A Simple Auroral Forecaster

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2 MATEMATICAL REPRESENTATIONS OF THE AURORAL OVALS

METHOD A: The Feldstein-Starkov ovals

Poleward and equatorward boundaries of auroral oval in geomagnetic co-latitude:

$$\theta = A_0 + A_1 \cos\left[15\left(t+\alpha_1\right)\right] + A_2 \cos\left[15\left(2t+\alpha_2\right)\right] + A_3 \cos\left[15\left(3t+\alpha_3\right)\right],$$

where amplitudes A_i and phases α_i is given by

$$A_i \; or \; \alpha_i = b_0 + b_1 \log_{10}|AL| + b_2 \log_{10}^2 |AL| + b_3 \log_{10}^3 |AL|.$$

The magnetic input parameter is the AL index – related to the planetary Kp index:

$$AL = 18 - 12.3 \cdot K_p + 27.2 \cdot K_p^2 - 2 \cdot K_p^3$$

REFERENCES

[1] Starkov, G. V., Mathematical model of the auroral boundaries, Geomagnetism and Aeronomy, 34, 3, 331-336, 1994.

[2] Starkov, G. V., Statistical dependences between the magnetic activity indices, Geomagnetism and Aeronomy, 34, 1, 101-103, 1994.

2 MATEMATICAL REPRESENTATIONS OF THE AURORAL OVALS

METHOD B: The Zhang-Paxton ovals

The electron energy flux is derived from GUVI imager data (TIMED satellite)

$$Q_m = \frac{A'_{0m} \cdot \exp\left[\left(x - A'_{1m}\right) / A'_{2m}\right]}{\left\{1 + \exp\left[\left(x - A'_{1m}\right) / A'_{3m}\right]\right\}^2}, \qquad x = \pi / 2 - \left|\theta\right|$$

where x is co-magnetic latitude. The coefficients $A'$is are calculated as

$$A'_{im} = b'_{0m} + \sum_{n=1}^{6} \left\{ b'_{nm} \cos\left(\frac{n\pi t}{12}\right) + b''_{nm} \sin\left(\frac{n\pi t}{12}\right) \right\}.$$

The coefficients *b'* is tabulated as a function of six sub-intervals (*m*) of Kp index.

REFERENCE

[3] Zhang Y., and L. J. Paxton, An empirical Kp-dependent global auroral model based on TIMED/GUVI data, *J. Atm. Solar-Terr. Phys.*, **70**, 1231-1242, 2008.

GEOGRAPHICAL TRANSFORM

Cartesian components:

$$x_m = \sin\theta \cdot \cos\phi$$
$$y_m = \sin\theta \cdot \sin\phi$$
$$z_m = \cos\theta$$

$$\phi = 2\pi \cdot t / 24 + \Delta\phi(t)$$

$\Delta\phi(t)$ - is the longitudinal difference between the sub-solar point and the magnetic poles at time *t* (hours).

Geographical coordinates:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\phi_0' \cos\lambda & -\sin\phi_0' & \cos\phi_0' \sin\lambda \\ \sin\phi_0' \cos\lambda & \cos\phi_0' & \sin\phi_0' \sin\lambda \\ -\sin\lambda & 0 & \cos\lambda \end{bmatrix} \cdot \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix}$$

