Reply to "Comment by P. K. Shukla and L. Stenflo on 'Kinetic effects in the acceleration of auroral electrons in small scale Alfvén waves: A FAST case study'"

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1. Introduction

[1] *Shukla and Stenflo* [2004] question the validity of combining the electron inertial and electron and ion kinetic corrections to the standard MHD Alfvén wave dispersion as used in the manuscript by *Chaston et al.* [2003]. We agree that these corrections are appropriate in different physical limits and their combination for use as a fluid approximation within the same expression is not strictly correct. However, we cite laboratory experiments which have verified the validity of the fluid approximation and demonstrate numerically that the fluid approximation does accurately describe the magnitude of the parallel electric field and the wave dispersion over the parameter range used in the above-mentioned manuscript. This has been achieved through the solution of the full kinetic dispersion relation by the use of a WHAMP like code. These results show that the simulations performed by *Chaston et al.* [2003] are meaningful for electron acceleration in small-scale Alfvén waves above the auroral oval.

2. Response to Comments

[2] *Kletzing et al.* [2003] have verified experimentally the validity of combining the electron inertial, and electron and ion kinetic corrections to standard MHD Alfvén wave dispersion as performed, for the purpose of simulations, in the manuscript by *Chaston et al.* [2003]. These researchers measured the parallel phase velocity of Alfvén waves as a function of the perpendicular wave number in a laboratory plasma. They show excellent agreement between observations and the approximate dispersion relation as given by Equation 7 of *Chaston et al.* [2003]. Previously, *Lysak and Lotko* [1996] have investigated numerically the fluid approximation to kinetic Alfvén wave dispersion including corrections due finite electron inertia, and electron and ion temperature. These researchers found that the 'basic topology of the fluid dispersion relation is preserved' by the full kinetic solution. Similarly, to investigate the validity of the fluid approximation as used by *Chaston et al.* [2003] we compare the magnitude of the parallel electric field given by Equation 6 of *Chaston et al.* [2003] with that obtained from the numerical solution of the full kinetic dispersion relation using a WHAMP like code [*Chaston et al.*, 2002] for the same range of altitudes, plasma parameters and perpendicular wave numbers used by *Chaston et al.* [2003].

[3] The perpendicular wavenumbers considered in the comparison are specified in the ionosphere and mapped outwards with the square root of the geomagnetic field strength as done by *Chaston et al.* [2003]. The Fourier transform in time and along the geomagnetic field, necessary for solving the dispersion relation in both the fluid and full kinetic cases, requires a frequency or parallel wavenumber to be specified. In the fluid case the wave frequency is taken as 0.5 Hz (roughly the frequency of the wave generated in the simulations by *Chaston et al.* [2003] from which the parallel wavenumber is estimated using Equation 1 from *Chaston et al.* [2003]. Then, as a check on the ability of the fluid case to replicate the full kinetic dispersion, this parallel wavenumber is set in the fully kinetic case and the appropriate wave frequency, satisfying the full dispersion relation, sought via Newtons' method. A wave frequency within 20% of 0.5 Hz is found at all altitudes considered by *Chaston et al.* [2003] and for most of the parameter range considered this agreement is better than 5%. This confirms the ability of the fluid dispersion relation given by Equation 1 from *Chaston et al.* [2003] to approximate the full wave dispersion correctly over the parameter range of interest.

[4] The ability of the fluid approximation to correctly replicate the full kinetic dispersion is shown most clearly in Figure 1. The solid lines here give the ratio $E_{\|}/E_{\perp}$ determined from Equation 6 while the dashed line is from the solution of full kinetic dispersion relation from the WHAMP like code discussed above. What these curves show is that the fluid model provides a good estimate of the size of the parallel field except for perpendicular wavelengths mapped to the ionosphere of greater than 5000 m at altitudes above 20000 km. This is the same range of scales and altitudes where *Chaston et al.* [2003] indicates that deviations from the fluid description may be significant. Over most of the range of scales and altitudes considered however, Figure 1 shows that close agreement is obtained.

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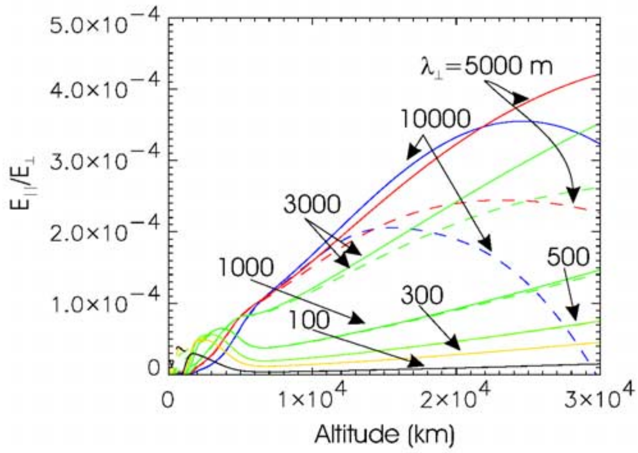

Figure 1. Comparison of the value of $E_{\|}/E_{\perp}$ for small scale Alfvén waves above the auroral oval from the fluid approximations as used by *Chaston et al.* [2003] (solid lines) and from the full kinetic dispersion relation (dashed lines). The perpendicular wavenumber labels correspond to values in the ionosphere at an altitude of 100 km.

Indeed, for perpendicular wavelengths of the order of 1 km and less this agreement is better than 2% over the entire altitude range.

3. Closing Remarks

[5] We agree with [*Shukla and Stenflo*, 2004] that the marriage between the inertial and kinetic terms as performed by *Chaston et al.* [2003] is not strictly correct. However, for the parameter ranges considered in the manuscript this fluid approximation adequately represents the magnitude of the parallel electric field carried by the waves over this altitude range except at the highest altitudes and largest perpendicular wavelengths considered. For this reason we believe that the results obtained from the simulations as presented in the manuscript by *Chaston et al.* [2003] are meaningful in the context for which they were intended. In fact the solution obtained from the full dispersion relation (where it deviates from the fluid approximation) more strongly supports the conclusion drawn by *Chaston et al.* [2003] that kinetic effects reduce the energy of electrons accelerated by the Alfvén wave since the size of $E_{\|}$ is further reduced.

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