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Decadal Variability and Predictability
Part 2: Monsoons and Pacific Sector

Weakening of the ENSO - Monsoon Rainfall Relationship - Possible Role of the Atlantic Circulation ?

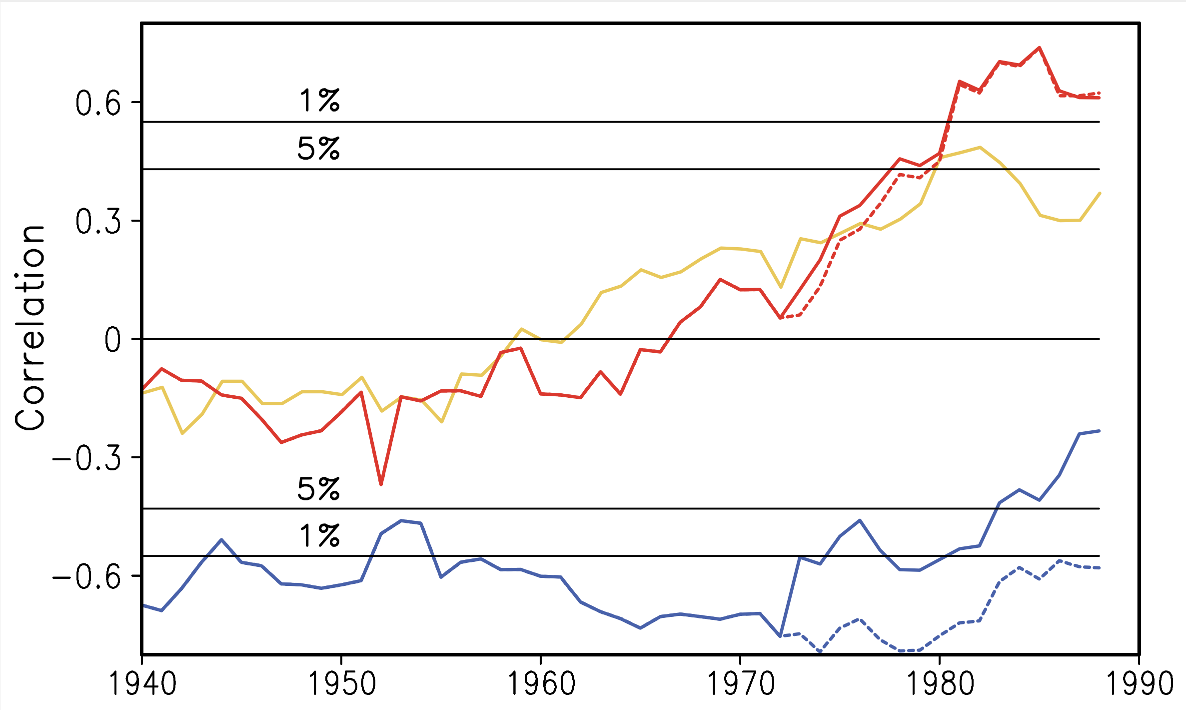

Figure 1 from paper *'Possible Roles of Atlantic Circulations on the Weakening Indian Monsoon Rainfall - ENSO Relationship' by C. P. Chang et al.: Correlation (based on a 21-year sliding window) between Indian summer monsoon rainfall and summer NINO3 SST (blue solid), winter western European SAT (red solid), and winter central Eurasian SAT (yellow). Dashed lines are the result of removing 1983 and 1997. The 1% and 5% significance levels are indicated as horizontal lines.*

The paper appears on page 5.

As a result of the series of scientific workshops this issue of Exchanges highlight recent scientific work on the field of decadal variability and predictability, one of the main streams of CLIVAR.

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Editorial

Dear CLIVAR community,

For many Europeans and North Americans 'Monsoon' and Pacific may sound very exotic and far away. But in fact more than half of the world's population is strongly influenced by monsoonal rainfall and a large number of them live around the world largest ocean basin, the Pacific. Thus, an important fraction of the CLIVAR programme deals with phenomena related to these two key words. Two Principal Research Areas: Variability of the Asian-Australian Monsoon System and Variability of the American Monsoon Systems deal with the two largest monsoon systems of the world. Better understanding of the range of variability of these climate phenomena leading to improved climate predictions is one of the major goals associated with these CLIVAR projects.

In addition, the variability of the monsoon systems interacts strongly with the ENSO phenomenon, the most dominant and prominent mode of climate variability within the Pacific as well as on global scales. Thus, the climate variations in the Pacific sector play a key role for global climate variability on interannual as well as on longer timescales. We have seen considerable progress in understanding and predicting ENSO for the benefit of the adjacent nations within the Pacific. The WCRP Tropical Ocean Global Atmosphere (TOGA) project established a firm foundation of observations and modelling and CLIVAR continues to build on its success with a focus on "Extending and Improving ENSO predictions". Ocean observations and coupled modelling are key tools to improve on the accomplishments made through TOGA. With respect to the role of the oceans in the global climate ocean, the World Ocean Circulation Experiment (WOCE) has delivered tremendous new insights into the oceans' mean structure and circulation and has stimulated a steady improvement of our modelling capabilities. Especially, when dealing with long-term climate fluctuations and anthropogenic change, the long memory of the ocean is crucial. Amongst others, this has let to the second CLIVAR focus within the Pacific to investigate the decadal variations within this region.

Although the last years have already shown considerable progress in our understanding of these climate phenomena and mechanisms, considerable gaps still exist in our observational database as well as in our modelling capabilities and naturally in our understanding of all these phenomena.

Several decadal workshops in the past year have amply demonstrated the accomplishments of the past years. In February addition an international Pacific implementation workshop (see article beginning on page 29), started the process of refining the CLIVAR Initial Implementation Plan published in 1998 and of co-ordinating and enhancing national contributions to the research in this area.

As a consequence, CLIVAR Exchanges has dedicated two issues related especially to problems to long-term climate variability. The first one in January of this year focused primarily on global issues and on the Atlantic sector. This one now emphases monsoons and the Pacific. We hope that we can present you a very interesting mix of papers, different views and opinions that should stimulate scientific discussions.

As a result of an article in the last issue, we are publishing here some correspondence relating to it. We encourage this type of contribution, since Exchanges is not a peer-reviewed journal, thus, some scientific discussion on recent results is natural, necessary and documents the vitality of CLIVAR research.

We have more good news to report. Firstly, CLIVAR was very well received during the annual review of the components of the World Climate Research Programme, the meeting of the WCRP Joint Scientific Committee. Many of you contributed to the presentation, with new interesting scientific results and eye-catching figures. Secondly, the ICPO is in the process of recruiting new staff members who will join the office in summer. The first will start in June, Dr. Yan Zhongwei got his PhD in Atmospheric Physics from Beijing in 1989 on "Northern hemisphere climatic jump in the 1960s". From 1999-2000 worked with P. Jones and T. Davies at University of East Anglia on climate extremes in Europe and China and most recently he was at University College London working on climate extremes. Zhongwei will take responsibility in the ICPO for the work of the Asia-Australia Monsoon panel under the new leadership of Julia Slingo and Peter Webster, for CLIVAR research in Africa and for all issues relating to climate indices and extremes

You will find also a report of the May meeting of the CLIVAR Scientific Steering Group held in Toulouse. This meeting (the tenth) demonstrated clear progress towards CLIVAR implementation in all science and geographical areas but also highlighted the enormous challenge of international co-ordination of such a diverse project. An essential tool in this will be SPRINT - a Searchable PRogramme InformaTion database on the CLIVAR web site. The structure is now in place but its contents are as yet sparse. A major challenge in the coming months will be to fill SPRINT with detailed information on national plans and on CLIVAR-relevant data sets and products.

Finally, with this issue we are mailing copies of the WMO annual Climate Review. We hope you will find it interesting that you all enjoy this issue of Exchanges highlighting the progress on decadal variability with the Indo-Pacific region. Note, that a call for papers for the next two issues can be found on page 14.

John Gould and Andreas Villwock

CLIVAR SSG Activities

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The Laboratoire d'Etudes en Geophysique et Oceanographie Spatiales (LEGOS) in Toulouse, France, provided a stimulating environment for the tenth session of the CLIVAR SSG which took place 15-18 May 2001. Our host, Dr. Christian LeProvost, organized several briefings on the French Mercator ocean forecasting and data assimilation system. This approach to routine oceanographic nowcasting is a very important contribution to the CLIVAR research agenda as it pertains to the evolving state of the world ocean as well as seasonal climate prediction.

Internationally, the implementation of CLIVAR is well underway. Implementation is proceeding via a combination of regional climate and monsoon initiatives focused on the Americas, the Asian-Australian monsoon system, and African climate and through initiatives organized around problems specific to the Pacific, Atlantic and Southern Ocean basins and adjacent regions. The global perspective for CLIVAR is provided by the CLIVAR Ocean Observations Panel, the Working Group for Seasonal to Interannual Prediction, and the Working Group for Coupled Modelling (WGCM). The major links between natural variability and anthropogenic climate change within CLIVAR continue to occur among the WGCM, the Working Group on Climate Change Detection (jointly sponsored with the WMO Commission on Climatology) and collaboration with IGBP/PAGES on past climate.

This past year the 52nd Session of Executive Council of the World Meteorological Organization as well as the Joint Scientific Committee of the WCRP both indicated that they were very impressed and pleased with the progress of CLIVAR to date. In particular, the WMO Executive Council was encouraged with the steps taken towards implementation of a number of specific regional activities, namely: VAMOS, the Asian-Australian monsoon system, and African climate variability. Bearing in mind the considerable potential for socio-economic benefits of progress in these activities, the Council urged all members in the regions concerned to participate. Other specific supportive comments included the importance of PIRATA in CLIVAR studies.

Although much of CLIVAR implementation is being organized regionally, the SSG reconfirmed the importance of the global integration of the programme by devoting the first day of its meeting to issues of global importance. This included a presentation by Chet Koblinsky on efforts by the CLIVAR Ocean Observations Panel to complement and integrate across the existing basin panels, to see that sustained and near-sustained observations in both the upper layers and deep ocean needed to support CLIVAR research are implemented, and to identify requirements for increased emphasis on ocean assimilation and surface fluxes.

On the second day of the SSG, regional and basin implementation progress and issues were discussed. Highlights include workshops and implementation plans for the Pacific and Southern Oceans, a workshop on decadal variability and predictability, the initiation of CLIVAR activities in Africa, and a Chapman Conference on the North Atlantic Oscillation.

Bob Weller reported on a very productive Pacific implementation planning workshop. Among the topics discussed were the recent commitments to repeats of key WOCE sections, the operational status of TAO/Triton observations and the use of these data in predictive models, and a number of regional Pacific process studies in the planning phase.

Martin Visbeck, the new chair of the Atlantic Panel, reported on the very successful NAO Chapman Conference in Ourense, Spain and subsequent panel meeting. Highlights include the rapid development of Argo deployments in the North Atlantic, funding of a major UK initiative on Atlantic Thermohaline Circulation and Abrupt Climate Change, continuation of the PIRATA array into an extended phase, and coordination with the ACSYS/CLIC initiative for an Arctic-Subarctic Flux Array for the monitoring of freshwater inflow.

