# Calculation of Birkeland currents during substorm injections

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**Question: Is the conventional substorm current wedge model enough to represent the large-scale Birkeland currents during substorm injections?**

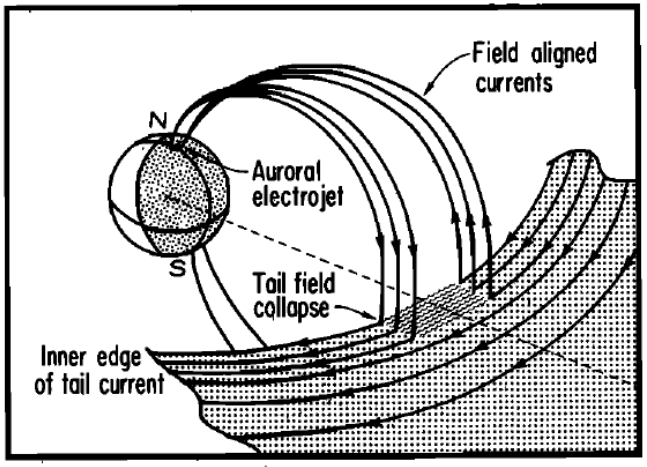



Fig. 8. A perspective drawing of the events described in Figure 7.

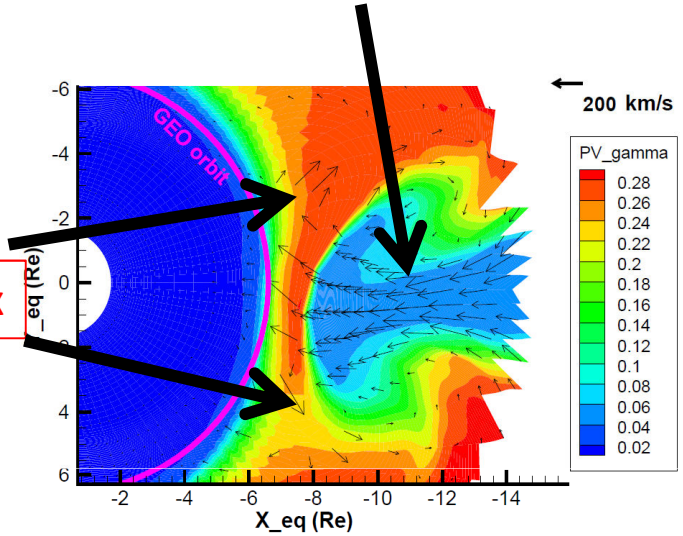
[McPherron et al., 1973, JGR]

# Simulation Approach

- A substorm injection is modeled in the RCM-E, by placing a plasma-sheet bubble in a sector around midnight along the tail boundary [e.g., *Zhang et al*., 2008 GRL; *Zhang et al*., 2009, JGR; *Yang et al., 2011*, JGR].
- A plasma-sheet bubble is a bundle of flux tubes with lower entropy $PV^{5/3}$ (where $P$ is plasma pressure and $V=\int ds/B$ is the flux tube volume per unit magnetic flux) than its neighbors [*Pontius and Wolf*, 1990, GRL]. The most intuitive picture of making a bubble is magnetic reconnection in the tail.
- Bubbles are often observed in the plasma sheet as bursty bulk flows (BBFs) [e.g., *Angelopoulos et al*., 1992, JGR*; Sergeev et al*., 1996, JGR; *Dubyagin et al*., 2010, JGR].
- The RCM-E calculates ***E***X***B*** and G/C drifts for isotropic plasma in self-consistent ***E*** and ***B***.
- The following calculation is based on an RCM-E simulation of an idealized bubble injection [*Yang et al., 2011*, JGR, 116, A05207, doi:10.1029/2010JA016346].

