On the meridional heat transport in the Kuroshio and adjacent regions.

Kanehito TAKEUCHI*

Abstract

Numerical values of the meridional heat transport by ocean currents in south of Japan are calculated from 227 serial oceanographic observations along the 35 oceanic sections, carried out from spring of 1965 to summer of 1969 for CSK (Cooperative Study of the Kuroshio and Adjacent Regions). The amount of calculated meridional heat transport across the oceanic sections takes from 40.6×10^{13}gcal·sec^{-1} towards north in south of Honsyu to 14.2×10^{13}gcal·sec^{-1} towards south in south-east of Yakushima Island. The amount of calculated heat transport per 1 km of zonal distance takes from 8.7×10^{11}gcal·sec^{-1} towards north in south-east of Yakushima Island to 8.6×10^{11}gcal·sec^{-1} towards south in south-east of Yakushima Island in another period. Fairly stationary northward heat transports are found to the south of Honsyu and to the east of Taiwan, on the other hand to the north-west of Ryukyu Islands the variation of heat transport is considerably large. In comparison with Bryan's investigation, southward heat transport is expected in the eastern part of the Pacific Ocean and great significance of the western Pacific is recognized. The results of 14 oceanographic observations in south-east off Yakushima Island, carried out from spring of 1965 to summer of 1969, show a periodic change in the meridional heat transport with a period of about 9.5 months.

1. Introduction.

It is a well-known fact that the surplus incoming radiation energy from the sun and sky over effective outgoing back radiation energy to the space in the regions of lower latitudes is transported to the regions in higher latitudes where there is incoming radiation deficit, in order to compensate this radiative imbalance. The meridional temperature gradient would continuously increase, which is contradictory to the observed fact, if there were no compensation for this radiative imbalance. Thus the meridional temperature gradient remains unchanged for many years and annual average temperature for a given locality remains essentially constant due to the meridional flow of heat. The required energy transport must take place with in the atmosphere and the oceans, since the solid earth is a very poor conductor of heat, while the formers are both fluids, where the heat amount can easily be transmitted in various ways. The contributions of the ocean cur-

* Laboratory of Geology, Faculty of Education, Kagoshima University.

rents to the heat transfer can not be neglected so far as variations of oceanic condition itself and also air-sea interaction, especially in some regions, such as the Gulf Stream in the Atlantic and the Kuroshio in the Pacific, though the atmosphere provides a major portion of the required transport. Jung (1955) and Bryan (1962) calculate, using direct method, the amount of the heat transpoted meridionally by ocean currents and discuss their results. For the direct method, the observed water temperature distribution must be required along with evaluations of the ocean current velocities to calculate the heat amount transported across a vertical section by the currents. On the other hand, Budyko (1956), Sverdrup (1957) and Albrecht (1960) calculated by the indirect method on the bases of observations of marine atmosphere, in which the whole heat budget for a particular oceanic region mus be taken into consideration. In the present study, the contribution of the Kuroshio and adjacent regions to the meridional heat transport by the ocean is examined. Since it is not suitable to calculate by use of indirect method for this limited area, the direct method is used. Furtheremore, there is such an advantage that the local conditions can be revealed, when the direct method is used.

2. Procedure and materials.

The oceanic region from 20°N to 35°N, from 120°E to 145°E, is treated for the purpose of investgating the heat transport due to the Kuroshio and adjacent regions. According to Bryan (1962), the amount of heat transport, H, by ocean currents is evaluated essentially by

$$H=\int_0^x\int_0^z C_p\theta\rho v dz dx \quad ,$$

where C_p is the specific heat of sea water at constant pressure, θ is potential temperature, ρ is density of sea water, v is the current velocity. Investigation is performed vertically from the sea surface (0) to a depth (z), and horizontally from the origin (0) to some distant point (x). Z is depth in meters and positive downward. For practical technics in calculations, C_p and θ are assumed to be linear functions of depth as follows: $C_p = 0.955-0.6\times10^{-5}z$ and $\theta = T-0.8\times10^{-4}z$, where T is sea water temperature. Numerical value of ρ is transformed from sigma-T value tabulated in preliminary data report of CSK.

Geostrophic calculation is made to obtain the numerical value of current velocity across each oceanographic section, adopting a depth of 1,000 m as the reference level, except for shallower area where a depth of 800m or 700m is taken as the reference level. Each oceanographic vertical section is divided into partial layers by every observing level and into partial section by every observing point on the section. For each subsection of solenoids made by the procedure stated above, the value of $C_p\theta\rho v$ is calculated, and then multiplied by area of the corresponding solenoid respectively. All the numerical values calculated by such procedure are added to obtain the amount of heat transport by ocean currents across the vertical section.

