1991SoPh..131..149Z

BEARALERTS: A SUCCESSFUL FLARE PREDICTION SYSTEM

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(Received 12 February, 1990; in revised form 26 July, 1990)

Abstract. We describe our BEARALERT program of predicting solar flares or rapid development of activity in certain sunspot groups. The purpose of the program is to test our understanding of the flare process by making public predictions via electronic mail. Neither the exact timing of the flare nor the possibility of emergence of new active regions can be predicted. But high-resolution observations of the magnetic configuration, Hα brightness and structure and other properties of a region enabled us to announce the onset of 15 of 23 major active regions over a two-year period, and 15 of 32 BEARALERTS were followed by this activity. We used high-resolution real-time data available at the Big Bear Solar Observatory (BBSO). The criteria for prediction are given and discussed, along with those for filament eruption.

The success fo the BEARALERT is evaluated by counting the M- and X-class flares in six days following the alert and comparing these results with those of a number of other predictive schemes. We find the single regions chosen had about 30% more flares than the whole disk on random days, or several times more than individual regions chosen at random. There was a gain of 1.5 to 2.0 times in flare frequency compared to regions selected by spot size or complexity. We also find an improvement of 20–40% over large or complex regions that have had some flares already. The ratio of improvement has increased with time as we gained experience. In the 24-hr period following each alert, one or more M-class or greater flares occurred 72% of the time.

We also checked the possibility of prediction by the 152-day interval which some workers have claimed, but found those results slightly worse than random and considerably inferior to the BEARALERTS. All of the particularly active regions that were missed either occurred during bad weather at BBSO or were missed because we only issued alerts for one region at a time.

1. Introduction

Many solar astronomers who have not regularly observed the Sun believe that it is not possible to predict solar flares. They are no doubt influenced by the lack of success of previous prediction efforts which had the science and equipment of yesterday. In fact, modern high-resolution data coupled with trained scientific staff make possible considerable success in flare prediction.

Because the high-resolution telescopes at the Big Bear Solar Observatory (BBSO) only image a limited fraction of the Sun, and because we have a great interest in solar flares, we have been required to select the active regions where flares were most likely to occur, and change our programs when we felt there was a high likelihood of flares. The same selectivity was required to direct the dishes of our interferometer at the Owens Valley Radio Observatory (OVRO), which also have limited field. This has been generally successful in the past, and has become more successful since real-time high-resolution magnetograms and transverse field measurements became available. Of course a number of direct studies of the evolution of active regions have added to our appreciation of the factors leading to flares.

To demonstrate that this could be done, to force ourselves to undergo a real test, and to aid those colleagues actively observing flare phenomena, in December 1987 we began

Solar Physics **131:** 149–164, 1991.

to issue BEARALERT messages via electronic mail. This way we must take a position and the recipients can judge for themselves the utility and accuracy of the predictions. We have predicted both flares and filament eruptions. However, we have only issued predictions when we felt the likelihood of flares was high. We take account of this in our analysis.

A person examining a typical full-disk solar image, even quite a good one, has little guidance in predicting the further evolution of activity. To be sure, the presence of a great active region will immediately presage flares, and a Sun devoid of sunspots will be quiet. If one follows the full-disk image carefully, one will occasionally find smaller regions that have produced many flares, and these may be expected to continue producing them; indeed persistence is the principal technique used by most flare predictors. But any more successful attack on the problem requires that the active regions on the Sun be examined in some detail to identify the configurations that we know to be rich in flares. Flare activity develops with flux emergence on a scale too small to be distinguished in the usual full-disk patrol. At BBSO, where we have a rather good full-disk image, the magnetic structure of the region cannot be understood without use of a more powerful telescope with limited field. For example, emerging flux is usually recognizable by the presence of arch filaments (AFS). Confirming the presence of AFS requires scanning the Hα filter to see the blue-shifted arch tops and red-shifted feet.

The problems of flare prediction have been summarized by Sawyer, Warwick, and Dennett (1986). They point out that the prediction ‘no flare will occur’ is right 88% of the time, but essentially useless. For this reason the BEARALERTS are presently only issued at the prospect of particularly active regions or sizable flares. We could also issue daily forecasts, but we assume that people will understand that if there is no BEARALERT, no important activity is to be expected. When BBSO is connected to the SPAN net we will consider more frequent alerts.

Persistence is an important prediction too, but has little physical significance other than to tell us that the same conditions prevail; it only provides short-term prediction and does not predict changes. As in weather prediction, we do not need to identify obvious factors, but need to predict changes in activity level. Another proven flare precursor, filament activation, is quite significant physically, but precedes the flare by too short an interval for anything other than very short-term prediction. Therefore, while we use persistence, our emphasis is on the physical characteristics that lead to the first flare.

In the present paper we list our criteria for issuance of a BEARALERT and evaluate our success. We do not claim to have invented them, although a few originated at BBSO; we simply communicate what we use.

