Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

No. 24 (Vol. 7, No. 2) June 2002

Special issue on: CLIVAR Pacific

Latest CLIVAR News

- Dr. Howard Cattle appointed new director of the ICPO (see page 2 and 6)
- CLIVAR-relevant literature in selected journals. Visit: our new entry under Publications.
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CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to decades.

CLIVAR is a component of the World Climate Research Programme (WCRP).

Pacific Ocean Warming in Early 2002

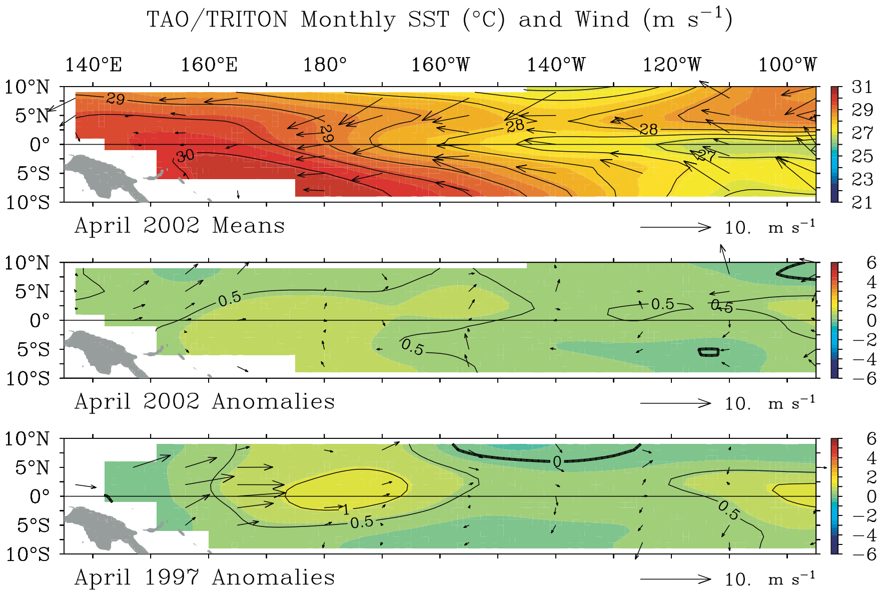


Figure 1 from paper *'TAO/TRITON Tracks Pacific Ocean Warming in Early 2002'* by M. McPhaden:
Wind vectors and sea surface temperatures from the TAO/TRITON array: monthly means for April 2002 (top panel), monthly anomalies for April 2002 (middle panel), monthly anomalies for April 1997 (bottom panel). Anomalies are based on the COADS wind climatology and Reynolds SST climatology.

The paper appears on page 7.

Call for Contributions

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for the next issue.The overarching topic will be on **science related to the Atlantic**, e.g., all aspects of THC, NAO, MOC, etc.) **The deadline for this issue is August 1, 2002.**

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http://www.clivar.org/publications/exchanges/guidel.htm

Editorial

Changes in the ICPO

In April 1998 John Gould was appointed as the Director of the ICPO. The CLIVAR Office moved from Hamburg to Southampton and John took on the challenge of managing the Project Offices of two WCRP Projects: WOCE and CLIVAR. It was a huge challenge for him. John built up the ICPO staff numbers so that the ICPO could better serve the increasing number of CLIVAR panels and Working Groups. Since 1994 he and the WOCE IPO staff have also brought WOCE to a very successful conclusion that will be marked by the Final WOCE Conference in San Antonio Texas (November 18-22 www.woce2002.tamu.edu). John reaches his 60th birthday at the beginning of August and will then retire from the ICPO director's position.

After an extensive and deliberate search process, it is our pleasure to announce and welcome Dr Howard Cattle as the next director of the International CLIVAR Project Office. Presently, Dr. Cattle is Head of Ocean Applications at the UK Met Office in Bracknell. Dr. Cattle's background in meteorology, oceanography, forecasting and management suit him and CLIVAR well for this position (see CV on page 6). Howard is clearly the right man at the right time for CLIVAR.

Howard and John will work together to make a smooth transition and then from mid October onwards Howard will assume sole responsibility for CLIVAR while John works until the end of the year on WOCE.

John is planning to spend next year at Scripps Institution of Oceanography working on the development of the Argo project. We wish him and his wife Hilary all the best for the future.

Tony Busalacchi and Jürgen Willlebrand

Footnote

Dr. Daniela Turk joined the ICPO in September 2001 and assumed responsibility for the Pacific Panel and for links to IGBP and ocean carbon. We are sorry to report that Daniela will be leaving the ICPO in mid-June. She will take up a post at the University of Dalhousie in Halifax Canada where she will become a project coordinator for the Canadian SOLAS (Surface Ocean Lower Atmosphere Study of IGBP). We thank her for all she has done for CLIVAR in the past year and wish her well for the future.

This creates a vacancy in the ICPO. An advertisement is enclosed with theis copy of Exchanges. Note the closing date for applications has been extended by 2 weeks from the date advertised

Status of CLIVAR

Antonio Busalacchi[1] and Jürgen Willebrand[2]
(co-chairs, CLIVAR SSG)

[1]Earth System Science Interdisciplinary Center
University of Maryland
College Park, USA
tonyb@essic.umd.edu

[2]Institut für Meereskunde
Kiel, Germany
jwillebrand@ifm.uni-kiel.de

Over the past year, CLIVAR has continued to grow and mature on a number of fronts. In March, 2002 the annual review of CLIVAR status was presented to the Joint Scientific Committee of the World Climate Research Programme in Hobart, Tasmania. Highlights and future challenges for CLIVAR were discussed within the context of a global perspective (OOP), ocean sectors panels (Atlantic, Pacific, Southern), monsoon panels (VAMOS, AAM, VACS), modelling (WGSIP, WGCM), and intersections with IGBP (PAGES, approach to carbon monitoring). The summary feedback and view of CLIVAR from the JSC continues to be highly favourable. Overall, the JSC was very pleased to see the degree of progress and coherence in CLIVAR. The JSC was quite impressed by the progress to date in areas of the program such as VAMOS, VACS, and basin panels such as the Southern Ocean. Much of the feedback that was received was along the lines that CLIVAR has really come of age now.

On a global scale, the work of the Ocean Observations Panel (OOP) has benefited greatly from the publication of the book that was the outcome of the CLIVAR co-sponsored Ocean Observations for Climate (OceanObs'99) conference. This conference was organized by the chairman of the OOPC, N. Smith, and CLIVAR OOP, C. Koblinsky. The chairmen of both of these panels have indicated that they wish to step down and their leadership and guidance on ocean observations for climate will be sorely missed. Implementation with ARGO floats has proceeded this year, and the OOP continues to stress the importance for coverage in all parts of the world ocean. The past year has also seen the launch of the JASON-1 satellite altimeter in December, 2001 and the ENVISAT platform in March, 2002. The CLIVAR approach to air-sea fluxes continues to evolve. A central part of which is the establishment of surface flux reference sites which represent characteristic meteorological/air-sea flux provinces. The high-quality in-situ data from these sites will be used to identify biases and errors in the ship, model and satellite data. The Tropical Moored Buoy Implementation Panel hosted a review of tropical moored buoy programs in support climate research and forecasting held at the NOAA Pacific Marine Environmental Laboratory in Seattle, Washington during 10-12 September 2001. In the Pacific, the TAO/

TRITON array continues to effectively serve a wide community of scientists involved in seasonal-to-interannual climate research and forecasting. Data from this array underpins recent forecasts of the evolving warm conditions in the tropical Pacific for 2002. Considerable progress was also made this past year under John Gould's leadership for the design of global repeat hydrography/carbon sampling and sections. CLIVAR interactions with the biogeochemical community build on the heritage established by WOCE and JGOFS. Lastly, as a result of the CLIVAR intersection with IGBP on PAGES, a strategy is developing for a Global Paleoclimate Observing System (GPOS). GPOS emerges against the backdrop of a need for paleo-environmental proxy data to put recent changes in greenhouse gas levels, global average temperature and interannual to decadal variability in a long term context.

The CLIVAR Atlantic and Southern Ocean panels have made significant strides this past year. The Atlantic Sector Panel sponsored a Workshop on Tropical Atlantic Variability (Paris 3-7 September 2001). Progress on the way towards a substantial CLIVAR presence in tropical Atlantic identified process studies on subtropical cells, meridional overturning circulation (MOC) transformation and North Atlantic Deep Water pulse effects on tropical Atlantic Variability, modelling studies on the role of interactions between ocean, atmosphere and land-surface patterns, gaps in surface ocean data, and the need for impact related research. Under the leadership of Atlantic Panel Chair, Martin Visbeck, links are being developed with VAMOS and VACS to plan joint activities in the tropical Atlantic. Similarly, a dialogue has begun with WGCM on MOC issues. At the JSC meeting, Steve Rintoul, Chair of the Southern Ocean Panel, gave an excellent scientific lecture on the advances on our understanding of the Southern Ocean during WOCE and now moving into CLIVAR. The panel was established jointly with the WCRP program on Climate and the Cryosphere (CliC) and met in Hobart March 11-13, 2002. At least 13 countries have Southern Ocean CLIVAR plans. All elements of CLIVAR Initial Implementation Plan have full or partial commitments. Monitoring of choke points South of Australia and across Drake Passage is ongoing.

This past year the Pacific panel was established and met in February 2002. Kelvin Richards is the chairman. Some of the scientific and implementation challenges to be taken on by this new panel are discussed later in this issue.

One of the best examples of the success of CLIVAR in an international context has been the progress made by the Variability of the American Monsoon (VAMOS) Panel under the direction of Roberto Mechoso. VAMOS consists of several elements. A South American Low Level Jet experiment is on track for November 2002-February 2003. The experiment includes enhancement of the observation networks in the form of an the increase of the frequency/installation of radiosondes and pibals stations, installation of an array of wind profilers and operations of a P-3 aircraft based on Santa Cruz, Bolivia. Research proposals have been funded in Argentina, and are being written/submitted in Brazil and the US. Together with GEWEX, a NAME (North American Monsoon Experiment) science and implementation plan has been drafted and a NAME Science working group has been established. A VAMOS extension of the US led Eastern Pacific Investigation of Climate (EPIC) Program is being developed to build upon the intensive observational period of EPIC September–October, 2001.

The Asian-Australian Monsoon Panel under the leadership of Peter Webster and Julia Slingo have identified several process studies being planned and coordinated with CEOP: JASMINE-2 and BOBMEX (2004) and ARMEX (2002-3). Together with VAMOS and VACS a monsoon modelling workshop is being planned to develop a CLIVAR-wide plan for monsoon simulations and model-based process studies. Whereas a few years ago, CLIVAR had no presence in Africa, Chris Thorncroft has guided the Variability of the African Climate System (VACS) Panel to a point where a West African monsoon experiment will be major activity for the panel in the coming years. Working with the French community interested in the West African monsoon, an international research project and field campaign known as AMMA (African Monsoon Multidisciplinary Analysis) is being developed.

In the modelling arena, the Working Group on Seasonal to Interannual Prediction headed by Steve Zebiak published a report on ENSO forecast skill, provided input to the WMO El Niño Assessment and reviewed observational requirements for seasonal to interannual prediction. Activities of the panel include a Seasonal Prediction Model Intercomparison Project (SMIP)-2 under way for almost a year. The initial SMIP-2 experiment investigates potential predictability, given perfect knowledge of global surface boundary conditions. SMIP-2/HFP (historical forecast project) is a second component of SMIP-2 and aims to investigate the actual 1-season forecast skill that can be obtained using current model-based objective methods. The Joint CLIVAR/JSC Working Group on Coupled Modelling continues to maintain a broad overview of modelling activities in the WCRP commensurate with its basic task of building up comprehensive climate models. Drawing from the list of uncertainties and priorities listed in the IPCC Third Assessment Report and from the experience of the members of WGCM (representing the main coupled modelling groups), the following items were set down as requiring urgent study and investigation: improved methods of quantifying uncertainties in climate projections and scenarios, including development and exploration of ensembles of climate simulations; increased understanding of the interaction between climate change and natural climate variability; the initialization of coupled models; the reduction of persistent systematic errors in cloud simulations, sea surface temperature

CLIVAR SSG and guests at the 11th Session in Xian, China.

etc.; the variations in past climate as a tool in understanding the response to climate forcing factors; the reasons for different responses in different models; improved knowledge of cloud/climate forcing and the direct/indirect effect of aerosols (including refined methodologies for refining the analysis of feedback processes); and improved simulation of regional climate and extreme events. Considerable time at the JSC was dedicated to the concept of an overarching WCRP Banner on Predictability in response to statements that there is no single organizational structure within the WCRP to provide opportunities for all WCRP components to interact on the question of the nature and predictability of the entire physical climate system.

Issues of concern to CLIVAR that were raised before the JSC included the most effective way to link with IGBP in terms of joint interests in the intersection of climate variability and biogeochemistry, free exchange and access to data especially at regional scales, funding for participation of developing nations, the WCRP approach to data management, and coordination between the WCRP research agenda and the operational activities of the WMO. Based on the interactions with the JSC and upon review of the highlights of the past year, some of the issues going into this year's SSG meeting in Xian, China were the global perspective in CLIVAR, pan-CLIVAR monsoon studies, the WCRP Banner on Predictability, the CLIVAR intersection with the carbon community, and intergovernmental mechanisms to advance CLIVAR.

CLIVAR SSG met in Xi'an

The CLIVAR SSG met in Xi'an China May 21-24 at the invitation of SSG member Prof. Wu Guoxiong (Institute of Atmospheric Physics, Beijing) and of Prof. An Zhisheng, Director of the Chinese Academy of Sciences' Institute of Earth Environment that provided the venue for the meeting. It was attended by a total of 30 SSG members, CLIVAR panel and WG chairs and by representatives of agencies and organizations. We were pleased that Dr. Peter Lemke JSC chairman also attended. The most pressing issue put before the SSG was the CLIVAR approach to global integration. Now that implementation is proceeding at the basin and regional monsoon levels, it is time for CLIVAR to build and scale up to a truly global perspective. One vital activity in this regard is reanalysis for both the atmosphere and ocean. Considerable discussion at the SSG was devoted to building on the heritage from TOGA in initiating reanalysis as a vital integration. Future initiatives for CLIVAR will be focused in this direction. Similarly, many of the monsoon modelling activities in CLIVAR be it VAMOS, AAM, or VACS suffer from common systematic errors. Thus, a workshop will be developed in the coming year to deal with these problems pan-CLIVAR. As for the WCRP Banner on Predictability there was a general sense that CLIVAR was already doing much of what was contained in the "banner". However, the discussion did serve to focus the attention on issues such as CLIVAR activities pertaining to a global assessment of predictability and the CLIVAR approach to linking observations and models.

- After much discussion it was agreed that the CLIVAR Ocean Observations Panel would evolve into a group that would focus on global reanalyses for both atmosphere and ocean and that observational issues would be devolved to the Ocean Observations Panel for Climate (OOPC) that would include representativeness of CLIVAR's basin sector panels
- The WG on Ocean Model Development (an offshoot of the WG on Coupled modelling will now fall under CLIVAR rather than WOCE. The WGOMD is initiating an ocean model intercomparison project. More information can be found on page 36.
- The ICPO will investigate sources of infrastructure funding to aid the development of CLIVAR's regional initiatives (e.g VAMOS)

The SSG co-chairs Jürgen Willebrand (left) and Anthony Busalacchi (middle) made a presentation to ICPO director John Gould (right) during a banquet at the CLIVAR SSG in Xi'an.

- The SSG is concerned about the slow pace of development of a comprehensive CLIVAR data management strategy. However it took steps to ensure that data of the type collected by WOCE will be safeguarded by the continuation of elements of the WOCE data system.

Note – CLIVAR Exchanges will in future have a regular feature on data-related topics.

- The SSG noted the need for a closer relationship between its WGs on Coupled, Ocean and Seasonal-Interannual predictive modelling and its more observationally focused regional panels. It welcomed plans for a pan-CLIVAR workshop on monsoon modelling.-

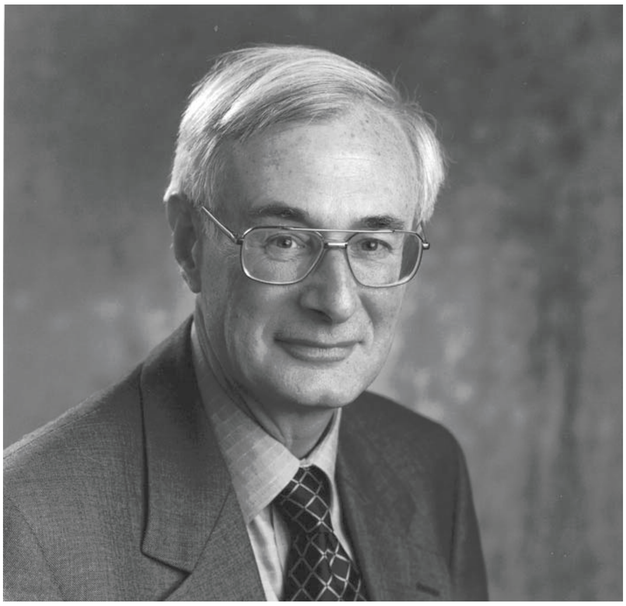
This CLIVAR SSG meeting (the 11th) was John Gould's last as ICPO Director. He had actually attended 9 CLIVAR SSGs (missing numbers 2 and 3). The CLIVAR SSG co-chairmen and Peter Lemke took the opportunity of a traditional Chinese dumpling banquet in Xi'an to thank John for his contribution to CLIVAR. On behalf of the SSG he was presented with a Chinese scroll, a wallet and a citation signed by the WCRP Director (see photo).

The week following the SSG, Professor Wu Gioxiong arranged visits in Beijing to the various agency heads with responsibility for climate science in China. During the course of the week we had a series of meetings with Chen Yiyu, Vice-President of the Chinese Academy of Sciences, Minister Xu Guan-Hua, Minister of Science and Technology (MOST), Qin Dahe, Administrator of the Chinese Meteorological Administration (CMA) and Ma Fuchen, Vice President Chinese National Natural Science Foundation. A number of common themes emerged regarding the coordination of climate science in China and how best to interface with the international CLIVAR community.

Focus of this issue

The recently formed CLIVAR Pacific panel met in February. It encompasess not just the important ENSO phenomenon but wider and lower frequency climate variability and links between the Pacific and the Indian and Southern Oceans. A report of the Pacific panel meeting can be found on page 30. To promote this new CLIVAR activity this issue of CLIVAR Exchanges is dedicated to research topics within the Pacific sector ranging from ENSO, decadal fluctuations to process type studies in the Kuroshio Extension region. We hope that you enjoy this issue of Exchanges.

New Director of the ICPO



Dr. Howard Cattle received his BSc in physics, University of London 1967 and PhD in Meteorology, Imperial College, University of London 1971. Howard joined the Met Office in 1973 as a Senior Scientific Officer working initially in Forecasting Research with responsibility for developing methods for 4-D data assimilation. He was promoted to Principal Scientific Officer 1975 and placed in charge of the group working on Physical Parameterisations. In 1976 he became Deputy Principal of the Met Office College that trains new graduate entrants to the Met Office. In 1980 he was transferred to the Dynamical Climatology Branch to head a new research group concerned with global modelling of the oceans and sea ice for climate studies. He has been involved in ocean modelling for climate research and operational oceanography since work in this area was initiated in the Met Office in the early 1980s. In 1987 he was promoted to become Assistant Director for Dynamical Climatology with overall responsibility for the Met Office's work on modelling of climate and climate change. 1989-90 he was involved in establishing the Hadley Centre for Climate Prediction and Research and in 1990 become the Programme Director of the Met Office's Climate Research Division and deputy Director of the Hadley Centre. In 1996 he become the Met Office's Head of Ocean Applications responsible for the Met Office's programme in ocean modelling for short term ocean forecasting, seasonal forecasting and climate prediction, a position he still holds. Particular interests include the polar regions where his leadership has been instrumental for the WCRP Arctic Climate System Study and Climate and Cryosphere initiative. He is currently Vice President of the Royal Meteorological Society and is the nominee for its next President starting this coming October.

We believe one of the reasons we were able to attract someone with Dr. Cattle's credentials to head the ICPO, was the solid foundation that John Gould has established within the ICPO. We have no doubt that a smooth transition will take place as a direct result of the leadership that John has displayed during the formative years of the project office. We are indebted to John for all his tireless efforts and for getting CLIVAR poised to where it is now. We look forward to working with Howard in taking CLIVAR to the next level. Howard has graciously agreed to join us at the SSG meeting in Xian to facilitate the transition. Please join us in extending our sincere thanks and debt of gratitude to John Gould and welcoming Howard Cattle on board.

Tony Busalacchi and Jürgen Willebrand
(CLIVAR SSG co-chairs)

CLIVAR Calendar

2002	Meeting	Location	Attendance
July 10-12	Atlantic Implementation Panel, 4th Session	Bermuda	Invitation
July 22-26	International TRMM Science Conference	Honolulu, USA	Open
Oct. 7-9	Working Group on Coupled Modelling, 6th Session	Victoria, Canada	Invitation
Oct. 15-18	NASA-CCR-CRCES Workshop on Decadal Climate Variability	Madison, USA	Open
Nov. 18-21	Working Group on Seasonal to Interannual Prediction 7th Session	Cape Town, South Africa	Invitation
Nov. 18-22	Final WOCE Conference	San Antonio, USA	Open
Dec. 6-10	AGU Fall Meeting	San Francisco, USA	Open
2004	**Meeting**	**Location**	**Attendance**
June 21-25	First CLIVAR Open Science Conference	Baltimore, USA	Open

Check out our Calendar under: ***http://clivar-search.cms.udel.edu/calendar/default.htm*** *for additional information*

TAO/TRITON Tracks Pacific Ocean Warming in Early 2002

Michael J. McPhaden
NOAA/Pacific Marine Environmental Laboratory
Seattle, USA
mcphaden@pmel.noaa.gov

Recent warming in the tropical Pacific Ocean has motivated organizations such as NOAA's National Centers for Environmental Prediction and the World Meteorological Organization to issue a series of El Niño/Southern Oscillation (ENSO) advisories beginning in January 2002. These advisories suggest that an El Niño may be developing this year, though there is considerable spread in model forecasts of tropical Pacific sea surface temperatures (SSTs) over the next 2-3 seasons. This report describes evolving conditions in the tropical Pacific as observed from the TAO/TRITON array which, along with other components of the ENSO Observing System, provides data for monitoring, prediction, and improved understanding of the ENSO cycle.

Introduction

The ENSO cycle is the most prominent year-to-year climate fluctuation affecting global climate. It originates through coupled ocean-atmosphere interactions in the tropical Pacific and influences the rest of the globe though oceanic and atmospheric teleconnections. Warm phases (El Niño) and cold phases (La Niña) recur with a peridiocity of roughly 3-7 years. The most recent El Niño in 1997-98 was the strongest of the 20th century; it was followed by cold La Niña conditions from 1998 to early 2001.

The ENSO Observing System was developed over a 10-year period (1985-94) under auspices of the Tropical Ocean Global Atmosphere (McPhaden et al., 2001). The system consists of satellite and in situ components, the latter of which include drifting and moored buoys, ship of opportunity XBT and meteorological measurements, and island and coastal tide gauge stations. More recently, these observations have been augmented with profiling floats as part of the Argo program.

