SW103: Lecture 4
Geomagnetic Indices and Space Weather Models

Outline:
• Geomagnetic Indices
  $K_P$, $D_{ST}$, $AE$
• Space Weather Models
  • Uses of Science Models
  • Types of Science Models
  • Space Weather Models
  • Model Validation and Metrics
Geomagnetic Indices
What is an index? An index is a single parameter that provides a measure of the state of the system. It may or may not measure a physical quantity, it may or may not have units. No index is perfect.

Examples of Indices:

Medical indices
• Temperature
• Pulse
• Blood pressure

The Dow Jones Industrial Average index
• Weighted average of 30 stocks
• Designed to measure the overall activity of the US equity market
Geomagnetic Indices

Geomagnetic variations provide the longest, most reliable, historical data set that monitors the space environment. In the early 19th century Gauss demonstrated that short period (less than years) geomagnetic variations are the result of electrical currents exterior to earth. Geomagnetic variations provide the simplest routine way to monitor the space weather system. The three most frequently encountered geomagnetic indices are:

• K index and its derivatives
• Dst storm index
• AE auroral electrojet index
The K index (Bartels et al, 1939)

The K index ("Kennziffer" or character) is a range index, which is derived separately for each magnetic observatory. The K value is obtained from the amplitude of largest variation in either of the horizontal components of the magnetic field in a 3-hour interval (after the regular daily variation, e.g. due to currents caused by ionospheric tides, is removed). K can take 10 values ranging from 0 (very quiet) to 9 (extremely disturbed). Each observatory has its own conversion table designed so that the distribution of K values over time is the same for all observatories.

### K Conversion Table for Boulder

<table>
<thead>
<tr>
<th>K</th>
<th>nT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-5</td>
</tr>
<tr>
<td>1</td>
<td>5-10</td>
</tr>
<tr>
<td>2</td>
<td>10-20</td>
</tr>
<tr>
<td>3</td>
<td>20-40</td>
</tr>
<tr>
<td>4</td>
<td>40-70</td>
</tr>
<tr>
<td>5</td>
<td>70-120</td>
</tr>
<tr>
<td>6</td>
<td>120-200</td>
</tr>
<tr>
<td>7</td>
<td>200-330</td>
</tr>
<tr>
<td>8</td>
<td>330-500</td>
</tr>
<tr>
<td>9</td>
<td>&gt;500</td>
</tr>
</tbody>
</table>
The Kp Index

The Kp index ("planetarische Kennziffer" or planetary character) is a global K index obtained from averaging the indices from 13 mid-latitude observatories. (Since K is not a linear quantity, it is first converted into a linear scale, the a index, averaged, then converted back.) Kp is the oldest index, first used by Bartels in 1949, and soon calculated back to 1932. The official Kp is still computed in Germany (at the GeoForschungsZentrum, Potsdam).

<table>
<thead>
<tr>
<th>Kp</th>
<th>ap</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
</tr>
<tr>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
</tr>
<tr>
<td>7</td>
<td>132</td>
</tr>
<tr>
<td>8</td>
<td>207</td>
</tr>
<tr>
<td>9</td>
<td>400</td>
</tr>
</tbody>
</table>

ap is a related index obtained from Kp using the table on the right. Whereas Kp is roughly logarithmic, ap is roughly linear.
Ap is a running 24 hr average of ap.
## The 13 Observatories used to compute official Kp listed in order of geomagnetic latitude

