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Decadal Signal in the Sea Surface Temperatures off the San'in Coast in the Southwestern Japan Sea

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Abstract

The decadal-scale variations in the southwestern Japan Sea are investigated on the basis of the offshore sea surface temperature (SST) measured by a ferryboat. The low-pass filtered SST shows alternate warm and cold periods of decadal scale, bounded by a sudden decrease and increase in 1976-1977 and 1983-1984, respectively. These temperature jumps correspond to the regime shifts that occurred in the North Pacific in the mid-1970s and late 1980s, suggesting that the Tsushima current in the Japan Sea is under the influence of the Pacific Decadal Oscillation. Similar warm and cold periods of decadal timescale are seen in the winter-mean SST variations, along with shorter-period fluctuations correlating with the winter monsoon intensity. In contrast, such a decadal variation is not observed in the summer-mean SST. This indicates that the decadal variations (and regime shifts) in the Japan Sea SST field appear clearer in winter, the same as in the North Pacific.

Key words : *decadal-scale variation, regime shifts, Tsushima Current, Pacific decadal oscillation*

1. Introduction

In relation to global climate change, decadal-scale variations in the oceans have been studied comprehensively. Particularly, in the North Pacific, a strong signal with a bi-decadal (20-year) period has been reported in some variables such as the sea surface temperature (SST) [1], the upper ocean heat content [2], and in the sea levels [3, 4]. These variations are called the Pacific Decadal Oscillation (PDO) and are characterized by what we call regime shifts, rapid transitions between successive regimes [5, 6].

Since the Kuroshio is the western boundary current in the North Pacific, it is considered to be under the influence of the PDO. This suggests that the Tsushima Current in the Japan Sea, a branch of the Kuroshio, is also influenced by the PDO. In this paper, we examine the decadal-scale SST changes in the Tsushima Current to clarify whether decadal variations synchronizing with the Kuroshio exist or not. If such variations are found in the Tsushima Current, there is the possibility that the PDO significantly controls the dynamical and biological conditions in the Japan Sea because the Tsushima Current is the only inflow-outflow system in the semi-closed Japan Sea area.

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The SST difference between before and after the regime shift that occurred in the mid-1970s is less than 1 °C in the North Pacific [7, 8]. To detect SST changes, low background noise data reflecting the Tsushima Current fluctuations are required; such datasets are obtained from the offshore region where the current path is relatively stable. In addition, needless to say, SST data spanning several tens of years are necessary for the investigation of decadal variabilities. We analyze an offshore SST dataset that satisfies both of these conditions measured by a ferryboat off the San'in coast in the southwestern part of the Japan Sea, with an observation period that spans longer than 30 years.

Since the San'in area corresponds to the most upstream region of the Tsushima Current in the Japan Sea (Fig. 1), the SST signals synchronizing with the Kuroshio variation, if any, must appear strongly in this area. Further, we may expect that the SST variations in this area represent those in the downstream region to a certain degree. For these reasons, we think that the SST in this region is the key to the study of decadal variations in the Japan Sea.

2. Data

The ferryboat line of the Hagi Kaiun Ltd. Co. connects Hagi and Mishima Island in the southwestern Japan Sea (Fig. 1). The ferryboat measures the SST once a day at the point

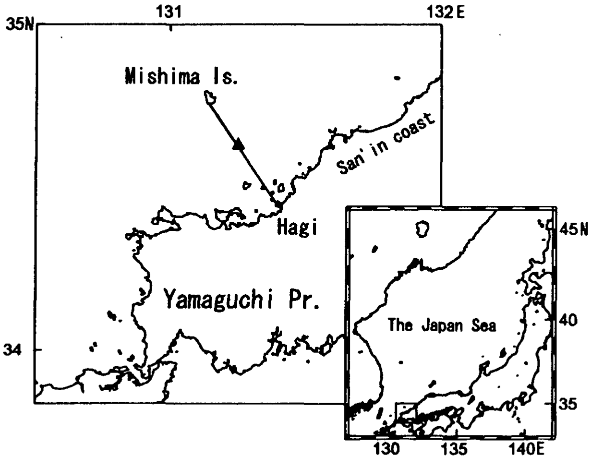

Fig. 1 Location of the SST measurement point (solid triangle). The inset shows the figure location relative to the Japan Sea.

