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Researches on the Variations of Oceanographic Conditions in the Region of the Ocean Weather Station "Extra" in the North Pacific Ocean (V)

— On a Short-Periodic Variation of Sea-Surface Temperature —

by

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(Received June 27, 1956)

Abstract

On plotting the daily means of sea-surface temperature at the Ocean Weather Station "Extra" (39°N, 153°E) against time, we find that there are oscillations of the temperature with periods of few ten days. The periods of these temperature oscillations were determined. Among possible causes for these oscillations the meandering of ocean currents may be mentioned as the most probable one.

1. Presentment of the phenomenon

From the data of sea-surface temperature observed, as a rule, eight times a day at the Ocean Weather Station "Extra" (39°N, 153°E; hereafter to be denoted by St. "X") during the period from March 1948 to November 1953, the series of the daily mean temperature are prepared. On plotting the daily means of the temperature against time, we find that there are variations with periods — though somewhat irregular — of few ten days, superimposed on the larger undulation of seasonal change. These short-periodic variations are shown in Fig. 1, where, to make it clearer to the sight, the moving average of ten days is used and the deviations from the yearly trend are given alone, except for 1948.

2. Character of the variation

Various characteristics of the variation can be read from Fig. 1. 1) The comparatively regular oscillation of the sea-surface temperature does not persist so long; the duration is at most 10 months. 2) The oscillation appears to show a phenomenon of beat in some terms, but it is obscure in other terms. 3) The period is not always constant; in different term prevails a different period. 4) No tendency can be found of any particular oscillation to be distinct in a given season, e.g. in summer or winter months. 5) The maximum range of the oscillation in the term under investigation is about 4°C, which occurred in summer 1948.

