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El Niño Tropical Pacific Ocean surface current and temperature evolution in 2002 and outlook for early 2003

Gary S. E. Lagerloef,[1] Roger Lukas,[2] Fabrice Bonjean,[1] John T. Gunn,[1] Gary T. Mitchum,[3]
Mark Bourassa,[4] and Antonio J. Busalacchi[5]

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[1] The timing and magnitude of the 2002–2003 El Niño/Southern Oscillation (ENSO) warm episode has been monitored for the first time with near real time satellite-derived surface current (SC) fields in addition to the operational temperature, wind and sea level satellite and in situ measurements previously used. The record of the past decade shows that dominant SC anomalies generally lead ENSO sea surface temperature (SST) anomalies by 2.5–3 months, and that a rapid SC anomaly reversal has coincided with the peak SST of warm events. During September to December 2002, SST anomalies increased and spread eastward in conjunction with strong, sustained eastward SC anomalies that began in July. The SC anomaly peaked in early October, followed by a sharp decrease in November and December to negative values in January. This was much like the SC sequence during the same months of the 1997–1998 El Niño when the SST anomaly peaked in December 1997. The recent SST anomalies were maximum in November 2002 and declined thereafter. These SC and SST trends signify that the present warm event has peaked and SST anomalies will continue to decline in early 2003. *INDEX TERMS:* 4522 Oceanography: Physical: El Niño; 4512 Oceanography: Physical: Currents; 4231 Oceanography: General: Equatorial oceanography; 4215 Oceanography: General: Climate and interannual variability (3309). **Citation:** Lagerloef, G. S. E., R. Lukas, F. Bonjean, J. T. Gunn, G. T. Mitchum, M. Bourassa, and A. J. Busalacchi, El Niño Tropical Pacific Ocean surface current and temperature evolution in 2002 and outlook for early 2003, *Geophys. Res. Lett.*, *30*(10), 1514, doi:10.1029/2003GL017096, 2003.

1. Introduction

[2] The oceanic and atmospheric conditions related to ENSO are closely monitored through an extensive in situ and satellite-based observing network [e.g. *McPhaden*, 1999; *Picaut et al.*, 2002]. The present El Niño became manifest in June 2002 when the sea surface temperature (SST) throughout the central equatorial Pacific had increased to 1°C or more above normal [*Kousky*, 2002a]. SST anomalies continued to increase to about 2°C later in the year. Forecasters succeeded in predicting the onset about six months in advance [*Kerr*, 2002]. As the event evolved, the SST anomaly growth was consistent with the light to moderate El Niño conditions generally forecasted one or two seasons in advance by some climate prediction models. Predictions for the previous El Niño onset timing were similar during 1997, but that event's very large magnitude was grossly underestimated [*Landsea and Knaff*, 2000]. Furthermore, the previous warm event ended with a sudden and rapid cooling of equatorial SST in May 1998 that was not anticipated [*McPhaden*, 1999]. The ensemble of climate prediction models now indicates that the present warm episode conditions will probably persist through 2002–2003 boreal winter and spring, and some models indicate that SST anomalies will decrease over this time [*Kousky*, 2002b]. Here, we present an equatorial ocean surface current (SC) and SST analysis indicating that the 2002–2003 El Niño reached a peak by early December 2002 and is now in decline.

[3] Tropical Pacific SC fields are computed in near real time (less than 2 week delay from satellite measurement) from basic dynamical equations with satellite observed sea level, wind and SST fields [*Bonjean and Lagerloef*, 2002; *Lagerloef et al.*, 1999]. The velocities are validated with drifting buoy and moored current meter measurements, and can be viewed on the Internet at www.oscar.noaa.gov. The continuous record begins in late 1992 with the availability of sea level measurements from the TOPEX/Poseidon satellite altimeter mission and subsequently from mid-2002 to the present with the Jason-1 altimeter data. Vector wind measurements are from the NASA QuikScat scatterometer mission after it became operational in 1999 [*Draper and Long*, 2002], and from the *Atlas et al.* [1996] variational analysis earlier. Satellite SST fields are continuous and produced operationally by the National Oceanic and Atmospheric Administration [*Reynolds and Smith* 1994].