denoted by a triangle in Fig. 1 (34° 38.0'N, 131° 15.0'E), except when passages are canceled due to stormy conditions, and sends the information by FAX to the Yamaguchi Prefectural Fisheries Research Center (YPFRC). The original dataset used in this study is the SST data compiled by YPFRC. Since the measurement point is near the path of the Tsushima Current near-shore branch [9], it is expected that the SST data reflect the variability in the Tsushima Current.

We analyzed about 37 years of SST data in the period from April 1963 to December 1999, though SST measurements have been made continuously up to the present time. It should be noted that the method of SST measurement was changed from the bucket sampling method to the intake method in April 1998.

Missing data correspond to days when the ferryboat service is cancelled due to stormy conditions, as above mentioned. However, as we are focusing on rather long-term variations, monthly mean SSTs were calculated regardless of the number of days of missing data. For the case of August 1971 in which no data are available, we interpolated the SST anomaly from those in the adjacent months in the year, and added it to the monthly mean SST in August. The time series of the monthly SST obtained by the above operation is shown in Fig. 2.

3. Regime shifts in the SST variation

The running mean for 84 months (7 years) was applied to the SST time series in Fig. 2 to extract the decadal variations. Since variations relating to the El Nino - Southern Oscillation (ENSO) have 2-5 year timescales [1], this operation filters out not only the seasonal variation but also fluctuations due to the ENSO. The time series of the low-pass filtered SST is shown in Fig. 3.

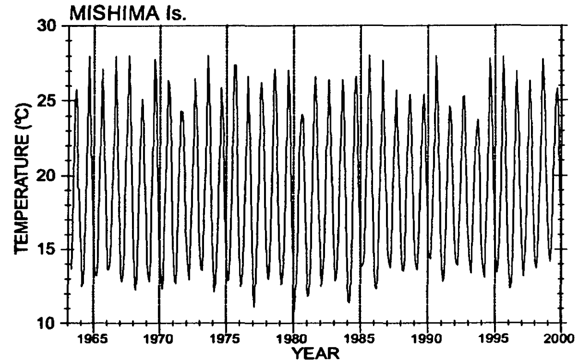

Fig. 2 Time series of the monthly mean SST off the San'in coast.

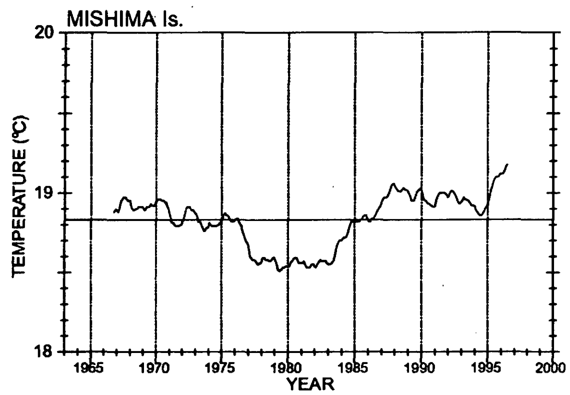

Fig. 3 Time series of the low-pass filtered SST. A horizontal thin line denotes the average low-pass filtered SST throughout the analyzing period (18.83 °C).

Figure 3 exhibits alternate warm and cold periods with a decadal timescale: the first warm period with positive anomalies is from October 1966 to February 1971, the cold period is from May 1977 to March 1983 showing stable negative anomalies, and the second warm period is after April 1986. It is noteworthy that a sudden temperature drop of 0.26 °C occurred over 14 months during the period from March 1976 to May 1977, which corresponds to the transition from the first warm to cold period. Another transition at the end of the cold period occurred within 19 months of the period from March 1983 to October 1984. Both transitions are much shorter than the duration of the warm and cold periods; this is the character of the regime shift.