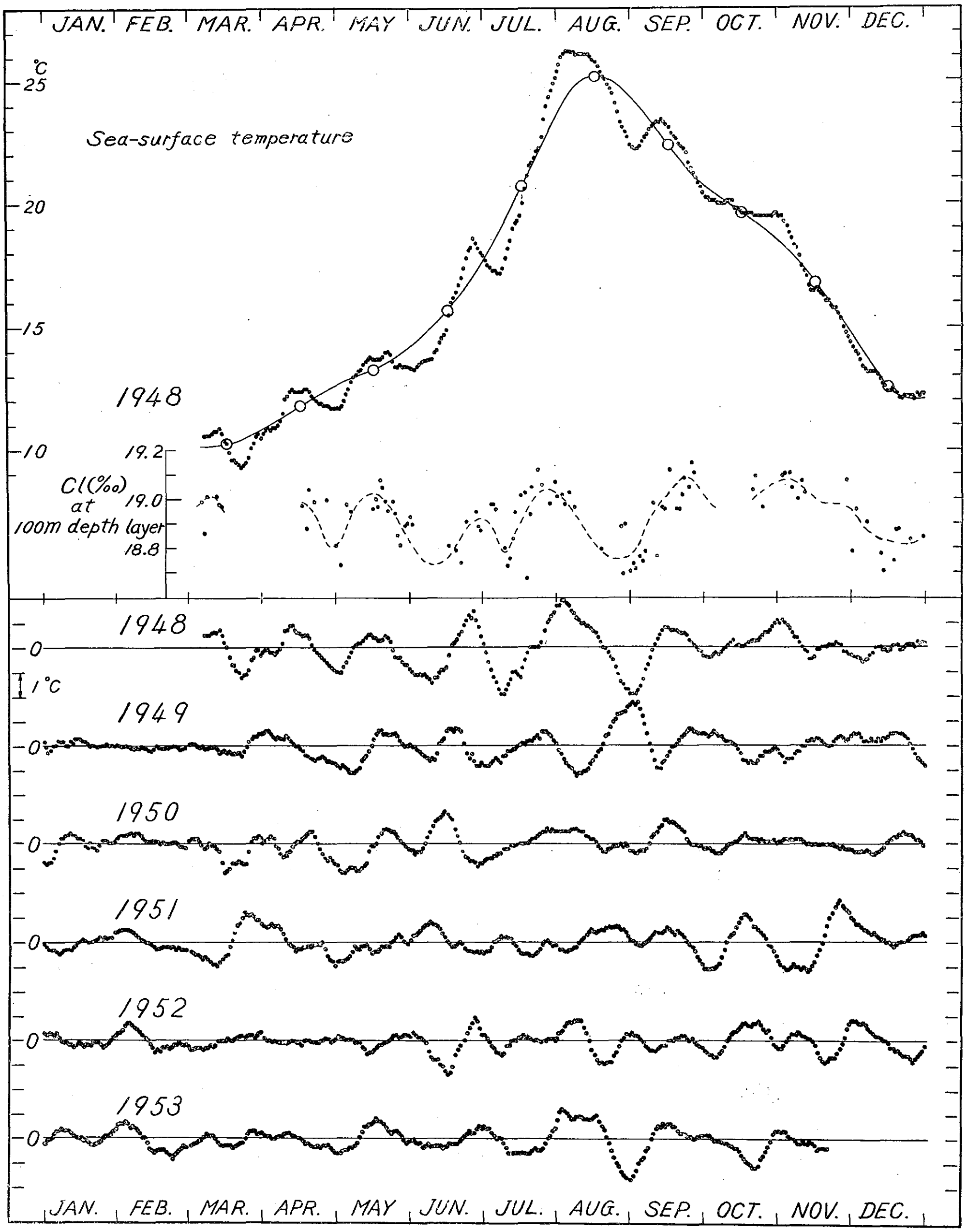

Fig. 1 Variations of sea-surface temperature and chlorinity at St. "X" (39°N, 153°E). Upper : The variation of sea-surface temperature (the moving averages of 10 days represented by small dots and the monthly means represented by large circles) and the variation of chlorinity at 100 m depth layer (the individual observed values are plotted). Lower : The variation of sea-surface temperature shown by the deviations of the moving averages from the trend of such a curve in the upper part as obtained by smoothing the monthly means.

3. Determination of the period

Some terms during which the oscillation shows a comparatively regular or definite periodicity, i.e. March to October 1948 and 1949, January to June 1950, September 1951 to February 1952, June 1952 to January 1953, and April to November 1953, are selected, as the characteristics may be scumbled if the total terms under investigation are treated without assortment. In order to determine the period of the oscillation, correlograms are prepared (Fig. 2). The coefficients of auto-

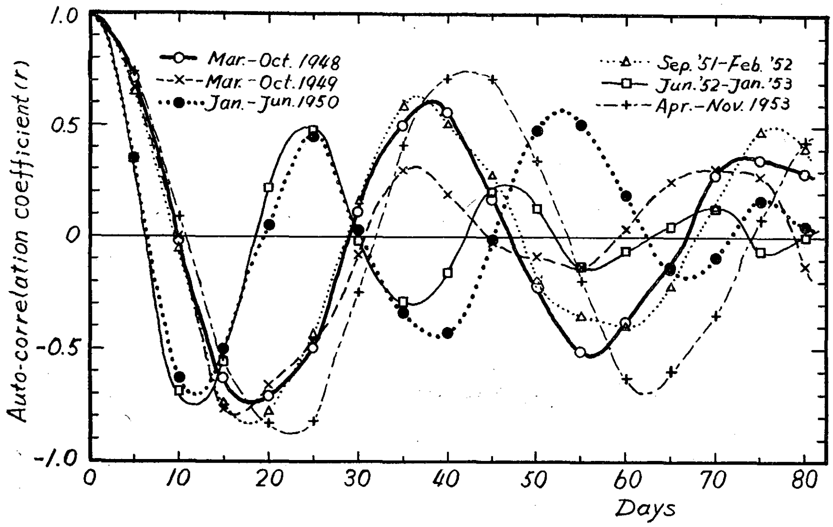

Fig. 2 Correlogram of time variation in sea-surface temperature at St. "X" (39°N, 153°E).

correlation are approximately calculated by Tomoda's method [1] on the basis of the series of temperature deviation. It is proved from Fig. 2 that periods of 25 to 45 days prevail in the oscillation of the sea-surface temperature.

4. Possible causes of the oscillation of sea-surface temperature

It is obvious that the air temperature, the amount of clouds, etc., or the weather conditions in general, influence the sea-surface temperature, and there are cases in which the oscillation of sea-surface temperature at St. "X" may be considered to have been influenced by the variation of the air temperature, and of the weather conditions in general. On plotting the moving average of ten days of the air temperature together on the graph of the sea-surface temperature (not inserted in Fig. 1), it can be found that in some terms the curve of the variation of air temperature runs roughly parallel to that of the variation of sea-surface temperature, but there exists a tendency for the times of maximum and minimum to occur a little earlier in the case of air temperature. This tendency may suggest that the sea-surface temperature varied following the variation of air temperature (weather conditions) in certain terms. It is well known that there are periods of 20, 25, 35, 45 days, etc. in the variation of weather conditions [2].

