Vortex asymmetries in rotating, convective dynamos

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Acknowledgements

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Cyclone-anticyclone asymmetry in rotating fluids and dynamos

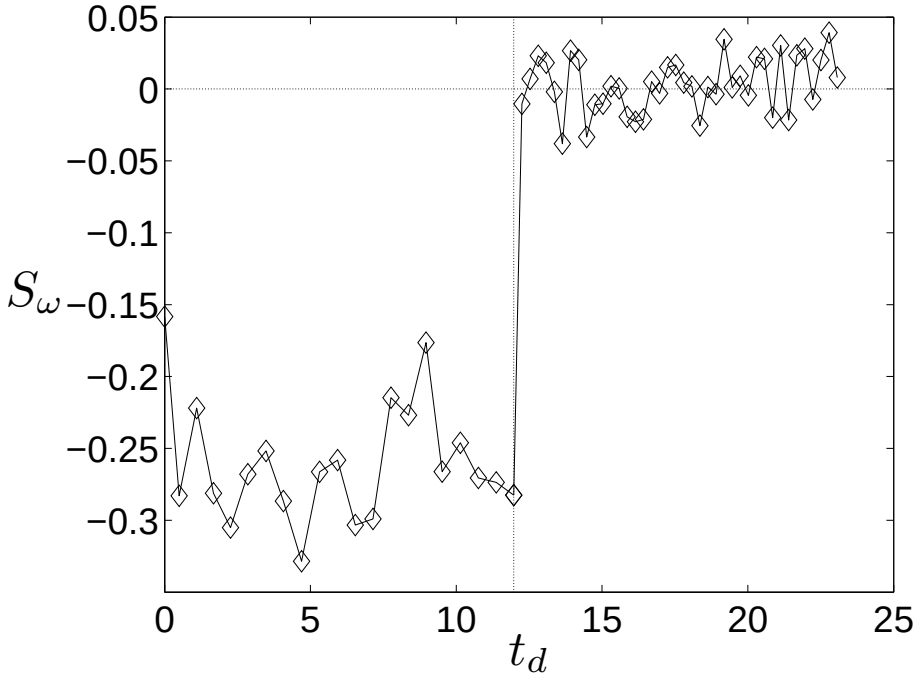
- Cyclonic (positive) vorticity is dominant in rotating turbulence at Rossby numbers of order unity. Anticyclones are unstable except at low Rossby numbers (Bartello et al., 1994; Morize et al., 2005)
- In shallow-water turbulence, anticyclonic vortices dominate when the Froude number is increased (Polvani et al., 1994).
- In rotating dynamos, dominant anticyclonic vorticity is produced from a balance between the Lorentz and Coriolis forces (e.g. Sakuraba & Kono, 1999).

Here we examine:

- How important is this asymmetry for dynamo action?
- What happens if this asymmetry is disturbed/neutralized?

Vorticity skewness: magnetic to non-magnetic

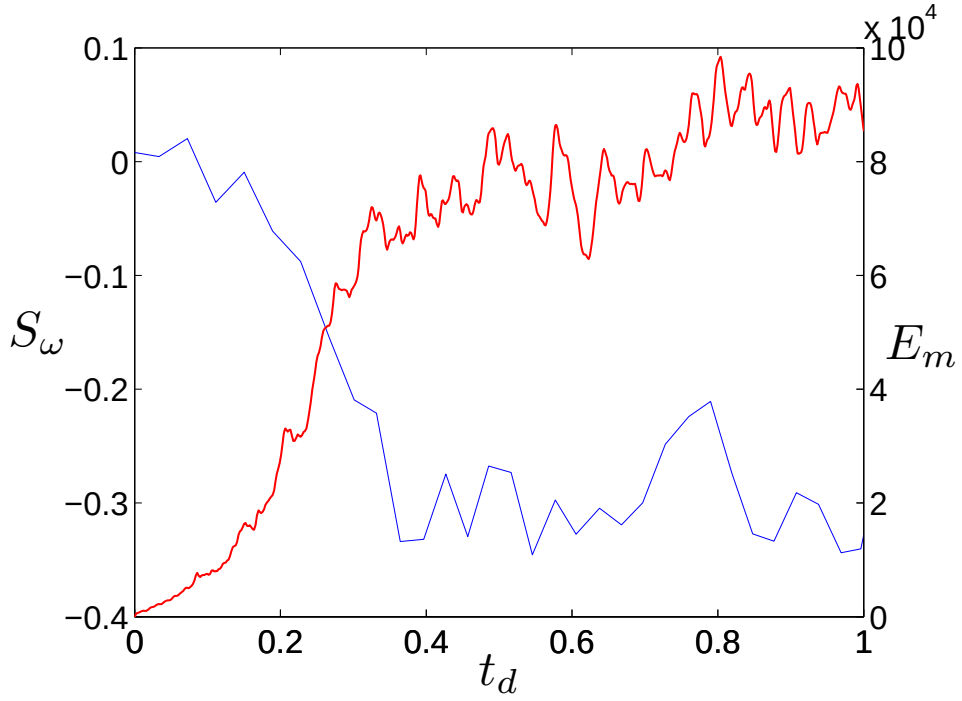
- Begin with a convection-driven dynamo state ($Ra/Ra_{crit} = 6$, $Pr = \nu/\kappa = 1$, $Pm = \nu/\eta = 1$, $E = \nu/\Omega L^2 = 10^{-4}$).
- At $t_d = 12$, set $\mathbf{B} = 0$.



