Abstracts

Invited

Mat COLLINS, and the CMIP modeling groups: El Niño or La Niña-like climate change?

Thierry CORREGE: The potential of massive corals to study low frequency tropical climate variability

Alexey V. FEDOROV: The effect of salinity on the wind driven oceanic circulation, or can global warming induce a permanent El Niño

Georg HOFFMANN: Decadal variability of the tropical hydrological cycle reconstructed by Andean ice core records

Mojib LATIF, K. LOHMANN, and P. WETZEL: The dynamics of the shallow subtropical cells: Implications for global climate and ocean biogeochemistry

Julian P. McCREARY: Pacific and ENSO decadal variability: Theories as to their cause.

Michael J. McPHADEN, and D. ZHANG: Circulation changes linked to ENSO-like Pacific decadal variability

Vikram M. METHA, and C. FAYOS: Decadal-multidecadal variations in ENSO and their impacts on global climate

Luc ORTLIEB: Reconstructing ENSO occurrences in the last few centuries: what is new after Bill Quinn's precursory work in western South-America?

Niklas SCHNEIDER: North Pacific Decadal Variability

Axel TIMMERMANN et al.: A non-linear theory for El Niño bursting

Yves TOURRE: QBO, interannual, and QDO signals in the Pacific

Contributed

Carole CIBOT, L. TERRAY, and B. DEWITTE: A model study of decadal variability in the tropical Pacific

Eric GUILYARDI, S. GUALDI, and J. SLINGO: Representing El Niño in coupled ocean-atmosphere GCMs: the dominant role of the atmosphere

Wilco HAZELEGER et al.: How can heat transport in the tropical Pacific vary?

Fei-Fei JIN et al.: Tropical mechanisms of Pacific decadal climate variability

Anne JUILLET-LECLERC: The interpretation of geophysical data from coral skeleton need to be revisited

Alicia KARSPEC, R. SEAGER, and M. CANE: Predictability of tropical Pacific decadal climate shifts: a view from a tropical model

Julie LELOUP, and J.-P. BOULANGER: Observed twentieth-century climate variability in the tropical Pacific

Andy MOORE, *et al.*: Stochastic forcing of ENSO - A null hypothesis for low-frequency variability?

Keith RODGERS, P. FRIEDERICHS, and M. LATIF: Tropical Pacific decadal variability

Paul S. SCHOPF and B. BURGMAN: The self regulation of ENSO

Bin WANG, and S.-I. AN: Why the properties of ENSO changed during the late 1970s: roles of the decadal shift in the background winds

Ron-Hua ZHANG, and A. J. BUSALACCHI: Changes in properties of El Niño in an intermediate coupled model: sensitivity to subsurface entrainment temperature parameterization

Posters

Rodrigo ABERCA DEL RIO: Comparative analyses of ENSO indexes over the last half millenia

Gaël ALORY et al.: Long-term trends and decadal variability in a forced OGCM in the tropical Pacific

Xavier BAILLARD, A. GANACHAUD, and B. DEWITTE: An assimilation system with Green's functions for ENSO forecast

Thierry DELCROIX: Can we detect decadal sea surface salinity changes in the western Pacific in using historical data?

Yosuke FUJII, S. ISHIZAKI, and M. KAMACHI: Three dimensional analysis of temperature and salinity in the equatorial Pacific using a variational method with vertical coupled temperature-salinity EOF modes

Carmen GRADOS et al.: Structure of the ENSO in the northern boundary of the Humboldt current system

Kathy HILL and K. RICHARDS: The CLIVAR Pacific implementation panel: focus and progress

Takeshi IZUMO and J. PICAUT: Study of the equatorial undercurrent using TAO data moored data over 1980-2002, and of its link with STCs in a model over 1951-1999 in the equatorial Pacific

Jurgen KROEGER, A. BUSALACCHI, and J. BALLABRERA: Decadal STC and equatorial SST variability in a numerical model of the Atlantic

Dimitry SONECHKIN and R. BROJEWSKI: ENSO: a quasiperiodic forced dynamical system

Thomas TONIAZZO: Change in ENSO in a greenhouse-warmed climate

Guomin WANG et al.: POAMA: an Australian ocean atmosphere model for climate prediction

Richard WASHINGTON, M. SWANN, and M. NEW: Multidecadal variability of ENSO: signatures over the Indian Ocean and Africa

EL NIÑO OR LA NIÑA-LIKE CLIMATE CHANGE?

Mat Collins and the CMIP Modeling Groups[2]

Centre for Global Atmospheric Modelling, Department of Meteorology, University of Reading, Reading, RG6 6BB, UK
Hadley Centre for Climate Prediction and Research, Met Office, London Road, Bracknell, UK
matcollins@met.rdg.ac.uk
[2]BMRC (Australia), CCC (Canada), CCSR/NIES (Japan), CERFACS (France), CSIRO (Australia), MPI (Germany), GFDL (USA), GISS (USA), IAP (China), INM (Russia), LMD (France), MRI (Japan), NCAR (USA), NRL (USA), Hadley Centre (UK) and YNU (South Korea).

The belief that the mean climate of the tropical Pacific will shift to more El Niño-like conditions (with corresponding global impacts) as a result of human induced climate change is subject to a considerable degree of uncertainty due to the wide range of responses of different atmosphere-ocean global circulation models (AOGCMs) and the lack of realism of the present day ENSO cycle in those models. By projecting the future pattern of tropical Pacific climate change onto the present day pattern of ENSO variability in 20 AOGCMs submitted to the Coupled Model Inter-comparison Project (CMIP), it is shown that large-scale coupled atmosphere-ocean feedbacks associated with ENSO do operate on longer time scales and can limit the range of response of models, narrowing the current levels of uncertainty. By linking the realism of the simulation of present day variability in the models to their patterns of future mean El Niño-like or La Niña-like climate change, it is found that those models that have the most extreme response also have the poorest ENSO variability and are thus down-weighted in the histogram of future possible states. The most likely scenario ($p=0.59$) is for no trend towards either mean El Niño or La Niña –like conditions, contrary to the widely held view. However, there remains a small probability ($p=0.16$) for a change to El Niño-like conditions of the order of 1 standard El Niño per century in the 1%/year CMIP scenario which, if it occurred, would have a considerable impacts on global climate and society.

THE POTENTIAL OF MASSIVE CORALS TO STUDY LOW FREQUENCY TROPICAL CLIMATE VARIABILITY

Thierry Corrège

IRD, BPA5, Noumea, New Caledonia
thierry.correge@noumea.ird.nc

One of the major drawbacks in low frequency climate study is the lack of long instrumental series. In the marine environment, massive corals can live up to a millennium, and the chemical composition of their skeleton can provide us with long records of past environmental parameters. The coupling of several tracers (Sr/Ca, and to a lesser extent, U/Ca and Mg/Ca for SST; $\delta^{18}O$ for SST and the hydrological cycle) is now a powerful tool to reconstruct past SST, and potentially past SSS. Live, as well as fossil corals retrieved from drill cores, are used to generate multi-century series representative of variable background conditions. The documentation of the way low frequency climate modulation has evolved through time and how it has been affected by background conditions is important to better constrain numerical climate models.

Although we still need to better understand how tracers are incorporated in coral skeletons, there is a growing body of work that suggests that Sr/Ca is a robust proxy for SST, and that its coupling with $\delta^{18}O$ can give relevant information on the variability of the hydrological cycle. Work is in progress to improve our knowledge of the relationship between surface water $\delta^{18}O$, salinity and the P/E balance in the tropical Pacific Ocean, in order to develop a paleosalinometer in corals.

Multi-century long records generated from tropical Pacific corals have been published in the past 10 years. Most records are based on the sole tracer $\delta^{18}O$, which is affected by both SST and the $\delta^{18}O$ of seawater (linked to the hydrological cycle). However, in the past few years, some long Sr/Ca records have been published, and coupled Sr/Ca - $\delta^{18}O$ records are now the standard towards which coral workers should strive. Those coupled studies provide the necessary tools to decipher the relative part of the ocean and the atmosphere in the low frequency modulation of tropical climate.

The increasing quality and quantity of coral data make it now possible to work on their assimilation in numerical models of intermediate complexity.

THE EFFECT OF SALINITY ON THE WIND-DRIVEN OCEANIC CIRCULATION OR CAN GLOBAL WARMING INDUCE A PERMANENT EL NIÑO?

