Recent development in the Lund Solar Activity Model (LSAM)

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Athen October 12, 2005
• Lund Solar Activity Model (LSAM)

• Results of exploring with wavelets (The state of the whole Sun)

• Predictions of solar activity and preprocessor neural networks predictions of flares using helioseismic data

• Lund Solar Workshop
Lund Solar Activity Model (LSAM)

is a

Hybrid Physics-Based Neural Network Model

that uses input solar data

that explores solar data using wavelet methods to first produce a

that uses neural networks to discover

that further also includes known

that facilitates forecasting, and finally merges all knowledge, into a so called

Indicators of solar activity

Preprocessor neural network

New numerical laws

Solar activity theory

Postprocessor neural network
Indicators of Solar Activity

- Proxies
  - isotopes
  - C14
  - Be10
- Indices
  - such as
    - F10.7, E10.7
    - MWSI, MPSI
- Classification systems
  - such as
    - McIntosh
    - MW
- Number of events
  - Solar flares
  - SPE
  - CMEs
- Physical parameters
  - measured
  - E. M. radiation
  - Particle flux
  - B, \( <B> \), gradB, twist
  - V flow and subflow

Heating of the corona and CHs
Solar Magnetic Field Data Catalogue

EU COST 724 Action Space Weather

Monitoring and Predicting Solar Activity for Space Weather, WG 1
Solar Magnetic Analysis, WP 11000
Technical Note

H. Lundstedt and J. Munk Jensen
Swedish Institute of Space Physics

October 5, 2005

• A mysql data base and a TN within
  ESA ISAC
  WP 201-
  Solar Output

• Virtual Solar Observatory
Wavelet Methods  
(developed by Wernik and Liszka)
Solar Activity (on time scales ≤11y) (F10.7, E10.7, R_z, MPSI) 1975 - 2002

Time Scale Spectra

F10.7

R_z

E10.7

MPSI
C14 production rate and Rg/Rz as indicators of long-term solar activity
Scalogram and Time scale spectra of long-term C14 production rate

2300-2500 years

900-1100 years

400-500 years

190-210 years
Multiresolution analysis (MRA): the idea is to separate the information to be analyzed into a “principal” (low pass) and a “residual” (high pass) part. The process of decomposition can then be applied again to both parts.

\[ s = A_f + \sum_{j \geq j} D_j \]

\[ A_{j-1} = A_j + D_j \]

\[ A_j = \sum_{j \geq j} D_j \]

\[ D_j(t) = \sum_{k \in \mathbb{Z}} C(j, k) \Psi_{j, k}(t) \]

\[ C(a, b) = \int s(t) \frac{1}{\sqrt{a}} \Psi \left( \frac{t - b}{a} \right) dt \]

\[ a = 2^j, b = k2^j, (j, k) \in \mathbb{Z}^2 \]
Multi-resolution analysis of C14 production rate

C14 shows also the variation of the weaker magnetic field.

We also see high solar activity about 1600 and in the end of 1700, not seen in Rg.
New picture of the solar magnetic activity needs to be included
**Results of wavelet studies**

**Short-term and mid-term indicators of solar activity**
- TSSs show many differences
- The indicators are hard to understand
- They indicate rather limited part of the solar activity (time scales, spatial scales and flux density range)

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

So does the number of sunspots really give a good measure of solar activity?

**Long-term indicators of solar activity**
- Ampligrams showed trends and weak structures
- Skeletons showed transients
- MRA showed that C14 production rates sometimes can be a better indicator of solar activity than group or sunspot number

**Papers:**
The solar activity state of the whole Sun

Mission Science Objectives
The primary goal of the SDO mission is to understand, driving towards a predictive capability, the solar variations that influence life on Earth and humanity’s technological systems by determining
- How the Sun’s magnetic field is generated and structured
- How this stored magnetic energy is converted and released into the heliosphere and geospace in the form of solar wind, energetic particles, and variations in the solar irradiance.

