# THE 1957-1958 OCEANOGRAPHIC CHANGES IN THE WESTERN PACIFIC

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## LONG TERM OCEANOGRAPHIC CHANGES NEAR JAPAN

During the earlier period of measurement the Kuroshio flowed closely along the south coast of Japan. In 1937 however, suddenly a cold region appeared off the Kii Peninsula. It became very cold in 1938 and remained so until 1946, although there were fluctuations in the location and the magnitude of the cold region during this period. Since 1946, this cold region has sometimes been present and sometimes not. Therefore, it is quite clear that there are two types of flow in the Kuroshio off the south coast of Japan, one in which a region of remarkably cold water appears and one in which the warm waters predominate everywhere. Figures 49, 50, and 51 show two typical types of the Kuroshio.

The changes of coastal water temperature at some stations along Pacific coast of Japan are shown in figure 52. As you see in the figure, the temperature at Tomisaki was very cold from 1934 to 1936. Then the cold water region off Kii Peninsula (34°N 136°E) appeared and the surface water temperature off Northern Japan became warm.

As Dr. Uda had already pointed out, when the region off Kii Peninsula is remarkably cold, the water temperature off Northern Japan is generally higher than average. Therefore, the two types in figures 49, 50, and 51 are to be considered as representing two models of warm and cold year.

## SURFACE WATER TEMPERATURE IN THE WESTERN NORTH PACIFIC

The surface water temperature in the northern part of the Western North Pacific had been high from the summer to the winter of 1955-1956, but by the spring of 1956 it had decreased, and in January of 1957 it was lower than normal. It continued to be lower than normal until the end of the year. In the spring of 1958, however, it became a little warmer than normal, figures 53-61. In years of low surface water temperature the climate of summer in Northern Japan is generally cooler than usual.

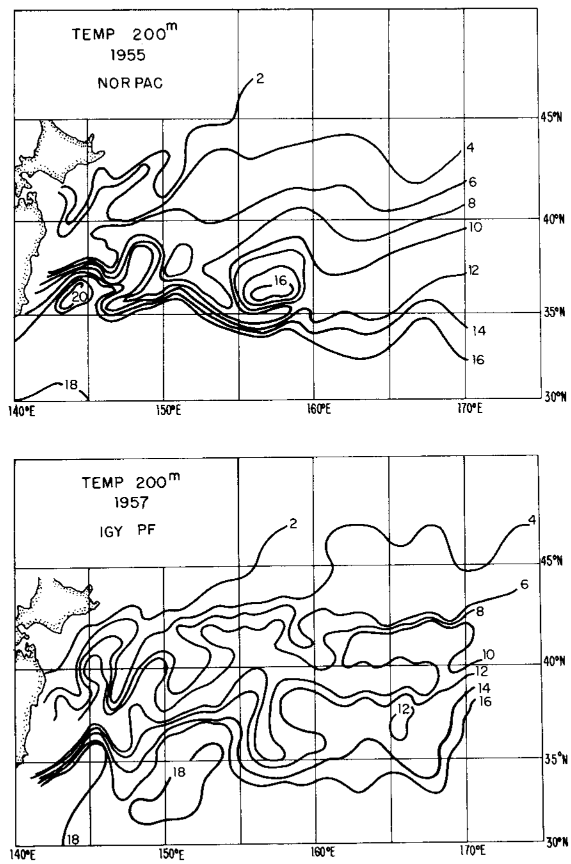


FIGURE 49. Comparison of the two types of Kuroshio Current 1955 warm, 1957 cold. 200 meter temperature.

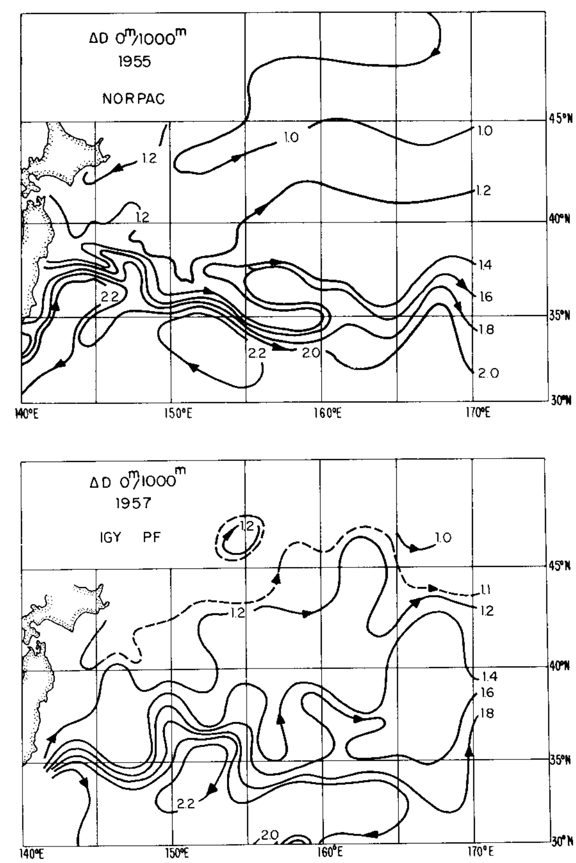


FIGURE 50. Comparison of the two types of Kuroshio Current 1955 warm, 1957 cold. Dynamic height anomalies (0 over 1000 decibars).

## THE CHANGES IN 1957-1958

In 1957 the IGY program for polar front survey was held in the area from 30°N to 46°N and from 170°W to the coast of Japan. In figures 49, 50, and 51, some results of the expedition are reproduced as well as similar figures for NORPAC in 1955. It is considered that the year of 1955 was a year of warm water and 1957 was that of cold in the western side of North Pacific.

The most striking difference between them is the change in the axis of Kuroshio off east coast of Japan. In 1957 the Kuroshio was flowing along 35°N while in 1955 it was along 38°N, except east of 155° where the Kuroshio was flowing along 35°N in both years. Comparing the temperature distributions at 200 m layer, we find that temperature was lower near the coast in 1957 than in 1955, but no remarkable differences are seen offshore. The T-S diagrams along 144°E of both years (Fig. 62) show almost no difference, and it may be concluded that the difference in the temperature distribution is due to the change of area occupied by the Kuroshio water mass and the Oyashio water mass, not the changes in the characters of the water masses.

As for the cold water region off Kii Peninsula, it was very obvious in 1955 and very faint in 1957.

