Space weather forecasts via PROGRESS

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Project website: https://ssg.group.shef.ac.uk/progress/html/index.phtml

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Overview

Project Overview

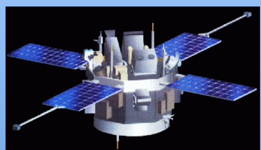
- Forecast of solar wind parameters at L1
- Evolution of the radiation belt electron environment
- Forecast of the evolution of geomagnetic activity

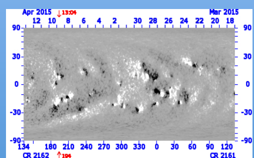
NARMAX modeling

- New Kp model for active periods

PROGRESS

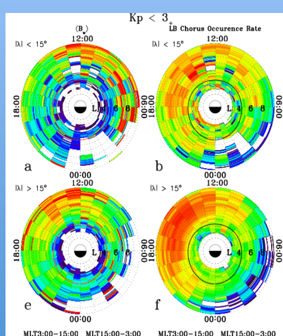
WP 2: Propagation of the Solar wind from the Sun to L1



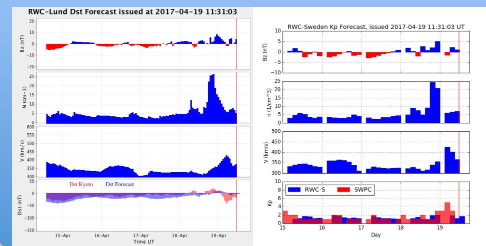


AWSoM/SWIFT

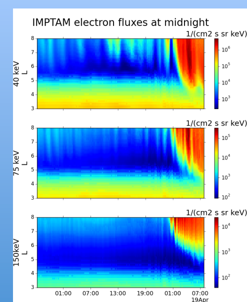
WP 4: Development of new statistical models and the re-estimation of quasi-linear diffusion coefficients



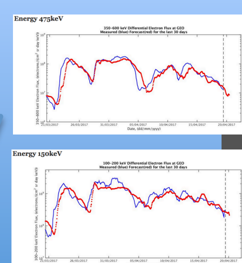
WP 3: Forecast of the Evolution of Geomagnetic indices

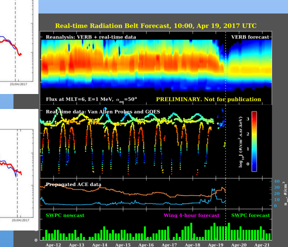


WP 5: Low energy electron model



WP 6: Radiation belt forecasts





WP 7: Fusion of forecast tools

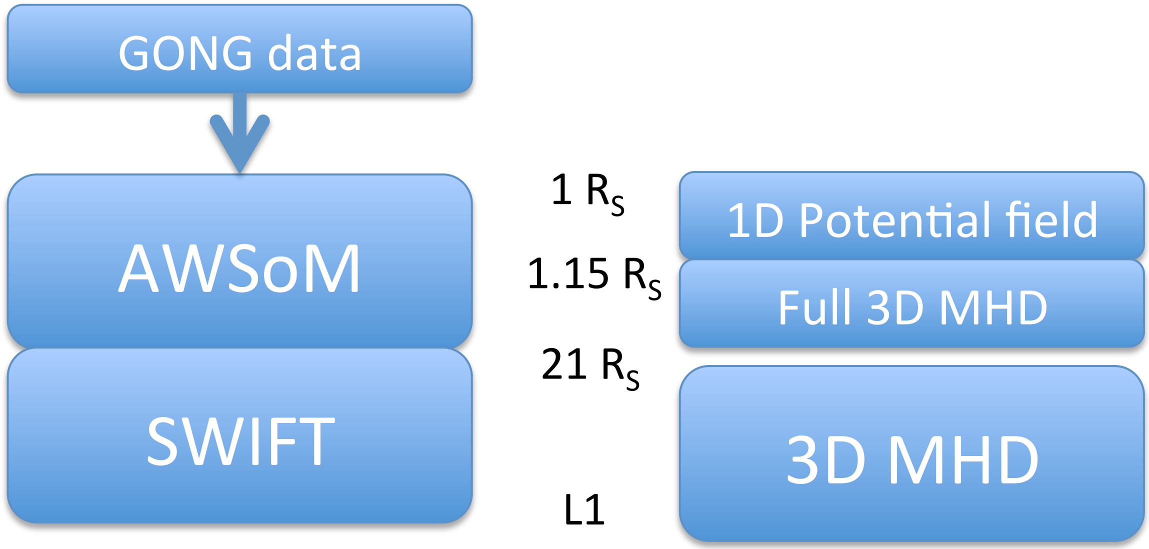
Current Conditions

Time: 2017-04-19 12:15:12 UTC

Magnetosphere	Current	Forecast
Dst (nT)	-18	-40
Kp	1	1
Solar wind	Current	Forecast
|B| (nT)	10.1	9.2
Bz (nT gsm)	3.2	1
Density (cm^{-3})	5	6.5
Velocity (kms^{-1})	375.1	382.2
GEO e^- flux	Current	Forecast
F>2MeV	7.6409	6.1694
F>800keV	9.0563	8.1747

AWSoM/SWIFT

AIM: Forecast of solar wind conditions at L1



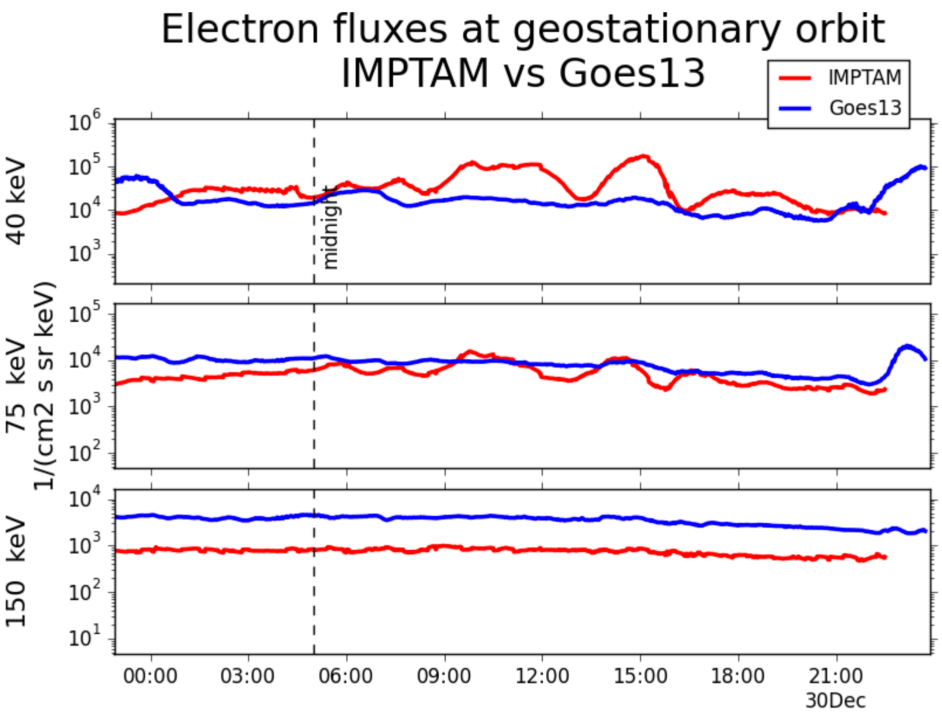
L1 forecasts from SWIFT available

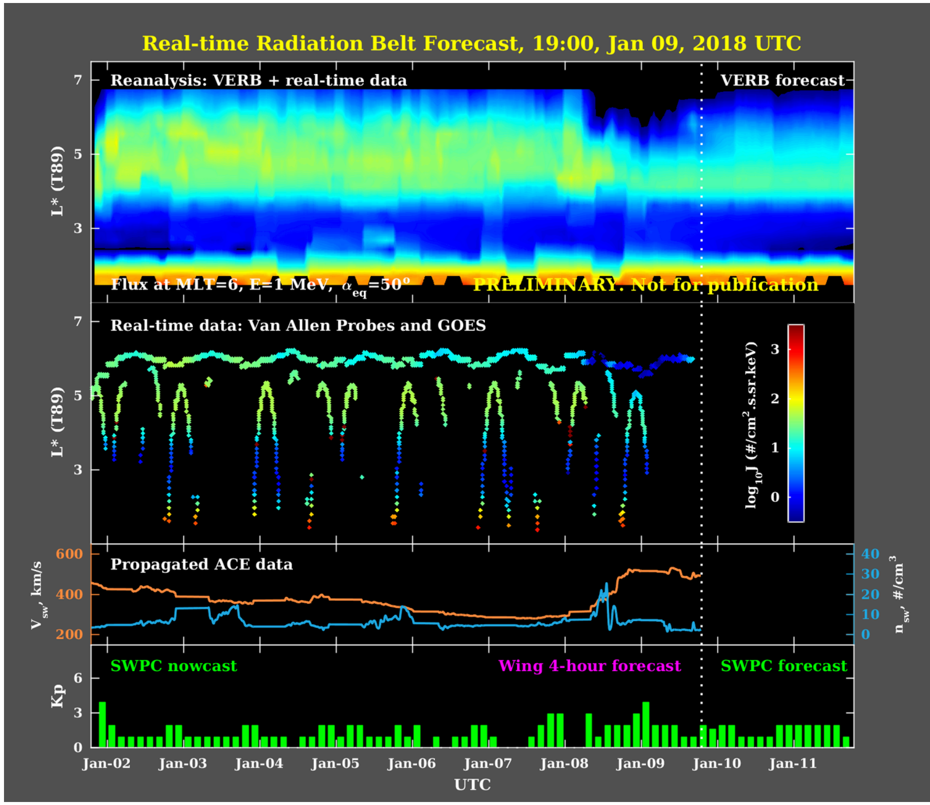
- JSON formatted, GSM and HGR coordinate systems
- https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/bennett/swift-data

