Absence of propagating upper ocean heat content anomalies in the eastern tropical South Pacific after ENSO events

Hasegawa Takuya, Hanawa Kimio, Tourre Yves M., White Warren B.

Geophysical Research Letters

Volume 35

Page range L09607

Year 2008

URL http://hdl.handle.net/10097/51474

Absence of propagating upper ocean heat content anomalies in the eastern tropical South Pacific after ENSO events

Takuya Hasegawa,1 Kimio Hanawa,2 Yves M. Tourre,3,4 and Warren B. White5

Received 19 December 2007; revised 16 February 2008; accepted 5 March 2008; published 15 May 2008.

[1] In order to explore why after a mature ENSO warm phase (MEWP), upper ocean heat content (OHC) anomalies disappear in the eastern tropical South Pacific (ETSP: 10°S–20°S, 140°W–100°W), relationships with sea surface temperature (SST), sea level pressure (SLP), wind-stress curl (WSC) and latent heat flux (LHF), are investigated. After a MEWP, positive SST anomalies in the ETSP are first associated with overlying negative SLP anomalies through enhanced atmospheric convection and atmospheric hydrostatic processes. Then negative SLP anomalies and surface winds, lead to positive WSC and negative LHF anomalies (i.e., oceanic heat loss) which dominate the region. The above mechanisms, combined with a weakened South Equatorial Current, contribute to a rapid decay of positive OHC anomalies. It is exactly the opposite of what has been observed in the western tropical North Pacific, where in contrast OHC anomalies associated with ENSO, do grow with time and propagate. Citation: Hasegawa, T., K. Hanawa, Y. M. Tourre, and W. B. White (2008), Absence of propagating upper ocean heat content anomalies in the eastern tropical South Pacific after ENSO events, Geophys. Res. Lett., 35, L09607, doi:10.1029/2007GL033065.

1. Introduction

[2] Upper ocean heat content (OHC, hereafter) anomalies associated with warm and cold events of ENSO, propagate along anticlockwise circuits in the eastern tropical North Pacific [e.g., Kessler, 1990]. OHC positive anomalies in the western Pacific are found to propagate eastward along the equator to trigger an ENSO warm event further east, and then propagate poleward along the eastern Pacific boundary. After ENSO warm phases, these anomalies are reflected from the eastern boundary and propagate westward as Rossby waves between 10°N–20°N. Finally, the OHC positive anomalies reach the western tropical north Pacific (WTNP: 10°S–20°N, 130°E–180°; see Figure 1a) where they will eventually also be reflected. Similar propagations are observed during ENSO cold phases but with reversed sign period. Thus, propagating OHC anomalies not only play an important role in generating and maintaining ENSO events, but contribute to meridional heat transport variation [e.g., Jin, 1996, 1997]. The above observations include mechanisms involved with the delayed-action oscillator in the Northern Hemisphere, as proposed by White and Tourre [2003] and White et al. [2003].

[3] Kessler [1990] pointed out that westward propagating OHC anomalies in the WTNP are greater in magnitude than those propagating eastward after reflection. This has been corroborated by recent studies using longer time-series [e.g., Hasegawa and Hanawa, 2003; White et al., 2003]. It has been further suggested that larger OHC anomalies in the WTNP are associated with negative wind stress curl (WSC) anomalies which appear after mature ENSO warm phases (MEWP), through Ekman downwelling. This mechanism has been evidenced by Kessler [1990], Wang et al. [1999], and White et al. [2003]. In addition, Hasegawa and Hanawa [2007] pointed out that latent heat flux (LHF) (i.e., positive/negative LHF anomalies associated with oceanic heat gain/loss, respectively) can also affect the overall tendency of OHC anomalies. That is, positive LHF anomalies appearing in the WTNP after MEWP, are linked with an increase in OHC anomalies together with negative WSC anomalies. Such relationships among OHC, WSC and LHF anomalies have not been reported in the eastern tropical North Pacific (ETNP: 10°N–20°N, 180°–110°W).

