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The Characteristics of the Oceanographical Structure near the Kuroshio Extension-Compared with that of the Gulf Stream Extension-*

Jiro FUKUOKA,** Yoshio AKIBA,*** Hideo MIYAKE,**
and Hitoshi TAKEDA**

Abstract

The Kuroshio is very similar to the Gulf Stream in view of the dynamics of ocean currents. But there are some different characters in both currents in oceanographical structure. As for water temperature distributions, the North Pacific has considerably lower temperature than the North Atlantic. In addition the path of the Kuroshio is at a more southern location than the Gulf Stream. It is seen that the difference of water temperatures is due to the different formations of intermediate water in both oceans. The difference of positions of the ocean current path is owing to the different situations of maximum west wind in the North Pacific and the North Atlantic.

Introduction

The studies of the Kuroshio have been strongly influenced by the studies of the Gulf Stream. The character of the Kuroshio is similar to the Gulf Stream. In order to clarify the image of the Kuroshio, we consider the comparison of the Kuroshio and the Gulf Stream is very important in emphasizing the characteristics of the Kuroshio. Though we have various information about the Kuroshio Extension, the investigation and comparison of both ocean current systems may give us new and fresh knowledge about the ocean current mechanism.

The comparison of water temperature distributions in the North Pacific and North Atlantic Oceans

The surface water temperature distributions in the North Pacific and North Atlantic Oceans are shown in table 1 as the average value in zonal 10 degree latitude. From this table water temperatures in the North Pacific Ocean (20°–60°N) are lower than those in the same latitude of the Atlantic Ocean. On the contrary, in the low latitude of the North Pacific Ocean the surface water temperatures are higher than those in the same latitude of the North Atlantic. The phenomena of lower water temperature in the low latitude of the North Atlantic were already explained by one of the authors. (Fukuoka 1971) We want to study

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** *Research Institute of North Pacific Fisheries, Faculty of Fisheries, Hokkaido University*
(北海道大学水産学部北洋水産研究施設海洋環境学部門)

*** *Laboratory of Oceanography and Meteorology, Faculty of Fisheries, Hokkaido University*
(北海道大学水産学部海洋学気象学講座)

Table 1. Average surface temperature of the oceans.

N (Lat.)	Atlantic	Pacific
70-60	5.60	—
60-50	8.66	5.74
50-40	13.16	9.99
40-30	20.40	18.62
30-20	24.16	23.38
20-10	25.18	26.42
10- 0	26.66	27.20

the cause of lower water temperature in the middle latitude in the North Pacific. According to the above-mentioned fact of surface water temperature, it is seen that the Gulf Stream has it's effects at a more northern part than the point where the Kuroshio influences the North Pacific. In order to grasp these effects clearly, the studies of water temperature distributions are carried out in detail. The north-south water temperature distributions across the Kuroshio Extension and the Gulf Stream Extension are shown in figure 1. Water temperatures of the Kuroshio section are remarkably lower than those of the Gulf Stream section; especially water temperatures in the intermediate layer (about 400 m–1000 m depth), are very much lower on the Kuroshio section than in the Gulf Stream section. At the same time salinities of the Kuroshio section are lower than in the Gulf Stream section, namely the salinity minimum of the Kuroshio section is found but is not seen on the Gulf Stream section. (figure 2) For further study of average thermal structure near the Kuroshio and the Gulf Stream, we calculated the average water temperature in the column from surface to 1000 m depth. (table 2) From this table we can find lower water temperatures in the Kuroshio Extension and the northern part of this Extension, than in the Gulf Stream Extension and the northern part of the Stream.

The average positions of the path of the Kuroshio Extension and the Gulf Stream Extension

The positions of the path of the Kuroshio and the Gulf Stream have been indicated in the pilot chart or oceanographical map. We would like to use the paths of the Kuroshio and the Gulf Stream which Kawai (1972) published. (figure 3) From this figure the path of the Kuroshio Extension occupies the more southern part than that of the Gulf Stream Extension.