Radiation Belts

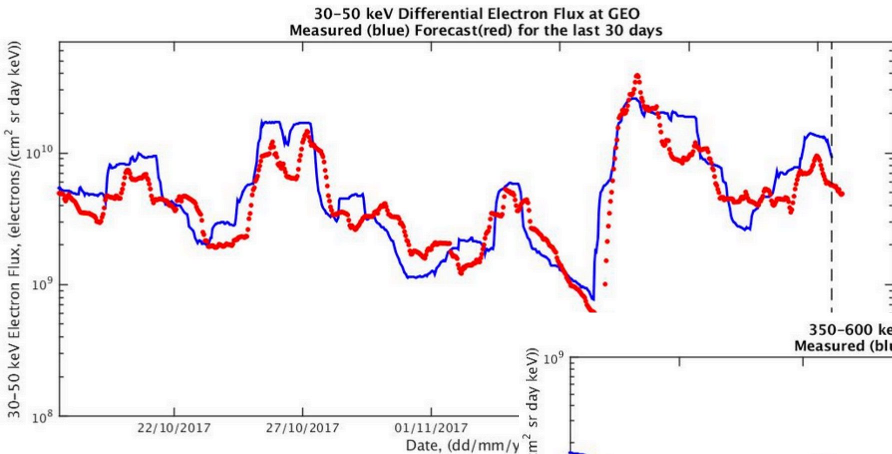
IMPTAM low energy electrons

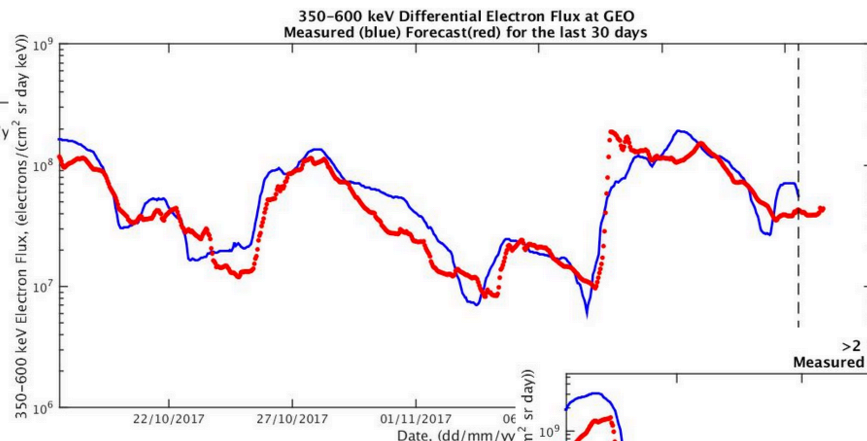
VERB high energy electrons

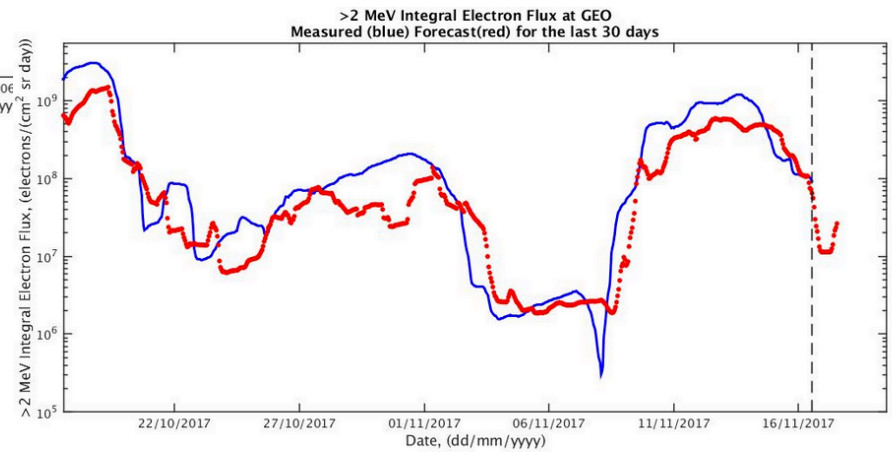




GSO e^- flux forecasts







Models for

- 30-50 keV
- 50-100 keV
- 100-200 keV
- 200-350 keV
- 350-600 keV
- >800 keV
- >2MeV

View latest forecasts at
https://ssg.group.shef.ac.uk/progress/html/
http://ssg.group.shef.ac.uk/ssg2013/proj_UOSSW.htm

GSO e$^-$ flux forecasts

Model comparison

One day ahead forecasted fluxes >2 MeV electrons compared with NOAA REFM

Prediction Efficiency

$$PE = 1 - \frac{1}{N}\sum \frac{(X_i - Y_i)^2}{\mathrm{Var}(X)}$$

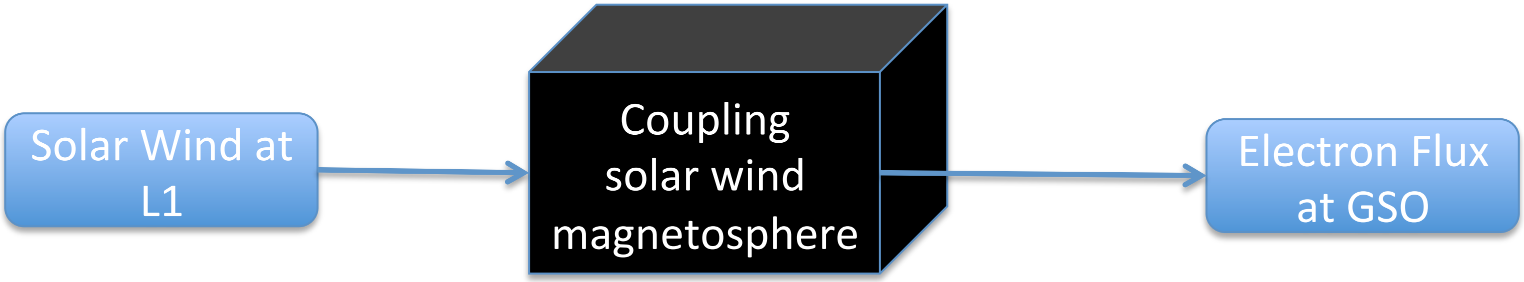
Correlation function

$$C_{\log(\mathrm{SNB})} = \frac{1}{N}\sum_{i=1}^{N} \frac{(\log_{10}(F_{2\mathrm{MeV}}(i)) - \langle \log_{10}(F_{2\mathrm{MeV}}(i))\rangle)(\log_{10}(F_{\mathrm{SNB}}(i)) - \langle \log_{10}(F_{\mathrm{SNB}}(i))\rangle)}{\sqrt{\mathrm{Var}(\log_{10}(F_{2\mathrm{MeV}}))\mathrm{Var}(\log_{10}(F_{\mathrm{SNB}}))}}$$

	e$^-$ Flux		Log10(e$^-$ Flux)	
Model	PE	Corr	PE	Corr
REFM	-1.31	0.73	0.70	0.85
SNB^{3}GEO	0.63	0.82	0.77	0.89

Balikhin, M. A., et al. (2016), Comparative analysis of NOAA REFM and SNB3GEO tools for the forecast of the fluxes of high-energy electrons at GEO, *Space Weather*, *14*, 22–31, doi:10.1002/2015SW001303.

Electron Fluxes at GSO



Energy	Term 1	%ERR	Term 2	% ERR
90 keV	V(t)	97.0	$V^2(t)$	2.7
127.5 keV	V(t)	74.8	V(t-1)	22.2
172.5 keV	V(t-1)	65.7	V(t)	31.6
270 keV	V(t-1)	97.5	$V^2(t-1)$	2.3
407.5 keV	V(t-1)	84.1	V(t-2)	13.7
625 keV	V(t-1)	75.9	V(t-2)	22.3
925 keV	V(t-2)	96.2	N(t)	0.3
1.3 MeV	$V^2(t-2)$	76.5	nV(t-1)	2.2
2.0 MeV	N(t-1)	53.7	nV(t-1)	13.6
1.8-3.5 MeV	N(t-1)	51.5	$N^2(t-1)$	15.1

Boynton, R. J., et al., (2013), The analysis of electron fluxes at geosynchronous orbit employing a NARMAX approach, J. Geophys. Res. Space Physics, 118, 1500–1513, doi: 10.1002/jgra.50192.

