Reverse Convection Potential Saturation in the Polar Ionosphere

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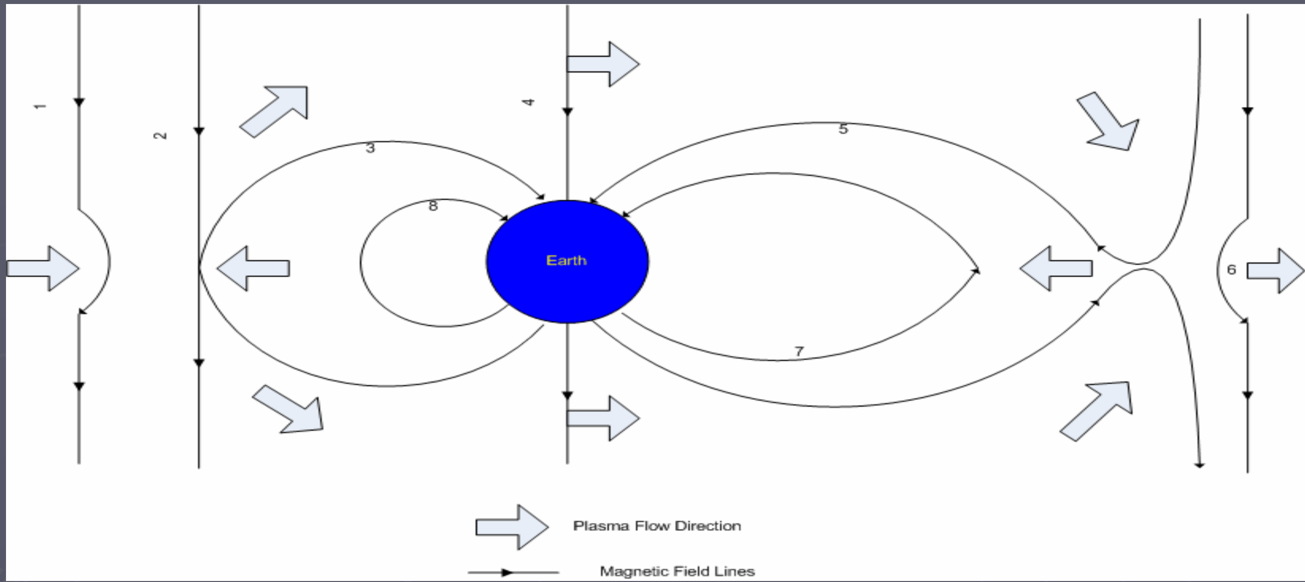
Outline

- Previous Results (Southward IMF):
  - Saturation of the polar cap potential
  - Models and explanations
- This Study (Northward IMF):
  - Does the polar cap potential saturate?
  - What do the results tell us about the models?
- Future Directions

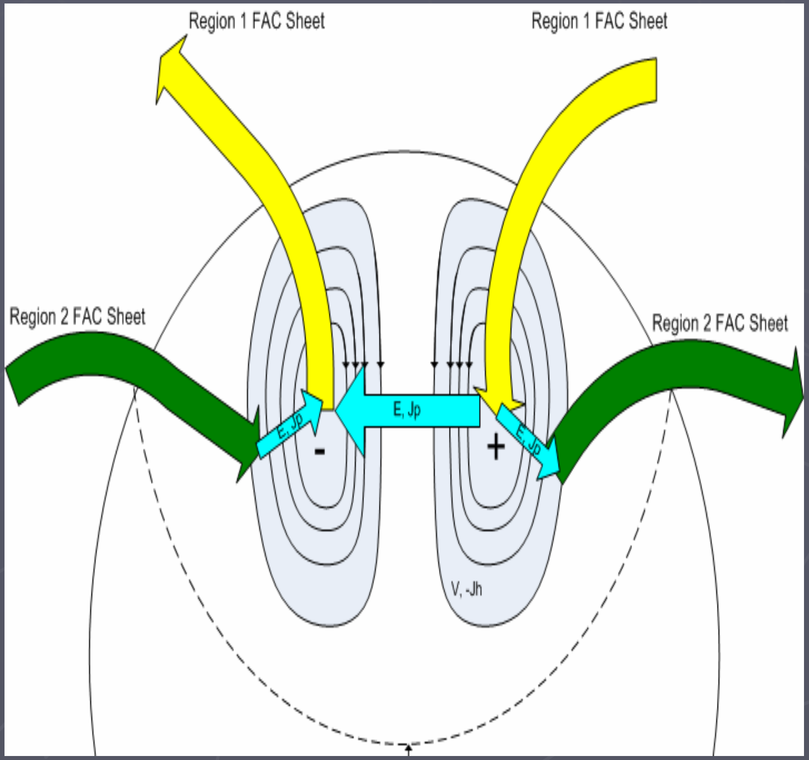
Magnetic Reconnection



- Convection of plasma in the magnetosphere and ionosphere is driven by the solar wind.
- The primary mechanism for coupling with the solar wind is magnetic reconnection [*Dungey,* 1961].
- The case above is for southward IMF.

