Climatological Studies on Air-Sea Interaction over the Northwestern Pacific

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Abstract

Sensible and latent heat fluxes from ocean to atmosphere are estimated over the Northwestern Pacific by the use of data of the weather reports from commercial ships. As a result of analysis by the bulk method, a large amount of upward energy fluxes are seen in the winter over the Kuroshio region, and the downward sensible heat flux in the summer almost over the whole region, in spite of upward latent heat flux, is found. Annual variations of turbulent heat fluxes are also analyzed in several different sections of the Northwestern Pacific. A large range of variations as well as a large amount of energy fluxes are seen near the coast of the Continent and Japan Islands. The thermal energy balance analysis over the ocean shows that the sea surface receives more energy from radiation than the outgoing energy by turbulent sensible and latent heat transport into the atmosphere in almost the whole region over the Northwestern Pacific except for the area near the coast where thermal energy balance is held.

1. Introduction

It is generally recognized that a knowledge of the amount of energy exchange between ocean and atmosphere is a fundamental requirement for a proper understanding of the atmospheric motion. Especially, over the ocean to the east of the continent, the rate of air-sea energy exchange is expected to be large on the average and also large in its seasonal variation, and the weather phenomena in this area are greatly influenced by heat and water vapor supply from the ocean.

For the purpose of better understanding of air-sea interaction and development of small scale disturbances over the ocean to the east of Eurasian Continent, an intensive study program of Air Mass Transformation Experiment (AMTEX) has been planned over the sea adjacent to Okinawa (Southwest Islands of Japan) as a subprogram of GARP.

Jacobs[1] had made a climatological study of global air-sea interaction, and a rough estimate of the rate of energy exchange in this area is also shown in his paper. Recently, Ninomiya[2] has estimated energy exchange over the East China Sea in the winter season by the use of Jacobs' method from the weather reports of the ocean research vessels of the Japan Meteorological Agency.

In the present paper energy exchange over the northwestern part of the Pacific Ocean to the east of Eurasian Continent including the East China Sea has been evaluated

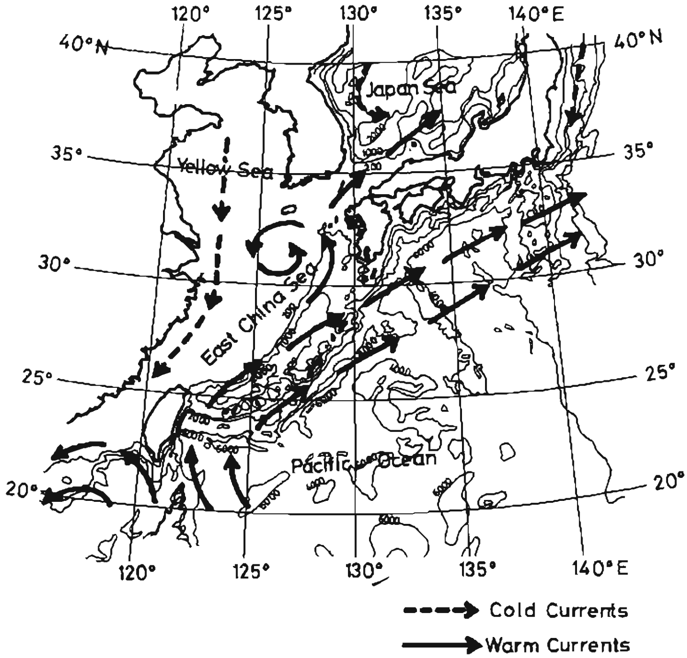


Fig. 1. Synoptic situation of Northwestern Pacific Ocean.

120°E 130°E 140°E; 34°N – 30°N – 20°N

6.1	9.4	11.1	11.3
8.2	11.4	13.6	14.5
10.6	13.4	15.7	16.1
14.5	16.1	17.8	17.4
16.9	18.8	19.4	19.2
20.5	20.6	21.0	21.3
22.2	22.6	22.6	23.2

MEAN AIR TEMPERATURE, °C

120°E 130°E 140°E; 34°N – 30°N – 20°N

13.1	13.8	14.1	16.3
12.6	14.9	15.2	16.8
14.5	15.9	14.3	14.2
16.5	14.7	12.4	11.9
17.8	13.1	11.5	10.6
15.2	13.4	11.1	11.4
16.9	13.1	12.5	11.3

MEAN SURFACE WIND SPEED, knots

120°E 130°E 140°E; 34°N – 30°N – 20°N

8.8	14.5	18.0	17.4
10.8	15.6	18.7	17.8
14.1	18.2	18.9	18.5
18.4	20.5	19.7	19.8
20.4	21.1	20.7	21.1
22.4	21.9	21.9	23.0
23.3	23.3	23.2	24.5

MEAN SEA SURFACE TEMPERATURE, °C

120°E 130°E 140°E; 34°N – 30°N – 20°N

1.3	1.0	1.3	1.8
1.3	1.5	1.5	1.9
1.6	1.7	1.5	1.6
1.8	1.3	1.5	1.6
1.9	1.5	1.3	1.3
[illegible]	1.5	1.4	1.3
[illegible]	1.5	1.5	1.5

MEAN WAVE HEIGHT, m

FEBRUARY 1962 - 1965

Fig. 2. Monthly means of marine meteorological parameters in February.

from the data of weather reports from commercial ships compiled by JMA, as the Marine Climatological Tables of the North Pacific Ocean. The geographic distribution and the seasonal change of energy exchange are discussed as well as the energy balance over the ocean.