Doug Martinson next presented implementation progress from the Southern Ocean stemming from a workshop held in Perth, Australia, in November, 2000. Highlights include commitments made to repeat sections across the Drake Passage and from Tasmania to Antarctica. Challenges for the region include the need for better understanding of changes in the character of the Antarctic Circumpolar Wave and links to temperate latitudes, Argo resourcing and deployments, repeat hydrography in the Pacific sector, and improved air-sea fluxes.

With respect to monsoon and regional climate activities, CLIVAR continues to benefit from Roberto Mechoso's leadership on behalf of VAMOS. Earlier this year, the 4th meeting of the VAMOS Panel was held in Montevideo, Uruguay (see page 32 for a summary). New VAMOS initiatives include a joint CLIVAR-VAMOS/GEWEX study of the South American monsoon within the La Plata River Basin (PLATIN). A preliminary science and implementation plan for a North American Monsoon Experiment

(NAME) has been drafted. Other VAMOS developments include a field campaign planned for South America in 2002/03 to study the American Low Level Jets (ALLS), and the extended study of the low-level cloud region in the eastern tropical/subtropical Pacific (VEPIC). Much of this progress was reported in a recent special issue of Exchanges devoted to VAMOS.

In 2001, the SSG welcomes Peter Webster and Julia Slingo as new co-chairs of the Asian-Australian Monsoon Panel and in so doing thanks the outgoing chairs Stuart Godfrey and Bill Lau for their years of service and leadership of the panel. Research areas of interest to the panel include changes in the ENSO-monsoon relationship, the importance of intraseasonal variability, and the zonal SST mode in the Indian Ocean. Among the challenges for the panel is the need to develop an integrated approach implementation of CLIVAR requirements in the Indian Ocean.

One of the more noteworthy developments of the past year has been the formation of the CLIVAR Variability of the African System (VACS) Panel. Chris Thorncroft, co-chair, with Laban Ogallo, of VACS, reported on the first meeting held in Nairobi, Kenya in January, 2001. VACS implementation is being developed around three key questions:

- What causes African climate variability (AVC) and how is this related to other parts of the globe?
- How well do current dynamical models simulate this variability and relationship?
- What are the deficiencies in the models that account for inadequacies in simulating ACV locally and in a global context?

This past year saw the Working Group on Climate Change Detection (WGCCD) host workshops in Africa and the Caribbean (see page 34) for the purpose of producing indices of climate change using daily meteorological data. In addition, as a result of the WGCCD efforts, an inventory of daily meteorological time series was produced for 30 African countries. Standard software was provided for quality control and calculation of indices for use in the workshops and for wider distribution. Approximately 40 scientists from the meteorological services in these two regions gained experience with data quality and homogeneity checks, and the calculation and analysis of climate indices. As a result of these workshops the concept of free exchange of “elaborated” (i.e., indices), rather than “raw” data, to promote the creation of global data sets for use in climate studies, was realized.

Much of the discussion of the CLIVAR activities on seasonal to interannual prediction revolved around the importance of developing a synergy between the CLIVAR basin and monsoon panels’ plans for observations and process studies and the activities of the Working Group on Seasonal to Interannual Prediction (WGSIP). As discussed by Steve Zebiak, the WGSIP has been involved in evaluating ensemble prediction methods, continued diagnostics of intraseasonal variability, development of standards for model simulation and prediction outputs, and means by which other components of CLIVAR could take advantage of the numerical experiments undertaken by WGSIP.

A special session at this year’s SSG was devoted to the application and applicability of CLIVAR science. Tim Palmer organized a series of presentations representative of applied climate research and actual climate applications being performed at ECMWF, the IRI, and the University of East Anglia. As a result of the ensuing discussion, over the next year the various CLIVAR working groups and panels will be identifying potential applications and partnerships emerging out of the basic research agenda and accomplishments within CLIVAR.

The SSG was pleased to note the initiation and strengthening of a number of CLIVAR and CLIVAR relevant initiatives including, but not exclusively, the aforementioned UK study of rapid climate change, continuation and initiation of a large number of European Union-sponsored projects, and the formation of a US CLIVAR Project Office. A particular area of focus for CLIVAR this past year was increased communication across the breadth of the program. Major strides were made as a direct result of the dedication of the scientific officers within the ICPO who have worked closely with each CLIVAR panel and chairperson. For example, the ICPO recently brought on Carlos Ereño to assist with CLIVAR implementation in South America.

In summary, CLIVAR implementation is making progress on a number of fronts. The CLIVAR research agenda as it pertains to observations, modelling, and process studies is moving forward at a healthy pace. That is not to say the program is without important challenges, among which include the need for continued dedicated resources at the national levels, issues pertaining to air-sea fluxes, data management, Northern Hemispheric bias to observations, WOCE-CLIVAR transition, coordination across the modelling components of the programme, continued interactions with GEWEX and CEOP, and the need to bring closer the natural variability and anthropogenic change portions of CLIVAR.

Lastly, we wish to thank the outgoing SSG members Kimio Hanawa, John Mitchell, Neville Nicholls, and Ed Sarachik who provided sage advice and valuable input for the past several years. In turn, we are pleased to welcome Pedro Silva-Dias, Ian Simmonds, Max Suarez, and Kensuke Takeuchi as new members of the SSG.

Possible Roles of Atlantic Circulations on the Weakening Indian Monsoon Rainfall - ENSO Relationship

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This is a summary of a paper to appear in J. Climate. The negative correlation between Indian Monsoon Rainfall (IMR) and ENSO, presumably through an anomalous Walker cell driven by tropical East Pacific sea-surface temperature (SST) anomalies, has weakened rapidly since the late 1970s (Kumar et al., 1999, or K99). This weakened relationship is defined by the correlation between June-September All-India rainfall and NINO3 (5°S-5°N, and 150°W-90°W) SST. This correlation (reproduced from K99 in Fig. 1 (page 1), and truncated at left) has been consistently around the 1% significance level from 1856 until the 1970s. Webster and Palmer (1997) related this interruption of the ENSO-monsoon relationship to the chaotic nature of the monsoon, while K99 viewed the rapid weakening of the correlation as systematic and proposed that it may be due to changes in the Pacific Walker circulation and the warming of the Eurasian Continent. These issues are addressed in this paper using the 1949-98 data of SST, surface air temperature (SAT), and wind, and velocity potential fields of the NCEP/NCAR Reanalysis. Also, the Department of Energy SAT data are used for the period 1856 - 1990.

Although the Walker cell during recent (1978-98) El Niño events moved southeastward with its downward branch moved away from the Indian Ocean to the maritime continent/Australia, the composite warm- and cold-event differences before and after 1977/78 have very similar patterns. This is because the cold-event Walker cell was shifted northwestward from 1950-77 to 1978-98, moving its upward branch closer to India. The shifts in both warm and cold events are consistent with the increase of the decadal-mean tropical East Pacific SST in the late 1970s (Trenberth and Hurrell, 1994), which results in no shift of the within-period anomalous circulation. Therefore, the interdecadal change of the Walker cells is unlikely to play an important role on the weakening ENSO-monsoon relationship.

Since it is expected that the monsoon rainfall will be decreased by El Niño and increased by warm winter-spring Eurasian surface temperature, the generally warmer Eurasian surface in recent decades may give rise to a wetter monsoon even in the presence of an El Niño. This was indeed observed in the composite of El Niño events during 1981-97 by K99, who argued that the effect of Eurasian surface temperature has dominated that of ENSO during recent decades. However, this implies that during cold events the ENSO effect should be stronger. Alternatively, relatively (within 1978-97) cold Eurasian winters should exert a weaker influence. Thus, there should not be a significant net change of ENSO-IMR correlation within the period of 1978-98.

For 1950-77, the correlation between IMR and the preceding winter Eurasian SATs (Fig. 2a, page 17) is weak over the entire domain. But during 1978-98 (Fig. 2b) significant positive correlation occurs over a large area of western Eurasia with the maximum centred near 50°N-60°N, 0°-20°E, which shall be called western Europe (wE). This is consistent with the results of Bamzai and Shukla's (1999), who were surprised to find that the only significant inverse correlation between the 1973-94 winter snow cover and the subsequent Indian summer monsoon rainfall occurred over western Europe. For the 1950-77 spring, the correlation (Fig. 2c) continues to be very weak over the midlatitudes, but positive correlations over localized subtropical areas around northern India and the Himalayas seem to support the hypothesis that snow cover over Tibet and the Himalayas influence the monsoon strength. However, for the 1978-98 spring (Fig. 2d) the correlation in this area is weak or even negative, so the Himalayan/Tibetan relationship disappears. On the other hand, the IMR-SAT correlation during the 1978-98 spring over most of midlatitude Eurasia remains weakly positive. The overall pattern suggests a possible continent-scale meridional thermal contrast effect (across about 30°N) on the ensuing monsoon.

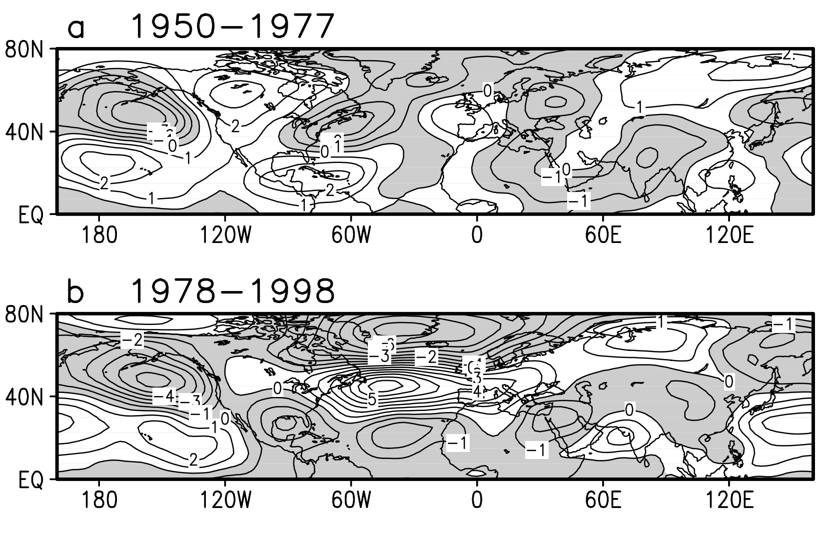

Fig. 3*: The 500 hPa streamfunction difference between summer Indian monsoon wet years and dry years for (a) 1950-1977 and (b) 1978-1998 (contour interval $1x10^6\ m^2 s^{-1}$). Negative values are shaded. The wet and dry years were identified by monsoon rainfall anomalies exceeding one standard deviation.*

The correlation between winter wE SAT and the subsequent IMR had been small until the most recent decades when it became significantly positive for the first time in more than a century (Fig. 1, page 1). This drastic change occurs around the time of the weakening of the monsoon-ENSO relationship. The composite preceding winter 500 hPa streamfunction differences between wet and dry monsoons during 1950-77 (Fig. 3a, page 4) exhibit an organized Pacific-North America (PNA) teleconnection pattern, which is indicative of the strong relationship with ENSO. During 1978-98 (Fig. 3b), the PNA pattern is nearly absent over North America, and the most organized pattern is an anomalous North Atlantic westerly jet stream that extends from northeast North America to northwest Eurasia during the winters preceding a wet Indian monsoon. Therefore, during these winters the jet stream is shifted to a more northerly location, which gives rise to an anomalously warm midlatitude Eurasia with less storm activity (therefore less snow cover or higher SAT). This would be a favorable condition for a subsequent wet Indian monsoon. Since the largest variation of the storm track is located in western Europe, the strongest signal of the winter SAT-IMR correlation during 1978-98 should occur there, rather than closer to South Asia.