Science Investigations
- Helioseismic and Magnetic Imager (HMI)
  PI Institution: Stanford University
  - Images the Sun’s helioseismic, longitudinal, and vector magnetic fields to understand the Sun’s interior and magnetic activity
- EUV Variability Experiment (EVE)
  PI Institution: University of Colorado
  - Measures the solar extreme ultraviolet (EUV) spectral irradiance to understand variations on the timescales which influence Earth’s climate and near-Earth space
- Atmospheric Imaging Assembly (AIA)
  PI Institution: Lockheed Martin Missiles & Space Advanced Technology Center
  - Images the solar atmosphere in multiple wavelengths to link changes to surface & interior changes

Mission Specs:
- April 2008 launch: GTO to GEO
- Inclined Geosynchronous Orbit (semiannual eclipse seasons)
- 3-axis stabilized spacecraft
- Data transmission: continuous high rate data stream ~150 Mbps compressed data at Ka-Band
- Dedicated ground station
- Mission development and management at GSFC

Key Spacecraft Technologies
- Ethernet Chipset
- Ka-Band Transmitter
- Active Pixel Star Tracker

Real-time synoptic maps of solar activity in the corona, on the solar surface, and below surface are analyzed

Along the latitudes
1D-Multi-resolution analysis gives
- Time scales, periods
- As input to neural network

For each time
1D-Multi-resolution analysis gives
- Spatial scales, flux densities
- As input to neural network

As a whole
2D-Multi-resolution analysis gives
- Overall pattern scales
- As input to neural network

The Sun's state as a whole
Synoptic maps give the Sun’s state (CR) “a general view of a whole.”

- The Corona
- Solar surface
- Subsurface
Synoptic maps give the Sun’s state, CR averaged.

The Corona

Solar surface

Subsurface
Synoptic maps 1975(6)-2005 (WSO) and Kitt Peak
Decomposition of synoptic B90N and B70N
Decomposition of synoptic B50N and B30N
Decomposition of synoptic B15S and B90S
## Prediction models based on AI

Lundstedt, H., Solar Activity Predicted with Artificial Intelligence, Space Weather, Geophys., Monograph 125, AGU, 2001

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Output</th>
<th>KBNM method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily sunspot number</td>
<td>Daily sunspot number</td>
<td>SOM and MLP</td>
<td>Liszka 93;97</td>
</tr>
<tr>
<td>Monthly sunspot number</td>
<td>Date of solar cycle max and amplitude</td>
<td>MLP and Elman</td>
<td>Macpherson et al., 95, Conway et al, 98</td>
</tr>
<tr>
<td>Monthly sunspot number and aa</td>
<td>Date of solar cycle max and amplitude</td>
<td>Elman</td>
<td>Ashmull and Moore, 98</td>
</tr>
<tr>
<td>Yearly sunspot number</td>
<td>Date of solar cycle max and amplitude</td>
<td>MLP</td>
<td>Calvo et al., 95</td>
</tr>
<tr>
<td>McIntosh sunspot class &amp; MW magn complex.</td>
<td>X class solar flare</td>
<td>MLP expert system</td>
<td>Bradshaw et al., 89</td>
</tr>
<tr>
<td>Flare location, duration X-ray and radio flux</td>
<td>Proton events</td>
<td>MLP</td>
<td>Xue et al., 97</td>
</tr>
<tr>
<td>X-ray flux</td>
<td>Proton events</td>
<td>Neuro-fuzzy system</td>
<td>Gabriel et al., 00</td>
</tr>
<tr>
<td>Photospheric magnetic field expansion factor</td>
<td>Solar wind velocity 1-3 days ahead</td>
<td>RBF &amp; PF MHD</td>
<td>Wintoft and Lundstedt 97;99</td>
</tr>
</tbody>
</table>
Next solar cycle 24

The ampligram and the solar polar magnetic field observations suggest a weak solar maximum 2011.

The results of Leif S. et al., suggest a low next cycle.
Predictions of cycle 24

NASA plans to arrange a prediction panel meeting on cycle 24.