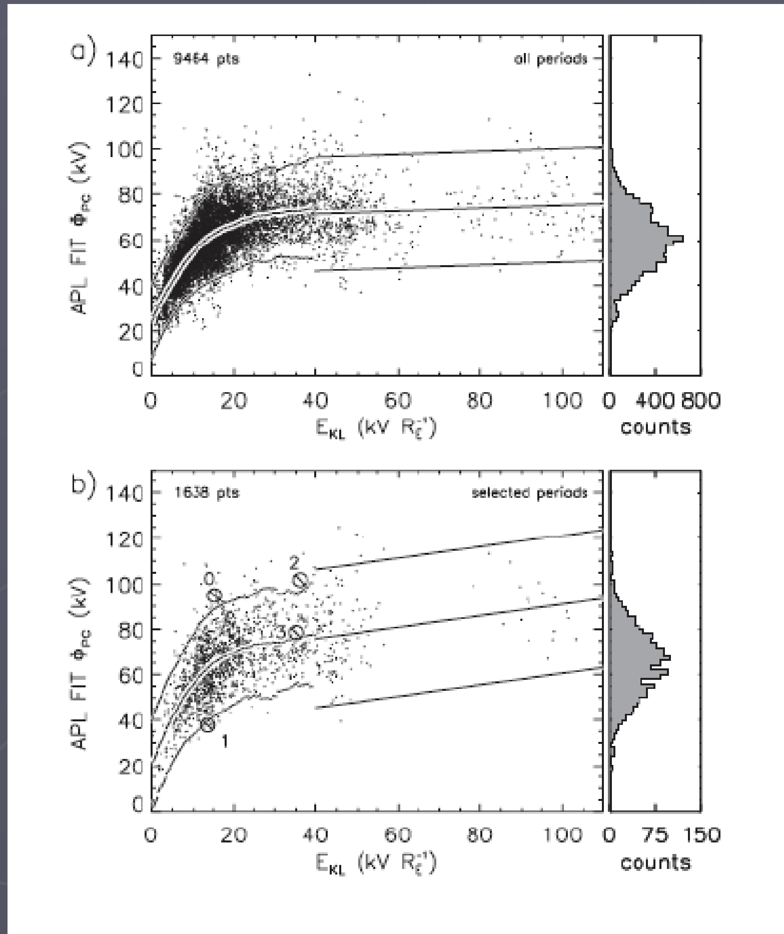
Polar Cap Potential

- Magnetospheric convection generates electric fields that are transmitted along quasi-equipotential magnetic field lines to the ionosphere.
- For southward IMF the ionospheric convection is a two-cell pattern.
- The potential difference across the two cells is called the "cross polar cap potential," denoted Φ_{pc}



Ionospheric Response Curve

- At first, it was thought that the polar cap potential had a linear response to the strength of southward IMF.
- Studies have shown that there is a "saturation" effect [*Shepherd et al.*, 2002; *Russell et al.* 2001, *Hairston et al.*, 2003].



From *Shepherd et al.* [2002]

The Hill Empirical Model

- In the Hill model of polar cap saturation the polar cap potential Φ_{pc} is related to the magnetospheric potential Φ_m and the saturation potential Φ_s by:

$$\Phi_{PC} = \frac{\Phi_m \Phi_s}{\Phi_m + \Phi_s}$$

- Studies have shown that the saturation potential is somewhere between 100 and 200 kV

