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Westward propagation of non-plane baroclinic Rossby waves in the North Atlantic

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Satellite altimetry shows westward propagation of baroclinic Rossby waves and eddies, but ray theory predicts significant meridional propagation of baroclinic Rossby waves over large topography. This discrepancy has been attributed to the limited lateral extent used to estimate propagation speed and direction from altimetry data, or a tendency for eddies to propagate westwards. We show that even linear but non-plane baroclinic Rossby waves propagate mostly westwards in the North Atlantic. The waves are also deformed and show apparent zonal speed-up.

The discrepancy between our result and ray theory is due to the neglect of two-dimensionality (in the horizontal) and inter-mode interactions in ray theory. To show this, we first introduce propagation velocity of Rossby wave field, which is different from phase speed or group velocity. Then, we investigate the propagation of a non-plane Rossby wave field in a continuously stratified ocean with sloping bottom. The analysis shows that zonal and meridional propagation are associated with different sets of vertical modes. Zonally propagating modes are given by the well-known solution for Rossby waves over meridional slopes, whereas meridionally propagating modes consist of a barotropic mode with non-zero propagation speed and baroclinic modes with zero propagation speed. Since the two sets of vertical modes (even the two barotropic modes) have different vertical structures, wave propagation in the two directions causes inter-mode interactions and apparent meridional propagation of the baroclinic wave field.

For plane waves over a uniform slope, the inter-mode interactions occur in a systematic way, such that the horizontal shape remains the same and the baroclinic wave field propagates both in zonal and meridional directions. This recovers the results obtained by plane wave and ray theory. On the other hand, for non-plane Rossby waves in the North Atlantic, the interactions occur in a less systematic way, resulting in deformation and small net meridional propagation of the baroclinic wave field.