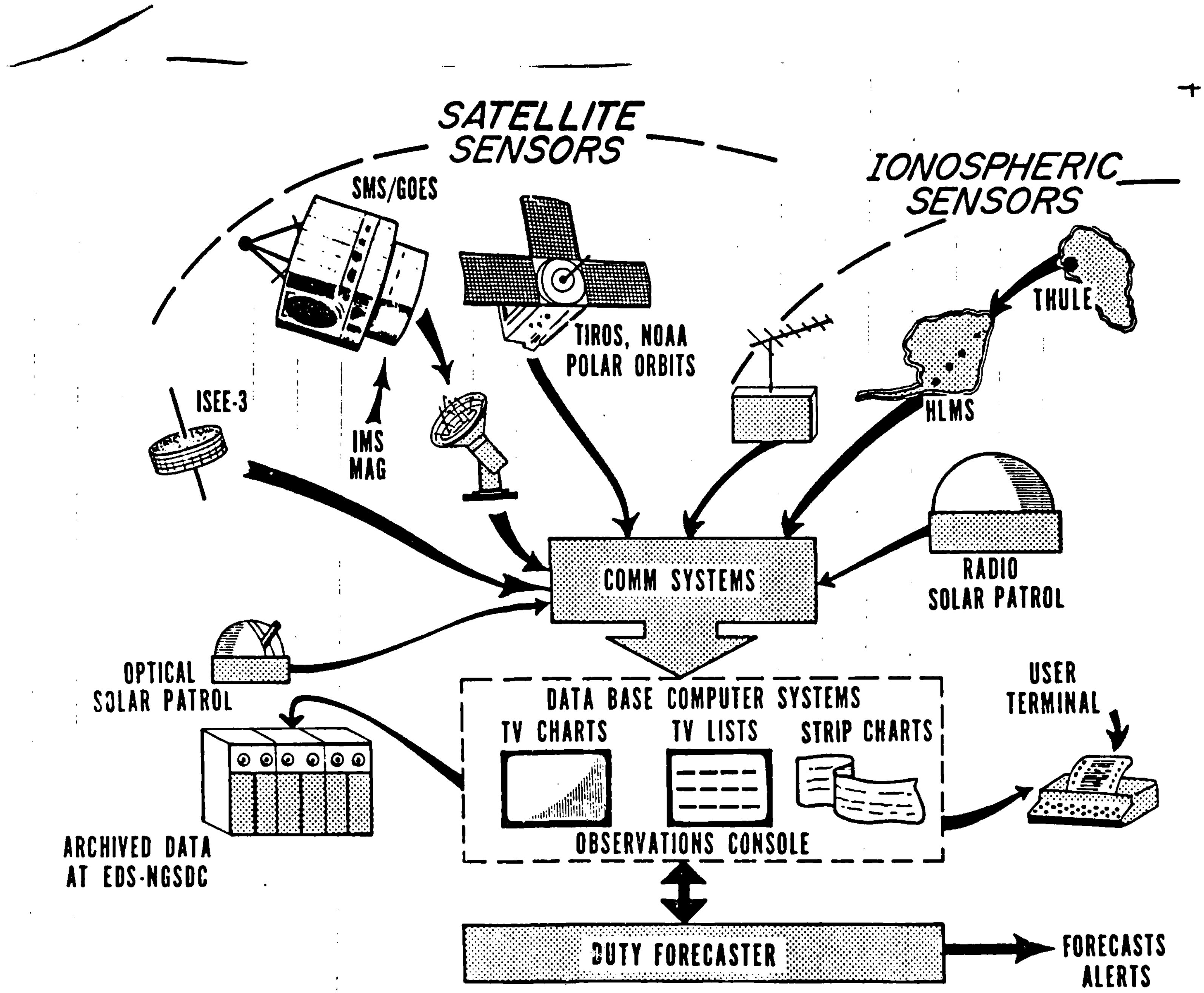


Figure 3. NOAA/ERL/SEL REAL-TIME DATA ACQUISITION AND DISPLAY SYSTEM (SEL DADS)

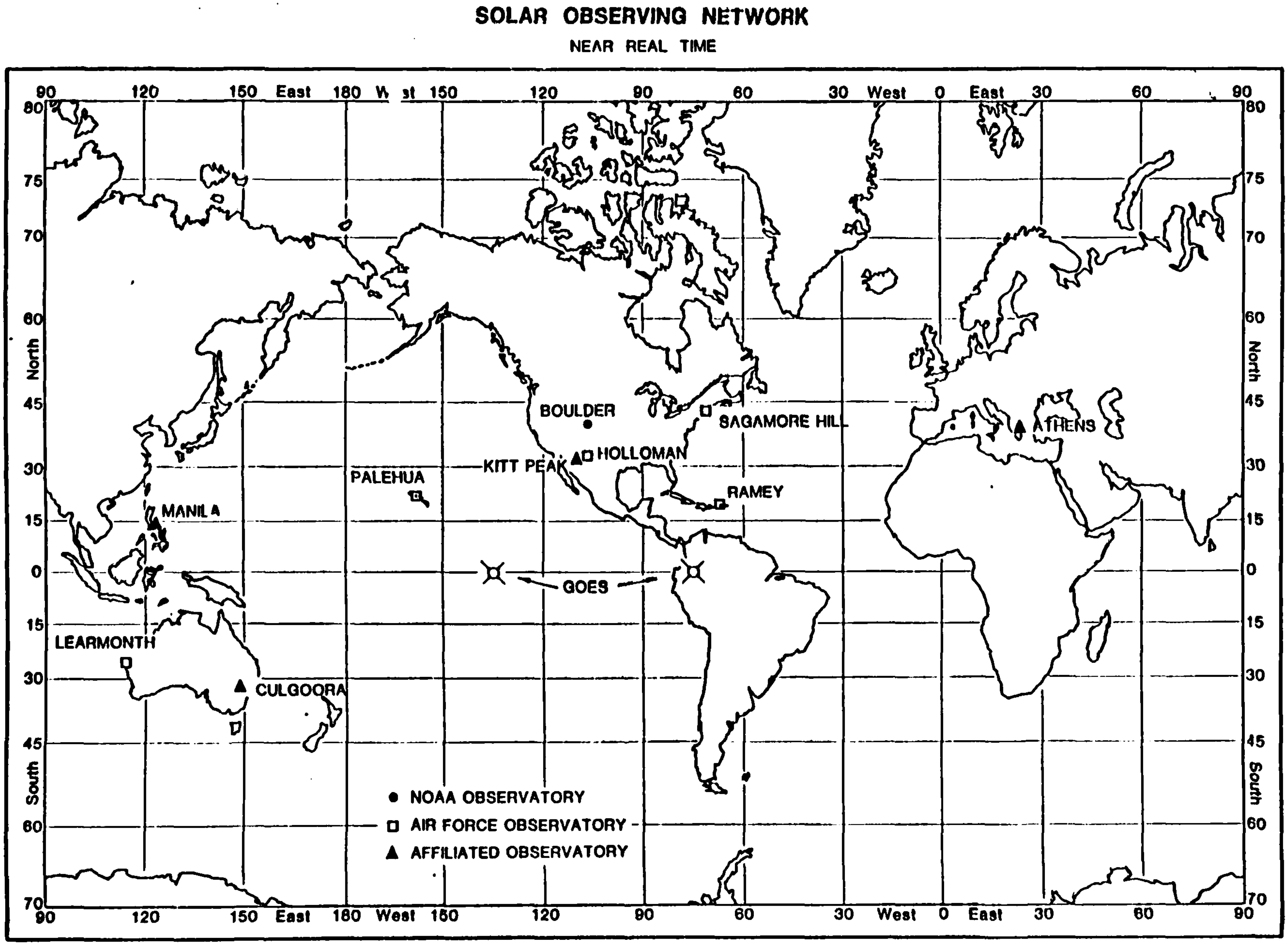


Figure 4. Solar Observing Network.

DATA 23 MAR 84

Table III. SELDADS I DATA SETS

SOLAR XRAYS AND ENERGETIC PARTICLES		
GOES XRAYS	1&5 MIN AVERAGES	GOES 5&6
GOES XRAY EVENTS	RT	GOES 5&6
GOES PARTICLE COUNTS	1&5 MIN AVERAGES	GOES 5&6
GOES PARTICLE FLUXES	1&5 MIN AVERAGES	GOES 5&6
GOES PARTICLE EVENTS	RT	GOES 5&6
XRAY BACKGROUND	RT & DAILY VALUE	GOES 5&6
PROTON FLUENCE (>1, >10 MeV)	DAILY	GOES 5&6
TIROS/NOAA PARTICLES		NOAA 7&8
SST RADIATION DOSE RATE		
RIOMETER	15 MIN	4 STATIONS
	1&5 MIN	5 STATIONS
NEUTRON MONITOR	15 MIN	THULE
ABSORPTION (UABSE)	DAILY	IUWDS
METEOR ENERGETIC PARTICLES	(USSR)	
GROUND LEVEL EVENTS - COSMIC RAYS		THULE NEUTRON MONITOR
FORBUSH DECREASES - COSMIC RAYS		THULE NEUTRON MONITOR
COSMIC RAY DAILY AVERAGE		THULE NEUTRON MONITOR
POLAR CAP ABSORPTION EVENTS		THULE RIOMETER
DAILY EVENTS EDITED - X-RAYS, PROTON, PCA, GLE, FORBUSH DECREASE, SST DOSE RATE		
EVENTS ASSOCIATED TO REGIONS - X-RAYS, PROTON, PCA		
INTEGRATED X-RAY FLUX FOR EVENTS		
SOLAR OPTICAL EVENTS & REPORTS		
H-ALPHA FLARES	RT & DAILY	6 STATIONS + IUWDS
H-ALPHA LIMB/DISK EVENTS	RT	6 STATIONS
H-ALPHA PLAIN LANGUAGE REPORTS	RT	4 STATIONS
H-ALPHA PATROL TIMES DAILY	RT	6 STATIONS
H-ALPHA REGION ANALYSIS	DAILY	4 STATIONS
H-ALPHA HISTOGRAMS	DAILY	4 STATIONS
H-ALPHA PLAGE	DAILY	IUWDS STATIONS
CALCIUM REPORTS	DAILY	MANILA
SUNSPOT REPORTS	DAILY	5 STATIONS + IUWDS
OPTICAL WHITE LIGHT SPOTS		
SUNSPOT NUMBER	DAILY	BOULDER
MAGNETIC FIELD STRENGTH	DAILY	MT WILSON
MAGNETIC DATA		
MAGNETIC MAPS		SOON NETWORK
CORONAL HOLE		BOULDER
CORONAL LINE	DAILY	IUWDS STATIONS
EPHEMERIS		
RETURNING REGION		
DAILY SESC CONSENSUS REGION SUMMARIES		
DAILY EVENT EDITED - FLARES, LIMB/DISK		
EVENTS ASSOCIATED TO REGIONS - FLARES, LIMB/DISK		
SRI PROBABILITIES		
SESC DAILY SUNSPOT NUMBER		
FLARES BY REGION		
NUMBER OF NEW SUNSPOT REGIONS ON THE DISK		
SOLAR RADIO EVENTS & INDICES		
SOLAR RADIO DISCRETE BURSTS		5 STATIONS + IUWDS
SOLAR RADIO SWEEP FREQ BURSTS		5 STATIONS + IUWDS
SOLAR RADIO NOISE		2 STATIONS + IUWDS
10CM FLUX	14,17,20Z	OTTWA
SOLAR RADIO BACKGROUND FLUX	DAILY	4 STATIONS + IUWDS
SOLAR MEAN FIELD	DAILY	STANFORD, THULE, VOSTOK
SOLAR RADIO PATROL TIMES	DAILY	3 STATIONS
DAILY EVENTS EDITED - RADIO BURSTS (DISCRETE & SWEEP), RADIO NOISE STORMS		
EVENTS ASSOCIATED TO REGIONS - RADIO BURSTS, NOISE STORMS		
INTEGRATED BURST FLUX FOR EVENTS		

