ZONAL JETS STANDING IN MERIDIONAL FLOW

as revealed by joint analysis of satellite and in situ data

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ABSTRACT

Jointly processed within a simplified model of balance of horizontal momentum, data of satellite altimetry, drifters, wind and GRACE mission provided a high quality multi-year mean absolute seasurface dynamic topography with fine mesoscale resolution and nearly global coverage. Its accuracy is good enough in a wide range of scales to outline jet-like structures associated both with known currents (such as Azores Current, Hawaiian Lee Countercurrent, etc.) and newly found systems (such as jets in eastern parts of all oceans). It is puzzling how these fine structures are capable of surviving the effects of advection and stirring by sensible meridional flows associated with gyres of wind-driven large-scale ocean circulation.

The answer found in this study suggests that the jets behave as Rossby waves standing in the background flow. Based on the dispersion equation, phase of a Rossby wave may propagate with a meridional component only if it also has a zonal component, i.e. to stand in the meridional external flow a jet can't be exactly zonal but must be tilted. Our analysis shows that, indeed, regardless of their origin all jets are oriented northeast-southwest, if in the southward flow, and northwest-southeast, if in the northward flow.

Figure 1. Anomaly of Aviso altimetry zonal geostrophic velocity averaged over 18 weeks (Maximenko et al., 2005)

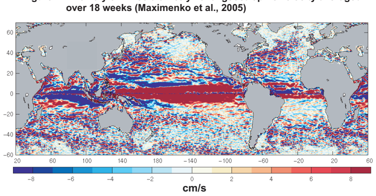


Figure 3. Pictures of cloud bands on Jupiter and Saturn from "Cassini"

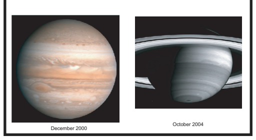


Figure 2. Time-smoothed zonal velocities in numerical ocean general circulation models

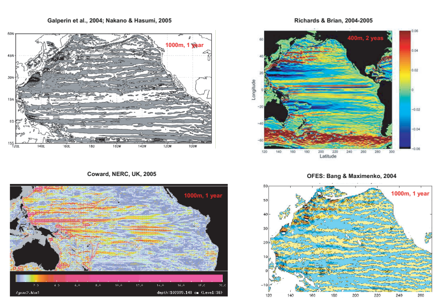


Figure 4. 1992-2002 mean surface dynamic topography (Maximenko & Niiler, 2005)

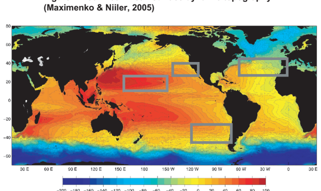
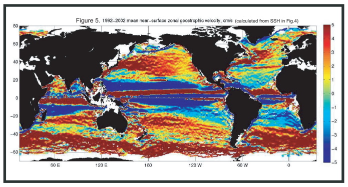


Figure 5. 1992-2002 mean near-surface zonal geostrophic velocity, cm/s (calculeted from SSH in Fig.4)



Question

While analogy between zonally oriented jet-like structures recently discovered in satellite altimetry data (Fig.1), outputs of high-resolution ocean general circulation models (e.g., Fig.2), and long-known banded cloud structures in atmospheres of giant planets (Fig.3) is tempting, there are significant differences between the systems that may have serious dynamical consequences.

Most importantly, the Earth is not an "aqua-planet". Existence of continents breaks zonal symmetry both in atmospheric winds and in oceanic currents. On a large scale, World Ocean circulation, except for its very southern, Antarctic part, is comprised of a set of strong wind-driven gyres. These gyres move large masses of waters in meridional directions to compensate the production of vorticity by the local wind stress at the sea surface. These gyres are best seen in the mean dynamic topography (Fig.4).

Question: Can a zonal jet be stationary in the presence of sensible meridional flow?

Data

We are using 10-year mean sea surface dynamic topography [Maximenko and Niiler, 2005] calculated by a joint analysis of drifter, satellite altimetry, wind and GRACE data. Description and data are public at http://apdrc.soest.hawaii.edu/projects/DOT. Meridional component of geostrophic velocity calculated from this data is shown in Fig.5 and it's small-scale component is in Fig.6.

