Explicit IMF By-dependence in high-latitude geomagnetic activity

Lauri Holappa and Kalevi Mursula
University of Oulu, Finland
Solar wind-magnetosphere coupling

- IMF $B_z$-component is the main driver of magnetic reconnection at the magnetopause

- IMF $B_y$ is included in coupling functions like the Newell coupling function, but its effect does not depend on its sign

\[
\frac{d\Phi_{MP}}{dt} = v^{4/3} B_T^{2/3} \sin \left(\frac{\theta}{2}\right)^{8/3},
\]

\[
B_T = \sqrt{B_z^2 + B_y^2}
\]

\[
\theta = \arctan \left(\frac{B_y}{B_z}\right)
\]

- Stronger auroral electrojets for $B_y > 0$ than for $B_y < 0$ in winter! [Friis-Christensen et al., 2017; Smith et al., 2017]

- This talk: quantifying the “$B_y$-effect” using geomagnetic indices
The Russell-McPherron effect

- IMF $B_z$ and $B_y$ are not statistically independent.
- Negative IMF $B_z$ in GSM coordinate system for IMF $B_y > 0$ in fall and for $B_y < 0$ in spring.

[Zhao et al., 2012]
• Solar wind driving of the magnetosphere is enhanced for IMF $B_y > 0$ in fall, and for $B_y < 0$ in spring.

Superposed monthly means and standard errors of the Newell universal coupling function $d\Phi_{MP}/dt$ in 1966-2015.
Seasonal variation of AL index

- Deep minimum in AL index during winter for $B_y < 0$

- **Cannot** be explained by the Russell-McPherron effect.

$=>$ Explicit $B_y$-effect

All data in 1966-2015
Explicit $B_y$-effect in AL index

• In NH winter, for the same value of $d\Phi_{MP}/dt$, $B_y > 0$ produces a stronger AL-index than $B_y < 0$.

• Opposite $B_y$-dependence in NH summer
Explicit $B_y$-effect in AL index

- Explicit $B_y$-dependence is very weak around spring and fall equinoxes.
a) We calculate measured and predicted ratios

\[
R_{\text{meas}}^{+/−}(AL) = \frac{|AL(B_y > 0)|}{|AL(B_y < 0)|}
\]

\[
R_{\text{pred}}^{+/−}(AL) = \frac{a \cdot d\Phi_{MP}/dt(B_y > 0) + b}{a \cdot d\Phi_{MP}/dt(B_y < 0) + b'}
\]

includes only the RMP-effect

b) The ratio of these two ratios

\[
R_{\text{expl}}^{+/−}(AL) = \frac{R_{\text{meas}}^{+/−}(AL)}{R_{\text{pred}}^{+/−}(AL)}
\]

quantifies the explicit \(B_y\)-effect

AL index is about \textbf{40-50\% stronger for} \(B_y>0\) \textbf{than for} \(B_y<0\) around the winter solstice.

[Holappa and Mursula, JGR, 2018]
The explicit $B_y$-effect (in NH) maximizes around 5 UT, i.e., when the Earth’s dipole axis points away from the Sun.

⇒ The explicit $B_y$-effect maximizes when the auroral region is maximally in darkness.

⇒ $B_y$-effect is efficient under low ionospheric conductivity?

Left: Ratio $R_{exp}^{+/-}(AL)$ for different UT hours and months.
Right: $R_{exp}^{+/-}(AL)$ averaged over months.
• $B_y$-dependence in the AU index (eastward electrojet) is solely due to Russell-McPherron effect
Summary

- IMF $B_y$ is an **explicit** driver of high-latitude geomagnetic activity
- Geomagnetic activity is **significantly stronger** for $B_y > 0$ than for $B_y < 0$ in winter
- $B_y$-effect maximizes at the winter solstice at 5 UT
- $B_y$ affects the westward electrojet but not the eastward electrojet
- IMF $B_y$ is important for space weather predictions
- **No physical explanation yet!**
- **K-index of Syowa station in Antarctica**

- During SH winter, for the same value of $d\Phi_{MP}/dt$, $B_y < 0$ produces stronger K-index than $B_y > 0$.

- $B_y$-dependence in SH is **opposite** to that in NH
During SH summer, for the same value of $d\Phi_{MP}/dt$, $B_y > 0$ produces stronger K-index than $B_y < 0$. 
• There is a correlation between $B_y$ and $B_x$. Which of the two components is the driver?

• Limiting the amplitude of $B_x$ has almost no effect to the results.

$\Rightarrow B_x$ has only little, if any, explicit effect on high latitude geomagnetic activity.