On Annual Variations of Sea Water and Air Temperatures, and Sea-Air Temperature Separation in the East Sea (Japan Sea)

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The annual variations of sea surface temperature (SST), air temperature (AT), and sea-air temperature separation (SST-AT) in the East Sea (Japan Sea) are studied by harmonic analysis of the monthly data in 2 by 2 degree rectangles. In the Tsushima Current region of the Japan Sea, the annual means of SST and AT are high due to warm water advection by the current, and the annual amplitudes of SST and AT are small because the annual variations of heat advection by the current and of the incoming solar radiation are almost out of phase each other. In summer the SST and the AT in the Japan Sea are almost the same, but in winter the SST is 6~10°C higher than the AT. The physical processes responsible for the observed SST-AT in the Japan Sea and their consequences in the sea-air thermal interactions are discussed in this paper.

1. Introduction

The annual variations of sea surface temperature (SST), air temperature (AT) and sea-air temperature separation (SST-AT) are important in understanding the air-sea thermal interactions, including the heat transfers across the sea surface by sensible and latent heat fluxes. The SST-AT also plays an import role in the stability of the atmospheric lower layer and in the modification of air mass flowing over the the see (e.g., Park and Joung, 1984).

The monthly maps of SST and/or AT in the Japan Sea were published by Maizuru Mar. Obs. (1972), Robinson (1976), and Gorshkov (1976). It should be noted that the AT is generally less persistent than the SST. At the North Atlantic weather stations, for example, the variance of At is a few times larger than the variance of SST for daily samples (Krauss and Morrison, 1966). A systematic measurement of AT over an open ocean is a very difficult task, and the estimates of monthly AT differ significantly depending on the investigator and the method employed. In thit paper I repretent the spatio-temporal distribution of SST, AT, and SST-AT by means of harmonic repretentation of the monthly data, and then discuss the physical processes involved.

2. Data and Analysis

The data set used in this paper is the monthly normals of SST and AT over 12 years (1958~1969) in 2 by 2 degree rectangles in the Japan Sea(Fig. 1) reported by the Maizuru Mar. Obs. (1972).

The monthly normals of SST, AT, and SST-AT are fitted by harmonic function $T(t)$:

$$T(t)=T_0+T_1\cos(\omega t-\phi_1)+T_3\cos(2\omega t-\phi_2),$$

where T_0 is the annual mean, ω the annual angular speed, t the time from January 1, T_1 and T_2 are

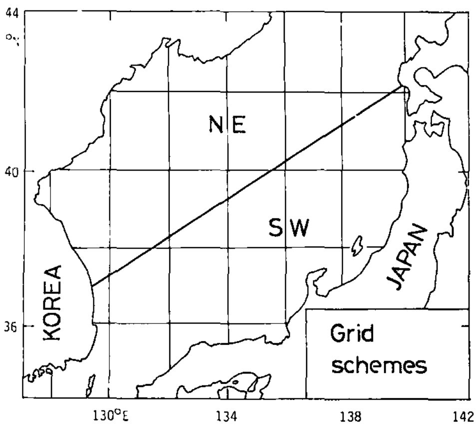

Fig. 1. Grid schemes in the Japan Sea (2 by 2 degree rectangles), and subdivison of the subareas: NW(northwest) and SE (southeast).

the annual and semi-annual amplitudes, respectively, and ϕ_1 and ϕ_2 are the annual and semi-annual phases. Harmonic constants (T_0, T_1, T_2, ϕ_1, and ϕ_2) are determined by the least squares method discussed by Kang and Jin (1984).

3. Results

For the sake of an easy reference, I divide the Japan Sea into the nortwestern part (subarea NW) and the southeastern part (subarea SE), as shown in Fig. 1. The distributions of annual mean, annual amplitude, and annual phase of SST in the Japan Sea are shown in Fig. 2. The annual mean of SST in the NW (8~16°C) is lower than that in the SE (13~19°C). The isotherms are tilted from the zonals, and the mean SST in the eastern part is a few degrees higher than the mean SST in the western part at the same latitudes. The annual amplitudes of SST in the NW (8~9°C) is larger than that in the SE (6.5~8.5°C). The annual phase of SST in the NW (230~234°) leads the annual phase in the SE (234~238°). The maximum SST in the Japan Sea occurs in the late August. The semi-annual amplitude of SST is less than 2°C, and phase varies irregulary (not shown in figure).

