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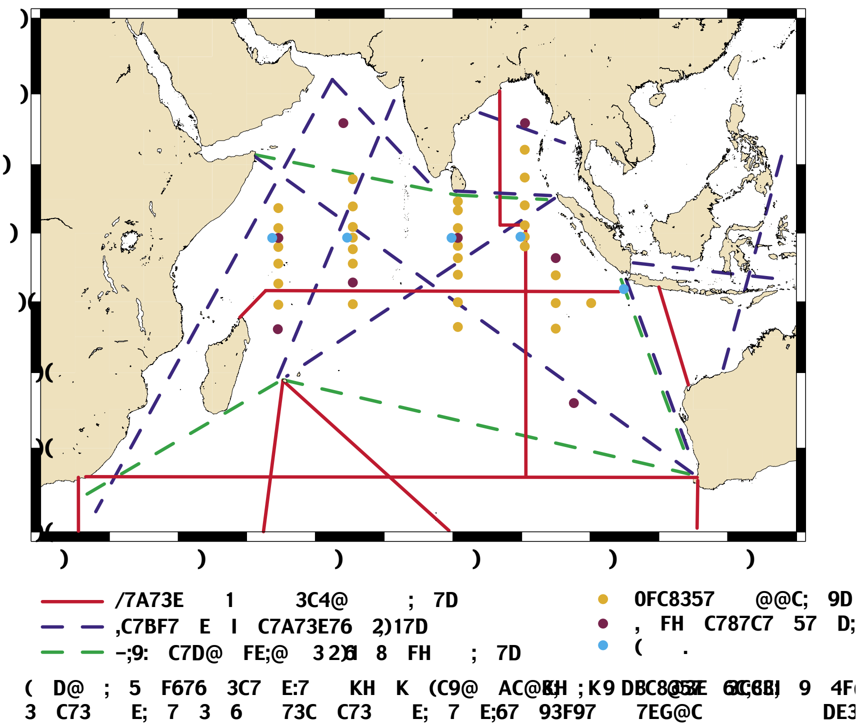
Indian Ocean Climate

From Meyers and Boscolo, page 2: The Indian Ocean Observing System (IndOOS)



Editorial

As you will see, this edition of Exchanges focuses on Indian Ocean Climate. A key activity of the joint CLIVAR/IOC GOOS Indian Ocean Panel has been to develop a plan for sustained observations over the Indian Ocean region, summarized in the paper by Gary Meyers and Roberta Boscolo. As it works to encourage implementation of this plan through national agencies and international ocean observation coordination mechanisms, illustrated by the paper by Mike McPhaden et al., the panel is also seeking to develop the science of the Indian Ocean's role in climate. It will do this in particular in conjunction with CLIVAR's Asian-Australian Monsoon and Variability of the African Climate System Panels. Linking these activities to the wider role of the Pacific in the climate system and CLIVAR activities in seasonal to interannual, decadal and climate change prediction is also a key integrating role for CLIVAR overall. Papers here represent recent developments in Indian Ocean observational and modelling studies. In addition, this edition also carries reports of two CLIVAR-related workshops, one linking the International Climate of the 20th Century Project and CLIVAR efforts in seasonal to interannual prediction and the other on much longer timescales - the joint PAGES/CLIVAR Workshop on past-millennia climate variability, illustrating the breadth and range of CLIVAR. The next edition of Exchanges (January 2007) will be joint with the International Council for the Exploration of the Sea (ICES) and will focus on North Atlantic and Nordic Sea climate variability.

Howard Cattle

WCRP World Climate Research Programme

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

The objectives of INSTANT are: 1. To determine the full depth velocity and property structure of the Throughflow and its associated heat and freshwater flux; 2. To resolve the annual, seasonal and intraseasonal characteristics of the ITF transport and properties; 3. To investigate the storage and modification of the ITF waters within the internal Indonesian seas, from their Pacific source characteristics to the Indonesian Throughflow water exported into the Indian Ocean; and 4. Contribute to the design of a cost-effective, long-term monitoring strategy for the ITF.

The initial deployment of ten INSTANT moorings was in December 2003 to January 2004 (the 11th, an Ombai mooring, was deployed in August 2003). Approximately 1.5 years later, in June/July 2005, the moorings were recovered and redeployed to acquire an additional 1.5 years of data. The final recovery is scheduled for November/December 2006. A glimpse of the first 1.5 years of INSTANT data is afforded with a composite view of the de-tided along channel speeds for a select mooring and depths within each passage (Fig. 2, page 16).

