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Sea-air Energy Exchange in the Eastern Yellow Sea

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Abstract

Each term of heat budget equation in the eastern Yellow Sea was calculated and the variation in relation to meteorological condition was shown for the period from September 1973 to February 1974.

At Mal-do near Gunsan the maximum heat exchange occurred at the last ten days of December (−522 ly/day), while at Sunmi-do near Incheon it occurred at the middle ten days of November (−665 ly/day). The contribution of the sensible heat to total heat exchange increased rapidly, while the effect of cloudiness decreased to be negligible in winter. The values of the heat exchange fluctuated considerably with the periodic occurrence of the cold Siberian air mass. The mean evaporation heat estimated indirectly from the aerological data was 82 ly/day at the northern part and 269 ly/day at the southern part of the Yellow Sea in December 1973.

INTRODUCTION

The knowledge of the heat exchange between the ocean and atmosphere is indispensible for forecasting the variation of water temperature and the modification of the lower atmosphere.

Following the studies by Sverdrup(1951), Jacobs (1951), and Budyko (1956), several works were carried out for the better understanding and the accurate evaluation of the heat exchange.

Studies on the heat budget of the Japan Sea were made by Miyazaki (1952), Manabe(1957), Kondo (1964), Ninomiya (1968) and Akamatsu (1971). By averaging data over two-degree square, Wyrtki (1966) reported on the seasonal variation of heat exchange in the North Pacific Ocean. Most of the information in the Yellow Sea, however, was excluded from the report probably due to the lack of available data.

Han (1972) estimated the mean latent and sensible heat for January in the south-western waters of Korea.

This paper is intended to present the energy exchange at the sea-air interface in the eastern Yellow Sea, or in the western coastal waters of Korea, during autumn and winter, and the relationship between the energy exchange and weather condition.

DATA AND ANALYSIS PROCEDURE

Data used in this study were taken from five coastal meteorological stations and sixteen light houses, the locations of which are shown in Fig. 1.

Meteorological parameters which are necessary for calculating the heat budget were obtained from the Monthly Weather Report of the Central Meteorological Office (1973—1974), Republic of Korea. Sea water temperatures were taken from the Annual Report of Oceanographic Observations of the Fisheries Research and Development Agency (1973—1974), Republic of Korea, which include 10-days mean surface water temperature

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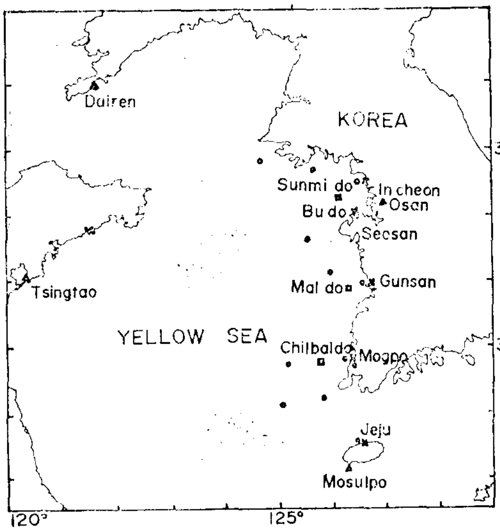

Fig. 1. Location of the stations.
×: Meteorological station
△: Upper air observatory
○: Light house station

observed at the light houses. Cloudiness and air temperature data for those light houses were also used in the heat budget calculations to obtain horizontal distribution.

Upper air observations at two eastern coastal stations of China and two western coastal stations of Korea (Fig. 1) taken from ROKAF Weather Central were used in calculating the precipitable waters of the air, from which the evaporation rate at the Yellow Sea was estimated indirectly.

The equation of heat budget may be

$$Q_\theta = Q_r - Q_e - Q_h + Q_v \qquad (1)$$

where Q_r: the effective radiation

Q_e: the latent heat spent for evaporation

Q_h: the sensible heat transfer

Q_v: the advective transport of heat by current

Q_θ: the heat used for the change of water temperature, and

$Q_t = Q_r - Q_e - Q_h$: the total heat exchange through the sea-air interface.

The effective radiation, Q_r, is determined by the difference between insolation, Q_s, and long wave back radiation, Q_b,

$$Q_r = Q_s - Q_b. \qquad (2)$$

The insolation may be obtained by the equation :

$$Q_s = 0.014\ A_n T_d (1 - 0.071\ C)\ (1 - r) \qquad (3)$$

where A_n: noon altitude of the sun

T_d: the length of day time in minutes

C: the cloudiness in tenth

r: the albedo of the sea surface.

A_n and T_d were taken from the almanac and r from Budyko's (1956) table. The effective long wave radiation was calculated with Lönnquist's equation for standard atmosphere of the International Civil Aviation Organization (ICAO) and Möller's cloudiness factor.

$$Q_b = 20.65\ (14.28 - 0.09\ T_w - 0.046U)\ (1 - 0.0765C) \qquad (4)$$

where T_w denotes the temperature of sea water and U the humidity of the air.

