NEWS RELEASE

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# Synchronicity discovered in the Gulf Stream and Kuroshio

## ～A path to understanding extreme weather events caused by air-sea interaction～


Tsubasa Kohyama

Assistant Professor, Department of Information Sciences, Ochanomizu University

Yoko Yamagami

Specially-appointed Postdoctoral Researcher, Atmosphere and Ocean Research Institute, The University of Tokyo

Hiroaki Miura

Associate Professor, Department of Earth and Planetary Science, The University of Tokyo

Shoichiro Kido

Postdoctoral Researcher, Application Laboratory (APL), Japan Agency for Marine-Earth Science and Technology

Hiroaki Tatebe

Senior Researcher, Research Center for Environmental Modeling and Application (CEMA),

Japan Agency for Marine-Earth Science and Technology

Masahiro Watanabe

Professor, Atmosphere and Ocean Research Institute, The University of Tokyo


## Keypoints

・The Gulf Stream and Kuroshio Current, the strongest warm currents in the Northern Hemisphere, are separated by about 10,000 kilometers across the continent. Nevertheless, we have discovered that, as the two currents fluctuate, the sea surface temperatures off the east coast of Japan and the east coast of the United States are warmed and cooled synchronously at interannual to decadal time scales.

・This phenomenon is linked to fluctuations of the atmospheric jet stream, which is a strong westerly wind that exists over the mid-latitudes all year round, and causes extreme weather conditions such as heat waves that target metropolitan areas in the mid-latitudes of the Northern Hemisphere.

・As our understanding of this phenomenon progresses, it is expected to make it easier to predict extreme weather events that occur in metropolitan areas in the mid-latitudes of the Northern Hemisphere, and to provide basic knowledge that will contribute to fisheries production, including the catches of sardines and saury, which are affected by oceanic temperature and current strength.

## Summary

**We have discovered that, as the Gulf Stream and the Kuroshio Current (the strongest warm currents in the Northern Hemisphere) fluctuate, the sea surface temperatures off the east coast of Japan and the east coast of the U.S. are warmed and cooled synchronously. We refer to this phenomenon as the boundary current synchronization (BCS) (Fig. 1). Although these warm currents are separated by about 10,000 kilometers across the North American continent, they exchange information on the strength and paths of the currents through the north-south movement of the westerly jet stream - a strong westerly wind that exists over the mid-latitudes all year round - and synchronize their water temperatures. Heat waves brought about by this phenomenon, which target metropolitan areas in the mid-latitudes of the Northern Hemisphere, have been repeatedly observed, including in July of 1994 and 2018. Our study will be published in *Science* on October 15, 2021.**


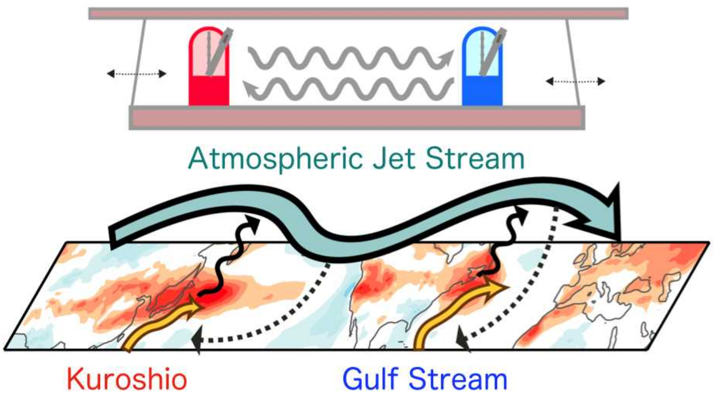


**Fig.1: Schematic showing the mechanism of the boundary current synchronization (BCS).** The Gulf Stream and Kuroshio Current are synchronized, which is associated with the north-south movement of the atmospheric jet stream, causing near-surface temperatures to fluctuate. The red and blue shadings on the map show the temperature distribution near the Earth's surface, which tends to be observed when both the Gulf Stream and Kuroshio Current are warmer than usual. A similar phenomenon is synchronization of pendulums. The metronome placed on a board suspended by strings transmits the information of directions and magnitude of the force to each other through the board, and the pendulum rods of the metronomes become eventually aligned. In BCS, the atmospheric jet stream plays a similar role to this board.

## Background

The Gulf Stream and Kuroshio Current are the strongest warm currents in the Northern Hemisphere, located on the western side of the Atlantic and Pacific Oceans, respectively, and are known as the **western boundary currents** (*1). The western boundary currents carry heat from the tropics to the mid-latitudes, and are known to affect local weather and climate in coastal metropolitan areas. Variations in the western boundary currents also have broad implications for paleoclimatology, anthropogenic climate change, and fisheries production.