<table>
<thead>
<tr>
<th>#</th>
<th>Code</th>
<th>Name</th>
<th>Location</th>
<th>Active</th>
<th>Geographic</th>
<th>Geomagnetic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lat.</td>
<td>Long.</td>
</tr>
<tr>
<td>1</td>
<td>LER</td>
<td>Lerwick</td>
<td>Scotland</td>
<td>1932-actual</td>
<td>60°08'</td>
<td>358°49'</td>
</tr>
<tr>
<td>2</td>
<td>MEA</td>
<td>Meanook</td>
<td>Canada</td>
<td>1932-actual</td>
<td>54°37'</td>
<td>246°40'</td>
</tr>
<tr>
<td>3</td>
<td>SIT</td>
<td>Sitka</td>
<td>Alaska (US)</td>
<td>1932-actual</td>
<td>57°03'</td>
<td>224°40'</td>
</tr>
<tr>
<td>4</td>
<td>ESK</td>
<td>Eskdalemuir</td>
<td>Scotland</td>
<td>1932-actual</td>
<td>55°19'</td>
<td>356°48'</td>
</tr>
<tr>
<td>5</td>
<td>LOV</td>
<td>Lovö</td>
<td>Sweden</td>
<td>1954-2004</td>
<td>59°21'</td>
<td>17°50'</td>
</tr>
<tr>
<td></td>
<td>UPS</td>
<td>Uppsala</td>
<td>Sweden</td>
<td>2004-actual</td>
<td>59°54'</td>
<td>17°21'</td>
</tr>
<tr>
<td>6</td>
<td>AGN</td>
<td>Agincourt</td>
<td>Canada</td>
<td>1932-1969</td>
<td>43°47'</td>
<td>280°44'</td>
</tr>
<tr>
<td></td>
<td>OTT</td>
<td>Ottawa</td>
<td>Canada</td>
<td>1969-actual</td>
<td>45°24'</td>
<td>284°27'</td>
</tr>
<tr>
<td>7</td>
<td>RSV</td>
<td>Rude Skov</td>
<td>Denmark</td>
<td>1932-1984</td>
<td>55°51'</td>
<td>12°27'</td>
</tr>
<tr>
<td></td>
<td>BFE</td>
<td>Brorfelde</td>
<td>Denmark</td>
<td>1984-actual</td>
<td>55°37'</td>
<td>11°40'</td>
</tr>
<tr>
<td>8</td>
<td>ABN</td>
<td>Abinger</td>
<td>England</td>
<td>1932-1957</td>
<td>51°11'</td>
<td>359°37'</td>
</tr>
<tr>
<td></td>
<td>HAD</td>
<td>Hartland</td>
<td>England</td>
<td>1957-actual</td>
<td>50°58'</td>
<td>355°31'</td>
</tr>
<tr>
<td>9</td>
<td>WNG</td>
<td>Wingst</td>
<td>Germany</td>
<td>1938-actual</td>
<td>53°45'</td>
<td>9°04'</td>
</tr>
<tr>
<td>10</td>
<td>WIT</td>
<td>Witteveen</td>
<td>Netherland</td>
<td>1932-1988</td>
<td>52°49'</td>
<td>6°40'</td>
</tr>
<tr>
<td></td>
<td>NGK</td>
<td>Niemegk</td>
<td>Germany</td>
<td>1988-actual</td>
<td>52°04'</td>
<td>12°41'</td>
</tr>
<tr>
<td>11</td>
<td>CLH</td>
<td>Cheltenham</td>
<td>USA</td>
<td>1932-1957</td>
<td>38°42'</td>
<td>283°12'</td>
</tr>
<tr>
<td></td>
<td>FRD</td>
<td>Fredericksburg</td>
<td>USA</td>
<td>1957-actual</td>
<td>38°12'</td>
<td>282°38'</td>
</tr>
<tr>
<td>12</td>
<td>TOO</td>
<td>Tooangi</td>
<td>Australia</td>
<td>1972-1981</td>
<td>-37°32'</td>
<td>145°28'</td>
</tr>
<tr>
<td></td>
<td>CNB</td>
<td>Canberra</td>
<td>Australia</td>
<td>1981-actual</td>
<td>-35°18'</td>
<td>149°00'</td>
</tr>
<tr>
<td>13</td>
<td>AML</td>
<td>Amberley</td>
<td>New Zealand</td>
<td>1932-1978</td>
<td>-43°09'</td>
<td>172°43'</td>
</tr>
<tr>
<td></td>
<td>EYR</td>
<td>Eyrewell</td>
<td>New Zealand</td>
<td>1978-actual</td>
<td>-43°25'</td>
<td>172°21'</td>
</tr>
</tbody>
</table>
Graphical display of Kp index for March - June 2010. Each row corresponds to a 27-day Carrington rotation. Notice the recurrent geomagnetic activity near the start of each rotation.
Real time Kp

NOAA SEC publishes a real-time estimate of Kp calculated by the US Air Force from primarily USGS and Canadian magnetic observatories.

NOAA uses estimated Kp to define levels of geomagnetic storm

<table>
<thead>
<tr>
<th>Kp-index</th>
<th>NOAA Space Weather Geomagnetic Storm Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kp=5</td>
<td>G1</td>
</tr>
<tr>
<td>Kp=6</td>
<td>G2</td>
</tr>
<tr>
<td>Kp=7</td>
<td>G3</td>
</tr>
<tr>
<td>Kp=8</td>
<td>G4</td>
</tr>
<tr>
<td>Kp=9</td>
<td>G5</td>
</tr>
</tbody>
</table>
So far this week is boringly quiet.
What does Kp measure.

- By using midlatitude observatories (away from auroral currents) Kp does a good job of defining the general state of the magnetosphere from quiet to disturbed.
- Kp is the best established index with the longest historical record.
- Kp is a very crude measure that does not monitor any specific type of disturbance.
The Dst Index

- The Dst (storm distension) index is used to compare the intensity of geomagnetic storms.
- Dst uses a signature of storms recognized by Sidney Chapman as the geomagnetic response of a current flowing westward around earth – the ring current.
- Dst uses 4 low latitude observatories to measure the global average geomagnetic perturbation of the ring current.
- Dst is measured in nT. The standard time resolution is 1 hour. However, higher resolution indices are also made available, typically down to 1-min.
The ring current is a westward flowing current producing a magnetic perturbation on the Earth’s surface. What is the direction of the perturbation for an observer near the equator?