The along-channel flow within various depth intervals reveals much variability across a wide range of temporal scales, marked with month long periods of significant imbalance between the inflow and export implying substantial convergence and divergence within the interior seas. Makassar Strait along channel speeds are relatively large, with a velocity maximum near 140 m. The southward thermocline speeds are greater towards the latter half of the southeast and northwest monsoons. The estimated Makassar transport is 8 to 9 Sv, about the same or maybe a bit larger than that observed in 1997 during the Arlindo program (Susanto and Gordon, 2005). The highest speeds within the deep water, shown on the >700 m panel of Fig. 2, are in Lifamatola Passage at a current meter ~300 m above the sill depth of ~1940-m. There speeds as high as 0.5 m/sec mark the overflow and descent of Pacific water into the depths of the Seram and Banda Seas. Lombok and Ombai are particularly rich in intraseasonal fluctuations; Makassar and Timor are fairly steady in comparison. Flow into the Indonesian seas is observed within the Lombok and Ombai Straits in late May 2004: a likely cause is a downwelling coastally trapped Kelvin wave propagating eastward along the archipelago as a consequence of a Wyrtki Jet in the equatorial Indian Ocean as was also observed in December 1995 (Molcard et al, 2001) and in May 1997 (Sprintall, et al., 2000). There is a hint of its presence at the Makassar Strait, with a similar 5 day delay as observed in Ombai after northward flows appear in Lombok. In the 350-450 m interval the Makassar flow exhibits the strongest Indian Ocean bound flow, but is matched by westward flow within Ombai within two periods, June-September 2004 and December 2004 to February 2005, coinciding with the peak times of the two monsoon phases.

The first 1.5 years if INSTANT measurements coincide with a weak El Niño, but since the redeployment a weak La Niña phase has ensued. As the ITF is thought to be reduced in El Niño and increased during La Niña, it will be interesting to compare the first 1.5 year record with the final 1.5 year record (though the swing in ENSO phase may not be sufficient to impact of the ITF transport).

Analysis of the INSTANT data in addressing the objectives listed above is a challenge we savor. Each time series is information rich and comparing and interpreting the phase differences between the passages and their varied spectra is an exciting prospect. In particular, comparison of these observations to model results will be a most challenging and interesting exercise. We all look forward to acquiring the full 3 year INSTANT record.

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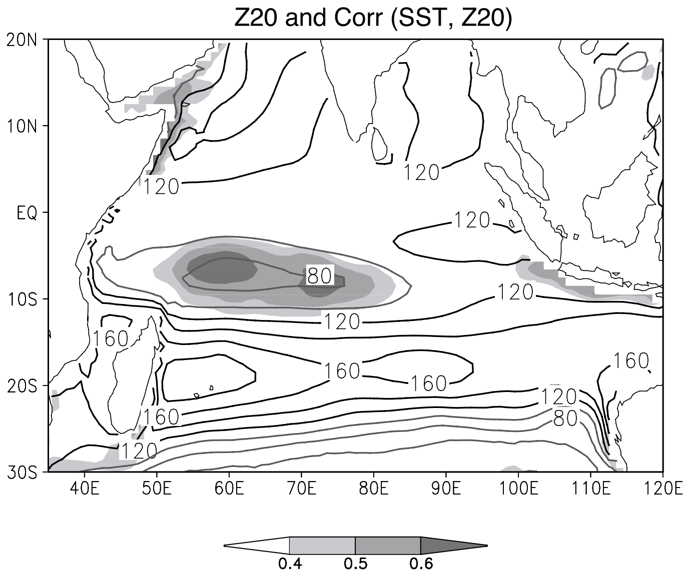