DATA 23 MAR 84

SELDADS I DATA SETS

GEOMAGNETIC FIELD		
SATELLITE MAGNETIC FIELD	1&5 MIN AVE 3 COMPONENTS	GOES 5&6
HEMISPHERICAL POWER INPUT	90 MIN VALUES	NOAA 7&8 (TED)
EQUATORWARD BOUNDARY	90 MIN VALUES	NOAA 7&8 (TED)
Q-INDEX	90 MIN VALUES	NOAA 7&8 (TED)
H,D & Z VALUES	1&5 MIN AVE	12 RGON STATIONS
H, D VALUES	15 MIN DATA	THULE & ANCHORAGE
X,Y,Z MIN/MAX, K VALUES	90 MIN	AF HIGH LATTITUDE NETWORK 7 STATIONS
AP, KP (running & daily)	3 HOURLY	AF HIGH LATTITUDE NETWORK
H,D & Z	1 MIN AVE	USGS MAGNETOMETER
TOTAL FIELD	1 MIN	USGS MAGNETOMETER
K VALUES	3 HOURLY	USGS MAGNETOMETER
QUIET DAY CURVES	DAILY	USGS MAGNETOMETER
AFR & KFR VALUES	DAILY & EVENTS	FREDERICKSBURG
EVENTS - SSC, STORM BEGIN & END TIMES	--	FREDERICKSBURK & AP
A & K VALUES	DAILY	20 IUWDS STATIONS
POLAR GEOMAGNETIC HOURLY VALUES	HOURLY	
INFERRED INTERPLANETARY FIELD DIRECTION		
IPS SOLAR WIND		
ISEE DATA		
ISEE SHOCK DETECTOR		ISEE
RGON SHOCK DETECTOR		RGON NETWORK
IONOSPHERIC DATA		
SUDDEN IONO. DIS.	EVENTS	IUWDS STATIONS
TOTAL ELECTRON CONTENT	HOURLY	5 STATIONS
FOF2	HOURLY	IUWDS STATIONS
M3000	HOURLY	IUWDS STATIONS
FOES	HOURLY	IUWDS STATIONS
FMIN	HOURLY	IUWDS STATIONS
HF SENSOR DATA	15 MIN	ALASKA STATIONS
AURORAL RADAR	15 MIN	ANCHORAGE
CRITICAL FREQUENCIES	HOURLY	IUWDS STATIONS
IONOSPHERIC DATA	HOURLY	IUWDS STATIONS
OBLIQUE IONOSPHERIC SOUNDER		
MISCELLANEOUS		
EQUIPMENT STATUS		
ALERTS		
ALERTS		
STRATWARMS		
PRESTOS		
GEOALERT forecasts		
GEOALERT advice from RWC's		
3-DAY FORECASTS		
M-CLASS XRAY EVENTS		
X-CLASS XRAY EVENTS		
PROTON EVENTS		
PCA		
OTTAWA 1700Z 10.7CM RADIO FLUX		
F KSBURG A-INDEX		
I RY AP-INDEX		
NORTH PACIFIC PROPAGATION (Anch advisory)		
Flare probabilities by region		

	FREQUENCY of REPORT	PERCENTAGE of time AVAILABLE
CODED DATA:		
Solar optical		
Sunspot	5/day	90%
Flare	activity dependant	96%
Region analysis	5/day	10%
Features	5/day	90%
Histograms	1/hour	90%
Indices	5/day	90%
Solar radio		
Events	activiy dependant	99%
Indices	5/day	95%
Ionospheric		
TEC	1/hour	98%
Ionosonde	1/hour	96%
Auroral radar	1/15 min	95%
Geomagnetic		
Component	1/min	98%
Events	activity dependant.	98%
Indices	1/three hours	98%
COMPUTER GENERATED PRODUCTS:		
Models		
Probabilities	on demand	98%
Proton	on demand	98%
10cm	on demand	98%
Numerical Guidance	on demand	98%
Activity Summaries	on demand	98%
Listings	on demand	98%
Events	on demand	98%
Regions	on demand	98%
Magnetic	on demand	98%

	FREQUENCY of REPORT	PERCENTAGE of time AVAILABLE
RAW DATA:		
Images		
H-Alpha	2/day	80%
Calcium	1/day	80%
White light	1/day	75%
Maps		
Magnetic	3/day	80%
Green line (5303A)	1/day	55%
Yellow line (5694A)	1/day	55%
Neutral line	1/day	90%
Helium (10830A)	1/day	80%
Drawings		
Sunspot	1/day	80%
E-W radio scan	1/day	90%
Spacecraft Data		
Solar xray	1/min	99%
Magnetic	1/min	99%
Particle	1/five min	99%
Interplanetary	1/five min	33%
DESCRIPTIVE DATA:		
Plain language		
Observatory	8/day	95%
Special events	activity dependant	98%
Forecasts		
Primary	1/day	99%
HF propagation	4/day	99%
GEOALERT advices	6/day	88%
WEEKLY	1/week	99%

Table IV. Near "real-time" data available at SESC Forecast Center.

Each day the duty forecaster must make a forecast for each visible A.R., those that have rotated off in the past 24 hours, and those due to return in the next three days. The A.R. forecasts are combined to form the daily whole-sun forecast.

Forecasts are made on schedule and on demand (for example, a call from a customer).

The forecaster is immersed in data, with inputs from numerous sources. He must quickly assimilate what has occurred and fine tune his forecast--a process that goes on continuously (shown in Figure 5).

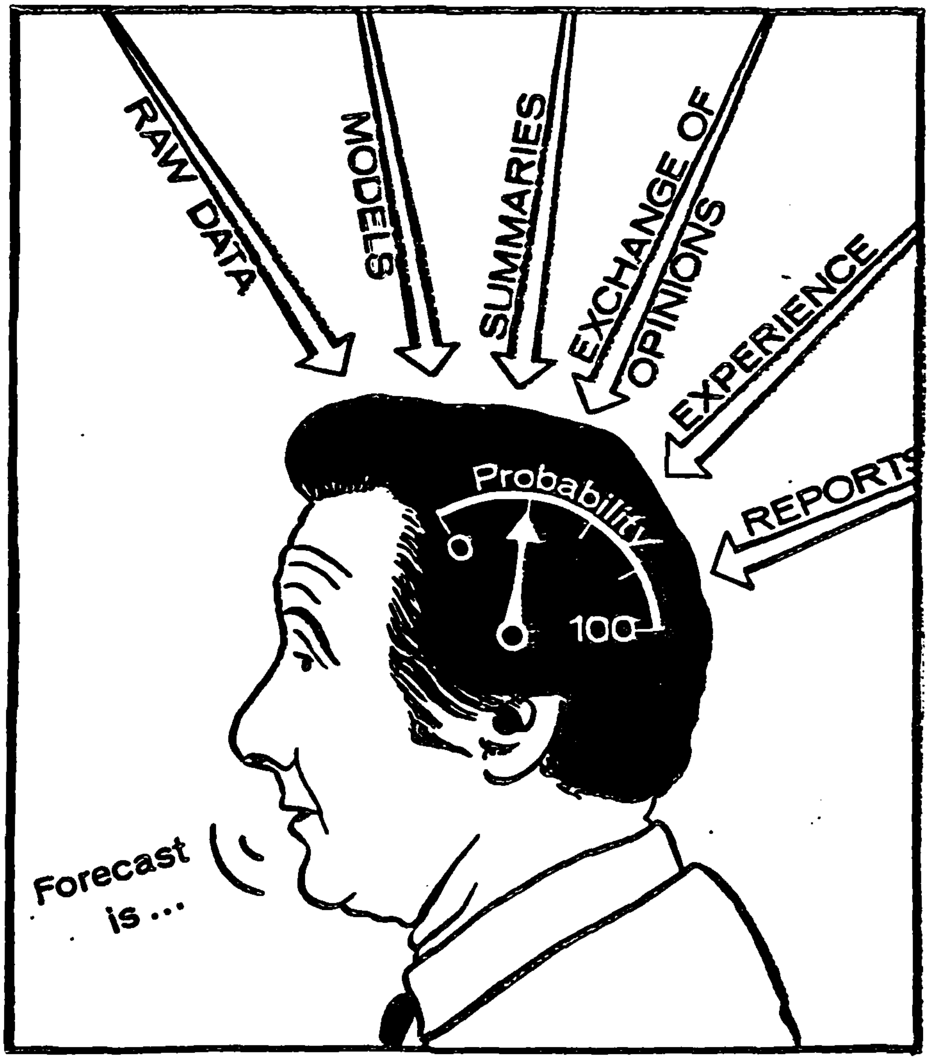


Figure 5. The mental process of forecasting.