Predictions of cycle 24

- D. Hathaway (strong cycle), based on the assumption that a fast meridional circulation speed during cycle 22 would lead to a strong solar cycle 24.
- K. H. Schatten (Rz = 100±30), based on the view that the Sun’s polar field serves as a predictor of solar activity on the basis of dynamo physics.
- J-L. Wang et al., (Rz = 83.2-119.4), based on statistical characteristics of solar cycles.
- Kane, R. P. (Rz= 105), based on statistical regression analysis of the sunspot number and geomagnetic activity.
- S. Duhau (Rz= 87.5±23.5), based on a non-linear coupling function between sunspot maxima and aa minima modulations found as a result of a wavelet analysis.
- L. Svalgaard et al., (Rz = 75±10), based on the solar polar magnetic field strength at sunspot minima.
- Badalyan et al., (Rz not exceeding 50), based on statistical characteristics of solar cycles.
- G. Maris, et al., (low), based on observing the flare energy release during the descendant phase of cycle 23 (empirical method).
- M. Clilverd et al., (weak cycle), based on the variation of the atmospheric cosmogenic radiocarbon.
Flows and Flares

CR1988  Depth 4.7Mm

Flow Divergence

•  C
•  M
•  X
Neural Network II
Announcing the International Workshop on

Solar Activity: Exploration, Understanding and Prediction

Lund, Sweden 19-21 September 2005

Did we predict the intense solar storm on Bastille Day in 2000, on Halloween in 2003 or in January 2005? Are we capable of predicting the strength of the next solar cycle? Are we capable of predicting the next Maunder Minimum? All these events have a strong impact on society and the climate. Despite that, predictions are not very good and need to be improved.

This workshop is devoted to exploring, explaining and forecasting solar activity. We welcome presentations of wavelet studies of solar activity, forecasts of solar activity using solar theory, helioseismic results and neural networks. New ideas on how to understand better long-term solar activity related to climate changes are also of great interest.

The workshop will also discuss how upcoming exciting new space and ground-based observations could improve forecasts and there will be presentations of newly started international solar programs.

It is planned that the workshop will end with a videoconference – ”A Forecast Forum”. Regional Warning Centers of International Space Environment Service and Solar Groups are going to participate and forecasts and observations in real-time will be discussed.

**Scientific Organizing Committee:**

Svanne Björck (CGB, Sweden), David Boteler (ISES/NRC, Canada), Alain Hilgers (ESA/ESTEC, Netherlands), Todd Hoeksema (Stanford, USA), Rickard Lundin (IRF-K, Sweden), Henrik Lundstedt (ISES/IRF-Lund, Sweden), Mauro Messerotti (INAF-Trieste, Italy), Bo Thidé (IRF-U, Sweden), Michael Thompson (Sheffield, U.K.)

**Local Organizing Committee:**
### Workshop program

**Tuesday 20/9**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.00</td>
<td>Poster presentations</td>
</tr>
<tr>
<td>09.30</td>
<td>Session III: Solar activity prediction</td>
</tr>
<tr>
<td>10.10</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>11.00</td>
<td>Lunch</td>
</tr>
<tr>
<td>14.00</td>
<td>Session III: Solar activity prediction (cont.)</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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</table>

**Wednesday 21/9**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.15</td>
<td>Session V: New space, and ground-based facilities for exploration and prediction (invited)</td>
</tr>
<tr>
<td>09.45</td>
<td>Session V: New space, and ground-based facilities for exploration and prediction (cont.)</td>
</tr>
<tr>
<td>11.00</td>
<td>Lunch</td>
</tr>
<tr>
<td>14.00</td>
<td>Session VII: Solar activity programs</td>
</tr>
<tr>
<td>15.00</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>15.30</td>
<td>Conclusion</td>
</tr>
</tbody>
</table>

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**Session I: Exploration of solar forcing**
- **09.15** | H. Svensmark | Influences of solar activity on Earth’s climate |
- **09.45** | R. Lundin | The Sun and the climate on Venus and Mars |
- **10.15** | H. Gleiser and P. Thejll | Climate responses to the 11-year solar cycle |

**Coffee Break**
- **10.30**

**Session I: Exploration of solar forcing (cont.)**
- **11.00** | L. Liszkai | Causal Analysis of Solar Indicators |
- **11.30** | D.I. Pentyavin | Cross wavelet and recurrence plot analysis of solar wind and climate time series |
- **11.45** | M. Messerotti and J. Chea Fizes | Solar activity and Solar Weather in the framework of life origin and evolution on Earth |