2. Criteria for BEARALERTS

Künzel (1960) showed that sunspots with opposite polarity umbrae in the same penumbra, which he classified as δ groups, accounted for many more flares than other groups. This was the first step forward beyond the simple notion of big or complex spots as the source of flares. Another important step was the identification of *structures magnetiques evolutif* by Martres *et al.* (1968), which were no more than emerging flux regions (EFR) coming up in existing regions. The significance of sheared fields, with the lines of force parallel to the neutral line, was first pointed out by Zirin and Tanaka (1973) and the experience gained in flare observations at BBSO was elaborated by Tanaka (1976). The Marshall Space Flight Center operates a vector magnetograph which gives further evidence of the significance of sheared fields (Hagyard *et al.*, 1982, 1984). Moore, Hagyard, and Davis (1987) concluded that an angle of 15° or less to the neutral line produced many flares. Our various studies of solar active regions over the years have provided additional input.

In a study of δ spots and high activity, Zirin and Liggett (1987) found that the δ configuration was necessary, but not always sufficient for high flare activity. They gave a set of characteristics of active regions where large flares had been observed, which form the basis of our BEARALERT criteria. To search for these, we have available in the BBSO dome real-time magnetograms, Hα, continuum and D3 images of high quality. We also occasionally use the radio intensity measured at OVRO. The following criteria are presently used:

(1) The presence of elongated umbrae, especially in pairs of opposite polarity. This is valid even if the umbrae are not part of a δ configuration.

(2) Large 'island delta' sunspots as defined by Zirin and Liggett (1987).

(3) High magnetic shear and kinks as evidenced by steep magnetic gradients and especially penumbral fibrils parallel to a neutral line. Quantitatively, the field must change sign within 2 arc sec of an inversion line at least 10 arc sec long; there must be no sensible decrease in the fields as the inversion line is approached. Penumbral fibrils must be aligned within 15 deg of the inversion line (Moore, Hagyard, and Davis, 1987). Transverse magnetograms must show a strong signal parallel to the neutral line.

(4) A δ configuration, with bright Hα plage obscuring sunspot umbrae or running along the neutral line. (All alerts require bright Hα or a rising filament.)

(5) An emerging *p*-spot which will move or is moving into an existing opposite polarity sunspot, or rapid motion of a sunspot away from the δ configuration.

(6) A filament curled around a sunspot (within 10 000 km) or separating bright plages with no channel or intermediate region.

(7) Intense surging or flares at the E limb. On the disk one may see, in a replay of time-lapse video, continuous eruption of Hα loops.

(8) The magnitude of the flares to be expected depends on the size of the sunspots involved.

The logical significance of the various criteria is as follows:

(1) Elongated umbrae only occur in sheared fields with motion along the long axis of the umbra. There are no published observations of their vector field configuration, but they may be associated with very strong horizontal fields instead of the vertical fields characteristic of normal umbrae*.

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* Note added in ms: in a paper mailed to us just before his death, K. Tanaka presents spectroscopic observations made in July 1974 of just such elongated umbrae, showing a completely transverse (i.e., horizontal) field.

(2) The δ configuration involves two umbrae of opposite polarity inside the same penumbra:; a potential field solution for poles of zero separation is not possible, and such fields are normally connected by sheared field lines. Energy release can occur as the opposite polarity spots draw closer (in black hole fashion), or, more rarely, when one of the spots moves out of the δ configuration. The latter is a process we do not understand at all (Zirin and Liggett, 1988). But we find that even the δ-spots are not flare-productive unless they are bright in Hα.

(3) Sheared magnetic configurations can make a transition to lower energy states via the flare process.

(4) One often observes continuous bright Hα emission (sometimes accompanied by enhanced soft X-ray emission) from a region, so protracted that it is clearly not a flare. The brightness may be twice that of the chromosphere, much more than normal plage. In our experience this occurs only when magnetic reconnection is taking place as the result of flux emergence. Furthermore, when the bright Hα covers an umbra, material must be suspended above the umbra. There must be horizontal field there, or the material would fall down; this means there is a sharp turn in the normally vertical field, which may only exist if strong currents are present. Bright Hα indicates higher densities and temperatures.

(5) These are the main occasion upon which sunspots move, and if the moving spot is connected magnetically to a stationary one of opposite polarity, flux lines will be stretched and sheared, storing up energy for flares.

(6) As in (4), such a configuration requires a sharp turn in the field lines, hence, a curl and a current.

(7) Obvious.

(8) Big flares require substantial magnetic energy.

While the great island-δ regions are most spectacular, the most common regions of high activity are δ configurations with two tightly connected spots of opposite polarity and extremely bright Hα emission in the narrow channel between them, or a rapidly growing EFR alongside a large umbra. A good example is given in Figure 1, which shows the region BBSO No. 1797/NOAA No. 5747 on October 17. A BEARALERT was issued that afternoon, followed by a substantial number of energetic flares (see Table I). Although the activity potential of this region is evident from the Hα photo alone, the strength of the transverse field was also used as a reason for the BEARALERT. We see in Figure 1 two large umbrae in a δ configuration with bright Hα on the neutral line. We know from experience that this configuration has high potential for flares; the bright Hα emission is a sign that magnetic flux was emerging on the neutral line, and in fact small new umbrae formed there during the day. In addition, there was rapid spot motion parallel to this line, increasing the shear. Instead of the normal E–W orientation, the magnetic axis was tilted at a high angle to the solar equator and the neutral line runs EW. This, too is an indicator of high activity. While published discussion applies to reversed polarity (Smith and Howard, 1968; Zirin, 1970), regions with a substantial tilt (60° or more) generally are more active, and very few regions without a tilt to the normal orientation are active. An alert might well have been issued the previous day, when the

