Working group reports

Working group #1: Data analysis: modern, historical and proxies

(Chairman: Alex Ganachaud)

The focus of our discussions was on proxy, historical and modern data. Bearing in mind the main scientific questions that were addressed during the workshop, the group discussed the status of the present data set, their limits, and potentially useful new data.

We know, from historical and proxy data that there was a lot of variability on all time scales in the past climate and that the recent warming in the Northern Hemisphere is anomalous compared to past evolutions (e.g. Tourre et al., 2001; Mann et al., 2000). However, the measurement network that is available is too recent to study long-period climate variability and, prior to 1950, there are strong differences amongst the different reconstructions. To understand the recent changes in tropical variability, a combined study of archives, proxies and modern data is necessary.

Documentary archives

So far, work on written archives has been essentially concentrated on central and South America to recover El Niño occurrences. Climatic events are indirectly recorded in written archives such as late harvests and flooding reports (Ortlieb, 2000). Also, different kinds of historical climate data have been gathered by scientists for different purposes (reconstruction of air temperature, precipitation, hurricanes, SST) from all around the Pacific Ocean (China, Japan, Indonesia, Australia, Pacific Islands, North and South America). These data should be synthesized. Because there is no global organization for archive work, it is necessary to contact the major groups and institutions interested in historical data gathering/processing. Historical sequences, inter-comparison specific to sensitive areas (e.g. to ENSO anomalies) will be important steps, using case-studies for specific periods. Also, there is a need to list what documentary data may help to consolidate other proxy oceanographic or climatic data. To proceed, we suggest to enhance archive work in Asia and consolidate databases in South America and Australia.

Paleoclimate Proxies

Examination of the climate in the past 1000 years shows a well documented and exceptional warming in the northern hemisphere during the last few decades. Nevertheless, the response of the tropics is not well understood. One could learn from proxies using farther past periods for which average conditions were similar to, or warmer than, present-day climate. For instance, it is not clear why El Niño behaved differently in the mid-Holocene given similar background mean conditions (as suggested by coral cores, Corrège et al. 2000).

The "proxy" community needs to know which data might best help improve our understanding (our models) of the low frequency variability: which parameters? To what relative accuracy? To what absolute accuracy? Many coral cores are available, but the high-resolution chemical analyses are expensive and priorities need to be drawn on sites and on temporal resolution. Oceanographers from the working group suggested to focus on thermocline processes (rather than seeking proxies from deeper organisms). Although climatic data from any time period are useful, enhanced analyses on the 1700-1950 period would be of major use as modern data were very scarce at that time in the Pacific Ocean. Systematic instrumentation of coral sites is highly desirable, with thermosalinographs in regions of high salinity variations, as the utility of data may suffer the lack of appropriate calibration. Older corals may help understanding mechanisms or testing hypotheses.

The use of multiproxy sets should be encouraged as it improves accuracy and allows for recovering variables other than temperature (e.g. salinity, which is of major interest to understand ocean mechanisms, Maes et al., 2002).

Accurate chronologies are necessary to the correct interpretation of coral signals and more work is needed on many of the available series.

Another useful approach is to develop simulation of the proxy itself in numerical models to avoid the need of calibration to a physical variable. Proxy data access is relatively well organized (NOAA and DecVar sites). However, more information on metadata is needed, particularly for tree-rings were the raw available series are of limited use.

Modern data

The current in situ observing system was designed to monitor and tentatively predict ENSO variability. For the study of decadal variability, a meridional extension of some of the observations is desirable, including profiling float deployments in the subtropical gyres, in particular in the South Pacific. Measurements of low latitude western boundary currents are highly necessary as in several models such currents propagate signals on decadal timescales from subtropical to tropical latitudes. So far, those currents have not been monitored adequately.

In altogether tropics, subtropics and mid-latitudes, one needs to improve the estimation of heat content and air-sea heat fluxes as well as freshwater fluxes. In that regard, reanalyzes would benefit from being retargeted toward ocean and climate studies. In situ measurements should also be enhanced in the Indian Ocean because of its teleconnections with the Pacific Ocean on decadal time scales.

The satellite observing system is currently excellent and there is a strong need to maintain its frequency and rate. The following parameters need long term monitoring: SSH, SST, winds, and bottom pressure (from gravimetric missions). New measurements of SSS from satellites will be very valuable to improve evaporation/precipitation estimates as well as oceanic processes on which tropical climate variability depends such as subduction and barrier layer formation.

