A Magnetospheric Perspective on Ionospheric Outflow

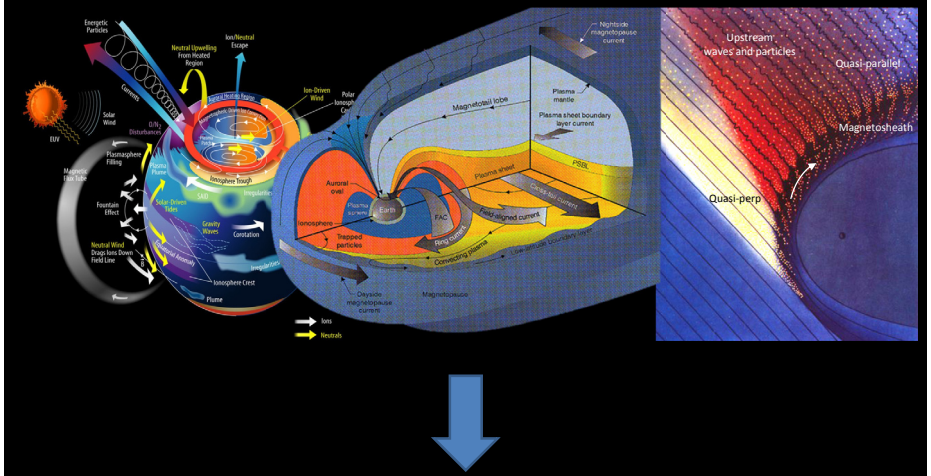
Bill Lotko, Dartmouth College

- Why are outflows important? (*focus on O^+*)
- What aspects of outflows are important?
- What controls outflows?
- What don't we understand about outflows?

(*Answer: causal relationships*)

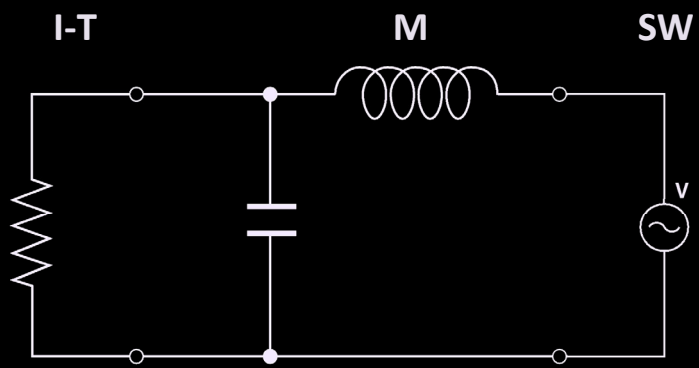
How do we view "other" parts of the geospace system?

I-T M SW



How do we view "other" parts of the geospace system?

I-T M SW



Mass flow through I-T-M modifies RLC.

How important is the effect in geospace dynamics?

Why are outflows important?

Impacts on Geospace System (results from models and observations)

- Enhance stormtime ring current (Nosé et al. 2005; Glocer et al. 2009)
- Regulate magnetospheric composition, EMIC waves, radbelts
- Modify magnetotail, plasmasheet dynamics and structure
  (Kistler et al. 2005; Nosé et al. 2009; Winglee 2004; Wiltberger et al. 2010)