To compare the current axes of the Kuroshio and the Gulf Stream in detail, we can use the water temperature distributions in both areas. (refer to figure 1 and table 2) From this figure and table, the steepest north-south gradient zone of water temperature in the Kuroshio is seen to be located further south in latitude, than the steepest gradient zone in the Gulf Stream.

Some oceanographical characteristics in the Kuroshio Extension and the Gulf Stream Extension and the reasons for their appearance

According to the oceanographical characteristics of the Kuroshio Extension in

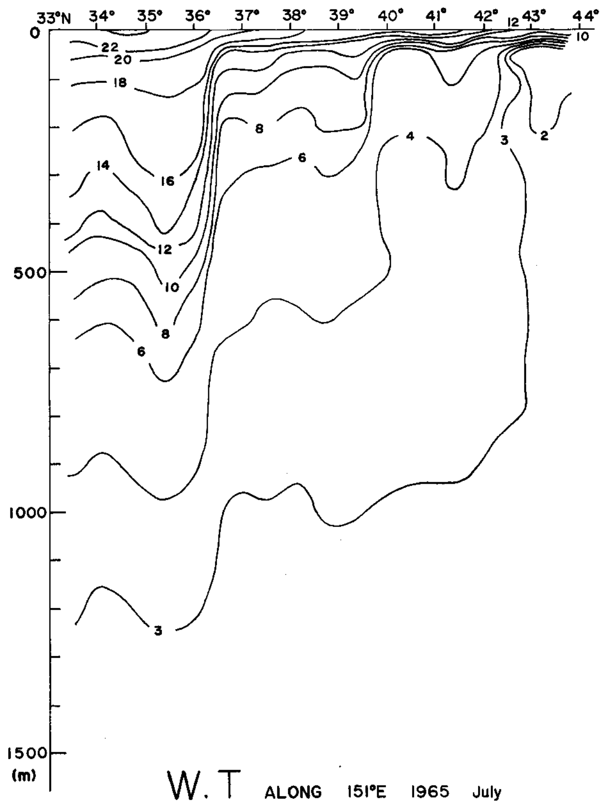

Fig. 1a. Water temperature on the north-south section of the Kuroshio.

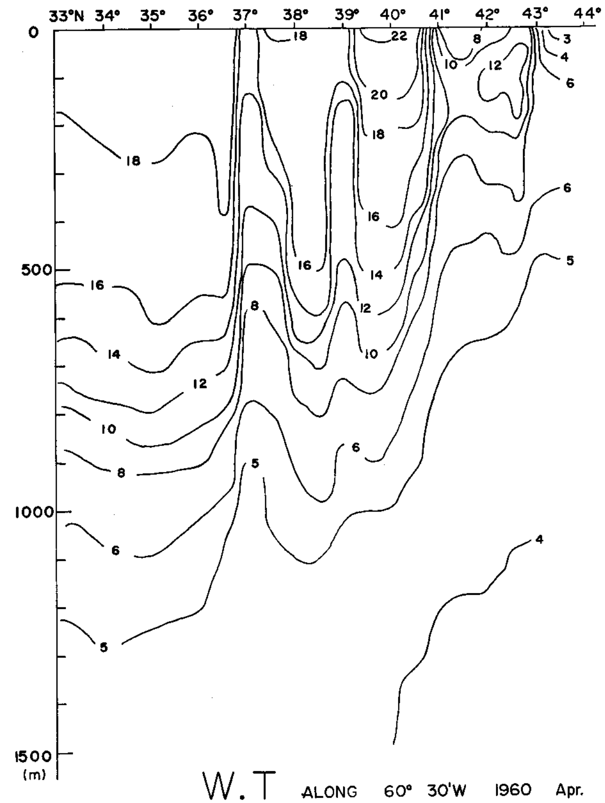

Fig. 1b. Water temperature on the north-south section of the Gulf Stream.

