EXAMINATION OF CORRECTED HISTORICAL SST DATA USING LONG-TERM COASTAL SST DATA TAKEN AROUND JAPAN

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1. INTRODUCTION

In order to precisely detect the climate variation, climate jump and/or so-called regime shift and global warming, to accumulate the historically long-term data as much as possible is very important and essential. However, since the measuring instruments and methods have been changed sometimes, we have to pay careful attention on the data quality, *i.e.*, existence of instrumental and/or methodological biases. For instance, before World War II, sea surface temperatures (SST) have been measured mainly by the bucket (wooden or canvas buckets) method on board, but after then the bucket method has been replaced by the intake method. For this methodological change, many researchers have pointed out the existence of systematic biases between the two (*e.g.*, Folland *et al.*, 1984). Therefore, based on this situation in historical SST data, correction for the historical SST data taken the bucket method has been investigated and proposed (*e.g.*, Folland and Parker, 1995).

Recently, the Japan Meteorological Agency (JMA) has released the historical marine meteorological data of approximately 1 million by CD-ROM (Manabe, 1999). Since these data have been archived mainly by the former Kobe Marine Observatory/JMA, these digitized data are called the '*Kobe Collection*'. The released data cover the data sparse era and area in the present available data set, that is, around World War I and the North Pacific. Therefore, it is expected these data can considerably contribute the clarification of more robust climate variation in the North Pacific before World War II. Especially, these may be useful for the clarification of the decadal to interdecadal variations found in the North Pacific sector (*e.g.*, Nitta and Yamada, 1989; Trenberth. 1990; Tanimoto *et al.*, 1993; 1997; Minobe, 1997).

The purpose of this article is to examine the validity of correction of historical SST data proposed by Folland and Parker (1995), using the independent data set of the long-term coastal SST (CSST) data, which have been conducted by JMA and Japan Fisheries Agency (JFA) around Japan. The remainder of this paper is organized as follows. In Section 2, the CSST and SST data used are described. In Section 3, the validation method adopted in the present paper is described and Section 4 describes the results. In section 5, the abrupt jump in SST fields occurred in mid 1940s are introduced. Section 6 gives concluding remarks.

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2. THE DATA USED

2.1. Coastal sea surface temperature (CSST)

JMA and JFA have conducted the CSST measurement at several tens stations since early this century and several stations of them are continued to the present (TRFRL, 1982; Yoshida, 1997). From the beginning of measurements to 1970s, JMA CSST data had been taken by the bucket and thermometer once (10 am at local time) every day. Figure 1 shows the locations of four CSST stations used in the present study.

2.2. Sea surface temperature (SST)

Monthly mean 5^{o} (lat.) x 5^{o} (lon.) grid SST data from 1950 to 1990 in the North Pacific are those prepared by Iwasaka and Hanawa

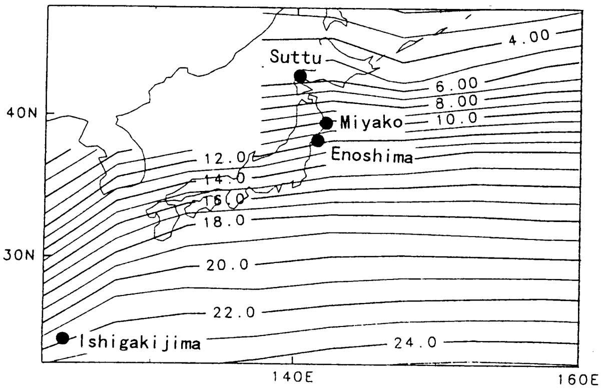

Fig. 1. Location of coastal sea surface (CSST) stations which have been conducted by the Japan Meteorological Agency and JapanFisheries Agency. Only four stations used in the present study are shown. Contours denote January SST climatology (1961-1990).