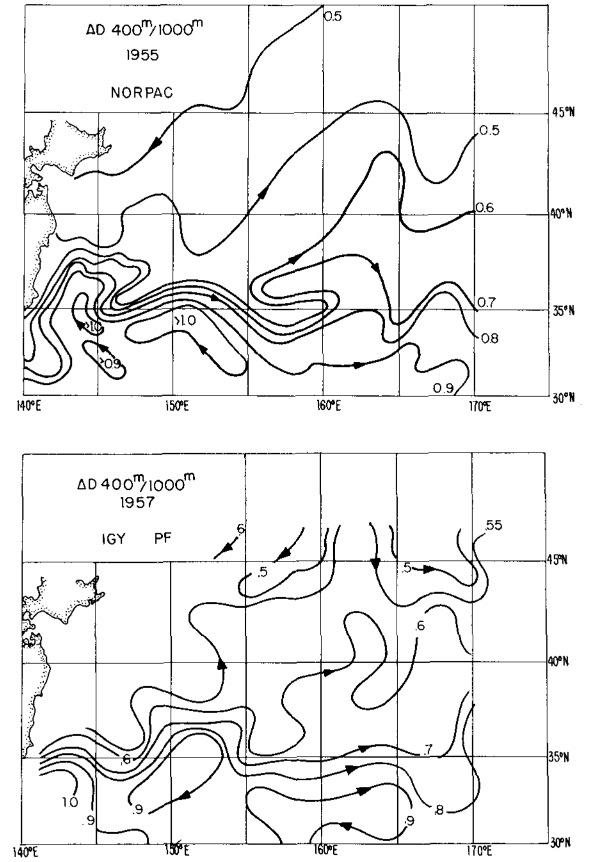


FIGURE 51. Comparison of the two types of Kuroshio Current 1955 warm, 1957 cold. Dynamic height anomalies (400 over 1000 decibars).

## PERIODIC CHANGES OF THE KUROSHIO AXIS

The locality of the Kuroshio axis at the longitude of 144°E is shown in figure 63. It shows that the axis changes periodically with a period of four to five years; the average is about four and one-half years. From 1942 to 1948, the position of the axis could not be fixed exactly owing to the sparseness of data, but from some oceanographic and meteorological data there is reason to infer that the axis was in the north in 1943 and 1947, and in the south in 1944 or 1945. It is hardly necessary to explain that when the axis is in the south, surface water temperature off Northern Japan is lower than average, especially in summer, and when it is in the north, higher than average. But I should like to emphasize when the axis is in the south, the climate in Northern Japan is cool in summer and warm in winter.

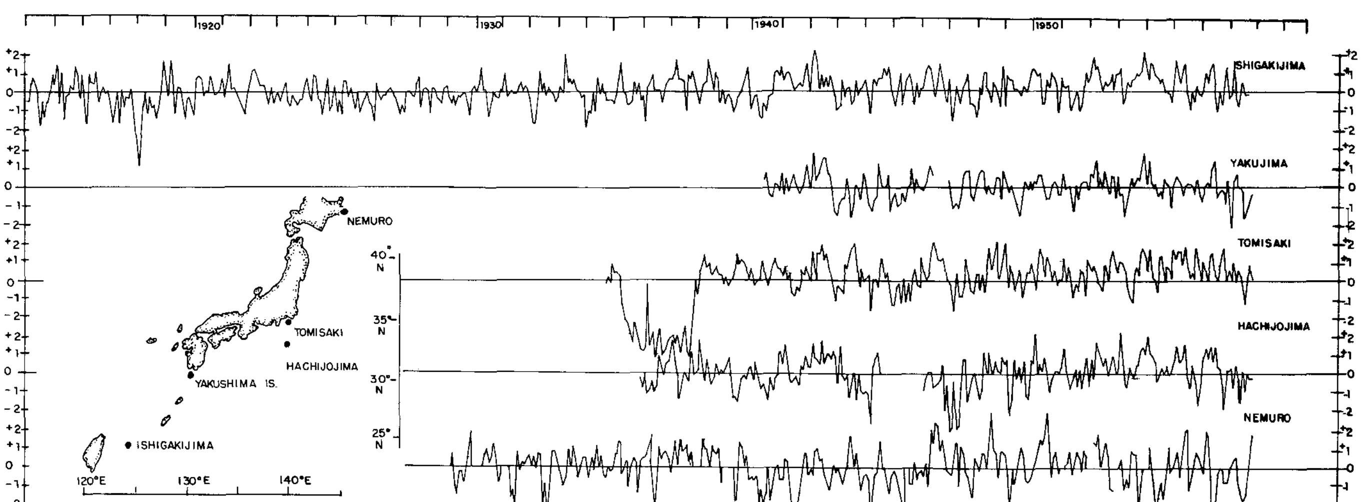


FIGURE 52. Monthly differences from averages sea surface temperature (degrees Centigrade).

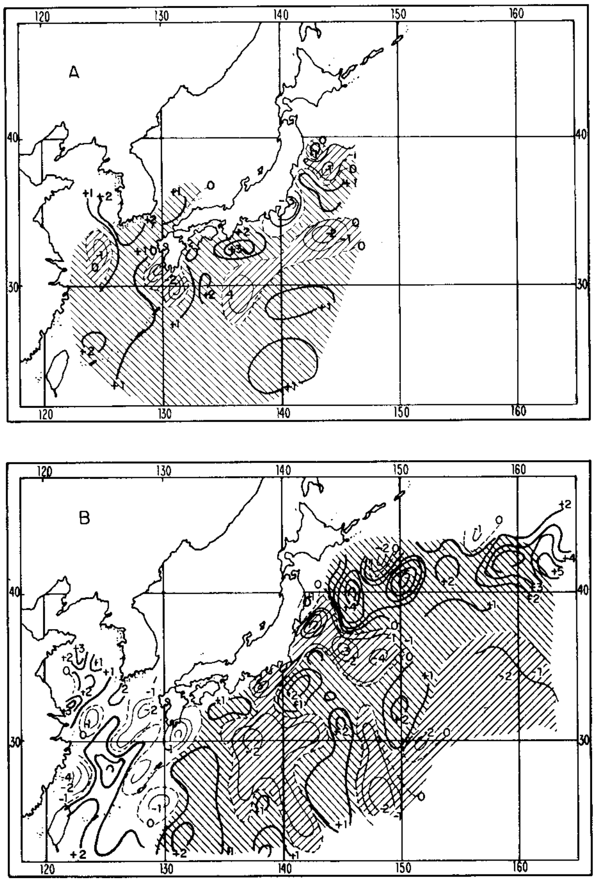


FIGURE 53. Anomaly of sea surface temperature for the second 10 days of April 1956 (A) from the mean of all data previous to 1942, and (B) from April 1955.