Alexey Fedorov

Atmospheric and Oceanic Sciences, Princeton University, Princeton, USA
alexey@princeton.edu

A rapid climate change in response to the current rise in the atmospheric concentration of greenhouse gases is a matter of considerable concern. Thus far attention has focused almost entirely on changes associated with the deep thermohaline circulation (THC). Numerous studies have investigated the effect of a freshening of the surface waters in high latitudes on THC and its poleward heat transport, including the THC collapse. Here we demonstrate, by means of idealized general circulation models, that a similar freshening can also affect the shallow, wind-driven circulation of the ventilated thermocline and its heat transport from regions of gain (mainly in the upwelling zones of low latitudes) to regions of loss in higher latitudes. A freshening that decreases the surface density gradient between low and high latitudes also reduces this poleward heat transport, thus forcing the ocean to gain less heat in order to maintain a balanced heat budget. The result is a deepening of the equatorial thermocline. (The deeper the thermocline in equatorial upwelling zones is, the less heat the ocean gains.) As the freshwater forcing approaches a critical value, several aspects of the wind-driven circulation change radically: the heat budget becomes balanced locally everywhere, the horizontal heat transport in the ocean all but vanishes, the equatorial thermocline becomes horizontal, and permanent El Niño-like conditions prevail in the tropics. Paleo data indicate that this may have happened before - there was no SST gradient along the equator in the Pacific ocean until approximately three million years ago. Since the processes involving the circulation of the ventilated thermocline can occur relatively fast, on the order of a few decades, a return to perennial El Niño conditions can occur rapidly, given a fresh water forcing of sufficiently large amplitude. Whether such a forcing affects mainly the thermohaline or the ventilated thermocline circulation is a matter that remains to be investigated.

DECADAL VARIABILITY OF THE TROPICAL HYDOLOGICAL CYCLE RECONSTRUCTED BY ANDEAN ICE CORE RECORDS

Georg Hoffmann

LSCE, Orme des Merisiers, Gif sur Yvette, France
Hoffmann@lsce.saclay.cea.fr

Direct observations of decadal variability in the tropics are rare for the beginning of the last century. This statement holds even for near surface temperatures which is certainly the best-monitored quantity in the climate system. But it is even more true for any observations of the hydrological cycle. Paleo-observations offer an intriguing opportunity to reconstruct shifts and changes of the hydrological cycle and to speculate on its role as a feedback mechanism in the coupled tropical climate system. Here I present results from a number of ice core drilling expeditions in the Andes which have been performed by the IRD/LSCE (France) and the Paul-Scherrer institute (Switzerland). The drilling sites are situated, from North to the South, on Chimborazo (0.5°C, Equador), Illimani (17°S, Bolivia) and Sajama (19°S, Bolivia) and results were compared with formerly analysed ice cores from Quelccaya (14°S, Peru) and Huascaran (9°S, Peru). The principal variable discussed in this study is the stable water isotope signal ($^{18}O/^{16}O$) of the ice. Usually interpreted as a temperature proxy in paleo records from high latitudes its interpretation in the tropics is more complicate. Here, I demonstrate that on an interannual to interdecadal timescale the water isotopes are dominantly controlled by ENSO typical precipitation anomalies. Once carefully dated all records from the inner to the outer tropics in South America show a strong and common decadal signal which leads to the definition of an Andean Isotope Index (AII). The AII will be compared to various climate parameters (SSTs, precipitation, other paleorecords) which strengthen the interpretation of the AII as an excellent indicator of variability of the tropical hydrological. Its extension back to the 17th century further proves that decadal variability was dominating throughout the second half of the 20th century. Its negative extremes were associated with the advances of Andean glaciers in the 17th and 19th century. Given our interpretation established on the decadal timescale in the 20th century is even valid on the centennial scale this observation strongly suggest that the Little Ice Age was characterized by comparably intense ENSO activity in the tropics.

THE DYNAMICS OF THE SHALLOW SUBTROPICAL CELLS: IMPLICATIONS FOR GLOBAL CLIMATE AND OCEAN BIOGEOCHEMISTRY

Mojib Latif[1], Katja Lohmann[2] and P. Wetzel[2]

[1]Institute for Marine Research, Kiel, Germany
mlatif@ifm.uni-kiel.de
[2]Max-Planck-Institute for Meteorology, Hamburg, Germany

Recent observational and modeling studies report a weakening of the shallow tropical cells (STCs) in the Pacific Ocean, and this may have been the cause of the warming in the equatorial Pacific observed over the last decades (McPhaden and Zhang, 2002). The STCs control the upwelling at the equator and thus a changing STC strength has a direct impact on the SST, which may be reinforced by coupled feedbacks. As such, the STCs may play an important role in low-frequency climate variability and global climate change. Furthermore, a change in the STCs may also affect ENSO variability.

First, The variability in the tropical Pacific is analyzed by investigating observations, forced ocean model simulations, and simulations with fully coupled ocean-atmosphere models. The results indicate that the decadal variability is strongly influenced by the variability of the shallow tropical cells (STCs). In particular, the leading mode of sea surface temperature (SST) observations in the western equatorial Pacific has a decadal timescale and is closely related to changes in the strength of the STCs. The El Niño/Southern Oscillation (ENSO) phenomenon is the second most energetic mode in this region. Long-term trends are visible only in the decadal mode but not in the ENSO mode. Thus, if the long-term trend reflects an anthropogenic impact on climate, it does not affect ENSO itself but modulates the mean state on decadal timescales, on which ENSO is superimposed. These observational results are consistent with coupled model integrations.

Next, we explore the sensitivity of the subtropical cells to global warming. This work is aiming at quantifying the spread in the Pacific STC behavior within the CMIP-2 (Coupled Model Intercomparison Project) coupled model ensemble. Preliminary results are discussed at the workshop.

PACIFIC AND ENSO DACEDAL VARIABILITY: THEORIES AS TO THEIR CAUSE. THE ROLE OF THE PACIFIC CELLS.

Julian P. McCreary, Jr

IPRC/SOEST, University of Hawaii, Honolulu, HI 96822, USA
jay@soest.hawaii.edu

The causes of North Pacific (PDV) and ENSO (EDV) decadal variability are currently not known. In one view, both PDV and EDV result from tropical processes alone. In another, PDV is generated at midlatitudes, and subsequently communicated to the tropics by atmospheric or oceanic teleconnections to generate EDV. Several recent studies point toward the latter idea, suggesting the importance of oceanic teleconnections via the Pacific Subtropical Cells (STCs). These cells are the shallow, meridional-overturning circulations that connect subtropical subduction regions to the upwelling region in the eastern, equatorial Pacific.

Gu and Philander (1997) hypothesized that midlatitude *SST anomalies* can be subducted into the thermocline and subsequently advected to the equator by the subsurface branch of the STC, where they upwell to the surface to affect equatorial SST. Solutions to oceanic GCMs, however, indicate that process produces weak equatorial SST variability, as the midlatitude anomalies are largely dissipated by the time they reach the equator (*e.g.*, Nonaka and Xie, 2000; Nonaka *et al.*, 2000).

Kleeman *et al.* (1999) and Klinger *et al.* (2002) used an intermediate ocean model to demonstrate that decadal wind anomalies along the tropical/subtropical boundary can alter the STC *transport*, leading to significant changes in equatorial SST. Nonaka *et al.* (2002) confirmed this result in a GCM solution forced by NCEP reanalysis winds, showing that warmer (cooler) equatorial SST anomalies are associated with weaker (stronger) STC transports. Consistent with this model results, McPhaden and Zhang (2002) reported that during the past 40 years the Pacific STCs have weakened at the same time that equatorial SSTs have increased. Nonaka *et al.* (2002) concluded further that equatorial wind anomalies *initiate* EDV whereas the changes in STC transport act to *maintain* it.

Solomon *et al.* (2003) developed an intermediate coupled model with two climate modes: an ENSO and a decadal mode, generated by tropical and midlatitude air-sea interactions, respectively. For sufficiently strong midlatitude coupling, the decadal mode was self-sustaining, generating PDV that was carried to the equator by transport changes in the North Pacific STC to cause EDV. For weaker midlatitude coupling, the decadal mode was damped but could still be maintained by tropical air-sea interactions (the ENSO mode) through tropical-to-midlatitude atmospheric teleconnections. In this parameter range, then, *both* tropical and midlatitude processes are required to cause PDV and EDV, a property consistent with the conclusions of Nonaka *et al.* (2002).

