Data driven models forecasting levels of geomagnetic disturbance related to GIC

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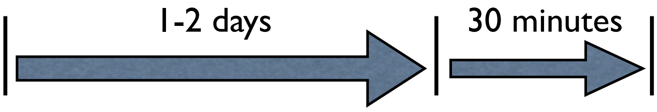
Abstract

- Models driven by upstream solar wind data from ACE spacecraft
- Two variants: 1) magnetic field and plasma; 2) magnetic fields only
- 30 minutes lead time
- Forecasting of a new index (d_{30}) based on local dB/dt
- Numerically the d_{30} index is similar to the *Kp* index
- However, d_{30} captures better dB/dt that is related to GIC

Sun–solar wind–Earth



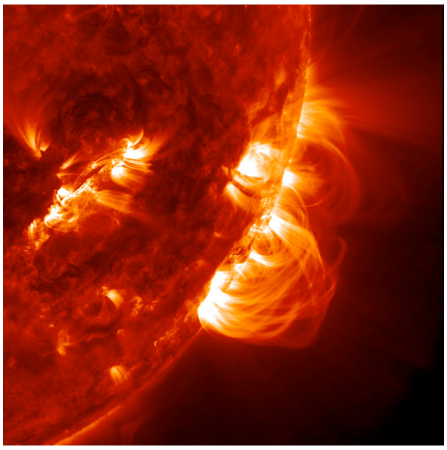


Image from
http://sdo.gsfc.nasa.gov

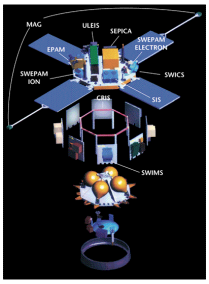


Image from
http://www.srl.caltech.edu/ACE/

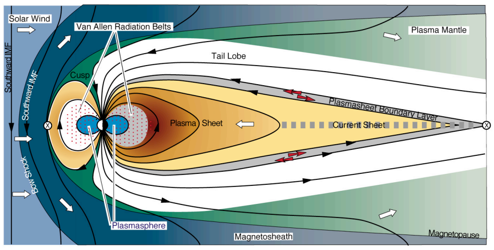
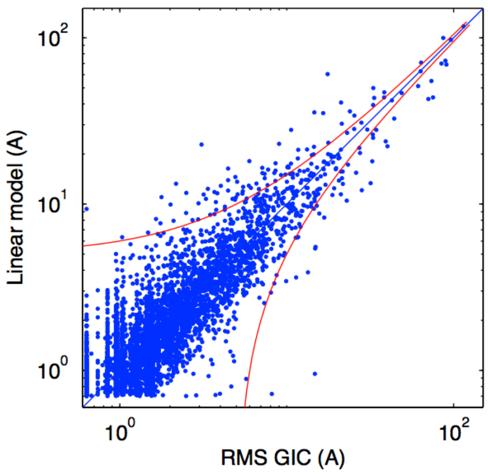