1. Northward
2. Southward
3. Eastward
4. Westward
5. Downward
6. Upward
7. Not enough information
These were record-breaking storms, Dst dropping below -150 nT is considered a “large storm”, and below -50 nT can be classified as a small storm.
Dst is available in “real time” at:
http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/index.html
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The AE (Auroral Electrojet) Indices

• The AE Index measures the strength of the east-west current flowing in the auroral ionosphere
• It uses typically 12 high latitude observatories spanning the typical auroral latitudes of the current.
An alternative view of the AE observatories – this projection is centered on the north geomagnetic pole.
The AE indices are obtained by superimposing the north-south magnetic component from each observatory (having subtracted the average daily variation) and finding the upper and lower envelope.

The upper envelope is $AU - A_{\text{upper}}$ – which measures the eastward electrojet.

The lower envelope is $AL - A_{\text{Lower}}$ – which measures the westward electrojet.

$AE = AU - AL$
$A0 = AU + AL$

All are measured in units of nT, usually at 1 min cadence.
AE indices for 30-31 May 2008
These are typical days showing some quiet periods and some substorm intervals.

Quiet period – probably IMF Bz northwards.

Sharp onset of western electrojet signifies substorm
Period on enhanced ionospheric convection – probably IMF Bz southwards.

Today’s AE is available in “real time” at:
http://swdcwww.kugi.kyoto-u.ac.jp/ae_realtime/index.html
Kp and AE

“Real time” Kp and AE for late June - early July 2010.

Note: AE has a much finer time resolution but only responds to auroral disturbances.
The AE indices during a storm period
March 31-April 1, 2001 Storm

The eastward electrojet (AU) peaks near dusk

The westward electrojet (AL) peaks near dawn, but shifts suddenly to midnight during substorms.

Model calculation of electrojet currents.
Uses of Science Models

Example – flow past an aerofoil

• To *Specify* — to find pressure at some point on the wing
• To *Explain* — to understand why wing fails
• To *Reveal* — to discover a previously unknown feature
• To *Interpret* — as an aid to understanding observations
• To *Predict* — to determine pressure around a new wing design
Uses of Space Weather Models

- To **Specify** – for engineering (specify radiation environment)
- To **Explain** – for scientific understanding
- To **Reveal** – for new understanding (magnetic topologies)
- To **Interpret** – for post-event analysis of data
- To **Predict** – for nowcasts and forecasts
Kinds of Models

• Empirical
  – Statistical Fit to Functions
  – Assimilative
  – Linear/Nonlinear Filters and Neural Nets

• Physics Based
  – Special Purpose
  – General
Kinds of Models -- Empirical

• Statistical Fit to Functions ("Objective" Forecasts)
Examples:
- IRI--International Reference Ionosphere
- MSIS--Mass Spectrometer & Incoherent Scatter Model*
- IGRF--International Geomagnetic Reference Field
- T96 & T89C--Tsyganenko external-source field models
- AE8/AP8--Magnetospherically trapped electrons and protons
- IZMEM polar cap potential model
- Weimer models of p.c. potential and FACs
- Garcia Solar Particle Event Model
- Shue Magnetopause Model
Kinds of Models -- Empirical (cont)

• Assimilative Examples:
  - Assimilative Model of Ionospheric Electrodynamics (AMIE)
  - Global Assimilation of Ionospheric Measurements (GAIM)

• Linear/Nonlinear Filters and Neural Nets Examples:
  - Relativistic Electron Forecast Model (REFM-SEC)
  - Costello NN models of Dst and Kp (SEC);
  - Vassiliadis Nonlinear Regressive Moving Average (ARMA) models of AE and Dst.
Physics-Based Models

- Special Purpose Examples:
  - Wang-Sheeley solar wind/IMF model*
  - CME Arrival Time model*
  - Proton Prediction System (PPS)
  - Parameterized Ionospheric Model (PIM)*
  - Magnetospheric Specification Model (MSM)*

- General Purpose Examples:
  - Various MHD models (e.g. MAS, Enlil, LFM)*
Stop and Think

Where should emphasis be placed in space weather model development?
1. Empirical Models
2. Physics-based modes
3. Models of specific, critical space weather threats (e.g. radiation belt fluxes, ionospheric scintillation)
4. Specification/climate models
5. Dynamic nowcasting/forecasting models
Putting it all together
GOES (geosynchronous) magnetometer data