Solar activity prediction studies and services in NAOC

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Abstract

Solar activity prediction services started in 1960's in National Astronomical Observatories, Chinese Academy of Sciences (NAOC). As one of the members of the International Space Environment Service (ISES), Regional Warning Center of China (RWC-China) was set up in 1990's. Solar Activity Prediction Center (SAPC), as one of the four sub-centers of RWC-China, is located in NAOC. Solar activity prediction studies and services in NAOC cover short-term, medium-term, and long-term forecast of solar activities. Nowadays, certain prediction models, such as solar X-ray flare model, solar proton event model, solar 10cm radio flux model, have been established for the practical prediction services. Recently, more and more physical analyses are introduced in the studies of solar activity prediction, such as the magnetic properties of solar active regions and magnetic structure of solar atmosphere. Besides traditional statistics algorithms, Machine Learning and Artificial Intelligence techniques, such as Support Vector Machine (SVM) method, are employed in the establishment of forecast models. A Web-based integrated platform for solar activity data sharing and forecast distribution is under construction.

Key words: Solar activity, Prediction, Space environment

1 Introduction

Solar activity prediction services started in 1960's in National Astronomical Observatories, Chinese Academy of Sciences (NAOC). At the beginning of

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the services, the prediction of the solar activities were mainly concerned with short-wave communications and Chinese space missions. In 1970, most of solar physicists at NAOC were involved in Chinese first satellite space mission.

In 1990's, Regional Warning Center of China (RWC-China) was set up, as one of the members of the International Space Environment Service (ISES) (Web site: http://www.ises-spaceweather.org/). Solar Activity Prediction Center (SAPC), as one of the four sub-centers of RWC-China, is located in NAOC. (Other three sub-centers are Space Environment Prediction Center (SEPC), Ionospheric Disturbance Prediction Center (IDPC), and Geomagnetic Storm Prediction Center (GSPC).) The tasks of RWC-China include data collection, user services, and data and information exchanges with other RWCs.

Nowadays, several ground-based solar observing instruments of NAOC have been set up in Beijing and Yunnan Province of China. By using both the domestic ground-based observation data and the international space-based observation data, the solar activity prediction services in NAOC cover all of the short-term, medium-term, and long-term prediction, and also include the special services for Chinese space missions. Certain prediction models, such as solar X-ray flare model, solar proton event model, solar 10cm radio flux model, have been established for the practical prediction services in NAOC. Recently, more and more physical analyses are introduced in the studies of solar activity prediction, such as the magnetic properties of solar active regions and magnetic structure of solar atmosphere. Besides traditional statistics algorithms, Machine Learning and Artificial Intelligence techniques, such as Support Vector Machine (SVM) method, are employed in the establishment of prediction models. A Web-based integrated platform for solar activity data sharing and forecast distribution is under construction and will be got ready at the end of 2006. All of these topics will be described in Section 2, 3, 4, 5. In Section 6, we give the summary and future expectation.

2 Observations in NAOC

During the last decades, several observing instruments of solar activity have been set up in NAOC, these instruments are located at the Huairou Solar Observing Station in Beijing and the Yunnan Astronomical Observatory in Yunnan Province. The observations that are used in solar activity prediction include vector magnetic field and the white light image of the photosphere, the Hα image of solar chromosphere, and the solar radio flux and spectrum.