There is a large difference in the influence of the wE winter SAT signals between the two decadal periods. The signals are confined to western Europe during 1950-77 (Fig. 4a, page 17) but extend across most of Eurasia during 1978-98 (Fig. 4c). Furthermore, during 1950-77 the signals decreased rapidly during spring (Fig. 4b), but during 1978-98 they persisted into spring across a large region of Eurasia (Fig. 4d). These results support the interpretation that in 1978-98 western Europe is the „gateway" for winter storm anomalies that affect the spring Eurasian SAT and the subsequent monsoon. The trend of the Eurasia-induced thermal contrast effect on the IMR may be seen from the 21-year sliding correlation between the IMR and the preceding winter SAT averaged over the central Eurasia area 40°N-70°N, 50°E-95°E. This correlation (Fig. 1) and the very similar correlation for spring (not shown) also become increasingly positive in recent decades. However, the correlation remains below the 5% level, apparently because the strong winter wE signal has spread over the much larger central Eurasian region. This result also indicates that the Eurasian meridional thermal contrast effect on the monsoon rainfall emerges only during recent decades.

The difference between winter mean 500 hPa streamfunction during 1978-98 and during 1950-77 reveals two wave patterns (Fig. 4e, page 17). A long wave is found over northern latitudes with trough axes over the Atlantic and near 60°E, and a short-wave teleconnection pattern exists across northern Africa and southern Asia. Therefore, westerlies across the North Atlantic turn northeastward towards western Europe, which is a noted feature of the positive phase of the North Atlantic Oscillation (NAO) (Hurrell, 1995), a regional manifestation of the Arctic Oscillation (AO) (Thompson and Wallace, 1998). The positive phase has been unusually dominant over recent decades. The short-wave teleconnection exhibits a down-shear tilt so that its momentum transport favors the strengthened mean westerlies to the north. This is consistent with an anomalous storm track and the eastward extension of correlation between IMR and wE winter SAT during 1978-98. The variation of the anomalous 500 hPa streamfunction gradient in northern Eurasia may also explain the weakening of the wE signal between 40°E-60°E and the increase farther east (Figs 4c-d) as due to changes of the baroclinic conditions for storm development.

We have shown that the weakening of the ENSO-IMR relationship may be due to the strengthening positive phase of NAO/AO and associated jet stream/storm track patterns over the North Atlantic and northern Eurasia during recent decades. It may be noted that this weakening is mostly due to the summer warm events of 1983 and, to a lesser extent, 1997 (1997 contributes only to the last two data points in Fig. 1). For both years, the influence of a warm Eurasian surface opposes the effect of a warm ENSO event, with 1983 having the highest positive NAO index in the twentieth century. If these two years are removed (Fig. 1), the ENSO correlation for the recent decades will return to the high (1%) level. However, there is little influence on the correlation of the winter wE SAT with the monsoon rainfall. Thus, the effects of circulation changes over the North Atlantic in the recent decades are robust and the disruption of the ENSO-IMR relationship is probably not accidental.

Acknowledgements

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Decadal Variability of the Summer Monsoon Rainfall in East Asia and Its Association with the SST Anomalies in the Tropical Pacific

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1. Introduction

East Asia is a region of strong monsoons with rainfall mainly concentrated in the summer season. As in other monsoon regions , the decadal variation of climate in East Asia is also significant (see Huang and Wang, 1996). In order to explain the decadal variability of the summer monsoon rainfall in East Asia and its possible causes, a data set of the daily precipitation and temperature at 160 stations in China for 50 years from 1950-1999 and NCEP/NCAR reanalysis data are used to look at the characteristics of the decadal variation of climate in East Asia and its association with the SST anomalies in the tropical Pacific.

2. Decadal Variability of Summer Monsoon Rainfall in East Asia

The decadal fluctuation of summer (June-August) monsoon rainfall is more obvious than the decadal variation of surface temperature in East Asia. From the decadal-mean anomaly distributions of summer precipitation in the 1950s, the 1960s, the 1970s, the 1980s and the 1990s (1991-1999), it can be found that the anomaly distributions of summer monsoon rainfall in the periods of the 1980s and the 1990s were obviously different from that in the 1970's in East Asia. Compared with that in the 1970s, the summer monsoon rainfall obviously increased in the Yangtze River valley, but opposite phenomena appeared in North China and the Yellow River valley, and prolonged severe droughts occurred in North China during the periods from the 1980s to the 1990s.

The decadal variation of summer monsoon rainfall may be seen from the interannual variations of summer precipitation in various region of China. The analysed results show that the interannual variations of summer precipitation in North China, the Yangtze River valley and South China before 1976 were very different from those after the late 1970s. Thus, the differences between the summer precipitation anomalies (percentage) averaged for 1977-1999 and those averaged for 1967-1976 at 160 stations in China are analysed (see Figure 1a). As shown in Fig.1(a), there are large differences between the summer precipitation anomalies averaged for 1977-1999 and those averaged for 1967-1976 in North China and the Yangtze River valley. From 1977 to 1999, the summer precipitation decreased continuously in North China and severe droughts occurred frequently in this region, but in the Yangtze River valley, the summer precipitation increased obviously and serious floods were frequently caused there.

3. Decadal Variation of SST Anomalies in the Tropical Pacific and Its Impact on the Summer Monsoon Rainfall in East Asia

In order to investigate the cause of the decadal variability of summer precipitation in East Asia, the ten-year running mean SST anomalies in the tropical Pacific and its impact on the summer monsoon rainfall in East Asia are analysed. The analysed result shows that the SST anomalies appeared an obvious decadal variability in the equatorial central and eastern Pacific. The equatorial central and eastern Pacific was cooling in the 1970s and warming remarkably in the 1980s and the 1990s. Thus, the difference between the SST anomalies averaged for 1977-1999 and those averaged for 1967-1976 in the Pacific is also analysed (see Figure 1b). As shown in Fig.1b, an obvious El Niño-like SST anomaly pattern appeared in the tropical central

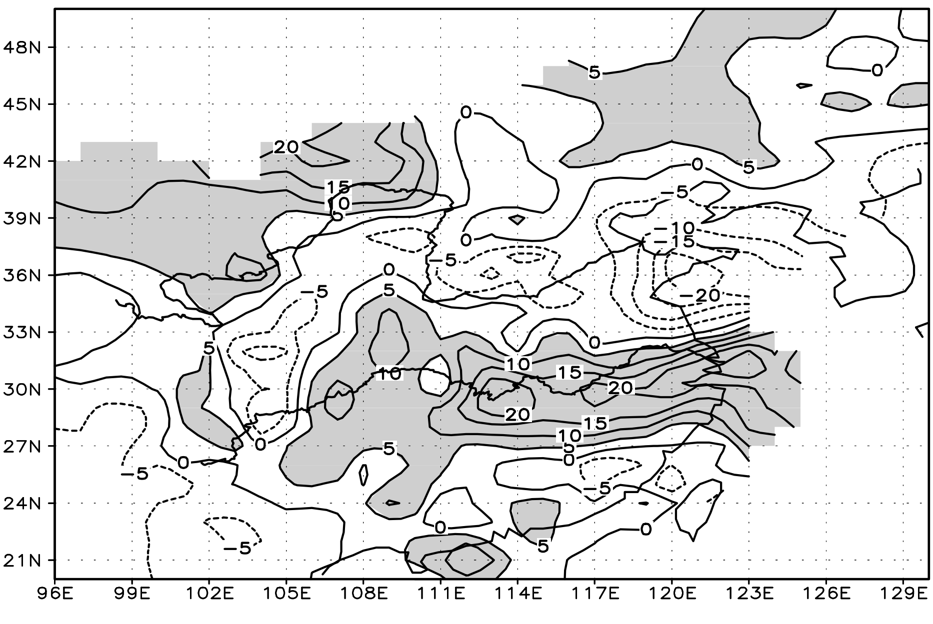

***Fig. 1a**: The differences between the summer precipitation anomalies percentages averaged for 1977-1999 and those averaged for 1967-1976 at 160 stations in China.*

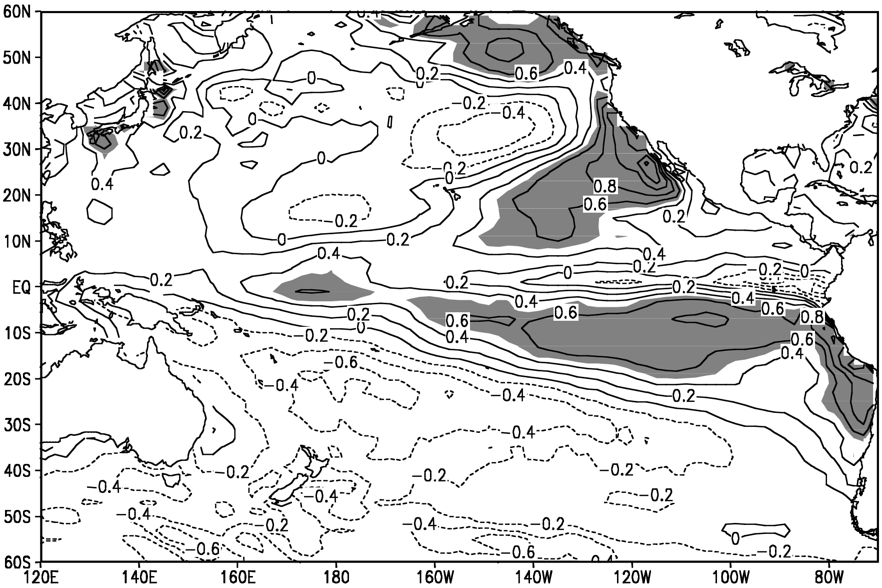

Fig. 1b: The difference between the SST anomalies averaged for 1977-1999 and those averaged for 1967-1976 in the Pacific.

and eastern Pacific from 1977 to 1999. This may explain that the "decadal El Niño event" appeared to occur from 1977 to 1999, while the "decadal La Niña event" occurred in the period of 1967-1976. Therefore, there may be a "decadal El Niño-like cycle" in the decadal variability of SST anomalies in the tropical Pacific.

Huang and Wu's (1989) investigation on the interannual variations of summer monsoon rainfall in East Asia showed that when the equatorial central and eastern Pacific is in a warming episode, the summer monsoon rainfall is strong in the Yangtze River valley, but it is weak in North China, Thus, droughts used to occur in North China, but floods frequently appear in the Yangtze River valley in the warm episode of the equatorial central and eastern Pacific.

The above-mentioned analyses show that the decadal variability of summer monsoon rainfall may be closely association with the decadal variation of SST anomalies in the tropical Pacific.

