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On Air-sea Interaction in the Kii Channel

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Abstract

Taking the Kii Channel and Osaka Bay as our model region, we have studied the interrelation between small scale oceanic phenomena in a narrow ocean area and meso-scale atmospheric phenomena.

Between a line connecting Murotomisaki and Shionomisaki and a line connecting Hinomisaki and Gamatazaki, a countercurrent of the Kuroshio flows along the Pacific Coast of Western Japan. And this same region is orographically open to the south, and favourable for southerly winds to flow into inland parts with horizontal convergence. Osaka bay, located in the inmost part of this area, has a remarkable inland character both meteorologically and oceanographically and the middle region from the line con necting Hinomisaki and Gamatazaki to the Kitan Strait is the intermediate region between the inland and open sea regions where, in winter, a remarkable discontinuous zone of surface water temperature appears. In this paper, we have summarized the oceanic conditions in these seas and then considered what kind of atmospheric phenomena produced these oceanic condition.

Then, we show in examples the effect of these oceanic conditions upon medium scale atmospheric phenomena occuring in the neighbouring regions. The existence of a discontinuity of surface water temperature affects the stability of the lower layer of the atmosphere and makes a local distribution of dense fog and air pollution.

We have explained that the existence of this discontinuous zone of surface water temperature produces a suitable condition for the developement of secondary small cyclones of low height. In summer, moist air currents in the lower layer flow into the central part of the Kinki District through the Kii Channel and make a narrow band of concentration of heavy rainfall.

Thus, the region of the Kii Channel and Osaka Bay has only a small area, but the oceanographic conditions of this region and its meso-scale atmospheric phenomena are intimately related.

1. Introduction

The Japanese Islands are surrounded by the sea, and the climate of Japan is much influenced by the sea. However, the district of the Seto Inland Sea and the central area of the Kinki District have a climate of a comparatively inland character, (Fig. 1). This area is surrounded by mountains, and both the northerly trade wind in winter and the southerly trade wind in summer are obstructed by these mountains, so the amount of the precipitation in this area is relatively small. Annual precipitation of this area is less than one third of that in the middle of Shikoku Island south of this area.

The Seto Inland Sea of about 17000 km^2 area and about 30 m depth has almost the character of a closed sea in spite of some effect from the tidal mixing through the narrow channels with the open sea. So, any mixing of it with the warm current along the Pacific Coast of Western Japan is quite little. In winter, the surface water temperature of this region is about 10°C lower than that of the shore of the Pacific Coast. This condition continues until spring. The chlorinity of the Seto Inland Sea has a value of 17~18‰ in the middle part, and is variable according to the inflow from the rivers. In recent years, the problem of water pollution has become very important, because of the closed nature of this sea.

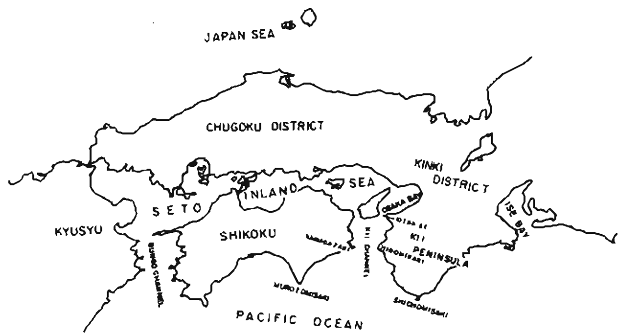

Fig. 1. Map of western Japan.

Among the disasters occurring in the Seto Inland Sea, these due to dense fog are very important. Dense fog appears very often in early spring, when warm moist winds blow from the south over the cold water in this region. In these cases, high stability due to the cooling from below and the weakness of the wind also makes suitable conditions for the formation of dense fog. For the same reasons, air pollution is also apt to occur in the cities along the coast of the Seto Inland Sea.