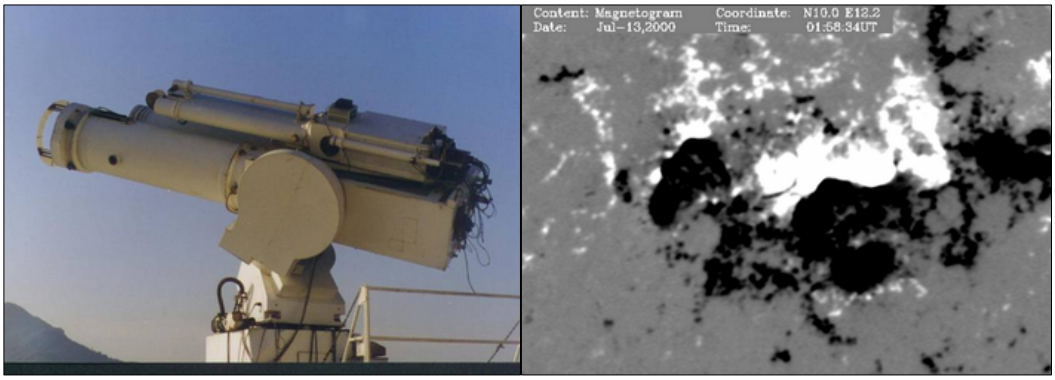

Fig. 1. Solar Multi-Channel Telescope at Huairou Solar Observing Station and the observed magnetogram.

2.1 Vector magnetic field observations of photosphere

The Solar Multi-Channel Telescope is located at Huairou Solar Observing Station which is situated at waterside of Huairou Reservoir in Beijing. This telescope can give good quality vector magnetic field measurements of solar active regions (See Fig. 1). The continuous data accumulation of the magnetic field of solar activity regions has lasted for nearly two solar cycles. From the point of view of solar activity prediction, these data are very valuable for the statistics research of the relation between the flare activities and the properties of solar magnetic fields. Very Recently, a full disk solar magnetic telescope has just been set up at Huairou Station. Full disk vector magnetic field on photosphere can be obtained with this new instrument. The research on large scale properties of the solar magnetic fields can be commenced from the new observations.

2.2 Hα image observations of chromosphere

Hα image is the traditional approach to trace and measure flares, prominences or filaments. Both Huairou Station and Yunnan Observatory can take the solar Hα images with their telescopes. Since the distance between the two sites is very large, the two observations can be complementarity to each other, and in a way can avoid the influence of bad weather.

2.3 Solar radio flux and spectrum observations

Solar radio spectrometers of NAOC are also located at the Huairou Station. They can observe the solar radio spectrum with frequency range 1.0-2.0 GHz, 2.6-3.8 GHz, and 5.2-7.6 GHz (Fig. 2 displays the picture of the 2.6-3.8 GHz

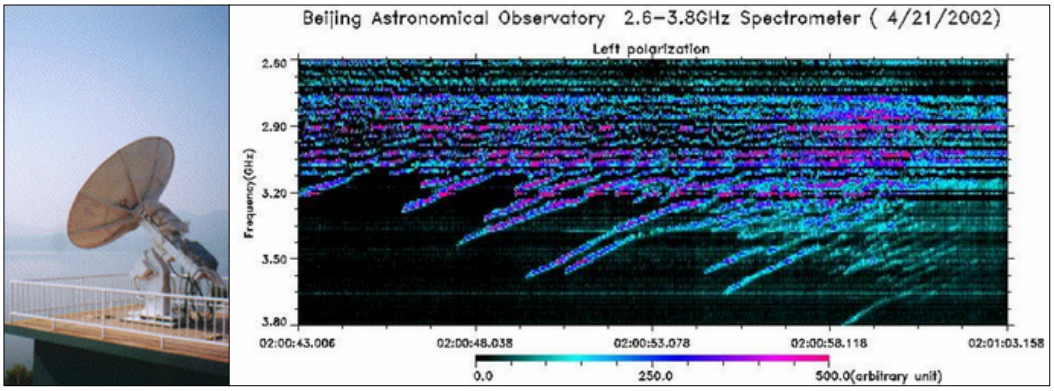

Fig. 2. Solar radio spectrometer (2.6-3.8 GHz) at Huairou Solar Observing Station and a sample of the observed solar radio spectrum.

spectrometer and a sample of the observed spectrum.). Meanwhile, the solar 10cm radio flux is also recorded by the 2.84GHz solar radio telescope. These observations can be used to analyse the solar flare events as well as the whole active level of the Sun. Recently, a new solar radio observation project: Chinese spectral radioheliograph (CSRH) in cm- and dm-wave range was proposed and has got much progress.