(1990) and Tanimoto *et al.* (1997), using COADS (Comprehensive Ocean-Atmosphere Data Set; Woodruff *et al.*, 1984). Detailed data processing procedures may be referred in Iwasaka and Hanawa (1990) and Tanimoto *et al.* (1997).

The same kind of monthly 5-degree box data have been newly prepared by the present study using both COADS and the Kobe Collection from 1854 to 1949. These monthly data are simple averages of the raw data available in given calendar month and in given 5-degree box.

These original data are uncorrected ones, that is, not adopted by the bucket correction of Folland and Parker (1995). In the present study, we used only the monthly grid data which are computed using the raw data more than 10.

3. VALIDATION METHOD : USING CSST DATA AT ISHIGAKIJIMA AS AN EXAMPLE

First, in order to extract the mean seasonal variation, monthly climatologies are calculated using the data of 30 years from 1961 to 1990 (reference period) at both CSST stations and SST grids. Then, anomaly fields during the whole period available are computed. Here, we used two SST data: uncorrected ones and ones corrected using the correction values proposed by Folland and Parker (1995). Next, in order to find appropriate SST grids to be compared with each CSST station, the correlation analyses are performed between CSST anomalies and corrected SST anomalies during the whole period available. Figure 2 shows the distributions of correlation coefficients between CSST at Ishogakijima station and SST grids. Here SST grids having high correlation coefficient greater than approximately 0.45 are selected for the following comparison. Those SST grids are also shown by stars in Fig. 2. Finally, anomaly fields of CSST and SST at selected grids are compared, for the two periods of before 1941 and after 1942 to 1990, although such comparisons can be made for freely selected periods. These periods are selected because the correction proposed by Folland and Parker (1995) should be applied to the data taken until 1941 and Manabe (1999) pointed out the abrupt jump in SST in 1940s in the North Pacific.

In comparison, scatter plots are prepared between CSST anomalies, and corrected and uncorrected SST anomalies. Figures 3(a) through (c) show those at Ishigakijima station in September: here Figs. 3(a) and (b) show those using the uncorrected and corrected SST anomalies, respectively. In each panel, closed circle with horizontal and vertical bars denotes the mean deviations from 30-year climatologies (1961-1990) and their standard deviations. For the period after 1942 shown in Fig. 3(c), mean deviations of CSST and SST anomalies are 0.01°C and –0.03°C, respectively. These are reasonably small and close to zero, since the climatologies are made for the period of 1961-1990 as mentioned before. On the other hand, those for CSST anomalies, the uncorrected and corrected SST anomalies before 1941 are -0.42°C, -0.93°C and -0.51°C, respectively. Here, the mean deviation of CSST anomalies can be regarded as real deviation between the periods before/after 1940s, since the measuring method has been unchanged. Mean deviation of the corrected SST anomalies coincides well with that of CSST anomalies, while that of uncorrected SST anomalies is considerably different from those of CSST and corrected SST anomalies. This fact shows the usefulness of correction proposed by Folland and Parker (1995).

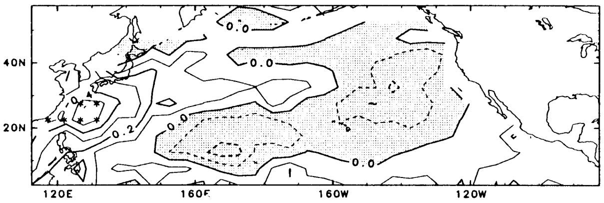

Fig. 2. Distributions of correlation coefficients between CSST anomalies at Ishigakijima and SST anomalies using the corrected data of the whole period. Contour interval is 0.1. Stars denotes the SST grids which are used in comparison described in Sections 3 and 4. The negative correlation areas are shaded.

In each panel, the linear regression line is also shown. Its slope for the period after 1942 is approximately unity and the intercept value is also very close to zero. The slope of unity means the amplitude of anomaly fields of CSST and SST is almost the same both at CSST stations and at SST grids. However, in general, we cannot necessarily expect the slope of unity. Because, due to the local condition of CSST station, amplitude of anomalies at some CSST station may differ from those of surrounding open ocean.