In order to examine the effect of the Kuroshio and adjacent regions on the meridional heat compensation and to compare the regional characteristics, the meridional component of the amount of heat transport obtained by the procedure stated above and that of meridional heat transport per 1km of zonal distance are calculated. The effect of wind stress is not taken into consideration. Calculations for 227 oceanographic stations in sections in Preliminary Data Report of CSK published by Japanese Oceanographic Data Center are performed. Observing points and sections are shown in Fig. 1. The selected and analyzed sections seem to be almost normal to the Kuroshio and to include the axis of the Kuroshio. According to the results of calculations, however, a few oceanographic sections do not seem to include the axis of the Kuroshio, as stated later.

3. Calculated heat transport in the Kuroshio and adjacent regions.

Local difference of the amount of heat transport by ocean currents depends mostly on current velocity and next on sea water temperature. Density and specific heat vary little, so these affections are very little. Especially the direction of heat transport is decided only by whether ocean currents have northward component or southward. Sea water temperature, however have serious significance in surface layer as far as differences between different seasons and localities. Observation data, geographical locality of selected sections, number of observation points on the respective section, and calculated heat transport are shown in Table 1. Minus sign shows southward heat transport. Numerical values of the highest,

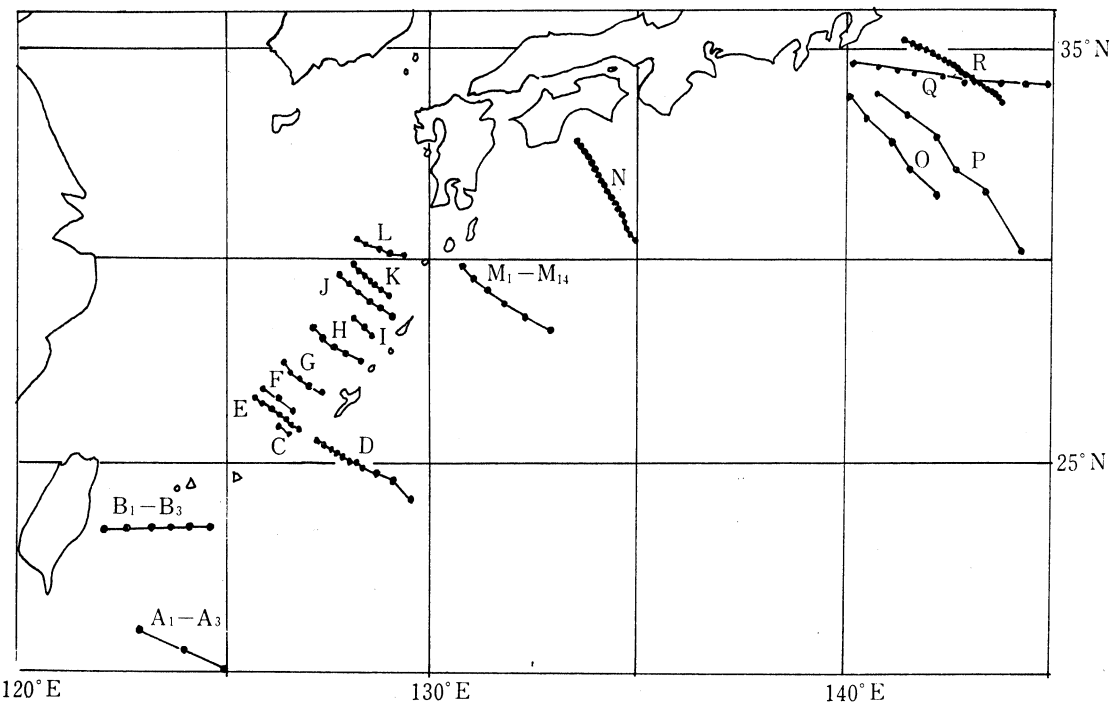

Fig. 1. Map showing the observation points and sections.

Table 1. Calculated heat transport.