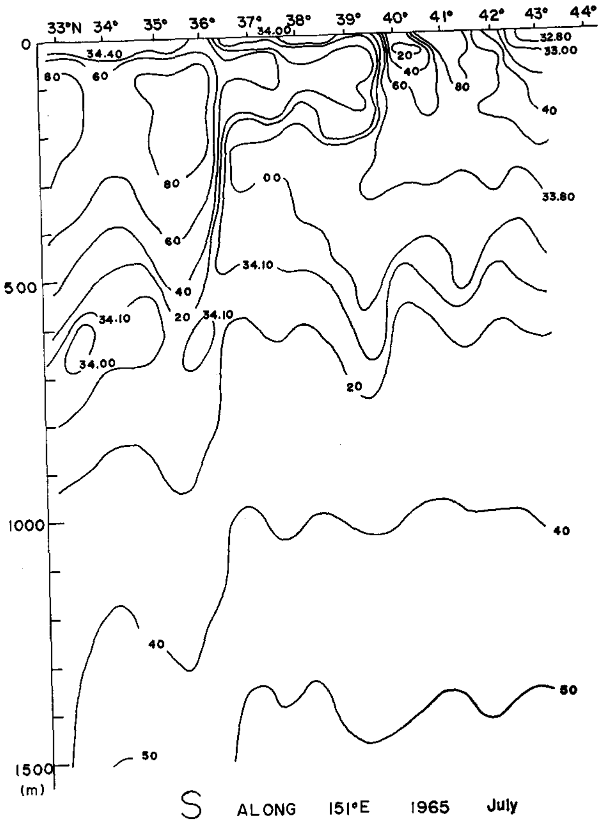

Fig. 2a. Salinity on the north-south section of the Kuroshio.

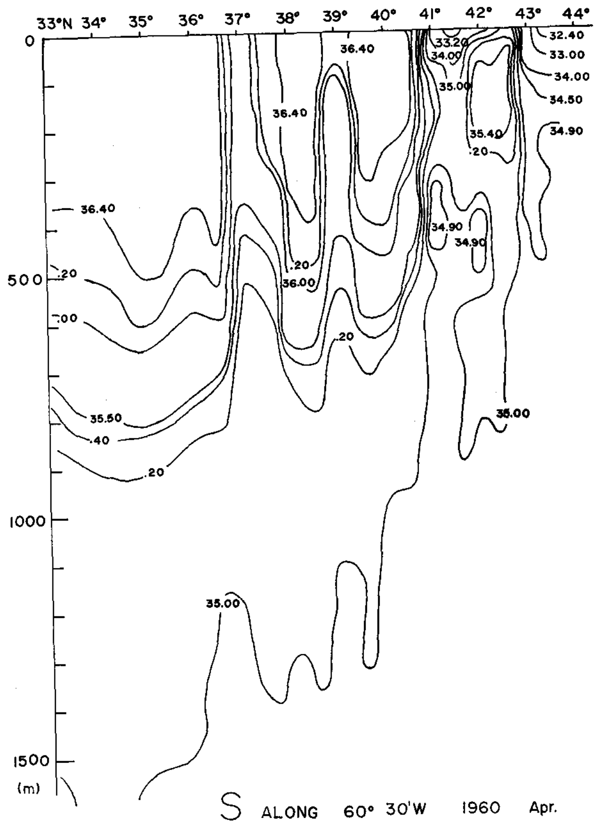

Fig. 2b. Salinity on the north-south section of the Gulf Stream.