Latent heat, Q_e, and sensible heat transfer, Q_h, were evaluated by using Laevastu's (1960) formulae,

$$Q_e = L_t \rho\ E \qquad (5)$$

where L_t denotes the latent heat of evaporation, ρ the density of sea water and E the evaporation rate (mm/day).

$$E = (0.26 + 0.077\ V)\ (e_w - e_a) \qquad (6)$$

where V represents the wind velocity($m \cdot sec^{-1}$), and e_w, e_a the vapour pressure of the sea water and the atmosphere (mb).

$$Q_h = 39\ (0.26 + 0.077V)\ (T_w - T_a) \qquad (7)$$

where T_w and T_a denote the temperatures of the sea water and the atmosphere respectively.

Precipitable waters of the air, W_p, were estimated by means of Solon's equation:

$$W_p = \Sigma\ 0.01\ q_i\ \Delta P_i \qquad (8)$$

where q_i denotes the mean specific humidity for each layer and P_i the thickness of the layer in mb. The lower atmosphere was divided into three layers; 1000–850 mb layer, 850–700 mb layer and 700–500 mb layer.

RESULTS AND DISCUSSION

The amount of heat exchanged at the sea-air interface was controlled chiefly by the weather conditon and surface water temperature. The values of each component of the heat budget for Mal-do near Gunsan are presented in Fig. 2.

1. Effective radiation

The effective radiation decreases slowly from approximately 250 ly/day at the beginning of September, to nearly zero at the last ten days of December, and increases thereafter slowly.

Fig. 2 shows that the short-term variation the effective radiation, caused by clouds, of disappears in winter. This can be explained by the fact that the effect of cloudiness on the back radiation cancels that on the insolation during winter. As shown in Fig. 3, the ratio of the increase or decrease of heat exchange caused by the change of cloudiness to the total heat exchange, $1/Q_t\ dQ_t/dC$, was approximately 0.2 at Chilbal-do during autumn, but it decreased rapidly to approximately 0.01 during winter. It may be stated that the effect of cloudiness on the heat exchange is almost negligible in winter.

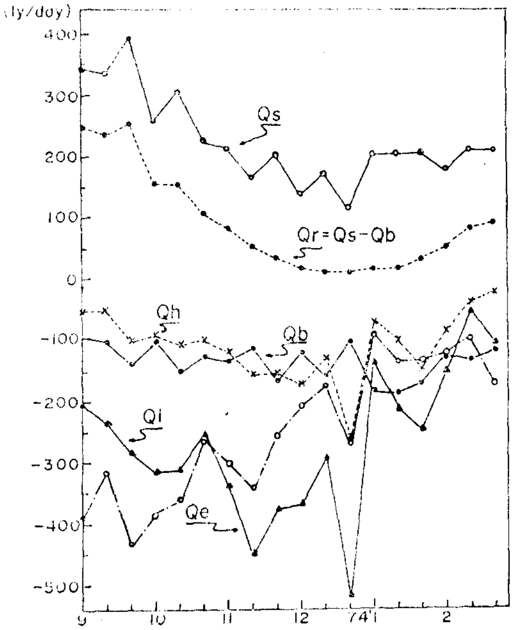

Fig. 2. Variation of each component of the heat balance; Q_s, Q_b, Q_r, Q_e, Q_h and Q_a at Mal-do near Gunsan.

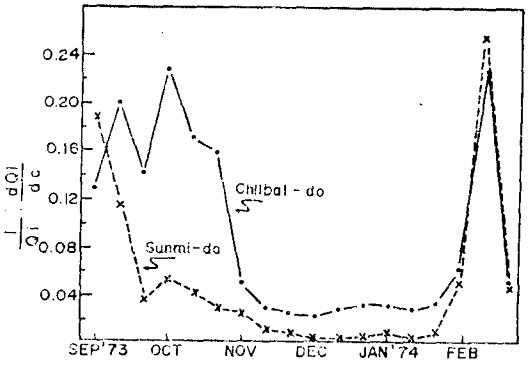

Fig. 3. Variation of the ratio, $\frac{1}{Q_t}\frac{dQ_t}{dC}$ at Mal-do and Chilbal-do.

2. Convective heat exchange, $Q_a = Q_e + Q_h$

Maximum evaporation occurred during September 21—30 at Incheon (−193 ly/day) and Gunsan(−438 ly/day), while it occurred during November 11—20 in the southern area (−355 ly/day at Mogpo and −503 ly/day at Jeju).