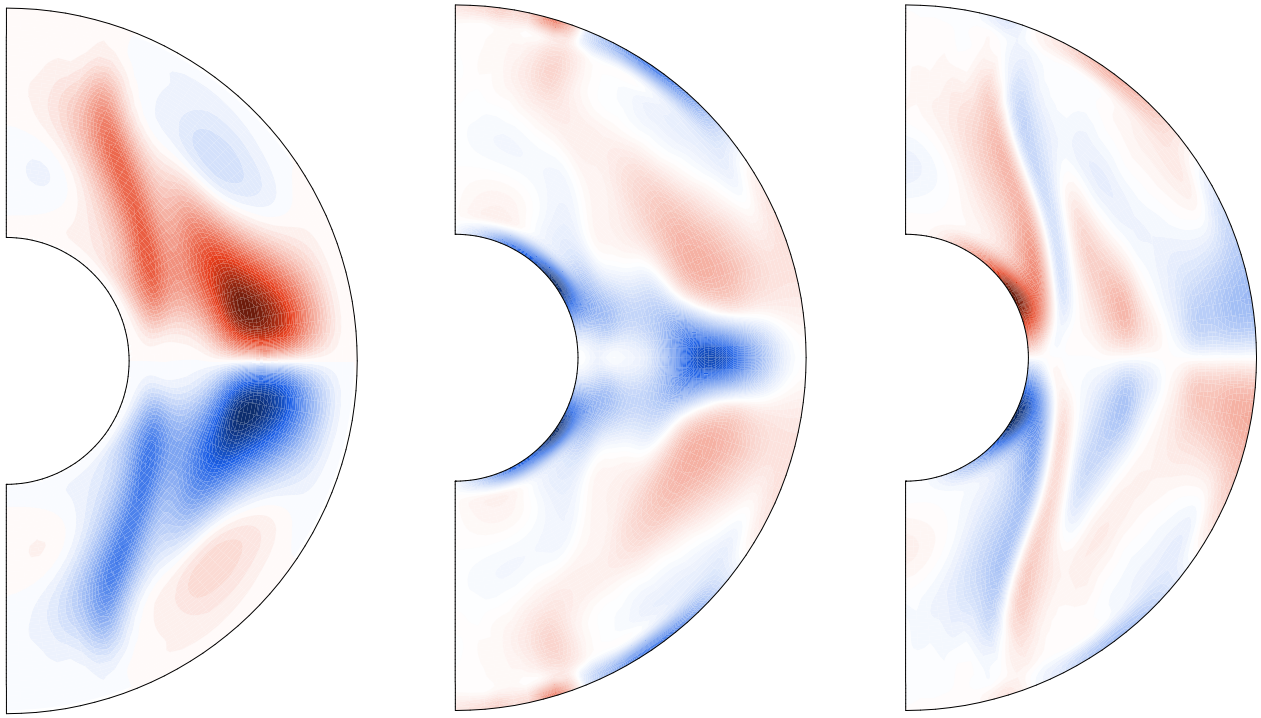
$S_\omega = \int \omega_z^3 dV / \left[\int \omega_z^2 dV\right]^{3/2}$. (Bartello et al., 1994)

Vorticity skewness: non-magnetic to magnetic

- Begin with a purely convective state ($Ra/Ra_{crit} = 6$, $\nu/\kappa = 1$, $\nu/\Omega L^2 = 10^{-4}$).
- Impose an equatorially antisymmetric B_ϕ on the flow.