2. General conditions

Typhoon, drought and the winter monsoon represent the various features of climate of Okinawa, which consists of the islands (Southwest Islands of Japan) extending from northeast to southewest in the latitude range from 29° N to 24° N, dividing the East China Sea from the Pacific Ocean. The western half of the East China Sea is a shallow continental shelf, but along the island arch there runs the deep which is as deep as the one along the eastern side of the arch as shown in Fig. 1.

The main flow of the warm current, called Kuroshio, flows into the East China Sea at the southwestern end of the island arch and runs to the northeast along the edge of the continental shelf, flowing out to the Pacific from the northeastern end of the island arch.

Figs. 2 and 3 show the monthly mean of the marine meteorological conditions over the seas around Okinawa for February and August. Even in the winter season, sea surface temperature in the Kuroshio region is about 20°C, resulting in the large air-

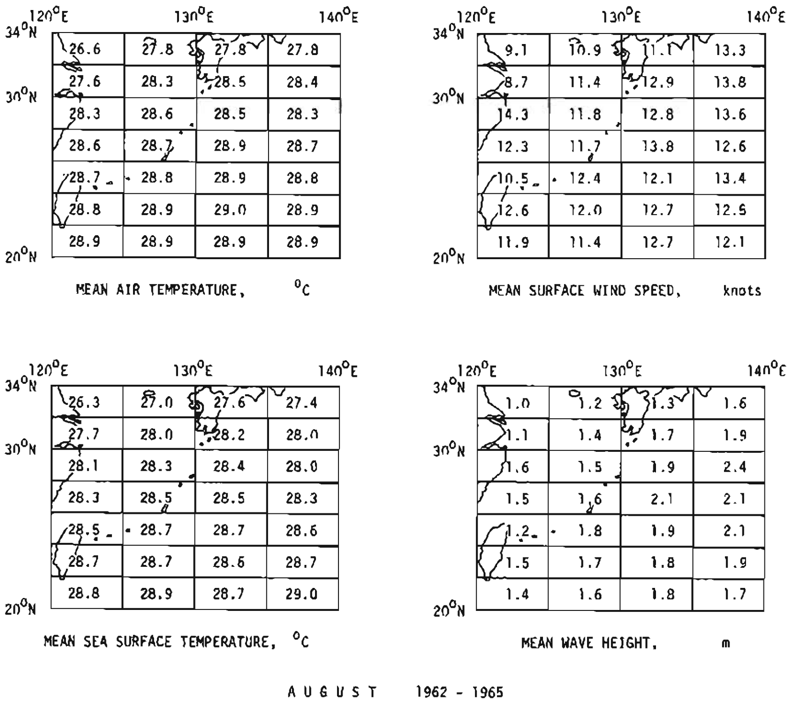


Fig. 3. Monthly means of marine meteorological parameters in August.

sea temperature difference. In the summer season both sea and air temperatures are as high as 28°C over the whole region.

The original data shown in the Marine Meteorological Tables are the annual monthly mean values of air temperature, dew-point temperature, sea surface temperature, wind speed, cloud amount, wave height and atmospheric pressure averaged over small rectangular sections of 2° Lat. by 5° Long. as shown in Figs. 2 and 3 over the whole North Pacific Ocean. In the present study the mean values during 4 years from 1962 to 1965 in the region (20–34° N and 120–140° E) were mainly analyzed. The averaged number of ship observations are shown in Fig. 4, which is about 270 data per month in the section near Okinawa. To compare this area of analysis to the other part of the North Pacific, five sections, shown in Fig. 5, are chosen for the computation of energy balance over the ocean.

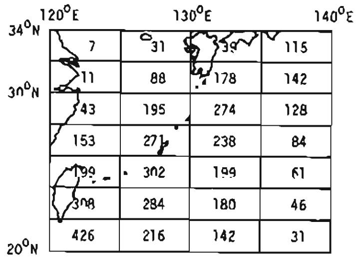


Fig. 4. Monthly mean numbers of data.

3. Method of calculation of air-sea energy exchange

The rate of vertical turbulent transports of sensible and latent heat over the sea surface can be estimated by the bulk method from monthly mean climatological data.

$$H = C_p \rho c_D U(\theta_w - \theta)\,, \tag{1}$$

$$L = L_v \rho c_D U(q_w - q)\,, \tag{2}$$

where H is sensible heat flux, L latent heat flux, $\theta_w - \theta$ potential temperature difference between sea surface and air, $q_w - q$ the difference of mixing ratio between sea surface and air, ρ density of air, U wind speed at the height of observation, C_p specific heat of air, L_v latent heat of vaporalization of water and c_D being drag coefficient. Introducing of the bulk method of these equations in turbulent flux estimation may be the subject of discussions because there still remains ambiguity in physical implications of these equations. However, these equations are the simplest and most convenient in evaluation of the first approximation of the fluxes and are used in this preliminary study. The value of c_D, 1.05×10^{-3}, obtained by the present author[3] over the Pacific Ocean by means of the direct method on the ship mast during the Severe Rainstorm Project, a Japanese national effort for GARP, is used. This value agrees well with the ones obtained by the other researchers over the ocean but is about a half of the equiva-