[4] Hasegawa and Hanawa [2003] and White et al. [2003] showed that interannual-scale OHC anomaly also appears around the eastern tropical South Pacific (ETSP: 10°S–20°S, 140°W–90°W) after an ENSO event. However, the OHC anomalies do not propagate westward from the ETSP, whilst Rossby wave reflection does not display the same degree of continuity as in its northern counterpart; weakens with time, and eventually disappears [Hasegawa and Hanawa, 2003; White et al., 2003]. White and Cayan [2000] also suggested that propagating sea surface temperature (SST) and sea level pressure (SLP) anomalies in the tropical Pacific might interfere with OHC anomaly in the western tropical South Pacific (WTSP: 10°S–20°S, 160°E–140°W).

[5] The reason for which observed OHC anomalies do not fully propagate westward in the tropical South Pacific and mechanisms for weakened and rapidly disappearing OHC anomalies in the ETSP, are still unclear. This study is thus to highlight relationships between interannual OHC, SST, SLP, WSC and LHF anomalies in the tropical South Pacific, especially in the ETSP, and propose potential mechanisms for the absence of OHC anomalies propagation there.

2. Data

[6] The subsurface ocean temperature data set prepared from the Scripps Institution of Oceanography [White, 1995] is used here to calculate OHC. Vertically averaged
temperature from the sea surface to the depth of 300 m is a proxy for OHC. Hasegawa and Hanawa [2003] pointed out that OHC anomaly displayed larger amplitude in the tropical Pacific after the 1976/77 rapid climate shift [e.g., Nitta and Yamada, 1989]. In this study and based upon previous results, the analyses are for a 27-year period (from January 1977 to December 2003). The analyzed area covers the Pacific basin from 30°S to 60°N with a 2°

**Figure 1.** (a) Lag correlation coefficients between Niño-3 index and OHC at lags of (a) zero seasons, (b) two seasons, (c) four seasons, and (d) six seasons. Contour interval is 0.2. Negative values are shaded and indicated by broken lines. Positive lag means that Niño-3 index leads OHC. The four key regions of the WTNP, ETNP, WTSP, and ETSP (see text) are shown in Figure 1a.
The SST data set from Smith and Reynolds [2003], wind stress, SLP and LHF data sets from the National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) [Kalnay et al., 1996] are also used. The Niño-3 SST index is from NCEP as well.

Monthly climatology is removed from all data sets and seasonally averaged anomalies are used for all variables. Boreal winter is regarded as January through March, and so forth for the other seasons. In order to analyze the interannual variability associated with ENSO events, all variables are band-passed with a 3- to 6-year window in period using a wavelet analysis [Torrence and Compo, 1998].

3. Results

Distribution of seasonal lagged correlation coefficients between OHC and Niño-3 index are displayed in Figure 1 (i.e., at zero-, two-, four- and six-season lags, respectively from top to bottom). In the following, results are discussed in association with ENSO warm phases; the same discussion applies for ENSO cold phases but with reversed sign. Zero-lag corresponds to a MEWP (Figure 1a), with positive OHC anomaly straddling the equator east of 155° W and covering both the ETSP and ETNP regions. In Figure 1b (2-season lag), the edge of OHC anomaly in the ETNP is at 170° W, while OHC maximum anomaly in the ETSP remains around 140° W. In Figures 1c–1d, positive OHC anomaly develops in the WTNP and eventually merges around 170°E whilst positive OHC anomalies continuing their westward propagation. On the contrary, positive OHC anomaly in the ETSP weakens and barely attains 150°W (4-to-6 season lags). The same propagation is observed in the sea surface height anomalies from the satellite altimeter of TOPEX/POSEIDON (not shown here). Therefore, the propagation characteristic of OHC anomalies is not affected by an uneven distribution of the subsurface temperature data.

