

# Kuroshio's Impact on Fog, Clouds, and Storms



Satellite monitoring of weather systems over the vast oceans has greatly changed scientists' view of the ocean's impact on weather and climate in the extratropics. Rather than passively reacting to winds, major ocean currents are now thought to be anchors of extratropical storm tracks. Thus the 2008 study, published in *Nature* and spearheaded by IPRC's Japanese colleague **Shoshiro Minobe** at Hokkaido University, found that the sharp temperature front created by the warm Gulf Stream as it flows northward in the cold North Atlantic leads to winds converging and a vertical pathway by which the warm, moist air over the Gulf Stream rises into the free troposphere. There, in the free troposphere, the strong heating gives rise to storms and generates planetary waves that can impact climate over Europe.

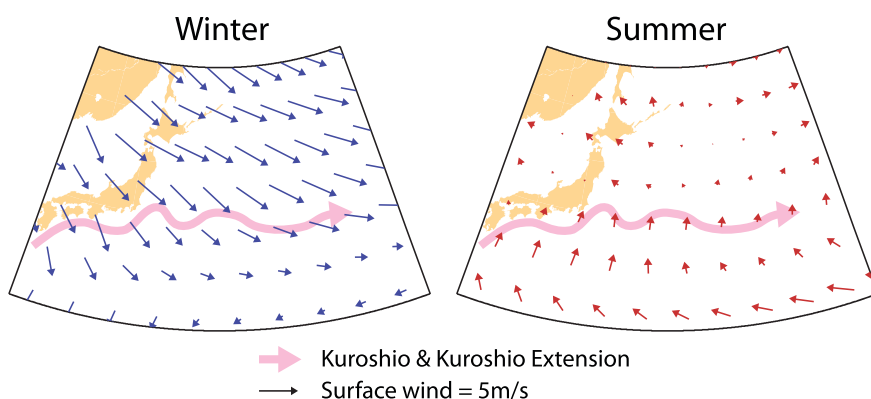
Similar to the Gulf Stream, the Kuroshio, flowing northeast past Japan, and its eastward Extension transport huge amounts of tropical warm water northeastward. And, similar to the Gulf Stream, warm, moist air rises high into the mid- to upper-troposphere, leading to deep clouds over the course of the Kuroshio and the Kuroshio Extension. But the winds over the Kuroshio blow very differently in summer than in winter (Figure 1), giving rise to very different cloud formations in summer and winter, according to a recent observational study headed by Visiting Assistant Researcher **Hiroki Tokinaga** at the IPRC.

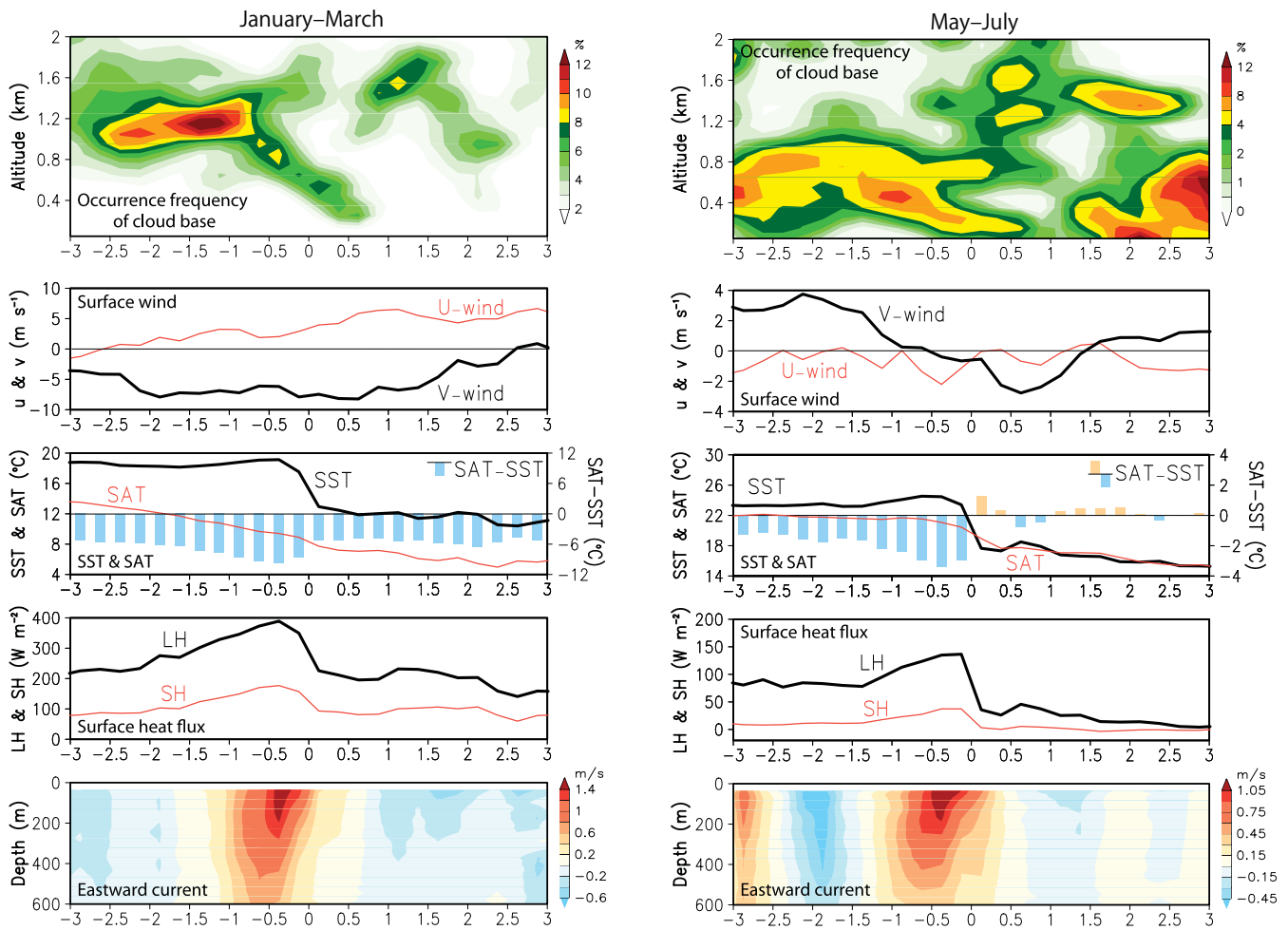
Tokinaga and his colleagues analyzed extensive observational data bases. Measurements taken from the JAMSTEC Research Vessel *Mirai* included sea surface temperature, sur-

