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310/1749-39

ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

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# *Solar Activity: Predictions and Real-Time Forecasts*

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*Scheelev 17*
*SE-223 70 Lund*
*SWEDEN*

These lecture notes are intended only for distribution to participants

# The Sun: Space Weather Applications:

## 4) Solar Activity: Predictions and real-time forecasts

### ICTP-COST-CAWSES-INAF-INFN, Trieste, 2006


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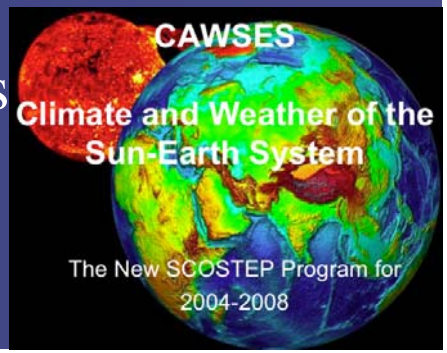
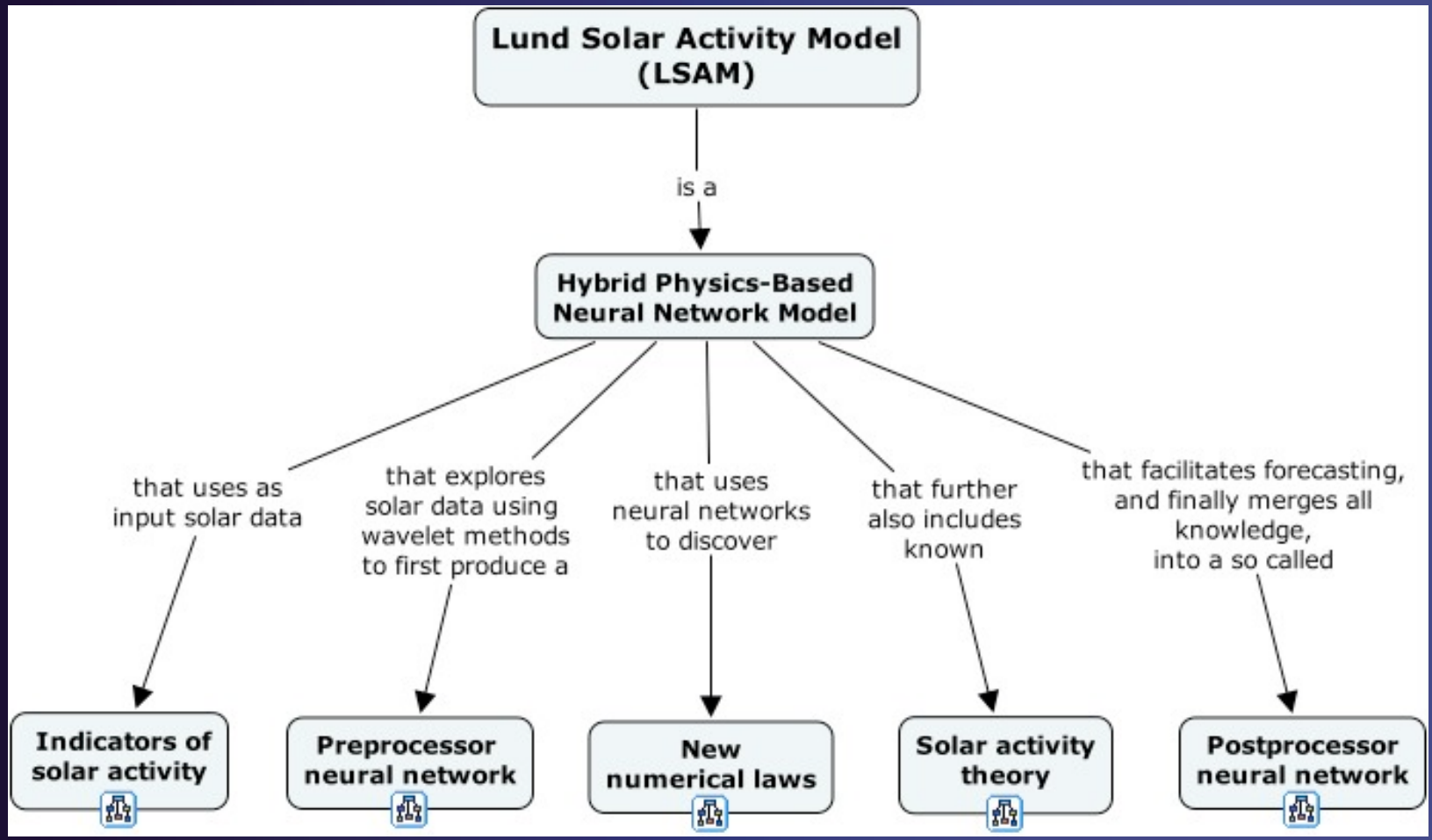


# Outline of my fourth talk

- AI and neural network methods
- **Forecasting** with NN and **services for users**
- **Real space weather events**: Bastille event 2001, Halloween event 2003, November event 2004 and events in January and September 2005.
- Today's event

# Hybrid physics-based neural network



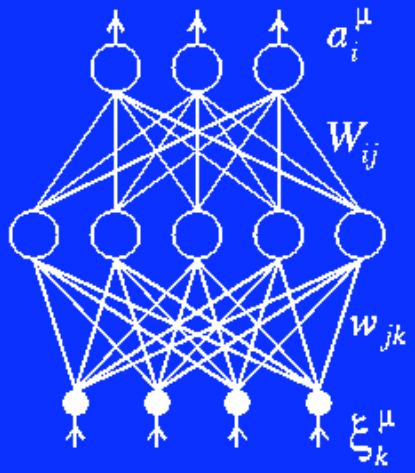
# Workshops arranged by us

Workshops on ”Artificial Intelligence Applications in Solar-Terrestrial Physics” were held in Lund 1993 and 1997. A third workshop was held in September 19-21, 2005

# Artificial neural networks

The basic element of every ANN is an artificial neuron or simply a neuron (which is an abstract model of a biological neuron (nerve cell)).

**Multi-layer error-back-propagation (MLBP)**

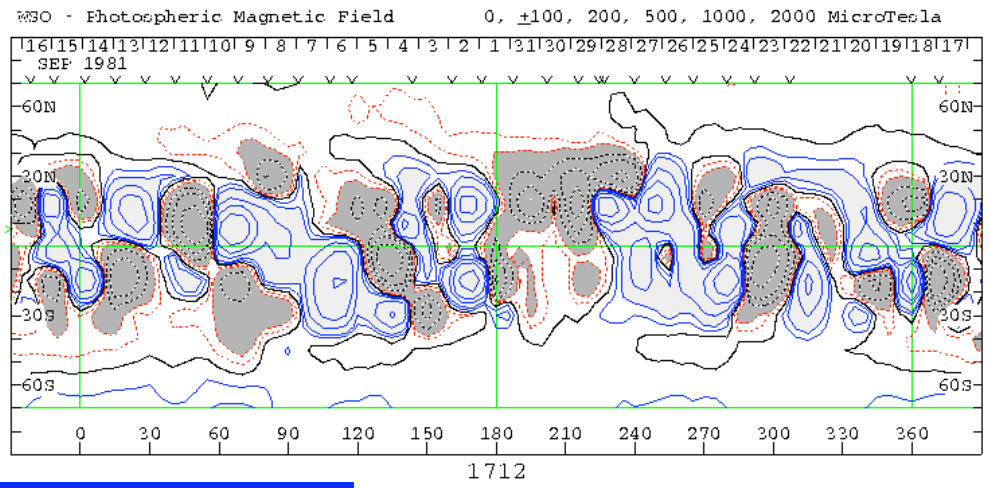



$$a_i^\mu = g_i\left(\sum_j W_{ij}\, g_j\left(\sum_k w_{jk}\xi_k^\mu\right)\right)$$

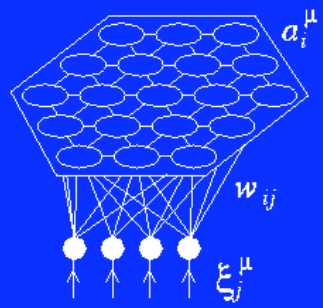
Back-propagation learning : $\Delta W_{ij}(t+1) = -\eta \frac{\partial E}{\partial W_{ij}} + \alpha \Delta W_{ij}(t)$

Error measure : $E = \frac{1}{2}\sum_{i\mu}\left(d_i^\mu - a_i^\mu\right)^2$

# Synoptic map of WSO




## Self Organized Map (SOM)




$$a_i^\mu = \begin{cases} 1 & \text{if } i = i^* \\ 0 & \text{if } i \neq i^* \end{cases}$$

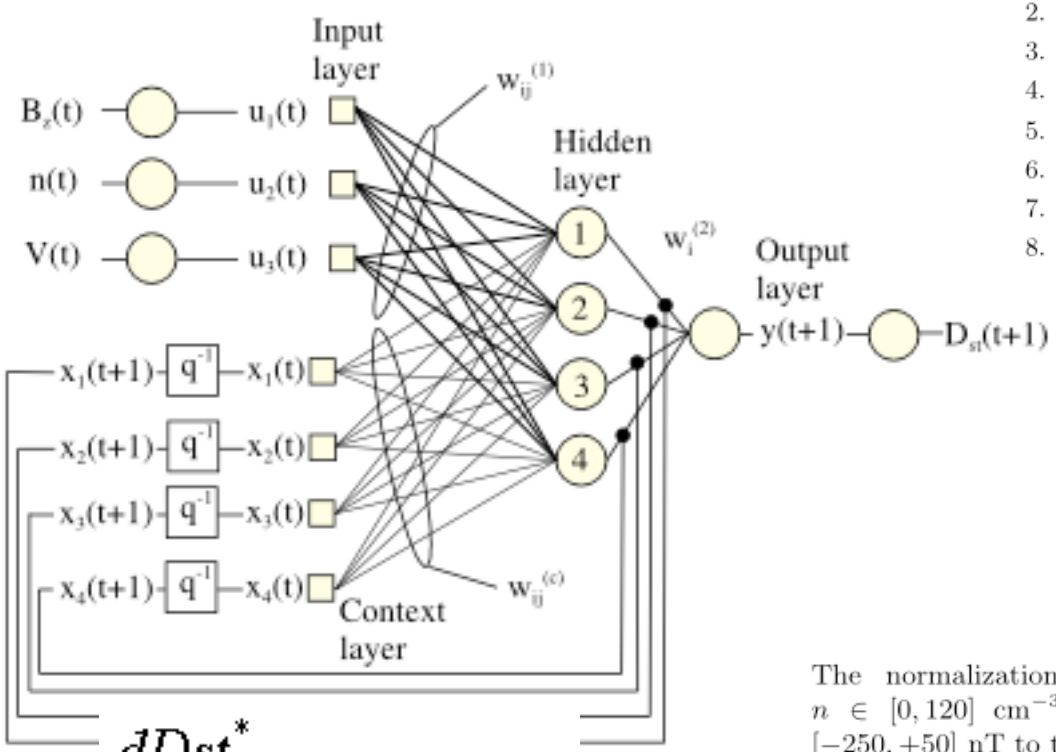
$$h_i^\mu = \sum_j w_{ij}\xi_j \qquad h_{i^*}^\mu \geq h_i^\mu \text{ for all } i$$

Kohonen learning : $\Delta w_{ij} = \eta\Lambda(i,i^*)(\xi_j^\mu - w_{ij})$

Neighborhood function : $\Lambda(i,i^*) = e^{-\frac{|\mathbf{r}_i - \mathbf{r}_{i^*}|^2}{2\sigma^2}}$

# Download Lund Dst model in Java and Matlab (www.lund.lrf.se/dst/models)

**Lundstedt, H., Gleisner, H. and P. Wintoft, Operational forecasts of the geomagnetic Dst index, Geophys. Res. Lett., 29, 34-1--34-4, 2002.**




$$\frac{dDst^*}{dt} = Q - \lambda Dst^*$$

The ARMA filter is obtained by adding auto-regressive terms to a MA filter.The partial recurrent network (Elman) becomes identical to a linear ARMA filter if it is assigned linear activations functions.