In order to explore the non-propagating nature of OHC anomaly in the ETSP, roles of WSC and LHF anomalous fields are investigated. Phase relationships between OHC, WSC (curl of the wind stress divided by the Coriolis parameter) and LHF anomalies, are thus compared in the four regions: WTNP, ETNP, WTSP and ETSP. Lag correlation coefficients between Niño-3 index and these variables are shown in Figure 2. In Figure 2a and for the ETSP area, OHC positive anomalies diminish gradually after a MEWP. Simultaneously, positive WSC and negative LHF anomalies appear in the ETSP with large values for lags 3-to-5 seasons (Figure 2a (bottom)). This suggests that after a MEWP, OHC positive anomalies in the ETSP are strongly damped from both positive WSC and negative LHF anomalies, via Ekman pumping and oceanic heat loss. The roles of the LHF and WSC are estimated assuming that the upper ocean includes the Ekman layer and 1.5-layer (0–300m). It is also assumed that the dominant process is one-dimensional in the vertical, with the “deepest layer” at 20°C. Results show that standard deviations of OHC anomalies generated by LHF and WSC anomalies can explain 47% and 33% of those of observed OHC anomalies in the ETSP during the analyzed period, respectively. Furthermore, it is also shown that temporal change rates of OHC anomalies due to LHF and WSC anomalies (−0.01°C/season ~ −0.02°C/season) can explain 10–50% of those of the observed OHC anomalies (−0.04°C/season ~ 0.02°C/season).
The present results indicate that both LHF and WSC are key parameters explaining the rapid decrease of OHC anomalies in the ETSP. In the eastern Pacific, negative LHF anomaly appears both in the ETNP and ETSP, whilst negative WSC anomalies only over the ETSP area (Figure 2b). The latter will cancel-out effects from LHF anomaly there. Thus, OHC anomalies do not display similar evolution. In the WTSP region (Figure 2c), OHC negative anomalies are associated first with positive WSC and negative LHF anomalies after a MEWP (lags 0-to-3 seasons). OHC anomalies remain negative until a mature ENSO cold phase (~7-season lag). On the other hand, OHC negative anomalies in the WTNP increase with time, accompanied with negative WSC and positive LHF after a MEWP (0-to-8 seasons lags) (Figure 2d). The OHC anomalies then become positive at the 4-season lag.

The above observations and results could explain why OHC positive anomalies disappear rapidly in the ETSP and thus cannot propagate westward in the ETSP after a MEWP, in sharp contrast with observed propagation in the ETNP. It is also interesting to note that the signs for WSC, LHF and OHC anomalies in the ETSP are opposite to those in the WTNP (compare Figure 2a to Figure 2d).

To further explore the mechanisms associated with WSC and LHF anomalies, SLP and zonal wind stress anomaly fields after a MEWP, are also investigated. In Figure 3a, lagged correlations between SLP and Niño-3 index are displayed (with 4-season lag). A tongue-like SLP pattern of negative anomalies, expanding westward is conspicuous in the tropical South Pacific. Positive and negative SLP anomalies appear after a MEWP over the WTSP and the ETSP, respectively. The negative SLP anomalies in the ETSP region are associated with cyclonic wind stress anomaly (Figure 3b) with easterly/westerly...
zonal wind stress anomalies to the south/north of ETSP (Figure 3c). This corresponds to a positive WSC anomaly in this region (Figure 2a). In addition, the enhanced easterlies over most of ETSP [Hellerman and Rosenstein, 1983] must trigger enhanced negative LHF there. A similar tongue-like pattern of positive SLP is also observed in the WTNP (Figure 3a). The pattern is accompanied with an anticyclonic wind stress pattern (Figure 3b) in sharp contrast with what happens in the ETSP. This result is also supported by results obtained from composite and linear-regression analyses (see Figures S2 and S3, in the auxiliary materials).

Finally the temporal evolution of SST anomaly after the MEWP is investigated. Figure 4 displays the distribution of lagged correlations between SST and Niño-3 index (0-, 2- and 4-season lags). Large pattern with positive correlations appear in the central and eastern tropical Pacific (values greater than 0.8 at 0-lag; Figure 4a). This is the well-known SST anomaly pattern during a MEWP [e.g., Tourre et al., 2001]. At the 2-season lag, the maximum positive correlation is of 0.6 except around the ETSP, where the lagged correlation is still greater than 0.8 (Figure 4b). Two seasons later (Figure 4c), an asymmetric SST pattern about the equator becomes conspicuous. That is, although correlation coefficients become very small in the ETNP, relatively lagged highly positive correlations of 0.4 still exist around the tropical South Pacific centered on the ETSP. This asymmetry pattern of SST anomalies in the South and North Pacific is confirmed by a result of composite analysis (see Figure S4, in the auxiliary materials).

