Formation Mechanism for Isopycnal Temperature–Salinity Anomalies Propagating from the Eastern South Pacific to the Equatorial Region

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(Manuscript received 6 February 2006, in final form 31 August 2006)

ABSTRACT
Equatorward propagation of temperature–salinity (or spiciness) anomalies on an isopycnal surface emanating from the eastern subtropical South Pacific and their formation mechanism are investigated based on a hindcast simulation with an eddy-resolving quasi-global ocean general circulation model. Because of density-compensating meridional distributions of temperature and salinity, the meridional density gradient is weak at the sea surface in the eastern subtropical South Pacific. With these mean fields, cool sea surface temperature anomalies (SSTAs) can make the outcrop line of an isopycnal surface migrate equatorward more than 5° and induce warm and salty anomalies on the isopycnal surface. Subducted warm, salty anomalies propagate to the equatorial region over approximately 5 yr and may influence equatorial isopycnal temperature–salinity anomalies. Although the associated effects are unclear, if these anomalies could further induce warm eastern equatorial SSTAs that are positively correlated with eastern South Pacific SSTAs, opposite sign temperature–salinity anomalies would be formed in the subtropical South Pacific, and a closed cycle having a decadal time scale might be induced.

1. Introduction
Following the finding that shallow overturning ocean circulation connects the subtropics and the equatorial region, climate change researchers have focused on these subtropical cells (STCs; McCreary and Lu 1994; Schott et al. 2004 for recent review) and their potential role in Pacific decadal-scale variability. Kleeman et al. (1999) proposed that stronger (weaker) STC strength induces cool (warm) sea surface temperature anomalies (SSTAs) in the equatorial region on a decadal time scale by transporting more (less) midlatitude cool waters. Nonaka et al. (2002) and McPhaden and Zhang (2002) showed that the relationship between the STC strength and equatorial SSTAs could be found in a realistic ocean general circulation model (OGCM) and in historical observational data, respectively. However, Gu and Philander (1997) proposed that temperature anomalies formed in the midlatitudes are transported by mean STCs to the equatorial region, inducing equatorial SSTAs. Although Deser et al. (1996) reported that decadal temperature anomalies were subducted into the subsurface layer and propagated equatorward in the North Pacific, no significant signal was found to reach the equatorial region from the North Pacific (Schneider et al. 1999; Nonaka et al. 2000; Nonaka and Xie 2000).

In the South Pacific, the STC transports more water into the equatorial region than in the Northern Hemisphere (Johnson and McPhaden 1999; Schott et al. 2004) and has wider pathways to the equatorial region through the interior ocean (Huang and Liu 1999; Nonaka and Takeuchi 2001). These differences may contribute to the discrepancy in anomalous signal propagations between the North and South Pacific Oceans. Recent studies have shown that significant signals propagate from the tropical/subtropical South Pacific to the equatorial region as wind-forced baroclinic Rossby waves (Luo and Yamagata 2001; Luo et al. 2003) and also as temperature–salinity [(T–S) or spici-
ness] anomalies on isopycnal ($\sigma$) surfaces (Giese et al. 2002; Yeager and Large 2004; Luo et al. 2005). Although spiciness anomalies do not affect ocean dynamics, they can influence air–sea interaction due to their temperature anomalies when they arrive at the sea surface, as suggested by coupled ocean–atmosphere GCM experiments (Schneider 2000, 2004).

Based on an OGCM with simple assimilation of observed temperature data, Giese et al. (2002) showed that significant T–S anomalies appeared in the mid-1960s in the eastern subtropical South Pacific and propagated to the equatorial region on $\sigma$ = 25.0 kg m$^{-3}$; the results of the study implied that the arrival of these anomalies induced sudden changes in the eastern equatorial SST in the mid-1970s. Giese et al. (2002) nudged the interior temperature to the observed value while conserving T–S relationships and did not specify the sources of the T–S anomalies. Using hindcast integration of an OGCM, Yeager and Large (2004) also inspected the spiciness anomalies that appeared in the mid-1960s and found that the anomalies were caused by diapycnal mixing at the base of the mixed layer in the eastern South Pacific. The importance of diapycnal mixing was confirmed by another OGCM study (Luo et al. 2005), but influences of signals directly subducted from outcrop lines were also suggested in that study. As a source of spiciness anomalies, anomalous advection across a mean isopycnal T–S front has also been proposed (Schneider 2000). In this study, we seek to confirm the propagation of the spiciness anomalies from the eastern subtropical South Pacific to the equatorial region using an eddy-resolving OGCM and to propose an additional formation mechanism for these anomalies.

