Application of Altimetry Measurements to Modeling and Observational Studies of Tropical Ocean Variability

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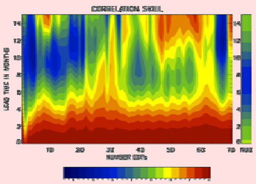
Introduction

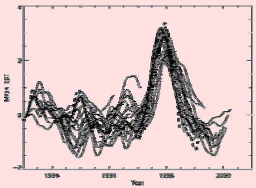
Improved understanding and prediction of seasonal to interannual climate variability is a priority of the WCRP CLIVAR Program (Climate Variability and Predictability), the US Global Change Research Program, and the climate programs of France and many countries around the world. In support of this priority, NASA and CNES are poised to develop and use remotely-sensed and in situ observations to monitor, describe, and understand seasonal-to-interannual variability, with the aim of developing and improving the capability to predict socio-economically important climate system events on these times scales. The unique role that CNES and NASA can play in this regard is to provide the satellite observations, and together with in situ observations from their sister agencies NOAA and IRD, use these data to improve the scientific understanding, monitoring, and forecasting of seasonal to interannual climate anomalies such as El Niño. The primary reason that order one-year lead times can be envisaged for the forecasts of El Niño is because the thermal inertia of the coupled climate system rests within the upper ocean and has a relatively slow time scale compared to the atmosphere. In view of the importance of sea level measurements in the context of the two-layer approximation that holds at low latitudes and the large expanse of the tropical Pacific Ocean, studies of the interannual variability of the tropical Pacific Ocean, and the other tropical oceans for that matter, are extremely well suited for the utilization of satellite altimeter data.

Summary of Projects

Activities of the past year include analysis of the mechanisms of the 1997-1998 El Niño-La Niña as inferred from space-based observations. Complementary studies included altimeter data as a basis for determining the optimal wind data for forcing ocean model based process studies of this event. Kalman filter work has proceeded in coupled and stand-alone tropical ocean models. The combined use of sea level, sea surface temperature, and wind stress has been assessed for their impact on El Niño prediction via the application of a reduced order Kalman filter in a coupled atmosphere-ocean model. Unlike most assimilation strategies the present approach recognizes that we are dealing with a coupled system and assimilates space-based observations in a coupled manner. Related Kalman Filter work follows the same multivariate approach, but within the context of an uncoupled tropical Pacific Ocean model. In the Atlantic Ocean, the relationship between zonal and meridional modes of subsurface thermal structure and sea level on interannual to decadal time scales has been examined. Lastly, remotely-sensed biological production in the tropical Pacific has been estimated from 1992-1999 using altimeter data, TAO buoy observations, and in situ measurements of biological new production.

Application of a Reduced Order Kalman Filter to Initialize a Coupled Atmosphere-Ocean Model: Impact on the Prediction of El Niño

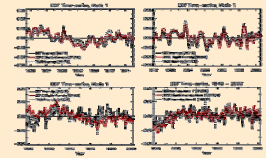


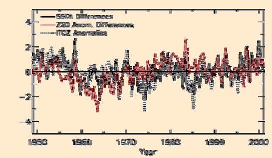


An ENSO prediction model is initialized by assimilating observed sea surface temperature, sea level, and a surface wind stress into the coupled ocean-atmosphere model of Zebiak and Cane. Ocean and atmosphere observations are simultaneously assimilated into the coupled model by using a reduced order Kalman filter. The assimilation scheme is based on the projection of the analysis equations of the Kalman filter onto the multivariate EOFs of a long-run of the model. Figure above left shows the prediction skill of the Nino-3 index as a function of the number of used EOFs and the length of the prediction lag. The results indicate that 3 modes are enough to reconstruct the signal. The skill of 6 month predictions increases rapidly and saturates when 10 modes are used. More modes are needed to increase the skill of longer predictions, but there is no discernible pattern. The method provided states of the equatorial Pacific Ocean predicting the 1997-98 warm event 15 months before its onset (above right).

Ballabrera, J., A.J. Busalacchi, and R. Murtugudde, Application of a Reduced-Order Kalman Filter to Initialize a Coupled Atmosphere-Ocean Model: Impact on El El Niño, J. of Climate, 14, 1720-1737, 2001.

Relationship Between Zonal and Meridional Modes in the Tropical Atlantic

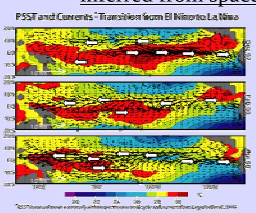


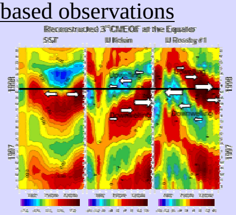


The tropical Atlantic displays two main modes of variability; the meridional or dipole mode and the equatorial zonal mode. It was proposed recently that these two modes are correlated and are both forced within the tropics by latitudinal displacements of the ITCZ. This modeling study shows that while the two modes are correlated for limited record lengths prior to and after 1976, the correlation falls apart when longer time-series from 1949 to 2000 are considered (see top left). The 1976 "climate shift" also occurred in the tropical Atlantic seen as a thermocline shift similar to the Pacific, forced dynamically within the tropics. The first EOF of the simulated thermocline depth captures the interdecadal mode with the 1976 shift. The first EOF of SST anomalies prior to (after) 1976 represents the meridional (zonal) mode, consistent with the previous finding that the relation between the eastern Pacific and Atlantic ITCZ is stronger in the 1980-90's (see top right).

