

South China Sea Takes Center Stage

At the Fourth Annual Symposium of the International Pacific Research Center, several researchers presented their recent findings on South China Sea climate. A group has now formed under the leadership of IPRC's **Tangdong Qu** to coordinate the research in this important climate region. The following pages feature the discovery of how the play among winds, ocean, and the Annamese Cordillera in Indochina results in an unusual cooling of the South China Sea during midsummer, and the search for an oceanic link that conveys El Niño's signal to the South China Sea.

Satellite Images Reveal a Dynamic South China Sea

Linking the Indian and the North Pacific oceans, the South China Sea has been an important sea lane for over thousand years. It formed part of the "oceanic Silk Road" on which Marco Polo returned from China to Venice in 1292–1295. The Chinese Admiral Zheng He's legendary fleet of 27,000 men and over 200 ships sailed seven times during 1405–1433 through the sea into the "West Ocean" (the Indian Ocean), reaching India and even East Africa (Figure 1).

Climatically, the South China Sea is part of the Indo-Pacific warm pool that anchors the strong atmospheric convection of the rising branches of the Walker and the global Hadley circulations. It is the moisture source for rain in southern China in spring and summer and for coastal Vietnam in fall and winter; it is a monsoonal sea, with winds and ocean currents reversing direction during the year. Admiral Zheng understood this reversal well 600 years ago, waiting to leave China during the winter northeasterlies and returning during the summer southwesterlies.

Today a half billion people live along the coast of the South China Sea with its fisheries and other important resources. Despite the region's economic and climatic importance, observations of this sea have been sparse, the few ships traveling the sea at



Figure 1. Map of the region around the South China Sea: White to light blue denotes the continental shelf (depth < 200 m) and the red line, Admiral Zheng's voyage to the Indian Ocean.

any one time taking only limited surface measurements. The resolution of nearly all the popular climatic datasets is therefore too coarse (about 200 km) for close study of this sea. Satellite remote sensing, especially use of cloud-penetrating microwave sensors with resolutions of about 25 km, however, now make possible a detailed study of the South China Sea and other marginal seas smaller than 1000 km. Taking advantage of this emerging opportunity, IPRC scientists are coming to understand this sea's climate better.

One discovery occurred while **Gordon Xie** from the South China Sea Institute of Oceanology (SCSIO) was visiting the IPRC and conducted a satellite study of the summer South China Sea with **Shang-Ping Xie** (co-leader of the Indo-Pacific Ocean Climate research at the IPRC). Together with **Dongxiao Wang** (SCSIO) and **Tim Liu** (NASA Jet Propulsion Laboratory), they set out to explain the seasonal upwelling that takes place off the Vietnamese coast and spreads eastward into the South China Sea, resulting in unusual cooling in midsummer. Previous studies had failed to determine whether this was a typical summer phenomenon and what caused the offshore cold filaments that extend for more than 1000 km over the ocean. Analyzing a suite of images by the QuikSCAT, Tropical Rain Measuring Mission, European Remote Sensing, and TOPEX/Poseidon satellites, the researchers found