Thermocline dome and climate variability over the tropical South Indian Ocean

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1. Thermocline dome

This article discusses the recent progress in studying intraseasonal to interannual variability over the South Indian Ocean. The southwest tropical Indian Ocean emerges as a region important for climate variability with high predictability owing to a unique thermocline dome. The dome is centered around 8ºS in response to the Ekman pumping between the southeast trades to the south and weak equatorial westerlies to the north. The shallow thermocline in the dome enables subsurface variability to affect sea surface temperature (SST), as manifested by their high cross-correlation (Fig. 1, page 11). In fact, this thermocline feedback is so strong that Klein et al. (1999) "were unable to match SST anomalies in the southwestern Indian Ocean to any local anomalies in cloud cover or latent heat flux". The collocation of the mean thermocline dome with the Indian Ocean intertropical convergence zone (ITCZ) suggests that the resultant SST anomalies further influence atmospheric convection. Their collocation is also critical to the formation of the thermocline dome as the intense latent heat release in the Indian Ocean ITCZ generates positive vorticity in the lower troposphere, maintaining an Ekman pumping south of the equator.

2. Interannual Rossby waves

Basin-scale ocean Rossby waves of large amplitudes are observed in the tropical South Indian Ocean (Masumoto and Meyers 1998) in response to El Nino/Southern Oscillation (ENSO) and/or the Indian Ocean dipole (IOD). Propagating into the thermocline dome in the western half of the basin, these subsurface waves induce SST anomalies. Figure 2 shows correlations of Indian Ocean thermocline depth and SST anomalies with an El Nino index. Toward the El Nino's mature phase (December), wind anomalies in the eastern half of the tropical Indian Ocean excite downwelling Rossby waves in the ocean with characteristic westward propagation. Anomalous winds are easterly on the equator, lifting the thermocline in the east on the equator and on the eastern boundary. Embedded in a basin-wide warming that peaks in February-April following the El Nino, SST anomalies display a positive core that co-propagates with the ocean Rossby waves. These Rossby wave-induced SST anomalies increase local precipitation and tropical cyclone activity, and are collocated with a cyclonic anomalous circulation in the lower troposphere (Xie et al. 2002). Thus, ocean subsurface waves produce a strong response in SST, precipitation, and atmospheric circulation over the thermocline dome. Such atmospheric response to Rossby wave-induced SST anomalies has recently been reproduced in an atmospheric general circulation model (GCM); Annamalai et al. 2005.

While earlier studies emphasize the forcing by ENSO, recent partial correlation analyses indicate that the forcing mechanisms for Rossby waves in the tropical Indian Ocean may vary in latitude. Rao and Behera. (2005) and Yu et al. (2005) show that the IOD and ENSO are the major Rossby wave forcing north and south of 10ºS, respectively. Yu et al. (2005) suggest that this variation in Rossby wave forcing is due to the differences in the meridional scale of wind anomalies associated with the IOD and ENSO. The former wind anomalies are more narrowly trapped near the equator than the latter, forcing near-equatorial Rossby waves.

The transit time for these ocean waves across the basin is about one year (Fig. 2), a delay that gives rise to enhanced predictability in a broad region over the tropical South Indian Ocean. Recent seasonal forecast experiments (e.g., Luo et al. 2005) identify the tropical South Indian Ocean as a region of high skills as measured by correlation between the forecast and observations. Figure 3a shows the skills at nine-month lead in the tropical South Indian Ocean of Luo et al.'s (2005) dynamical forecast system based on a fully coupled GCM. Useful skill scores (say, correlation > 0.5) are found across the basin during February-May, and persist in the western basin as late as August. Using the persistence as a baseline, we evaluate the benefits of using a dynamical forecast system. The dynamical system increases the forecast skills over most of the region (Fig. 3b) partly due to an improved ENSO forecast compared to persistence. In the tropical South Indian Ocean, the skill improvements peak in the central basin during February-April and then show a tendency of westward propagation that is characteristics of ocean Rossby waves in Figure 2. Thus, the slow propagation of remotely forced Rossby waves is an important source of predictability.

Modeling the South Indian Ocean Rossby waves and their effects on SST and atmospheric variability remains a challenge. In 17 coupled GCMs submitted for the IPCC fourth assessment report, only a few simulate the ENSO-forced Rossby waves and even fewer capture the co-propagating SST anomalies (Saji et al. 2006a). Forced with observed SST in the tropical Pacific, Huang and Shukla (2006) show that in their coupled model of the Indian Ocean, ENSO-forced Rossby waves exert a discernible influence on SST and the atmosphere as late as during June-August in the year after ENSO peaks. The failure of most IPCC models to simulate this Rossby wave effect may be due to the poor simulation of ENSO, its teleconnection, or the thermocline dome in the South Indian Ocean. This contrasts with the general success of these models in simulating the mean state of the equatorial Indian Ocean, the IOD, and its relationship with ENSO (Saji et al. 2006a).

