Multivariate autoregressive (AR) prediction of MeV electron flux variation in Geostationary and Medium Earth orbits

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Outline

• Introduction
  – Satellite Anomaly
  – New particle observation by Himawari/SEDA

• Method and results of our model
  – Himawari/SEDA
  – Van Allen Probes

• Summary
High-energy particles in Geospace and risk for space utilities

Topic of this presentation (radiation belt electrons)
Spacecraft anomaly by deep dielectric charging

High-energy particles (e.g., MeV electrons) penetrate satellite shielding materials and deposit charge on internal spacecraft components.

When it exceeds the breakdown threshold, electrostatic discharges (ESDs) occur in the insulating materials.
Examples of anomalies:
Communications satellites at GEO [Lohmeyer and Cahoy, 2013, 2015]

Inmarsat power amplifier anomalies

- frequently occur in the declining phase of solar cycle.
- tend to occur electron fluence accumulated over 14 and 21 days.
Energetic particle monitoring over Japan by the meteorological satellite HIMAWARI-8

- **Instrument:** SEDA (Space Environment Data Acquisition monitor)
- **Purposes:** house-keeping and failure analysis
- **Launch:** 2014/10/07, Himawari-9 Launch; 2016 (plan)
- **Longitude:** ~140 deg.
- **SEDA data is available from Nov. 03, 2014**
- **Near-real time SEDA data is archived at NICT.**

<table>
<thead>
<tr>
<th>electron sensors</th>
<th>proton sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrons:</strong> 8 ch. (8 series plate)</td>
<td><strong>Protons:</strong> 8 ch. (8 sensors)</td>
</tr>
<tr>
<td><strong>Electrons:</strong> 0.2 MeV ~ 5 MeV</td>
<td><strong>Protons:</strong> 15 MeV ~ 100 MeV</td>
</tr>
<tr>
<td><strong>Electron sensor:</strong> ± 78.3°</td>
<td><strong>Proton sensor:</strong> ± 39.35°</td>
</tr>
<tr>
<td><strong>Time resolution:</strong> 10 s</td>
<td></td>
</tr>
</tbody>
</table>
SEDA observation data
electron flux (0.2 – 1.5 MeV)

Start on Nov. 2014

After St. Patrick’s day storm
Himawari-8/SEDA data as a source of global space environment monitoring around GEO,

Japanese GEO Satellites are operated in this area.
How to Predict?

✓ Numerical simulation?

✓ Empirical model?
Multivariate autoregressive (AR) model + Kalman filter

Autoregressive (AR) model can estimate future flux variations on the basis of its lagging correlation with changes in other parameters [Sakaguchi et al., 2013].

\[ Y_t = \sum_{n=1}^{m} A_n Y_{t-n} + v_t, \]

\[ Y = \begin{bmatrix} y_1 & \cdots & y_k \end{bmatrix}^{-1} \]

\( y_1 \): predictor variate (flux)
\( y_k \): explanatory variate (solar wind)

✓ Daily average electron flux variations correlate positively with corresponding averages of the solar wind flow speed near the Earth [e.g., Paulikas and Blake, 1979]
✓ Relativistic electron flux largely decreases, when the solar wind dynamic pressure increases. [e.g., Turner et al., 2012].
✓ The high-speed solar wind stream with southward offset in the IMF \( B_Z \) enhances the electron flux more than that without offset. [Miyoshi and Kataoka, 2005]
Cross-correlation functions between HIMAWARI SEDA electron flux and other parameters

- +38 hours delay with solar wind velocity
- +4 hours delay with pressure
- +38 hours delay with Dst index
Time series prediction result of GEO MeV flux by AR model + Kalman filter

\[ Y_t = \sum_{n=1}^{m} A_n Y_{t-n} + v_t, \]

Regression order
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28 hours

Inputs
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- Solar wind velocity
- Solar wind pressure
- Dst index

#Coefficient matrix \( A \) is estimated by the least square method
Cross correlation functions with Vsw for each L shell (by Van Allen Probes data)

Higher correlation with higher L values
Cross correlation functions w/ Psw for each L shell (by Van Allen Probes data)

Cross correlation with solar wind pressure

Higher negative correlation with higher L values

REPT 2.3MeV electron
# Effective combinations of input parameters

<table>
<thead>
<tr>
<th>$L$ values</th>
<th>Regression</th>
<th>Input parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L=3.0$</td>
<td>5 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=3.2$</td>
<td>5 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=3.4$</td>
<td>2 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=3.6$</td>
<td>2 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=3.8$</td>
<td>2 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=4.0$</td>
<td>2 days</td>
<td>Dst index</td>
</tr>
<tr>
<td>$L=4.2$</td>
<td>2 days</td>
<td>Dst index + GEO flux</td>
</tr>
<tr>
<td>$L=4.4$</td>
<td>2 days</td>
<td>Dst index + GEO flux</td>
</tr>
<tr>
<td>$L=4.6$</td>
<td>2 days</td>
<td>Dst index + GEO flux</td>
</tr>
<tr>
<td>$L=4.8$</td>
<td>2 days</td>
<td>Dst index + solar wind speed + GEO flux</td>
</tr>
<tr>
<td>$L=5.0$</td>
<td>2 days</td>
<td>Dst index + solar wind speed + GEO flux</td>
</tr>
<tr>
<td>$L=5.2$</td>
<td>2 days</td>
<td>Dst index + solar wind speed + GEO flux</td>
</tr>
<tr>
<td>$L=5.4$</td>
<td>8 days</td>
<td>Dst index + solar wind speed</td>
</tr>
<tr>
<td>$L=5.6$</td>
<td>2 days</td>
<td>Dst index + solar wind speed + solar wind pressure</td>
</tr>
<tr>
<td>$L=5.8$</td>
<td>2 days</td>
<td>Dst index + solar wind speed + solar wind pressure</td>
</tr>
<tr>
<td>GEO (6.6 RE)</td>
<td>3 days</td>
<td>Kp index + solar wind speed + solar wind pressure</td>
</tr>
</tbody>
</table>
Discussion about input parameter transition by L values

• The **Dst** index is the best overall single parameter for predicting at $3 \leq L \leq 6$, while for the **GEO** flux prediction, the **Kp** index is better than Dst.

• The **V_{SW}** parameter is effective for the models at $L \geq 4.8$ only. This might be related to the inner edge of particle acceleration by ULF waves, a role of inward radial diffusion to lower L shells, the average, location of the plasmapause and the role of local acceleration by electrons interacting with whistler mode chorus outside of the plasmasphere.

• The **P_{SW}** parameter is effective for the models at $L \geq 5.6$ only. The boundary seems to be related to MeV electron loss owing to magnetopause shadowing. (statistical threshold from September 2012 to December 2013).
The model successfully predicts the timing and location of the flux maximum as much as 2 days in advance and that the electron flux decreases faster with time at higher L values, both model features consistent with the actually observed behavior.
Summary

- We have developed prediction models of MeV electron flux in the outer radiation belt using energetic particle data from GOES, HIMAWARI, and Van Allen Probes. These models are based on multivariate AR analysis and Kalman filter [Sakaguchi et al., *Space Weather*, 2013, 2015]. These models also give us some clue for understanding RB dynamics.

- GEO MeV electron flux data from the Japanese HIMAWAEI-8 metrological satellite is available for the real-time monitoring since November 2014. Data will be provided from NICT soon.
Radiation Belt Electron Forecast Web

[Image of the Radiation Belt Electron Flux Forecast website]

[Image of the Hazard Map at GEO (geostationary earth orbit) page]
Thank you for attention