

Analysis on selected geo-effective events using observations and models at Space Environment Prediction Center

Siqing Liu, <u>Ercha Aa</u>, Qiuzhen Zhong, Bingxian Luo, Zhitao Li, Jingjing Wang, and Jiancun Gong

Space Environment Prediction Center,

National Space Science Center, Chinese Academy of Sciences

SEPC (<u>http://eng.sepc.ac.cn</u>)

- Established in 1992 to support space exploration
- Started to issue space environment prediction in 1998
 - > 7 days/week & 365 days/year



Space Weather Forecasting Services

 SEPC is now an Associate Warning Center of The International Space Environment Service (ISES).

	Space Weather Indices	Ap, Kp, F107, Dst, AE/AU/AL
General Products	Space Weather Events	Solar Flares, SPE, Geomagnetic Storm, Relativistic Electron Enhance
Tailored Products	Manned Space Mission, Lunar Exploration	
Publishing Ways	Website, Text Message, Mail, Email, Mobile App	



Outline

- Overview of the Space Environment
 - > 24th Solar Cycle
 - ≻ Year 2014
- Verification of SEPC/NSSC Forecasting
 - Single Storm Event
 - ➢ Jun, 2014 Jan, 2015

Overview of the 24th Solar Cycle



Entering Decreasing Phase

Plot of Smoothed monthly mean sunspot numbers of Solar Cylce 24 110 prediction 100 Smoothed sunspot # low prediction high prediction 90 smoothly observed O- monthly 80 70 60 50 40 30 2nd Peak 20 1st Peak 10 Feb, 2012 Apr, 2014 0 2012-06 2009-06 2010-06 2011-06 2011-06 2013-06 2015-06 2016-06 2017-06 2018-06 2019-06

Two Peak profile has shown



Estimated Total Sunspot #: ~4400



2014 Overview: Solar Activity

	2013	2014
No sunspot day	0	1
Active Region #	302	319 (+6%)
Average Sunspot #	97	121 (+25%)
Mean F10.7	123	146 (+ 19%)
C-class Flares	1357	1798 (+32%)
M-class Flares	100	208 (+108%)
X-class Flares	12	16 (+ 33%)
SEP Events	7	6 (-14%)









Active Region with Maximum Area in the 24th solar cycle







2014 Overview: Geomagnetic Activity



Kp Values	Geomagnetic Activity level
Kp = 4	Active
Kp = 5	Minor Storm
Kp = 6	Moderate Storm
Kp = 7/8	Strong Storm
Кр = 9	Severe Storm

	2013	2014
Average AP	8	9 (+13%)
# of Days for AP≥15	41	49 (+ 20%)
Geomagnetic Active Days	154	170 (+10%)
Minor/Moderate Storm Days	49	47 (-4%)
Strong Storm Days	1	1 (0%)
Maximum AP	51	47 (-8%)
Maximum Kp	7	7 (0%)

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SEPC Space Weather Forecasting Products (Index/Flux)



Geomagnetic Storm Lists from Jun, 2014-Jan, 2015

Time (Y/M/D)	Storm Level/Duration	Causes Description	Remarks
2014/06/08-06/09	Minor/ 3 hours	CME from Filament	
2014/06/18	Minor/ 3 hours	CIR	
2014/08/19	Moderate/ 3 hours	CME from Filament	
2014/08/27-08/31	Minor/ 6 hours	CME + CIR	
2014/09/13-09/14	Strong/ 3h+ Moderate/ 3h + Minor/ 9h	CME from AR2158, X1.6 flare	
2014/09/19	Minor/ 3 hours	CME from AR2157 + following CIR	
2014/10/14-10/15	Minor/ 9 hours	CME from filament	Storm Levels
2014/10/20-10/22	Minor/ 3 hours	CIR	Minor: Kp=5
2014/11/10-11/12	Minor/ 6 hours	CME from AR2205 + following CIR	Moderate: Kp=6
2014/12/06-12/09	Minor/ 6 hours	CIR	Strong: $Kp = 7/8$
2014/12/12	Minor/ 3 hours	CIR	Severe. Kp = 9
2014/12/21-12/24	Minor/ 6 hours	CME from AR2242 + following CIR	
2014/12/28-12/30	Minor/ 6 hours	CIR	
2015/01/02-01/03	Minor/ 3 hours	CME from filament	
2015/01/04-01/05	Minor/ 9 hours	CME	
2015/01/07-01/08	Strong/3h + Moderate/3h	CME	

