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The effect of small-scale forcing on large-scale structures in two-dimensional flows. (English)

Zbl 0900.76191
Physica D 98, No. 2-4, 321-334 (1996).

Summary: The effect of small-scale forcing on large-scale structures in β-plane two-dimensional (2D) turbulence is studied using long-term direct numerical simulations (DNS). We find that nonlinear effects remain strong at all times and for all scales and establish an inverse energy cascade that extends to the largest scales available in the system. The large-scale flow develops strong spectral anisotropy: $k^{-5/3}$ Kolmogorov scaling holds for almost all ϕ, $\phi=\arctan(k_y/k_x)$, except in the small vicinity of $k_x=0$, where Rhines's k^{-5} scaling prevails. Due to the k^{-5} scaling, the spectral evolution of β-plane turbulence becomes extremely slow which, perhaps, explains why this scaling law has never before been observed in DNS. Simulations with different values of β indicate that the β-effect diminishes at small scales where the flow is nearly isotropic. Thus, for simulations of β-plane turbulence forced at small scales sufficiently removed from the scales where β-effect is strong, large eddy simulation (LES) can be used. A subgrid scale (SGS) parameterization for such LES must account for the small-scale forcing that is not explicitly resolved and correctly accommodate two inviscid conservation laws, viz. energy and enstrophy. This requirement gives rise to a new anisotropic stabilized negative viscosity (SNV) SGS representation which is discussed in the context of LES of isotropic 2D turbulence.

MSC:

76F99 Turbulence
86A05 Hydrology, hydrography, oceanography

Full Text: DOI

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