There are many different inputs to the forecasting process, all arriving at different times (or sometimes not at all). The forecaster's use of these inputs (shown in Table V) can be viewed as four different forecast outputs that he considers in developing his A.R. forecast:

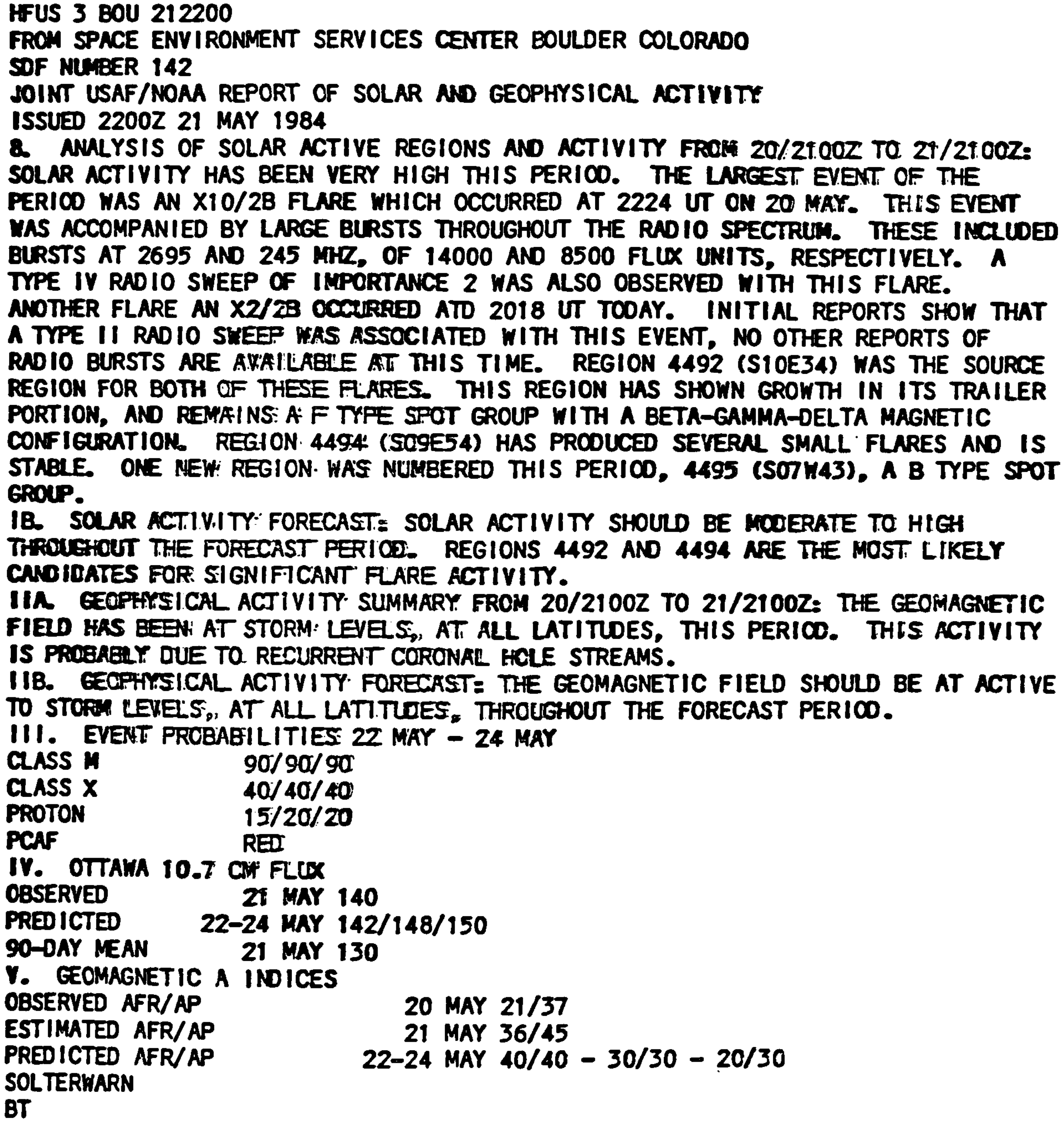
1. Climatology Forecast. What is the current configuration compared to past A.R? FKC regions historically produce 3M flares per day.
2. Trend Forecast. What is the evolutionary state of the A.R? Growing, decaying, stable? What will it be in one, two, or three days?
3. Persistence Forecast. Using A.R. flare history, what is the approximate likelihood of flares tomorrow?
4. Analogy Forecast. What has a similar A.R. done in the past? This relies on the forecaster's experience.

Table V. INPUTS FOR DEVELOPING FLARE FORECAST

1. Current configuration - - - - - Climatological forecast
2. Evolutionary stage - - - - - - Trend forecast
3. Flare production - - - - - - - Persistence forecast
4. Experience and interactions - - Analogy forecast

Output

Persistence is a usual starting point, but forecasters are better (see Figure 6).



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HFUS 3 BOU 212200
FROM SPACE ENVIRONMENT SERVICES CENTER BOULDER COLORADO
SDF NUMBER 142
JOINT USAF/NOAA REPORT OF SOLAR AND GEOPHYSICAL ACTIVITY
ISSUED 2200Z 21 MAY 1984
IA. ANALYSIS OF SOLAR ACTIVE REGIONS AND ACTIVITY FROM 20/2100Z TO 21/2100Z:
SOLAR ACTIVITY HAS BEEN VERY HIGH THIS PERIOD.  THE LARGEST EVENT OF THE
PERIOD WAS AN X10/2B FLARE WHICH OCCURRED AT 2224 UT ON 20 MAY.  THIS EVENT
WAS ACCOMPANIED BY LARGE BURSTS THROUGHOUT THE RADIO SPECTRUM.  THESE INCLUDED
BURSTS AT 2695 AND 245 MHZ, OF 14000 AND 8500 FLUX UNITS, RESPECTIVELY.  A
TYPE IV RADIO SWEEP OF IMPORTANCE 2 WAS ALSO OBSERVED WITH THIS FLARE.
ANOTHER FLARE AN X2/2B OCCURRED ATD 2018 UT TODAY.  INITIAL REPORTS SHOW THAT
A TYPE II RADIO SWEEP WAS ASSOCIATED WITH THIS EVENT, NO OTHER REPORTS OF
RADIO BURSTS ARE AVAILABLE AT THIS TIME.  REGION 4492 (S10E34) WAS THE SOURCE
REGION FOR BOTH OF THESE FLARES.  THIS REGION HAS SHOWN GROWTH IN ITS TRAILER
PORTION, AND REMAINS A F TYPE SPOT GROUP WITH A BETA-GAMMA-DELTA MAGNETIC
CONFIGURATION.  REGION 4494 (S09E54) HAS PRODUCED SEVERAL SMALL FLARES AND IS
STABLE.  ONE NEW REGION WAS NUMBERED THIS PERIOD, 4495 (S07W43), A B TYPE SPOT
GROUP.
IB.  SOLAR ACTIVITY FORECAST:  SOLAR ACTIVITY SHOULD BE MODERATE TO HIGH
THROUGHOUT THE FORECAST PERIOD.  REGIONS 4492 AND 4494 ARE THE MOST LIKELY
CANDIDATES FOR SIGNIFICANT FLARE ACTIVITY.
IIA.  GEOPHYSICAL ACTIVITY SUMMARY FROM 20/2100Z TO 21/2100Z:  THE GEOMAGNETIC
FIELD HAS BEEN AT STORM LEVELS, AT ALL LATITUDES, THIS PERIOD.  THIS ACTIVITY
IS PROBABLY DUE TO RECURRENT CORONAL HOLE STREAMS.
IIB.  GEOPHYSICAL ACTIVITY FORECAST:  THE GEOMAGNETIC FIELD SHOULD BE AT ACTIVE
TO STORM LEVELS, AT ALL LATITUDES, THROUGHOUT THE FORECAST PERIOD.
III.  EVENT PROBABILITIES 22 MAY - 24 MAY
CLASS M          90/90/90
CLASS X          40/40/40
PROTON           15/20/20
PCAF             RED
IV.  OTTAWA 10.7 CM FLUX
OBSERVED          21 MAY 140
PREDICTED      22-24 MAY 142/148/150
90-DAY MEAN       21 MAY 130
V.  GEOMAGNETIC A INDICES
OBSERVED AFR/AP             20 MAY 21/37
ESTIMATED AFR/AP            21 MAY 36/45
PREDICTED AFR/AP         22-24 MAY 40/40 - 30/30 - 20/30
SOLTERWARN
BT
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Figure 5. Example of SESC product using flare probabilities.

V. How Well Do We Do?

1. Skill in A.R. to flare (see Figure 7a)
2. Next in size (X-ray class)
3. Poorest in time of flare (shown in Figure 7b)

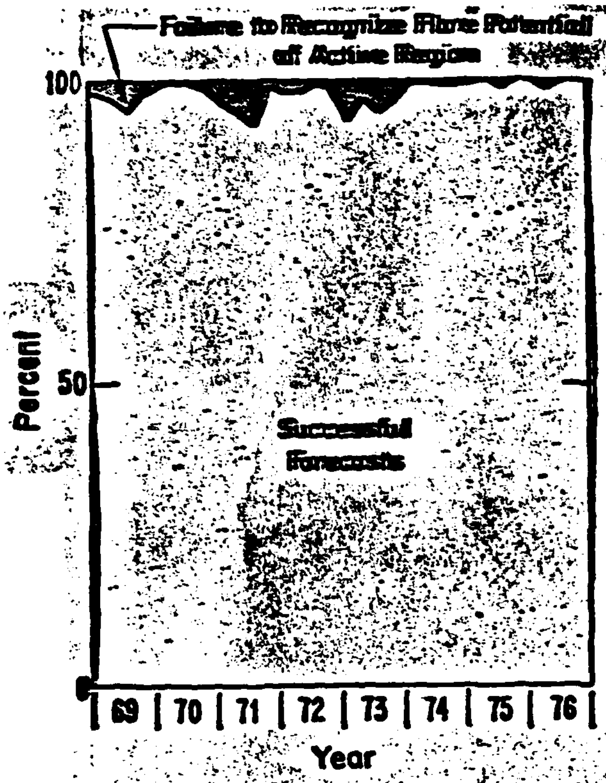

Figure 7a. Percentage of failure to recognize flare potential of active region.

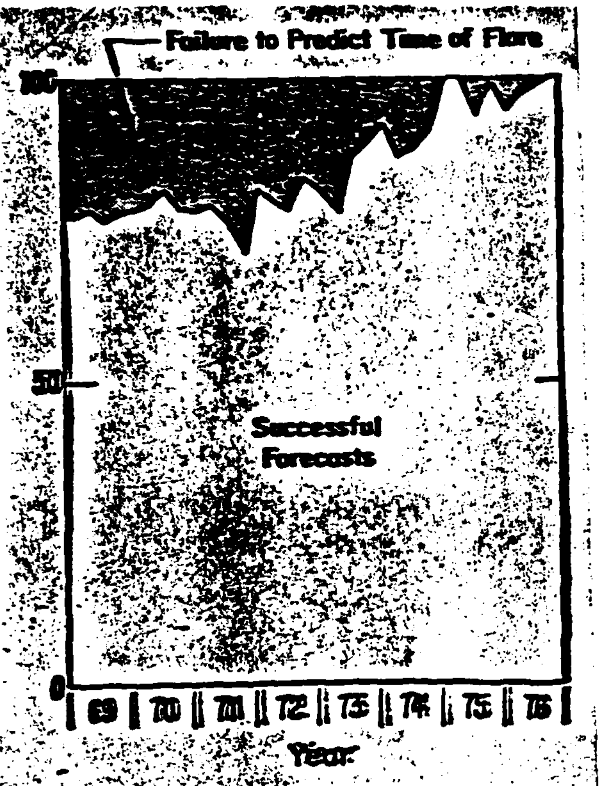

Figure 7b. Percentage of failure to predict time of flare.