The moored buoy component of the ENSO Observing System, previously known as the TAO (Tropical Atmosphere Ocean) Array, was officially christened TAO/TRITON on 1 January 2000 in recognition of the JAMSTEC's contribution of TRITON (Triangle Trans-oceanic Buoy Network) moorings to replace ATLAS moorings at 12 sites in the western Pacific. TAO/TRITON is supported primarily by the US (NOAA) and Japan (JAMSTEC), with additional contributions from France (IRD). ATLAS and TRITON moorings utilize compatible sensor suites, sampling strategies, and data processing procedures. Near real-time and delayed mode TAO/TRITON data are managed and distributed as a unified and integrated data set via the World Wide Web from mirror sites in the US and Japan (http://www.pmel.noaa.gov/tao/ and http://www.jamstec.go.jp/jamstec/TRITON/). TAO/TRITON data are also distributed in real-time via the Global Telecommunications System.

Ocean Warming in Early 2002

TAO/TRITON captured the basin scale development of warm conditions in the tropical Pacific in early 2002 with considerable detail. In April 2002 (most recent full month for which data are available), SSTs were close to their seasonal highs and slightly warmer than normal (by about 0.5°C) near the equator between 160°E-160°W and east of 110°W (Figure 1, front page, top and middle). Near normal easterly trade winds prevailed throughout much of the eastern and central equatorial Pacific, though west of the date line weak westerly anomalies were evident. Below the surface, the thermocline sloped down to the west along the equator east of 165°E (Figure 2, page 19, top) in response to easterly trade wind forcing. However, the upper part of the thermocline was slightly depressed in the eastern and central Pacific as indicated by the warm 1-2°C subsurface anomalies in the upper 50-150 m (Figure 2, middle).

The evolution of these weak warm conditions can be seen in 5-day averaged zonal wind, SST, and 20°C depth anomalies along the equator for the past 2 years (Figure 3, page 19). Cool La Niña conditions, which were established in the aftermath of the 1997-98 El Niño, extended into early 2001. These cool conditions were associated with stronger than normal trade winds in the western basin and reduced cloudiness and rainfall in the central Pacific. Then, in mid-2001 SSTs began to warm near the date line coincident with an increase in westerly wind burst activity in the western Pacific. These westerlies were associated with active phases of the Madden-Julian Oscillation (MJO) whose origins could be traced to the equatorial Indian Ocean in various atmospheric analyses (http://www.cpc.ncep.noaa.gov/). Episodic westerly wind forcing excited several equatorial intraseasonal Kelvin waves in late 2001 and early 2002 as evident from the eastward phase propagation of the 20°C isotherm depth. The largest of these oceanic Kelvin waves, in response to the strongest westerly wind forcing in December 2001, depressed the thermocline by 20-30 m and left above normal SSTs in its wake at all longitudes east of the date line. At the same time, intensified surface winds in the western Pacific produced cooling of the warm pool west of 160°E. These SST changes lead to a weakening of the large-scale zonal SST gradient, and to an eastward shift in deep atmospheric convection along the equator to near the date line (http://www.cpc.ncep.noaa.gov/).

Comparison with Early 1997

This sequence of events described above is similar in some respects to what occurred during the onset of the 1997-98 El Niño in early 1997. The onset of that event was characterized by several westerly wind events in the western Pacific, the excitation of equatorial intraseasonal Kelvin waves, SST warming east of the date line, SST cooling west of 160°E, and a weakening of the thermocline slope along the equator. The westerly wind bursts, dynamical ocean responses, and SST changes in early 1997 were generally stronger than in early 2002 however (see plots similar to Figure 3 in McPhaden, 1999). Conditions in April of each year for example indicate that zonal wind, SST, and subsurface temperature anomalies were significantly larger in April 1997 than in April 2002 for the region encompassed by the moored buoy array (Figures 1 and 2).

Table 1 contrasts the relative magnitude of anomalies and trends in April 1997 and April 2002 based on large-scale oceanic and atmospheric indices from NOAA's Climate Prediction Center (http://www.cpc.ncep.noaa.gov/).

Except in the NINO1+2 region near the South American Coast, warm phase ENSO-like conditions were more pronounced in April 1997 than in April 2002. Trends toward ENSO warm phase conditions were also larger between January-April 1997 than for the same four month period in 2002. Moreover, the development of warm conditions appears to be waning at present rather than amplifying as in April 1997. In the past few weeks, warm anomalies both at and below the surface have weakened in the eastern Pacific, and by the end of April anomalously cool SSTs re-emerged in the equatorial cold tongue (Figure 3). SSTs have also risen west of 160°E as westerly wind burst activity diminished, and the SOI rose from –0.9 in March to –0.3 in April.

Discussion

TAO/TRITON data indicate that heat content near the equator rebounded from low values observed in 1998-99 at the height of the recent La Niña to higher levels in 2000-01 (http://www.pmel.noaa.gov/tao/jsdisplay/). This rebound has created conditions favouring possible development of an El Niño in 2002. TAO/TRITON data also suggest that large scale ocean-atmosphere interactions in the Pacific are being mediated by intraseasonal time scale fluctuations, consistent with the notion that the ENSO cycle may be thought of as a damped or weakly unstable oscillator (Moore and Kleeman, 1999; Fedorov and Philander, 2000). Heat content was higher west of the date line in early 2000 and than in early 2001 but widespread and sustained warm SST anomalies did not appear until in mid-2001 coincident with the greater prevalence of synoptic scale wind forcing. It is possible therefore, that one or two strong westerly wind events with broad zonal fetch could accelerate the development of warm conditions this year as happened during early 1997 (Kessler and Kleeman, 2000).

Currently, several statistical and dynamical ENSO forecast models predict that the ocean warming observed in early 2002 will continue for the next two to three seasons (http://www.bom.gov.au/climate/ahead/ENSO-summary.shtml). However, other forecast models indicate persistent neutral conditions, or diminishing warm anomaly amplitudes over the same period. Boreal spring is the most difficult season from which to predict tropical Pacific SST development (Latif et al., 1998), so the spread in various model forecasts at this time is not unexpected.

Even if an El Niño does not develop in 2002 however, anomalous ocean warming has already altered weather patterns in some parts of the Pacific basin. Unusually heavy rains in Ecuador and Peru in March 2002, for example, fell in association with warmer than normal eastern Pacific SSTs. These rains led to significant flooding, crop losses, and fatalities. (The author witnessed first hand these torrential rains and the devastation they brought to Ecuador on his return to the U.S. after a TAO mooring cruise in the eastern Pacific). While such regional climate anomalies are not necessarily the harbinger of more wide spread global climatic disruptions (unless the ocean warming evident along the equator in early 2002 significantly strengthens in coming months), developments to date underscore the importance of monitoring, understanding and predicting anomalous oceanic and atmospheric conditions in the tropical Pacific, whether or not they achieve the status of El Niño (or La Niña).

Table 1: NINO temperature anomalies (in °C) and the Tahiti minus Darwin Southern Oscillation Index (SOI) for April 1997 and April 2002. Numbers in parentheses indicate the changes in these indices from the preceding January.

	NINO1+2	NINO3	NINO3.4	NINO4	SOI
Apr 97	1.3 (1.9)	0.4 (1.0)	0.5 (0.9)	1.0 (0.7)	-0.9 (-1.4)
Apr 02	1.3 (2.2)	0.2 (0.7)	0.2 (0.2)	0.6 (-0.1)	-0.3 (-0.7)

References

Fedorov, A.V., and S.G.H. Philander, 2000: Is El Niño Changing? *Science*, **288**, 1997-2001.

Kessler, W.S., and R. Kleeman, 2000: Rectification of the Madden-Julian Oscillation into the ENSO cycle. *J. Climate*, **13**, 3560-3575.

Latif, M., D.L.T. Anderson, T.P. Barnett, M.A. Cane, R. Kleeman, A. Leetmaa, J. O'Brien, A. Rosati, and E. Schneider, 1998. A review of the predictability and prediction of ENSO. *J. Geophys. Res.*, **103**, 14375–14393.

McPhaden, M.J., 1999: Genesis and evolution of the 1997-98 El Niño. *Science*, **283**, 950-954.

McPhaden, M.J., T. Delcroix, K. Hanawa, Y. Kuroda, G. Meyers, J. Picaut, and M. Swenson, 2001: The El Niño/Southern Oscillation (ENSO) Observing System. In: *Observing the Ocean in the 21st Century*. Australian Bureau of Meteorology, Melbourne, Australia, 231-246.

Moore, A.M., and R. Kleeman, 1999: The non-normal nature of El Niño and intraseasonal variability. *J. Climate*, **12**, 2965-2982.

ENSO and Atmospheric Circulation Cells

Chunzai Wang
NOAA Atlantic Oceanographic and Meteorological Laboratory
Miami, USA
Chunzai.Wang@noaa.gov

1. Introduction

Bjerknes (1969) first visualized a close relation among the Southern Oscillation, east-west SST contrast in the equatorial Pacific Ocean, and the thermally driven zonal Walker circulation. Since then, the Walker circulation has been recognized to be associated with the interannual phenomenon of ENSO and schematic diagrams of the Walker circulation cell during ENSO have been well-known (e.g., Webster and Chang, 1988; McPhaden et al., 1998). However, how the Walker circulation cell evolves during ENSO from data has not been well studied, probably because of a lack of observational data. The atmosphere also has meridional circulation cells: the Hadley cell and the Ferrel cell (e.g., Trenberth et al., 2000; and references there). Little is known about how these atmospheric meridional cells vary during the evolution of ENSO. The recently available data of the NCEP-NCAR reanalysis field provide an opportunity to study the atmospheric circulation associated with ENSO. This note also reports an atmospheric mid-latitude zonal cell (MZC) over the North Pacific. Additionally, it shows how the Pacific El Niño affects the tropical North Atlantic through the Walker and Hadley cells.

2. Mean and interannual atmospheric cells

This note briefly summarizes mean and interannual atmospheric circulation cells over the Pacific that are analysed from the NCEP-NCAR reanalysis field from 1950-1999. Detailed data analyses are available in Wang (2002a, b). Atmospheric circulation cells are identified by atmospheric vertical motion and the divergent component of the wind.

Based on the data analysed from the NCEP-NCAR reanalysis, the mean state and anomaly of the equatorial zonal Walker cell, the tropical meridional Hadley cell, the extratropical meridional Ferrel cell, and the MZC are summarized in Fig. 1. The mean Walker circulation cell is characterized as the air ascending in the equatorial western Pacific, flowing eastward in the upper troposphere, sinking in the equatorial eastern Pacific, and returning toward the equatorial western Pacific in the lower troposphere (Fig. 1a). The western Pacific shows a single mean Hadley cell, with the air rising in the tropical region, flowing poleward in the upper troposphere, and returning to the tropics in the lower troposphere. In the eastern Pacific, the tropical circulation has two meridional cells with moist air rising in the intertropical convergence zone (ITCZ), then diverging northward and southward in the upper troposphere, and descending over the regions of the subtropical high and the equatorial eastern Pacific cold tongue. The extratropics shows a classical Ferrel cell, with upward motion in the mid-latitudes and downward motion in the southern extratropics.

The mean MZC shows that the air rises in the central North Pacific, diverges eastward and westward in the upper troposphere, descends over regions of the west coast of North America and the east coast of Asia, then flows back to the central North Pacific in the lower troposphere. As in the Walker and Hadley cells, the MZC is identified by the divergent wind and the pressure vertical velocity. If we also consider the rotational wind, the MZC is not a closed cell (Wang, 2002a).

The atmospheric cells also vary with the interannual phenomenon of ENSO. Figure 1b shows the anomalous atmospheric cells for the mature phase of El Niño. During the mature phase of El Niño, both the Walker cell and the MZC are weakened. The anomalous Hadley cell in the eastern Pacific during the mature phase of El Niño shows the air rising in the tropical region, flowing northward in the upper troposphere, descending in the mid-latitude, and returning to the tropics in the lower troposphere. The anomalous Hadley cell in the western Pacific has an opposite rotation as that of the anomalous Hadley cell in the eastern Pacific.

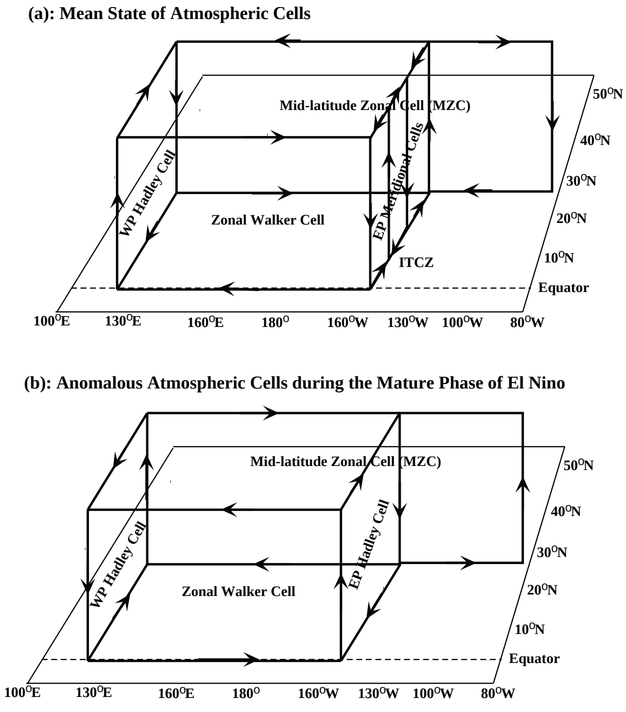


Fig. 1: Schematic diagrams summarizing (a) mean state of atmospheric circulation cells and (b) anomalous atmospheric cells during the mature phase of El Niño. Shown are the equatorial zonal Walker cell, the merdional Hadley cell in the western Pacific (WP), the meridional Hadley and Ferrel cells in the eastern Pacific (EP), and the mid-latitude zonal cell (MZC). The schematic diagrams are drawn, based on the data analysed from the NCEP-NCAR reanalysis field (Wang, 2002a).

3. Influence of the Pacific El Niño on the tropical North Atlantic

The SST anomalies in the tropical North Atlantic (TNA) and in the Niño3 region are shown in Fig. 2. The maximum positive correlation of 0.47 occurs when the TNA SST anomalies lag the Nino3 SST anomalies by five months, consistent with previous studies (e.g., Curtis and Hastenrath, 1995; Enfield and Mayer, 1997). Since the mature phase of the Pacific El Niño occurs around December of the Pacific El Niño year, the TNA SST anomalies thus tend to peak around subsequent May of the Pacific El Niño year. Previous studies have suggested that the Pacific El Niño affects TNA northeast (NE) trade winds that reduce latent heat flux and then increase the TNA SST. The question is: how does the Pacific El Niño affect the TNA trade winds? Herein, the Walker and Hadley circulations are emphasized for linking the Pacific El Niño with the TNA.

The anomalous Walker and Hadley cells during the mature phase of El Niño, analysed from the NCEP-NCAR reanalysis field (Wang, 2002b; Wang and Enfield, 2002), are summarized in Fig. 3. The air anomalously ascends in the far equatorial eastern Pacific, diverges eastward in the upper troposphere, and then descends over the equatorial Atlantic. Associated with this anomalous Atlantic Walker circulation is an anomalous Hadley circulation cell in the Atlantic. The Hadley cell shows anomalous ascending motion in the region of the subtropical high. The anomalous ascending motion weakens subsidence in the region of the subtropical high pressure system. This corresponds to a weakening of the subtropical high and the associated NE trade winds over its southern limb in the TNA region. The weaker NE trades reduce evaporation, leading to warm SST anomalies over the TNA in the subsequent spring of the Pacific El Niño year. When the warm TNA SST anomalies are established in spring, the TNA region shows anomalous ascending motion (Wang, 2002b).

Relationship of ENSO with the tropical North Atlantic

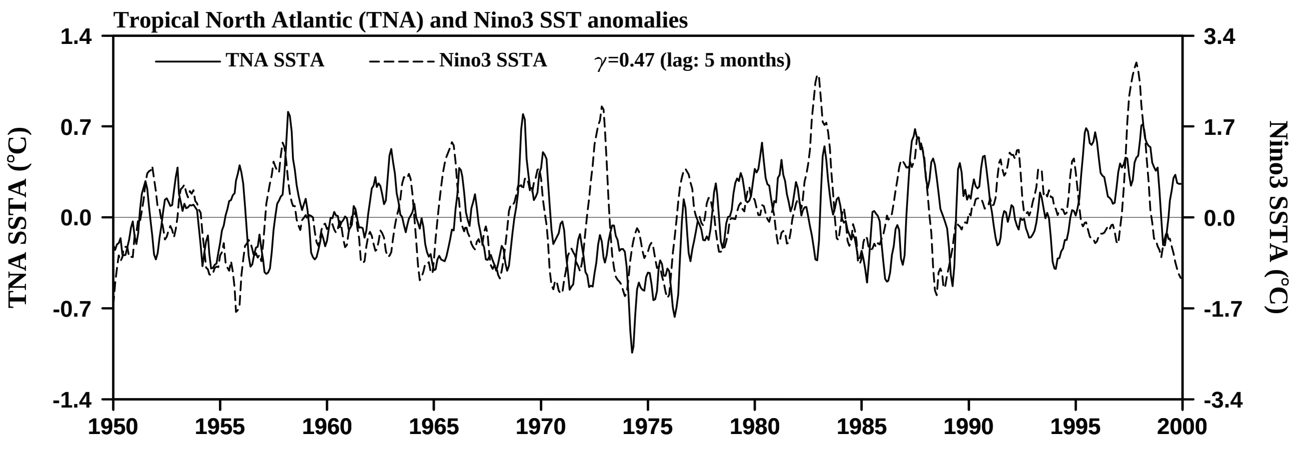


Fig. 2: Three-month running means of SST anomalies in the tropical North Atlantic (TNA) region (5°N-25°N, 55°W-15°W) and SST anomalies in the Nino3 region (5°S-5°N, 150°W-90°W). The γ represents correlation coefficient. The data are from the NCEP SST.

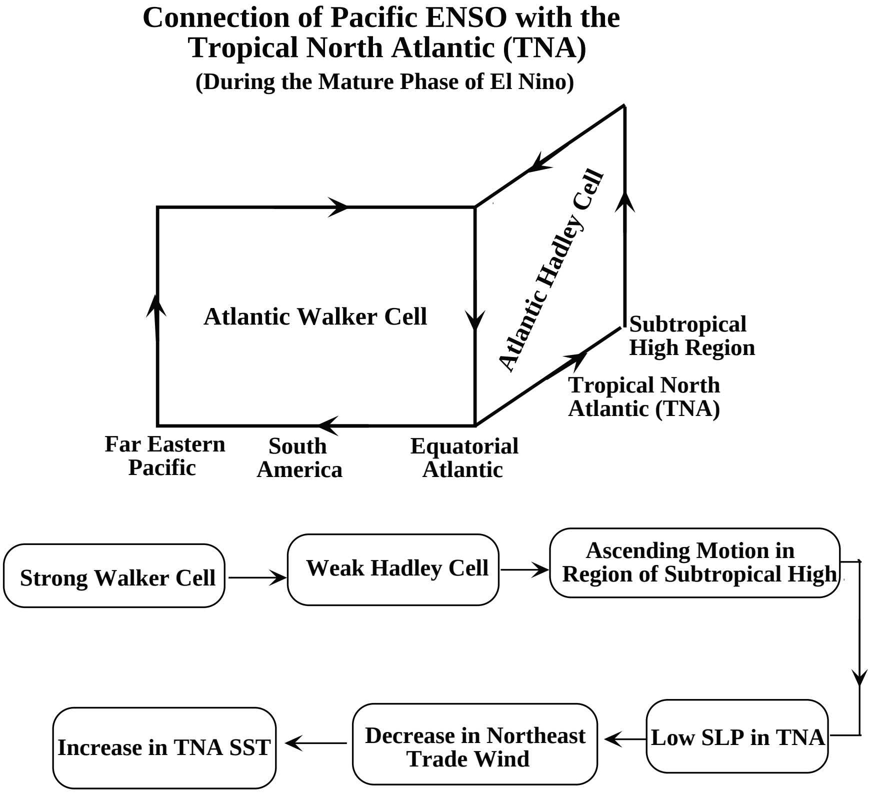


Fig. 3: Schematic diagrams showing linkage of the Pacific El Niño with the tropical North Atlantic (TNA). The anomalous Atlantic Walker and Hadley circulation cells are drawn, based on the data analysed from the NCEP-NCAR reanalysis field (Wang, 2002b).

4. Summary

The NCEP-NCAR reanalysis field shows interannual variations of atmospheric circulation cells. During El Niño, the equatorial zonal Walker cell is weakened. The anomalous meridional Hadley circulation cell in the eastern Pacific shows the air rising in the tropics, flowing poleward in the upper troposphere, sinking in the subtropics, and returning to the tropics in the lower troposphere. The anomalous Hadley cell in the western Pacific is opposite to that in the eastern Pacific. The divergent wind and vertical velocity also show a MZC over the North Pacific. The mean MZC is characterized by the air rising in the central North Pacific, flowing westward and eastward in the upper troposphere, descending in the east coast of Asia and the west coast of North America, then returning back to the central North Pacific in the lower troposphere. The anomalous MZC during the mature phase of El Niño shows an opposite rotation to the mean MZC, indicating a weakening of the MZC. During the boreal winter a strong Hadley cell emanates northward from the Amazon heat source with subsidence over the subtropical North Atlantic, sustaining a strong North Atlantic anticyclone and associated NE trade winds over its southern limb in the TNA. This circulation, including the NE trades, is weakened during Pacific El Niño winters and results in a spring warming of the TNA.

Acknowledgments

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References

Bjerknes, J., 1969: Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev.*, **97**, 163-172.

Curtis, S., and S. Hastenrath, 1995: Forcing of anomalous sea surface temperature evolution in the tropical Atlantic during Pacific warm events. *J. Geophys. Res.*, **100**, 15835-15847.

Enfield, D.B., and D.A. Mayer, 1997: Tropical Atlantic sea surface temperature variability and its relation to El Niño-Southern Oscillation. *J. Geophys. Res.*, **102**, 929-945.

McPhaden, M.J., A.J. Busalacchi, R. Cheney, J.R. Donguy, K.S. Gage, D. Halpern, M. Ji, P. Julian, G. Meyers, G.T.Mitchum, P.P. Niiler, J. Picaut, R.W. Reynolds, N. Smith, and K. Takeuchi, 1998: The Tropical Ocean-Global Atmosphere observing system: A decade of progress. *J. Geophys. Res.*, **103**, 14169-14240.

Trenberth, K.E., D.P. Stepaniak, and J.M. Caron, 2000: The global monsoon as seen through the divergent atmospheric circulation. *J. Climate*, **13**, 3969-3993.

Wang, C., 2002a: Atmospheric circulation cells associated with the El Niño-Southern Oscillation. *J. Climate*, **15**, 399-419.

Wang, C., 2002b: Atlantic climate variability and its associated atmospheric circulation cells. *J. Climate*, **15**, 1516-1536.

