Imprint of PDO on South China Sea Throughflow

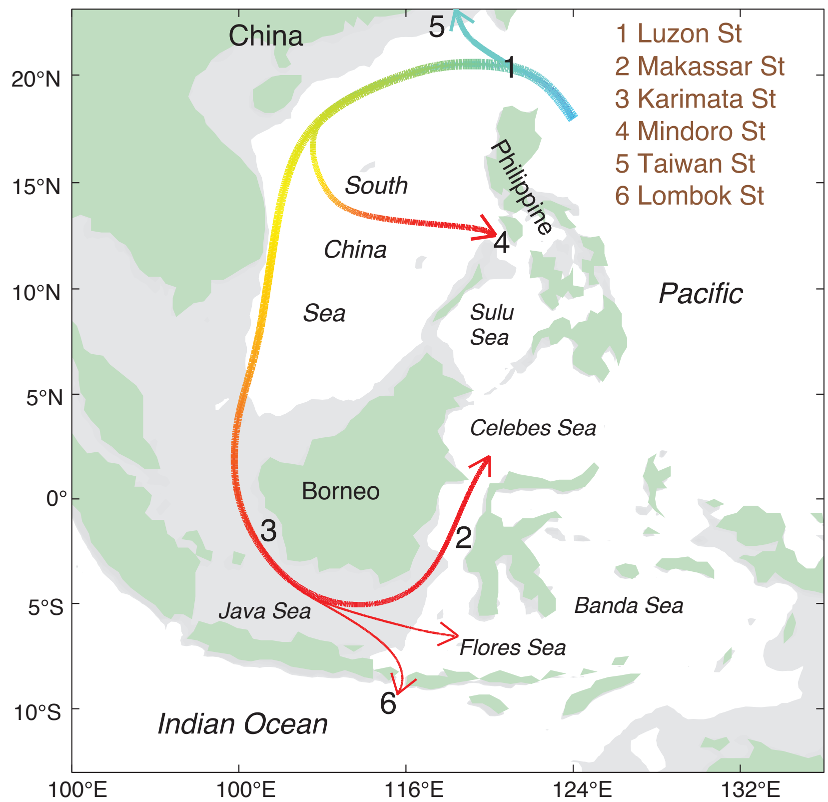
The highest water temperatures over the large expanse of the global ocean are found at the surface of the tropical "warm pool" that stretches from the eastern Indian Ocean to the western Pacific Ocean. Small changes in the region's sea surface temperatures (SST) can significantly alter atmospheric circulation, convection and rainfall across the Pacific and the Indian Ocean.

IPRC Senior Researcher **Tangdong Qu** and his colleagues have been studying this region for over a decade. They have discovered that the South China Sea is not a passive body of water as many oceanographers have thought, but contributes significantly to the water exchange between the Pacific and the Indian Ocean.

A useful research tool for their studies has been the high-resolution Ocean General Circulation Model For the Earth Simulator (OFES), which they have demonstrated represents the complex topography of the passages through the Indonesian Archipelago and the region's ocean floor much more realistically than most other ocean models.

Qu, together with former IPRC Postdoctoral Fellow **Yan Du** and JAMSTEC's **Hideharu Sasaki**, had shown in an OFES hindcast of conditions existing from 1950 to 2003 that a significant amount of Pacific water flows through the South China Sea into the Indonesian Seas. They called this flow the South China Sea throughflow (SCSTF): Pacific water enters the South China Sea through Luzon Strait and leaves the South China Sea through three straits: Karimata, Mindoro, and Taiwan, each transporting on average approximately 1.3 million cubic meters of water per second. The team's calculations showed that an appreciable amount of heat, between 0.1 to 0.2 Petawatts, leaves the South China Sea through Karimata and Mindoro straits. (For comparison, 4 Petawatts is thought to be the total heat flux transported by Earth's atmosphere and oceans away from the equator towards the poles.) This large transfer of heat into the Indonesian Seas can be expected to have considerable effect on climate in both the Indian and the Pacific Ocean.

In his most recent work, Qu together with **Kai Yu**, a long-term IPRC visitor from the Ocean University of China, studied the variability of the strength of the South China Sea



Map of the South China Sea throughflow.