In the next section, similar analyses will be performed in each month and using four CSST stations.

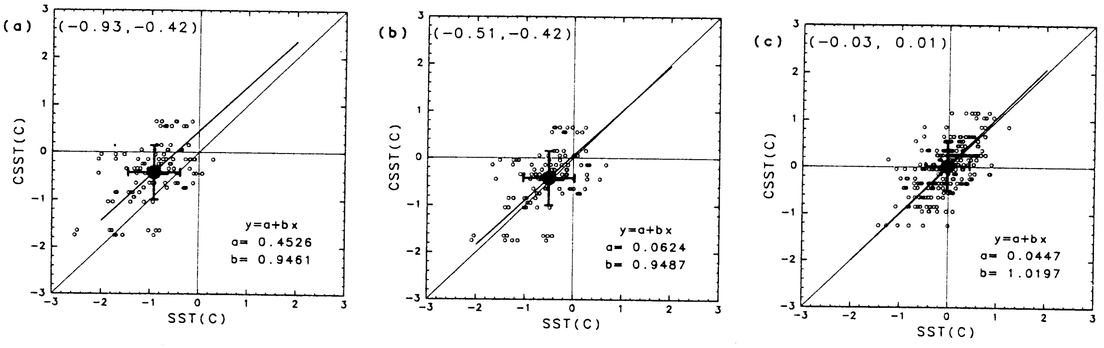

Fig. 3. Scatter plots of SST and CSST anomalies at Ishigakijima for the period from 1914 to 1941 and from 1942 to 1990. Six SST grids having high correlation with Ishigakijima CSST are used in this analysis (see Fig. 2). (a) CSST versus uncorrected SST from 1914 to 1941, (b) as in (a) but for corrected SST and (c) as in (a) but for from 1942 to 1990. Closed circle with vertical and horizontal bars denotes mean values of the anomalies with standard deviations. The inclined straight line is the linear regression line. Numerals in brackets are mean values of SST anomalies (left) and CSST anomalies (right). The slope and intercept value are also denoted in the right corner of each panel as b and a.

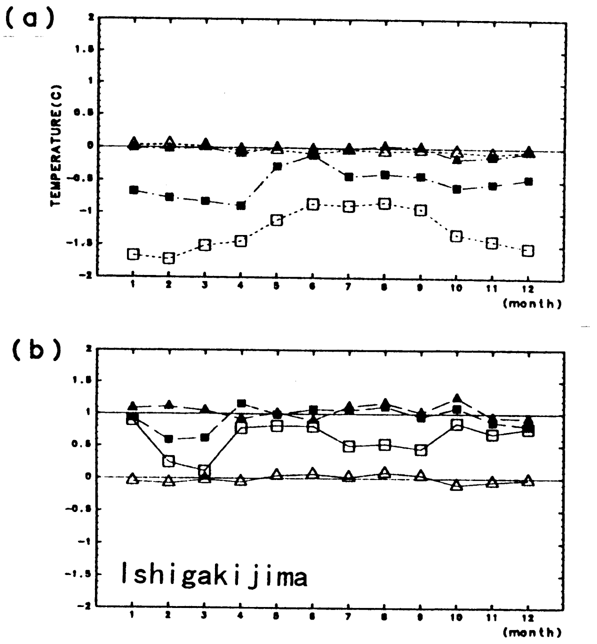

Fig. 4. Monthly values of each parameters in comparison between CSST and the uncorrected SST data. (a) Monthly values of mean deviations of CSST (closed symbols) and SST (open symbols) anomalies. Squares denote those for anomalies before 1941 and triangles denote for the anomalies after 1942. (b) Monthly values of the slope (closed symbols) and intercept value (open symbols) of the linear regression line. Squares denote those for anomalies before 1941 and triangles denote for the anomalies after 1942.