Fig. 4 shows that the variation of the ratio of Q_h to Q_e, known as Bowen ratio, is about 0.1—0.2 in September. It increases rapidly to more than 0.8 in December and January. This indicates that the sensible heat transfer also plays an important role in winter due to the large sea-air temperature difference and the strong monsoon, though the heat loss from the surface is, in general, due chiefly to the evaporation.

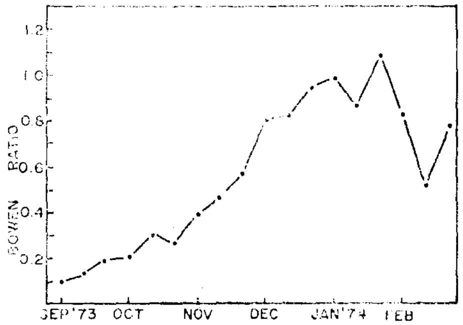

Fig. 4. Variation of the mean Bowen ratio in the eastern Yellow Sea.

3. The variation of heat exchange in relation to meteorological condition

Fig. 5 shows the variation of the total heat exchange, Q_t, and evaporation heat, Q_e, calculated daily for the coastal waters near Incheon (Sunmi-do) in relation to the variation of sea-air temperature difference, T_w-T_a.

Q_t increased remarkably with the break out of the cold Siberian air mass and decreased when the air mass was modified to warmer air mass or when a trough passed. The occurrence of cold CP High Pressure is more or less periodic during the winter, as it is called "three days cold and four days warm", and their resultant heat exchange fluctuates somewhat periodically (Fig. 5).

4. Horizontal distribution of the heat exchange

The pattern of the horizontal distribution of the total heat exchange is similar to that of the sea water temerature (Fig. 6). The water along the shore loses less heat than the offshore waters, since the rapid decrease of water temperature near the shore does not allow a large sea-air temperature difference.

In the southern part of the Yellow Sea, a great south-north gradient is shown, which is probably due to the effect of the warm Tsu-

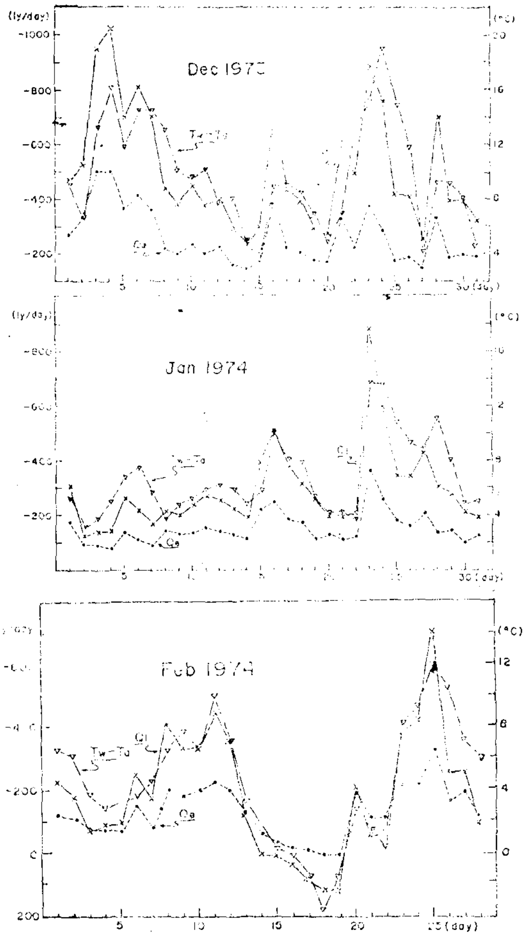

Fig. 5. Variation of total surface heat exchange, Q_t, and evaporation heat, Q_e, in relation to the sea-air temperature difference, T_W-T_a.