The Seto Inland Sea has 4 mouths to the open sea, but all of them are very narrow. The Naruto Strait has width of 1.48 km and its mean depth is 16.8 m. The Kitan Strait has width of 5.55 km and its mean depth is 55.9 m. The largest is the Hoyo Strait between Kyushu and Shikoku; it has width of 12.4 km and mean depth of 91.5 m. These straits are very important for the Seto Inland Sea. Through them, both air and water come into and go out from this inland region.

The members of the Kobe Marine Meteorological observatory have made many observations and research studies about the oceanographical and meteorological elements of the Seto Inland Sea.[1,2] In recent years, the thermal and water budgets between air and sea have interested many researchers. The problem of air-sea interaction is interesting from the points of view both of large-scale phenomena such as the general circulation of atmosphere and ocean, and of small-scale phenomena such as evaporation from a small pond. Now, we want to see how meso or medium-scale phenomena in the atmosphere are related to meso or medium-scale phenomena in the ocean. For this purpose, we have selected Osaka Bay in the eastern part of the Seto Inland Sea and the Kii Channel, and the land area surrounding these seas as a model region.

2. Oceanic Conditions in the Kii Channel

The water temperature of the Seto Inland Sea falls in winter by the transporting of both its real heat and its latent heat to the atmosphere from the sea surface. In winter, cold and dry trade winds prevail in this region. The inflow of cold river water may be also a factor in this cooling. The heat capacity of the water of this inland sea is relatively small due to the shallow depth. Mixing of the water in this sea with that of the open sea is very weak. Thus the surface temperature of this sea is much lower than that off the Pacific Coast. The difference is more than 10°C.

At the Seto Inland Sea and the Kii Channel, water temperature and chlorinity are measured monthly by the sectional observation by the Prefectural Fish. Invest. Stations. From the observations of Feb. 1966, the surface water temperature and the chlorinity distribution at the Kii Channel are drawn as Fig. 2 and Fig. 3. Fig. 4 shows the bottom topography of the Kii Channel. In Fig. 5, the distributions of the water temperature, the chlorinity and the density in a vertical section, north to south, through the center of the Kii Channel are shown for Feb. 1966. As shown in these figures, in winter and early spring, the surface water temperature does not change continuously from the open sea to Osaka Bay, but it changes discontinuously near the mouth of the Kii Channel. In Fig. 2, we can find discontinuity in the surface temperature of 8°C/km near Ishima. And we can find in Fig. 3 a corresponding discontinuous change in the chlorinity distribution from 18.0‰ to 19.2‰; however there is no discontinuous change in the density distribution, as can be seen from Fig. 5. It is interesting that these discontinuities of temperature and chlorinity exist not only near the sea surface but also in the whole sea layer. As can be seen

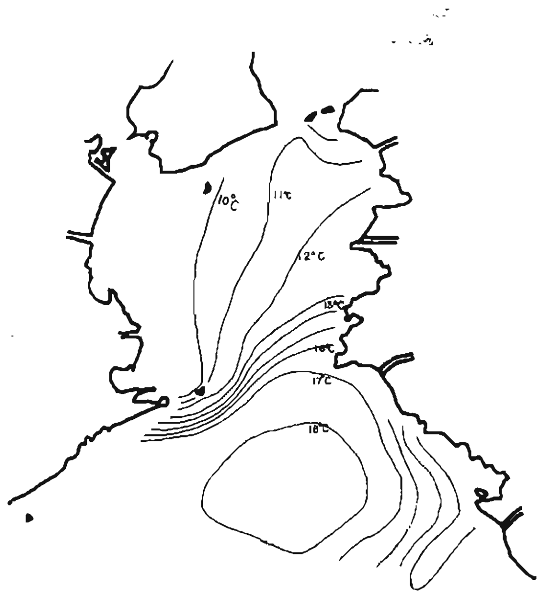

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Fig. 2. Distibutrion of surface water temperature in the Kii Channel in Feb. 1966.