4. Decadal Variability of Water Vapour Transport in East Asia

The influence of SST anomalies in the tropical Pacific on the decadal variability of summer monsoon rainfall may be clearly seen from the anomaly distributions of water vapour transport flux. The anomaly distribution of water vapour transport flux calculated by using the NCEP/NCAR reanalysis data show that in the period of 1967-1976, the trade wind along the equator was strong, the cross-equatorial flow over the Indo-China Peninsula was strong and the southwest monsoon flow was also strong in East Asia. Therefore, a large amount of water vapour were transported into North China from the tropical western Pacific, the South China Sea and the Bay of Bengal.

However, in the period of 1977-1999, the trade wind became weak, and the westerly wind anomalies appeared along equator, the cross-equatorial flow over the Indo-China Penusula was weak, and the southwest monsoon flow was also weak and the northerly wind anomalies appeared in East Asia. Therefore, a large amount of water vapour was transported into the Yangtze River valley, but the water vapour transport by Asian monsoon flow became weak in North China. This caused the remarkable decrease of summer precipitation in North China and the increase of summer precipitation in the Yangtze River valley from the late 1970s to the 1990s.

5. Conclusions

The results presented in this paper show that the decadal variability of summer monsoon rainfall is very obvious in East Asia. This decadal variability may be closely association with the decadal variability of SST anomalies in the tropical Pacific. The result analysed by using the observed SST data shows that the decadal El Niño-like pattern of SST anomalies occurred in the tropical central and eastern Pacific from the late 1970s to the late 1990s. This decadal ENSO-like cycle had a large impact on the decadal variability of summer monsoon rainfall in Est Asia through the water vapour transport by Asian monsoon flow.

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Decadal Monsoon Variability over South and East Asia

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Introduction

One of the objectives of the CLIVAR Project is to describe and understand climate variability on decadal time-scales through the collection and analysis of observed instrumental data.

Seasonal variation of rainfall is the most distinguishing feature of the monsoonal regions of the world. A major portion of the annual rainfall over most of the Asian domain occurs during the summer monsoon period (June – September). The year-to-year variability in the monsoon rainfall occasionally leads to extreme situations of droughts and floods affecting the agricultural output and the national economy. Hence the variations in seasonal monsoon rainfall may be considered a measure to examine climate variability / change over the Asian monsoon domain.

Our recent studies have shown that monsoon rainfall over South and Southeast Asia exhibits decadal variability with certain epochs of above and below normal rainfall. The epochs tend to last for about 3 decades. Further these studies have also revealed that the impact of El Niño (La Niña) is more severe during the below (above) normal epochs than the above (below) normal epochs. Thus the impact of ENSO events is modulated by the decadal variability in monsoon rainfall (Kripalani and Kulkarni, 1997a; 1997b). This article examines the decadal monsoon rainfall variability over South and East Asia.

Data and Method of Analysis

i. Monthly station rainfall data for 120 stations over East Asia (China, Japan, Mongolia, Korea) has been extracted from numeric data package "The Global Historical Climatology Network" prepared by the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, USA. Recent data has been updated from "Monthly Climatic Data for the World" prepared by NOAA, USA in co-operation with WMO.

ii. Based on correlation analysis and Empirical Orthogonal Functions regional seasonal (June to September) time series for coherent regions over north China (36° – 41° N, 109° – 124° E) and southern Japan (31° – 36° N, 130° – 141° E) are prepared for the 118-year period (1881-1998).

Since India constitutes a major portion of South Asia, monsoon rainfall for India has been downloaded from the website of the Indian Institute of Tropical Meteorology (http://www.tropmet.ernet.in/). A long homogeneous summer monsoon rainfall series has been prepared for the period 1871-1999 for the country as one unit.

Rainfall series over India, China and Japan for the period 1881-1998 are subjected to statistical tests. Long term changes are examined with the Mann-Kendall rank statistic, while the short-term climate fluctuations have been studied by applying Cramer's test for the running means (WMO, 1966). No significant long-term trends are detected. However, the Cramer's statistic, which compares the means of the subperiods with the mean of the whole period, reveals interesting results.

Results and Discussion

The Cramer's statistic with varying window lengths (11-, 21-, 31-year) convey similar information, however with larger window lengths that patterns become smoother. Hence, the 31-year Cramer's statistic for India, China and Japan are presented in Figure 1 (page 10). The most striking features are the epochs of above and below normal rainfall in each series.

The Indian series shows major turning points around 1895, 1930 and 1963 with the period 1895-1930 (1930-1963) depicting below (above) normal rainfall. China shows major turning points around 1906, 1945 and 1972 with the period 1906-1945 (1945-1972) depicting below (above) normal rainfall. Chen et al. (1992) have noted that rainfall over north China has generally been decreasing since the 1950s especially in the 1980s and shows an apparent trend towards a more arid climate. Figure 1b shows these features.

The most interesting feature is that the turning points for China follow those of India about a decade later. This time-lag seesaw between India and China was suggested by Fu and Flether (1988). Monsoon rainfall over India has entered into an above normal epoch with a turning point around 1990 (Kripalani and Kulkarni, 1997b – this may be a possible reason that none of the El Niños after 1990 have had any adverse impact on Monsoon rainfall over India). Hence, one can speculate that Monsoon rainfall over China may enter / may have entered into an above normal epoch around the year 2000. These cyclic oscillations appear to be a part of some natural variability, hence the trend towards arid climate speculated by Chen et al. (1992) over China may not be true. Generally the epochs tend to last for around three decades over India and China. For Japan the major turning point is around 1937 with the period before 1937 depicting subdued below normal epoch, while the period after 1937 depicts above normal rainfall activity. Over Japan the epochs tend to last for about five decades. More details on this study are available in Kripalani and Kulkarni (2001).

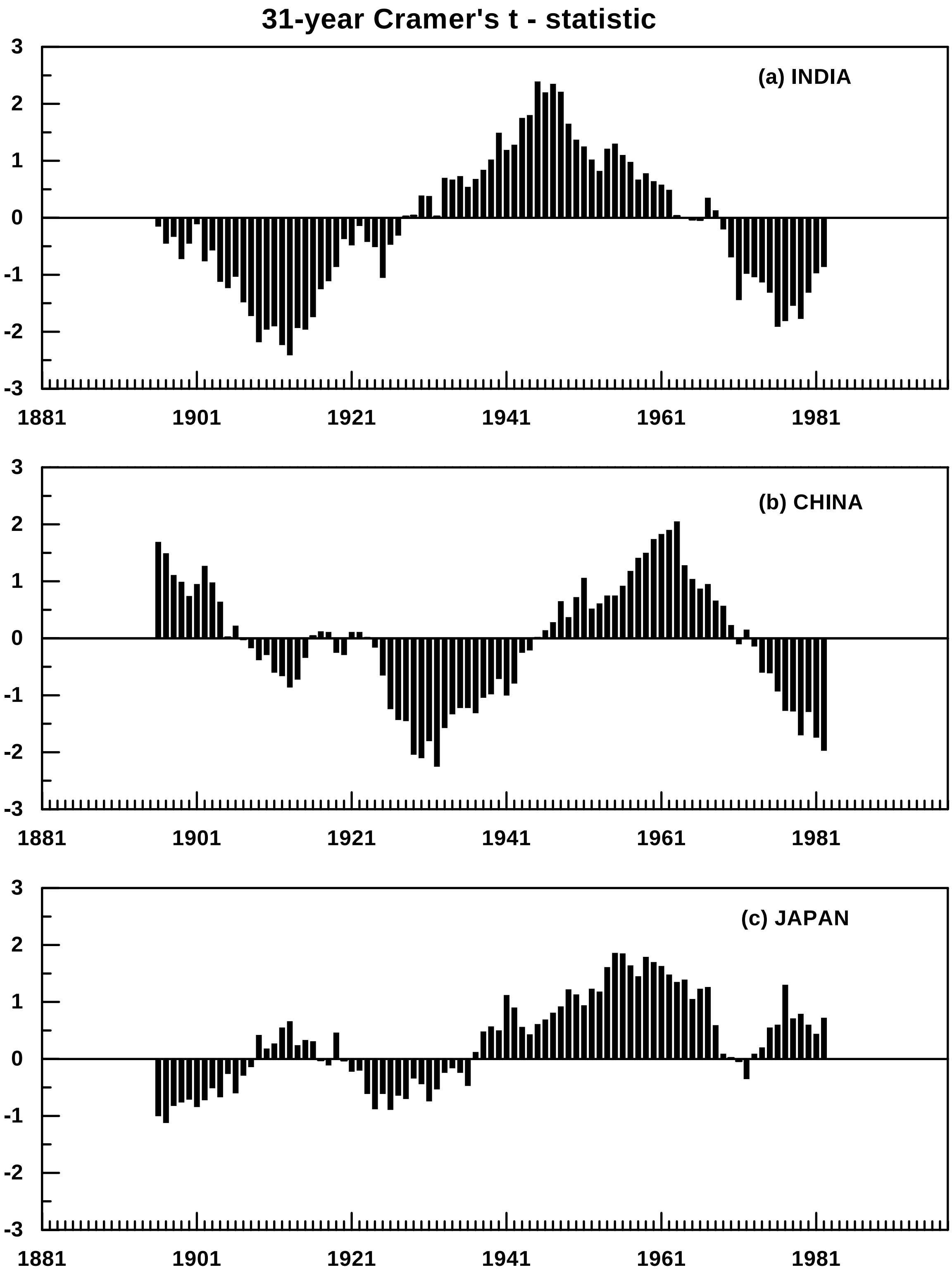

Figure 1: Values of the Cramer's t statistic for the 31-year running means of monsoon rainfall for India, China and Japan depicting decadal variability. The t-values are plotted at the center of the 31-year period.

Though the reasons for this decadal variability are not clear, Chen et al.(1992) attribute the thermal contrast between the continent and the adjacent ocean to be the primary factor for the decadal-scale variations of monsoon activity over China. During recent years it has become clear that there is a strong interdecadal variability in the ENSO cycle. Hence, the Pacific ocean's influence on monsoon should vary interdecadally as well (Webster et al., 1998). However, our analysis (Kripalani et al., 1997; Kripalani and Kulkarni, 1999) suggest that the decadal variability over India is more associated with events in the Northern Hemisphere mid-latitudes than over the tropical oceanic regions.

While the often-cited anthropogenic factors (global warming, deforestation, air pollution, etc.) may play some role in the regional extreme weather conditions, they are not likely to contribute to the decadal / epochal or oscillatory behaviour of the rainfall regimes.

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Influence of the Indian Ocean Dipole on Asian Monsoon Circulation

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1. Introduction

According to analyses in the SSTA, a dipole oscillation of the Indian Ocean SSTA was indicated (Sagi et al., 1999), which represents the reverse variation feature of mean SST between (10°S-10°N, 50°E-70°E) region and (10°S-0°, 90°E-110°E) region. This dipole was regarded as one to be not always related to the ENSO. Webster et al. (1999) also suggested that the Indian Ocean dipole in 1997-98 was independent of the ENSO and caused by strong atmosphere-land-sea interaction. Usually, the dipole is not only shown in the variation of SST, but also in the variation of subsurface ocean temperature (SOT) of the Indian Ocean (Anderson, 1999).