Table 2. Average Temperature for

Lat. N / Long. E	Pacific											
	32		33		34		35		36		37	
144 (July 1965)			13.33	13.46			12.68		4.19		4.60	6.59
144 (July 1965)					12.68		4.93		4.18		4.39	6.17
144 (July 1971)			12.47		13.17	11.72			10.90		5.64	
151 (July 1965)			12.01	10.76	9.96	10.66		11.74	10.68		6.03	6.05
155 (May 1969)			10.22		9.50		7.77		8.39		8.04	
Lat. N / Long. W	**Atlantic**											
	32		33		34		35		36		37	
64 31 (Apr. 1960)							13.90		9.69	13.89	15.74	15.92
62 29 (Apr. 1960)									14.20		16.48	16.07
56 30 (Apr. 1960)									16.12		13.71	14.00
54 40 (Apr. 1960)											14.48	

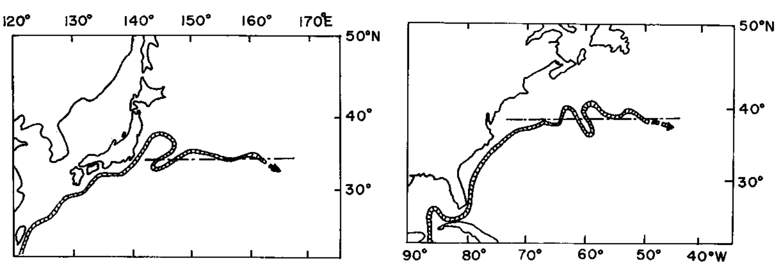

Fig. 3. Average positions of path of the Kuroshio and Gulf Stream.

the above-stated explanation, we can summarize that water temperatures in the Kuroshio are considerably lower than in the Gulf Stream region, and the path of the Kuroshio Extension occupies a more southern location than the Gulf Stream path.

First we would like to consider the reasons for low water temperature in the Kuroshio area. In the North Pacific the water temperature minimum layer in summer is seen near 41°N and the more north part near the North-west Pacific and further north, is more than 44°N as in the central part in the Pacific. (figure 4) While, in the northern part of the Gulf Stream this water temperature minimum layer is not seen in the sea area from 42°N to 55°N. (figure 5) The region where we first find water temperature minimum layer in the North Atlantic is near 60°N. (figure 6)

1000 m Water Column.

38		39		40		41		42		43		44		45
6.91		3.76	3.43	3.13		3.26	3.06							
6.67		3.78	3.39	3.11		3.25	3.05							
9.70		6.54		4.18										
5.84		5.75		4.14		4.15	4.49	4.02	3.28					
7.81		6.88		7.68		4.57		4.92		3.82				

38		39		40		41		42		43		44		45
15.61	14.49	7.35	7.31	7.08	7.30	6.32	6.14							
16.64	16.28	15.24	9.11	11.24	10.25	9.02	8.16	7.07	6.66					
14.55	15.80	14.44	10.68	9.93	8.33	8.01	8.33	8.04	5.48	5.41	6.08	5.51	4.52	
14.10	14.01	14.37	12.22	6.69	8.13	8.21	8.10	7.36	7.53	6.79	6.64	5.27		

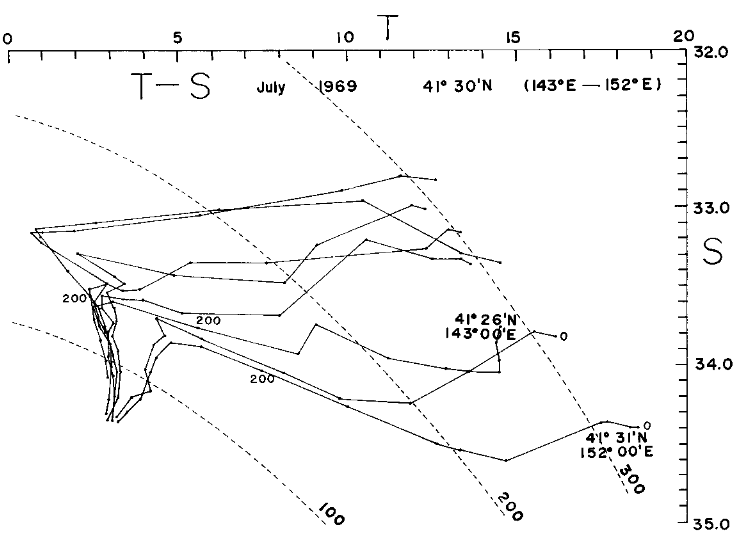

Fig. 4a. T-S diagram in the North-west Pacific in summer.