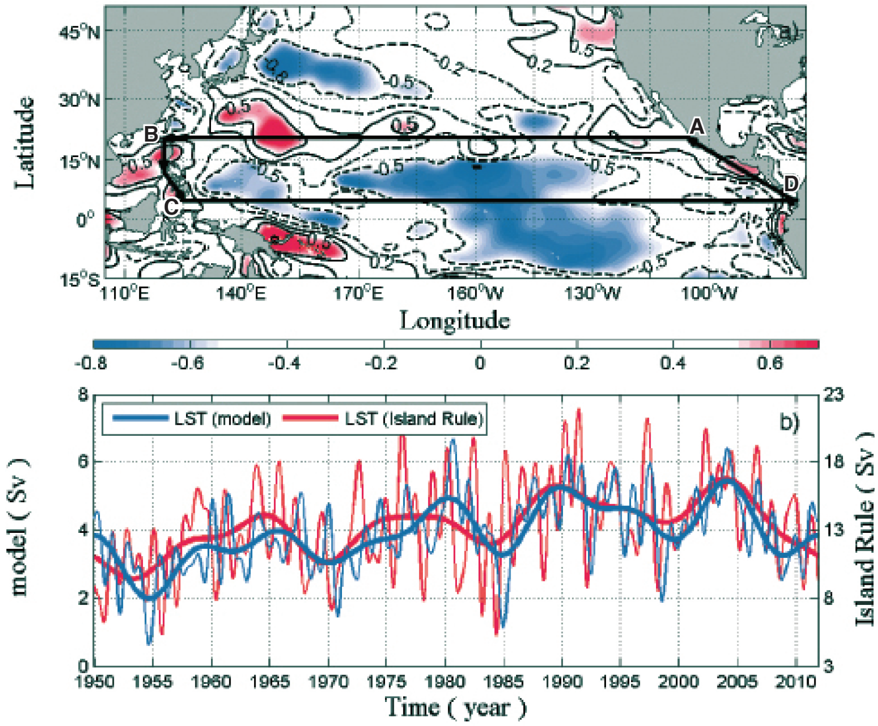


Figure 1. (a) Correlation between the upper-layer (0–745 m) Luzon Strait transport (LST) and zonal wind stress anomalies (contour) on the decadal timescale, and (b) time series of LST from the model (blue) and the "island rule" (red) smoothed by a 13-month (thin) and 84-month low-pass (thick) filter. The shading in (a) indicates the area satisfying the 95% significance level by t-test. The path ABCD in (a) is the path along which wind stress is integrated in applying the "island rule" to the LST. See Yu and Qu, *J. Climate*, for details.

throughflow in an OFES hindcast from 1950 to 2011. Since the Luzon Strait is the only inflow from the Pacific into the SCS, variations in transport through this strait determine much of the variations in the SCSTF. As expected, analysis of the OFES hindcast showed that the greatest variability in Luzon Strait transport (LST) comes from the seasonal cycle, which accounts for about 68% of the total variation in the flow.

Removal of the impact of the seasonal cycle revealed two time scales that captured most of the remaining 32% variation in transport strength in the upper-layer of Luzon Strait: a 3.3-year interval and a 14.2-year interval, each period accounting for about 11% of the total variation in the transport.

Since Qu and his colleagues had already studied causes of the higher-frequency interannual variability in the transport, they focused in this latest study on what causes the decadal variability. OFES results showed that the decadal inflow into the Luzon Strait is highly correlated with the outflow from the South China Sea through the three straits. Moreover, transport through Mindoro Strait, which varies the most among the three straits, correlates nearly perfectly with the upper-layer inflow through Luzon Strait (r=+0.95).

Where is the source of this decadal variability of inflow into Luzon Strait? Previous studies have pointed to the basin-wide winds. The OFES zero-lag correlation between LST and NCEP zonally integrated wind stress along 4.75°N is –0.87, confirming the existence of a link between variations in Luzon Strait transport and variations in the westerly winds across the central Pacific: the stronger the westerly winds, the greater the transport through the upper-layer of Luzon Strait (Figure 1).

Given these findings, the scientists suspected that the Pacific Decadal Oscillation (PDO) modulates LST by affecting the strength of the North Pacific Tropical Gyre: during warm or positive phases of the PDO, the western Pacific is unusually cool and part of the

The Earth Simulator. Credit: JAMSTEC.