The distributions of annual mean, annual amplitude, and annual phase of AT are shown in

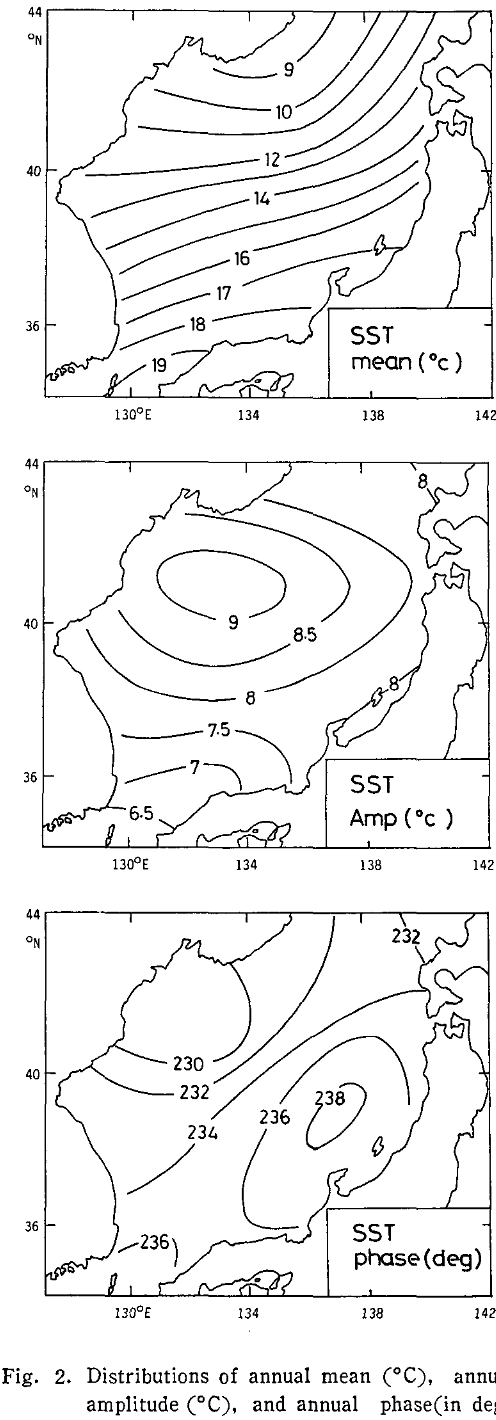

Fig. 2. Distributions of annual mean (°C), annual amplitude (°C), and annual phase (in degrees to January 1) of SST.

Fig. 3. Isotherms of mean AT are tilted from the zonals, and the mean AT in the eastern part is a few degrees higher than that in the western part at the same latitudes. The annual ampli-

