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Beta-plumes and origin of striated patterns in the ocean

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Dynamics of "striations", quasi-zonal jet-like features seen on maps of multi-year mean geostrophic velocity (see Figure), is analyzed in the framework of beta-plumes, ocean circulations generated by localized sources of vorticity. Beta-plumes are exemplified in the ocean by the Azores Current (AzC) induced by the outflow of Mediterranean water from Gibraltar, the Hawaiian Lee Countercurrent (HLCC) generated by the orographic wind stress curl in the lee of Big Island of Hawai'i, and features off of the California coast resulting from nonlinear interaction between baroclinic meanders of the California Current and Ekman flow. Experiments with the idealized ROMS model demonstrate formation of the system of jets west from the source area in linear regime and of system of eddy trains in nonlinear regime. In the presence of the background meridional flow, common in the regions populated by striations, beta-plumes change orientation. Axes of beta-plumes are tilted by the large-scale advection in the same manner both in linear and non-linear regimes. In linear case, tilted axes allow trapped Rossby waves to propagate meridionally against the flow. In nonlinear case, the tilt is achieved by a superposition of westward drift of eddies and their meridional advection by the flow.

In the presence of vertical diffusion and, particularly, viscosity, momentum of beta-plumes initially induced at the surface is gradually redistributed into deeper layers. This makes surface signatures of beta-plumes too short compared to ocean striations. Analysis of statistics of oceanic eddies reveals striated patterns in density of cyclones and anticyclones somewhat resembling striations in the mean dynamic ocean topography (MDOT). At the same time, careful consideration shows that, although significant fraction of eddies can live for many weeks while traveling over thousands of kilometers, eddies generated in the source region of HLCC and AzC take a broad suite of pathways and are unlikely to be resposible for establishment and maintenance of beta-plumes. Moreover, many eddies seem to formed by the meandering mean fronts, not vice versa. Even more remarkable controversy is found between eddies and striations in the eastern subtropical North and South Pacific. Preferred paths of cyclonic eddies there, carrying negative sea level anomaly (SLA), are collocated with crests in striations. Correspondingly, anticyclones with positive SLA are more frequent along striation troughs. The study uncovers a new, higher level of complexity of eddy interaction with striations. Also mechanisms, sustaining striations, remain unknown.

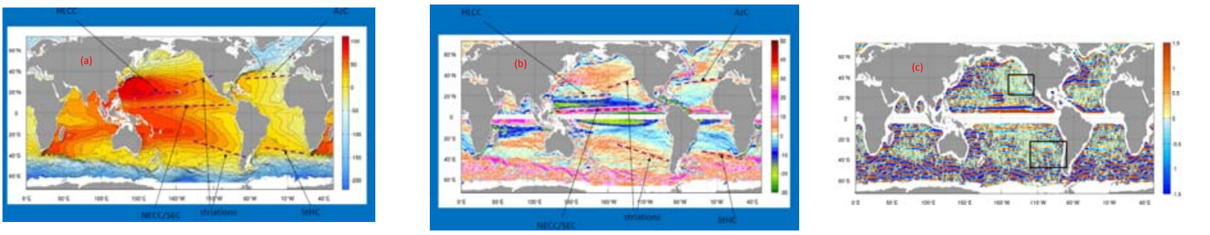

Figure 1. (a) Mean dynamic ocean topography (MDOT)[1], (b) mean geostrophic zonal velocity, derived from MDOT, and (c) the same velocity after application of two-dimensional high-pass filter with half-width of 4° [2].
Notations on (a,b): HLCC – Hawaiian Lee Countercurrent, AzC – Azores Current, StHC – St Helena Current[3].

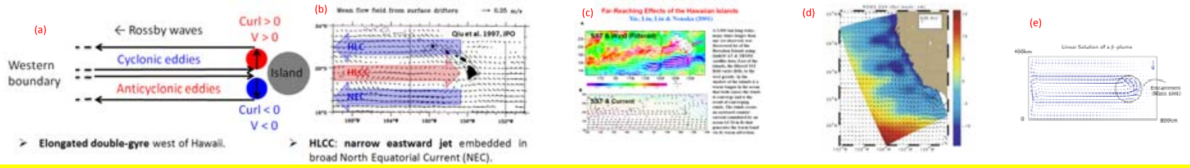

Figure 2. (a) Schematic of beta-plume forced by wind stress curl dipole, (b, c) mean currents and winds around Hawaii[4], generating HLCC[5], (d) ROMS solution in the California Current System[6], where nonlinear interaction between Ekman flow and baroclinic meanders produces off-shore striations, and (e) schematic of the Azores Current induction by sinking Mediterranean water