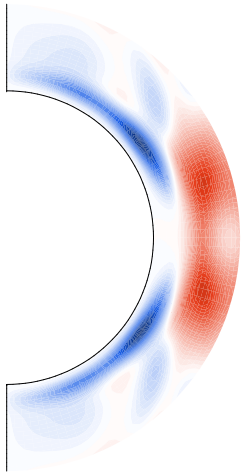
Structure of B_ϕ, j_s, j_z



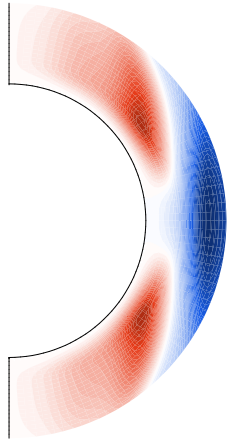
$< B_\phi >$ $< j_s >$ $< j_z >$

$\sim -\partial B_\phi / \partial z$ $\sim \partial B_\phi / \partial s$

Creation of stronger anticyclones

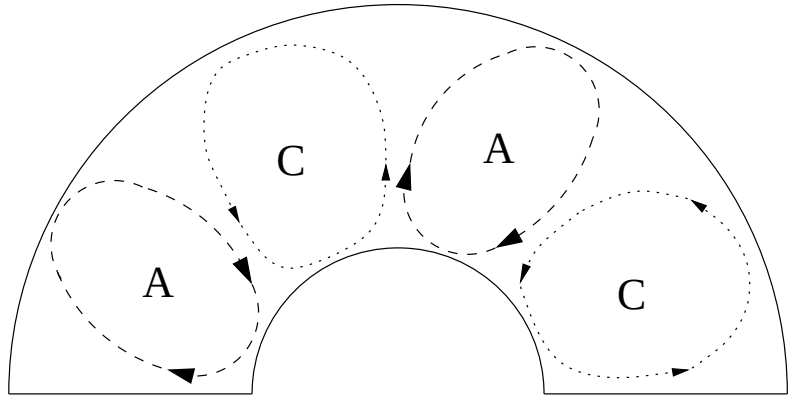


$< u_s >$

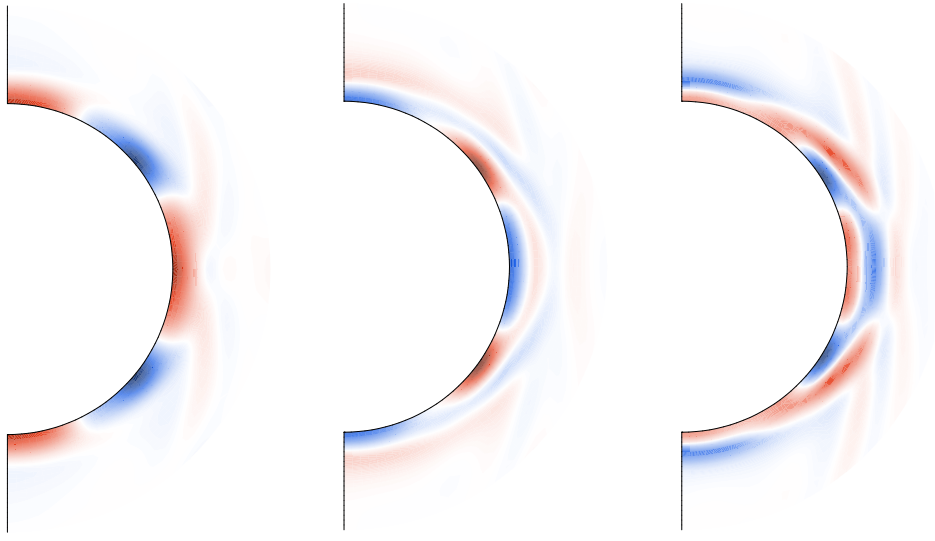


$< u_\phi >$

$\sim < (\mathbf{j} \times \mathbf{B})_\phi >$



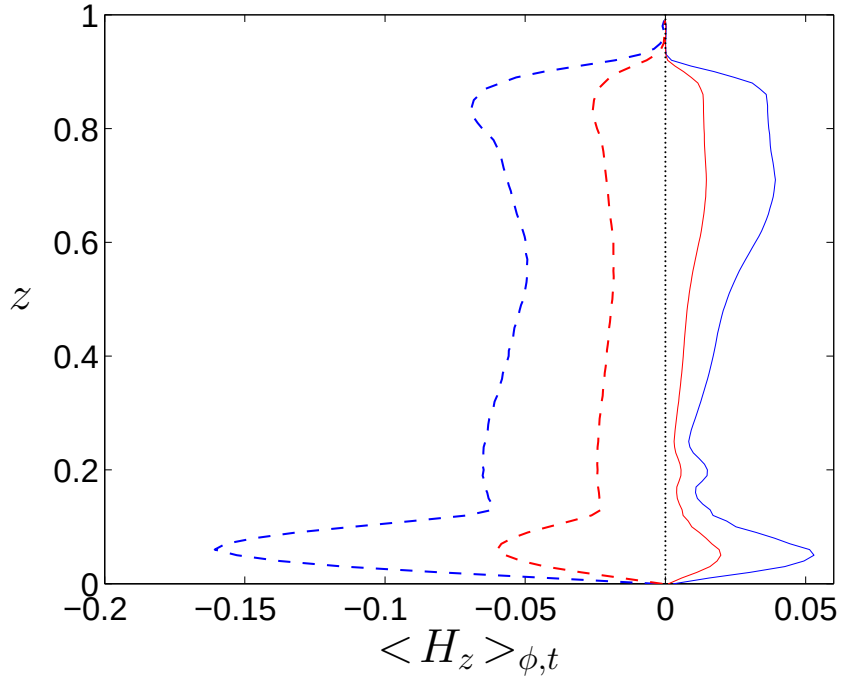
Force balance: inner boundary



$<[\nabla \times (\mathbf{j} \times \mathbf{B})]_z>$ $<\partial u_z/\partial z>$ $<E[\nabla^2 \boldsymbol{\omega}]_z>$