M

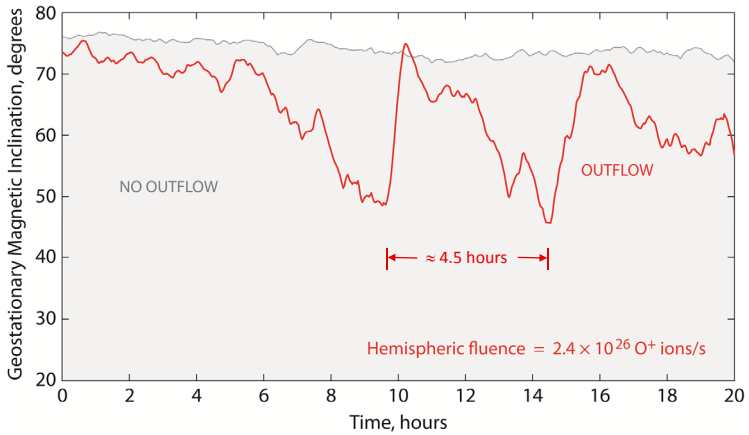
- Inflate magnetosphere (Garcia et al. 2010; Brambles et al. 2010)
  ⇒ modifies solar wind – magnetosphere interaction
- Reduce transpolar potential (Winglee et al. 2002; Glocer et al. 2009)
- Change threshold for KH instability at MP (Bouhram et al. 2005)
- Induce periodic (2-5 hr) substorms (Brambles et al. 2011)

I-T

- *Cause* (?) topside cavitation (Chaston et al. 2006)
- *Correlate* with thermospheric upwelling (Liu et al. 2005)

No Outflow vs. Outflow ⇒ "Sawtooth" Substorms

Brambles et al. (2011)



IMF B_z = - 10 nT, V_{sw} = 400 km/s, n_{sw} = 5 cm^{-3} // Geo inclination angle ≡ $\sin^{-1}(B_z/B)$ at z = 0.5 R_E, r = 6.6 R_E

Case A (conic "like")

$v_{||}$ = 50 km/s , T = 100 eV

Projections to 100 km from 6 R_E

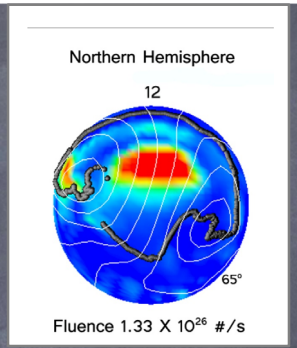
Empirical outflow model

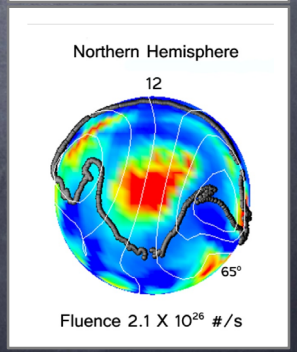
$F_{||O} = 2.1 \times 10^7 S_{dc}^{1.3}$

Strangeway et al. 2005

Case B (polar wind "like")