3. Intraseasonal variability

Nearly free of cloud interference, the Tropical Rain Measuring Mission (TRMM) satellite's microwave imager (TMI) improves the spatio-temporal sampling of SST observations dramatically over the cloudy tropical Indian Ocean. TMI observations reveal, previously unknown, large intraseasonal SST variability over the tropical South Indian Ocean (Harrison and Vecchi 2001). These intraseasonal anomalies of SST are nearly zonally uniform and occasionally exceed 3ºC in range over a large area (Fig. 4a, page 17). They are preceded by increased atmospheric convective activity and westerly wind anomalies. Analysis of multi-year TMI observations indicates that such intraseasonal SST variability is most pronounced in the tropical South Indian Ocean between 10ºS and 5ºS over the thermocline dome/ridge, and peaks in December-March (Fig. 4a) when the ITCZ is overhead and the mean wind is westerly (Saji et al. 2006b). Thus the decreased solar radiation and intensified westerly winds associated with increased convection both work in the same direction to reduce SST over the region of a shallow thermocline. Based on an ocean GCM study, Duvel et al. (2004) suggest that solar radiation and latent heat flux variability contribute about

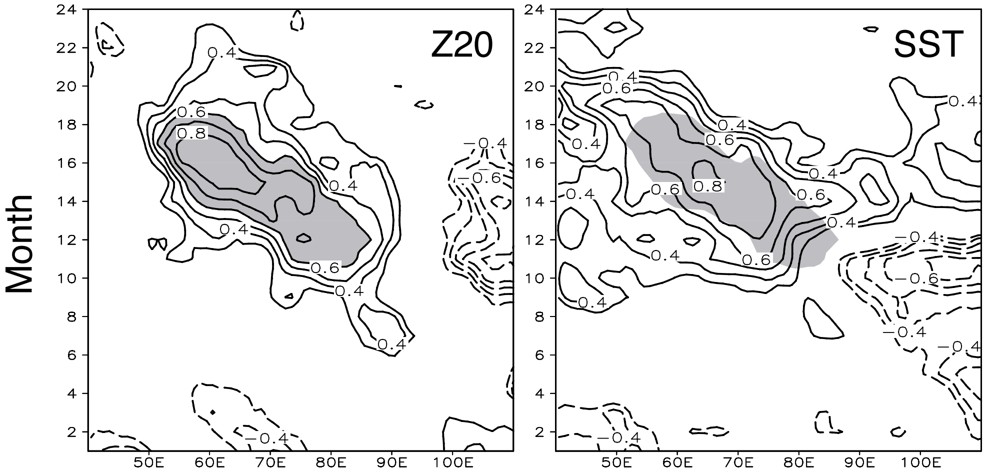

Fig. 2. Correlation of the depth of the 20°C isotherm (Z20) and SST in the Indian Ocean, both averaged over 12-8°S with October-December (months 10-12) eastern Pacific SST as a function of longitude and calendar month.

equally to intraseasonal cooling events in 1999 while horizontal advection and mixing with thermocline water are secondary in importance. Horizontal advection is small because background SST gradients are weak during December-March on and south of the equator in the tropical Indian Ocean. Recent observations using Argo floats reveal large variability in the mixed layer depth, which is negatively correlated with the intraseasonal SST anomalies over the tropical South Indian Ocean (W. Yu, pers. comm.).

During November-April, the Madden-Julian Oscillation (MJO), considered to be an intrinsic mode of atmospheric convection and circulation, displays pronounced eastward propagation along the equator, especially in the Indo-western Pacific sector. The fact that atmospheric anomalies lead those of SST indicates the importance of atmospheric forcing (by wind and surface radiation). An important question is whether intraseasonal SST anomalies feed back onto the atmospheric MJO at all. The power spectrum of outgoing longwave radiation (OLR) suggests two modes of OLR variability (Fig. 4b, page 17): the equatorial mode centered on the equator with periods of 30-50 days, and a lower-frequency southern mode with large power between 10°S and the equator and periods longer than 50 days. Noting that the southern mode displays higher coherence with SST in the tropical South Indian Ocean, Saji et al. (2006b) suggest that the interaction with the ocean may have slowed down the timescale of the southern mode and displaced its center toward the Southern Hemisphere where the thermocline is shallow and SST variability is large. More research is necessary to clarify the mechanisms for intraseasonal SST variability, and its role in modulating the atmospheric MJO.

