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Equatorial waves on the β-plane in the presence of a uniform zonal flow: Beyond the Doppler shift

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Numerical solutions of the eigenvalue equation associated with zonally propagating waves of the Linearized Rotating Shallow Water Equations are derived in a channel on the equatorial β-plane in the presence of a uniform mean zonal flow. The meridionally varying mean height field is in geostrophic balance with the prescribed mean zonal flow. In addition to the trivial Doppler shift of the free waves' phase speeds, the mean state causes the dispersion curves of each of the free Rossby and Poincaré waves to coalesce in pairs of modes when the zonal wavenumber increases. For large zonal wavenumber or large mean flow, the latitudinal variation of the waves' amplitudes differs from that of free waves i.e., Hermite Functions (in wide channels) and Harmonic Functions (in narrow channels) do not describe the amplitude structure. For large mean speed and for large zonal wavenumber the eigenvalue problem loses its Sturm-Liouville structure and the eigenfunctions have multiple extrema between successive zeros of the function itself. In contrast to free Kelvin waves, in the presence of a mean flow the meridional velocity component of these waves does not vanish identically. For zonal stratospheric winds of order 20 m s^{-1} and for gravity wave speed of order 25 m s^{-1} the phase speed with mean wind can be twice that of the classical theory with no mean zonal wind.