This paper is organized as follows. Section 2 outlines the model, while section 3 describes the propagation of the spiciness anomalies. A formation mechanism is investigated in section 4, and section 5 provides a summary and discussion.

2. The OFES

We use the Modular Ocean Model version 3 (MOM3) OGCM (Pacanowski and Griffies 2000) with substantial modification for the vector-parallel hardware system of Japan’s Earth Simulator. Our Ocean Model for the Earth Simulator (OFES; Masumoto et al. 2004) covers a near-global domain extending 75$^\circ$N–75$^\circ$S, with a horizontal resolution of 0.1$^\circ$. The model has 54 vertical levels with 5-m resolution at the surface, and the maximum depth is 6065 m. For horizontal mixing of momentum and tracers, we use scale-selective damping with a biharmonic operator (Smith et al. 2000). The nonlocal K-profile parameterization (KPP) boundary layer mixing scheme (Large et al. 1994) is employed for vertical mixing.

Surface heat flux and evaporation are calculated by bulk formulas with atmospheric variables based on the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data (Kalnay et al. 1996) and the simulated SST field. Freshwater fluxes are evaluated from the evaporation fields and daily precipitation rate data, under the constraint that sea surface salinity (SSS) is restored to the observed monthly climatology at a time scale of 6 days. For details, see Masumoto et al. (2004) and Sasaki et al. (2007).

Following a 50-yr integration with climatological monthly mean forcing from the annual-mean temperature and salinity climatological fields without motion, we conducted a 54-yr hindcast integration with daily mean atmospheric fields of the NCEP–NCAR reanalysis data from 1950 to 2003. This hindcast simulation successfully captures variability with intraseasonal-to-decadal time scales (Sasaki et al. 2007) and has been used to investigate decadal variability in the western North Pacific region (Nonaka et al. 2006).

3. Isopycnal T–S anomalies

In this study we focus on isopycnal T–S anomalies on $\sigma$ = 25.3 kg m$^{-3}$. This isopycnal surface outcrops in the subtropics of the South Pacific. In the equatorial region, this surface is around the core of the thermocline and the Equatorial Undercurrent. It shallows to just below the surface mixed layer in the eastern equatorial region (not shown), suggesting that anomalies on this surface could be entrained into the surface layer in the eastern equatorial region. Additionally, this isopycnal surface corresponds to the core of the South Pacific Eastern Mode Water (SPESTMW) according to observations (Wong and Johnson 2003) and OFES hindcast simulations. In this study, we inspect T–S anomalies on this surface because isopycnal T–S variance has a vertical maximum around this surface in the tropical South Pacific (data not shown). The high T–S variability on this surface may be attributable to density-compensating vertical stratification of temperature and salinity in the SPESTMW (Wong and Johnson 2003), which can induce large spiciness anomalies with small temperature and/or salinity anomalies (Johnson 2006). Those vertical structures in temperature and salinity are likely due to the lateral distribution of SST and SSS as discussed in section 4.

The distribution of T–S variance on this surface (Fig. 1) shows that except for the equatorial region, high T–S
variances are found in the outcrop region of the eastern South Pacific around 120°W and extend northwestward in the direction of the mean flow field. The outcrop latitude also has large variability in the eastern basin, while it is nearly steady in the western part of the basin (Fig. 1). Reasons for this distribution and its importance are discussed in section 4.

Warm, salty anomalies were subducted from the outcrop region at around 120°W in 1967 and propagated westward at around 15°S all the way to the western boundary, where they arrived in 1971; these anomalies then extended farther northward to the equatorial region (Fig. 2). Moreover, some parts of the warm, salty anomalies extended northward and/or northwestward and entered into the equatorial region (e.g., in 1969) on the way to the western boundary. Peaks of the warm anomalies reached 1°C, while they diffused during their propagations. These years illustrate anomaly subduction and propagation.