$v_{||}$ = 3 km/s , T = 1 eV



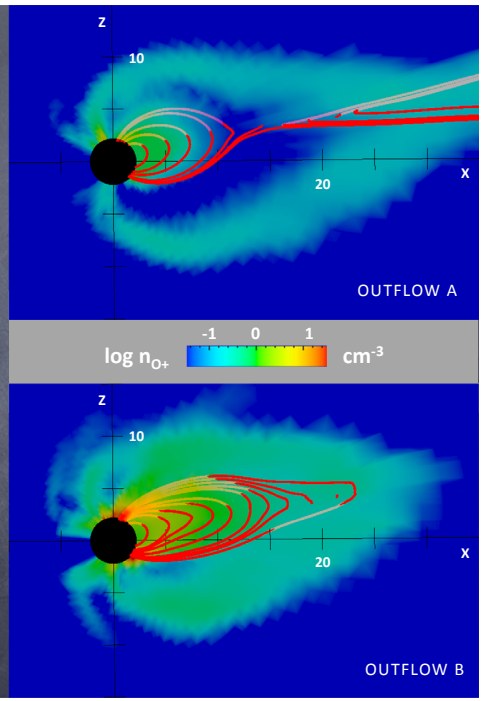


Brambles et al. 2010

"Conic-like" cusp outflow
$V_{||}$ = 50 km/s
→ Increases CPCP

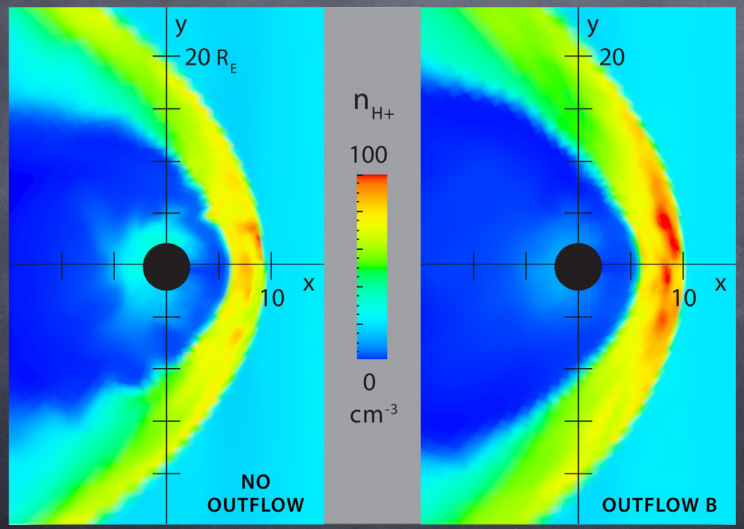
O⁺ interaction with nightside reconnection

"Polar-wind" cusp outflow
$V_{||}$ = 3 km/s
→ Decreases CPCP



Brambles et al. 2010

Magnetospheric Inflation



Brambles et al. 2010

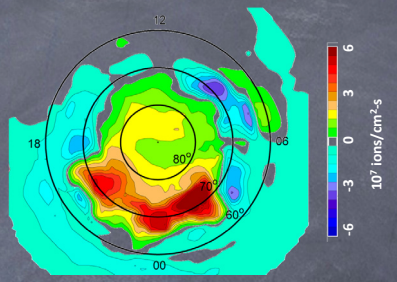
What aspects of outflows are important?

O^+ Source Location

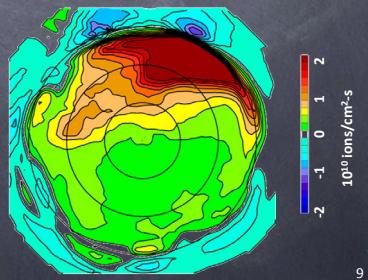
Winglee 2009

- Substorms: nightside dominant
- Storms: dayside dominant
  - — but nightside still significant
- Tail dynamics similar
  - — except recurrent activity feeds off preloaded O^+ to give faster responses during later activity

18 Mar 2007 Non-Storm



29 Oct 2003 Storm

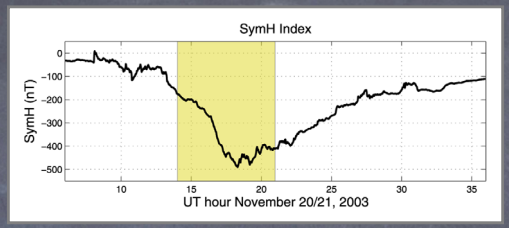


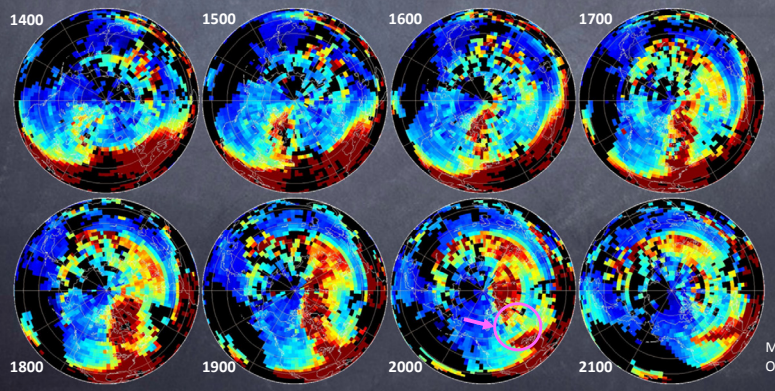
What controls outflows?