Section	Period	Locality	Number of stations	Calculated heat transport per section 10^{13} gcal/sec	per 1Km of zonal distance 10^{11} gcal/sec
A_1	APR. 27— APR. 29 1966	20°00.0′N 125°00.0′E — 20°54.0′N 123°00.0′E	3	−1.7	−0.8
A_2	APR. 27 1967	20°00.0′N 125°00.0′E — 21°04.0′N 122°47.3′E	3	4.3	1.9
A_3	APR. 29— MAY 3 1968	20°00.0′N 125°00.0′E — 21°38.0′N 122°47.4′E	3	−3.3	−1.4
B_1	JUL. 29— JUL. 30 1965	23°00.0′N 124°15.0′E — 23°01.0′N 122°10.0′E	5	9.0	4.2
B_2	JAN. 28— JAN. 29 1966	23°00.0′N 123°46.0′E — 23°06.0′N 121°41.0′E	6	10.4	3.2
B_3	JUL. 12— JUL. 13 1966	23°00.0′N 124°21.0′E — 22°58.0′N 121°38.0′E	6	16.4	5.9
C	FEB. 5 1967	26°31.7′N 126°08.3′E — 26°14.3′N 126°35.8′E	2	−3.5	−7.7
D	AUG. 21— AUG. 23 1965	25°41.0′N 127°25.0′E — 23°54.8′N 129°23.5′E	11	1.0	0.5
E	AUG. 20— AUG. 21 1965	26°53.0′N 126°02.0′E — 26°00.8′N 127°02.0′E	7	0.9	0.9
F	FEB. 2 1966	26°52.0′N 125°39.0′E — 26°16.0′N 126°35.0′E	3	0.0	0.0
G	OCT. 13— OCT. 14 1968	27°35.0′N 126°21.0′E — 26°45.0′N 127°16.0′E	5	−7.7	−8.4
H	OCT. 13— OCT. 14 1968	28°20.0′N 127°09.0′E — 27°38.0′N 128°10.0′E	5	−1.3	−1.3
I	AUG. 31 1968	28°55.2′N 127°46.1′E — 28°15.5′N 128°23.0′E	3	−2.8	−4.4
J	OCT. 14 1968	29°29.0′N 127°41.0′E — 28°49.0′N 129°10.0′E	6	5.7	3.9
K	AUG. 8 1968	29°00.0′N 129°00.5′E — 29°45.2′N 128°19.3′E	7	4.5	6.8
L	OCT. 13— OCT. 14 1968	30°36.0′N 128°19.0′E — 30°20.0′N 129°38.0′E	5	3.5	2.8
M_1	MAY 15— MAY 16 1965	29°36.0′N 131°08.0′E — 28°14.5′N 132°44.0′E	6	−13.3	−8.6
M_2	JUL. 1— JUL. 2 1965	29°50.0′N 130°50.0′E — 28°16.0′N 132°43.0′E	6	−2.7	−1.5
M_3	NOV. 1— NOV 2 1965	29°52.0′N 130°50.0′E — 28°14.0′N 132°43.0′E	6	5.7	3.1
M_4	JAN. 18— JAN. 19 1966	29°53.0′N 130°51.0′E — 28°14.0′N 132°45.0′E	6	−0.5	−0.3

Section	Period	Locality	Number of stations	Calculated heat transport per section 10^{13} gcal/sec	Calculated heat transport per 1Km of zonal distance 10^{11} gcal/sec
M_5	APR. 19— APR. 20 1966	29°52.0′N 130°53.0′E — 28°14.0′N 132°43.0′E	6	7.5	4.1
M_6	JUL. 2— JUL. 3 1966	29°53.0′N 130°50.0′E — 28°13.0′N 132°44.0′E	6	9.2	5.0
M_7	OCT. 27— OCT. 31 1966	29°51.0′N 130°53.5′E — 28°14.0′N 132°48.0′E	6	2.8	1.5
M_8	JAN. 13— JAN. 14 1967	29°53.0′N 130°51.0′E — 28°13.7′N 132°44.5′E	6	6.1	3.3
M_9	APR. 14— APR. 15 1967	29°52.0′N 130°51.0′E — 28°11.0′N 132°44.0′E	6	11.2	6.2
M_{10}	AUG. 28— AUG. 29 1967	28°14.0′N 132°43.0′E — 29°53.0′N 130°50.0′E	6	−7.5	−4.1
M_{11}	OCT. 6— OCT. 7 1967	29°53.0′N 130°51.0′E — 28°14.0′N 132°44.0′E	6	−4.1	−2.2
M_{12}	FEB. 25— FEB. 26 1968	29°52.0′N 130°50.0′E — 28°13.0′N 132°44.0′E	6	12.9	7.0
M_{13}	APR. 27— APR. 28 1968	29°50.0′N 130°51.0′E — 28°12.0′N 132°43.0′E	6	15.8	8.7
M_{14}	JUL. 30— JUL. 31 1969	29°54.0′N 130°49.0′E — 28°13.0′N 132°43.0′E	6	−14.2	−7.7
N	SEP. 2— SEP. 11 1965	33°00.0′N 133°42.0′E — 32°33.0′N 134°05.0′E	22	14.0	5.6
O	FEB. 27 1966	34°01.0′N 140°10.0′E — 31°16.0′N 142°16.0′E	5	4.0	2.0
P	JUL. 13— JUL. 15 1965	29°29.5′N 144°05.0′E — 33°30.0′N 140°58.0′E	6	−3.8	−1.3
Q	MAR. 1— MAR. 2 1966	34°00.0′N 145°00.0′E — 34°41.0′N 140°14.0′E	9	10.0	2.3
R	SEP. 15— SEP. 23 1965	35°16.0′N 141°29.0′E — 35°15.0′N 141°13.0′E	21	40.6	8.3