Murtugudde, R., J.Ballabrera, J. Beauchamp, and A.J. Busalacchi, Relationship between zonal and meridional modes in the tropical Atlantic,G. Res. Let., 28, 4463-4466,2001.

Mechanisms of the 1997-1998 El Niño/La Niña, as inferred from space-based observations

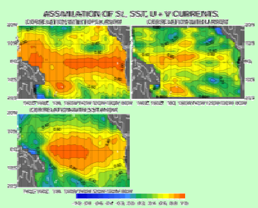


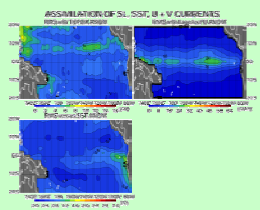


The intensity of the 1997 El Niño and the 8°C sudden drop in SST around 0°-130°W during the turn into La Niña in 1998 were observed from start to finish with a comprehensive set of remotely-sensed and *in situ* observations. In this study, we employ space-based observations to capture the preconditioning, onset, evolution and decay of the 1997 El Niño and its transition into the 1998 La Niña. The demise of El Niño and its turn into La Niña in spring 1998, were due to the arrival in the east of upwelling which was brought from the west by favorable off-equatorial wind stress curl, and equatorial Kelvin waves generated by easterly winds and wave reflection on the western ocean boundary. Additional upwelling was brought from the east by equatorial Rossby waves generated by westerly winds. These various upwelling signals were added to the general uplifting of the thermocline, due to the slow discharge of the upper layer of the equatorial basin by diverging surface currents (above left). A series of equatorial Kelvin and Rossby waves characterized by upwelling and opposite surface currents, led to the break-up of the warm waters, the surfacing of the thermocline and the drastic drop in SST in May 1998 around 0°-130°W. This is best shown by complex multivariate analysis of the components of geostrophic currents derived from TOPEX and SST (above right).

Picaut, J., E.C. Hackert, A.J. Busalacchi, R. Murtugudde and G.S.E. Lagerloef, Mechanisms of the 1997-1998 El Niño-La Niña, as inferred from space-based observations, J. Geophys. Res., 107, 2002.
Hackert, E.C., A.J. Busalacchi and R. Murtugudde, A wind comparison study using an ocean general circulation model for the 1997-1998El Niño, J. Geophys. Res, 106, 2345-2362, 2001.

Multivariate Assimilation of Sea Level, SST and Currents for the Tropical Pacific

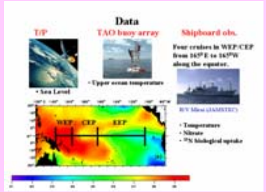


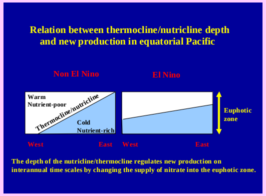


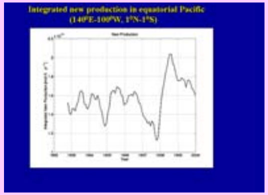
Over the past number of years great strides have been made in the field of ocean data assimilation. New data types such as those provided by the extended altimetry missions (e.g. TOPEX/Poseidon and Jason 1) now provide ocean modelers with enough high-quality data to allow data assimilation on basin-wide scales. In this study, a Reduced Order Kalman Filter (ROKF) approach is used to assimilate various data types into a general circulation model of the tropical Pacific Ocean. The ocean model is a high-resolution, reduced gravity, primitive equation, sigma-coordinate model with variable depth oceanic mixed layer (Gent and Cane, 1989). Consistent with previous studies, the assimilation data include sea surface height (SL) from the TOPEX/Poseidon altimeter and sea surface temperature (SST) analyses from satellite and in situ observations. In addition, this study now incorporates fields of surface currents (U+V) derived from SL and wind stress by combining the geostrophic approximation and Ekman dynamics (Bonjean and Lagerloef, 2001). The impact of using a multivariate approach is demonstrated by correlation (above left) and RMS (above right) between model which assimilates all data versus observed quantities.

Hackert, E.C., J.Ballabrera, A.J. Busalacchi, L.Gourdeau, Multivariate assimilation of sea level, SST and currents for the tropical Pacific, in preparation.

Remotely Sensed Biological Production in the Equatorial Pacific







A combination of ship, buoy, and satellite altimeter observations in the tropical Pacific during the period from 1992 to 2000 provides a basin-scale perspective on the net effects of El Niño and La Niña on biogeochemical cycles. New biological production during the 1997-99 El Niño/La Niña period varied by more than a factor of 2. The resulting interannual changes in global carbon sequestration associated with the El Niño/La Niña cycle contributed to the largest known natural perturbation of the global carbon cycle over these time scales.

Turk,D., M.J. McPhaden, A.J. Busalacchi, and M.R. Lewis, Remotely sensed Biological Production in the Equatorial Pacific, Science, 293, 471-474,2001.