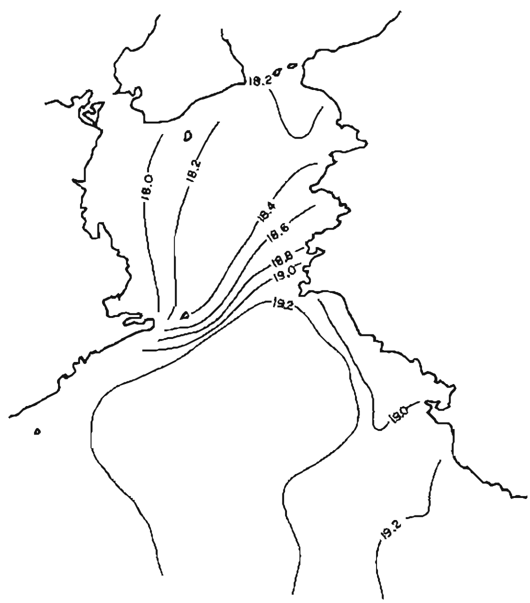

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Fig. 3. Distribution of surface chlorinity in the Kii Channel in Feb. 1966.

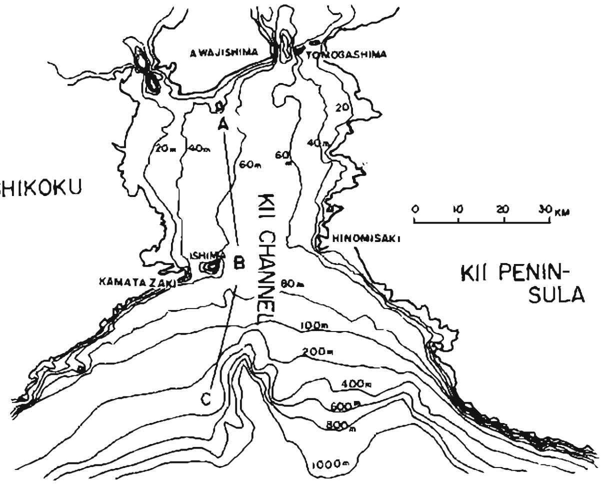

Fig. 4. Bottom topography of the Kii Channel.

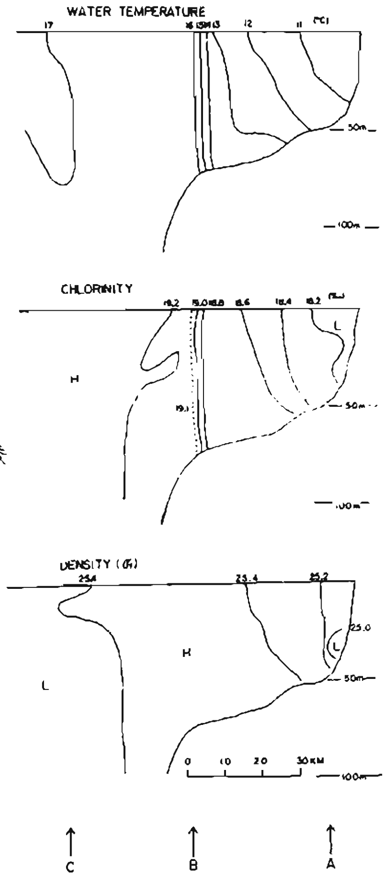

Fig. 5. Distribution of water temperature, chlorinity and density in the vertical cross section, north to south, through the center of the Kii Channel. Positions of the points A. B. C are shown in Fig. 4.

from Fig. 4, this discontinuous zone locates along the equi-depth of the sea where the dedth abruptly increases. So, the main reason for the formation of this discontinuity may be the difference of the heat capacity of the water layer owing to the differences in the depth of the sea. On the other hand, in the south of this discontinuous zone the width of the channel becomes large abruptly. From this point of view, the main reason for the formation of the discontinuity may be the difference in the horizontal mixing.

