Spatial and temporal features of ENSO meridional scales

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1. Introduction

[2] The El Niño/Southern Oscillation (ENSO) is the most prominent interannual climate phenomenon owing to tropical ocean-atmosphere interaction and its basic dynamics are now largely understood [e.g., Bjerknes, 1969; Wyrtki, 1975; Cane and Zebiak, 1985; Battisti and Hirst, 1989; Jin, 1997a, 1997b; Neelin et al., 1998]. Recently, there have been increased interests in decadal variability of ENSO. A number of studies have demonstrated that ENSO displays significant changes in its amplitude, period and onset time [Wang, 1995; Trenberth and Hoar, 1996; Gu and Philander, 1997; Latif et al., 1997; Zhang et al., 1997; Knutson and Manabe, 1998; Zhang et al., 1998; An and Wang, 2000; Wang and An, 2002].

[3] Although many studies have been carried out regarding the various characteristics of ENSO, little attention has been paid to its meridional scales. During ENSO years, sea surface temperature anomalies (SSTA) at the equator, mainly associated with subsurface upwelling over the eastern equatorial Pacific, are spread away from the equator. The ENSO SSTA patterns in the meridional direction show a parabolic shape, with SSTA centered at the equator and decreasing poleward. Figure 1 presents meridional patterns of ENSO SSTA in 1950–2007 composites. The SSTA meridional scales of warm and cold episodes are different, and the meridional scales in La Niña events are obviously wider than those in El Niño events are.

2. Data and Methods

[5] The main data sets employed in this study are the Hadley Center Global Sea Ice and Sea Surface Temperature (HadISST) analysis data set (1870–2007) [Rayner et al., 2003], zonal wind stress from the European Centre for Medium Range Weather Forecasting (ECMWF) 40-year (ERA40) reanalysis data set (1958–2001) [Simmons and Gibson, 2000] and Simple Ocean Data Assimilation (SODA) data set (1958–2004) [Carton et al., 2000]. The present analyses use the oceanic and atmospheric data sets from 1950 to 2007 and wind stress and SODA data sets for the periods of 1958–2001 and 1958–2004, respectively. For testing the accuracy of the sea surface temperature (SST) data in resolving the meridional scales of ENSO, we have also examined the features of the ENSO meridional scales in extended reconstruction SST (ERSST) [Smith and Reynolds, 2004] and results from different data sets are consistent (not shown).
It should be pointed out that this measure is independent of the normalization of SSTA, whereas the normalization allows us to examine composite patterns of ENSO in terms of their meridional scales. We obtain the ENSO composites through a simple average by calendar month, considering the phase-locking nature of ENSO.

3. Some Characteristics of ENSO Meridional Scales

From the ENSO meridional patterns shown in Figures 1a and 1b, positive anomalies in the El Niño composite extend to about 10°N and near 15°S, based on a 0.2 contour. In the La Niña composite, negative anomalies extend to above 15°N and 15°S. The meridional extent of negative anomalies in the cold events is wider than that of positive anomalies in the warm events. The results are similar based on 0.4 or 0.6 contour. In spatial patterns of ENSO composites from September of year 0 to March (+1) in the 1950–2007 period for (c) El Niño and (d) La Niña events. The year 0 refers to the ENSO year in which an anomalously high SST first appeared and was amplified in the tropical Pacific, year +1 refers to the subsequent years.