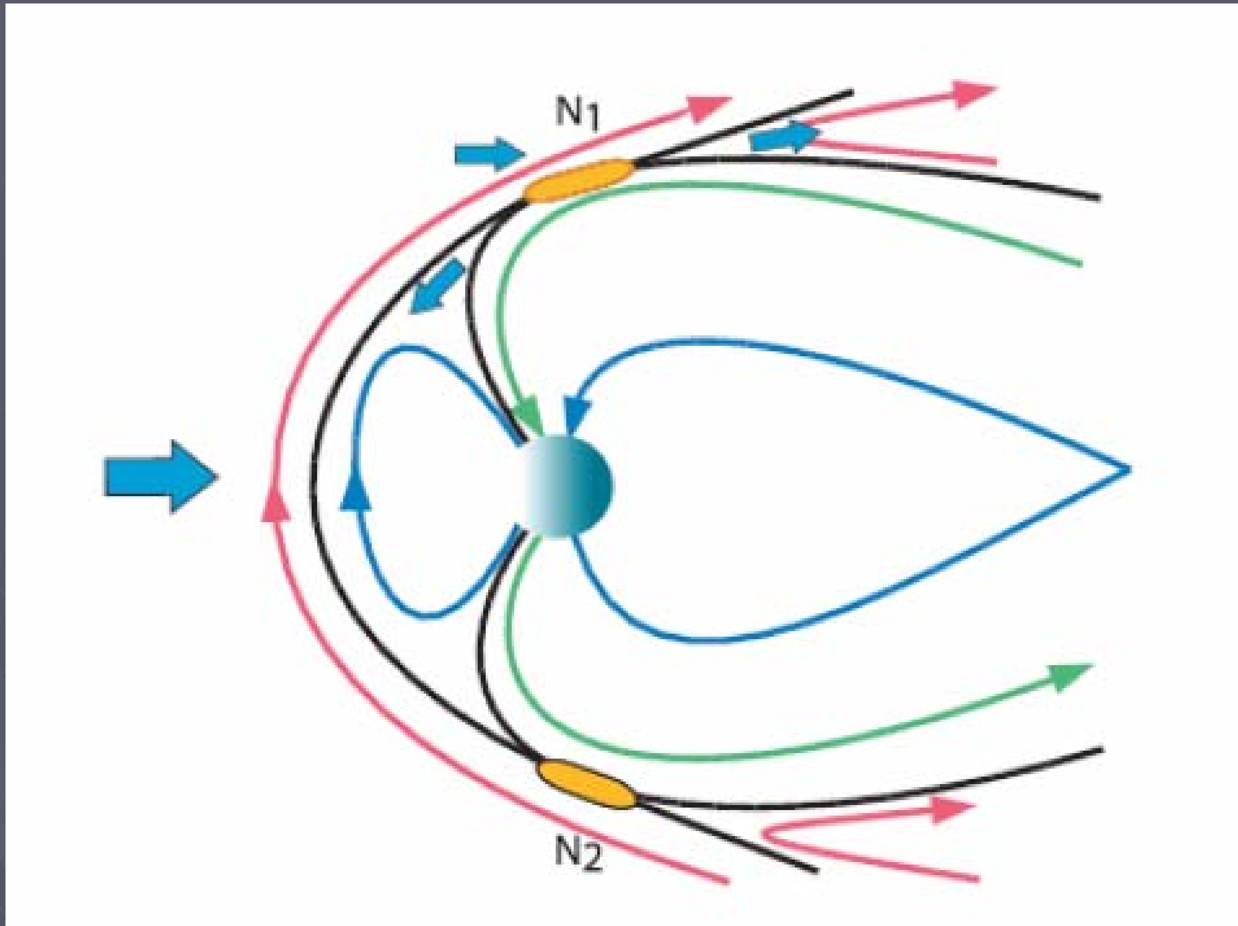
Explanations for Saturation

- The Region 1 Currents become strong enough to standoff the solar wind.
- The magnetopause becomes blunt, erodes, or forms a dimple which limits reconnection
- There is a limit to the amount of current the ionosphere can carry.

Comments

- The saturation potential determined by *Shepherd et al.* [2002] was lower than that in other studies.
- Some suggested that the saturation seen by SuperDARN was premature because the auroral activity expands equatorward of the radars during the most extreme southward IMF conditions.
- SuperDARN is much better suited to examine saturation during northward IMF conditions.
- No previous studies have investigated whether saturation occurs during northward IMF.

Reconnection Under Northward IMF

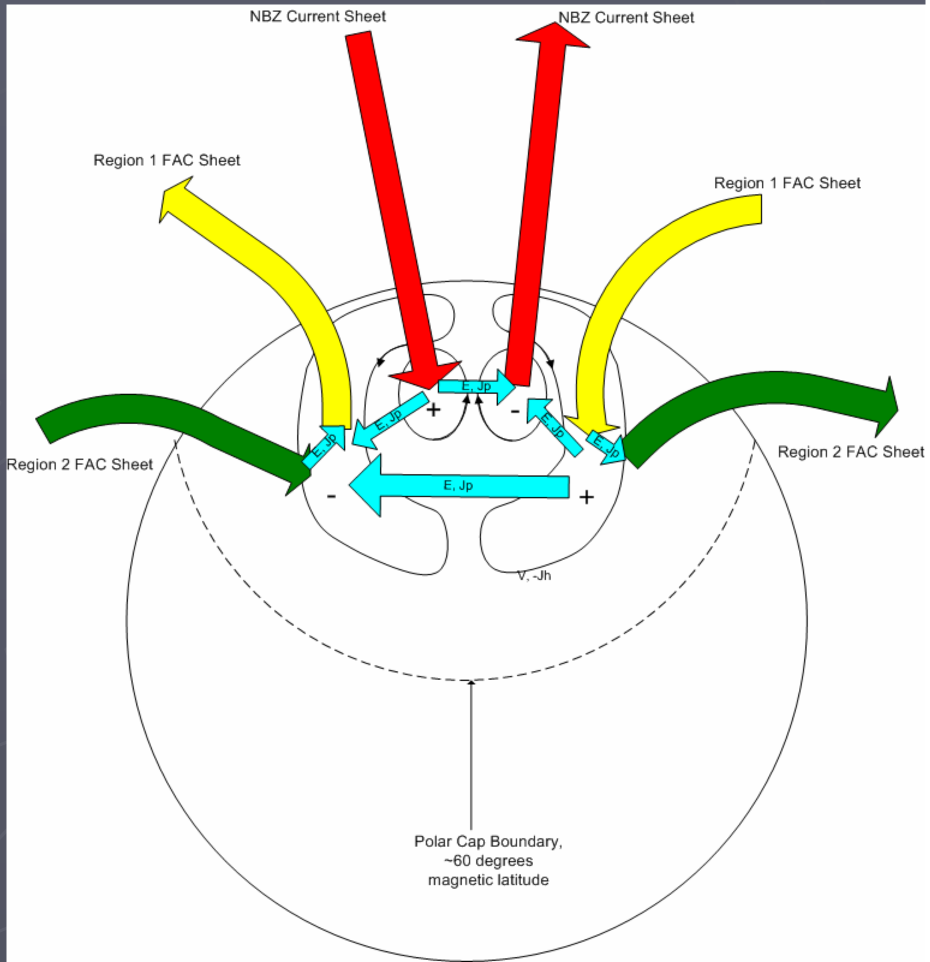


From *Dorelli et al., 2007*

- Reconnection for northward IMF is poleward of the cusp.