One of our observations is shown in Fig. 6. On Jan. 19. 1970, we took a passenger liner from Kochi to Osaka and measured the engine cooling water temperature by a recording thermister thermometer. A sharp discontinuous change of surface water temperature was observed. The speed of the ship was about 12 knots. The surface water temperature (the temperature of the engine cooling water) fell from about 18°C to 11~12°C in a short time when the ship moved from south to north at the east side of Ishima at about 01 LST 19 Jan. We also measured the air temperature on board the ship and the dew point at 7 m height above the sea level. These data are also plotted in Fig. 6. The discontinuity of the air temperature is not so distinct as that of the water temperature. We also made observations in the same way several times during the winter of 1970, and the detailed results have been reported in another paper.[3]

Next, we must consider the annual variations of the distribution of surface temperature in the Kii Channel. There are no daily oceanographic observations;

but the passenger ship from Osaka to Kochi measures the temperature of its engine cooling water twice in each voyage, once in Osaka Bay, and again in the Kii Channel. The accuracy of these observations is not too high, but daily data covering several years are available. We have plotted these data in Fig. 7. In summer, the surface temperatures of the Kii Channel and of Osaka Bay are almost same and uniform; then, the scattering of the temperature values is very small. But, in winter, the observations in the Kii Channel were made in the warmer side of the discontinuity area on one day and in the colder side on another day. Then the scattering of the temperature values here is very large, as can be seen from Fig. 7. In winter the width of this scattering reaches about 10°C in the Kii Channel, but only about 2°C in Osaka Bay. We have used this scattering as our measure of the intensity of the discontinuity. From Fig. 7, we can see that, the discontinuity is very distinct from Dec. to the following April. Fig. 7 also show the annual variations of sea temperature in this area. The max. temperature occurs at the end of August and the min. temperature occurs in Feb., and the amplitude of the annual variation is about 15°C in the Kii Channel and about 20°C in Osaka Bay.

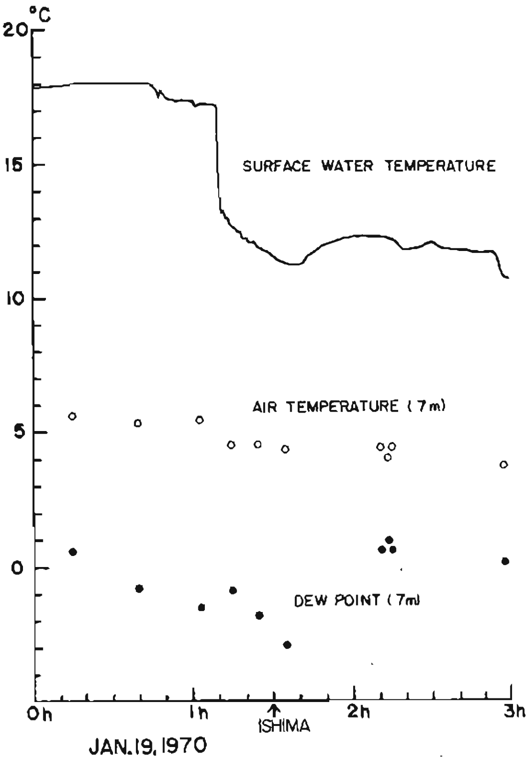

Fig. 6. Records of observation on a ship moving from south to north along the central part with speed of about 12 knots on Jan. 19, 1970.
——surface water temperature measured by thermister thermometer.
○ air temperature at 7 m height above the sea surface measured by Asmann ventilated psychrometer.
● dew point measured in the same way.