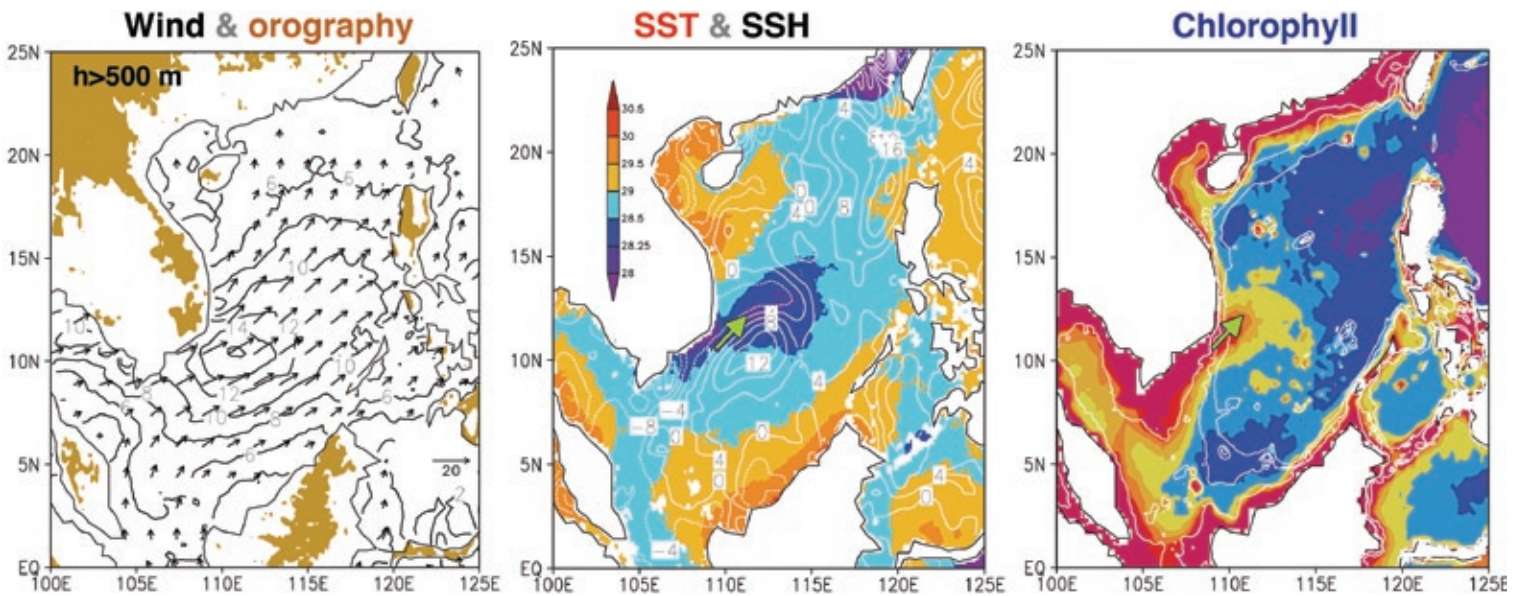


Figure 2. Summer climatology over the South China Sea. From left, wind stress vectors and land orography (brown > 500 m); SST (color bar in °C) and sea surface height deviation from the annual mean (cm); chlorophyll concentration (high values red, low values blue and purple) and 50-, 200-, and 500-m-depth contours. Green arrows in the middle and right panels indicate the offshore jet that advects cold and nutrient-rich upwelled water from the coast.

that the Annamese Cordillera affects the winds along Indochina's eastern coast, causing the upwelling filaments. Blocked by this coastal range, about 1 km high, the southwest monsoon accelerates at its southern tip, forming a strong offshore wind jet (Figure 2). This jet upwells coastal water; Ekman downwelling on the southern flank of the wind jet forces a stationary oceanic anticyclonic eddy east of Saigon. Reaching 50 cm/s, the offshore jet of the eddy draws in the cold, upwelled water from the coast and spreads the cooling. The wind jet also cools the ocean offshore through strong evaporation and open-ocean Ekman upwelling on its northern flank.

This sequence of events happens each summer except during unusual climate conditions in the Pacific. For instance, in 1998, an El Niño year, little midsummer cooling took place. A statistical analysis shows that the extent of the cooling

is affected by sea surface temperature (SST) in the eastern equatorial Pacific six months earlier.

This study, thus, casts the mountain range's blockage of the monsoon as the cause of the cooling along the coast and the open sea, with conditions in the eastern equatorial Pacific modulating the mountains' effect. Recently Gordon Xie obtained a grant from the Natural Science Foundation of China to study further the South China Sea upwelling and the remarkable eddy.