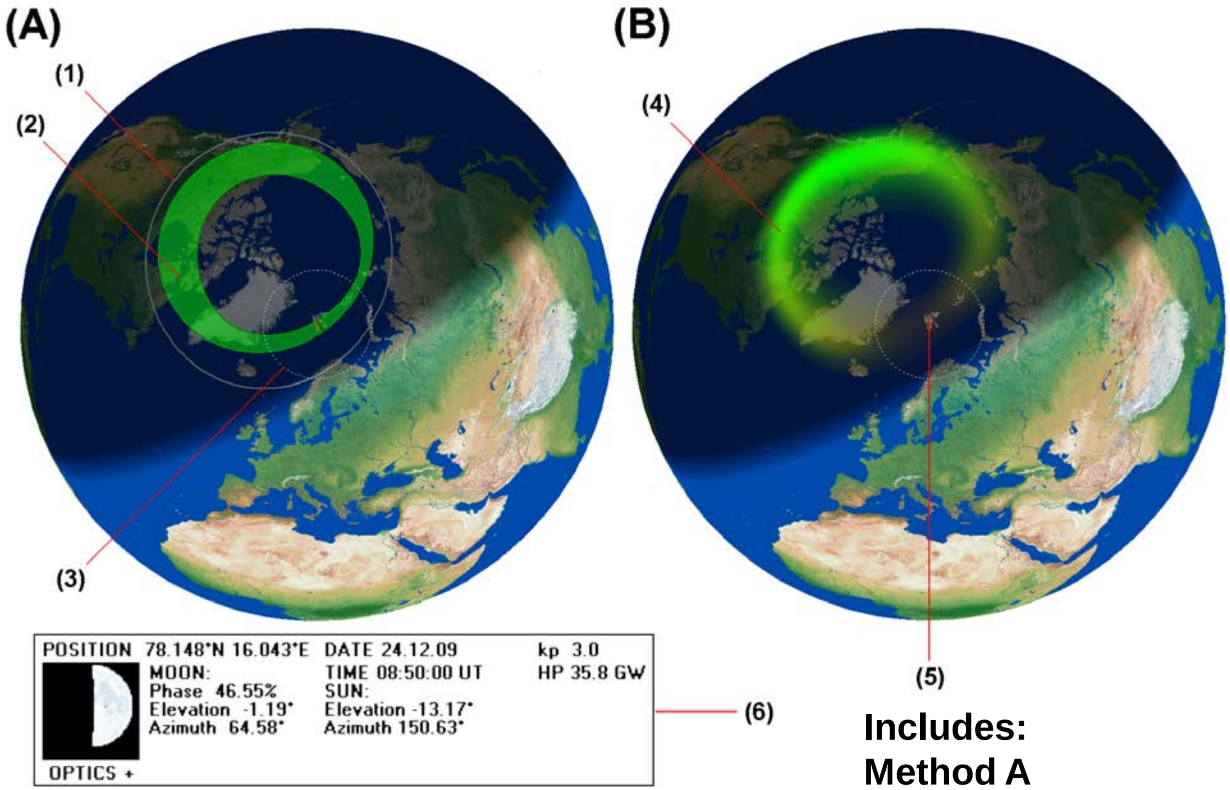
$$\theta_0' = 82.41^o N$$
$$\phi_0' = -82.86^o E$$
$$\lambda = \pi / 2 - \theta_0'$$

Latitude and longitude:

$$\theta' = \frac{\pi}{2} - \cos^{-1}(z) \qquad \phi' = \begin{cases} \psi & \forall \quad x > 0 \\ \psi + \pi & \quad x < 0 \end{cases}$$

$$\psi = \tan^{-1}(y / x)$$

VISUALIZATION



The ovals are visualized with a stand alone 32-bit executable Windows program called

SvalTrackII.

The program is written in Borland Delphi 5 – Pascal and uses a Geographic Information system (GIS) unit called TGlobe.

The twilight zone, night- and dayside of the Earth are projected with grades of shade on the Globe as a function of time.

Includes:

Method A

(1) Equatorward boundary of the diffuse aurora
(2) Feldstein & Starkov oval
(3) Field of view aurora observer

Method (B)