1. Set $\mathbf{x} = (0.39, 0.22, -0.83, 0.14)^T$.
2. Get the first observation of $B_z$, $n$, and $V$.
3. Compute $\mathbf{u} = (u_1, u_2, u_3)^T$ from Eq. 7.
4. Compute $\mathbf{x} \leftarrow \tanh\left(\mathbf{W}^{(1)}\mathbf{u} + \mathbf{W}^{(c)}\mathbf{x} + \mathbf{b}^{(1)}\right)$.
5. Compute $y \leftarrow \mathbf{w}^{(2)}\mathbf{x} + b^{(2)}$.
6. Compute $Dst$ from Eq. 8.
7. Get the next observation of $B_z$, $n$, and $V$.
8. Go back to step 3.

The weights and biases are

$$\mathbf{W}^{(1)} = \begin{pmatrix} -0.5946 & 0.0904 & 0.0428 \\ 0.6215 & 0.4485 & 0.2516 \\ -1.4217 & 0.4988 & 0.1409 \\ 0.3372 & -0.5065 & 0.7190 \end{pmatrix}$$

$$\mathbf{W}^{(c)} = \begin{pmatrix} 0.6099 & 0.2223 & -0.4379 & 0.0053 \\ 0.7935 & 0.5000 & -1.2654 & -0.0428 \\ -0.3496 & 0.1024 & 0.3605 & 0.1790 \\ -0.2067 & 0.2270 & 0.5446 & 0.1019 \end{pmatrix}$$

$$\mathbf{b}^{(1)} = \begin{pmatrix} -0.1081 \\ -0.7252 \\ -0.2307 \\ 0.5406 \end{pmatrix}$$

$$\mathbf{w}^{(2)} = \begin{pmatrix} 0.2535 & 0.3172 & -0.4860 & -0.2346 \end{pmatrix}$$

$$b^{(2)} = 0.0712$$

$$Dst = 150y - 100. \quad (8)$$

The normalization transforms $B_z \in [-30, +30]$ nT, $n \in [0, 120]$ cm$^{-3}$, $V \in [200, 1000]$ km/s, and $Dst \in [-250, +50]$ nT to the $[-1, +1]$ interval.

The output from the network is described by the following equations

$$x_i(t+1) = \tanh\left(\sum_{j=1}^{n_1} w_{ij}^{(1)} u_j(t) + \sum_{j=1}^{n_c} w_{ij}^{(c)} x_j(t) + b_i^{(1)}\right) \quad (9)$$

$$y(t+1) = \sum_{i=1}^{n_2} w_i^{(2)} x_i(t+1) + b^{(2)}. \quad (10)$$

# Applications

| Input parameters | Output | KBNM method | Reference |
|---|---|---|---|
| Daily sunspot number | Daily sunspot number | SOM and MLP | Liszka 93;97 |
| Monthly sunspot number | Date of solar cycle max and amplitude | MLP and Elman | Macpherson et al., 95, Conway et al, 98 |
| Monthly sunspot number and aa | Date of solar cycle max and amplitude | Elman | Ashmall and Moore, 98 |
| Yearly sunspot number | Date of solar cycle max and amplitude | MLP | Calvo et al., 95 |
| McIntosh sunspot class & MW magn complex. | X class solar flare | MLP expert system | Bradshaw et al., 89 |
| Flare location, duration X-ray and radio flux | Proton events | MLP | Xue et al., 97 |
| X-ray flux | Proton events | Neuro- fuzzy system | Gabriel et al., 00 |
| Photospheric magnetic field expansion factor | Solar wind velocity 1-3 days ahead | RBF & PF MHD | Wintoft and Lundstedt 97;99 |

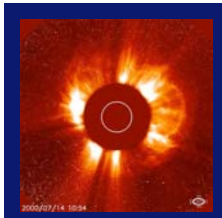
# Applications

| Input parameters | Output | KBNM method | Reference |
|---|---|---|---|
| Solar wind n, V, Bz | Relativistic electrons in Earth magnetosphere hour ahead | MLP | Wintoft and Lundstedt, 00 |
| Solar wind n,V, Bz, Dst | Relativistic electrons one hour ahead | MLP, MHD, MSFM | Freeman et al., 93 |
| ΣKp | Relativistic electrons day ahead | MLP | Stringer and McPherron, 93 |
| Solar wind V from photospheric B | Daily geomagnetic Ap index | MLP | Detman et al., 00 |
| Ap index | Ap index | MLP | Thompson, 93 |
| Solar wind n, V, Bz | Kp index 3 hours ahead | MLP | Boberg et al., 00 |
| Solar wind n, V, B,Bz | Dst 1-8 hours ahead | MLP, Elman | Lundstedt, 91; Wu and Lundstedt, 97 |
| Solar wind n, V, B,Bz | AE 1 hour ahead | Elman, MLP | Gleisner and Lundstedt,00 ,Gavrishchaka et al.,00, 01 |

# Applications

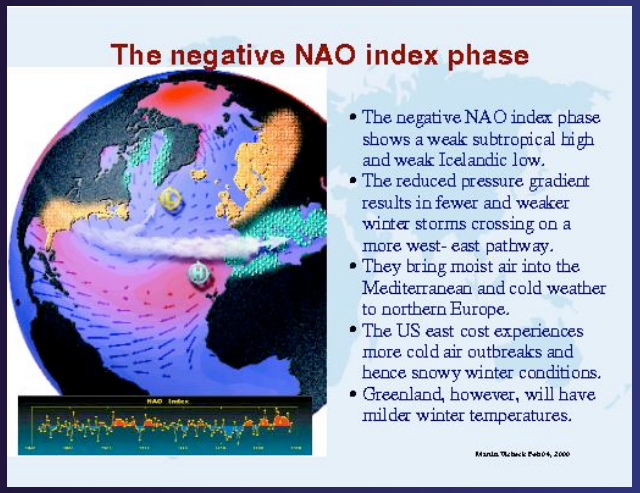
| Input parametrs | Output | KBNM method | References |
|---|---|---|---|
| Solar wind $V^2B_s$, $(nV^2)^{1/2}$, LT, local geomag $\Delta x^e$, $\Delta Y^w$ | Local geomagnetic field $\Delta X$, $\Delta Y$ | MLP and RBF | Gleisner and Lundstedt 00 |
| Solar wind n,V, Bz | None, weak or strong aurora | MLP | Lundstedt et al., 00 |
| foF2 | foF2 1 hour ahead | MLP | Wintoft and Lundstedt, 99 |
| AE, local time, seasonal information | foF2 1-24 hours ahead | MLP | Wintoft and Cander, 00 |
| foF2, Ap, F10.7 cm | 24 hours ahead | MLP | Wintoft and Cander, 99 |
| ΣKp | Satellite anomalies | MLP | Wintoft and Lundstedt 00 |
| Solar wind n, V, Bz | dBx/dt, GIC | Elman, MLP | Kronfeldt et al., 01 and Weigel et al.,02 |

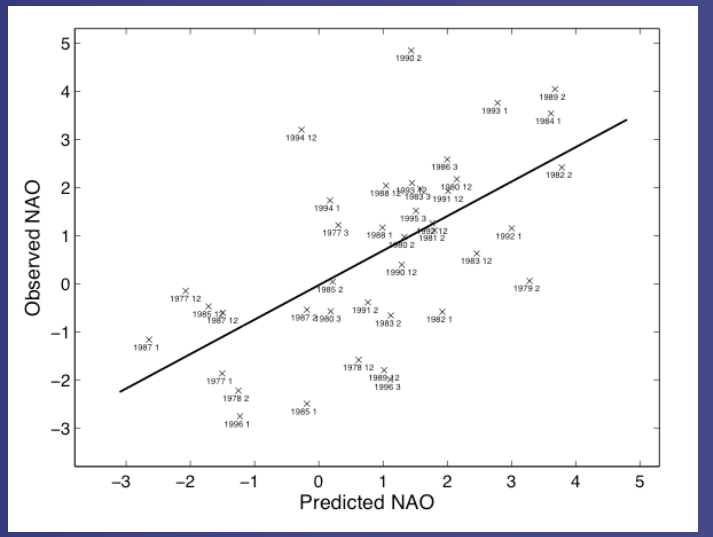
Lundstedt, H., Progress in space weather predictions and applications, Adv. in Space Res., 36, 2516-2523, 2005.