Fig. 1. An Hα frame of BBSO No. 1797 on October 17, 1989 showing strong Hα emission along the neutral line between the spots of the δ configuration.

brightening was considerably less, but detectable. Time-lapse films show continuous motion and brightness change in fibrils at the neutral line. This another characteristic of flare-producing regions that may be detected with stop-motion video recorders. We emphasize that the information listed above must be obtained with adequate resolution, at least 2 arc sec. There are few telescopes and no full-disk systems that offer this.

If there is real-time information from OVRO that a region is bright in radio, we use that evidence also, although a statistical relation has not been established.

Most of the criteria are properties of high active regions which may last no longer than a day or two; if they obtain, one can expect a flare shortly. Only the fifth gives a longer term prediction. The emergence of new flux in a critical area will often lead to development of high shear in a few days. This was the case with the three X-class flares of 24 June, 1988. New flux was seen emerging on 20 June and a BEARALERT was issued. Two days later a δ spot had formed and a second alert was issued; on 24 June elongated umbrae were seen; the flares occurred before the third alert could be sent. This kind of prediction is only possible with high-resolution continuous observation.

As noted by Zirin and Liggett large flares (with the exception of spotless flares),

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TABLE I

Cumulative flares in BEARALERT regions excluding March 1989

Days after alert		Cumulative No. of flares, M class = 1, X = 10					
Region	Date	1	2	3	4	5	6
1039/4912	26 Dec., 1987	2	2	2	2	2	2
1043/4921	8 Jan., 1988	0	0	0	0	0	0
1081/4964	11 Mar., 1988	0	0	0	4	11	13
1108/4990	15 Apr., 1988	1	3	4	4	5	6
1142/5027	23 May, 1988	0	0	1	3	4	5
1156/5047	20 June, 1988	0	0	11	32	44	45
1167/5060	26 June, 1988	1	4	8	10	11	11
1169/5062	3 July 1988	0	0	0	2	3	3
1174/5073	12 July 1988	1	1	1	1	1	1
1183/5084	25 July 1988	1	1	1	1	1	1
1221/5127	26 Aug., 1988	0	0	0	0	0	0
1274/5171	3 Oct., 1988	11	12	13	13	13	13
1302/5200	17 Oct. 1988	1	1	3	3	3	3
1338/5229	13 Nov., 1988	4	6	10	12	12	12
1378/5278	17 Dec., 1988	1	1	1	1	1	1
1403/5312	10 Jan., 1989	14	15	29	41	55	60
1446/5368	18 Feb., 1989	0	1	4	7	8	8
1483/5409	21 Mar., 1989	1	2	12	13	14	14
1532/5464	4 May, 1989	4	4	5	6	6	6
1564/5497	23 May, 1989	1	2	2	3	4	6
1592/5521	4 June, 1989	4	15	19	22	24	25
1603/5533	10 June, 1989	3	5	6	7	8	18
1637/5569	26 June, 1989	0	1	1	3	3	3
1642/5575	3 July, 1989	1	2	2	2	2	2
1691/5629	14 Aug., 1989	12	28	39	39	39	39
1710/5643	14 Aug., 1989	1	1	1	1	1	1
1738/5669	29 Aug., 1989	6	8	20	25	37	51
1757/5698	20 Sept., 1989	0	3	3	3	4	5
1797/5747	18 Oct., 1989	3	14	17	20	32	44
1834/5783	9 Nov., 1989	6	7	17	17	19	21
1839/5786	15 Nov., 1989	10	10	10	10	10	10
1846/5793	18 Nov., 1989	12	15	36	38	38	38
Active regions predictors:							
BEARALERTS:							
Flares after BEARALERTS		3.16	5.13	8.69	10.78	12.97	14.59
Same, after 1 Nov., 1988		4.37	7.37	12.32	14.21	16.68	19.16
Big or complex spots:							
Big spots (> 700)		2.27	3.69	5.39	6.72	8.25	9.03
Complex spots		1.98	3.09	4.80	5.52	6.52	7.21
Ratio of BEARALERTS/complex		1.59	1.66	1.81	1.95	1.99	2.02
Persistence:							
Regions with $N = 3$		2.63	4.98	6.57	8.19	9.98	12.20
Big spots after $N = 1$		2.00	5.36	6.82	8.04	9.25	11.00
Full disk predictors:							
Average 152-day		2.33	4.94	6.70	8.00	9.55	11.58
Random		2.50	4.64	6.33	8.53	10.42	11.94

generally occur in two sets of circumstances. First, there may appear on the Sun a great island-shaped δ region. Second, we may see the eruption of new flux inside, or alongside the active region. The first is easy to pick out, the second can be more difficult. In most cases our predictions have to do with the latter.