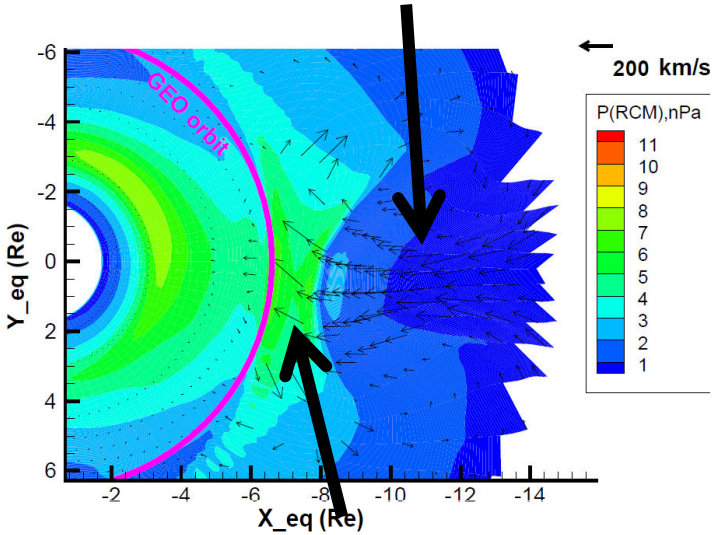
# Idealized bubble injection

**Earthward moving bubble**

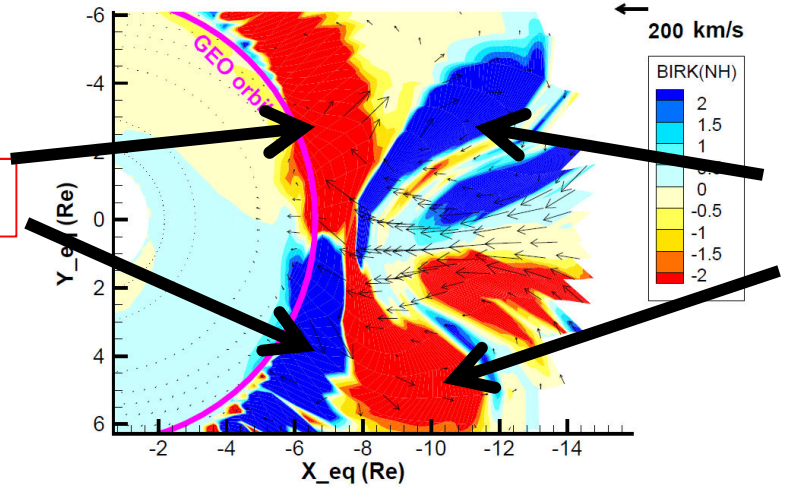



**Flow vortex**

**Plasma pressure depletion Inside the bubble**



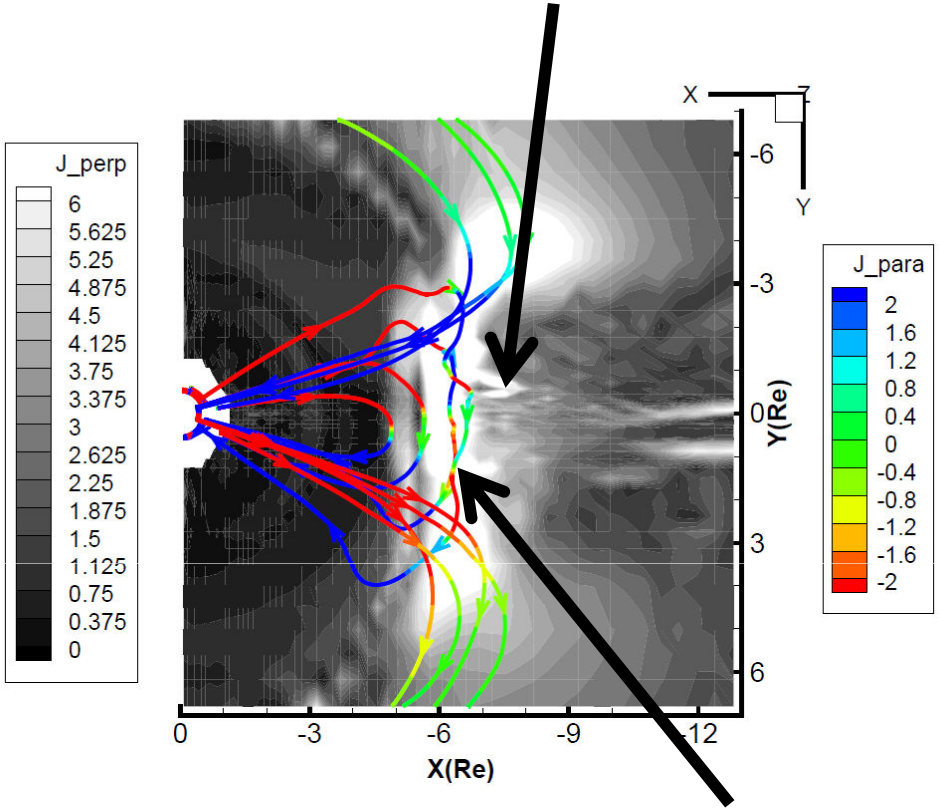