# Solar wind E parameter correlated with atmospheric pressure

## Forecasts of NAO from solar activity and solar wind E



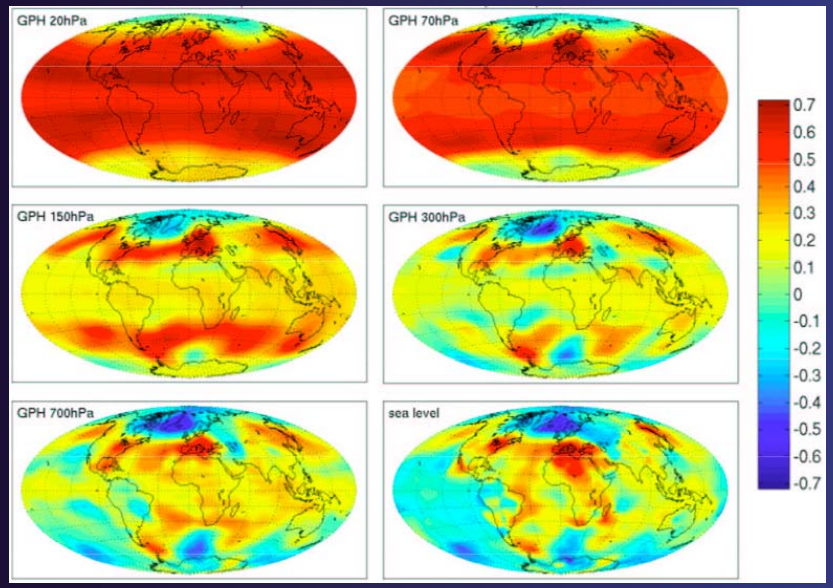

20hPa = 26km

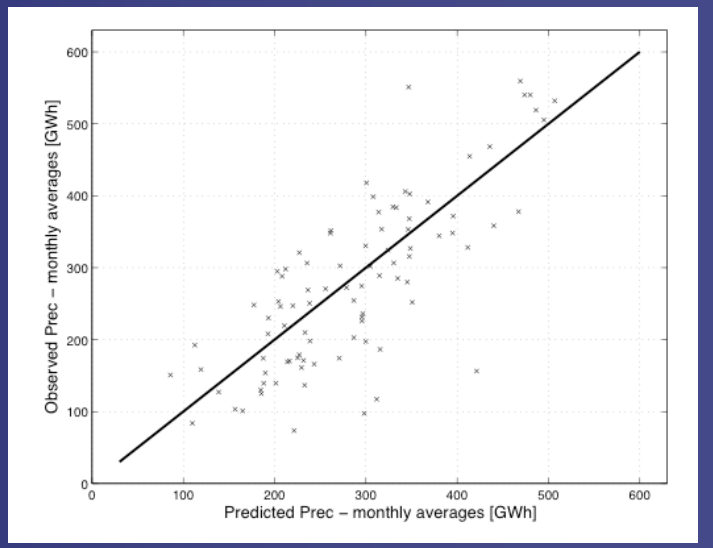
70hPa = 18km

150hPa = 14km

300hPa = 9.2km

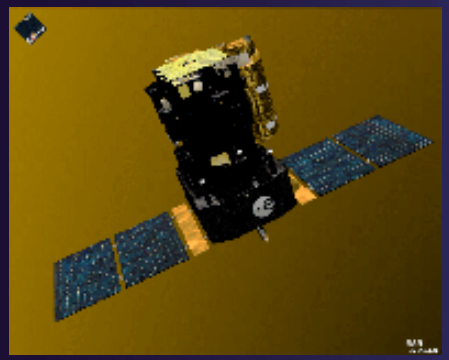
700hPa = 3.0km



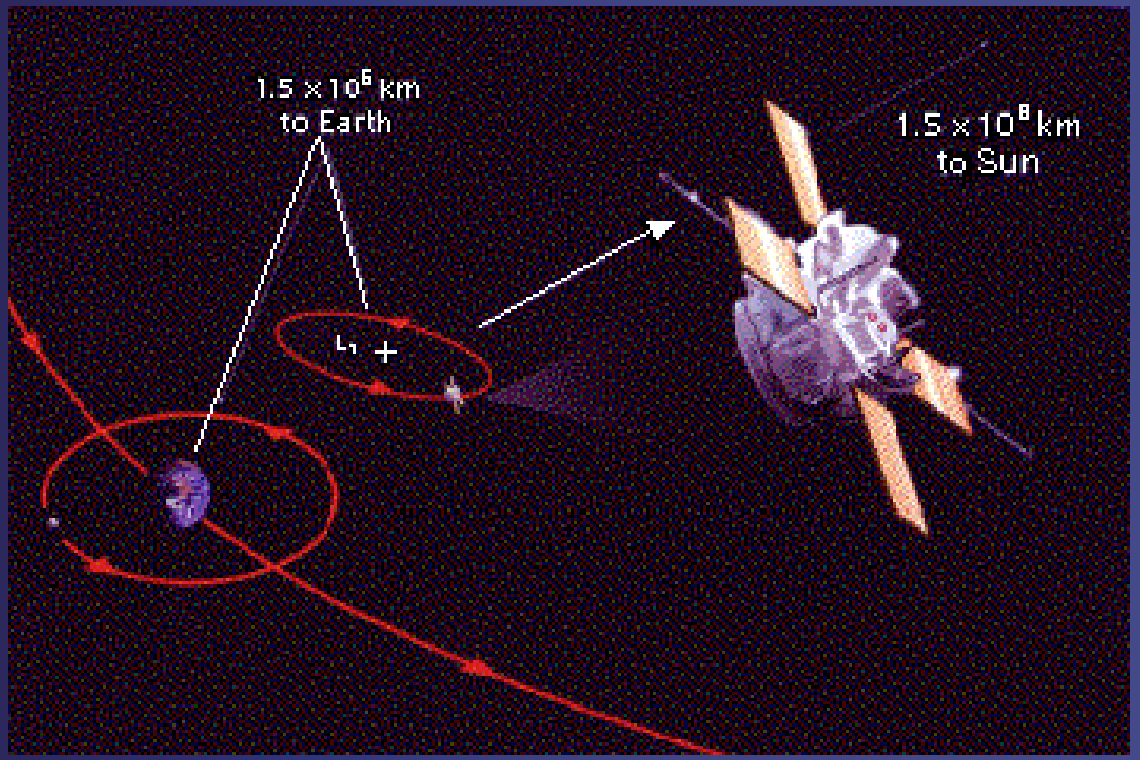



# Real-time forecasts and warnings based on KBN

## Solar input data

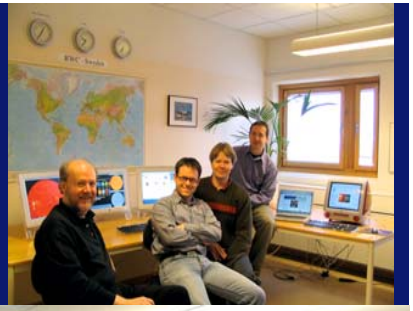


Solar observations with SOHO make warnings 1-3 days ahead possible.

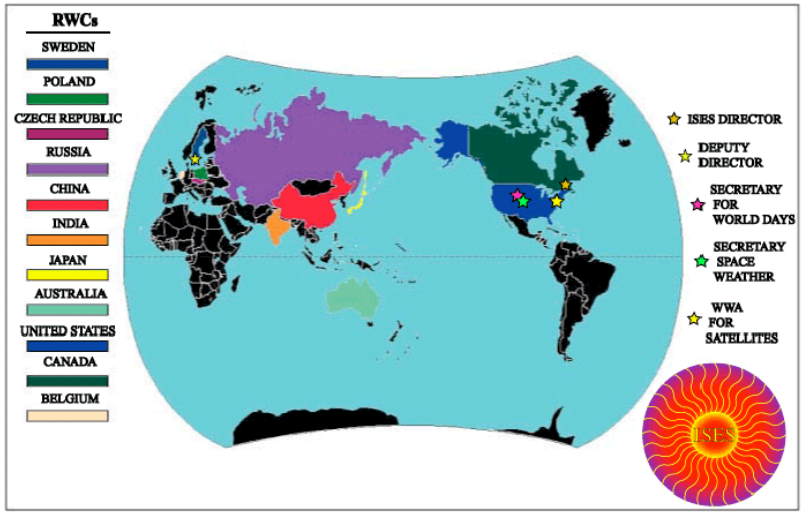



Solar wind observations with ACE make accurate forecasts 1-3 hours ahead possible.

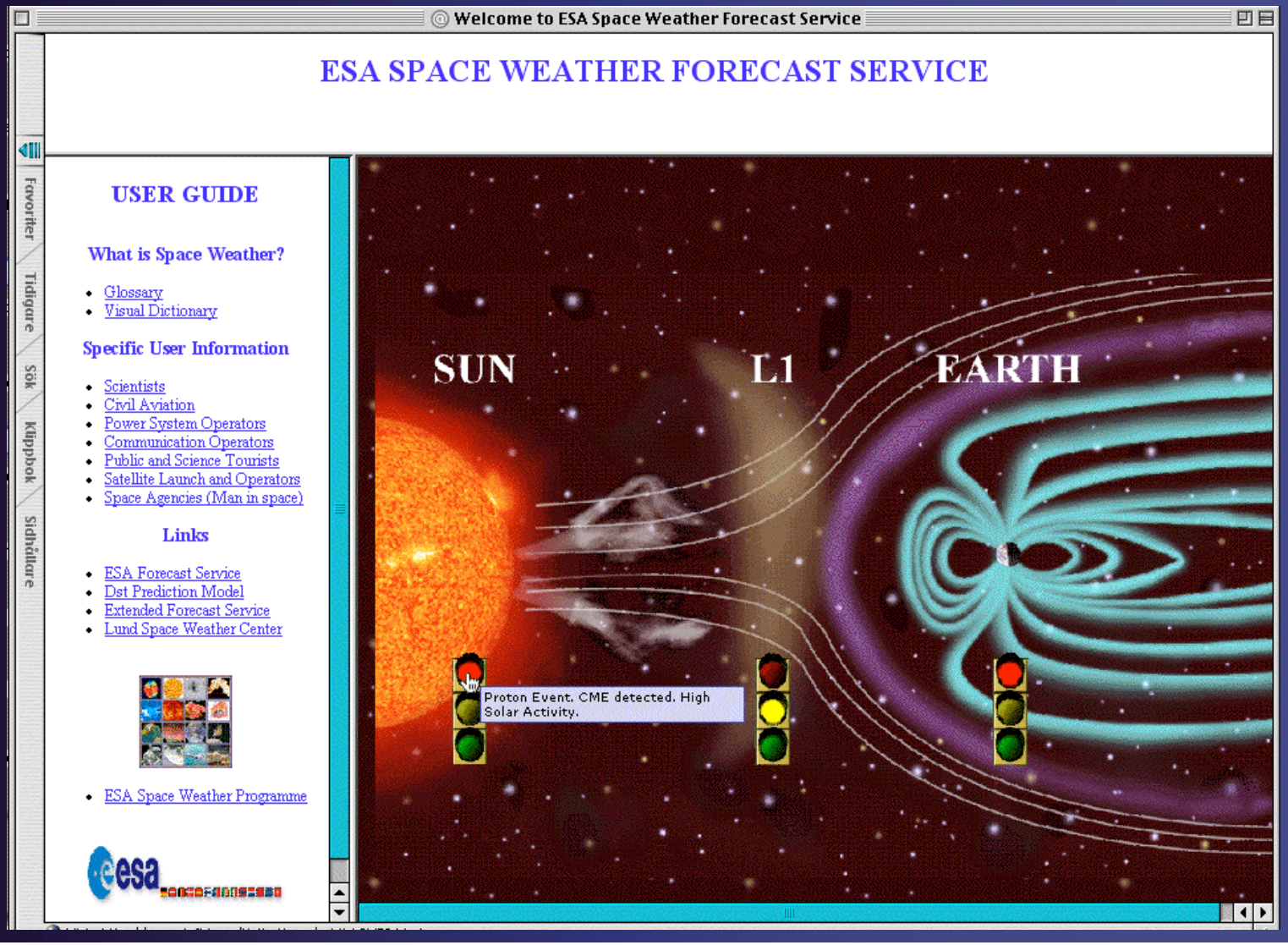
# Today general forecast service is given by RWCs within ISES



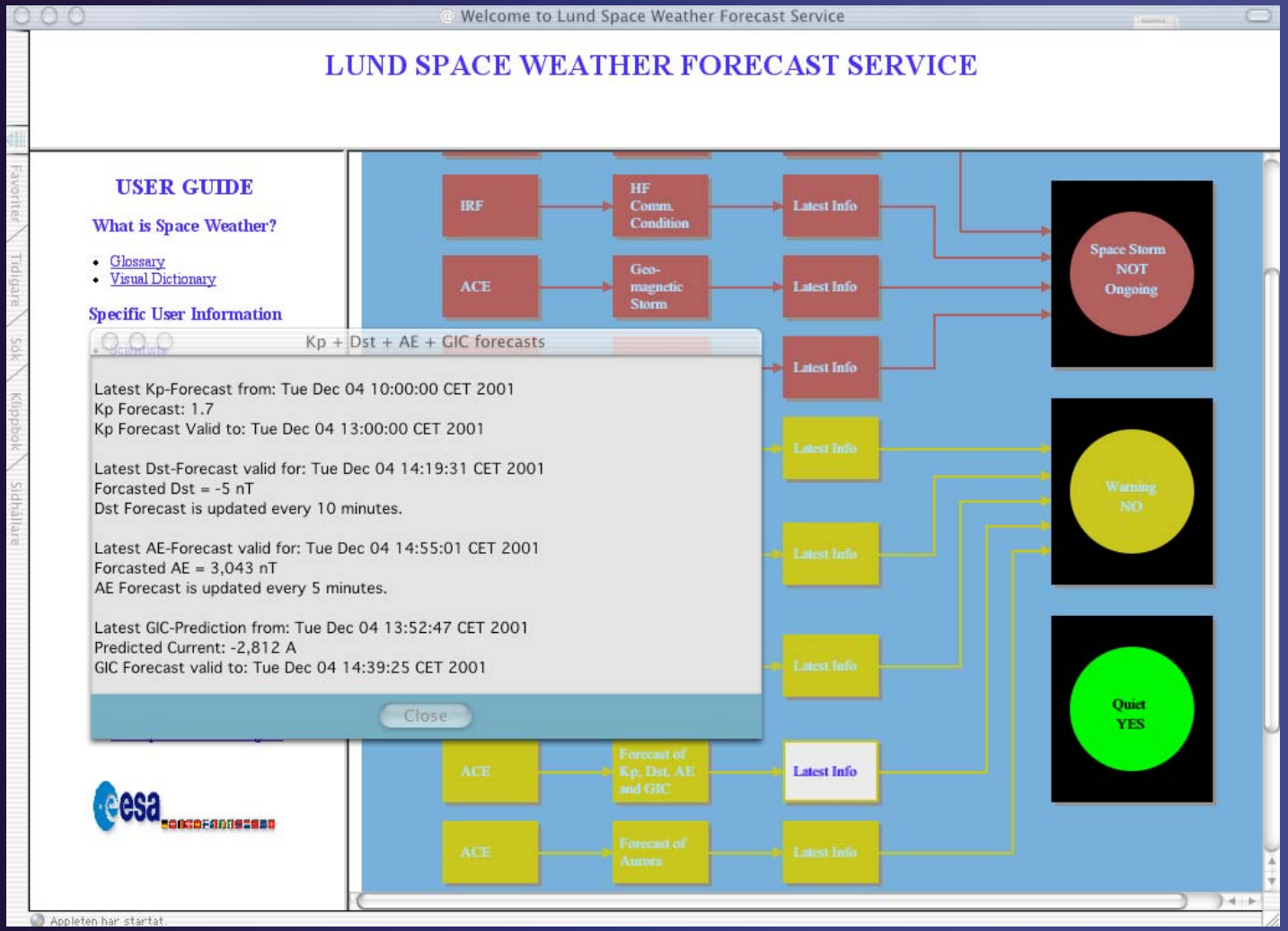

**ISES Director**: D. Boteler
**Deputy Director**: H. Lundstedt
**Secr. for World days**: H. Coffey
**Secr. Space Weather**: J. Kunches
**WWW for Satellites**: J. King



# ESA/Lund Space Weather Forecast Service Package



# Latest information on forecasts of Kp, Dst, AE and GIC



# Implemeted real-time GIC forcasts to a user: ESA GIC Project

ESA GIC Pilot Project

http://www.lund.irf.se/gicpilot/

Google

**ESA Pilot Project**

**Real-time forecast service for geomagnetically induced currents**

**Lund**

Swedish Institute of Space Physics

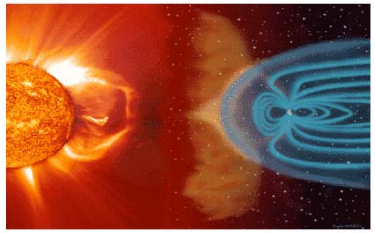
Lund Space Weather Cente

**Project Summary**

The goal of the project is to develop a forecast service to be used by electrical power companies to mitigate the effects of geomagnetically induced currents (GIC) caused by the space weather.Swedish power companies (Elforsk) are the users of the service and shall also take active part in the project.