While direct measurement of strong transverse fields is likely an important flare indicator, our transverse field system at BBSO has only recently come into general use and has affected only a few BEARALERTS. We think it is important, but cannot give reliable evidence on its use for prediction. Furthermore, our experience is that shear without bright Hα is not a good predictor. This was illustrated by the 24 April, 1984 event, which occurred in a double δ configuration. Hagyard (1990) mentions that the great flare on that date occurred in the δ spot with less-sheared field; Zirin and Liggett (1987) point out that it occurred in the smaller δ spot with bright Hα. While great effort has been expended in the study of vector magnetograms, little has been invested in studying the sources of bright Hα, which may be more important, probably because it is a measure of the time derivative of field. Nonetheless we have the Hα already, and the on-line vector magnetograph will be a welcome addition.

While we have omitted the filament eruptions from Table I, we note with pride that three of the four filament eruption predictions were successful. While all filaments eventually erupt or disappear, in this case this happened quickly. Two erupted in the first day, and the third disappeared 3 days later. We have not tried to estimate the eruption rate of filaments chosen at random, but since all filaments erupt eventually, we require eruption within 3 days for a successful prediction. The criteria for predicting filament eruptions are:

(1) An EFR coming up under a filament.
(2) A filament at a height over 50000 km.
(3) A filament superposed on a bright plage.

On the disk the filament height is estimated by the projected displacement from the neutral line. Figure 2 shows an active region for which a BEARALERT was issued 25 July, 1988, because the EFR was growing into the active region. Filament eruption was predicted, and this occurred a few hours later.

3. Evaluation of BEARALERT Success

It is important to test if our criteria and methods are successful. This has been extensively done for the various official prediction services (Sawyer, Warwick, and Dennett, 1986; Neidig *et al.*, 1984, and others). These methods are mainly applicable to daily predictions, while we only issue BEARALERTS on the 6% or so of days when we feel the probability of a flare during the next five days is high. On the other 94%, we feel there is no great likelihood of flares, or it may have simply been cloudy at BBSO. As noted by the various authors, predicting no flares every day gives high statistical success level, but is useless. Similarly, most of the regions on the Sun are quite small and will not produce flares. So if we predict that no regions will have flares we may be 95% correct, but that, too is a useless prediction. Since we want to learn about flares, we must