On the other hand, it was noticed that the water temperature and chlorinity at greater depths showed periodic variations similar to that of the sea-surface tepmerature. As an example, the individual observations of chlorinity at 100 m depth layer in 1948 are plotted in Fig. 1 (the moving average is not computed because the observation was not made every day). From this it seems that some of the oscillations appearing in the sea-surface temperature are not due to the thermostatic relations near the sea surface but to the movement of water masses down to a certain depth. If water masses of different property are alternately distributed within an ocean current, an observer at a station in the zone of the current will catch such oscillation in water temperature and other elements. But the meandering of ocean current is considered to be a more probable cause of the oscillation. Many oceanographic surveys hitherto made indicate that near St. "X" there lies the subarctic convergence, on the south of which the general current (the Kuroshio Extension) flows from west to east. If a horizontal boundary wave is formed between the subarctic water and the Kuroshio water —that is to say, if the current meanders— the variation in the characteristics of water with the same period as that of the boundary wave is to be observed at such a station as St. "X" located in the frontal zone. Observations at St. "X" will be able to give an information on the period of such a boundary wave but not on the wave length and wave velocity. The present author supposed, however, that the propagation of the boundary wave may be traced on the time isopleth of sea-surface temperature on the line including the C-line (the observational line along the latitude of 38°16′N, to the east of Kinkazan) and St. "X", but concerning the existence and propagation of the boundary wave any conclusive evidence could not be found from the isopleth diagram, perhaps on account of the scantiness of observations on the C-line (at most twice a month).

HAURWITZ and PANOFSKY [3], considering various models of current system, theoretically discussed the meandering of ocean current. We shall try to apply their "Model 3" of current system (Fig. 3) to our present case. According to these authors, the frequency equation for "Model 3" is for the case of $U_1=U_4$ (see Fig. 3)

$$C'^3A-C'^2[A+\zeta_3(B-E)+\zeta_2(D-E)]+C'[\zeta_3B+\zeta_2D-\zeta_3^2J-\zeta_2^2I-\zeta_2\zeta_3(J+I-H)]+\zeta_2\zeta_3[\zeta_2+\zeta_3-H]=0,$$

where

$C'=(C-U_1)/(U_{23}-U_1)$ $\quad C$: wave speed,

$A=(a_1+a_2)(1+a_3a_4)+(a_3+a_4)(1+a_1a_2)$,

$B=1+a_1a_2+a_1a_3+a_2a_3$,

$D=1+a_2a_3+a_2a_4+a_3a_4$,

$E=(a_1+a_2)(a_3+a_4)$,

$J=a_1+a_2$, $\quad H=a_2+a_3$, $\quad I=a_3+a_4$,

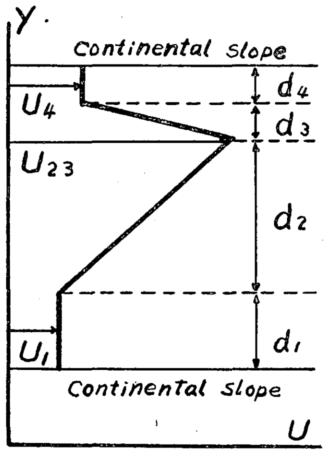

Fig. 3 "Model 3", one of the current systems discussed by HAURWITZ and PANOFSKY [3]. U: current velocity

$a_n=\coth(2\pi d_n/L)$ $\quad L$: wave length,

$\zeta_2=L/2\pi d_2$, $\quad \zeta_3=L/2\pi d_3$.

In the present case, we are interested in the unstable waves formed far off the shore. Therefore we assume that d_1, $d_4 \gg L$, consequently $a_1=a_4=1$. One of the roots of the above equation is always real, which is hardly interesting to us, and the other two roots are conjugate complex for a certain range of the wave length (the wave is unstable only in this range). Fig. 4 shows the relations

