Evolution of the Geomagnetic Field: A Multi-scale analysis

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This Master's thesis investigates the generation and long-term evolution of the Earth's magnetic field through a multi-scale physical modeling approach. In the first phase, local magnetohydrodynamic (MHD) simulations of differentially rotating flows demonstrate that scale separation effectively shields the large-scale magnetic field from small-scale turbulent dissipation. Crucially, as the magnetic Prandtl number is lowered , large-scale coherent magnetic structures become even more pronounced. This emergent structural coherence actively suppresses turbulent mixing; as a result, a robust mean field is sustained in the local model, and polarity reversals typical of the global geodynamo emerge. To study geological timescales, the second phase employs a low-dimensional phenomenological Rikitake system with viscous friction and asymmetry, exhibiting rare-reversal chaos. Crucially, we first demonstrated that driving the system with a single 95-kyr Milankovitch cycle successfully reproduces the multiplicative stochastic resonance mechanism identified in real paleomagnetic data. Building on this foundational validation, we introduced amplitude-modulated orbital forcing, where the 26-kyr precession is modulated by the 95-kyr eccentricity cycle acting as an envelope. Under these conditions, envelope of the Residence Time Distribution exhibits prominent peaks at 95-kyr periods. Furthermore, spectral analysis corroborates the orbital pacing of the system's reversal dynamics. Ultimately, this thesis provides a cohesive conceptual framework, linking the local MHD mechanisms of field generation to the macroscopic, orbitally-paced dynamics of geomagnetic reversals.