3 Prediction services

3.1 Special services

Special services of solar activity prediction in NAOC are mainly provided for the Chinese space missions, such as the services for the Chinese first satellite mission in 1970. In recently years, the services are emphasized on the Chinese Shenzhou series of manned spaceflight and Chang'e lunar exploration mission. Shenzhou V spacecraft sent the first Chinese astronaut into space and returned back successfully on October 15, 2003. Shenzhou VI sent two astronauts into space on October 12, 2005 and returned back on October 17, 2005. The tasks of the special services include keeping close watch on the Sun, forecasting and warning the possible solar activity events, especially the solar proton events which can be dangerous both for the astronauts and for the spacecrafts.

3.2 Routine services

The routine services of solar activity prediction include long-term, medium-term, and short-term prediction. The long-term prediction is in the time scale of solar cycle, the medium-term prediction is in the timescale of solar rotation,

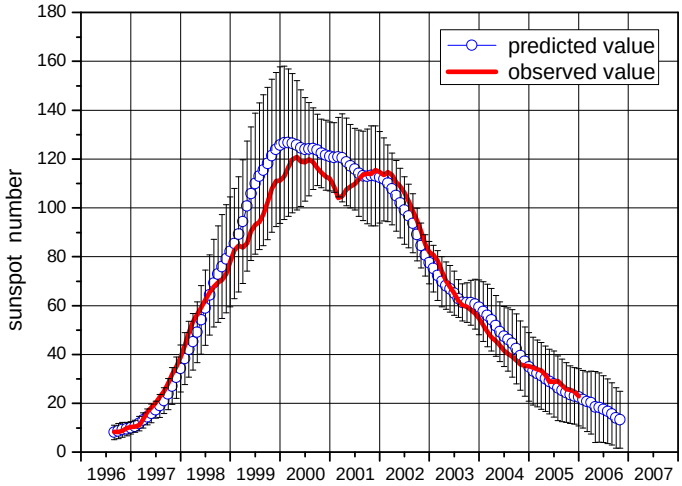

Fig. 3. SMMSN forecast of solar cycle 23 (Wang and Han, 1997; Wang et al., 2002). The small circles represent the forecast results and the thick line gives the observed values. The uncertainties in the predicted values are indicated by short vertical bars.

and the short-term prediction is to forecast the possible solar activities within 3 days. The daily solar activity forecasts are distributed both by Web pages (http://rwcc.bao.ac.cn) and emails.

3.2.1 Long-term prediction

In 1997, just at the beginning of solar cycle 23, Wang and Han (1997) at NAOC forecast the Smoothed monthly mean sunspot number (SMMSN) of solar cycle 23 by using the Similar Cycles Method. The forecast results and the practical observed value are compared in Fig. 3, the small circles represent the forecast results and the thick line gives the observed values. It can be seen that the forecast results agree well with the observed values (Wang et al., 2002). In 1999, Zhang and Wang (1999) predicted the maximum monthly smoothed sunspot number in solar cycle 23 with a linear regressive method. The results of this prediction indicated that the intensity of solar activity in the solar cycle 23 will be at an average level with the maximum sunspot number of 117 ± 40, which is consistent with the real value.

Recently, Du (2006a,b) and Du et al. (2006) proposed a weighted average method for the solar cycle prediction. According to Du's predictions, the next (24th) solar cycle is estimated to start in March 2007±7 months (Du, 2006a), with a amplitude of 150±22 (sunspot number) (Du, 2006b).

3.2.2 Medium-term prediction

The medium-term prediction of solar activities include three aspects: monthly mean sunspot number of the coming month, possible proton event, and possi-

ble influence on shortwave communication. Currently, the medium-term forecast mainly relies on the forecaster's experiences, with the help of a preliminary model for the mean sunspot number forecast. The medium-term prediction is performed every half month in NAOC.

3.2.3 Short-term prediction

The short-term routine prediction services in NAOC should forecast: (1) The maximum class of the possible solar X-ray flares within 2 days (none, C-, M-, X-Class); (2) Daily 10cm radio flux in the following 3 days; (3) Solar proton event (SPE) probability within 3 days. The corresponding models for the three aspects of the short-term prediction have been established (See Section 4). As for the routine prediction, it is still necessary that the forecasts given by models are adjusted according to the forecaster's experiences. The short-term prediction is performed every day. Zhu and Wang (2003) verified the short-term predictions of solar X-ray flares issued by RWC-China in the period January 2000 to December 2001, and found a rate of correct predictions of 66%, which is basically the same as that of the World Warning Agency (WWA) of the ISES.

