651-2124-00:

Atmospheric General Circulation Dynamics (HW 2, due April 6):

Barotropic Rossby waves. Consider barotropic (two-dimensional) flow on a β-plane with a mean zonal flow $\bar{u}$ that may vary slowly with latitude.

1. Explain in physical terms why Rossby waves always propagate westward relative to the mean flow. (You may want to sketch a Rossby wave and explain how it propagates.) What is the zonal phase speed relative to the mean flow of a Rossby wave with a typical scale of 1500 km, located at 30° latitude?

2. Explain why the meridional group velocity of Rossby waves implies that generation of Rossby waves at some latitude y_0 implies convergence of momentum at that latitude. Sketch the associated streamlines of the Rossby waves.

3. The most energetic Rossby waves are generated by baroclinic instability in midlatitudes of Earth's atmosphere, where mean zonal flows are strong. They have westerly phase velocities (relative to the solid Earth). As they propagate equatorward, they propagate toward a region of mean easterly winds. Explain why they cannot propagate into that region, and describe qualitatively what happens as they approach it.

4. The results of (1)–(3) together imply that Rossby waves generated in midlatitudes of Earth's atmosphere lead to momentum flux divergence in a region of weak or easterly zonal flow, and convergence in a region of stronger westerly zonal flow. In what sense is this momentum flux "upgradient," that is, it is "unmixing" momentum?

5. Why is it not as surprising as it might seem at first glance that a turbulent flow leads to "unmixing" of momentum? That is, what kinds of tracers does turbulence tend to homogenize, and why is momentum not one of them?