It is well known that in the tropical region, positive SST anomalies can induce negative SLP anomalies through enhanced atmospheric convection and boundary-layer hydrostatic adjustment [Graham and Barnett, 1987]. Here, SST and SLP anomalies are highly negatively
correlated in the ETSP region ($r = -0.94$), as already suggested in Figures 3a and 4c. This relationship between SST and SLP anomalies in the ETSP is also found through linear regression analysis (see Figure S5, in the auxiliary materials).

4. Summary and Discussion

[16] To summarize, a scenario based on physical mechanisms responsible for the rapid decay of OHC anomalies in the off-equatorial South Pacific is proposed. After a MEWP, the amplitude of positive SST anomalies gradually weakens starting from the central equatorial Pacific. However, SST and OHC anomalies in the ETSP remain with an anomalous asymmetric SST pattern about the equator. At this time, SST anomalies are associated with negative SLP anomaly (i.e., hydrostatic adjustment in the boundary layer), with positive WSC and negative LHF anomalies. The combined effects of WSC and LHF anomalies (see Figure 2) induce negative feedbacks on OHC anomalies, with a subsequent rapid decrease of the latter. Unlike OHC anomalies in the ETSP, those in the ETNP remain. The importance of the asymmetric SST anomaly pattern about the equator seems crucial. Since coastal upwelling in the southeast Pacific diminishes after a MEWP, positive SST anomalies remain advected by the South Equatorial Current [Kessler, 2006] whilst positive OHC anomalies are damped first from both anomalous WSC and LHF (as explained above) and disappear quickly (Figures 1, 2, and 4). Moreover, the asymmetry of the ITCZ and SPCZ and associated wind-stress curl [Vecchi and Harrison, 2003] may play an additional role in generating local Ekman pumping to the south, along with propagation differences between the eastern tropical North and South Pacific. This remark contributes as well to diminishing the extent to which reflected Rossby waves propagate westward in the ESTP. Finally, it is acknowledged that the ocean geometry in the eastern Pacific is asymmetric; i.e. at 10°–20° south of the equator, the eastern coastal boundary is found ~20°–25° further east as compared to its northern counterpart. The latter could contribute to signal weakening over the larger area.

[17] Strong decrease of ETSP OHC anomalies, from both WSC and LHF anomalies are not associated with an increase in OHC anomalies in the WTSP in sharp contrast to the WTNP. Present results suggest that OHC anomalies after disappearing in the ETSP (with small displacement of the depth of the 18°C isotherm as in White et al. [2003]), can not reappear in the WTSP. That could also explain why remaining OHC anomalies cannot propagate westward in the tropical South Pacific after a MEWP.

[18] In contrast to interannual observations, the quasi-decadal signals display westward OHC propagation in the tropical South Pacific [White et al., 2003; Hasegawa et al., 2007]. The authors inferred that the quasi-decadal OHC propagation is linked to the overlying atmospheric anomaly of the WSC and Ekman pumping. Additional modeling work is required to explore with more details differences between the interannual and quasi-decadal OHC signals propagation in the tropical South Pacific.

[19] Acknowledgments. The authors wish to express their sincere thanks to members of Climate Variations Observational Research Program at Japan Agency for Marine-Earth Science, Oceanographic Research Department at Meteorological Research Institute and Physical Oceanography Group at Tohoku University for their useful discussions. We also appreciate constructive comments from the reviewers. Tourre would like to thank Mike Purdy, Arnold Gordon, Jean-Claude André, and Patrick VanRunkelbeek, Director of LDEO of Columbia University, Associate Director and Head of ‘Ocean and Climate Physics’ (LDEO), Director of CERFACS, and Director of MEDIAS-France, respectively, for their constant support. This is LDEO contribution # 7144.

References


K. Hanawa, Department of Geophysics, Tohoku University, Sendai 980-8578, Japan.

T. Hasegawa, Institute of Observation Research for Global Change, JAMSTEC, Yokosuka 237-0061, Japan. (takuya.hasegawa@jamstec.go.jp)

Y. M. Tourre, MEDIAS-France, 18 avenue Edouard Belin, F-31401 Toulouse Cedex, France.

W. B. White, Scripps Institute of Oceanography, University of California, San Diego, La Jolla, CA 92039-0230, USA.