Table 2. Highest, lowest and mean values of calculated heat transport.

	Calculated heat transport per section 10^{13} gcal/sec	Calculated heat transport per 1 km of zonal distance 10^{11} gcal/sec
Northward : highest	40.6	8.7
: lowest	0.9	0.5
Southward : highest	14.2	8.6
: lowest	0.5	0.3
Mean (northward)	3.8	1.1

the lowest and the mean of the calculated heat transport are shown in Table 2.

The amount of northward heat transport across the vertical sections takes from the highest value, 40.6×10^{13} gcal·sec^{-1}, at section R (south of Honsyu) to the lowest, 0.9×10^{13} gcal·sec^{-1}, at section E (west of Ryukyu Island). The amount of southward heat transport takes from the highest value, 14.2×10^{13} gcal·sec^{-1}, at section M_{14} (south-east of Yakushima Island) to the lowest, 0.5×10^{13} gcal·sec^{-1}, at section M_4 (south-east of Yakushima Island in another period). The mean value for all the sections is 3.8×10^{13} gcal·sec^{-1} towards north. The amount of northward heat transport along meridian across vertical sections per 1 km of zonal distance takes from the highest value, 8.7×10^{11} gcal·sec^{-1}, at section M_{13} (south-east of Yakushima Island in another period) to the lowest, 0.5×10^{11} gcal·sec^{-1} at section D (south-east of Ryukyu Island), while that of southward takes from the highest value, 8.6×10^{11} gcal·sec^{-1}, at section M_1 (south-east of Yakushima Island in another period) to the lowest, 0.3×10^{11} gcal·sec^{-1} at section M_4 (south-east of Yakushima Island in another period). The mean value for all the sections per 1km of zonal distance is 1.1×10^{11} gcal·sec^{-1} towards north.

The geographical representation of the amount of meridional heat transport in the Kuroshio and adjacent regions per 1km of zonal distance is shown in Fig. 2, using numerical values in Table 1. Following facts are seen from Table 1 and Fig. 2. The 35 observing sections comprise 21 showing northward heat transport and 13 showing southward and one vanishing. Sections A_1, A_2, A_3 (around 21°N, 124°E) were observed in spring of 1966, 1967, 1968, and the amounts of calculated heat transport per 1 km of zonal distance are -0.8×10^{11} gcal·sec^{-1}, 1.9×10^{11}