The service developer is the Swedish Institute of Space Physics (IRF) in collaboration with the Finnish Meteorological Institute (FMI).

The project shall result in a software package implementing a prototype service, and a cost-benefit analysis of the service. The service shall also be coordinated with the Space Weather European Network (SWENET).



**Learn more about GIC**

- IRF-Lund
- FMI
- NRCan
- SEC
- Metatech Corp.
- Nordic GIC Network
- Topical Group Ground Effects

**Documents and Data**

- Prototype GIC forecast service
- GIC pilot project poster (pdf)
- Internal information

ELFORSK

SVENSKA ELFÖRETAGENS FORSKNINGS- OCH UTVECKLINGS - ELFORSK - AB

esa

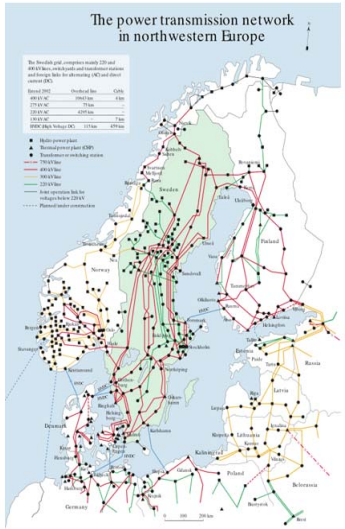
Contact Henrik Lundstedt, Swedish Institute of Space Physics in Lund

Welcome to Adobe GoLive 6

Prototype GIC Forecast Service

**Warning long beforehand**

- Active regions/ Sunspots on far side ?
- Front side halo Coronal Mass Ejections ?
- Solar wind shock ?
- Geomagnetic storm ?




**Short-term forecasts**

- dB/dt at Brorfelde and Uppsala
- GIC for one station in Southern Sweden
- GIC for any station in Southern Sweden and for current power grid configuration (internal)

ESA GIC Pilot Project

# RWC-Sweden

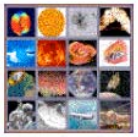
RWC-Sweden

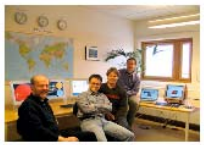
http://www.lund.irf.se/rwc/

Google

IRF

## Regional Warning Center Sweden
## of
## International Space Environment Service

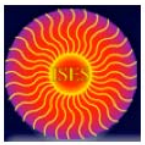




SPACE WEATHER
The International Journal of Research and Applications

Glossary and Dictionary

- Solar and space weather glossary
- Visual space weather dictionary
- NOAA space weather scales



### Space Weather Now

The solar activity is increasing (7-day forecast).

Active sunspot region 649 poses the greatest threat for a major solar flare.

The holographic images (SOHO/MDI) reveal a big sunspot on the far side of the Sun.

Earth is not inside a fast solar wind from a coronal hole.

### Rymdvädret nu

Solaktiviteten är ökar (7-dagars prognos).

Aktiva solfläcksområdet 649 kan producera en kraftig "solar flare".

De holografiska (SOHO/MDI) bilderna visar en stor solfläcksgrupp på solens baksida.

Jorden ligger inte inuti en snabb solvind från ett koronahål.

### Contact Information

ISES home

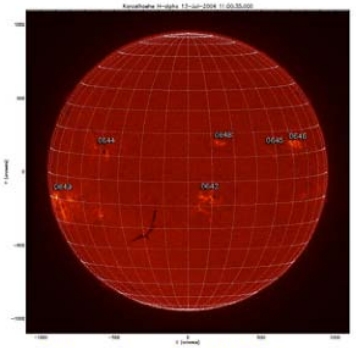
Director - D.Boteler

Deputy - H.Lundstedt

Secretary Space Weather - J.Kunches

Secretary for World Days - H.Coffey

Regional Warning Center Sweden

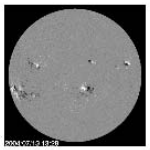
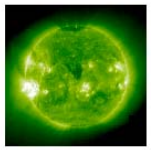
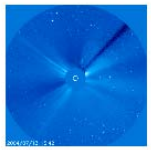
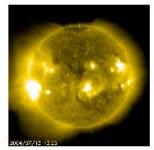


Active region monitor (Big Bear)

# RWC-Sweden web

RWC-Sweden

## CURRENT SOLAR AND SPACE WEATHER

| Sunspots<br>Solfläckar | Solar magnetic field<br>Solens magnetfält | Solar flares<br>Strålningsutbrott | Coronal mass ejections<br>Solplasmautbrott | Coronal holes<br>Koronahål |
|---|---|---|---|---|
|  |  |  |  |  |
| SOHO/MDI | SOHO/MDI | SOHO/EIT | SOHO/LASCO | SOHO/EIT |

Sunspot number (SEC)

Latest active region summary (SEC)

Solar cycle progress (SEC/ISES)

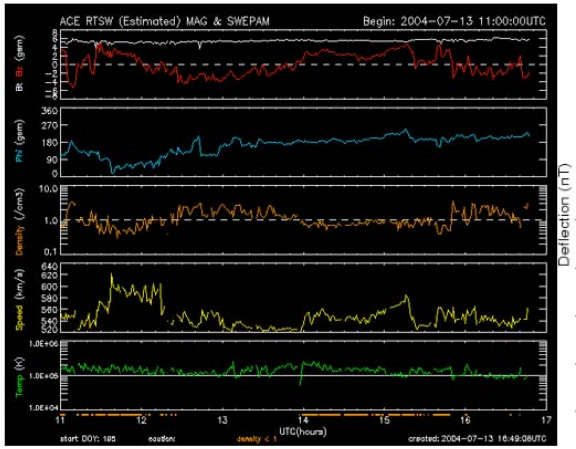
Solar cycle 24 (Lund)

MDI/STANFORD

Solar X-ray flux (SEC)

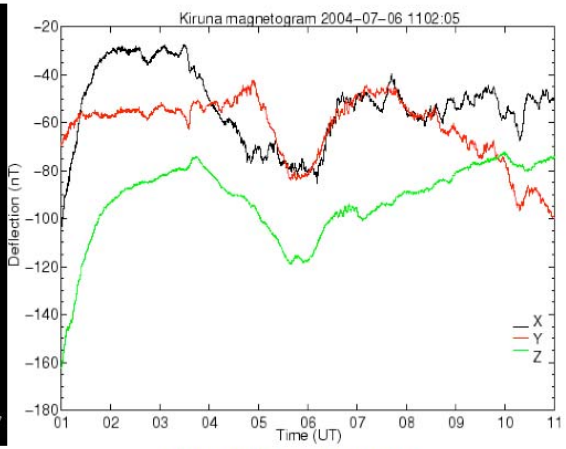
GOES proton flux (SEC)

### Solar wind
### Solvinden




Shocks and 48 hour of solar wind data (SOHO/CELIAS)

### Earth's magnetic field
### Jordens magnetfält
### (IRF-Kiruna)




Latest Magnetogram (Brorfelde/DMI)

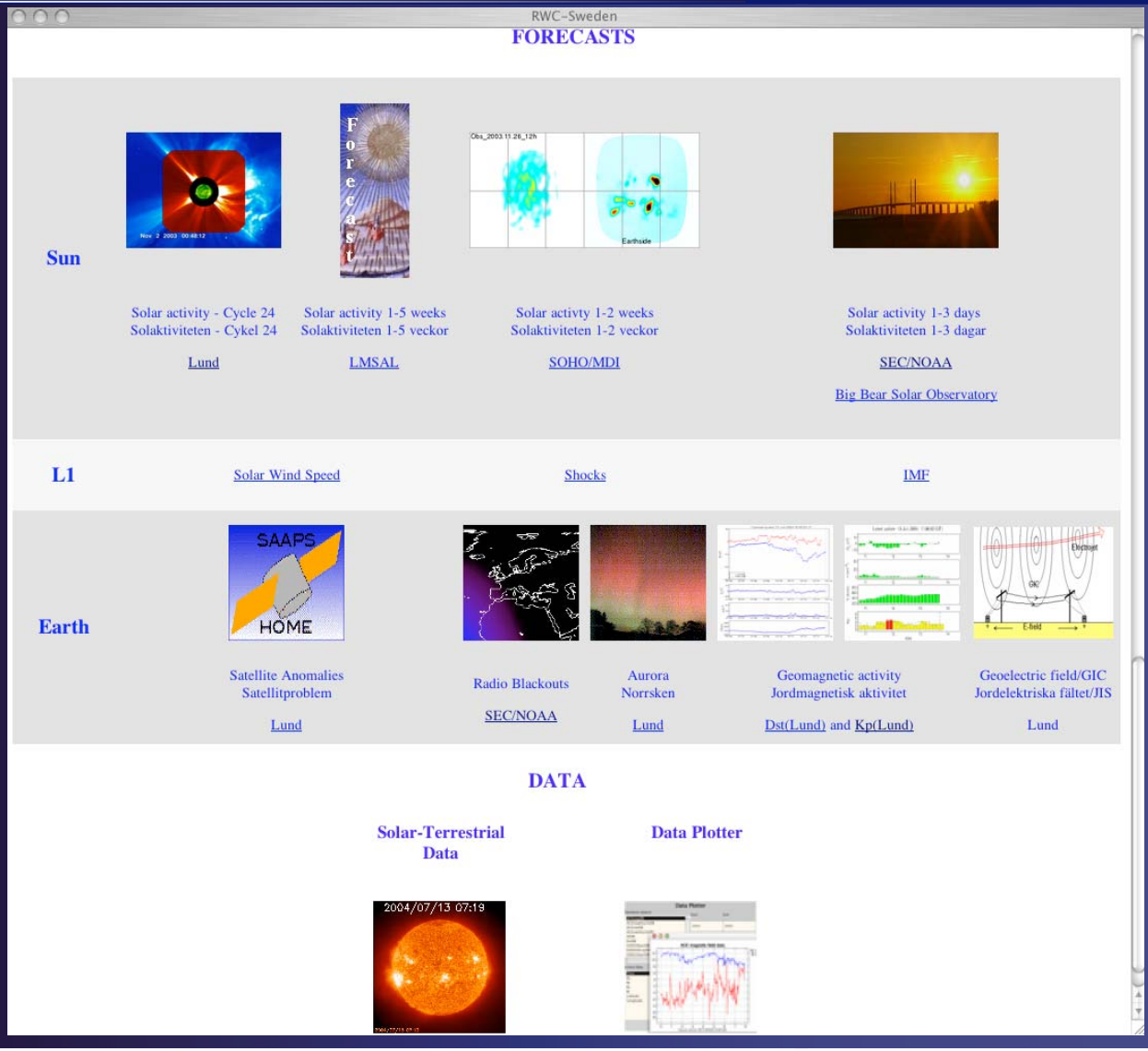
Fast solar wind and large negative Bz value cause geomagnetic storms.

Snabb solvind och stort negativt Bz värde orsakar jordmagnetisk storm.

The plot shows the deviation from the expected means of the three components (X, Y and Z) of the geomagnetic field

Diagrammet visar avvikelsen från förväntade medelvärdet för jordmagnetiska fältets tre komponenter (X, Y och Z).

