A Phenomenological Theory of Rotating Turbulence

YASIR BIN BAQUI, PETER DAVIDSON, University of Cambridge — We present direct numerical simulations of statistically-homogeneous, freely-decaying, rotating turbulence in which the Rossby number, $\text{Ro} = \frac{u}{2\Omega \ell}$, is of order unity. The initial condition consists of fully-developed turbulence in which $\text{Ro}$ is sufficiently high for rotational effects to be weak. However, as the kinetic energy falls, so also does $\text{Ro}$, and quite quickly we enter a regime in which the Coriolis force is relatively strong and anisotropy grows rapidly, with $\ell \ll \ell \equiv \ell \Omega t$. This regime occurs when $\text{Ro} \sim 0.4$ and is characterised by an almost constant perpendicular integral scale, $\ell \equiv \ell \Omega t$, a rapid linear growth in the integral scale parallel to the rotation axis, $\ell \sim \ell \Omega t$, and a slow decline in the value of $\text{Ro}$. We observe that the rate of dissipation of energy scales as $\varepsilon \sim \frac{u^3}{\ell}$ and that both the perpendicular and parallel energy spectra exhibit an $k^{-5/3}$ inertial range; $E(k) \sim \varepsilon^{2/3} k^{-5/3}$ and $E(k) \sim \varepsilon^{2/3} k^{-5/3}$. We show that these power-law spectra have nothing to do with Kolmogorov’s theory and are not a manifestation of traditional critical balance theory, as this requires $\varepsilon \sim \frac{u^3}{\ell}$ and $E(k) \sim \left(\frac{\varepsilon^{4/5}}{\Omega^{2/5}}\right) k^{-7/5}$. Finally, we develop a spectral theory of the inertial range that assumes that the observed linear growth in anisotropy, $\ell \sim \Omega t$, also occurs on a scale-by-scale basis all the way down to the Zeman scale.

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Date submitted: 31 Jul 2014

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