Image from
http://space.rice.edu/IMAGE/

Current models – GIC at www.irf.lund.se/rwc

2 years of GIC measurements with 1-minute resolution



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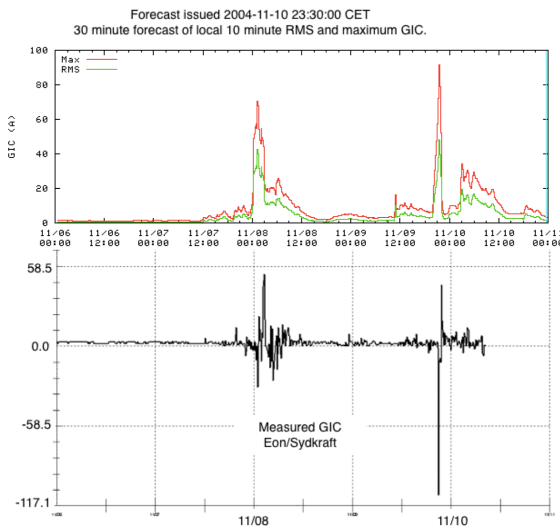
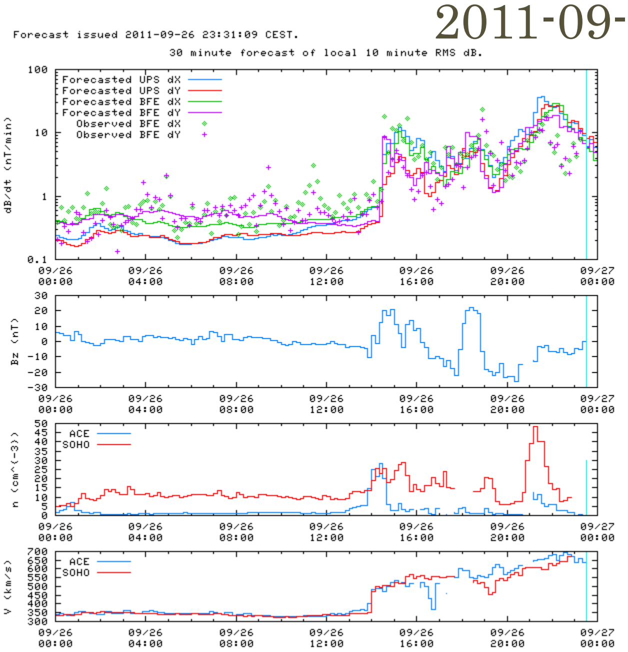
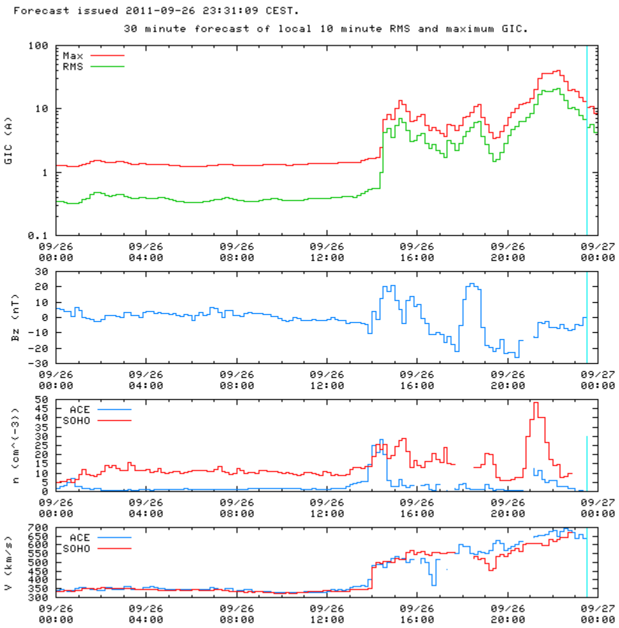


$$\mathrm{RMS(GIC)} \approx a_0 + \sum_{i \in \{\mathrm{BFE,UPS}\}} a_{x,i}\mathrm{RMS}(dB_{x,i}/dt) + a_{y,i}\mathrm{RMS}(dB_{y,i}/dt)$$