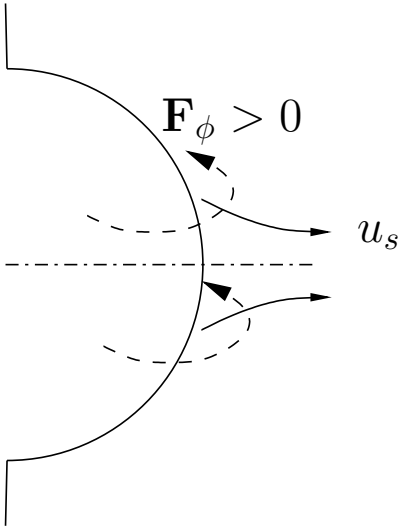
$\sim <\partial j_z/\partial z>$

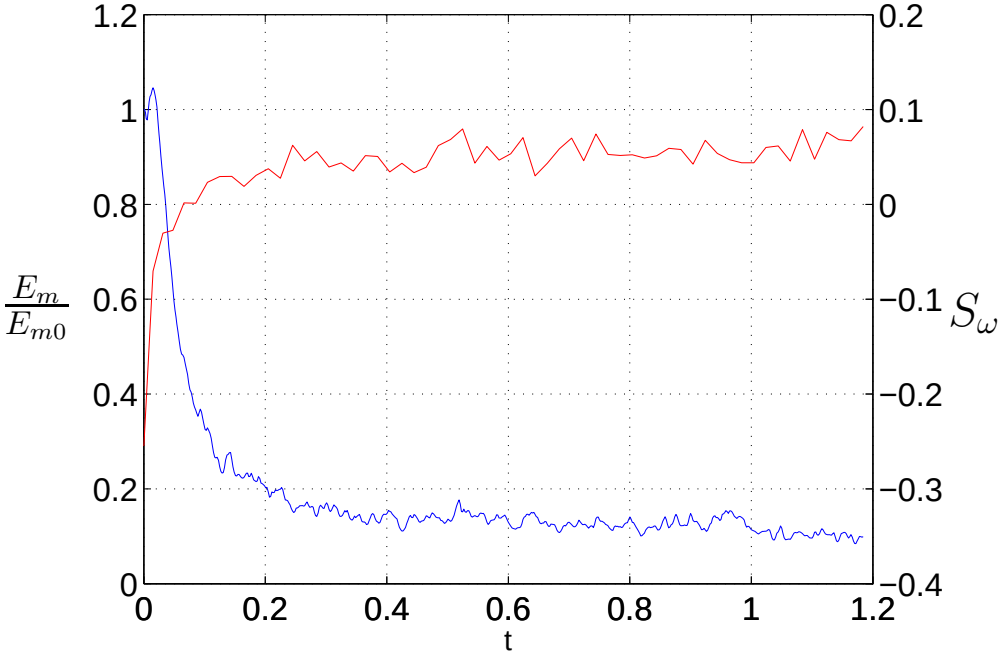
Helicity: magnetic vs. non-magnetic



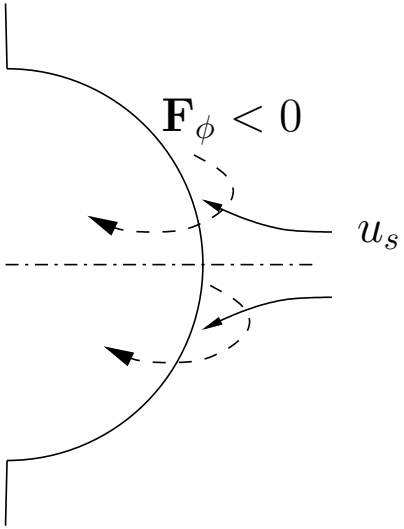
Additional helicity is generated by the magnetic field (Busse, 1976).

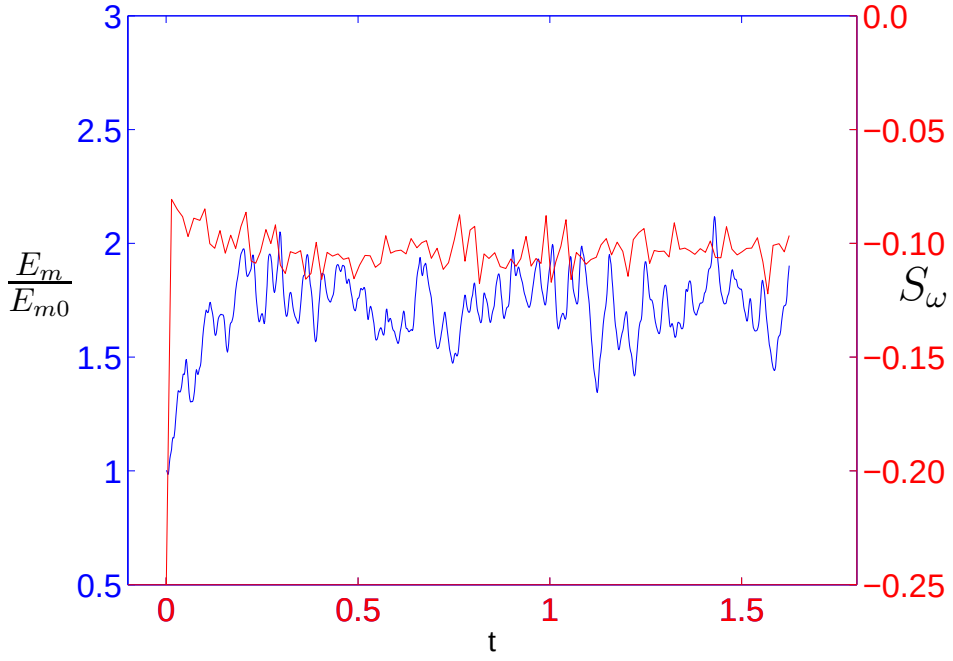
Modifying vorticity skewness through the velocity field (case 1)