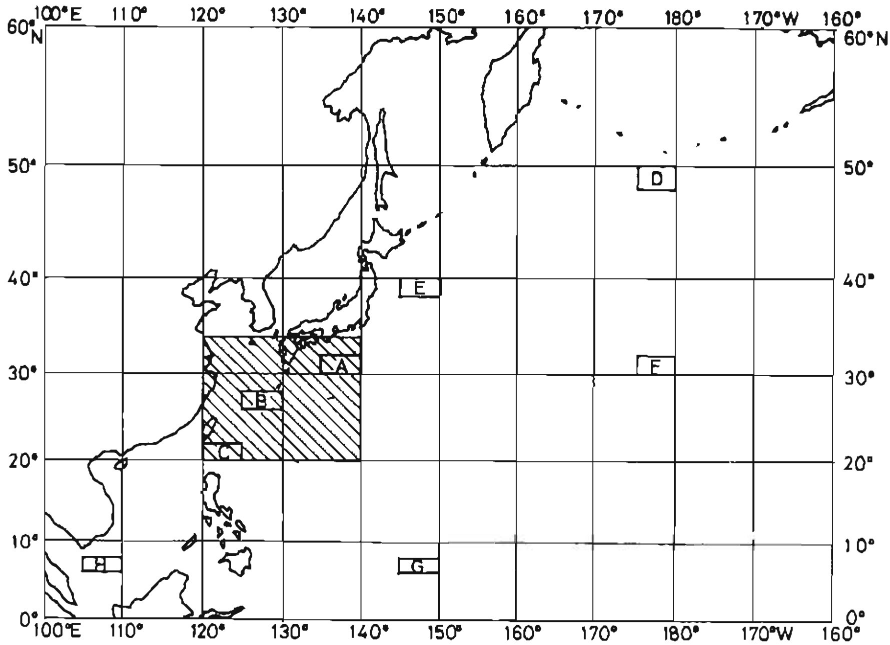


Fig. 5. Locations of sections selected for the analysis of annual variation of fluxes.

lent value used by Jacobs,[4] which was estimated by the energy balance method.

The net radiation over the ocean surface can be expressed as the difference of incoming short wave radiation and effective radiation in the following formula after Budyko,[5]

$$R=(Q+q)\ (1-a)-I, \tag{3}$$

where R is net radiation, Q direct solar radiation, q diffuse radiation, a albedo of sea surface and I being effective radiation, and $(Q+q)$ is called global radiation. In spite of long history of the study of radiation, only a few methods of approximation have been proposed for climatological evaluation of global radiation under various weather conditions. The amount of global radiation at a clear sky $(Q+q)_0$ has been estimated by Budyko, after U.V. Ukraintsev's method. Table 1 shows the monthly mean of global radiation at a clear sky, $(Q+q)_0$, for each latitude derived from the Budyko's results. The global radiation in general case can be expressed in the following form,

$$(Q+q)=(Q+q)_0\ \{1-k(1-n)\}, \tag{4}$$

where k is an emperical constant and n being cloud amount. The parameter k represents the influence of cloudiness and it must be the function of mean solar height, the feature of clouds and other meteorological conditions. However, the relation is not clear and climatological data other than total cloud amount are hardly obtainable, therefore in the present study the averaged value for each latitude shown by Budyko

Table 1. Annual variation of total daily global radiation with a clear sky in different latitudes, in ly/day.

Latitude	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
80°N	0	0	83	320	597	677	630	360	120	13	0	0
75°	3	20	133	373	623	697	657	410	177	57	7	0
70°	7	47	193	423	647	713	677	457	233	100	23	3
65°	27	83	253	470	670	730	700	503	293	150	50	13
60°	57	130	320	513	693	743	720	547	350	203	87	40
55°	100	187	383	553	717	757	737	590	410	257	137	77
50°	157	250	450	593	737	767	750	627	473	320	193	127
45°	220	313	513	633	753	777	763	670	533	387	257	190
40°	290	383	567	667	763	783	773	703	587	447	323	257
35°	360	453	617	700	767	783	777	727	627	503	393	320
30°	423	507	650	720	767	783	777	740	660	550	453	380
25°	477	550	677	727	763	780	770	743	683	587	500	437
20°	517	583	693	727	753	763	757	740	700	617	543	483
15°	553	610	700	720	733	740	736	727	703	640	577	523
10°	580	633	700	710	707	707	707	707	703	653	600	553
5°	600	650	693	693	680	660	670	683	693	663	620	577
0°	617	660	680	673	640	600	623	653	680	667	633	600

Table 2. Latitudinal variation of coefficient, k. After Budyko[5].

Latitude, deg.	75	70	65	60	55	50	45	40
k	0.55	0.50	0.45	0.40	0.38	0.36	0.34	0.33
Latitude, deg.	35	30	25	20	15	10	5	0
k	0.32	0.32	0.32	0.33	0.33	0.34	0.34	0.35

Table 3. Annual variation of monthly mean albedo of the sea surface for global radiation. After Budyko[5].