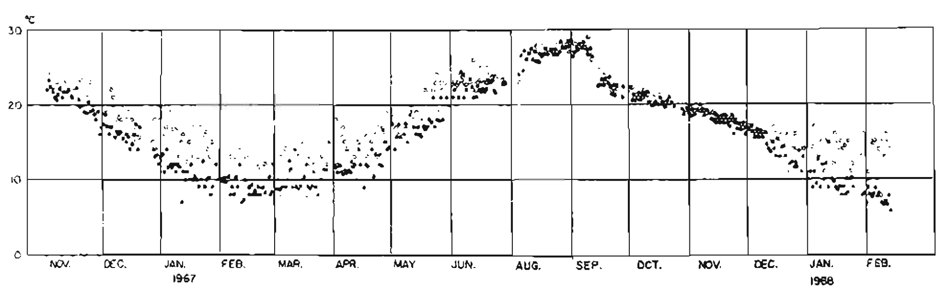

Fig. 7. Daily surface water temperature in Osaka Bay (●) and the Kii Channel (○).

3. Meso-scale weather phenomena relating to oceanic conditions in the eastern part of the Seto Inland Sea

As mentioned above, in winter the surface water temperature in Osaka Bay is much colder than that of the open sea south of the Kii Channel, and distinct discontinuity of water temperature exists. Related to this oceanic condition, there are special types of local weather around this region.

First, one example. On 16th Mar. 1965, a developed cyclone moved eastward over the Japan Sea and a strong cold front passed the central area of the Kinki District. The 850 mb chart at 21 LST, 16th is shown in Fig. 8. Before the passing of the cold front, a strong southward wind was flowing into the Kii Channel and Osaka Bay at 850 mb level. At sea level, there was a strong south wind over the Kii Channel, but in Osaka Bay, the air was calm and a dense fog occurred.

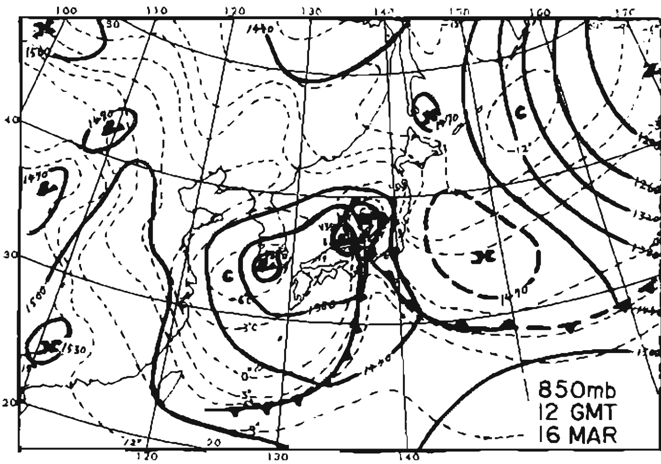

Fig. 8. 850 mb Weather chart at 21 LST 16, Mar. 1965. The thick lines are contour lines and the broken lines are isotherms.

The surface chart at 15 LST of that day is shown in Fig. 9. A strong cold front was approaching from the west, while the local cold air mass remained in the surface layer over the Kii Peninsula, and between these two cold air masses a strong warm current blew from the south into the Kii Channel. The difference of the temperatures of the cold air and the warm air reached about 15°C. This shows that the Kii Channel is orographically favourable to the introduction of warm currents from the south into the inland part of the Kinki District. The Bungo Channel, west of Shikoku Island, and

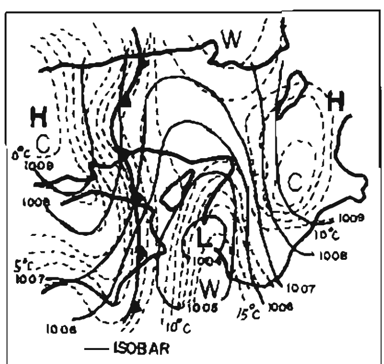

Fig. 9. Suface weather chart at 15 LST 16, Mar. 1965.

Ise Bay, east of the Kii Peninsula, have nearly same the natures, as can be seen in Fig. 1. In fact, when this cold front moved to the east, the warm current did not flow into the Kii Peninsula, but at 21 LST, it flowed inland through Ise Bay, as shown in the surface chart of Fig. 1.

