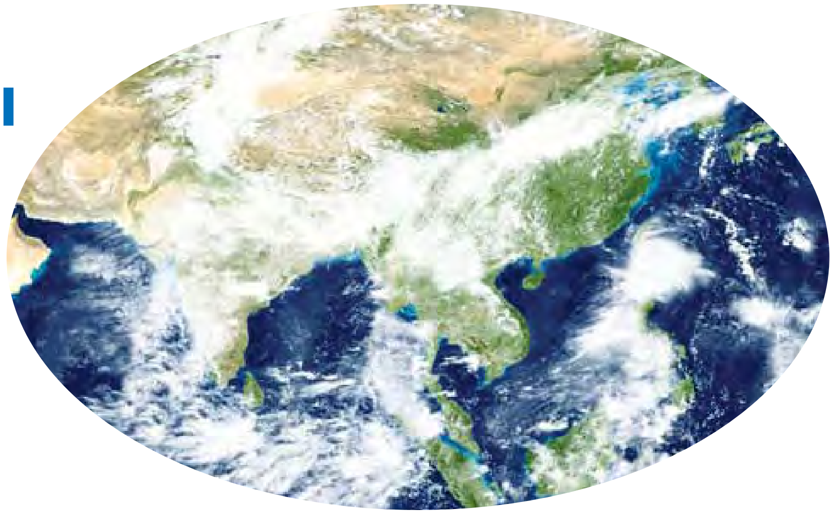
Mysterious Summer Rains

How Does the Tropical Indian Ocean Affect Summer Climate of the Northwest Pacific and East Asia?



Satellite image of clouds over Asia. Earth observatory NASA blue marble

Summer is the rainy season for much of East Asia. In some summers or some regions, the rains may be strong, causing severe floods, in other summers or other regions, they may fail. Already in the 1980s, meteorologists noted a peculiar relationship: the Meiyu-Baiu rainfall and summer rainfall in certain parts of East Asia correlate not with concurrent equatorial Pacific sea surface temperature (SST) as would be expected, but with an El Niño that occurred two seasons earlier. The major floods that devastated vast regions in the Yangtze River Basin during 1998 summer are a striking example of prolonged effects of a major El Niño event. A series of studies by **Shang-Ping Xie, Jan Hafner, Hiroki Tokinaga,** and **Takeaki Sampe** at the IPRC, and colleagues at the Ocean University of China and the Chinese Academy of Sciences, now provide strong evidence that these anomalous rainfall patterns are induced by El Niño conditions that linger on in the far away tropical Indian Ocean.

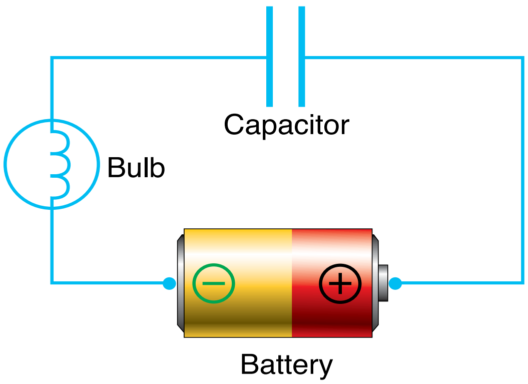
The Mystery

El Niño peaks in December and by the following summer, the atypical warm surface water in the central and eastern Pacific has usually disappeared. What provides the memory of these conditions that impact East Asia's summer climate six months after the El Niño peak? Previous studies linked these East Asian climate anomalies to an El Niño-induced anticyclonic circulation and suppressed atmospheric convection over the subtropical Northwest Pacific. Other anomalies, however, also persist into the next summer after an El Niño. For example, the troposphere in the tropics warms when El Niño peaks in winter, and this warming persists into the next summer. These two sets of anomalies—the surface circulation in the subtropics and the tropospheric warming trapped mostly in the narrow equatorial belt—are far apart both geographically and vertically. The team of scientists, however, discovered that they are intimately linked through something happening in the tropical Indian Ocean.

