Validation of the Kp Geomagnetic Index Forecast at CCMC

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Introduction

- **Space weather** refers to the sun's solar activity and conditions in the solar wind, magnetosphere and ionosphere that can affect satellites, airplanes, communication, power grids, navigation and human health.
- The Community Coordinated Modeling Center (CCMC) Space Weather Research Center (SWRC) sub-team provides space weather services to NASA robotic mission operators and science campaigns and prototypes new models, forecasting techniques, and procedures.
- In addition to this study, I was trained as a space weather student forecaster.
- A **geomagnetic storm** is a **disturbance** in the **magnetosphere** caused by a solar event such as a coronal mass ejection, and high speed solar wind streams.
- The **Kp index** is a **measure of geomagnetic disturbances** in the magnetosphere such as geomagnetic storms and substorms. The index is produced every 3 hours with values **ranging from 0 to 9** from **weak to severe.**
- The index value corresponds to the **maximum of the horizontal component of the Earth's magnetic field** at magnetometer ground stations during each 3 hour synoptic period and is a measure of how disturbed the magnetosphere is.
- The CCMC **predicts the Kp index** using the **Newell et al. (2007) equation** to give **1 hour advance notice** of the intensity of a storm in real time. The relation uses **ACE and DSCOVR data at L1** (235 R_E ahead of Earth) **as input.**
- It is important to quantify **Kp forecast performance** so that NASA missions have **confidence in the space weather forecast** and **understand its limitations**.
- In this study we performed **validation** on the Newell et al. (2007) Kp prediction equation from **December 2010 to July 2017.**

Background

The Newell et al. (2007) Kp prediction equation is based on a solar wind-magnetosphere coupling function. Coupling functions relate solar wind parameters to processes in the magnetosphere.

$$\frac{d\Phi_{MP}}{dt} = v_{bulk}^{4/3} B_T^{2/3} \sin^{8/3}\left(\frac{\theta_C}{2}\right)$$

$\frac{d\Phi_{MP}}{dt}$ Change over time of the magnetic flux at the magnetopause

v_{bulk} Solar wind speed

B_T Perpendicular component of the magnetic field using the two axis By and Bz.

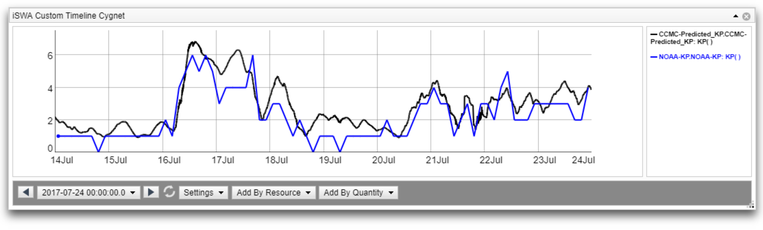
θ_C Clock angle of the interplanetary magnetic field of 90◦ (westward), 135◦ (southwestward), or 180◦ (southward).

$$K_P = 9.5 - e^{2.17676 - 5.2001\left(\frac{d\Phi_{MP}}{dt}\right)}$$

This equation is based on the correlation between observed Kp values and the coupling function.

Methodology

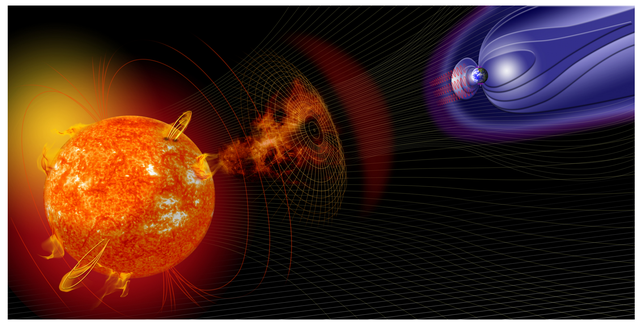
- The **observed and predicted Kp data** was downloaded in text format from the iSWA web service API for 12/02/2011 to 07/02/2017



