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Verification of Short-Term Predictions of Solar Soft X-ray Bursts for the Maximum Phase (2000–2001) of Solar Cycle 23 *

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Abstract We present a verification of the short-term predictions of solar X-ray bursts for the maximum phase (2000–2001) of Solar Cycle 23, issued by two prediction centers. The results are that the rate of correct predictions is about equal for RWC-China and WWA; the rate of too high predictions is greater for RWC-China than for WWA, while the rate of too low predictions is smaller for RWC-China than for WWA.

Key words: Sun: X-ray bursts — Sun: Short-term prediction

1 INTRODUCTION

The International Space Environment Service (ISES) is a permanent service of the Federations of Astronomical and Geophysical Data Analysis Services (FAGS) under the auspices of the International Union of Radio Science (URSI) in association with the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG). Three basic functions form the task of the ISES. First, the International URSIgram Service provides standardized rapid free exchange of space weather information and forecasts through its Regional Warning Centers (RWC). Second, ISES prepares the International Geophysical Calendar (IGC) each year. This calendar gives a list of 'World Days' during which scientists are encouraged to carry out their experiments. Third, the monthly Space Warning Bulletins summarize the status of satellites in earth orbit and in the interplanetary medium.

At present, there are 11 Regional Warning Centers scattered around the globe. These centers are located in China (Beijing) , USA (Boulder), Russia (Moscow), India (New Delhi), Canada (Ottawa), Czech Republic (Prague), Japan (Tokyo), Australia (Sydney), Sweden (Lund), Belgium (Brussels) and Poland (Warsaw). A data exchange schedule operates with each center providing and relaying data to the other centers. The center in Boulder plays a special role as "World Warning Agency" (WWA), acting as a hub for data exchange and forecasts.

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Data collection at RWC-China is mainly made through its sub-centers consisting of the Solar Activity Prediction Center, the Geophysical Prediction Center, the Space Environmental Prediction Center, and the Ionospheric Prediction Center. The first three belong to the Chinese Academy of Sciences and the fourth belongs to the Chinese Research Institute of Radio wave Propagation. The collected data include daily sunspot number, sunspot area, parameters of sunspot groups, Hα flares, 10.7 cm flux and bursts, cosmic ray intensities, geomagnetic indices (K and A_k) and storms, and SIDs (Sudden Ionospheric Disturbances). The data are sent to users and sub-centers in both China and abroad, including WWA and RWCs. Then they are published in the Chinese Solar Geophysical Data (CSGD). The ionospheric data received at RWC-China are not included in CSGD but are sent to WWA and RWCs directly.

As one of important daily works, WWA and some RWCs of ISES provide short-term predictions of solar soft X-ray bursts with a lead time of 24 hours. This prediction is issued once a day and five days a week. Various methods and prediction factors have been used in the studying of the prediction. The goal of these efforts is to try to satisfy the needs of users of this prediction, who are working in fields of radio communications, navigation and space activities, etc. (e.g., Allen & Wilkinson 1993; Kleusberg 1993). However, there is still a large distance between the actual level of this prediction and what the users would like it to be (Shea & Smart 1993; Wang & Ma 1996). Thus, forecasters of the short-term prediction are facing problems of assessing and increasing the level of prediction.

In this paper, first we will verify the short-term predictions of solar X-ray bursts issued respectively by RWC-China and WWA for the period from January 2000 to December 2001. The predictions will be compared with the observations, month by month. Then, we will discuss the results of the comparison and a possible way which may help us to increase the level of the prediction. The prediction data used in this paper come from RWC-China and WWA, and the solar X-ray burst data are taken from NOAA Space Environment Center.

2 VERIFICATION AND COMPARISON OF SHORT-TERM PREDICTIONS OF SOLAR SOFT X-RAY BURSTS

A comparison of the short-term predictions issued by RWC-China with the observations of solar X-ray bursts for individual months in the period January 2000 to December 2001 is shown in Table 1. In the table the number of predictions (d) is equal to the number of observations (d) because the prediction is made and issued once per working day, the three following columns, labelled 'equal', 'high', 'low' refer to, respectively, the number of days where the predicted largest class of soft X-ray burst is equal to, higher than, or lower than the observed largest class on the day, the column 'Burst' gives the number of the days having, at least, one burst, then follow three columns expressing the 'equals', 'highs' and 'lows' as percentages of the total number of predictions. The last column R is the ratio Low / Burst, expressed as a percentage. Similar data for WWA are given in Table 2. Table 3 lists, for RWC-China and WWA, the sum of the verifications over the two years, 2000–2001.

