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Space environment (natural and artificial) — Methods for estimation of future geomagnetic activity

Environnement spatial (naturel et artificiel) — Méthodes d'estimation de l'activité magnétique future

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Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

ISO/TS 16698 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space environment (natural and artificial)*.

Introduction

This International Standard provides guidelines for specifying the process of estimating future geomagnetic activity. Geomagnetic indices describe the variation of the geomagnetic field over a certain time period, and provide a measure of the disturbance of the magnetosphere.

The accuracy and method of prediction of geomagnetic indices depend on a time scale of prediction. This fact introduces some of existing works with 3 classifications of their focusing time scales:

(1) short-term (1 hour to a few days) prediction
(2) middle-term (a few weeks to a few months) prediction
(3) long-term (half year to one solar cycle) prediction

They are required as input parameters for magnetospheric magnetic field (IS22009), upper atmosphere (IS14222), ionosphere, plasmasphere (TS16457), magnetosphere charged particles, and other models of the near Earth space environment. They are also used as the input parameters for orbital lifetime prediction and worst case environment analysis of electrostatic charging.

The Earth magnetic field is provided by three standards including internal magnetic field (CD16695), magnetospheric magnetic field (IS22009), and this standard.

Space environment (natural and artificial) — Methods for estimation of future geomagnetic activity

1 Scope

This International Standard specifies the process for estimating geomagnetic indices for time intervals from the short-term (hours-a few months) to the long-term (months-years).

Geomagnetic indices are used to describe the activity levels of the disturbance of the geomagnetic field. These indices are applicable to estimate upper atmospheric and plasmaspheric densities and many other space environment models. They are also used as the input parameters for orbital lifetime prediction and worst case environment analysis of electrostatic charging.

This International Standard is useful for users who intend to predict future geomagnetic indices and space environment.

2 Terms and definitions

2.1 Geomagnetic field variations

The geomagnetic field consists of internal and external magnetic fields. Internal (main) magnetic field is produced by the source currents mostly inside the Earth's core and the induced currents in the solid Earth and the ocean caused by the temporal variation of external magnetic fields. External magnetic field is produced by the magnetospheric and the ionospheric currents.

The magnetosphere is highly dynamic with time scales of minutes to days. The solar wind is the ultimate source of magnetospheric dynamics. The role played by the IMF north-south component, Bz, is particularly important, and its southward component, Bs, plays a fundamental role in substorm and magnetic storm activity through the process of magnetic field line reconnection. The solar wind speed also plays essential role in the dynamics.

2.2 Quiet level and disturbance fields

Five days in every month are selected as the "Five International Quietest Days" by using the Kp index. Note that a selection of the five quietest days is made regardless of the absolute level of quietness. Thus, in a disturbed month, the quietest days may not be very quiet.

Derivation: The selection of the quietest days (Q-days) of each month is deduced from the Kp indices on the basis of three criteria for each day: (1) the sum of the eight Kp values, (2) the sum of squares of the eight Kp values, and (3) the maximum of the eight Kp values. According to each of these criteria, a relative order number is assigned to each day of the month, the three order numbers are averaged and the days with the first to fifth lowest mean order numbers are selected as the five international quietest days.

Reference: Website of Deutsches GeoForschungsZentrum (http://www-app3.gfz-potsdam.de/kp_index/qddescription.html)

Once the quiet level is determined by using the five international quietest days, disturbance fields can be obtained as deviations from the quiet level of geomagnetic field.

2.3 K index (Local 3-hour range index)

The K index is a number in the range 0 (quiet) to 9 (disturbed) that classifies locally the observed variations of the geomagnetic field after subtraction of the regular daily variation (Sq). Each activity level relates almost logarithmically to the corresponding disturbance amplitude of the horizontal field component during a 3-hour UT interval. In a day, eight K indices are given in successive 3-hour UT intervals (0-3 hr, 3-6 hr, ... , 21-24 hr UT).

Derivation: The ranges R for the H and D (or X and Y) components are defined as the difference between the highest and lowest deviation, within the three-hour interval, from a smooth curve (a regular daily variation) to be expected for that element on a magnetically quiet day. Only the larger value of R, that is, R for the most disturbed element, is taken as the basis of K. In conversion from R to K, a permanent scale prepared for each observatory is used. Table 1 is an example of the permanent scale for Niemegk observatory.