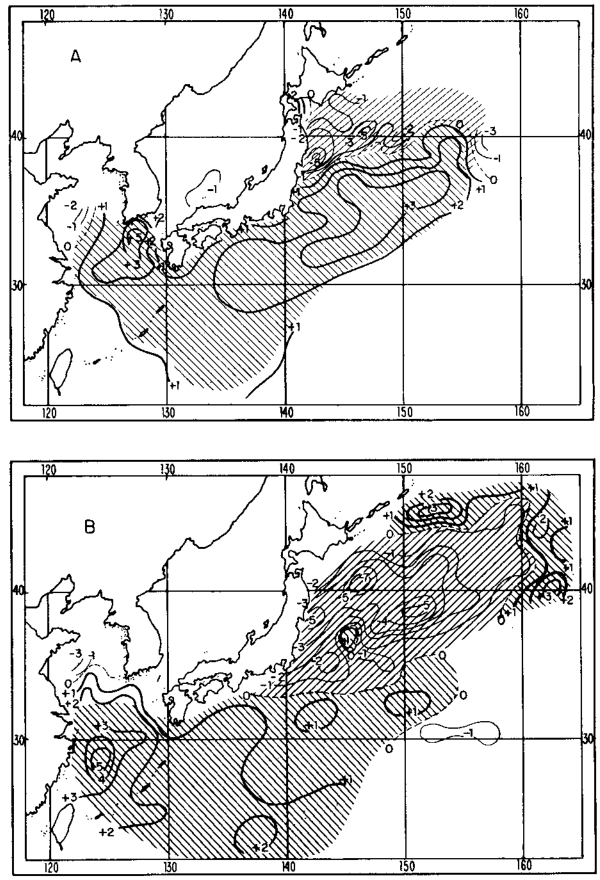


FIGURE 54. Anomaly of sea surface temperature for the second 10 days of July 1956 (A) from the mean of all data previous to 1942, and (B) from July 1955.

## CHARACTERISTIC METEOROLOGICAL PHENOMENA IN 1957-1958

The winter of 1957-1958 in Japan was slightly warmer than usual. It was reported that when the surface water temperature was lower than usual the summer climate in Northern Japan was also generally cooler, and the climate of the preceding and/or succeeding winter was warmer; therefore the warm winter in 1957-1958 conforms to the general rule mentioned above.

In 1957 the rainy season was long as is the general rule in years of low water temperature. However, heavy rains were most conspicuous. From July 25 to 29 heavy rain was observed in Western Japan at Saigo, a small town in the west of Kyushu. More than 1,000 mm fell in 24 hours, and in Oomura more than 600 mm fell in one hour. During the long rainy season heavy rains were observed a couple of times in various localities along the southern coast of Japan.

## RELATIONS BETWEEN THE TEMPERATURE CHANGE IN THE EASTERN AND WESTERN SIDES OF THE PACIFIC

Some years ago Mr. Hanzawa had pointed out that in the year of cool summer in Japan, there are two types in the surface water temperature distributions. For example, in 1934 a cold region of surface water was observed only at the west of 160°E, but in 1941 it was observed as far as the west of 135°W. Figures 64-66 show the relations between the anomaly of monthly mean coastal water temperature in 1926, 1931 and 1955, a vertical axis for the western side and a horizontal axis for the eastern side. In these remarkable years we can find reversal of temperatures on the two sides of the Pacific. In the figures you will find that the points lie in the second and fourth quadrants. Therefore, it is considered that when the Oyashio is flowing strongly southward (i.e. coastal water is colder than usual) the water temperature

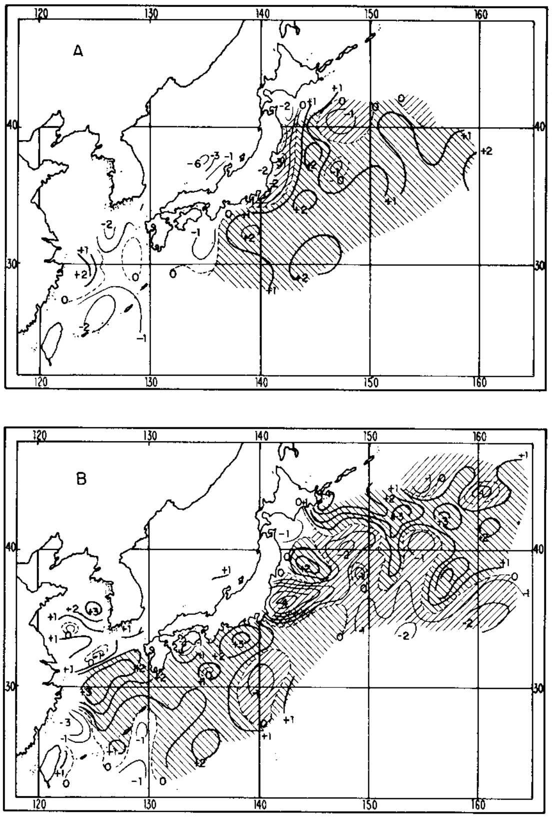


FIGURE 55. Anomaly of sea surface temperature for the second 10 days of October 1956 (A) from the mean of all data previous to 1942, and (B) from October 1955.

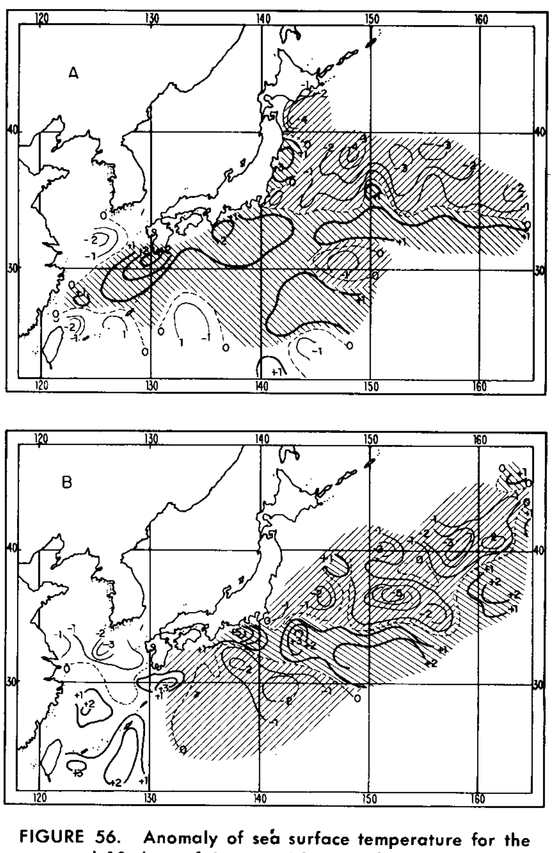


FIGURE 56. Anomaly of sea surface temperature for the second 10 days of January 1957 (A) from the mean of all data previous to 1942, and (B) from January 1956.