In fact, the importance of SSTA in the Indian Ocean and its influence on summer rainfall in the middle and lower reaches of the Yangtze River have been indicated early (Luo et al., 1985; Chen, 1991). But the Indian Ocean SSTA as a dipole need to be studied further, particularly the influence of the dipole on the Asian monsoon circulation and climate.

The SST data (1900-1997) used in this paper are obtained from the Hadley center in UK, which are monthly 5° x 5° grid point data and have been used in some studies (Parker et al., 1994; Smith et al., 1998). The spatial-temporal features of the Indian Ocean dipole were studied by using above data (Li and Mu, 2000). The influences of the Indian Ocean dipole on the Asian monsoon circulation will be studied by using NCEP-NCAR reanalysis and other data further. In order to represent this dipole, we take the difference of averaged SSTA between in the (5°S-10°N, 50°E-65°E) region and the (10°S-5°N, 85°E-100°E) region as the dipole index, which will be better since some Islands and the Laut Jawa sea have been ruled out the definition domain.

2. Influences of Indian Ocean Dipole on Asian monsoon circulation

The ENSO has been regarded as important signal and factor to cause interannual climate variation. The series of studies in relation to the impact of the ENSO on climate have been completed (Namias and Cayan, 1981; Rasmusson and Wallace, 1983; Li, 1995). In another paper, the data analyses have clearly showed that the Indian Ocean dipole is related closely to the ENSO mode (Mu and Li, 2000), although it is not understood yet that which dipole is more initiative and important in the interaction. But at least we can suggest that the Indian Ocean dipole also plays an important role in atmospheric circulation / climate variation and anomalies over the globe, particularly through its interaction with the ENSO. In the following, the analyses will show some important impacts of the Indian Ocean dipole on Asian monsoon circulation emphatically.

In order to reveal the feature of Indian Ocean dipole and its influence on monsoon circulation, we respectively take 4 years (1961, 1972, 1994 and 1997) with larger positive index and 5 years (1958, 1959, 1960, 1970 and 1996) with larger negative index to engage in composite analyses. The anomalous circulation patterns at 850hPa in summer (June-August) for positive phase and negative phase of the Indian Ocean dipole are shown in Fig.1, respectively. It can be seen that there is different pattern in Asian monsoon region for different phase of the dipole. Corresponding to positive phase, there are anomalous southeasterly wind over the equatorial Indian Ocean, anomalous westerly wind over Indian Peninsula and anomalous westerly wind over the region from Bay of Bengal to the South China

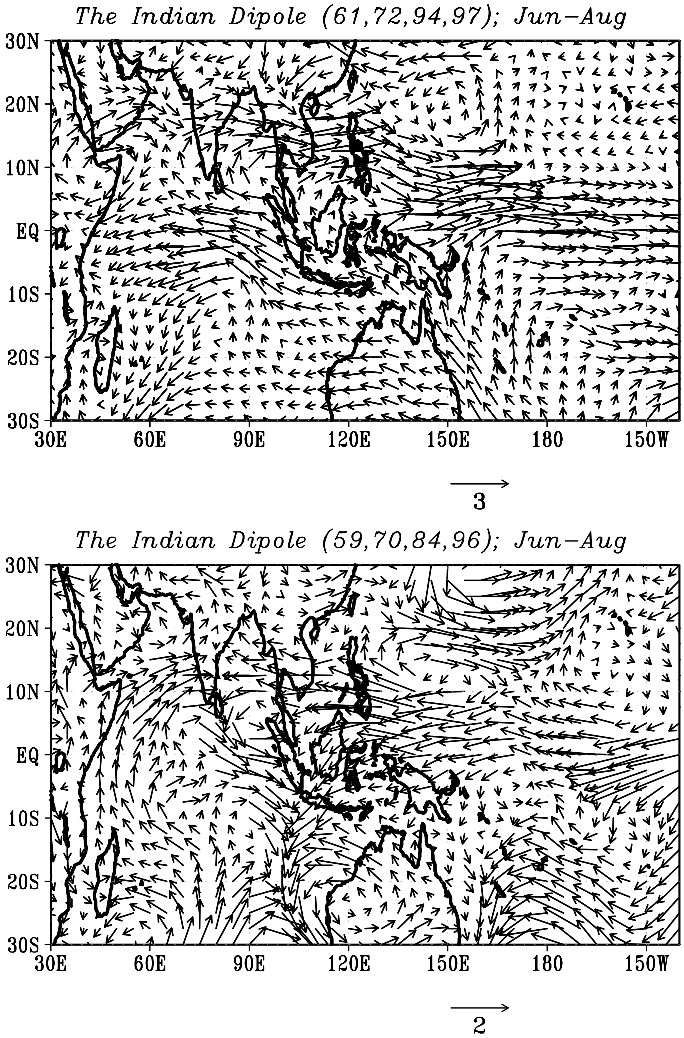

Fig. 1: The circulation patterns at 850hPa in summer (June-August) over the southern Asia, corresponding to positive phase (a) and negative phase (b) of the Indian Ocean dipole, respectively.

Sea. This means that the summer monsoon over the South China Sea and Indian Peninsula are stronger for positive phase of the Indian Ocean dipole. But in negative phase, there are anomalous weaker southerly wind over the equatorial western Indian Ocean, anomalous weaker northwesterly wind over the equatorial eastern Indian Ocean, anomalous westerly wind over the southern Indian Peninsula, anomalous easterly wind over the region from the Bay of Bengal to the South China Sea. This means that the summer monsoon is weaker over the South China Sea region but stronger over the southern India for negative phase of the Indian Ocean dipole.

In order to show the influence of the Indian Ocean dipole on the Asian summer monsoon further, some correlation coefficients of the Indian Ocean dipole index with the geopotential height at the middle-high troposphere are calculated by using the NCEP reanalysis data (1958-1997). It is known that the anticyclone in upper troposphere over the Tibetan plateau (called Tibetan high or South Asian high) is an important component of the Asian summer monsoon system, the intensity of South Asian high can partly represent the activity of the Asian summer monsoon. In Fig.2a, the distribution of correlation coefficient of the Indian Ocean dipole index with the geopotential height at 200hPa over the globe is shown. The strong negative correlation center over the Tibetan Plateau shows that the dipole index has negative correlation with the intensity of the South Asian high. In other words, the South Asian high is weaker for positive phase of the Indian Ocean dipole; but corresponding to negative phase of the dipole, the South Asian high is stronger and to the west. The Indian Ocean dipole will still impact on the Asian summer monsoon (especially the East Asian summer monsoon) through the South Asian high (Tao and Zhu, 1964).

The subtropical high over the northwestern Pacific is also an important component of the East-Asian summer monsoon system, and it can cause serious climate anomalies in East Asia (Huang and Yu, 1972; Tao et al., 1998). According to the data analysis, it is also clear that the subtropical high over the North Pacific is related to the Indian Ocean dipole. As shown in Fig.2b, the subtropical high is weaker for positive phase of the Indian Ocean dipole; but corresponding to negative phase of the Indian Ocean dipole, the subtropical high is stronger. Over the

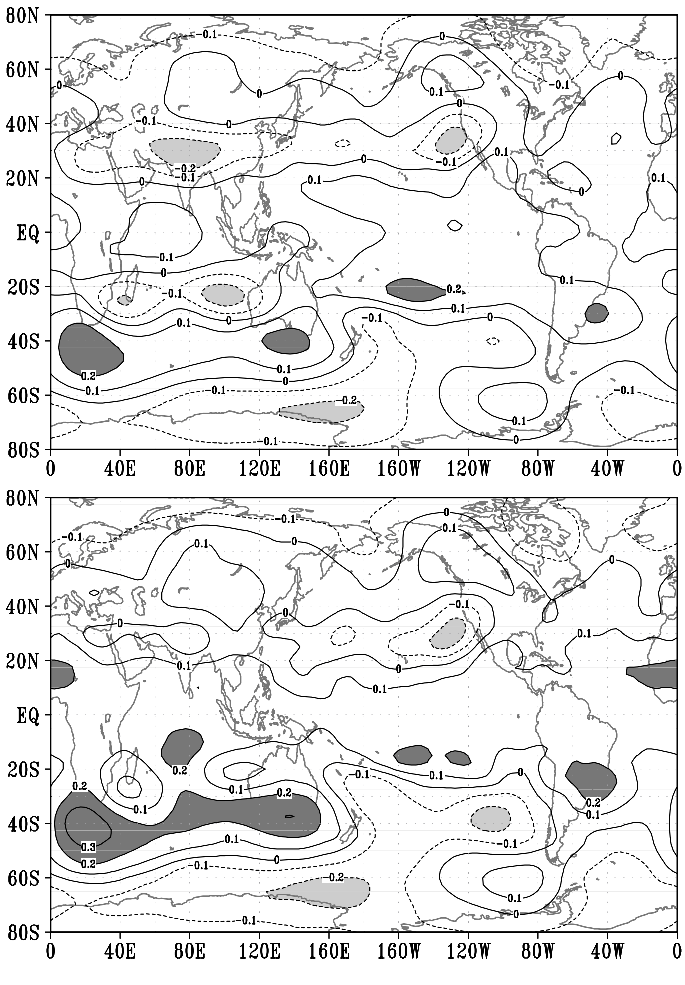

Fig. 2: Distributions of correlation coefficient of the Indian Ocean dipole index with the geopotential height at 200hPa (a) and 500hPa (b) over the globe, respectively. The shadow represents the area, in which the correlation coefficient is more than statistical significance test.

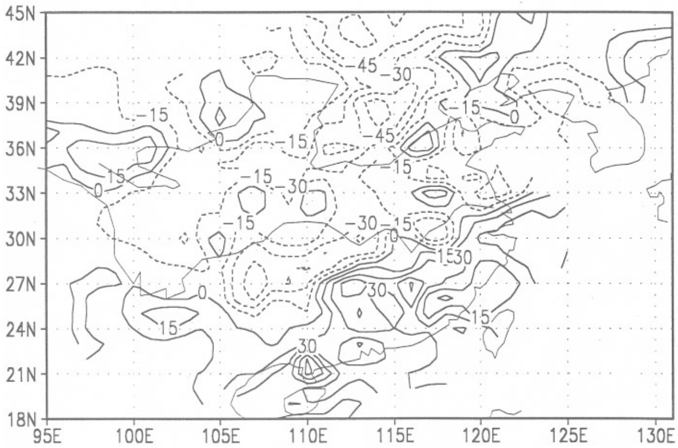

Fig. 3: The differences of summer precipitation anomalies (%) in eastern China for positive phase with negative phase of the Indian Ocean dipole.

East-Asian continent, the correlation is positive. There is anomalous ridge (trough) over the East-Asian continent region corresponding to positive (negative) phase of the Indian Ocean dipole.

The summer precipitation anomalies in Eastern China result mainly from summer monsoon activity and its anomaly. The precipitation anomalies in Eastern China can also represent the influence of the dipole on Asian summer monsoon. The difference of the precipitation anomalies (%) during summer (June – August) in China corresponding to positive phase and negative phase of the Indian Ocean dipole is shown in Fig.3, which is calculated for 4 strongest positive phase years and 5 strongest negative phase years, respectively. Although the Indian Ocean dipole is weaker in summer generally, it is still shown for the positive phase of the Indian Ocean dipole that there is more summer rainfall in southeastern China/southern China and northeastern China, but is less summer rainfall in the other regions of China (particularly in northern China). For negative phase of the Indian Ocean dipole, the precipitation pattern is inversion.