Geomagnetic Indices

AIM: Forecasts of Kp, Dst, and AE

Methodologies – data driven

- Neural Network –IRF Lund, Sweden
- NARMAX – U. Sheffield, UK
- NARMAX, bi-linear, and Lyapunov exponent – SRI, Ukraine

Model inputs – solar wind parameters at L1

- Measurements from ACE/DSCOVR
- L1 forecasts from AWSoM/SWIFT

Geomagnetic Indices

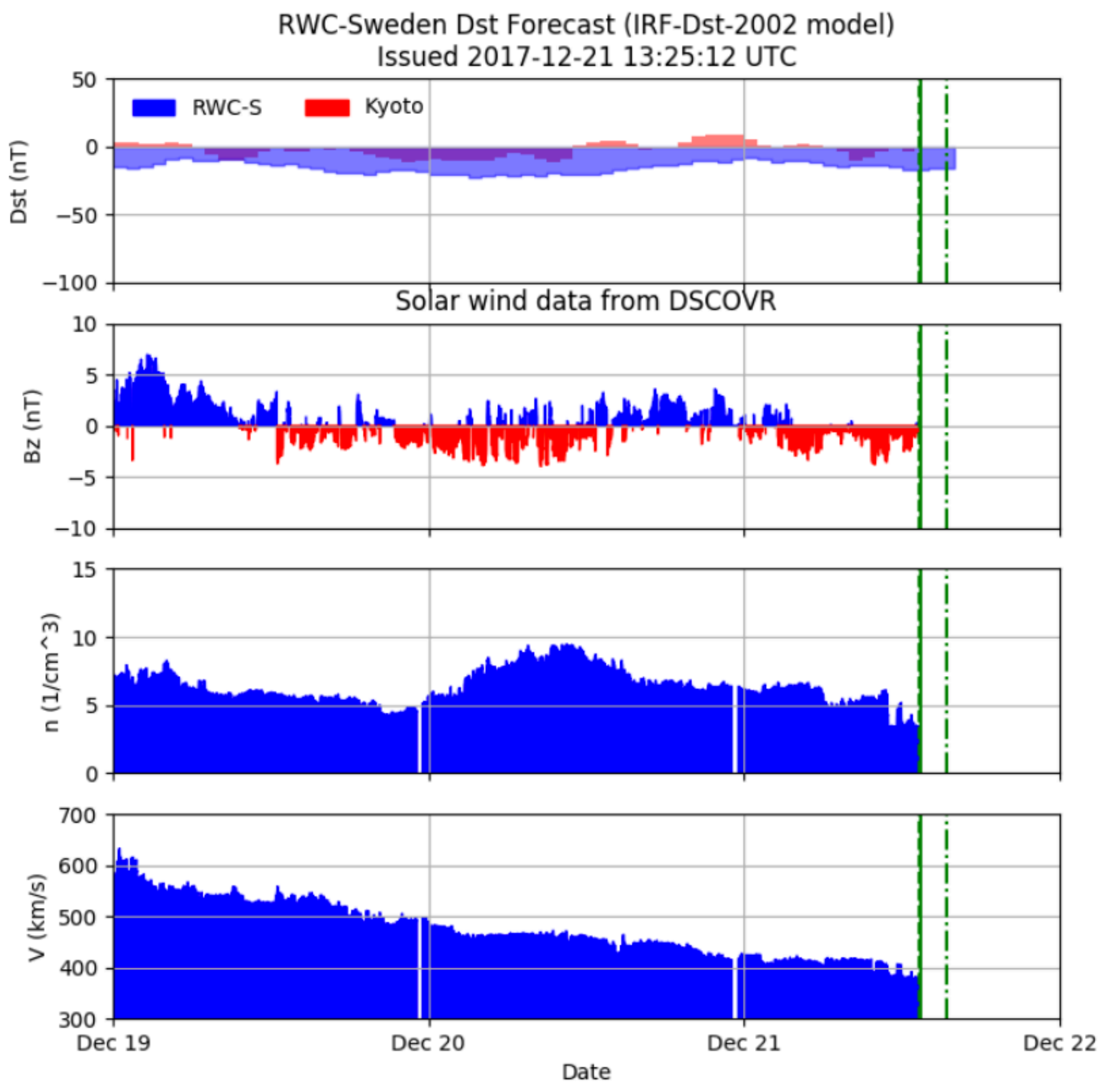
Forecasts available

IRF Lund Dst, and Kp

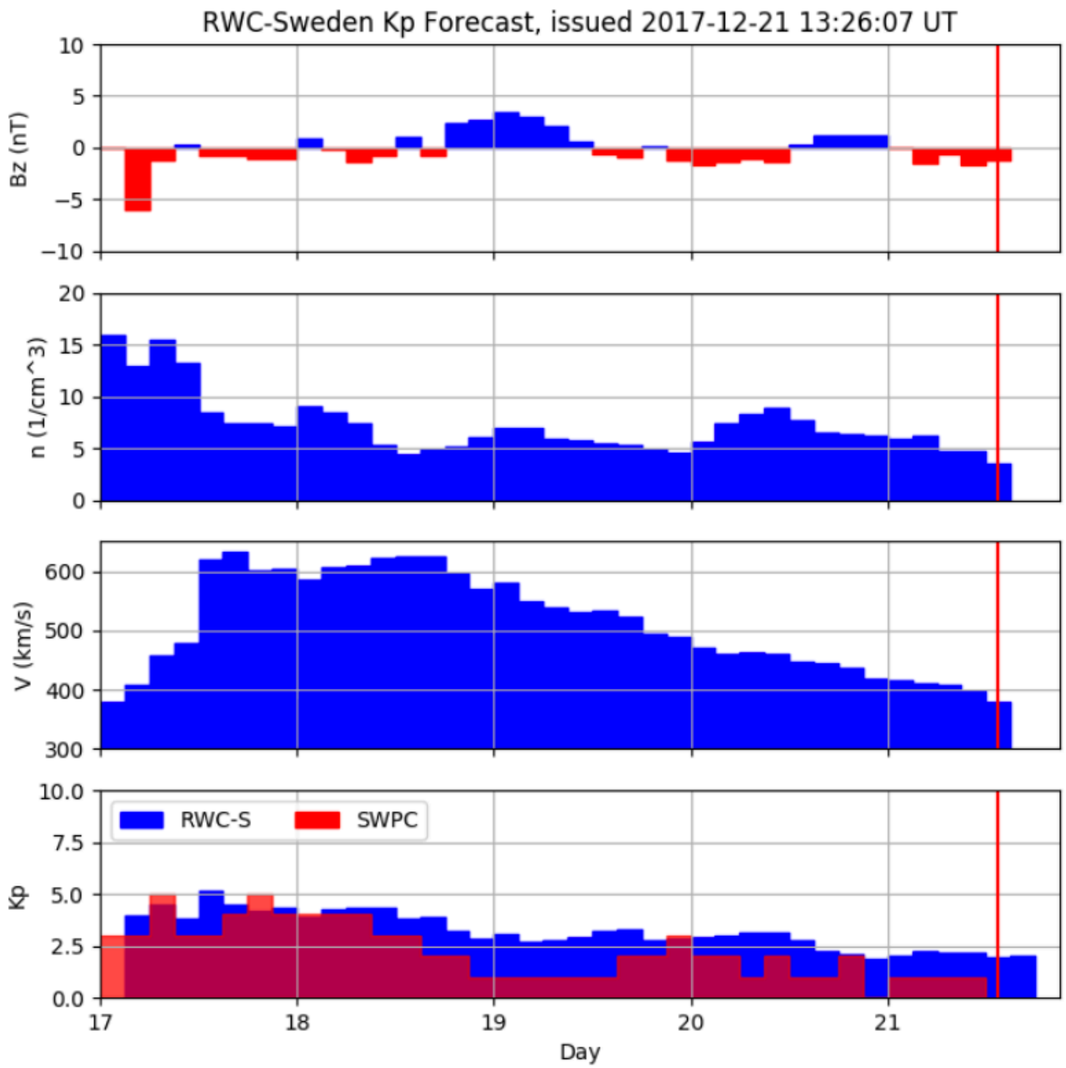
Plots
http://lund.irf.se/forecast/dst/dst.png,
http://lund.irf.se/forecast/kp/kp.png

Data (Kp available now, Dst, AE available soon)
RESTful data server created
e.g. latest 10 Kp predictions:
http://lund.irf.se/progress/rest/datasets/irfkp2017/latest?limit=10

IRF Lund Dst


RWC-Sweden Dst Forecast (IRF-Dst-2002 model)
Issued 2017-12-21 13:25:12 UTC
RWC-S
Kyoto
Dst (nT)
50
0
−50
−100
Solar wind data from DSCOVR
Bz (nT)
10
5
0
−5
−10
n (1/cm^3)
15
10
5
0
V (km/s)
700
600
500
400
300
Dec 19
Dec 20
Dec 21
Dec 22
Date