Geomagnetic storms @ Aug 27-31, 2014



Forecasting Verification Factors

Factor	Formulation	Reflection
Mean Error (ME)	$ME = \frac{1}{N} \sum_{i=1}^{N} (F_i - O_i)$	Bias
Mean Absolute Error (MAE)	$MAE = \frac{1}{N} \sum_{i=1}^{N} F_i - O_i $	Accuracy
Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (F_i - O_i)^2}$	Accuracy
Correlation Coefficient (CC)	$CC = \frac{\sum_{i=1}^{N} (F_i - \overline{F})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{N} (F_i - \overline{F})^2} \sqrt{\sqrt{\sum_{i=1}^{N} (O_i - \overline{O})^2}}}$	Association
MSE Skill Score (MSESS or PE)	$MSESS = 1 - \frac{MSE_{forecast}}{MSE_{reference}}$	Skill

Geomagnetic Storm@ Aug. 27-31, 2014 : Ap forecasting results Model Description

> Ap forecasting for future 27-days using auto-regression analysis model



Evaluation	Ap model forecasting results	Ap artificial forecasting results	
What is the forecasting performance	Larger bias during storm time Fair accuracy agreement Higher correlation coefficients but lower skills	Smaller bias during storm time Better accuracy agreement Lower correlation coefficients & Higher skills	
Why such Performance	Focus on the general consistence of the 27- days prediction with details being neglected	More flexible reaction & adjustment of people based on the level and duration of the current storm	
Where it can be used and how to use	Where: Space Weather prediction, research and application, and SEPC/NSSC online forecasting tools How : Forecasting results (future 27-days by model and 3 days by artificial) are updated and published on the website & mobile App simultaneously, and can be browsed & downloaded conveniently by user		

Geomagnetic Storm@ Aug. 27-31, 2014 : $F_{10.7}$ forecasting results Model Description

 \succ F_{10.7} forecasting for future 27-days using auto-regression analysis model with 54-orders

	F _{10.7}	F _{10.7} Deflection		Better One		160		
	mod art	Reflection	Mod	Art	150 — OBS — MOD			
ME	-0.583	0.75	Bias	٧				
MAE	7.583	6.083	Accuracy		V			
RMSE	10.571	9.543	Accuracy		V			
СС	0.781	0.748	Association	V				
MSESS	0.011	0.194	Skill		V	110 ⊑∃ Aug 25 Aug 27 Aug 29 Aug 31 Sep 02 Sep 04		

Evaluation	F _{10.7} model forecasting results	F _{10.7} artificial forecasting results	
What is the forecasting performance	Comparable bias between mod and art results Fair accuracy agreement (~7-8% relative errors) Higher correlation coefficients but lower skills 1-day delay in grasping inflection point	Comparable bias between mod and art results Fair accuracy agreement (~7%-8% relative errors) Lower correlation coefficients & moderate skills 1-day delay in grasping inflection point	
Why such	Generally stable variation trends, which is readily to grab		
Performance	Historical periodical data cannot reflect the sudden appearance/disappearance of active region		
Where it can	Where: Space weather prediction, and empirical/theoretical models with F _{10.7} as driven factor		
be used and	How: Forecasting results (future 27-days by model and 3 days by artificial) are updated and published		
how to use	on the website & mobile App simultaneously, and can be browsed & downloaded conveniently by users		

Geomagnetic Storm@ Aug. 27-31, 2014 : D_{st} forecasting results Model Description

I-h forecasting of D_{st} index using real time solar wind data from ACE observation based on the influence of S_w dynamic pressure to the decay & injection of ring current



Geomagnetic Storm@ Aug. 27-31, 2014 : Kp forecasting results

- **Model Description**
- I-hour in advance forecasting of Kp index using real time solar wind data from ACE observation based on neural network algorithms.