Recent forecasts

2011-09-26



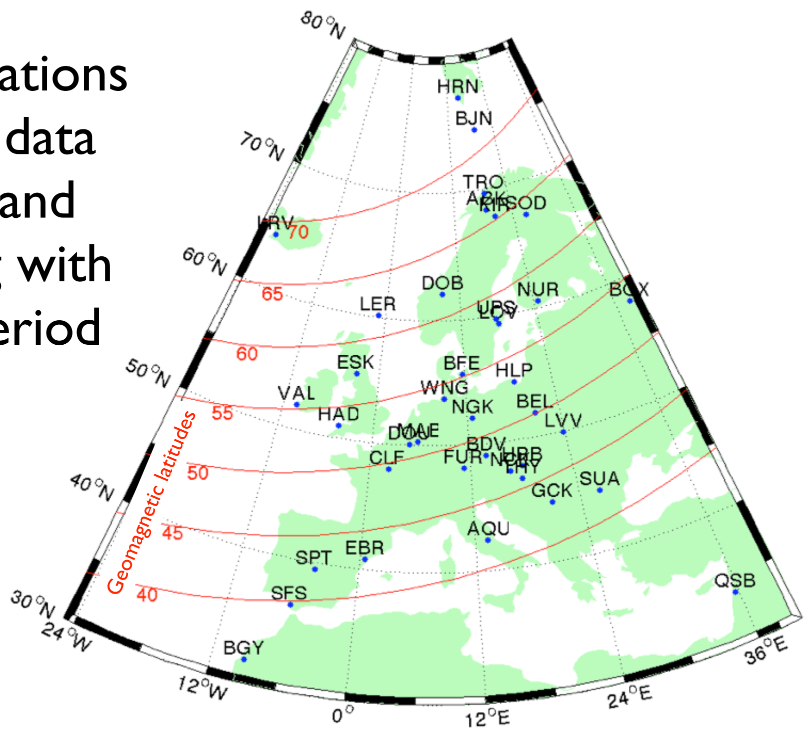


Direct link also including archived forecasts: http://solarwind.lund.irf.se/forecast/

RWC-Sweden: http://www.lund.irf.se/rwc/

Geomagnetic stations in study

European stations with good data coverage and overlapping with the ACE period



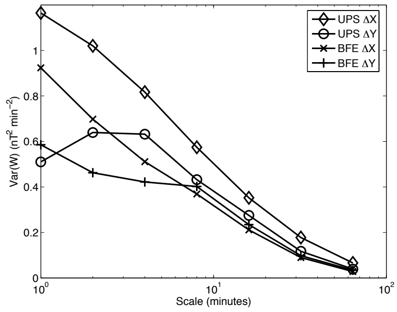
38 stations with 5 years of data or more in 1998-2010.

Local magnetic field variation

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Most of the variability occurs on scales less than 20 minutes

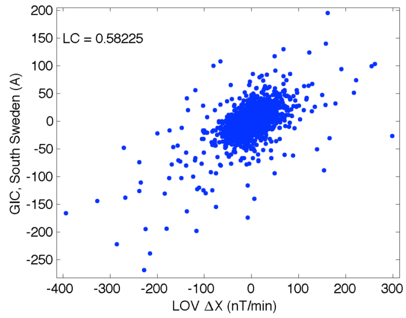
Power distribution of ΔX as function of temporal scale

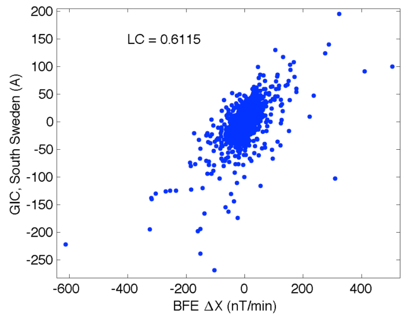


P. Wintoft. Study of the solar wind coupling to the time difference horizontal geomagnetic field. Annales Geophysicae, 23:1949–1957, 2005.

Relation between ΔX and observed GIC

97 610 one-minute samples





Relation between *Kp*, NOAA G and dB/dt

Range of 3-hour |dB/dt| maxima for selected stations (nT/min)