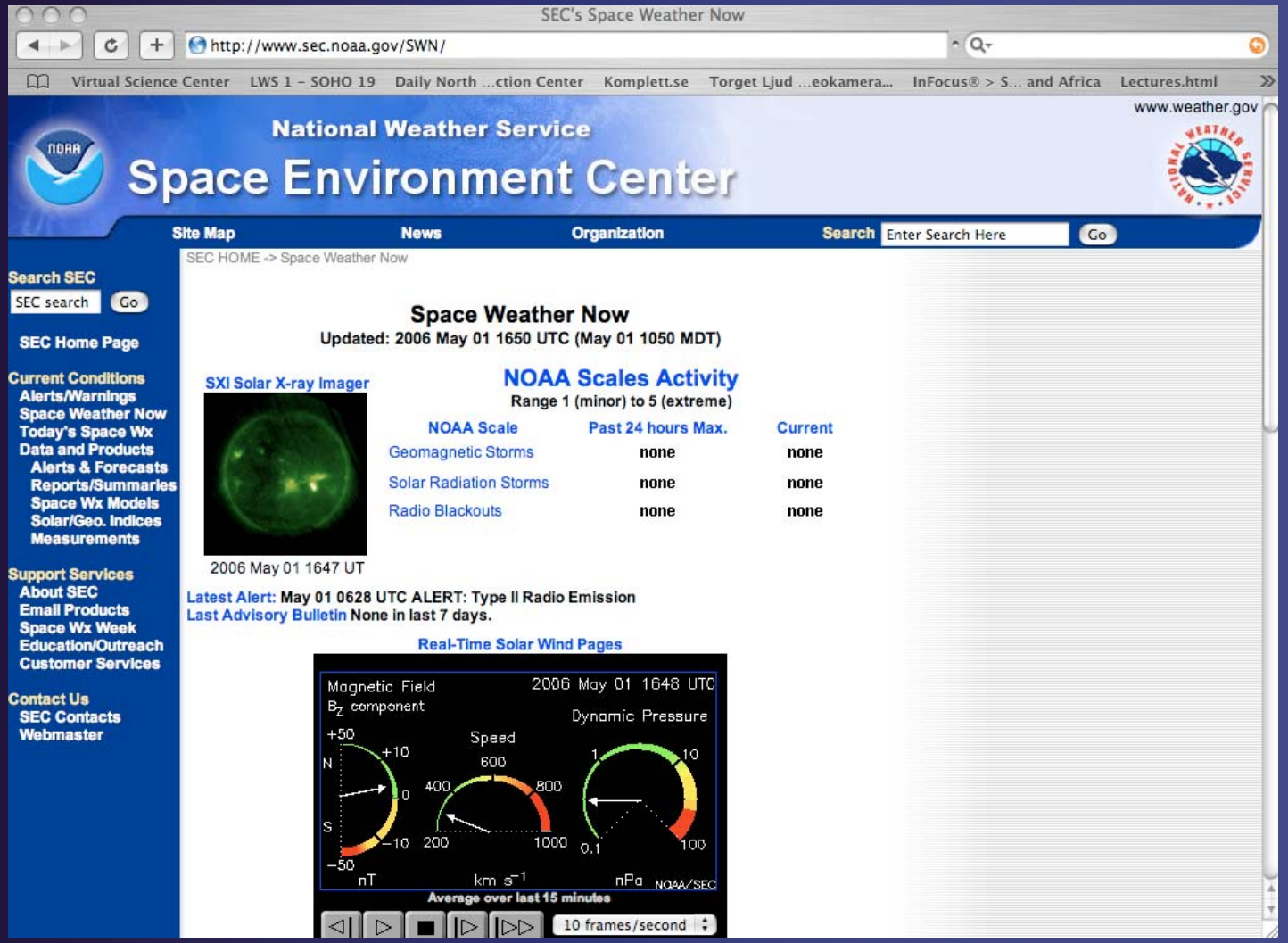
# RWC-Sweden web

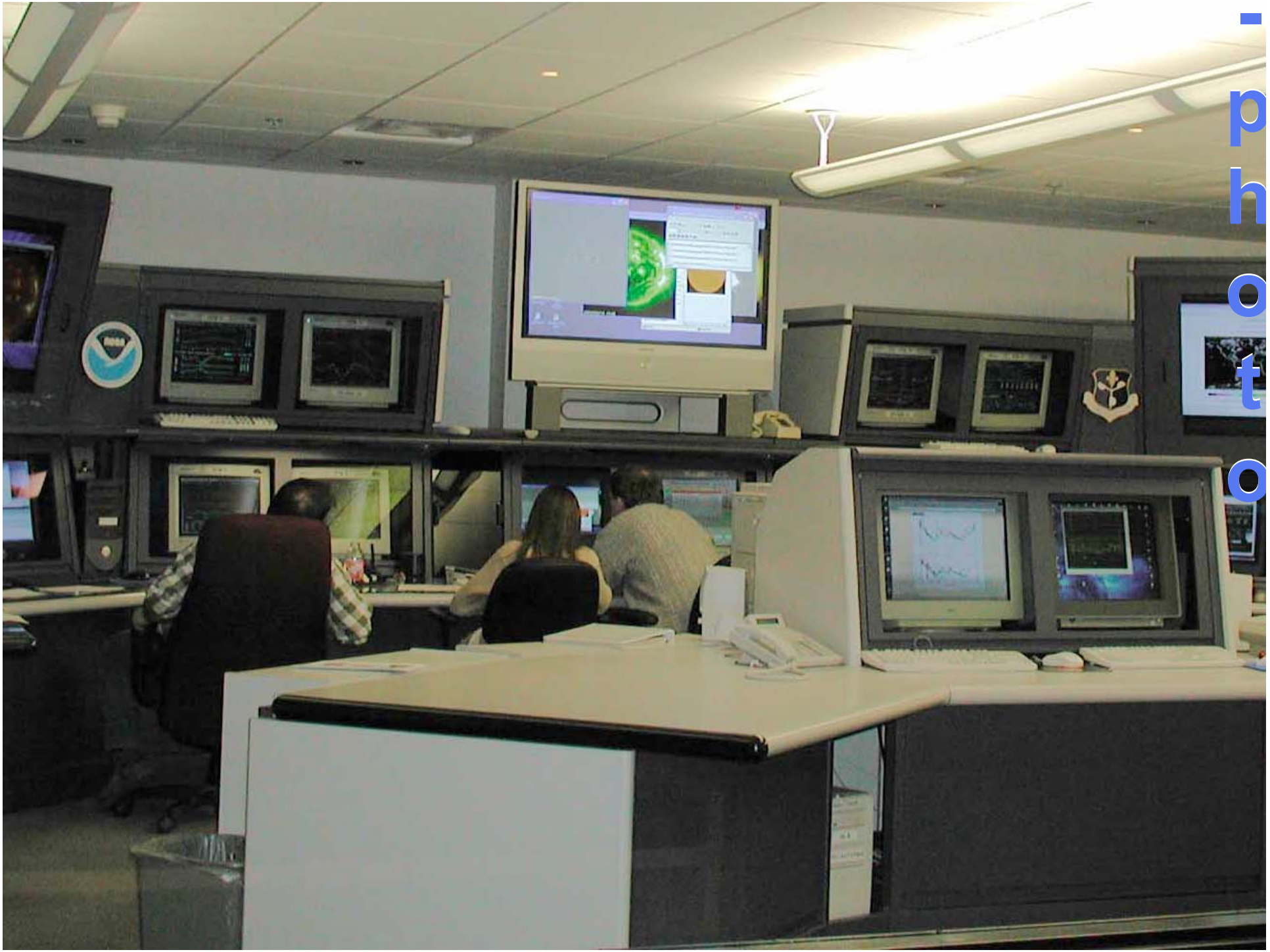


# ISES RWS Centers


ISES REGIONAL WARNING CENTRES

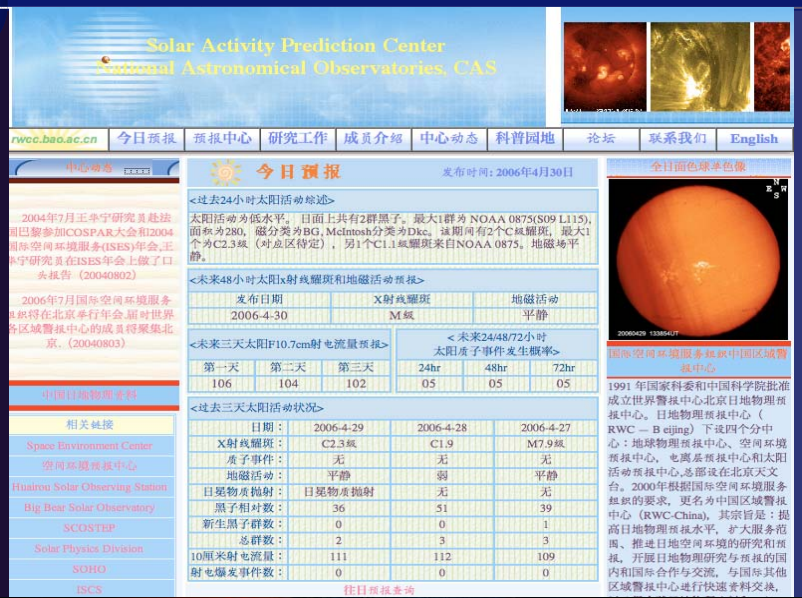
# RWC-USA

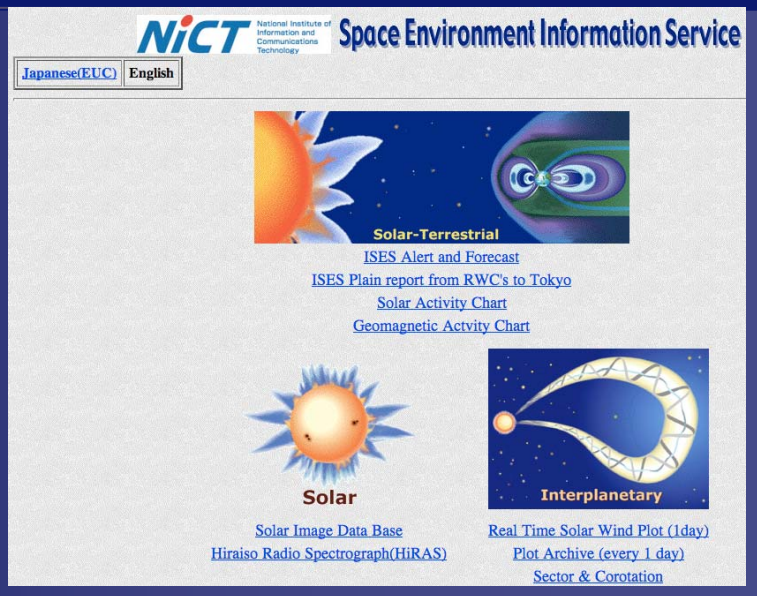

SEC's Space Weather Now
http://www.sec.noaa.gov/SWN/
Virtual Science Center
LWS 1 - SOHO 19
Daily North ...ction Center
Komplett.se
Torget Ljud ...eokamera...
InFocus® > S... and Africa
Lectures.html
www.weather.gov
National Weather Service
Space Environment Center
Site Map
News
Organization
Search
Enter Search Here
Go
SEC HOME -> Space Weather Now
Search SEC
SEC search
Go
SEC Home Page
Current Conditions
Alerts/Warnings
Space Weather Now
Today's Space Wx
Data and Products
Alerts & Forecasts
Reports/Summaries
Space Wx Models
Solar/Geo. Indices
Measurements
Support Services
About SEC
Email Products
Space Wx Week
Education/Outreach
Customer Services
Contact Us
SEC Contacts
Webmaster
Space Weather Now
Updated: 2006 May 01 1650 UTC (May 01 1050 MDT)
SXI Solar X-ray Imager
2006 May 01 1647 UT
NOAA Scales Activity
Range 1 (minor) to 5 (extreme)
NOAA Scale
Past 24 hours Max.
Current
Geomagnetic Storms
none
none
Solar Radiation Storms
none
none
Radio Blackouts
none
none
Latest Alert: May 01 0628 UTC ALERT: Type II Radio Emission
Last Advisory Bulletin None in last 7 days.
Real-Time Solar Wind Pages
Magnetic Field
Bz component
2006 May 01 1648 UTC
Dynamic Pressure
Speed
+50
+10
0
−10
−50
N
S
nT
600
400
800
200
1000
km s−1
1
10
0.1
100
nPa
NOAA/SEC
Average over last 15 minutes
10 frames/second