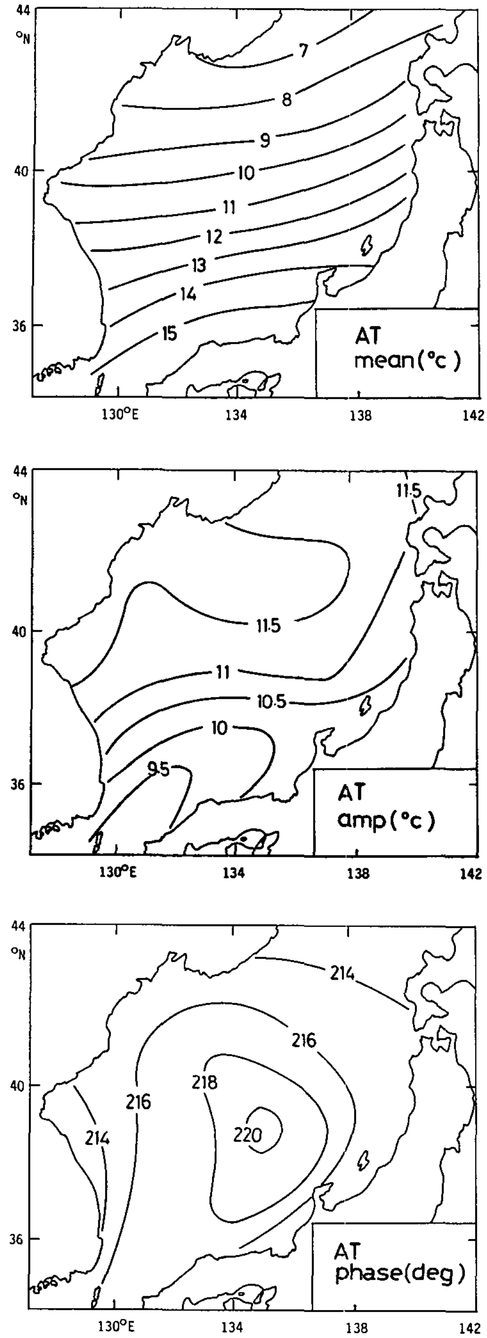

Fig. 3. Distributions of annual mean (°C), annual amplitude (°C), and annual phase (in degrees referred to January 1) of AT.

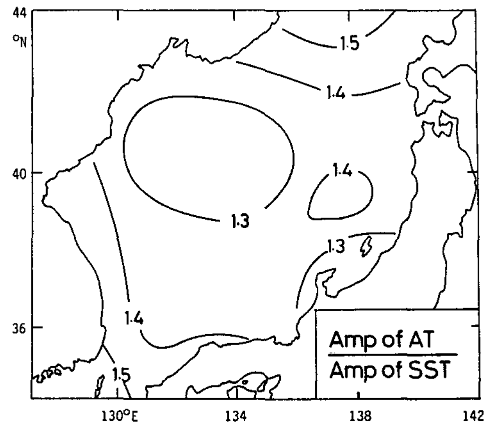

Fig. 4. Distribution of the ratio between the amplitudet of AT and SST.

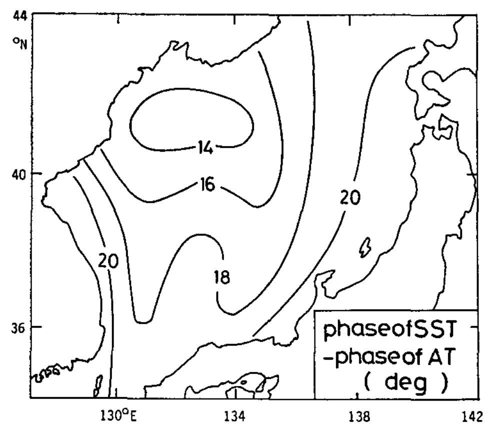

Fig. 5. Difference between the annual phases of SST and AT (in degrees).

tude of AT in the NW (10~12°C) is larger than that in the SE (9~11°C). The annual phase of 214~220° in Fig. 3 indicates that the maxium AT in the Japan Sea occurs in early August. The annual phase of AT has a tendency to be delayed as the distance from the land increases. The amplitudes of semi-annual variation of AT is less than 2°C (not shown in figure).

The annual amplitude of AT in the Japan Sea is 1.3 to 1.5 times larger that than of SST(Fig. 4). The phase difference between the SST and the AT in the Japan Sea is 14~20°, and this indicates that the annual variation of SST lags that of AT by two or three weeks (Fig. 5)