Kp	G	CLF		WNG		BFE		ESK		UPV		ABK		n
0	0	1	4	1	5	1	17	1	6	1	6	1	17	2158
0_+	0	1	5	1	6	1	11	1	76	1	15	1	63	4316
1_-	0	1	11	1	30	1	10	1	12	1	45	1	43	5797
1	0	1	13	1	32	1	15	1	11	1	14	1	60	6081
1_+	0	1	17	1	10	1	12	1	12	1	19	2	97	6255
2_-	0	1	52	1	14	1	17	1	15	1	22	2	140	6152
2	0	1	24	1	15	1	30	1	20	1	27	2	214	6109
2_+	0	1	61	1	19	1	27	1	23	1	36	1	204	5848
3_-	0	1	25	1	28	1	46	1	26	1	35	3	325	5202
3	0	1	30	1	62	1	40	1	35	1	57	3	430	4710
3_+	0	1	21	1	28	1	40	1	35	1	50	4	402	4169
4_-	0	1	20	1	38	2	48	2	37	1	62	5	337	3205
4	0	1	25	1	48	2	71	2	63	1	52	6	507	2539
4_+	0	1	50	2	60	2	92	2	78	2	70	9	504	1841
5_-	1	1	45	2	85	3	65	2	77	2	111	11	832	1428
5	1	1	64	2	131	3	104	3	89	2	167	11	729	1005
5_+	1	1	46	3	82	3	95	3	89	2	96	11	637	706
6_-	2	2	58	3	69	4	81	3	82	4	118	17	591	487
6	2	2	53	4	91	4	83	4	87	4	136	20	535	351
6_+	2	3	92	4	135	6	164	6	132	7	279	32	569	231
7_-	3	3	78	5	148	5	195	7	186	8	225	32	916	185
7	3	2	70	6	111	7	142	8	151	9	282	37	546	118
7_+	3	3	92	7	187	9	305	10	254	7	342	34	758	102
8_-	4	6	133	12	214	19	271	18	460	20	401	39	694	74
8	4	6	166	14	237	27	324	27	684	31	715	62	547	41
8_+	4	7	108	20	267	24	506	23	482	40	455	58	738	35
9_-	4	12	186	28	385	40	613	42	1271	59	823	67	1128	30
9	5	35	109	92	713	227	1972	247	901	317	693	200	1245	7

Counts per *Kp* bin (years 1985–2008)

The d_{30} index

Differenced 1-minute local magnetic field: $\Delta X(t) = X(t) - X(t-1)$

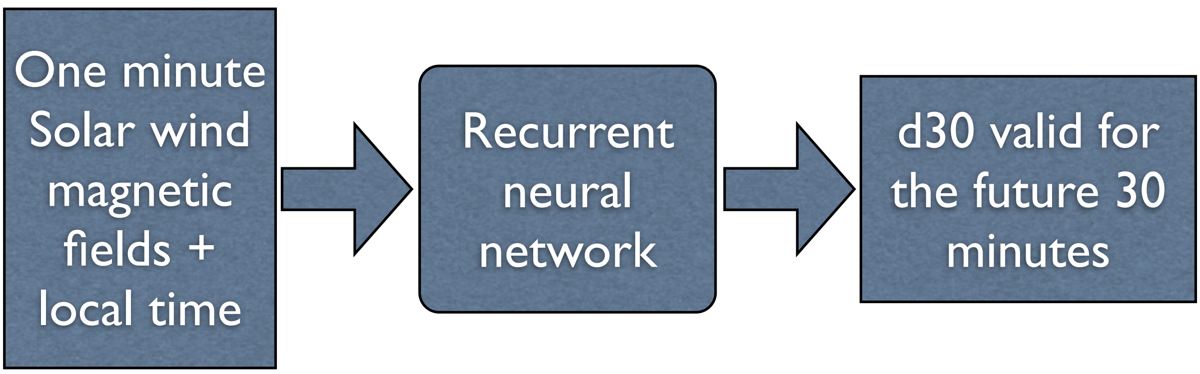
30 minute forward maximum: $m_{30} = \max\{|\Delta X(\tau)|\}$ for $t \leq \tau < t + 30$

Definition of d_{30}: $d_{30} = \frac{9}{7}\ln(m_{30} + 1)$ Numerically similar to *Kp*

d_{30}	m_{30} (nT/min)	CLF	WNG	BFE	ESK	UPV	ABK
0	0	1397	672	321	628	1047	287
1	1	396153	346442	322146	326718	333118	122946
2	4	19515	60902	79837	76255	67566	118021
3	9	2267	9845	15060	14117	15087	93647
4	21	396	1367	2066	1982	2790	56235
5	48	75	271	445	463	749	21457
6	105	9	72	127	133	273	5030
7	230	0	13	40	40	58	657
8	503	0	2	4	5	7	49
9	1096	0	0	1	1	1	2

Counts per station and bin (years 1985–2008)

The models



Storm events using plasma & magnetic field inputs

All big events are missing due to the ACE SWEPAM outages during proton events.