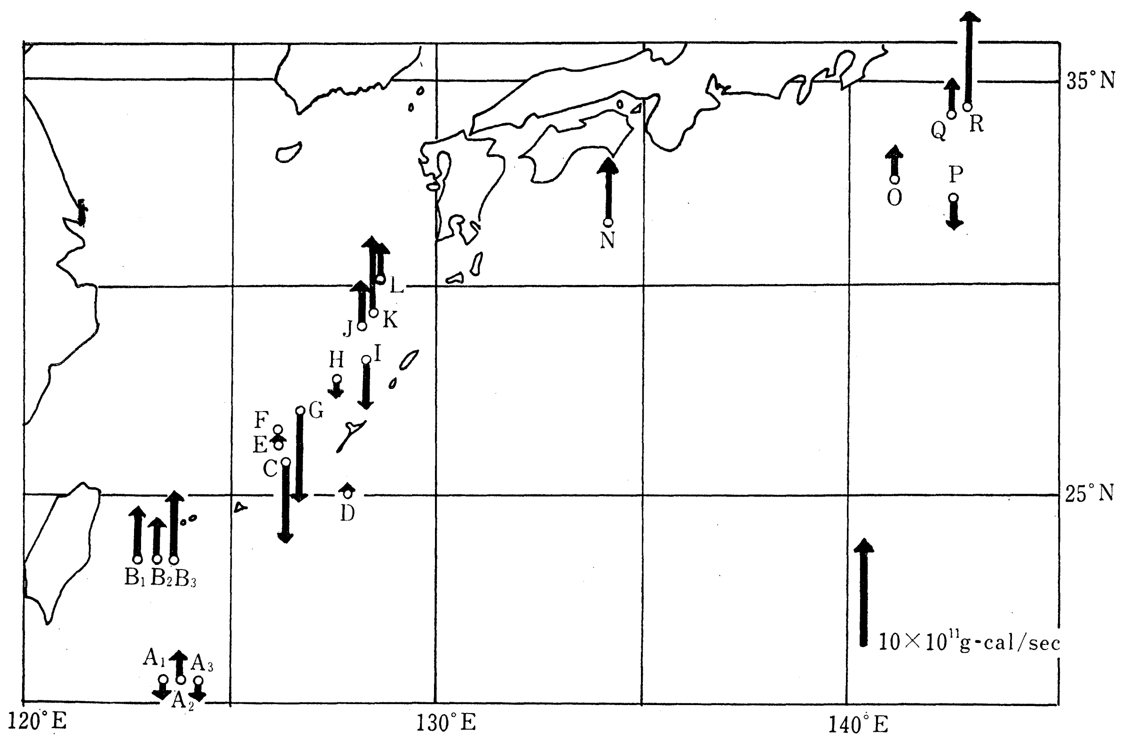

Fig. 2. Geographical representation of heat transports per I km of zonal distance.

gcal·sec^{-1}, and -1.4×10^{11} gcal·sec^{-1} respectively. These values are relatively small. Sections B_1, B_2, B_3 (east off Taiwan) were observed in summer of 1965, in winter and in summer of 1966, and the amounts of calculated heat transport per 1 km of zonal distance are 4.2×10^{11} gcal·sec^{-1}, 3.2×10^{11} gcal·sec^{-1}, and 5.9×10^{11} gcal·sec^{-1} respectively. These values show northward heat transport and relatively stationary. Sections G, H, J, L (north-west of Amami and Ryukyu Islands) were simultaneously observed on October 13 and 14 in 1968 by Japan Meteorological Agency, i. e., Seifu maru, Chofu maru, Shumpu maru and Kofu maru, the amounts of calculated heat transport per 1 km of zonal distance are -8.4×10^{11} gcal·sec^{-1}, -1.3×10^{11} gcal·sec^{-1}, 3.9×10^{11} gcal·sec^{-1} and 2.8×10^{11} gcal·sec^{-1} respectively, which are different considerably to the each other in spite of simultaneous observations. Only section D is situated in south-eastern area of Ryukyu Island, and the amount of calculated heat trnsport per 1 km of zonal distance is 0.5×10^{11} gcal·sec^{-1}, i. e., a little contribution to northward heat transport is found. Sections N, O, P, Q, R (south off Honsyu) show northward heat transport except P, and the amounts of calculated heat transport per 1 km of zonal distance are 5.6×10^{11} gcal·sec^{-1}, 2.0×10^{11} gcal·sec^{-1}, -1.3×10^{11} gcal·sec^{-1}, 2.3×10^{11} gcal·sec^{-1}, and 8.3×10^{11} gcal·sec^{-1} respectively.

Though the variation in the effect of the Kuroshio can not be discussed directly from all these values, it is possible to see its condition roughly, that is, in south of Honsyu and in east of Taiwan, the contribution of the Kuroshio seems to be stationary almost all seasons and years but it varies very much in north-west of Ryukyu Islands.

