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Controlling the Dual Cascade of Two-dimensional Turbulence

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It has been established that monoscale forcing cannot produce the dual cascades of energy and enstrophy with the scaling laws predicted by Kraichnan–Leith–Batchelor (KLB) theory. However, we have been able to find forcings which do produce the KLB scalings: $E(k) \propto k^{-5/3}$ for the inverse energy cascade and $E(k) \propto k^{-3}$ for the forward enstrophy cascade. We find these forcings using a novel adjoint-equation-based optimal control technique. First, the control problem is formulated and a method for controlling the energy spectrum of solutions of the incompressible Navier–Stokes equations is proposed. The control process is validated by several test cases. Then, this control method is applied to a pseudo-spectral numerical computation of the 2-D incompressible Navier-Stokes equations with doubly periodic boundary conditions in order to find the forcing that reproduces the scaling laws of KLB theory. Finally, we demonstrate that the flows we obtain are indeed dynamically active by measuring directly the energy and enstrophy fluxes. We also compare our forcing and the resulting turbulence with results obtained using a linear forcing recently proposed by Lundgren (2003). The results presented here show that the choice of forcing can fundamentally alter the dynamics and spectral properties of the turbulence, and that the theoretically attractive choice of band-width limited forcing is actually inconsistent with KLB theory.

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