Cross-scale coupling and particle energization in Alfvénic Aurora

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1. Introduction

Solar wind-magnetosphere-ionosphere coupling encompasses a complex interplay of processes that produce convective flows (for example via reconnection) that can be laminar or turbulent. These flows couple to the ionosphere via field aligned currents that are carried by electrons. Observational studies have linked electron acceleration by magnetospheric shear Alfvén waves as a source of precipitating electrons leading to the formation of auroral arcs, and it is now recognized that these accelerated populations are a major sink of Alfvén wave energy (*Wygant et al.,* 2000*; Chaston et al.,* 2002, 2005). *Wygant et al.* (2000) noted that the energy transferred to the electrons from the waves via the Poynting flux detected by the POLAR satellite in the plasma sheet boundary layer was sufficient to power the aurora. In order to accelerate these electrons, Alfvén waves can support significant parallel electric fields when the perpendicular scale length of the wave is on the order of the electron inertial length ($\lambda_e = c/\omega_{pe}$ with $\beta \ll m_e/m_i$) or the ion-acoustic length ($\rho = (T_e/m_i)^{1/2}/\Omega_i$ with $\beta \gg m_e/m_i$). These scale lengths (along with the ion gyroradius, ρ_i) are termed dispersive since they facilitate the propagation of wave energy across the ambient magnetic field.

Chaston et al. (2008) presented a case study from FAST satellite observations, which illustrates the properties of waves that are associated with Alfvénic aurora. While monoenergetic precipitation is seen in the upward current region, broadband electron acceleration is associated with Alfvénic current systems, where intense broadband waves are seen in conjunction with intense electron precipitation (*Chaston et al.,* 2008). Analysis of the wave spectrum suggested that the broadband nature of the observations is consistent with Doppler shifted inertial Alfvén waves with small scale structure. The wave spectrum satisfies a power law spectrum, suggestive that the Alfvénic aurora may be powered by a turbulent cascade from global to kinetic scales, which facilitates electron dissipation through parallel acceleration (*Chaston* et al., 2008, and references therein). More recently, *Lund* (2010) analyzed dissipation in broadband ELF turbulence and found evidence of wave dissipation on both the electron inertial and ion gyroradius scale lengths. *Paschmann* (1997) found that large ion outflow fluxes are also usually associated with regions of Alfvén wave activity (as compared with static upward and downward current regions). *Chaston et al.* (2005) also found significant outflowing oxygen populations were associated with kinetic Alfvén waves propagating from the magnetopause into the ionosphere and MHD simulations have illustrated that these ion outflows likely play a role in regulating magnetotail reconnection and the associated dynamics (e.g. *Wiltberger et al,* 2010*; Brambles et al.,* 2010). Additionally, Alfvénic electron precipitation in itself may regulate magnetotail dynamics by its effect on the ionospheric conductance (*Zhang et al.,* 2012).

2. Modeling challenge

In order to truly understand the generation of the Alfvénic aurora and its influence on magnetosphere ionosphere coupling, it is necessary to encompass the range of scales from the global driver (which occurs on scales of tens of thousands to hundreds of thousands of kilometers) to kilometer scale kinetic dissipation lengths in a single modeling paradigm. Global MHD simulations are able to capture many of the details of the magnetospheric response to upstream solar wind conditions. For example, fast flows emerging from reconnection in the magnetotail have been studied extensively using MHD simulations (e.g. *Birn et al.,* 2011*, Zhang et al.,* 2012) where the breaking of these flows has been observationally associated with the generation of kinetic Alfvén waves (e,g. *Chaston et al.,* 2012) that can in-turn contribute to the energization of electrons to form the Alfvénic aurora. MHD simulations however, lack the kinetic electron physics needed to understand how energy incident in the flows couples to electron energization. On the other hand, kinetic simulations, which are able to address the characteristics of Alfvénic electron energization along terrestrial magnetic field lines (e.g. *Watt and Rankin,* 2006*; Damiano et al.,* 2015), are unable to address the global scale solar-wind-magnetosphere interaction that is driving the flows**.** The challenge then is to create reduced models that can describe electron wave-particle interactions in a global description. This goal can be accomplished through an integrated process whereby global simulations are used to identify regions of energy input and then more localized kinetic simulations are used to examine the evolution of the turbulence and associated electron energization.

3. Impact

Through such an integrated effort we will gain a better understanding of the processes that couple global scale dynamics to Alfvénic electron energization at kinetic scale lengths. This is a question of fundamental importance as similar principles apply to Alfvén waves as a source of particle energization in other planetary magnetospheres (e.g. *Hess et al,* 2010), and as a source of electron energization (e.g. *Fletcher and Hudson,* 2008) and ion heating (*Chandran et al*., 2011) in the solar corona. Additionally, as stated previously, electron precipitation can regulate magnetotail dynamics and transport either via ionospheric outflow or by regulating ionospheric conductance. Coupling between global MHD and ionospheric models incorporates the precipitating electron flux (prescribed from the MHD variables). Most global MHD models incorporate electron acceleration by static potential drops via the Knight relation (or some close analogy) (*e.g. Wiltberger et al.,* 2009) but limited consideration has been given to Alfvén wave induced electron precipitation. Therefore, prescriptions of electron precipitation as a function of upstream solar wind conditions developed from an integrated modeling paradigm and incorporated into enhanced MHD descriptions, will allow us to better model the magnetospheric response to the Alfvén wave induced electron precipitation. Such a capability would be of fundamental importance to both our understanding of and our ability to predict space weather.

4. References

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