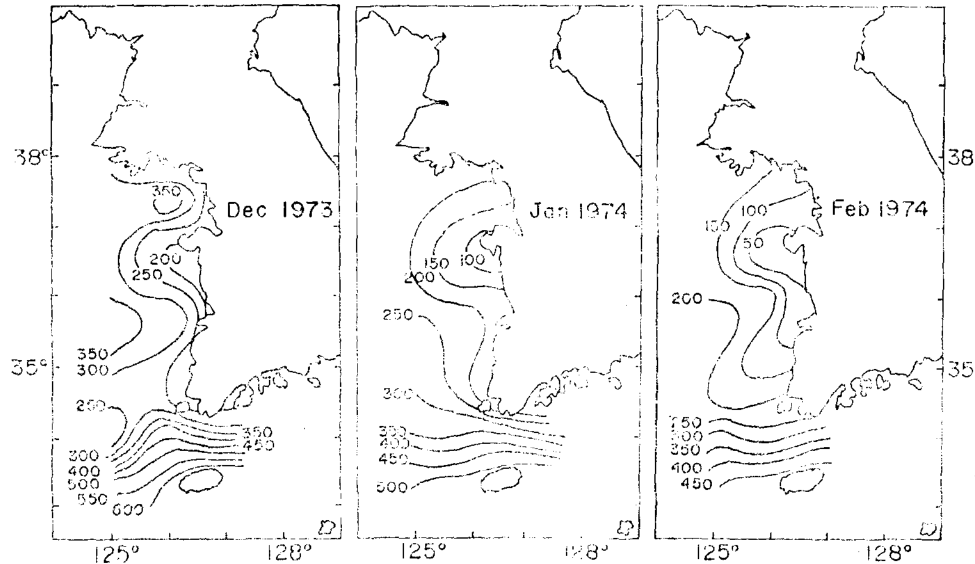

Fig. 6. Horizontal distribution of the monthly mean total heat exchange in ly/day.

shima Current. In the southeastern Yellow Sea near Jeju Island, the total heat exchange was approximately -500 ly/day in January, which is less than the mean value for several years obtained by Wyrtki (1966).

5. Increase of precipitable waters of the air over the Yellow Sea

The difference in precipitable waters between China and Korea (Table 1) may be ascribed to the evaporation from the surface waters of the Yellow Sea.

Table 1. Precipitable waters in mm of the lower atmosphere, 1000 mb to 500 mb level, between China and Korea

Date		China		Korea	
		Dairen	Tsingtao	Osan	Mosulpo
Dec.	1—10	4. 0	4. 1	5. 1	6. 1
1973	11—20	5. 3	6. 0	5. 8	8. 1
	21—31	4. 2	3. 2	4. 7	7. 3
	mean	4. 5	4. 1	5. 2	7. 2
Jan.	1—10	4. 5	5. 6	5. 9	—
1974	11—20	6. 1	6. 3	4. 4	6. 6
	21—31	3. 1	6. 6	4. 4	8. 3
	mean	4. 5	6. 2	4. 9	7. 5
Feb.	1—10	3. 7	5. 2	5. 3	8. 7
1974	11—20	5. 3	9. 1	7. 2	7. 8
	21—28	4. 3	6. 0	4. 9	8. 7
	mean	4. 4	6. 8	5. 9	8. 4

The monthly mean evaporation heat, estimated from the increase of the precipitable waters of the air over the Yellow Sea, was 81 ly/day at the northern part and 269 ly/day at the southern part of the Yellow Sea, while the result of the direct calculation by use of equations (5) and (6) was 220 ly/day at Mal-do near Gunsan in December 1973. The former might include errors owing to the unsteady wind direction and some other factors.

SUMMARY

The heat budget in the western coastal waters of Korea was calculated by use of the oceanographic and meteorological data during the period from September 1973 to February 1974.

The maximum value of the heat exchange was —665 ly/day at Incheon, —423 ly/day at Mogpo during November 11—20, and —522 ly/day at Gunsan, —814 ly/day at Jeju during December 21—31.

The effective radiation amounts to approximately 250 ly/day at the beginning of September, and decreases slowly to nearly zero at the last of December.

The effect of cloudiness on the heat exchange is negligibly small in winter, though it plays an important role during the other seasons.

Although the heat loss from the sea surface was due chiefly to the evaporation, the sensible heat transfer played an important role in winter, as seen by the increase of Bowen ratio from 0. 1—0. 2 in September to 0. 8 or more in December and January.

The values of the total heat exchange fluctuated considerably in accordance with the periodic occurrence of the cold Siberian air mass, and their horizontal distribution was similar to that of water temperature.

The mean evaporation heat estimated indirectly by means of changes in precipitable waters of the air was 82 ly/ day at the northern Yellow Sea and 269 ly/day at the southern Yellow Sea, while the result of direct calculation by use of empirical equation at Mal-do was 220 ly/day in December 1973.

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韓國西海의 海洋과 大氣間 에너어지 交換

李 東 永 · 張 善 德

1973년 9월부터 1974년 2월 사이의 해양 및 기상관측자료를 사용하여 황해 동부해역의 해양과 대기간 열에너지 교환량을 계산하고 기상조건과 관련된 열 교환량의 변동에 관하여 검토하였다.

열 교환량이 가장 많은 시기는 인천근해에서는 11월 중순이고 (−665 ly/day) 군산근해에서는 12월 하순이다(−522 ly/day). 년중 최대 열교환량은 12월 하순에 제주도 근해에서 −814 ly/day였다. 유효복사량은 9월 초순에 약 250 ly/day였으나 12월 말까지 차츰 감소하였다.

해면의 열손실은 주로 증발에 의한 것이지만 겨울에는 현열에 의한 손실도 무시할 수 없을 정도이다. 열교환량은 한냉한 Siberia 기단의 발달에 큰 영향을 받으며, 그 수평분포는 해류계 및 수온의 분포와 대응관계를 갖는다.