[4] In this note, we identify the dominant ENSO SC variability and its leading phase relationship to SST of the past decade. We portray how the SC and SST fields co-evolved during the 2002 El Niño event, and describe the abrupt SC anomaly changes in recent months that give strong evidence for a peak of the El Niño SST in the last months of 2002. The added information from SC anomalies forms the basis for an outlook that SST anomalies will decline significantly over the coming months.

2. The Relationship Between SC and SST Anomalies Over the Past Decade

[5] The interannual SC variations have a very strong ENSO signal as seen in the principal empirical orthogonal

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[1] Earth and Space Research, Seattle, Washington, USA.

[2] Department of Oceanography, University of Hawaii, Honolulu, Hawaii, USA.

[3] Department of Marine Science, University of South Florida, St. Petersburg, Florida, USA.

[4] Center for Ocean Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, USA.

[5] Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, Maryland, USA.

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function (EOF) in Figure 1. Eastward equatorial current anomalies (difference from an average annual cycle) occur across the Pacific basin during warm events, and reverse during cold events. The principal SST anomaly EOF, also shown in Figure 1, helps illustrate certain key relationships of the SC and SST variations during ENSO. The signals are very coherent, yet with a distinct phase difference. SC anomalies consistently tended to rise, peak and fall ahead of SST. The lagged correlations indicate an average lead time of 2.5 to 3 months. For the warm events of 1993, 1994–1995 and 1997–1998, a rapid reversal of the SC anomaly coincided with the peak SST anomaly. The SC maxima are located along the equator and are strongest in the west-central basin between longitudes 150°E and 160°W, whereas the maximum equatorial SST anomalies are in the eastern half of the basin. This indicates a spatio-temporal phasing where the maximum eastward low frequency SCs in the western half of the equatorial Pacific basin lead the associated SST anomaly maxima in the eastern half. Also, during the 1994 and 1997 El Niño events, the relative SC anomaly magnitude (in standard deviations) was comparable to that of SST. This proportionality and phasing underscore the important role of horizontal advection in the surface heat budget [cf. *Picaut et al.*, 2002; *Jin and An*, 1999; *Cronin and McPhaden*, 1997].

[6] SC anomalies reversed rapidly as the previous El Niño peaked in late 1997, reached a minimum in mid-1998. Both SC and SST EOFs have since maintained a gradual increasing trend superimposed on shorter episodic fluctuations. The residual near annual periodicity during 1999–2001 in the SC anomaly EOF, and less prominently in the SST anomaly, appears because the annual cycle was stronger after the 1997 peak than before. Aside from this, the SC anomaly EOF was negative on average from 1998 through 2000. SST anomalies declined more slowly than SC in 1998. The period of negative SST anomalies that remained into 2001 constitutes the recent cold (La Niña) episode.

[7] The SST anomaly EOF rose gradually from early 2000 and became positive by mid-2002, signifying the present El Niño onset, and continued to rise until late in the year. In contrast, the SC anomaly EOF exhibited major fluctuations during the past two years. It became positive for the first half of 2001, leading some of these authors to speculate publicly that a warm event onset was imminent in 2001. However, the SC anomaly reversed mid-year and SST anomalies remained negative. SC then rose sharply at the end of 2001, which preceded an SST anomaly jump in early 2002 that eventually ushered in the warm event by June 2002. The SC anomaly EOF fell sharply in the spring, rose sharply mid year to an autumn peak followed by increasing SST. SC anomalies declined again through December 2002, reaching negative values in early January 2003.

3. Monthly SC and SST Anomaly Sequences During 2002

[8] The correspondence between SC and SST anomaly development during 2002 is illustrated further in Figure 2. In June, positive SST anomalies appeared along the equator across most of the basin, coincident with the announcement that the El Niño had started, as noted above. Positive SC anomalies then grew steadily during July, August and September, reaching a peak in October at about 70% of the 1997 peak (Figure 1). Simultaneously, the SST anomalies intensified and spread eastward reaching a peak in November. The SC anomaly growth during the year was associated with a persistent series of intra seasonal oscillations (ISOs, or MJOs after *Madden and Julian*, 1994), bringing westerly wind events (not shown) that excited a progression of eastward propagating Kelvin waves typically associated with El Niño onset [e.g. *Kessler et al.*, 1995]. On average, the SC anomalies declined considerably during November and December 2002, as reflected in the abrupt downward trend of the EOF time series (Figure 1). SST anomalies decreased in late December and January, especially in the eastern portion.