Wang, C., and D.B. Enfield, 2002: A further study of the tropical Western Hemisphere warm pool. *J. Climate*, submitted.

Webster, P.J., and H.R. Chang, 1988: Equatorial energy accumulation and emanation regions: impacts of a zonally varying basic state. *J. Atmos. Sci.*, **45**, 803-829.

Intraseasonal Oscillation Anomalies in the Tropical Atmosphere and El Niño Events

Chongyin Li and Zhenxia Long
Institute of Atmospheric Physics, CAS
Bejing, China
lcy@lasg.iap.ac.cn

1. Introduction

Although the relationship between the ISO and El Niño has been studied as two kinds of climate systems, and their linking relation (Lau and Chan, 1986; Lau and Chan, 1988) and their interaction (Li and Zhou, 1994) have been indicated preliminarily. For the El Niño event in 1997, some studies also show that the occurrence of El Niño in 1997 was closely related to abnormal enhancement of the ISO over the western equatorial Pacific during winter 1996 - spring 1997 (Nakazawa, 1999; Li and Long, 2001). But until now, the relationship between the ISO and El Niño events has not been understood very well.

Based on data analyses, this paper will focus on describing the relationship between the ISO and El Niño. The 40-year (1958-1997) daily NCEP reanalyses wind data at 850hPa are used in this study. Besides the NCEP data, the monthly OLR and monthly SST (1^ox1^o) data from Hadley Centre are also used.

2. Interannual Variation of the ISO and El Niño Event

In this study kinetic energy of the intraseasonal oscillation in the tropical atmosphere is used because it is an important parameter that characterizes the activity of the ISO and it is more convenient than the wind data. In this paper, K is used to describe the relationship between interannual variation of the ISO and El Niño events. The kinetic energy analysis was performed in the following way: After filtering the daily wind field at 850hPa on the 30-60 day window, the kinetic energy $K=(u_b{}^2+ v_b{}^2)/2$ can be calculated by using the band-passed filtered data (u_b, v_b).

In Figure 1 (page 20) the climate averaged kinetic energy of the ISO is showing higher values in the tropical Indian ocean, but its interannual variation is. The maximum of the interannual variability of the ISO kinetic energy is located over the equatorial Pacific (figure omitted). Fig. 1 shows the standard variance distribution of the normalized ISO kinetic energy (approximately representing the interannual variation of the ISO kinetic energy), the shaded area denote values larger than 0.9. This means the equatorial central to western Pacific is a key region for the interannual variation of the ISO.

The SSTA in the Niño3.4 region is used to describe the ENSO cycle and the mature phase of El Niño that generally appears in November. The correlation coefficients between the ISO kinetic energies and the SSTA in Niño3.4 documents that the correlation is strong in spring and summer prior to the mature phase of El Niño. At the same time, the centre of maximum correlation move slowly along with the centres of positive anomalies of the ISO kinetic energy. After the mature phase of El Niño, the correlation becomes very weak.

The distribution of the correlation coefficient between the SSTA in Niño3.4 during October-December and the ISO kinetic energy in the former May-September is shown in Fig.2. In the shaded area the 99% significance level is exceeded. The strong positive correlations over the western equatorial Pacific region document that the ISO kinetic energy is significantly strengthened prior to the mature phase of El Niño, but very weak prior to the mature phase of La Niña. The results suggest that the ISO enhancement in spring and summer plays a possible important role in the formation of El Niño events.

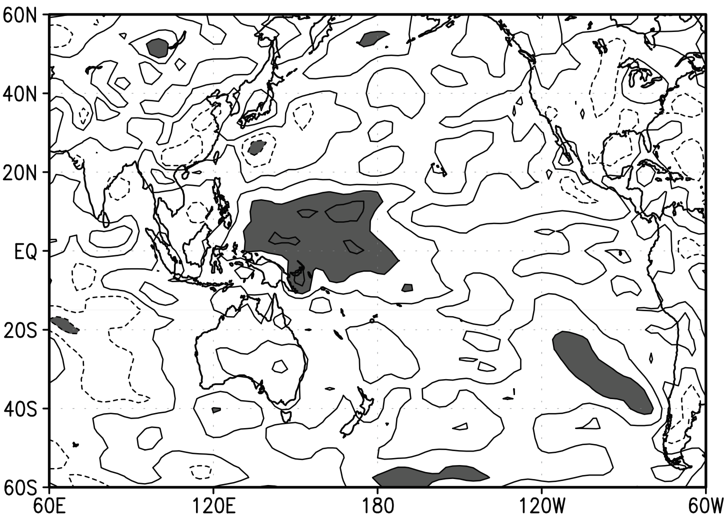


Fig. 2: Distribution of correlation coefficient between the SSTA in Niño3.4 in October-December and kinetic energy of the ISO during the last May-September, interval: 0.2; The shaded area represents the area with significance level above 99%.

To further emphasize the relationship between the ISO kinetic energy and El Niño the five stronger El Niño events in 1965-66, 1972-73, 1982-82, 1986-87, 1997-98 were chosen to conduct composite analyses of the ISO kinetic energy. Note, that the same events are chosen for all the composite figures in this paper. It is clear (figure omitted) that in the winter prior to the occurrence of El Niño, there are positive anomalies of the kinetic energy in the region to the southeast of Philippines. In spring (March-May) and summer (June-August), the centres of positive anomalies strengthen and move eastward. During the mature phase of El Niño in fall,

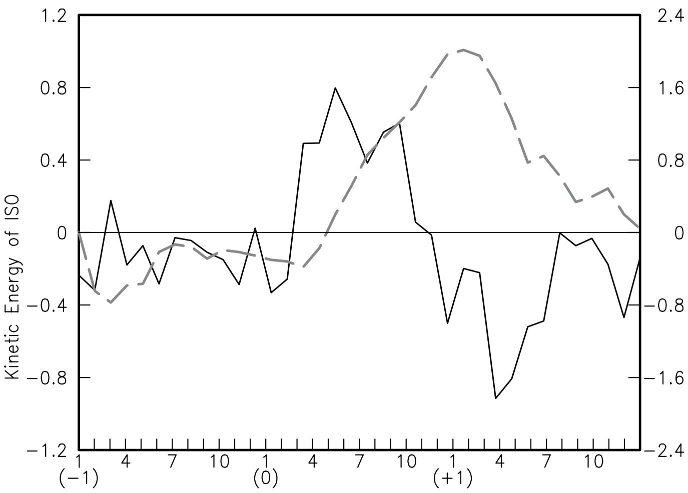


Fig. 3: Temporal evolutions of composite SSTA (broken line) in Niño3.4 and composite ISO kinetic energy anomaly (solid line) over the equatorial western Pacific (10°S-10°N, 130°E-180°).

the centres of positive anomalies continue to move eastward but with very weak amplitude. Thereafter, there are weak negative anomalies over the equatorial Pacific.

Fig 3 displays the composite results of the SSTA in Niño3.4 and the ISO kinetic energy over the western equatorial Pacific to further understand the relationship between the ISO kinetic energy and El Niño. The horizontal coordinate (-1), (0) and (+1) represent the last year of El Niño occurrence, the year of El Niño mature phase and the year after the of El Niño mature phase, respectively. The SSTA in Niño3.4 (broken line) clearly documents a life cycle of El Niño. The evolution of the ISO kinetic energy (solid line) shows that there are positive anomalies of the ISO kinetic energy over the western equatorial Pacific during spring-summer prior to the mature phase of El Niño. When El Niño reaches its mature phase, the ISO kinetic energy significantly decreases. Based on the analyses with ECMWF data in the 1980s, a similar relationship between El Niño and the ISO over the western equatorial Pacific was found by Li and Zhou (1994). Therefore, we conclude that a significant correlation between interannual variation of the ISO over the western equatorial Pacific and El Niño exists.

3. Interannual Variation of the ISO and Winter Monsoon Anomalies in East Asia

It has been suggested in some other studies that stronger cumulus convection over the western equatorial Pacific are closely related with stronger winter monsoon in East Asia (Li, 1988; Li, 1990). In the following we focus therefore the relationship between the interannual variation of the winter monsoon in East Asia and the ISO.

Fig.4a shows the distribution of the correlation coefficient between the winter monsoon index (defined as mean meridional wind component (v) over the region (120°-150°E, 20°-35°N) in November-April) and the OLR over the tropical Pacific (in shaded areas the 99% significance level is exceeded). It is clear that the cumulus convection over the tropical western Pacific (including South China Sea region) is stronger if the East-Asian winter monsoon is stronger than normal. In contrast, if the winter monsoon is weaker than normal, the cumulus convection over tropical western Pacific is also weaker. In Fig. 4b the temporal evolution of winter monsoon index and OLR anomalies over the tropical western Pacific are displayed. Significant positive correlations between the winter monsoon index in East Asia and the OLR anomalies over the tropical western Pacific can be

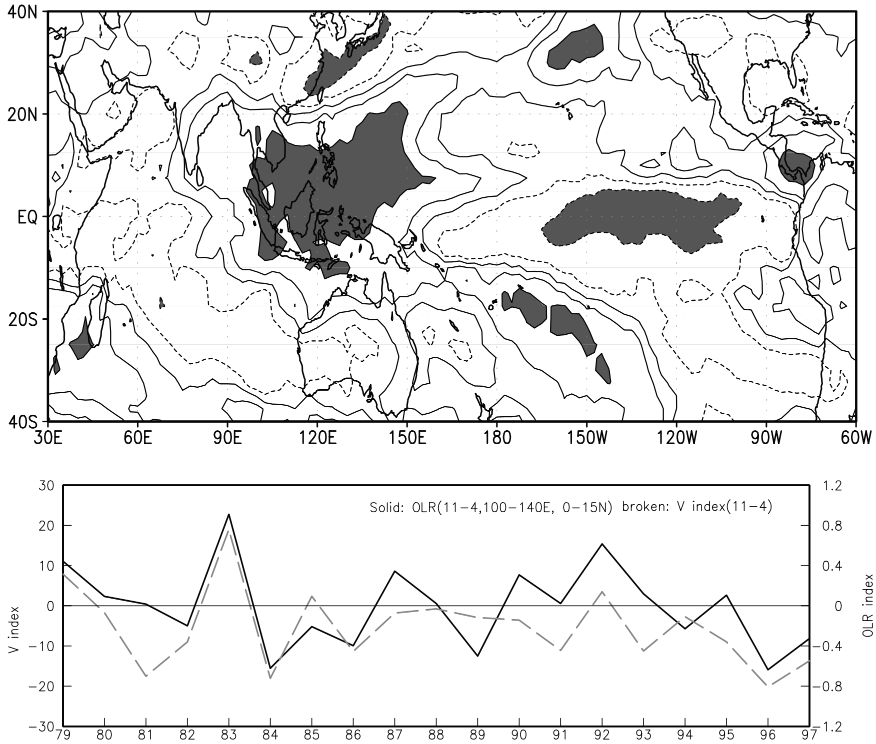


Fig. 4 (top): Distribution of correlation coefficient between the winter monsoon index anomalies, averaged v in region (120°-150°E, 20°-35°N) in November-April, and OLR anomalies, where the shaded area represents the area with significance level above 99%, interval: 0.3;
Bottom: Temporal evolution of winter monsoon index anomalies (broken line) and OLR anomalies (solid line) over the equatorial western Pacific (0°-15°N, 100°-140°E).

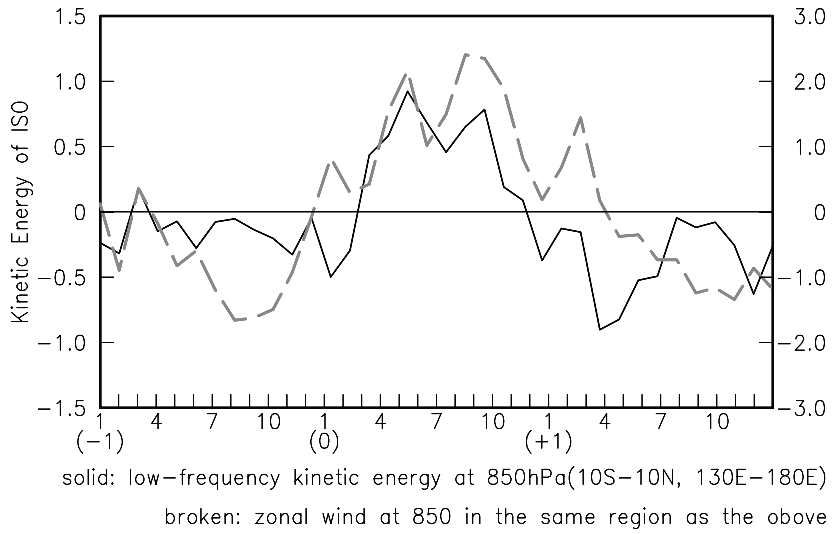


Fig. 5: Temporal evolutions of composite zonal wind anomalies (broken line) at 850hPa and kinetic energy anomaly of the ISO (solid line) over the equatorial western Pacific.

found. This means that the cumulus convection (or the ISO) is enhanced over tropical western Pacific by strong East-Asian winter monsoon.

To further investigate the effect of an anomalous winter monsoon in East Asia on interannual variation of the ISO over the western equatorial Pacific, the temporal evolutions of the winter monsoon index and kinetic energy anomalies of the ISO over tropical western Pacific are analysed. It is clear that the winter monsoon index is negatively correlated with the ISO kinetic energy over the western equatorial Pacific. It also means that the stronger (weaker) ISO over the western equatorial Pacific is associated stronger (weaker) East-Asian winter monsoon in the former period. Based on the discussions above, the winter monsoon in East Asia stimulates the ISO through the excitation of cumulus convection over the tropical western Pacific. The effect of an anomalous winter monsoon can last for a long time through coupled feedbacks. This is consistent with the previous statistical analysis results by Ji and Sun (1996).

4. Possible Mechanism of El Niño Event Excited by the ISO

El Niño results from tropical air-sea interactions, but its exact mechanism is still questionable, particularly the role of the ISO. To understand it, the impact of the interannual variation of the ISO as an external forcing on ENSO cycle was studied in a simple air-sea coupled model (Li and Liao, 1998). The result suggested that the coupled mode without external forcing is a periodic oscillation due to the air-sea interaction; under an external forcing with interannual variations, the coupled mode shows realistic ENSO-like aperiodic solutions.

It is well known that the cumulus convection over the equatorial Pacific is an important mechanism of the ISO. But the ISO itself has also a positive feedback to the cumulus convection. A strengthened cumulus convection leads to westerly wind anomalies over the western equatorial Pacific. Eastward propagating westerly wind anomalies over the western equatorial Pacific, which are associated with the eastward propagation of the centre of positive ISO kinetic energy anomalies, will weaken the Walker circulation and accelerate the formation of an El Niño event. To prove and understand this process, the composite analyses of zonal wind anomalies at 850hPa and kinetic energy anomaly of the ISO were performed. It is shown (Figure omitted) that the maximum positive anomaly of kinetic energy originates over tropical western Pacific in winter, then gradually strengthens and propagates eastward. Corresponding to the centre of kinetic energy anomalies, there is anomalous cyclonic circulation north to the equator and there are westerly wind anomalies along the equator. Accompanying with the strengthening and eastward movement of the centre of positive ISO kinetic energy anomalies, the anomalous cyclonic circulation and the equatorial westerly anomalies will also be gradually strengthened and move eastward. In Fig. 5 the temporal evolutions of composite zonal wind anomalies and kinetic energy anomalies of the ISO over the western equatorial Pacific also show a consistent variability feature but the zonal wind anomaly lags the kinetic energy increase of the ISO. It is clear that in the spring and summer prior to the mature phase of El Niño, the ISO kinetic energy over the western equatorial Pacific increases followed by westerly wind anomalies. The ISO kinetic energy over the western equatorial Pacific will decrease after the occurrence of El Niño, as well as the westerly winds. Therefore, the ISO possibly plays an important role in the formation of El Niño through atmospheric feedbacks, especially with the zonal wind anomalies.

5. Conclusion

Significant correlations between interannual anomalies of the ISO over the western equatorial Pacific and El Niño have been found. The ISO over the western equatorial Pacific is stronger than normal and gradually moves eastward prior to the mature phase of El Niño; during and after the mature phase of El Niño, the ISO is weaker than normal.

A strong East-Asian winter monsoon leads to the strengthening of the cumulus convection and further leads to a strong ISO over the western equatorial Pacific. Due to atmospheric feedbacks, the effect of East-Asian winter monsoon can last for a long time.

Corresponding to the enhanced ISO over the western equatorial Pacific, there are anomalous cyclonic circulations north side of the equator and westerly wind anomalies along the equator. Along with the strengthening and eastward movement of the centres of positive ISO kinetic energy anomalies, westerly wind anomalies appear over the western equatorial Pacific. Thus, the Walker circulation will be reduced and the El Niño event will be generated through the air-sea interaction.

References

Ji, L., and S. Sun, 1996: Observational and model study on interseasonal connection of atmospheric circulation. In: *From Atmospheric Circulation to Global Change*. China Meteorological Press, Bejing, 365-376.

Lau, K.M., and P.H. Chan, 1986: The 40-50 day oscillation and the El Niño/Southern Oscillation: A new perspective. *Bull. Amer. Meteor. Soc.*, **67**, 533-534.

Lau, K.M., and P.H. Chan, 1988: Intraseasonal and interannual variations of tropical convective: a possible link between the 40-50 day oscillation and ENSO? *J. Atmos. Sci.*, **45**, 506-521.

Li, C., 1988: Frequent activities of stronger aerotroughs in East Asia in wintertime and the occurrence of the El Niño event. *Science in China (B)*, **32**, 976-985.

Li, C., 1990: Interaction between anomalous winter monsoon in East Asia and El Niño events, *Advances Atmos. Sci.*, **7**, 36-46.

Li, C., and Y. Zhou, 1994: Relationship between intraseasonal oscillation in tropical atmosphere and ENSO. *Chinese J. Geophysics*, **37**, 213-223.

Li, C., and Q. Liao, 1998: The exciting mechanism of tropical atmospheric intraseasonal oscillation to El Niño event. *J. Trop. Meteor.*, **14**, 113-121

Li, C., and Z. Long, 2001: El Niño occurrence in 1997 and intraseasonal oscillation anomalies in the tropical atmosphere. *Chinese J. Atmos. Sci.*, **25**, 435-446.

Nakazawa, T., 1999: MJO triggered 1997/98 ENSO. *Proceedings of the 22nd General Assembly of IUGG*, Birmingham, UK, 18-30 July 1999 .

The Indian Ocean Dipole: a Physical Entity

Toshio Yamagata[1,2], Swadhin K. Behera[2], Suryachandra A. Rao[2], Zhaoyong Guan[2], Karumuri Ashok[2] and Hameed N. Saji[2]

[1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo Tokyo, Japan
[2]Climate Variations Research Program, Institute for Global Change Research, Frontier Research System for Global Change, Yokohama, Japan
yamagata@eps.s.u-tokyo.ac.jp

1. Introduction

The El Niño/Southern Oscillation (ENSO) phenomenon has been discussed for more than a century and is now recognized, after the active TOGA decade, as the most important tropical ocean-atmosphere coupled phenomenon. Recently, the Indian Ocean Dipole (IOD) phenomenon has been catalogued as another important manifestation of the tropical air-sea interaction (Saji et al., 1999; Webster et al., 1999; Behera et al., 1999; Vinayachandran et al., 1999; Murtugudde et al., 2000; Rao et al., 2002; Vinayachandran et al., 2002). It has also turned out that the impact of the IOD is not limited to the equatorial Indian Ocean; it influences the Southern Oscillation (Behera and Yamagata, 2002), the Indian summer monsoon rainfall (Ashok et al., 2001) and even the summer climate condition in Asia (Saji and Yamagata, 2002c). The robust nature of the IOD as an ocean-atmosphere coupled phenomenon is simulated successfully using high-resolution coupled GCMs that also resolve ENSO in the Pacific (Iizuka et al., 2000; Cai et al., 2002 (personal communication)). However, because of its inevitable short history of research, several interesting issues related to its existence/nonexistence and dependence/independence of ENSO have been raised by some researchers (e.g., Allan et al., 2001; Dommenget and Latif, 2002; Baquero-Bernal and Latif, 2002).

In this study, using multiple datasets such as GISST 2.3b (Rayner et al., 1996), sea surface height from SODA (Carton et al., 2000), rainfall (Xie and Arkin, 1996) and atmospheric data derived from NCEP-NCAR reanalysis (Kalnay et al., 1996), we demonstrate that the Indian Ocean Dipole (IOD) is a physical mode involving dynamics of the tropical Indian Ocean. We believe that the concept of IOD has raised a new question, and a new possibility to regard the old problems such as the relation between the Indian summer monsoon rainfall and El Niño from a new angle, and to make a real advance in the predictability of climate variations originated in the tropics.

2. IOD as a physical entity

As noted by previous studies using the EOF analysis, a basin-wide SST anomaly, mainly ENSO induced, appears statistically as the most dominant interannual mode in the Indian Ocean (Cadet, 1985; Klien et al., 1999; Wallace et al., 1998; Venzke et al., 2000). The zonal dipole pattern of the present concern appears as the second EOF mode. It may be noted here that the dipole mode shows up as the dominant signal in some years. For example, it was the case during May through November in 1994. Behera et al. (1999) showed that a remarkable dipole in OLR anomalies also overlies the SST dipole (Fig. 1a, page 20). In contrast to the 1994 event where the dipole is prominent only in the Indian Ocean, a similar phenomenon in 1997 was accompanied by another dipole pattern in the Pacific due to simultaneous occurrence of the well-known El Niño event (Fig. 1b).

The IOD phenomenon is not confined only to these recent events. According to the GISST data, SST anomalies show opposite polarities in the eastern and western Indian Ocean during 178 months in total 504 months from 1958 to 1999. The opposite polarity in SST anomalies is associated with corresponding opposite anomalies in the zonal winds in central equatorial Indian Ocean. In response to the anomalous winds, the sea level was depressed (raised) in the eastern (western) Indian Ocean during the positive (negative) dipole events. The IOD indices derived from all these oceanic and atmospheric variables are shown in Fig. 2 (page 20); all those indices are remarkably consistent with each other. Interestingly, either of the poles in the sea level anomalies capture the dipole mode very well as it is the IOD that dominates the variability in the subsurface layer (Rao et al., 2002). This establishes the physical existence of the IOD beyond any doubt.

In contrast to the above observation, Dommenget and Latif (2002) (hereafter referred to as DL) have questioned the existence of the IOD by only analyzing the SST, statistically, despite the fact that the IOD is introduced as a physical mode based on various oceanic and atmospheric variables as discussed above. Recently Behera et al. (2002) (hereafter referred to as BRSY) using a synthetic example, just like that in DL, demonstrated the fallacy in DL's approach. Since correlation reflects the dominant mode of variability (cf. Jolliffe, 1987), which is the basin-wide monopole mode in the Indian Ocean, DL fail to capture the dipole. In a reconstructed dataset, after removing the dominant mode, BRSY showed the existence of dipole using linear regression (Fig. 3, page 21), EOF and even the VARIMAX method.

