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Equatorial balance model for planetary scale dynamics

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As slow dynamics often dominate in geophysical fluid models, it is desirable to filter out fast motions by constructing simplified 'balanced' models; the most notable example is the quasi-geostrophic model for mid-latitude dynamics. Attempts to derive similar balance models for the tropics have not been entirely successful, as Kelvin waves, which contribute significantly to tropical low-frequency variability, are generally filtered out. In the long-wave limit of the equatorial wave theory, both Kelvin and Rossby waves are slow relative to inertia-gravity and mixed-Rossby-gravity waves, and thus a balance model in this regime should retain Kelvin waves to capture the slow dynamics accurately.

In the present study, an asymptotic expansion is used to systematically derive a family of balance models for the shallow water equations on the equatorial beta-plane, with anisotropy (ratio of meridional to zonal scale) as the small parameter. In the weakly nonlinear, small Froude number limit, we recover the traditional linear long-wave model of Gill (1980) at leading order, while the higher order terms in the expansion introduce nonlinearity and dispersion for Rossby waves. The method is shown to be applicable to the fully nonlinear regime (i.e Froude number approaching unity), as well as linearly stratified models.

The slow dynamics in the nonlinear balance model are characterized by an advective timescale and small horizontal divergence, which is in agreement with the 'balanced' view of equatorial dynamics (e.g. Charney 1963) where vortical motions dominate. As Gill's long-wave model emerges from the nonlinear balance model in the small Froude number limit, our theory then suggests that the equatorial long-wave theory is fully consistent with the balanced view of equatorial dynamics.

In addition to the adiabatic models, we also consider a case where a diabatic heat source is present, with the aim of further clarifying the role of diabatic heating in large scale balanced dynamics in the tropics.

References:
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