Are Sea Surface Temperature Variations in the Kuroshio Extension and Subarctic Frontal Zones in the Western North Pacific Ocean Coherent?

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ABSTRACT

The western North Pacific region is one of the centers of action of decadal time scale variations in the atmosphere and ocean, and also oceanic ecosystem can be strongly influenced by the variations. One of the key variable of the decadal variations is sea surface temperature (SST) that varies as a result of interaction between the atmosphere and ocean. To improve our understanding of the key element, SST variaions in the two frontal zones in the western North Pacific Ocean, the Kuroshio Extension and subarctic frontal zones, are investigated on the basis of an *in situ* observational dataset. Interannual-to-decadal variations in these two frontal zones are not highly correlated, indicating that to some extent different mechanisms induce the SST variations in the frontal zones and those two frontal zone cannot be considered as a single frontal zone as has been done in most of previous studies. Meanwhile, the results are consistent with the recent studies that suggest different mechanisms for the variations in the two frontal zones on the basis of a solution to an eddy-resolving, i.e., very high horizontal resolution, ocean general circulation model.

Keywords: North Pacific, Sea surface temperature, Decadal variability

INTRODUCTION

It has been well known that populations of sardine and anchovy vary on (inter-) decadal timescale with amplitude of more than one order (e.g., [1]). For the Japanese sardine, Ref. 2 showed that sea surface temperature anomalies (SSTAs) in the western North Pacific (NP) region have crucial impact on the natural mortality coefficient for the period from the postlarval stage to age 1, and thus the population, although how the SSTAs affect the oceanic ecosystem in the region has not been clarified yet. The western NP region is also known as one of the centers of action of Pacific decadal variability ([3], among others), and several studies have suggested that air-sea interactions in the region may have a key role to induce or intensify the decadal variations [4–6]. The corresponding decadal SSTAs in the western NP are most prominent along the so-called Kuroshio-Oyashio Extension (KOE) front, the zonal oceanic front between the NP subtropical and subarctic gyres. Thus, to improve our knowledge on decadal variations in the atmosphere, ocean and ecosystem in the NP, it is crucial to understand how the SSTAs in the KOE region are induced and if the SSTAs have feedback to force atmospheric variations.

Ref. 7 then investigated the mechanism for the SSTAs on the basis of a hindcast integration of an eddy-resolving ocean general circulation model

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(OGCM), the OGCM for the Earth Simulator (OFES) [8, 9], focusing on variations in the Kuroshio Extension frontal zone (KEFZ, ~ 35°N) and in the Oyashio Extension, the subarctic, frontal zone (SAFZ, ~ 42°N), the two prominent frontal zones in the KOE region. Their results indicated that decadal SSTAs in the western NP region have their maxima in the two frontal zones, especially in the SAFZ, where SST has the largest meridional gradient (Fig. 1), suggesting importance of meridional migration of the fontal zones. Latitude-depth section of temperature difference apparently shows that the two frontal zones migrate meridionally in association with the decadal SSTAs, inducing temperature anomalies in the surface (subsurface) layer in the SAFZ (KEFZ) due to different vertical structures of the frontal zones (Fig. 2). Although vertical displacement of thermocline also has some contribution to subsurface temperature anomaly, influences of the associated changes in warm water advection by the Kuroshio Extension Current are not apparent in the model.

In the SAFZ, heat flux anomalies appear in association with the SST anomalies, and the former tend to damp the latter, indicating that the SST anomalies are not caused by atmospheric thermal forcing [7]. In other words, the SST anomalies induced in the frontal zone by the aforementioned oceanic processes can have feedback on the atmosphere through modifying heat flux to the atmosphere. This cool (warm) SST-downward (upward) surface heat flux anomaly relation is also shown by Ref. 10 in the SAFZ on the basis of an *in situ* observational dataset.

The results of the previous studies indicate that the SAFZ has higher SST variability and higher possibility to affect the atmosphere than the KEFZ, suggesting that the two frontal zones have different properties. Then, do the interannual SSTAs in the SAFZ and KEFZ vary coherently? In this study, we investigate this based on a dataset of observed SST compiled by the Japan Meteorological Agency (JMA-SST).