3. IOD as a coupled mode inherent in the Indian Ocean

Since we have demonstrated that IOD really exists in the Indian Ocean, the next question is whether IOD events in the Indian Ocean are independent of ENSO events in the Pacific. This is a natural question now that we have two oscillators under the global atmosphere. Owing to the non-orthogonality between the two time series, the simultaneous correlation coefficient between DMI and Niño-3 indices is 0.37. The correlation coefficient increases in the seasonally stratified data, reaching up to 0.54 for September through November. Therefore, we are apt to conclude that IOD events occur as a part of ENSO events (Allan et al., 2001; Baquero-Bernal and Latif, 2002). However, the non-orthogonality of two time series does not necessarily mean that the two phenomena are always connected in a physical space. It is also important to note in general that the apparently high correlation of 0.54 explains only about 30% of total variance in terms of possible ENSO association; we still have 70% variance unexplained by this external influence.

To understand the physical nature of the possible connection, we investigate the Walker circulation that may connect the Indian Ocean with the Pacific through the atmospheric bridge. Here the Walker circulation is diagnosed from the zonal mass flux formulation as described by Newell et al. (1974) and Bergman and Hendon (2000). In order to distinguish the nature of the zonal cell in response to all IOD events and pure IOD events, we made two different composites. A positive (negative) IOD event is considered as a pure event when it is not accompanied simultaneously by El Niño (La Niña) (see Table I). The presence of the anomalous Walker cell in the Indian Ocean is clearly seen in both plots (Figs. 4a and 4b, page 21). The cell in the Indian Ocean is much stronger compared to the Pacific counterpart. However, the composite for the pure IOD events (Fig. 4a) clearly shows an anomalous cell operating only in the Indian Ocean, thereby confirming the independent occurrence of the pure IOD. To escape from misunderstanding, we repeat that this analysis does not exclude the possibility that some IODs may be physically linked with some ENSO events.

The point of the matter is further clarified when we make similar composites for SST and sea surface height (Figs. 5 and 6, pages 21 & 22). The SST composites (Fig. 5a and 5b) for all IOD events show dipole patterns in both the Indian Ocean and the Pacific Ocean. The warm anomaly pattern seen in eastern Pacific (Fig. 5a), however, disappears in the composite map of pure IOD events (Fig. 5b). Those are consistent with the composites of the Walker circulation shown in Fig. 4. In contrast, the pure ENSO composite (see Table I) does not show any basin-wide dipole pattern in the Indian Ocean, as expected. Cold SST anomalies are, however, seen along the coast of Australia and near the Indonesian throughflow region in the pure ENSO composite (Fig. 5d). Fig. 6d shows negative sea surface height anomalies associated with this coastal phenomenon without the basin-wide scale. This phenomenon is due to intrusion of the western Pacific signal during the mature phase of El Niño through the Indonesian passage and the subsequent spreading of water mass along the Australian coast by coastal Kelvin waves. It is discussed by Clarke and Liu (1994) theoretically and confirmed by Meyers (1996) using XBT data; we prefer to call this as the Clarke-Meyers effect.

Although the above coastal phenomenon explains partly the high correlation between DMI and Niño-3 particularly during the boreal fall, it should not be confused with the basin-wide phenomenon of IOD (Fig. 5d). Both the pure and all IOD composites show clearly that the lower sea surface height anomaly in the eastern Indian Ocean is accompanied by the higher anomaly in the central Indian Ocean (Fig. 6a and 6b). However, such a pattern is completely missing in the pure ENSO composites. The fact that sea surface height does not show any significant east-west slope in case of the pure ENSO suggests that basin-wide ocean dynamics do not play a major role in the development of SST anomalies associated with the pure ENSO; this has been demonstrated by Rao et al. (2002).

4. IOD influence on the surrounding climate

Since the indices of ENSO and the IOD are non-orthogonal, it is reasonable to raise a counter issue that the Pacific ENSO itself may be affected by the IOD. Using partial correlation analysis, Behera and Yamagata (2002) are successful in revealing such an inverse influence on the Southern Oscillation Index. It is found that the DMI has a peak correlation coefficient of 0.4 with the Darwin pressure index when the former leads the latter by one month. This suggests that some IOD events precede some ENSO events. In Fig. 2, we find that three of the major warm ENSO events (i.e., those in 1972, 1982, 1997) are associated with major positive IOD events.

The above relationship undergoes decadal modulation. In last 50 years, the correlation drops below significance level only during 1980-89. Less frequent occurrences of IOD in the decade explain the reduction in the correlation. Similar decadal modulation of the IOD impact on the Indian summer monsoon rainfall has recently been discussed by Ashok et al. (2001).

The influence of the IOD is not just confined to the tropical region, but reaching far to the whole globe (Saji and Yamagata, 2002c). Owing to the non-orthogonality of the IOD and ENSO indices, however, the vast IOD influences have not been appreciated so far. In a series of articles, Saji and Yamagata (2002a,b, c), using a partial correlation analysis, have demonstrated that the enhancement of the East African rain is dominated by the positive IOD rather than El Niño. Interestingly, the positive IOD and the warm episode of ENSO have opposite influences in the Far East including in Japan and Korea; positive (negative) IOD events give rise to warm and dry (cold and wet) summer owing to enhancement of downdraft in the troposphere. This was clearly recorded (Japan Meteorological Agency monograph) during the IOD events in 1961, 1967, 1977 and 1994, as compared to the simultaneous occurrence of the positive IOD and the El Niño during 1997. The Indian summer monsoon rainfall (ISMR) is enhanced (decreased) during positive (negative) IOD events; the recent weakening of ENSO-ISMR relation may be interpreted in terms of frequent occurrence of the positive IOD in the recent decade (Ashok et al., 2001). In the Southern Hemisphere, the IOD impact is remarkable in the southwestern Australia and Brazil because of propagation of planetary waves in the winter hemisphere; positive (negative) IOD events cause warm and dry (cold and wet) conditions. The mechanism for these global teleconnection certainly needs further investigation.

As discussed, IOD may evolve without the external forcing from the Pacific ENSO but it interacts with the Pacific phenomenon in some occasions possibly through the atmospheric bridge and partly via the oceanic throughflow around the Australian continent. The strong seasonal phase-locking of the interannual IOD events may be related to the latter. However, it is crucially important to appreciate first the real unique nature of the Indian Ocean Dipole as the air-sea coupled phenomenon unique to the tropical Indian Ocean and then to clarify ways of interaction with other important phenomenon such as the ENSO events. We believe that this approach is a healthy way in understanding underlying dynamics. We get busy.

We have not discussed here much about the subsurface IOD signals and coupled model simulations; interested readers are referred to Rao et al. (2002) and Iizuka et al. (2001).

References:

Abram, N.J., M.K. Gagan, W.S. Hantoro, M.T. McCulloch, and J. Chappell, 2001: Coral records of the Indian Ocean Dipole. *EOS Trans*. AGU, **82** (47), Washington, USA.

Allan, R., D. Chambers, W. Drosdowsky, H. Hendon, M. Latif, N. Nicholls, I. Smith, R. Stone,Y. Tourre, 2001: Is there an Indian Ocean dipole, and is it independent of the El Niño - Southern Oscillation? *CLIVAR Exchanges*, **6**, No. **3**, International CLIVAR Project Office, Southampton, UK, 18-22.

Ashok, K., Z. Guan, and T. Yamagata, 2001: Impact of the Indian Ocean Dipole on the Decadal relationship between the Indian monsoon rainfall and ENSO. *Geophys. Res. Lett*., **28**, 4499-4502.

Baquero-Bernal, A., and M. Latif, 2002: On dipole-like variability in the tropical Indian Ocean. *J. Climate*, in press.

Behera, S.K., R. Krishnan, and T. Yamagata, 1999: Unusual ocean-atmosphere conditions in the tropical Indian Ocean during 1994. *Geophys. Res. Lett*., **26**, 3001-3004.

Bergman, J.W., and H.H. Hendon, 2000: Cloud radiative forcing of the low latitude tropospheric circulation: linear calculations. *J. Atmos. Sci*., **57**, 2225-2245.

Cadet, D.L., 1985: The Southern Oscillation over the Indian Ocean. *J. Climatol.*, **5**, 189-212.

Carton, J.A., G. Chepurin, X. Cao, and B.S. Giese, 2000: A Simple Ocean Data Assimilation analysis of the global upper ocean 1950-1995, Part 1: methodology. *J. Phys. Oceanogr.*, **30**, 294-309.

Clarke, A. J., and X. Liu, 1994: Interannual sea level in the Northern and Eastern Indian Ocean. *J. Phys. Oceanogr.*, **24**, 1224–1235.

Dommenget, D., and M. Latif, 2002: A cautionary note on the interpretation of EOFs. *J. Climate*, **15**, 216-225.

Iizuka, S.,T. Matsuura, and T. Yamagata, 2000: The Indian Ocean SST dipole simulated in a coupled general circulation model. *Geophys. Res. Lett*., **27**, 3369-3372.

Jolliffe, I.T., 1987: Rotation of principal components: some comments. *J. Climotol.*, **7**, 507-510.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, Roy Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc*., **77**, 437-471.

Klein, S.A., B.J. Soden, and N.C. Lau, 1999: Remote sea surface temperature variations during ENSO: Evidence for a tropical atmospheric bridge. *J. Climate*, **12**, 917-932.

Meyers, G., 1996: Variation of Indonesian throughflow and El Niño - Southern Oscillation. *J. Geophys. Res.*, **101**, 12255-12263.

Murtugudde, R.G., J.P. McCreary, and A.J. Busalacchi, 2000: Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997-1998. *J. Geophys. Res.*, **105**, 3295-3306.

Newell, R.E., J.W. Kidson, D.G. Vincent, and G.J. Boer, 1974: The General Circulation of the Tropical Atmosphere. Vol. **2**, The MIT Press, Cambridge, MA, USA, 371 pp.

Rao, S.A., S.K. Behera, Y. Masumoto, and T. Yamagata, 2002: Interannual variability in the subsurface tropical Indian Ocean. *Deep-Sea Res. II*, **49**, 1549-1572.

Rayner, N.A., E.B. Horton, D.E. Parker, C.K. Folland, and R.B. Hackett, 1996: Version 2.2 of the Global Sea-Ice and Sea Surface Temperature Data Set, 1903-1994. *Clim. Res. Tech. Note* **74**, Meteorological Office, Bracknell, UK.

Saji, N.H., B.N. Goswami, P.N. Vinayachandran, and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature*, **401**, 360-363.

Saji, N.H., and T. Yamagata, 2002a: Structure of SST and surface wind variability in COADS observations during IOD years. *J. Climate*, submitted.

Saji, N.H., and T. Yamagata, 2002b: A view of the tropical Indian Ocean climate system from the vantage point of Dipole Mode events. *J. Climate*, submitted.Saji, N.H., and T. Yamagata, 2002c: Interference of teleconnection patterns generated from the tropical Indian and Pacific Oceans, in preparation.

Venzke, S., M. Latif, and A. Villwock, 2000: The coupled GCM ECHO-2. Part II: Indian Ocean Response to ENSO. *J. Climate*, **13**, 1371-1387.

Vinayachandran, P.N., N.H. Saji, and T. Yamagata, 1999: Response of the equatorial Indian Ocean to an anomalous wind event during 1994. *Geophys. Res. Lett.*, **26**, 1613-1616.

Vinayachandran, P.N., S. Iizuka, and T. Yamagata, 2002: Indian Ocean Dipole mode events in an ocean general circulation model. *Deep-Sea Res.*, in press.

Wallace, J.M., E.M. Rasmusson, T.P. Mitchell, V.E. Kousky, E.S. Sarachik, and H. von Storch, 1998: On the structure and evolution of ENSO-related climate variability in the tropical Pacific. *J. Geophys. Res.*, **103**, 14241-14260.

Webster, P.J., A.M. Moore, J.P. Loschnigg, and R.R. Leben, 1999: Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98. *Nature*, **401**, 356-360.

Modulations in the North Pacific storm track activity associated with the recent decadal weakening of the East Asian winter monsoon

Hisashi Nakamura and Takeaki Sampe
Department of Earth and Planetary Science
University of Tokyo, Tokyo, Japan
hisashi@eps.s.u-tokyo.ac.jp

The climate system is a complex hierarchy of a number of components with various spatial and temporal scales. Its decadal-scale variability, by nature, must be associated with decadal modulations in higher-frequency phenomena and their feedback onto decadal components. For example, decadal modulations in the activity of synoptic-scale eddies migrating along midlatitude storm tracks must be involved in decadal variations in heat and moisture exchange between the ocean and atmosphere by influencing precipitation and their turbulent fluxes in the boundary layer. Studying such "scale-interactions" is therefore necessary towards our complete understanding of the decadal-scale climate variability. At the same time, studying modulated behaviour of intraseasonal fluctuations under the anomalous basic state may lead us to deeper understanding of their fundamental dynamics. In this short contribution, we give a brief documentation of the recent decadal weakening of the East Asian winter monsoon and the associated modulations observed in the North Pacific storm track activity, as a typical example of such scale-interactions.

We used the NCEP/NCAR reanalysis data, unless otherwise noted, to document the interannual variability in the North Pacific storm track observed over 17 recent winters (1979/80-1994/95). The local storm track activity is measured as a 850-mb meridional heat flux associated with subweekly fluctuations (VT_{850}). The first empirical orthogonal function of the interannual variability in midwinter (Fig. 1a) captures the decadal tendency towards the enhanced storm track activity in midwinter over the Northwestern (NW) Pacific (Nakamura et al., 2002). As shown in, this tendency occurred in association with the decadal weakening of the East Asian winter monsoon (Siberian High) and the Aleutian Low, both of which coincidentally occurred in the late 1980s (Nakamura and Yamagata, 1999). The most marked signature of this enhancement is that the midwinter minimum in the storm track, which had been apparent until the mid-1980s as a characteristic of the seasonal march in the storm track activity (Nakamura, 1992), almost disappeared afterwards (Fig. 2). As opposed to linear theory of baroclinic instability, the enhanced activity occurred despite the weakening of the Pacific jet (see Fig. 3). Over the Far East, tropospheric warming to the north of the weakened jet (Fig. 1) appears to be associated with an anomalous overturning in thermally direct sense, which is not attributable to the feedback from the concomitant enhancement in the local storm track activity.

The decadal-scale modulation observed in the East Asian winter monsoon and the associated modulation in the storm track activity influenced the atmosphere-ocean heat exchange and the hydrological cycle over the entire North Pacific as well. Over the NW Pacific, the weakened monsoonal flow and enhanced storm track activity since the late 1980s led to the reduction in evaporation and associated latent heat release from the ocean

continued on page 23

From McPhaden: TAO/TRITON Tracks Pacific Ocean Warming in Early 2002 (page 7)

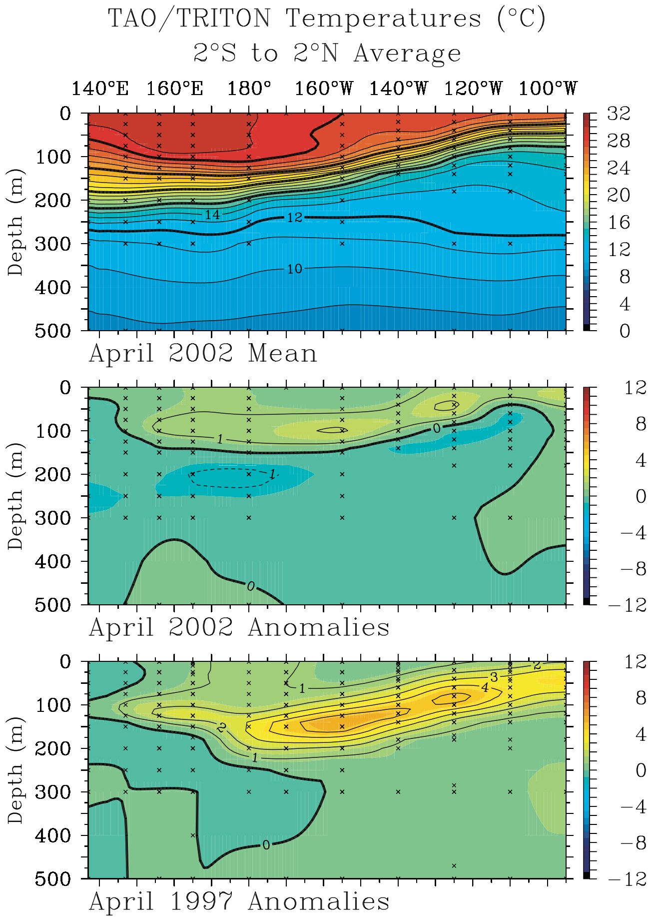
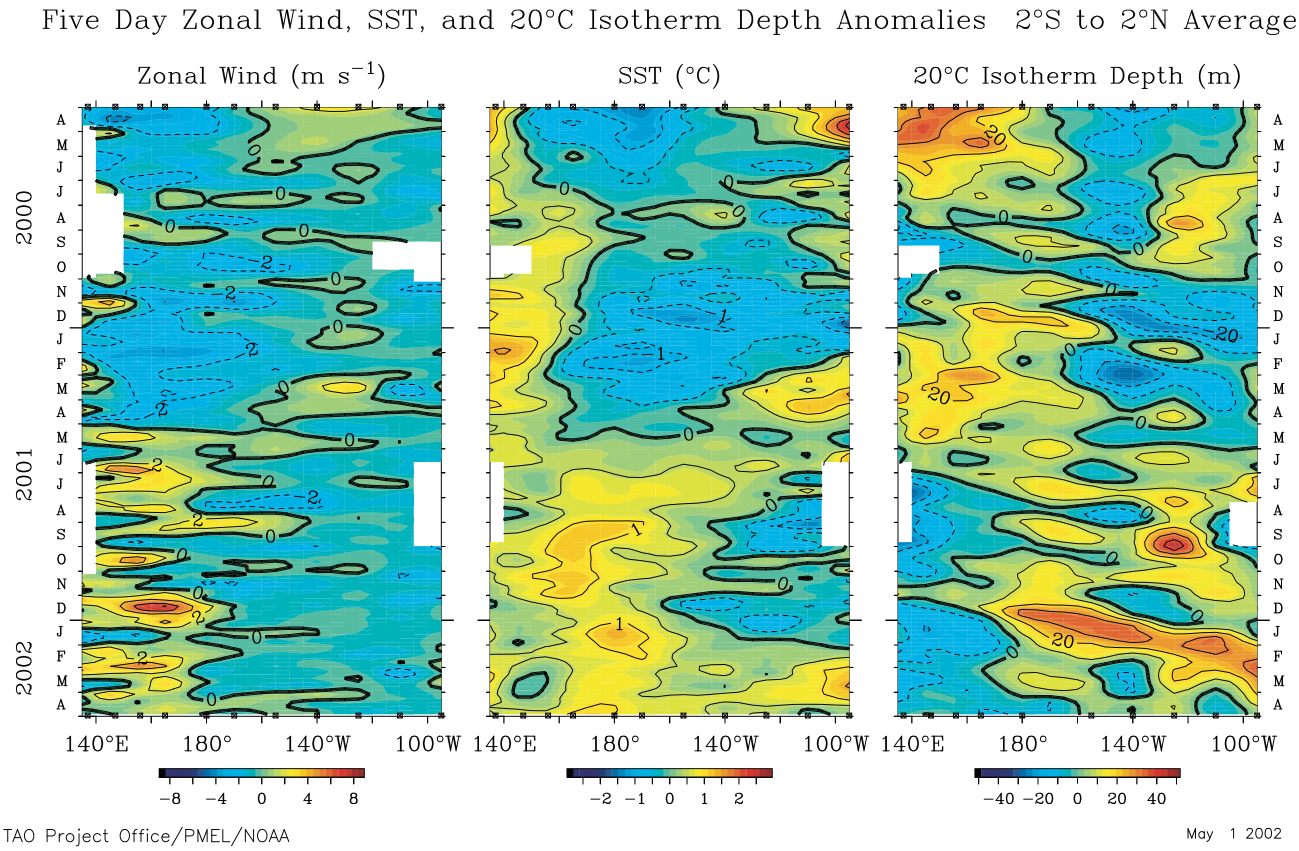


Fig. 2: Temperatures (in °C) from the TAO/TRITON array averaged between 2°N-2°S: monthly means for April 2002 (top panel), monthly anomalies for April 2002 (middle panel), monthly anomalies for April 1997 (bottom panel). Anomalies are based on the Kessler XBT/CTD climatology.

Fig. 3 (below):Time/longitude sections of anomalies in surface zonal winds (in m/s), sea surface temperature (in °C) and 20°C isotherm depth (in m) for April 2000 to April 2002. Analysis is based on 5-day averages between 2°N-2°S of moored time series data from the TAO/TRITON array. Anomalies are relative to monthly climatologies cubic spline fitted to 5-day intervals (COADS winds, Reynolds SST, CTD/XBT 20°C depths). Positive winds are westerly. Squares on the abscissas indicate longitudes where data were available at the start of the time series (top) and the end of the time series (bottom).



From Li and Long: Intraseasonal Oscillation Anomalies in the Tropical Atmosphere and El Niño Events (page 12)

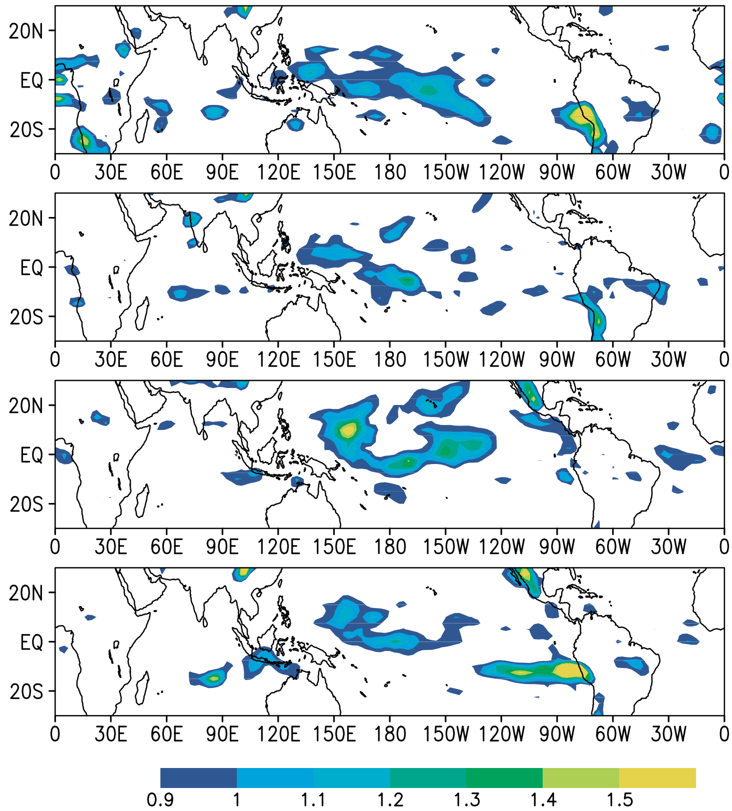


Fig. 1: Distribution of standard variance of normalised kinetic energy of the ISO, where the shaded area represents the area with the value above 0.9, a: December-February, b: March-May, c: June-August, d: September-November.