**Enhanced partial ring current pressure ahead of the bubble**




**Intensified region-2 FACs**

**Region-1 SCW on edges of the bubble**

**Cross tail current disrupted**

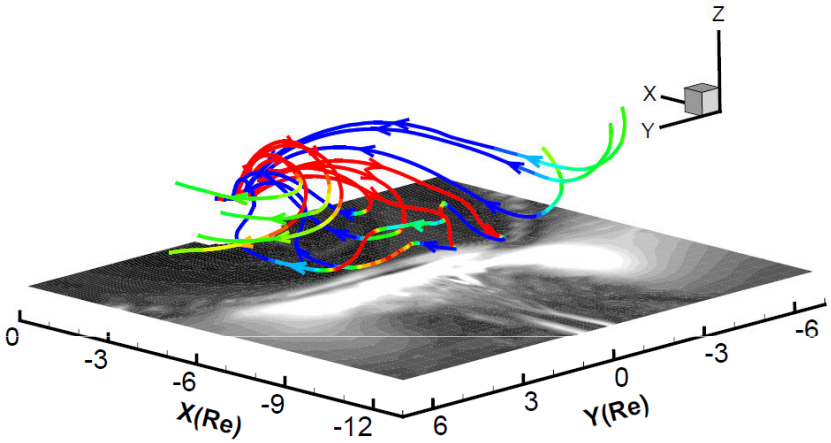



**Enhanced partial ring current**

**(Top view)**

- **Gray contours: J_perp in the equatorial plane**
- **Colored lines: J_para**