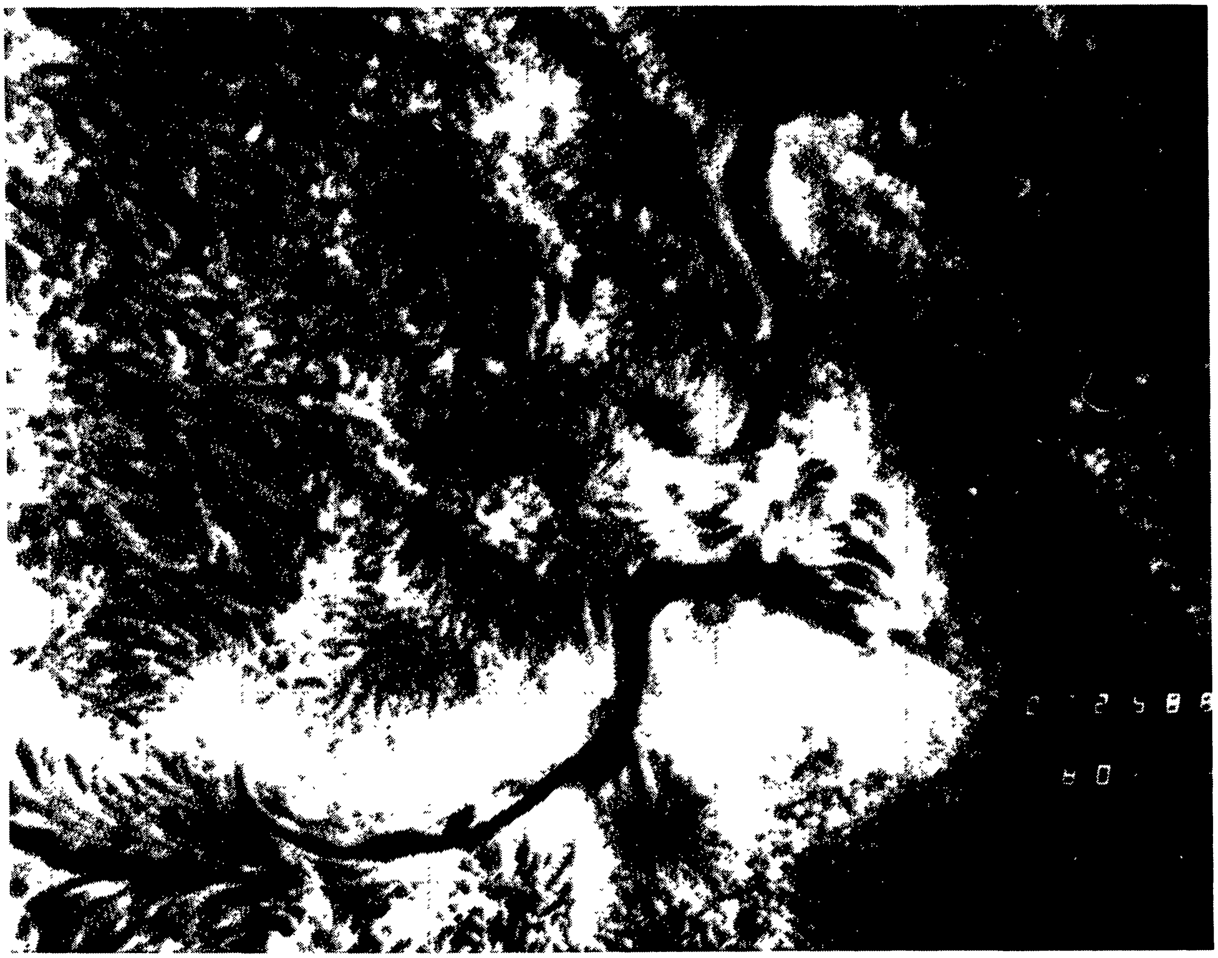

Fig. 2. Active region July 25, 1988, 18:40 UT. An EFR is expanding into the middle of the AR and two filaments are imperiled. One of the filaments erupts a few hours later.

compare with various techniques of prediction, and this is what we have done. Of course the most valuable alerts are those where traditional means gave little hint of activity.

We evaluated the success of BEARALERTS in a six-day period following the issuance of the alert. This is far from completely impartial; in some cases activity had surged during the night and flares had already occurred. Any sensible person would have predicted more flares. A more accurate measure might be to examine all BBSO films and determine what fraction of the flare events were picked up (such a study is tedious, but now in progress). Our forecasts are not issued for a definite period; they are supposed to be valid until the region rotates off the disk or a 'hibernation' message is sent out. But in fact no such messages were sent out, we usually were too busy. So we chose a 6-day period for evaluation. This really is arbitrary; in some cases the region remains quiet, then a surge of activity occurs a few days later.

Table I gives the cumulative flare data for 6-day periods following 32 BEARALERTS issued since the first one on 12 December, 1987. Since a few flares occurred while the BEARALERT message was being typed, we figure 'days' as 24-hr periods beginning when we first sat down to type the message. From the original 45 alerts we have excluded

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repeated BEARALERTS for the same region (i.e., the six days are reckoned from the first alert), alerts warning of filament eruption, a polar field alert, and the alert issued 6 March, 1989 after the X-15 flare at the east limb, which required no special skill. This activity could in retrospect have been predicted on the basis of observations 5 March, when a series of small flares and continuous surging coming from behind the east limb were recorded by our full-disk telescope. We have also excluded the 6–20 March period from all our control comparisons, because the number of flares is so great that it washes out the other regions. For each BEARALERT we compute an index N which is *the cumulative number of reported M-class events plus* 10 *times the number of X-class flares from the region*. The value of N is given for 6 days following. Thus the cumulative number 22 means 2 X- and 2 M-class flares, or 22 M-class flares, or 1 X-class flare and 12 M-class flares observed. These numbers were taken from the weekly NOAA Preliminary Reports.

The average of these is given in the first summary row; the second summary row gives data for BEARALERTS following 1 November, 1988. In two cases where the region rotated off the disk before six days were up, we simply assumed no more flares occurred, so our result is a lower bound. This did not obtain for the control samples. We regard a group with $N \geq 10$ as highly active, and ones with $N < 5$ as not very active.

If the BEARALERT program and our criteria are useful, our predictions have to be more successful than control samples that may be achieved without high-quality real-time data. We have, therefore, added at the bottom of Table I flare data for various alternative methods of selecting active regions.

Because the flare frequency was rising sharply at this time it was important to take the control sets for the same period and roughly the same number of cases for each; thus if there are 30 BEARALERTS, we take the 30 biggest, or most complex regions (for various reasons there are slight inequalities). First, we chose the 35 largest spots > 700 millionths of the disk, the value chosen to give a similar number of regions. The cumulative results following the appearance of such spots appear in the row marked 'Big spots > 700'. In the following row wwe see the values obtained for the 36 biggest and most complex spot groups we could find on sunspot drawings during this period. These were all classified $\beta\gamma$ or δ by the reporting services. In all cases we omitted the great March 1989 active region, which would distort the statistics.

We see that the frequency of flares for these regions is considerably less than for the BEARALERT regions. The ratio of cumulative results for the entire period is given in the next row. Thus the BEARALERT selection increases the number of flares per day by a factor 1.6 to 2.0. This is a minimum; if we exactly matched the areas of the two sets the increase would be greater. It is interesting that the 'Big spots' were somewhat more productive than complex spots; we expected the opposite. Possibly this is because, as Künzel showed, many of the groups commonly classified $\beta\gamma$ are in fact not complex enough to produce many flares.