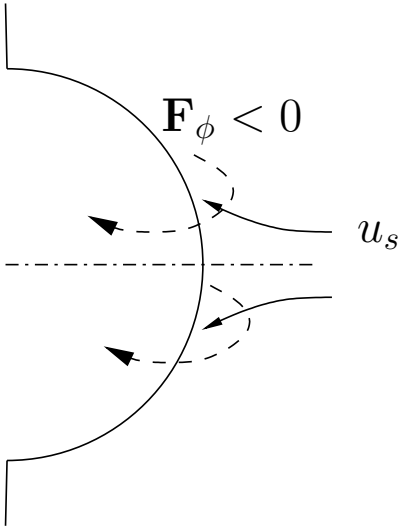
Modifying vorticity skewness (case 2)

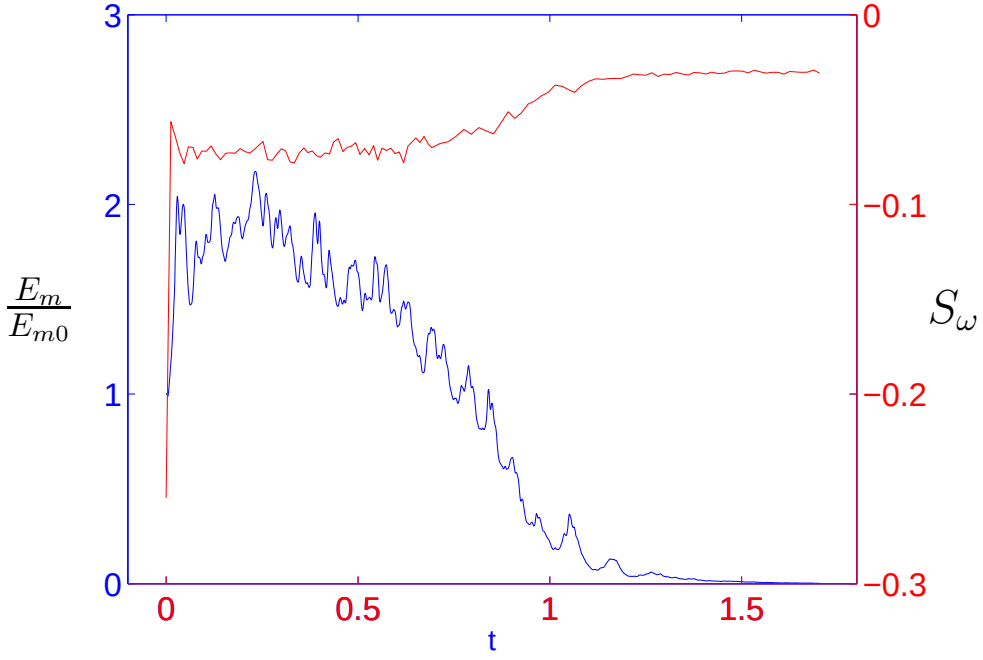




$$\omega_z = \frac{1}{s}\left[\frac{\partial}{\partial s}(su_\phi) - \frac{\partial u_s}{\partial \phi}\right].$$