Latitude	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
70°N	---	0.23	0.16	0.11	0.09	0.09	0.09	0.10	0.13	0.15	---	---
60°	0.20	0.16	0.11	0.08	0.08	0.07	0.08	0.09	0.10	0.14	0.19	0.21
50°	0.16	0.12	0.09	0.07	0.07	0.06	0.07	0.07	0.08	0.11	0.14	0.16
40°	0.11	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.08	0.11	0.12
30°	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.08	0.09
20°	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07
10°	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07
0°	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

is adopted, which is shown in Table 2. The albedo a of the sea surface also changes with solar altitude and the state of the sea surface. But in the climatological investigation, albedo can be considered as the function of solar altitude only. Budyko and others obtained the monthly mean values for each latitude as shown in Table 3 by the use of the data by Savinov.

The effective radiation from the sea surface under general weather conditions can be expressed by the effective radiation with a clear sky and the cloud amount, just in the same way as in the global radiation, when following after Budyko,

$$I=I_0(1-cn), \quad (5)$$

where I_0 is effective radiation with a clear sky, c an empirical constant and n being the monthly mean value of cloud amount. The value of 0.76 is adopted as the value of c after Kondratiev[6] in the present study. The value of I_0 can be obtained by the

$$I_0=\sigma T^4\ (0.254-0.005e), \quad (6)$$

where T is air temperature in absolute temperature, e water vapor pressure in mb and σ being the Stefan-Boltzmann constant being 8.14×10^{-11}.

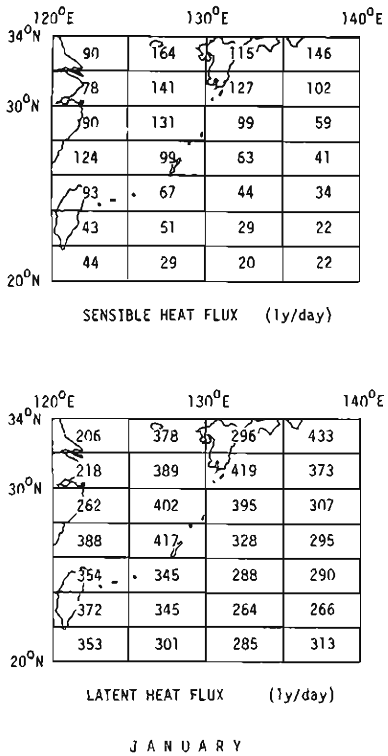


Fig. 6. Distributions of sensible and latent heat fluxes in January.

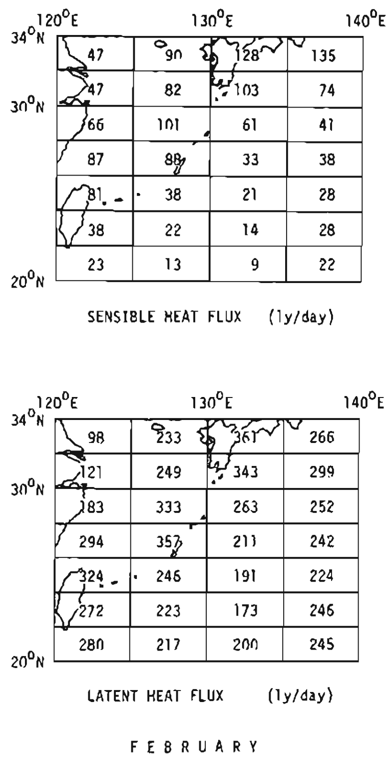


Fig. 7. Distributions of sensible and latent heat fluxes in February.

4. Sensible and latent heat supply from the sea surface.

To see the typical climatological feature of air-sea interaction, sensible and latent heat fluxes from the ocean surface to the atmosphere in winter and summer seasons were estimated. The distributions of sensible and latent heat fluxes in the sea area around the Southwest Islands in January and February are shown in Figs. 6 and 7. The considerably large areal difference of sensible heat flux is seen in January, when the sensible heat flux shows the maximum value in the year. The daily mean value is about 20 ly/day on the Pacific Ocean, but the large amount of heat, larger than 100ly/day, is supplied from the ocean surface in the sections involving the Southwest Islands and neighbouring Kyushu and Shikoku. Near the coast of China the flux becomes small. As is clear from this, a great deal of sensible heat is supplied over the Kuroshio region. The same tendency can be mentioned for February, as shown in Fig. 7. However, on the whole, the amount is a little smaller than that of January. The average flux over the whole area shown in this figure is about 56 ly/day, which is about 3/4 of that of January (77 ly/day).

The latent heat flux distribution over this area in January resembles that of the

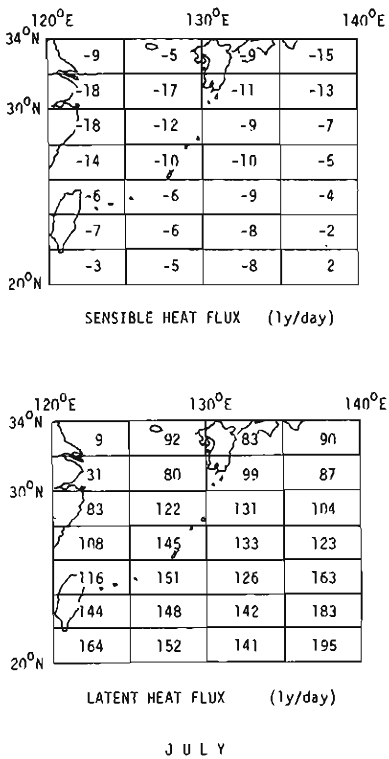


Fig. 8. Distributions of sensible and latent heat fluxes in July.