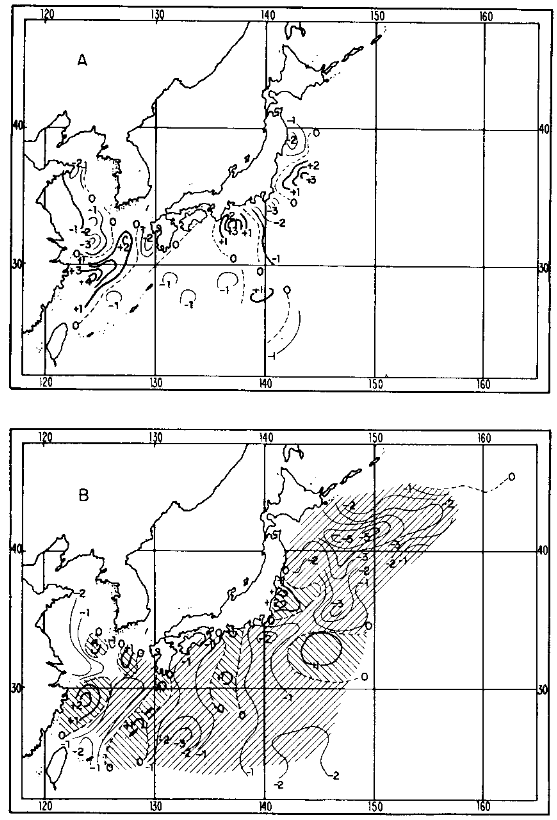


FIGURE 57. Anomaly of sea surface temperature for the second 10 days of April 1957 (A) from the mean of all data previous to 1942, and (B) from April 1956.

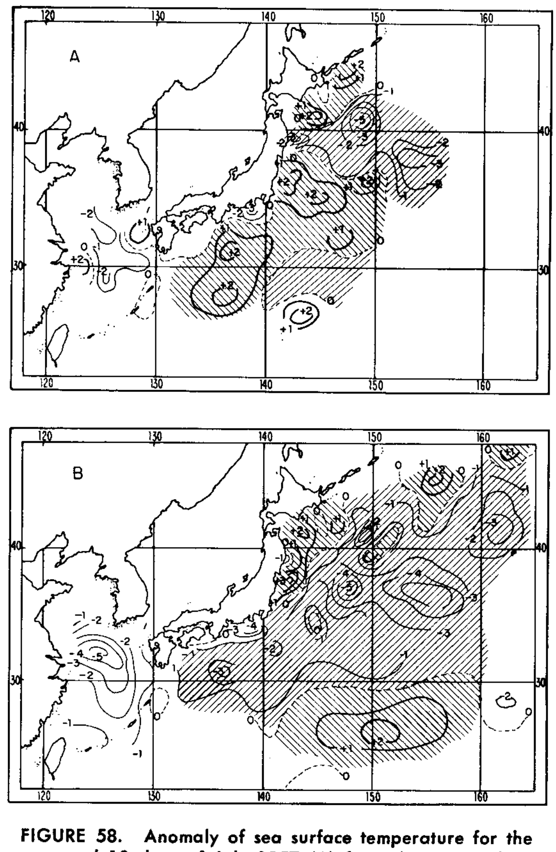


FIGURE 58. Anomaly of sea surface temperature for the second 10 days of July 1957 (A) from the mean of all data previous to 1942, and (B) from July 1956.

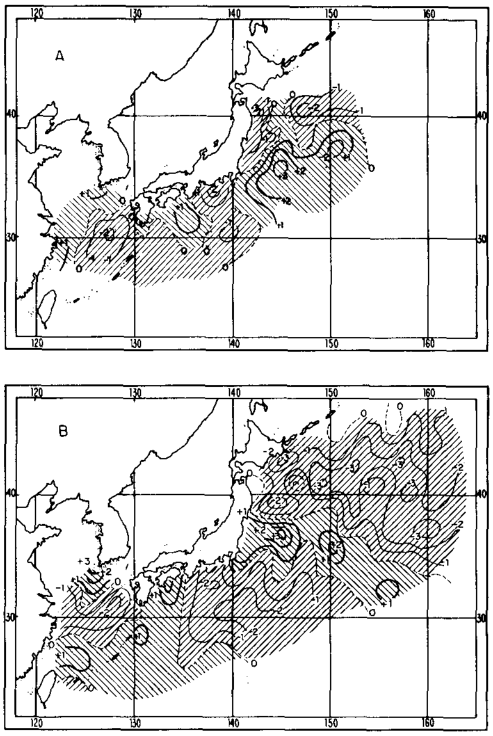


FIGURE 59. Anomaly of sea surface temperature for the second 10 days of October 1957 (A) from the mean of all data previous to 1942, and (B) from October 1956.

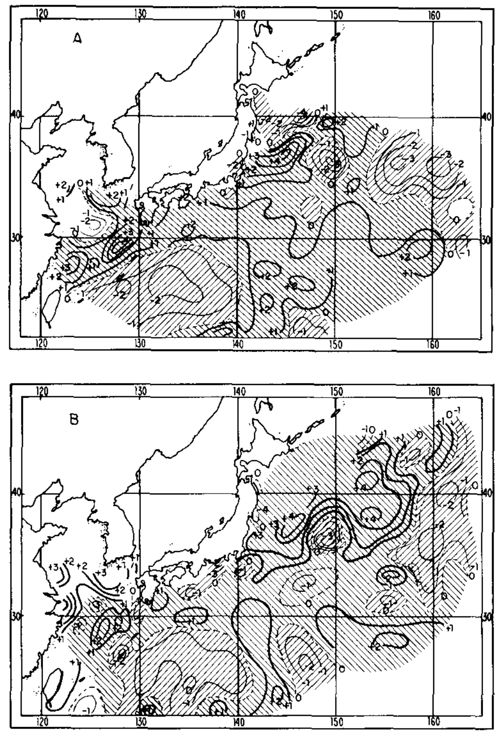


FIGURE 60. Anomaly of sea surface temperature for the second 10 days of January 1958 (A) from the mean of all data previous to 1942, and (B) from January 1957.

along the West Coast of the American Continent becomes high.

During the year 1957-1958 in the western side of the Pacific, the Kuroshio had only small meanderings. The axis of Kuroshio at 144°E was located rather in the south and the eddies producing northward spread of warm water were also less developed. The surface water of northern part of the Western North Pacific was cooler than usual but not so remarkably as in the year 1931 or 1934.

## DISCUSSION

*Namias:* Excuse me, to what did you relate the cold summers and warm winters?