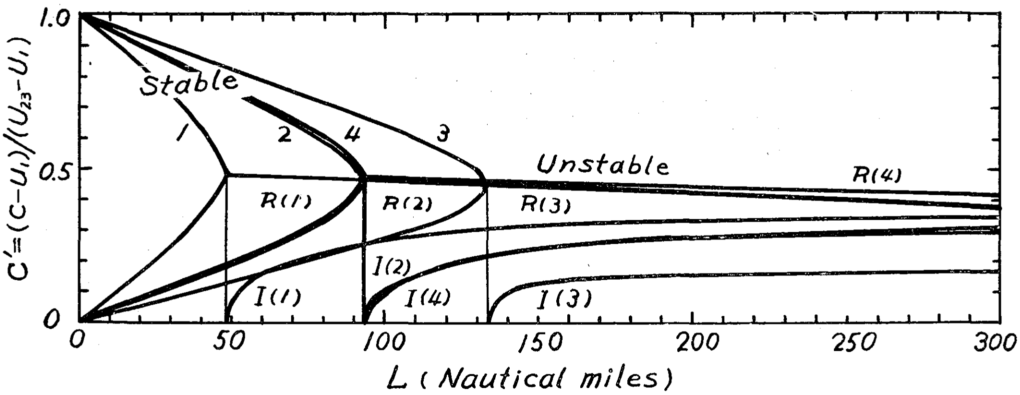

Fig. 4 Relations between roots of the frequency equation and wave length for cases (1. d_2=100mi, d_3=10mi ; 2. d_2=100mi, d_3=20mi ; 3. d_2=100mi, d_3=30mi ; 4. d_2= 150mi, d_3=20mi). In the region of the real roots the wave is stable and only in the region of the conjugate complex roots the wave is unstable. In this case the real part (R) of the complex roots relates to the speed of wave and the positve imaginary part (I) represents the instability of wave.

between C' and L for various sets of d_2 and d_3. The critical wave length at which the stability changes its sign becomes larger with increasing width of the shear zone (d_3), but C' in the unstable region is scarcely influenced by the change of d_3, at least for $L<300$ mi. And, even if the transition zone (d_2) changes from 100 mi (Case 2) to 150 mi (Case 3), the effect on C' is only small in both the stable and unstable regions ($L<300$ mi).

As seen from charts of sea-surface temperature, e.g. the Ten-Day Marine Report of the Central Meteorological Observatory [4] which are prepared on the basis of the data of oceanographic observations and the reports from vessels, the isotherms are generally dense and present pronounced wavy forms in the sea region east of the Tōhoku District and there often appears such a pattern that 2~3 waves lie between the coast of that district and the meridian of St. "X". Consequently, the wave length is estimated at about 200 mi, as the distance between the coast and St. "X" is about 550 mi. The speed of the current in the region concerned may be estimated, on an average, at 0.5~1 knot without large error.

Thus, assuming that $U_1=0$ and $U_{23}=0.5$ knot and 1.0 knot for Case 2, we get the following table for the speeds of propagation (C) and the periods (T) of the unstable waves of various wave lengths.

Possibility that such oscillations of sea-surface temperature as obtained here may be caused by the meandering of ocean current will be increased by the values in this table, even though the value of T can be adjusted to fit the periods of sea-

Case 2 (d_2=100 mi and d_3=20 mi)

L (mi)	$C'=\frac{C-U_1}{U_{23}-U_1}$	$U_1=0$, $U_{23}=0.5$ kt			$U_1=0$, $U_{23}=1.0$ kt		
		C		T	C		T
		(kt)	(mi/day)	(day)	(kt)	(mi/day)	(day)
100	0.46	0.23	5.52	18.1	0.46	11.04	9.1
150	0.44	0.22	5.28	28.4	0.44	10.56	14.2
200	0.42	0.21	5.04	39.7	0.42	10.08	19.8
250	0.40	0.20	4.80	52.1	0.40	9.60	26.0

surface temperature variation at St. "X" by taking suitable assumptions of conditions.

If those temperature oscillations are really dependent upon the meandering of ocean current, we can estimate the amplitude of the boundary wave and the speed of migration of the current course. According to the examination of many of the Ten-Day Marine Report [4], the N-S gradient of sea-surface temperature is 1.5~2.5°C/60 mi on an average in the vicinity of St. "X". Therefore, it results that if the temperature oscillation has a range of 3°C the double amplitude (range) of the boundary wave is 72~120 mi and further that if the period is 40 days the current course migrates by 3.6~6.0 mi/day on an average in the N-S direction.

Acknowledgment———The author wishes to express his sincere thanks to Dr. K. HIDAKA, Dr. M. UDA and Dr. M. NAKANO for their kind advice and constant encouragement.

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