From Yamagata et al.: The Indian Ocean Dipole: a Physical Entity (page 15)

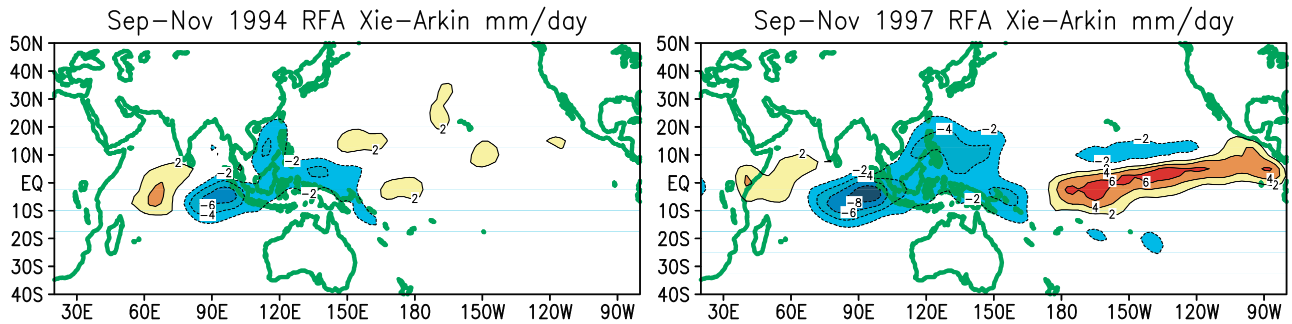
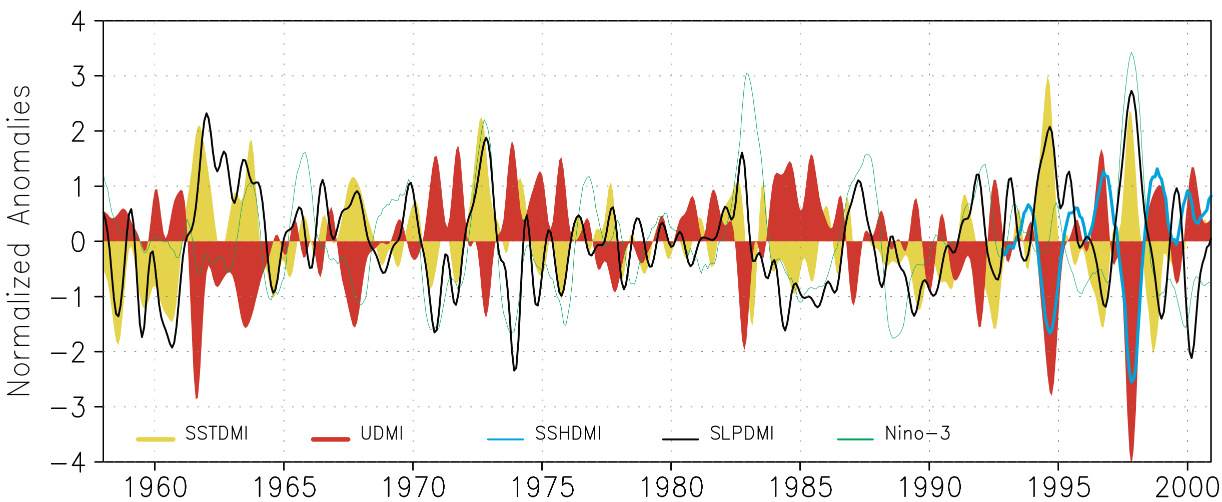


Fig. 1: Anomalies of OLR for September-November for 1994 (left) and 1997 (right).



From Yamagata et al.: The Indian Ocean Dipole: a Physical Entity (page 15)

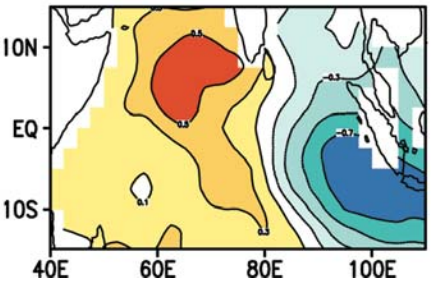


Fig. 3: Correlation between eastern pole and the whole basin anomalies after removal of anomalies due to the first EOF mode.

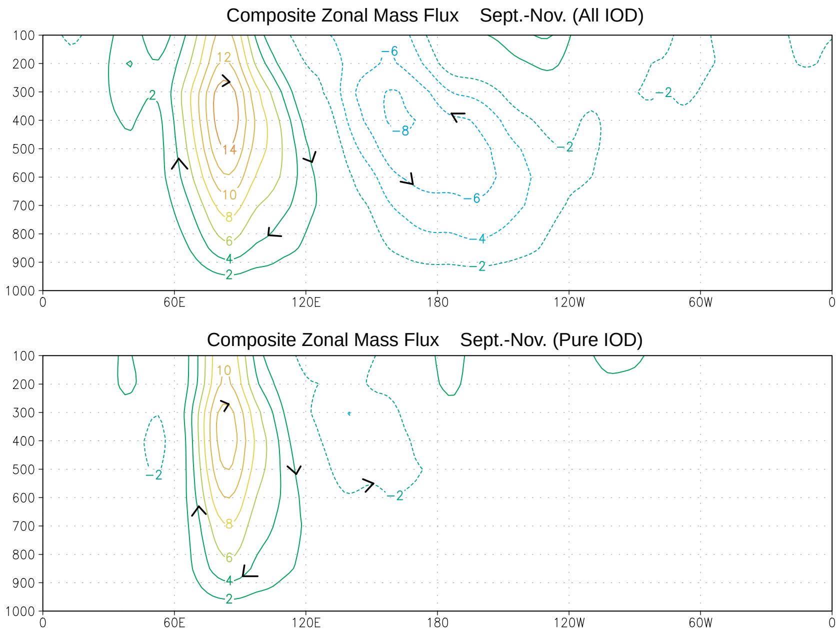


Fig. 4: (right) September through November IOD composite ((positive events-negative events)/2) of zonal mass flux in the equatorial band (5^0N-5^0S) for all *IOD (top) events and* pure *IOD events (bottom). Contour interval is $4*10^9$ kg s^{-1}.*

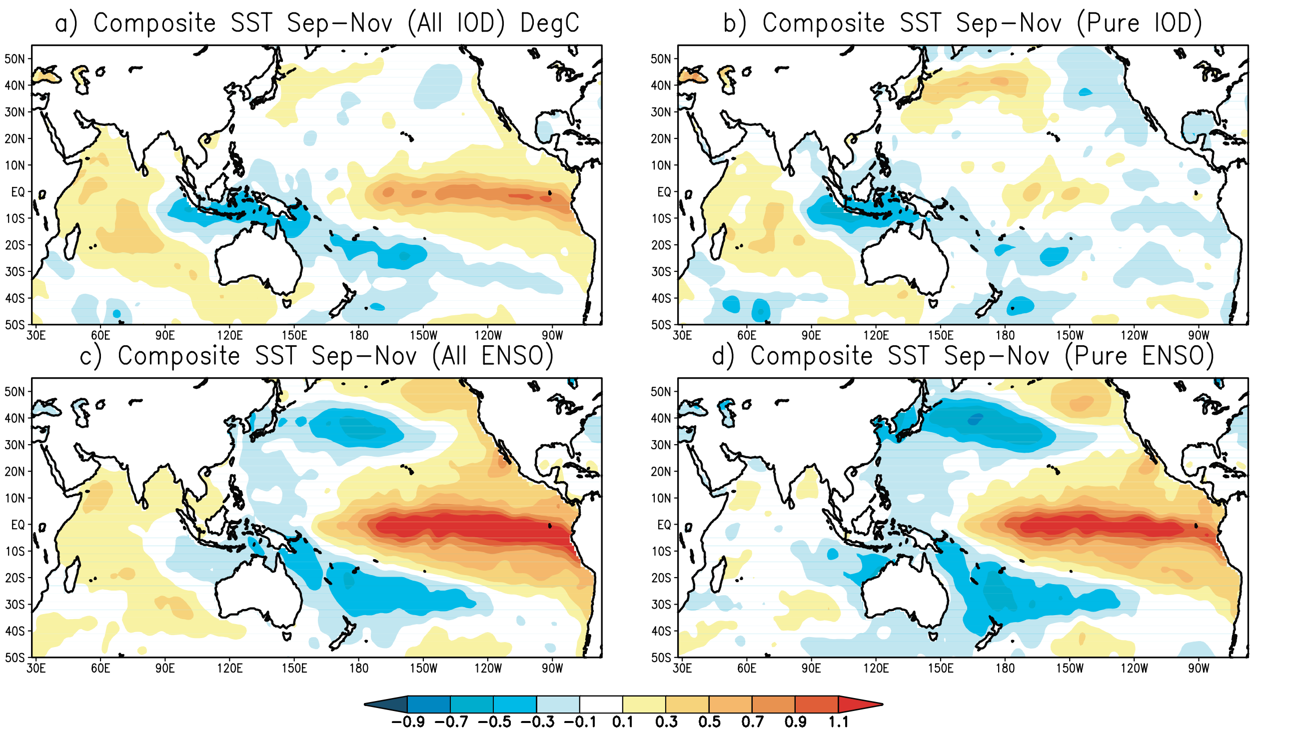


Fig. 5: Composite of SST ((positive events-negative events)/2) during September through November for (a) all *IOD events (b)* pure *IOD events, (c)* all *ENSO events and (d)* pure *ENSO events. Values are in ^{0}C.*

Fig. 2 (left): Normalized indices of IOD, based on the anomalies of SST (SSTDMI) , zonal wind (UDMI), sea level (SSHDMI) and sea level pressure (SLPDMI). SSTDMI is obtained by taking anomaly difference between box (50^0E-70^0E, 10^0S-10^0N) and (90^0E-120^0E, 10^0S-Eq), whereas SLPDMI is obtained by taking the difference between box (86^0E-87^0E, 10^0S-9^0S) and (44^0E-45^0E, 15^0S-14^0S). The UDMI is obtained by taking area-average in the central equatorial region (70^0E-90^0E, 5^0S-5^0N). The SSHDMI is obtained by taking area -average of the TOPEX/POSEIODN sea level anomalies in a region in the eastern Indian Ocean (90^0E-110^0E, 10^0S-Eq). Niño-3 index from the eastern Pacific is shown for reference.

From Yamagata et al.: The Indian Ocean Dipole: a Physical Entity (page 15)

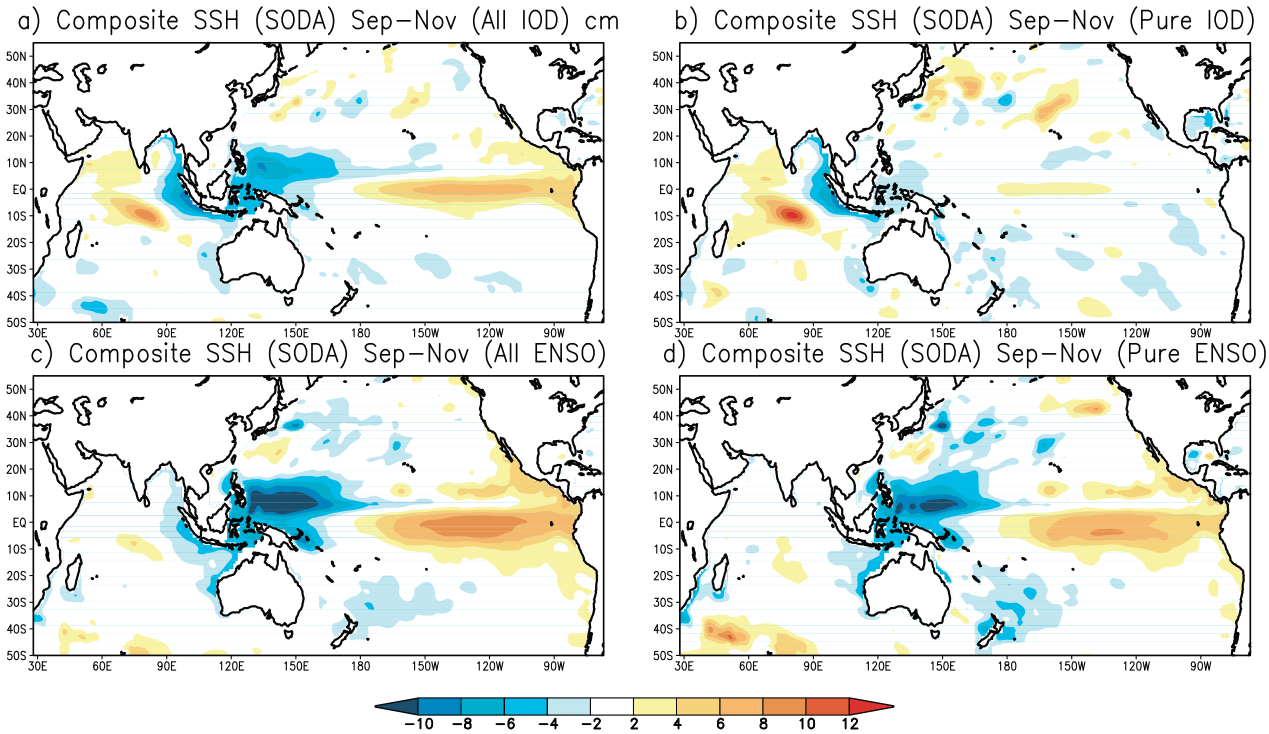


Fig. 6: Same as in Fig. 4 but for the composite of SSH. Values are in cm.

From Maximenko et al.: Near-surface Dynamical Structure of the Kuroshio Extension derived from drifter and altimetry data (page 25)

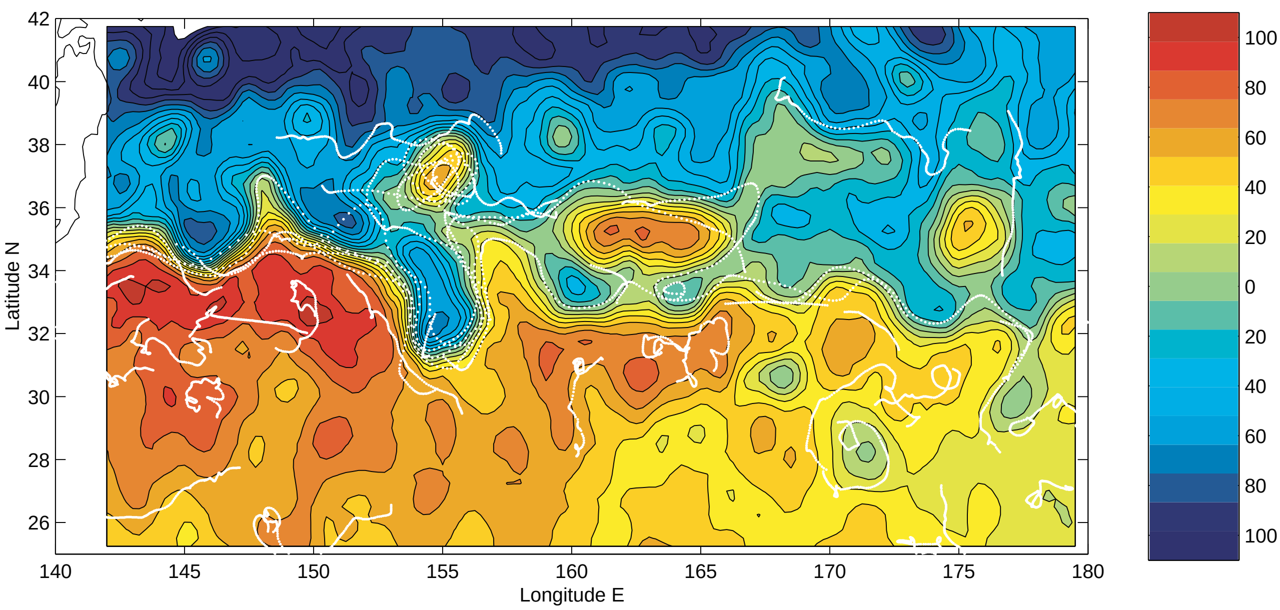


Fig. 4: Absolute sea level on December 6, 1993 computed from the AVISO MSLA data referenced to absolute sea level shown in Figure 3. Contour interval is 10 cm. Dots mark 6-hourly positions of all drifters from November 16, 1993 to December 26, 1993.

continued from page 13

surface and increased precipitation (Figs. 1c-d), respectively. The resultant anomalous moisture deficit was compensated from the anomalous moisture transport from the Northeastern Pacific, where the enhanced evaporation and reduced precipitation gave rise to anomalous moisture surplus. The precipitation anomalies may be influential on the ocean circulation through changing the upper-ocean density structure. In fact, Lukas (2001) observed a marked salinity increase in the early 1990s at the main thermocline level near the Oahu Island of Hawaii.

To explore how the counterintuitive modulations in the storm track activity occurred, we examine whether any systematic changes were observed in the structure of synoptic-scale eddies migrating along the NW Pacific storm track. Specifically, the local correlation between the subweekly fluctuations in meridional (v) or vertical (w) velocity component and temperature (T) was contrasted between a pair of the 5 midwinters for the strongest and weakest storm track activity accompanied by the weakened and enhanced monsoon activity, respectively, within our analysis period. Along the storm track, the 850-mb v-T correlation was found significantly stronger under the enhanced monsoon than under the weakened monsoon, and so is the 500-mb w-T correlation (Nakamura et al., 2002). As the excessively strong westerlies were relaxed in recent winters, eddy T field tended to become better correlated with the eddy v and w fields, suggesting that eddy structure tends to become more efficient in converting the mean-flow available potential energy into eddy kinetic energy for growth. In further exploring how these systematic changes in eddy structure occurred (Nakamura and Sampe, 2002), we found that in those midwinters with the strong winter monsoon, wave activity of baroclinic eddies migrating southeastward along the subpolar jet into the midlatitude northwestern Pacific tends to be trapped more strongly into the tight core of the excessively strong subtropical jet (Fig. 3). Since the subtropical jet core is positioned at a higher altitude (200-mb level) than the subpolar jet core (300-mb level) and shifted to the south of the surface baroclinic zone (~40°N) by almost 1000km, the trapping must act against the baroclinic growth of those eddies in the Pacific storm track.

References

Lukas, R.B., 2001: Freshening of the upper pycnocline in the North Pacific subtropical gyre associated with decadal changes of rainfall. *Geophys. Res. Lett.*, **28**, 3485-3488.

Nakamura, H., 1992: Midwinter suppression of baroclinic wave activity in the Pacific. *J. Atmos. Sci.*, **49**, 1629-1641.

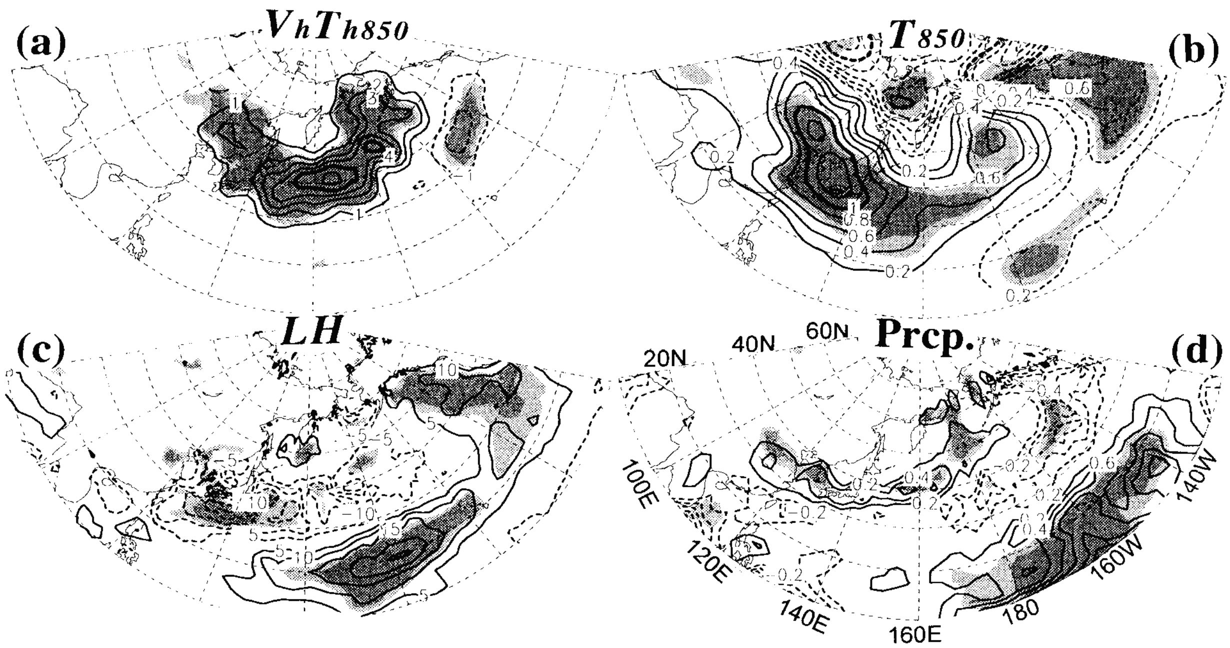


Fig. 1: The leading mode of the interannual variability in Jan-Feb VT_{850} over the NW Pacific, which accounts for 49% of the variance within [20°~60°N, 100°E~180°], plotted in its linear regression map (every 1 K m/s; heavy line for 5) with the leading principal component (PC1). Corresponding Jan-Feb regression maps of (b) 850-mb temperature (every 0.2 K, heavy lines for ±1), (c) latent heat flux (5 W m^{-2}), and (d) CMAP precipitation (0.2 mm/day). Negative contours are dashed and zero lines omitted. Shaded lightly and heavily where the local correlation with PC1 exceeds the 90% and 95% confidence levels, respectively. After Nakamura et al. (2002).

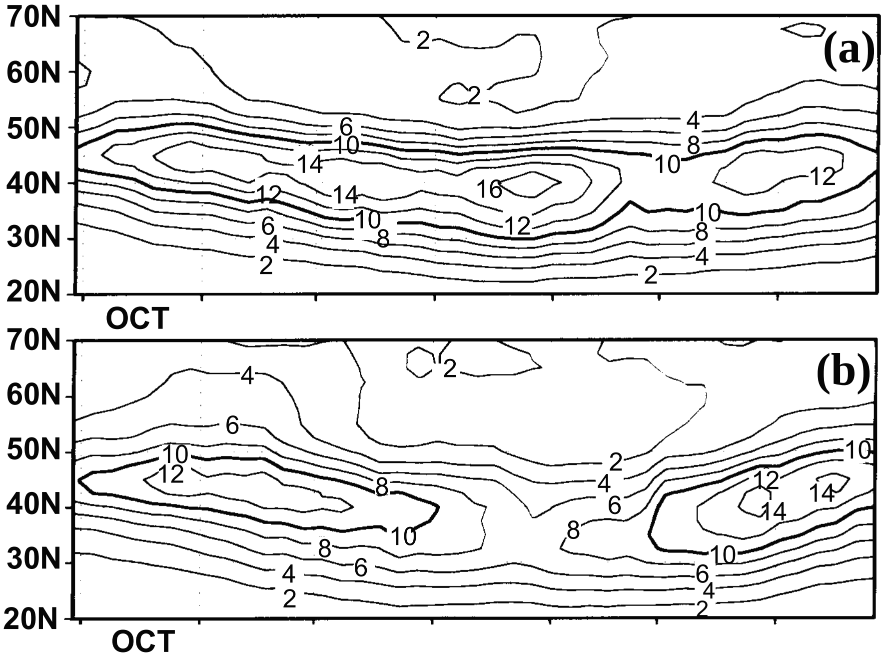


Fig. 2: Composite seasonal marches in VT_{850} over the NW Pacific for (a) 5 winters (1987, 89, 90, 92 and 94) of the strongest midwinter storm track activity and (b) 5 winters (1981, 83, 84, 86 and 95) of the weakest activity. Contour intervals: 2 (K m/s; heavy lines for 10). After Nakamura et al. (2002).