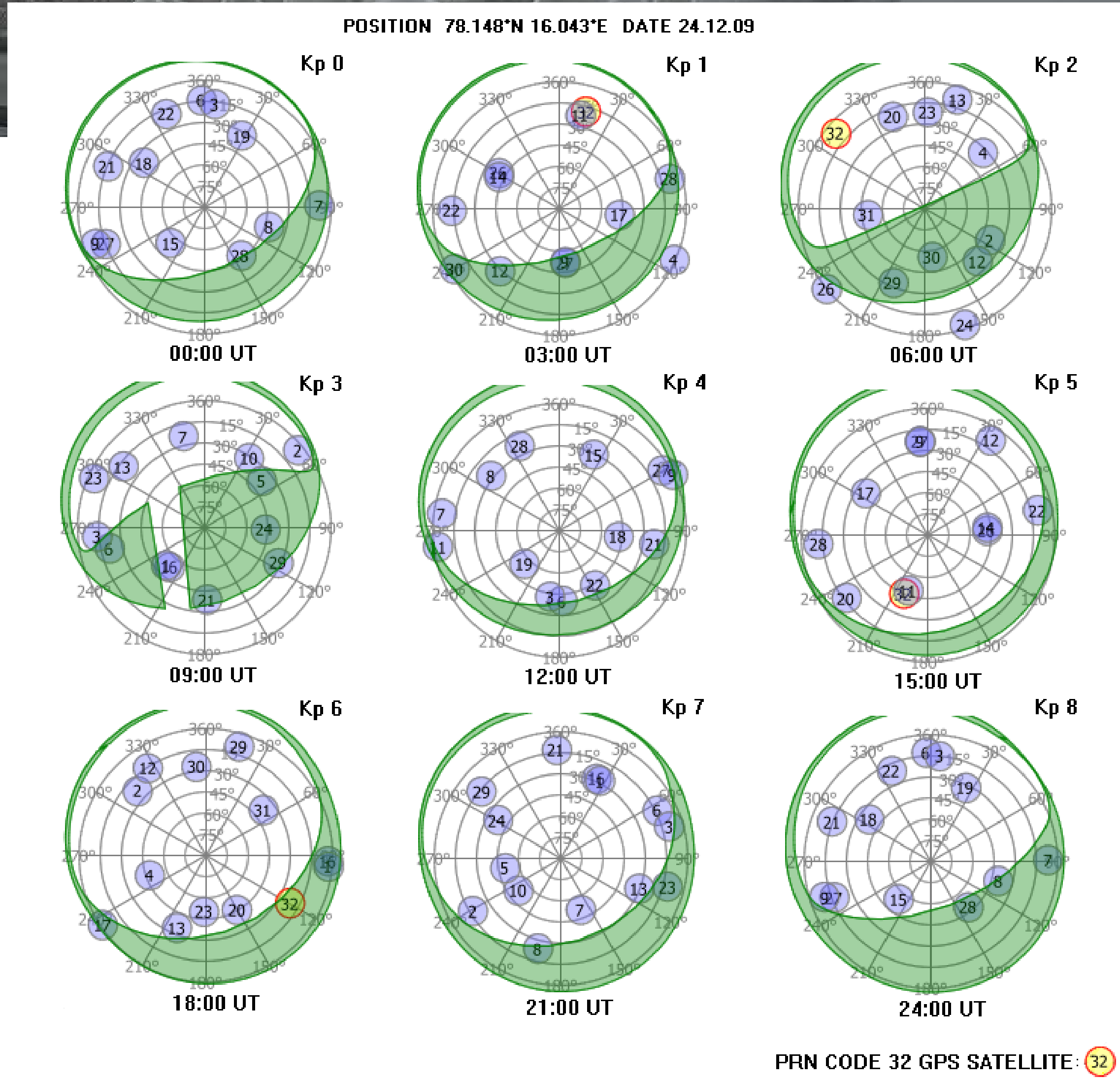
(4) Zhang & Paxton oval
(5) Observer location
(6) Moon and Sun information at local site

VISUALIZATION

All Sky Satellite View

Local all sky satellite view of ovals as a function of *Kp* index [0…8] and time for 24th Dec. 2009 from KHO (78N,16E).

Based on Feldstein & Starkov and TLE element SGP4 code by [4]



