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The structure of waves during Geostrophic Adjustment on the mid-latitude β-plane

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The theory of the transition from an unbalanced initial state to a geostrophically balanced state, referred to as geostrophic adjustment, is a fundamental theory in geophysical fluid dynamics. The theory originated in the 1930s on the f-plane and since then the theory was barely advanced to the β-plane. The present study partially fills the gap by extending the geostrophic adjustment theory to the β-plane in the case of resting fluid with a step-like initial height distribution η_0. In the presentation, we focus on the one-dimensional adjustment theory in a zonally-invariant, finite, meridional domain of width L where $\eta_0 = \eta_0(y)$. By solving the linearized rotating shallow water equations numerically, the effect of β on the adjustment process is examined primarily from the wave perspective while the spatial structure of the geostrophic steady-state will be addressed only briefly. The gradient of $\eta_0(y)$ is aligned perpendicular to the domain walls in our zonally-invariant set-up which implies that the geostrophic state only represents the time-averaged solution over many wave periods rather than a steady-state that is reached by the system at long times. We found that: (i) the effect of β on the geostrophic state is significant only for $b = \cot(\varphi_0)R_d/R \geq 0.5$ (where R_d is the radius of deformation, R is Earth's radius and φ_0 is the central latitude of the domain). (ii) In wide domains the effect of β on the waves is significant even for small b (e.g. b=0.005). EOF analysis demonstrates that for b=0.005 and in narrow domains (e.g. $L = 4R_d$) harmonic wave theory provides an accurate approximation for the waves, while in wide domains (e.g. $L = 60R_d$) accurate approximations are provided by the trapped wave theory. Preliminary results derived in the two-dimensional case, where $\eta_0 = \eta_0(x)$ is symmetric, imply that the results outlined in item (ii) above hold in this case too.