A warm, salty spiciness anomaly in the subtropical region appeared around 120°W in 1967 and propagated westward to the western boundary in nearly 5 yr (Fig. 3b). The mean zonal current velocity in the latitude band illustrated was −5.6 cm s⁻¹, so advection by the mean current from 120°W to 150°E would be about 4.9 yr, consistent with the propagation rates (Fig. 3b). It is also apparent (Fig. 3b) that the 1967 signal (Fig. 2) is not unique; rather, warm, salty and cold, fresh anomalies have appeared repeatedly in the eastern South Pacific and propagated westward. We used no temporal filter for Fig. 3: the isopycnal $T-S$ anomalies indicate that a decadal rather than an interannual time scale was dominant. Although interannual variability was large in the eastern basin, decadal variability became dominant in the central to western basin, likely due to mixing during propagations.

While signals on $\sigma_s = 25.3$ kg m⁻³ have been shown, similar signals are found for $25.1 < \sigma_s < 25.5$ kg m⁻³ in the OFES. As noted in the introduction, previous modeling studies have already shown this phenomenon (Fig. 2 of Giese et al. 2002; Fig. 12 of Yeager and Large 2004; Fig. 9 of Luo et al. 2005). Our results generally agree with the other results, but some discrepancies exist. Specifically, positive anomalies in the 1960s (1990s) were weaker (stronger) than their counterparts in the former two studies, and the anomalies in the
Fig. 2. Simulated monthly mean temperature (contours) and temperature (and salinity) anomalies (shading, as indicated below the bottom panels in °C) on $\sigma_z = 25.3$ kg m$^{-3}$ in September from 1967 to 1976, as indicated near the lower-right corner of each panel. Contour intervals are 1°C.
Fig. 3. (a), (b) Long–time section of temperature (°C) (and salinity) anomalies ($\sigma_\theta = 25.3$ kg m$^{-3}$) averaged between (a) 2°N–2°S and (b) 13°–17°S. The lon axis is reversed and compressed in (a). (c) Lat–time section ($\sigma_\theta = 25.3$ kg m$^{-3}$) SSD averaged between 100°–120°W (black curve) and 90°–100°W (green curve). (d) Time series of 15°–25°S, 100°–120°W (black), 15°–25°S, 90°–100°W (green), and 4°S–4°N, 90°–150°W (red) area mean SSTAs. Equatorial SSTAs are reduced by a factor of 0.5 for easy comparison with other curves. All panels are based on monthly mean September fields from the OFES hindcast simulation.
1950s had the opposite sign of those found by Giese et al. (2002). Meanwhile, the OFES did not capture the isopycnal salinity variations reported by Kessler (1999), likely due to insufficient representation of the mean salinity distribution in the near-equatorial region. Although some differences occur, we have confirmed the spiciness anomaly propagation in our very high horizontal resolution OGCM, which is presumably less influenced by the parameterization of horizontal/isopycnal mixing than models used in previous studies as our model does resolve mesoscale eddies reasonably well (Smith et al. 2000). Additionally, because the models compared above have different representations of surface freshwater flux, the similarity of the results among the models implies that surface freshwater flux anomalies are not crucial to the spiciness anomaly formation (see also the discussion at the end of section 4).

4. A mechanism

How, then, are the isopycnal $T$–$S$ anomalies caused? Yeager and Large (2004) suggested that these anomalies are attributable to diapycnal mixing associated with density-compensating vertical profiles of salinity and temperature at the base of the mixed layer in the eastern South Pacific. Such vertical profiles were also found in the fields of the OFES simulation, suggesting the mechanism may be operative in our model. Nevertheless, we investigate another possible mechanism in this study; namely, the subduction of isopycnal $T$–$S$ anomalies from the outcrop region rather than those injected at the base of the mixed layer. This mechanism is attributable to the large meridional migration of the outcrop line (Fig. 1). Kessler (1999) studied the possible importance of meridional migration in his study on the sources of isopycnal salinity anomalies at $\sigma_p = 24.5$ kg m$^{-3}$ in the South Pacific, but found that meridional migration was not essential for forming anomalies on that particular surface. We note that the $\sigma_p = 24.5$ kg m$^{-3}$ outcrop migrates much less (less than 5° latitude) than the $\sigma_p = 25.3$ kg m$^{-3}$ outcrop in the OFES simulation.

We start our discussion by examining SSS, SST, and SSTAs in September 1967 (Fig. 4, left panels), the year of the subduction of the warm, salty anomalies, and 1968 (right panels), when no major spiciness anomalies occurred (Fig. 2). Comparing the surface fields in the 2 yr, note the presence of strong, more than $-1^\circ$C, cool SSTAs in 1967 (bottom-left panel), while the warm, salty isopycnal anomalies also began to appear in that year (Fig. 2). This means that the warm isopycnal anomalies cannot be explained from sea surface heat flux anomalies and from the resultant SSTAs, consistent with previous studies that showed that some spiciness anomalies cannot be explained by changes in sea surface flux in their source regions (Kessler 1999; Suga et al. 2000).

