The North Pacific Subtropical Countercurrent

Mystery Current with a History

By Fumiaki Kobashi*and Shang-Ping Xie

In the subtropical North Pacific, the surface wind field is characterized by westerlies to the north and the northeasterly trade winds to the south. For the most part, these winds have an anticyclonic spin and their wind stress curls drive the North Pacific subtropical gyre. In the central to southwestern part of the subtropical gyre around 19°–26°N, an unusual current flows eastward in the otherwise westward current (Figure 1). Called the North Pacific Subtropical Countercurrent (STCC), this shallow current flows against the broad westward flow and against the flow predicted from the wind field. Discovered more than 40 years ago, the unexpected counter flow was first thought to be driven by a local change in the wind field, a theory later disproven. Together with **Naoto Iwasaka** at Tokyo University of Marine Science and Technology and **Takashi T. Sakamoto** at JAMSTEC, we recently revisited the wind field over the STCC and found something surprising: the STCC actually drives the winds!

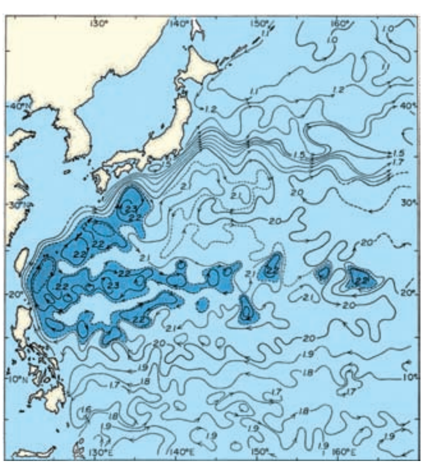

Figure 1. Long-term mean sea surface dynamic height anomaly relative to 1000 dbar, in dynamic meters (10 m^2/s^2). The STCC is marked by the filled contours (darker blue areas) stretching eastward around 19°–26°N. From Hasunuma and Yoshida (1978).

Michitaka Uda of Tokyo University of Fisheries (now at Tokyo University of Marine Science and Technology) and **Keiichi Hasunuma** (an undergraduate at Tokyo Fisheries University at the time of the discovery and later at the University of Tokyo) discovered the STCC from hydrographic observations and direct current meter measurements. They presented their discovery at the annual meeting of the Oceanographic Society of Japan in 1967 (the paper was formally published two years later in 1969). Their analysis revealed that the STCC persists throughout the year and accompanies the subsurface subtropical front, which shows large north-south temperature and density gradients at 100–200-m depth.

Uda and Hasunuma's discovery caught the attention of **Kozo Yoshida**, the great University of Tokyo theoretician, who is known for the prediction of the Yoshida-Wyrtki jet on the equator. He and his secretary **Toshiko Kidokoro** immediately proposed a wind-driven theory for the STCC and supported it with an analysis of historical ship-based wind data compiled by **Koji Hidaka** of the University of Tokyo. In a pair of papers in 1967, they reported weak anticyclonic wind curls roughly along the STCC and suggested that this minimum, or trough, in anticyclonic wind curls forces the STCC.

The Yoshida and Kidokoro explanation was, however, overturned 17 years later in 1984 by Yoshida's own student, **Kensuke Takeuchi** (former co-chair of the IPRC Scientific Advisory Committee). Takeuchi simulated an STCC using an idealized ocean general circulation model and found that the STCC is reproduced even under wind stress forcing that does not have the wind curl trough, indicating that the wind curl trough proposed by Yoshida and Kidokoro is not essential for the STCC. He also showed that the STCC is not caused by frontogenesis due to meridional Ekman convergence, another possible mechanism that was suggested at the time for STCC formation.