Another noteworthy South China Sea climate feature occurs in winter, when the northeast monsoon dominates the sea. Markedly cool SST (<28°C) stretches toward the equator (Figure 3, page 4). Over the cool ocean south of Vietnam, atmospheric convection is suppressed. Analyzing satellite data, Shang-Ping Xie and his colleagues (Qinyu Liu and Xia Jiang of Ocean University of China, and Tim Liu of JPL) discovered a surprising reason for this cold tongue: ocean bottom topography. An extensive continental shelf (Sunda Shelf) lies south of Indochina, with a deep basin that reaches in places a depth of more than 4000 m to the east (Figure 3). In response to the cyclonic winter monsoon, the steep shelf break along 108°E

steers a southward jet as a western boundary current. Flowing up to 50 cm/s (as determined from calculations using satellite altimetry observations), this swift current draws in cold water from the northern South China Sea, where the chill and dry continental air cools the warm ocean. A close look shows that the center of the cold tongue is systematically displaced to the west of the southward ocean jet, something that Xie and colleagues attribute to the advection by a shallow westward Ekman current that flows to the right of the prevailing winds in the Northern Hemisphere. Over the deep eastern basin, a broad northward-moving current which is part of the same cyclonic gyre, advects warm water from the south. As a result, large SST gradients develop in the east-west as well as the north-south direction.

During and following an El Niño (which tends to peak in December), the winter and summer monsoons both weaken, causing the ocean circulation to spin down. As a result, the winter cold tongue and the summer upwelling filaments are weaker or disappear altogether. Such changes in ocean circulation, in turn, affect SST and the monsoon. Indeed, SST varies the most from one winter to the next south

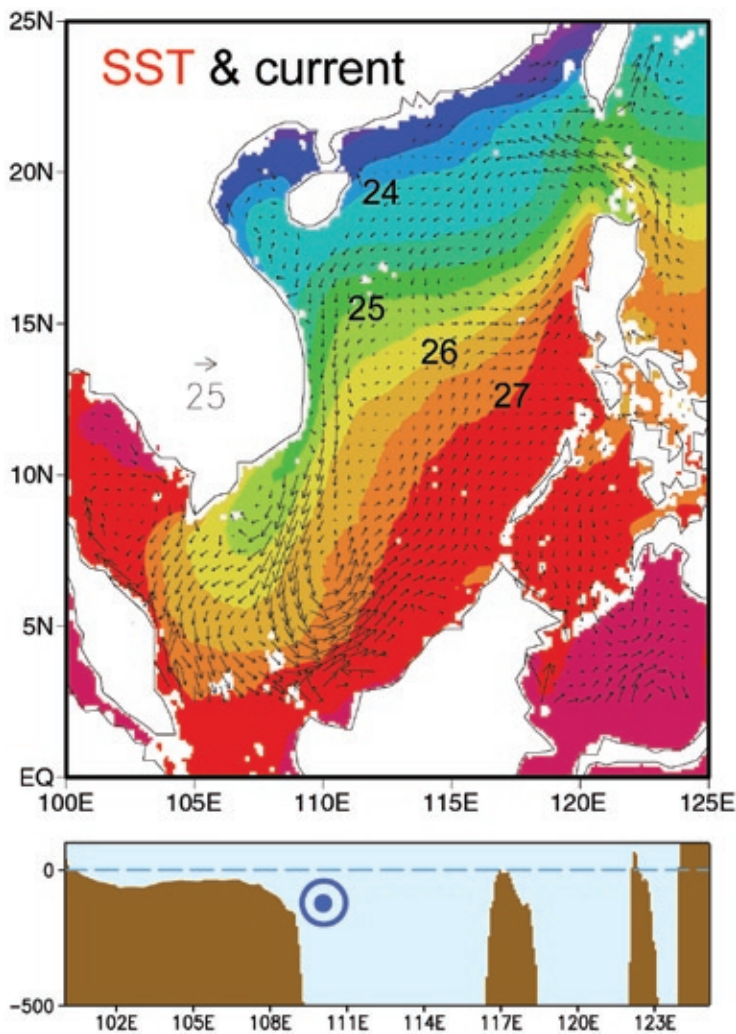


Figure 3: (Top) Winter climatology with SST (color in °C) and surface geostrophic current vectors (cm/s); (bottom) bathymetry (m) along 7° N. The steep continental break steers a southward jet in the upper ocean.

of Vietnam and from one summer to the next east of South Vietnam. Both regions have strong seasonal ocean jets, and their SSTs correlate highly with El Niño as measured by an SST index in the eastern Pacific.

