Geophysical Research Abstracts, Vol. 8, 01714, 2006
SRef-ID: 1607-7962/gra/EGU06-A-01714

Local and nonlocal advection of a passive scalar

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Surface quasi-geostrophic (SQG) dynamics describes the slow vortical motion of rotating, stratified fluid under the assumption that interior gradients of potential vorticity (an active scalar) vanish; it has applications in atmospheric and oceanic dynamics in places such as the mid-latitude tropopause, where there is a sharp jump in stratificiation. This talk considers passive and active scalar mixing in a simple one-parameter family of 2D flows based on surface quasi-geostrophic dynamics, and parametrized by the distance of the flow from the dynamical surface. On the surface, the flow is determined by the surface quasi-geostrophic system; as distance from the surface increases, the spectral character of the flow becomes nonlocal at increasingly larger scales until a chaotic advection-type regime is reached. Scaling arguments suggest a transition where the slope of the passive scalar spectrum changes from $k^{-5/3}$, determined by local dynamics, to k^{-1}, determined by nonlocal dynamics. Direct numerical simulations reproduce the qualitative aspects of this transition. Other characteristics of the simulated scalar fields also depend strongly on the degree of locality: the ratio of coherent to filamentary structures diminishes as the flow becomes more nonlocal and the typical form of large-scale coherent structures changes from annular to spiral.