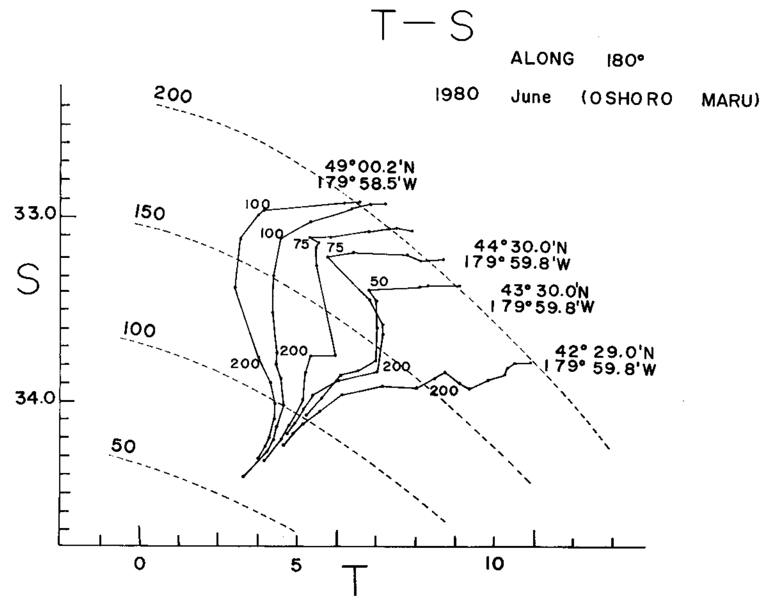

Fig. 4b. T-S diagram in the Central Pacific in summer.

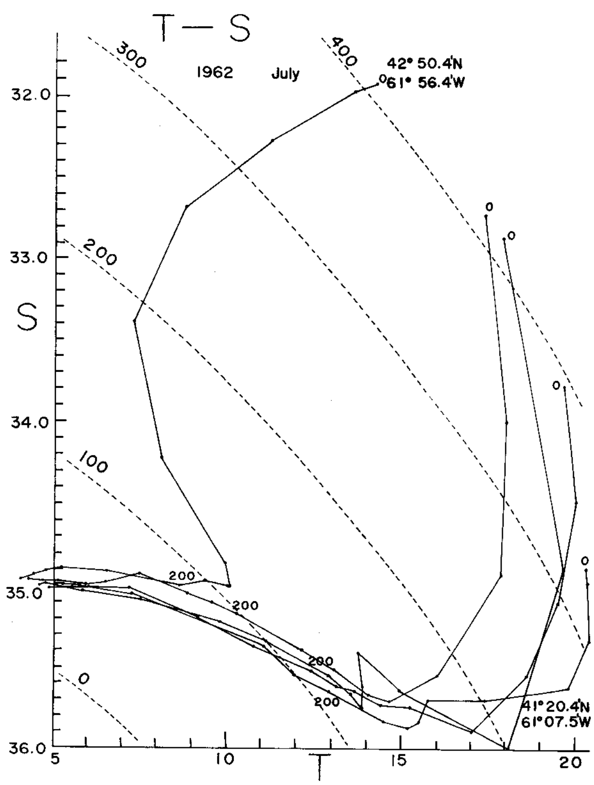

Fig. 5. T-S diagram on the West Atlantic.