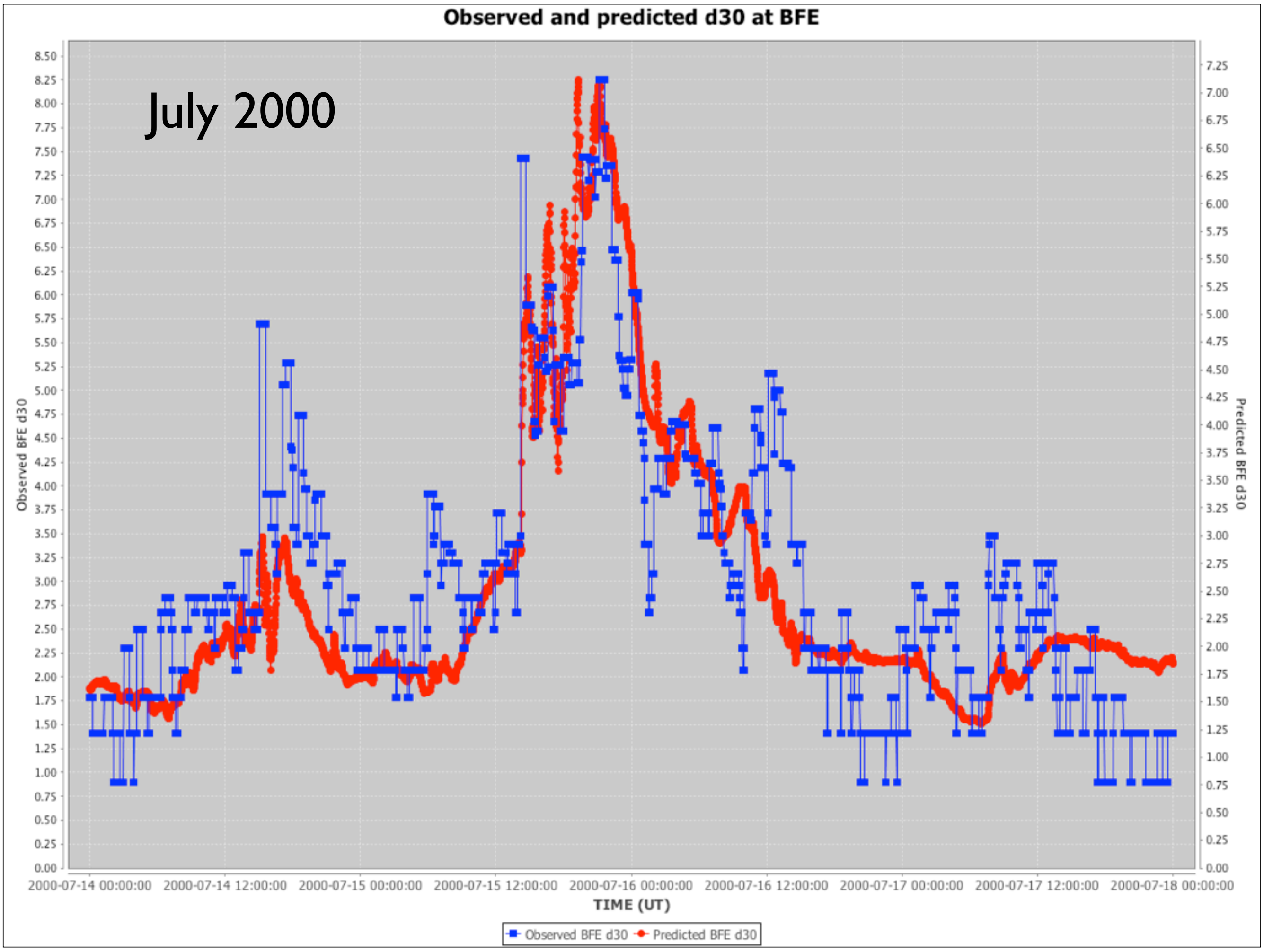
Id	Start date	End date	BFE	CLF	ESK	UPV	WNG
1	1998-03-10 03:50:00.0	1998-03-11 19:26:00.0	74	17	64	168	35
2	1998-05-03 10:05:00.0	1998-05-05 15:48:00.0	176	31	164	168	70
3	1998-09-23 22:53:00.0	1998-09-26 10:43:00.0	124	48	62	157	91
4	1998-11-12 21:03:00.0	1998-11-14 23:04:00.0	48	9	41	114	30
5	1999-01-12 20:45:00.0	1999-01-14 23:08:00.0	54	10	48	182	31
6	1999-09-21 20:21:00.0	1999-09-24 00:36:00.0	71	39	62	157	67
7	2000-04-05 15:42:00.0	2000-04-08 11:02:00.0	506	43	280	255	267
8	2000-06-07 12:09:00.0	2000-06-09 14:08:00.0	90	27	66	112	47
9	2000-09-16 20:16:00.0	2000-09-19 13:18:00.0	89	34	129	148	63
10	2000-11-05 17:06:00.0	2000-11-07 19:59:00.0	47	19	35	115	30
11	2001-03-19 10:22:00.0	2001-03-20 20:07:00.0	27	12	60	177	41
12	2001-03-29 23:51:00.0	2001-04-02 00:57:00.0	92	78	137	161	146
13	2001-04-10 14:49:00.0	2001-04-13 02:16:00.0	169	25	191	238	119
14	2002-05-22 14:44:00.0	2002-05-24 18:27:00.0	114	44	106	122	90