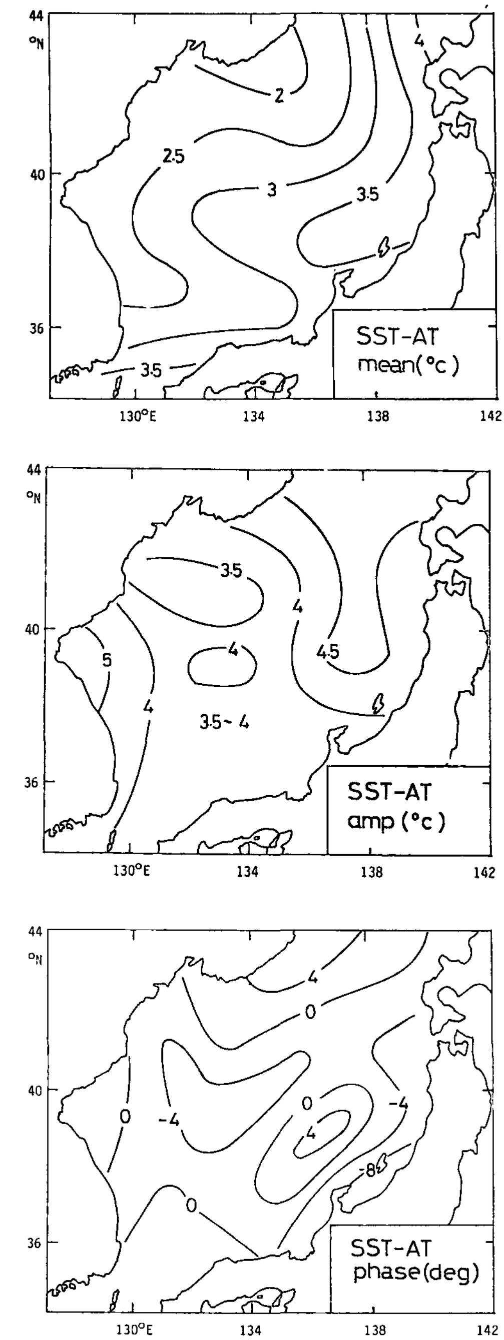

Fig. 6. Distributions of annual mean (°C), annual amplitude (°C), and annual phase (in degrees referred to January 1) of SST-AT.

The distributions of annual mean, annual amplitude, and annual phase of SST-AT are shown in Fig. 6. The annual mean of SST-AT in the SE (3~4°C) is larger than that in the NW (2~3°C). The annual amplitude of SST-AT in the Japan Sea is 3.5~5°C. The annual phase of SST-AT (−8 to 4°) indicates that the SST-AT is maximal in late December or in early January. In summer, SST is almost the same as the AT, but in winter, the SST is 6~10°C higher than the AT (Fig. 7). The amplitude and phase of semi-annual components of SST-AT are 0.5~2°C and 10~50°, respectively (not shown in figure).

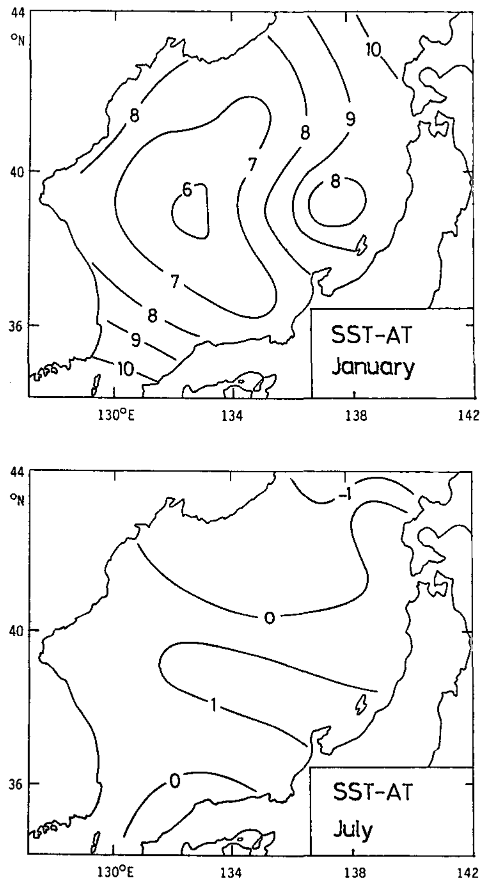

Fig. 7. Distributions of SST-AT (°C) in January and July.