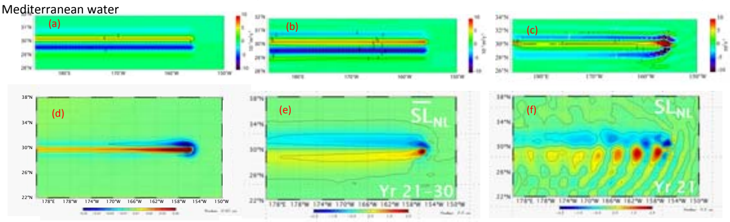

Figure 3. Model runs of a simplified baroclinic ROMS, forced by a localized (Gaussian) wind stress monopole: (a) analytical mean vertically-integrated transport, transport in linear (b) and non-linear (c) regimes, mean sea surface height in linear (d) and non-linear (e) regimes, and (f) snapshot of nonlinear SSH[7].

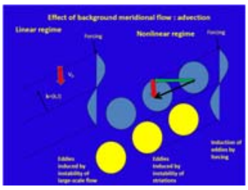

Figure 4. Schematic of tilting of linear (left) and non-linear (right) beta-plume due to interaction with meridional flow.

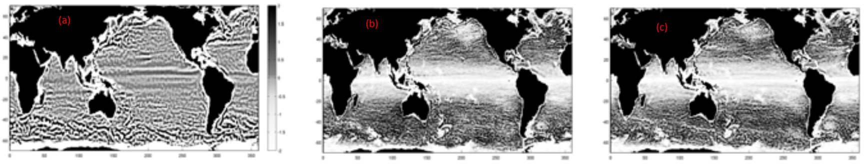

Figure 5. (a) MDOT, high-pass filtered with two-dimensional 4-degree filter, (b and c) density of cyclones and anticyclones[8].

Surprise! cyclonic eddies move along crests of MDOT

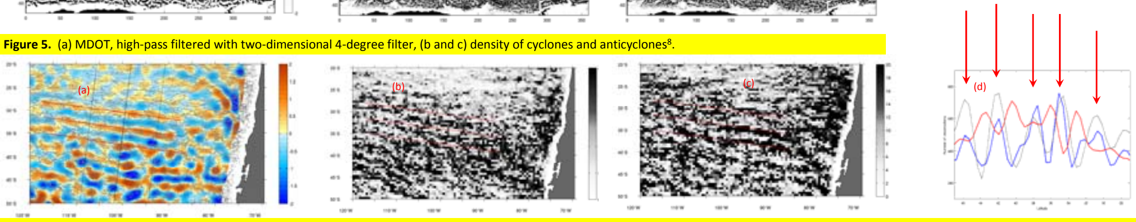

Figure 6. (a) MDOT, high-pass filtered with two-dimensional 4-degree filter, (b and c) density of cyclones and anticyclones[8].in the South Pacific domain, shown in Fig.1c. (d) cross-striation structure of high-pass filtered MDOT (dashed) , density of cyclones (blue) and anticyclones (red).

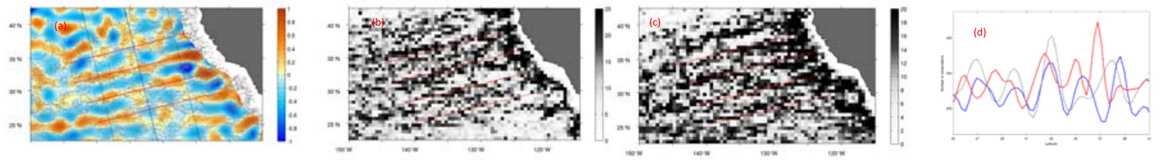

Figure 7. (a) MDOT, high-pass filtered with two-dimensional 4-degree filter, (b and c) density of cyclones and anticyclones[8].in the North Pacific domain, shown in Fig.1c. (d) cross-striation structure of high-pass filtered MDOT (dashed) , density of cyclones (blue) and anticyclones (red).

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