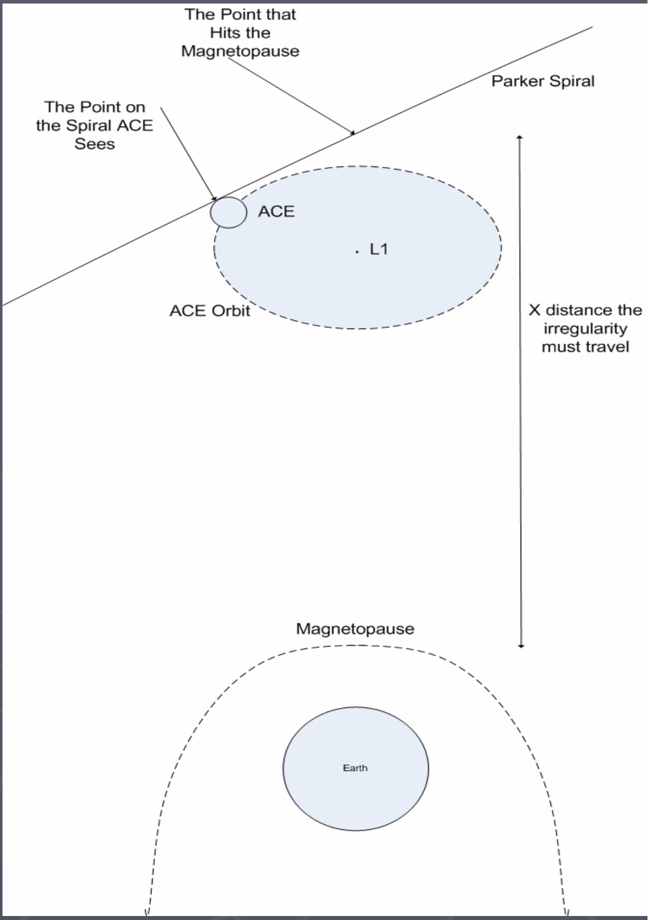
Saturation Under Northward IMF?

- When cusp reconnection occurs, a new set of field aligned currents is generated, termed NBZ by *Iijima et al.* [1984].
- These currents drive reverse convection vortices in the dayside high latitude ionosphere.
- Does the potential across the reverse cells saturate?



Methodology: Solar Wind Analysis

- IMF and Solar Wind Plasma data was gathered from the ACE spacecraft between the years of 1998 and 2005.
- The ACE data was propagated to the magnetopause using the "Minimum Variance" technique, outlined by *Weimer et al.* [2001].



The Kan and Lee Energy Coupling Function

- Many studies have used the "Energy Coupling Function" derived by *Kan and Lee* [1979] as a metric of the reconnection electric field.

$$E_{KL} = V_x B_T \sin^2(\theta/2)$$

$$B_T = \sqrt{B_y^2 + B_z^2}$$

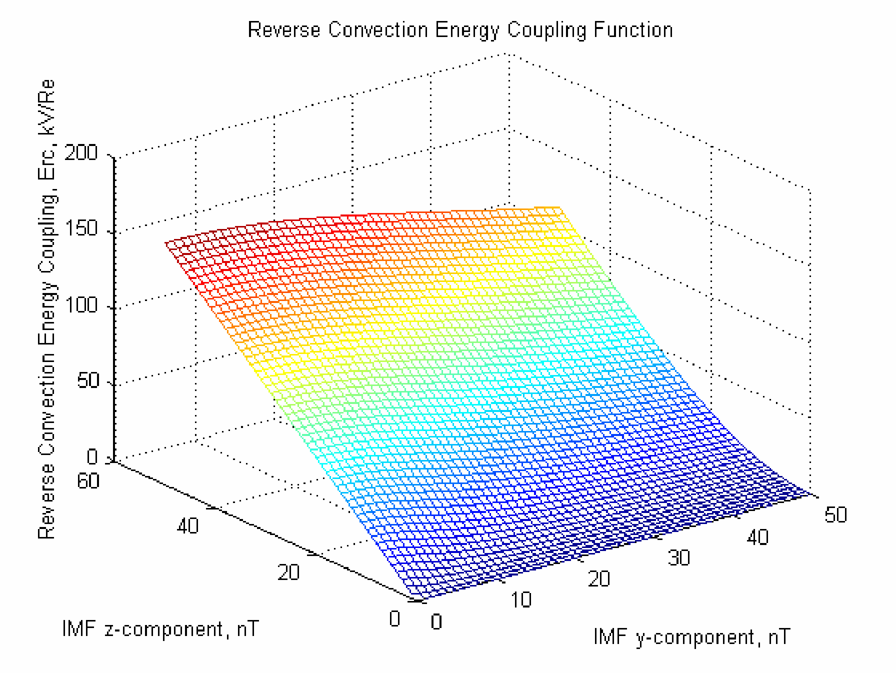
$$\theta = \cos^{-1}(B_z/B_T)$$

- This formulation assumes that the response of the magnetosphere-ionosphere system to the Solar Wind is a half-wave rectifier.