RESULTS

Figure 3a indicates that wintertime SST variance is large in the SAFZ, in the Oyashio frontal zone (the western end of the SAFZ with southwest-northeast extending strong SST gradient), and in the upstream region of the KEFZ. To investigate if these SST variations are temporally coherent or not, we plot a simultaneous correlation map (Fig. 3b) of wintertime SST on the area mean SSTAs in a part of the SAFZ (black rectangular in Fig. 3a, b). High correlation region extends along the SAFZ and also to the Oyashio frontal zone. However, correlations gradually decrease southward to the KEFZ, especially in the upstream region (around 140–150°E), and negative correlations appear to the south of 35°N, the southern recirculation region of the Kuroshio Extension Current. Consequently simultaneous correlations between the SAFZ and the KEFZ are less than 0.5, and lower in the upstream region.

Time series of area mean SSTAs in the SAFZ and in the upstream KEFZ (32°–38°N, 141°–153°E, following Ref. 11) indicate that they are not coherent

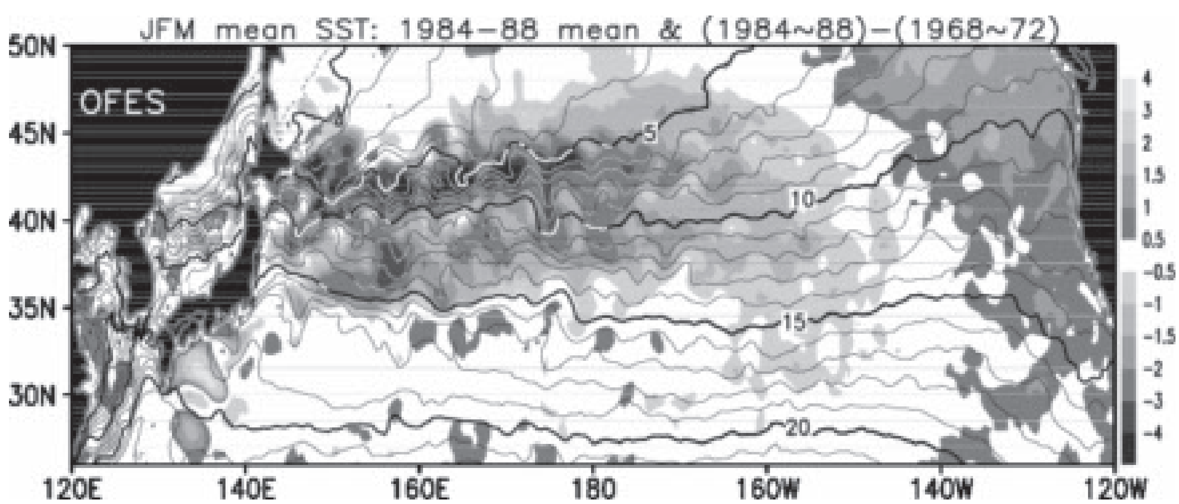

Fig. 1 Wintertime (January-March) mean SST fields over the North Pacific based on the OFES hindcast simulation. Contours indicate the five-winter mean for 1984–88 (every 1°C), and shading indicates the difference of that mean field from another five-winter mean for 1968–72, as indicated to the right of the panel.