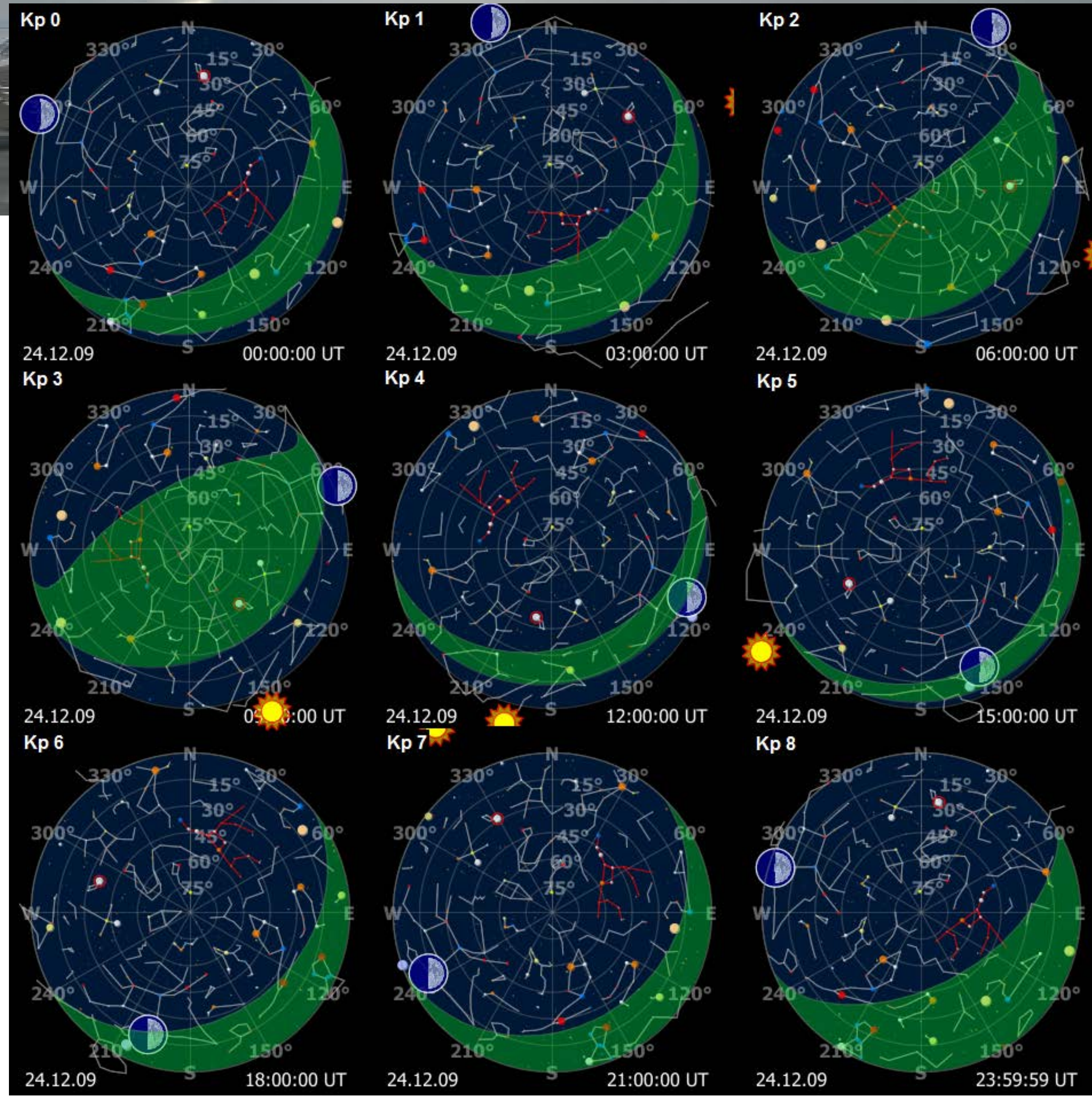
[4] Vallado, D. A., P. Crawford, R. Hujsak, and T. S. Kelso, Revisiting Space track Report #3, American Institute of Aeronautics and Astronautics (AIAA), Report No. AIAA 2006-6753, 1-88, 2006.

All Sky Star View

Local all sky star view of ovals as a function of *Kp* index [0…8] and time for 24th Dec. 2009 from KHO (78N,16E).