Strong anticyclonic forcing

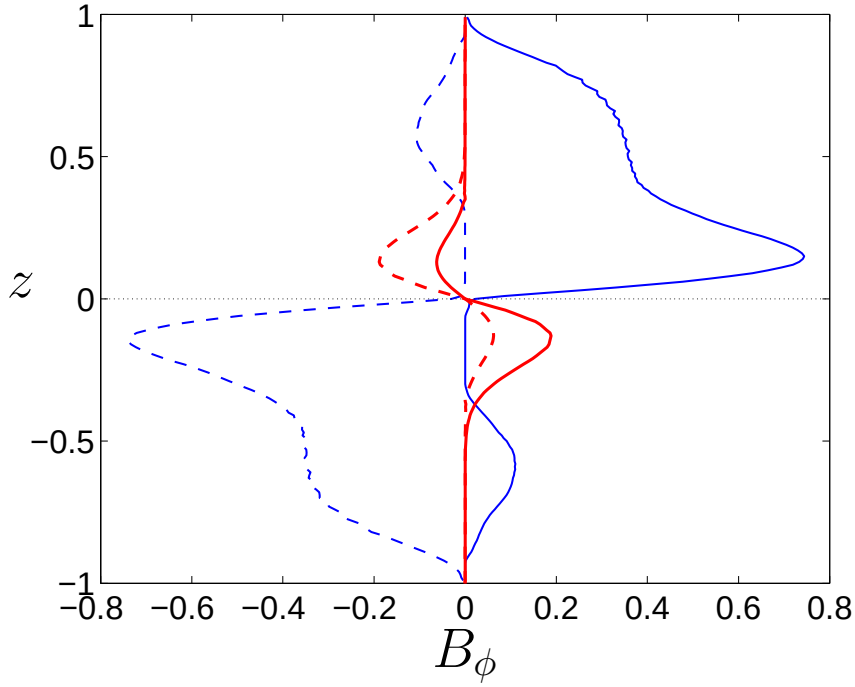




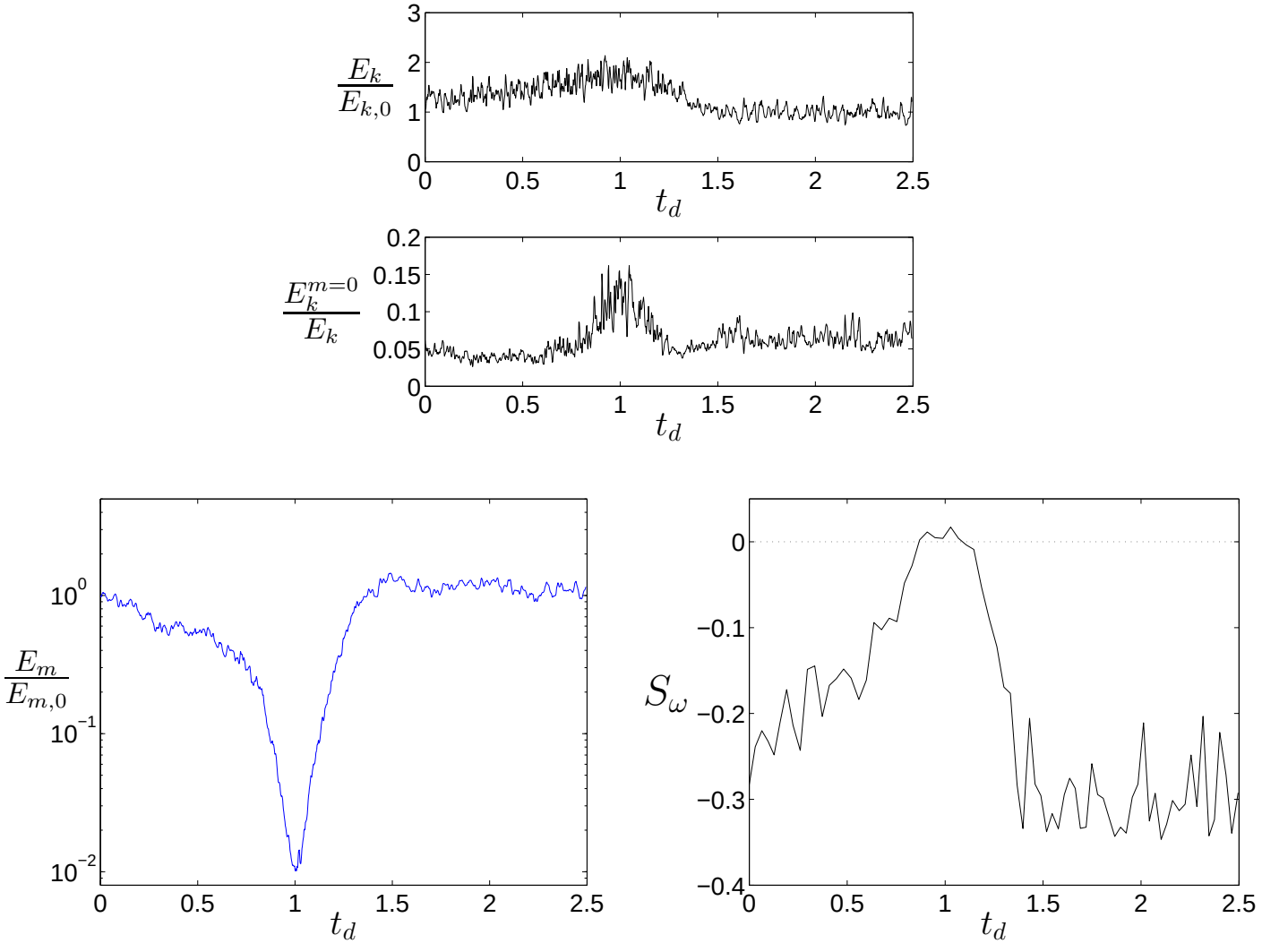
Control of vorticity skewness by magnetic means

Impose an equatorially antisymmetric toroidal field:

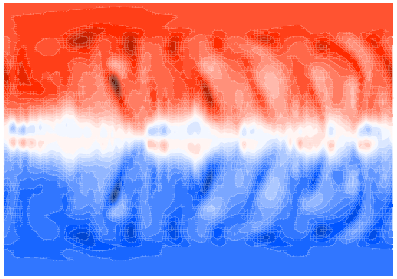
$B_\phi = c \sin\theta \ (r/r_o) \ z \exp(-z^2/\delta^2)$.