CIRCULATION CHANGES LINKED TO ENSO-LIKE PACIFIC DECADAL VARIABILITY

Michael. J. McPhaden[1] and Dongxiao Zhang[2]

[1]NOAA/PMEL, Seattle, USA
mcphaden@pmel.noaa.gov
[2]NOAA/PMEL and University of Washington, Seattle, USA

The Pacific Decadal Oscillation (PDO) is a fluctuation of the coupled ocean-atmosphere system having ENSO-like patterns of spatial variability but time scales of a decade or longer. Understanding the mechanisms responsible for the PDO is a high priority for climate studies since it is unclear at present whether the PDO is a cause of, or a consequence of, the decadal modulation of ENSO. In this presentation, we use 50 years of hydrographic and wind data from the Pacific to examine hypotheses concerning the PDO and how they may relate to ENSO.

We begin with a brief review of hypotheses about decadal variability in the Pacific, focusing on those that invoke a role for changes in either circulation or water mass properties in the subtropical cells. We then present evidence for a slowdown in the shallow meridional overturning circulation of the subtropical cells from the "regime shift" of mid-1970s to the late 1990s. This slowdown is associate with a reduction in equatorial upwelling rates and a rise equatorial sea surface temperatures over the same period of time. Whether this slowdown has reversed in the past few years coincident with a possible change in the sign of the PDO in 1998-99 is a question that will be examined with the most recent data. We will also describe the magnitude of decadal changes in temperature and salinity in the tropical and subtropical Pacific Ocean, complementing previous work that focused primarily on the formation and fate of thermocline temperature anomalies only.

Implications of these results for understanding the decadal modulation of ENSO will be discussed, as will the possible impacts of changes in the circulation on CO2 outgassing and biological productivity in the tropical Pacific.

DECADAL-MULTIDECADAL VARIATIONS IN THE EL NIÑO-SOUTHERN OSCILLATION AND THEIR IMPACTS ON GLOBAL CLIMATE

Vikram M. Mehta and Carolina Fayos

The Center for Research on the Changing Earth System, 10211 Wincopin Circle, Suite 240, Columbia, Maryland 21044, USA
vikram@crces.org

The global climate is significantly influenced by the El Niño (EN) and the Southern Oscillation (SO) at seasonal to interannual timescales. It is becoming increasingly obvious, however, that the EN, the SO, their influences on global climate, and their predictability vary at decadal-multidecadal timescales. The causes of these variations are not so obvious.

We will present results of analyses of *in situ* observations, the NCEP-NCAR and ECMWF reanalyses of atmospheric observations, and ocean observations assimilated in the SODA system for the 1950-2000 period. In addition to quantitative descriptions of decadal-multidecadal variations in EN, SO, and their influences on global climate, we will address the following questions.

- Are the decadal-multidecadal EN and SO variations, and their influences on global climate statistically and physically significant?
- What are the likely causes of decadal-multidecadal variations in EN, SO, and their influences on global climate as inferred from these analyses of observations?

RECONSTRUCTING ENSO OCCURRENCES IN THE LAST FEW CENTURIES: WHAT IS NEW AFTER BILL QUINN'S PRECURSORY WORK IN WESTERN SOUTH-AMERICA?

Luc Ortlieb

IRD, 32 avenue Henri-Varagnat, 93143 Bondy cedex, France
luc.ortlieb@bondy.ird.fr

The reconstruction of the evolution of ENSO modality through time, at a decadal/century scale is undoubtedly of utmost relevance for a better understanding of the system. Obvious limitations of instrumental data for the past few centuries need to be compensated for by proxy data. W. Quinn had developed in the eighties a documentary record of El Niño occurrences which has been extensively used by many researchers involved in calibrating tropical ice-core data, massive coral record or sedimentary sequences.
Reappraisal of the documentary data used by Quinn in several countries of South America (and Egypt) led me to question a good number of reconstructed occurrences of El Niño manifestations. As a result of these investigations, it came out that important changes in the teleconnection system between regions which are nowadays affected by the meteorological impacts of El Niño/La Niña conditions, seem to have happened in the first half of the nineteenth century. Basically, a decoupling of El Niño manifestations is observed between northern Peru and central Chile, between, at least, 1540 and 1817. As this lapse grossly corresponds to the Little Ice Age, it has been proposed that during cooler (global?) conditions different regional circulation patterns were active in the South Eastern Pacific and western South America.
One of the points to be stressed is that documentary information on climatic anomalies in regions affected by ENSO should be taken into account, but with much more caution that Quinn could do it. This approach of paleo-ENSO studies in key areas still constitutes a major proxy, against which can be compared other paleodata. Another conclusion is that the intensity of the reconstructed El Niño events may not be as easily and precisely determined as proposed by Quinn, in his successive chronological sequences.
Future development of paleo-ENSO studies for the last few centuries should aim at a closer correlation between coral and documentary data from selected areas. And a particular attention should be paid to the period prior to the nineteenth century.

NORTH PACIFIC DECADAL VARIABILITY

Niklas Schneider

IPRC and SOEST, University of Hawaii, Honolulu, HI 96822, USA
nschneid@hawaii.edu

Decadal variability of the North Pacific will be reviewed, with focus on the adjustments of the subtropical gyre, and the subduction of temperature anomalies into the thermocline. The former process can affect the tropical state and ENSO via atmospheric bridge or wave processes, while the latter induces temperature anomalies of the source waters upwelled at the equator.

Ekman pumping associated with North Pacific atmospheric variability forces Rossby waves that propagate to the west, and after a few years, affect the surface heat budget in the Kuroshio extension region. The associated temperature variations in the Kuroshio extension region are dominated by decadal time scale, as are the air-sea fluxes of heat that balance the ocean heat flux convergences. The atmospheric response to these fluxes is uncertain. Coupled ocean atmosphere models are consistent with stochastic atmospheric forcing without significant feedback, while atmospheric models forced by the heat flux show a downstream response.

The coupled response to the equatorial emergence of water mass anomalies in the thermocline has been implicated in the decadal climate variability and modulation of El Niño. Important questions relate to the generation of these density compensating temperature and salinity anomalies in the extratropical subduction regions, their alteration during transit to the equator, and the coupled response to the equatorial emergence to these anomalies. Coupled models suggest that the eastern subtropical North and South Pacific are dominant source regions of these anomalies, with salinity variations playing a major role. The transit to the equator is relatively direct on the southern hemisphere, and models indicate that its anomalies reach the Undercurrent. On the northern hemisphere, gradients of temperature on isopycnals lead to the possibility of in-situ generation of water mass anomalies by anomalous advection. Once at the equator, the coupled response to the water mass anomalies includes a weak modulation of ENSO amplitude by its control of the thermocline feedback. If this process is sufficient to explain the observed modulation of ENSO remains an open question.

A NON-LINEAR THEORY FOR EL NIÑO BURSTING

Axel Timmermann, Fei-Fei Jin[2], Jan ABshagen, and Oliver Timm

Institute for Marine Research, Duesernbrooker Weg 20, 24105 Kiel, Germany
atimmermann@ifm.uni-kiel.de
[2]Department of Meteorology, SOEST, 2525 Correa Road, HI 96822, USA

We propose a new mechanism that explains two key features of the observed El Niño-Southern Oscillation (ENSO) phenomenon -- its irregularity and decadal amplitude changes. Using a low order ENSO model we show that the nonlinearities in the tropical heat budget can lead to bursting behavior that is characterized by decadal occurrences of strong El Niño events. La Niña events are not affected, a feature that is also seen in ENSO observations. One key result of our analysis is that decadal variability in the tropics can be generated without invoking extratropical processes or stochastic forcing. The El Niño bursting behavior simulated by the low order ENSO model can be understood in terms of the concept of homoclinic and heteroclinic connections. The skewed nature of ENSO in combination with the decadal bursting behavior leads also to decadal changes in the climate background state in the tropical Pacific. Our hypothesis is that decadal background changes are generated by changes in the variability of ENSO, rather than vice versa. This scenario relies on the asymmetry between El Niño and La Niña. Several reasons will be presented why the observational record exhibits very strong El Niño events, but a lack of similarly strong La Niña events.