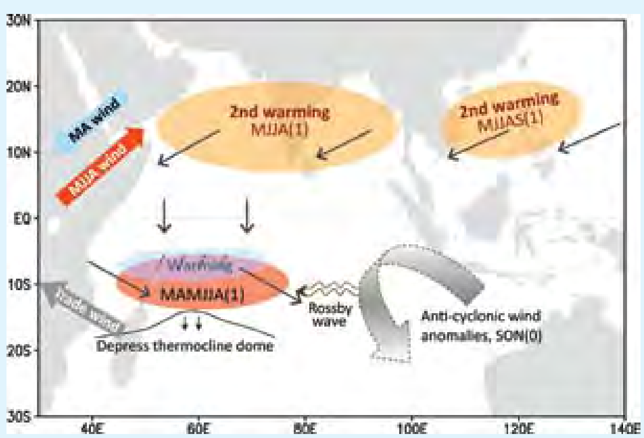
Hukou County (Jiangxi Province) government building in summer 1998. Photo source: Hukou government website.

The Capacitor Effect

It has been well known that El Niño conditions warm the tropical Indian Ocean basin-wide through teleconnection mechanisms. A 2007-collaborative study by Xie and colleagues at the Ocean University of China proposed that El Niño charges the tropical Indian Ocean like a battery charges a capacitor, and the persisting tropical Indian Ocean warming exerts its climatic effect like a discharging capacitor after El Niño itself has dissipated. See "Charging the Indian Ocean Capacitor" [Side Bar] for details of this significant study.



How a capacitor works.



Schematic of the asymmetric atmospheric anomalies triggered by Rossby Waves over the thermoclime dome in the tropical South Indian Ocean, and the northeasterly wind anomalies that lead to the second summer warming over the North Indian Ocean.

Charging the Indian Ocean Capacitor

The basin-wide surface warming of the tropical Indian Ocean a few months after an El Niño peaks came to scientific attention in the late 1970s. Then in 1999, in a survey of historical ship observations, **Stephen Klein** and colleagues at the Geophysical Fluid Dynamics Laboratory found that the changes in clouds and wind-induced evaporation during an El Niño form an atmospheric bridge in which the descending circulation branch warms the tropical Indian Ocean. Experiments with atmospheric GCMs coupled to ocean mixed-layer models support this bridge effect.

The work led by **Yan Du**, formerly at IPRC and now at the South China Sea Institute of Oceanology, Chinese Academy of Sciences, revealed that in the North Indian Ocean and the South China Sea the sea surface temperature peaks twice. The first peak occurs during the peak of El Niño, signaling the direct effect of the atmospheric bridge from the Pacific. The second peak, however, occurs in June–July after El Niño has dissipated. This second peak must be induced by some form of memory mechanism beyond the Pacific, the scientists concluded.

That mechanism, they found, consists of downwelling ocean Rossby waves triggered during El Niño in the tropical Southern Indian Ocean. As these waves propagate westward, they warm the tropical southwestern Indian Ocean by deepening the usually shallow thermocline. The slowly propagating warm Rossby waves anchor a wind pattern that intensifies atmospheric deep convection during the spring after El Niño. This excites a basin-wide asymmetric atmospheric circulation, with anomalous northeasterlies north of the equator and anomalous northwesterlies south of the equator (see figure). As the prevailing winds turn southwesterly with the summer monsoon onset, the opposing northeasterlies weaken the southwest monsoon, giving rise to the pronounced second warming over the northern tropical Indian Ocean and the South China Sea.

This second warming is confined in the North Indian Ocean to the mixed layer and results mostly from a change in wind-induced evaporation, as Klein and colleagues have shown. The new piece in the climate-dynamics puzzle is the finding that the slow Rossby waves propagating on the thermocline anchor the North Indian Ocean wind anomalies. Given the climatic effects (see main text), this ocean-atmosphere interaction can be exploited for seasonal climate prediction.

Tropospheric Warming and Kelvin Wave Induced Rainfall

The work on the capacitor effect led to a new puzzle: Why are the most pronounced anomalies of rainfall and surface circulation observed in the subtropics and not on the equator?

Xie and his colleagues at the IPRC and the Chinese Academy of Sciences found the answer to these questions. During the summer following an El Niño, the warm tropical Indian Ocean heats the troposphere in towering cumulonimbus convection. This tropospheric warming spreads horizontally in accordance with equatorial wave dynamics first described by Taroh Matsuno in 1966. Specifically, Rossby waves carry the warming westward off the equator, while to the east, a wedge-like Kelvin wave, trapped on the equator, penetrates into the western Pacific (red contours in Figure 1). The tropospheric temperature warming resembles the equatorial wave response to isolated heating on the equator, a solution first described by Adrian Gill in 1980.