References: Bartels et al. [1939], Mayaud [1980], Menvielle et al. [2011]

Table 1. A permanent scale to convert from R to K for Niemegk observatory

Range (nT)	0-5	5-10	10-20	20-40	40-70	70-120	120-200	200-330	330-500	500-
K value	0	1	2	3	4	5	6	7	8	9

2.4 Kp, ΣKp, ap, and Ap indices (Planetary indices)

The planetary indices, Kp, ΣKp, ap, and Ap, are derived from 13 selected mid-latitude observatories (Table 2). Derivation scheme for each index is described in the corresponding subsection.

Table 2. Thirteen observatories that contributed to the Kp index

Observatory, Country	Code	GLat (°N)	GLon (°E)	MLat (°)	Notes

Meannook, Canada	MEA	54.617	246.667	62.5	
Sitka, USA	SIT	57.058	224.675	60.0	
Lerwick, Shetland Is.,UK	LER	60.133	358.817	58.9	
Ottawa, Canada	OTT	45.400	284.450	58.9	replaced Agincourt in 1969
Uppsala , Sweden	UPS	59.903	17.353	58.5	replaced Lovo in 2004
Eskdalemuir , UK	ESK	55.317	356.800	54.3	
Brorfelde, Denmark	BJE	55.625	11.672	52.7	replaced Rude Skov in 1984
Fredericksburg , USA	FRD	38.205	282.627	51.8	replaced Cheltenham in 1957
Wingst, Germany	WNG	53.743	9.073	50.9	
Niemegk, Germany	NGK	52.072	12.675	48.8	replaced Witteveen in 1988
Hartland , UK	HAD	50.995	355.517	50.0	replaced Abinger in 1957
Canberra, Australia	CNB	-35.317	149.367	-45.2	replaced Toolangi in 1981
Eyrewell , New Zealand	EYR	-43.424	172.354	-50.2	replaced Amberley in 1978

2.4.1 Kp index (Planetary 3-hour range index)

The Kp index is assigned to successive 3-hour UT intervals (0-3 hr, 3-6 hr, ... , 21-24 hr UT) giving eight values per UT day and ranges in 28 steps from 0 (quiet) to 9 (disturbed) with intermediate values denoted by -, o, or +, resulting in 0o, 0+, 1-, 1o, 1+, 2-, 2o, 2+, ..., 8-, 8o, 8+, 9-, and 9o.

Derivation: The K indices at the 13 observatories given in Table 2 are standardized by means of conversion tables that have been established through the rather complicated procedure introduced by Bartels [1940]. The standardized K indices, called the Ks index, are averaged with weighting factors to derive the Kp index.

References: Bartels [1949], Mayaud [1980], Menvielle et al. [2011]

2.4.2 ΣKp index (Planetary daily range index)

ΣKp is a sum of 8 Kps of the day.

2.4.3 ap index (Planetary 3-hour equivalent amplitude index)

The Kp index is not linearly related to the geomagnetic disturbances measured in the unit of nT. Instead, the ap index is introduced as it is roughly proportional to the geomagnetic disturbances. One ap unit corresponds to ~2 nT of geomagnetic variations.

Derivation: The ap index is derived directly from the Kp index by using the conversion table shown in Table 3.

References: Bartels and Veldkamp [1954], Mayaud [1980], Menvielle et al. [2011]

Table 3. Conversion table from the Kp index to the ap index

Kp		0o	0+	1-	1o	1+	2-	2o	2+	3-
	3o	3+	4-	4o	4+					
ap		0	2	3	4	5	6	7	9	12
	15	18	22	27	32					
Kp	5-	5o	5+	6-	6o	6+	7-	7o	7+	8-
	8o	8+	9-	9o						
ap	39	48	56	67	80	94	111	132	154	
	179	207	236	300	400					

2.4.4 Ap index (Planetary daily equivalent amplitude index)

The Ap index is the average of the 8 values of the ap index in a UT day.

2.5 aa index (Antipodal amplitude index)

The aa index is a simple measure of global geomagnetic activity, which can continuously be traced back to 1868.