VI. Advice and Precautions

Advice on how to predict flares is plentiful. Nearly everyone has his own ideas on how to improve solar flare prediction.

Foecasting is inherently one of the most difficult and scientifically demanding tasks that man attempts on a routine basis. As the science continues to advance, the forecaster faces an increasingly difficult challenge in equipping himself to apply the state of science to his task.

While a researcher can specialize and is not constrained by rigid time schedules, the forecaster is faced with the challenge of bringing to bear, on a set of incomplete and error-prone initial data, whatever may be relevant from a vast and complex science, within strict deadlines. He must retain the confidence to do so day after day with the chance only rarely to go back and try to find out why he might have been right or wrong.

While the availability of more and better data and advances in the science could be seen as simplifying the forecaster's task, the reverse may be true because of the sheer volume of potentially relevant knowledge of the processes becoming available.

It is essential to remember that time is important to the busy forecaster, and the amount of output he must peruse must be kept to a minimum.

Not only is there a severe limit on the time available to the forecaster, but there is also a very effective maximum on the time that can be spent on thinking over a situation. Forecasting demands rapid thinking and high concentration; hence, the point of diminishing returns is reached rather quickly.

The forecaster is in a very critical position. He makes forecasts. He decides to accept or reject any guidance (i.e., raw data and other information) reaching him, and he decides how to use what he does accept.

If he is incapable of taking advantage of improved guidance, then no matter how much is spent on improvement elsewhere in the forecast system (described above), there will be no benefit in terms of forecast improvements (accuracy).

Forecasting is not an exercise in physics and applied mathematics. It is an exercise in recognizing, recalling, categorizing, and decision making. The forecaster needs all the help he can get.

EVALUATION OF FLARE FORECASTS

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Abstract

Lacking a method of verifying and evaluating forecasts, we have no way of knowing the status of flare prediction. Without evaluation, there is no way to measure progress by comparing current forecasts with those of the past, no comparison of one forecast center with another, no way of measuring the success of individual forecasters.

Some of the problems of evaluating forecasts of rare events are illustrated by the verification matrix for daily yes/no forecasts of flares of importance 2 or greater in 1967. Entries are the number of days that fit each situation.

Table I. Verification Matrix for Forecasts of Flares of Importance 2

OUTCOME: / FORECAST:	"FLARE"	"NONE"	
FLARE	correct "flare" forecast 18 (9)	miss, underforecast 27 (36)	45
NONE	false alarm overforecast 53 (62)	correct "quiet" forecast 267 (258)	320
	71	294	365

The numbers in parentheses are the numbers expected if the forecasts were unrelated to flare occurrence: 9 = (71 x 45)/365. Given the totals (71 and 45), the probability of getting 285 correct by chance is less than one in a thousand, according to a standard (chi-square) test; the forecasts _do_ contain useful information.

In this example, 285, or 78 percent, of the forecasts are correct. If a mindless forecast of "no flare" had been issued each day, 320/365 = 88 percent would have been correct. As a forecast score, "percent correct forecasts" is not only uninformative, it is "improper" because it discourages forecasters from expressing their best judgment.

Note these properties of useful forecasts of rare events: (1) the relatively small number of "FLARE" forecasts and the even smaller number of actual occurrences; (2) the relatively large proportion of flare occurrences in the "flare forecast" group; (3) the fact that, nevertheless, because of the overwhelmingly large number of days with "NONE" forecast, among flares that occurred, fewer (18) were forecast than not (27); and among forecasts of "FLARE," fewer (18) occurred than not (53).

Probability forecasts allow expression of an estimate of what will happen and also an estimate of the uncertainty of the first estimate. The Brier F score is the average squared difference between forecast and outcome; forecasts close to reality yield low F. It is a "proper score" that rewards expression of the best estimate of occurrence probability, and it is, at least in some circumstances, related to forecast utility.

Taking "climatology" as a standard, meteorologists calculate the score C that would result from a set of forecasts made with no knowledge other than the relative frequency of occurrence of the forecast event. Then, $S = (C - F)/C$ is the "skill score." The range of possible values of S is defined (-1 to 1), and it follows the familiar convention that big is good. Solar climatology, however, is not so easily determined; advance knowledge is really a long-term forecast. An appropriate standard for forecasts of solar activity might be persistence--using today's activity as the forecast for tomorrow.

Calculations of the F score and skill score for a set of flare forecasts showed the scores to be very sensitive to precise labeling of the forecast probability; description of all forecasts above 50 percent as "yes," equal to 1, made the the score much worse. In a typical set of probability forecasts for flares, outcome was strongly correlated with forecast, but forecast probability was about half again greater than occurrence frequency (as in Table I). With climatology as the standard in the skill score, this bias led to negative S, despite the close relation of forecasts to outcome.

Although forecasters express the need for a means of evaluating and comparing forecasts, they are wary of unrealistic scores. They say forecasters who are scored soon learn to "beat the system." This will be detrimental unless a high score is synonymous with a useful forecast; an improper score is worse than no score.

Defining an adequate method of evaluation may not be simple, but the disadvantages of trying to do without evaluation are serious. An effort to develop and apply a procedure for verification and evaluation appears to be one of the surest routes to improving the utility of solar-flare forecasts.

ON THE POSSIBILITY OF FUNDAMENTAL LIMITATIONS IN THE 24-HR FORECAST

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Abstract

First, we note the fact that the present 24-hr flare forecast is based on data received once daily and that the forecast is not based on a physical model for flares; even if it were, the once-per-day data rate would probably be too infrequent to take advantage of the physics. Thus, the present 24-hr flare forecast is based on observables that are, at best, statistically related to flare occurrence.

As a result of the above, we hypothesize that the upper limit on the predictive content of the data (as presently collected) is the mean rate of flare occurrence (per day) for a particular flare size (None, C, M, or X) for each active region on the disk.

The consequences of the above hypothesis are (1) that the success of the daily forecasts is fundamentally limited by stochasticism, in accordance with Poisson statistics, and (2) that the verification scores of the forecasts tend to represent the summation of attempts to choose between the larger of P(0) and P($\geq$ 1), where

$$P(n) = \mu^n e^{-\mu}/n!$$

and where μ, the rate of flare occurrence varies between some small number ($\lesssim$ 0.1/day for the vast majority of regions--hence, P(0) >> P($\geq$ 1), and the forecasts for "no flare" are almost always correct) and a larger number ($\mu \simeq 1$) in the case of large flares. In the latter situation P(0) and P($\geq$ 1) are comparable in size; and as a result, the forecasts for such events hover near 50 percent accuracy.

It would appear that in order to improve forecasts, the data must be recorded and analyzed more frequently and that the forecast and the data formats must be based on a physical model for flares.

SUMMARY OF USAF's "SAMEX," "SAMSAT," AND "SIMPL"

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Abstract

SAMSAT - Solar Activity Monitoring Satellite: An operationally oriented package in polar, sun-synchronous orbit designed to monitor flares, coronal holes, coronal mass ejections, X-ray and EUV flares, and magnetic fields. The payload definition study is completed; the instruments are:

1. soft X-ray imager (5" resolution)
2. vector magnetograph (5" resolution)
3. coronagraph
4. X-ray and EUV flux monitor.

SAMEX - Solar Activity Measurements Experiments: Research-oriented package to be flown as part of Space Test Program. Instruments to include high-resolution filtergraph/polarimeter and high-resolution soft X-ray imager.

SIMPL - Synoptic Interplanetary Measurement Platform at L1: Operationally oriented complement to SAMSAT to be positioned at the Lagrangian point. Will monitor the IP medium (particles and fields, shocks). Instruments to include:

1. solar wind monitor
2. magnetometer
3. kilometric radiometer.

PHYSICAL ASPECTS OF SOLAR FLARES

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Abstract

Theorists have not yet converged upon a single flare "model." However, since there are different kinds of flares from an observational point of view, there are probably different types of flares also from a theoretical point of view. Hence it is useful to review the different components and processes that may go into flare models.

It is generally agreed that the energy released in a flare is that of magnetic free energy. This may be due either to distributed currents, probably in the form of force-free fields, or current sheets, or a combination of the two. The distributed currents may be present in magnetic flux as it erupts, or they may be caused by shear or vortical photospheric motion after the field has erupted. Current sheets may be due to the small-scale "quantized" magnetic field structure, the conjunction of large-scale flux systems, or spontaneous changes of magnetic topology due, for instance, to MHD instabilities.

The energy released during a flare may be transformed into a combination of the following forms: MHD motion; thermal plasma; high-energy but non-relativistic particles; and relativistic particles. These forms in turn give rise to observed radiation such as UV, X-ray, gamma-ray, and radio.

Similarly, there are several possibilities concerning the initiation of a flare, including the following. A flare may be due to spontaneous reconnection; it may be due to an MHD instability that leads to a magnetic-field structure that rapidly reconnects; or it may be due to a

combination of an MHD process and a reconnection process that, in combination, give rise to an explosive instability.

AN INFORMAL COMMENT

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After hearing Peter Sturrock's discussion, I am reminded of the possibility that considerable progress might be made using *only* optical data. Thus, a major attempt to improve forecasts using new methods of analysis for ground-based data might be warranted.

MAGNETIC FIELD CHANGES RELATED TO FLARES

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Abstract

INTRODUCTION

Two fundamental relationships of magnetic fields to flares are currently used in flare forecasting:

1. The invariable occurrence of flares at polarity inversion lines (for references, see review by Martin, 1980. Solar Phys., 68, 217).

2. The strong statistical tendency for flares to occur in active regions that are magnetically complex. The term "magnetically complex" refers to the degree of mixing of large-scale areas of opposite polarity (Smith, S. F., and Howard, R. F.. in K. O. Kiepenheuer (ed.), Structure and Development of Solar Active Regions, IAU Symp., 35. 33).

We suspect that any reliable information on how magnetic fields change or become complex may offer new clues about the nature of flares and potentially lead to better flare prediction.

In this presentation, I will first review a few key papers on relationships of magnetic-field configurations and changes that should be useful in forecasting. Then I will discuss new results from a paper that I have recently co-authored on the association between disappearing magnetic flux and flares.