IRF Lund Kp


RWC-Sweden Kp Forecast, issued 2017-12-21 13:26:07 UT
Bz (nT)
n (1/cm^3)
V (km/s)
Kp
RWC-S
SWPC
Day
17
18
19
20
21

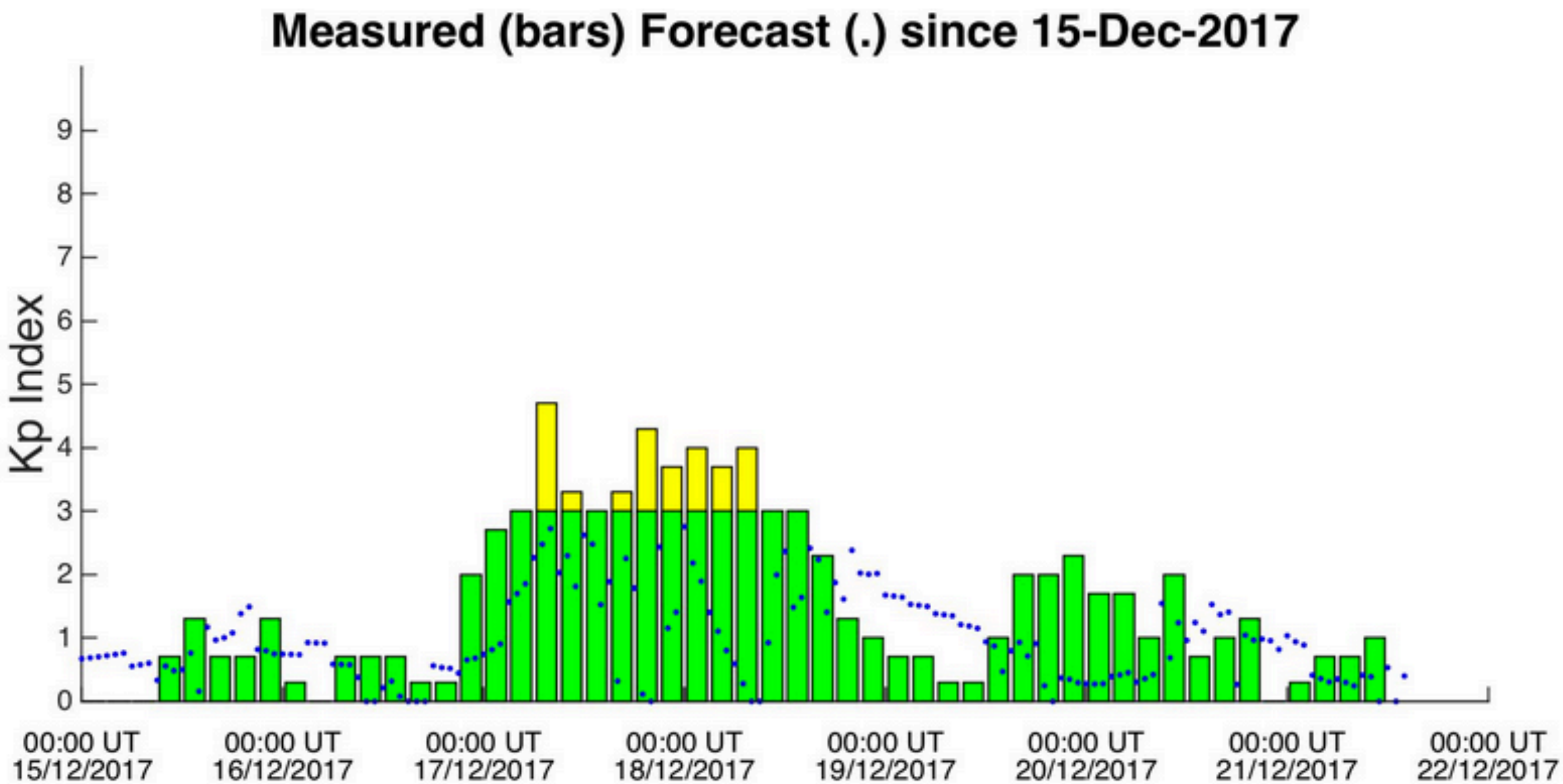
Geomagnetic Indices

Forecasts available

U. Sheffield Kp – Plots
https://ssg.group.shef.ac.uk/USSW2/Kp/fKp_1d.jpg

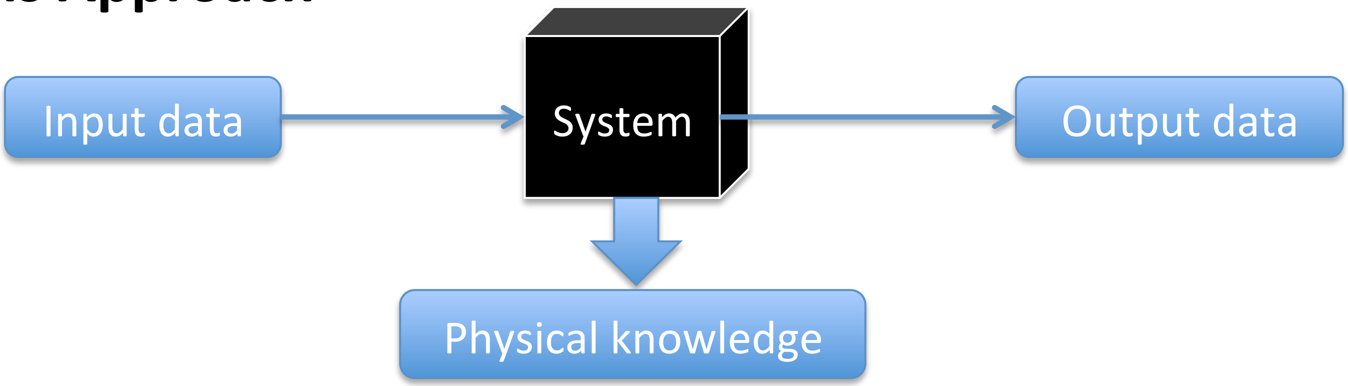
U. Shef Kp

1 Week



Modeling Methodologies

Systems Approach

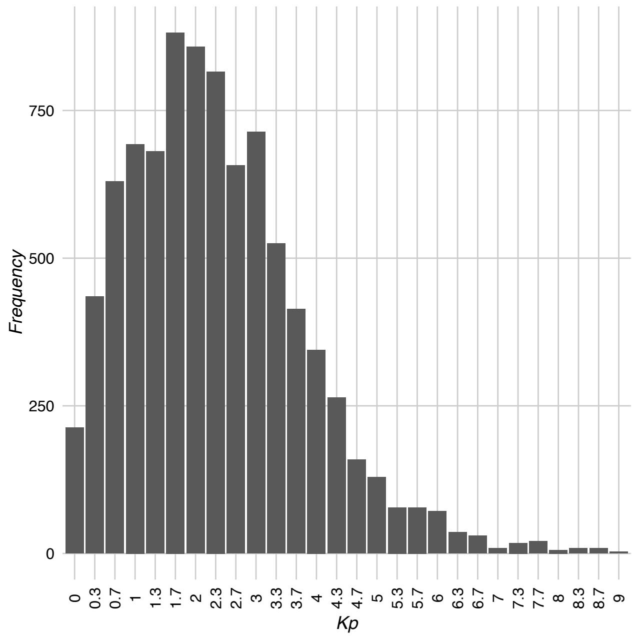


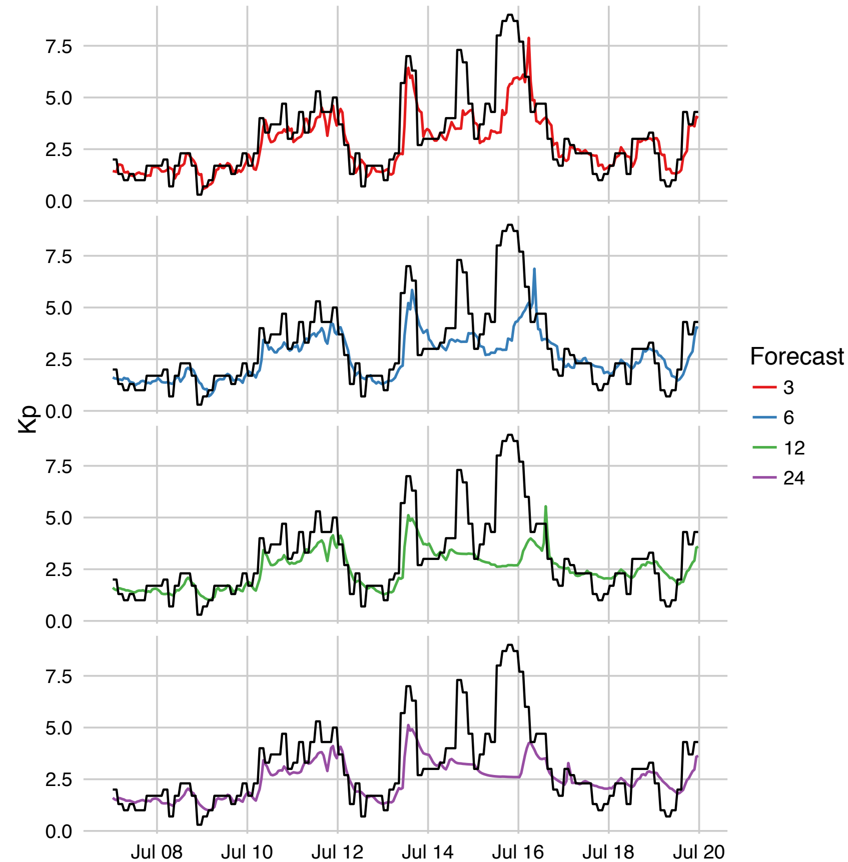
$$y(k) = F[y(k-1),\ldots,y(k-ny),$$ System outputs

$$u(k),\ldots u(k-nu),$$ System inputs

$$e(k-1),\ldots e(k-ne)]$$ Noise/errors

F[] is a nonlinear function (polynomial, B-spline, radial basis function)