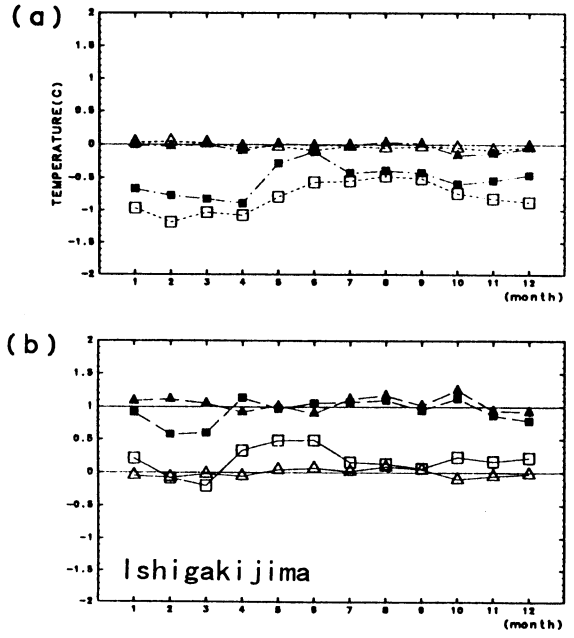

Fig. 5. As in Fig. 4 but for the corrected SST data.

4. VALIDATION OF CORRECTED HISTORICAL SST DATA

Figures 4 and 5 show the results of comparison between anomalies of CSST at Ishigakijima station, and uncorrected and corrected anomalies of SST grids. For the period after 1942, both mean deviations of CSST (closed triangles) and SST (open triangles) anomalies (Figs. 4(a) and 5(a)) are reasonably close to zero values. This is because, as mentioned before, climatologies used in calculation of anomalies are obtained for the period of 1961-90. On the other hand, for the period before 1941, mean deviations of CSST anomalies (closed squares of Figs. 4(a) and 5(a)) are generally negative. This suggests that the climate of the period before 1941 is cooler compared with that after 1942.

In the period before 1941, when mean deviations of the uncorrected (open squares in Fig. 4(a)) and corrected (open squares of Fig. 5(a)) SST anomalies are compared with those of CSST anomalies (closed squares of Figs. 4(a) and 5(a)), we can point out the those of corrected SST anomalies coincide well with those CSST anomalies.

Figure 4(b) and 5(b) show the slope of linear regression line and the intercept values. If the appearance of the anomalies in both

CSST and SST fields is same situation in time, before 1941 and after 1942, then the slope (not necessarily unity) should be same each other and the intercept value is also close to zero. Comparing Figs. 4(b) and 5(b), we also find the relationship between CSST anomalies and corrected SST anomalies is much better than that of uncorrected SST anomalies.

Similar analyses were performed using other three CSST stations (not shown). They also suggest that corrected SST anomalies coincide well with those CSST anomalies. Then we can confirm the correction proposed by Folland and Parker (1995) functions very well.

5. ABRUPT JUMP IN SST FIEIDS FOUND IN 1940S

5.1. Abrupt jump in SST field found in 1940s

Barnett (1984) and Wright (1986) pointed out the abrupt increase of SST field in the North Pacific in 1940s. However, they also mentioned that some fraction of this abrupt change in SST field could be attributed to the instrumental bias according to the methodological change from the bucket method to the intake method, because the differences of SST and air temperature over the sea also increased in phase. Manabe (1999) has pointed out the abrupt jump in SST field in 1940s in the North Pacific using the uncorrected SST data which have been calculated from COADS and the newly digitized Kobe Collection. In the present study, since we found the correction by Folland and Parker (1995) functions very well, we applied this correction to the whole area of the North Pacific and examined this abrupt jump in SST field in 1940s. Figure 6 shows the time series of wintertime (from January to March) SST anomalies averaged in the area of 30°N-35°N, 145°E-180°., *i.e.,* the Kuroshio Extension including part of the Kuroshio recirculation area. Even in the corrected SST time series, we can clearly observe the abrupt jump occurred in early 1940s. Magnitude of this jump between the period of two decades of 1922-41 and that of 1942-61 amounts to 0.98°C in the corrected data (1.57°C in the uncorrected data).