Budyko (1956), Sverdrup (1957) and Albrecht (1960) investigate the heat transport by ocean currents by use of indirect method obtaining 0.9×10^{14} gcal·sec^{-1}, -1.4×10^{14} gcal·sec^{-1}, 0.3×10^{14} gcal·sec^{-1} across 20°N latitude circle and 0.7×10^{14} gcal·sec^{-1}, 0.7×10^{14} gcal·sec^{-1}, 0.0 across 30°N latitude circle respectively for the Pacific Ocean, where minus value indicates transport to the south. Jung (1955), Bryan (1962) also investigate the heat transport by ocean currents by use of direct method. Jung did not take into consideration the effect of wind stress and obtained 1.3×10^{14} gcal·sec^{-1} across 18°N latitude circle for the Atlantic Ocean. Bryan (1962) also calculates on the bases of geostrophic consideration and wind stress and from climatological summeries, obtaining 1.5×10^{14} gcal·sec^{-1} from Meteor Atlas, 3.1×10^{14} gcal·sec^{-1} from IGY data across 16°S, 0.8×10^{14} gcal·sec^{-1} across 24°S, 1.8×10^{14} gcal·sec^{-1} across 36°N and 0.0 across 40°N from IGY data for the Atlantic Ocean, and -2.8×10^{14} gcal·sec^{-1} from IGY data across 32°N for the Pacific Ocean. These results are listed in Table 3. All these investigations are made for nearly complete latitude circles at each particular latitude for the Atlantic Ocean and the Pacific Ocean.

Seasonal variation can not be found from the results shown in Fig. 2. It is recognized that the axis of the Kuroshio is not included in sections C (south-west of Ryukyu Island), G (west of Ryukyu Island), and I (west of Amami Island), at which the amounts of southward heat transport are large due to large southward currents. Thus the selection of oceanographic sections comes to have a significant meaning.

The mean value for all the sections per 1km of zonal distance, 1.1×10^{11} gcal·sec^{-1}, multiplied by the width at about 30°N in the Pacific Ocean, 9600km, gives 10.6×10^{14} gcal·sec^{-1}. Comparing this numerical value with Bryan's result across 32°N for the Pacific Ocean, -2.8×10^{14} gcal·sec^{-1}, southward heat transport is expected in the eastern part of the Pacific Ocean. Furthermore, it is recognized that the northward heat transport in the western Pacific is great important.

4. Conditions in south-east off Yakushima Island.

In order to investgate the seasonal variations, 14 observations are available in south-east off Yakushima Island from spring of 1965 to summer of 1969, as shown in Table 1 stated above. Oceanographic stations and the sections are shown in Fig. 3. Numerical values of the highest, the lowest and the mean of the calculated heat transport are shown in Table 4. The positions of the stations slightly differ in each individual observation. The mean positions of each stations are as follows: st. 1 (29°52′.2N, 130°50′.8E), st. 2 (29°38′.6N, 131°08′.6E), st. 3 (29°24′.4N, 131°25′.0E), st. 4 (29°10′.0N, 131°40′.0E), st. 5 (28°41′.8N, 132°12′.2E) and st. 6 (28°25′.0N, 132°44′.0E). Individual observing points in 14 observations are

Table 3. Ocean heat transports northward across the stated latitude circles in units of 10^{14}gcal/sec (previous investigations by other authors).

Latitude \ Author	Jung (1955)	Budyko (1956)	Sverdrup (1957)	Albrecht (1960)	Bryan (1962)	Region	Method
40°N					0.0	N. Atl.	Direct
36°N	1.3				1.8	N. Atl.	Direct
32°N					−2.8	N. Pac.	Direct
30°N		0.7	0.7	0.0		N. Pac.	Indirect
27°N	1.9					N. Atl.	Direct
20°N		0.9	−1.4	0.3		N. Atl.	Indirect
18°N	1.3					N. Atl.	Direct
16°S					3.1	S. Atl.	Direct
24°S					0.8	S. Atl.	Direct

Table 4. Highest, lowest and mean velues of calculated heat transport south-east off Yakushima Island.

	Calculated heat transport	
	per section 10^{13} gcal/sec	per 1 km of zonal distance 10^{11} gcal/sec
Northward : highest	15.8	8.7
: lowest	2.8	1.5
Southward : highest	14.2	8.6
: lowest	0.5	0.3
Mean (northward)	2.1	1.0