Kp values are not evenly distributed

Low to mid range values modeled OK

Forecasts of peak Kp values missed

Model Parameters

Input parameters

- Kp – GFZ Potsdam
- Solar wind – OMNI data set 5 min

Name	Description
Kp	Kp index
V	solar wind speed/velocity (flow speed) [km/s]
Bs	IMF southward component
P	Solar wind pressure [nPa]
N	Solar wind density [per cc]
VBs	Product of Velocity and Bs
√p	Square root pressure

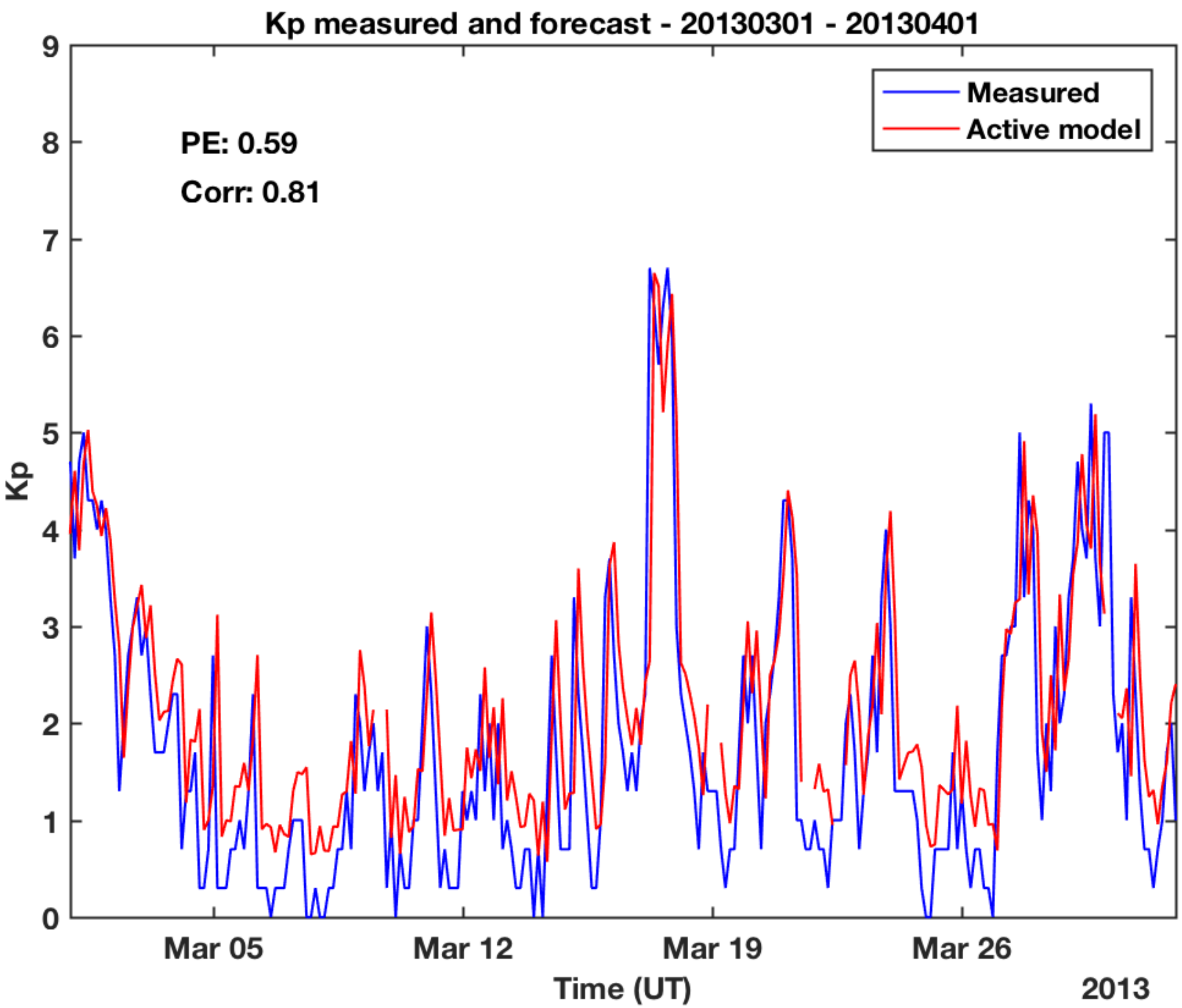
New U. Shef Kp model

New model

- Target large Kp values
- Training dataset balanced to give more prominence to high values

```
kp= ...
  8.8088e-1 * Kp(1) + ...
  7.6502e-1 + ...
 -4.9010e-03 * p(2)*n(2) + ...
  -1.9820e-04 * V(2) * Kp(2) + ...
  1.5981e-02 * p(2) * Kp(2) + ...
  2.3706e-04 * V(1) * VBs(1) + ...
  -3.7429e-03 * Bs(1) * n(1) + ...
  -3.9727e-04 * V(2) * VBs(2) + ...
  5.6176e-02 * Bs(2) * sqrtp(1) + ...
  -7.1004e-03 * n(1) * VBs(2);
```