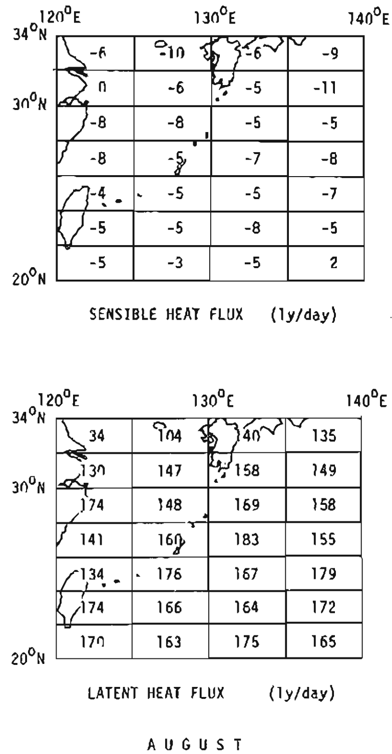


Fig. 9. Distributions of sensible and latent heat fluxes in August.

sensible heat flux while a large amount of latent heat flux is also found over the Kuroshio region along the Southwest Islands and south of Kyushu and Shikoku. In these sections more than 400 ly/day of latent heat is transported, that is, the rate of evaporation is about 7 mm/day. The areal difference is smaller than the case of sensible heat flux, and latent heat flux over the Pacific is about 300 ly/day or 5.2 mm/day of evaporation, and near the continent the flux is about 250 ly/day or 4.3 mm/day. The over all areal average is 332 ly/day and the Bowen ratio is 0.23 on average. This ratio is large near the continental coast and decreases with distance from the coast down to about 0.07. The amount of latent heat flux in February shows a little smaller value than in January in the same way as for the sensible heat flux. The areal average in February is 75% that of January, however, the distribution pattern is the same as January. Large values are found in the Kuroshio region.

The distributions in July and August are shown in Figs. 8 and 9 respectively. The remarkable feature is that the sign of sensible heat flux is changed in summer, that is, sensible heat is transported downward from the air to the ocean surface. As is clear from Figs. 8 and 9, the negative values of sensible heat flux in the whole area are seen except on the southeast corner. But the amount of sensible heat exchange is far smaller than the that of winter. The areal mean is only 9 ly/day, which is 11% of the flux in winter. The heat supply from the air to the sea is large near the coast of the Continent and Japan, and decreases with the distance from the coast. In August the values of sensible heat fluxes are also negative in almost whole area as well as in July. However the magnitude is smaller than that in July and the areal mean is 6 ly/day being 66% of the value in July.

The latent heat flux is upward but smaller than that in the winter season. The amount of its areal average is 120 ly/day, so the evaporation amount being about 2 mm/day. This value is about 36% of the amount in January. From Fig. 8, it is found that latent heat flux is larger in the south and smaller near the continent. For example in the section near Okinawa Island it is about 145 ly/day or 2.5 mm/day, while in the section in the southeast corner it is 195 ly/day or 3.4 mm/day. The over all average of the Bowen ratio is -0.07, and on the southeast corner the ratio is 0.07, which is the same as that in the winter season. In August, the latent heat flux increases to the value of 153 ly/day or 2.6 mm/day on the areal average. This amount is about 1.3 times of the amount in July. The distribution becomes more uniform than in August.

5. Energy balance on the ocean surface.

It is revealed that the direction of sensible heat flux reverses itself over the sea in this area in the summer season. To clear the time period in which downward sensible heat flux is seen and also to check the energy balance over the ocean, net radiation, as well as the sensible and latent heat fluxes, was calculated in several sea sections throughout the year.

Three sections are selected in the area around Southwest Islands, which are (A), (B) and (C) in Fig. 5, and five other sections (D) to (H) outside the area, also shown in

Fig. 5, are selected for the purpose of comparison. Fig. 10 shows the annual changes of sensible and latent heat fluxes and net radiation together with the related meteorological elements. In these figures heat transport from the sea surface to the atmosphere is taken to be positive and shown in the unit of ly/day. In all of the three sections (A), (B) and (C), in the area of analysis in the preceeding the section, sensible and latent heat fluxes show the maximum values in January, and the latent heat flux is always positive showing its minimum in June, and the sensible heat flux is negative during the summer season from April to September. However, the negative value of the sensible heat flux is not so large and, at most, it is about 10 ly/day. The minimum can not be clearly distinguished as in the case of the latent heat flux. The ranges of annual variations of fluxes and other meteological parameters are large in (A) and (B), but they become smaller in the low latitude section (C). The annual mean values of sensible heat fluxes are 24, 31 and 9 ly/day respectively. In the sections (A) and (B), sensible heat fluxes in the winter months are much larger than the mean values as shown before.