Convective transport to the cusp

→ 10^{10} ions / cm²-s

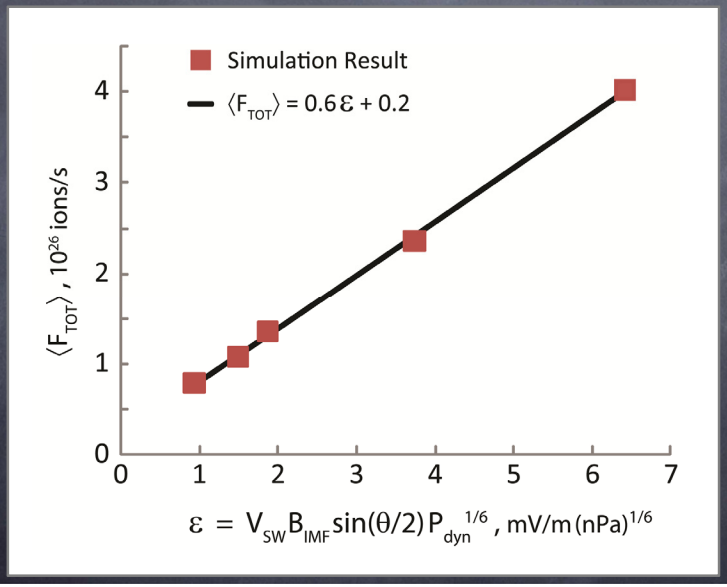
Coster, Erickson, Foster (2009)





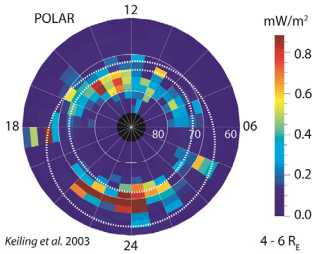
What controls outflows?

Outflow Fluence $\langle F_{TOT} \rangle$ vs. SW Driving ε



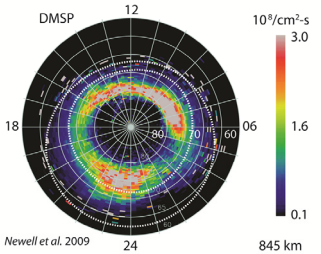
What controls outflows?

Alfvénic Poynting Flux



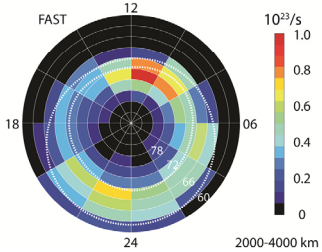
Keiling et al. 2003

Electron Number FLux

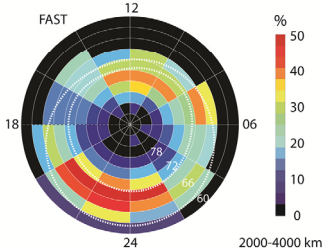


Newell et al. 2009

Outflow Fluence



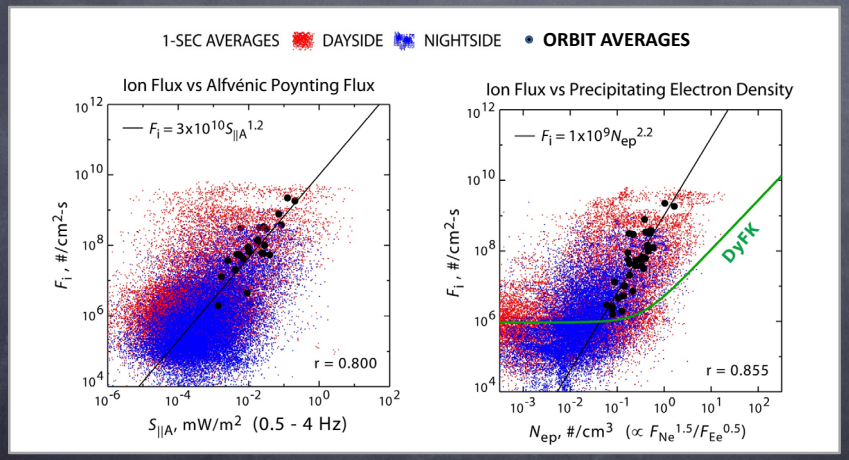
% Associated With Alfvén Waves



Chaston et al. 2007

What don't we understand about outflows?