The readers may suspect that the observed variation is a pseudo variation due to the change in the observation method that occurred during the analyzing period. Folland and

Parker [10] and Hanawa et al. [11] reported systematic biases between SSTs obtained by the bucket sampling and the intake methods. However, as the period of the intake method is limited in the last 21 months, the systematic bias is absent in Fig. 3, at least for the period before September 1994. Since the intake method shows positive biases to the bucket sampling method, the rapid increase in the positive anomaly after 1994 may be a reflection of the influence of the method change.

It is well known that a regime shift from warm to cold conditions occurred during the middle of the 1970s and that another shift from a cold to a warm condition occurred in the late 1980s in the North Pacific [8), 12)]. Since the phase and amplitude of these shifts agree with those observed in the SST variation in the Japan Sea, we can conclude that the regime shifts synchronizing with the North Pacific occurred in the Tsushima Current in the Japan Sea, at least in the San'in area.

4. Interannual variation in summer and winter SSTs

The monthly mean SST in Fig. 2 shows a significant interannual variation in the maximum and minimum temperatures. We can confirm this from the seasonal change in the SST standard deviation; Fig. 4 shows the year-cumulative monthly mean SST and its standard deviation. The standard deviation tends to be large in summer and winter: especially in July, August, and September in the summer (0.99, 1.25, and 0.96 °C, respectively) and January and February in the winter (0.83 and 0.89 °C, respectively). Therefore, we define the summer- and winter-mean temperatures by these means, respectively, and examine their interannual variation. The time series of the summer- and winter-mean temperatures are shown in Fig. 5.

The summer-mean temperature fluctuates around its mean value (thin line in Fig. 5a, 25.2 °C) with an amplitude of about 1 °C. The period of the fluctuations is 2-3 years until the middle of the 1970s, but seems to become longer (4-6 years) after the late 1970s. Although the cause of the fluctuations is obscure, we suspect this is a result of the atmospheric conditions because the summer of 1993 when the minimum SST (23.1 °C) occurred was an abnormally cold summer in which the lowest monthly air temperature and daylight hours were recorded in many places in Japan [13)].

Unlike in the summer variation, the time series of the winter-mean temperatures can be divided into three periods with a decadal timescale (Fig. 5b): the moderate period from 1964 to 1971 which shows SST near the mean winter temperature (13.6 °C), the cold period from 1974 to 1984, and the warm period since 1987. It is noteworthy that these periods and transitions nearly correspond to the warm/cold periods and regime shifts that appeared in Fig. 3, respectively.

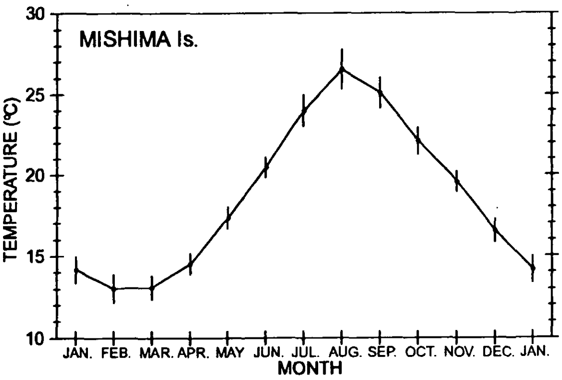

Fig. 4 Seasonal variation in the year-cumulative monthly mean SST (solid circles) with two standard deviations (vertical bars).