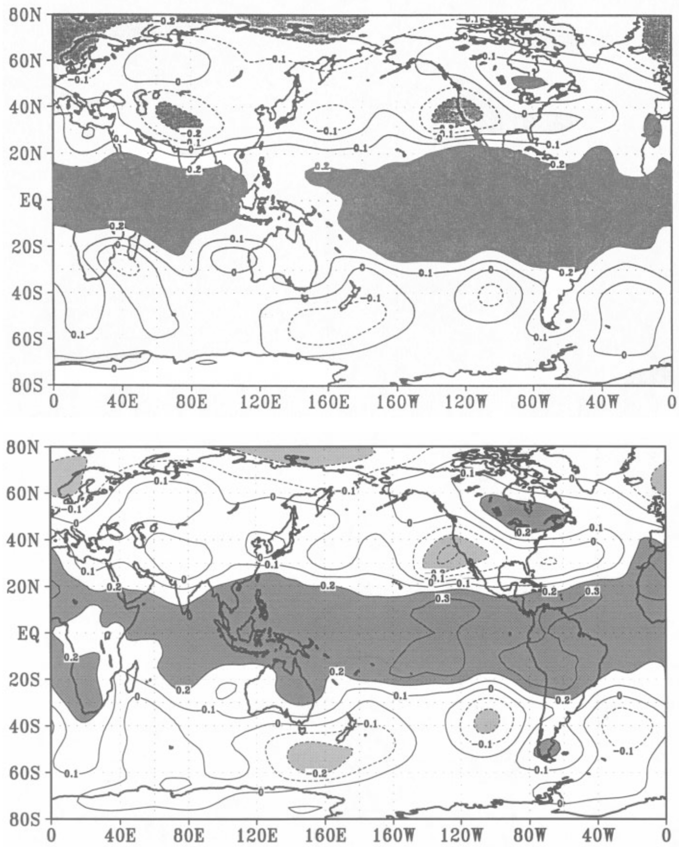

Fig. 4: Distributions of correlation coefficient of the Indian Ocean dipole index with geopotential height at 200 hPa (a) and 700 hPa (b) in the globe, but the dipole index leads 5 month.

In Fig.2, we can still find the strong correlation zone in the 40-50°S latitudes over the southern Indian Ocean and the western coast of North America. This means that the variations of atmospheric circulation and climate in those regions are also related to the Indian Ocean dipole. Corresponding to positive (negative) phase of the Indian Ocean dipole, there is an anomalous trough (ridge) at upper troposphere over the western coast region of North America and the weather and climate in the United States, particularly in the western region, will be impacted prominently. For positive phase of the Indian Ocean dipole, there are anomalous easterly winds in northeastern Australia and the cyclonic circulation in southwestern Australia and in western South Africa; for the negative phase of the dipole, there are anomalous easterly winds in southeastern Australia and an anticyclonic circulation in South Africa.

3. Omen signification of the Indian Ocean dipole

When we analyse the correlation of the Indian Ocean dipole index with geopotential height, an obvious lag correlation is shown. The variations of atmospheric circulation and climate in some regions are lagging to the variation of the dipole index, so that, the Indian Ocean dipole index can be a predictive signal of the climate variation in some regions. This may be very important and variable.

In Fig. 4, the distributions of correlation coefficients of the dipole index leading 5 months to global geopotential height at 200hPa and 700hPa (similar with that at 500hPa) are shown, respectively. It is clear that there is an obvious PNA pattern over the eastern Pacific / the North America region and a negative center over the Tibetan Plateau. This means that the positive (negative) phase of the Indian Ocean dipole can be regarded as a factor to predict the appearance of inverse (direct) PNA pattern and weak (strong) situation of the Tibetan high after 5 months. Although the geopotential height is not best to use in the tropics, the strong correlation over the global tropics can be believed. This means that the easterly wind will be enhanced (weakened) in all tropical troposphere after positive (negative) phase of the Indian Ocean dipole for 5 months.

Therefore, it can be suggested that the Indian Ocean dipole may be a predictor for atmospheric circulation and climate variations although the further research in relation to this respect is necessary.

4. Conclusion

Based on above data analyses, some interesting results on the influence of the Indian Ocean dipole on Asian monsoon are obtained, the major results can be sum up as following:

1. Through impacting the wind field in the lower troposphere, the Indian Ocean dipole will directly affect the Asian summer monsoon. Corresponding to positive phase of the Indian Ocean dipole, summer monsoon is stronger in India and South China Sea; but summer monsoon is weaker in the South China Sea and stronger in southwestern part of Indian peninsula for negative phase of the Indian Ocean dipole.
2. Corresponding to positive (negative) phase of the Indian Ocean dipole, the Tibetan high over the northwestern Pacific is weaker (stronger) and the subtropical high is also weaker (stronger). The influence of the Indian Ocean dipole on the Tibetan high and the subtropical high is another way to affect the Asian-summer monsoon, particularly the East Asian summer monsoon.
3. The Indian Ocean dipole can impact on summer rainfall in eastern China certainly.
4. The Indian Ocean dipole can also lead atmospheric circulation and climate anomalies in North America, Australia and South Africa regions.
5. The positive (negative) phase of the Indian Ocean dipole can be regarded as a factor to predict the appearance of inverse (direct) PNA pattern and weak (strong) situation of the Tibetan high after 5 months.

Acknowledgements

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CLIVAR Exchanges
Call for contributions

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for the next two issues.

The next one which will appear in September will be dedicated to issues related to climate change prediction, detection and attribution. Since one of the main foci of CLIVAR is related to anthropogenic change and the Third Assessment Report of the Intergovermental Panel on Climate Change (IPCC) has recently been finalised, we would like to highlight the recent accomplishments in CLIVAR related research on this sector.
The deadline for this issue is August 5, 2001.

Secondly, the last issue of this year will be dedicated to climate research in the Southern Ocean area. CLIVAR's focus on Southern Ocean Climate Variability has recently been fostered by a meeting in Perth (see Exchanges No.18) and will soon be organised through a Southern Ocean Implementation Panel. Thus, scientific input for this part of the CLIVAR programme will stimulate the development for a strong Southern Ocean component within CLIVAR.
The deadline for this issue is November 5, 2001.

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

Epochal Variation of Indian Summer Monsoon

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Mean monsoon rainfall over India as a whole during the period, June-September is 88 cm with a coefficient of variation of 10%. Indian summer monsoon rainfall (ISMR) exhibits large inter-annual variations, which generate profound socio-economic impact on many spheres of national activities. Therefore the long-range prediction (seasonal prediction) of summer monsoon rains over India is very useful. The Indian Meteorological Department (IMD) has been using the statistical approach successfully for monsoon seasonal prediction for many decades.

Studies based on data analysis (Ajaymohan and Goswami, 2000, Webster et al., 1998) and numerical models, have suggested that mean monsoon circulation may not be entirely forced by the boundary conditions but is also governed by internal dynamics to some extent, which ultimately limits the predictability of ISMR. The statistical models are based on the assumption that the association measured by the correlation coefficient (CC) between predictor and the predictant, computed based on past data would persist in future also. However, secular variations between the predictors and ISMR have been noted (Parthasarathy et al., 1991; Hastenrath and Greisher, 1993). These variations have been found to be linked to changes in the global and regional circulation patterns. These secular changes therefore pose serious challenge to long-range forecasting. Analysis of more than 20 known predictors has revealed that many of the predictors have lost the significant relationship with ISMR during the recent years (not shown).

Epochal changes in Indian monsoon empirical predictability for the last 100 years have been examined using a statistical model developed with 100 years of data (1901-2000). Five predictors (NW India Minimum temperature in May, N.H.Temperature (January+February), Argentina Pressure (Spring), Darwin Pressure Tendency and Niño 3 SST Index tendency (MAM-DJF)) for the period 1901-2000 have been used to develop a statistical model. These predictors represent the ENSO forcing, land surface conditions over Eurasia and the intensity of the heat low over NW India. The principal component analysis (PCA) of these 5 predictors was made and the resultant 3 significant principal components were further used to develop a multiple regression model. The results are shown in Fig.1 (page 18), which shows the 11 year moving correlation between a) the first principal component and ISMR b) correlation coefficient between the actual and hindcast ISMR or skill of the model. The 11 year running mean of standard deviation anomaly (subtracted from long term mean of 10%) of ISMR is also shown.

The correlation coefficient (C.C.) between the first principal component (P.C.) and ISMR reflects the general relationship between the predictors and ISMR. This relationship was weak in 1930s and 1940s. During the recent years also this relationship was found to be weak. During the 1960s to 1990s this relationship was however very strong. Obviously, the skill of the model also shows similar type of variations. The model skill was positive during 1960s to 1990s. However, the model skill was found to be negative during 1930s and 1940s and also during the recent years. It is also interesting to note that the standard deviation of ISMR was found to be smaller (or ISMR remains within normal limits) during 1930s and 1940s and again during the recent years. It is to be mentioned that ISMR was normal successively for last 12 years since 1989. Therefore the periods of normal monsoon rainfall coincide with the periods of weaker relationship between the predictors and ISMR and also negative model skill. This is curious because it is generally believed that statistical models do not show good skill when the inter-annual variation of monsoon is very large. However, here we have seen that good positive model skill was observed when the inter-annual variability of ISMR was also very large. This is because the predictor-ISMR relationship was also stronger during those periods when the inter-annual variability was very large. Thus stronger boundary forcing-ISMR coupling leads to large inter-annual variations of ISMR. When this coupling becomes weak, monsoon tends to remain normal as observed in the recent years. But during these periods empirical models based on these boundary forcing parameters will show poor predictive skill.

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Freshening of the upper Thermocline in the North Pacific subtropical Gyre associated with decadal Increase of Rainfall

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Much progress has been made in observing, understanding and predicting ENSO, and attention has turned towards decadal variability of the coupled ocean-atmosphere system in the Pacific sector. Decadal variability is as important as ENSO to observe, understand and predict because it has significant effects on climate in many places around the world, because these effects may combine with those of ENSO to produce climate extremes, and because these natural decadal variations must be taken into account in attempting to identify anthropogenic changes to the Earth's climate.

Among other hypotheses about Pacific decadal variability, it has been suggested that decadal variability in the North Pacific interacts with ENSO through subduction of upper ocean thermal anomalies in the subtropics (possibly forced by ENSO), and their subsequent re-emergence in the eastern equatorial Pacific upper ocean (Gu and Philander, 1997).

A number of recent model and empirical studies of decadal variability of the North Pacific Ocean have made unwarranted assumptions that salinity doesn't vary, or that any variability is explained by a time invariant T-S relationship. A slightly more sophisticated assumption is a relatively stable T-S relationship, below the surface mixed layer, that varies regionally and possibly seasonally. Thus, knowledge of temperature is considered sufficient to determine the density field in the ocean interior. However, the Earth's hydrological cycle is subject to climate variability that includes salinity variations not simply correlated with temperature variations (e.g. Lukas and Lindstrom, 1991; Webster and Lukas, 1992). In fact, I show here that the T-S relationship in the North Pacific subtropical gyre varies on climate time scales.