- The observed Kp index has a time cadence of 3 hours while the Kp forecast has a cadence of roughly 1 minute. For this reason, the **forecast was reduced to a single number every 3 hours by computing the average, minimum, and maximum for each 3 hour synoptic period.**

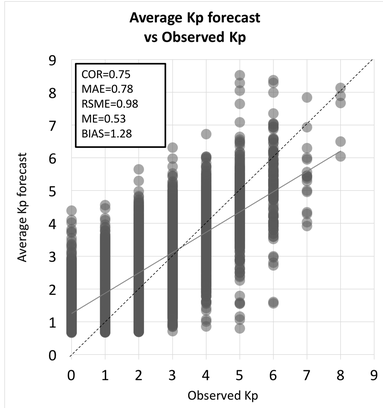
Forecast verification:

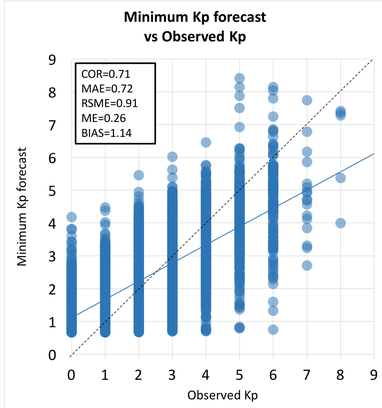
- Persistence is taken as the **reference forecast**, this assumes the forecast for the next synoptic period is the same as the current Kp value.
- Next we computed the Kp error for each forecast (average, minimum, maximum) and each synoptic period: **Kp error = Kp forecast - Kp observed**
- To **quantify forecast performance** we computed the mean error, mean absolute error, root mean square error, multiplicative bias and correlation coefficient.
- We also computed a **contingency table** for each forecast and produced **skill scores**. The results are compared to the perfect score and reference forecast skill score.

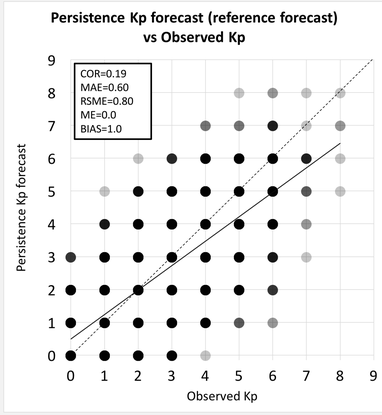


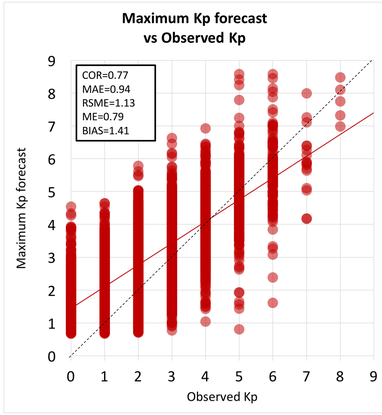
Kp Error Results

Kp error = Kp forecast - Kp observed

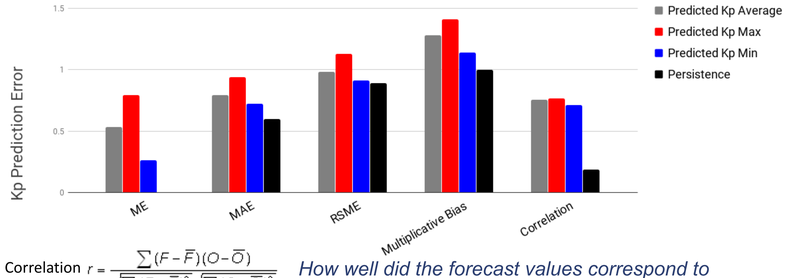








Persistence: Provides a **reference forecast** to compare performance against. Persistence assumes the **Kp index** for the **next synoptic period** is the **same** as the **current synoptic period** (no change in value).