In modeling its SST variations, scientists have often treated the Indo-Pacific warm pool as a motionless mixed layer 50 m deep. The above studies, however, reveal a highly dynamic South China Sea circulation that affects SST greatly and has an atmospheric teleconnection from the Pacific El Niño contributing to its interannual variations.

Variations in Pacific climate may also be communicated to this sea by oceanic pathways such as the water exchange through the Luzon Strait. In the next section, IPRC scientists explore this communication pathway.

Anthropogenic increase in atmospheric carbon dioxide is contributing to global warming. Moreover, the amount and types of nutrients discharged by rivers are changing the physics and biology of marginal seas around the world. A better

understanding of the dynamics of South China Sea climate and its interaction with the larger-scale ocean-atmosphere system would be a significant step toward tackling difficult issues of the climate variability and climate change in such regions. The complex bathymetry and dynamic nature of the circulation in the South China Sea require, however, studies with high-resolution models and comparisons of their solutions with satellite images in order to project how climate may change in this important sea. The next step is now to synthesize the various research approaches described above and in the next section by using a regional ocean-atmosphere model, such as the IPRC Regional Atmospheric Model.

Does an Oceanic Pathway Transmit El Niño's Signal to the South China Sea?

Although South China Sea climate is part of the East Asian monsoon system, evidence is mounting that the El Niño–Southern Oscillation (ENSO) in the Pacific affects also this sea. The transmission of this signal has been sought mainly in atmospheric data. For example, the work of **Bin Wang**, co-leader of IPRC's Asian-Australian Monsoon System research team, and his colleagues showed that during and after the mature phase of El Niño, an anomalous anticyclonic circulation over the Philippine Sea cools the sea surface of the western North Pacific and warms that of the South China Sea.

Tangdong Qu, with colleagues at IPRC and elsewhere, is exploring an oceanic connection: the transport of water through the Luzon Strait between Taiwan and the Philippines. This connection is well known, but how transport through the straits affects South China Sea's climate has not been studied in detail.

The Luzon Strait transport is formed by a branch of the Kuroshio. Once this water has passed through the strait into the South China Sea, it becomes part of a cyclonic circulation in the northern basin (Figure 4). In their 2004 study, **Max Yaremchuk** and Qu used a 3-dimensional variational data-assimilation technique to diagnose the mean seasonal cycle of the circulation east of Luzon. They found that in late fall–early winter, in response to the general upward Ekman pumping resulting from the monsoon winds east of Luzon, the Kuroshio becomes weaker, allowing deeper penetration and larger transport through the Luzon Strait (Figure 5). After entering the South China Sea, the relatively warm Kuroshio waters are drawn into the cyclonic circulation in the northern part of the basin. Numerical simulations show that it takes approximately 5–6 months for a water parcel to travel from northern Luzon to the region east of Vietnam (Figure 4). Increased monsoon winds in October–January, therefore, may increase the upper-layer heat content east