Derivation: The aa index is produced from the K indices of two nearly antipodal magnetic observatories in England and Australia, which are listed in Table 4. The K indices at the two observatories are converted back to amplitudes by using Table 5. The aa index is computed as an average of the northern and southern values of amplitude with weighting factors, λ, shown in Table 4.

References: Mayaud [1971]

Table 4. Observatories in England and Australia contributing to the aa index

Observatory, Country	Code	Period	GLat (°N)	GLon (°E)	MLat (°)	λ
Greenwich, England		1868-1925				1.007
Ablinger, England	ABN	1926-1956	51.18	359.62	53.4	0.934
Hartland, England	HAD	1957-	50.97	355.52	54.0	1.059

Melbourne, Australia		1868-1919				0.967
Toolangi, Australia	TOO	1920-1979	-37.53	145.47	-45.6	1.033
Canberra, Australia	CNB	1979-	-35.30	149.00	-42.9	1.084

Table 5. Conversion table from the K index at the aa observatories to amplitudes

K index	0	1	2	3	4	5	6	7	8	9
Amplitude	2.3	7.3	15	30	55	95	160	265	415	667

2.6 Dst index (Storm time disturbance index)

The Dst index is a measure of the axially symmetric part of the H component along geomagnetic equator on the ground, and the main physical source is a combination of the equatorial ring current, the plasma sheet current and the magnetopause current.

Derivation: The Dst index is defined as the average of the disturbance variations of the H component, D_i, at the four observatories (i=1-4), which is listed in Table 6, divided by the average of the cosines of the dipole latitudes at the observatories for normalization to the dipole equator. Dst is computed for each UT hourly interval from the four observatories.

References: Sugiura [1964], Sugiura and Kamei [1991]

Table 6. Four observatories contributing to the Dst index

Observatory, Country	Code	GLat (°N)	GLon (°E)	Dipole Lat (°)
Kakioka, Japan	KAK	36.230	140.190	26.0
San Juan, USA	SJG	18.113	293.850	29.6
Honolulu, USA	HON	21.320	201.998	21.1
Hermanus, South Africa	HER	-34.425	19.225	-33.3

2.7 ASY and SYM Indices (Mid-latitude disturbance indices)

The disturbance fields in mid- and low-latitudes are generally not axially symmetric, in particular, in the developing phase of a magnetic storm. To describe the asymmetric and symmetric disturbance fields in mid-latitudes with a high time resolution of 1 min. longitudinally asymmetric (ASY) and symmetric (SYM) disturbance indices were introduced and derived for both the H and D components.

The SYM-H index is approximately the same as the Dst index, while its time resolution is 1 minute.

Derivation: The ASY/SYM indices are derived from 6 selected mid-latitude observatories (Table 7) in the following four steps: (1) subtraction of the geomagnetic main field and the Sq field to obtain the disturbance field component, (2) coordinate transformation to a dipole coordinate system, (3) calculation of the longitudinally symmetric indices, SYM-H and SYM-D, by taking averages of disturbance fields of the 6 stations, and (4) calculation of the asymmetric disturbance indices, ASY-H and ASY-D, by computing the range between the maximum and the minimum asymmetric fields.

References: Iyemori et al. [1992], Menvielle et al. [2011]

Table 7. Six observatories contributing to the SYM/ASY indices

Observatory, Country	Code	GLat (°N)	GLon (°E)	MLat (°)	MLon (°E)	Rotation angle (°)
Memambetsu, Japan	MMB	43.9	144.2	34.6	210.2	-16.1
Honolulu, USA	HON	21.3	202.0	21.5	268.6	0.5
Tuscon, USA	TUC	32.3	249.2	40.4	314.6	2.7
Fredericksburg, USA	FRD	38.2	282.6	49.1	352.2	0.4
Hermanus, South Aflica	HER	-34.4	19.2	-33.7	82.7	-10.1
Urmuqu, China	WMQ	43.8	87.7	34.3	162.5	7.7

2.8 AU, AL, AE, and AO indices (Auroral electrojet indices)

The auroral electrojet indices are measures of the intensity of the auroral electrojets and consist of four indices, AU, AL, AE and AO. The AU and AL indices are intended to express the strongest current intensity of the eastward and westward auroral electrojets, respectively. The AE index represents the overall activity of the electrojets, and the AO index provides a measure of the equivalent zonal current.