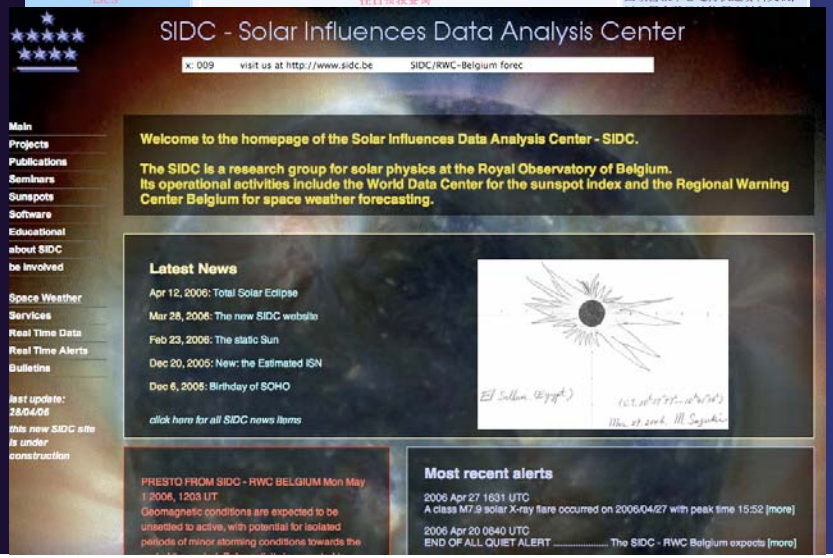


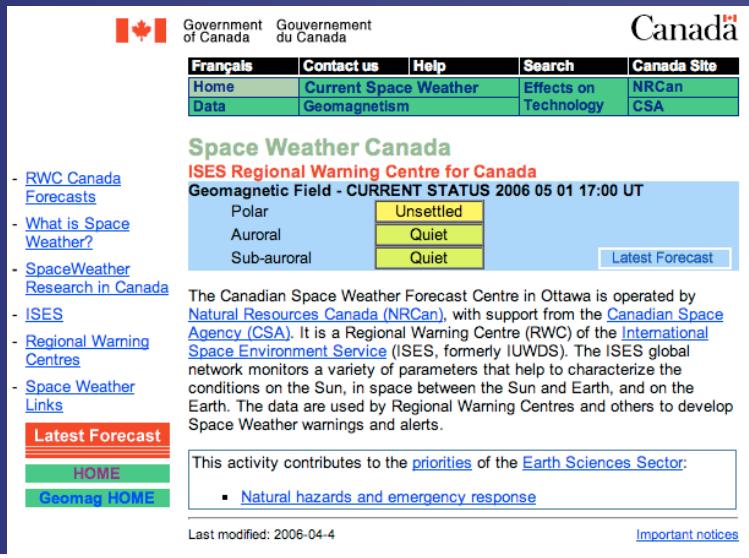
photo

# ISES RWS Centers
# China,Japan,Belgium,Canada

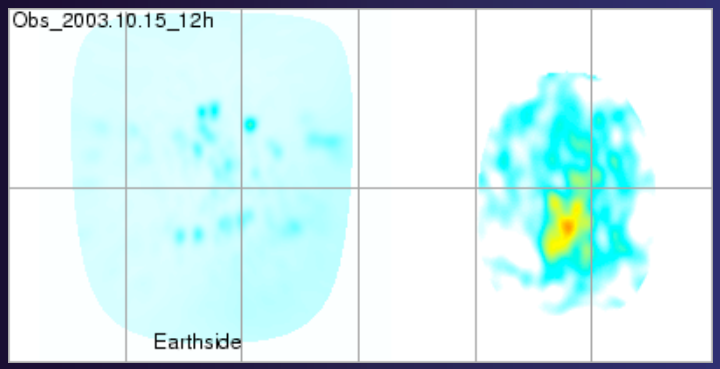


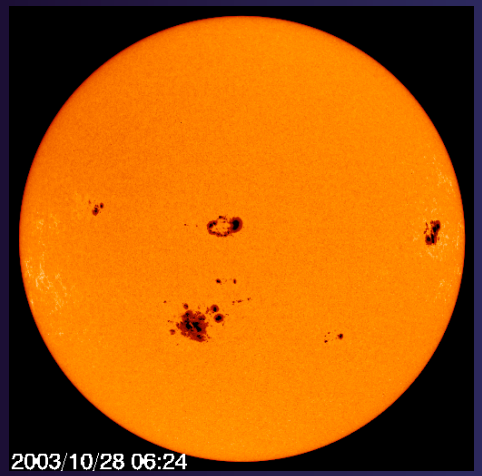



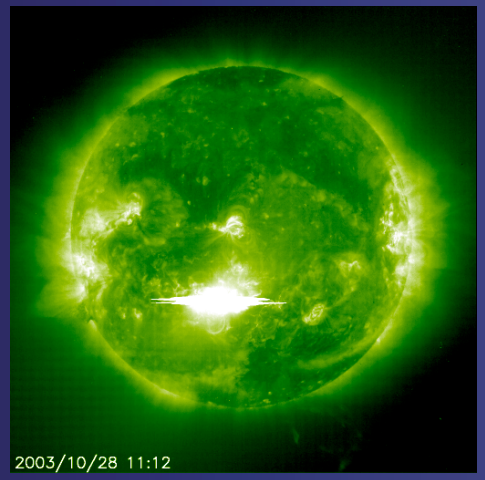
# The October 14 -November 6 events: It all started with no sunspots

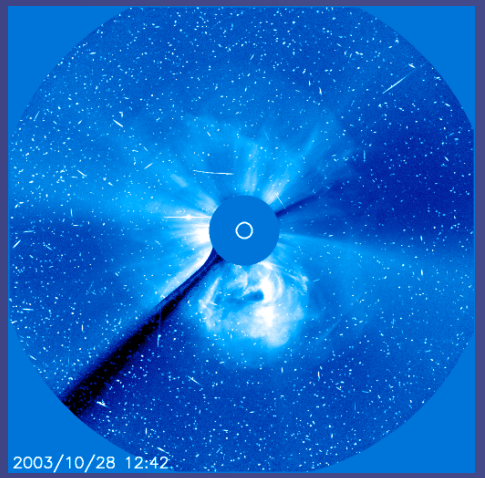




- No sunspots (R=24)
- Aurora observed in Southern Sweden (Gothenburg, Lund)
- Media got interested
- SOHO/MDI far side images had told me Large ARs were to come

# Then came the AR 486, October 28 event



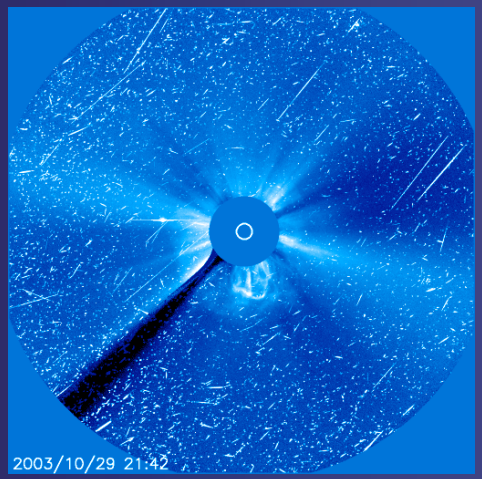




- Even more interviews
- Warnings and reports were sent to power industry
- Discussions with power operators

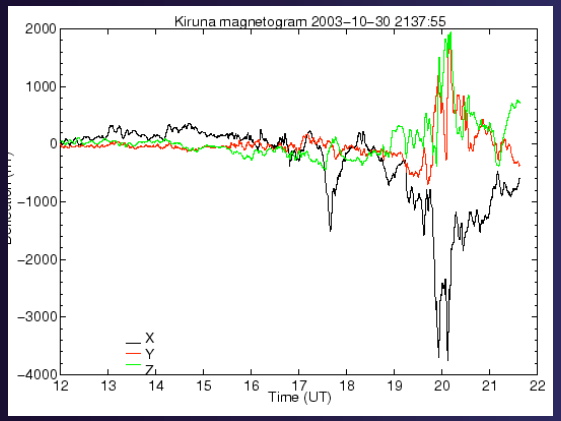
# Power outage in Malmö

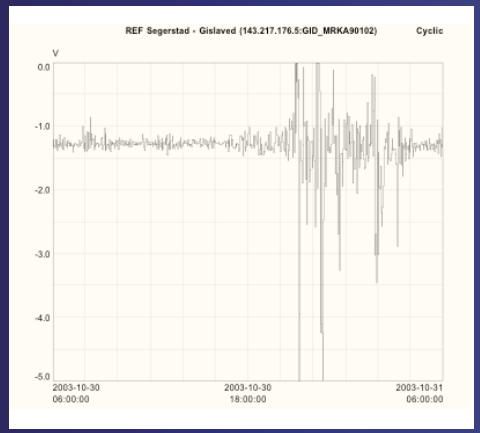
2003-10-30 at 21:07:15 (20:07:15 UT) The tripping of a 130-kV power line in the Malmö caused an outage of 50 000 customers. The outage time ranged from 20 to 50 minutes.
(Sture Lindahl, ELFORSK report 2004)




The halo CME
arrived ~16.20-30UT
October 30, 2003:
Dst = - 342nT

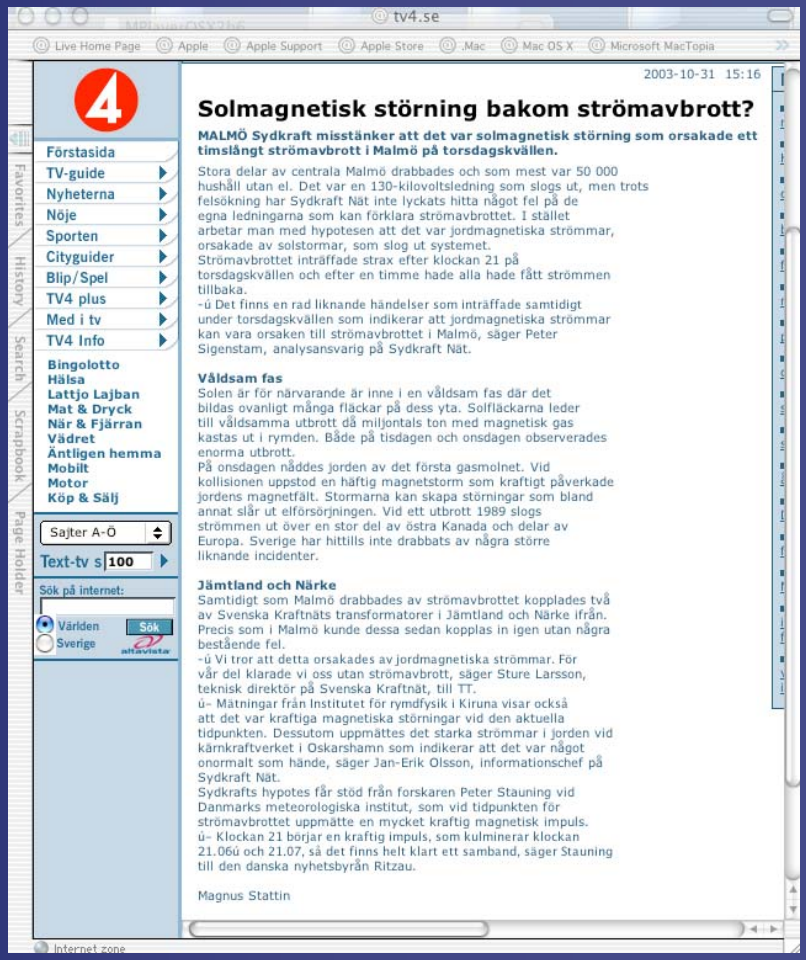
## Power Outage in Southern Sweden, October 30, 2003




Courtesy Sydsvenskan Bild.

# The power failure got enormous media attention in Sweden and around the world


Every TV, radio station and newspaper had something

# Grid impacts in Sweden Halloween 2003

"Circuit breakers for several power lines and transformers were tripped from the most sensitive non-directional residual overcurrent relays. More than 50% of the disconnected objects were energized within 1 to 5 minutes, either by automatic switching equipment of by manual switching operations. In the other case, it took some 25 to 90 minutes to inspect the disconnected objects before they were re-energized.