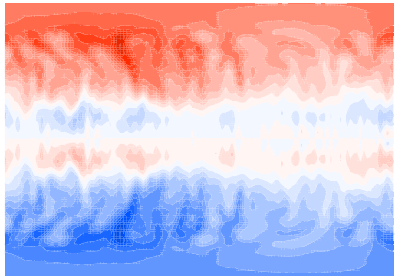
Kinetic, magnetic energies; vorticity skewness



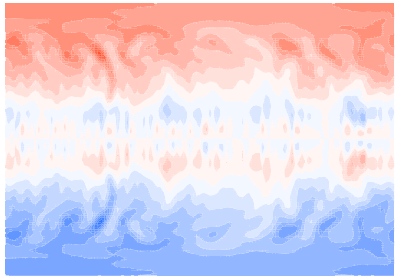
Evolution of B_r



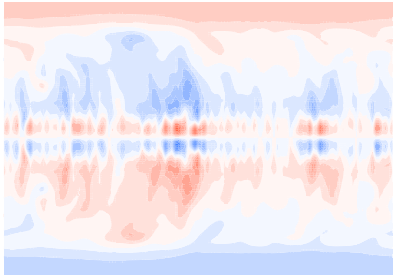
$t = 0$



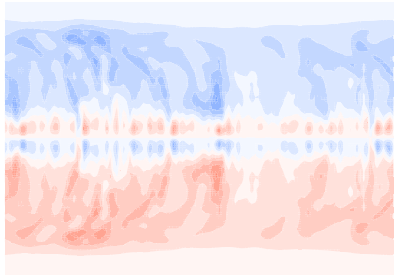
$t = 0.83$



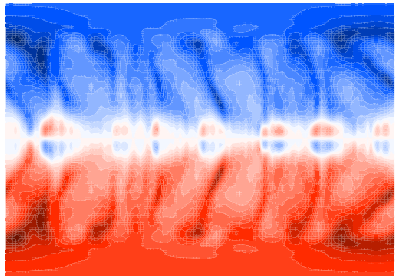
$t = 0.95$



$t = 1.03$

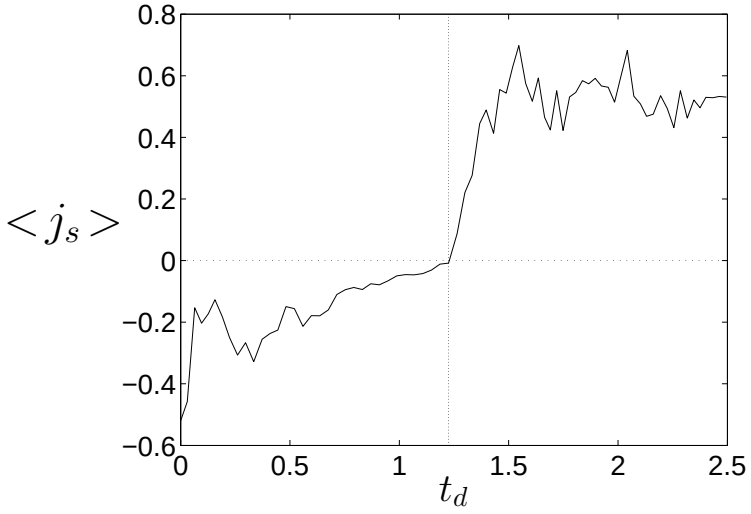


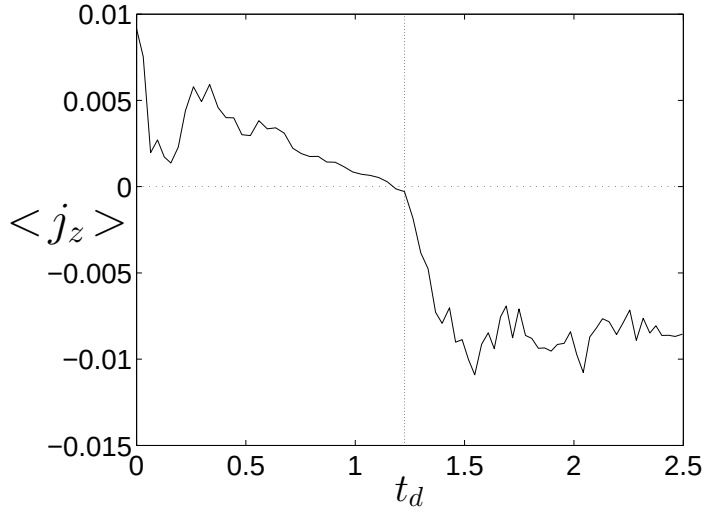
$t = 1.07$

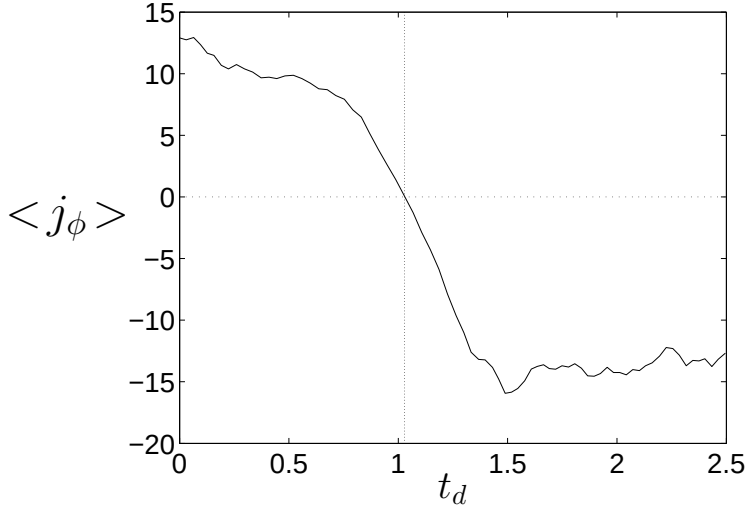


$t = 1.4$

Electric current densities







Vorticity skewness through boundary inhomogeneities

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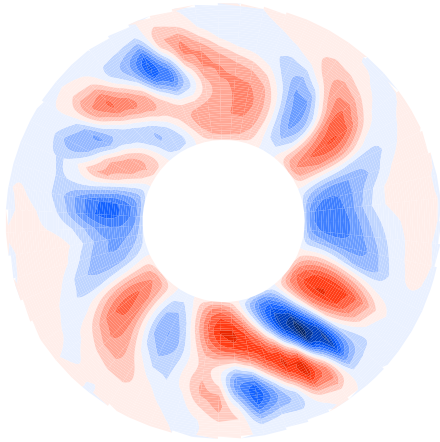
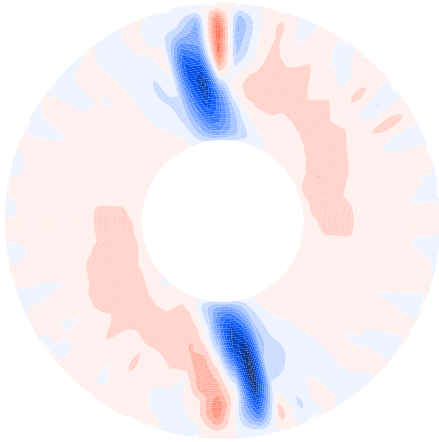
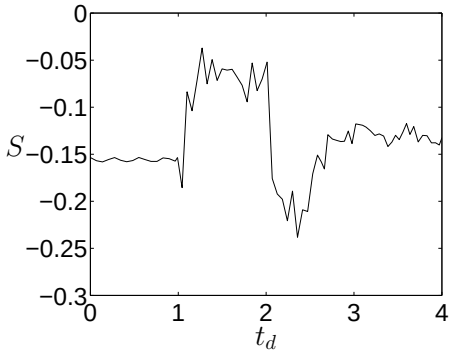