We show that this new paradigm for ENSO amplitude modulations and irregularity, although difficult to prove, might explain some features of ENSO dynamics seen in more complex climate models and the observations. We focus, in particular on a multi-century long simulation performed with a state-of-the-art Coupled General Circulation Model (CGCM) which exhibits very pronounced decadal changes in ENSO amplitude. A careful linear statistical analysis of this simulation does not provide insight into the generation of the bursting behavior of ENSO. It is shown that in this simulation decadal amplitude changes of ENSO are accompanied by decadal background changes in the tropical Pacific. However, using linear arguments we show that it is very unlikely that decadal ENSO bursting originates from these background state changes. Using nonlinear statistical techniques we are able to prove the reverse scenario. Nonlinear inverse modeling techniques are applied in order to show that decadal ENSO bursting in this simulation can be traced back to homoclinic dynamics.

Furthermore, we explore whether nonlinear decadal bursting may offer the possibility for long-term regime forecasts.

QBO, INTERANNUAL, QDO SIGNALS IN THE PACIFIC

Yves Tourre

Medias-France, 18 av. Edouard Belin, 31401 Toulouse cedex 9, France
Yves.Tourre@medias.cnes.fr

Today we recognize the El-Niño -Southern Oscillation (ENSO) phenomenon as having global extent, confined not just to the Indian and Pacific oceans but extending eastward across the Atlantic Ocean and southward across the Southern Ocean. This phenomenon is now identified with global standing modes and global traveling waves with quasi-periodicity of 3 to 7 years, the global wave propagating slowly eastward as a coupled wave in the ocean/atmosphere system and taking 1 to 2 cycles to circle the globe. Thus, the impact of the ENSO phenomenon is felt globally over land as well as ocean, affecting year-to-year variability in temperature and precipitation. Yet, there is much more to year-to-year global climate variability of ENSO. While in the Pacific there exist global standing modes and traveling waves of the quasi-biennial oscillation (QBO) on 2- to 3-year time scales, the low-frequency variability of ENSO such as quasi-decadal oscillation (QDO) displays patterns which resemble the other patterns and evolution [Tourre et al.,2001].
Moreover it is found that these three signals share patterns and evolution in the 18°C isotherm depth (Z18), zonal surface wind (ZSW), and wind stress curl (WSC) anomalies. Each signal is characterized by warm SST anomalies in the eastern/central equatorial Pacific Ocean, generating westerly ZSW anomalies both overhead and displaced to the west [Gill, 1980]. The latter are associated with cyclonic WSC anomalies off the equator [Graham and White, 1988], which pump shallow baroclinic Rossby waves off the equator in the western/central tropical North Pacific Ocean near ~7°N, ~12°N, and ~18°N for biennial, interannual, and decadal signals respectively. These shallow Rossby waves propagate westward, taking ~6, ~12, and ~36 months, respectively, to travel from the western/central ocean to the western boundary. There they reflect as cool equatorial coupled waves, propagating slowly eastward in covarying SST, Z18 and ZSW anomalies, taking ~6, ~12, and ~24 months to reach the central/eastern equatorial Pacific Ocean. These cool coupled waves produce a delayed negative feedback to the warm SST anomalies there. The decrease in Rossby wave phase speed with latitude, the increase in meridional scale of equatorial SST anomalies with period scale, and the associated increase in latitude of WSC forcing, can be handled by the delayed action oscillator (DAO) used to explain El Niño [e.g., Schopf and Suarez, 1988]. But the western boundary reflection of Rossby waves into slow equatorial coupled waves cannot, require modification of the existing DAO. We construct a conceptual model of the observed DAO to demonstrate the mechanisms, the size and sources of the delay, and the resulting frequency produced on each period scale.

A MODEL STUDY OF DECADAL VARIABILITY IN THE TROPICAL PACIFIC

Carole Cibot, Laurent Terray, and Boris Dewitte

Cerfacs, Toulouse, France
cibot@cerfacs.fr

This work proposes to study the decadal variability of the tropical Pacific and his link with the low frequency modulation of ENSO.
Previous studies have proposed different mechanisms to explain the decadal variability in the tropical Pacific. Some suggest a tropical-subtropical interaction, via the STCs (shallow tropical-subtropical overturning cells) for example. Others argue that tropical variability is influenced by the mid-latitude decadal variability. The main idea advanced is that these mechanisms have an impact on the decadal variability, which in turn influences the ENSO variability. More recently, some studies focus directly on the low frequency modulation of ENSO, and suggest it leads the decadal variability.
Observations and model experiments are used to investigate the low frequency modulation of ENSO. We use in particular a 300-year simulation from a global ocean/atmosphere coupled model.
To characterize the low frequency modulation of ENSO variability, we have computed the "N3VAR index" (interannual variance of the sea surface temperature anomalies in the Niño3 region). This index varies on the same time-scale as the decadal variability, with a peak around 16 years. A correlation analysis indicates that the N3VAR index leads the decadal variability by one year.
We have then tested the idea of subtropical cells as triggering decadal variability. We have investigated the relationship between the annual-mean STC overturning strength for the Pacific and the N3VAR index. The first results seem to indicate that the N3VAR index lags by 3 years the STC strength.

REPRESENTING EL NIÑO IN COUPLED OCEAN-ATMOSPHERE GCMs: THE DOMINANT ROLE OF THE ATMOSPHERE

Eric Guilyardi, Silvio Gualdi, and Julia Slingo

CGAM, University of Reading and LSCE, Gif-sur-Yvette.

A systematic modular approach to investigate the respective roles of the ocean and atmosphere in setting El Niño characteristics in coupled general circulation models is presented. Several state-of-the-art coupled models, integrated for several hundred of years and sharing either the same atmosphere or the same ocean are compared.
Major new findings include 1) the dominant role of the atmosphere model in setting El Niño characteristics (periodicity and base amplitude) and errors (regularity); 2) the apparent secondary role of the ocean model -- in disagreement with ENSO theories; and 3) the considerable improvement of simulated El Niño characteristics -- towards lower frequency and up to decadal -- when the atmosphere resolution is significantly increased. Likely reasons for such behavior and implications for decadal variability mechanisms and El Niño prediction are discussed, with an emphasis on the role of the coupling strength between the ocean and the atmosphere.
It is argued that this new modular strategy represents a generic approach to identifying the source of both coupled mechanisms and model error and will provide a methodology for guiding model improvement.

HOW CAN HEAT TRANSPORT IN THE PACIFIC VARY?

Wilco Hazeleger[1], R. Seager[2], M. Cane[2], N. Naik[2] and C. Severijns[1]

[1]KNMI, PO Box 201, 3730 AE De Bilt, The Netherlands
hazelege@knmi.nl
[2]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA

Recent studies suggest that changes in the strength of Subtropical Cells generate changes in ocean heat transport that are associated with decadal variability in the tropical Pacific. Here, the response of ocean heat transport in the Pacific to atmospheric variability is studied. The meridional overturning circulation in the tropics and subtropics transports heat away from the equator. The horizontal gyre circulation transports a smaller amount of heat towards the equator in the tropics. Model experiments show a relatively small reduction in ocean heat transport in response to El Niño-like winds. The changes in heat transport by the overturning and gyre circulation are large, but tend to compensate. That is, the overturning transport reduces and the gyres spin down. This compensation breaks down when the Indonesian Throughflow is allowed to vary. In general, during El Niño-like conditions the volume transport in the Indonesian Throughflow is small and causes a large reduction of poleward heat transport in the South Pacific. Also, changes in heat loss in the midlatitudes can significantly change the heat transport in the tropics by an enhanced buoyancy-driven overturning that reaches into the tropics. The results are related to observed changes in the overturning circulation in the Pacific in the 1990s, sea surface temperarture changes, and changes in atmospheric circulation. The results imply that the ratio of heat transport in the ocean to that in the atmosphere can change.

TROPICAL MECHANISMS OF PACIFIC DECADAL CLIMATE VARIABILITY

Fei-Fei Jin

Department of Meteorology, University of Hawaii at Manoa, Honolulu HI96825, USA
jff@soest.hawaii.edu

Our understanding of the decadal modulations of the frequency, amplitude and predictability of El Niño-Southern Oscillations (ENSO) is still limited.
This paper focuses on the roles of the tropical ocean-atmosphere interaction in the decadal climate variations of the tropical Pacific and decadal modulations of ENSO. Particularly, we will address two issues.
The first is to examine the relevance of the decadal modes of tropical ocean dynamics to the decadal climate variability of the tropic Pacific. Using simple coupled models, we will investigate the coupled mechanisms that may modify the decadal modes of the tropical ocean into coupled modes.
The second is to explore non linear scenarios that allow large amplitude modulations of ENSO. Results from simple coupled model will be presented and evidence of non linear feedbacks between the decadal changes in climate mean state and ENSO activity will is discussed.