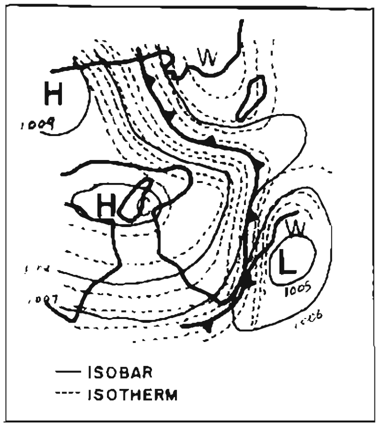

Fig. 10. Surface weather chart at 21 LST 16, Mar. 1965.

The local surface chart at 15 LST shows also the developement of a secondary cyclone near the northern part of the Kii Channel. This small cyclone was not very tall, and can not be seen in the 850 mb chart (Fig. 8). It can be traced from the west, but it developed in the warm air current in the Kii Channel. When this cyclone moved east, it disappeared over the Kii Peninsula, but developed again over Ise Bay. This cyclone was not very strong, but it was very important in connection with disaster prevention measures in this sea. In fact, along the Kii Channel itself, the southerly surface wind was very strong and many ships were damaged. However, in Osaka Bay, north of this small cyclone, the air was calm, dense fog occurred, and ships could not move. At Osaka, the surface wind was calm before the arrival of the cold front, but a warm strong wind blew above this calm layer of a thickness of only 500~1000 m. This calm layer was very stable due to cooling from below. Thus, the difference of the weather conditions between Osaka Bay and the Kii Channel occurred mainly because of the difference in the surface temperatures of the sea. The developments of such secondary cyclones in the Kii Channel occur several times each spring season when developed cyclones move eastward along the Japan Sea Coast.

The region around the middle of the Seto Inland Sea has relatively little rainfall even in the warm season because the currents from the open sea can not easily flow into it. However, in the eastern part of this inland sea there is heavy rainfall because of the moist current through the Kii Channel from south-west and south-south-west. In the same way, the western part of this inland sea has heavy rainfall because of the moist current through the Bungo Channel from the same direction. The same condition also occurs in Ise Bay.

We have analysed many heavy rains of such character; now, one example. Fig. 11 shows hourly rainfall distributions from 4 to 7 LST 30, August 1960. In this case, 24-hour precipitation became nearly 500 mm in the central part of the rainfall region. Fig. 11 shows that even the hourly precipitation was 70 mm in the center of the rainy region. The rainfall axis runs from Osaka Bay to Lake Biwa. It is very characteristic that the zone of heavy rainfall is very narrow and steady. In this case a severe typhoon went across Osaka Bay to the north-eastward, and heavy rainfall in this region started only after the passage of this typhoon. After this typhoon had gone into the Japan Sea, a south-sohth-westerly wind blew for a long time.

In the warm season, we can find many cases of such heavy rainfall in this

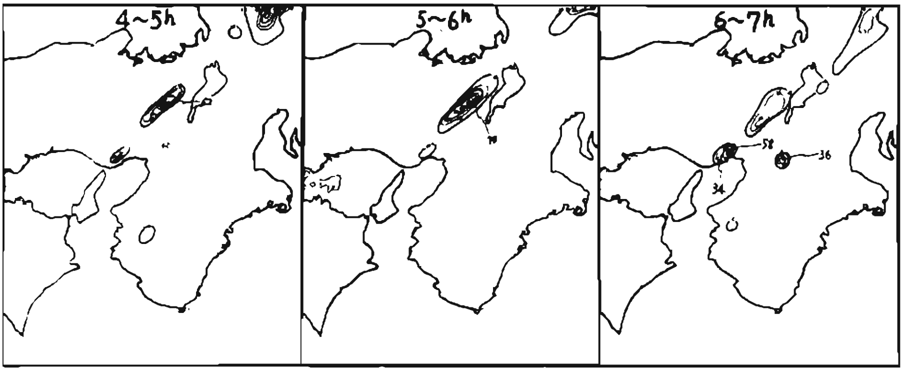

Fig. 11. Distribution of hourly rainfall in the Kinki district from 4 to 7 LST 30, Aug. 1960.