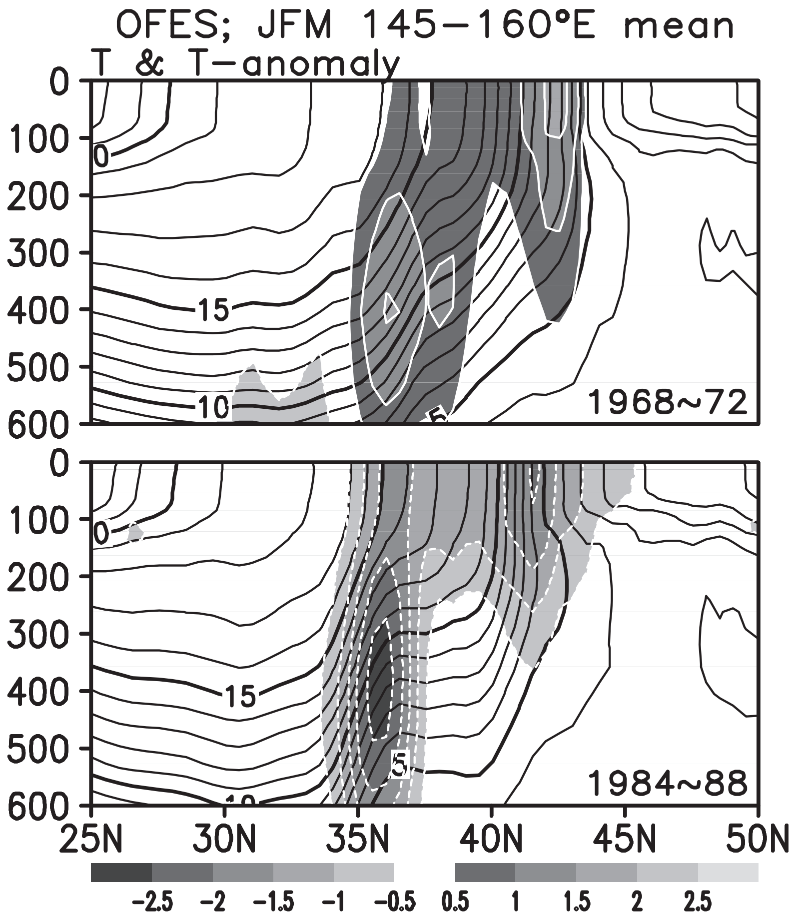

Fig. 2 Latitude-depth sections of five-winter (January-March) mean temperature fields for the (top) 1968–72, and (bottom) 1984–88 periods averaged between 145° and 160°E based on the OFES hindcast simulation. Contour intervals are 1°C, and the temperature anomalies from the 1950–2003 mean field are plotted with shading, as indicated below the bottom panel.

on interannual and also decadal time scales (for example, from the end of 1960s to the early 1970s, SSTAs tend to be positive in the SAFZ but they tend to be slightly negative in the KEFZ, and negative peak in the 1980s appeared several years earlier in the KEFZ than in the SAFZ). As a result, their correlation coefficient (r) is only 0.37, and if we see area mean SSTA in [32°–36°N, 141°–153°E], excluding the Oyashio frontal zone from the upstream KEFZ in Ref. 11, their correlation becomes lower further to $r = 0.15$ (Fig. 3c, thin line). These results indicate that SST variations in the SAFZ and in the KEFZ are not highly correlative, and it can be misleading to consider them as one single frontal zone as has been done in most of previous studies on variations in the western NP Ocean, owing to rather coarse horizontal resolution of the models or datasets used.

SUMMARY AND DISCUSSION

In this study, we investigate whether interannual variations in the two frontal zones in the so-called KOE region, the KEFZ and the SAFZ, are coherent on the basis of an observational SST data product, JMA-SST. The result of the correlation analysis indicates that the interannual-to-decadal SST variations in the SAFZ and KEFZ are not highly correlative, indicating that to some extent those variations are governed by different mechanisms.

Previous studies have suggested that decadal timescale variations in the KOE region are strongly influenced by westward propagation of Rossby waves driven by wind-stress curl anomalies over the central portion of the North Pacific ([12, 13] among others). Ref. 7 confirmed this process in the KEFZ on the basis of an eddy-resolving OGCM, while Ref. 14 further pointed out a probable role of some