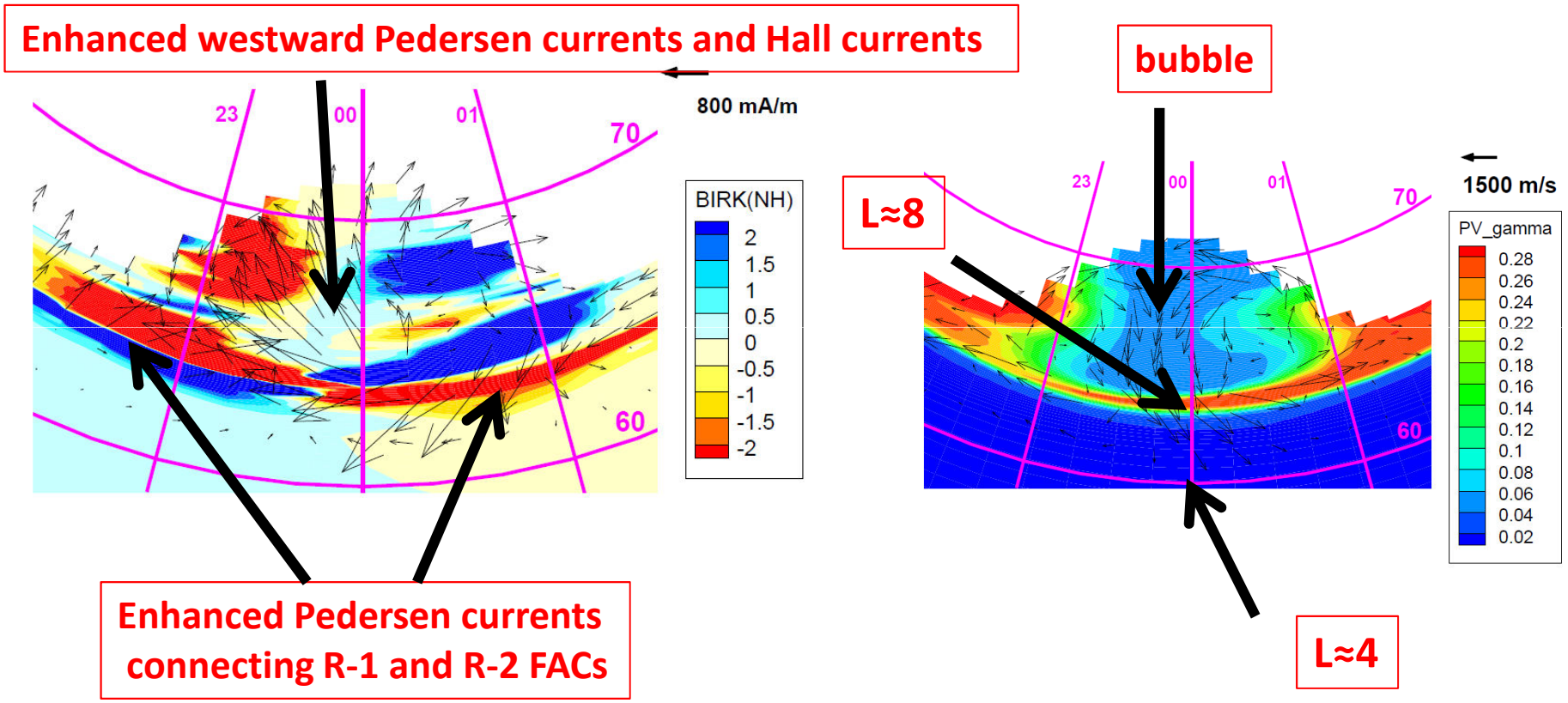
(Blue: downward current Red: upward current)




**(Side view)**

- R-1 Birkeland currents in the higher latitude region
- R-2 Birkeland currents in the lower latitude region, closed via enhanced partial ring current in the magnetosphere

