The Substorm

Q1) The "onset arc" is observed to be coincident with auroral features that indicate it is on magnetic field lines that thread a radially sharp boundary between nearly dipolar and highly stretched magnetic field lines. These field lines most likely cross the neutral sheet at around 7-9 Re (geocentric) on the evening-sector nightside. The Near Earth Neutral Line (NENL) will be tailward of this, perhaps at around 15 or 20 Re (assume 18 Re exactly). The Distant Neutral Line (DNL) will be further tailward still, perhaps at 60 to 100 Re (assume 80 Re exactly). Assume a "hinging distance" (tailward of which field lines are parallel to the noon-midnight meridian) of 8 Re, and that the onset arc maps to exactly 8 Re. Further, assume that the equatorial magnetic field strength tailward of the hinging distance is X nT, that the onset arc maps to 65° magnetic latitude, that the Earth's magnetic field at the surface is exactly dipolar, and its strength at the equator is 30000 nT. How far poleward of the onset arc are the ionospheric footprints of the NENL and DNL if the equatorial magnetic field strength (e.g., X) tailward of the hinging distance is (a) 5 nT; b) 10 nT; c) 15 nT? Given that auroral arcs are 10s of kilometers in north-south extent, comment briefly (four or five sentences) on the validity of using information from auroral images in the last few minutes of the growth phase.

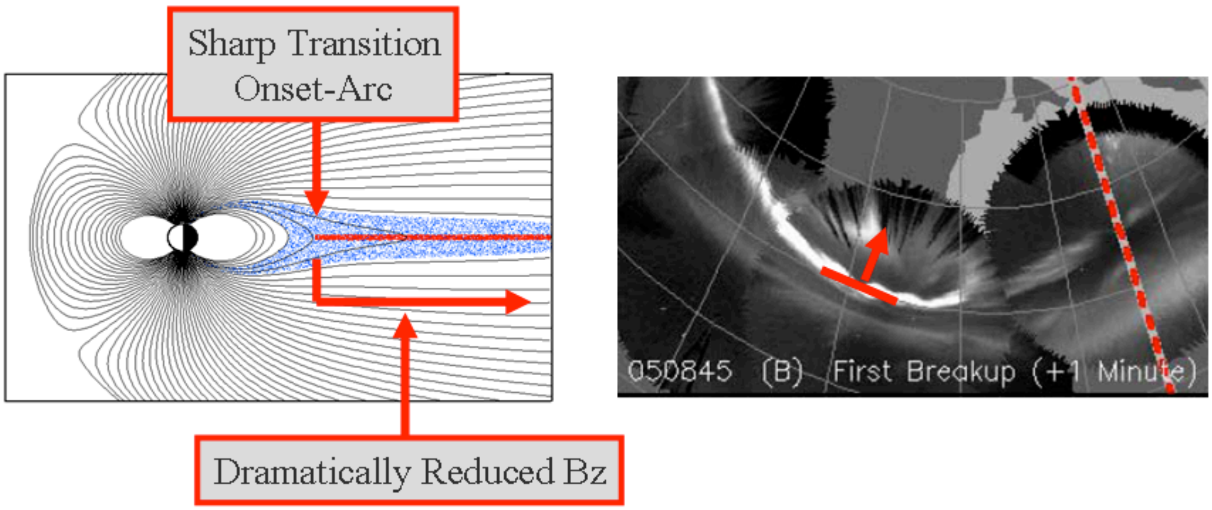

Figure for Question 1: The magnetic flux crossing the equatorial plane tailward of the inner edge of the thin current sheet (roughly speaking the "hinging distance") is small in the late growth phase. How far poleward of the onset arc (which sits on the transition) is the ionospheric footprint of a point that is 5, 10, 20, etc. Re tailward of the transition? This complicates the interpretation of auroral observations in the late growth phase.

Q2) Use the magnetic field configuration from Q1 as an initial condition, and the Earth-centred dipole (equatorial strength at equator 32000 nT) as a final condition. A) In the "dipolarization", estimate the amount of energy (as a function of X) that is imparted to the plasma in a 1 Re X 1 Re X 1 Re cube centred on the neutral sheet at midnight due to the dipolarization. In doing so, assume that the number density is 10 H+ and 10 e- per cc, and that the particles have energies of 5 keV to start with. Comment briefly (one paragraph for each) on where you think the energy comes from, and the timescale over which the dipolarization must occur in order for the first adiabatic invariant to be conserved for the protons.

Q3) The timescales for various processes that occur around onset are frustrating for researchers who want to elucidate how things unfold based on ionospheric and sparse *in situ* observations. Estimate

a) The time it take a 5 keV proton to travel from the equatorial plane at 8 Re to the ionosphere (assume it is a dipolar magnetic field, and the proton mirrors at the ionosphere.
b) The time it takes for a shear Alfven wave to propagate from the equatorial plane to the ionosphere from X=-4, -8, and -18 Re
c) The time it takes for a BBF to propagate from X=-18 Re to X=-8 Re.
d) The time it takes for a fast mode wave to propagate from X=-18 Re to X=-8 Re.
e) The time it takes for a fast mode wave to propagate from X=-18 Re to X=-4 Re.

Note that I mean for you to take a back of the envelope approach here... you can use values for wave & BBF speeds from the literature, and assume a dipole field for part a.