4. Discussion

The observed annual variations of SST, AT, and SST-AT in the Japan Sea can by physically understood as follows. The annnal variation of SST depends on the annual variatious of incoming solar radiation, back radiation, heat storage rate in the atmosphere and in the ocean, and heat advections by ocean currents and winds. The warm water advection in the SE by the Tsushima Current increases the mean SST, and therefore the mean SST in the eastern part of the Japan Sea is higher than that in the western pars at the same latitudes (Fig. 2). The distribution of mean AT is similar to the distribution of mean SST (Fig. 3).

The annual amplitude of SST in the SE is smaller than that in NW (Fig. 2). Kang (1985) showed that the annual phase of heat advection by the Tsushima Current is almost opposite to that of the incoming solar rdaiation, and therefore the warm water advection by the current decrases the annual amplitud of SST in the Japan Sea. Due to the thermal interactions between the ocean and the atmosphere, the annual amplitude of AT in the SE is also smaller than that in the NW (Fig. 3).

The annual amplitude of 9~12°C over the Japan Sea (Fig. 3) is much smaller than the annual amplitude of AT of 12~19°C over the Peninsula of Korea (Kang, 1984a). This feature can be understood from the fact that the annual range of SST is much smaller than the annual range of ground surface temperature. The contrast between the annual ranges of ground surface temperature arises from the fact that the seasonal storage of heat in the upper layer of the ocean is many times larger than that in upper layer of the ground (Kang, 1984b).

Along the eastern coast of Korea, the annual phase of SST is about 240° (Kang and Jin, 1984), and that of AT is about 210° (Kang, 1984a). This implies that the phase difference between the annual variations of SST and AT are about 30° along the eastern coast of Korea. In the central part of the Japan Sea, the phase difference is less than 20°(Fig. 5). This agree with the theoretical investigation by Kang (1984a) that the the phase difference between SST and AT decreases with the distance from the coast.

In the Japan Sea, the mean SST is higher than the mean AT by 2 to 4°C, and the mean SST-AT in the SE is larger than the mean SST-AT in the NW (Fig. 6). Kang (1984c) showed that that difference between mean SST and mean AT in the Japan Sea is almost proportional to the heat advection by Tsushima Current. Due to the surplus of heat advection by Tsushima Current in the SE, the mean SST-AT in the SE is larger than that in the NW.

The heat advection into the Japan Sea by the Tsushima Current is larger in winter than in summer (Kang, 1985). On the other hand, the Siberian air-mass blowing over the Japan Sea in winter is very cold. Therefore, the SST-AT in winter in the Japan Sea reaches up to 10°C in winter. In summar, the AT of the summer monsoon blowing from the Pacific is basically the same as the SST, and the SST-AT in the Japan Sea is only 1°C order (Fig. 7).

It is worthwhile to note that the mean SST-AT of 2~4°C in the Japan Sea is larger than in any other parts of the oceans. In the central North Atlantic and central North Pacific, the annual mean SST-AT is generally less than 1°C, and mean SST-AT over 2°C is found only in the Gulf Stream and Kuroshio regions (Cayan, 1980).

Note that the SST is higher than the AT in winter, whereas the ground surface temperature is higher than the AT in summer in Korea. The contrasting temporal chracteristics between the temperature differences across the sea surface and across the ground surface arises due to the fact that the seasonal storage of heat in the ocean is much larger than that in the ground (Kang, 1983).

The heat flux into the atmosphere from the surface of Japan Sea in wintre is larger than the heat received by the incoming solar radiation. In January, the heat supply into the atmospher by the sensible and latent fluxes are 100 and 140 W/m^2, respectively, and they are larger than the solar radiation of 60 W/m^2 reaching the sea surface in the same month (Maizuru Mar. Obs., 1972). The heat supply into the atmosphere from the sea surface of the Japan Sea in winter is expected to play a significant influence on the climates of Japan and of the eastern part of Korea.