4 Prediction models and studies

4.1 Solar X-ray flare prediction model

The solar X-ray flare prediction model forecasts the maximum class of the possible solar X-ray flares over the next 2 days. This model is based on a statistical study of the relationship between flares and morphological evolution of active regions. The input for the model includes white light data and magnetic field data of the sunspot group of the concerned active regions, and the 10 cm radio flux data (Zhang et al., 1994; Zhu and Wang, 2003). Fig. 4 compares the forecast results of the model with the observed maximum X-ray flare classes during an interval of 190 days in 2001. It can be seen that the forecast line is basically consistent with the observation line.

Recently, besides traditional statistics algorithms, Machine Learning and Artificial Intelligence techniques are employed to construct the prediction models (Wang et al., 2006), such as Support Vector Machine (SVM) method. Based on a proved relationship between SVM and K-Nearest Neighbors (KNN), Li et al. (2006a) developed the original SVM algorithm to SVM combined with KNN (SVM-KNN) modeling algorithm, and try to improve the solar X-ray flare prediction model through this new method.

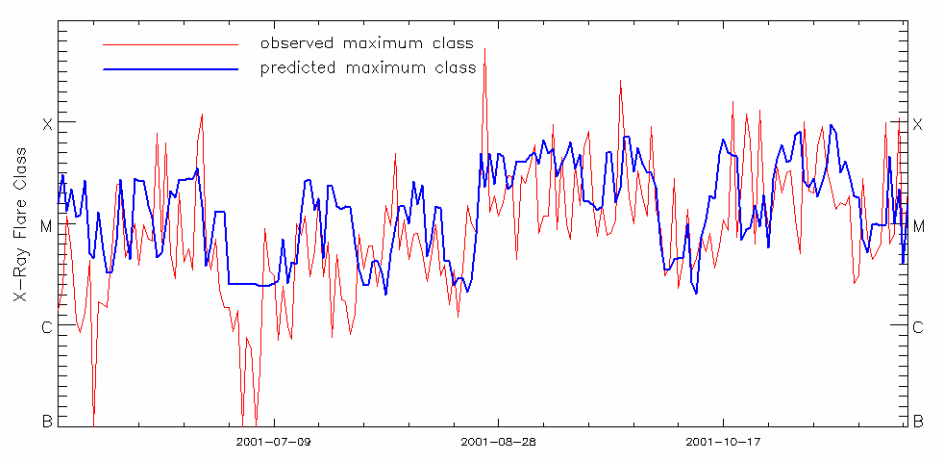

Fig. 4. Forecast results of the Solar X-ray flare prediction model (thick line) compared with the observed maximum X-ray flare classes (thin line) during an interval of 190 days in 2001.

Meanwhile, Cui et al. (2006) attempted to find new input parameters for the solar X-ray flare prediction model. From a large number of SOHO/MDI longitudinal magnetograms, Cui et al. (2006) computed three physical measures of solar active regions, including the maximum horizontal gradient, the length of the neutral line, and the number of singular points. These measures are used to describe photospheric magnetic field properties including nonpotentiality and complexity, which is believed to be closely related to solar flares. The statistical results demonstrate that solar flare productivity increases with nonpotentiality and complexity. Furthermore, the relationship between the flare productivity and these measures can be well fitted with a sigmoid function in Boltzmann style (Fig. 5 gives an example of this relationship through the measure of maximum horizontal gradient). These results can be beneficial to future operational flare forecast models.

Very recently, from the vector magnetograms observed by Huairou Solar Observing Station, Cui and Wang (2006) computed more physical measures, including the strong-shear neutral line, the total unsigned current, and the total unsigned current helicity. The statistical results also show that the solar flare productivity has a very intimate relationship with the three measures.