St. Patrick's Day 2013



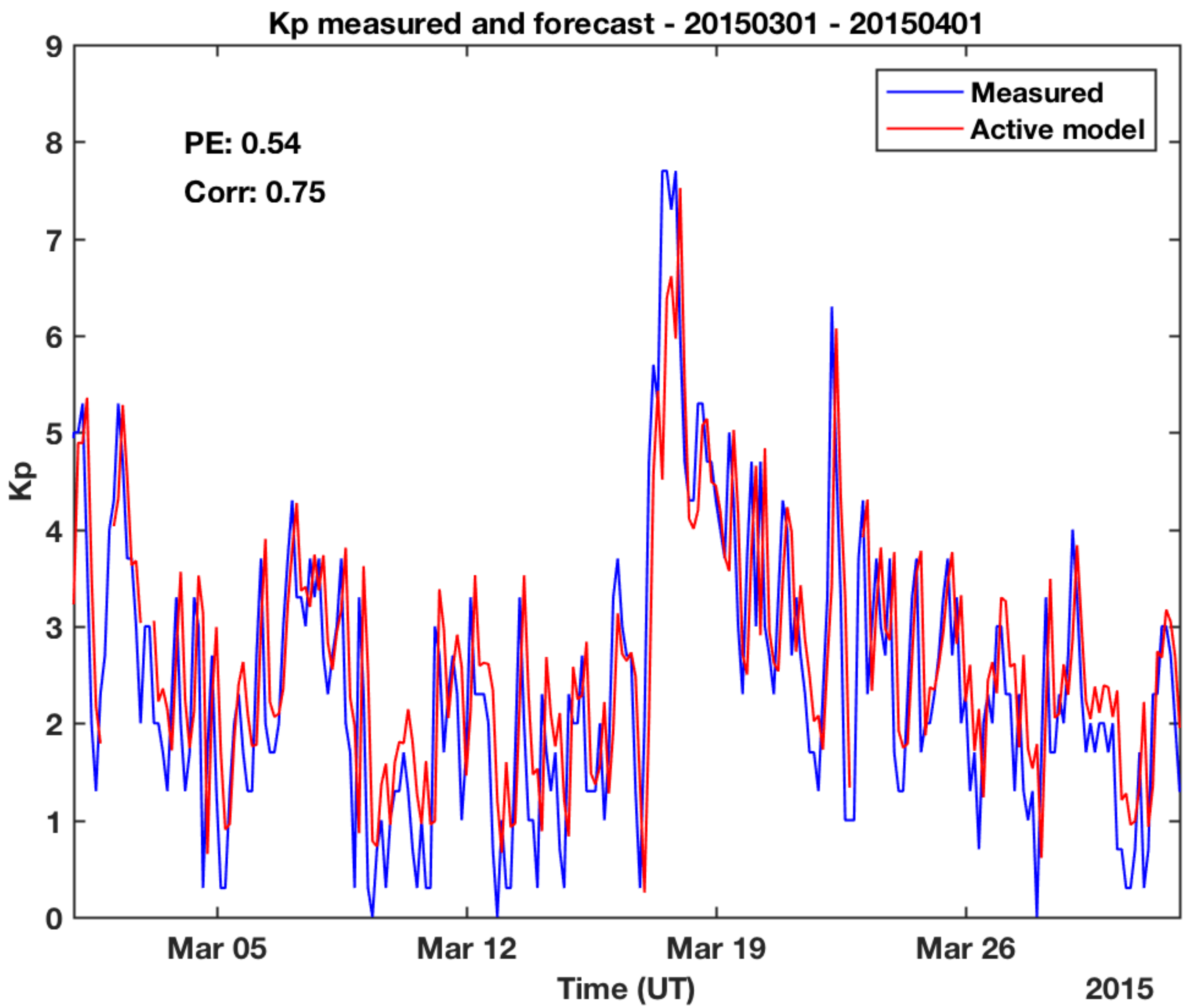
Auto-regressive models

- Good agreement with measured values
- One time step delay

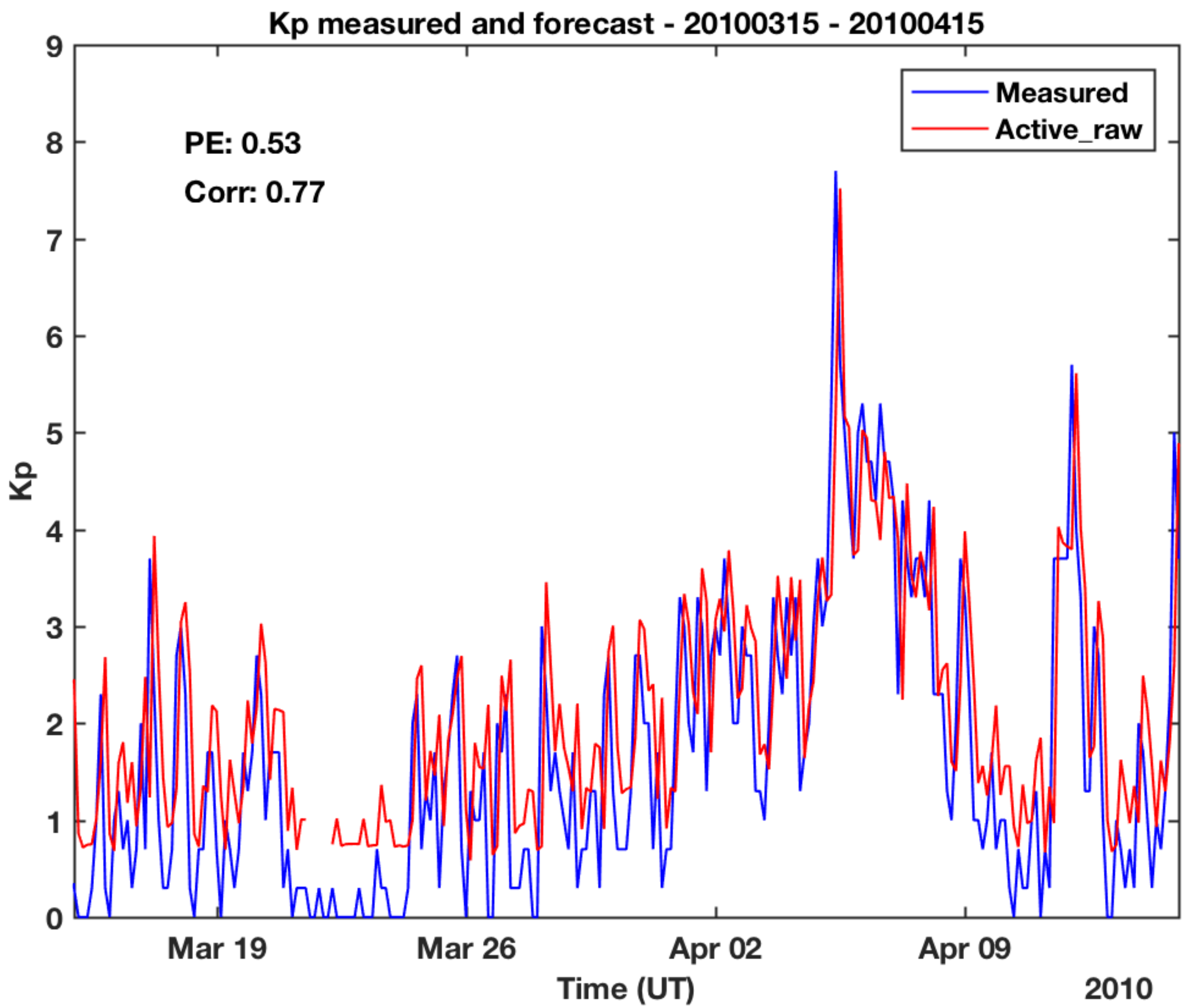
Non-auto-regressive models

- Not particularly good agreement with measured values
- No time delays

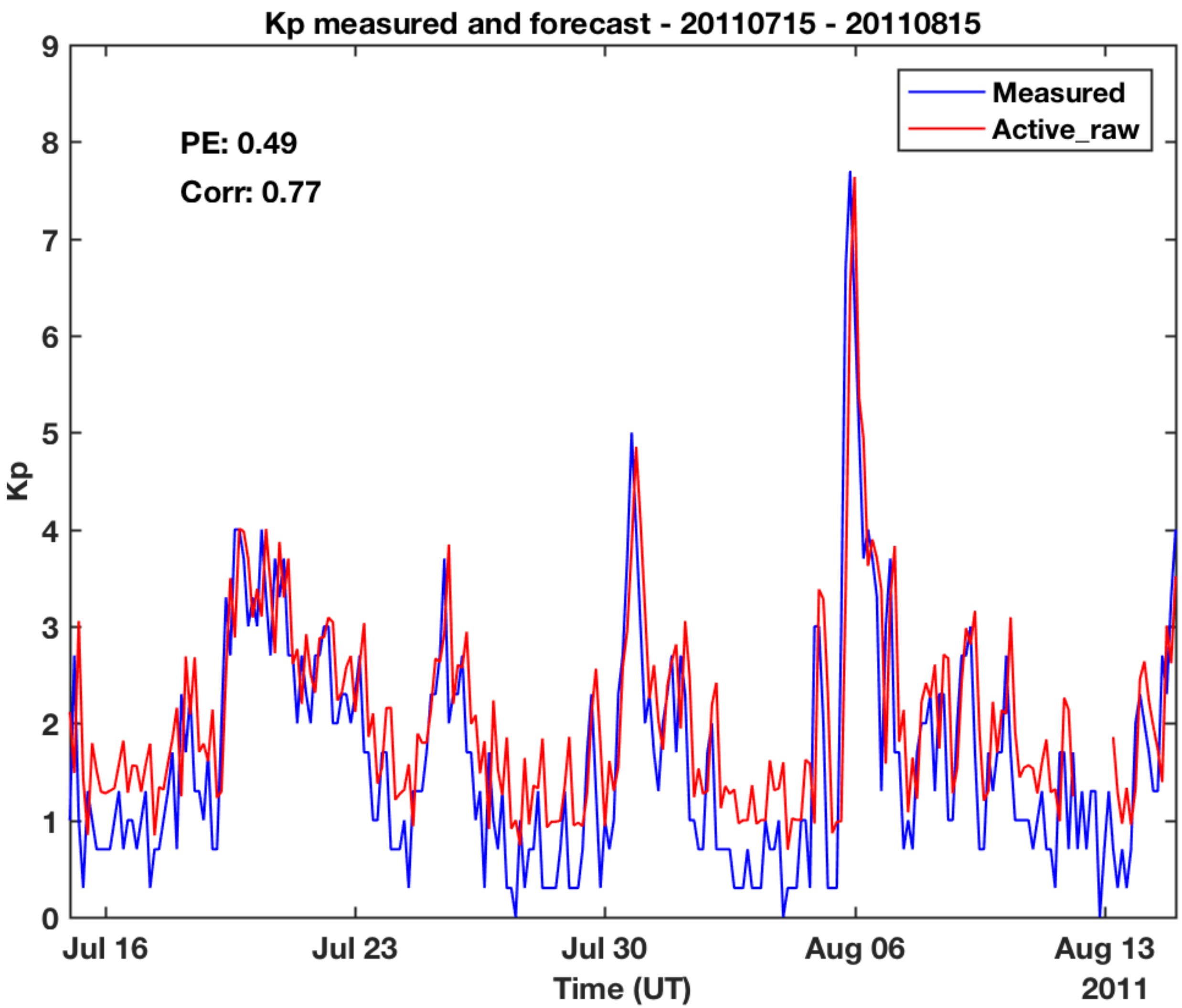
St. Patrick's Day 2015



April 2010