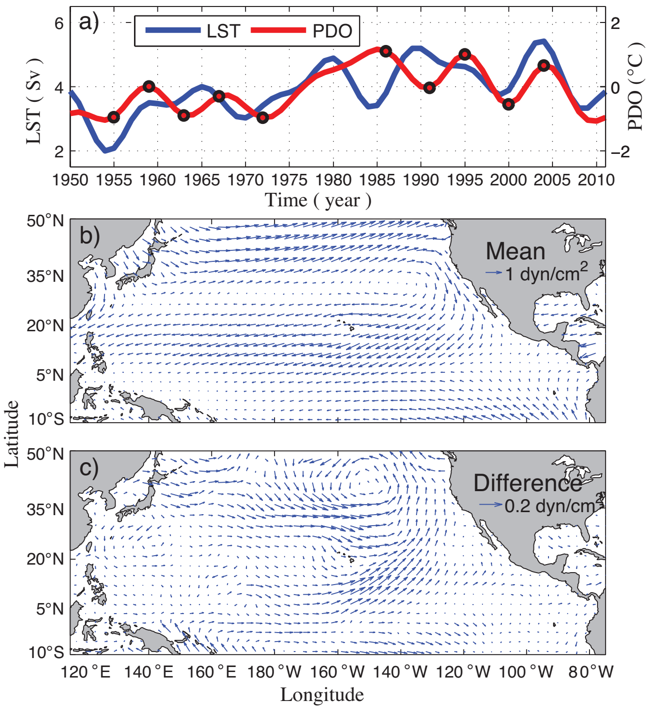


Figure 2. (a) Time series of the upper-layer (0–745 m) Luzon Strait transport (blue) and PDO index (red), (b) long-term (1950–2011) mean wind stress, and (c) its difference between the strong (1959, 1967, 1986, 1995, and 2004) and weak (1955, 1963, 1972, 1991, and 2000) PDO years as marked by the black circles in (a). A 7-year low-pass filter has been applied before plotting.

eastern Pacific unusually warm, resulting in stronger westerlies; during cool or negative phases the opposite happens.

Their hunch was right: further analysis showed that LST is related to the PDO, the correlation being +0.60. In other words, during warm PDO phases, the flow into the upper-layer Luzon Strait tends to be stronger and during cold phases weaker (Figure 2).

To trace the source of this link even further, the scientists filtered their data to include only variations with periods longer than 7 years and then compared composites of positive and negative PDO phases. This revealed that during positive PDO phases an unusually strong Aleutian Low develops and intrudes southward with a positive wind stress curl near 40°N. This intrusion results in the following sequence of events: the northeasterly trades weaken, leading to stronger westerly winds over a large part of the central tropical Pacific; the North Equatorial Current bifurcation (NECb) shifts northward, leading to weaker Kuroshio flow and stronger LST. See Figure 3. (On decadal timescales, the OFES correlation between the NECb latitude and LST is +0.72 and between Kuroshio transport and LST –0.82.)

From 1980 to 1993, the PDO and LST, though, were not in phase. The reason was the effect of the remarkable regime shift observed in the North Pacific during the 70s. Examination of wind-stress anomalies in OFES showed that the center of the Aleutian Low did not move as far south during this period as during other periods, preventing the PDO signals from penetrating into the tropics and from affecting the trade winds.

"In addition to the atmospheric teleconnections described in our study, variability in ocean temperatures and spiciness very likely also impact the decadal variations in Luzon Strait transport," concludes Qu. "These are features we are now beginning to study."

This study is based in part on Kai Yu and Tangdong Qu: Imprint of the Pacific Decadal Oscillation on the South China Sea throughflow variability, *J. Climate* (in press).

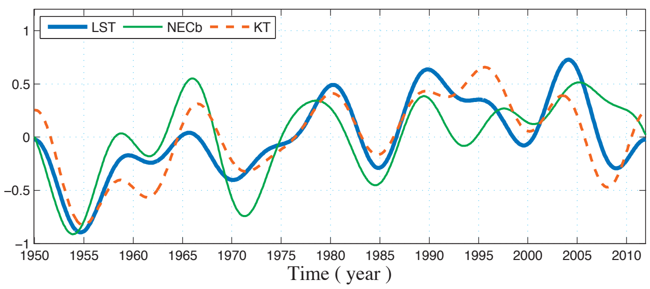


Figure 3. Normalized decadal variability of the upper layer (0–745 m) Luzon Strait transport (blue) and Kuroshio transport (KT: dashed line) compared with the latitude of the North Equatorial Current bifurcation (NECb) (green). Positive values indicate westward transport in the LST, southward transport in the Kuroshio, and northward movement of the NECb.