4.2 Solar 10cm radio flux prediction model

The input parameters of the Solar 10cm radio flux model are the historical data of daily 10cm flux and sunspot number. This model is developed from the widely used autoregressive integrated moving average (ARIMA) processes (Box and Jenkins, 1994; Zhang, 1986). Short-term and medium-term prediction of the 10cm radio flux can be given simultaneously by this model. In Fig.

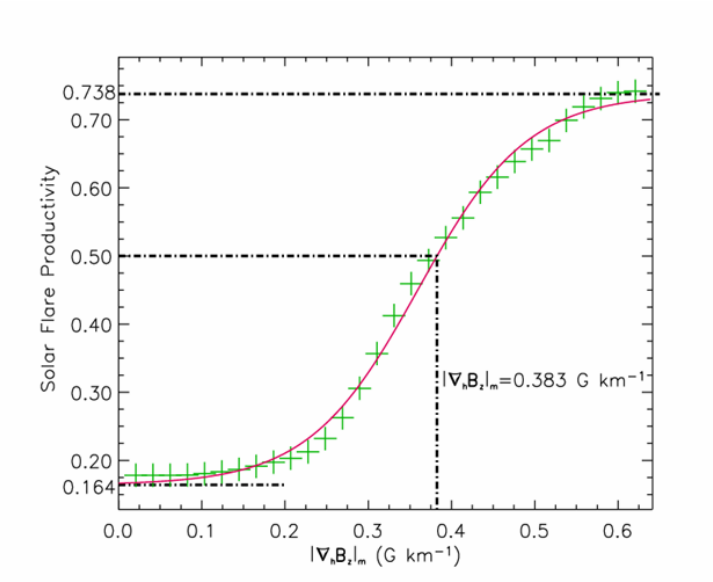

Fig. 5. The relationship between the flare productivity and maximum horizontal gradient of solar active regions (Cui et al., 2006). '+' denotes each data point. The solid line is the Boltzmann sigmoidal fitting curve for all data points.

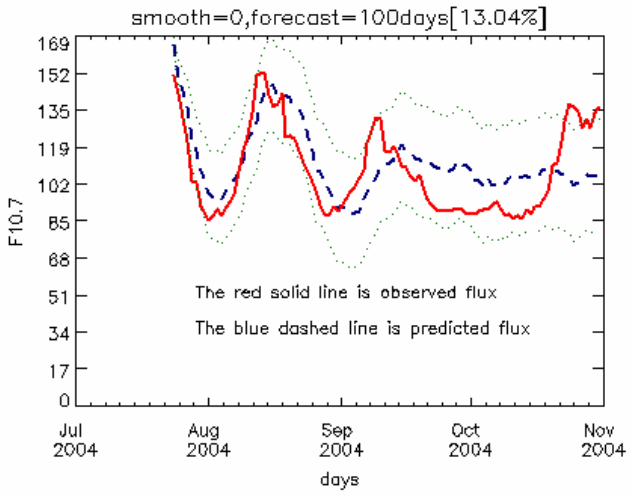

Fig. 6. Forecast results of the Solar 10cm radio flux prediction model (dashed line) compared with the observed data (solid line) in a period of 100 days in 2004. The dotted lines indicate the uncertainties in the predicted flux.

6, the forecast results are compared with the observed data in a period of 100 days in 2004. The averaged error is under 15%.

4.3 Solar proton event prediction model

Currently, the solar proton event prediction model is still in preliminary stage. The input parameters include the area, magnetic type and Mclntosh type of the sunspot groups, the 10 cm radio flux of the sun, the longitudes of the active regions, and the differential areas of the sunspot groups. Supported Vector Machine combined with K-Nearest Neighbors (SVM-KNN) modeling algorithm (See Section 4.1) is adopted to construct this model (Li et al., 2006b). In the testing forecast for the year 2004, 18 SPEs (66.6%) are correctly forecasted among the total 27 SPEs. Only 15 (4.5%) non-SPEs are falsely alarmed among the total 333 non-SPE periods.