Correlations with outflow flux (FAST)



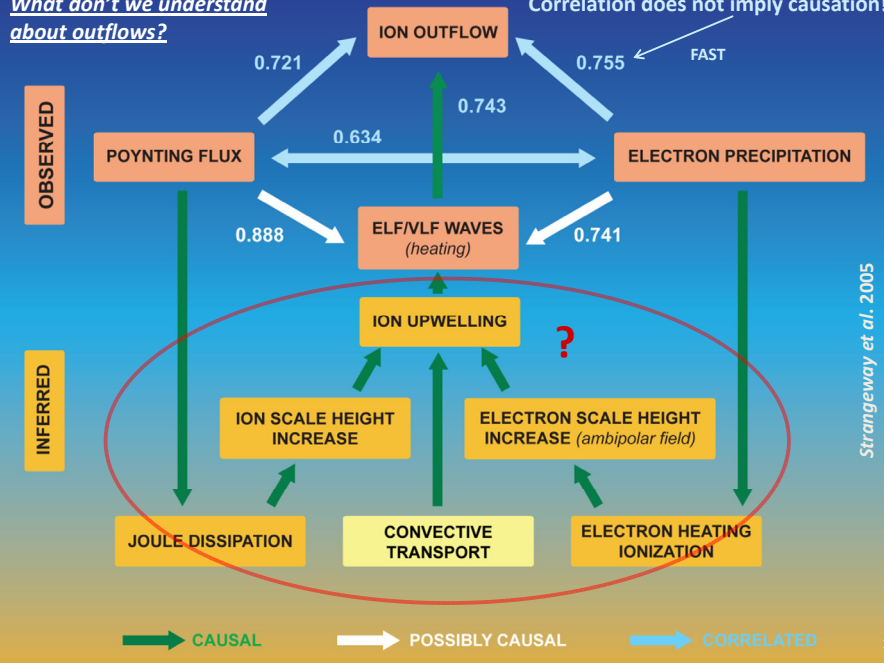
Strangeway, 2009

Are Alfvén waves direct or indirect drivers?

13

What don't we understand about outflows?

Correlation does not imply causation!

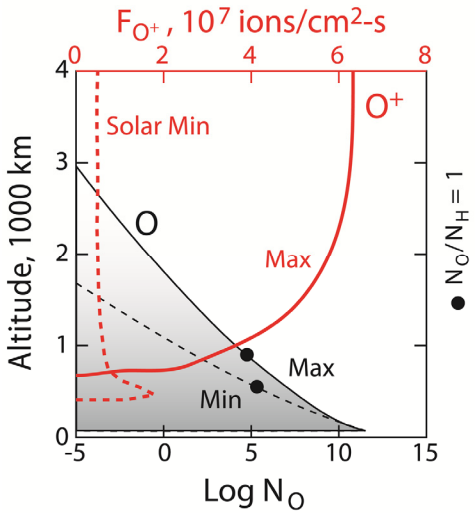


Strangeway et al. 2005

14

What controls outflows?