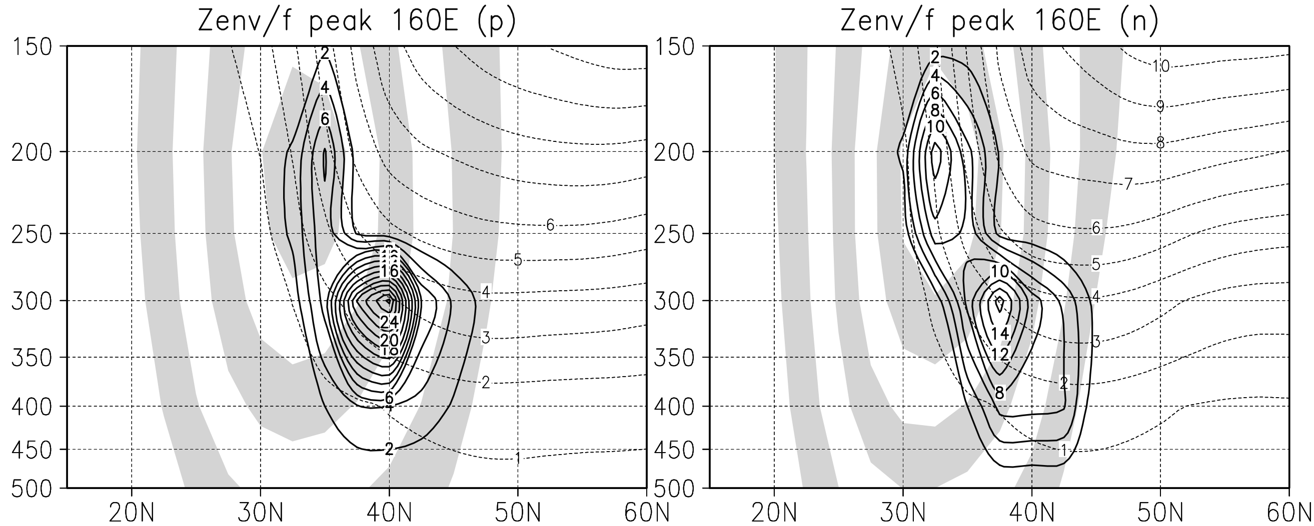


Fig. 3: Meridional sections for 160^{o}E showing the frequency of the storm track core (contoured for every 2) identified during 5 midwinter periods (as in Fig. 2a) of the strongest storm track activity (left) and during another 5 midwinter periods (as in Fig. 2b) of the weakest activity (right). The core is defined at a point on the meridional plane where the instantaneous eddy amplitude in streamfunction is largest, and the frequency is represented as the number of days within a 59-day period (Jan-Feb). Mean zonal wind speed (m/s) is indicated with shading (20~30, 40~50, 60~70) and mean potential vorticity is with thin lines (every 1 PVU). Adopted from Nakamura and Sampe (2002).

Nakamura, H., and T. Yamagata, 1999: Recent decadal SST variability in the Northwestern Pacific and associated atmospheric anomalies. In: *Beyond El Niño: Decadal and Interdecadal Climate Variability*, A. Navarra, (Ed.), Springer, Berlin, Heidelberg, 49-72.

Nakamura, H., T. Izumi, and T. Sampe, 2002: Interannual and decadal modulations recently observed in the Pacific storm track activity and East Asian winter monsoon. *J. Climate*, **15**, in press.

Nakamura, H., and T. Sampe, 2002: Feeding of baroclinic eddies along the subpolar jet and their trapping into the subtropical jet core over the North Pacific. *J. Atmos. Sci.*, to be submitted.

Near-surface Dynamical Structure of the Kuroshio Extension derived from drifter and altimetry data

Nikolai A. Maximenko[1,4], Peter P. Niiler[2], Gleb G. Panteleev[3,4], Toshio Yamagata[5], and Donald B. Olson[6]

[1] **International Pacific Research Center*, SOEST, University of Hawaii, Honolulu, USA**
[2] **Scripps Institution of Oceanography, La Jolla, USA**
[3] **International Arctic Research Center* University of Alaska, Fairbanks, USA**
[4] **Also at P.P. Shirshov Institute of Oceanology Russian Academy of Sciences, Moscow, Russia**
[5] **Graduate School of Science, Department of Earth and Planetary Physics, University of Tokyo Tokyo, Japan**
[6] **Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, USA**
nikolai@musashimaru.soest.hawaii.edu

1. Introduction

Previous studies of upper ocean circulation in the Kuroshio Extension region (KE: 25-42°N; 142-180°E) were mainly based on indirect dynamical methods (e.g. Qu et al., 2001; Mitzuno and White, 1983) or sparse direct velocity measurements by current meters (Schmitz et al., 1987) and ADCPs (e.g. Wijffels et al., 1998). These data are able to provide either a snapshot along some sections or "climatology" with unresolved interannual variability. With the start of the World Climate Research Program in 1985, Lagrangian drifters began to be deployed in large numbers in the Pacific for the purpose of observing near-surface circulation directly (Niiler, 2001). Since October 1992 there have been nearly continuous sea level observations from the TOPEX/Poseidon (TP) and ERS altimeter sensors of the time variable sea level, from which an increasing number of studies of the surface structure of the KE region have been published (for a review, e.g. Qiu, 2002).

The objective of this investigation is to develop 0.25-degree spatial resolution views of the statistics of the surface circulation and momentum balance of the KE region for the decade of 1990s.

2. Mean circulation

It was found that drifter data kriged at NOAA/AOML onto six-hourly intervals (325 drifters with a total data length of 141 years) and CNES/AVISO TP-ERS merged sea level anomaly (MSLA) maps on 0.25-degree grid (Ducet et al., 2000) covering period from 1992 to 2000 greatly supplement each other. Average correlation between properly smoothed drifter velocities (with Ekman drift subtracted according to Ralph and Niiler (1999) using NCEP winds) and geostrophic velocities estimated from the MSLA set was about 0.8 in the KE region. Advantage of joint analysis of these two datasets is that drifter velocities provide sea level altimetry data with a missing reference and altimetry data being uniformly sampled in time can correct the bias in temporal distribution of drifter observations toward early 1990s. The latter is important as during the decade remarkable interannual changes were detected in the KE (Ducet and Le Traon, 2001) and, especially, in the Kuroshio Extension recirculation (KER). Qiu (2002) showed that during 1992-99 the KER was in "contracted" state in 1996-97 and in "elongated" one before and after that period.

Deviations between drifter and altimetry velocities are not only due to intrinsic errors in the data, but also because of ageostrophic regime of the currents. It was expected that eddy kinetic energy derived from the MSLA is always lower than that derived from drifters, because altimetry data could be oversmoothed by a mapping procedure. It appeared to be not the case in the KER, where dominance of cyclonic eddies increase slope of

* International Pacific Research Center and International Arctic Research Center are partly sponsored by Frontier Research System for Global Change.

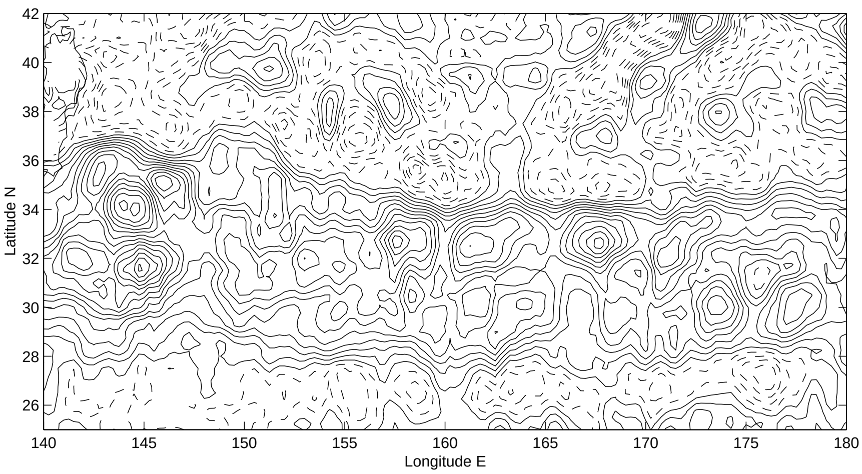


Fig. 1: Spatial distribution of $\langle\zeta^3\rangle/(\langle\zeta^2\rangle)^{3/2}$, where ζ is an anomaly of quasi-geostrophic vorticity computed from the AVISO MSLA data. $\langle\ldots\rangle$ denotes 1992-2000 time averaging.

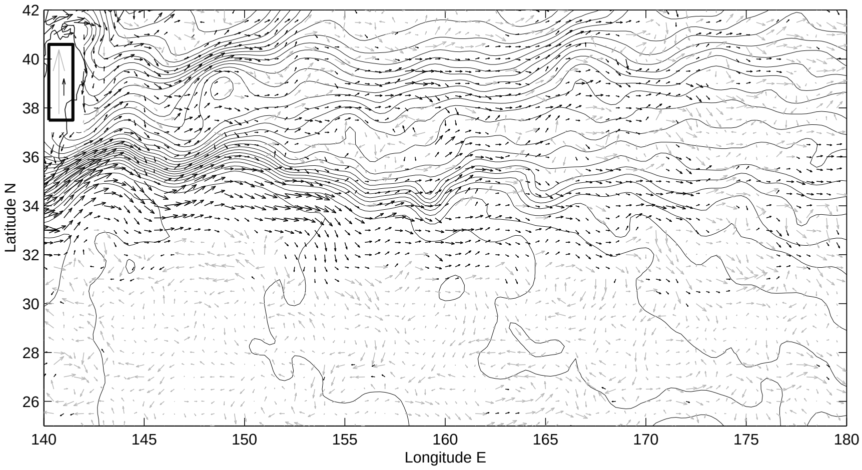


Fig. 2: Vectors of unbiased decade-mean velocity over mean temperature at 200 m depth. Grey color is for the vectors smaller than 10 cm/s. 50 cm/s scales are shown in the box. Contour interval is 0.5°C with a general northward decrease of the temperature values.

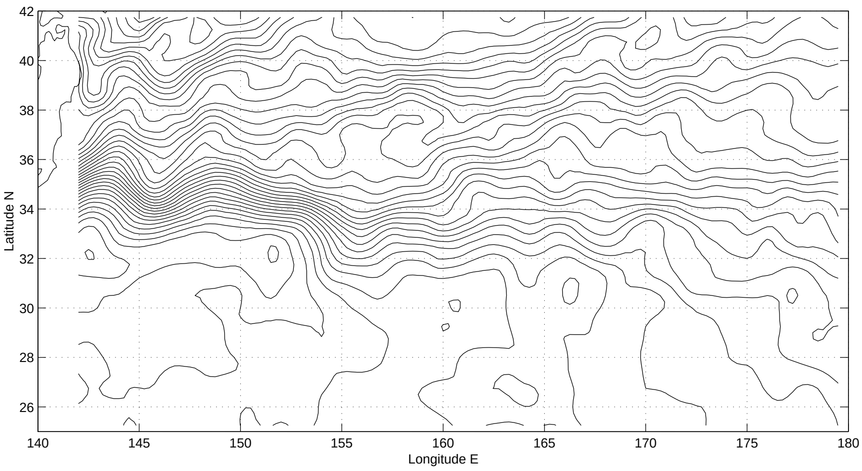


Fig. 3: Decade-mean absolute sea level. Contour interval is 5 cm with a general northward decrease of the sea level values.

sea surface to balance both Coriolis and centrifugal forces. Analogously, north of the KE anticyclonic eddies prevailed. Inhomogeneous distribution of most energetic eddies in the KE is seen in Figure 1.

Unbiased mean velocities were computed using linear regression method assuming 15-day temporal decorrelation scale and adopting AVISO mapping function, but with its coherence scale reduced by 0.5, as a spatial correlation function. These mean velocities are in accordance with the mean temperature at 200 m depth computed from the Levitus 1998 dataset (Figure 2) and outline two quasi-stationary KE meanders at 144 and 148°E and northward deflection of the KE axis east of the Shatsky Rise at 160°E. Remarkably, the mean KE axis lies just between the regions of large interannual trends described by Ducet and Le Traon (2001) that can be an indication of relative stability of its position.

3. Absolute sea level

Absolute mean sea level shown in Figure 3 was computed then by integration of full 2D momentum equation written in the Bernoulli form (Niiler et al., 2002). Clearly visible is the KE jet across which is a sea level decrease to the north by 110 cm from 32°N to 38°N at 142°E. At 145°E and 160°E part of the KE bifurcates northward (Kawaii, 1972; Olson, 2001) forming a number of quasi-zonal jets. Sea level difference further decreases east of 155°E where southern part of the KE turns to the south closing the recirculation cell seen at 32°N, 142-153°E. Another decrease of 50 cm occurs across the Oyashio front (Favorite et al., 1976) at the approximate latitudes of 38-42°N. One jet flows along 40°N through 165°E and then turns more to the north following the position of the subarctic front. Another jet seen at 40.5-42°N, 143-147°E turns north immediately and follows the Oyashio water mass front. In Figure 3, the KER appears as a relative high of 15 cm south of the KE jet and west of 157°E, or the western margin of the Shatsky Rise.

Because of ageostrophic terms in the momentum equation, vectors of mean velocities (Fig. 2) do not follow exactly the sea level contours (Fig. 3). The wind stress term, if not balanced by the Ekman drift, would produce large sea level difference across the study area in east-west direction. The vorticity (with maximum effective Rossby number reaching 0.25) and Bernoulli terms add up to 3 cm in the total mean sea level in the area around the KE axis. This value being small compared to the sea level difference across the KE may become significant in the deep ocean where geostrophic pressure anomaly is greatly compensated by the density field.

Eventually, computed mean absolute sea level was added to AVISO data to produce a set of 10-day maps of absolute sea level in the KE (Maximenko and Niiler, 2002). Such a map drawn in Figure 4 (page 22) for December 6, 1993 illustrates tremendous complexity of the flow pattern. Ability of thus derived sea level maps to resolve major eddies is confirmed by good correspondence between sea level contours and trajectories of the drifters. Analysis of the maps showed that when eddies of both signs can be generally found at any location, the most energetic eddies are cyclonic/anticyclonic rings detached from the KE jet and residing in agreement with Figure 1 on the southern/northern side of the KE.

4. Conclusions

When importance of interannual variability of oceanic circulation is acknowledged, most of historical datasets are not able to describe this variability in satisfactory detail. Existing climatological means represent ensemble average sensitive to the dataset structure rather than motivated temporal mean. Continuous flux of satellite data would help to solve this problem if necessary reference and calibration are provided by in situ observations. This study illustrates how well-defined mean dynamic fields can be obtained from a limited number of drifters and existing satellite altimetry products.

5. Acknowledgements

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References

Ducet, N., and P.-Y. LeTaon, 2001: A comparison of surface eddy kinetic energy and Reynolds stresses in the Gulf Stream and the Kuroshio Current system from merged TOPEX/Poseidon and ERS-1/2 altimetric data. *J. Geophys. Res.*, **106**, 16603-16662.

Ducet, N., P.-Y. LeTaon, and G. Reverdin, 2000: Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and –2. *J. Geophys. Res.*, **105**, 19477-19498.

Favorite, A., J. Dodimead, and K. Nasu, 1976: Oceanography of the Subarctic Pacific Region, 1960-1971. *Bull. Int. N. Pac. Fish. Comm.*, **33**, Kenkyusha Printing Co. Tokyo, Japan, 134pp.

Kawai, H., 1972: Hydrography of the Kuroshio Extension. In: *KUROSHIO: Physical aspects of the Japan Current*, H. Stommel and K. Yoshida, (Eds.). University of Washington Press, Seattle, USA.

Maximenko, N.A., and P.P. Niiler, 2002: Absolute sea level maps in the Kuroshio Extension derived from drifter and satellite altimetry data. IPRC Tech. Note 3, IPRC, University of Hawaii, Honolulu, USA, 109pp (http://www.soest.hawaii.edu/~nikolai/KE-SSH/KE-SSH.html)

Mizuno, K., and W.B. White, 1983: Annual and interannual variability in the Kuroshio Current System. *J. Phys. Oceanogr.*, **13**, 1847-1867.

Niiler, P.P., 2001: The World Ocean Surface Circulation. In: *Ocean Circulation and Climate - Observing and Modelling the Global Ocean*, J. Church, G. Siedler, and J. Gould, (Eds.). Academic Press, London.

Niiler, P.P., N.A. Maximenko, G.G. Panteleev, T.Yamagata, and D.B. Olson, 2002: Near-surface Dynamical Structure of the Kuroshio Extension derived from drifter and altimetry data. *J. Geophys. Res.*, submitted.

Olson, D.B., 2001: Biophysical dynamics of western transition zones: a preliminary synthesis. *Fish. Oceanogr.*, **10**(2), 133-150.

Qiu, B., 2002: The Kuroshio Extension System: Its large-scale variability and role in the mid-latitude ocean-atmosphere interaction. *J. Oceanogr.*, **58**, 57-75.

Qu, T., H. Mitsudera, and B. Qiu, 2001: A climatological view of the Kuroshio/Oyashio system east of Japan. *J. Phys. Oceanogr.*, **31**, 2575-2589.

Ralph, E.A., and P.P. Niiler, 1999: Wind driven currents in the tropical Pacific. *J. Phys. Oceanogr.*, **29**, 2121-2129.

Schmitz, W.J., P.P. Niiler, and C.J. Koblinsky, 1987: Two-year moored instrument results along 152°E. *J. Geophys. Res.*, **92**, 10826-10834.

Wijffels, S.E., M.M. Hall, T. Joyce, D.J. Torres, P. Hacker, and E. Firing, 1998: Multiple deep gyres of the western North Pacific: A WOCE section along 149°E. *J. Geophys. Res.*, **103**, 12985-13009.

Deep Convection Over the Tropical East Pacific

David Raymond[1,2], Graciela Raga[1], and Christopher Bretherton[3]
[1]Universidad Nacional Autónoma de México
México City, México
[2]On sabbatical leave from New Mexico Tech
Socorro, USA
[3]University of Washington, Seattle, USA
raymond@kestrel.nmt.edu

The EPIC (East Pacific Investigation of Climate) project is a study developed under the auspices of the U. S. CLIVAR program to improve our understanding of climate processes in the eastern tropical Pacific. Coupled ocean-atmosphere climate models perform poorly in this region (Mechoso, et al., 1995). The purpose of EPIC is to investigate those processes known to be inadequately represented in such models, in particular

1. the processes that determine the nature of deep convection in and near the ITCZ (or monsoon trough), including its variability, strength, and location;
2. the evolution of the vertical structure of the atmospheric boundary layer as the surface winds flow northward over the cold tongue and strong SST gradient of the equatorial front;
3. how air-sea coupling affects ocean mixed layer dynamics and SST in the east Pacific warm pool; and
4. the processes in the upper ocean that affect the structure and evolution of the shallow thermocline in this region.

The field phase of EPIC took place in September-October of 2001. In addition to addressing the above goals, exploratory observations were made in the southeastern tropical Pacific focused on obtaining the dynamical, radiative and microphysical data needed to evaluate models and parameterizations of boundary layer stratiform cloud formation and evolution and to determine feedbacks between the ocean and the stratus clouds.

This note presents a preliminary report on progress made toward satisfying the first of the above goals. Figure 1 shows the EPIC study region. The National Center for Atmospheric Research (NCAR) C-130 aircraft made traverses along the 95° W line from 12°N to 1°S, while the National Oceanic and Atmospheric Administration (NOAA) P-3, executed a "lawnmower" pattern in the monsoon trough study region centered near 95°W, 10°N. Both aircraft dropped numerous dropsondes.

Earlier results from the TOGA COARE project suggested that surface heat fluxes exerted a strong control on convective forcing, with subsidiary roles for convective available potential energy (CAPE), mid-tropospheric moisture, etc. (Raymond, 1995). We found in EPIC that deep convection was indeed sensitive to surface heat fluxes. In addition, higher values of the moist entropy in the 850 - 950 mb were also found to promote deep convection. In contrast, surface-based CAPE seemed to have little relationship to such convection.

We hypothesize that deep convective thermals need a relatively thick layer of conditionally unstable air to form, comparable to the depth of the marine layer, which tops out near 850 mb. This follows from laboratory studies of thermals in a stratified medium, which show that thermals typically ascend only about four times their own diameter in such a medium (Sánchez, Raymond, Libersky, and Petschek, 1989). Since the diameter of an atmospheric thermal should scale with the depth of the layer from which it forms, deeper unstable layers should favor deeper convection. Higher moist entropy in the marine cloud layer (typically 850 - 950 mb) makes this layer more unstable, and should therefore favor deep convection, as observed.

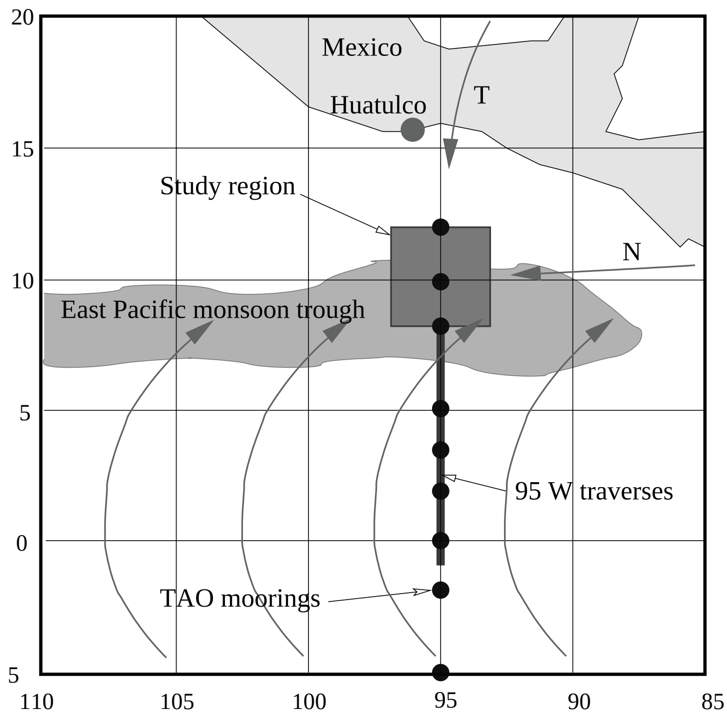

Fig. 1: Map of the eastern tropical Pacific showing the monsoon trough, general surface flows, locations of TAO moorings and the monsoon trough study region, and the aircraft base in Huatulco, Mexico. The arrows labeled T and N represent sporadic gap flows through the Isthmus of Tehuantepec and the lowlands of Nicaragua.