Derivation: The auroral electrojet indices are derived from geomagnetic variations in the H component observed at 12 selected observatories along the auroral zone in the northern hemisphere (Table 8). The AU and AL indices are respectively defined by the largest and the smallest values so selected. The symbols, AU and AL, derive from the fact that these values form the upper and lower envelopes of the superposed plots of all the data from these stations as functions of UT. The difference, AU minus AL, defines the AE index, and the mean value of the AU and AL, i.e. (AU+AL)/2, defines the AO index.

References: Davis and Sugiura [1966], Kamei and Maeda [1981]

Table 8. Twelve (and obsolete three) observatories contributing to the AE index

Observatory, Country	Code	GLat (°N)	GLon (°E)	MLat (°)	MLon (°E)	Notes
Abisko, Sweden	ABK	68.36	18.82	66.06	114.66	
Dixon Island, Russia	DIK	73.55	80.57	64.04	162.53	
Cape Chelyuskin, Russia	CCS	77.72	104.28	67.48	177.82	
Tixie Bay, Russia	TIK	71.58	129.00	61.76	193.71	
Pebek, Russia	PBK	70.09	170.93	63.82	223.31	Opened in 2001/04
Barrow, USA	BRW	71.30	203.25	69.57	246.18	
College, USA	CMO	64.87	212.17	65.38	261.18	
Yellowknife, Canada	YKC	62.40	245.60	68.87	299.53	
Fort Churchill, Canada	FCC	58.80	265.90	67.98	328.36	
Sanikiluaq, Canada	SNK	56.5	280.8	66.6	349.7	Opened in 2007/12
Narssarssuaq, Denmark	NAQ	61.20	314.16	69.96	37.95	
Leirvogur, Iceland	LRV	64.18	338.30	69.32	71.04	
Cape Wellen, Russia	CWE	66.17	190.17	62.88	241.36	Closed in 1996
Great Whale River, Russia	GWR	55.27	282.22	65.45	351.77	Closed in 1984/07
Poste-de-la-Baleine, Canada	PBQ	55.27	282.22	65.45	351.77	Opened in 1984/09 Closed in 2007/11

2.9 Some remarks: Time lag in the derivation and temporal resolution (sampling)

Some of the indices have different class (generation) for operational use. That is, for quasi-real time derivation, different naming is used for them to distinguish from original definition with quality controlled data. For example, in the case of the Dst index, Real-Time (Quick-Look) Dst, Provisional Dst and Final Dst exist, Attempts to increase the temporal resolution of the indices are also made (e.g., Gannon and Love, 2011). (See Annex A).

3 Symbols and abbreviated terms

Bs	Southward component of the interplanetary field (Bs=0 when Bz≥0 and Bs=Bz when Bz<0)
Bz	North-south component of the interplanetary field
F10.7 flux	Measure of the solar radio flux at a wavelength of 10.7 cm at the earth's orbit. Given in units of 10^{-22} W m^{-2}
GLat	Geographic latitude
GLon	Geographic longitude
IMF	Interplanetary magnetic field
MLat	Geomagnetic latitude
MLon	Geomagnetic longitude
MHD	Magnetohydrodynamics
Sq	Daily geomagnetic field variations during quiet conditions (Solar quiet)
UT	Universal Time

4 Classification of Prediction

The accuracy and method of prediction of geomagnetic indices depend on a time scale of prediction. This section introduces some of existing works with 3 classifications of their focusing time scales: short-term (1 hour to a few days), middle-term (a few weeks to a few months), and long-term (half year to one solar cycle). Some of them are actually used and the results are put online (See Annex B)

4.1 Short-term prediction

Stimulated by the space weather programs, there are many proposed methods and related research papers to predict geomagnetic indices in a time scale of 1 hour to a few days. They are categorized into 4 types: (1) Linear prediction technique, (2) Neural network model, (3) Probabilistic prediction with solar wind data, and (4) MHD simulation. Most of recent techniques need real-time solar wind parameters and near real-time geomagnetic observations as the input. Prediction of the solar wind disturbance from solar surface observation may be a key to improve the geomagnetic index prediction.