5. Conclusions

In this paper, the annual variations of SST, AT, and SST-AT in the Japan Sea are represented in terms of annual means, annual amplitudes, and annual phases. Due to the heat advection by the Tsushima Current, the mean SST and the mean AT in the eastern part of the sea (Japanese side) are higher than those in the western part (Korean side). The annual amplitudes of SST and AT in the Tsushima Current region are smaller than those in the northwestern part of the sea, because the annual variations of the heat advection by currents and the incoming radiation are almost out of phase each other. Due to the moderating effect of the sea to the AT variation, the annual arange of AT over the Japan Sea is smaller than that over the ground of Korea.

The SST-AT in the Japan Sea in summer is only about 1°C, but that of up to 10°C in winter is very large compared to the SST-AT in any other parts of the oceans in the globe. Due to warm water advection, the mean SST-AT in the Tsushima Current region is larger than the mean SST-AT in the northwestern part of the Japan Sea.

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References

Cayan, D.R. 1980. Large-scale relationships between sea surface temperature and surface air temperature. Mon. Wea. Rev. 108, 1293—1301.

Gorshkov, S.G. (Editor). 1976. World Ocean Atlas. Vol. 1. The Pacific Ocean. Pergamon Press. Oxford. 340pp.

Kang, Y.Q. 1983. On the temperature differences across ground and sea surfaces in Korea. J. Kor. Meteor. Soc. 19(2), 88—95.

_______ 1984a. Influence of sea surface temperature on the annual variation on air temperatures in Korea. J. Kor. Meteor. Soc. 20(2), 73—81.

_______ 1984b. One-dimensional model of the oceanic and continental seasons. J. Kor. Meteor. Soc. 20(1), 60—66.

_______ 1984c. Atmospheric and oceanic factors affecting the air-sea thermal interactions in the East Sea (Japan Sea). J. Oceanol. Soc. Korea. 19, 163—171.

_______ 1985. Influence of the Asian Monsoon and the Kuroshio on the sea surface temperatures in the Yellow, the Japan and the East China Seas. J. Oceanol. Soc. Kor. 20 (in press).

_______ and M.S. Jin. 1984. Seasonal variation of surface temperatures in the neighbouring seas of Korea. J. Oceanol. Soc. Kor. 19, 31—35.

Krauss, E.B. and R.E. Morrison. 1966. Local interactions between the sea and the air at monthly and annual times scales. J. Roy. Meteor. Soc. 92, 114—127.

Maizuru Marine Observatory. 1972. Marine Meterological Study of the Japan Sea. Jap. Meter. Agency. Tech. Rep. No. 80, Tokyo. 116 pp. (in Japanese).

Park, S.U. and C.H. Joung. 1984. Air modification over the Yellow Sea during cold-air outbreaks in winter. J. Kor. Meteor. Soc. 20 (2), 35—50.

Robinson, M.K. 1976. Atlas of North Pacific monthly mean temperatures and mean salinities of the surface layer. Naval Oceanographic Office Publ. No. 2, Dept. Navy. Washington. D.C. 173 pp.

동해의 수온, 기온 및 해면 온도차의 연변화

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12년간(1958~1969) 동해의 경위도 2도 간격 격자상의 자료에 대한 조화분석을 통하여 동해의 표면수온, 기온 및 해면온도차의 계절적인 변화를 분석한 결과에 의하면, 동해에서 수온과 기온은 복사에너지뿐만 아니라 해류와 계절풍에 의한 열이류의 영향을 크게 받고 있다. 동해에서 쓰시마난류가 흐르는 남동해역은 같은 위도상의 북서해역에 비하여 표면수온과 기온의 연평균이 높고 연교차의 폭이 작다. 이는 쓰시마난류에 의한 열이류 변화의 위상이 복사에너지 변화의 위상과 반대여서 계절적인 온도의 변화폭을 줄이기 때문이다. 동해에서 연평균 수온은 연평균 기온보다 2~4°C 높으며, 수온과 기온간의 차이는 계절에 따라 크게 변한다. 즉 여름에는 표면수온과 기온간에 차이가 거의 없지만, 겨울에는 수온이 기온보다 6~10°C 높으며, 겨울에 현열과 증발열을 통하여 해면으로부터 대기로 공급되는 에너지는 태양복사에너지의 2배에 달한다.