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On the meridional structure of extra-tropical Rossby waves

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The most common derivation of Rossby waves is based on the quasi-geostrophic approximation, which is usually assumed to be valid for planetary meridional scales of the order of 1000 kilometers. Several decades-long numerical simulations using a general circulation model are used to demonstrate that initial conditions of the quasi-geostrophic solution do not propagate westward with a uniform phase speed, which implies that these harmonic solutions are not eigensolutions of the shallow water equations in channels of width exceeding several hundred kilometers. It is shown that the latitudinal variation of the phase speed of these numerical solutions results from the fact that the eigensolutions are the parabolic cylinder functions and not sinusoidal functions, where the higher modes are slower and extend further poleward. To explain these numerical results a simple non-harmonic approximation for extratropical Rossby waves on the sphere is proposed, where the meridional coordinate turns out to be a parameter instead of as a continuous variable. It is shown that, in contrast to the quasi-geostrophic solution, the meridional structure of Rossby waves is irrelevant to a first order approximation. The proposed approximation closely reproduces the numerical results and captures the latitudinal dependence of the Rossby-waves-phase speed, when starting from arbitrary initial meridional structure. We propose a similar approximation for topographic Rossby waves that accounts for the wave structure and the phase speed for arbitrary depth profile in one direction and cross bathymetry initial conditions. In all these cases the theory yields explicit expressions both for the dispersion relations and the non-harmonic wave structure.