15	2002-09-04 13:05:00.0	2002-09-06 14:58:00.0	7	52	9	7	8
16	2002-09-06 16:04:00.0	2002-09-08 21:01:00.0	128	17	99	342	64
17	2002-09-30 15:26:00.0	2002-10-02 17:46:00.0	121	19	67	234	56
18	2003-02-01 14:49:00.0	2003-02-03 16:41:00.0	30	11	31	103	25
19	2003-05-28 12:34:00.0	2003-05-31 03:17:00.0	93	31	107	167	60
20	2003-08-17 13:21:00.0	2003-08-19 16:48:00.0	65	45	72	154	60
21	2003-10-13 17:24:00.0	2003-10-15 19:23:00.0	72	11	65	282	44
22	2003-11-19 07:14:00.0	2003-11-22 00:47:00.0	261	28	206	162	385
23	2004-07-25 21:49:00.0	2004-07-28 22:21:00.0	125	92	149	149	94
24	2004-11-07 01:54:00.0	2004-11-09 12:07:00.0	151	50	173	268	55
25	2005-01-21 04:02:00.0	2005-01-23 01:57:00.0	206	39	254	221	69
26	2005-05-07 12:17:00.0	2005-05-09 15:08:00.0	47	16	56	183	39
27	2005-05-14 01:38:00.0	2005-05-16 03:44:00.0	89	58	89	90	68
28	2005-05-29 16:57:00.0	2005-05-31 18:58:00.0	25	13	64	151	21
29	2006-12-13 21:42:00.0	2006-12-16 03:51:00.0	33	20	44	117	28

