Scale interactions and scaling laws in rotating flows at moderate Rossby numbers and large Reynolds numbers

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Strong rotation is present in many geophysical and astrophysical flows. Its effect is considered to become important when the Rossby number is sufficiently small. For rapid rotation significant progress have been made by applying resonant wave theory and weak turbulence theory. In this approach, the flow is considered as a superposition of inertial waves with a short period, and the evolution of the system for long times is derived considering the effect of resonant triad interactions. This explains successfully the observed enhanced transfer of energy from the small to the large scales, and sheds light on the mechanism that drives the flow quasi-two dimensional at large scales.

However, resonant wave theories are only valid when the rotation period is much shorter than the eddy turnover time at all scales. For large Reynolds numbers, small scales are excited with a characteristic timescale proportional to the eddy turnover time. Therefore the approximations made in such theories can break down at sufficiently small scales, provided that the Reynolds number is large enough for these scales to be excited.

Here we present a study of the effect of rotation in a turbulent flow in high resolution direct numerical simulations. Our main objective is to study the statistical properties of the fluctuations in flows with moderate Rossby numbers (down to $Ro \approx 0.1$) but at Reynolds numbers large enough to observe the beginning of a turbulent scaling at scales smaller than the energy injection scale. To this end, we use coherent forcing at intermediate scales, leaving enough room in the spectral space for an inverse cascade of energy to develop when the Rossby number is small enough. We also use the largest value of the Reynolds allowed by our grid to observe a direct transfer of energy at small scales.

We analyze the spectral behavior of the simulations, the shell-to-shell energy transfer, scaling laws, and intermittency, as well as the geometry of the structures in the flow. At late times, the direct transfer of energy at small scales is mediated by interactions with the largest scale in the system, the energy containing eddies with $k_\perp \approx 1$. The inverse cascade of energy at scales larger than the energy injection scale is non-local, and energy is transferred directly from the forcing scale to the largest available scale. The transfer between modes with wavevector parallel to the rotation is strongly quenched. Also, as time evolves and the energy piles up at the largest available scale the system becomes less intermittent, as showed by the probability density functions of the velocity increments and the convergence of the scaling exponents to the values predicted by phenomenological theories that neglect intermittency.