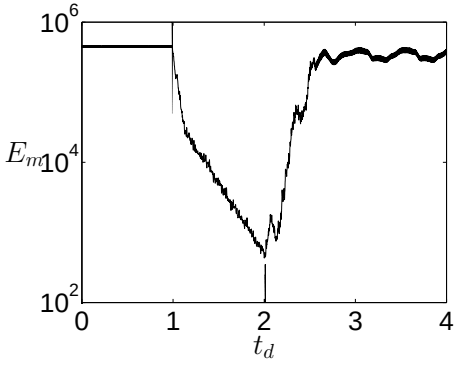
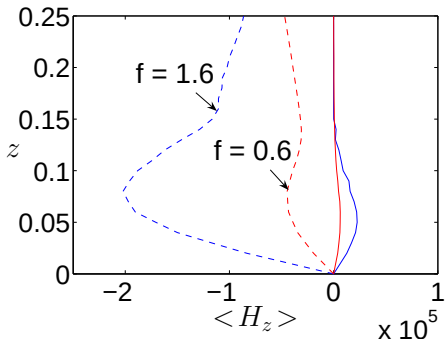




$f = 1.6$







Concluding remarks

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- Cyclone-anticyclone asymmetry is found to be crucial for dipolar dynamo action. If this asymmetry is suppressed, dynamo action weakens/fails.

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- Additional helicity is generated from these strong anticyclones which, in turn, supports dynamo action.
- Cyclone-anticyclone asymmetry is found to be crucial for dipolar dynamo action. If this asymmetry is suppressed, dynamo action weakens/fails.
- Any source of anticyclonic vorticity (magnetic, thermal..) can amplify a seed magnetic field.