Geophysical Research Abstracts,
Vol. 11, EGU2009-9966-1, 2009
EGU General Assembly 2009


# Mixed layer deepening by Langmuir circulation

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Mixed layer deepening has important consequences for general ocean circulation and climate models, as well as for the dynamics of lakes and reservoirs. Among the various surface-induced mixing processes such as shear, convection and precipitation, a mechanism that has drawn increasing interest is Langmuir circulation. Though Langmuir circulation occurs in the mixing layers of oceans and lakes for relatively low wind speeds, its relevance to mixed layer deepening is still an open question. In order to estimate the contribution to mixing in the upper layer of oceans and lakes by Langmuir vortex-cells relative to shear-induced mixing, we employ results on entrainment rate obtained from laboratory experiments with Taylor vortex cells. New information about mixing by horizontal vortices like langmuir vortices has been obtained from recent experimental results by Guyez et al. (J. Fluid Mech. 2007) on mixing across a density interface by turbulent Taylor vortices in a Taylor-Couette flow. Using the analogy between these vortex cells and Langmuir vortices, we relate the vortex flow and the shear across the mixed layer to a surface friction-velocity $u_*$ and show that up to a Richardson number of $Ri_* \approx 50$, layer deepening is predominantly by shear-generated turbulence, whereas for $Ri_* > 50$ the contribution by coherent Langmuir cells is of increasing importance and dominates, since there is no critical Froude-number criterion for the arrest of mixing by Langmuir cells. These results confirm observations in that shear-generated turbulence dominates during initial layer deepening under relatively weak buoyancy effects, and that subsequently Langmuir-cell mixing is of equal importance or even dominate mixed layer deepening.