Prediction of plasma bubble occurrence using the atmosphere-ionosphere coupled model GAIA

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Outline

- Whole atmosphere-ionosphere coupled model GAIA
- Linear growth rate of Rayleigh-Taylor instability
- Method of analysis
- Results
- Summary
Whole Atmosphere-Ionosphere Coupled Model (GAIA)

(GAIA: Ground-to-topside model of Atmosphere and Ionosphere for Aeronomy)

Horizontal Grid: $5^\circ \times 5^\circ$; $2.5^\circ \times 2.5^\circ$; $1^\circ \times 1^\circ$

- Solar Wind
- Magnetosphere
- EUV
- Ionosphere [0 – 3000 km]
- Dynamo [tilted dipole]
- Atmosphere [0 – ~500 km]
- Meteorological Data (JRA-25/JRA-55)

[Jin et al., 2008; 2011, Miyoshi et al., 2012]
Rayleigh-Taylor Instability in $\mathbf{E}$ and $\mathbf{B}$

Flux-tube integrated linear growth rate

\[ g = \frac{F}{P} \cdot V_p + \frac{E}{P} \cdot U_n^p + \frac{g_{L_{\text{eff}}}}{L_n} \cdot \frac{1}{R_T} \]

$V_p$: Vertical plasma drift (Vertical ExB drift)
$U_n^p$: Vertical neutral wind velocity perp. to $\mathbf{B}$
$R_T$: Flux-tube integrated recombination rate
$L_n$: Flux-tube integrated scale length of plasma density

Plasma Bubble Model

[Yokoyama et al., 2014]
Method of Analysis

- Long-term simulation database using GAIA
  - Data: 1996 – present at every 30 min
- Spatial resolution of GAIA
  - Horizontal: ~2.5° x 2.5°
  - Vertical: 10 km (ionosphere)
    - 2 – 5 km (atmosphere)
- Tilted dipole magnetic field
- No polar disturbance included
- Daily F10.7 cm index is given.
- Meteorological reanalysis data (JRA25/JRA-55) in the lower atmosphere are incorporated.
- Linear growth rate is calculated.
- Compared with daily observations of plasma bubbles (EAR, GPS)
Longitudinal and Seasonal Variations in Daily Maximum Linear Growth Rate of GAIA

Maximum Linear Growth Rate in 2011

Longitude (deg)

Day of Year

(s⁻¹)

0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0

NICT
Longitudinal and Seasonal Variations in Daily Maximum Linear Growth Rate of GAIA

Maximum Linear Growth Rate in 2007

Longitude (deg)

Day of Year

(s⁻¹)
Contours of equatorial plasma bubble (EPB) occurrence rates measured by DMSP satellites between 1989 and 2002 [Burke et al., JGR, 2004]
Comparison with daily observations

**EAR observation**
(Equatorial Atmosphere Radar)
@100.32°E, 0.20°S
– FAI data is used for plasma bubble detection.

**GPS Observation**
@100°E, 0°S
– Scintillation data is used for plasma bubble detection.

Field-Aligned Irregularity (FAI)

Plasma bubble occurrence day is determined with eyes (courtesy of Dr. Otsuka). 2011–2013 is chosen because complete dataset is available for both observations.
Plasma Bubble Detection by EAR and GPS

There are some discrepancies for some days between the two observations.

=> PB occurrence days = EAR + GPS
Plasma Bubble Daily Occurrence – Year 2011

Summation of EAR and GPS observations @100°E, magnetic equator

Maximum of linear growth rate for each day (blue line), and plasma bubble occurrence days (red bars).
**Predictability – Year 2011**

### Simple prediction

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>0.54</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(69/127)</td>
<td>(58/127)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0.24</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(58/238)</td>
<td>(180/238)</td>
<td></td>
</tr>
</tbody>
</table>

Tomorrow is the same as today.

### Prediction with model

If $\text{LGR} > 7.3 \times 10^{-4}$, PB will occur.
If $\text{LGR} < 4.5 \times 10^{-4}$, PB will not occur.
If $7.3 \times 10^{-4} > \text{LGR} > 4.5 \times 10^{-4}$, tomorrow is the same as today.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>0.57</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(73/127)</td>
<td>(54/127)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0.18</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(54/238)</td>
<td>(194/238)</td>
<td></td>
</tr>
</tbody>
</table>

A few percent to several percent improvement.
Plasma Bubble Daily Occurrence – Year 2012

Summation of EAR and GPS observations @100°E, magnetic equator

Year 2012

Day of Year

Linear Growth Rate

Plasma Bubble Occurred

Linear Growth Rate (s⁻¹)
### Predictability – Year 2012

#### Simple prediction

*Tomorrow is the same as today.*

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>(121)</td>
<td>0.55 (67/121)</td>
<td>0.45 (54/121)</td>
</tr>
<tr>
<td>No</td>
<td>(245)</td>
<td>0.22 (54/245)</td>
<td>0.78 (191/245)</td>
</tr>
</tbody>
</table>

#### Prediction with model

If $LGR > 6.0 \times 10^{-4}$, PB will occur.
If $LGR < 5.4 \times 10^{-4}$, PB will not occur.
If $6.0 \times 10^{-4} > LGR > 5.4 \times 10^{-4}$, tomorrow is the same as today.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>(127)</td>
<td>0.57 (69/121)</td>
<td>0.43 (52/121)</td>
</tr>
<tr>
<td>No</td>
<td>(238)</td>
<td>0.18 (44/245)</td>
<td>0.82 (201/245)</td>
</tr>
</tbody>
</table>
Plasma Bubble Daily Occurrence – Year 2013

Summation of EAR and GPS observations @100°E, magnetic equator
# Predictability – 2013

## Simple prediction

Tomorrow is the same as today.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (113)</td>
<td>Yes</td>
<td>0.65 (74/113)</td>
<td>0.35 (39/113)</td>
</tr>
<tr>
<td>No (252)</td>
<td>No</td>
<td>0.15 (39/252)</td>
<td>0.85 (180/252)</td>
</tr>
</tbody>
</table>

## Prediction with model

If LGR > 7.0x10^{-4}, PB will occur.
If LGR < 2.0x10^{-4}, PB will not occur.
If 7.0x10^{-4} > LGR > 2.0x10^{-4}, tomorrow is the same as today.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Prediction</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (113)</td>
<td>Yes</td>
<td>0.70 (79/113)</td>
<td>0.30 (34/113)</td>
</tr>
<tr>
<td>No (252)</td>
<td>No</td>
<td>0.22 (55/252)</td>
<td>0.78 (197/252)</td>
</tr>
</tbody>
</table>
Problems

- Neither EAR nor GPS can detect all of plasma bubbles.
- Present version of GAIA is not able to completely reproduce the actual ionosphere.
- Linear growth rate may not be a suitable index for evolution of plasma bubbles.
- Background ionospheric conditions vary continually.
- Magnetic storm effect is not included in the present analysis.
- In actual prediction, meteorological forecast data needs to be used instead of reanalysis data.
Summary

- Linear growth rate is calculated using GAIA data and the daily maximum values are compared with plasma bubble occurrence observations.
- Linear growth rate in GAIA is roughly consistent with seasonal and longitudinal occurrence rates deduced from satellite observations.
- Simple prediction tests using EAR and GPS data suggest that the linear growth rate given by GAIA is likely to improve the precision of the plasma bubble prediction.
Thank you for your attention