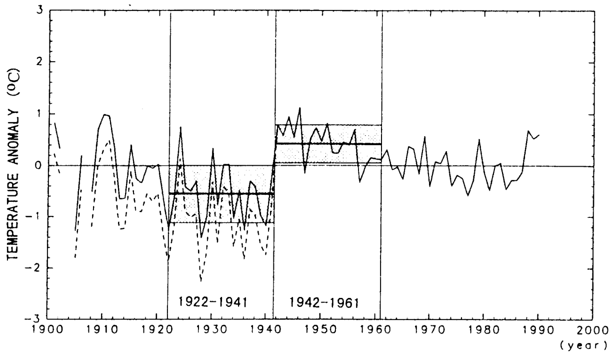

Fig. 6. Time series of wintertime (January to March) SST anomalies averaged in the area of 30°N-35°N, 145°E-180°, *i.e.,* the area of the Kuroshio Extension and its recirculation. Anomalies are defined as the deviation from 30-year (1961-1990) climatology. Thick horizontal lines denote mean anomalies in two two-decades of 1922-1941 and 1942-61 and shaded areas show +/- one standard deviations in each two-decade. The broken line before 1941 denotes that of uncorrected SST anomalies.

In order to see the spatial distribution of this abrupt SST jump, difference of yearly mean SST anomalies between the above two periods are calculated, as shown in Fig. 7. In this calculation, the grids whose data are less than 10 seasons of total number of 80 seasons (20 years x 4 seasons) are omitted in the figure. Positive SST jump is seen in almost the whole North Pacific, and especially in the western mid latitudes it exceeds 1°C, although in the westernmost area its distribution is somewhat noisy. From the same type of figures for each season (not shown here), this yearly mean distribution is found to be almost same irrespective of season, and in addition SST jump is smaller or having negative sign in the lower (equatorial) and higher latitudes.

5.2. Indirect evidences on climate shift of 1940s

In addition to the previous finding, we can give another indirect evidence on occurrence of SST jump in 1940s. Bingham *et al.* (1992) compared the upper ocean thermal conditions between two pentads of 1938-42 and 1978-82, using the hydrographic data taken by the old Japanese Imperial Navy and by the TRANSPAC XBT (Expendable Bathy-thermograph) data. From their original figure, we can point out that the core layer temperature of the North Pacific subtropical mode water (NPSTMW) along 145°E line is

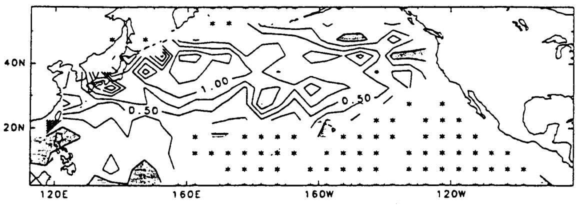

Fig. 7. Distribution of jump magnitude in SST field. Jump magnitude is defined as the difference between two two-decade mean SSTs of 1922-41 and 1942-61. Stars denote the SST grids discarded in drawing the contours due to the lack of enough data. Negative values (lower temperature in the latter two decades) are shaded.

lower by approximately 0.5°C in 1938-42 than that in 1978-82 as in shown Fig. 8. Since the NPSTMW whose formation area is south of the Kuroshio Extension (approximately 28°N-35°N, 140°E-180°; see, *e.g.*, Suga and Hanawa, 1990) is formed in the upper ocean mixed layer due to the a huge amount of heat release from the ocean in winter, the core layer temperature of NPSTMW can reflect the winter time SST in the formation area (see, *e.g.*, Hanawa and Yoritaka, 1999). Even at 200m depth (Fig. 7 of Bingham *et al.*), the temperature difference between the two pentads amounts to 0.5°C in the whole zonal band of 20°N-35°N: temperature in the former pentad is lower than that of the latter pentad.