Based on Feldstein & Starkov ovals and Sky Charts software by [5]

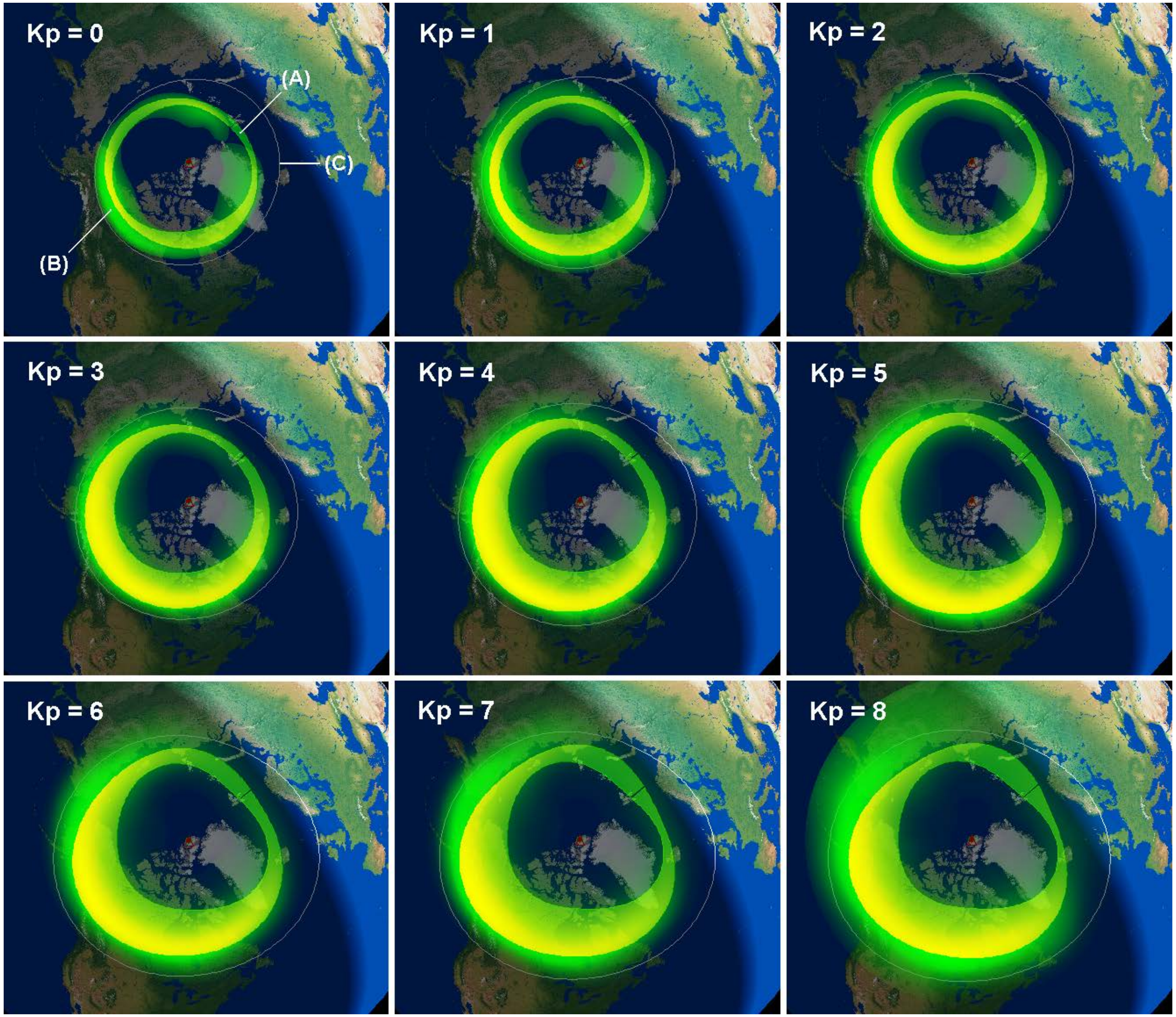
Catalog: BSC5



[5] Cartes du Ciel, http://www.ap-i.net/skychart/

ANIMATION

Animated aurora ovals as a function of *Kp* index [0…8] at 08:50 UT, 24th December 2009