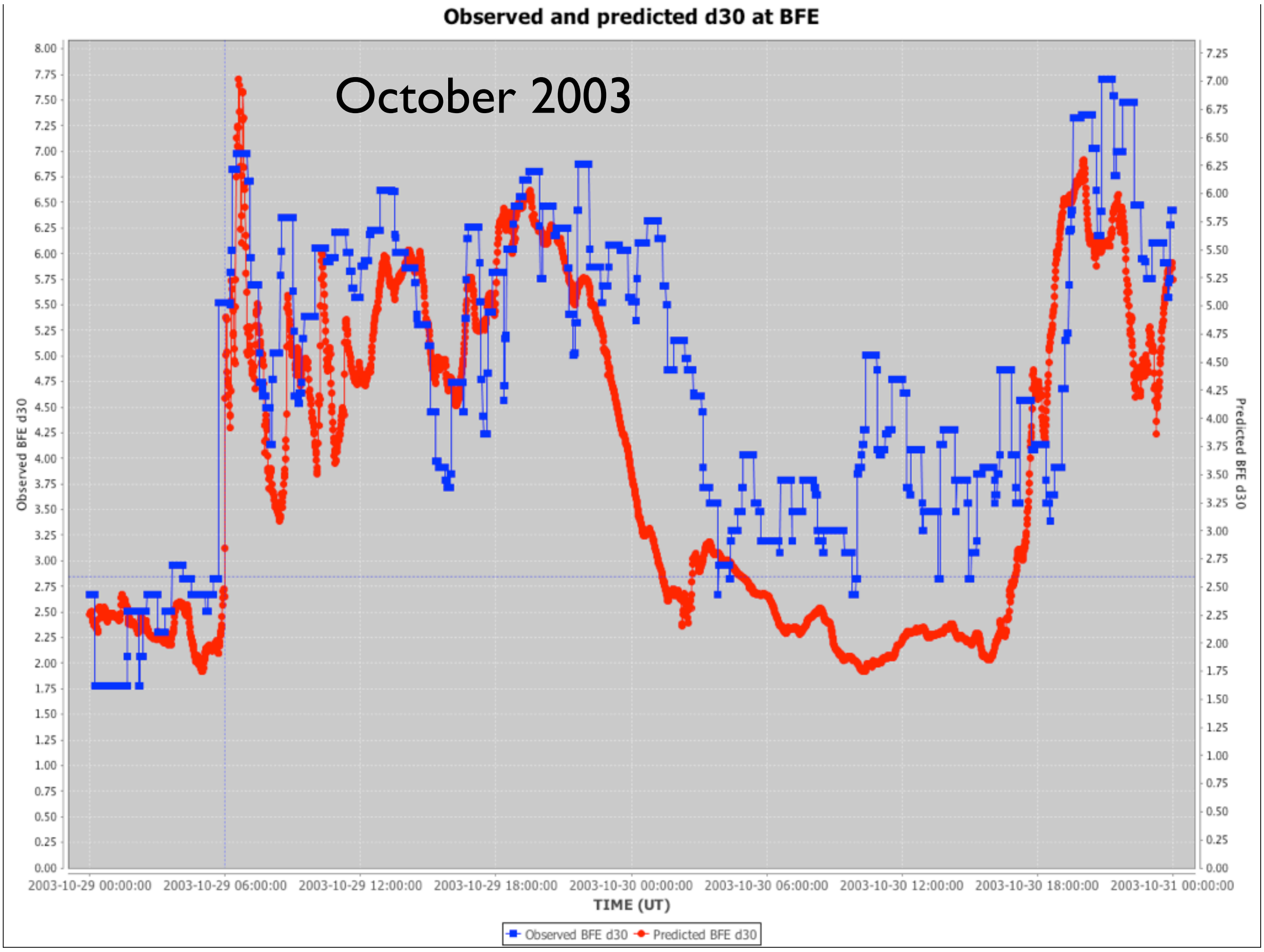
Storm events using only magnetic field inputs