	Kp mod	Reflection	Evaluation	
ME	-0.83	Bias		
MAE	0.897	Accuracy	~20%-30%	
RMSE	1.13	Accuracy		
СС	0.813	Association	High	
MSESS	0.340	Skill	Moderate	0 5 Aug 27 Aug 29 Aug 31 Sep 02 Sep 04

Evaluation	Kp model forecasting results
What is the forecasting performance	Commonly Underestimation of Kp index around 20%-30% High correlation coefficients Moderate skill score
Why such Performance	Relative stable and subtle fluctuation of the geomagnetic field for the 24 th solar cycle, which as been used as the background values of the input of neural network
Where it can be used and how to use	Where: Space weather prediction, geomagnetic storm alert and warning How: Forecasting results (1-hour in advance) are updated and published on the website & mobile App simultaneously, and can be browsed & downloaded conveniently by users.

Geomagnetic Storm@ Aug. 27-31, 2014 : Relativistic Electron Forecasting Model Description

1-day in advance forecasting of daily integrated relativistic electron flux > 2Mev at geosynchronous orbit using linear prediction combined with Kalman filter



Evaluation	Electron flux model forecasting results
What is the	Sometimes lagged by 24 hours in grasping the sudden variation of the values
forecasting	Less than 10% prediction errors
performance	High correlation coefficients and skills
Why such Performance	Restriction of linear prediction in representing sudden variation
Where it can	Where: Space weather prediction, aircraft alert and warning at GEO orbit
be used and	How: Forecasting results (1-day in advance) are updated and published on the website & mobile App
how to use	simultaneously, and can be browsed & downloaded conveniently by users.

Geomagnetic Storm@ Aug. 27-31, 2014 : AE Index Forecasting Model Description

I-hour in advance forecasting of AE Index with 10 min resolution based on empirical functions by using solar wind data, IMF parameters, and F10.7 index as input



Evaluation	Electron flux model forecasting results
What is the forecasting performance	Very good performance in grabbing the trends of the variation and the level of the peak values 15%-20% prediction errors High correlation coefficients and skills
Why such Performance	Proper settings of the empirical function in establishing the relationship between solar wind and electro-jet in polar region
Where it can be used and how to use	Where: Space weather prediction, or driven factor for other empirical/theoretical models How: Forecasting results (1-hour in advance and 10 min resolution) are updated and published on the website & mobile App simultaneously, and can be browsed & downloaded conveniently by users.

Verification of SEPC Forecasting Jun 2014 - Jan 2015

Verification of SEPC Forecasting: Accuracy

- > How to choose appropriate factor to represent forecasting accuracy?
- > RMSE for index with low base values, and NRMSE for high base values

	$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (F_i - O_i)^2}$	$NRMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{F_i - O_i}{O_i}\right)^2}$
Ap Model	6.76	
Ap Artificial	5.87	
Кр	1.19	
Dst	14.37	
F10.7 Model	7.11	4.89%
F10.7 Artificial	7.60	5.22%
AE	72.03	32.43%
Relativistic Electron	0.47 (after log10)	6.54%

Verification of SEPC Forecasting: Association and Skill



Correlation Coefficients

Evaluation: Association

Relative high correlation coefficients for various parameters except for **Ap index model**

Skill Score (PE)



Evaluation: Skill Score

Relative high skill score for **F10.7**, **Relativistic electron**, and AE index comparing with persistence model.

Summary and Conclusions

Overview of the 24th solar cycle

The current 24th solar cycle has a relative small activity level, and the solar activity has reached the highest point and began to decrease.

Overview of 2014

The solar activity is stronger than that of the year before. The geomagnetic activity remains almost the same. The average Ap levels and geomagnetic active days are increased, but the storm days are almost the same with the year before.

□ Verification of SEPC forecasting results

The forecasting results of Ap, Kp, F_{10.7}, Dst, Relativistic Electron, and AE index have been verified for selected event and for period of Jun 2013-Jan 2014 based on the bias, accuracy, association, and skill respectively. The performance of the model as well as the artificial forecast have been evaluated accordingly. The forecasting results can be used for space weather prediction, operational system in SEPC/NSSC, and web-based forecasting tools. The forecasting results are updated and published on the website & mobile App simultaneously, and can be browsed & downloaded conveniently by users.

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Thanks for your attention!



Space Environment Prediction Center, NSSC/CAS