UNIS

MODEL COMPARISION

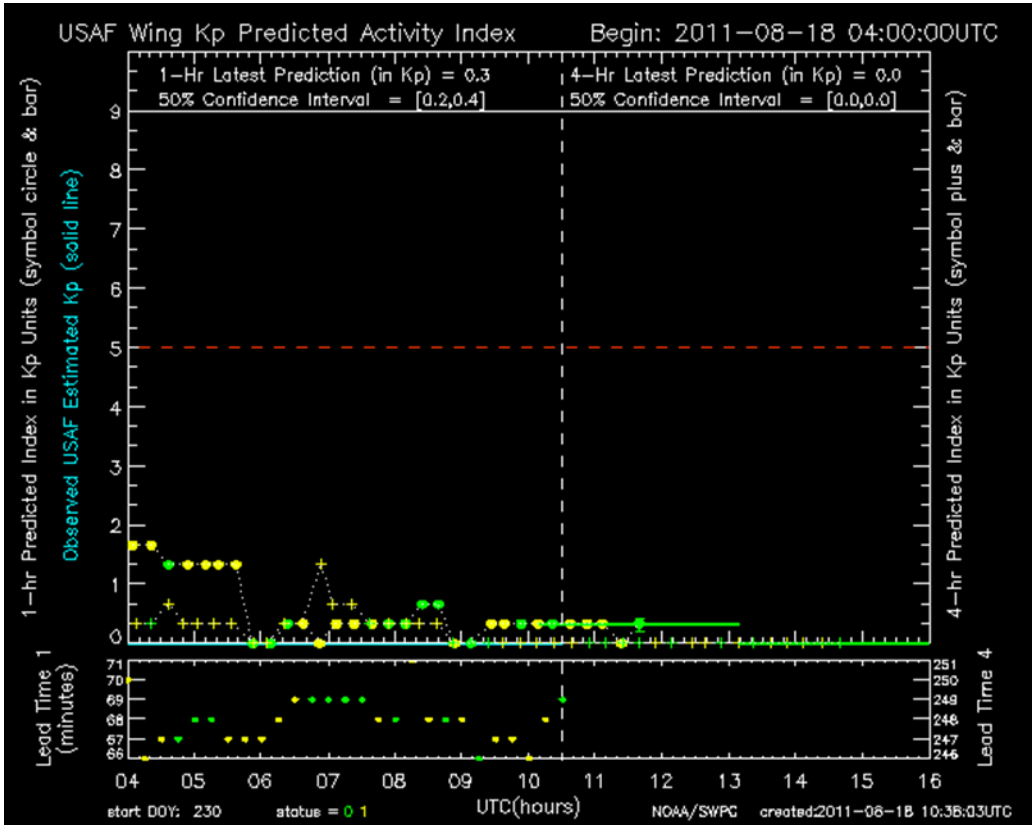
Kp	Auroral activity	Level	A∩B [%]	B∩C [%]	Q_{max} [mW/m^2]
0	Very low	Low normal conditions	32	99	1.65
1	Low		26	86	2.10
2	Low normal		33	87	3.20
3	Normal		35	87	4.34
4	Calm storm		36	89	5.34
5	Minor storm	Storm conditions	35	88	6.45
6	Moderate storm		32	84	8.36
7	Strong storm		30	83	12.18
8	Severe storm		24	68	12.91
9	Extreme storm		22	62	18.10

Auroral intersections: (A) Zhang-Paxton, **(B)** Feldstein-Starkov and **(C)** Equatorward boundary of diffuse aurora

Q_{min}= 0.25 *ergs cm^{-2} s^{-1}*.

THE +1 or +4 HOUR PREDICTED Kp INDEX

SOURCE: Space Weather Prediction Centre (SWPC) at the National Oceanic and Atmospheric Administration (NOAA).



The Wing Kp predicted Activity Index model.

Reference

Wing, S., J. R. Johnson, J. Jen, C.-I. Meng, D. G. Sibeck, K. Bechtold, J. Freeman, K. Costello, M. Balikhin, and K. Takahashi, Kp forecast models, *J. Geophys. Res.*, 110, A04203, doi:10.1029/ 2004JA010500, 2005.

It is a neural network algorithm that trains on the response of the Kp geomagnetic activity index to solar wind parameters / data. It predicts +1 or+ 4 hours ahead.

The model returns an one hour prediction in units of Kp. It updates / predicts every 15 minutes.