The annual mean values of latent heat fluxes in three of these sections are almost the same and are about 230 ly/day. This means that the annual total evaporation in these areas is about 1400 mm. The Bowen ratioes are about 0.1 for the sections (A) and (B), and 0.04 for the section (C).

The annual change of the net radiation is largely influenced by solar height and cloudiness. The minimum values of the magnitude of the net radiation is seen in December in all of these three sections and the maximum values are seen in June in the sections (A) and (B) because of large cloud amount in May and June, and May and July in the section (C) which is to the south of the Tropic of Cancer. The annual mean of the net radiation in the section (C) is 350 ly/day, which is the largest of these three, and those of the sections (A) and (B) are almost the same, and are 300 ly/day and 290 ly/day respectively.

As the difference of the heat gain by radiation and the heat loss by turbulent transport of sensible and latent heat, the amount of heat, which is conducted into the ocean from the surface, can be estimated. The annual mean values of heat gain of the ocean are 33, 14 and 110 ly/day respectively. This shows that, in the sections (A) and (B), the heat gain and the heat loss are almost balanced on the ocean surface but in the section (C) in low latitude the solar heat gain on the ocean surface is greater than heat loss by turbulent diffusion to the atmosphere by about 30%. Therefore, heat supplied to the ocean in the low latitudes must be advected to the higher latitudes by the ocean current. In other words, the thermal energy source of the warm current of the Northwest Pacific is apparently the tropical ocean.

In the sections (A) and (B), in which the thermal balance is held for the whole year, the ocean has the net heat gain from March to September, during which the maximum value is seen in July (about 350 ly/day) and the ocean losses heat in the period from October to February and the maximum heat loss, which is almost the same in magnitude with maximum heat gain, is seen in January. The same tendency is seen even in the section (C) where a net heat gain is seen for the whole year. The annual change of the rate of the total energy supply into the ocean is strongly related to the seasonal changes of the weather and the ocean current in this area.

To compare the feature of thermal balance of the area around Okinawa above obtained with the other part of the Northwestern Pacific, five sections (D) to (H) were chosen in the positions shown in Fig. 5.

In the section (D), which is in the northen edge of the Pacific, the annual mean of latent heat flux is 59 ly/day and annual total evaporation amount being about 350 ly/day. This value is the smallest of all 8 sections analyzed. The maximum value is seen in November but its magnitude does not exceed 100 ly/day. While sensible heat flux is also small and its annual mean is only 4 ly/day. Here also the negative value of sensible heat flux in summer is seen and the summer minimum is almost the same as the winter peak which is almost 20 ly/day. Net radiation in December is negative because the effective radiation exceeds the global radiation in this month. The annual mean of net radiation is 156 ly/day which is 2.5 times of the total heat fluxes of sensible and latent heat, therefore a large heat gain of the ocean is seen in this area.

In the section (E), which is near the northern part of Japan, the maximum values of both sensible and latent heat flux are found in February and a large value of Bowen ratio of 0.77 is seen, which is the largest of all sections. The snesible heat transport in the summer season is also downward, but the amount is not so large. The annual mean value of net radiation is 221 ly/day, and this value is almost the same as the sum of the sensible and latent heat loss of this section, which is 213 ly/day on average, and the thermal balance is held in this section.

In the section (F), which is in the central part of the North Pacific, the ranges of annual variation of sensible and latent heat fluxes are small compared with the ranges in (A), which is located in the same latitude range. The annual mean of the latent heat loss is 181 ly/day, and the total evaporation being 1100 mm, which is smaller than that in (A), while the annual mean sensible heat fluxes is about 10 ly/day and is also smaller than that in (A). The annual mean value of the net radiation is 300 ly/day, which is 1.5 times of the total of the amount of the turbulent fluxes.

In the sections (G) and (H), which are far south near the equator, the annual variations of snesible and latent heat fluxes are mainly due to the change of wind speed and are the minimum of all sections. The amount of sensible heat flux is very small throughout the year and its sign changes irregularly. The net radiation does not change widely and its annual mean value is 350 ly/day, which is almost twice of the sum of the sensible and latent heat loss in the year.

6. Discussions.

From the results shown above, the following climatological features of air-sea interaction may be pointed out in the Northwestern Pacific. There are active sensible and latent heat supplies from the sea surface to the atmosphere over the Kuroshio region