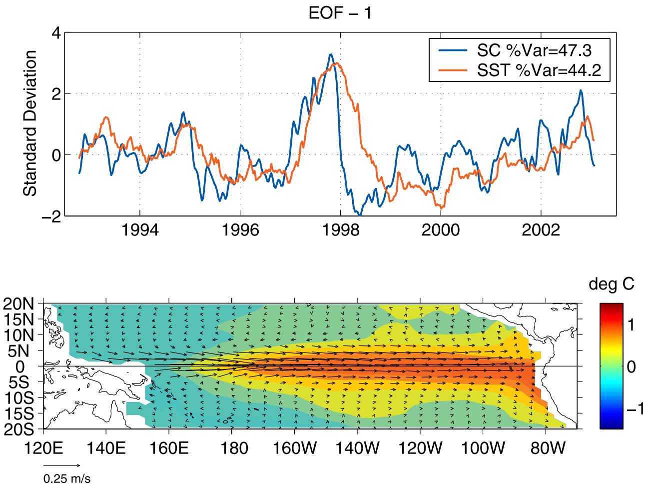

Figure 1. The first EOF mode of SC and SST anomalies for the period 1 January 1993 through 10 January 2003. Top panel shows the amplitude time series normalized by their respective standard deviations. Bottom panel shows the corresponding EOF maps scaled accordingly for SC (vectors) and SST (color).

4. El Niño Peak in Late 2002 and an Outlook for Early 2003

[9] The Niño 3 and Niño 3.4 SST index records are shown in Figure 3 over an 18-month period starting January 2002 and 1997 to compare the progression of the present and previous warm events. The 1997–1998 indices peaked in December and declined steadily for the next six months. The maxima in 2002 appeared about a month earlier and show the start of a negative trend in December, particularly in the Niño 3 index farther to the east. The 1997 and 2002 SC peaks came around mid October, followed by a decrease to less than zero in January (Figure 3). As noted above, SC EOF reversals coincided closely with the peak SST during the previous warm events of the past decade (Figure 1). In 1998, the negative SC trend continued for another four to five months, followed by the negative SST trend. A similar negative SC trend is anticipated into 2003 and suggests an SST anomaly decline similar to that in 1998.

5. Discussion and Conclusions

[10] The important new diagnostic information provided by the SC anomalies is their leading relationship relative to