**Following disconnections were reported:**

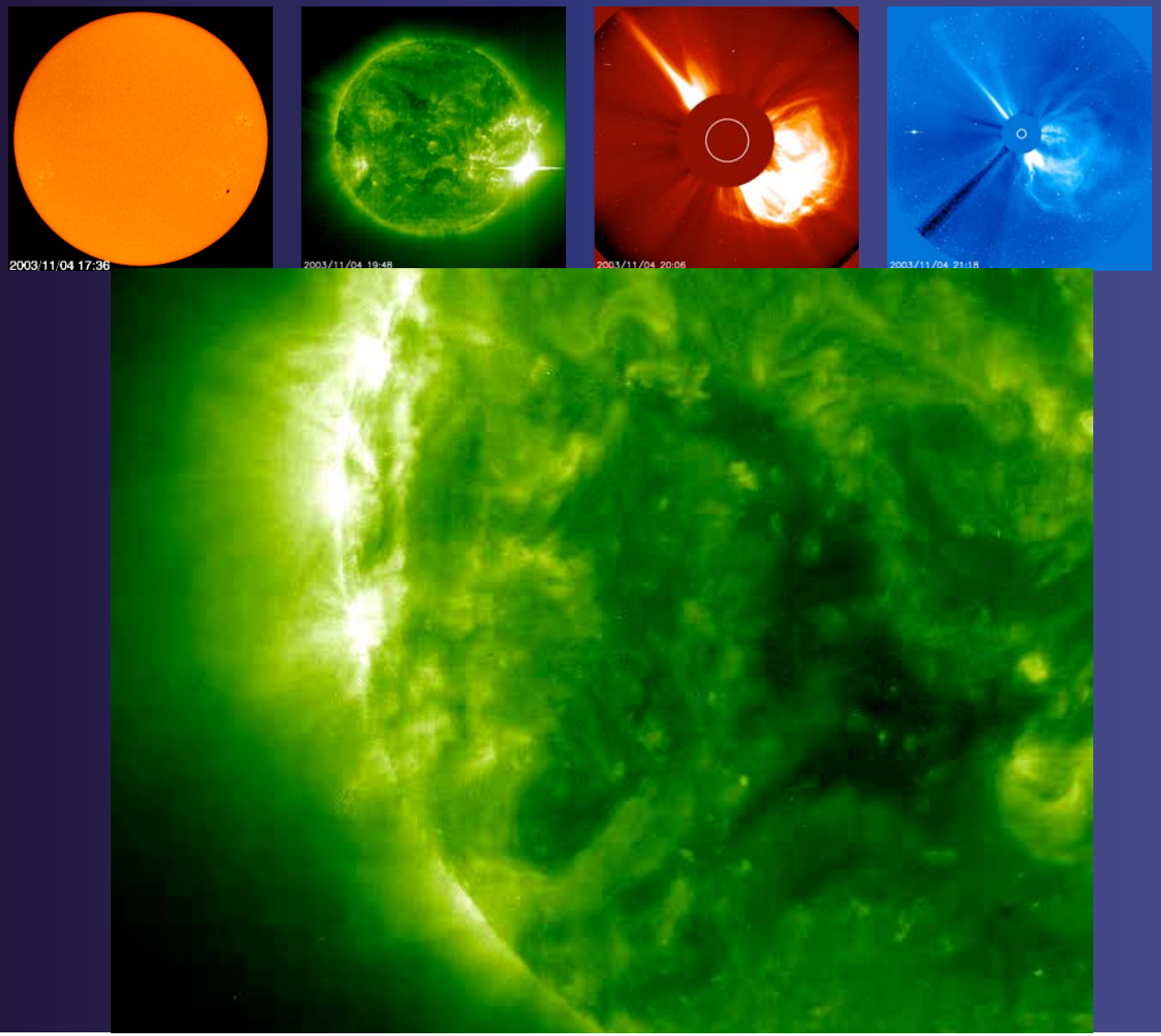
- 2003-10-29 at 07:11:42: A 220-kV power line from a power station in Härjedalen was disconnected and 140-MW generation was disconnected.
- 2003-10-29 at 07:12:29: A 130-kV power line in Östergötland was disconnected. the same line was disconnected a second time at 08:04:10
- 2003-10-29 at 07:46:04: The 400-kV power line from Hemsjö to Karlshamnsverket caused the interruption of 300 MW power import from Poland via the HVDC-link SwePol link.
- 2003-10-30 at 20:55:28. A 400/220-kV transformer near Östersund.
- 2003-10-30 at 21:03:43: A 400/130-kV transformer near Örebro caused overload in the 130-kV network.
- 2003-10-30 at 21:03:44: A 130/10kV transformer near Norrköping was tripped.
- 2003-10-30 at 21:07:15: The tripping of a 130-kV power line in the Malmö caused an outage of 50 000 customers. The outage time ranged from 20 to 50 minutes.
- 2003-10-30 at 21:08:00: A 130-kV power line from Örebro.
- 2003-10-30 at 21:08:32: A 130 kV power line near Boden.

**•Increased temperature:**

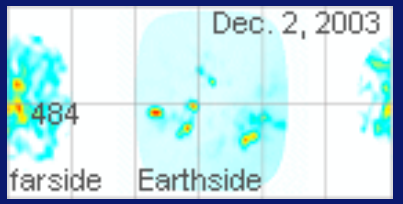
- 2003-10-29 at 08:00:00: High temperatures in the step-up transformer of Oskarshamn 2 nuclear power unit, which was repeated several times."

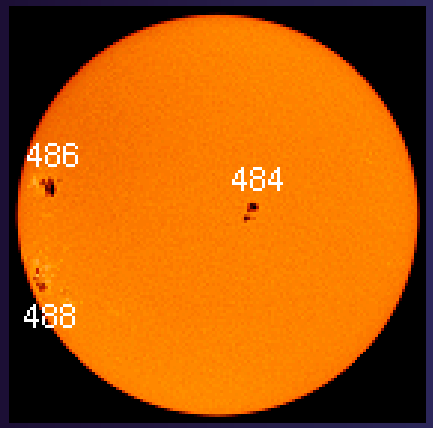
( **Lindahl, S.X., Effect of Geomagnetically Induced Currents on Protection Systems, pp.132-133, Elforsk report 03:34, 2003)**

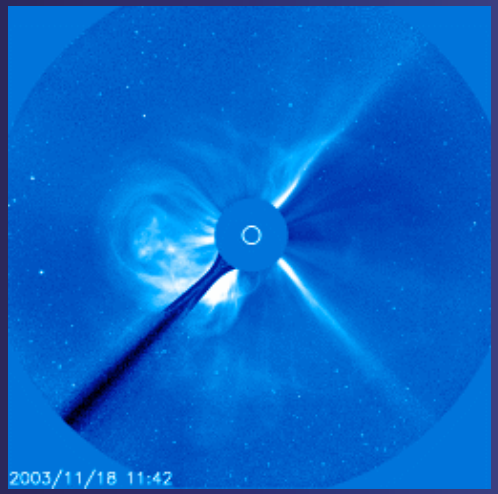
# And then ….X28 (45) !!!! solar flare on November 4, 2003 (ESA Space Weather Meeting)

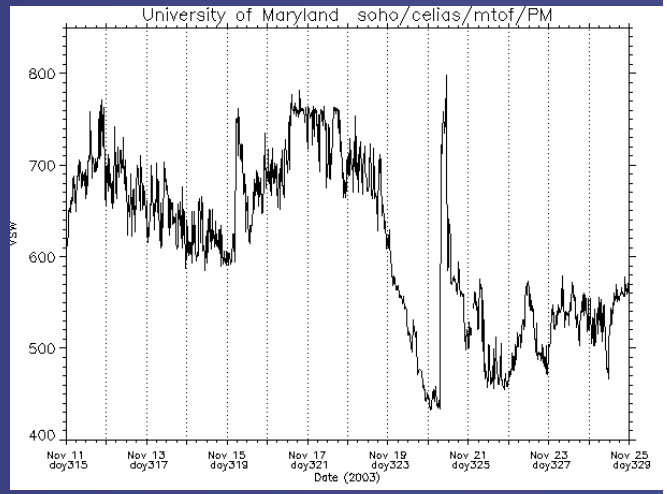


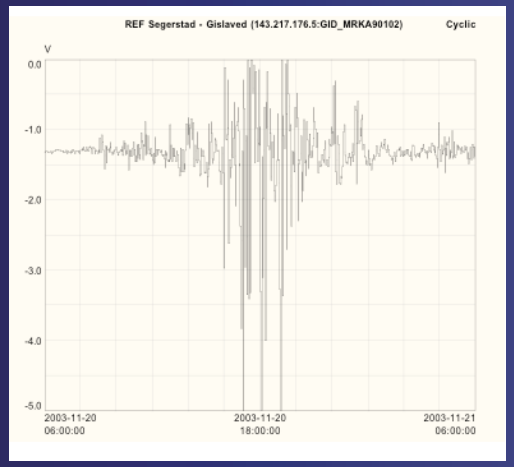
# Active Regions 484/486/488 one rotation later