Density-compensating SST and SSS distributions occur in latitudes from 20° to 40°S in the central to eastern parts of the basin with warm, salty water to the north and cool, fresher water to the south (Fig. 4, top and middle panels), resulting in a very small meridional sea surface density (SSD) gradient in the region compared to the western part of the basin (black contours). Johnson (2006, his Fig. 1) quantified this distribution in a map of the horizontal Turner angle. In 1967, associated with the SST cooling, the SSD became higher in the cool SSTA region, and as a result, the outcrop line of $\sigma_p = 25.3$ kg m$^{-3}$ (thick black contour) was found at lower latitudes in 1967 (around 20°S) compared to 1968 (25°–30°S) near 120°W. Because of the weak meridional SSD gradient, the outcrop line easily migrated more than 5° in latitude from 1967 to 1968, and large meridional migrations were also found in other years (Fig. 1). In association with the equatorward migration of the outcrop line, the SST on the outcrop line (middle panels) was warmer in 1967 than in 1968, and warm, salty anomalies were subducted on the isopycnal surface (Fig. 2), while local SST cooling occurred in 1967.

A schematic $T$–$S$ diagram (Fig. 5a) helps to illustrate how SST cooling induces warm, salty anomalies on an isopycnal surface (see also Bindoff and McDougall 1994). Given the density-compensating horizontal distributions of the SST and SSS, the SST–SSS distribution (thick gray line) is nearly parallel with the isopycnal (dotted line) in the $T$–$S$ diagram. Because we focus on limited extents of temperature and salinity, we can approximate the isopycnal line on the $T$–$S$ diagram by a straight line here. For simplicity, we assume uniform cooling, then the SST–SSS line moves downward (thick black line) in the diagram. In this case, the temperature on the isopycnal line (T2) becomes higher than the original temperature (T1) with higher salinity, indicating the isopycnal warming (and salinization) with local SST cooling. Because of the SST–SSS relationship, the density of water with the original SST (T1) is higher than the prescribed density in the cooling case, and the higher temperature T2 has the prescribed density. At the same time, the higher temperature requires lower outcrop latitudes, as SSTs are higher in lower latitudes (Fig. 4, middle panels).

To examine if this scenario holds in the OFES during 1967, we plotted a $T$–$S$ diagram for the region of 25°–10°S, 120°–110°W for monthly mean SST and SSS in September of 1967 and 1968 (Fig. 5b). Consistent with the SST field (Fig. 4), crosses for 1967 (black) are
distributed beneath those for 1968 (gray). Squares for water $25.28 < \sigma \theta < 25.32$ kg m$^{-3}$ apparently indicate that SST on the outcrop line of $\sigma \theta = 25.3$ kg m$^{-3}$ was warmer and saltier in 1967 than in 1968 (as schematically shown in Fig. 5a).

In Figs. 3c,b it appears that the outcrop line migrated meridionally from the south of 30°S to the north of 20°S, and a large part of the equatorward (poleward) migrations were accompanied by subduction of warm, salty (cool, fresh) anomalies that propagated westward. At the same time, a large part of the equatorward migrations of the outcrop latitude was associated with cooling of local SST, and vice versa (Figs. 3c,d). These results indicate that the above explanation for the event of 1967 is valid for a large part of the meridional migration of the outcrop line (e.g., in the early 1980s and mid-1990s), the outcrop latitude averaged between 90° and 100°W (green curve in Fig. 3c) and migrated poleward when cool, fresh anomalies originated near 100°W; these migrations were associated with local SST warming (green curve in Fig. 3d). Church et al. (1991) and Bindoff and McDougall (1994) have also suggested that subduction of warm water can lead to a cool, fresh anomaly on isopycnal surfaces, depending on the ratio of vertical gradients of temperature and salinity (the stability ratio).