Examples of prediction:

Kp, ap, and Ap indices

McPherron, Predicting the Ap index from past behavior and solar wind velocity, Phys. Chem. Earth (C), 24,45-56,1999. (Type 1)

Boberg et al., Real time Kp predictions from solar wind data using neural networks, Phys. Chem.

Earth (C), 25, 275-280, 2000. (Type 2)

Costello, Moving the Rice MSFM into a real-time forecast mode using solar wind driven forecast models, Ph.D. dissertation, Rice Univ., Houston, Texas, 1997 (http://hdl.handle.net/1911/19251). (Type 2)

Thomson, Non-linear predictions of Ap by activity class and numerical value, PAGEOPH, 146, 163-193, 1996. (Type 2)

Wing et al., Kp forecast models, J. Geophys. Res., 110, A04203, doi:10.1029/2004JA010500, 2005. (Type 2)

Detman and Joselyn, Real-time Kp predictions from ACE real time solar wind, Solar Wind Nine, edited by Habbal et al., AIP Conf. Proc., 271, 729-732, 1999. (Type 2)

McPherron, Probabilistic forecasting of the 3-h ap index, IEEE Trans. Plasma Science, 32, 1425-1438, 2004. (Type 3)

Dst index

Balikhin et al., Terrestrial magnetosphere as a nonlinear resonator, Geophys. Res. Lett., 28, 1123-1126, 2001. (Type 1)

Boaghe et al., Identification of nonlinear processes in the magnetospheric dynamics andforecasting of Dst index, J. Geophys. Res., 106, 30047-30066, 2001. (Type 1)

Iyemori, T. and H. Maeda, Prediction of Geomagnetic Activities from Solar Wind Parameters Based on the Linear Prediction Theory, in Solar-Terrestrial Predictions Proceedings, Vol. IV, ed. by R.F. Donnelly, Apr.23-27, 1979, Boulder, 1980. (Type 1)

Lundstedt, Solar origin of geomagnetic storms and prediction of storms with the use of neural networks, Surveys in Geophysics, 17, 561-573, 1996. (Type 2)

Stepanova et al., Prediction of Dst variations from polar cap indices using time-delay neural network, J. Atmos. Solar-Terr. Phys., 67, 1658-1664, 2005. (Type 2)

Burton et al., An empirical relationship between interplanetary conditions and Dst, J. Geophys. Res., 80, 4204-4214, 1975. (Type 3)

O'Brien and McPherron, Forecasting the ring current Dst in real time, J. Atmos. Solar Terr. Phys., 62, 1295-1299, 2000. (Type 3)

Temerin and Li, A new model for the prediction of Dst on the basis of the solar wind, J. Geophys. Res., 107, 1472, doi:10.1029/2001JA007532, 2002. (Type 3)

Fok et al., Comprehensive computational model of the Earth's ring current, J. Geophys. Res., 106, 8417-8424, 2001. (Type 4)

AE indices

Iyemori, T. and H. Maeda, Prediction of Geomagnetic Activities from Solar Wind Parameters Based on the Linear Prediction Theory, in Solar-Terrestrial Predictions Proceedings, Vol. IV, ed. by R.F. Donnelly, Apr.23-27, 1979, Boulder, 1980. (Type 1)

Pallocchia et al., AE index forecast at different time scales through an ANN algorithm based on L1 IMF and plasma measurements, J. Atmos. Solar Terr. Phys., 70, 663-668, 2008. (Type 2)

Takalo and Timonen, Neural network prediction of the AE index from the PC index, Phys. Chem. Earth (C), 24, 89-92, 1999. (Type 2)

Li et al., Prediction of the AL index using solar wind parameters, J. Geophys. Res., 112, A06224, doi:10.1029/2006JA011918, 2007. (Type 3)

Kitamura et al., Prpoerties of AE indices derived from real-time global simulation and their implications for solar wind-magnetosphere coupling, J. Geophys. Res., 113, A03S10, doi:10.1029/2007JA012514, 2008. (Type 4)

4.2 Middle-term prediction

There are only a few research papers which use recurrences of geomagnetic disturbances in a time scale of a few weeks to a few months.