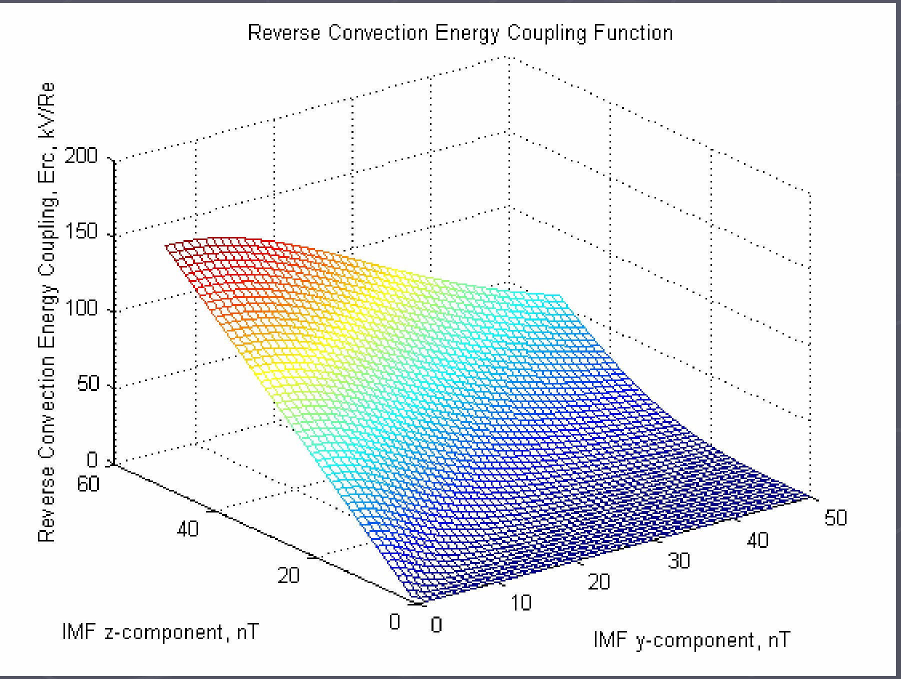
The Reverse Convection Coupling Function

- For northward IMF, a new coupling function was used: $$E_{RC} = -V_x B_T \cos^n(\theta)$$

n=2:



n=4:



Northward IMF Selection Criteria

- Periods of quasi-stable northward IMF were placed into bins of Erc.
- Quasi-stability criterion:
  - Erc remained in a single bin for at least 40 minutes.
  - Discarded first 30 minutes of each period.
- The stability criterion was made particularly strict to account for:
  - Uncertainty in propagation time to magnetopause.
  - The time taken for the reverse cells to fully develop.
- The sizes of the Erc bins were chosen to maximize SuperDARN statistics and simultaneously provide enough discretization in the response curve.