And how does the Kelvin wave circulation induce rainfall anomalies in the subtropics? Surface friction is the key. The warm Kelvin wave is accompanied by low surface pressure centered on the equator. Surface friction drives southwesterly winds (green vectors in Figure 1) on the northern flank of the Kelvin wave. The resulting surface divergence suppresses atmospheric convection in the subtropical Northwest Pacific (light gray in Figure 1), and the reduced latent heat release spins up the anomalous anticyclonic circulation, which in turn intensifies surface divergence. These anomalous conditions are part of a north-south dipolar teleconnection that retains a memory of this past. This meridional atmospheric teleconnection with suppressed convection over the Philippines and Guam and a low pressure center just east of Japan is called the Pacific-Japan pattern, first discovered by **Tsuyoshi Nitta** in 1987. This teleconnection favors the summer hemisphere because feedback between circulation and convection is stronger there than in the winter hemisphere.

The atmospheric circulation adjustment due to Kelvin-wave induced Ekman divergence illustrates that convective feedback in the tropics can result in moist teleconnections that differ from those in dry wave dynamics. More research into moist teleconnection dynamics should improve understanding and prediction of climate impacts that are of tropical origin.

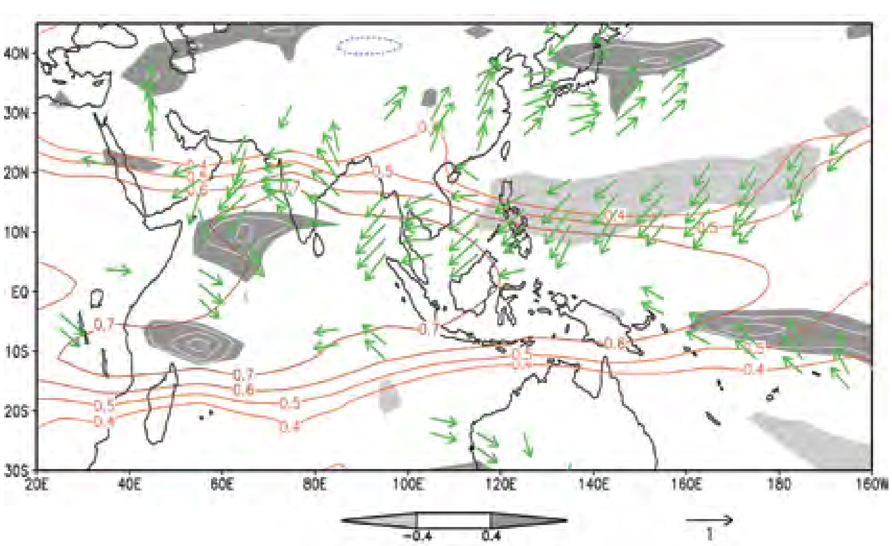


Figure 1. June–August correlation with previous November–January Niño-3.4 SST index: tropospheric (850–250 hPa) temperature (contours), precipitation (white contours at intervals of 0.1; dark shade > 0.4; light < −0.4), and surface wind velocity (vectors).

Above: Flooded boulevard in Huangshi City along the Yangtze River in summer 1998. Source: http://www.hsdcw.com/html/2009-8-18/211092.htm.

Prediction Experiment

Postdoctoral fellow **Jasti Chowdary** led an IPRC–JAMSTEC collaboration to study a hindcast of East Asian climate for 1997–98, the period of the "El Niño of the century." Peaking in December 1997, El Niño had decayed almost completely when in the following summer, stations of the Yangtze River Basin recorded the highest river levels ever. Although the government spent enormous efforts to build levees along great stretches of the riverbanks, the destruction was immense. The floods left 14 million people homeless.