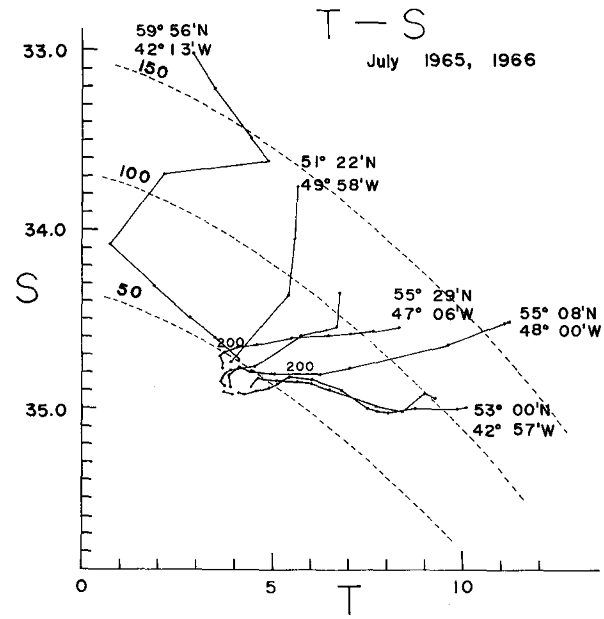

Fig. 6. T-S diagram in the North-west Atlantic.

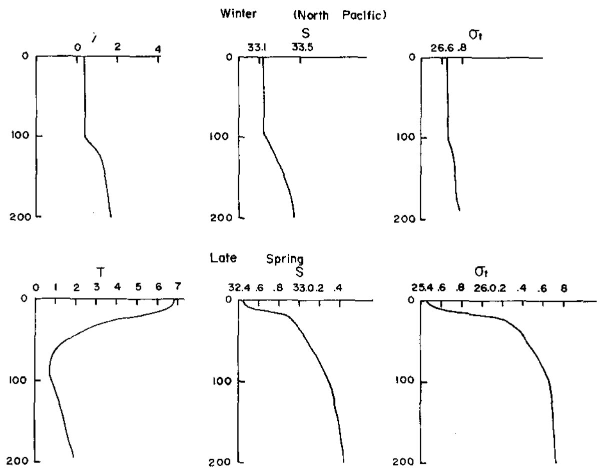

Fig. 7. Schematic expression of vertical distributions of temperature, salinity and density in winter and summer.

From T-S analysis the water masses in the North Atlantic have generally higher temperatures than in the North Pacific. (Worthington 1981) The occurrence of this temperature minimum layer may be explained by the following procedure. The air temperatures on the northern part of the North Pacific are very low in winter. So the homogenous layer appears from the surface to about 100 m depth by the convection. Naturally the water temperature in winter forms the homogenous layer with low temperatures there. In spring and summer the surface temperature rises by radiation, and the surface salinity becomes low by the effects of ice melting, discharge of fresh land water and precipitation. So the vertical gradient of water density is steep and shows the strong stable condition. The vertical mixing of sea water is difficult to develop because of strong stability and the low water temperature near 100 m depth is apt to continue until summer. In figure 7 this procedure is shown schematically. We can not exactly explain the diffrernce of occurrence of water temperature minimum layer in the North Pacific and the North Atlantic, but we can give some guess for this difference. We know the difference of air temperature distributions in winter between the North Pacific and the North Atlantic. (figure 8) In this figure the area lower than 40°F air temperature in the North Pacific is wider than in the North Atlantic. According to this fact we can estimate that the formation of water mass with low temperature, is easier in the North Pacific than in the North Atlantic. We don't have sufficient data for the difference of ice melting, the discharge of land water and the precipitation in both oceans, but we know that the volume of sea ice in winter is more abundant in the North Pacific than in the North Atlantic.