**Session II: Exploration of solar activity**
- **14.00** | H. Lundstedt | Solar activity explored with wavelets |
- **14.30** | R. Muscheler | Solar activity changes over centuries and millennia (invited) |

**Coffee Break**
- **15.30**

**Session II: Exploration of solar activity (cont.)**
- **16.00** | I.G. Usoskin | Solar activity throughout Holocene: how regular is it? |
- **16.30** | S. Björk | What has the Earth’s core got to do with the reconstruction of solar activity? |
- **17.00** | V.V. Zharkov, S.I. Zharkov and A.K. Beneshev | Statistical sunspot and active region analysis of the solar cycle 23 with the solar feature catalogue |

**End**
- **17.15**

**Public lecture**
- **19.00** | P. Brekke | Unexpected effects of solar activity |

**Poster presentations**
- **09.00** | M.A. Gilvand | Prediction of solar activity the next 100 years (invited) |
- **10.00** | I.G. Usoskin | Dominant 22-year periodicity in solar activity during grand minima |
- **10.15** | G. Mars | Tentative neural network forecast of the 24th solar cycle |
- **10.30** | S. Gabriel | Solar energetic particle event prediction using advanced signal processing: Challenges and possibilities |

**Coffee Break**
- **11.00**

**Session III: Solar activity prediction**
- **11.30** | J. M. Jensen | Predictions of Solar Flares using Neural Networks and Local Area Helioclimatology |
- **12.00** | Y. Tulunay, M. Messerotti, E. Tulunay, K. Kharrazi and Y. Cizik | Neural network modeling in forecasting near earth space parameters: solar radio flux forecasting |

**Lunch**
- **12.30** (AF - Academic Society)

**Session IV: How do we understand solar activity?**
- **14.00** | L. Gizon | Helioclimatological diagnostics of solar activity |
- **14.30** | S. Tobias | The solar dynamo: timescales and modulational processes |
- **15.00** | A. Brandenburg | The case for a distributed solar dynamo shaped by a near-surface shear |

**Coffee Break**
- **15.30**

**Session III: Solar activity prediction (cont.)**
- **16.00** | L. Svalgaard and E. W. Cliver | Prediction of solar cycle 24 (invited) |
- **16.30** | End |

**Dinner**
- **19.00** | Festsalen - Banquet hall at AF |
Participants at the Lund solar workshop

Participants not on photo: Krister Bengtson (E.ON, Sweden), Axel Brandenburg (Nordita, Denmark), Alexi Glover (ESA/ESTEC), Alain Hilgers (ESA/ESTEC), Christian Jacobsson (E.ON, Sweden), Nina von Krusenstierna (Aerotech, Sweden), Rickard Lundin (IRF-Umeå), Nigel Marsh (DNSC, Denmark), Gunilla Sundberg (E.ON, Sweden), Henrik Svensmark (DNSC, Denmark) and Bo Thidé (IRF-Uppsala).
The END
Solar polar field

- 130 µT (21)
  - gives max 22 (R=158)

- 103 µT (22)
  - gives max 23 (R=120)

- 63 µ 09/04?
  - gives max 24
  - ~2011 75?
Transferring a differential equation to a difference equation and then comparing with a recurrent neural network.

\[ \frac{dD_{st}^*}{dt} = Q - \lambda D_{st}^* \]

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

The output from the network is described by the following equations:

\[ x_i(t + 1) = \tanh \left( \sum_{j=1}^{N_1} w_{ij}^{(1)} u_j(t) + \sum_{j=1}^{N_2} w_{ij}^{(2)} x_j(t) + b_i^{(1)} \right) \] (9)

\[ y(t + 1) = \sum_{i=1}^{N_2} w_{ii}^{(2)} x_i(t + 1) + b_i^{(2)}. \] (10)

Open solar flux, where \( E \) is the flux emergence rate, \( \tau \) is decay time scale.
Neural Network Output

- Hit Rate: 20.8%
- False Alarm Rate: 0.25%

Diagram:
- Green circles: Hit
- Red circles: False Alarm

Sample vs. Target/Prediction graph