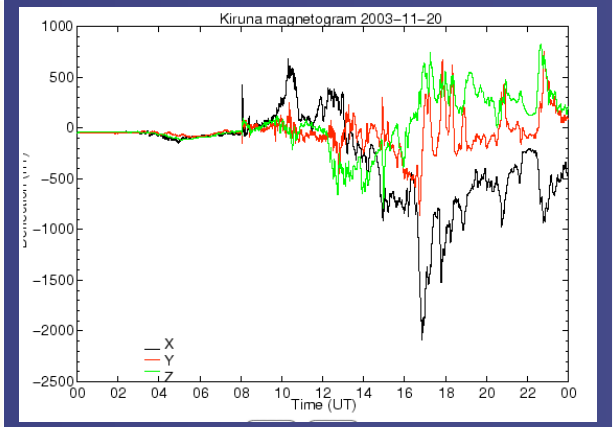


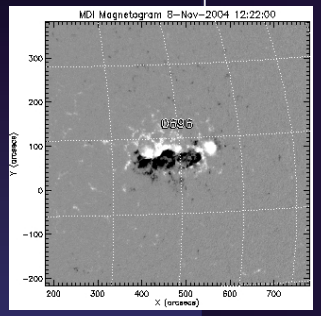



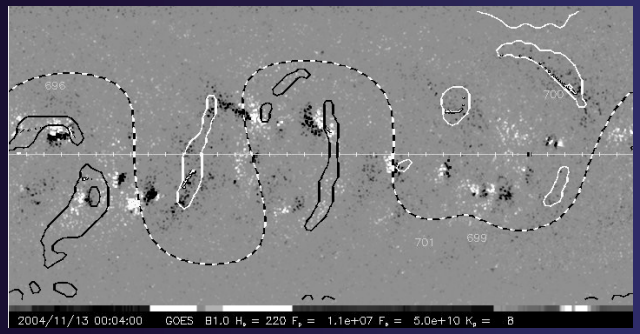



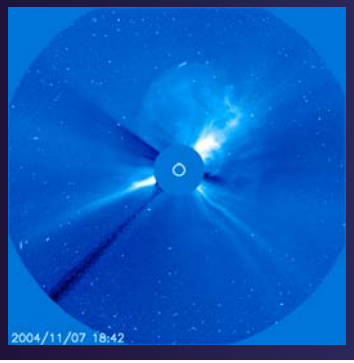



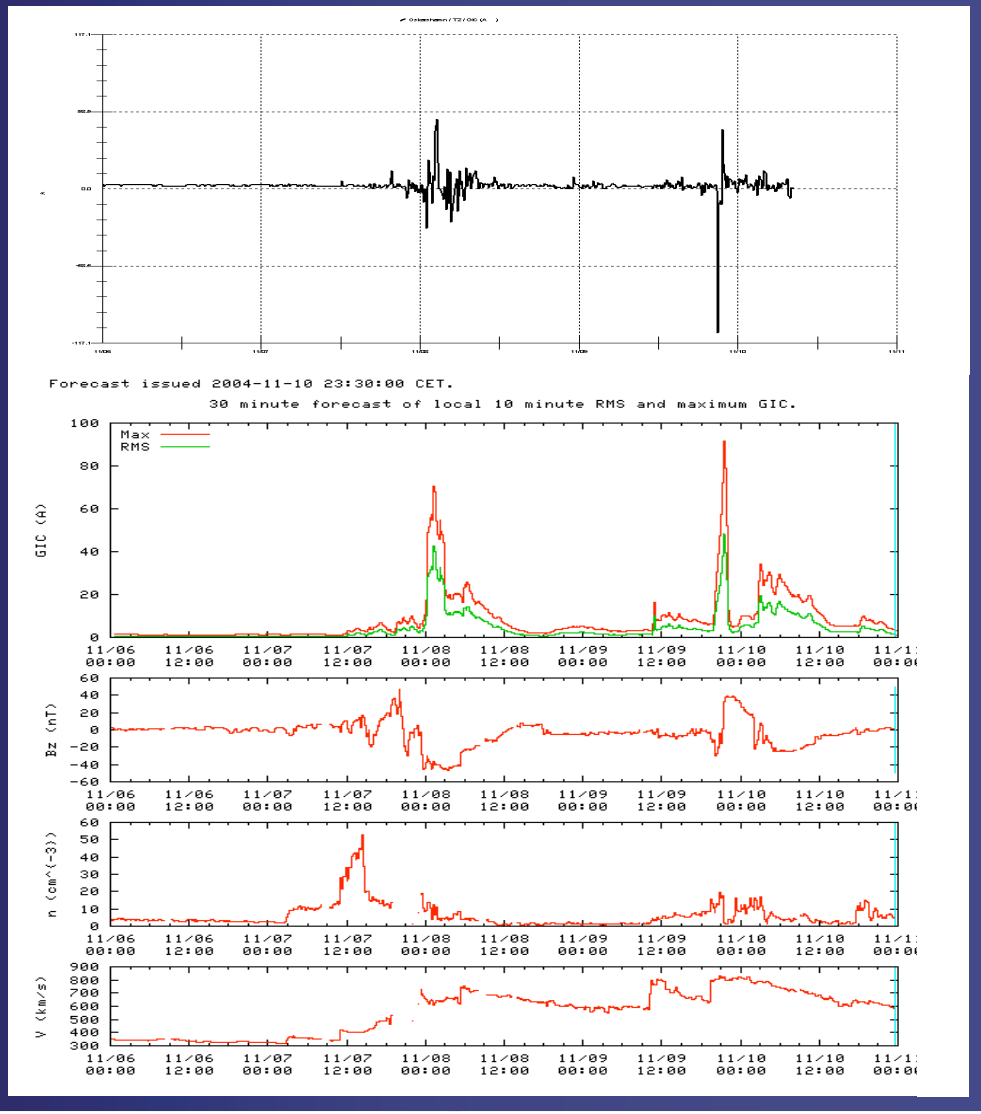
# The Sun
# GIC measurements vs GIC forecasts
# November 6-11, 2004

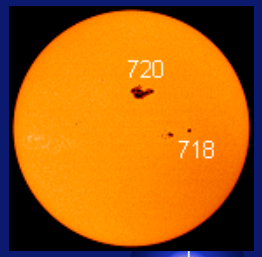




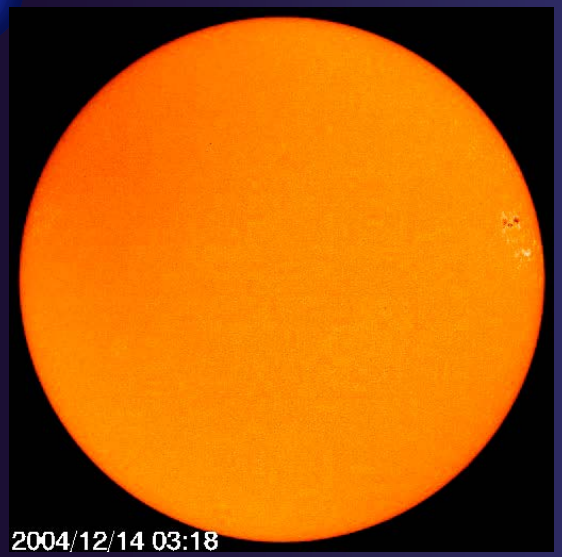


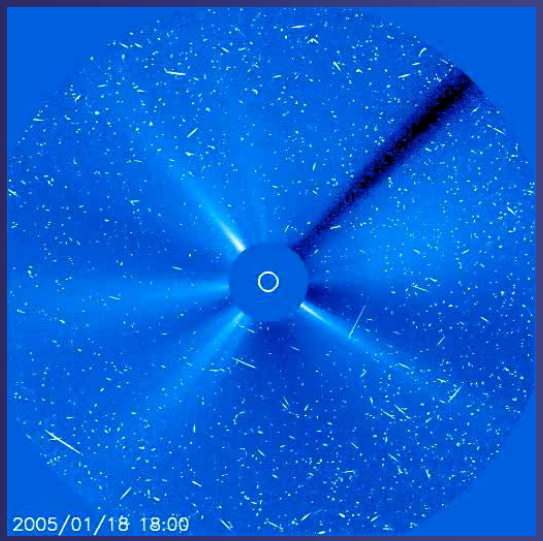



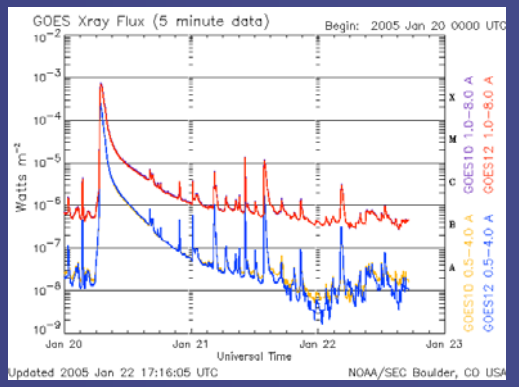



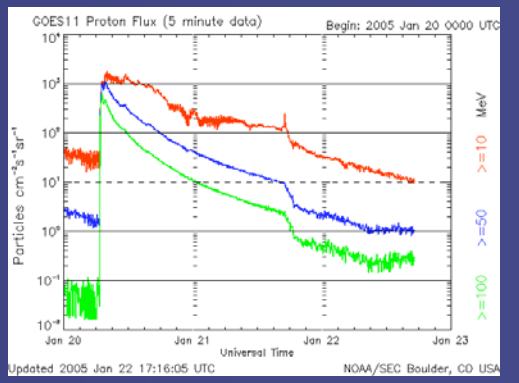



# Events in January 2005

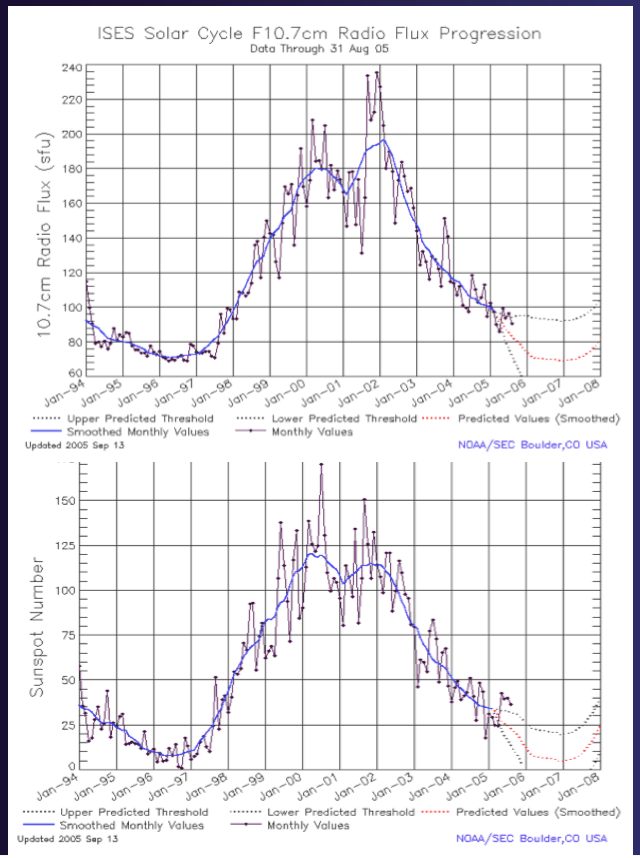




Proton events
Severe geomagnetic storms
Aurora seen in Arizona
Satellites failure

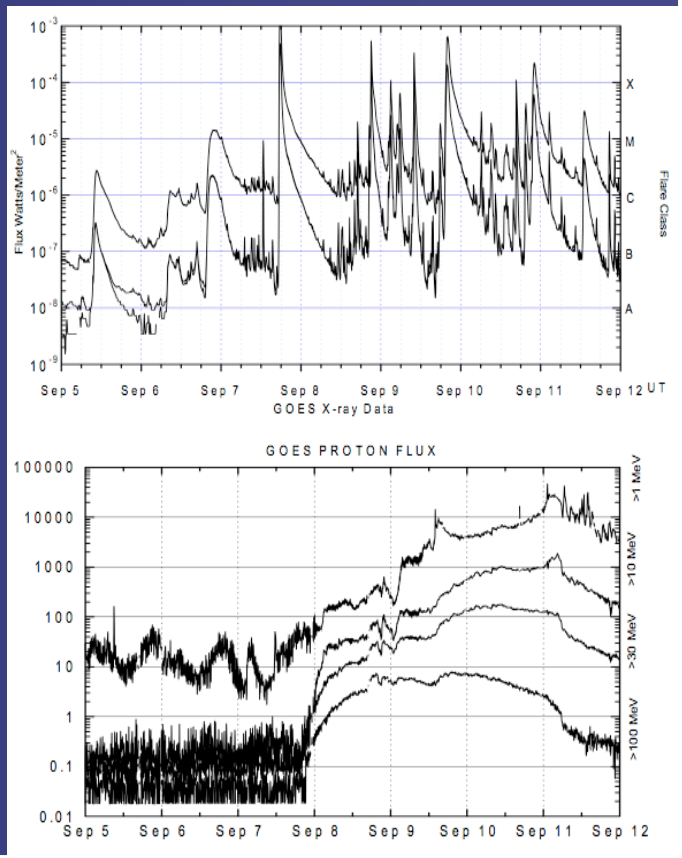
# Rz and F10.7 are no good indicators of coronal activity (1D): The activity in September 2005 might not be unusual!

On September 7, 2005 an X17 solar flare occurred(!) and we have had as many severe geo-magnetic storms and X flares in 2005 (i.e. close to sunspot min) as during Solar Max (2000)!

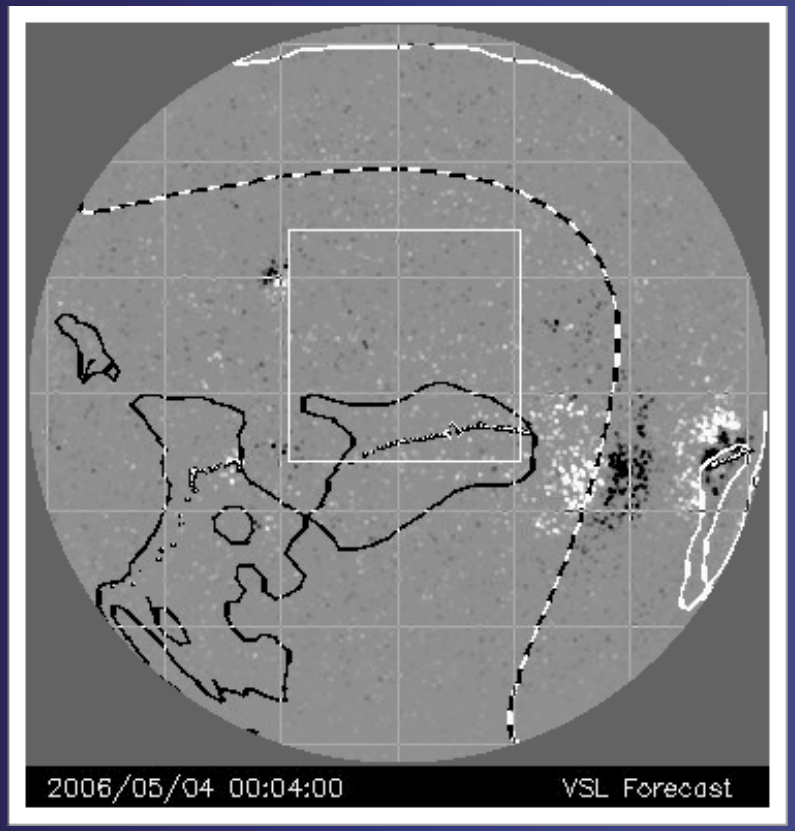
**Strong solar surface magnetic field activity represented by sunspots**




**Coronal flare, CME/proton activity and coronal hole/fast solar wind**



# Today's space weather



# THE END

Thanks!