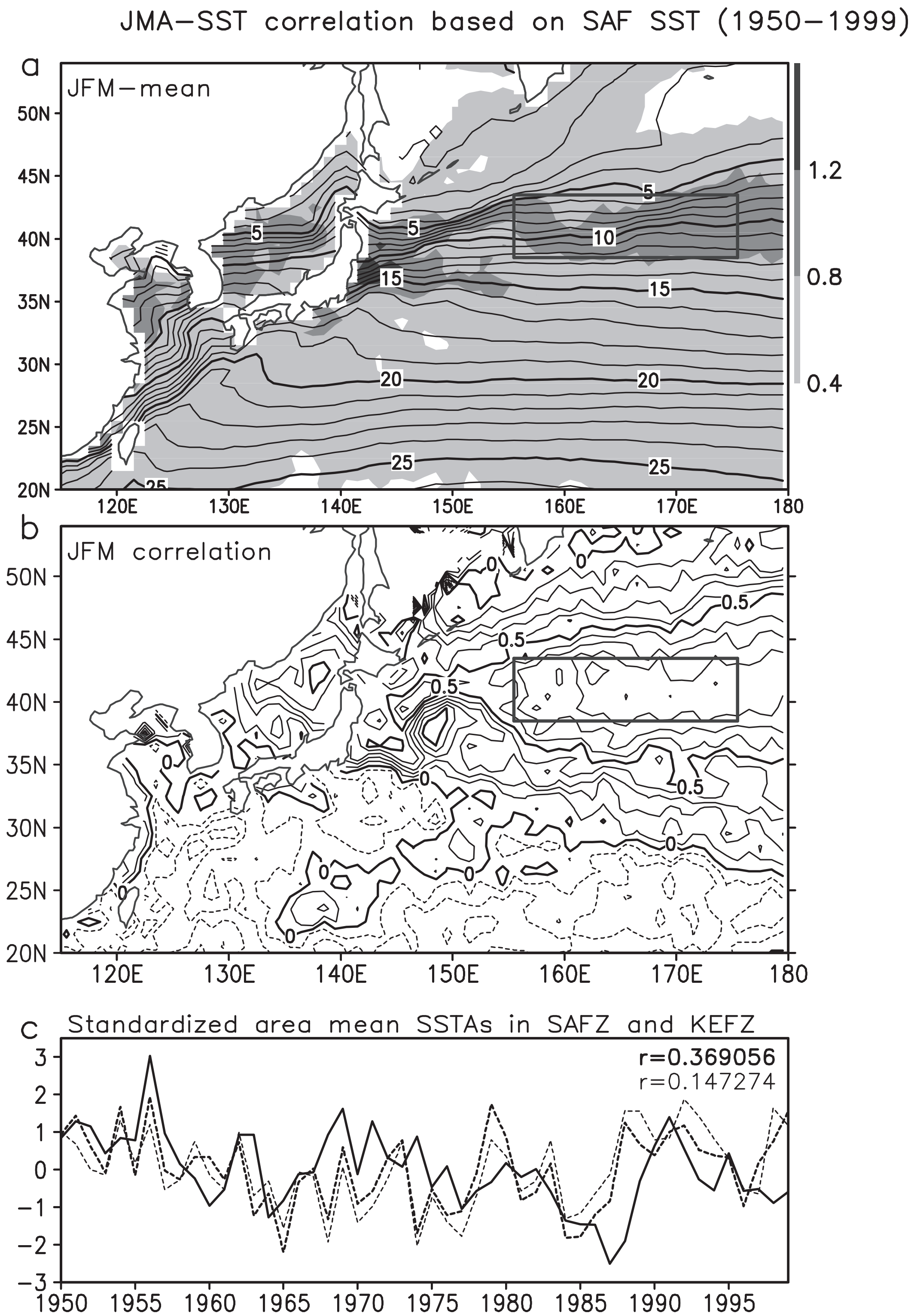

Fig. 3 Winter (January-March) mean SST based on the JMA-SST for 1950–1999. (a) Long-year mean (contours with intervals of 1°C) and standard deviations of interannual variations (shadings as indicated to the right of the panel). (b) Simultaneous correlation map of winter mean SST on the area mean SSTA in [38.5°–43.5N, 155.5°–175.5°E] in the SAFZ (black rectangular in the panels a and b). (c) Time series of area mean SSTAs standardized by their standard deviations for [38.5°–43.5N, 155.5°–175.5°E] (thick solid line), [32°–38°N, 141°–153°E] (thick dashed line), and [32°–36°N, 141°–153°E] (thin dashed line).

nonlinear oceanic processes to induce prominent anomalies strongly trapped to the narrow oceanic front. In contrast to the KEFZ, westward propagations of anomalies are sometimes not clear in the SAFZ, and some eastward propagating signals appear in the western portion of the basin [7; Fig. 12 there], suggesting the mechanisms that induce interannual-to-decadal variations in the SAFZ to be different than those in the KEFZ. Indeed, using the solution to the same eddy-resolving OGCM, Ref. 15 indicated that variations in the Oyashio Current tend to induce SST anomalies that develop eastward in the SAFZ from off Hokkaido Island. That these different mechanisms are suggested by an OGCM for variations in each of the KEFZ and the SAFZ is consistent with the SST variations, with not very high degree of correlation, in those frontal zones indicated in this study.

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