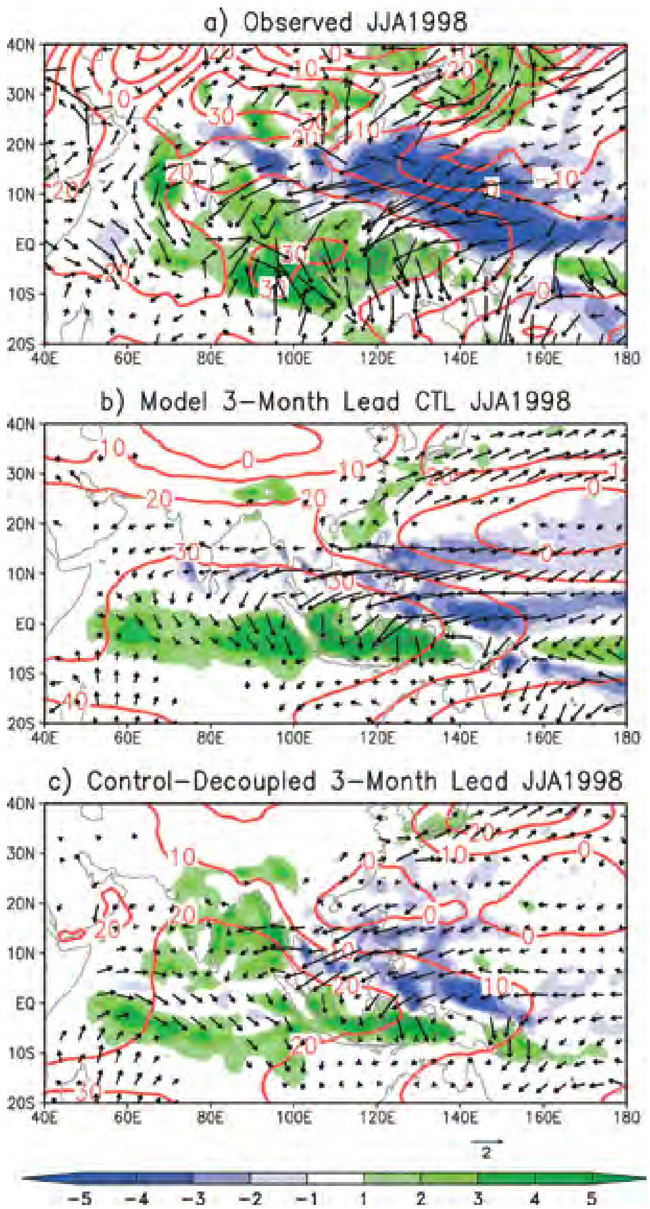


Figure 2. Anomalies of precipitation (shaded in mm/day), tropospheric temperature represented by geopotential height difference between 200 hPa and 850 hPa (contours in m) and surface winds (vectors in m/s) during June–August 1998: (a) observations, (b) Control run, and (c) Control minus No Tropical Indian Ocean (NoTIO) run. Both Control and NoTIO runs were initiated with conditions 3 months earlier, in March.

The 1998 summer floods fit the typical pattern of the Northwest Pacific–East Asian response to El Niño. A strong anomalous anticyclone circulation with suppressed convection developed over the subtropical Northwest Pacific, exciting the Pacific-Japan pattern with unusually heavy rainfall from eastern China to Japan.

The hindcast was run with the coupled ocean-atmosphere forecast model developed by **Jing-Jia Luo** at JAMSTEC. The control run, initiated three months beforehand, showed the unusual circulation pattern over Asia in summer 1998 and the anti-cyclonic circulation over the subtropical Northwest Pacific (Figures 2a and 2b). Although the model run displaced the heavy rainfall over eastern China and the Yangtze Basin offshore to the southeast, it captured the strong southwest winds that fed the huge rainfall over eastern China, and it showed the broad tropospheric warming over the tropical Indian Ocean and the warm Kelvin wave wedge penetrating into the western Pacific along the equator.

The team tested specifically for the capacitor effect in a model run without the tropical Indian Ocean warming due to El Niño. Results are shown in Figure 2c. This run reproduced only a weak version of the El Niño related pattern, supporting Xie's and his colleagues' explanation for the mysterious lingering effects of El Niño on East Asia and Northwest Pacific climate. This new understanding of the link between climate conditions in the Pacific and Indian Oceans, and the East Asian summer rainfall and Pacific-Japan pattern, bodes well for predicting future extreme events.

This story is based on the following scientific articles:

Chowdary, J. S., S.-P. Xie, J.-J. Luo, J. Hafner, S. Behera, Y. Masumoto, and T. Yamagata: Predictability of Northwest Pacific climate during summer and the role of the tropical Indian Ocean. *Clim. Dyn.*, in press.

Xie, S.-P., K. Hu, J. Hafner, H. Tokinaga, Y. Du, G. Huang, and T. Sampe, 2009: Indian Ocean capacitor effect on Indo-western Pacific climate during the summer following El Niño. *J. Climate*, **22**, 730–747.

Du, Y., and S.-P. Xie, K. Hu, G. Huang, 2009: Role of air-sea interaction in the long persistence of El Niño-induced North Indian Ocean warming. *J. Climate*, **22**, 2023–2038.