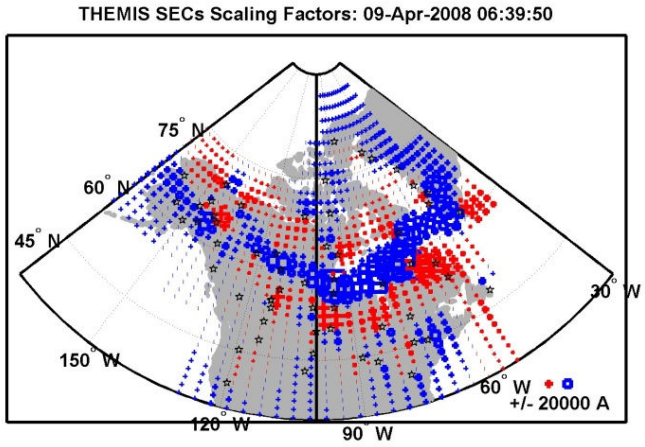
# Birkeland Currents in the ionosphere

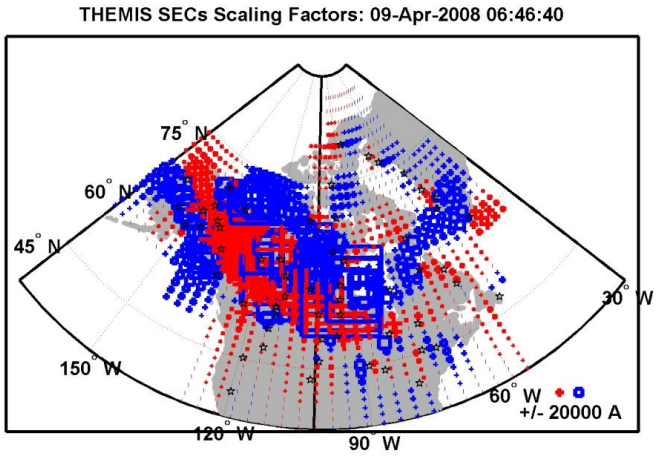



(Blue: downward current Red: upward current)

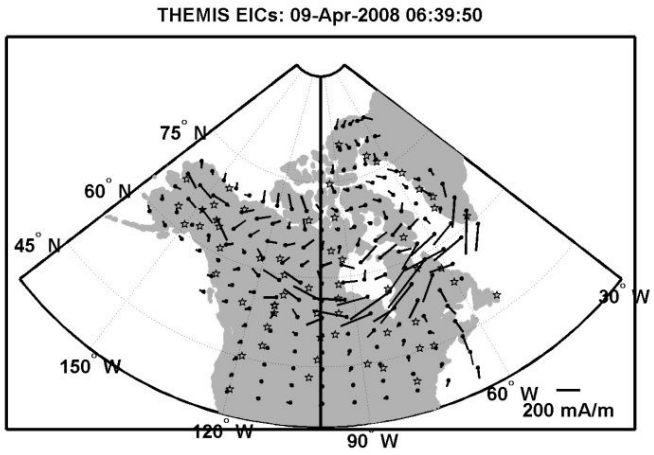
# Observational support

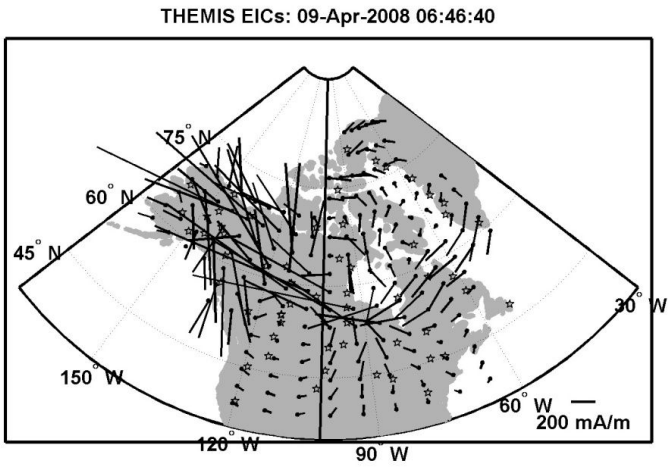
## Vertical currents




## Equivalent ionospheric currents




[ Figure courtesy of J. Weygand]