Table I shows a secular increase in the success of BEARALERTS. For the 'spots' regions slected after 1 November, 1988 the ratio of flares in BEARALERT regions to 'Big spots' or 'complex spots' rose to from 1.8 to 2.0. We feel that, had we not begun the program of publishing our predictions, we would not have achieved this improvement. This improvement was not merely due to the increase in activity; the value of N for our control groups actually decreased in the second half. The point is that the probability of flares in a single important region does not increase as we go to maximum, but the total number of flares does because there are more active regions. Therefore, the full-disk data in the last two rows does increase with time, but the control samples do not.

The next two rows of Table I display the data for regions selected by persistence, which has been a mainstay of activity prediction. We chose regions in two ways: First we took key days starting on the day after any region had $N \geq 3$ (three M-class or one X-class) in 48-hour period and second, we chose that day after a spot > 700 had a single M- or X-class event. There were 41 of the former and 28 of the latter. Both of these were better predictors than the complex or big regions, but still inferior to the BEARALERTS overall. The post-October 1988 BEARALERT regions outperformed persistence of 1.7 times. We found the $N \geq 3$ regions only slightly more flare-productive after October 1988, and the big spots with $N = 1$, less productive. Thus a person with a simple white-light telescope and a modem to access the flare data banks can do fairly well at flare prediction, but only about 60% as well as a subscriber to the BEARALERTS. Further, this comparison is not quite fair, since every effort was made to issue BEARALERTS as early as possible in the development of the region, and sometimes a few days were required for the observed flux emergence to produce flares.

An additional problem with persistence prediction is that the first flare cannot be predicted. Further, while an alert can be issued after the first X-class flare, if one requires several smaller flares before triggering an alert, one must wait until more occur (usually one or two days), thereby losing some of the advantages of prediction. A prediction issued before the flares occur is obviously more valuable.

Finally, in the last two rows 'full-disk predictors', we compare control samples of 'astrological' and random predictions, techniques having no relation to known physics of solar activity (except the 11-yr cycle). In particular we investigated the utility of the supposed 153-day periodicity of flares (Bogart and Bai, 1985; Rieger *et al.*, 1984). Periods of 152 and 154 days have been found by various authors. Of course, the existence of statistically significant periodicities does not ensure predictive value, but it would obviously be useful to extend the predictive period to 152 days. Clearly such a system is hopeless for predicting the first flares of a cycle, since it only starts after they occur; but once the first activity has occurred, it might be useful.

To test the 152-day predictor we chose trigger periods when $N = 3$ (for the whole disk) was reached in 48 hr and counted the flares that occurred between 152 and 158 days after these regions achieved that value. Because $N = 3$ is reached for the whole Sun almost every day during peak activity, the next trigger was only chosen after 7 days. The choice of $N = 3$ was somewhat arbitrary but gave about 35 periods, comparable to the other samples. The result of this method of prediction is given in the penultimate row of Table I.

To test random predictions we chose 32 days from a random number table during the period since December 1987 and determined our cumulative index of M- and X-class flares over the entire Sun. These are given in the last row. While the cumulative flare index for these is almost as large as for the BEARALERTS, it should be recalled that this index perforce includes flares from the entire Sun. This was not a big effect in 1988, when there usually was only one active region on the Sun, but as activity picked-up there were many. This the results of these control groups should be divided by two or three for comparison with predictions for BEARALERTS or big or complex spots. On a per-region basis, there are considerably fewer events in the regions selected by either the 152-day or random predictors than either the BEARALERT or 'big spot' regions.

Note that the cumulative number of flares increases steadily, if not quite linearly with time after the alert. Some regions continue active, while others do not. Only in cases where the EFR structure is clearly visible can we predict the long-term evolution. The regions can change quite rapidly, with resurgence due to new flux eruption, or rapid simplification after large flares.

McIntosh (1989) has discussed the use of his sunspot classification in flare prediction, pointing out that most of the great flare-producing groups of the last few cycles fall into his class *Fkc*. These groups correspond generally to the 'island δ' classification suggested by Zirin and Liggett (1987), but the McIntosh class has no magnetic information. However the substantial latitude extent of the McIntosh *Fkc* groups is a characteristic of the 'island δ' spots, which are as wide as they are long. As Künzel (1960) showed, and our comparative data confirm, for classification by sunspot class only, it is only δ spots that show an excess of flares. δ spots may only be recognized with good magnetic or high-resolution data. Of course BEARALERT spots show an even greater frequency than δ spots, because δ spots without bright Hα do not produce many flares. McIntosh provides no data on the success of predictions made with his method.

The reader is probably curious about the comparison of our results with the forecasts issued by the Space Environment Lab (SEL) of NOAA. Comparison is difficult because the forecasts are issued in different ways: NOAA *must* issue a forecast every day, we only issue one when we are moderately certain a flare will occur. However, our alerts are infrequent enough that recipients expect something to happen; NOAA presently makes full-disk predictions in fairly non-comittal language ('M flares are possible') and succeeds if a flare occurs anywhere on the Sun. Thus quantitative comparison is difficult.