4.4 Solar flare active longitudes

Zhang et al. (2006) analyzed the raw data of powerful solar X-ray flares (class above X) observed by GOES satellites during the period from January 1975 to December 2005. The main results are as follows: (1) The raw Carrington longitude distribution presents that the place where X flares occur migrates increasingly in longitudes; (2) In a new reference frame inferred from Carrington longitudes and the migration periods in longitudes, two parallel migration curves are found, even though without being smoothed or filtered by any method; (3) In another dynamic reference frame deduced from the differential rotation law on the sun, the diagram shows that there are two persistent preferred flare longitudes separated by about 180 degrees (See Fig. 7). This suggests that strong X flare active longitudes exist indeed for tens of years. The non-axisymmetries of the flare distributions are found highly significant, 42.5% for the northern hemisphere and 43.0% for the southern hemisphere.

4.5 Magnetic structure in the solar atmosphere

The explosive events on the Sun: Flare, Solar Proton Event (SPE), and Coronal Mass Ejection (CME) initiate in the solar atmosphere. It is important to understand the 3-D structure of the magnetic field in the solar atmosphere for the prediction of solar activities. By using the Boundary Integral Equation (BIE) method proposed by Yan and Sakurai (2000), Wang et al. (2000, 2001) extrapolated the field lines above solar active regions AR 7321 based on force-free field model. Fig. 8 shows that the alignment of reconstructed force-free field lines is mostly in agreement with the structures in soft X-ray image obtained by Yohkoh satellite.

Recently, by using the force-free solutions given by Low and Lou (1990), He

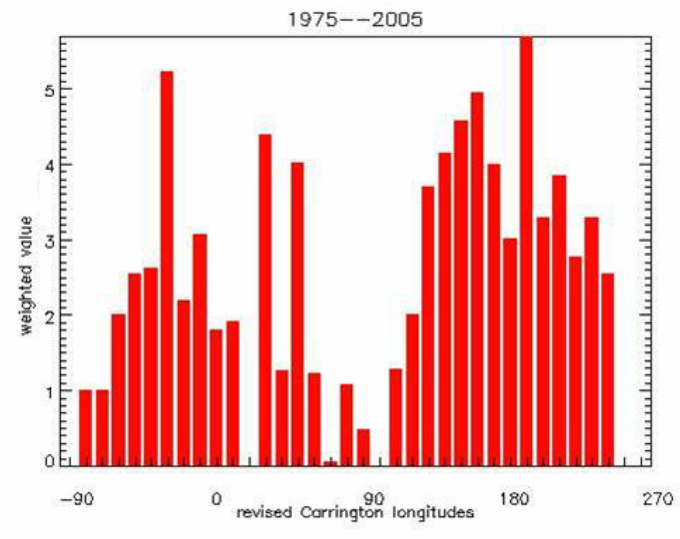

Fig. 7. Longitudinal distribution of powerful X-ray flares during 1975-2005 in a dynamic reference frame (revised Carrington longitude) deduced from the differential rotation law on the sun. The diagram shows that there are two persistent preferred flare longitudes separated by about 180 degrees (Zhang et al., 2006).

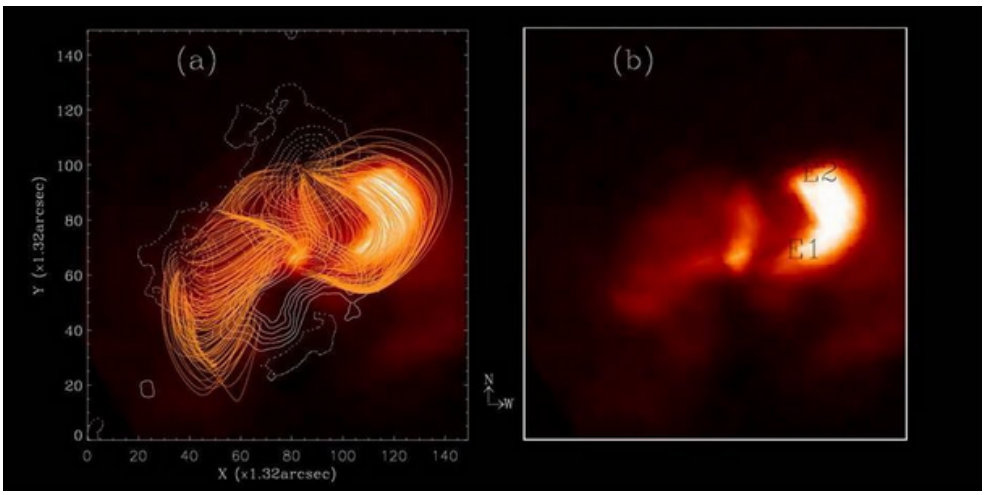

Fig. 8. Comparison between reconstructed force-free field lines and soft X-ray image of AR 7321 on 26 October 1992 (Wang et al., 2000, 2001).