Much debate about what drives the STCC then followed in the 1980s and 1990s, and several theoretical and numerical studies were conducted to unravel the mystery. In 1999 **Atsushi Kubokawa** of Hokkaido University proposed that the STCC and the subtropical front form along the southern edge of the North Pacific mode waters, the vertically homogeneous water masses that form in the deep mixed layer east of Japan and ventilate the thermocline to the south in the subtropical gyre. Kubokawa's mode-water ventilation mechanism quickly won support from observational studies at Tohoku University (Yoshikazu Aoki, Toshio Suga, and Kimio Hanawa) in 2002 and at the IPRC (Fumiaki Kobashi, Humio Mitsudera, and Shang-Ping Xie) in 2006. Generating the STCC with smooth wind forcing, this mechanism does not require the wind curl trough that Yoshida and Kidokoro reported.

There have been no follow-up studies of the wind curl trough since Yoshida and Kidokoro's study. The Hidaka wind charts they used were based on sparse ship observations prior to 1958. Is their wind curl trough a robust feature or an artifact of the Hidaka's wind charts?

Recently our team of scientists at Tokyo University of Marine Science and Technology, the IPRC, and JAMSTEC revisited the winds and the wind curl trough using QuikSCAT and TRMM satellite observations and an atmospheric reanalysis. We discovered that a wind curl trough similar to the one described by Yoshida and Kidokoro really does exist but it is the atmosphere's response to the STCC instead of the other way around!

Satellite observations reveal that the wind stress curl turns slightly cyclonic around 22°N during April and May, forming a wind stress curl trough in the general background of anticyclonic curls (Figure 2a). The wind curl trough is collocated with a band of a tall column high in water-vapor content and is anchored by the higher sea surface temperature (SST) of the subtropical front (Figure 2b). The team has found that during April and May, midlatitude weather disturbances trigger subsynoptic-scale low-pressure systems along

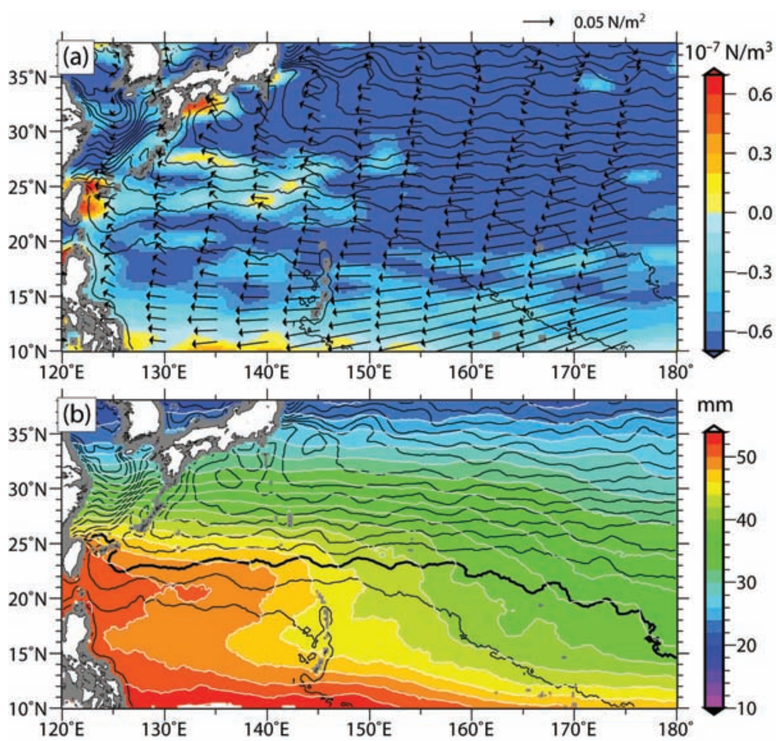

Figure 2. May climatology of satellite observations: (a) vector wind stress and its curl (color: the light blue, at times yellow color, around 25°N shows a trough of wind curl over the STCC), and (b) columnar water vapor (color), along with sea surface temperature (black contours at intervals of 1°C). The thick black contour marks the 27°C isotherm. The wind curl trough accompanies a high water-vapor band to the south.