Neidig *et al.* (1984) synthesized the forecasts of M or X flares that would have been issued by NOAA in past cases. They found that 37% of the predictions of M or X flares to occur in regions were followed by such an event. Sawyer, Warwick, and Dennett (1986) Figure 6.2 gives 28%. Table I shows we succeed in having one or more M- or X-flares 72% of the time in the predicted region. The Neidig *et al.* data were compiled for 1977–1979, roughly the same stage of the cycle. However, the NOAA predictions are made for every kind of region, while the BEARALERTS are selected, so the comparison is really not definite.

More instructive is to compare the parameters used. As Sawyer, Warwick, and Dennett note, the criteria used by NOAA and by BBSO are not greatly different. The principal difference is in the weight given to bright Hα and the δ configuration. In addition we would normally give inverted polarity, Hα emission over the umbrae, or elongated umbrae, etc., sufficient weight to issue a BEARALERT. This is only possible when high-resolution data are available. We do not believe good forecasting is possible without such data.

4. Failures and Excuses

Besides picking the most active regions, we wanted to make sure that especially active regions were not missed. Although we did not strive at the beginning to predict all major active regions, there is no reason why we should not. We, therefore, checked to see if we had missed any region producing more than $N = 10$, i.e., 10 M- or 1 X-class flare in a six-day period. In the two years, we found eight such active regions that were not predicted by BEARALERTS. Four of these occurred in late-January and February 1989 during an interval of bad winter weather and a computer failure that prevented us from obtaining magnetograms. The other four occurred while we were involved with cooperative programs or observing other flare-productive BEARALERT regions; until now, we have only picked the most active region on the disk. Thus the BEARALERTS announced the onset of 15 of 23 highly active regions during this period. Therefore, we feel our techniques would have called all major activity in this period had the Sun been visible and that has been our target. Of course, there would have been additional false alarms as well.

We examined the cases where only very few or no flares occurred following the BEARALERTS. While a few could be ascribed to inexperienced observers, most were issued after both of the authors had examined the region. In most of the cases the Hα intensity was not great, and we may have been deceived by the high-contrast on our video monitors. In a few cases, we still would issue alerts, and we do not know why more flares did not occur. Note that the regions can change quickly and the flux emergence, which is the main driver, simply may stop.

Projection effects make predictions on regions near the limb quite difficult. Since most flare-producing situations require close proximity of certain elements, such as opposite fields, spots, etc., it is easy to underestimate the separation of features near the limb. On 28 July, 1989, for example, we saw an EFR coming up under a filament at E 79, and saw substantial blue shift in the filament. A BEARALERT was issued. Bu the filament did not erupt, and in fact we received a message from Dr V. Gaizauskas of Ottawa River Solar Observatory pointing out this all-too-obvious fact. As the region rotated on to the disk, we saw the problem: perspective had placed the EFR under the filament, while it was actually some distance removed. While active regions coming up under a filament invariably disrupt it, the effect of nearby-EFR eruption has not been established, and we presently cannot predict the future course of an erupting EFR.

The psychological aspects of prediction are important, and not obvious until one tries it. After all, while fifteen of the 32 regions exceeded $N = 10$ in six days, seventeen of the 32 regions did not, and one is tempted to avoid the embarrassment of failure by doing nothing. Since a proper BEARALERT should be issued before *any* flares appear in the region, the observer needs some confidence in himself to issue one. Some of the alerts have been issued later than necessary, but such delays have decreased steadily with growing experience. One possible improvement may come from issuance of daily forecasts, which force a commitment.

The reader will note that there are two distinct types of BEARALERTS. In some cases we see a region has become highly active and immediate activity is expected; in some cases the flares have occurred before we could get the alert out (this will be improved by pending connection of BBSO to the SPAN network). In other cases we see flux emerging and predict increased activity in several days. It is difficult to evaluate these predictions separately.

So far as longer-term prediction is concerned, about half the activity we see is connected with EFR emergence in existing regions, and can be predicted within our 6-day window. However, no prediction can be made until the flux emergence actually occurs. More important, we are entirely unable to make longer term predictions of the emergence of great groups such as that of March 1989, which probably produce the largest events. These groups amerge in most complex form, and can only be recognized after they appear. It is possible that there is a global pattern to these regions, such as active longitudes or the 152-day periodicity. We have referred to these as 'astrological' schemes, because they bear no relation to what is known of the physics of active regions. Our test of the 152-day period showed that pattern was not useful for prediction. However, the fact that we see global outbreaks of activity shows that there are global patterns, and objective assessment of longitudinal and other global patterns would be valuable.

While we succeeded in warning of all but eight of the most active regions in this period, there were 17 BEARALERT regions with $N < 10$, and 11 with $N < 5$. Although some might regard a region with 3 or 4 M-class flares as fairly active we should eliminate at least those 6 with $N \leq 1$. We hope this will come from studying further aspects of active region evolution to improve our understanding of the process. At present when an EFR appears, we have no idea if it will grow to large size or peter out. The Doppler patterns are just coming under study. And continuous transverse field monitoring will enable us to test the significance of that data.

Neidig (1989) has recently surveyed current flare prediction and statistics and points out that Poisson statistics limit the prediction improvement achievable. This is of course true, and the improvements we see in Table I, around 50%, are close to the limit he derives. However, if we are interested in region growth and the total number of flares over some days, we see that a significant gain is forthcoming. As long as this can be recognized, we are on the track of phenomena associated with flare production.