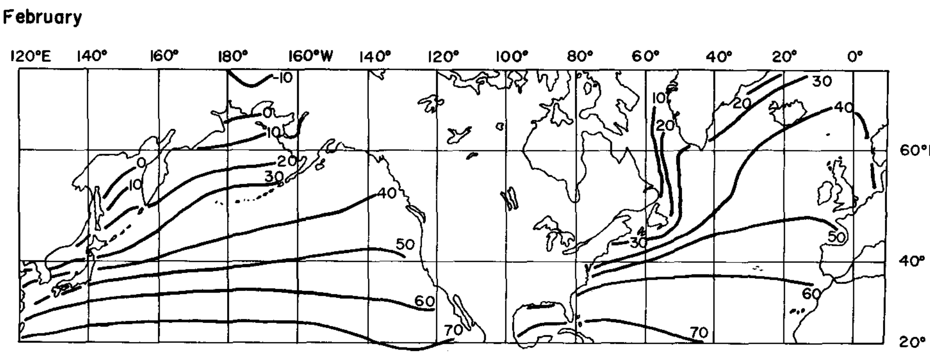

Fig. 8. Air temperature distributions in winter (°F).
(From Marine Climate Atlas of the World, U.S. Navy)

Next, we would like to discuss the difference of the path position between the Kuroshio Extension and the Gulf Stream Extension. By refering to the wind-driven ocean current theory by Stommel (1948) and Munk (1950) the boundary of the subtropical gyre and the subpolar gyre corresponds to the zone for the rotation of wind stress $\tau=0$. The zone, curl $\tau=0$ indicates the maximum west wind belt in the North Pacific and the North Atlantic. From rough distributions of wind, the maximum west wind belt in the North Pacific occupies a more southern part than in the North Atlantic. (figure 9)
The positions of curl $\tau=0$ in the world are shown in the paper published by Evenson and Veronis (1975). According to their work, although the positions, curl $\tau=0$ in the North Pacific and the North Atlantic are similar in the west side of the oceans, in the central and east parts of the oceans these positions in the North Atlantic appear at a more northern location than in the North Pacific. From these

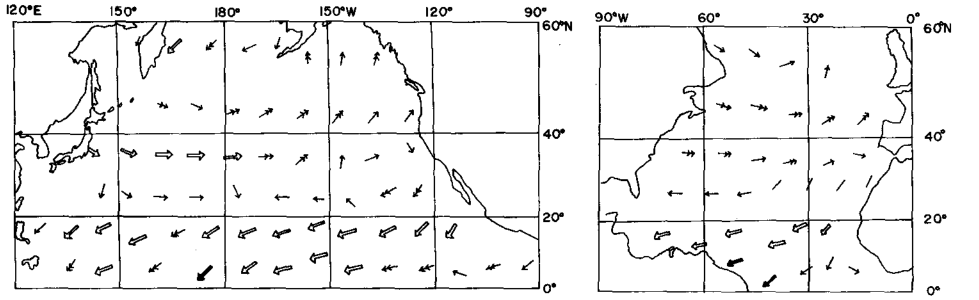

Fig. 9. Wind distributions in the North Pacific and the North Atlantic in winter.
(World Ocean Atlas, USSR Navy)

m/s
→ <3
⇢ 3–5
⇨ 5–7
➡ >7

results the southward shift of the path of the Kuroshio Extension may be partly expalined by the difference of the maximum west wind position.

Another consideration for low water temperature appearing in the North Pacific

According to the above explanation, the role of water mass with low temperature is very important for the investigation of oceanographical structure in the North Pacific. That is to say, the existence of this cold water mass in the North Pacific has an intimate relation to the ocean circulation in the subtropical gyre, and its existence indicates the different character from the oceanographical structure in the North Atlantic. Why can't we find the water mass with low temperature in the northern part of the North Atlantic ? A key to answering this problem is found in the different character of the intermediate layer in both oceans. In the North Atlantic there are some influences of the intermediate water outflow from the Mediterranean Sea. Its influence reaches near Newfound Land or Nova Scotia. (Worthington 1976) In the North Pacific the intermediate water originates in the northern part, and is formed by water mass with low temperature and salinity. Thus, the intermediate water in the North Pacific may flow and diffuse southward but in the North Atlantic it may disperse northward. Recently we can obtain the data of direct measurement of intermediate and deep ocean currents. According to Schmitz (1980) the data of ocean currents with southward components are not seen from 1000 m to 4000 m depth along 55°W between 28°N and 38°N. (POLYMODE) But in the North Pacific we have many examples of southward component of ocean current on the intermediate layer along 152°E from 42°N to 30°N. (Schmitz et al. 1982) It is said that these differences of ocean current directions indicate the significant characteristics in both oceans. We are carrying out current measurements on the intermediate layer (about 1400 m depth) and deep layer (about 5000 m depth) east off Boso Peninsula. (two stations, 34°N, 143°20'E and 35°N, 143°20'E) Although we have not yet formulated the data, we hope that the currents on the intermediate layer indicate a southward component.