Thermospheric Control of Outflows (Cannata and Gombosi, 1989)



- Accidently resonant charge exchange chemistry couples H^+, O^+ flows to the neutral density profiles of atomic H and O.
- Larger O^+ outflows arise at solar max based solely on thermospheric changes
- Higher neutral O scale heights at solar max shifts maximum production level of O^+ to higher altitudes where loss by reaction with O_2 and N_2 is less frequent

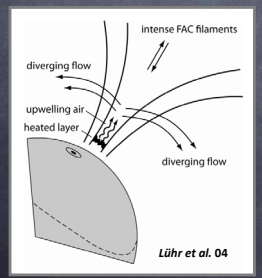
15

What don't we understand about outflows?

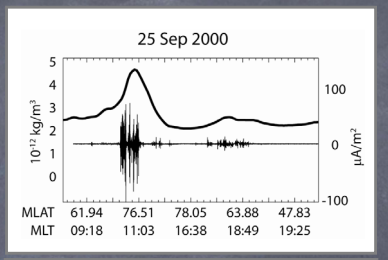
Thermospheric Control

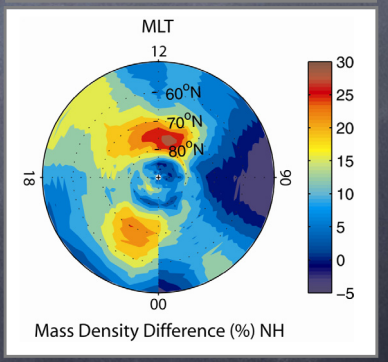
Causes of upwelling

- Large-scale Joule heating
- Ion upflow
- Soft electron precipitation
- Alfvén waves, small-scale FAC



CHAMP thermospheric density enhancement





16

Open Questions

- ***How are ionospheric O^+ outflows energized?***
  - EM energy conversion, particle precipitation, waves/turbulence, …
- ***How do interplanetary and I-T-M conditions control outflows, their distributions and fluxes?***
  - Outflow distribution, ionosphere-thermosphere upwelling and chemistry, magnetospheric power flows, sub/storms, …
- ***How does the I-T-M system respond to ionospheric outflows?***
  - Thermosphere-ionosphere upwelling, ionospheric cavitation, episodic dynamics, reconnection potential , transpolar potential, …

References

Bouhram, M., Klecker, B., Paschmann, G., Haaland, S., Hasegawa, H., Blagau, A., Rème, H., Sauvaud, J.-A., Kistler, L. M., and Balogh, A. (2005), Survey of energetic O^+ ions near the dayside mid-latitude magnetopause with Cluster, *Ann. Geophys., 23*, 1281-1294, doi:10.5194/angeo-23-1281-2005.

Brambles, O. J., W. Lotko, P. A. Damiano, B. Zhang, M. Wiltberger, and J. Lyon (2010), Effects of causally driven cusp O^+ outflow on the storm time magnetosphere-ionosphere system using a multifluid global simulation, *J. Geophys. Res., 115*, A00J04, doi:10.1029/2010JA015469.

Brambles, O. J., W. Lotko, B. Zhang, M. Wiltberger, J. G. Lyon and R. J. Strangeway (2011), Magnetosphere sawtooth oscillations induced by ionospheric outflow, *Science 332*, 1183, doi:10.1126/science.332.6034.1124-a.

Cannata, R. W., and T. I. Gombosi (1989), Modeling the Solar Cycle Dependence of Quiet-Time Ion Upwelling at High Geomagnetic Latitudes, *Geophys. Res. Lett., 16*(10), 1141-1144.

Chaston, C. C., V. Genot, J. W. Bonnell, C. W. Carlson, J. P. McFadden, R. E. Ergun, R. J. Strangeway, E. J. Lund, and K. J. Hwang (2006), Ionospheric erosion by Alfvén waves, *J. Geophys. Res., 111*, A03206, doi:10.1029/2005JA011367.

Chaston, C. C., C. W. Carlson, J. P. McFadden, R. E. Ergun, and R. J. Strangeway (2007), How important are dispersive Alfvén waves for auroral particle acceleration?, *Geophys. Res. Lett., 34*, L07101, doi:10.1029/2006GL029144.