region. In all these cases, relatively strong south-westerly or south-south-westerly winds blow through the Kii Channel. The direction of the axis of rainfall varies according to the wind directions. In most cases the regions of heavy rainfall are about 100 km long and 20~30 km wide and remain in nearly the same place for a few hours or more. Topographical features such as the Kii Channel, may play the role of a trigger releasing the static instability by converging the flow. On the other hand, the Kii Channel may supply vapours into the air current above.

4. On air-sea interaction in the Kii Channel

Studies of air-sea interaction have become very active in recent years. Relating to the problem of the general circulation of the atmosphere and the ocean, heat and water budgets are studied by climatological methods. On the other hand, the experimental work is done on small areas of water surface by micrometeorological methods. But the problem of air-sea interaction on a synoptic scale is very difficult.

The heavy snowfall along the coast of the Japan Sea in winter is known to have an intimate relation with the variations of the air mass over the Japan Sea. How much area is needed for the sea to produce variations in the meso-scale weather condition? Osaka Bay and the Kii Channel have only a small area, but they seem to be able to vary the stability condition of the meso-scale air mass. Two kinds of weather phenomena explained in the previous section are the examples of this. When the northerly current blows in winter, the area of Osaka Bay is in the leeward of the Chugoku Mountains and has a clear sky. However, over the small mountains south of Osaka Bay, we can see snowfall. This is partly due to the variation of the stability of the air mass over Osaka Bay.

Fig. 12 shows the annual variations of surface water temperature and air temperature in the Kii Channel. The amplitudes are about 15°C for the sea and about 25°C for the air. In the warm season, from April to September, the temperatures of the air and sea are almost the same, but in the cold season the temperature of the air is below that of the sea. So the lower atmosphere is heated by the warm sea below, and its stability decreases. Also, evaporation

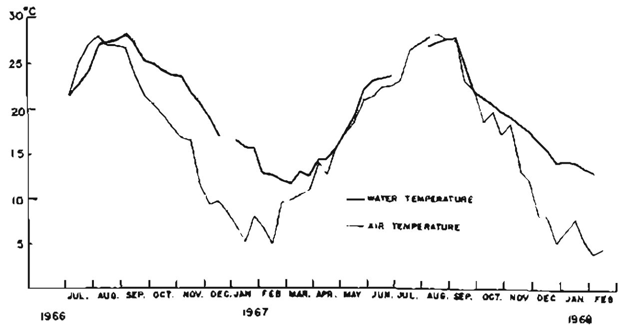

Fig. 12. Annual variations of surface water temperature and air temperature near the sea surface in the Kii Channel. The curves are smoothed by making 10 days mean. Air temperature measured at Ishima small island in the Kii Channel. The data of water temperature is from the same origin as Fig. 7.

becomes active in winter and real heat is transported from the sea to the air. However, in the warm season the heat transport between the air and sea is not so active, as the temperatures are nearly same.

The stability of the sea increases in summer and decreases in winter. So the vertical temperature distribution is almost uniform in winter, but the temperature decreases with the depth in summer. When strong winds blow over the sea surface in summer, the sea temperature becomes uniform vertically. In the other hand, when strong winds blow in winter, the discontinuous zone in the Kii Channel mentioned above disappears.

In the case of the Inland Sea, heavy rainfall around this region makes the chlorinity of the sea surface decrease, and the stability of the water layer near the surface increases.

The problem of the air-sea interaction in a small scale region is very important for disaster prevention, but many points remain to be solved, especially quantitatively.

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