To confirm this mechanism, we further estimated the meridional migration of the outcrop line ($\Delta y$, northward is positive), the corresponding isopycnal temperature anomalies ($\Delta T$) from local anomalies in density ($\Delta \sigma$), and the temperature ($\Delta SST$) at the sea surface. Here, we estimated $\Delta T$ as follows:

$$
\Delta T = \Delta y \left( \frac{\partial SST}{\partial y} \right) + \Delta SST,
$$
where $\Delta y$ is estimated from $\Delta SSD$ and the mean meridional SSD gradient is

$$\Delta y = -\left(\frac{\partial SSD}{\partial y}\right)^{-1} \Delta SSD,$$

where $(\partial SST/\partial y)$ and $(\partial SSD/\partial y)$ are meridional SST and SSD gradients, respectively, and the overbar indicates the 54-yr September mean. In Eq. (1), the first term of the right-hand side (rhs) indicates the influence of the meridional migration of the outcrop latitude, and the second term denotes the direct effect of local cooling. The formulation is closely related to that used by Schneider (2004) and Schneider et al. (2005) (see also Church et al. 1991; Bindoff and McDougall 1994) for the temperature and/or salinity anomaly associated with vertical displacement of the isopycnal surface. Here, the influence of meridional displacement is considered. In Eq. (2), the minus sign means that the given $\Delta SSD$ is compensated for by meridional migration $(\Delta y)$ of the outcrop line. For example, given a positive $\Delta SSD$, the outcrop line migration in the direction of lower SSD (equatorward in this case) compensates for the given $\Delta SSD$ following the constant SSD of the outcrop line. Based on Eqs. (1) and (2), $\Delta T$ was estimated from the September area mean values for the $20^\circ$–$25^\circ$S, $100^\circ$–$120^\circ$W region (Fig. 6, solid line) and compared with isopycnal temperature anomalies from the same region in the OFES simulation (dashed line). While magnitude is overestimated, the estimated $\Delta T$ captures interannual variability in the simulated isopycnal $T$–$S$ anomaly well (correlation coefficient $r = 0.69$). Variations in $\Delta T$ are dominated by the first term of the rhs of Eq. (1), and $\Delta SST$ generally has an opposite sign to $\Delta T$ and the first term. This result strongly supports the proposal that the mechanism discussed above is operative at least in the OFES. Very recently, Johnson (2006) suggested that a high horizontal Turner angle region can be a source of high spiciness variability, consistent with this mechanism.

Much of the simulated SSD variability in the eastern South Pacific is caused by SST variability, and thus cool SSTAs accompany warm isopycnal temperature anomalies. The relationship between the variations in SST and SSD in the OFES simulation, however, may be overestimated because simulated SSS variability may be underestimated due to restoration to the monthly climatology at the sea surface (see section 2). Unfortunately, few historical salinity observations are available.
to us for the eastern South Pacific, and thus we cannot compare the simulated salinity variability with observational data. Our additional analyses, however, show that the development of interannual SSTAs in the eastern South Pacific region in September has high correlation ($r = 0.82$) with turbulent heat flux (the sum of latent and sensible heat fluxes) anomalies integrated for 1 yr from the previous September. This means that surface heat flux anomalies can explain about 67% of interannual SST variance in the eastern South Pacific region. In contrast to this, surface Ekman advection anomalies, which may induce nearly density-compensating SST and SSS anomalies, can explain only 23% of the SST variance in the region. If the turbulent heat flux anomalies are dominated by sensible heat flux anomalies, the SSTAs induced by them are associated with small SSS anomalies, and the SSS anomalies are largely determined by the SSTAs. However, on the basis of the observational study of Jenkins (1982), turbulent heat flux anomalies may be dominated by latent heat flux anomalies. Assuming the dominance of the latent heat flux, we can calculate the ratio of the effect of latent cooling to the effect of accompanying evaporation (and resultant salinity change) on SSD. With typical SST and SSS in the eastern South Pacific (21.7°C and 36.3 psu) that ratio is 6.23, suggesting that even with latent heat dominating total heat flux anomalies, the interannual SSS variability that cannot be captured in the OFES will have little influence on SSD compared to that of SSTA. This implies that the surface boundary condition for salinity in the OFES is not a crucial problem for the argument in this study. Additionally, a similar relationship between SST and isopycnal temperature anomalies in the eastern South Pacific region has also been found in a dataset that assimilates observed data by the four-dimensional data assimilation method (Masuda et al. 2003).