We calculated the mean wintertime (January to March) SST difference in the area of 30-35°N and 140-150°E. It is found that this SST differences between the two pentads are 0.66°C for the corrected data (1.20°C for the uncorrected data). That is, this well coincidence between differences of the NPSTMW core layer temperature and the wintertime SST strongly suggests that the corrected SST data are more plausible and reasonable compared with the uncorrected ones, and support the occurrence of 1940s abrupt jump in SST field in the North Pacific is real phenomena.

This 1940s abrupt jump is also detected in sea level pressure field as described by Minobe (1997) using the North Pacific index proposed by Trenberth (1990) and Trenberth and Hurrel (1994). In addition, Yamamoto *et al.* (1986) reported the "climate jump" was seen in several meteorological elements taken in Japan in late 1940s and early 1950s. Although there is some phase lag between SST fields and those detected by Yamamoto *et al.*, it may be said these are in line with the present finding. That is, the climate jump as well as abrupt jump in SST field actually occurred in 1940s in the real world.

6. CONCLUDING REMARKS

In the present article, we have examined the validity of correction for historical SST data recently proposed by Folland and Parker (1995), using the long-term CSST data taken around Japan. It can be concluded that the correction to the historical SST data proposed by Folland and Parker (1995) functioned well in the historical SST data computed from COADS and the Kobe Collection, at least to the sea area around Japan. Precisely speaking, since only the CSST data around Japan were used here, we can no say anything on the validity of this correction in the other areas. If another appropriate long-term CSST data are available in the world ocean, the same comparison will be useful and the validation of SST correction will be able to be confirmed much more. Further, it can be pointed out that the present method using the coastal meteorological stations as well as CSST stations can be applied for another marine elements such as sea level pressure and so on.

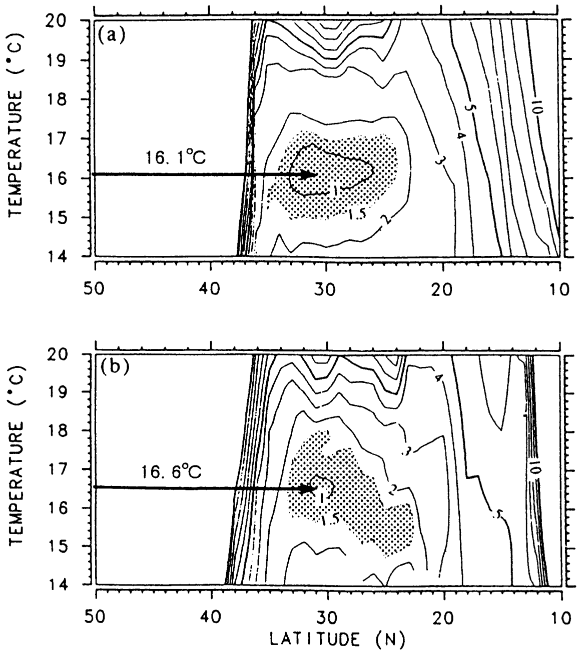

Fig. 8. Temperature-latitude diagrams of vertical temperature gradient for the two pentads of 1938-42 (a) and 1978-82 (b). Unit of vertical temperature gradient is $10^{-2\circ}$C/100m. Shaded areas denote the layers with vertical temperature gradient less than $1.5\times10^{-2\circ}$C/100m which can be regarded as the North Pacific subtropical mode water (NPSTMW). Arrows attached in the present study show the core layer temperature of NPSTMW. After Bingham *et al.* (1992).

In the present study, the abrupt jump of SST field in 1940s in the North Pacific was also pointed out based on the direct and indirect evidences. Although several authors already suggested this change, the present study could confirm its robustness. Detailed investigation on this abrupt change (climate jump and or regime shift) may be very interesting subject and should be done in near future.

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