4. Conclusions

The doming thermocline in the South Indian Ocean makes SST there sensitive to subsurface variability and atmospheric forcing. On interannual timescales, remotely forced ocean Rossby waves induce SST anomalies over the southwest Indian Ocean dome, affecting precipitation and atmospheric circulation. The slow propagation of ocean Rossby waves gives rise to considerable predictability of SST anomalies up to nine-month lead. On intraseasonal timescales, SST variability is high again over the shallow thermocline in the South Indian Ocean during December-March when the ITCZ moves overhead.

Few in-situ observations exist in the tropical South Indian Ocean. The planned CIRENE field experiment in early 2007 is very timely to observe intraseasonal variability in the ocean and atmosphere as well as the processes by which subsurface anomalies influence SST over the thermocline dome. The formation of the barrier layer under the ITCZ and surface heat flux, for example, are likely important for intraseasonal SST variability.

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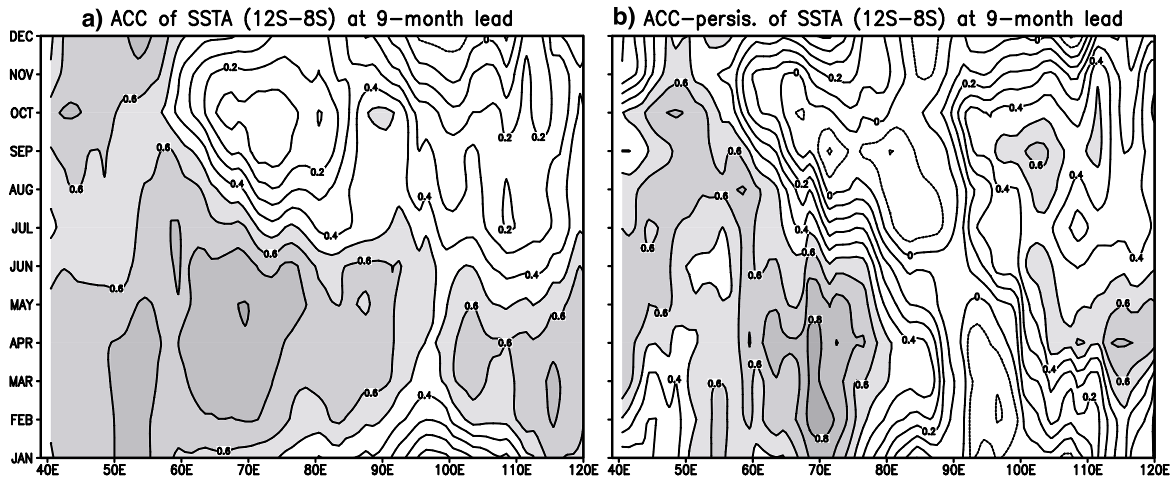

Fig. 3. (a) Skills of SST forecast at nine-month lead in the Luo et al. (2005) model as measured by correlation between observations and foreca for a 23-year period of 1982-2004. (b) Skill differences from the persistence.

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The Active Role of South West Indian Ocean

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1. Introduction

During an El Niño event, the tropical Indian Ocean, witnesses a basin-wide warming in boreal winter (January – March) with a local maximum over southwest Indian Ocean (SWIO; 15°S-0°, 50°-80°E). These regional SST anomalies (Fig. 1a, page 17) peak in spring and persist into early summer. Xie et al. (2002). Huang and Kinter (2002) demonstrated that much of SWIO SST variability is not locally forced but is due instead to oceanic Rossby waves that propagate from the east. More details on the role of ocean dynamics causing SWIO SST variations are available in Xie (this issue). The present article summarizes the author's recent research that explored the possible role of SWIO SST on: (a) the intensity of convective anomalies over the tropical West Pacific – Maritime Continent and East Asian Winter Monsoon (EAWM), (b) the onset of the Indian Summer Monsoon (ISM), and (c) the intensity of the circulation anomalies over the Pacific-North American (PNA) region.