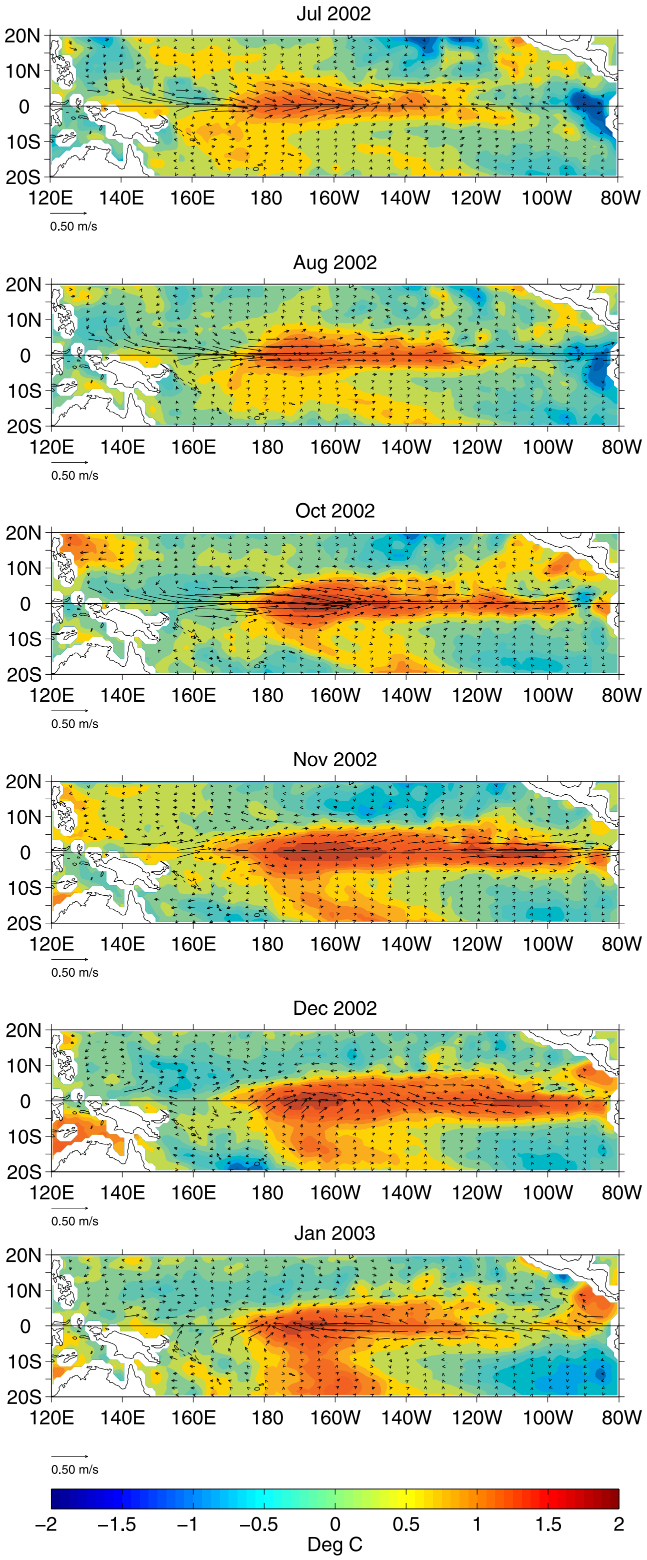

Figure 2. The progression of monthly mean SC (vectors) and SST (color) anomalies during the latter half of 2002 and January 2003.

SST. A rapid sign reversal from positive to negative is shown to coincide, within a month or so, of the peak SST during an El Niño. This is followed by a negative SST trend and appearance of negative SST anomalies a few months later. This diagnostic indicator appears to be somewhat more reliable for identifying the end of an El Niño event than for identifying the onset, at least for the past decade. Several reversals from negative to positive SC anomalies since 1999 have coincided with SST minima (Figure 1), but a positive El Niño SST anomaly did not materialize until mid 2002. Nonetheless, SC anomalies clearly contributed to the eastward migration and expansion of the west Pacific warm pool as the event unfolded, also indicated by the 28.5°C isotherm eastward longitude displacement (not shown), which previous studies have shown to be influenced by horizontal advection [*Picaut et al.*, 2001].

[11] Certainly, the negative SST trend could be interrupted by the return of strong positive SC anomalies during the next several months. This may occur if the ISO activity remains high and brings additional strong westerly wind events to the western equatorial Pacific. The latest of these in early January 2003 has not proven to be very strong and SC anomalies have grown negative. Other signs also indicate that the El Niño is in decline. Negative SSH anomalies appeared in the far west Pacific (Figure 3) after the peak of the positive SC surge in October 2002. This