Although the Gulf Stream and Kuroshio Current have many similarities in climate science, there have been few studies focusing on the simultaneity of their fluctuations because they are far apart across the North American continent. On the other hand, using recent high-resolution satellite observations and high-resolution global climate model simulations, the role of the western boundary current in the climate system can now be studied in more detail than ever before.

## What we found in this study

### ●Statistical demonstration of BCS

Tsubasa Kohyama, an assistant professor at Ochanomizu University, and his colleagues have discovered that, as the Gulf Stream and Kuroshio Current fluctuate, the sea surface temperatures off the east coast of Japan and the east coast of the United States are warmed and cooled synchronously at interannual to decadal time scales. We refer to this phenomenon as the **boundary current synchronization (BCS)**. BCS is detected in both high-resolution satellite data, which measures sea surface temperature using infrared, and high-resolution simulations using global climate models (*2) that reproduce the atmosphere and ocean on a supercomputer (Fig. 2). In addition, the statistical significance of this phenomenon is demonstrated by the cross-spectral analysis and the lag correlation analysis. We have also identified that **BCS is reproduced better in high-resolution simulations**, in which the atmosphere and ocean are divided into finer grids for numerical simulation.

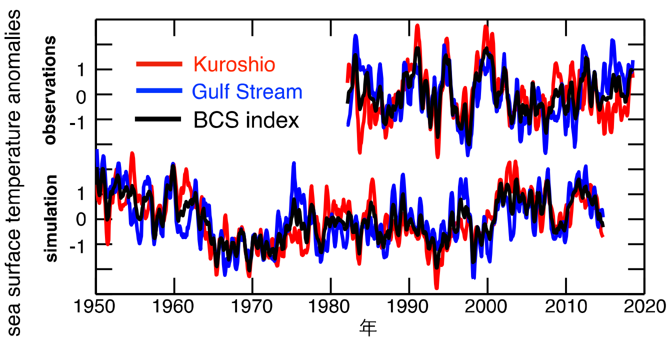


**Fig. 2: Sea surface temperatures estimated by satellite observations and high-resolution global climate model simulation.**
Sea surface temperatures of the Kuroshio Current (red curve) and the Gulf Stream (blue curve) regions are shown as deviations from the long-term mean calculated for each month, divided by their own standard deviation. The black curve is the BCS index defined by the average of the red and blue curves.

### ●Definition of BCS index and a hypothetical BCS mechanism

We defined the **BCS index** (*3) by averaging the sea surface temperature anomalies (deviations from the long-term mean calculated for each month) between the Gulf Stream and Kuroshio regions divided by their own standard deviation (black curve in Fig. 2). In other words, the BCS index is defined to be positive when both the Kuroshio Current and the Gulf Stream are warmer than usual, and negative when both are colder than usual.

Sea surface temperature variations in the western boundary currents affect the atmospheric flow through changes in heat transport to the atmosphere due to seawater evaporation, for example. By analyzing the relationship between the BCS index and the atmosphere, we found that, when the BCS index is positive (when the two ocean currents are warmer than usual), **the atmospheric jet stream, which is a strong westerly wind that persists above the mid-latitudes all year round, tends to move northward**. Conversely, variations in atmospheric flow cause ocean currents to fluctuate due to the dragging effect of winds on the ocean surface and other factors. Based on the simulation results, we found that, in a positive BCS event, the latitude of the "ripping point", where the western boundary current leaves the shore and moves eastward, shifts to the north. For example, when the BCS index is positive at two standard deviations, the Gulf Stream flows to the coast of the Virginia state and then leaves the shore and heads east, whereas when it is negative at two standard deviations, it leaves the shore near the South Carolina state and heads east. These variations in the oceanic warm current path modulate the downstream sea surface temperature, which will again affect the atmospheric flow.

The mechanism of synchronization through northward shifts of the atmospheric jet stream can be explained by an idealized model that extracts the essence of the phenomenon, and it was also verified by simulating the atmosphere above the sea surface condition in 1994 when the BCS index was positively large. The results are consistent with the idea that BCS is an air-sea coupled mode (*4) in which the atmosphere and ocean fluctuate while influencing each other. This point, however, is still at the stage of hypothesis proposal and needs to be further verified. An important issue is whether the influence of the ocean current to the atmosphere is essential as a constituent of BCS. Our study concludes that the influence of the ocean current to the atmosphere is essential, because the sea surface temperature fluctuation cannot be explained only by the heat transfer from the atmosphere to the ocean, and because a remarkable resolution dependence exists in the ocean-side simulation.