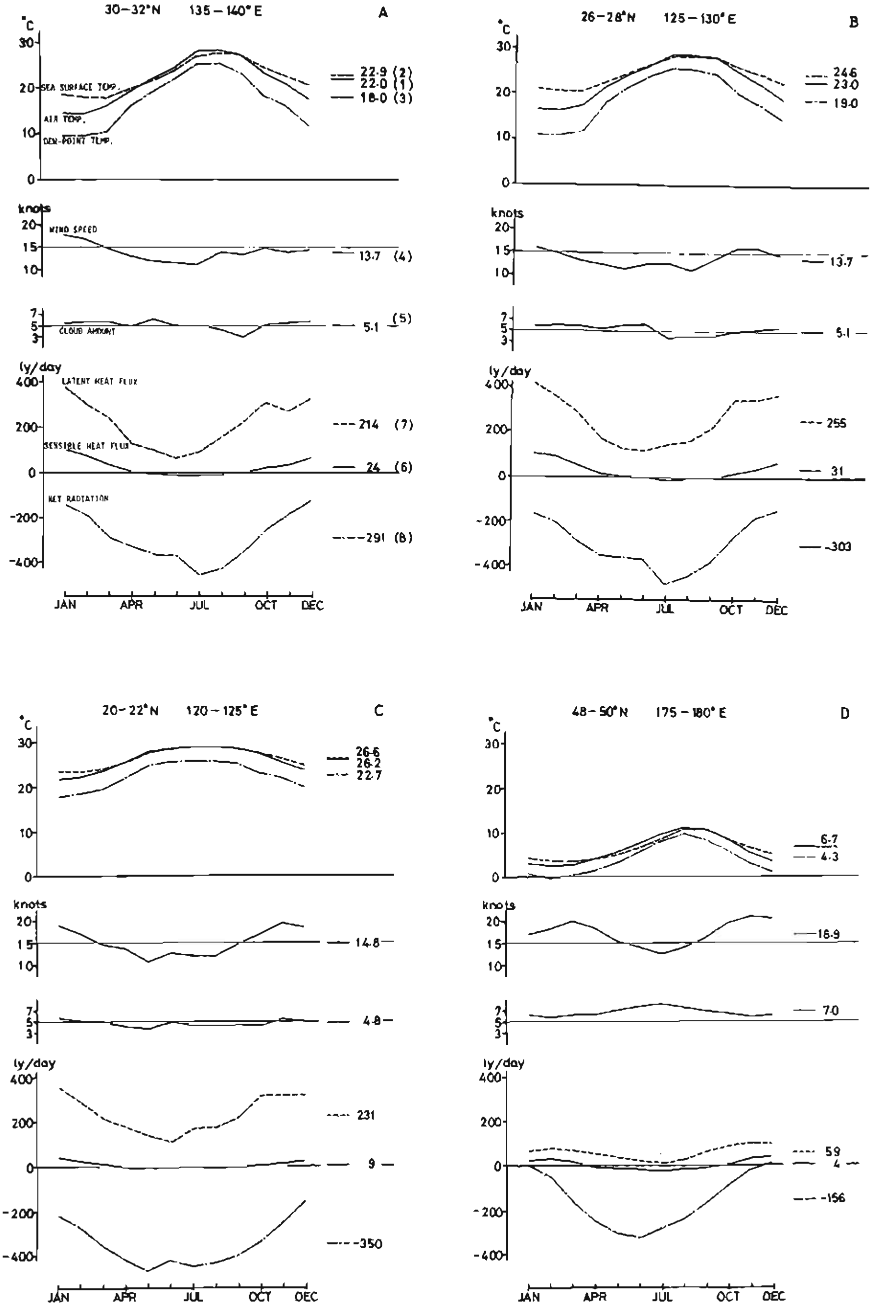
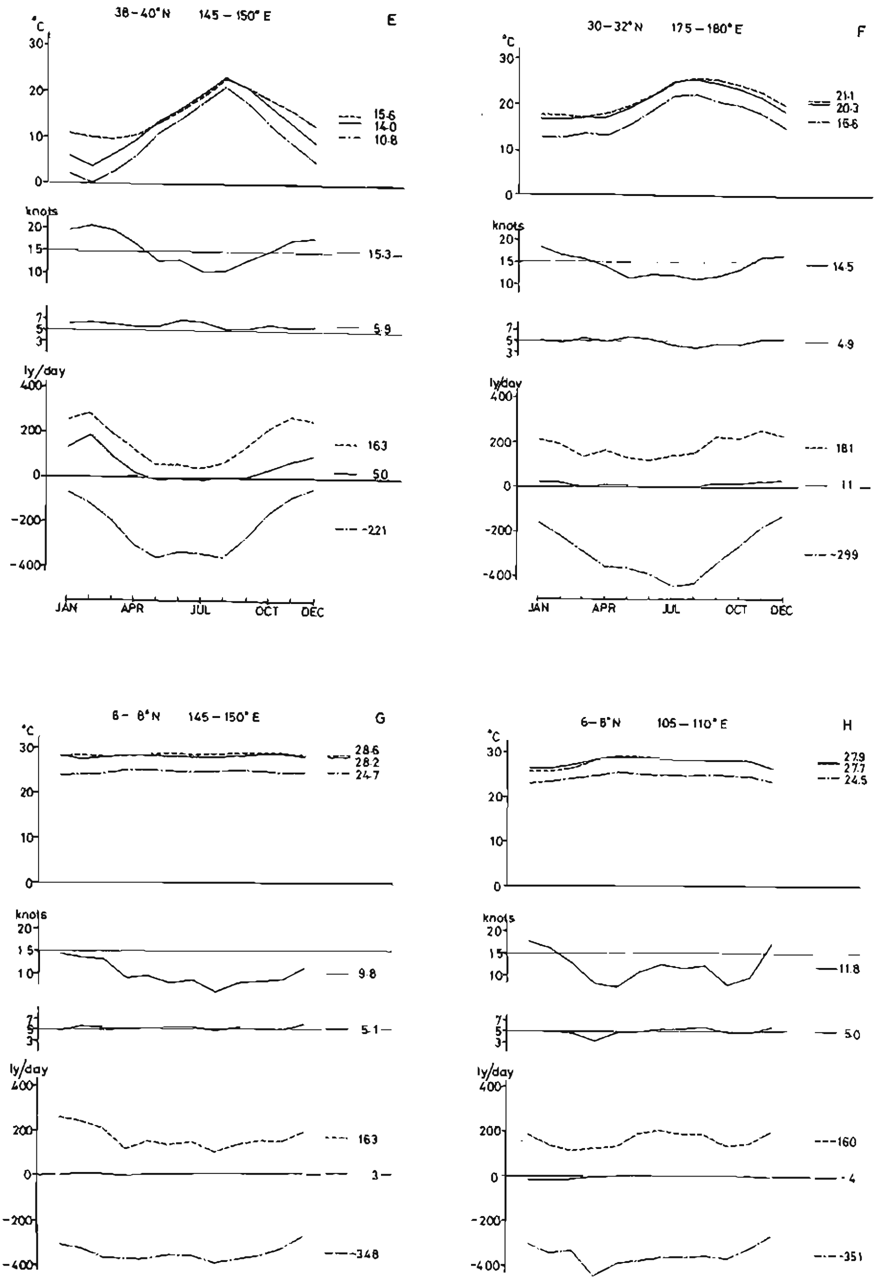