Id	Start date	End date	BFE	CLF	ESK	UPV	WNG
1	1998-03-09 16:46:00.0	1998-03-11 19:28:00.0	74	17	64	168	35
2	1998-05-03 02:22:00.0	1998-05-05 15:50:00.0	176	31	164	168	70
3	1998-09-23 22:53:00.0	1998-09-26 10:45:00.0	124	48	62	157	91
4	1998-11-12 21:03:00.0	1998-11-14 23:06:00.0	48	9	41	114	30
5	1999-01-12 20:45:00.0	1999-01-14 23:10:00.0	54	10	48	182	31
6	1999-09-21 20:21:00.0	1999-09-24 00:49:00.0	71	39	62	157	67
7	2000-04-05 15:42:00.0	2000-04-08 11:04:00.0	506	43	280	255	267
8	2000-06-07 12:09:00.0	2000-06-09 14:21:00.0	90	27	66	112	47
9	2000-07-14 13:36:00.0	2000-07-17 02:28:00.0	613	166	394	394	237
10	2000-09-16 20:16:00.0	2000-09-19 13:20:00.0	89	34	129	148	63
11	2000-11-05 17:06:00.0	2000-11-07 20:01:00.0	47	19	35	115	30
12	2001-03-18 17:35:00.0	2001-03-20 20:09:00.0	27	12	60	177	41
13	2001-03-29 23:51:00.0	2001-04-02 00:59:00.0	92	78	137	161	146
14	2001-04-10 14:49:00.0	2001-04-13 02:18:00.0	169	25	191	238	119
15	2001-09-24 21:47:00.0	2001-09-27 00:16:00.0	69	44	87	149	70
16	2001-10-20 15:47:00.0	2001-10-23 02:16:00.0	74	53	90	170	77
17	2001-11-05 00:51:00.0	2001-11-07 14:53:00.0	108	80	159	219	75
18	2001-11-23 04:58:00.0	2001-11-25 16:57:00.0	109	78	155	336	104
19	2002-05-22 14:44:00.0	2002-05-24 18:29:00.0	114	44	106	122	90
20	2002-09-04 13:05:00.0	2002-09-06 15:00:00.0	7	52	9	7	8
21	2002-09-06 16:04:00.0	2002-09-08 21:03:00.0	128	17	99	342	64
22	2002-09-30 15:23:00.0	2002-10-02 17:48:00.0	121	19	67	234	56
23	2003-02-01 14:47:00.0	2003-02-03 16:43:00.0	30	11	31	103	25
24	2003-05-28 12:34:00.0	2003-05-31 03:19:00.0	93	31	107	167	60
25	2003-08-17 13:21:00.0	2003-08-19 16:50:00.0	65	45	72	154	60
26	2003-10-13 17:24:00.0	2003-10-15 19:25:00.0	72	11	65	282	44
27	2003-10-28 05:10:00.0	2003-10-31 04:18:00.0	399	133	621	693	713
28	2003-11-19 07:14:00.0	2003-11-22 00:49:00.0	261	28	206	162	385
29	2004-07-25 21:49:00.0	2004-07-28 22:23:00.0	125	92	149	149	94
30	2004-11-06 17:45:00.0	2004-11-09 12:09:00.0	151	50	173	268	55
31	2005-01-06 21:30:00.0	2005-01-09 00:36:00.0	46	15	35	145	23
32	2005-01-20 16:21:00.0	2005-01-23 01:59:00.0	206	39	254	221	69
33	2005-05-07 12:16:00.0	2005-05-09 15:10:00.0	47	16	56	183	39
34	2005-05-14 01:38:00.0	2005-05-16 03:46:00.0	89	58	89	90	68
35	2005-05-29 16:57:00.0	2005-05-31 19:00:00.0	25	13	64	151	21
36	2005-08-23 07:46:00.0	2005-08-25 13:52:00.0	92	38	97	144	68
37	2005-09-10 00:13:00.0	2005-09-12 02:14:00.0	142	73	151	95	111
38	2006-12-13 21:42:00.0	2006-12-16 03:53:00.0	33	20	44	117	28

Preliminary results

- Models using only solar wind magnetic field as inputs.
- Tested for two big storms:
  - July 2000
  - October 2003
- Typical total run time on standard desktop is less than 4 seconds. Includes:
  - Extract data from database and preprocessing
  - Run model and provide output





Future development

- Further optimization of models
- Full testing and verification
- Implement for real time operation at RWC-Sweden
- EURISGIC and MSB tailored access
- Paper under preparation

Acknowledgements

- This work is being funded by
  - The Swedish Civil Contingency Agency (MSB) in project "Solar storms and space weather"
  - EU/FP7 research project EURISGIC
- Data provided by
  - ACE SWEPAM instrument team and the ACE Science Center: ACE solar wind science level data
  - NOAA/SWPC: ACE real time solar wind data
  - World Data Centre Edinburgh: Local geomagnetic data
  - DTU/Space, Denmark: Real time local geomagnetic data