A FEW PAPERS RELEVANT TO FLARE FORECASTING

1. Martres, M. J., Michard. R., Soru-Iscovici. I., and Tsap, T: 1968, Solar Phys., 5, 187.

It is shown for all of the flares in this study (~ 80) that the magnetic field was increasing on one side and decreasing on the other side of the polarity inversion line at the sites of the flares.

2. Bumba, V., Krivsky, L., Martres, M. J., and Soru-Iscovici, I: 1968: in K. O. Kiepenheuer (ed.), Structure and Development of Solar Active Regions, IAU Symp., 35, 311.

   A common property for the majority of flares is stated to be their occurrence at sites where there is evidence of the compression of opposite polarity fields at the polarity inversion line.

3. Marsh, K: 1978, Solar Phys., 64, 93.

   The author showed statistically that flares associated with ephemeral regions primarily occur when either pole becomes abutted against opposite-polarity network magnetic field.

4. Martin, S. F., Bentley, B., Schadee, A., Dezso, L., Gezstelyi, L., Antalova, A., Kucera, A., Harvey, K., Jones, H., Livi, S. H. B., Wang, J: 1984, Adv. Space Research, COSPAR XV, Graz, Austria, in press.

   This paper outlines five possible relationships between emerging flux regions and flares. They range from (1) the very close relationship of flares occurring at the boundary of an emerging flux region to (5) no relationship, meaning that some flares occur in the absence of new emerging flux regions.

RECENT RESULTS

5. Martin, S. F., Livi, S. H. B., and Wang, J: 1985, Proc. Ron Giovanelli Commemorative Colloquium (Tucson, AZ), to be published as a special issue of the Australian Journal of Physics.

   The decay of an active region was studied in detail using time-lapse videomagnetograms from Big Bear Solar Observatory. The decay was observed to be the conseqence of three interrelated processes that are described as (1) fragmentation, (2) migration, and (3) cancellation of small elements of magnetic flux. In the first process, small fragments break away from larger concentrations of magnetic flux at discrete sites around the periphery of each dominant area of positive and negative magnetic flux. The fragmentation is followed by the continued migration of the small elements of flux until they either merge with other elements of similar polarity or collide with fragments of opposite polarity. The third process, "cancellation," is defined as "the mutual disappearance of magnetic flux in closely spaced features of opposite polarity." Cancellation of the fragements of magnetic flux was invariably observed whenever fields of opposite polarity collided. The approach of opposite-polarity flux fragments was observed to be an irreversible process after motion of opposite-polarity fragments of fields toward each other was seen. The subsequent disappearance of flux is thus predictable on the time-scale of hours.

All flares observed during the five days of decay of this region began at sites where the magnetic flux of opposite polarity was moving together and was disappearing. Flares occurred only at these sites, but some sites of disappearing flux had no associated flares. The disappearance of flux proceeded slowly before, during, and after the flares. A few flares spread to other parts of the active region where no magnetic flux was disappearing.

DISCUSSION

A commonality exists between these seemingly diverse results in the first four papers cited above. They all relate flares to circumstances in which magnetic flux was disappearing or could be inferred to have been disappearing in the light of our recent observations, (5) above. New data need to be acquired. and analyses need to be conducted to verify or determine whether magnetic flux loss takes place during all flares.

Because the disappearance of flux is an invariable consequence after the approach of increments of opposite-polarity fields is observed, flux disappearance is predictable in the short term (several hours to one day). If flares occur only at these predictable sites of disappearing magnetic flux, then the prospect of improving present-day short-term flare forecasting is very good. However, we need to learn which sites of disappearance are associated with flares and to understand when the necessary conditions for a flare have been established at a site of flux disappearance.

EMPIRICAL RELATIONSHIPS BETWEEN FLARES AND SHEARED MAGNETIC FIELDS INFERRED FROM SUNSPOT MOTIONS AND FIBRIL GEOMETRY

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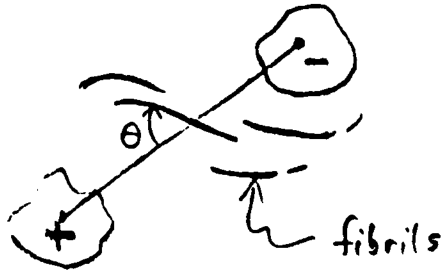
Abstract

Motions of photospheric footpoints of magnetic fields (as inferred from sunspot proper motions) are observed to lead to H-α fibril orientations indicative of stressed fields. The critical parameter is the angle θ, as shown in the figure below. In a potential configuration the angle θ is zero but may acquire values on the order of 90° in the presence of rapid spot motions or rotations. When θ is non-zero, the energy in excess of the potential configuration is given by Nakagawa's approximation:

$$E \simeq \frac{B^2 L^2 W^2}{32\pi^2 \sqrt{L^2+W^2}} (\sec\theta - 1) \quad \text{erg}$$

where B is the photospheric field strength (gauss) and L and W are characteristic length and width (cm) of the volume under consideration.

Observations of active regions show θ increasing in response to shearing motions, as well as relaxations (θ decreasing suddenly) at times when flares occur. For further details see Neidig *et al.* 1978: AFGL-TR-78-0194 and Neidig 1979: *Solar Phys.*, 61, 121.



TWO CLASSES OF GAMMA-RAY/PROTON FLARES: IMPULSIVE AND GRADUAL

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Abstract

We have studied various properties of γ-ray/proton flares, which produce nuclear γ-rays and/or interplanetary energetic protons. We have found that there exist two classes of γ-ray/proton (GR/P) flares, with each class having many distinct characteristics in common. Gradual GR/P flares (so named because of gradual variations of hard X-ray fluxes with duration of spike bursts longer than 90 s) have the following characteristics: long duration (> 10 min) hard X-ray and microwave emission, gradual variation of microwave flux, relatively large ratios of microwave to hard X-ray fluxes, large H-α areas, long-duration soft X-ray emission (> 1 hr), hard X-ray emission from extended coronal loops, interplanetary type II emission, coronal mass ejections, and production of large numbers of interplanetary energetic protons. Impulsive GR/P flares display directly opposing behavior in the above respects. However, the two classes of GR/P flares have a few characteristics common to both of them. We have reached the following conclusions: (1) In both classes of GR/P flares protons are accelerated in closed magnetic loops during the first phase by the second-step mechanism, and these protons have a low escape probability and produce γ-rays interacting with the solar atmosphere. (2) In gradual GR/P flares additional protons are accelerated in the high corona by shock waves, and these protons easily escape into interplanetary space. This is the main reason the correlation is poor between γ-ray fluence and interplanetary proton flux.

SOLAR-TERRESTRIAL RESEARCH MONITORING - STATUS REPORT 1984

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Abstract

A status report of solar-terrestrial research monitoring sensors has been compiled from information contained in the second edition of the Directory of Solar-Terrestrial Physics Monitoring Stations. The directory contains detailed information on solar-terrestrial monitoring sensors believed to be in operation in 1984, thus providing the most comprehensive available worldwide listing of these sensors. A comparison has been made of the net change in monitoring sensors since 1976 using the station information given in the first edition of the Directory of Solar-Terrestrial Physics Monitoring Stations. In general, there has been an ~ 10 percent decrease in the operation of sensors routinely monitoring the solar-terrestrial environment with the largest decrease in the ionosphere and aurora disciplines. Although the monitoring of quiet-sun phenomena has also significantly decreased, there has been a significant increase in solar-flare-associated monitoring activities with the worldwide installation of OMEGA stations. A comparison of the relative change in United States-sponsored solar-terrestrial monitoring activity with non-U.S.-sponsored activities for the period 1976-1984 is also made.

1. INTRODUCTION

The solar-terrestrial environment is monitored by a wide variety of scientific sensors located throughout the world and on space platforms. Since 1973 there has been an international program, MONSEE, dedicated to the Monitoring of the Sun-Earth Environment. This program operates under the auspices of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) of the International Council of Scientific Unions (ICSU).

The MONSEE Steering Committee members are appointed by the various scientific unions and the Committee on Space Research (COSPAR), in addition to having representatives from the World Data Centers and other related international organizations. The purpose of MONSEE is to maintain current information on the scientific program in which various parameters of the solar-terrestrial environment are monitored. The goal of MONSEE is the expeditious collection, exchange, and distribution of solar-terrestrial data for use by all scientists to aid them in their various scientific analyses.

Most of the major monitoring networks have specific relationships to specialized commissions or committees of one of the scientific unions; the arrangements vary from case to case. The MONSEE program serves to bring these individual efforts together and to provide an interdisciplinary focus. In addition, the committee ascertains the "health" of the solar-terrestrial monitoring activities in the community as a whole.

2. THE MONSEE DIRECTORY

Over the past few years the compilation of detailed information on the various solar-terrestrial monitoring sensors throughout the world has been a major part of the MONSEE program. In 1974 the MONSEE Steering Committee decided to compile the first directory of stations engaged in monitoring the solar-terrestrial environment. The initial directory, published in 1977, contained information primarily from questionnaires specifically prepared for that directory. At the time of publication, it was recognized that the directory did not contain a complete listing of all solar-terrestrial physics monitoring stations existing at that time; however, it was the start of what has turned out to be a major effort to obtain and maintain as complete a record as possible for solar-terrestrial monitoring stations.

The second edition of the directory has just been compiled. The directory presented detailed information for 1168 sensors used to monitor the solar-terrestrial environment. The scientific disciplines covered are solar and interplanetary phenomena, ionospheric phenomena, flare-associated events, geomagnetic variations, aurora, cosmic rays, airglow, and miscellaneous related phenomena such as atmospheric ozone. The entries are arranged by discipline with detailed information such as geographic coordinates, dates of operation and instrument description as well as including names and addresses for specific information about the station.

3. CURRENT STATUS OF SOLAR-TERRESTRIAL MONITORING ACTIVITIES

One of the charges to the MONSEE Steering Committee is to ascertain the "health" of the solar-terrestrial monitoring activities in the community as a whole. This entails the following functions:

(a) The identification of areas where established monitoring activity has decreased, without an acceptable replacement, to the point where the non-availability of these data is detrimental to the future of solar-terrestrial activities, and

(b) The identification of areas where new measurements and/or techniques are classified as monitoring activities essential for the advancement of scientific knowledge.

Until now it has been difficult to provide an adequate assessment of the vitality of the entire area of solar-terrestrial monitoring, primarily because of the lack of a homogenous data base. With the compilation of the second edition of the MONSEE directory, it is possible to compare directly the data summarized from the first MONSEE directory to ascertain whether the various solar-terrestrial disciplines are being adequately monitored. Although the second directory still does not include every station engaged in the synoptic measurements of the solar-terrestrial environment, nevertheless, these two publications provide the most comprehensive data base of solar-terrestrial research monitoring activities available.