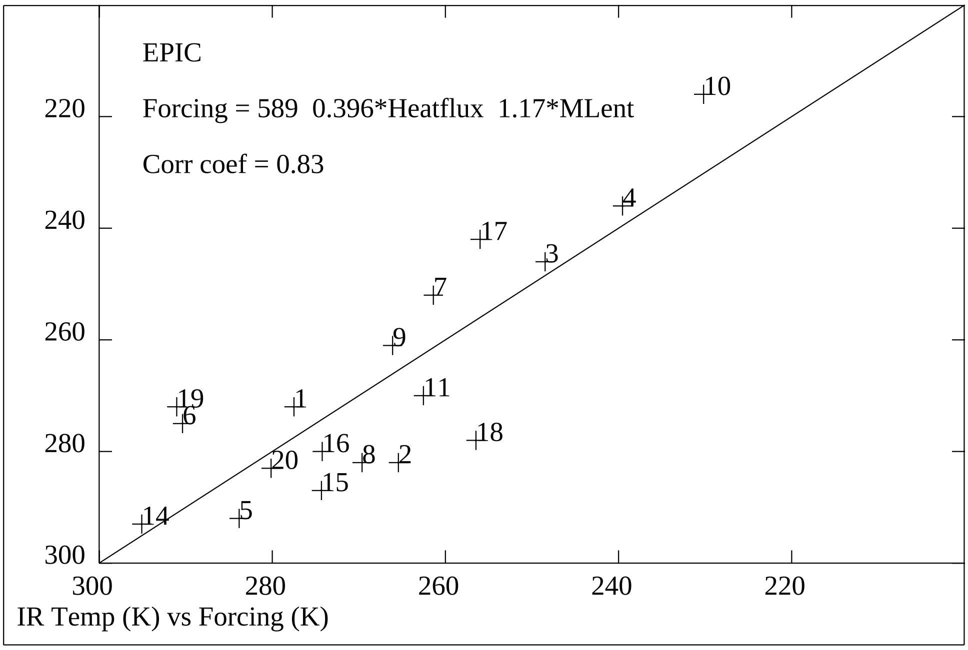

Fig. 2: Prediction of GOES infrared temperature in the monsoon trough study region by a linear combination of surface heat flux and marine cloud layer entropy in the region.

We regressed convective intensity, as represented by GOES satellite infrared temperature, in the monsoon trough study region against a linear combination of average surface heat flux and marine cloud layer entropy in the region, as obtained from C-130 and P-3 dropsondes, resulting in a prediction of infrared temperature. The results are shown in figure 2.

This simple formula does a remarkably good job of predicting convective intensity, accounting for almost 70% of the variance. Thus, we now know what the most important processes are in the control of deep convection in the study region. The next task is to determine how the large-scale flow invokes these processes. Stay tuned!

Acknowledgments

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References

Mechoso, C.R., A.W. Robertson, N. Barth, M.K. Davey, P. Delecluse, P.R. Gent, S. Ineson, B. Kirtman, M. Latif, H. Le Treut, T. Nagai, J.D. Neelin, S.G.H. Philander, J. Polcher, P.S. Schopf, T. Stockdale, M.J. Suarez, L. Terray, O. Thual, and J.J. Tribbia, 1995: The seasonal cycle over the tropical Pacific in coupled ocean-atmosphere general circulation models. *Mon. Wea. Rev.*, **123**, 2825-2838.

Raymond, D.J., 1995: Regulation of moist convection over the west Pacific warm pool. *J. Atmos. Sci.*, **52**, 3945-3959.

Sánchez, O., D.J. Raymond, L. Libersky, and A. Petschek, 1989: The development of thermals from rest. *J. Atmos. Sci.*, **46**, 2280-2292.

CLIVAR Pacific Panel - Report of the 1st Session

Kelvin Richards and Daniela Turk
Southampton Oceanography Centre
Southampton, UK
kelvin@soc.soton.ac.uk

The participants of the Pacific Panel meeting. Back row from left to right: David Legler, Bob Weller, Kelvin Richards, John Gould, Daniela Turk, Howard Freeland, Thierry Delcroix, Humio Mitsudera, Sergey Varlamov, Oscar Pizzaro, Ming Ji. Front row from left to right: Wenju Cai, Rehne Zhang, Richard Todaro, Masao Fukasawa, Bo Qui. Missing: Peter Hacker, Yanli Jia, In-Sik Kang, Roger Lukas, Jay McCreary, Michael McPhaden

The first meeting of the newly formed CLIVAR Pacific Panel took place in Honolulu, 7-9 February 2002, in the East-West Center, University of Hawaii. The International Pacific Research Center, who are to be thanked for the smooth running of the meeting. The main purpose of the first meeting was to establish the role of the Panel, to identify the major issues the Panel needs to address and to setup a framework to address these issues. The Panel chaired by Kelvin Richards (SOC, UK) has at present 11 members from 10 different nations. The Panel was joined by a number of invited experts. The report of the meeting will be available soon on the CLIVAR web pages (www.clivar.org). Here we give a brief overview of the meeting.

The meeting opened with a statement from John Gould, Director of the International CLIVAR Project Office (ICPO), who stressed the need to consider the legacy of CLIVAR, which should not only a better understanding of climate variability but also an observing that adequately captures future climatic changes.

The enormity of the task in making such advances should not be underestimated. The resources required will be larger than has hitherto been applied, the need for a well coordinated international effort making best use of those resources is paramount, but there is the potential for a large step-like gain in our understanding and predictive capabilities of climate variability

Panel members gave reports on national programmes followed by reports on sustained observational networks and process studies, both underway and in the planning stages. An impressive array of on-going and planned science programmes observations focused on the Pacific were presented to the meeting. A selection is given here.

The TAO/TRITON array continues to give high quality data essential for seasonal to interannual climate research and forecasting. The readily available data are being used in ocean state estimations and predictive models. Goals in the next few years are to improve data return, introduce new technologies, and to work with the broader community to ensure TAO/TRITTON is fully integrated with other elements of the global ocean observing system. Implementation of ARGO in the Pacific is proceeding apace with increasing numbers of floats in the water. The coverage in the North and equatorial Pacific is improving. However there is serious shortfall in the South Pacific. There are commitments to repeat many hydrographic sections in both hemispheres. A notable commitment is from the Japanese to repeat the very long section across the S Pacific at 30^{o}S.

A major ongoing process study is the East Pacific Investigation of Climate (EPIC) study looking at the interaction between the ocean and atmospheric boundary layer and controls on the cold tongue. EPIC is well underway and producing interesting results. The Panel was also briefed on a number of other process studies in planning phase which include the Kuroshio Extension System Study (KESS), Thorpex, and the Pacific Basin Extended Climate Study (PBECS). PBECS is a long-term process experiment to test and improve dynamical models of ocean processes that participate in climate variability. The project is based on the belief that the best hope for climate prediction and assessment lies in models that have sound approximations of important physics and models that are initialised with abundant and accurate observations.

Two major issues emerged from the resulting discussion. The first is the need for coordination of national and international observational programmes. Gaining an overview of the science, how to integrate it in some way and particularly identifying gaps proves difficult as it stands. The framework adopted by PBECS (a US CLIVAR programme) provides an effective way of integrating studies across a range of time and scale scales. PBECS is at an advanced stage of planning and has considered at length the issues involved. The international Panel agreed to look to adopt an implementation and strategy closely aligned to PBECS. The exact nature of the framework needs careful consideration so that it fulfils the requirements of the international community, but the adoption of such a framework makes it easier to see the relevance of individual programmes and to spot the gaps

The second major issue was the need to assess the adequacy of the observational/modelling systems to achieve CLIVAR Pacific objectives. Is the observational system capable of 'adequately' capturing the season-to-interannual variability of the ocean and atmosphere? How well does a given oceanic observation improve our ability to describe the system and/or predict? Will an improvement in quantifying a given 'process' improve the predictive skill of a model? The only way forward is a close working relationship between observationalists and modellers. Exploring ways of best achieving the necessary linkages will be a major task of the Panel.

Data, and its handling, is big issue for CLIVAR. CLIVAR, as a global multidisciplinary project, requires diverse data (ocean, atmos, model, paleo) in both real-time and delayed mode, and has struggled with the definition of an appropriate data structure. Discussion at the meeting identified the need to identify relevant datasets, review how information about data is made available to the user, identify data exchange and availability problems and for their to be good communication with GOOS, GCOS and GODAE to relay requirements specific to the Pacific.

Peter Hacker gave a presentation on the newly created Asia-Pacific-Data Research Center (APDRC) at the IPRC. The vision of the APDRC is to link data management and preparation activities to research activities within a single center, and to provide one-stop shopping of climate data and products to local researchers and collaborators, the national climate research community, and the general public. The Pacific Panel welcomed the establishment of APDRC and agreed to work closely with the APDRC on both the identification of CLIVAR related data sets and on the management of ocean and atmosphere data from the Pacific sector.

Finally, much progress has been made on the understanding of the impacts of changes to the physical ocean/atmosphere system on biogeochemical cycles and also their feedbacks on climate. Hence the Pacific region remains an area in which links between CLIVAR and biogeochemical and ocean carbon community have a potential for strong development. Daniela Turk (ICPO liaison for CLIVAR links with biogeocehemistry and carbon) gave an overview on current CLIVAR interaction with biogeochemical and carbon community and discussed the possible future direction in strengthening these links. To this aim a joint PICES/CLIVAR workshop will take place as part of PICES XI annual meeting in Qingdao this coming October, co-convened by Kelvin Richards (CLIVAR) and Kimio Hanawa (PICES).

We would like to acknowledge the sponsorship of meeting by WCRP, US CLIVAR and IPRC.

WCRP/CLIVAR VAMOS Panel Report on the Fifth Annual Meeting

Carlos Ereño[1] and C. Roberto Mechoso[2]
[1] International CLIVAR Project Office
Southampton Oceanography Centre,
Southampton, UK
[2] Dept. of Atmospheric Science, UCLA
Los Angeles, USA
ereno@fibertel.com.ar

The Centre for Geophysical Research (CIGEFI) of the University of Costa Rica, in San Jose, Costa Rica, provided a stimulating environment for the Fifth Annual Meeting of the WCRP/CLIVAR VAMOS panel (VPM5), March 13-16, 2002. VPM5 was organised around three main topics:

1. To report on progress and to develop plans towards the realisation of a NAME field campaign in 2004, co-ordinate modelling and diagnostic activities, and help to establish international partnerships.
2. To identify the scientific goals of a VEPIC programme, in view of the need for coordination with other CLIVAR programmes in the eastern Pacific, and to identify possible field campaigns with a tentative calendar.
3. To inform the VAMOS community on the status of the several VAMOS initiatives and discuss the future of the programme.

Professor Jorge Amador, of the University of Costa Rica and principal local organiser, welcomed more than 70 participants from various countries. The panel for the opening ceremony included Dr. Guy de Taeramond, Minister of Science and Technology of Costa Rica, Dr. Yamileth Gonzalez, Vice-Rector of Research representing the Rector of the University of Costa Rica, Dr. Eladio Zarate, Director, Instituto Meteorologico Nacional of Costa Rica and Representative of Costa Rica to WMO, and Dr. Oscar Arango, Director, WMO Subregional Office in San Jose, Costa Rica. Professor Tony Busalacchi, co-Chair, Scientific Steering Group, and Professor C. Roberto Mechoso, Chair, VAMOS panel, represented CLIVAR. Professor Carlos Ereño represented the International CLIVAR Project Office.

After a brief report on the progress of CLIVAR during the last year by Prof. Ereño with special emphasis on VAMOS related items, Prof. Mechoso described the objectives and goals of the VAMOS programme. He stated that VAMOS has completed a science study phase and selected its first targets for research, and is now entering an implementation phase. This phase is organised as two internationally coordinated efforts: Monsoon Experiment South America (MESA) and North American Monsoon Experiment (NAME). MESA and NAME both target important aspects of climate research within the Americas and the adjacent oceans.

Dr. Gonzalez, on behalf of the Rector of the University of Costa Rica, emphasised the importance of climate research and its benefits to the countries economies. She expressed the University's great pleasure in hosting a VAMOS meeting, and welcomed the large group of visiting scientists from varied institutions.

Dr. Taeramond, Minister of Science and Technology, gave a presentation on the Project for Establishing an Advanced Internet Network. The project is aimed at providing Costa Rica with state-of-the-art technology tools by allowing generalised access to communication and information networks. Dr. Taeramond indicated that Costa Rica is ideally suited for providing a node for communication between Central American countries, the Caribbean and other networks throughout the world.

Following the opening ceremony Professor Busalacchi provided an overview of the CLIVAR Programme and its goals, placing emphasis on the added value of international programmes to national research. He described the progress of the different CLIVAR panels, in particular the basin panels, and the need to implement sustained ocean observations in support of CLIVAR research, including the oversight of the ENSO observing system for research purposes. Increased emphasis will be placed on ocean assimilation and surface fluxes. He ended with a discussion of the El Niño Outlook in February 2002.

Prof. Mechoso reviewed the goals and strategy of the VAMOS programme and presented the VAMOS Implementation Plan. This is based on three coordinated efforts:

- Investigation of American Monsoon Systems: NAME, MESA, VEPIC
- Development of the VAMOS database and research programs on the Tropical Cyclones and Bolivian Altiplano.
- Establishment of long-term climate monitoring capability spanning the monsoon regions in the Americas and the tropical Pacific and Atlantic.

The South American Low-Level Jet (SALLJ experiment), will have a field campaign in December 2002-February 2003. NAME is developing actively, and some of its component subprojects have already started. There are several activities leading to the establishment of a research programme on the climatology and hydrology of the Plata Basin in South America (PLATIN). VAMOS will contribute to CEOP (Co-ordinated Enhanced Observing Period). CEOP is a GEWEX element that aims to provide a unique hydroclimatological dataset combining information from in situ stations, special and operational satellites, and model output that focuses on two annual cycles (2003-2004). CEOP will have a major Data Management activity and two science objectives: 1) water and energy cycle simulation and prediction, and monsoon system studies.

Prof. Mechoso finished his presentation with the reminder that the VAMOS panel requires that its component projects actively seek to create a legacy; including a project data base, education and training for regional scientists, observational systems that may have been proven to be of value for improved climate and hydrological prediction, implemented upgrades to the operational systems used by interested stakeholders and published records of progress that reflect the international framework of the project.

Dr. Carolina Vera (University of Buenos Aires) presented a report on the VAMOS Conference on the South American Low Level Jet, which was held in Santa Cruz, Bolivia from February 5-7, 2002 (see page 32 in this issue). More than 60 scientists from all countries in the SALLJ region (Bolivia, Argentina, Uruguay, Brazil, and Paraguay) as well as scientists from U.S.A and Chile attended. The aim of the conference was to review the current scientific knowledge about the Low level Jet in South America and to develop a unified conceptual model of the South American Monsoon System.

Dr. Steven Esbensen (Oregon State U.) reviewed progress achieved in the Eastern Pacific Investigation of Climate (EPIC) programme. EPIC is a process study sponsored by the US NSF and NOAA under the US CLIVAR program. He gave an overview of the US CLIVAR Pan American Research Plan, and its co-operation with GEWEX. He described the scientific goals of EPIC2001, and reported on the field phase that took place in the fall 2001 in Huatulco, Mexico and San Cristobal, Galapagos Islands, Ecuador. Further information on these activities can be found at http://www.joss.ucar.edu/epic/

Drs. José Meitín (Co-Chair, VAMOS Data Working Group) and Steve Williams (NOAA National Severe Storms Lab and UCAR Joint Office for Science Support) described the current status of the VAMOS Database and data management activities within the CLIVAR Data Task Team. The presentation included a description of the ongoing data collection and archival activities at UCAR Joint Office for Science Support and NOAA National Severe Storms Laboratory in support of the Pan American Climate Studies (PACS) over the past year.

Dr. Chris Bretherton (U. Washington) reviewed the motivation, goals, and current status of the VEPIC project. He emphasised that an improved knowledge of the stratocumulus decks along the western coasts of North and South America, particularly the latter, could improve the regional models through better boundary conditions and could also contribute to the improvements of coupled atmosphere-ocean GCMs for more successful ENSO forecasting.

Dr. Wayne Higgins (Climate Prediction Center - NCEP/NWS/NOAA) introduced NAME as an internationally coordinated, joint CLIVAR-GEWEX process study aimed at determining the sources and limits of

predictability of warm season precipitation over North America. The leading hypothesis is that the North American Monsoon System (NAMS) provides a physical basis for determining the degree of predictability of warm season precipitation over the region. NAME's objectives are to promote a better understanding and more realistic simulation of monsoon evolution and variability, the response of the warm season circulation and precipitation patterns to slowly varying boundary conditions (e.g. SST, soil moisture), the diurnal cycle of heating and its relationship with the seasonally varying mean climate, and intraseasonal variability of the monsoon. NAME is based on a multi-scale (tiered) approach with focused monitoring, diagnostic and modelling activities in the core monsoon region on the regional and continental-scale. The NAME programme has strong links between VAMOS, US CLIVAR Pan American research, and the GEWEX America Prediction Project (GAPP). An online version of the NAME Science and Implementation Plan is available at
http://www.cpc.ncep.noaa.gov/products/precip/monsoon/NAME.html.

Dr. Gus E Emmanuel (UCAR/JOSS) presented the VAMOS Project Office. This will support the different field programs to be developed under VAMOS, starting with the planning and field implementation of NAME and SALLJ. The Project Office will address all facets of data management, including data collection, validation, quality control, and archiving, and will support the efforts of the SWG Data Management Sub-Group and individual Project Supports Team. The functions of the NAME International Project Support Team are 1) to assess the scientific requirements for field-specific site surveys, and 2) interface with relevant countries/specific locations to secure the necessary clearance and permits for ground-based research sites, aircraft flight tracks, etc.;

In the following, the VPM5 participants split up into the NAME Workshop and the VEPIC Working Group meeting. The NAME Workshop was organised into seven sessions: 1) NAME International Partnerships, 2) NAME Field Campaign, 3) NAME Work Session, 4) NAME Modeling and Diagnostic Studies, 5) CLIVAR/PACS, GEWEX/GAPP, 6) NAME and Human Dimensions and 7) NAME Education and Training

The VEPIC Science Working Group revisited the project's science goals and implementation issues with the need of developing the "climate process team" concept in mind for their strategies. The group recommended that the VAMOS Project Office should also be task to implement the field phase of VEPIC. A time-line was drawn for the period, within which various intensive observation periods are planned.

During the executive session, the VAMOS panel welcomed four new members: Jorge Amador (University of Costa Rica), Kingtse Mo (CPC/NCEP/NWS/NOAA), Maria Assunçao Silva Dias (University of Sao Paulo) and Andrew Robertson (International Research Institute - IRI). The panel reviewed the status of the field projects followed by a discussion on the science issues related to SALLJ, PLATIN, NAME, and VEPIC. In view of imminence of SALLJ's field campaign, the panel discussed the activities that will be carried out during this experiment in great detail. A workshop is planned immediately after the experiment to discuss data policies as well as ancillary data to be received from other sources. In this regard, it was stated that daily historical precipitation observations archived at the different national weather services of the region have not been organised in a single dataset yet. There is consensus agreement by SALLJ Project scientists that the availability of such dataset is crucial for achievement of the programme goals, namely the better understanding and simulate precipitation variations.

The panel was informed that of the PLATIN Scientific Group will meet in Buenos Aires, Argentina, April 8-10, 2002. This meeting will be organised jointly with the American Association for the Advancement of Science (AAAS) in the framework of the "Ecosystem Dynamics and Essential Human Needs (EDEHN) entitled: Developing a Multidisciplinary Research Agenda in the Plata Basin" Project. The PLATIN group is working to establish of an international group on modelling the climatology and hydrology of large river basins.

Prof. Mechoso encouraged the panel members to consider the contribution that VAMOS could make to the CLIVAR Science Conference in 2004. In closing, all the members of the panel thanked Dr. Jorge Amador and his collaborators at the University of Costa Rica for the excellent organisation of the VPM5.

VAMOS/CLIVAR/WCRP Conference on the South American Low-Level Jet

Carolina Vera
CIMA/University of Buenos Aires-CONICET
Buenos Aires, Argentina
carolina@at.fcen.uba.ar

The VAMOS Programme is in the planning process for a field experiment on the South American Low-Level Jet (SALLJ). The SALLJ is a large-scale atmospheric feature in the lower troposphere. The mean flow of the SALLJ is southward along the eastern flank of the Andes mountains. The field campaign (SALLJEX) is currently planned for a three month period (Nov. 15, 2002 – Feb. 15, 2003) with two (one-month each) special observing periods. The data gathered will allow for a better understanding of several important issues related with the tropical-extratropical moisture transport over central and subtropical South America. As a preceding activity, the VAMOS/CLIVAR/WCRP Conference on the South American low-level jet took place at the Royal Lodge Hotel in Santa Cruz de la Sierra, Bolivia, from 5-7 February 2002. The objectives of the Conference were to:

- bring together researchers interested in SALLJ and related aspects of the South American Monsoon System (SAMS).
- stimulate discussion on the current knowledge of the SALLJ and its role in moisture and energy exchange between tropics and extratropics and related aspects of regional hydrology, climate and climate variability.
- promote the integration of scientists, especially in the countries of South America along the SALLJ and consider the need for any other internationally coordinated initiative.

Over 60 scientists from all the countries on the SALLJ region (Bolivia, Argentina, Uruguay, Brasil, Paraguay) and also from the U.S.A and Chile participated. 50 papers were presented in 4 session each summarized by plenary discussions to integrate the different results and conclusions in a single conceptual model of the SAMS.

The different elements acting on the moisture transport between the tropics and extratropics over South America are summarized in Figure 1. On the large scale, easterly trade winds transport moisture from the equatorial Atlantic into the continent. The Amazon region and the southwestern Atlantic ocean are considered as additional moisture sources. Moisture is then mainly advected along the eastern slope of the Andes to the south and near the Andes “elbow” a maxima of the low-level winds are observed in all seasons with frequent low-level jet (LLJ) episodes. Although the LLJ definition is related with the mesoscale characteristics of the flow intensity and shear, this name has been extended by the VAMOS community to identify, from a large-scale perspective, the moisture corridor flowing to subtropical and middle latitudes. Poleward moisture penetration is strongly modulated on synoptic, intraseasonal and even interannual timescales. Moisture convergence occurs over La Plata Basin and enhanced precipitation is observed mostly due to mesoscale convective system activity.

