Zonally Elongated Transient Flows in the Oceans: Phenomenology, Origins and Energetics

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Satellite observations and numerical simulations reveal a series of zonally elongated transient flow patterns populating every basin of the World Ocean. The dynamical origins of these transient patterns remain unclear, although they have been hypothesized to be similar to stationary zonal jets in the atmospheres of giant gas planets. This study explores zonally-elongated large-scale transients (ZELTs) in a quasi-geostrophic (QG), stratified flow on a beta plane, and focuses on their spatial structure, sensitivity to environmental parameters, dynamical origins and energetics.

Both spectral analysis and Empirical Orthogonal Functions (EOF) decomposition consistently demonstrate the presence of ZELTs in a wide range of environmental parameters relevant to oceanic flows. The velocity streamfunction in this ZELT-dominated regime exhibits a well-pronounced anisotropic spectral peak and several leading EOFs of mesoscale variability that are profoundly anisotropic (zonally elongated; Fig.1). The autocorrelation function of the Principal Components (PCs) for these anisotropic EOFs is oscillatory, which is consistent with ZELT persistence and zonal propagation at the speed ~ 0.01 m s^{-1}. Outside of this parameter range, the decrease in the planetary vorticity gradient and increase in the bottom drag coefficient each leads to flattening of the variance spectrum, isotropization of the leading EOFs and a rapid decay of the autocorrelation function of the PC.

To elucidate the origins and energetics of ZELTs, we perform a series of sensitivity experiments with specific components of the energy and enstrophy transfer turned off. The results demonstrate that nonlinear interactions between transient eddies are of vital importance for ZELT emergence and maintenance, and that these modes are highly non-linear phenomena, owing its existence to anisotropic upscale energy cascade. The major contribution to this energy transfer comes from the baroclinic-baroclinic and mixed-mode eddy interactions, while barotropic-barotropic interactions are of less or no importance for ZELTs dynamics. Further analysis of the spectral energy fluxes reveals persistent upscale transfer of baroclinic and barotropic kinetic energy along the zonal wavenumbers. In contrast, the energy fluxes along the meridional wavenumbers have a clear tendency to transfer baroclinic and barotropic kinetic energy to the meridional scales associated with ZELTs. This property is most pronounced in the ZELT-dominated regimes.

The results illustrate the underlying anisotropy in a turbulent flow on a beta plane. In an oceanographically relevant regime, both the leading modes of mesoscale variability and the associated energy transformation exhibit a pronounced difference between the zonal and meridional directions. This anisotropy has potentially important implications for the energy transformation as well as for the transport of various oceanic properties.

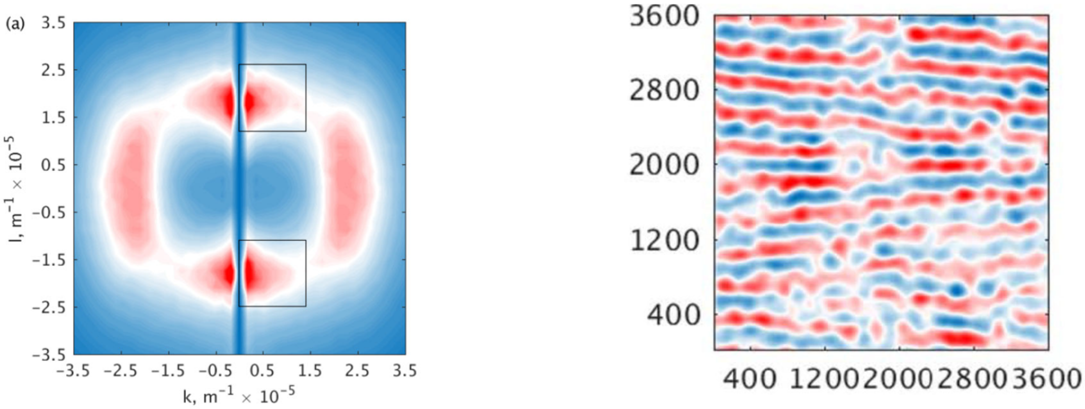

Figure 1: ZELTS in a baroclinic QG flow on a beta-plane. Left panel shows the two-dimensional wavenumber spectra of the velocity streamfunction. Boxes outline spectral regions associated with ZELTs. Zonally-averaged component is removed from the flow prior to calculation of the spectrum. Right panel shows the leading EOF in the same flow. After *Rudko et al.* (2018)

References:

Rudko, M.V., I. V. Kamenkovich, M. Iskadarani, and A. J. Mariano, 2018: "Zonally-elongated transient flows: phenomenology and sensitivity analysis", *J. Geophys. Res.*, DOI 10.1029/2017JC013173

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