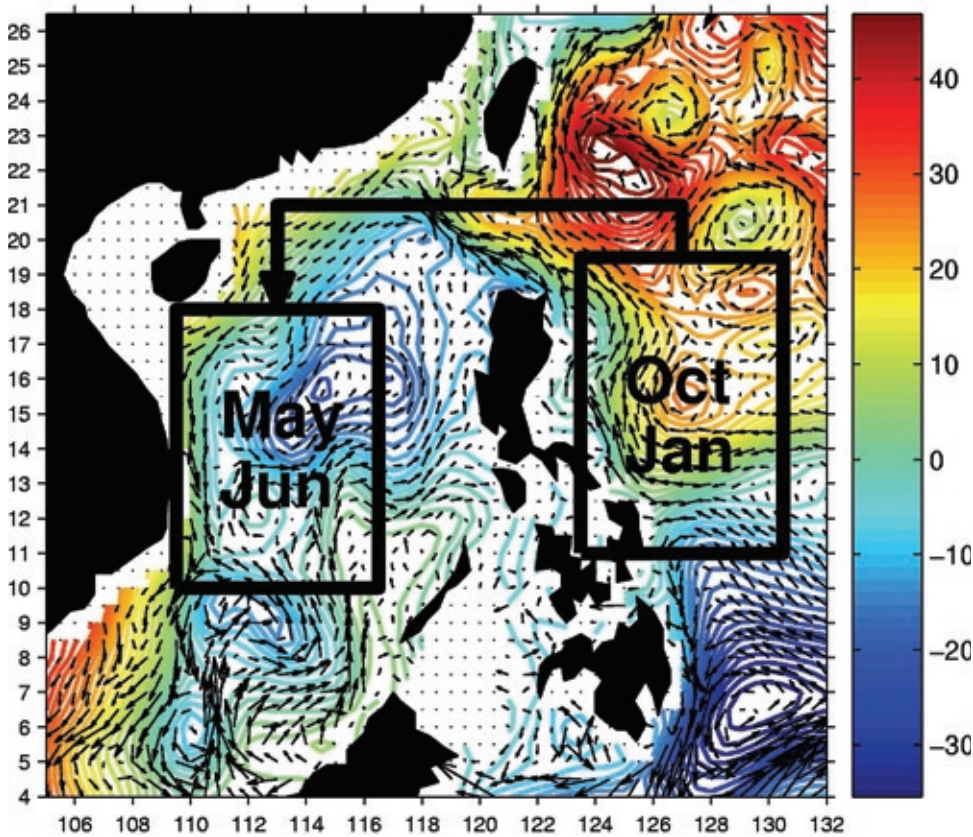


Figure 4. Mean January sea surface height (color) and currents at 30-m depth in the 6-year OFES model simulation. Black rectangles show the regions of late fall–early winter monsoon forcing of the Kuroshio (right) and the sea surface temperature response during late spring–early summer (left).

of Vietnam the following May–June and may affect the development of the summer monsoon over the South China Sea.

To verify this hypothesis, Yaremchuk and Qu studied the effect of transport variations through the Luzon Strait on the SST and upper-layer heat content in the region shown in the left box of Figure 4. First, they analyzed statistically long-term numerical model runs of the circulation and characteristics of the South China Sea and found that December transport variations and subsequent June SST east of Vietnam are significantly correlated. Then using a numerical simulation that captures more realistically the South China Sea seasonal cycle, they reconstructed the seasonal cycle by assimilating climatological variational data into a regional South China Sea model that was controlled by open boundaries and

surface forcing. In the model solution, they assessed the sensitivity of SST to the transport by computing the derivative

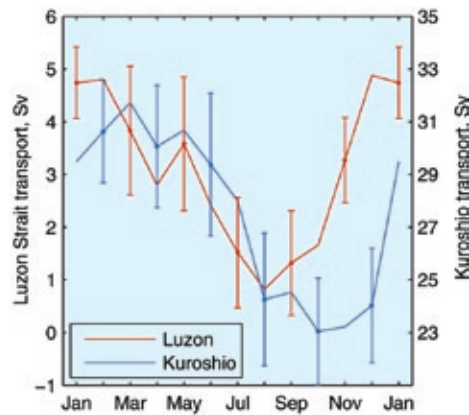


Figure 5. Mean annual cycle of the Luzon Strait and Kuroshio transports obtained by a 3-dimensional diagnostic analysis of climatological data (Yaremchuk and Qu, 2004).

of the mean May–June SST east of Vietnam with respect to the magnitude of inflow velocities in the Luzon Strait during the preceding months (Figure 6). These computations support the result from the statistical analysis of the long-term numerical simulations and give an estimate of the impact of the Luzon Strait transport on SST in terms of the local heat-flux anomalies: 1 Sv increase in transport during November–January is equivalent to a 2 W/m² increase in surface heat flux during the development of the summer monsoon the following May–June. Since the October–January transport through the strait correlates positively with the winter monsoon wind forcing east of the Philippines, the transport may account for the negative correlations seen not only between the SSTs but also between the winds in the two regions. Indeed, they noted these negative correlations in independent sets of monthly averaged anomalies of ocean surface characteristics during May–June east of Vietnam and during the previous October–January east of the Philippines

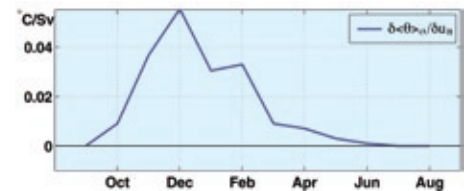


Figure 6. Time evolution of the derivatives of the mean SST $\langle \theta \rangle_{\sigma}$ with respect to the Luzon Strait transport temperature averages. The $\langle \theta \rangle_{\sigma}$ are defined as the mean values from end of April to end of May over the region in the left rectangle in Figure 4.