THE INTERPRETATION OF GEOCHEMICAL DATA FROM CORAL SKELETON NEED TO BE REVISITED

Anne Juillet-Leclerc

LSCE Domaine du CNRS, 91198 Gif sur Yvette, France
anne.juillet-leclerc@lsce.cnrs-gif.fr

Long-live massive corals, developed all around tropical belt, are unique archives to recognize ENSO occurrence during the past offering both annual resolution and multi century record length needed for reconstructing seasonal to centennial variations of tropical surface ocean changes. Numerous studies prove that geochemical records are strongly related to environmental parameters. Unfortunately major inconsistencies derived from a "classical" interpretation of these data indicated that the chemical signature of coral skeleton is much more complex than we supposed.
Measurements (isotopes and trace elements) performed at micrometer scale revealed a great heterogeneity of the geochemical distribution which does not correspond to a simple seasonal variation. It could justify that the significance of inter and intra-annual variations differs. The seasonal records remain to be understood.
However, information may be provided by annual measurements. The Weber and Woodhead (1972) revisited data reveal that the classical isotopic thermometer appears after removing biological variability from annual data. In addition, coral cultures demonstrated that oxygen and carbon are both kinetically fractionated. Thus, by considering both oxygen and carbon data series of long coral records (at least 100 years) it is possible to eliminate biological signal and extract the isotopic variations due to the usual formula giving oxygen isotopes versus SST and water isotopic ratio. Examples illustrating climatic changes will be given.

PREDICTABILITY OF TROPICAL PACIFIC DECADAL CLIMATE SHIFTS: A VIEW FROM A TROPICAL MODEL

Alicia Karspeck, Richard Seager, and Mark Cane

Lamont-Doherty Earth Observatory

The Zebiak-Cane model for simulation of the El Niño-Southern Oscillation is shown to be capable of producing sequences of variability that exhibit shifts in the time-mean state of the eastern equatorial Pacific that resemble observations of tropical Pacific decadal variability. The model's performance in predicting these shifts is compared to two naive forecasting strategies. It is found that the ZC model consistently outperforms the two naive forecasts that serve as null hypothesis in assessing the significance of results. Forecasts initialized during anomalously warm and anomalously cold decades are shown to have the highest predictability.

These modeling results suggest that, to a moderate extent, the state of the tropical Pacific in one decade can predetermine its time mean state in the following decade. However, even in this idealized context decadal forecasting skill is too low to be useful. Results are discussed in the context of their implications for the ongoing debate over the origin of decadal variations in the Pacific.

OBSERVED TWENTIETH-CENTURY CLIMATE VARIABILITY IN THE TROPICAL PACIFIC

Julie Leloup and Jean-Philippe Boulanger

LODYC, CNRS/UPMC/IRD, Paris, France
jllod@lodyc.jussieu.fr

The present study aims at investigating the observed twentieth-century climate variability in the tropical Pacific focusing on three frequency bands: the interannual 2-8 year band usually associated to the ENSO mode, the decadal-to-interdecadal variability (8-30 year) and a trend or very low-frequency signal (periods longer than 30 years).
In order to identify the most robust patterns and characteristics of variability in each frequency band, we use four sea surface temperature (SST) datasets (ERSST, GISST, HADISST and Kaplan) and historical sea level pressure data including the Southern Oscillation Index (SOI).
First, various studies have suggested climate warming due to anthropogenic activity to be responsible for the most recent increase in warm ENSO amplitudes. Considering such an assumption, we studied the ENSO variance in running 30-year windows covering the 1880-2001 period. Our results show that ENSO estimated in the Niño3.4 region (in the four datasets) is coherent with the one estimated from the SOI over the last 40 years. Prior to the 1930's, all SST datasets clearly underestimate the ENSO variance estimated from the SOI. The higher spatio-temporal density of SST data since the 1940's-1950's is certainly crucial to properly capture ENSO amplitudes. Another major result is that actually the recent ENSO activity estimated from the SOI is not significantly different from the one observed in the late 1800's suggesting that it is too early to relate recent increase in ENSO variance to a greenhouse warming effect.
In terms of long-term trend over the 1880-2001 period, the four SST datasets present a large variety of behaviors. First, ERSST data suggests a 0.26°C/century increase, GISST has an almost zero slope, while Hadisst and Kaplan display a cooling (respectively of -0.1°C/century, and -0.26°C/century). This variety of slopes simply derives from differences in the Niño3.4 mean state during the earlier period (1880-1950). Later on, all the datasets display a clear positive trend al-though of slightly different slopes (between 1 and 1.5°C/century). A strong linear trend is also observed in the SOI although only from the late 60's. Whether such trends in the second half of the twenthieth-century are related to a global climate warming is still an open question.
Finally, we investigate in all datasets (SST and SLP) the robust patterns of decadal-to-interdecadal variability. Its potential relation with ENSO is also discussed.

STOCHASTIC FORCING OF ENSO – A NULL HYPOTHESIS FOR LOW-FREQUENCY VARIABILITY?

Andy Moore[1], Javier Zavala-Garay[2], Jérôme Vialard[3], Anthony Weaver[4], Kamran Sahami[1], David Anderson[5], and Richard Kleeman[6]

[1]PAOS, University of Colorado, CB 311, Boulder, CO 80309 USA.
andy@bondi.colorado.edu
[2]RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA.
[3]LODYC - Case 100 - UPMC, 4 Place Jussieu, 75252 Paris Cedex 05, France
[4]CERFACS, 42 avenue Gaspard Coriolis, 31057 Toulouse Cedex, France
[5]ECMWF, Shineld Park, Reading, RG2 9AX, UK.
[6]Courant Institute, NYU, 251 Mercer Street, New York, NY 10012, USA.

The response of a hierarchy of intermediate and hybrid coupled ocean-atmosphere models to stochastic forcing is explored. The stochastic forcing is identified as the internal variability of the tropical atmosphere which, on ENSO timescales, can be thought of as a stochastic process. It is demonstrated that low-frequency variability in ENSO activity can be generated in a stochastically-forced coupled system which possesses a stable ENSO oscillation. Thus a null hypothesis for the origin of the observed decadal variability of ENSO activity is that it is simply the response of the coupled system to the ubiquitous stochastic forcing.
The structure of the stochastic forcing that is most effective for inducing ENSO variability is the gravest stochastic optimal of the coupled system. The structure of the stochastic optimals is controlled by processes that govern the non normal character of the coupled system. Air-sea interaction and atmospheric deep convection over the western Pacific warm pool are shown to be two processes that have a strong influence on the non normality of the system, and as a result govern the response of the coupled ocean-atmosphere system to stochastic forcing, particularly in relation to intraseasonal variability over the warm pool region. The stochastic optimals of the coupled model hierarchy will be presented, and their likely occurrence in nature will be assessed using estimates of the stochastic forcing based on reanalysis data.

TROPICAL PACIFIC DECADAL VARIABILITY

Keith B. Rodgers[1], Petra Friederichs[2], and Mojib Latif[3]

[1]LODYC, Paris
[2]Meteorologisches Institut, Bonn
[3]Institut fur Meereskunde, Kiel

A 1000-year integration of a coupled ocean/atmosphere model (ECHO-G) has been analyzed to describe decadal to multi-decadal variability in equatorial Pacific sea surface temperature (SST) and thermocline depth (Z20), and their relationship to decadal modulations of ENSO (El Niño-Southern Oscillation) behavior. Although the coupled model is characterized by an unrealistically regular 2-year ENSO period, it exhibits significant modulations of ENSO amplitude on decadal to multi-decadal timescales.

Our main finding is that the dominant mode of equatorial Pacific decadal SST and Z20 variability in the model is due to an asymmetry between the anomaly patterns associated with the model's El Niño and La Niña states, this asymmetry reflecting a nonlinearity in ENSO variability. As a result, the residual (i.e. the sum) of the composite El Niño and La Niña patterns exhibits a dipole structure across the equatorial Pacific, with positive perturbation values in the east and negative values in the west for SST and Z20. During periods when ENSO variability is strong, this difference manifests itself as a change in the mean state.

For comparison, a similar analysis was applied to a gridded SST dataset spanning the period 1871-1999. The data confirms that the asymmetry between the SST anomaly patterns associated with El Niño and La Niña for the model is realistic. However, the ENSO in the observations is weaker and not as regular as in the model, and thus the changes due to ENSO asymmetries are not dominant on decadal timescales.