Coster, A. J., J. C. Foster, P. J. Erickson, (2009), Workshop on "Ionospheric-Magnetospheric Plasma Redistribution During Storms: Causes and Consequences" held at HAO/NCAR on 28–29, September 2009.

Coster, A. J., J. C. Foster, P. J. Erickson, (2009), Workshop on "Ionospheric-Magnetospheric Plasma Redistribution During Storms: Causes and Consequences" held at HAO/NCAR on 28–29, September 2009.

Garcia, K. S., V. G. Merkin, and W. J. Hughes (2010), Effects of nightside O^+ outflow on magnetospheric dynamics: Results of multifluid MHD modeling, *J. Geophys. Res*., 115, A00J09, doi:10.1029/2010JA015730.

Glocer, A., G. Tóth, T. Gombosi, and D. Welling (2009), Modeling ionospheric outflows and their impact on the magnetosphere, initial results, *J. Geophys. Res., 114*, A05216, doi:10.1029/2009JA014053.

Keiling, A., Wygant, J.R., Cattell, C.A., Mozer, F.S., Russell, C.T. (2003), The global morphology of wave Poynting flux: Powering the aurora. *Science 299*, 383–386, doi:10.1126/science.1080073.

Kistler, L. M., et al. (2005), Contribution of nonadiabatic ions to the cross-tail current in an O^+ dominated thin current sheet, *J. Geophys. Res., 110*, A06213, doi:10.1029/2004JA010653.

Liu, H., H. Lühr, V. Henize, and W. Köhler (2005), Global distribution of the thermospheric total mass density derived from CHAMP, *J. Geophys. Res., 110*, A04301, doi:10.1029/2004JA010741.

Lühr, H., M. Rother, W. Köhler, P. Ritter, and L. Grunwaldt (2004), Thermospheric up-welling in the cusp region: Evidence from CHAMP observations, *Geophys. Res. Lett., 31*, L06805, doi:10.1029/2003GL019314.

Newell, P. T., T. Sotirelis, and S. Wing (2009), Diffuse, monoenergetic, and broadband aurora: The global precipitation budget, *J. Geophys. Res., 114*, A09207, doi:10.1029/2009JA014326.

Nosé, M., A. Ieda, and S. P. Christon (2009), Geotail observations of plasma sheet ion composition over 16 years: On variations of average plasma ion mass and O^+ triggering substorm model, *J. Geophys. Res., 114*, A07223, doi:10.1029/2009JA014203.

Strangeway, R. J., R. E. Ergun, Y. Su, C. W. Carlson, and R. C. Elphic (2005), Factors controlling ionospheric outflows as observed at intermediate altitudes, *J. Geophys. Res., 110*, A03221, doi:10.1029/2004JA010829.

Strangeway, R. J. (2009), (2009), Workshop on "Ionospheric-Magnetospheric Plasma Redistribution During Storms: Causes and Consequences" held at HAO/NCAR on 28–29, September 2009.

Wiltberger, M., W. Lotko, J. G. Lyon, P. Damiano, and V. Merkin (2010), Influence of cusp O^+ outflow on magnetotail dynamics in a multifluid MHD model of the magnetosphere, *J. Geophys. Res., 115*, A00J05, doi:10.1029/2010JA015579.

Winglee, R. M., D. Chua, M. Brittnacher, G. K. Parks, and G. Lu (2002), Global impact of ionospheric outflows on the dynamics of the magnetosphere and cross-polar cap potential, *J. Geophys. Res. , 107, 1237, doi:10.1029/2001JA000214.*

Winglee, R. M., (2004), Ion cyclotron and heavy ion effects on reconnection in a global magnetotail, *J. Geophys. Res.*, *109*, A09206, doi:10.1029/2004JA010385.

Winglee, R. M., (2009), Workshop on "Ionospheric-Magnetospheric Plasma Redistribution During Storms: Causes and Consequences" held at HAO/NCAR on 28–29, September 2009.