Fig. 10. Annual variations of fluxes and some meteorological (3) dew-point temperature, (4) wind speed, (5) cloud net radiation. A, B, C, D, E, F, G and H indicate and (H) shown in Fig. 5 respectively. The numerals of the parameters.



parameters. (1) is air temperature, (2) sea surface temperature,
amount, (6) sensible heat flux, (7) latent heat flux, (8) being
annual variations in the sections (A), (B), (C), (D), (E), (F), (G)
shown to the right of curves indicate the annual mean values

in the winter. This is due to a large temperature difference between warm sea surface and the cold and dry airmass from the Continent, as is expected. About 6 mm/day of evaporation is estimated in February over the Kuroshio region. Those values obtained here, are less than the values estimated by Ninomiya which are 300 ly/day of sensible heat supply and 10 mm/day of evaporation. This difference mainly comes from the difference of the exchange coefficient, which should be studied in the future.

In the summer season, the surface layer of the atmosphere over the sea surface over the Northwestern Pacific shows stable stability, as far as the monthly means are concerned, because the downward sensible heat flux is seen all over the area. This shows that thermal convection in the lower atmosphere cannot be expected in the summer season in this area, which corresponds to the fine and settled weather over this part of the ocean in the summer. However, once a large convection with clouds is formed, it will be maintained by the latent heat supply from the lower layer of atmosphere and the ocean surface. Therefore, a typhoon can develop and maintain its energy even over the ocean where a drought causes the people on the islands to suffer. In these circumstances, we can see interactions between the surface layer phenomena and the large scale weather phenomena.

The amount of evaporation in the summer is not so large, in the section around the Okinawa Island it is only 2 mm/day. This value and downward sensible heat flux suggest the cause of the drought on the Okinawa Islands in the summer season. The annual total evaporation in this section is 1588 mm, which is almost the same as the value obtained by evaporation measurement using the small dish pan (1677 mm at Naha). Nevertheless, this value is smaller than the annual precipitation observed at Naha, which is 2118 mm. So this area cannot become a water source to the atmosphere. The source must exist in an other region, probably in the tropic.

The total annual evaporation in other part of the Northwestern Pacific are smaller than that over the Kuroshio region. They are about 100 mm in the tropic (G) and (H), about 1100 mm in the middle latitude (F), and about 360 mm in the northern edge (D). The data of total annual precipitation over the Northwestern Pacific Ocean have not been obtained, though these values of evaporation might be samller than precipitation.

Total amounts and ranges of annual variation of sensible and latent heat fluxes are large in the sections near the coast of the Eurasian Continent. In the other regions, far off the coast, the amounts of sensible heat supply are small and do not differ largely from place to place in spite of the difference of latitude, they are about 10 ly/day on the annual mean. While the amounts of latent heat supply or evaporation differ largely in the different latitudes. The amount in the sections (G) and (H) is about 3 times the amount in section (D).

From the analysis of the energy balance over the ocean surface the following facts can be mentioned. The thermal balance is held in the area near the coast of the Continent except in the tropics, but in other regions far off the coast and in the tropics, the net radiation exceeds the sum of the turbulent fluxes by 100–200 ly/day on the annual mean. This shows that the ocean gets heat in the central part and in the tropics while heat is advected by ocean currents resulting in the large temperature gradient near the coast.

The feature of air-sea interaction shown above agrees with climatological characteristics seen over the ocean fairly well. However, for the detailed analysis and discussion, more knowledge of weather conditions over the ocean is required, which will be supplied as the results of AMTEX, starting in 1973.

At the same time, the method of the turbulent flux estimate itself must be re-examined. As is clear from the results of the present analysis, the thermal energy balance in the ocean surface is doubtful. Therefore, the method used to obtain the exchange coefficient assuming the balance, which was adopted by Jacobs, has fundamental difficulties. Detailed experiments to measure turbulent heat flux over the ocean is expected together with the observation of other related meteorological parameters.

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