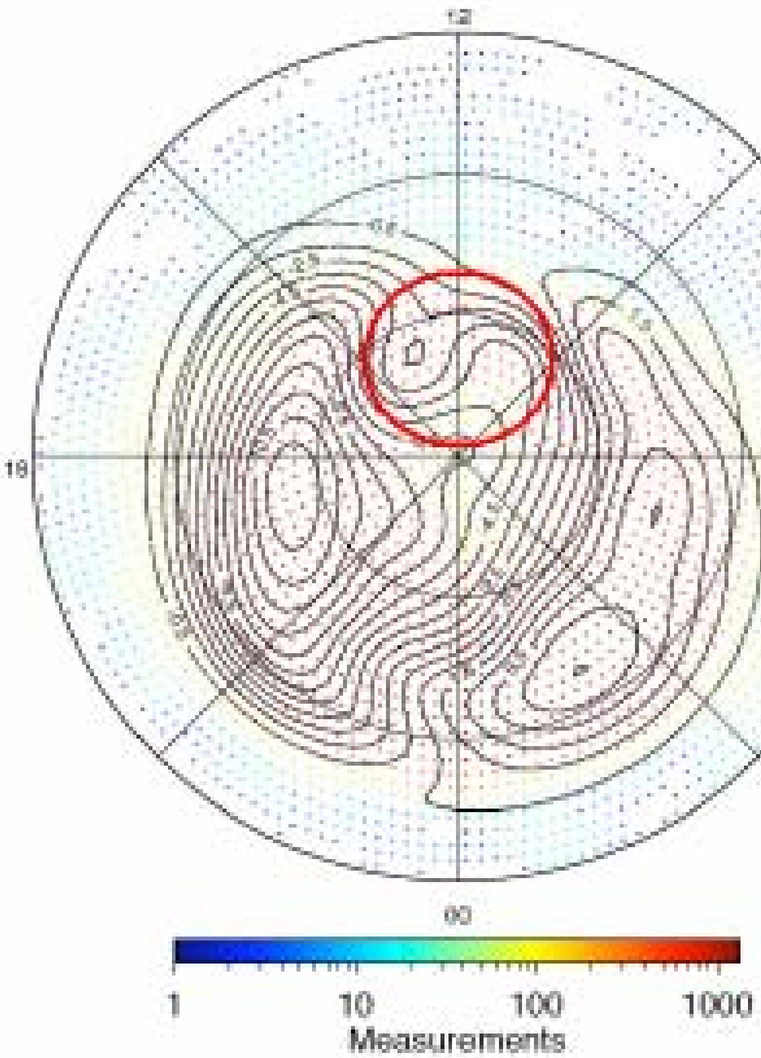
The Erc Bins Used

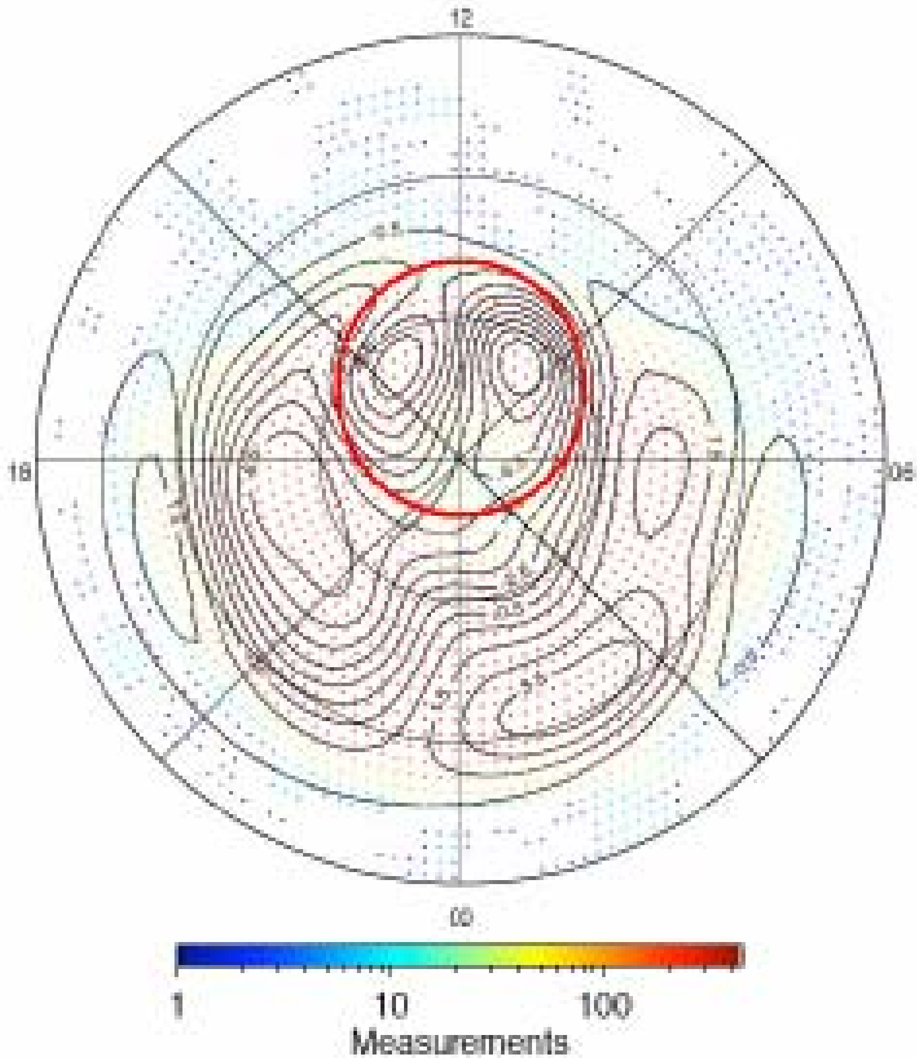
Range (kV/R_E)	Events	Range (kV/R_E)	Events	Range (kV/R_E)	Events
0-2	4,286	19-23	33	31-38	10
2-4	175	20-24	38	31-40	25
4-6	79	21-25	31	32-36	11
10-16	65	22-26	26	32-39	15
12-15	54	23-27	20	37-47	13
13-16	45	24-28	15	40-50	15
14-18	27	25-30	23	43-53	10
16-19	22	27-32	21	46-56	8
16-21	26	28-36	26		
18-22	33	30-36	11		

Convection Map Fitting

- Gridded Doppler velocities were sorted into 10° azimuth bins at each point on the uniform spatial grid.
- For each azimuth direction a "most likely" Doppler velocity was calculated:
  - Determine if the majority of velocities are positive or negative and discard the smaller fraction.
  - Calculate a median value for the remaining velocity distribution.
  - Use the variance around the median value as a "most likely" error.
- Feed the "most likely" vectors and errors into the map potential fitting routine.
- NOTE: no vectors from the statistical IMF patterns were used