and Wang (2006a,b) studied the validity of BIE for magnetic extrapolation in open space above a spherical surface. The results of the examination support the application of the BIE method to large-scale and global extrapolation.

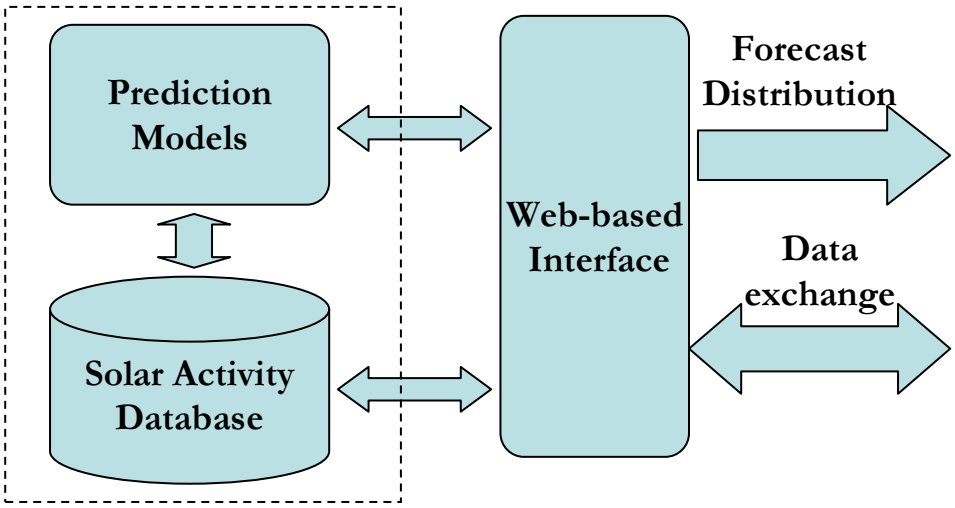

Fig. 9. The framework of the integrated platform for solar activity data sharing and forecast distribution.

5 Database and Web site

A Web-based integrated platform for solar activity data sharing and forecast distribution is under construction in NAOC. Fig. 9 demonstrates the framework of the system. The Database stores all the data concerned with solar activities: the observation data, the daily forecast result to be distributed, the data exchanged with other RWCs, etc. The prediction model server reads input parameters from the database, runs the prediction models and sends the results back to the database. The Web-based interface server controls the running of the prediction models, distributes the daily forecast result, exchanges data with other RWCs and sub-centers, and displays the forecast results and the related materials on the public Web site. After this system will be got ready at the end of 2006, the current web site of RWC-China, http://rwcc.bao.ac.cn, will be replaced by this new platform.

6 Summary

Solar activities are the sources of the disturbances of space environment. Solar activity prediction services play an important role in the whole space environment services.

As for the solar activity prediction studies and services in NAOC, in the near future, the new integrated platform for solar activity data sharing and forecast distribution will be put into service; Physical measures of active region's magnetic properties will be merged into prediction models; Active longitudes will be incorporated into prediction models; An improved solar proton flux

model is expected to be established; A practical global force-free extrapolation scheme is expected to be developed; The SVM method is expected to be used in the operational prediction models.

In 2006, new solar observing spacecrafts, such as Solar-B and STEREO, will be sent into space. In particularly, the STEREO twin spacecrafts can provide first-ever stereoscopic observations of the CME. Inspired by these new observations, CME prediction model will be on the way. Nevertheless, the field of solar activity prediction is also faced with challenges, coming from the essential scientific problems as well as the practical services for the manned spaceflight missions. Further international cooperation will be needed to make a scientific breakthrough in the field of solar activity prediction studies and services.

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