Methods

There is a need to improve the spectral methods currently used to analyze low frequency ENSO behavior and more generally climate/oceanic reconstructions. Linear statistics, like EOF have their limitations, for instance to identify skewed signals. Non-linear methods could be applied to the field to improve our statistical tools. Combined different approaches such as conjoint wavelet analysis and principal components should also provide better understanding of the changes in signal characteristics.

The comparison between models and data assimilation was not discussed in the workshop. Common indices of model performances may be more widely used as a necessary preliminary to numerical sensitivity experiments.

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Working Group #2: ENSO decadal variability and subtropical/tropical interactions

(Chairman: Julian P. McCreary)

Working Group #2 discussed possible relationships between ENSO decadal variability (EDV) and interactions between the subtropics and tropics. They explicitly did *not* address the question: Do extratropical processes *cause* EDV? There simply is not yet enough available data to allow this question to be answered with any reliability. Instead, the group focused on identifying processes that are, or might be, involved in tropical/subtropical interactions at decadal time scales, without considering whether they are the cause or effect of EDV.

The discussion focused on three questions: What subtropical/tropical processes might affect equatorial SST? What is currently known about the possible influence of these processes in decadal variability? What can (should) be done to confirm or reject them?

What subtropical/tropical processes might affect equatorial SST?:

The Group considered four possible processes, spending most of its time on process 4):

1) Atmospheric bridge:

It has been long known that there is a tropics-to-midlatitude teleconnection (*e.g.*, ENSO-forced PNA variability). Recently, several studies have pointed toward a midlatitude-to-tropics atmospheric teleconnection as well (Pierce et al., 2000; Vimont et al., 2002; Nonaka et al., 2002). In this view, decadal variability of the winds generated at midlatitudes extends into the tropics to affect ENSO.

2) Subtropical Rossby waves:

Several studies have suggested that there are oceanic Rossby waves crossing the Pacific at various latitudes with decadal time scales, and that they provide a time-delay feedback that generates decadal variability (Knutson and Manabe, 1998; Yukimoto et al., 2000; Tourre and White, 2003, presentation at meeting). This process is essentially the same as the time-delay feedback proposed for ENSO, with the time delay being longer because the Rossby waves cross the basin at higher latitudes. A conceptual difficulty with this view is that there is no obvious process that selects particular latitude for the Rossby waves. In addition, the source of the Rossby waves is not clear in these studies, nor is their influence on equatorial SST quantified.

3) Advection of temperature anomalies by the STCs:

Another hypothesis for EDV is that SST anomalies subducted at midlatitudes can be advected to the equator by the subsurface branch of the Subtropical Cells (STCs), where they upwell to affect the size or strength of the cold tongue, and thereby ENSO (Gu and Philander, 1997). Deser et al. (1996) provided observational support for this idea, following the downward and equatorward propagation of temperature anomalies, but they did not follow the anomalies to the equator. A number of modeling studies have considered the idea, finding that by the time the anomalies arrive at the equator they are too weak to be climatically important (Schneider et al., 1999; Nonaka and Xie, 2000). A possible exception is the advection of spiciness anomalies, that is, salinity-compensated temperature anomalies with zero density change (Schneider, presentation at the Workshop).

4) Changes in STC strength:

A final idea is that EDV is caused by changes in the STC strength. In this scenario, wind anomalies at the subtropical/tropical boundary generate anomalous Ekman drift that drains more (or less) warm surface water from the tropics, thereby strengthening (or weakening) the STCs (Kleeman et al., 1999). McPhaden and Zhang (2001) provided observational support for this idea, noting that both the North and South Pacific STCs have been spinning down since the 1970's, while at the same time equatorial SST has been warming and wind-stress at the subtropical/tropical boundary weakening. The idea has been explored in intermediated coupled models (Kleeman et al., 1999; Solomon et al., 2003) and ocean-only models (Klinger et al., 2002; Nonaka et al., 2002). There were several presentations of ocean-only solutions at the Workshop that focused on this topic (e.g., Latif, Kröger).