In the future, we plan to add new measurements to our prediction parameters. These will include radio brightness spectra, shear as measured by vector magnetograms, Doppler amplitude (Harvey and Harvey, 1980) and Hα dynamics. The latter is obtained by replay of stop-motion Hα videos, which give a measure of the tempo of Hα fluctuations.

5. Summary and Conclusions

We have given a list of parameters that we use in predicting high levels of solar activity. These differ from those in common use by reliance on Hα brightness, elongated spots, sheared penumbral fibrils, and other parameters. In addition more familiar tests are used, but to greater advantage due to Big Bear's wealth of real-time high-resolution data. The criteria are presented, mostly based on the work of Zirin and Liggett (1987).

We have compared the outcome of BEARALERT predictions with those made by other techniques and found the frequency of flares significantly exceed that obtained by other prediction methods. BEARALERTS chose regions that had between 15 to 50% more flares than the entire Sun on randomly chosen days, or 2–3 times as many as random active regions. BEARALERT regions had between 1.5 and 2.0 times as many flares as big, complex regions chosen from sunspot maps and spot groups of area > 700 millionths. BEARALERT regions also produced greater activity than large or complex groups that had already produced flares. All but eight of the most active regions in this two-year period were anticipated, usually before they had any substantial flares. The failures were due to poor winter weather, rather than prediction failures.

We also tested use of a 152-day periodicity scheme, finding it no better than random selection.

In the past year, the technique has improved considerably, the relative flare frequency after BEARALERTS rising to 1.8–2.0 times the control groups. This appears to have been due to experience and requiring that all BEARALERT regions be particularly bright in Hα. This indicates that while large or complex regions will always have some flares, the various factors used in the BEARALERT predictions are important to the flare process.

Three of four filament eruption predictions were successful.

We emphasize that these predictions can be made only with live, high-resolution images. On the other hand, it is clear that with two good stations manned by capable observers, almost complete success could be achieved in predicting sizable activity.

Acknowledgements

We acknowledge several valuable suggestions by the referee. This research has been supported by the NSF under ATM-8816007, by NASA under NGL 05 002 034, and by the ONR under N00014–89-J-1069.

Appendix

Sample BEARALERTS

9 BEARALERT 20 June 1988

REGION BB # 1156 AT S16E03 HELIOGRAPHIC OR 79″ E 277″ S GEOGRAPHIC SHOWS AN EFR COMING UP IN ITS MIDDLE. THE NEW DIPOLE HAS THE SAME POLARITY AS THE REGION AND WILL PROBA-

BLY MERGE IN WITHOUT TOO MUCH ACTION. BUT SOME MODERATE ACTIVITY MAY BE EXPECTED. CURRENTLY IT IS AT FLARE BRIGHTNESS IN H-ALPHA. HZ, WHM

#10 BEARALERT 22 June 1988

REGION #1156, FOR WHICH WE SENT OUT AN ALERT TWO DAYS AGO, NOW SHOWS PROBABILITY OF HIGH ACTIVITY. TWO LARGE NE DIPOLES HAVE EMERGED. THE LATEST OF WHICH HAS ITS TRAILING SPOT JUST BEHIND THE MAIN SPOT AND HAS FORMED A DELTA CONFIGURATION WITH IT. THERE IS OW A HIGH PROBABILITY OF LARGE FLARES. HZ

#11 Continued BEARALERT 24 June 1988

WE HAD A 2b FLARE AT 16:05 UT IN REGION 1156. COORDS ARE 15.4S. 49.8W (16:44/24 Jun). THE FLARE OCCURRED ACROSS THE ELONGATED UMBRAE TYPICAL OF THE SHEAR IN SUCH EFR-DRIVEN DELTA CONFIGURATIONS. WE SHOULD EXPECT A CONTINUED HIGH LEVEL OF ACTIVITY AS IT CROSSES THE LIMB. HZ

#16 BEARALERT 25 July 1988

THE ACTIVITY PREDICTED IN THE SAC PEAK ALERT IS SHOWING UP ON THE DISK WITH TWO RAPIDLY GROWING EFR'S IN BBSO#1183. THESE SHOULD DISRUPT THE MAIN FILAMENT SHORTLY. ALSO, MOST OF THE UMBRA ARE COVERED WITH H-ALPHA EMISSION. WE EXPECT INTENSE ACTIVITY IN THE NEXT FEW DAYS. POSITION AT 1412 UT 7/25: 631E, 530S GEO, (S23E54) WM, HZ

NOTE: The main filament erupted a few hours after the alert was issued. (see Fig. 2)

#42 BEARALERT 17 October 1989

THE REGION BB#1797 (28.4 S, 29.4 E @23:30 UT) IS NOW CAPABLE OF PRODUCING LARGE FLARES. IT SHOWS A DELTA CONFIGURATION WITH STEEP MAGNETIC GRADIENTS AND BRIGHT H-ALPHA PLAGE ALONG THE NEUTRAL LINE THROUGH THE PENUMBRA. WM, JV

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