THE SELF-REGULATION OF ENSO

Paul S. Schopf and Rob Burgman

Climate Dynamics Program, School of Computational Sciences, George Mason University, Fairfax, VA, 22030, USA.
schopf@scs.gmu.edu

The behavior of ENSO on decadal time scales depends importantly on how close the system is to the of underlying oscillator. In one model, Kirtman and Schopf (1997) found that the system crosses the bifurcation between self-sustained and damped conditions. Other models (Thompson and Battisti, 2001, Flugel and Chang, 1999) seem to indicate that the system would be damped in the absence of stochastic forcing. This paper presents a mechanism by which the existence of ENSO has a feedback on the mean climate which maintains the system close to bifurcation. This mechanism implies that the system is self-regulating, and that changes in ENSO due to climate change may be less sensitive than one would expect.

WHY THE PROPERTIES OF ENSO CHANGED IN THE LATE 1970s: ROLES OF THE DECADAL SHIFT IN THE BACKGROUND WINDS

Bin Wang and Soon-Il An

Department of Meteorology
University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA.

Following the abrupt North Pacific climate shift in the mid-1970s, the period, amplitude, spatial structure, and temporal evolution of the El Niño has all notably changed. Theory is needed to explain why a number of ENSO properties changed in a coherent manner and why these changes concurred with the Pacific decadal climate shift. While some attribute the change of ENSO behavior to the decadal variations in the equatorial thermocline, observations indicate that from the pre-shift (1961 – 1975) to the post-shift (1981 – 1995) period the change of equatorial eastern Pacific thermocline is insignificant. In addition, Oceanic subduction takes decade to convey the subtropical anomalies to equatorial thermocline which does not explain nearly simultaneous changes in North pacific and ENSO behavior.

Analyses of available observations suggest that from the pre-shift (1961-1975) to the post-shift (1981-1995) epoch, most significant changes in the tropical Pacific had occurred in the surface winds and sea surface temperature (SST). Using a modified coupled model of Zebiak and Cane, we demonstrate that the changes in the tropical surface winds associated with the Pacific decadal climate shift can qualitatively reproduce the observed changes of the afore-mentioned ENSO properties. Both the change of the long-term mean and the presence of an annual cycle are indispensable for the background state to modulate ENSO.

The fundamental factor that altered the model's ENSO behavior is the variations of the background equatorial winds and associated equatorial upwelling. From the pre- to the post-shift period, the decrease of zonal mean SST gradients in the central Pacific and the increase of mean upwelling in the eastern Pacific have increased the role of the vertical advection while reduced that of the zonal advection. As a result, the prevailing westward propagation was replaced by stationary oscillation or eastward propagation. The changes of the winds also affected the structure of the coupled mode by eastward reallocating anomalous atmospheric heating and zonal SST gradients along the equator.

A conceptual model is advanced to illustrate that the eastward displacement of the equatorial westerly anomalies, in turn, prolongs the oscillation period and amplifies the ENSO cycle by enhancing the growth of the coupled mode and by delaying transitions from a warm to a cold state or vice versa.

The model results emphasize critical roles of the atmospheric teleconnection, which could rapidly convey influences of extratropical decadal variations to ENSO through changing tropical winds and equatorial upwelling. This mechanism is appealing because it explains why changes of ENSO behavior nearly concur with the extratropical Pacific decadal variation.

CHANGES IN PROPERTIES OF EL NIÑO IN AN INTERMEDIATE COUPLED MODEL: SENSITIVITY TO SUBSURFACE ENTRAINMENT TEMPERATURE PARAMETERIZATION

Rong-Hua Zhang and Antonio J. Busalacchi

Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland, USA

An intermediate coupled model (ICM) is used to examine the sensitivity of El Niño properties (the oscillation period, spatial structure, and temporal evolution) to the parameterization of subsurface entrainment temperature anomalies (T_e) in the tropical Pacific. The ocean component is based on an intermediate complexity model developed by Keenlyside and Kleeman (2002) that is an extension of the McCreary (1981) baroclinic modal model with the further inclusion of varying stratification and nonlinearity effects. One crucial component with such an ICM is the parameterization of T_e entrained into the surface mixed layer within which the SST is computed. An empirical scheme is developed to estimate T_e fields from sea surface pressure (SSP) anomalies using a singular value decomposition (SVD) of the covariance between historical T_e and SSP data. The improved ocean model is then coupled to a statistical atmospheric model that estimates wind stress anomalies also based on a SVD analysis. The coupled system exhibits a variety of behavior for a range of parameters. Four versions of the ICM, differing from each other only in the details of the statistical formulations for T_e and wind stress, show significantly different coupled interannual variability associated with El Niño (e.g., oscillation periods and SST propagation features). The implication of these results for the low-frequency modulation of ENSO are discussed in terms of the role of observed decadal variability of subsurface ocean thermal structure and entrained temperature anomalies.

COMPARATIVE ANALYSES OF ENSO INDEXES OVER THE LAST HALF MILLENIA

Rodrigo Abarca del Rio

DEFAO-FCFM, Universidad de Concepcion, casilla 160-C, Concepcion, Chile
Rodrigo.abarcadelrio@udec.cl

We investigated through different spectral methods the interannual to secular time scales present in all indices available of ENSO variability over the last half millennia.
Although a general description can be drawn on the secular increase of frequencies in the ENSO events, the available indices show an incoherent picture in the oscillations present from interdecadal to secular time scales, where as roughly over the last two centuries a general agreement is found from interannual to decadal time scales.
On the interannual time scales, at least during the last 150 years, the extent of lower frequencies appears to have been decreasing according with patterns of about 30-40 years (1880/85-1925/30-1960/65- …). The investigation of modulation of amplitude and frequency variability of each of the interannual bands (QB, QQ, SE) shows that both characteristics are modulated by interdecadal patterns and should be understood separately to increase ENSO understanding and predictability.
On the decadal time scales, over the last century a period of about 13-15 years has been present over much of the century, with different patterns of amplitudes depending on the index analyzed. This cycle is modulated interdecadally in both its amplitude and periodicity according with a recent reconstruction.

LONG-TERM TRENDS AND DECADAL VARIABILITY IN A FORCED OGCM IN THE TROPICAL PACIFIC

Gaël Alory[1], Sophie Cravatte[2], Takeshi Izumo[2], and Keith Rodgers[3]

[1]Université de Nouvelle-Calédonie/Institut de Recherche pour le Développement, Nouméa, Nouvelle-Calédonie
alory@noumea.ird.nc
[2]Université Paul Sabatier/Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Toulouse, France
[3]Laboratoire d'Océanographie Dynamique et de Climatologie, Paris, France

In order to study the tropical Pacific decadal variability, the OPA ocean model is forced with NCEP reanalysis on the 1951-1999 period. The simulated dynamic height and sea level are respectively compared to the dynamic height computed from Levitus hydrological data, and to the sea level measured by tide gauge at ten tropical Pacific islands. The comparison reveals a mostly artificial trend in the long simulation which consists of a decreasing dynamic height and sea level in the southwest and northwest of the tropical Pacific. It is shown using several test forcing that this trend is related to the NCEP wind, more precisely to a weakening in the trade winds and a trend in the off-equatorial wind curl, mainly existing before 1980.
While over-estimated compared to observations, the continuous rise in the equatorial SST in the model seems to be linked to a decrease in the pycnocline convergence during the last 50 years, which is consistent with recent data analysis.
This study illustrates the difficulty in separating realistic and artificial parts of simulated trends. In similar cases, due to the in-homogeneities in the data used in reanalysis products and the non-linearity of GCMs, the simple removal of a linear trend is an inadequate way to solve the problem.

AN ASSIMILATION SYSTEM WITH GREEN'S FUNCTIONS FOR ENSO FORECAST

Xavier Baillard[1], Alexandre Ganachaud[2] and Boris Dewitte[2]

[1]Ecole Polytechnique, Paris
[2]Institut de Recherche pour le Développement, LEGOS, Nouméa
ganacho@noumea.ird.nc

The main objective of coral data and other paleo sensors is to reconstruct past climate. Coral series can provide fairly accurate time series of temperatures and in some cases salinities over the past 400 year or so. The location of those data is necessarily limited islands or continents, and their number is limited by their high cost. To reconstruct the past ocean state and surrounding climate, one needs a dynamical model that can propagate the dense temporal information from individual series over large spatial areas.
We use here an Intermediate Coupled Model of the Pacific Ocean. The intermediate coupled model simulates and predicts reasonably well modern ENSO variations. A Green's functions approach is used to finding euristically a linearized version of the model sensitivity to its parameters. Each adjustable parameter is perturbed individually and the model response is calculated. The Green's function is composed of this response for each parameter, defining an equivalent linear dependence upon parameters. Then, a linear assimilation scheme may be used to estimate the parameters according the proxies.