Some Example Maps





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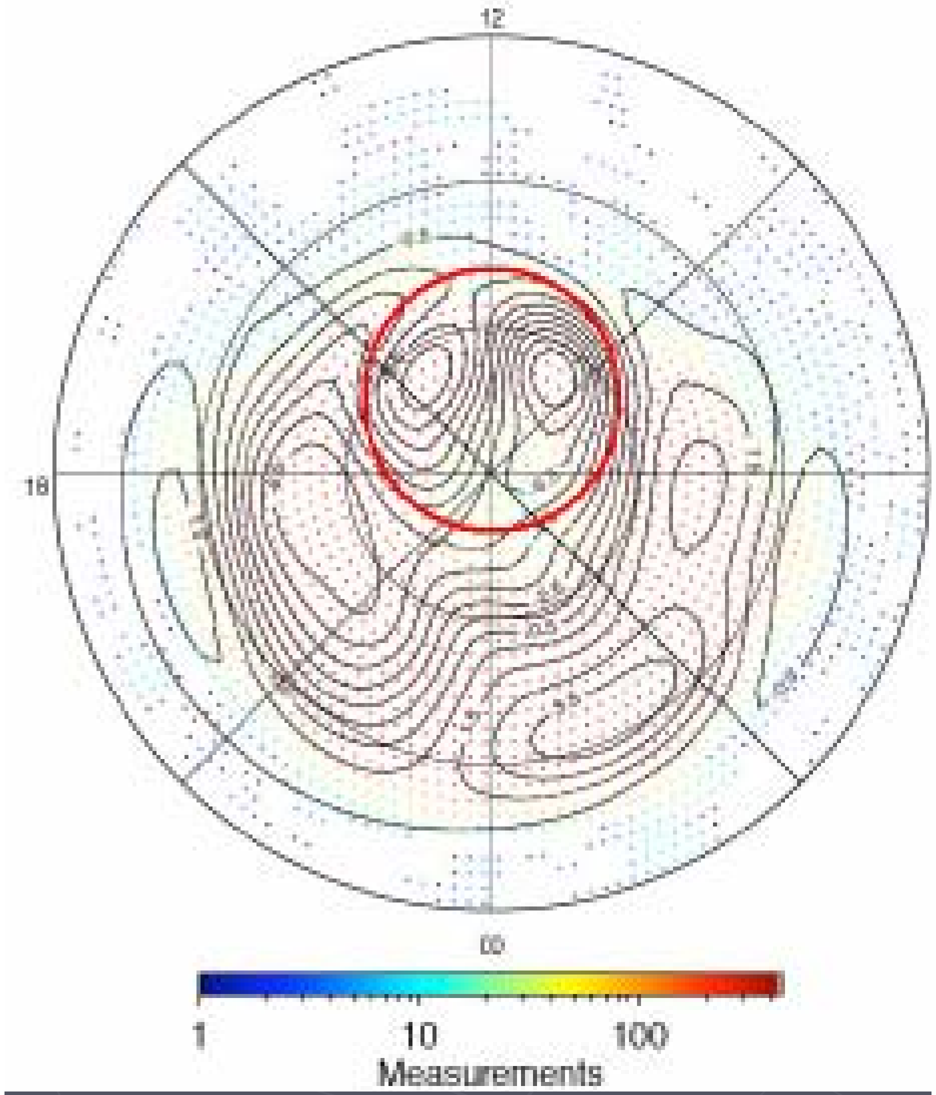
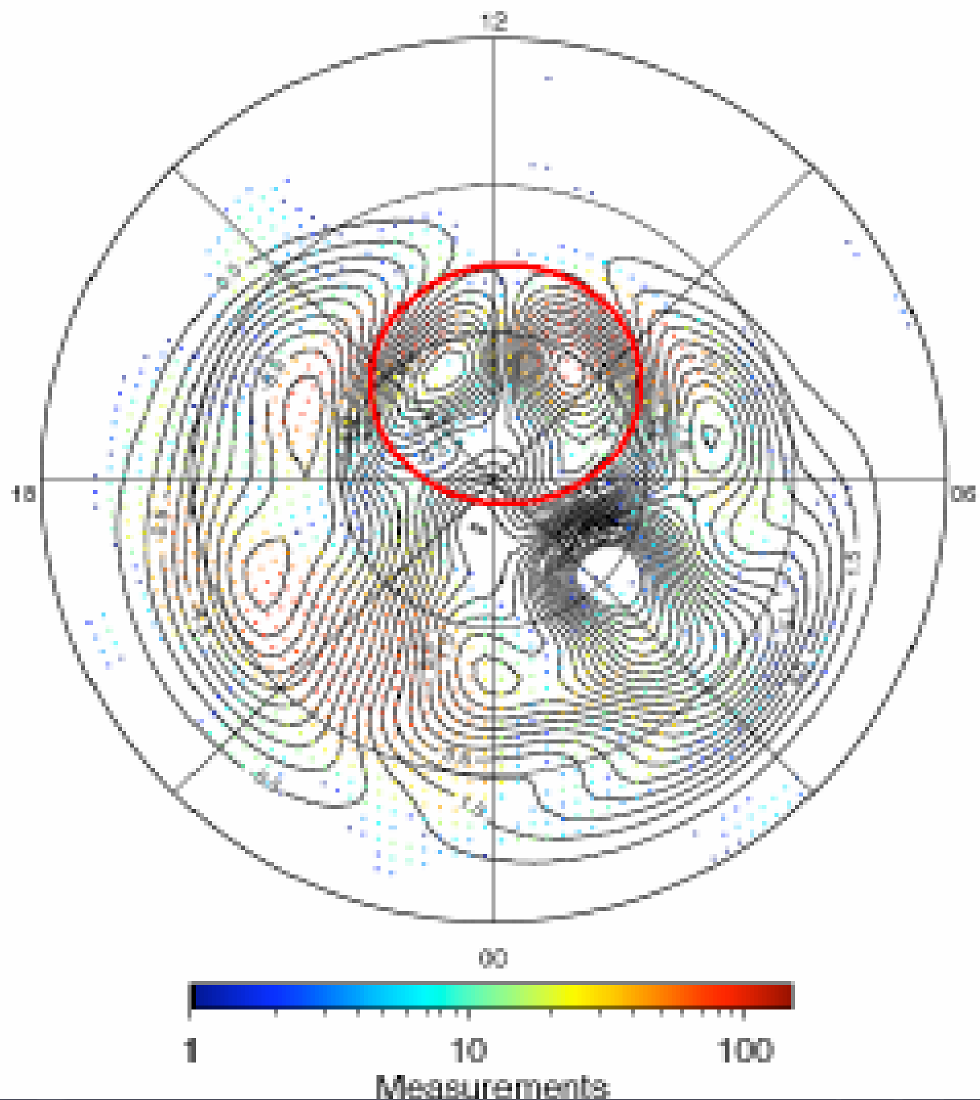
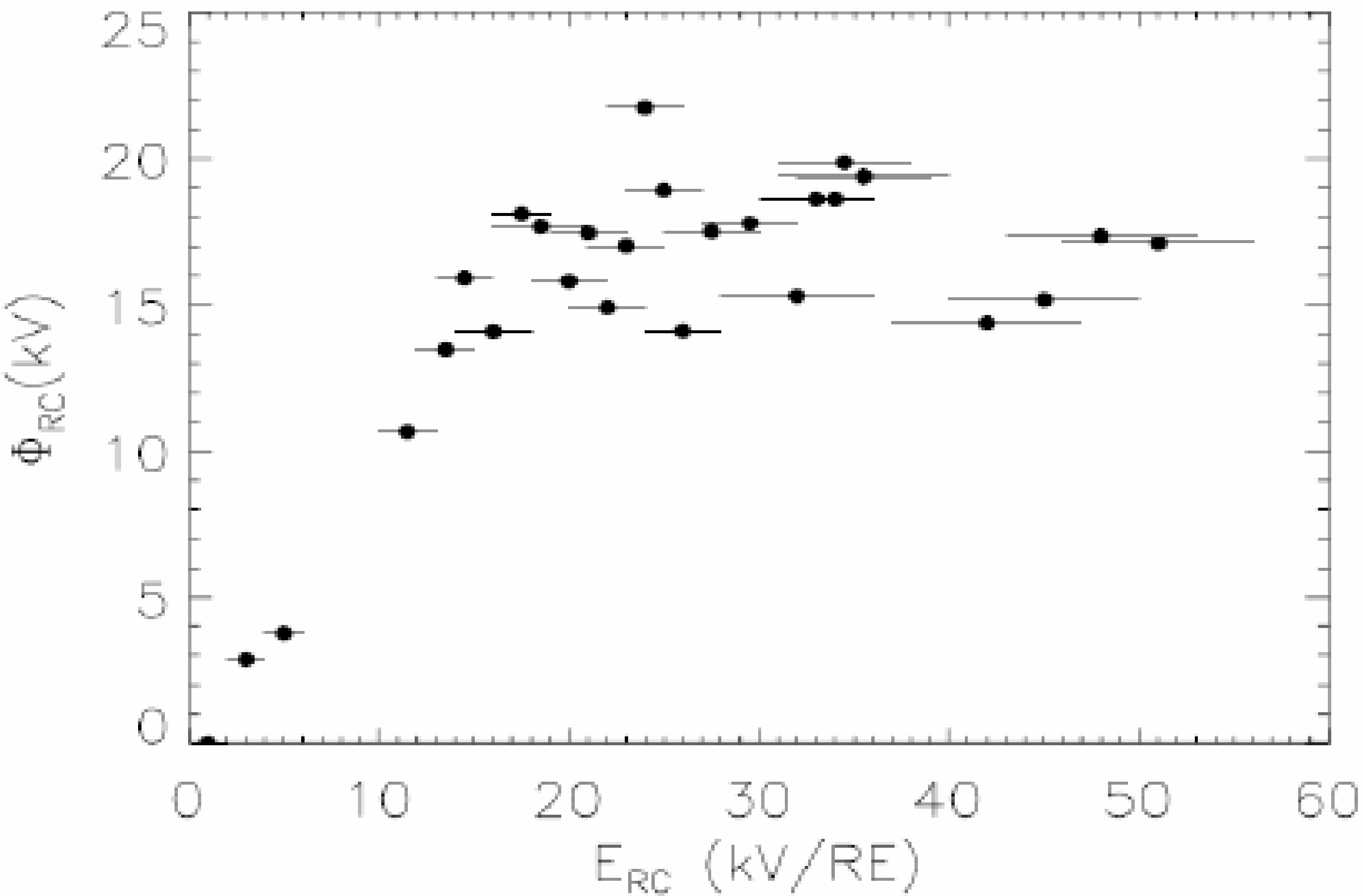




Response Curve for Northward IMF



Discussion

- There is clear evidence of a saturation effect during northward IMF similar to what has been found during southward IMF.
- Most explanations for why saturation occurs under southward IMF assume that reconnection at the nose of the magnetosphere becomes limited.
- It is unlikely that these explanations can be adapted to explain why saturation occurs when the reconnection site is poleward of the cusp.
- Limitations on the amount of current that can be carried by the ionosphere is perhaps the most likely explanation.

Further Research

- More extreme northward IMF events should be examined using other datasets in addition to SuperDARN to see what the maximum potential across the reverse cells is.
- Plasma parameters in the solar wind such as pressure and mach number should also be examined to look for a connection.
- Studies of Summer vs. Winter months or Northern vs. Southern hemisphere can be done to determine the role of conductivity.

Thank You!

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- Thanks also to Dr. Baker, who assisted me with the SuperDARN data.
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