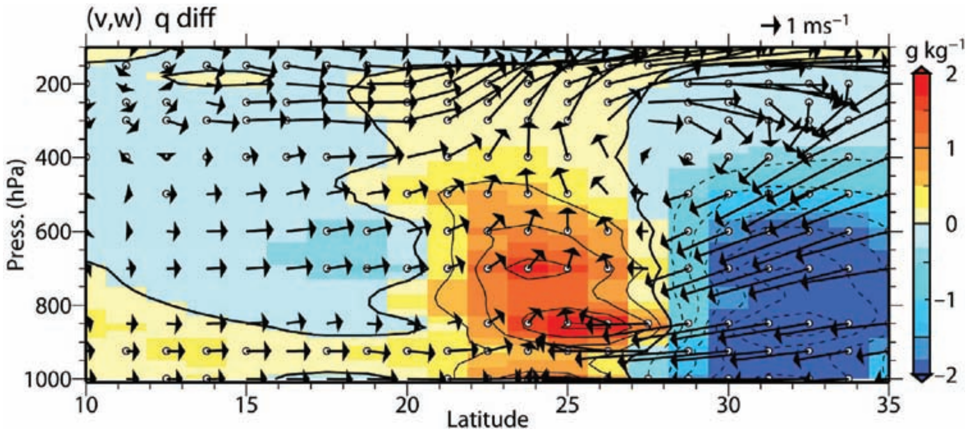

Figure 3: Latitude-height section at 142.875°E showing composite differences in cyclonic minus anticyclonic curl between meridional and vertical winds (vectors) and specific humidity (color). The vertical wind speed is multiplied by 100. Open circles show grid points where specific humidity is higher than the mean humidity field with 95% or greater certainty.

the SST front. In the lows, convective rain takes place, with deep upward motion moistening the entire troposphere (Figure 3). The lows are enhanced by condensational heating and grow on the baroclinicity anchored by the SST front, giving rise to the formation of cyclonic wind curls. The subtropical front seems unique among major SST fronts in featuring temperatures above 27°C on its southern flank, temperatures high enough to support deep convection.

We found enhanced rainfall associated with the wind curl trough. Previous meteorological studies have noted that this increase in rainfall appears to correspond to the so-called pre-Baiu/Meiyu front. The pre-Baiu/Meiyu front is manifested as a cloud and rain band just before the onset of the Baiu/Meiyu, one of the most remarkable events in the East Asia summer monsoon. The subtropical front seems to anchor this pre-Baiu/Meiyu band, a hypothesis that needs further investigation.

Thus, 40 years after the original work by Michitaka Uda and Keiichi Hasunuma, our study shows that the wind curl trough is not the cause but an effect of the STCC. Although not essential to the formation of the STCC, the wind curl trough, however, may yet influence and feed back onto the STCC. For example, the STCC varies on seasonal and interannual timescales but the mechanism by which this happens has not been pinpointed. For a fuller understanding of STCC variations, we are now studying the impact of the wind curl trough and potential vorticity on the STCC.

***Keiichi Hasunuma**, the co-discoverer of the STCC and now owner of an ocean consulting company in Japan, kindly commented on this news article and gave his perspective of future STCC research. A translated summary of his comments follow.*

I really enjoyed reading this article and was amazed by the advance in STCC research. The article tells well the history of how the research has evolved over the past four decades. Here I first would like to tell you a bit of history how we discovered the STCC.

Since I liked the ocean and wanted to become a sailor, I entered Tokyo University of Fisheries. In my junior year, I wavered whether to go into the training for ship officers or to study fisheries and ocean science. Prof. Uda taught classes in the latter field. At the time I belonged to the Ocean Study Club, which I helped to start. One of the senior students at the club told me about interesting features of the ocean such as cold water upwelling around the equatorial islands of the Galapagos, where amazingly one can find penguins and iguanas living side by side. His talks attracted me to ocean science, and I decided to work with Prof. Uda.