*Takenouti:* I would like to indicate the 1957 water temperature was cold in summer, was cool generally in Japan. And also the winter was warm. This is one of the correlations between the summer temperature and winter temperatures. My point—in 1957 the year is one of cool water temperature and cool summer, but I hope to indicate that such an abnormality is not so striking, a small anomaly, I would like to indicate. But most striking anomaly of the region in 1957 was very heavy rain in rainy season of Japan. In the summertime last year we had most striking heavy rains in July 25 to 29. The small town of Saigo was almost washed into the Pacific Ocean with 1000 mm of rainfall per hour. In another small town there were 600 mm in one hour. Many lives were lost. Such heavy rains occurred several times and this is most striking anomaly of 1957 in Japan. Thank you.

*Charney:* I am intrigued that you are not surprised that you found this correlation between the cool summer and warm winter. This is surprising to me. Why isn't it surprising to you? I would appreciate if you would explain why.

*Takenouti:* I do not know that I should be surprised. I am not a meteorologist.

*Wooster:* In comparing 1955 with 1957 data in the surface dynamic topography, the surface circulation appears to be much weaker and much more diffuse in 1957 than it is in 1955. The horizontal gradients are weaker in 1957 than in 1955.

*Fleming:* However, the total relief in the surface dynamic topography across the current is about the same in the two years—from 1.2 meters in the north to 2.0 in the south. There is nothing unusual in the 1955 chart, there is no indication of a double current, whereas there is in the 1957 chart.

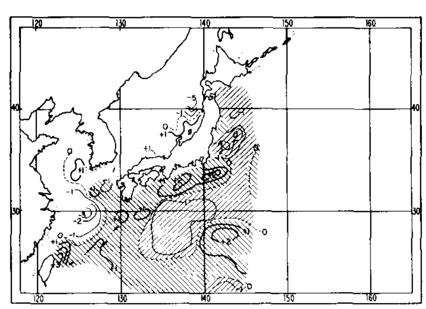

FIGURE 61. Anomaly of sea surface temperature for the second 10 days of April 1958 from the mean of all data previous to 1942.

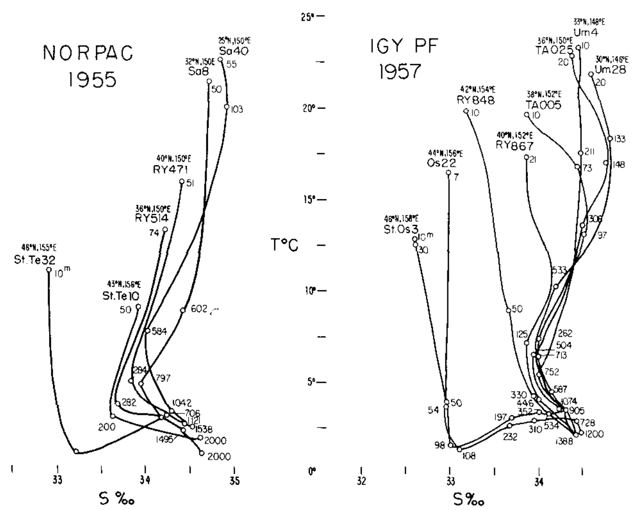


**FIGURE 62. Temperature-salinity diagrams along 144°E for 1955 and 1957.**

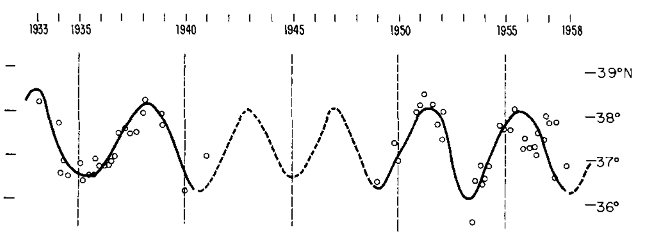


**FIGURE 63. Location of the axis of the Kuroshio at the longitude of 144°E from 1933 to 1958.**

*Wooster:* This also shows in the 200 meter temperature charts. There is a grouping of the isotherms both in the north and in the south in 1957. You do not have that in the 1955 data where the principal gradient is in the south.

A point I want to make is that if the 200 meter temperatures have any relationship to circulation, as some people believe, it seems to me that the currents must have been stronger in 1955, as the isotherms are much more closely packed for a considerable distance out from the coast of Japan than they are in 1957. My question is, do you have current measurements and GEK measurements in these years?

*Takenouti:* We do have for both.

*Wooster:* Do you find any difference in the measured surface velocities from the general picture of the circulation in the two years?

*Takenouti:* I understand that they do agree (i.e., the dynamic topography and the current measurements, Eds.).

*Charney:* Have you made any attempt to associate these rather remarkable fluctuations of the axis of the current with the atmospheric circulation?

*Takenouti:* Some Japanese scientists have tried to associate them, but I do not know how significant the results have been, but it is not always so that there is any clear association.

*Charney:* You have shown a very marked four-year periodicity (Fig. 63) in the position of the Kuroshio axis. It does not appear one chance in a million that this could happen by chance. Is there anything corresponding to this four year period in the atmosphere?