During the boreal winters of El Niño years, negative convective anomalies over the tropical West Pacific – Maritime Continent force an anticyclone in the lower atmosphere over the South China Sea – Philippine Sea region that in-turn influences the EAWM (Wang et al. 2000). Using different atmospheric general circulation models (AGCMs), Wang et al. (2000) and Lau and Nath (2000) showed that the Philippine Sea anticyclone is forced by El Niño. These AGCM studies, however, did not consider the effect of SWIO SST anomalies. Forcing a linear model with Indian Ocean SST anomalies, Watanabe and Jin (2003) noted that an increase in precipitation over the western Indian Ocean is accompanied with a precipitation decrease over the tropical West Pacific, an encouraging result that needs to be verified with AGCMs.

In their correlation analysis between the ISM onset date and SST anomalies in the preceding winter and spring, Joseph et al. (1994) identified significant positive correlations with SST over SWIO. Based on this observational result, they proposed that SWIO SST anomalies could cause the interannual variability of the ISM onset through affecting the timing of the northwestward movement of the equatorial convective maximum, a hypothesis to be tested with AGCMs. Since the effect of oceanic Rossby waves on SWIO SST variations is felt in early summer, we expect for an active role of these spatially well-organized SST anomalies (Fig. 1a) on the ISM onset.

One of the outstanding issues in the tropical-extratropical linkage is to understand if the SST anomalies beyond the equatorial central-eastern Pacific feed back onto the PNA pattern (Kumar and Hoerling 1998). Using an NCEP AGCM, Barsugli and Sardeshmukh (2002) pointed out that there is a nodal line in the sensitivity at about 100°E longitude, with warm SST anomalies in the Indian Ocean resulting in a negative value of the PNA index. On noting low correlation between basin-wide indices of Indian Ocean SST and precipitation some AGCM studies (Kumar and Hoerling 1998) have disallowed the Indian Ocean as a source of predictability.

The motivation for the present research stems from two aspects: (i) SWIO SST anomalies are forced by ocean dynamics, and (ii) significant local SST-precipitation association exists there. Since these SST anomalies co-occur with those in the tropical Pacific it is difficult to quantify their effects separately from observations. However, experiments with a realistic AGCM forced with SST anomalies in each ocean basin (Fig. 1a) offer a means to separate their effects. By performing multi-member ensemble simulations with ECHAM5 AGCM the sensitivity of SWIO SST anomalies on the above aspects of the climate system is tested by comparing and contrasting model solutions in which SST anomalies for combined (Tropical Indo-Pacific: TIP), and individual (Tropical Pacific Only – TPO; Tropical Indian Ocean – TIO) oceans are prescribed as boundary forcing. Here, we highlight the salient results but more details are available in Annamalai et al. (2005; 2006).

2. Results

2.1 Convective anomalies over the tropical est Pacific Maritime Continent and EA M:

Figure 1b shows the simulated precipitation anomalies from TIO integrations. One notes an increased precipitation over the western Indian Ocean is accompanied with a substantial decrease in precipitation (4-5 mm/day) over the TWP – Maritime Continent. The interpretation for this notable difference is that in the TIO solutions warm SST anomalies increase the convection over SWIO and the resultant heat source forces low-level (upper-level) easterly (westerly) wind anomalies

