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Revisiting the use of hyperdiffusivities in numerical dynamo models

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The groundbreaking numerical dynamo models of Glatzmaier & Roberts (1995) and Kuang & Bloxham (1997) received some criticism due to their use of hyperdiffusivities, whereby small scale processes artificially experience much stronger dissipation than large scale processes. This stronger dissipation they chose was anisotropic, in that it was only effective in the horizontal direction, and parameterized in spectral space using the following generic formula for any diffusive parameter ν

$$\begin{aligned} \nu(l) &= \nu_0 \text{ if } l \leq l_0, \\ \nu(l) &= \nu_0 \left[1 + a\,(l - l_0)^n\right] \text{ if } l > l_0, \end{aligned}$$

in which l is the spherical harmonic degree, ν_0 is a reference value, l_0 is the degree above which hyperdiffusivities start operating, and a and n are real numbers.

Following the same choice as the studies mentioned above (which had most notably $l_0 = 0$), Grote & Busse (2000) showed in a fully nonlinear context that the usage of hyperdiffusivities could lead to substantially different dynamics and magnetic field generation mechanisms.

Without questioning the physical relevance of this parameterization of subgrid scale processes, we wish here to revisit the use of hyperdiffusivities (as defined mathematically above), on the account of the observation that today's models are run with a truncation at much larger spherical harmonic degree than early models. Consequently, they do not require hyperdiffusivities to kick in at the largest scales (l_0 can be set to several tens). An exploration of those regions of parameter space less accessible to numerical models could therefore benefit from their use, provided they do not alter noticeably the largest scales of the dynamo (which are the ones expressing themselves in the record of the geomagnetic secular variation). We compare the statistics of a direct numerical simulation with the statistics of several hyperdiffusive simulations. In the prospect of exploring the parameter space and constructing statistics for their subsequent use for geomagnetic data assimilation practice, we conclude that a sensible use of hyperdiffusivities can lead to a much wanted decrease in computational cost, while not altering the nature of the solution.

References

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