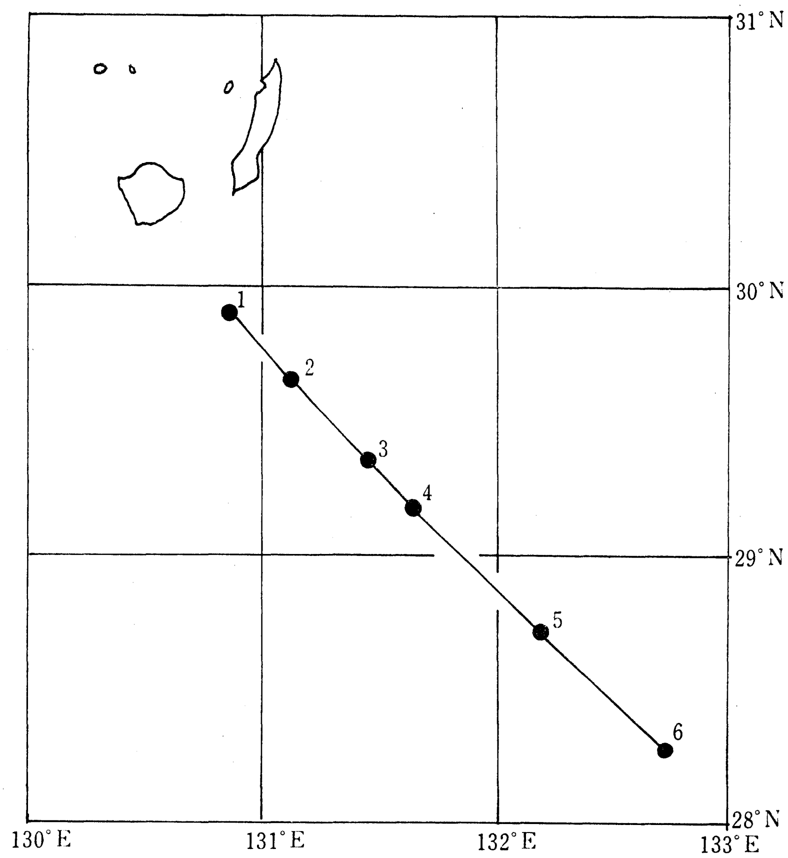

Fig. 3. Map showing the observation points and section in south-east off Yakushima Island.

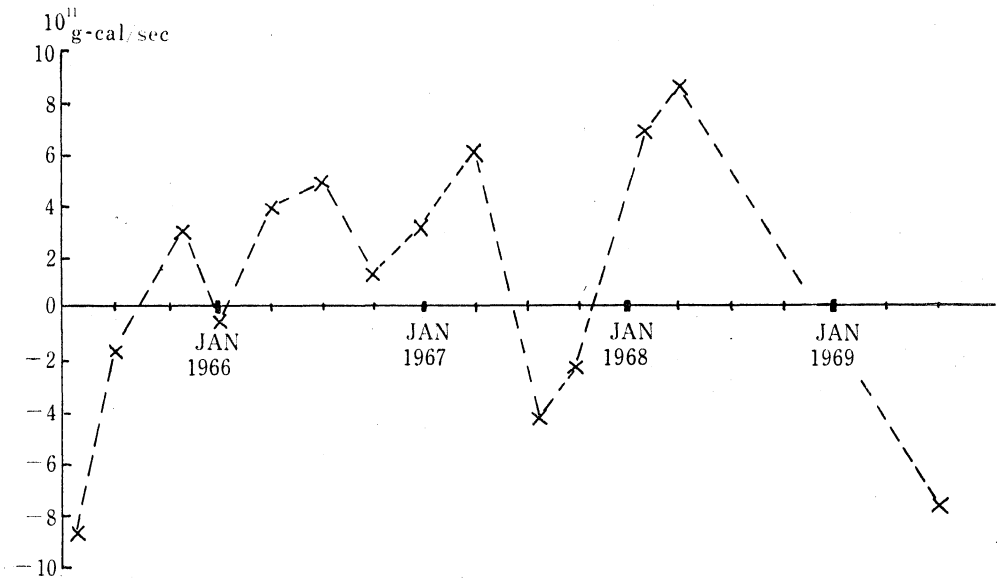

Fig. 4. Variation of heat transport per I km of zonal distance in south-east off Yakushima Island.

included within 5km from mean positions with the percentage of 92.3, 78.6, 57.1, 71.4, 92.9 and 92.9 respectively. Since the amounts of heat transport calculated from the 14 successive observations are different from time to time, the variation with time is shown in Fig. 4.