Jets

Fig.6 reveals both well-known jets (such as frontal jets, Hawaiian Lee Countercurrent and Azores Current) and recently reported new jets in the eastern parts of all oceans. Orientation of jets is not exactly zonal and tilt is coherent with the sign of meridional geostrophic flow (Fig.7)

Answer: Yes, it can. To survive the effect of background meridional flow, "zonal" jet has to tilt meridionally to allow meridional phase propagation of Rossby waves against the oncoming flow. This agrees with what we observe in our ocean data. (see Figs. 6-8.)

Figure 6. 3-degree high-pass filtered mean zonal U from Fig.5

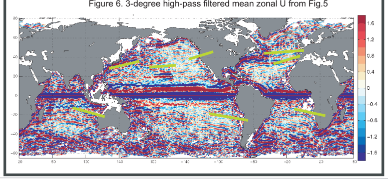


Figure 7. 3-degrees low-pass filtered mean meridional component of sea surface geostrophic velocity (calculated from SSH in Fig.4)

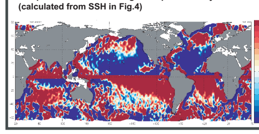
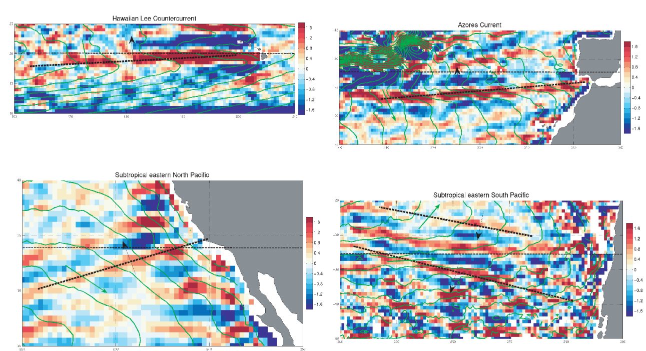


Figure 8. Interraction between mean small-scale zonal jets and large-scale meridional flow in four regions. Colors are same as in Fig.6 and contours are mean dynamic topography (Fig.4) plotted at 5 cm interval. Dashed lines indicate the tilt of the jets, green vectors show directions of geostrophic flows and black vectors are in directions of hypothetical phase propagation of the Rossby waves.



Interpretation

For a linear Rossby wave: $\omega = -\beta k/(|\mathbf{k}|^2 + L_D^{-2})$ $\qquad \mathbf{k} = (k, l)$

Meridional component of phase speed: $V_{rossby} = \omega l / |\mathbf{k}|^2 \sim \sin\alpha$

where α is the angle of tilt of the jet. By choosing proper angle, the jet can withstand the effect of meridional flow.

Interestingly, this applies to zonal jets regardless of their origin:
HLCC is induced by the wind interacting with Hawaiian islands;
Azores current is believed to be induced by Mediterranean outflow through Gibraltar;
source of the "eastern" jets is not understood yet.

Acknowledgments

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REFERENCES

Maximenko, N.A., B. Bang, and H. Sasaki, 2005: Observational evidence of alternating zonal jets in the World Ocean, Geophys. Res. Lett., 32, L12607, doi:10.1029/2005GL022728

Galperin, B., H. Nakano, H.-P. Huang, and S. Sukhoriansky, 2004: The ubiquitous zonal jets in the atmospheres of giant planets and Earth's oceans, Geophys. Res. Lett., 31, L13303, doi:10.1029/2004GL019691.

Nakano, H., and H. Hasumi, 2005: A series of zonal jets embedded in the broad zonal flow in the Pacific obtained in eddy-permitting ocean general circulation models, J. Phys. Oceanogr., 35(4), 474-488.

Richards, K.J., N.A. Maximenko, F.O. Bryan, and H. Sasaki, 2006: Zonal Jets in the Pacific Ocean, Geophys. Res. Lett., 33, L03605, doi:10.1029/2005GL024645

Maximenko, N.A., and P.P. Niiler, 2005: Hybrid decade-mean global sea level with mesoscale resolution. In N. Saxena (Ed.) Recent Advances in Marine Science and Technology, 2004, pp. 55-59. Honolulu: PACON International (http://iprc.soest.hawaii.edu/~nikolai/Papers/P04Maximenko_Niiler.pdf)

Maximenko, N.A., Multi-scale aspects of oceanic circulation, IPRC Symposium, May 8-9, 2006, Honolulu, Hawaii.

Maximenko, N.A., and P.P. Niiler, Mean surface circulation of the global ocean inferred from satellite altimeter and drifter data, Proceedings of the Symposium on "15 years of Progress in Radar Altimetry", March 13-18, 2006, Venice, Italy, ESA: SP-614.