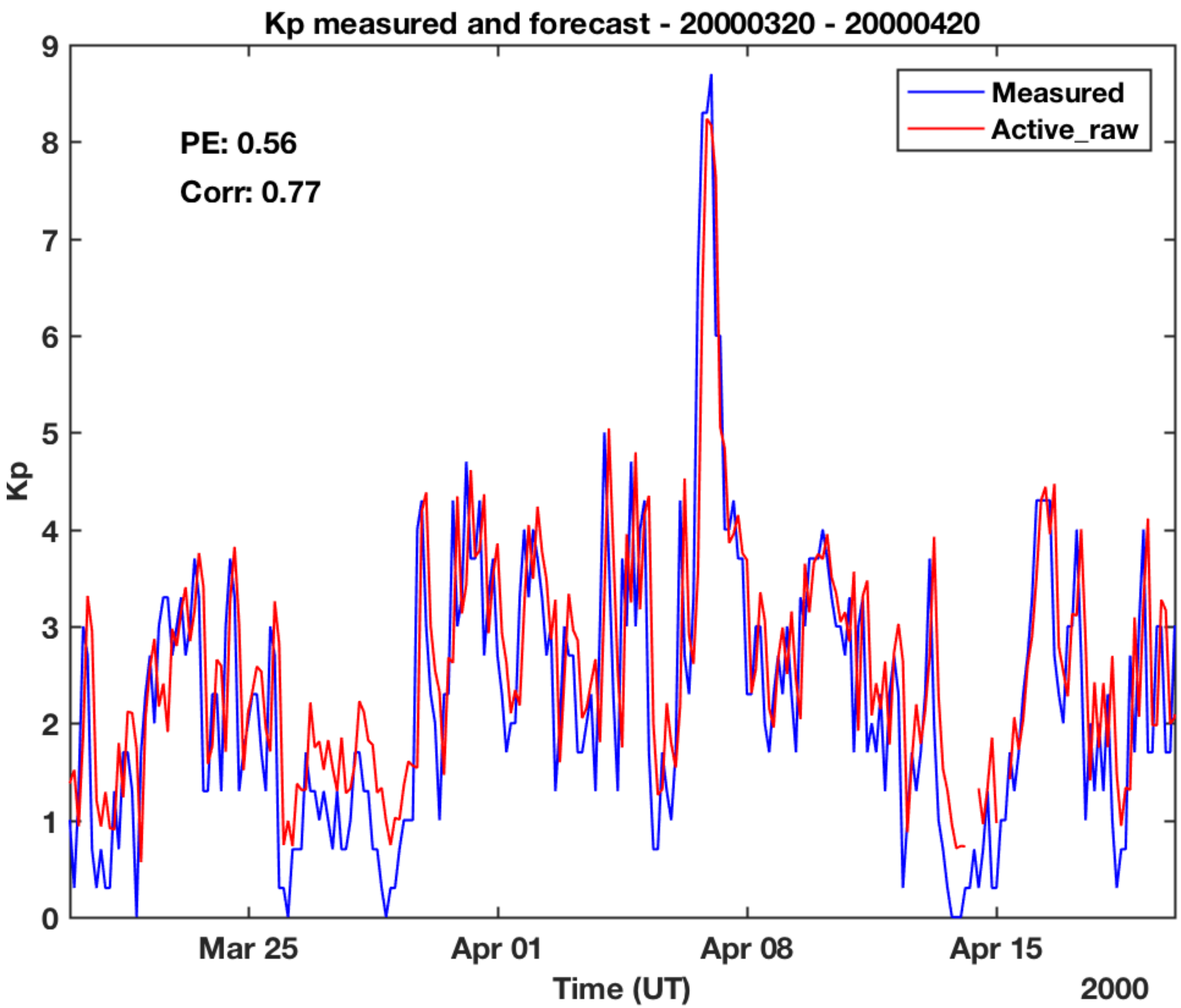

Kp measured and forecast - 20100315 - 20100415
PE: 0.53
Corr: 0.77
Measured
Active_raw
Kp
0
1
2
3
4
5
6
7
8
9
Mar 19
Mar 26
Apr 02
Apr 09
Time (UT)
2010

August 2011

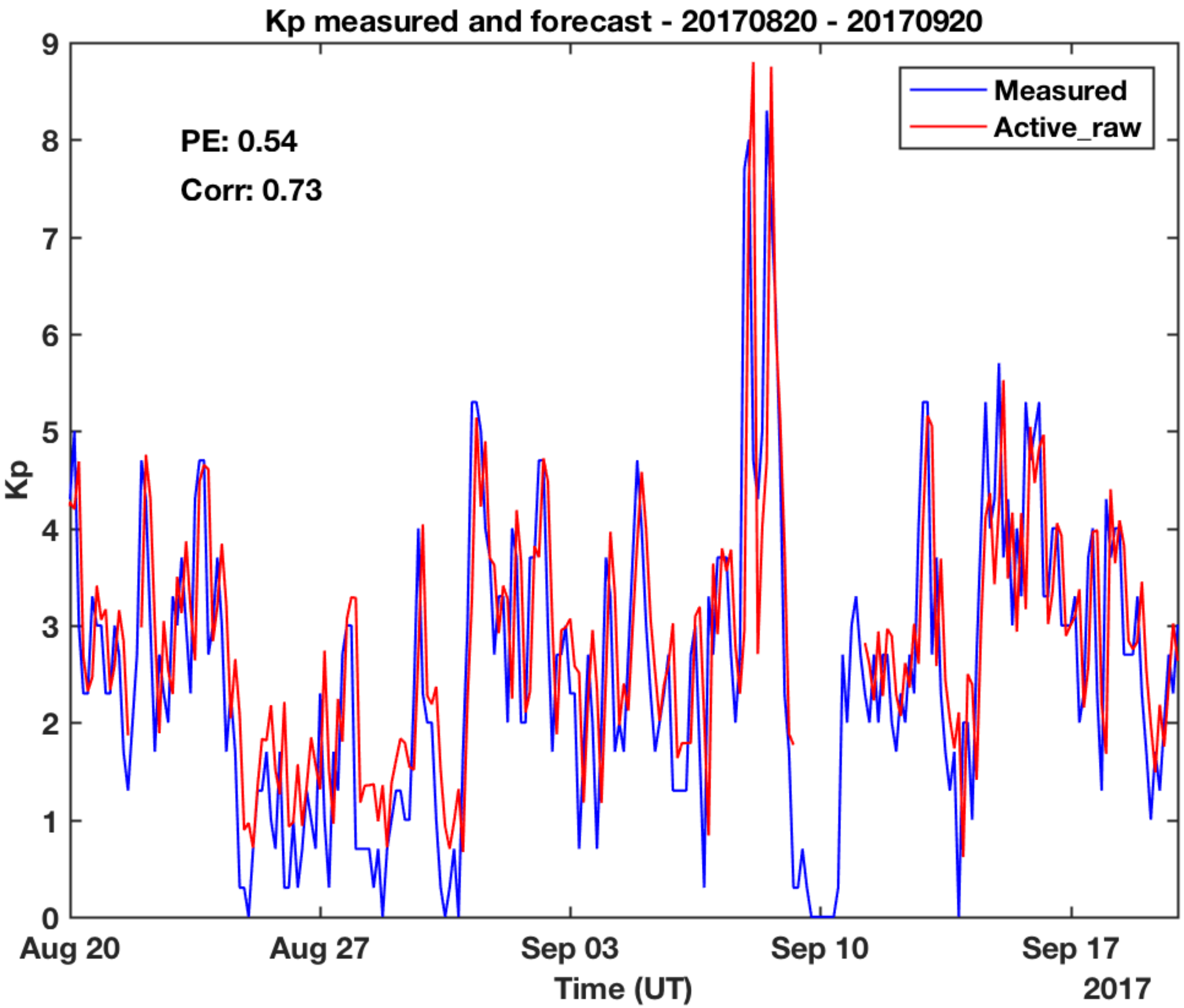


Kp measured and forecast - 20110715 - 20110815
PE: 0.49
Corr: 0.77
Measured
Active_raw
Kp
9
8
7
6
5
4
3
2
1
0
Jul 16
Jul 23
Jul 30
Aug 06
Aug 13
2011
Time (UT)