Example of prediction:

Zhou and Wei, Prediction of recurrent geomagnetic disturbances by using adaptive filtering, Earth Planets Space, 50, 839-845, 1998. (prediction of the Kp index)

4.3 Long-term prediction

For prediction of geomagnetic indices in a time scale of half year to one solar cycle, proposed technique and/or research papers are very few comparing with those of solar activities such as sun spot numbers or F10.7 flux. However, the sun spot number or F10.7 flux indicates quite different behavior from geomagnetic indices such as aa during some solar cycles. Therefore the long-term prediction method of geomagnetic indices is necessary.

Examples of prediction:

Niehuss et al., Statistical technique for intermediate and long-range estimation of 13-month smoothed solar flux and geomagnetic index, NASA Technical Memorandum 4759, 1996. (prediction of the Ap index)

Cliver et al., A prediction of geomagnetic activity for solar cycle 23, J. Geophys. Res., 104, 6871-6876, 1999. (prediction of the aa index).

The long-term prediction of solar activities (sun spot number and F10.7 flux) is presented by NOAA/Space Weather Prediction Center (Annex B). There could be a possibility to combine the technique of solar activity prediction with solar-geomagnetic disturbance relationship that has been examined by a number of studies.

Examples of solar-geomagnetic disturbance relationship:

Cliiverd, M. A., et al., Increased magnetic storm activity from 1868 to 1995, J. Atom. Solar Terr. Phys., 60, 1047-1056, 1998.

Stamper, R., et al., Solar causes of the long-term increase in geomagnetic activity, J. Geophys. Res., 104, 28325-28342, 1999.

5. Types of prediction method

The prediction methods would be categorized mainly to (1) those based on statistical model and (2) those based on physical principle.

5.1 Prediction based on statistical model

5.1.1 Prediction filter

This prediction method uses the data of precedent interval having the length similar to (or longer than) the period to be predicted. The precision of prediction depends, in general, the temporal distance between most recent data and the epoch when we want to predict. There are two types of prediction: One is to use the index of precedent interval as the input data [see Zhou and Wei, 1998] and another is to use the solar wind parameters [see Iyemori and Maeda, 1980; McPherron et al., 2004; Li et al., 2007].

5.1.2 Neural network model

There exist several models with neural network. This method is applicable for the time scale of several days to sun spot cycle. It has been concluded that the interplanetary magnetic field and solar wind plasma data are significant components for any of the models [see Thomson, 1996: Wing et al., 2005].

5.1.3 Regression analysis

This method is based on the periodicity of geomagnetic disturbances such as the sun spot cycle, annual or semi-annual variation [see Joselyn, 1995]. For long time scale (one to 10 years) prediction, we need a prediction of sun spot number. [see Feynman and Gu]. Similar technique used in the prediction of F10.7 flux and the Ap index [e.g., Niehuss et al.,1996] would be available.

5.2 Prediction based on physical principle

This type of prediction is based on numerical MHD simulation of magnetospheric process or energy principle. These methods need the solar wind parameters as the input. For example, see Burton et al. (1975), Kitamura et al [2008].

6. Evaluation of prediction efficiency

6.1 Definition of prediction error

For a simple time series, the most popular definition of prediction error would be an average of square of differences between the predicted values and the observed values. It is reasonable to adopt this as a measure of prediction error.

6.2 Methods of evaluation

It has been reported that the accuracy of prediction is different for the sun spot maximum and minimum period. It has been also reported that the accuracy is different for different solar cycle. (see Feynman and Gu, 1986) Accuracy is also different for the time scale of prediction. Therefore the prediction efficiency should be shown with specification of various conditions applied for evaluation.

Evaluation of the prediction can be measured by the skill score. In case of a dichotomous forecast, the true skill statistics, the Gilbert skill score, the Heidke skill score, and others can be used (Detman and Joselyn, 1999). In case of prediction of continuous variables, the mean square skill score can be used. (Murphy, 1988). Details of definition of these skill scores are shown in Annex C.

7. Compliance criteria

7.1 Rationale

Prediction principle and scheme should be concisely and clearly described. It is highly required to be published as scientific articles in refereed/peer-review international journals. References of the published articles should be given to public. Otherwise, journal style documents suitable for international journals should be accessible from public.