One day I asked Prof. Uda about what I should do for my graduation thesis. He gave me a few volumes of hydrographic data, and advised me to look at the ocean by graphing plots from the data. He also suggested that I focus first on the Oyashio front region east of Japan where there were relatively many observations. In studying and graphing the Oyashio front, I realized that in regions of high temperature, a change in temperature causes a relatively large change in density (due to nonlinearity of the seawater equation of state). This means that modest temperature gradients in a warm ocean can form a substantial density front. I hit on an idea that, though the temperature gradient of the subtropical convergence zone is much weaker than at the Oyashio front, it could produce a density front and support an eastward current. I got to work and was very happy that we got enough results for Prof. Uda to give a talk on the STCC at the Oceanographic Society meeting.

Prof. Yoshida reacted very strongly to our talk at the meeting. His secretary, Toshiko Kidokoro, immediately went to work with a mechanical computer. The results were the Yoshida and Kidokoro papers in 1967. While my study with Prof. Uda was purely hydrographical, Prof. Yoshida thought of the same phenomenon in terms of wind-driven ocean circulation. I vividly remember that one of their papers had the subtitle "A prediction of eastward flows." I was impressed by their dynamical approach of simulating the STCC from the wind atlas. Yoshida and Kidokoro's papers were published quickly, right after we presented our discovery. We were really excited and began to prepare publishing our results. Around that time I moved to the University of Tokyo for graduate school. I worked with Prof. Yoshida on another project and did not spend much time on STCC research. Our observational paper was finally published two years after Yoshida and Kidokoro's.

Though many new observational facts have come out since then, I still feel that they do not fully capture all the features of the STCC. For further understanding, we should have a new perspective for STCC research. In the paper published in 1978, Yoshida and I showed that the North Equatorial Current, which flows westward along the southern side of the subtropical gyre, veers to the north near the western boundary and then mostly connects to the STCC, forming a subgyre of anticyclonic circulation with the STCC. The STCC is considered to interact with this subgyre system, though it has not been studied so far from this point of view. Evaluating the STCC not alone but as part of the subgyre system could open a new door for STCC research.

Finally I would like to tell you that at an international meeting held in Japan in 1972, I had an opportunity to talk with Prof. **Raymond B. Montgomery** of Johns Hopkins University. He showed great interest in the STCC, and after returning home, wrote a short letter to me. He said that he thought that it would be more appropriate to use the term "Tropical Countercurrent" than "Subtropical Countercurrent." Although he did not explain the reason, I guess he thought this because the countercurrent flows along the tropic of Cancer. I really liked the name "Tropical Countercurrent," but after all, did not use it in our papers. I hope that we will reconsider the nomenclature most suitable for "STCC."

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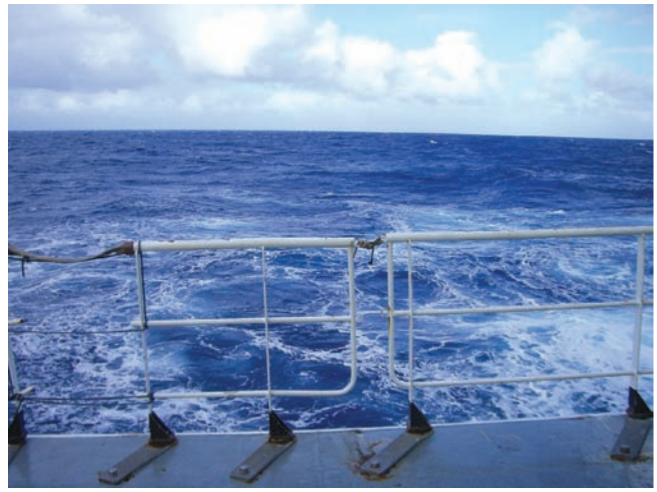

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