Associated with positive (negative) SSTA in the eastern tropical Pacific, the Walker Circulation weakens (strengthens) with westerly (easterly) wind anomalies. Recently, many observed investigations indicated that the mean state displays significant interdecadal variability over the tropical Pacific [Gu and Philander, 1997; Zhang et al., 1997; Latif et al., 1997; Zhang et al., 1998]. For example, the mean trade winds have decreased after the late of 1970s in both ENSO warm and cold events (Figure 2). To relate this changes in mean trade wind stress with ENSO meridional scale, we plotted in Figure 2 the zonal wind stress averaged over the region of 5°S–5°N, 180°–90°W as a function of the ENSO widths. From the monthly scatter diagram, there is a weak negative correlation (−0.34) between ENSO widths and zonal wind stress, which is statistically significant at the 0.01 confidence level. This correlation indicates that stronger zonal wind stress tends to favor the occurrence of wider meridional scales.
Saravanan and = 0 indicates the region within about 3°
V = (\hat{Z}H) indicates the intrinsic damping coefficient. This equation is
is only a function of the meridional currents
\hat{A}e^{\omega t}, \quad (3)
where \omega is the frequency, and \hat{T}(y) denotes the SSTA
meridional pattern. The boundary condition is:
\frac{\hat{T}(y)}{A} = e^{-1} \int_{-\infty}^{y} \frac{\omega}{\omega + \alpha} dy. \quad (4)
For simplicity, we consider a steady SSTA (\omega = 0) and a
constant damping coefficient, such that the meridional
pattern \hat{T}(y)/A is only a function of the meridional currents
V(y). Over the eastern equatorial Pacific, meridional
currents V(y) are closely related to the equatorial upwelling.
Therefore, strong (weak) upwelling and meridional currents
correspond to large (small) SSTA meridional scales.

[12] The mechanism can be used to understand the
meridional scale asymmetry for El Niño and La Niña phases
of ENSO cycle. During El Niño (La Niña) phase, weakened
(strengthened) trade winds can lead to weak (strong) up-
welling and meridional currents. As shown in Figure 4a, the
meridional currents in La Niña events are stronger than
those in El Niño events over the equatorial Pacific, especially
at the region south of the equator. Following equation (4),
the meridional scales during La Niña events would be
wider than those during El Niño events, as shown in
Figures 1 and 2. Furthermore, the anomalous meridional
heat transport in La Niña events is stronger than that in El
Niño events. In southern equatorial Pacific (Figure 4b), the
anomalous meridional heat transport during La Niña years
is more than twice as much during El Niño years.
In comparison with El Niño events, the meridional spread of
La Niña SSTA away from the eastern equatorial belt is
larger.

[13] The Walker Circulation has been weakening since the
late half of the 20th century in the tropical Pacific
[Tanaka et al., 2004; Vecchi et al., 2006; Power and Smith,
2007]. Concurrently, the upwelling decreased by about 25%
in an equatorial strip between 9°N and 9°S in the period
1950–1999 [McPhaden and Zhang, 2002]. As a result, the
meridional scales of ENSO warm and cold events are both
getting narrower (Figures 2 and 3).

5. Concluding Remarks

[14] The meridional structure of El Niño events differ
from that of La Niña events. Over the central and eastern
equatorial Pacific, the meridional currents increase (de-
Figure 3. Time-latitude diagram of zonal mean (180°–90°W) 2–7-year band-pass filtered SSTA for (top) El Niño and (bottom) La Niña composites for (left) 1950–1976 and (right) 1977–2007.

Figure 4. (a) The zonal mean (180°–90°W) surface meridional currents (cm/s) and (b) anomalous surface meridional heat transport (10^2 s^-1) during ENSO years. The surface meridional heat transport of Figure 4b is through the advection of SSTA by mean meridional flows. The solid (dashed) lines denote the average from September (0) to February (+1) of El Niño (La Nina) composites. The La Nina values in Figure 4b are reversed. The data used here is from Simple Ocean Data Assimilation (SODA) reanalysis (1958–2004).
crease) during La Niña (El Niño) years, associated with the strong (weak) upwelling induced by strong (weak) trade winds. Thus, the La Niña meridional scales are significantly wider than El Niño’s, because SSTA over the equator can be transported further to the off-equatorial regions during La Niña years than El Niño years. In recent decades, the Walker Circulation has exhibited a weakening tendency, with anomalous westerly winds over the equator. This causes the mean meridional currents to decrease, with weak upwelling over the central/eastern equator. Hence, the SSTA meridional scales of El Niño and La Niña events both are reduced in the post-1976 period.

[15] Different meridional patterns of ENSO SSTA may affect tropical and extratropical atmospheric circulations through air-sea interaction and atmospheric teleconnection. Through observational analyses and modeling, our ongoing work shows that the anomalous atmospheric circulations are different in different ENSO meridional patterns for both ENSO warm and cold events. These results will be reported in a forthcoming paper.

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References


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