The difference of air temperature on the Pacific side of Japan and the Atlantic side of U.S.A.

We have explained the character of low water temperature in the North Pacific Ocean. The formation of the intermediate water in the North Pacific is seen in the northern part and it advects and diffuses southward with low temperature and salinity. When we compare the distributions of air temperature in Japan and U.S.A., the air temperature in Japan is usually lower than in the U.S.A. at almost same latitude. (table 3) Although we can not explain the cause of low air temperature in Japan, it cannot be neglected that the climate in Japan is affected by

Table 3. Air temperature in Japan and U.S.A.

	Pacific												
	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Kushiro (42 59N 144 24E)	−6.6	−6.2	−2.1	3.2	7.7	11.1	15.4	17.9	15.2	9.6	3.3	−2.7	5.5
Urakawa (42 08N 142 44E)	−3.3	−3.1	−0.2	4.7	9.3	12.8	17.4	20.0	16.9	11.5	5.4	−0.4	7.6
Miyako (39 39N 141 58E)	−0.1	0.0	2.7	8.6	13.2	16.2	20.3	22.5	18.6	12.8	7.6	2.5	10.4
Onahama (36 56N 140 55E)	3.0	3.1	5.7	10.7	14.9	18.3	21.9	24.1	20.9	15.3	10.3	5.6	12.8
Choshi (35 43N 140 51E)	5.7	6.0	8.6	13.1	16.7	19.4	22.9	25.0	22.8	18.1	13.5	8.5	15.1
Miyazaki (31 55N 131 25E)	6.7	7.9	11.0	15.5	19.2	22.4	26.6	26.9	24.1	18.4	13.8	8.8	16.8
	Atlantic												
Boston (42 22N 71 01W)	−1.2	−0.9	3.2	8.8	14.9	19.9	23.2	22.1	18.5	12.8	7.2	0.7	10.8
New York (40 46N 73 52W)	0.9	0.9	4.9	10.7	16.7	21.9	24.9	24.1	20.4	14.8	8.6	2.4	12.6
Washington (38 51N 77 02W)	2.7	3.2	7.1	13.2	18.0	23.4	25.7	24.7	20.9	15.0	8.7	3.4	13.9
Cape Hatteras (35 16N 75 33W)	7.4	7.6	10.3	14.9	19.5	23.5	25.6	25.3	23.1	18.5	13.3	8.7	16.5
Charleston (32 54N 80 02W)	10.2	10.8	13.7	17.9	22.2	25.7	26.7	26.5	24.2	19.0	13.3	10.0	18.3

the low water temperature in the North Pacific as oppsosed to the high temperature intermediate water in the North Atlantic. In a word it is said that the air temperatures in Japan are under the influence of the "freezer", as the North Pacific intermediate water is called.

Summary

We can find differences of oceanographical character in the North Pacific and the North Atlantic. One example is low water temperature in the North Pacific. Another point is that the Kuroshio Extension is located further south than the Gulf Stream Extension. These phenomena are due to the different oceanographical structures. For example, there are different intermediate waters in both oceans and different meteorological conditions, as well as different positions of maximum west wind and areas with varying low air temperatures in winter in both oceans. We believe that in order to undersatnd the difference of oceanographical structure in both oceans, accurate information about the Kuroshio and the Gulf Stream should be further examined.

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