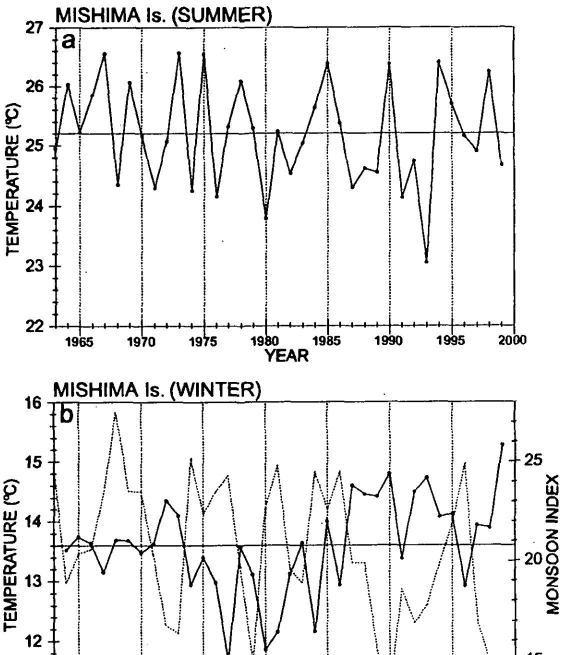

Fig. 5 Time series of the summer-mean (a) and winter-mean SST (b). The horizontal thin line denotes the average SST in each season during the analyzing period. The winter monsoon index is also shown in (b) by a dashed line; the right-hand vertical axis is for the monsoon index.

Another fluctuation with a 3-4 year period is seen in the winter-mean SST (Fig. 5b), superimposed on the decadal variation. The shorter period fluctuation is out of phase with the winter monsoon index which is defined by the mean of the atmospheric pressure differences between Irkutuk in Russia and Nemuro in Hokkaido, Japan in December, January, and February. The correlation diagram between them (Fig.6) exhibits a significant negative correlation with a 1% confidence level (r=-0.61). This fact indicates that a strong winter monsoon decreases the SST by active heat exchange, and suggests that similar SST variations to that in the San'in area are found in the wider Japan Sea area under the influence of the winter monsoon.

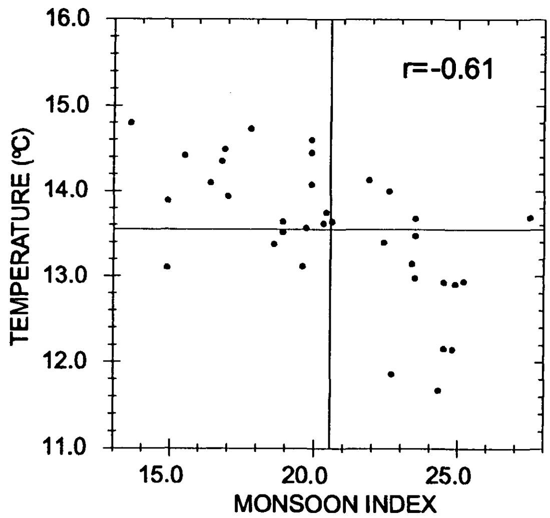

Fig. 6: Correlation diagram between the winter-mean SST and the winter monsoon index. The correlation coefficient is shown in the upper-right corner.

5. Discussions

We have shown that the winter-mean SST is classified into three periods with a decadal timescale and that they correspond to the decadal variation shown in Fig. 3. Such a correspondence is not seen in the summer-mean SST in Fig. 5a. This indicates that the decadal variation (and regime shifts) appears more clearly in the winter, and therefore the decadal variation in Fig. 3 is caused by the winter SST. Recent studies have reported that the regime shift in the North Pacific appears clearly in the winter and that a similar variation is seen in the atmospheric circulation field in the winter related to the Aleutian Low activity [14), 15), 16)]. The SST variation found in the San'in area is consistent with their results.

It should be noted that the winter monsoon index does not show a decadal variation, though the winter-mean SST in each year shows a significant correlation with the monsoon index (Fig. 5b). This indicates that the decadal SST variation seen in the San'in area is not caused by the monsoon variability. It is probable that the observed decadal SST variation is not a local phenomenon within the Japan Sea such as the winter cooling, but part of a larger scale phenomenon in the whole of the North Pacific or the whole of the Kuroshio Current system.

Since the deep water in the Japan Sea (the Proper Water) is formed by the deep convection due to the wintertime sea surface cooling in the northwestern Japan Sea [17), 18)], it is suggested that the PDO controls the thermohaline circulation in the Japan Sea. Indeed, Watanabe et al. [19)] reported the bi-decadal variation of the dissolved oxygen concentration in the Proper Water, which is synchronized with that in the subsurface water in the subarctic North Pacific. To clarify the dynamical impact of the regime shifts on the thermohaline circulation in the Japan Sea, studies based on long-term data from a wide area are needed.

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