Fluctuation of the Kuroshio in this region has been proved to be large due to the topographical features (Tsuchida and Yamagata, 1968). From Fig. 4 it can not be found that the amount of heat transport in this region varies with seasons. The arithmetic mean value of variational period is about 9.5 months, excluding M_{14}, since there is 15 months between M_{13} and M_{14}, and therefore another one peak is expected between M_{13} and M_{14}. The period of 9.5 months is supposed to be the very variation of the Kuroshio itself which is characterized by current velocity and direction, because the temperature varies annualy.

The amounts of heat transport per 1 km of zonal distance vary from 8.7×10^{11} gcal·sec^{-1} towards north in spring of 1968 to 8.6×10^{11} gcal·sec^{-1} towards south in spring of 1965, and those in spring of 1965, in summer of 1967 and in summer of 1969 are 8.6×10^{11} gcal·sec^{-1}, 4.1×10^{11} gcal·sec^{-1} and 7.7×10^{11} gcal·sec^{-1} towards south respectively. These amounts of southward heat transport suggest that whether the axis of the Kuroshio has not been included in the observing section or has southward component across the section, when these observations were performed.

5. Summary and conclusion.

The earth loses more energy by long-wave radiation to space than it receives in the form of solar radiation in polar regions, and it receives more energy than it loses in the form of long wave radiation in the tropics. This radiative imbalance is mostly compensated by the advection of heat towards polar regions within both atmosphere and oceans. Though the atmosphere provides a major portion of the required heat transport, the contribution of the ocean currents may amount to a good deal in some regions.

The heat transport along a meridian in the Kuroshio and adjacent regions across 35 vertical sections takes from 40.6×10^{13} gcal·sec^{-1} towards north to 14.2×10^{13} gcal·sec^{-1} towards south, on the bases of calculations using oceanographic data of serial observations for CSK during the time interval from spring of 1965 to summer of 1969. The 35 observing sections comprise 21 showing northward heat transport and 13 showing southward and one vanishing. The amount of meridional heat transport per 1 km of zonal distance varies from 8.7×10^{11} gcal·sec^{-1} towards north to 8.6×10^{11} gcal·sec^{-1} towards south. The amount of meridional heat transport is stationary through all seasons and years in south of Honsyu and in east of Taiwan, on the other hand it varies very much in north-west of Ryukyu Islands. Comparing the mean value for all the sections per 1km of zonal distance, 1.1×10^{11} gcal·sec^{-1} with Bryan's result across 32°N for the Pacific Ocean, -2.8×10^{14} gcal·sec^{-1}, southward heat transport is expected in the eastern part of the Pacific Ocean and great significance of the western Pacific for the heat compensation is recognized.

In south-east off Yakushima Island, the amount of the heat transport varies with a period of about 9.5 months, as the result of calculations based on the 14 successive observations from spring of 1965 to summer of 1969. The amounts of heat transport per 1km of zonal distance vary from 8.7×10^{11} gcal·sec^{-1} towards north in spring of 1968 to 8.6×10^{11} gcal·sec^{-1} towards south in spring of 1965.

Acknowledgements: The author wishes to his gratitude to Dr. T. Takahashi and Mr. M. Chaen, Faculty of Fisheries of the Kagoshima University, for their helpful suggestions through this study. He is also indebted to Dr. H. Ishikawa, Faculty of Education of the Kagoshima University for his kind support.

References

Albrecht, F. (1960): Jahreskarten des Warme-und Wasserhaushaltes der Ozeane, Ber. Deut. Wetterdienstes, 66, Bd.9, 19pp.

Bryan, K. (1962) : Measurements of meridional heat transport by ocean currents. J. Geophys. Res., 67, No. 9, 3403-3414.

Budyko, M. L. (1959): The Heat Balance of the Earth's Surface, translated by Z. Ushijima, 181 pp. Kasen Suion Chosa Kai, 1959.

Cox, R. A., and N. D. Smith. (1959): The specific heat of sea water, Proc. Roy. Soc. London, A, 252, 51-62.

Jung, G. H. (1952) : Note on the meridional transport of energy by the oceans, J. Marine Research, Sears Foundation, II, 2.

Jung, G. H. (1955) : Heat transport in the Atlantic Ocean, Ref. 53-34T, Dept. of Oceanography, A. and M. College of Texas, College Station.

Sverdrup, H. U. (1957): Oceanography in "Encyclopedia of Physics", Vol. 48, No. 28, Berlin, Springer Verlag, pp. 608-670.

Tsuchida, T. and T.Yamagata (1968): On the cold water region in the offing of Tanegashima Island. Umi to Sora 44 (2, 3).