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Meridional component of oceanic Rossby wave propagation

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Abstract

A three-dimensional spectral analysis of Topex altimeter data reveals a large meridional component k_y of the wavevector $\boldsymbol{k}$ for baroclinic Rossby waves of all timescales. Its existence necessitates some refinements in our estimates of certain basic properties of the Rossby wave field. In particular, by taking into account an actual off-zonal direction of $\boldsymbol{k}$ (often exceeding 70°), one finds that the wavelength, phase speed, and group velocity of mid-latitude Rossby waves (with periods less than 2 years) are much smaller than they appear to be on the assumption of a purely zonal wavenumber vector. Because of a shorter wavelength (yielding kL as high as 0.6, where L is the Rossby radius of deformation), these waves are essentially dispersive. Their group velocity vector may depart from zonal by more than 30°. An important intrinsic feature of the wave spectrum confirmed by our analysis is a broad-band distribution with respect to k_y. Some of the dynamical implications of the large k_y/k_x ratio are discussed.

Keywords: Rossby waves; Satellite altimetry

1. Introduction

Present interest in large-scale oceanic Rossby waves, especially those in the Pacific, was heightened by satellite-based observations (Chelton and Schlax, 1996) showing very

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long (up to thousands of kilometers) baroclinic Rossby waves originating at ocean eastern boundaries and crossing the entire ocean basin. The extremely large wavelength reported in this analysis, making these waves appear non-dispersive, would also imply a purely westward group velocity vector, equal in magnitude to the wave phase speed. As should be expected due to the presence of ubiquitous background currents, the apparent zonal phase speed was found to be at least twice as large as it would be in the absence of background flows. These westward propagating waves are claimed to provide teleconnections between El Niño-Southern-Oscillation (ENSO) events and global weather patterns by influencing ocean gyres and air–sea fluxes in the western Pacific (Chelton and Schlax, 1996). In recent years, Rossby wave motions were found to account for 5–20% of the observed variability in chlorophyll concentration and the latter to be coherent with westward propagating anomalies of sea surface height (SSH) (Cipollini et al., 2001; Uz et al., 2001). The latter studies, along with observations of Rossby wave effects on sea surface temperature (SST) variations (e.g., Hill et al., 2000), provided an independent confirmation of trans-Pacific transport of heat and other quantities at the rate reported by Chelton and Schlax (1996). In addition to the standard analysis of SSH variations in the longitude-time plane at a fixed latitude (used in all the above studies), Cipollini et al. (2000) and Challenor et al. (2001) examined possible deviations from zonal propagation by applying a 3D Radon transform technique to 3D data "cubes" which included a latitudinal dimension. However, due to the intrinsic difficulties of analyzing latitudinal variations—explained in detail in Section 3, and also because the range of off-zonal angles explored by these authors was limited to $\pm 40^\circ$, they did not find significant deviations, and thus confirmed the purely zonal propagation of the Rossby wave phase at all latitudes.

As shown in the present work, the off-zonal deviations of the characteristic wavenumber vector, $\boldsymbol{k}$, are often well outside the $\pm 40^\circ$ range. As explained in Sections 2 and 3, and confirmed by the data analysis in Section 5, the wavelength and wave speed of mid-latitude Rossby waves (for a given wave frequency) rapidly decrease as $\boldsymbol{k}$ tends to a near meridional orientation. The effect is most important for waves with periods less than 2 years. The existence of a large meridional component of $\boldsymbol{k}$ suggest a more complex view of the Rossby wave field than has emerged in recent years. To advance this view, we explore the full 2D nature of the wave field by using a three-dimensional spectral analysis. One of its features is the separation of the wave field, usually characterized by a very broad range of spatial and time scales, into individual components—namely (near-)semi-annual, (near-)annual, etc., which are clearly identifiable in the 3D spectra. Another important advantage of this analysis is that it permits (as shown in Section 4) extracting information on the meridional structure of the wave field separately for eastward and westward moving disturbances of the SSH field. This "spectral filtering" is crucial because latitudinal variations of the SSH field are too complex (i.e., broad-banded) to be discerned directly from SSH field data.

In most previous studies, the characteristic speeds, wavelengths and frequencies of Rossby waves were inferred from longitude-time plots (also called the "Hovmöller diagrams") of SSH (or SST, or other quantities) variations. In Section 3 we discuss this approach and point out some of its shortcomings. The three-dimensional spectral analysis of Sections 4 and 5 allows one to obviate these shortcomings and explore directional properties of the wave field. This is particularly important in view of the fact that knowledge of the meridional component, k_y, of the wavenumber vector is crucial to test some recent models