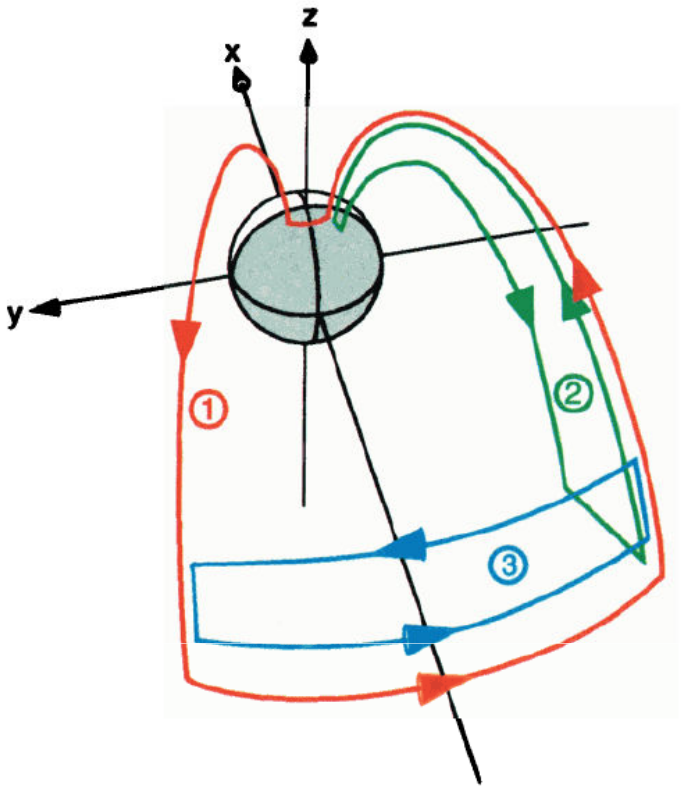
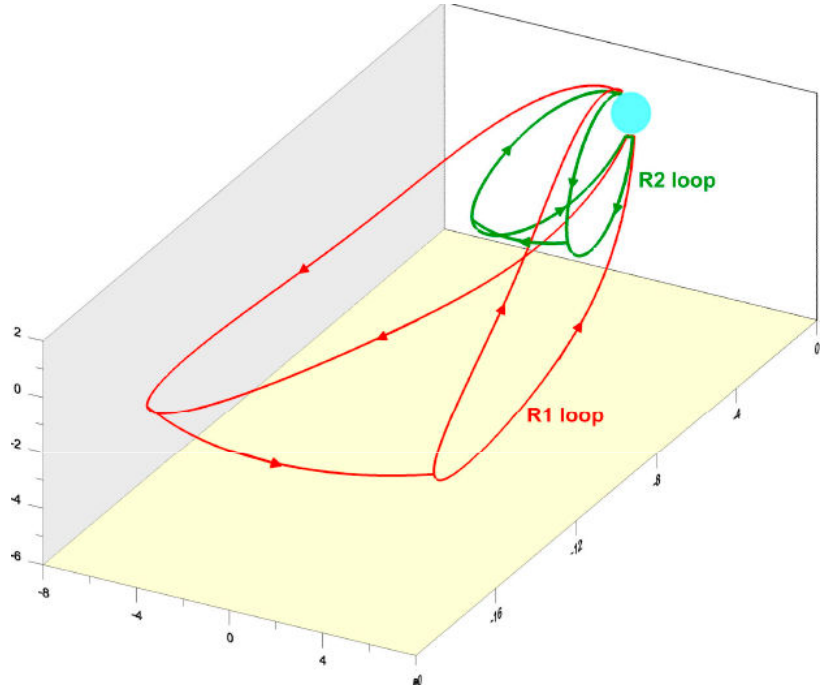



**Plate 4.** Schematic of the dominant current systems contributing to the diversion of currents in the substorm current wedge.

**[Birn et al., 1999, JGR]**




**[Sergeev et al., 2011, JGR in press]**

Similar suggestions from different perspectives
[e.g., Untiedt and Baumjohann, 1993, SSR; Lui and Kamide, 2003, GRL]

# Summary and Open Questions

- The RCM-E simulation shows two sets of Birkeland currents during substorm injections.
- Accurate mapping may require modeling both conventional SCW and R-2 Birkeland currents and enhanced partial ring current.
- The R-2 currents are associated with the head of the bubble (dipolarization front).
- Do these two sets of Birkeland currents appear in all substorm injections?
- Are times scales of their growth the same?
- Are time scales of their decay the same?
- How to characterize the ratio of total currents in R2 to R1?
- …