Tables 1 and 2 show that, for every month in the period January 2000 to December 2001 and for both RWC-China and WWA, the percentage of correct predictions greatly exceeds that of incorrect (either too high, or too low) predictions. Table 3 shows that the rate of correct predictions is about equal for RWC-China and WWA, that the rate of too high predictions is greater for RWC-China than for WWA, while the rate of too low predictions is smaller for RWC-China than for WWA.

Table 1 A Verification of the Short-term Predictions of X-ray Bursts for 2000–2001 by RWC-China

Yr. Mn	Predic. (d)	Observ. (d)	Equal (d)	High (d)	Low (d)	Burst (d)	Equal (%)	High of (%)	Low (%)	R (%)
2000.1	21	21	17	2	2	20	81	10	10	10
2	15	15	10	4	1	13	67	27	7	8
3	23	23	19	0	4	23	83	0	17	17
4	22	22	18	4	0	22	82	18	0	0
5	18	18	13	4	1	17	72	22	6	6
6	22	22	15	3	4	22	68	14	18	18
7	21	21	14	3	4	21	67	14	19	19
8	23	23	15	6	2	23	65	26	9	9
9	22	22	13	7	2	22	59	32	9	9
10	18	18	15	1	2	18	83	6	11	11
11	22	22	10	8	4	22	45	36	18	18
12	21	21	14	5	2	20	67	24	10	10
2001.1	16	16	9	3	4	16	56	19	25	25
2	20	20	16	3	1	17	80	15	5	6
3	22	22	16	6	0	20	73	27	0	0
4	23	23	13	6	4	22	57	26	17	18
5	18	18	13	5	0	17	72	28	0	0
6	21	21	13	7	1	21	62	33	5	5
7	22	22	14	7	1	13	64	32	5	8
8	23	23	16	5	2	23	70	22	9	9
9	22	22	14	8	0	22	64	36	0	0
10	18	18	10	5	3	18	56	28	17	17
11	22	22	14	7	1	22	64	32	5	5
12	23	23	9	10	4	23	39	43	17	17

Table 2 A Verification of the Short-Term Predictions of X-ray Bursts for 2000–2001 by WWA

Yr. Mn	Predic. (d)	Observ. (d)	Equal (d)	High (d)	Low (d)	Burst (d)	Equal (%)	High (%)	Low (%)	R (%)
2000.1	21	21	12	3	6	20	57	14	29	30
2	15	15	8	4	3	13	53	27	20	23
3	23	23	12	2	9	23	52	9	39	39
4	22	22	13	7	2	22	39	32	9	9
5	18	18	11	6	1	17	61	33	6	6
6	22	22	9	8	5	22	41	36	23	23
7	21	21	14	4	3	21	67	19	14	14
8	23	23	21	0	2	23	91	0	9	9
9	22	22	12	6	4	22	55	27	18	18
10	18	18	15	0	3	18	83	0	17	17
11	22	22	9	6	7	22	41	27	32	32
12	21	21	14	3	4	20	67	14	19	20
2001.1	16	16	11	0	5	16	69	0	31	31
2	20	20	16	3	1	17	80	15	5	6
3	22	22	13	3	6	20	59	14	27	30
4	23	23	13	5	5	22	57	22	22	23
5	18	18	12	1	5	17	67	6	28	29
6	21	21	14	3	4	21	67	14	19	19
7	22	22	16	4	2	13	73	18	9	15
8	23	23	16	4	3	23	70	17	13	13
9	22	22	17	5	0	22	77	23	0	0
10	18	18	12	2	4	18	67	11	22	22
11	22	22	16	5	1	22	73	23	5	5
12	23	23	10	9	4	23	43	39	17	17

Table 3 Sum of the Verifications of the Monthly Short-Term Predictions of X-ray Flares for 2000–2001 by RWC-China and WWA

Center	Predic. (d)	Observ. (d)	Equal (d)	High (d)	Low (d)	Burst (d)	Equal (%)	High of (%)	Low (%)	R (%)
RWC-China	498	498	330	119	49	477	66	24	10	10
WWA	498	498	316	93	89	477	63	19	18	19

3 CURRENT METHODS OF THE SHORT-TERM PREDICTION OF SOLAR SOFT X-RAY BURSTS

Different methods are currently being used by different prediction centers for the short-term prediction of solar soft X-ray bursts. WWA developed an artificial intelligence prediction model, the expert system model (Kunches & Carpenter 1990). A combined method of the expert system with the forecaster's experience has been used for the prediction at WWA. Observations of the predicted active region such as area, variation, magnetic configuration and Mclntosh classification of the sunspot group and knowledge of flare activity of the region in the past 24 hours are used as predictors in the method, and what issued by WWA is the occurrence probability of M-class and X-class flares for the next 24 hours.