## ●Extreme weather caused by BCS

Variations in the westerly jet stream associated with BCS tend to produce **large temperature fluctuations that target metropolitan areas in the mid-latitudes of the Northern Hemisphere, such as East Asia, the west and east coasts of the United States, and Europe** (Fig. 3). The hot summers of 1994 and 2018 are two typical examples where temperature distribution associated with positive BCS events clearly emerged. It should be noted, however, that the actual temperature distribution is determined by atmospheric disturbances with shorter time scales, so a positive BCS index does not necessarily mean that this particular temperature distribution will always emerge. Rather, it just means higher probability for an emergence of a similar temperature pattern to the top panel of Fig. 3.

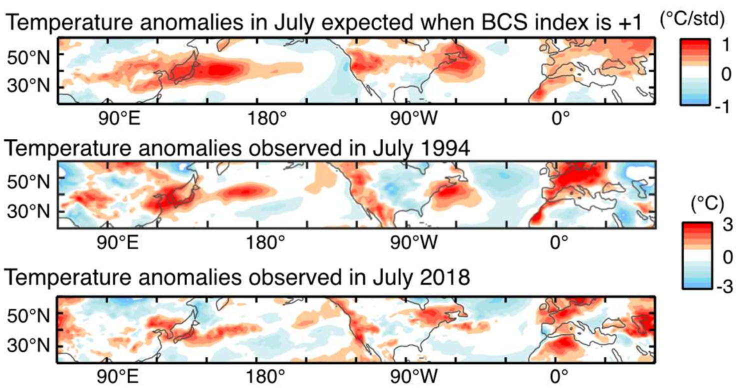


**Figure 3: Typical near-surface temperatures when the two oceanic currents are warmed at the same time.**

The red and blue shadings on the map shows the distribution of temperature anomalies in July expected when the BCS index is equal to one standard deviation (top) and the distribution of temperature anomalies observed in July of 1994 (middle) and 2018 (bottom).

## Future works and societal implications

Our study strongly suggests that high-resolution simulations are essential for understanding mid-latitude extreme weather events. Presumably, the reason why high-resolution simulations are better at reproducing BCS is that they can represent the long and narrow warm ocean currents in more detail and can reproduce the interaction between the atmosphere and the ocean currents more precisely. Our research marks a milestone in the future direction of modern atmospheric and oceanic science, foreseeing that the abundant computational resources of supercomputers will substantially deepen our understanding of atmospheric and oceanic phenomena in the mid-latitudes and will improve the prediction of extreme weather events.

In addition, the implications of our research will not be limited to atmospheric and oceanic science, but it extends to agriculture and fisheries production. For example, the catches of sardines and saury, which spawn and grow in the Kuroshio basin, are affected by the temperature and current strength off the east coast of Japan. Therefore, further research on BCS is expected to contribute to the management of agricultural resources as well as to improve the prediction of fisheries production.

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## Glossary

(*1) western boundary currents

Ocean currents that flow strongly from the tropics to the extratropics on the west side when viewed from the ocean (i.e., east side when viewed from the continents). Examples in the southern hemisphere are the Agulhas Current and the Brazil Current.

(*2) global climate model

Computer programs that are essential for projecting the future of the climate, and have been researched for their sophistication and refinement. **Dr. Shukuro Manabe, who will be awarded the 2021 Nobel Prize in Physics, constructed the first global climate model in 1969 with Dr. Kirk Bryan.**

(*3) index

A time series that is representative of the information of interest. A well-known index in meteorology is the Niño 3 index, which describes the state of the El Niño Southern Oscillation.

(*4) air-sea coupled mode

A phenomenon in which the atmosphere and oceans fluctuate while influencing each other. Typical examples include the El Niño Southern Oscillation in the tropical Pacific Ocean and the Indian Ocean Dipole in the tropical Indian Ocean.

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Contact information for inquiries on our research

・Tsubasa Kohyama

Assistant Professor, Department of Information Sciences, Ochanomizu University

TEL：+81-3-5978-5773 / E-mail：tsubasa@is.ocha.ac.jp

・Hiroaki Miura

Associate Professor, Department of Earth and Planetary Science, The University of Tokyo

TEL：+81-3-5841-4664 / E-mail：h_miura@eps.s.u-tokyo.ac.jp