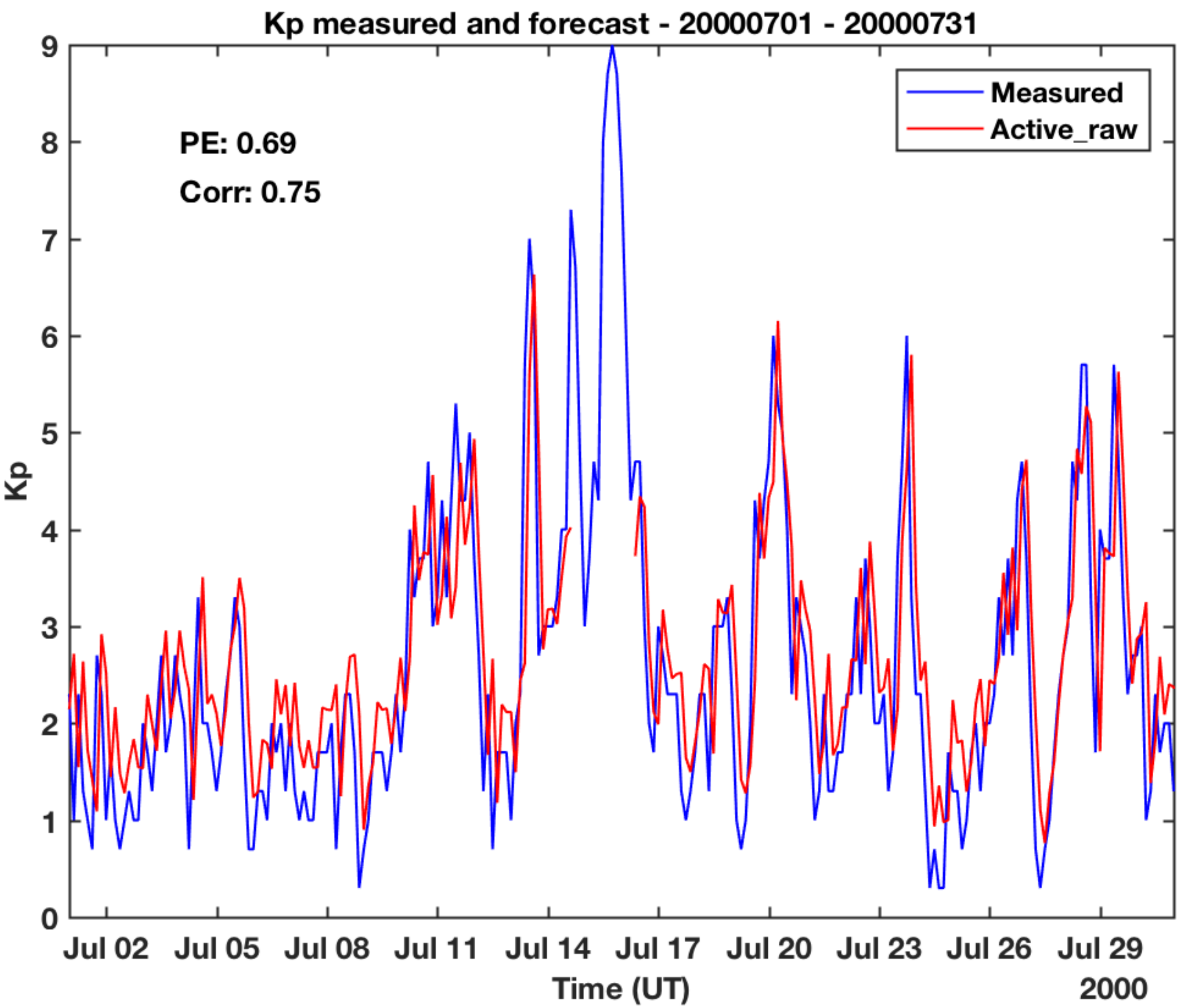
April 2000


Kp measured and forecast - 20000320 - 20000420
PE: 0.56
Corr: 0.77
Measured
Active_raw
Kp
0
1
2
3
4
5
6
7
8
9
Mar 25
Apr 01
Apr 08
Apr 15
Time (UT)
2000

September 2017

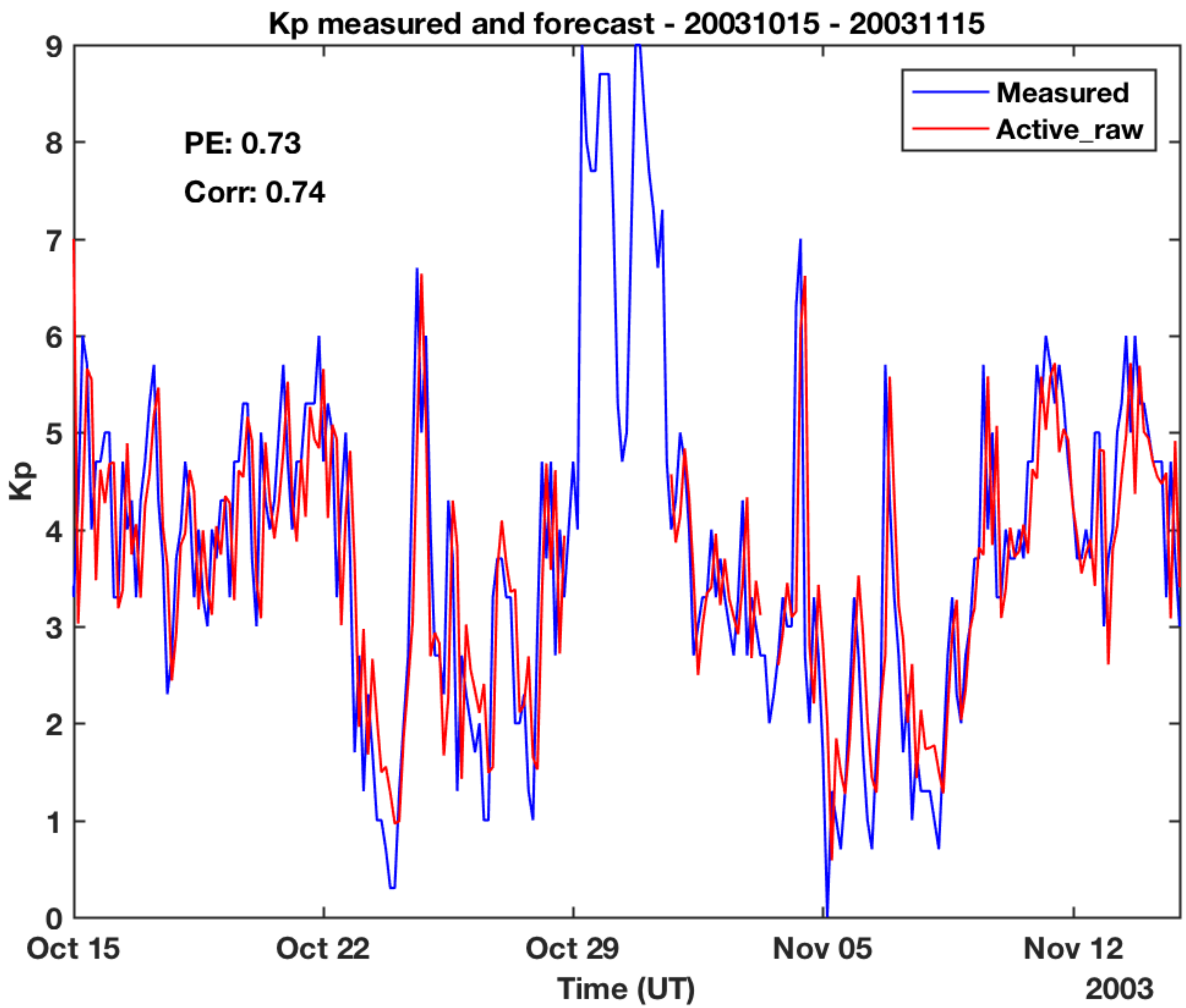


Bastille Day Storm



Gap in OMNI plasma data, therefore no forecast

Halloween Storms



Summary

Overview of the EU funded project PROGRESS

- Forecast of solar wind parameters at L1
- Forecast of electron fluxes at geostationary orbit
- Forecast of Radiation Belt electron environment

Briefly described new Sheffield NARMAX model to forecast Kp

- Main target to forecast high Kp

Forecasts show good agreement for a number of major storms

Thank you for your attention

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302.

NARMAX model

Table II. Regular model with autoregressive variables

No	Term	ERR (100%)	Parameter
1	$Kp(t-1)$	84.7580	1.2377e+00
2	$p(t-1) \times V(t-2)^{\frac{1}{2}}$	2.0343	1.7675e+00
3	$V(t-1) \times V(t-1)^{\frac{1}{3}}$	0.3777	4.3448e-01
4	$Kp(t-1) \times V(t-2)^{\frac{1}{5}}$	0.0773	-9.9249e-01
5	$p(t-1) \times p(t-1)$	0.1165	-3.5290e-01
6	$V(t-2) \times p(t-1)$	0.1031	-2.0913e+00
7	$p(t-1) \times V(t-2)^{\frac{1}{2}}$	0.0714	-1.6569e+00
8	$n(t-2) \times Bs(t-1)^{\frac{1}{5}}$	0.0540	-3.4770e-02
9	$Kp(t-2) \times VBs(t-2)$	0.0575	3.5096e+03
10	$V(t-2)^{\frac{1}{5}} \times Bs(t-2)^{\frac{1}{5}}$	0.0329	-5.5428e-03
11	$Bs(t-1) \times Bs(t-1)^{\frac{1}{2}}$	0.0208	4.7001e-01
12	$Bs(t-1) \times Bs(t-2)$	0.0296	-2.1801e+00
13	$n(t-2) \times Kp(t-1)$	0.0445	5.6394e-01