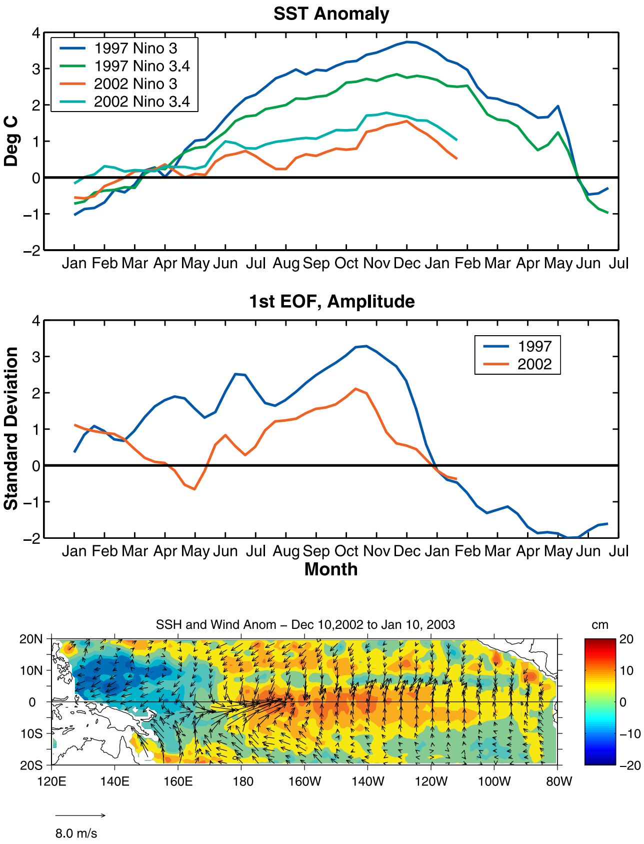

Figure 3. Compared progressions of the 1997–1998 and 2002–2003 (to date) El Niño events. The abscissa indicates the month starting in 1997 or 2002. Top panel: SST anomalies in the Niño 3 and Niño 3.4 index regions [the area average between 5°N and 5°S in longitude zones 150°W–90°W (Niño 3) and 170°W–120°W (Niño 3.4)]. Middle panel: SC EOF-1 time series (from Figure 1). Bottom Panel: Superimposed SSH (color) and wind (vector) anomaly maps for the period 10 December 2002 to 10 January 2003.

indicates that the excess warm pool heat storage anomaly that precedes El Niño has been fully discharged, and that the cycle is in the mature phase leading to warm-cold transition [*Jin and An*, 1999]. Although positive SSH anomalies remain between the date line and 110°W, they are associated with residual upper ocean heating of the lingering warm state of the El Niño. The resultant zonal SSH gradient favors westward (negative) zonal SC anomaly development in the western region upon the relaxation of positive wind anomaly [*Jin and An*, 1999, equation 4]. The far-western negative equatorial wind anomalies (Figure 3) are associated with the establishment of an anomalous anticyclone in the Philippine Sea. As described by *Wang et al.* [2001], this occurs in phase with the peaking of Niño 3 SST. These easterly wind anomalies cause the thermocline to shoal in the central and eastern Pacific as Kelvin waves carry the signal eastward. That signal is brought to the surface when the trades intensify as the end of the eastern Pacific warm season (April). Lastly, *Harrison and Vecchi* [1999] showed that a late year southward displacement of west Pacific positive zonal wind anomalies portends the El Niño termination by a few months. Such a displacement is evident in the 10 December to 10 January averaged surface wind anomaly pattern (Figure 3).

[12] One further observation from the EOF time series (Figure 1) pertains to the greater offset between the SST and SC anomalies that appeared after the 1997–1998 El Niño. The cause has not yet been analyzed. However, one can observe from the data record (not shown) that there was a noticeable westward displacement of the trade winds and SST anomalies from the east to central Pacific after the 1997–1998 event. Given that this period covers half of the decade studied here, it is reasonable to expect some statistical differences between the years before and after such a change. This westward shift appears to have affected the nature of this El Niño as well. SST anomalies were concentrated in the central Pacific throughout the event, rather than emerging near the South American coast as they often do. In fact, SST anomalies in the eastern boundary remained quite weak and intermittent throughout this episode (Figure 2). Such indicators signify a superposition and modification of the 2002–2003 El Niño by significant longer term ocean and atmosphere climatic variations in the tropics.

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F. Bonjean, J. T. Gunn, and G. S. E. Lagerloef, Earth and Space Research, 1910 Fairview Av E, Seattle, WA 98102, USA. (bonjean@esr.org; gunn@esr.org; lager@esr.org)

M. Bourassa, Center for Ocean Atmospheric Prediction Studies, Florida State University, Tallahassee, FL 32306-2840, USA. (bourassa@coaps.fsu.edu)

A. J. Busalacchi, Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, MD 20742-2425, USA. (tonyb@essic.umd.edu)

R. Lukas, Department of Oceanography, MSB 312, University of Hawaii/JIMAR, Honolulu, HI 96822, USA. (rlukas@hawaii.edu)

G. T. Mitchum, Department of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA. (mitchum@marine.usf.edu)