CAN WE DETECT DECADAL SEA SURFACE SALINITY CHANGES IN THE WESTERN PACIFIC IN USING HISTORICAL DATA?

Thierry Delcroix

IRD/ LEGOS, 18, avenue Ed. BELIN, 31400 Toulouse
Thierry.Delcroix@cnes.fr

Decadal variability in the Pacific ocean has been evidenced in many studies, both in the ocean and the atmosphere, from in situ and model-derived data. When using observations, such variability has been found mainly in sea level pressure, surface wind, SST, and subsurface water temperature. Due to a scarcity of data, relatively few works exist about potential salinity changes at decadal time scales. Hence, this poster will, firstly, review our knowledge of observed decadal salinity changes in the Pacific, and, secondly, focus on sea surface salinity (SSS) changes in the tropical Pacific ocean using observations obtained with voluntary observing ships during 1970-2001. It will be shown that SSS exhibits significant changes during the so-called regime shift in the mid-1970 in the western part of the tropical basin, with a 0.1-0.3 increase (saltier after 1976) in the equatorial band and a 0.2 decrease poleward of about 10-15° latitudes. Assuming that they can be differentiated, the respective roles of ENSO and PDO in these changes will be discussed in light of the proposed physical mechanisms accounting for these oscillations.

THREE-DIMENSIONAL ANALYSIS OF TEMPERATURE AND SALINITY IN THE EQUATORIAL PACIFIC USING A VARIATIONAL METHOD WITH VERTICAL COUPLED TEMPERATURE-SALINITY EOF MODES

Yosuke Fujii, Shiro Ishizaki, and Masafumi Kamachi

Meteorological Research Institute / Japan Meteorological Agency
yfujii@mri-jma.go.jp

A method of analyzing salinity, as well as temperature, is adopted in the equatorial Pacific without an Ocean General Circulation Model (OGCM). It is a Three-Dimensional Variational (3DVAR) method with vertical coupled temperature-salinity Empirical Orthogonal Function (EOF) modes. The salinity field is estimated from temperature observation alone such that the Surface Dynamic Height (SDH) calculated from the estimation has realistic variability compared with TOPEX/POSEIDON (T/P) altimetry data. Using T/P altimetry data with temperature observation further improves the analysis of the salinity field, which is validated by the comparison with in-situ salinity data. From these analysis fields, we confirmed that interannual variabilities of the near-surface salinity field and the barrier layer in the period of 1993-2000 in the analyses are consistent with former studies. The fresh water is confined to the west, sea surface salinity in the central equatorial Pacific is relatively high, and a thick barrier layer develops in the western equatorial Pacific during La Niña periods. The fresh water spreads to the central equatorial Pacific and the thick barrier layer moves to the east during El Niño periods. The correlation between near-surface temperature and the barrier layer thickness is also confirmed. The analysis fields presented here are quite adequate to study the salinity interannual variability.

STRUCTURE OF THE ENSO MODE IN THE NORTHERN BOUNDARY OF THE HUMBOLT CURRENT SYSTEM

Carmen Grados[1], Sara Purca[2], Luis Vásquez[1], and Julio Hurtado[1]

[1] Instituto del Mar del Perú
cgrados@imarpe.gob.pe
[2] Universidad Nacional Federico Villarreal, Facultad de Oceanografía, Pesquería y Ciencias Alimentarias. Escuela de Pesquería.

Two meridional hydrographic sections at 5°S and at 09°S to 300 km offshore, were realized regularly from 1960 to 2003. Regular hydrographic monitoring of these sections in Paita (5°S) and Chimbote (9°S) give information for the northern boundary of the Humboldt Ecosystem, where small pelagic fishes concentrate.
The objective of this work is to assess the structure of the dominant ENSO mode after the regime shift. Seasonal data of winds, coastal upwelling index and Sea Surface Temperature, local thermocline depth anomaly from Paita and Chimbote, and, the Multivariate ENSO Index (MEI), and the Pacific Decadal Oscillation (PDO), were used to distinguish local and remote causes of variability in oceanographic physical conditions.
The mean temperature and salinity sections were calculated from the 1960-2003 period providing the basis for comparison the thermohaline vertical distribution, coastal thermocline and water mass characteristics during ENSO events. We observed decadal variability for the thermohaline vertical distribution off Peru. During the 80's period, the thermohaline structure was shallower than the 90's period when the warm equatorial and subtropical oxygenated waters predominated in the upper 150 m, while a change in the mass structure was observed after 2000. El Niño in 2002-2003 presented lesser anomalies than El Niño 1964-1966. Besides, a comparison of the two strongest warm periods in the last 50 years, El Niño in 1982-83 and 1997-98, during the warm phase of the PDO is presented.

THE CLIVAR PACIFIC IMPLEMENTATION PANEL: FOCUS AND PROGRESS.

Katy Hill[1] and Kelvin Richards[2]

[1]CLIVAR IPO, Southampton Oceanography Centre
klh@soc.soton.ac.uk
[2]IPRC/SOEST University of Hawaii

The CLIVAR Pacific Implementation Panel's terms of reference are to oversee and facilitate the implementation of CLIVAR in the Pacific sector in order to meet the objectives outlined in the Science and Initial Implementation Plans particularly with respect to:

- Expanding and Improving ENSO predictions
- Variability and predictability of the Asian-Australian Monsoon system
- Indo-Pacific Decadal Variability

And also on Pacific impacts on:

- Variability and predictability of the American Monsoon system
- Southern Ocean Climate variability
- Climate change prediction/detection and attribution

Aspects of ENSO research are also central to the terms of reference of the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) and the GOOS/GCOS - CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). The Pacific Panel works closely with these groups to ensure a coordinated approach to ENSO research.

In light of contributions from TIP and WGSIP, the Pacific Panel will be focusing on decadal modulation of the climate system in the Pacific basin: in particular, the Pacific Decadal Oscillation and the decadal modulation of ENSO. These foci are to be supported by a number of process studies to include:

- Boundary Currents
- Bifurcations
- Marginal Seas (Seas of foci: Bering Sea, Japan sea)
- Equatorial vertical/lateral mixing
- Ocean/Atmosphere exchange.

Most studies are at the planning stages. A notable exception is the Kuroshio Extension System Study (KESS), for which funding has now been approved. Deployment of the observation network is due to start in the spring of 2004.

The further details of Pacific Implementation Panel can be found at:
http://www.clivar.org/organization/pacific/index.htm

STUDY OF THE EQUATORIAL UNDERCURRENT USING TAO MOORED DATA OVER 1980-2002, AND OF ITS LINK WITH THE SHALLOW MERIDIONAL OVERTURNING CELLS IN A MODEL OVER 1951-1999 IN THE EQUATORIAL PACIFIC.

Takeshi Izumo[1] and Joël Picaut[2]

[1]Université Paul Sabatier, Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), 18, avenue Edouard Belin, 31401, Toulouse cedex, France.
izumo@notos.cst.cnes.fr
[2]Institut de Recherche pour le Développement, LEGOS, Toulouse, France.

The EUC is part of the shallow meridional overturning cells, and by feeding the equatorial upwelling it may have strong influences on the eastern equatorial sea surface temperature and thus on ENSO and its long-term variations. Transport, and transport-weighted temperature and depth of the EUC over its complete meridional section are estimated by using TAO moored data of current and temperature right at the equator. The time series at 170°W, 140°W and 110°W, show strong variations on seasonal to decadal time scales over 1980-2002. These variations are physically linked to the zonal wind over the central equatorial Pacific and to the thermocline depth. In a validated OGCM forced by NCEP fluxes over 1948-1999, EUC transport is compared to pycnocline convergence, equatorial upwelling and surface divergence between 5°N and 5°S. Their interannual and long-term variations are all nearly equal, with some lags due to wave propagation. Such variations are mostly explained by linear ocean adjustment to zonal wind over the equatorial Pacific. A decrease of about 30% in transport is seen over the last fifty years in the EUC and meridional overturning circulation, due to the decrease in NCEP easterlies. A long-term decrease in EUC transport-weighted temperature of about 1°C is also seen, due to a shallower thermocline. Finally, a heat budget quantifies the roles of mass transport and temperature variations of the EUC on the upper layer of the eastern equatorial Pacific. EUC transport appears dominant on interannual timescale, but EUC transport-weighted temperature becomes important on decadal scale.