The original MONSEE directory, published in 1977, contained station and equipment information on 1033 sensors; the second edition of the MONSEE directory contains information for 1168 sensors. On the surface, with 135 additional entries in the second MONSEE directory, the stability of solar-terrestrial monitoring appears relatively good; however, this is not the case. In the preparation of the second directory, 210 sensors were identified that were in operation in 1976 but not listed in the first edition. Thus, a total of 1243 sensors were identified as in operation in 1976 compared with 1128 sensors presumably in operation in 1984. (There were a total of 40 sensors, added in the second edition, for which no start date could be determined; these sensors are not included in this statistical study.) Thus, there has been a net decrease of 115 sensors (i.e., ~ 9 percent). Table I summarizes these results by discipline; Figure 1 graphically illustrates the changes in solar-terrestrial monitoring since 1976. It is noted that included in the 1128 sensors listed in the second edition of this directory are 85 sensors listed in the first directory for which no confirmation or updating information was received for the second edition. Although for the purpose of this status report these sensors are included as "currently in operation," many of them may no longer be in operation. Therefore, the approximately 9 percent decrease in monitoring sensors is a minimum estimate; the actual decrease may be in the range of 12-14 percent.

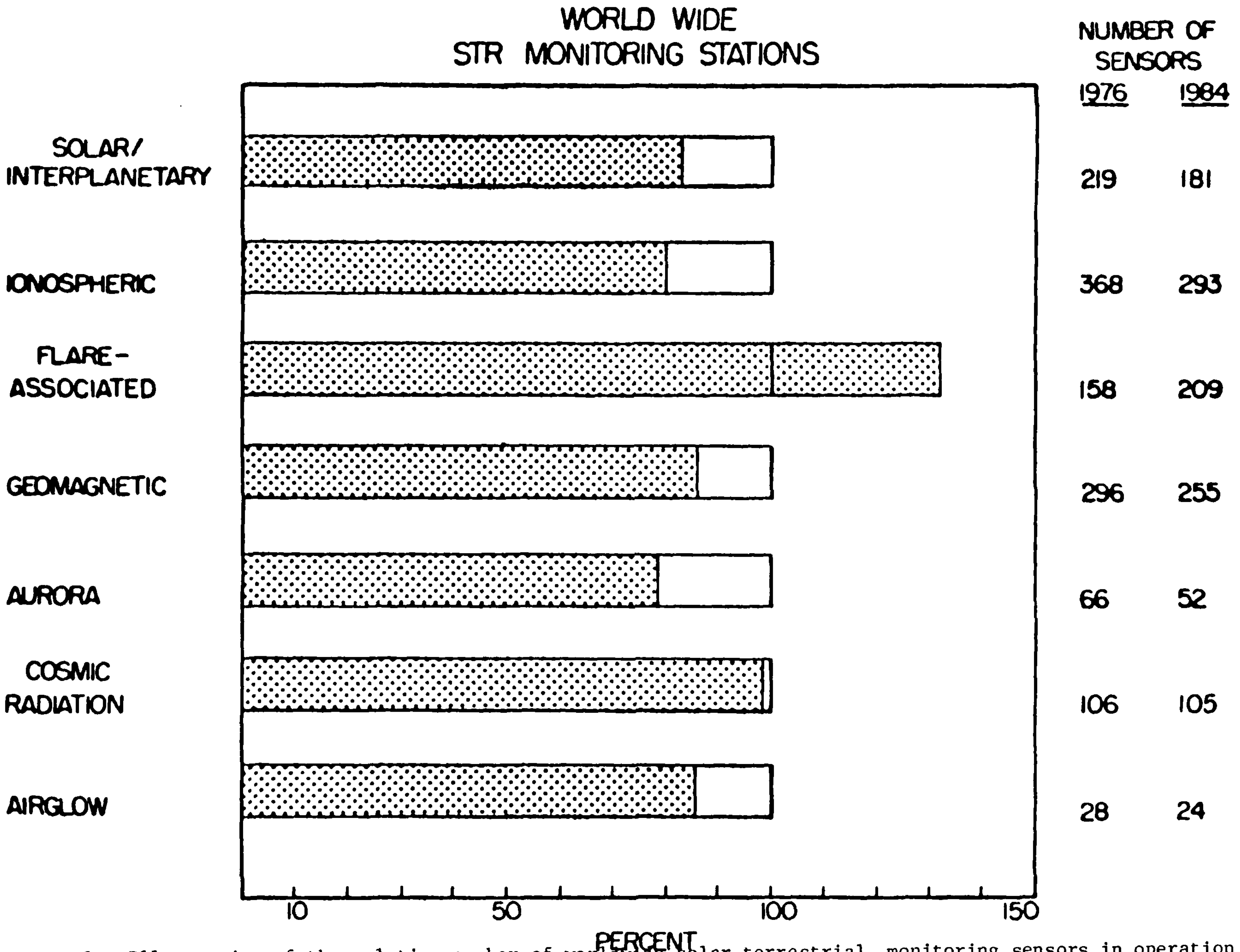

Figure 1. Illustration of the relative number of worldwide solar-terrestrial monitoring sensors in operation in 1976 compared with those in operation in 1984. The 100 percent level is assumed for 1976; the dotted section shows the percentage in operation in 1984. The actual number of sensors is given on the right side of the figure.

An inspection of Table I shows that the total number of solar-terrestrial physics stations has decreased on a worldwide basis in the past eight years. Decreases are evident in most disciplines; however, a significant increase occurred in the number of flare-associated event sensors where 41 and 40 newly opened OMEGA (U.S. Coast Guard) stations were added to the sudden ionospheric and solar proton (other types of measurements) subdisciplines.

TABLE I

CHANGES IN SOLAR-TERRESTRIAL RESEARCH MONITORING

1976 TO 1984

DISCIPLINE	PERCENT CHANGE (1976 to 1984)		
	U.S. SPONSORED SENSORS	NON-US SPONSORED SENSORS	WORLD-WIDE SENSORS
SOLAR & INTERPLANETARY PHENOMENA	-30	-13	-17
IONOSPHERIC PHENOMENA	-37	-17	-20
FLARE-ASSOCIATED EVENTS	+100	-16	+32
GEOMAGNETIC VARIATIONS	-31	-16	-14
AURORA	-31	-18	-21
COSMIC RAYS	-7	0	-1
AIRGLOW	0	-16	-14

PRELIMINARY

It is of interest to compare the changes in solar-terrestrial physics monitoring activities sponsored by the United States with the activities sponsored by foreign countries. Figure 2 graphically illustrates these changes. In compiling the statistics shown on the right side for Figure 2, all U.S.-sponsored activities, even those sponsored in a foreign country perhaps by a cooperative program, were included. In comparing Figures 1 and 2 it is evident that for most disciplines the U.S.-sponsored activities have decreased more than those conducted by other foreign countries. (See also Figure 3.)

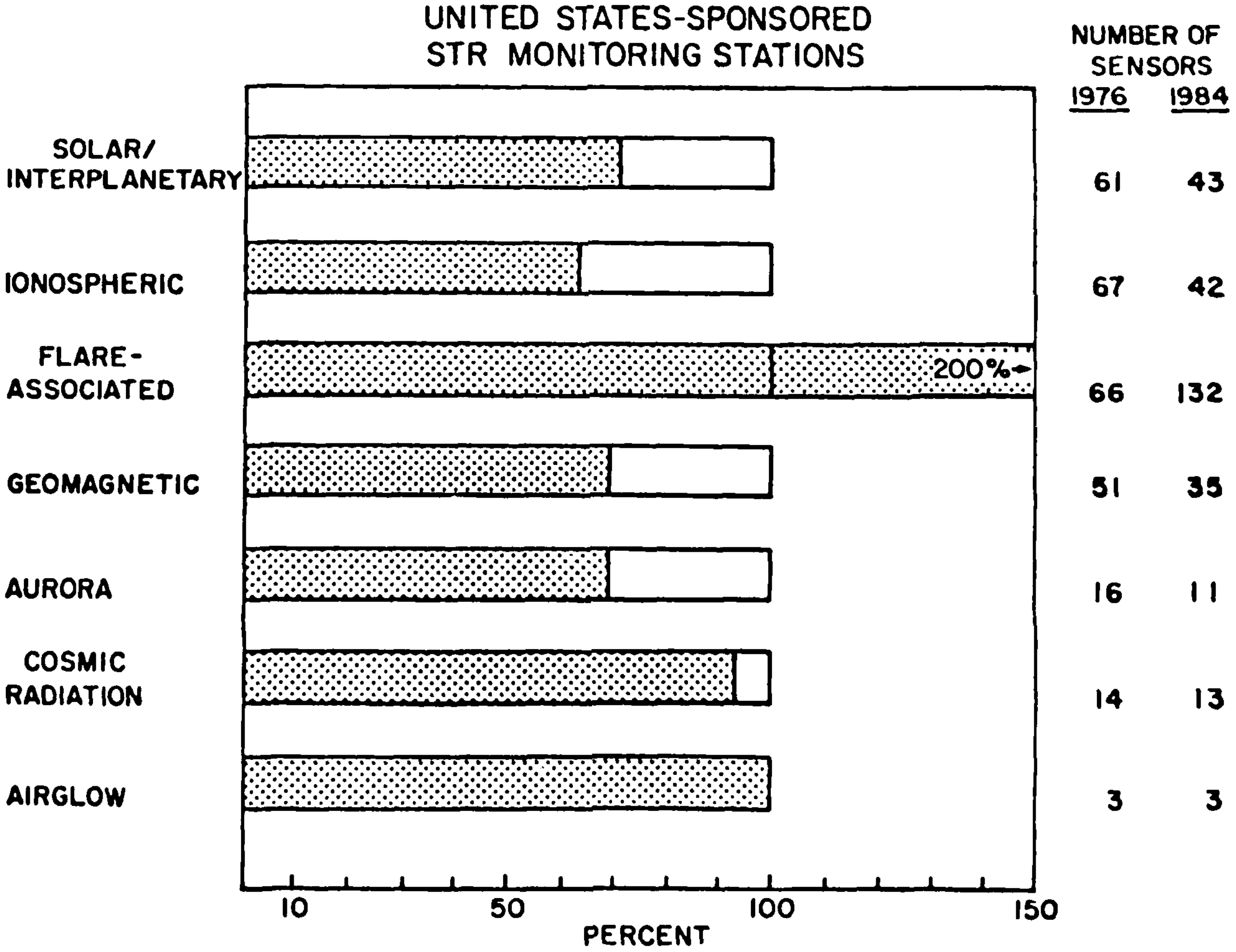

Figure 2. Illustration of the relative number of U.S.-sponsored solar-terrestrial monitoring sensors in operation in 1976 compared with those in operation in 1984. The 100 percent level is assumed for 1976; the dotted section shows the percentage in operation in 1984. The actual number of sensors is given on the right side of the figure.