5. Summary and discussion

Based on a solution to a hindcast integration of an eddy-resolving quasi-global OGCM forced by daily mean atmospheric fields, we investigated interannual/decadal variability in temperature and salinity on an isopycnal surface in the South Pacific and its formation mechanism. Major $T$–$S$ anomalies that were subducted from the eastern subtropical South Pacific were revealed on the $\sigma_t = 25.3$ kg m$^{-3}$ isopycnal surface. Consistent with previous studies, the isopycnal $T$–$S$ anomalies propagated westward all the way to the western boundary in a period of about 5 yr, and part of the anomalies reached the equatorial region through both the interior and western boundary pathways (Figs. 2 and 3).

Based on their study of density-compensating vertical stratification of temperature and salinity in the eastern South Pacific, Yeager and Large (2004) suggested that spiciness anomalies are induced by diapycnal mixing at the base of the surface mixed layer. In this paper, we propose an additional mechanism associated with a density-compensating meridional distribution of SST and SSS in the region. Given the meridional density-compensating distribution, SST cooling requires equatorward migration of the outcrop line and warmer and saltier water on the outcrop line (Fig. 5), as found for 1967 (Fig. 4), and induces a warm, salty anomaly on the isopycnal surface. We observed this relationship for a large part of the events from 1950 to 2003 (Figs. 3–6). This mechanism was operative even in the absence of diapycnal mixing and can explain the subduction of spiciness anomalies from the outcrop region rather than the injection of these anomalies at the base of the mixed layer, the mechanism favored by Yeager and Large (2004; see also Luo et al. 2005). Additionally, in the mechanism presented here, positive and negative anomalies are produced by the same processes with opposite signs, different from the mechanism presented by Yeager and Large (2004).

The mechanism proposed in this study may indicate a relationship between atmospheric forcing and isopycnal temperature anomalies. Through large-scale atmospheric variability, eastern equatorial SSTAs (Fig. 3d, red curve) were positively correlated with SSTAs in the source region of the isopycnal $T$–$S$ anomalies (Fig. 3d, black and green curves). Thus, via this mechanism, the isopycnal $T$–$S$ anomalies can be related with equatorial SST, that is, cool (warm) eastern equatorial SSTA tends to induce cool (warm) SST in the eastern South Pacific and warm, salty (cool, fresh) isopycnal anomalies. While isopycnal $T$–$S$ anomalies have interannual variations just after their subduction, they tend to diffuse faster, and decadal-scale variability dominates in the western part of the basin as shown in Fig. 3b. The decadal isopycnal $T$–$S$ anomalies in the western part of the South Pacific tend to be continuous to those in the equatorial region (Fig. 3a; note that the longitude axis is reversed in this panel), implying the influence of the propagation on the equatorial isopycnal $T$–$S$ anomalies. We should, however, note that Johnson (2006) suggested that double diffusion, which likely operates in the SPESTMW and is not included in the OFES, may reduce the spiciness anomaly and thus the extent of its propagation.

Although it is still unclear how the isopycnal $T$–$S$ anomalies influence the eastern equatorial SSTAs, if warm, salty equatorial isopycnal anomalies propagating from the eastern South Pacific could induce warm east-
ern equatorial SSTAs, as suggested by a coupled GCM experiment (Schneider 2004), and warm eastern South Pacific SSTAs, then, as discussed above, cool, fresh isopycnal anomalies would form and create a closed cycle having a decadal time scale. This hypothesis is similar to that proposed by Gu and Philander (1997) and Schneider (2000) for Pacific decadal variability, but the key mechanism of the reversal in sign of the isopycnal anomalies is completely different. To what extent this current hypothesis can be operative is strongly dependent on how equatorial SSTAs are induced by equatorial spiciness anomalies through delicate tropical air–sea interactions (Schneider 2004). As shown in Fig. 3, equatorial spiciness anomalies do not always correspond to SSTAs. This is also the case in Giese et al. (2002, their Fig. 2). Thus, further studies are necessary to clarify the relationship between equatorial spiciness anomalies and SSTAs.

Acknowledgments. We thank the members of the OFES group, including Drs. Y. Masumoto, T. Kagimoto, H. Sakuma, and T. Yamagata, for their efforts in the model development. We also thank Drs. H. Nakamura and J.-J. Luo for valuable discussions and Dr. N. Schneider and anonymous reviewers for their comments and suggestions, which improved our manuscript significantly. The OFES integrations were performed on the Earth Simulator. The ocean assimilation dataset was produced by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) RR2002 Project in Japan and kindly provided by Dr. S. Masuda. This work was supported by the Frontier Research Center for Global Change and partly by a Grant-in-Aid for Young Scientists (B) (16740277) by MEXT of Japan.

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