Correlation Coefficient $r = \frac{\sum(F-\bar{F})(O-\bar{O})}{\sqrt{\sum(F-\bar{F})^2}\sqrt{\sum(O-\bar{O})^2}}$ *How well did the forecast values correspond to the observed values?*

$Bias = \frac{\frac{1}{N}\sum_{i=1}^{N} F_i}{\frac{1}{N}\sum_{i=1}^{N} O_i}$ *How does the average forecast magnitude compare to the average observed magnitude?*

$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$ *What is the average magnitude of the forecast errors, weighted according to the square of the error?*

$MAE = \frac{1}{N}\sum_{i=1}^{N}|F_i - O_i|$ *What is the average magnitude of the forecast errors?*

$Mean\ Error = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$ *What is the average forecast error?*

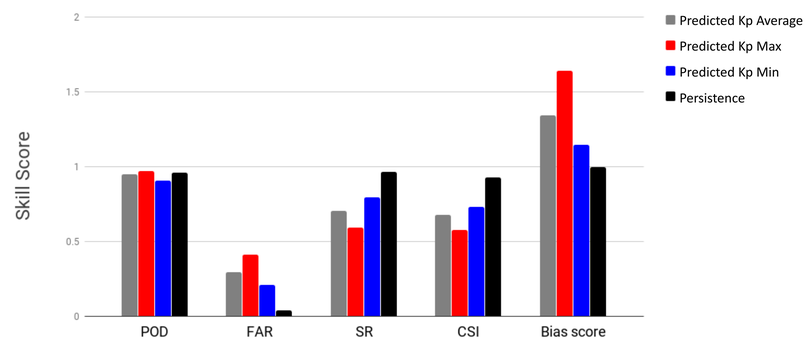
Skill Score Results

Contingency Table: Is used to organize and describe the associated outcomes between four combinations of predicted and observed.

	Observed Occurred	Observed Did Not Occur
Predicted Kp Average Occurred	Hit (H) (11000) -1< Kp error <1	False Alarm (FA) (624) Kp error > +1
Predicted Kp Average Did Not Occur	Miss (M) (4608) Kp error < -1	Correct Rejections (CR) N/A

Skill Score: The forecast verification skill scores assess the quality of the forecast, by comparing it to observations.

Skill Score		Equation	Perfect Score	Description
POD	Hit Rate	$\frac{H}{H+M}$	1	The fraction of predicted hit that did occur.
FAR	False Alarm Rates	$\frac{FA}{FA+H}$	0	The fraction of predicted hit that did not occur.
SR	Success Ratio	$\frac{H}{H+FA}$	1	The fraction of observed Kp values that were predicted
CSI	Critical Success Index	$\frac{H}{H+FA+M}$	1	Fraction of observed and forecast events that were correctly predicted
Bias Score	Frequency Bias	$\frac{H+FA}{H+M}$	1	Ratio of the frequency of forecast events to the frequency of observed events



Conclusions

- **Skill score** and **error results** show that the **minimum of the predicted Kp** over each synoptic period from the Newell et al. (2007) Kp prediction equation **performed better than the maximum or average of the prediction**.
- **Persistence** (reference forecast) **outperformed all of the Kp forecasts** (minimum, maximum, and average)
- While the persistence forecast beats the **Newell Kp forecast**, the forecast still has a reasonable **mean absolute error of less than 1,** but has overall **bias towards overprediction**.
- Future work: compare with persistence forecasts constructed with a lag larger than 1 day.

References

Newell, P.T., Sotirelis, T., Liou, K., Meng, C. I., Rich, F.J.: 2007, A nearly universal solar wind-magnetopause coupling function inferred from 10 magnetospheric state variables. J. Geophy. Res. 112, 1206.

http://ccmc.gsfc.nasa.gov/iswa

http://www.cawcr.gov.au/projects/verification/

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