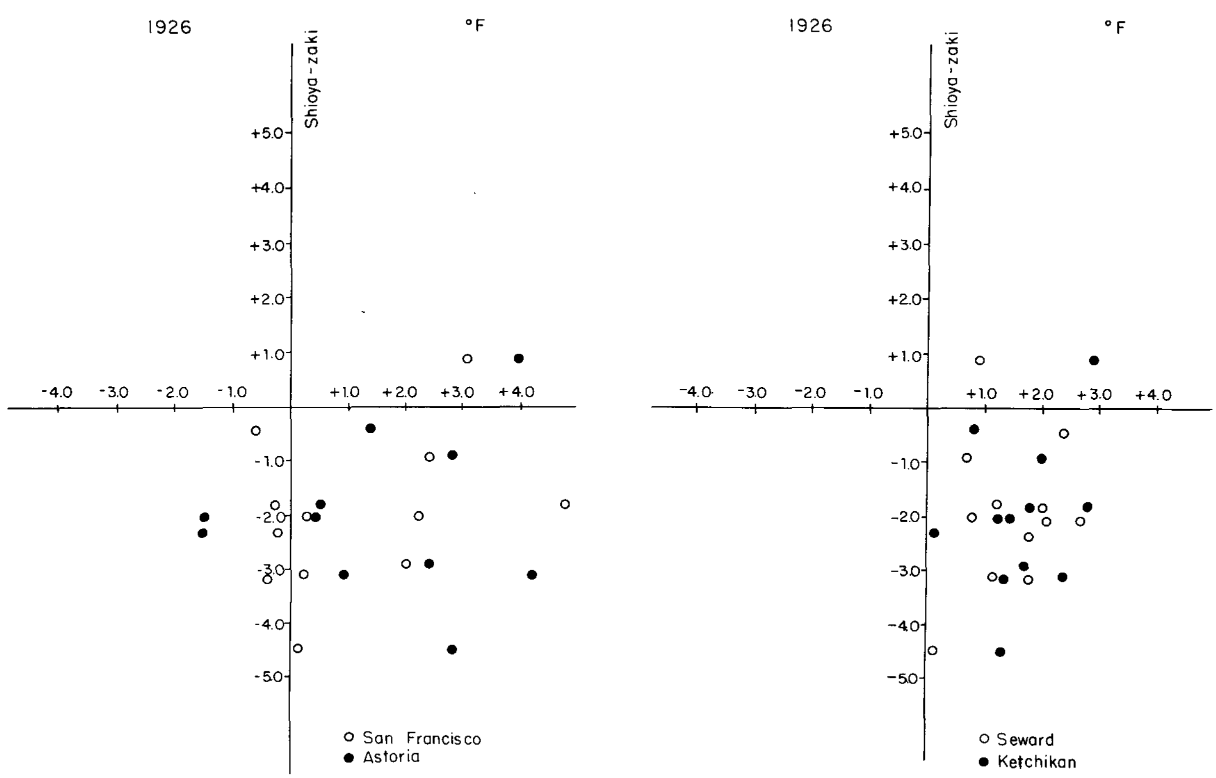


**FIGURE 64. The relations between the anomaly of monthly mean coastal water temperature in 1926. (Vertical axis for Western Pacific and horizontal axis for Eastern Pacific.) Anomalies in degrees Fahrenheit.**

*Takenouti:* This period in the ocean actually has not been documented sufficiently.

*Schaefer:* How do you measure the latitude of the Kuroshio axis?

*Takenouti:* We draw these charts (Figs. 49, 50 and 51) and then wherever the isobars are closest packed, we assume this point to be the axis of the Kuroshio.

*Fuglister:* Could I ask a question about something a little bit different? We have this interest in the area of changing temperatures, but what about along the southern part of your figure 49? You seem to have temperatures around 17 degrees at 200 meters, between 16 and 18 degrees, anyway. I was wondering how much that varies? It is about the same temperature we find in the Gulf Stream, within a degree probably. I have never seen much variation in this contour in the Gulf Stream data that I have looked at. It varies little from year to year. Over a period of time the changes are rather small in these temperatures on the seaward side of the Gulf Stream. This water has a remarkably constant temperature for a period of years—so constant that the variation is not more than plus or minus 0.2°C.

In a region in the Atlantic that presumably changes from season to season, there is a remarkable constancy in the 200-400 meter layer as far back as the time of the Challenger Exposition.

*Stommel:* On 100 meter charts if you pick some sort of characteristic point on the temperature sounding where you can identify a layer—for instance where the isotherm spread a lot, and if you place your attention on some feature like that rather than on a map or chart of temperatures, then you find a remarkable constancy and you can follow the layer over a big area.

*Saur:* This layer that is so constant in temperature, is it also one of constant thickness and vertical position in time?

*Fuglister:* Well, I am almost certain that there are variations in those parameters, but they must be very small as far as we know. This has not been measured exactly because it is very difficult to measure the thickness of the layer. There is no abrupt top or bottom to it. It seems to occupy the whole western basin of the North Atlantic, getting thinner as you approach the center and stopping or disappearing as you reach the mid-Atlantic ridge. Going west, the left hand edge of it is near the Gulf Stream and there it occasionally is interrupted by currents.

*Question:* Does it maintain its geographic position within narrow limits, that is, a relatively constant position?

*Fuglister:* I know of no shifting at all, but I think you could never get enough observations to show if it were shifting. It goes to about 20 degrees north, just north of the Antilles chain and then stretches out. It always seems to disappear as we come to mid-Atlantic. I am fairly sure these limits vary, moving in and out, but not much.

*Question:* Is there a great deal of mixing in that area?

*Fuglister:* There must be in the longitude of Cape Hatteras to mid-ocean in winter. Why is it with all

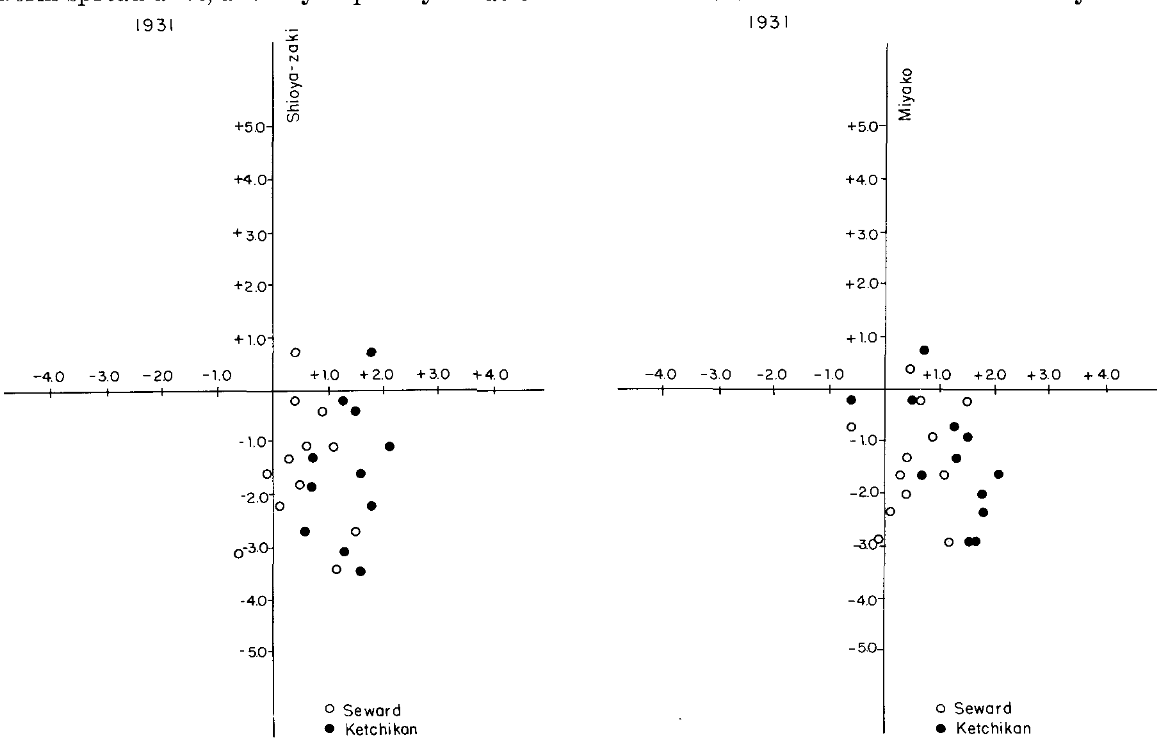


**FIGURE 65. The relations between the anomaly of monthly mean coastal water temperature in 1931. (Vertical axis for Western Pacific and horizontal axis for Eastern Pacific.) Anomalies in degrees Fahrenheit.**

the big climatic variations this layer always stays so close to the same temperature?