face air temperature, the height of the cloud base, and ocean current velocity. A total of 561 radiosonde soundings over the northwest Pacific taken from several research vessels provided information for the structure of the marine atmospheric boundary layer, the lowest 1-1.5 km layer of the atmosphere over the ocean. The International Comprehensive Ocean-Atmosphere Data Set yielded long-term surface meteorological measurements and weather information. Furthermore, from instruments on different satellites came measures of sea surface temperature, sea surface wind, cloud liquid water, cloud-top pressure, lightning flash frequency, as well as air temperature and humidity. These and more measures were synthesized into three-dimensional pictures of cloud structures and the influences from sea surface temperature fronts over the western North Pacific.

During both winter and summer, the ship observations show sharp differences in sea surface temperature and the marine atmospheric boundary

Figure 1. Climatological surface winds (left) in winter and (right) in summer. Block arrows represent the Kuroshio and its Extension.





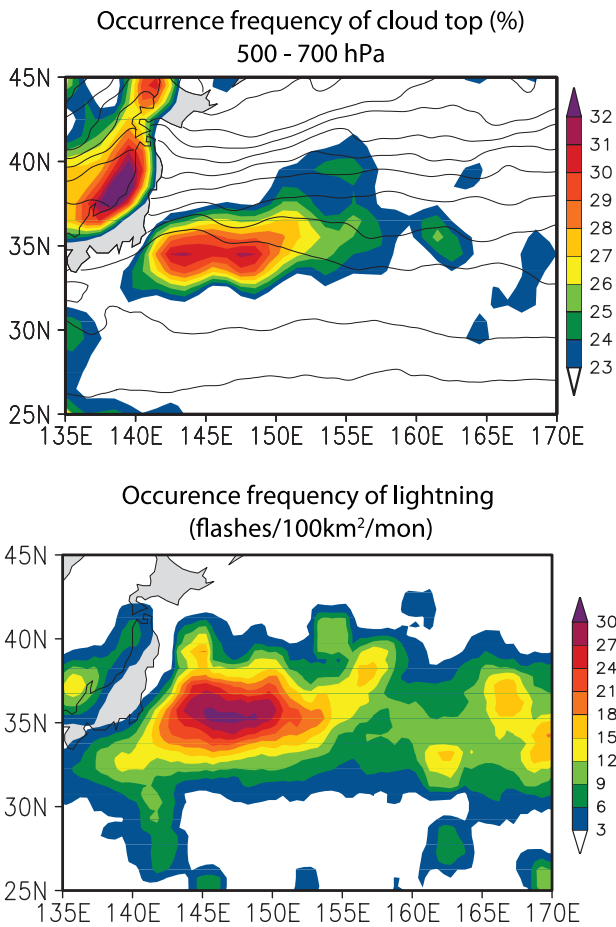
**Figure 2.** Cross-frontal observations from the R/V *Mirai* (left panels) during January–March: (a) frequency of cloud-base occurrence as a function of latitude and height observed by a laser ceilometer; (b) surface zonal (red) and meridional (black) winds; (c) surface air temperature (red), sea surface temperature (SST; black), and their difference (bar); (d) upward surface latent (black) and sensible (red) heat fluxes; and (e) eastward ocean current speed observed by ship-mounted ADCP. All variables are composited referenced to the maximum SST gradient of the Kuroshio Extension front ( $y=0$ ); distance to the center of the SST front ( $y$ ) is in degrees latitude; (right panels) observations for May–July.

layer at the northwestern front of the Kuroshio and its extension. Satellite observations reveal conditions across the front that generate deep clouds rising into the mid-to-upper troposphere, where they affect weather systems.