DECADAL STC AND EQUATORIAL SST VARIABILITY IN A NUMERICAL MODEL OF THE ATLANTIC

Jürgen Kröger, Antonio Busalacchi and Joaquim Ballabrera

University of Maryland / ESSIC
2207 Computer Space & Sciences Building (#224) College Park, MD 20742-2465 USA
kroeger@essic.umd.edu

The relative role of extra-equatorial mechanisms modulating decadal SST anomalies in the equatorial Atlantic is investigated using an eddy resolving, reduced gravity, sigma coordinate PE model forced by observed wind stress and/or computed heat flux from the associated advective atmospheric mixed layer model.
Longterm variability of the shallow meridional overturning circulation, the Subtropical Cells (STCs), which conduit subducted water to lower latitudes, can lead to potential SST anomalies in the eastern tropics by either (1) equatorward advection of temperature anomalies formed by the subduction process in the subtropics or (2) by changes in the strength of the STCs themselves, varying the amount of cold water that is transported into the tropics. A suite of sensitivity studies is applied to isolate each of the mechanisms at work and to estimate their particular impact on equatorial SST anomalies in the model.

ENSO: A QUASIPERIODIC FORCED DYNAMICAL SYSTEM

D. M. Sonechkin and R. Brojewski

Hydrometeorological Research Center of Russia, Moscow, Russia
dsonech@rhmc.mecom.ru

Several years ago an explanation of the ENSO timing has been proposed (a phase-locking of ENSO events to the annual periodic forcing of the atmosphere). A bifurcation sequence (an invariant two-torus–a resonant cycle at a combination harmonic of the annual period–period doubling, tripling or quadrupling–chaos with a more or less smooth shape of power spectra) under such a phase-locking scenario is well known in the dynamical systems theory (DST). But the observed shape of the ENSO spectra is quite different from the shape indicated by this scenario.

My goal is to show that the shape of ENSO spectra can be better understood if the existence of a second periodic force at a frequency that is incommensurate to the annual frequency is taken into consideration. In such case, another scenario connected with the loss of an invariant tree-torus smoothness and the excitation of the so-called strange (aperiodic) but nonchaotic (predictable without any limit) fluctuations (SNFs) is actual. The spectra of SNFs are prominent. They reveal innumerable peaks and spikes re-distributed at the frequency axis by a self-similar manner. It is just observed for real ENSO spectra.

I propose the quasiperiodic conductor of the ENSO timing is a couple of the annual heating of the atmosphere and the oceanic pole tide excited by the Chandler wobble (14-month period) in the Earth's pole motion. The ratio of their frequencies (0.8393…) is one of the "worst" irrational numbers. The main eigen frequency of the ENSO dynamics (of about 20 months, see: Tsonis and Elsner) perhaps is incommensurate to both. A parametric excitation is the main reason for an enhancement of the oceanic pole tide influence on the ENSO dynamics, and so, the Schroedinger equation with a quasiperiodic potential may be used to model ENSO.

Two main peaks exist in the ENSO spectra: at the tripled Chandlerian period (42 months), and at the almost tripled annual period. Besides there are several weaker peaks at the Chandlerian period itself and at some mixed harmonics of it, the annual and eigen periods. The difference between the annual and Chandlerian frequencies (6-7-year period), its subharmonic, and the power of the second degree (40-year period) constitute a skeleton of the interdecadal ENSO variability.

Basing on the tide-like nature of ENSO one can speculate that the El Niño-prevailing epoch of the 1970-1990s has been completed by the greatest El Niño of 1997-98 (at the same time moment with the recent (1998) peak of the current warming). During the next few decades we perhaps will experience a new La Niño-prevailing epoch combined with a new global cooling like those observed during 1940-1960s.

CHANGES IN ENSO IN A GREENHOUSE-WARMED CLIMATE

Thomas Toniazzo

Hadley Centre for Climate Prediction and Research, Met Office, London Road, RG12 2SZ Bracknell, Berkshire, UK
ttoniazzo@meto.gov.uk

Given its significant impact on the climate of the global tropics, there is much interest in predicting how ENSO might be affected by climate change. Here we present some results from a HadCM3 CGCM run where the CO2 is increased by 2% per annum and stabilized at four times the pre-industrial level.
Although El Niño events in HadCM3 are affected by model systematic errors in the mean climate, by a lack of resolution in the ocean thermocline, and by the particular response of convection to SST's, the general SST anomaly pattern, its timing, and the related global atmospheric response in the control-climate run are similar to those observed.
In a warming scenario, HadCM3 El Niño SST maximum anomalies are seen to move from the East Pacific to the central and West Pacific. The amplitude of the anomalies increases, as well as their dominant frequency. This is superimposed to the general warming of the upper ocean, which is stronger in the East than in the West Tropical Pacific.
Some of these results could be model-dependent as a deeper Equatorial ocean thermocline and warmer tropical SST's are likely to exacerbate HadCM3 model deficiencies. The larger amount of energy available to ENSO under global warming might on the other hand be a more robust result, which we are currently investigating.

POAMA: AN AUSTRALIAN OCEAN-ATMOSPHERE MODEL FOR CLIMATE PREDICTION

Guomin Wang[1], Oscar Alves[1], Aihong Zhong[1], Neville Smith[1], Andreas Schiller[2],Gary Meyers[2], Faina Tseitkin[1], Stuart Godfrey[2] and Scott Power[1]

[1]Bureau of Meteorology Research Centre GPO Box 1289K, Melbourne, 3001, Australia
g.wang@bom.gov.au
[2]CSIRO Marine Research Hobart, Tasmania, Australia

The Predictive Ocean Atmosphere Model for Australia (POAMA) is a state-of-the-art seasonal to interannual seasonal forecast system based on a coupled ocean/ atmosphere model. POAMA was developed in a joint project involving the Bureau of Meteorology Research Centre (BMRC) and CSIRO Marine Research. POAMA uses the Bureau of Meteorology atmospheric model and the Australian Community Ocean Model and is initialized with ocean temperature data. The model has been tested and verified over the period since 1987 and a new 8-month forecast is produced every day. The ensemble of forecasts is used to provide guidance for operational climate services. This paper will describe some of the unique characteristics of the POAMA system, including its ability to capture aspects of the Madden-Julian Oscillation. Several specific cases will be presented to illustrate the strengths and weaknesses of the model and to show some of the factors that determine the different evolution of individual ensemble members.

MULTIDECADAL VARIABILITY OF ENSO: SIGNATURES OVER THE INDIAN OCEAN AND AFRICA

Richard Washington, Matthew Swann and Mark New

Climatology Research Group, University of Oxford, OX1 3TB, UK
rwashing@nimbus.geog.ox.ac.uk

We study the structure of the Pacific and Indian Ocean corresponding to periods of high and low ENSO activity on multidecadal time scales in observed and model data sets. We define multi-decadal periods of high and low activity through the variability of the SOI, Niño3 indices and SST/SLP EOFs as well as the strength of ENSO teleconnections to African tropical diabatic heating. In the observed data (SST, SLP, rainfall) covering the period 1900-1998, inactive (active) events feature a strengthened (weakened) zonal SLP gradient in the equatorial Pacific and a weakened (strengthened) teleconnection structure to Africa. These features are replicated in an ensemble of century long integrations of an AGCM (HadAM2) forced with observed SST (1900-1996) although the multi-decadal modulation of ENSO is somewhat phase shifted and the periodicity shorter in the case of the AGCM experiment.
We go on to examine the evidence for multi-decadal variability in a 100 year control run of an AOGCM (HadCM3). Multi-decadal inactive and active ENSO eras are evident in these runs, although the modulation of subtropical Indian Ocean SSTs accompanies the modulation of the ENSO system. We compare this pattern of variability with the AOGCM forced in climate change mode. While the broad signature in the observed, AGCM and control AOGCM data is similar, a distinct structure emerges in the climate change perturbation experiments. The adjustments to the basic state of the Pacific evident in the AGCM and the observed data are only evident in 1 of 6 climate change experiments.