7.2 Reporting

Prediction results of geomagnetic indices should be open to public for evaluation and application by the third party (e.g., individuals or institutes who are interested in the prediction results). Digital values of the prediction results should be given, at least, in the same data format as the corresponding geomagnetic indices, such as the WDC exchange format.

7.3 Documenting

Information of the following items regarding prediction should be clearly documented or displayed.

Input: (1) Types of data, (2) Source of data, (3) Time resolution of data, (4) Number of data points, (5) Time of data acquisition

Output: (1) Types of predicting data, (2) Time of predicting data, (3) Time of prediction performed

Miscellaneous: (1) Types of prediction method (choose one/some from the 4 types listed in section 4, otherwise describe briefly), (2) Point of contact

7.4 Publishing

When the geomagnetic index becomes available, comparison with the prediction results should be conducted. The comparison includes calculation of prediction error, skill score, correlation coefficients, and so on, as listed in section 5.

7.5 Archiving

Results of prediction should be archived and open to public for evaluation.

Annex A

(informative)

Web sites where geomagnetic indices are available

(1) GFZ-Potsdam

http://www-app3.gfz-potsdam.de/kp_index/ (Kp)

(2) Service International des Indices Geomagnetiques (ISGI)

http://isgi.latmos.ipsl.fr/lesdonne.htm (aa, am, Kp, AE, Dst, PC)

(3) WDC for Geomagnetism, Kyoto

http://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html (AE, Dst, ASY/SYM, RT-AE, RT-Dst)

(4) Arctic and Antarctic Research Institute

http://www.aari.nw.ru/index_en.html (PCS)

(5) WDC for Geomagnetism, Copenhagen

ftp://ftp.space.dtu.dk/WDC/indices/pcn/ (PCN)

(6) US Geological Survey

http://geomag.usgs.gov/dst/ (RT-USGS-Dst)

Annex B

(informative)

Web sites where the space weather predictions and/or now casting are presented.

(1) NOAA Space Environment Center
http://www.sec.noaa.gov/
(2) Magnetospheric Specification and Forecast model (MSFM)
http://space.rice.edu/ISTP/dials.html
(3) International Space Weather Service
http://www.ises-spaceweather.org/
(4) NiCT Space Invironment Information Service
http://www2.nict.go.jp/y/y223/sw_portal/sw_portal-e.html
(5) Belgium SIDC
http://sidc.oma.be/
(6) The Australian Space Weather Agency
http://www.ips.gov.au/Space_Weather
(7) WINDMI model
http://orion.ph.utexas.edu/~windmi/
(8) Lund space weather model
http://www.lund.irf.se/rwc/
(9) CISM forecast model
http://www.bu.edu/cism/
http://lasp.colorado.edu/cism/
(10) Solar Cycle Progression, NOAA/Space Weather Prediction Center
http://www.swpc.noaa.gov/SolarCycle/

Annex C

(informative)

Definition of various skill scores

(1) Dichotomous Forecast

In the following contingency table:

		Forecast	
		Yes	No
Observed	Yes	*x* (hits)	*y* (misses)
	No	*z* (false alarm)	*w* (correct negatives)

The true skill score (TSS) is defined as:

$$\mathrm{TSS}=\frac{xw-yz}{(x+y)(z+w)},$$

The Gilbert skill score (GSS) is defined as:

$$\mathrm{GSS}=\frac{x-c_1}{x+y+z-c_1},$$

$$c_1=\frac{(x+y)(x+z)}{x+y+z+w},$$

The Heidke skill score (HSS) is defined as:

$$\mathrm{HSS}=\frac{x+w-c_2}{x+y+z+w-c_2},$$

$$c_2=\frac{(x+y)(x+z)+(w+y)(w+z)}{x+y+z+w}.$$

(2) Continuous Variables

The mean square skill score (SS) is defined as

$$\mathrm{SS}=1-\frac{MSE(f,x)}{MSE(\bar{x},x)},$$

MSE(f,x)= $\frac{1}{n}\sum_{i=1}^{n}(f_i - x_i)^2$ **,**

where MSE represents “mean square error”; f_i and x_i denote the *i*th forecast and *i*th observation, respectively. $\bar{x}$ is the mean value of x over i=1-n.

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