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Deep zonal jets in the ocean

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The ocean basins are populated by narrow, alternating, eastward and westward currents, called "(deep) zonal jets" (Fig. 1). They generally have amplitudes of $\lesssim 0.1$ m/s and north-south wavelengths of $\sim$200–400 km, and extend over thousands of kilometers in the east-west direction and from the sea surface down to 1000–3000 m depth in the vertical. The instantaneous flow field tends to show wiggly stripes because of mesoscale eddies (Fig. 1a) and the zonal jets become clear in temporal averages over $\sim$2 yr (Fig. 1b).

A few of such zonal jets have well-accepted explanations: for example, the eastward jet toward the Hawaiian islands is driven by the spatial irregularity in wind stress due to the tall and large mountains of Hawaii blocking the trade winds. Except for such examples, the dynamics of most of these zonal jets are much less clear.

In numerical simulations, the jets in mid-latitudes are found to migrate equatorward slowly and systematically and in low latitudes, poleward migration has been identified. In high latitudes, no systematic migration has been found. There are other zonal jets that are anchored to bottom topographic features or, near the continent, to coastal features.

A number of hypotheses have been proposed to explain these jets. One plausible theory is that mesoscale eddies tend to generate large-scale circulations but this growth in scale is inhibited in the north-south direction by the north-south change in the vertical component of the Earth's rotation vector, leading to circulations that are elongated in the east-west direction. This explanation has also been proposed to explain the zonal jets on Jupiter.

An interesting question is whether the positions of these jets are determined entirely by the external forcing (boundary conditions to the ocean). If they indeed emerge from mesoscale eddies, their positions should be random unless there is something to anchor them, because the eddies are generated by the instability of large-scale circulation and their positions are random as a result. Indeed, an ensemble of numerical simulations—ones under exactly the same forcing but with just slightly different initial conditions—shows that the ensemble members do not agree on the positions of the mid-latitude jets (except for those anchored to something) even though the set of the jets systematically and regularly migrates equatorward in each member. In contrast, ensemble members tend to agree on the positions and poleward migrations of certain jets near the equator. Their positions must be determined by some mechanism.

There are also jets that extend from the sea surface to the bottom which are anchored to steep bottom cliffs. They are steady and the ensemble members agree on their positions. Interestingly, these jets seem to anchor other shallower jets on their northern and southern flanks. Also, there are other zonal jets, some quite tall, that extend upward from the bottom. The horizontal flow field at mid-depths, therefore, includes both jets extending from the surface and those extending from the bottom.

This talk is based on
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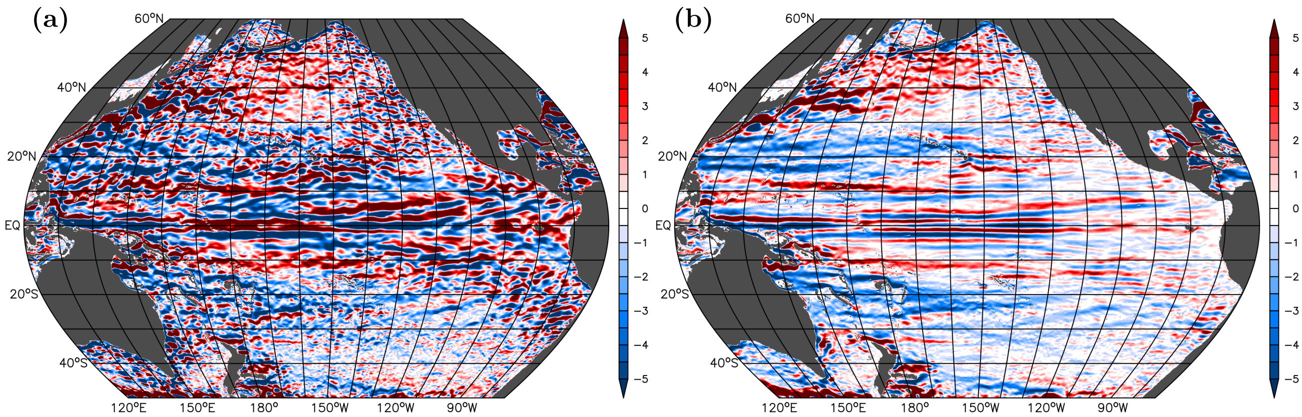

Figure 1. The eastward velocity at the depth of 500 m from a high-resolution (0.1° × 0.1° horizontally) oceanic general circulation model: the average over a selected month (a) and a 2-year average centered at the month (b).