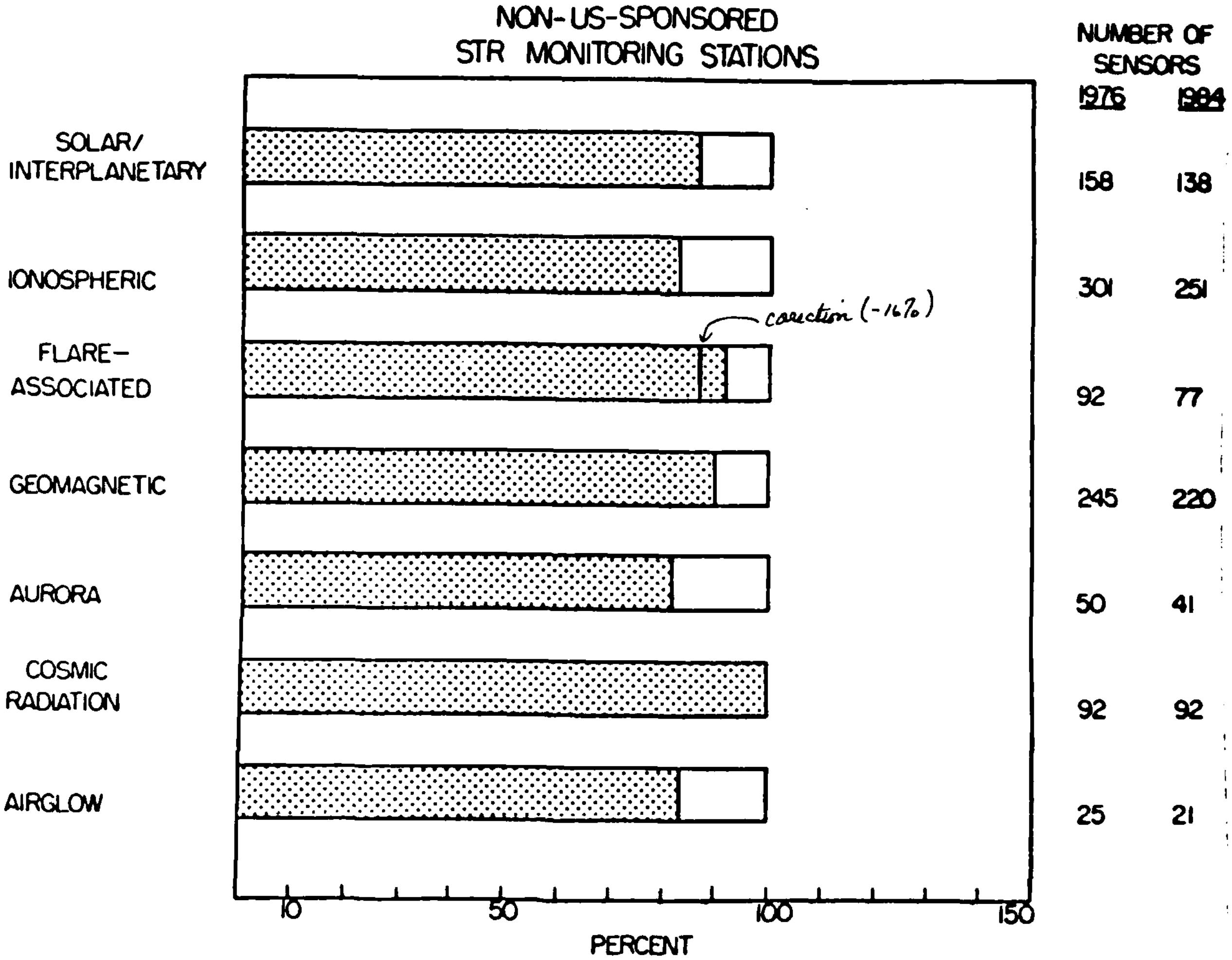

Figure 3. Illustration of the relative number of non-U.S.-sponsored solar-terrestrial monitoring sensors in operation in 1976 compared with those in operation in 1984. The 100 percent level is assumed for 1976; the dotted section shows the percentage in operation in 1984. The actual number of sensors is given on the right side of the figure.

Care should be noted in using the data in this paper without consulting the more detailed tables contained in the second edition of the MONSEE directory. In some cases the termination of a specific sensor or sensors may result from the availability of a more sophisticated monitoring technique not readily available in 1976. An excellent example of this is the auroral measurements now available via satellite. Nevertheless, it appears clear that in most disciplines the worldwide network of synoptic solar-terrestrial measurements has diminished in the past seven years.

MEASUREMENT OF CORONAL MAGNETIC FIELDS USING MICROWAVE SPECTROSCOPY

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Abstract

One of the critical quantities needed for prediction of solar flares is knowledge of the free energy associated with magnetic fields in the corona. This paper discusses an observational technique, microwave spectroscopy, by which the distribution of magnetic fields in the corona can be observed directly.

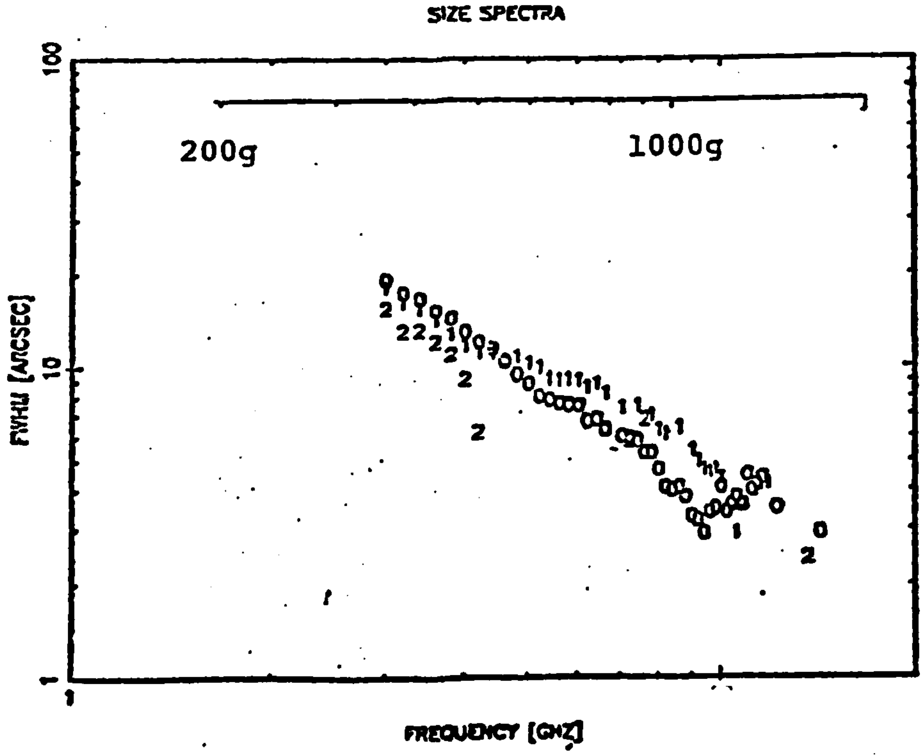
In the quiet sun, the solar corona is optically thin at microwave frequencies. In the presence of strong magnetic fields, however, gyroresonance opacity renders the corona optically thick at frequencies that are low multiples of the local gyrofrequency. Thus, coronal brightness temperatures are generated in coronal "shells" corresponding to the appropriate isogauss surfaces. This picture is confirmed by VLA images of active regions that often show microwave sources with 10**6 K brightness temperatures near sunspots.

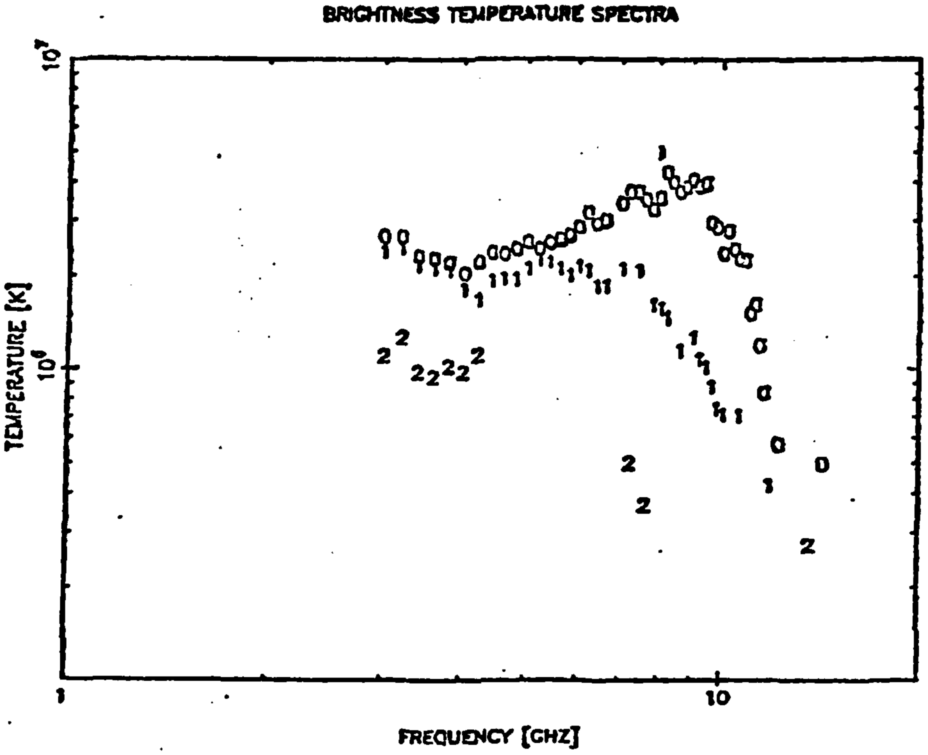
High spatial resolution microwave spectroscopy has the ability to measure the location and size of these isogauss shells as a function of frequency (viz., as a function of field). The technique is illustrated with data acquired by the three-element frequency-agile interferometer of the Owens Valley Radio Observatory. This instrument can observe in both right- and left-circular polarization at up to 86 frequencies between 1 and 18 GHz. The source diameter at each frequency is measured by noting the decrease in signal amplitude with increasing antenna separation. The average brightness temperature at each frequency then is obtained from the

ratio of amplitude to source area. The figure shows results obtained for an isolated sunspot.