*Hubbs:* Look at San Diego Bay—it gets up to 23 degrees and then does not vary all summer long, while the outside ocean varies.

*Stommel:* Really, what we want to find out, is whether or not there was such a uniform layer in the Western Pacific, south of the Kuroshio.

*Fleming:* Could we get Mr. Namias to correlate what we have just heard about the Japanese area.

*Namias:* I would like to bring the attention of this group to what I thought was one of the most striking abnormalities in the Pacific as far as the layer of air up to 10,000 feet is concerned (the thickness anomalies). The striking thing in the southwestern portion of the North Pacific is that this entire period has been above normal. For example, figure 6 is for summer 1957. From the Philippines to Southern Japan it is warmer than normal. It is also above normal in the fall, the winter and also this spring (Figs. 6, 7, 8). To me, this long period abnormality is just as striking as some of the other anomalies elsewhere. At the same time at the northern latitudes we have cool Asiatic air. In particular during this past winter (Fig. 8), this Asiatic air was extremely cold and this contrast between the warm and the cold in a way helped the cyclones find their way across the North Pacific and end up as a maximum low. Frequently something of this sort accounts for correlation between temperatures in one area and temperatures in another. Very heavy rains in July were caused by a series of storms in this zone of thermal contrast one after another. Then this winter, part of the great development of the Aleutian low, was associated with these storms that fed on the thermal contrast. Assuming that there is a correlation between sea water temperature and overlying air temperatures, why should that area (southwest North Pacific) have become so warm? I would guess from looking at these things routinely, that there are long period variations in the surface water temperatures over the Southwest Pacific (Northern) as well as in other areas.

*Schaefer:* In other words, this cooler water off Japan correlated with warmer water in the eastern North Pacific—is this simply circulation around your anomaly?

*Namias:* Advection is probably associated with it; although I profess to know little about oceanography. I am just drawing parallels with meteorology, but it seems to me from these charts that the dimensions and orientation of these anomalies indicate a large scale advective mechanism. I am reminded of the early days of weather map analysis when it was fashionable to show that local heating and radiation effects explained almost everything. This philosophy ignores the central reason for changes in temperature, namely advection from cold or warm source regions. For example, air from Canada in the winter time usually starts out much colder than the temperature in the States, and so produces most of the temperature change by simple advection. Something of this sort in the free ocean may be the main process of producing changes and anomalies.

*Fleming:* What I wish to ask, is whether there are possibly two low cells across the North Pacific? We have been looking at anomalies, but what is the dominant atmospheric circulation? There is a characteristic type with a split Aleutian low. It is rather common in shorter period means—particularly monthly and five-day means. When you have these split Aleutian cells, it is another type of circulation. It must have operated part of the time during the winter of 1956-1957. I mention this because Favorite has information on it, and as we see it, cold water came down near Japan and very much warmer water found its way into the Bering Sea. I have a feeling from some of Murphy's data, that at other times maybe this colder water is coming down essentially in mid-Pacific when we again have two cells. In other words, although they may not operate simultaneously, there are two gyres.

*Stommel:* If you look at Schott's chart of mean temperatures, you can hardly believe that this is so. There is very good indication that there is a single great big gyre.

*Stewart:* Thinking along the lines of the interrelation of air temperature and sea temperature, I worked up some data from along the Pacific Coast and I think it might be given here, since the matter has been brought up. From four weather stations located near the Coast and Geodetic Survey tide stations, where we also measure coastal water temperature, I worked out the monthly mean air temperature anomaly and compared this with the monthly mean sea water temperature anomaly. The anomalies were, in fact, very nearly parallel for January and February. During the fifty months prior to April 1958, January and February 1958 had the highest sea water temperature anomaly and also the highest air temperature anomaly. However, at the three stations that we were using north of San Francisco, 33 out of 42 station-months had higher sea water temperatures than air temperatures. That was in the Eastern Pacific and along the coast. The air temperatures were considerably higher than the long term mean used as the normal, but not so high as the ocean water temperatures. The ocean temperatures were higher than normal and also higher than the air temperatures, so the warmer waters could not have been caused by warmer air. More probably the reverse is true—the air is warmed by the warmer water. Working with this same sea water temperature and air temperature relationship along the East Coast of Florida, we found that the following periods of colder coastal water, air temperatures were colder with onshore winds than they had been previously. In other words, the water in that case evidently was cooling the air.

*Charney:* Dr. Takenouti's data on the shifts in the Kuroshio calls to mind a Goldbergian theory that I once dreamt up relating coastal topography to the separation of the western boundary current from the edge of the continental shelf. According to my in-

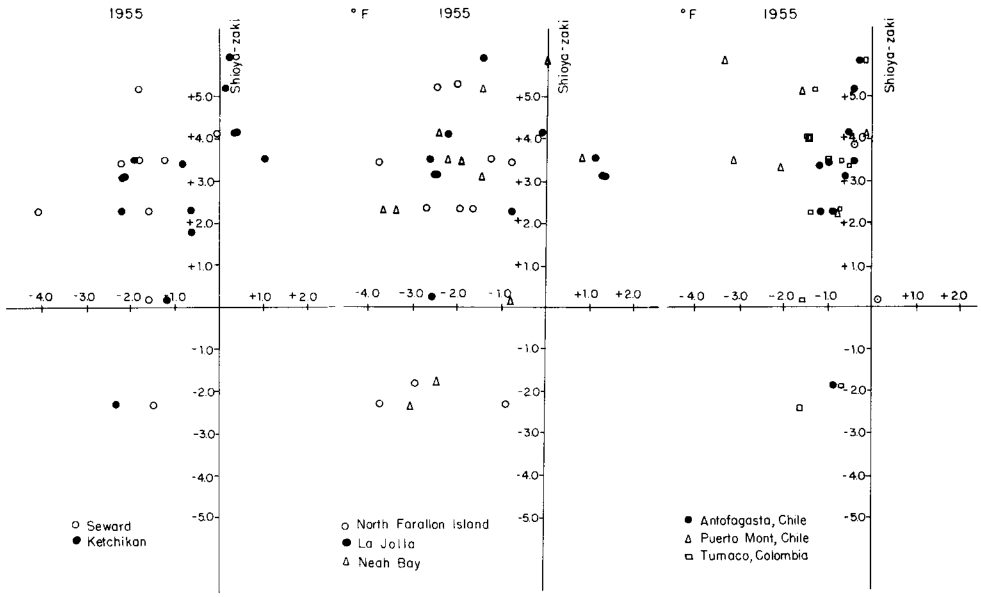


**FIGURE 66. The relations between the anomaly of monthly mean coastal water temperature in 1955. (Vertical axis for Western Pacific and horizontal axis for Eastern Pacific.) Anomalies in degrees Fahrenheit.**