Several issues emerged during the Working Group's deliberations.

a) It was noted that wind-forced solutions differ considerably in the strength and structure of their STCs, particularly for those pathways that approach the equator in the interior ocean, indicating that STC structure is model sensitive (*e.g.*, to their resolution or mixing parameterizations).

b) In addition, the dynamics of STC variability have not been adequately discussed. For example, the adjustment processes by which subtropical/tropical wind anomalies alter STC strength and affect SST (Ekman drift, Ekman pumping, Rossby and Kelvin wave propagation, *etc.*) have not been adequately described in GCM solutions.

c) Finally, there were large phase differences among various measures of STC strength. For example, with a measure of STC strength based on heat transport led equatorial SST, whereas with one based on the 2-d mass-transport streamfunction it lagged (Nonaka et al., 2002). A likely cause of this difference is that the various STC branches do not spin up at the same rate, the subsurface branch lagging behind the surface one by several years (Klinger et al., 2002). As a result, the use of streamfunctions, in which both branches necessarily respond simultaneously, is questionable.

What is currently known about the possible influence of these processes in EDV?

To summarize, the observational database is not sufficient to determine the relative importance of any of these processes in EDV. For example, the only observational support for process 4) is the McPhaden and Zhang (2001) result. Modeling results point toward the potential importance of 1), 2), and 4), although in 2) neither the source of the Rossby waves nor their influence on equatorial SST is clear. Process 3) produces weak equatorial SST anomalies, but the influence of spiciness anomalies may be larger.

What can be done to confirm or reject these ideas?

Given the paucity of observational data, the Working Group could only recommend further modeling studies. Topics of particular interest include the following. *a)* Idealized modeling studies, using both oceanic GCMs and simpler systems (layer models), are needed that explore the detailed processes of how STCs respond to wind anomalies along the subtropical/tropical boundary. The influence of these remotely forced variations in STC strength on equatorial SST should be quantified. *b)* Research is needed to determine an adequate measure for STC variability in GCMs. *c)* Analysis of solutions to coupled GCMs should be carried out.

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Working Group #3 report: Self-sustained low-frequency variability in the tropics
(Chairman: Axel Timmermann)

Working Group #3 reviewed and discussed the tropical mechanisms that can generate decadal variability in the tropics (DTV), without invoking extratropical dynamics. The key questions we addressed were the following:

Is there any observational evidence that DTV is generated in the tropics?

How can we falsify extratropical hypotheses?

How can we "understand" nonlinear tropical dynamics?

Is the PDO just the low-pass filtered residuum of strong El Niño events?

What is the origin of long timescales in the tropics?

What is the origin for ENSO skewness?

Is there any possibility for decadal ENSO predictability?

Tropical Mechanisms for Decadal Variability:

Several tropical mechanisms have been suggested which may explain the presence of DTV in the Pacific as well as the emergence of decadal changes of ENSO behavior.

Neglecting ocean dynamics, even the mixed layer has the ability to integrate the stochastic momentum and heat fluxes, yielding a red-noise spectrum. The overall response of the mixed layer to stochastic wind perturbations in the whole Pacific has the same type of pattern as the PDO. In addition if ocean dynamics becomes active the stochastic wave generation becomes an important modulator of dynamical and thermodynamical variables. SST spectra will also show enhanced variability on oceanic resonance frequencies, in addition to a red-noise background. If also the atmosphere can respond to the SST changes, we may see a variance enhancement on the frequencies of the coupled modes, such as ENSO. Furthermore atmosphere-ocean-coupling may lead to a frequency selection, which may lead also to the suppression of stochastically generated decadal variability. This variance suppression has received very little scientific attention.

Another source for ENSO irregularity (chaos) and hence decadal variability in the tropical Pacific is the nonlinear interaction between ENSO and the annual cycle (Jin et al. 1994, Tziperman et al. 1994). For certain coupling strengths the annually varying background state in the tropical Pacific can trigger low-dimensional ENSO chaos as a result of nonlinear resonances and the devil's staircase. Timmermann and Jin (2002) and Timmermann et al. (2002) and Timmermann (2003) hypothesize that ENSO chaos as well as the emergence of decadal El Niño bursting can be generated without invoking neither extratropical processes nor annual cycle and stochastic forcing. Timmermann et al (2002) argue that a heteroclinic connection in phase-space between a saddle node (weak La Niña state) and the saddle point (radiative convective equilibrium) organizes ENSO dynamics in a particular way: ENSO variations grow until they reach the maximum intensity El Niño, then a quick reset takes place and the small ENSO variations grow again. Due to the skewness of El Niño and La Niña in this model, the decadal growth of the ENSO amplitude is immediately translated into decadal background state changes. Hence DTV is a residuum of skewed ENSO amplitude modulations. This idea had been supported by Timmermann (2003) using a CGCM simulation and by Rodgers et al (2003).