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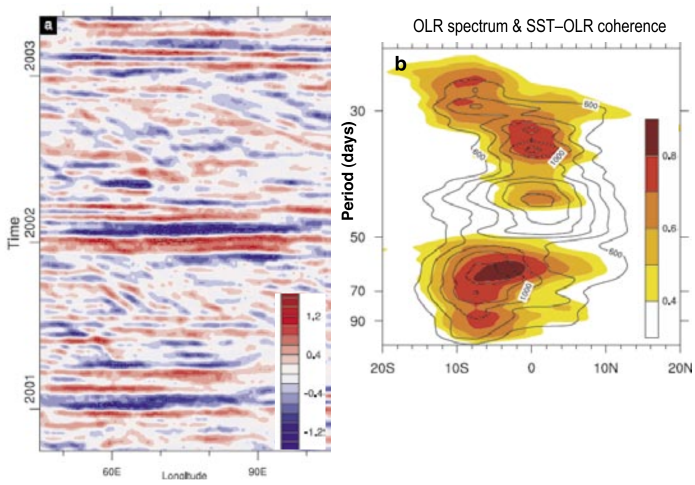
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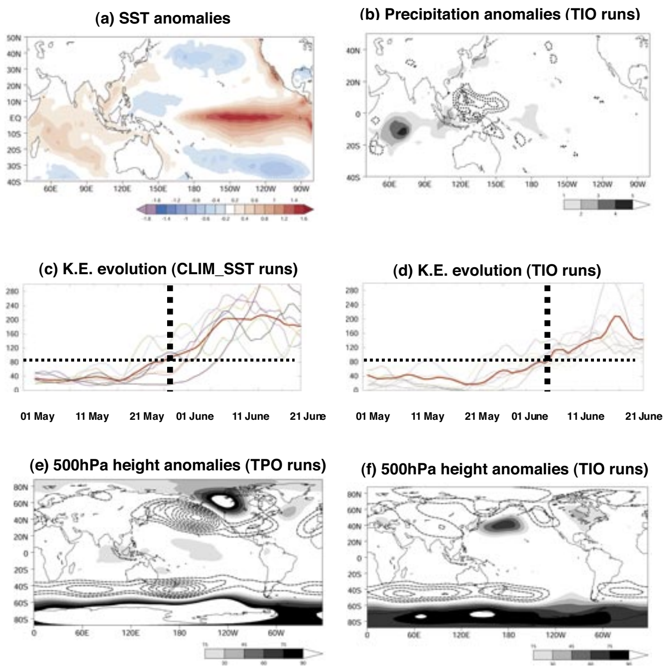
(a) SST anomalies
(b) Precipitation anomalies (TIO runs)
(c) K.E. evolution (CLIM_SST runs)
(d) K.E. evolution (TIO runs)
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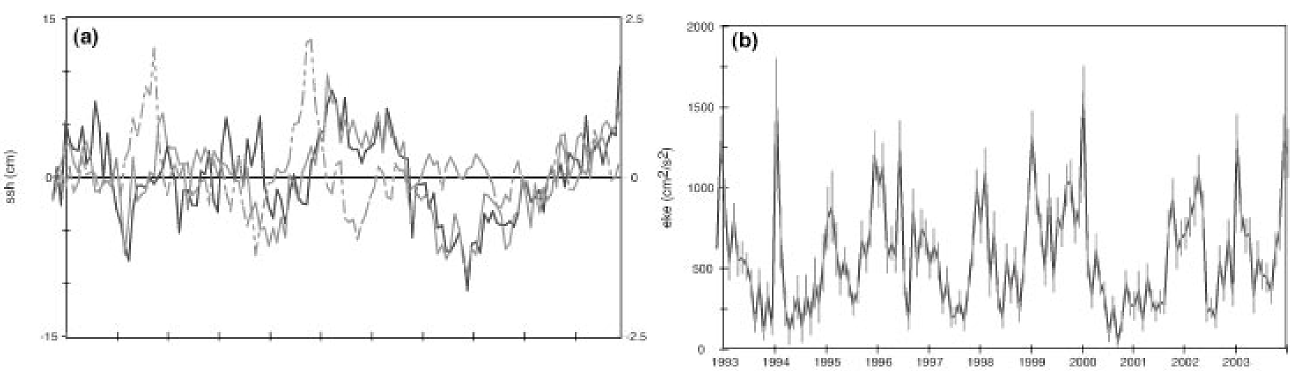
(e) 500hPa height anomalies (TPO runs)
(f) 500hPa height anomalies (TIO runs)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Announcement:
The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) is organizing an expert meeting on climate-society-environment interactions that are important to understanding climate change and its potential implications: Integrating Analysis of Regional Climate Change and Response Options. Our purpose is to explore and stimulate innovative research on connections and feedbacks across space, time and systems at scales appropriate to mitigation and adaptation decision-making. The 3-day expert meeting will be held June 20-22 2007 in Nadi, Fiji. Abstracts are requested no later than 30 November 2006. Approximately 40 persons will be selected from the submitted abstracts and invited to participate in the conference. Financial support will be available for invited participants from developing and transition economy countries. Further information, conference announcement, a call for paper abstracts, and a form for submission of abstracts are available from ipcc-wg1@al.noaa.gov .

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