ertial theory of the Gulf Stream the separation should take place at the latitude of the maximum wind-induced transport. The fact that the separation of the Gulf Stream occurs near Cape Hatteras, where there is a protrusion of land, can be accounted for if one assumes that the coast line south of Cape Hatteras was at one time more or less straight and that the present crescentic contour was produced by the scouring action of the Florida Current. Indeed, when you look at a chart of bottom topography you find that the 1000-fathom contour, which is beneath the swift part of the current, goes straight from the southern tip of Florida to Cape Hatteras, whereas only the surface contours have the indentations. Once the Cape was formed one has to postulate that there was a tendency for the current to "lock in" to the topography. In other words, it is not that the separation takes place because of the existence of Cape Hatteras, but rather Cape Hatteras exists because of the separation.

But the geology of the Japanese Islands and the configuration of the Kuroshio gives the theory a jolt. The volcanic composition of these Islands seems to preclude scouring action south of the latitude where the separation sometimes takes place. Moreover, the separation apparently does not necessarily occur where there is a protrusion of the coast. However, the theory does relate fluctuations in the latitude of separation to long-term fluctuations in the mean wind field over the oceans. I would like to know if it is possible to relate the observed fluctuations in the Kuroshio to long-term changes in the wind field and whether comparable fluctuations are ever observed in the Gulf Stream.

*Fuglister:* I have a couple of statements. It may seem as though the Kuroshio changes positions more than the Gulf Stream does, but what I worry about is whether it is the Gulf Stream separating from the coast? I think of the coast as separating from the Gulf Stream, because if you look at the globe, you would find that the Gulf Stream generally continues on a great circle course, if you forget its meanders. You can almost consider a great circle course from just north of Florida to the Grand Banks as the mean path of the stream.

*Takenouti:* In the spring of 1957 we made a study of the western and eastern side of the Ryukyu Islands. We found about half of the Kuroshio Current was flowing to the east of the islands. In general, the Kuroshio flows along the continental shelf from the east side of Formosa. In the spring of 1957 it flowed on both sides of the islands, whereas normally it flows to the east. It then joined together and ran straight again north of these Ryukyu Islands.

*Fleming:* Charney, I think you started with the right sort of concept here. Somewhere the current is going to have to turn to the right, and if you had a straight coast running north and south, the point where the current would turn away from the coast would fluctuate considerably in location, and there is a topographical control exerted which, in the case of the Gulf Stream, tends to localize the break at Cape Hatteras. I think you can see a number of examples of this. On the West Coast of North America the circulation pattern change is in the vicinity of Point Conception. I think these same events would probably be displaced if Point Conception were 2 or 4 degrees south or north.

*Wooster:* Could I make a remark? You have been talking about the breaking away of the current from the coast, or the coast from the current, and the same problem comes up in the Peru Current which leaves the coast about 4 degrees south and heads toward the Galapagos Islands. A few years ago, we tried to fix the location of the north boundary of the Peru Current by making many BT observations back and forth in the region off Talara. We found that first of all, this boundary is very clearly marked both by an abrupt change of surface temperature and by a change in the subsurface temperature distribution. We did not find the boundary extending in a more or less straight line out to the Galapagos from the Peruvian coast. Instead it was clearly U-shaped near the coast, and in the course of a week, moved around a great deal. I am sure it moves around in other time scales too. One of the curious things is that while the Peru Current is turning northwestward, the surface winds veer towards the northeast into Panama Bight, so that the current suddenly seems to become oblivious to the winds.

*Schaefer:* Probably again a matter of scale and measurement over a short piece of ocean. Won't the local currents respond much more rapidly?

*Munk:* Yes. On operation CABOT the Gulf Stream showed variations with a time scale of a week that were not wind-induced.

*Wooster:* In this case, I would say there is a quasi-permanent condition. The north boundary of the Peru Current certainly moved around, but it is always in this general area and the winds predominantly go right around the corner into Panama Bight.

*Charney:* I have the impression that these short-period currents are not directly excited by the wind, and that currents excited by the short period winds would be almost imperceptible. The observed unsteadiness in the Gulf Stream region is due to eddies in the Gulf Stream. These might have been produced by barotropic instabilities associated with horizontal shear or by barotropic instabilities associated with strong horizontal density gradients. In either case the currents would be free, not wind-driven.

*Saur:* On the West Coast of California you have the upwelling occurring in the spring, and near the end of the season the upwelling ceases. There is some evidence that eddies develop in May. I believe that it was one of Sverdrup's ideas that this was perhaps due to some type of instabilities after the winds slacked off.

*Comment:* This eddying does not necessarily occur only at the end of windy periods, but exists all the time.

*Saur:* Current work was done for the city of San Diego during 1956 and 1957. One thing that came out of that, was that following periods of strong offshore winds, Santa Ana winds, there oftentimes were fairly strong currents moving north along the coast. Some other observations indicate this was occurring as far north as Santa Barbara. These would continue as long as two days following the termination of the Santa Ana wind. Just by luck, these were documented very well by scientists who happened to be working in these areas on these days. Therefore, in the days following the Santa Ana winds, we have strong northerly currents moving, in effect, against winds blowing at the same time. Later, offshore the currents were generally from the northwest there, between the islands and the mainland.

*Reid:* It might be interesting to look into the matter of ocean temperature anomalies over the short periods for which you can make averages, and find out the times when periods of the correlation holds and when it vanishes. Would the net effect of wind become a predominant one?

*Munk:* Some work has been done on this. First of all, Hela tried to correlate the Gulf Stream with the wind curl over the whole Atlantic. It was a complete flop. Roden has had better luck with somewhat similar studies in the Pacific.

*Charney:* It may be that we are looking at the wrong data. At one time Stommel and I figured out that the present wind systems would require something like ten years to produce the existing ocean currents. In order to bring about a total balance, one has to transport enormous water masses, a process that is very slow. Just to establish the currents and without the isostatic adjustment, would be very fast, but there must be adjustment. The fluctuations are an appreciable fraction of the whole current. In order to produce them, one would need the integrated effect of the winds over a period of years. If one took the integrated data over five years, one might get the right influence.

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