Interannual-to-decadal variation of tropical-subtropical mass exchange in the Pacific Ocean: boundary versus interior pathways

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Abstract: Tropical-subtropical mass exchange is considered important to climate variability in the tropical Pacific. On average, warm surface waters travel to the subtropics where they are subducted into the pycnocline, transported via the western boundary and interior towards the equator and then upwelled. This study examines interannual-to-decadal variability of the exchange, focusing on the relative contribution of boundary and interior transport and the corresponding forcing mechanisms. Differences from the picture of time-mean exchange are highlighted.

Approach: Analyze sea level slope across western boundary & interior using TOPEX/Poseidon data and pycnocline transport simulated by a model without & with assimilation of sea level data (see [1] and [2]).

Finding: boundary vs. interior variability

Sea level difference across the western boundary is (I) anti-correlated to and (2) smaller in magnitude than that across the interior, implying the same tendency in near-surface geostrophic transport.

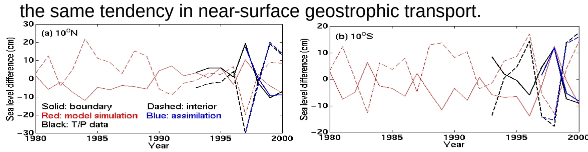


Fig.1 East-west sea level difference across the western boundary & interior. The longitudes separating the two are 130E at 10N and 158E at 10S.

Pycnocline transport via the boundary partially compensates that via the interior (Fig.2), consistent with sea level signature. There is less pycnocline water going into the tropics in the 90's than in the 80's, in agreement with recent observation [3].

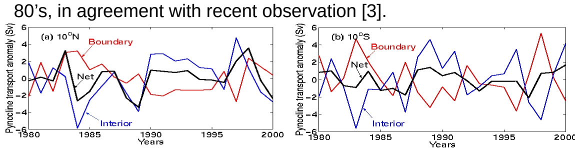
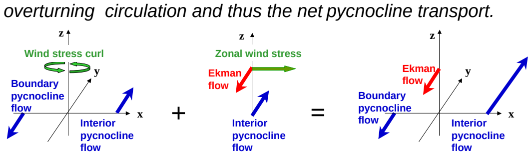


Fig. 2 Pycnocline transport via western boundary and interior, and their sum. Pycnocline is defined as sigma 22-26.5 and deeper than 50 m.

Proposed forcing mechanisms

Wind stress curl changes the strength of horizontal circulation and creates counteracting boundary and interior flow.

Zonal wind stress modifies the strength of the shallow meridional overturning circulation and thus the net pycnocline transport.



Local wind stress curl: affects horizontal circulation and causes counteracting boundary & interior flow

Mean wind stress curl has a maximam near 10N and minimum near 10S (Fig 3a-b), both giving rise to enhanced Ekman pumping. Temporal shift of these bands results in large variability of curl in the western Pacific in nearby latitudes (Fig. 3c-d).

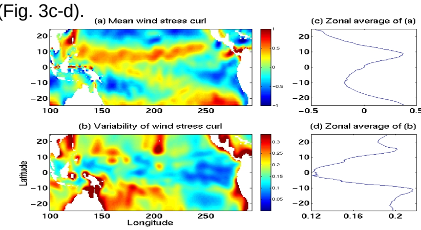


Fig.3 Mean and variability of wind stress curl, and their zonal averages over the Pacific.

Boundary pycnocline transport is well correlated to Sverdrup transport computed from local curl (Fig.4), suggesting that local curl is a possible forcing which modulates the strength of horizontal circulation.

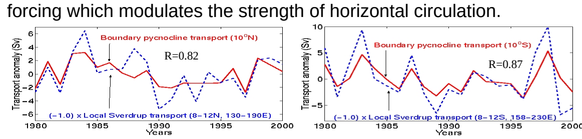


Fig.4 Boundary pycnocline transport & Sverdrup transport computed from local curl.

To demonstrate effect of local curl, a sensitivity experiment is performed with a positive curl anomaly near 10N with a magnitude close to off-equatorial variability shown in Fig. 3. Resultant change in boundary & interior pycnocline transports oppose each other (Fig.5), with a magnitude close to that simulated with real-time forcing (Fig.1).

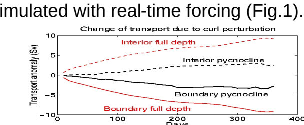


Fig.5 Change in boundary and interior transports at 10N due to local wind stress curl perturbation.

Zonal wind stress: affects meridional circulation and controls net pycnocline transport

Zonal wind stress can change the strength of the shallow meridional overturning and thus the net pycnocline transport (the lower branch of the shallow overturning). This is consistent with the correlation between zonal wind stress and net pycnocline transport (Fig. 7).

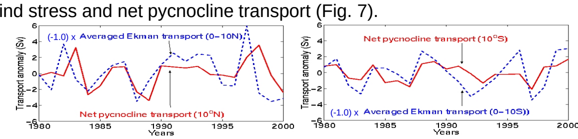


Fig.6 Net pycnocline transport & averaged Ekman transport.

A sensitivity experiment with a globally uniform zonal wind perturbation (to avoid wind stress curl) shows that this forcing indeed causes a net pycnocline transport (Fig.7).

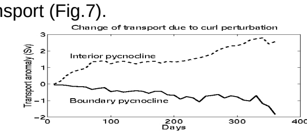


Fig.7 Change in boundary and interior transports at 10N due to local wind stress curl perturbation.

Co-variability of wind stress curl and zonal wind stress

Sverdrup transport due to local wind stress curl & Ekman transport due to tropical zonal wind stress are correlated (Fig.8). When the former causes southward (northward) anomaly of boundary (interior) pycnocline transport, the latter causes a northward anomaly of (primarily) interior transport. The combined effect is a stronger interior transport anomaly than that of the boundary, which explains Fig. 2.

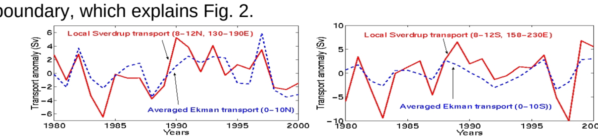


Fig.8 Local Sverdrup transport and Ekman transport are correlated.

Conclusion

- Interannual-to--decadal variation of tropical-subtropical exchange is different from the time mean as (1) anomalous boundary & interior transports are anti-correlated and (2) the latter has a larger magnitude.
- Boundary flow, compensating for about 50% of interior transport, cannot be neglected in estimating variability of tropical-subtropical exchange.
- The anti-correlation is primarily caused by off-equatorial wind stress curl which changes the strength of horizontal circulation.
- The larger magnitude of interior transport is because of change in tropical zonal wind stress (correlated to off-equatorial curl) which modifies the strength of the shallow meridional overturning circulation.

Reference

[1] Lee T., I. Fukumori, D. menemenlis, and L.-L. Fu, Upper ocean heat budget inferred from ECCO-2 ocean data assimilation. "En route to GODAE".

[2] Fukumori I., T. Lee, D. Menemenlis, L.-L. Fu, and the ECCO Group, A prototype GODAE routine global ocean data assimilation system: ECCO-2. "En route to GODAE".

[3] McPhaden M.J. and D. Zhang, 2002: "Slowdown of the meridional overturning circulation in the upper Pacific Ocean. *Nature*. 415, 603-608.

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