During winter, sea surface temperature rises  $7^{\circ}\text{C}$  in less than 100 km across the southern flank of the Kuroshio Extension (Figure 2, left panel). The prevailing winds are cold, dry northwesterlies from Siberia (Figure 1, left panel), and the surface air arriving at the Kuroshio is significantly colder than the sea surface and warms only gradually as it blows across the current. The largest difference in temperature and moisture between the air and the sea surface occurs right over the strong current and on the warmer flank of

the front where the air is more than  $8^{\circ}\text{C}$  colder than the sea surface. This huge difference between the warm ocean and the cold, dry air produces turbulent heat fluxes that release huge amounts of heat and moisture into the atmosphere. The cloud bases and cloud tops are much higher on the southern than the northern flank of the current. The cloud bases are often more than 1 km high and cloud tops can tower as high as 5 km, with frequent lightening along this southern flank of the Kuroshio and its Extension (Figure 3).

In summer, due to the prevailing southerly winds that bring warm, moist air, the temperature over the southern flank is only slightly cooler than the Kuroshio (Figure 2, right panel). As a result, surface heat fluxes and atmospheric



**Figure 3.** December to February climatology: (top) horizontal pattern of cloud-top occurrence in the 500–700-hPa layer (color in %) with superimposed climatological SST derived from AVHRR (contours at 2°C intervals); (bottom) lightning observed by LIS/OTD (color in units of flashes per 100 km<sup>2</sup>/month).

vertical mixing are strongly suppressed, and the cloud bases are typically lower than in winter, around 0.4–0.8 km. But on the northern flank, sea surface temperature drops nearly as sharply as it does in winter, leading to a drastic vertical gradient in temperature and moisture. The icy subarctic water cools and saturates the warm, moist air north of the Kuroshio, and the water vapor condenses. Thus sea fog occurs over 40% of the time on the northern flank of the Kuroshio, southeast of Hokkaido, and northeastward (Figure 4). Over the Kuroshio and the Extension itself, sea fog occurs rarely during summer because the warm ocean current destabilizes the lower atmosphere and promotes vertical mixing.

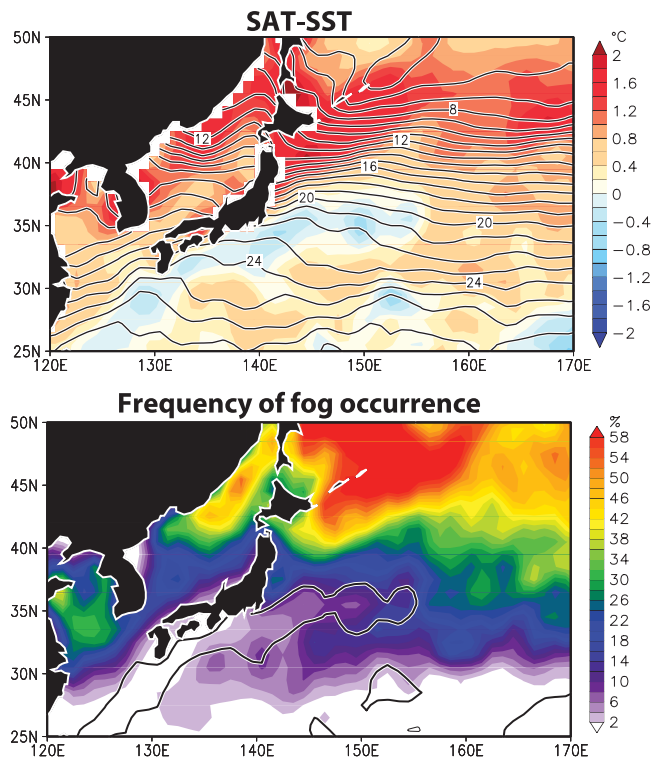
In June–July, the narrow band of surface wind convergence over the Kuroshio Extension (KE) supports a broad

spectra of upward motion that is associated with the eastward extension of the Baiu rainband, and the air warmed by the current rises up high through the entire troposphere. This particular oceanic influence of the KE on the Baiu rainband, however, needs further investigation according to Tokinaga and his colleagues.

This careful, detailed study of the impact of ocean temperature fronts on cloud patterns in the western North Pacific will help to understand better how these fronts anchor storm tracks and how their effects on the atmosphere can lead to the growth of cyclones in the extratropics.

This story is based on:

Tokinaga, H., Y. Tanimoto, S.-P. Xie, T. Sampe, H. Tomita, H. Ichikawa, 2009: Ocean frontal effects on the vertical development of clouds over the western North Pacific: In situ and satellite observations. *J. Climate*, 22 (16), 4241–4260.



**Figure 4.** Southerly composite of (top) the difference in surface air temperature and sea surface temperature (SAT-SST; color in °C) and SST (contours at 1°C intervals); (bottom) frequency of fog occurrence (color in %) and the zero contour of SAT-SST. This difference measure is an indicator of stability in the lower atmosphere. (ICOADS, June 1982 to 2006 average)