In this way, progress has been made in the improvement of predictions. Meanwhile, as it was pointed out by Hirman & Nelson (1997) that WWA continues to strive to make its products more meaningful to its users, and that predictions continue to be made using the forecaster's experience and are therefore mostly subjective.

At RWC-China, on the other hand, a statistical prediction model has been build up for the prediction (Zhang et al. 1994). This model is based on a statistical study of the occurrence rate of X-ray bursts for different states of the active region. This model forms the main part of the method used at RWC-China, the other part being the forecaster's experience, including, specially, the forecaster's consideration of the predictions of sunspot numbers for Solar Cycle 23 (e.g., Wang et al. 2002a) when the short-term prediction of solar soft X-ray bursts is made for a period in the present cycle.

The input for the statistical model includes white light data and magnetic field data of the sunspot group of the predicted active region, and the 10 cm radio data. Specifically, they are the area, magnetic type and Mclntosh type of the associated sunspot group, the 10 cm radio flux of the sun and the configuration of the longitudinal magnetic field of the active region. All together are five prediction factors.

It is necessary to mention here the way the configuration of the longitudinal magnetic field is classified. Using longitudinal magnetic field maps obtained at the Huairou Solar Observing Station for the period 1988 April 1 to 1990 October 7, nine types of configurations of the longitudinal magnetic field of active regions, which are associated with the occurrence of $\geq$M-class X-ray bursts, are identified (Zhang & Wang 1994). Features in active regions of these nine types are as follows:

Type 1: intrusion or compression of magnetic fields with opposite polarities

Type 2: magnetic flux surrounded by another magnetic flux with the opposite polarity

Type 3: incorporation of magnetic fluxes with the same polarity

Type 4: emergence of magnetic fluxes with a polarity different from that of the existing fluxes

Type 5: super-long magnetic reverse line ($\geq 120''$)

Type 6: the magnetic axis of the active region being approximately perpendicular to the solar equator

Type 7: large gradient of the longitudinal magnetic field ($\geq 0.7\,\mathrm{G\ km^{-1}}$)

Type 8: the magnetic polarity distribution being opposite to that according to the Hale rule

Type 9: rapid increase of the intensity of the longitudinal magnetic field ($\geq 960\,\mathrm{G\ day^{-1}}$)

These nine types of magnetic configurations are then grouped into three classes. They are: Class 1 consists of Types 2, 3, 5, and 6, Class 2 consists of Type 1 and 4, and Class 3 consists of Types 7, 8 and 9. In addition, another two classes, Class 4 and Class 5, are defined to complete the classification of the magnetic configuration as one predictor of the prediction model.

The final prediction, the occurrence of $\leq$ C-class, M-class and X-class bursts in the region for the next 24 hours, is the product of the combination of the result given by the statistical model and the classifying threshold given by the forecaster's experience for the final prediction. Actually, the forecasting is mainly a process of a multivariate discrimination analysis, and therefore is mainly objective.

4 DISCUSSION

(1) It is clear from Table 3 and from a comparison of Table 1 with Table 2 that the short-term prediction of solar soft X-ray bursts, made at RWC-China and made at WWA, is basically of the same level. As mentioned above, different prediction methods are used by WWA and RWC-China. WWA uses mainly the forecaster's experience (Hirman & Nelson 1997) with an expert system (Kunches & Carpenter 1990) for the prediction; while a combination of a linear regression prediction equation with the forecaster's experience is used at RWC-China (Zhang et al. 1994). Therefore, the fact that the predictions issued by these two centers are of the same level should be attributed to the fact that they use similar solar indexes and characteristics of solar activities as prediction factors in their tasks.

(2) According to Wang (1993), in the early 1990s, the short-term x-ray burst prediction issued by RWC-China had a rate of correct prediction of 58%, a rate of too high predictions of 20%, and a rate of too low predictions of 21%. Now, according to Tables 1 to 3, our present short-term prediction of X-ray bursts achieves a rate of correct predictions of 66%, a rate of too high predictions of 24%, and a rate of too low predictions of 10%. Thus, for RWC-China, between the early 1990s and the present, the rate of correct predictions has gone up by 8%, the rate of too high predictions has gone up by 4% and the rate of too low predictions has gone down by 11%. Obviously, to raise the level of the short-term prediction, we must try to reduce the rate of too high predictions. Meanwhile, an appropriate selection of the criterion used by RWC-China will be very helpful for this purpose. For example, a different criterion in the prediction method should be taken when a short-term prediction of solar soft X-ray bursts is made for Solar Cycle 24 which will probably be a cycle lower than Solar Cycle 23 (Kane 1999; Landscheidt 1999; Wang et al. 2002b).

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