Nonlinear subcritical MHD beta limit

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Abstract. Published gyrokinetic simulations have had difficulty operating beyond about half the ideal magnetohydrodynamic (MHD) critical beta limit with stationary and low transport levels in some well established reference cases. Here it is demonstrated that this limitation is unlikely due to numerical instability, but rather appears to be a *nonlinear subcritical MHD beta limit* [R.E. Waltz, Phys. Rev. Lett. **55**, 1098 (1985)] induced by the locally enhanced pressure gradients from the diamagnetic component of the nonlinearly driven (zero frequency) zonal flows. Strong evidence that the zonal flow corrugated pressure gradient profiles can act as an MHD-like beta limit unstable secondary equilibrium is provided. It is shown that the addition of sufficient $E \times B$ shear or operation closer to drift wave instability threshold, thereby reducing the high-n drift wave turbulence nonlinear pumping of the zonal flows, can allow the normal high-n ideal MHD beta limit to be reached with low transport levels. Example gyrokinetic simulations of experimental discharges are provided: one near the high-n beta limit reasonably matches the low transport levels needed when the high experimental level of $E \times B$ shear is applied; a second experimental example at moderately high beta appears to be limited by the subcritical beta.