SALLJ Characterization and Variability

- The observed east-Andes LLJ is modulated by an orographically-bound, lower-tropospheric cyclonic circulation in both winter and summer. The LLJ and cyclone both tend to accelerate in the presence of enhanced cross-Andes westerly winds. Certain aspects of these observations may be explained in terms of simple, adiabatic models in which orography provides only mechanical, rather than heating modifications of the zonally averaged circulation.
- More complete model studies probe the mechanical effects of South American orography with more detailed diagnoses of LLJ phase and response to ambient circulation and to baroclinically evolving Rossby waves. Superposition of a baroclinic wave train upon realistic southern hemisphere circulation, allows favorable conditions for southward LLJ penetration in the presence of an evolving cyclonic perturbation over South America. This appears to be a dominant mechanism in stronger jet cases.
- Highly resolved regional models show that in some cases the LLJ tends to be progressively more confined to the immediate slopes of the Andes as the horizontal model resolution increases to 4km grid spacing. Because the jet narrows with increasing resolution, attendant moisture fluxes become smaller as model resolution increases. This carries important implications for possibly over-estimated LLJ fluxes in crude reanalyses. The result also indicates the need for high-resolution cross-jet aircraft observations in field campaigns.
- Regional simulations also point out diurnal signatures in pressure oscillations as well as in wind fields, and show phase variation with latitude. The maximum jet lags minimum surface pressure by approximately 2 hours, and LLJ initiation often starts around 18^{o}S, and then spreads toward 30^{o}S in strong LLJ cases.
- Comparisons of reanalyses against surface-based wind soundings show some qualitative agreement in scatter plots of analyzed and measured winds for Santa Cruz, Bolivia, located on the slopes of the Andes at the mean maximum wind area. Larger scatter of observed/analyzed winds characterizes a site further removed from the orography, at Rondonia, Brazil. The fact that local processes over that area are not well reproduced by numerical models could

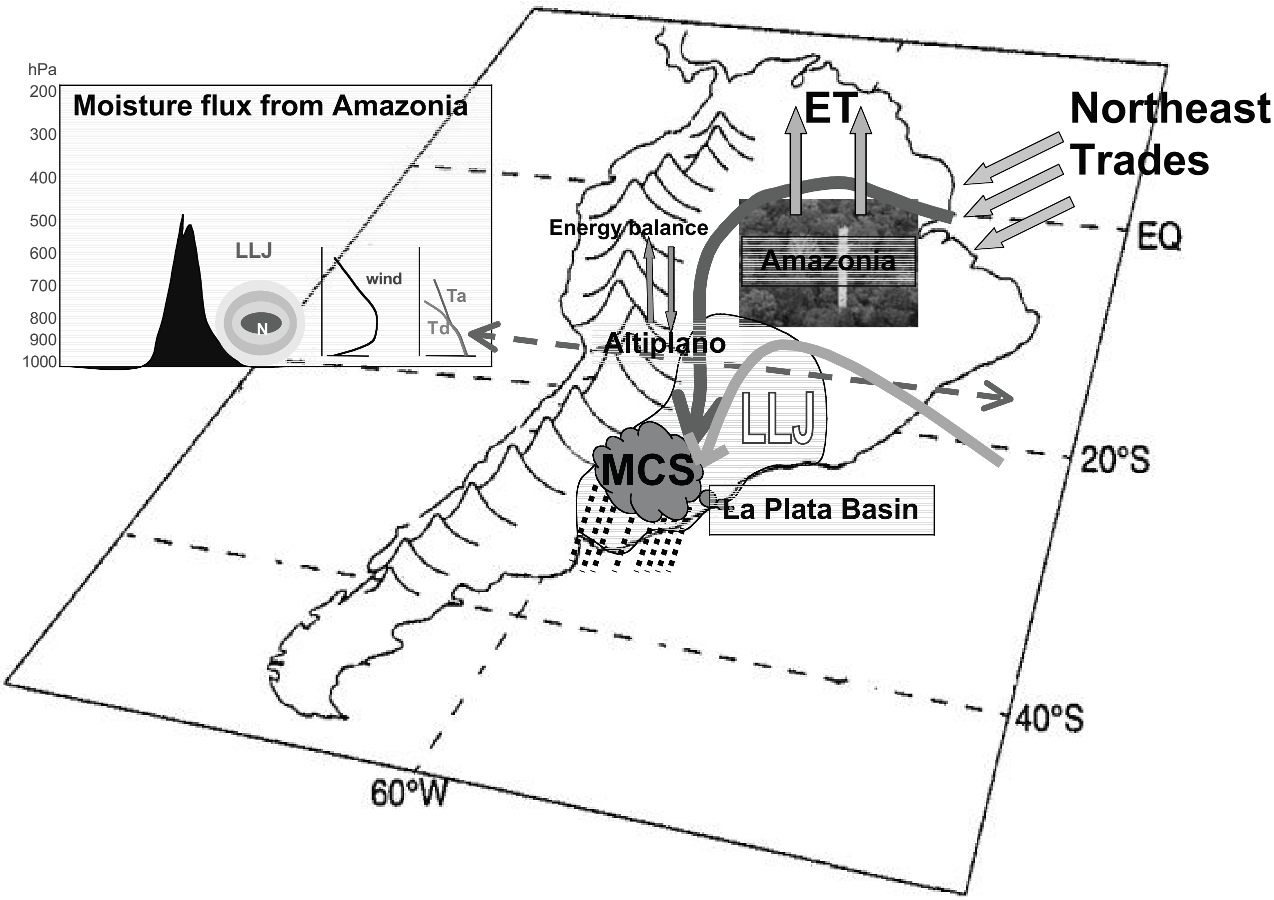

Fig. 1: Schematic diagram of elements relevant to poleward moisture transport over South America (courtesy Jose Marengo, CPTEC/INPE, Brazil)

explain such result.

- There were some discussions on the validity of the Bonner criterion to detect a LLJ. This criterion was developed for LLJ in North America with radiosonde observations with higher resolution in time, and may need some sort of adjustment to make it suitable for South America in order to adequately account for the apparently deeper character of the SALLJ. A revision of the Bonner criteria for SALLJ was suggested using SALLJEX data.

The SALLJ and precipitation development

- The relationship between SALLJ events and mesoscale convective system (MCS) activity over South America was also discussed. The two primary regions for MCS formation are the central United States and central South America. In both of these regions the MCSs appear to be maintained by the advection of warm moist tropical air via the low-level jets found in the two regions. Evidence was presented showing that the SALLJ was present prior to the onset of convection, with 80% of the MCSs occurring during periods with intense northerly low-level flow. The LLJ seems to provide maximum moisture flux convergence that intensifies the MCS, becoming its primary moisture source.
- The observed diurnal cycle of MCS activity includes an onset period between 1500-2100 LT, a mature phase at night and a dissipation phase in the morning. The diurnal cycle as identified with observed rainfall and TRMM products in southern South America (south of 15°S) shows a nocturnal maximum consistent with that of the MCS activity. In contrast, over most of the Amazon rainfall exhibits a maximum in early afternoon. There is a need for more observations of rainfall in order to validate TRMM and other satellite-derived precipitation products.
- Analyses suggest that above 45 % percent of austral summer precipitation over la Plata Basin can be explained by the occurrence of LLJ events. The presence of a LLJ is related to a large-scale wave pattern at upper-levels, that extends from the central Pacific eastward to South America. This pattern has also been linked in previous studies to the modulation of the position of the South Atlantic Convergence Zone (SACZ). during austral summer. The connection between SACZ and LLJ episodes was exten-

sively discussed with the intensification of the LLJ related to an inactive SACZ, and vice versa. This impacts the precipitation in southern Brazil-northern Argentina, the South American monsoon region, and the region of the SACZ. In the specific cases of JFM 1998 and 1999, 1998 (El Niño year) showed strongest LLJ and more MCS and rainfall in subtropical South America, and a less active SACZ. On the other hand, 1999 presented more than six times the number of MCS and large precipitation in the tropics, an active SACZ and fewer LLJ episodes.

- Analyses of the circulation anomalies accompanying anomalous warm and cold surface waters in the western subtropical South Atlantic on interannual timescales, show that during austral summer, warm conditions are associated with a strong advection of moist air from the Amazon basin toward SE South America. These features explain enhanced southward moisture flow and above normal precipitation over la Plata Basin. At the same time, easterly wind anomalies prevail over the SACZ, where convection is relatively weak. Moreover, circulation differences between wet and dry periods in the southeastern Amazon, during the wet season, show a close relationship to changes in the orientation and strength of the LLJ. Similar circulation changes were also found to occur during the onset and demise stages of the wet season.

SAMS numerical simulations

- Regional and global models were shown to successfully simulate the synoptic variability associated with LLJ events. However, different models have similar problems reproducing correct amounts of seasonal precipitation over Amazonia and the Altiplano while they reproduce SACZ stronger than normal. The fact that most models underestimate MCS precipitation promoted the discussion about the importance of improving cumulus parameterizations in models. Also, mesoscale structure (dynamic and thermodynamic) needs further observations and studies to relate MCSs to LLJ and baroclinic influences and thus improve numerical simulations of precipitation.

Further conclusions

Another main conclusion of the Conference was the need for a historical daily precipitation dataset available at the VAMOS dataset site for the SALLJ Project scientists. The main problem is that daily historical precipitation observations archived at the different national weather services of the region have not yet been gathered in a single dataset. The regional national weather services (NWS) have been generally reluctant to freely provide those data to scientists even from their own countries. As a consequence scientists have been using in their investigations partial datasets just of their own countries and in general with specific restrictions not to transfer them to others. SALLJ Conference participants are convinced that the availability of such datasets is crucial to better understand and simulate precipitation variations over tropical and subtropical South America from synoptic to interannual timescales and also to describe the role of the SALLJ on precipitation development. In an effort to remedy this situation, a letter formally requesting the historical daily precipitation dataset was sent to the NWS of the SALLJ region. Although the wisdom of this approach has been generally acknowledged within the region, difficulties have been experienced in expeditiously resolving this issue.

The Conference was chaired by C. Vera (CIMA/UBA, Argentina). C. Ereño (ICPO), Ramiro Villarpando (UMSA, Bolivia) and Carlos Diaz (SENAMHI, Bolivia) were members of the organizing committee. Members of the program committee were: Patricio Aceituno (Univ. of Chile, Chile), Pedro Silva Dias (IAG/USP, Brazil), Jan Paegle and Julia Paegle (Univ. of Utah, USA), Matilde Nicolini (CIMA/UBA, Argentina), Vernon Kousky (NOAA/CPC, USA), Jose Marengo (INPE/CPTEC, Brazil), Alice Grimm (UFPR, Brazil) and Rong Fu (EAS, USA).

Further information about the Conference available at http://www-cima.at.fcen.uba.ar/sallj/

WOCE/CLIVAR Working Group on Ocean Model Development (WGOMD) 3rd Session

Claus Böning
Institut für Meereskunde, Kiel, Germany
cboening@ifm.uni-kiel.de

The WGOMD meeting, hosted by the Max-Planck-Institut fpr Meteorology in Hamburg , Germany, 6-8 May 2002, brought together 21 experts from major climate, ocean, and ocean-ice modelling groups, to discuss the status and ongoing efforts in the development and assessment of the ocean component models used in climate studies. The format of the meeting was similar as that of the previous one in Santa Fe, i.e., WGOMD committee members plus invited representatives from various modelling centers, from the CliC-NEG and its AOMIP, and from PCMDI.

The prime agenda item was a discussion of the first experiences from the pilot phase of the Ocean Model Intercomparison Project (P-OMIP), and decision on the next steps towards the launch of a fully-fledged OMIP.

1. P-OMIP

Based on the reports of six participating groups with six different global (mostly, ocean-ice) models, and an extensive discussion of the key choices in the common integration protocol, the meeting endorsed the main elements of the OMIP plan developed at the previous meeting, and agreed on pushing ahead in the following

WGOMD and guests at MPI, Hamburg

way: refinement of certain elements in the forcing fields and initial conditions, and subsequent integration of all (six) presently participating models until July 2002; joint analysis of model output, with the aim of a preliminary public presentation and discussion in fall 2002 (e.g., at the final WOCE conference); final definition of integration and analysis protocols for a launch of a full OMIP by spring 2003.

It is noted again that an important prerequisite for launching a full-scale OMIP is the clarification of organisational and technical service functions, such as identification of necessary support in archiving, distributing and diagnosing the large amount (Terabytes) of model output involved. WGOMD appreciates any assistance the CLIVAR-SSG could offer in allocating ressources in this regard.

2. Air-sea fluxes

Re-iterating a previous observation, it has to be emphasized that OMIPs are now becoming feasible only because of the significant efforts (by ocean modeling groups) needed to produce a flux dataset suitable for forcing global ocean-ice models (i.e., including budgets of heat flux in ice covered regions and runoff). WGOMD points out a need for, and encourages efforts to further refine flux datasets based on re-analysis products, as a necessary pre-requisite for improved ocean simulations.

3. General WGOMD issues, links to CLIVAR panels

WGOMD presently reports to both WGCM and WOCE-SSG. It is suggested that, with the end of WOCE, WGOMD should become a sub-group of WGCM and CLIVAR-SSG. The terms of reference have to be changed accordingly.

The need for interaction with other CLIVAR panels should be reflected in the respective TORs; e.g., the Atlantic Implementation Panel is presently requested to collaborate with the WGCM and WGSIP, while there is no reference to the WGOMD and, thereby, to ocean model developments for decadal variability.

The Climate of the Twentieth Century Project

Chris Folland[1], Jagadish Shukla[2], Jim Kinter[2], and Mark Rodwell[1]
[1] Hadley Centre, Met Office, Bracknell, UK
[2] COLA, IGES, Calverton, USA
chris.folland@metoffice.com

The Climate of the Twentieth Century (C20C) project was originally established by the Hadley Centre in the early 1990s. Then, as now, the main purpose was to run many atmospheric general circulation models (AGCMs) in ensemble mode against a common sea surface temperature (SST) and sea ice extent data set to study climate variability and predictability on time scales of a season to many decades. C20C differs from the Atmospheric Model Intercomparison Project (AMIP) in several ways. Firstly the length of the integrations is considerably greater. Some integrations are carried out since the late nineteenth century, with a core period from 1950 onwards which has better verifying data. The C20C project is more about predictability than is AMIP and includes decadal time scales, though aspects of model evaluation are included. One of the important goals of C20C is to determine the extent to which atmospheric models are able to simulate the observed climate variations during the 20th century. Of particular importance is the potential ability of ensembles of AGCM runs to simulate specific historical events such as regional floods and droughts, the Dust Bowl in North America, the persistent drought in the Sahel and other extreme seasons. C20C is also concerned with simulating trends and so provides an interface with more formal climate change detection projects. Although use of AGCMs remains central to the project, coupled ocean-atmosphere general circulation models (CGCM)s now play an important role. They are used to explore the limitations of AGCM runs and to guide the design of AGCM climate variability analyses on longer time scales, e.g. for identifying possible thermohaline circulation-related climate variations.

The first workshop was held in late 1994 (Folland and Rowell, 1995) and its results used in the Climate Models - Evaluation chapter of the Second Assessment Report of IPCC published in 1996. In addition, a special C20C session was held at the First International AMIP Conference in 1995. Although this activity led to bilateral collaboration, in the late 1990s, the project was revitalised as a joint project of the Hadley Centre and the Center for Ocean-Land-Atmosphere Studies (COLA) under CLIVAR auspices with administrative support from COLA. C20C now also reports to the Working Group on Numerical Experimentation (WGNE). A number of groups have consequently run experiments forced with the new Hadley Centre HadISST SST and sea-ice extent data set (Rayner et al., 2000, 2002).

A second workshop was held at COLA on 22-25 January 2002 to review progress and particularly to plan a more highly structured C20C project. The workshop was held just before a World Meteorological Organization (WMO) Global Climate Observing System (GCOS) Workshop on Advances in the Use of Historical Marine Climate Data (29 Jan - 1 February 2002), chaired by the first author, so that participants could communicate their ideas about further improvements to SST and sea ice data sets that might be used by C20C.

At the workshop two days of presentations were made by participating groups summarising the results from ensembles of runs forced with HadISST from the recent informal phase of C20C. Besides a number of diagnostic methods and new results on simulating 20th century climate, a presentation (Jim Hurrell, NCAR) was made on the question of how limited AGCMs may be in simulating the variance of climate adequately. A specially designed experiment was created whereby the Hadley Centre HadAM3 AGCM was forced in ensemble mode with daily SSTs from part of a very long control run of the CGCM HadCM3. The initial conclusion is that the variance of those quantities looked on seasonal to decadal time scales are not significantly less in the AGCM than in the CGCM. Small differences that did occur were, however, consistent with the notion of excessive thermal damping in AGCM simulations (Saravanan, 1998). This supports the general validity of the AGCM approach for many types of climate predictability and trend studies. However an unresolved issue is whether some specific modes are missing in the AGCM that are present in the CGCM due to the lack of coupling. This work is being extended to include another AGCM/CGCM pair.

The HadCM3 model was also used to show that natural variations in the thermohaline circulation exist in that model which may be reflected in SST data since the late 19th century. This appears particularly in the form of strong North Atlantic SST variability on a nearly 70-year time-scale with an interhemispheric component in the Atlantic. If so, analyses of multidecadal variability may need to take this into account.

The workshop decided that more emphasis should be placed on including forcings in addition to SST. The need for this was shown by a presentation (David Sexton, Hadley Centre) on detecting the influence of individual time-varying forcings in AGCM experiments all forced with GISST3 using a sensitive method based on the general linear statistical model (Sexton et al., 2002). Specific additions of forcings other than those contained in SST and sea ice will have additional (significant) effects in recent decades on regional model temperatures from the surface to the lower stratosphere. Thus ozone depletion in recent decades is essential to simulating changing temperature of the latter and greenhouse forcing has additional effects on warming land surface air temperature to that contained in the SST. Because of uncertainties in some forcings, and their tendency to partially cancel, it was agreed to use the following forcings :

1. Data from the Hadley Centre on changes in carbon dioxide since 1871.
2. Volcanic stratospheric forcing from 1950 only, as data before then are more uncertain.
3. Changes in tropospheric and stratospheric ozone, the former based on an off-line chemistry model used by the Hadley Centre. The latter data start around 1975 the former cover the twentieth century.

Other explicit forcings are being ignored either because residual effects that are not included in SST are small and uncertain (like direct solar forcing) or for practical reasons. The neglect of increasing methane and the other trace greenhouse gases is seen as offsetting the neglect of increases in direct and indirect tropospheric aerosol forcing, remembering that a part of these effects is included in HadISST. Participants (where possible) will carry out a set of 6 such integrations for 1871-2002 and a further set of 10 from 1950-2002 giving an ensemble of 16 integrations from 1950-2002. HadISST will soon be updated in near real-time to make this possible. The latter period will allow analysis of two c.25 year periods on either side of the 1976 climate "jump". A significant issue in the workshop was the characterisation of naturally occurring modes that occur in the absence of interannual SST variations. Given that such modes may be model dependent, all participants will carry out a further 100-year control run forced with the 1961-90 climatology of HadISST.

At a later stage, the additional impact of land surface changes on recent regional climate change and variability will be explored. These integrations will probably start from about 1970. Three variables are being considered if data sets become available: observed changes in surface vegetation, observed changes in soil moisture and observed changes in snow cover.

A series of standard diagnostics was agreed which will c ater for many of the more specific investigations. A series of special possible topic investigations was also identified. Participants will have the freedom to choose which they are involved in and details of these investigations remain to be agreed. However since everyone will run a full set of integrations, considerable flexibility and choice is built into the programme.

The special topics fall broadly into the following categories:

1. Predictability of seasonal to decadal phenomena such as the 1930s USA droughts, the 1962-63 cold winter and the autumn 2000 floods in Europe, and decadal changes in interannual ENSO climate responses, particularly in Australasia.
2. Time series and trends of simulated quantities. Examples are the SOI index, the NAO index, the PNA

index, rainfall in Asian monsoon regions, the Sahel and Northeast Brazil and the occurrence of the Madden Julian Oscillation. In addition each model's ability to simulate observed regional and global land surface air temperature changes will be investigated

3. Other topics such as validation of modelled river runoff.

A variety of validating data sets will be used. For the period since 1950, the NCEP and ERA40 reanalyses will be important, recognising that the former at least cannot be used to evaluate model trends. For atmospheric circulation before 1950 particularly, the monthly HadSLP data set will be used, a further development of the mean sea-level pressure data set described by Basnett and Parker (1997). A gridded set of daily mean sea level pressure data also exists back to the late nineteenth century for the extratropical Northern Hemisphere which will be enhanced through a new European Community funded project, "EMULATE". Over land, the Climatic Research Unit data sets of land surface air temperature and precipitation are readily accessible. Other data sets will be identified by project co-ordinators as needed.

For some projects a set of agreed statistical diagnostics will be made available or the methodology agreed. An example is the method of estimating forced variability using analysis of variance.

It is intended that model and observed data will be stored and exchanged through the COLA GrADS-DODS server (GDS). The GDS is a software system that facilitates the access to, and analysis and display of geophysical data distributed on the Internet (http://www.iges.org/grads/gds/index.html). The total amount of data served at each participating center is expected to be at least several tens of gigabytes, making the distributed analysis model the most practical way of exchanging data. A C20C home page will be maintained at COLA (http://www.iges.org/c20c/), with links to C20C home pages of individual institutions where possible.

Finally it is intended to create links between the C20C group, the CLIVAR Working Group on Sesonal to Interannual Prediction (WGSIP), the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and AMIP. A focus of the work will be a C20C meeting in spring 2004 and possible involvement in the International CLIVAR Conference in June 2004. A longer-term focus will be a likely input to the IPCC Fourth Assessment Report around 2006.

References:

Basnett, T.A., and D.E. Parker, 1997: Development of the global mean sea level pressure data set GMSLP2. Hadley Centre Climate Research Technical Note **79**, Met. Office, Bracknell, UK.

Folland, C.K., and D.P. Rowell (Eds), 1995: Workshop on simulations of the Climate of the Twentieth Century using GISST. Hadley Centre Climate Research Technical Note 56, Met. Office, Bracknell, UK.

Rayner, N.A., D.E. Parker, P. Frich, E.B. Horton, C.K. Folland, and L.V. Alexander, 2000: SST and sea-ice fields for ERA40. In: *Proc. 2nd WCRP International Conference on Reanalyses*. WCRP-**109**, WMO/TD-No. **985**, World Climate Research Programme, Geneva, Switzerland, 18-21.

Rayner, N.A., D.E. Parker, D.E., E.B. Horton, C.K. Folland, and L.V. Alexander, D.P. Rowell, E.C. Kent, and A. Kaplan, 2002: Globally complete analyses of SST, sea ice and night marine air temperature, 1871-2000. *J. Geophys. Res*., submitted.

Saravanan, R., 1998: Atmospheric low-frequency variability and its relationship to midlatitude SST variability: Studies using the NCAR Climate System Model. *J. Climate*, **11**, 1386-1404.

Sexton, D.M.H., H. Grubb, K.P. Shine, and C.K. Folland, 2002: Design and analysis of climate model experiments for the efficient estimation of anthropogenic signals. *J. Climate*, submitted.

Gravity satellite launched.

On March 17 a joint NASA/German venture launched the GRACE satellites from the Plesetsk cosmodrome. The twin satellites fly in a polar orbit circling the earth 16 times per day. GRACE (the Gravity Recovery and Climate Experiment) should produce gravity fields of much greater accuracy than those presently available to researchers. These will impact a number of climate related research activities such as monitoring seasonal and interannual changes in hydrological reservoirs and as a means of removing uncertainties from the sea surface height and ocean circulation fields from ERS, Topex-Poseidon and Jason.
Further information can be found at
http://www.jpl.nasa.gov/grace
http://www.csr.utexas.edu/grace and
http://op.gfz-potsdam.de/grace

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International CLIVAR Project Office
Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, United Kingdom