15 minutes oval update:
http://kho.unis.no

http://www.swpc.noaa.gov/wingkp/

THE KHO AURORAL OVAL FORECAST SERVICE

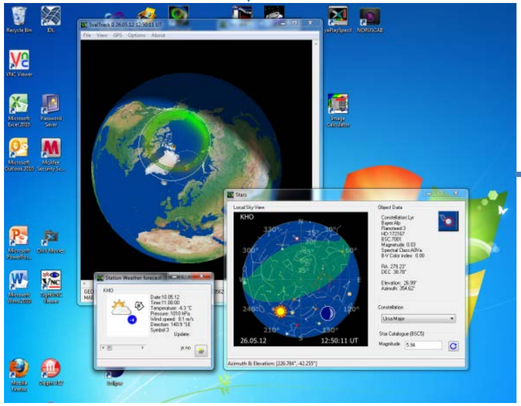
Weather forecasts
YR.NO (60 min.)

Kp index
NOAA-SWPC
(15 min.)

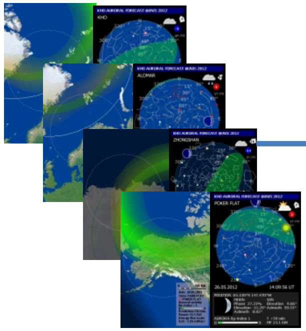
SERVER / PC
RUNS
SVALTRACKII.EXE

WEB SERVER
http://kho.unis.no

Internet



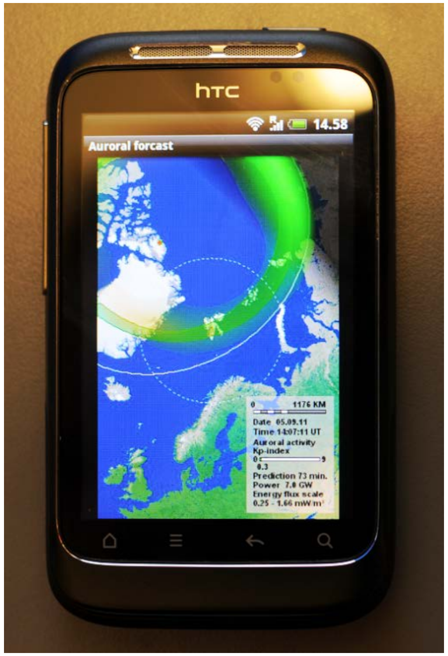
Stations
(60 sec.)



+1 or +4 hours predictions

Mobile Auroral forecast

THE KHO MOBILE AURORAL OVAL FORECAST SERVICE



The auroral forecast on a HTC wildfire phone.

QR-code for Android app

In August, as part of the Andøya rocket range 50 years celebration, we will release mobile applications for all smart phones:

1) Android
2) iPhone
3) Windows phone

Company http://appex.no

Some REMARKS and QUESTIONS

1) As expected the Zhang-Paxton ovals deduced by space borne data are wider than the ground based Feldstein-Starkov ovals.

2) In spite of difference in methods and platforms, the model ovals coincide fairly well in shape for low to normal conditions on the nightside.

3) The equatorward border of the diffuse aurora is well defined by both methods on the nightside for *Kp*<7.

4) On the dayside, there is a need to study further oval shapes for all levels of auroral activity, especially the equatorward border of the diffuse aurora.

5) Is it possible to derive / predict the *Kp* index from the Norwegian chain of magnetometers, as a real time service?

6) Can other data sources like our new HF radar looking east and future GPS scintillations receiver chains contribute?

7) Optical validation …

Acknowledgement

We wish to thank

1) The National Oceanic and Atmospheric Administration (NOAA) - Space Weather Prediction Centre for allowing us to download the predicted value of the K_p index every 15 minutes.

2) The Research Council of Norway through the project named: Norwegian and Russian Upper Atmosphere Co-operation On Svalbard part 2 # 196173/S30 (NORUSCA2).

3) The Nordic Council of Ministers: Arctic cooperation program # A10162.

PS!
The Svaltrack II program is *fredware*…it cost II beers.