It is worth noting that microwave spectroscopy responds to magnetic fields in the lower corona, as distinct from optical techniques that measure magnetic flux in the photosphere. Diameter measurements correspond to the base of the corona. The data are inherently well calibrated in gauss while absolute locations are measured interferometrically to arsecond accuracy. Measurements require only a few seconds, and in the near future some results are expected to be available in real time.

Disadvantages of the technique include potential harmonic ambiguities under some circumstances, a weakness that can be partially overcome by numerical modeling of the microwave emission. More serious is the lack of morphological detail that can be achieved with present hardware. To characterize the development of coronal fields in complex active regions (of most interest for flare prediction), more antennas need to be added to the interferometer to provide measurements at additional antenna spacings.





The diameter and average brightness temperature are shown as a function of frequency for a decaying, isolated sunspot observed over three successive days (represented by 0, 1, and 2). Note that coronal temperatures are observed up to a maximum frequency corresponding to the strongest magnetic field in the corona. The decay in this maximum field on successive days is quite apparent. Below this frequency, the increase in source size represents the larger coronal area covered by weaker fields. A scale of magnetic field strength (assuming emission at the third gyroresonant harmonic) is given at the top.

CORONAL HOLES AND CORONAL MASS EJECTIONS AS FORECASTERS OF TERRESTRIAL DISTURBANCES

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Abstract

I am reporting specifically on work being conducted in the Solar-Terrestrial Relations Branch, principally under the direction of Neil Sheeley and Don Michels. We have a very broad program at NRL that addresses research issues in this area with the ultimate goal of providing qualitative advances in both near-real-time assessment of conditions in the upper atmosphere and developing better forecasting tools.

From the perspective of forecasting conditions in the ionosphere, the occurrence of aurorae, and the level of geomagnetic activity, solar flares represent only one of a number of transient solar phenomena that must be considered. It is well established that coronal holes (CH) and coronal mass ejections (CME) are responsible for major perturbations in the vicinity of the Earth. In contrast with flares, where the efflux travels at the velocity of light and reaches us simultaneously with the signal that the flare has occurred, for CHs and CMEs the ejecta are shock waves and plasmas traveling ~ 1000 km/sec (although on occasion relativistic particles accompany CMEs). Thus, the arrival time at the Earth can be several days following the appearance of the event on the surface of the sun, and predicting their occurrence is not the issue it is for solar flares.

Figure 1 (Sheeley, Harvey, and Feldman 1976) provides a useful summary of both the potential for forecasting coronal holes and their geophysical effect. Three Bartel's diagrams are shown for the period 1973-1975. The left panel displays the occurrence of a coronal hole on the sun's central meridian; the middle panel, the solar wind speed; and the right panel, the C9 index of magnetic activity. The basis for the correlation is well understood, at least qualitatively. The coronal holes are regions of the sun where the magnetic field lines are open, thus allowing plasma to escape at high bulk velocity compared to elsewhere on the sun, where the dominant field morphology is in the form of loops. This plasma remains a permanent feature of the solar wind comprising the high-speed streams. These streams induce geomagnetic disturbances when they sweep across the magnetosphere. The second significant point is that coronal holes recur from rotation to rotation at about the same longitude; in fact, the persistence may continue for years. This fact is not so well understood.

The coronal mass ejections have their origin in solar prominences that spontaneously erupt from the surface. Occasionally, they originate with a solar flare. To date they have been observed only with coronagraphs. The accompanying shock wave will often achieve a velocity of ~ 100 km/sec and reach the Earth in two to three days. However, the effect is confined to a cone that may not strike the Earth; thus, only a fraction of the observed CMEs result in terrestrial disturbances. Figure 2 shows an unusually large event for which a broad data set was obtained (Sheeley *et al*. 1983). The CME itself was seen near the sun by the NRL coronagraph on P78-1, the advancing shock wave was observed by its radio emission as recorded by the ISEE spacecraft, precipitating particles were seen by the Dynamic Explorer, and finally a major aurora was observed unusually far south in Sudbury, Massachusetts.

In summary, it seems likely that coronal holes can be utilized as a forecast tool at the present time. They can be observed from the ground and the geomagnetic effects reasonably forecast. The potential utility of coronal mass ejections is very high; however, a new observational technique must be developed to allow their detection against the disc of the sun. This will most likely require a space instrument. Also, there may be a high degree of variability in the actual geomagnetic effect.

References

Sheeley, N. R., Jr., Harvey, J. W., and Feldman, W. C. 1976, Solar Physics, 49, 271.

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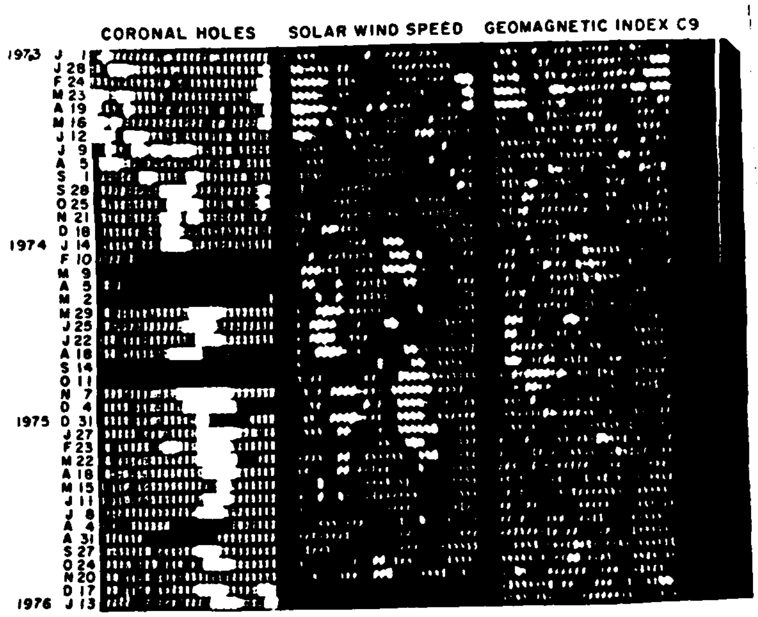

Figure 1. Bartel's diagrams showing, from left to right, the presence of coronal holes at the sun's central meridian, the solar wind speed, and the C9 magnetic activity index.

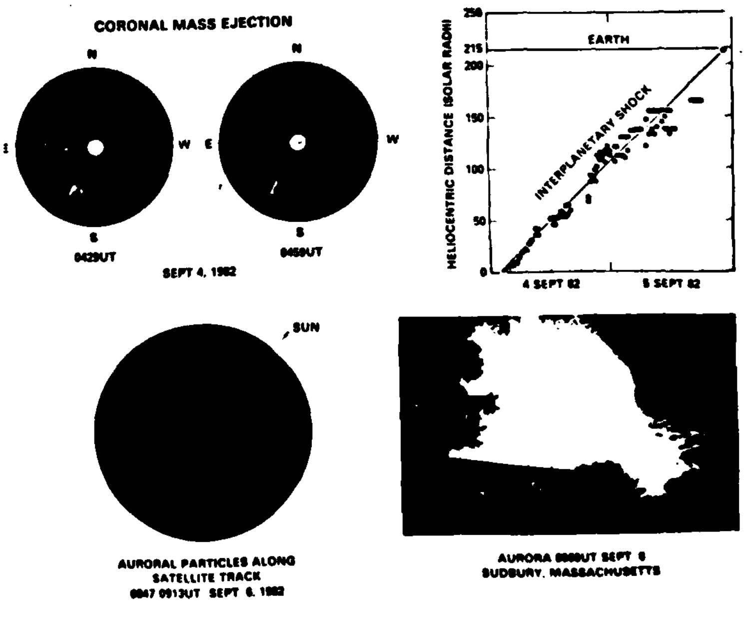

Figure 2. Observations of the 4, 5 September 1982 heliospheric disturbance. Auroral photograph taken by Dennis di Cicco of Sky and Telescope.

FUTURE POSSIBILITIES FOR FLARE PREDICTION

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Abstract

One possibility is that it would prove possible to calculate the coronal magnetic field structure, including force-free fields and current sheets, based on measurements of the vector magnetic field at the photosphere, or based on a combination of the line-of-sight magnetic field at the photosphere plus evidence of the magnetic connectivity at the chromospheric level.

Another possibility is that it would prove possible to calculate the evolution of the magnetic field in an active region, working with a combination of flux-emergence data and/or data concerning the line-of-sight magnetic field and the horizontal velocity field of the photosphere. It may prove possible to determine the horizontal velocity field by means of a correlation analysis of a sequence of white-light "photographs" or magnetograph maps.

The prediction of solar flares would be facilitated if we could determine the magnetic field structure and topology typical of active regions. This would involve determining the magnetic field structures typical of filaments and of emerging-flux regions. It may also prove possible to obtain valuable information concerning the coronal magnetic field structure from radio observations made either with the VLA or with interferometers.

Improved ability to predict solar flares might also result from improved understanding of the sub-photospheric processes that give rise to centers of activity, filaments, sunspots, etc. We may gain additional

insight into these processes by studying the well-known phenomenon of "homologous flares," and the recently discovered periodicity of about 160 days in flare sequences and active-region appearances.

There may also be scope for improved statistical analysis, especially if such analysis could be combined with the acquisition of new forms of physically significant data such as the vector magnetic field or the horizontal velocity field, and especially if the analysis could be related to a firm physical understanding of the flare process.

In attempting to improve flare prediction, it may be crucial to classify flares into types. This classification would probably involve a combination of data analysis and theoretical modeling. If such a classification can be made, we may find that different processes, based on different combinations of data, are required for the prediction of different types of solar flares.

FUTURE DIRECTIONS IN GROUND-BASED PREDICTIONS

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Abstract

Solar mapping from all available solar images will be performed soon from digital images received from several observatories and possibly including an X-ray imager in the 1990s. Synoptic charts will combine these data so that active regions, filaments, and coronal holes are viewed in context with large-scale solar magnetic fields. High-speed color graphics processing will enable motion studies of these charts. We expect to monitor the patterns of global solar circulation, including areas of anomalous shear and convergence. Such areas are tentatively identified as sites of strong episodes of flux emergence as well as sites where existing flux is distorted from potential form. We expect to relate active-region evolution to the large-scale dynamics.

Experimentation with artificial-intelligence systems (so-called "expert systems") may develop unforeseen abilities to assess the rich "textures" of solar activity that play a role in the subjective, but skillful, aspects of solar-flare prediction.

A more sophisticated background of statistics and case histories of active regions will be accessed routinely by larger and faster database-management computers.

STANFORD UNIVERSITY WORKSHOP ON SOLAR FLARE PREDICTION

February 28-March 1, 1985

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