(Figure 7). Thus, the heat transported through the Luzon Strait during late fall–early winter seems, indeed, to affect the South China Sea monsoon the following summer.

In a related study, Qu and his colleagues (2004) analyzed results from the JAMSTEC model and found that the Luzon transport tends to be greater during El Niño years and lesser during La Niña years. Being associated with variations in the Kuroshio transport east of Luzon, these interannual variations

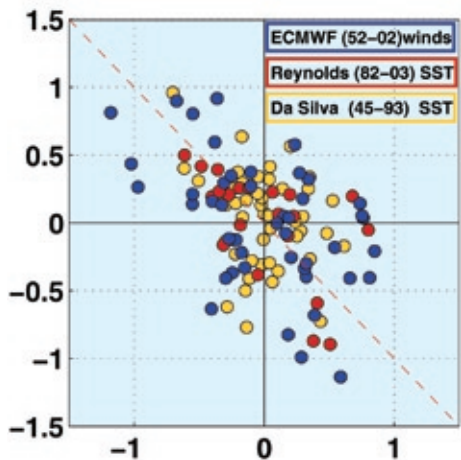


Figure 7. Scatter plot of the monthly averaged observations east of Vietnam in May–June and east of the Philippines in the preceding October–January. Observations cover 1952–2003 (ERA40 winds, in m/s), 1946–1992 (Da Silva SST in °C), and 1982–2004 (Reynolds SST in °C). The axes are in °C for SST and in m/s for wind.

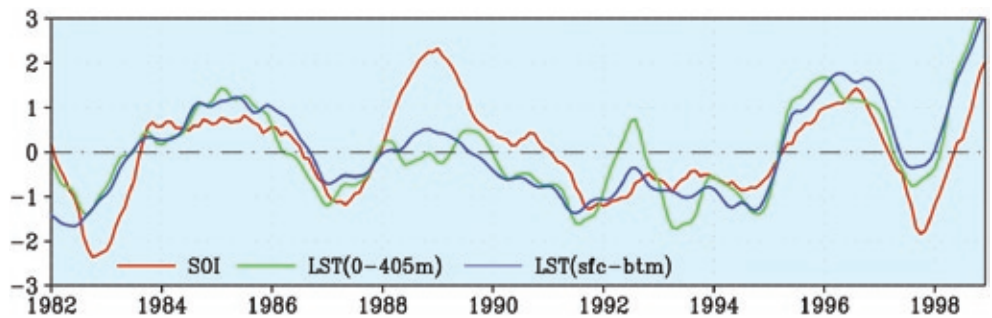


Figure 8. Interannual variations in Luzon Strait transport and the Southern Oscillation Index normalized by their respective root mean square variance from the JAMSTEC model (after Qu et al., 2004).

appear to be driven by hysteresis of the Kuroshio. The correlation between the transport and the Southern Oscillation Index (SOI) reaches 0.63 (Figure 8). El Niño and La Niña also leave strong signatures in the upper-layer (0–400 m) heat content of the South China Sea. Thus, in the summer following an El Niño, the heat content in the upper layer of the South China Sea increases owing to increased Luzon Strait transport, which could have been one of the reasons why the midsummer cooling in the South China Sea during the 1998 was much weaker (p. 3).

Given this evidence that transport through the Luzon Strait is capable of transmitting seasonal and interannual large-scale ocean-atmosphere phenomena from the western Pacific to the South China Sea, IPRC scientists are now determining in detail how this transport affects the dynamics of South China Sea climate.

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