Furthermore, during the workshop it was shown that in addition to these studies two other CGCM simulations show a similar behavior. This raises the question: Is the PDO just the residuum of very strong El Niño events? During the negative phase of the PDO from 1945 to 1976 the level of ENSO variability was lowest. Since 1976 there was a dramatic increase in ENSO variability as well as of the PDO index. Tropical ENSO residuum changes have an influence on the atmospheric circulation in the extratropics both in the Northern and Southern Hemisphere. This scenario can also explain why the PDO exhibits such a strong equatorial symmetry. Furthermore additional persistence of the teleconnections and extratropical SST anomalies may originate from extratropical ocean dynamical changes or the re-emergence mechanism. Further analysis is needed to show or falsify that the PDO is just the expression of a skewed decadal ENSO amplitude modulation and its remote extratropical effect.

Mechanisms for nonlinear ENSO dynamics and skewness

An important feature of tropical Pacific SST anomalies is that strong El Niño events, such as the 1982-83 and the 1997-98 events occur more often than similarly strong La Niña events. This characteristic is also manifested in the probability density function (PDF) of the SST anomalies. It turns out that the eastern Pacific SST anomalies have a positively skewed PDF, whereas the PDF of the western Pacific SST anomalies exhibits negative skewness, due to thermostat processes. In the recent two years, several mechanisms have been proposed to explain the asymmetry of the observed PDF in the eastern equatorial Pacific. It was suggested by Jin et al. (2003) that nonlinear dynamic heating, associated mostly with anomalous vertical advection of anomalous vertical temperature gradients ($w'T'$) has been particularly strong after the 1976 climate shift. Nonlinear dynamic heating leads to an intensification of eastward propagating El Niño events and a damping of La Niña events. Vialard et al. (2001) suggested on the other hand that tropical instability waves (TIWs) contribute about 0.5-1°K/month to the equatorial heat budget. TIWs which occur preferentially during La Niña events, due to the stronger vertical and horizontal current shear pump heat from the off-equatorial regions to the equatorial cold tongue. This leads to a net warming of La Niña events, whereas El Niño events are not affected by the effects of TIWs.

Along the same lines Timmermann and Jin (2002) have argued that the surface ocean heat budget is also altered during La Niña events by the ocean biological absorption of solar light in the surface layers. During La Niña events cold-tongue upwelling brings nutrients to the surface. This leads to enhanced phytoplankton concentrations and an increased absorption of photosynthetically available radiation. Furthermore, during La Niña conditions the mixed layer in the eastern equatorial Pacific is quite shallow. This condition will enhance the biologically induced mixed layer warming. In total a net cold tongue warming of about 1-2°K can be generated by ocean biology. Since chlorophyll concentrations are very low during El Niño events, the biological-dynamical heating provides an asymmetric feedback with implications for ENSO skewness.

Galanti et al. (2002) argue that mixed-layer thermocline outcropping nonlinearities can also provide a mechanism to generate ENSO skewness. Furthermore, it is well documented that the atmosphere-ocean coupling strength depends largely on the intensity of atmospheric deep convection, which in turn is determined by the area characterized by temperatures larger than about 28°C. This area changes significantly during an ENSO cycle. The overall effect is that El Niño events can be easily amplified, whereas La Niña events experience a weaker coupling strength and a less strong amplification.

In total our working group has concluded that these processes have to be investigated much more in detail. Very little is known, e.g., about their relative contributions to ENSO skewness.

C. Outstanding problems

How can we translate nonlinear ENSO dynamics into an intuitive understanding?

Relative roles of nonlinearities

The role of ocean mixing in the ENSO context has not been studied extensively

Westerly-wind-burst cascades: What is chicken, what is egg?

Is linear statistics (EOF) still valid when we are dealing with strongly skewed signals?

What is a mode: Eigensolution of the equation vs. Statistical pattern?

What is the meaning of a mean basic state for the Pacific, if ENSO is skewed?

Do we have to linearize models around the time-mean basic or the most probable state?

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