There are very few long-term observations of the Pacific Ocean that can be used to quantify and improve our understanding of decadal modes of climate variability, and most concern only near-surface variations. Long-term observations of temperature profiles are available, but their space-time distribution has varied on climate time scales, making interpretation difficult at best. As suggested above and shown later, conclusions about ocean dynamics and thermodynamics based on temperature alone are potentially very misleading. All but a handful of the long time series of subsurface salinity are along the coasts, rather than in the deep ocean interior. A notable exception is the time series from Ocean Station Papa in the northeast Pacific. The Hawaii Ocean Time-series (HOT) program was established, in part, to help address these deficiencies (Karl and Lukas, 1996).

The HOT Station ALOHA is 100 km north of Oahu, Hawaii at 22°45'N, 158°W (Fig. 1, page 18) in approximately 4800 m of water. The site has been occupied 10-12 times each year from October 1988 through January 2001. Station visits last about 3 days, and include 36 hours of 3-hourly "burst" CTD profiling of temperature and salinity over the upper 1000 m, required to average out the ubiquitous baroclinic tides which are a strong source of noise for ocean climate studies. Many other observations, including carbon cycle related biogeochemistry, are made during each cruise (Karl and Lukas, 1996).

The annual mean North Pacific sea surface salinity (SSS) shows an elongated maximum (>35‰) centred along 25°N, from about 150°E to 135°W. This salinity maximum lies under a zonal band where there is a net loss of freshwater from the ocean to the atmosphere, on average, but the SSS maximum is about 500 km north of the maximum freshwater loss. This is due to the northward Ekman flow driven by the easterly Trade Winds, and to the cumulative loss of freshwater along the trajectory of the surface water parcels. The meridional SSS gradient reverses under the region of net loss due to southward flow of fresher waters from the storm track region (c.f. Fig. 1, page 18) under the influence of the midlatitude westerlies. The SSS maximum is in a region of convergence associated with the Subtropical Front, where SST anomalies have a relative maximum (Nakamura et al., 1997). At this front, waters are subducted into the pycnocline during late winter each year, forming the shallow salinity maximum of the central North Pacific Ocean observed at ALOHA. Wind, rainfall and evaporation are subject to interannual and decadal variations, and these cause low frequency salinity changes near the Subtropical Front that appear with some delay at ALOHA, as shown below.

Variation in summertime rainfall over the central North Pacific (CNP) is relatively small, but there are pronounced differences in the winter season peak rainfall rate and its timing (Fig. 2a, page 19). During the first half of the 1980s, CNP winter rainfall is relatively high and relatively low during 1990-94. From 1995-1997, winter rainfall is relatively high, with two of the highest years in the record. The monthly departures from the 1979-1997 climatology (not shown) reveal that events of a month or two dominate, which is consistent with storm track variability. There is, however, an underlying decadal variation, with a peak in the mid-1980s, a minimum in 1990, and another peak in 1996. This decadal variation is relatively small in compari-

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Chang et al.: Possible Roles of Atlantic Circulations on the Weakening Indian Monsoon Rainfall - ENSO Relationship, page 5:

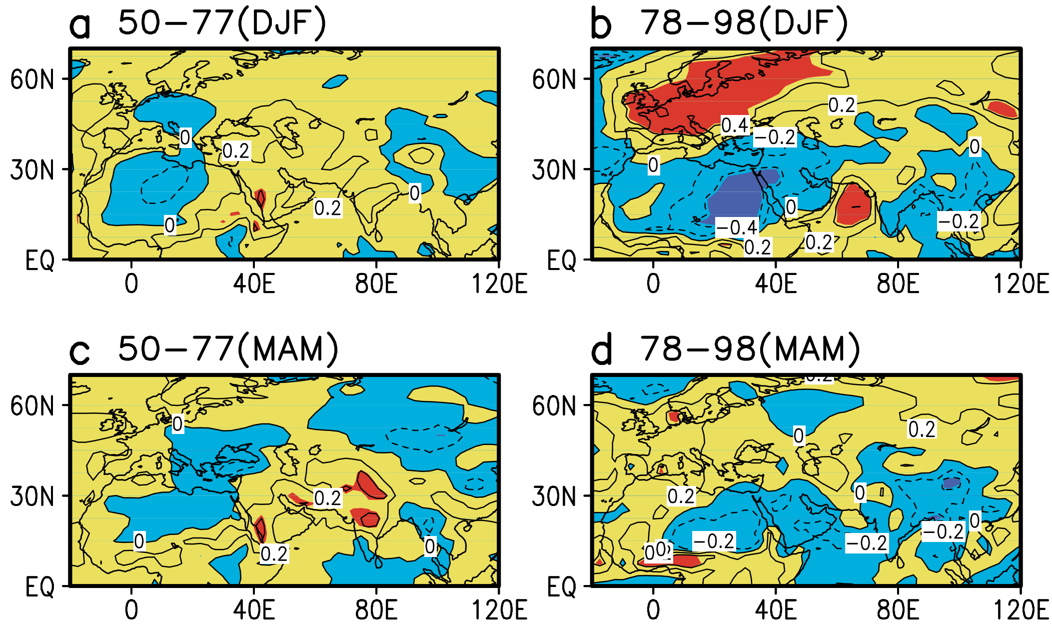

Fig. 2*: Correlation between Indian summer monsoon rainfall and winter SAT for (a) 1950-1977 and (b) 1978-1998, and spring surface temperature for (c) 1950-1977 and (d) 1978-1998. The contour interval is 0.2 and significant (5% level) correlations are shaded (positive - red, negative - blue).*

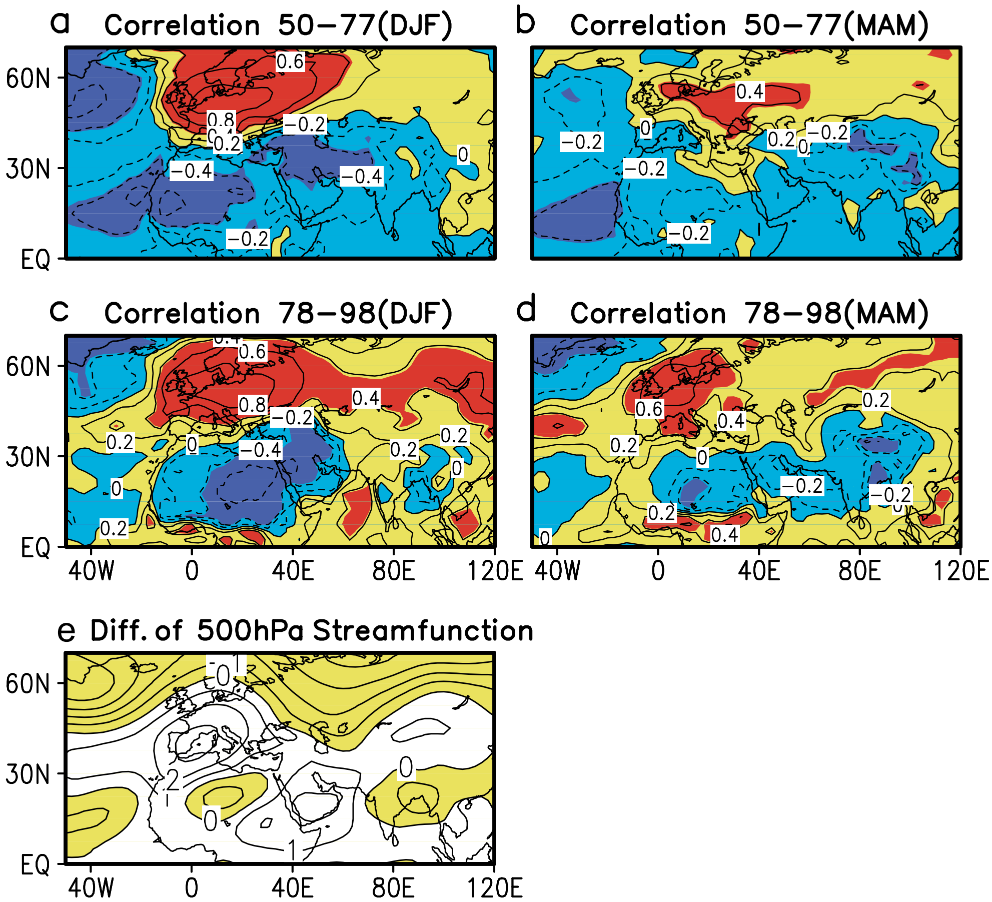

Fig. 4*: Distribution of correlations between winter western European SAT index and the 1950-1977 (a) winter and (b) spring global SAT, and the 1978-1998 (c) winter and (d) spring global SAT. Correlation significant at 5% and above are shaded red for positive values and blue for negative values (contour interval 0.2). Panel (e) contains the 500 hPa streamfunction difference between the 1978-1998 and 1950-1977 periods (contour interval is 1x10^{6} m^{2} s^{-1}, negative values are shaded).*

Rejeevan: Epochal Variation of Indian Summer Monsoon Rainfall Predictability, page 15:

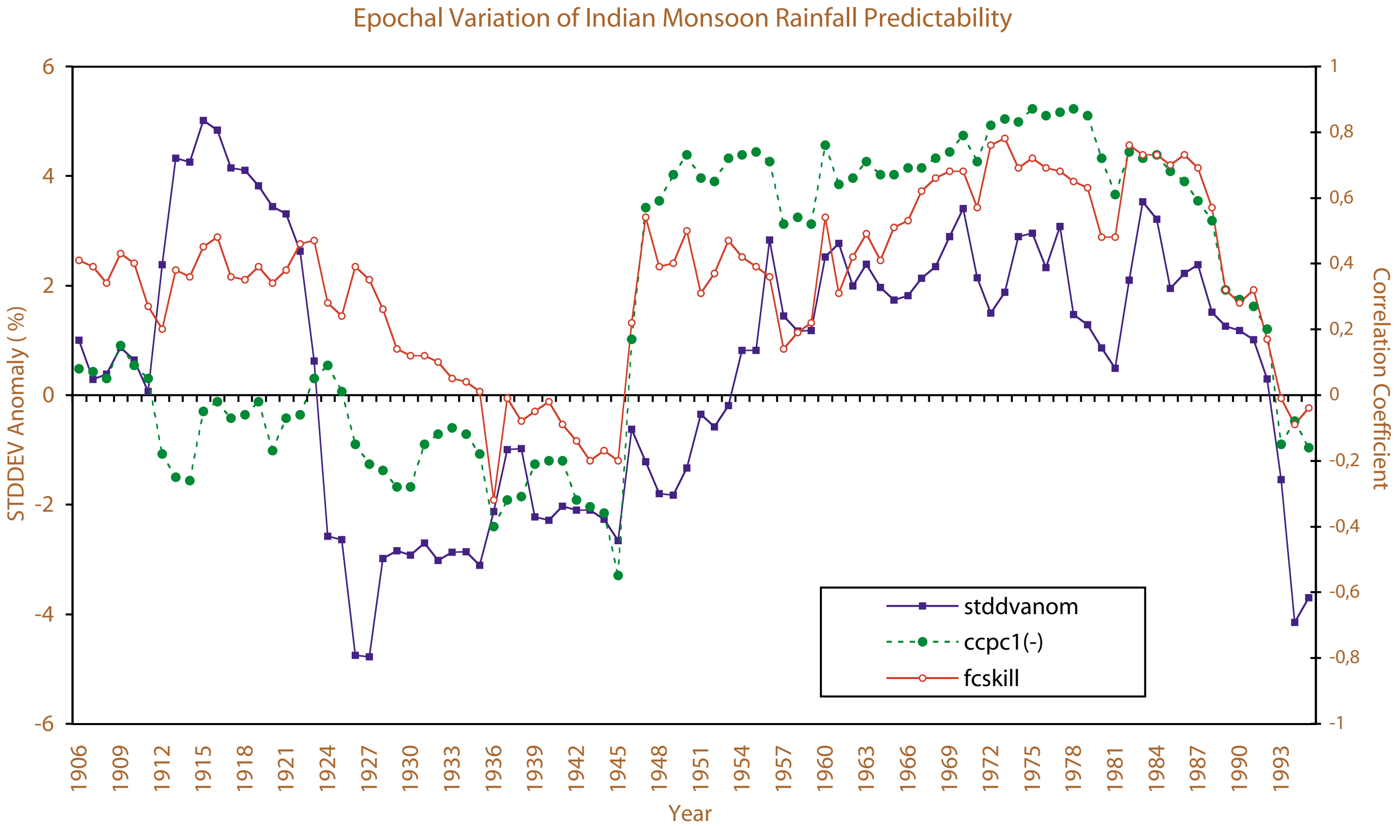

Figure 1*: 11 year moving correlation between the first principal component and ISMR (green) and correlation coefficient between the actual and hindcast ISMR or skill of the model (red). The 11 year running mean of standard deviation anomaly (subtracted from long term mean of 10%) of ISMR also is shown (blue).*

R. Lukas: Freshening of the upper Thermocline in the North Pacific subtropical Gyre associated with decadal Increase of Rainfall, page 16:

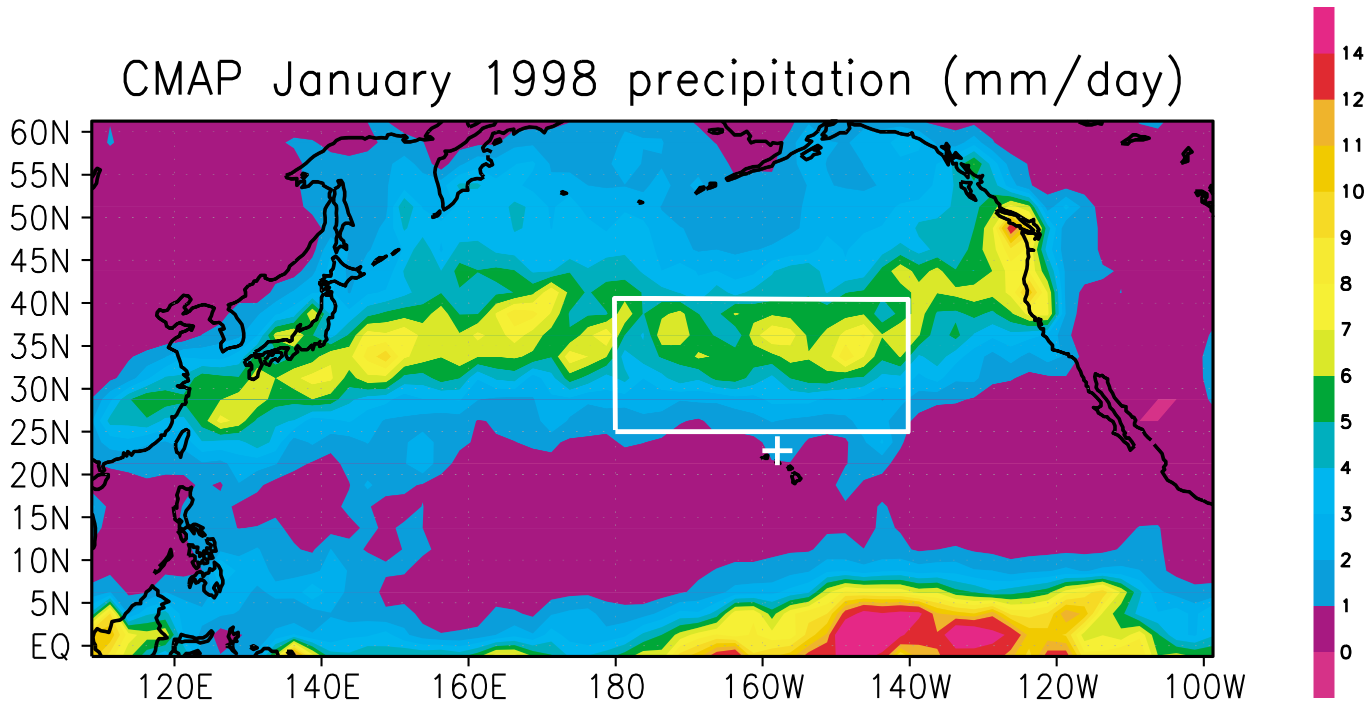

Figure 1*: Daily average rainfall (mm/day) for the month of January 1998. The region enclosed by the box in the central North Pacific is used in subsequent figures. The white cross indicates the location of the Hawaii Ocean Time-series station.*

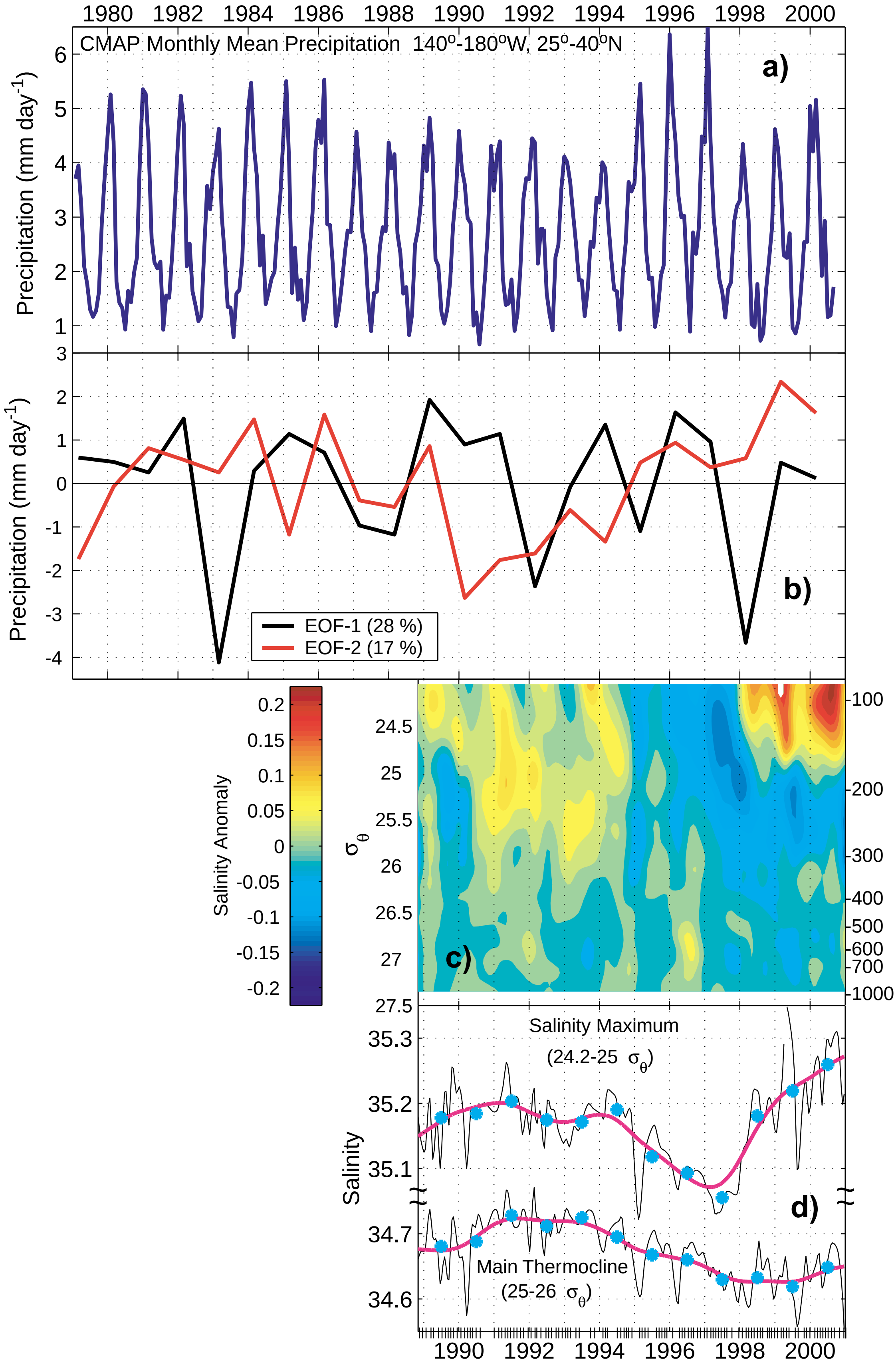

Figure 2: (a) Time series of monthly rainfall (Xie and Arkin, 1997) over the North Pacific area indicated in Fig. 1. (b) Time series of the first two EOFs of winter rainfall over the entire North Pacific. (c) Time series of salinity anomaly versus potential density. The scale along the right axes indicates the mean depth of the corresponding isopycnal surface. (d) Time series of layer- averaged salinity for the salinity maximum layer and the main thermocline. Light lines connect individual cruise values. Heavy lines are smoothing cubic splines. Closed circles are annual averages. Tick marks along the time axes indicate the timing of individual HOT cruises.

continued from page 16

son to the intraseasonal variability, but it is coherent over a large area of the ocean, and the anomalies persist for several years. Thus, we may expect a cumulative impact on upper ocean salinity.

While monthly observations are not adequate to resolve all of the important forcing, they give us some insight. Because of the variable timing of the maximum precipitation during each winter (Fig. 2a), we average the January through March rainfall observations as a gross indicator of the "winter hydrological cycle imprint" on the mixed layer subduction process.

The dominant empirical orthogonal function (EOF) of winter rainfall over the North Pacific consists of an out-of-phase relationship between the midlatitude storm track and the tropics (not shown), accounting for about 28% of the total variance (Fig. 2b). There is a node along 30°N over much of the North Pacific, and the Hawaiian Islands are in a region of relative maximum. The temporal modulation of this pattern is dominated by the 1982-83, 1986-87, and 1991-92 ENSO events bringing drier conditions in the band between 10°N and 30°N, and wetter conditions along the storm track and the west coast of North America. La Niña lead to wetter conditions in the subtropics during the winter of 1989.

EOF2 is dominated by the decadal variation discussed above, accounting for about 17% of the total variance (Fig. 2b). Elongated regions of maximum variability trend from southwest to northeast. There is an apparent connection of the maximum in the CNP between 30-45°N with the western tropical Pacific region. The nodal line on the equatorward side of this region extends from just north of the Hawaiian Islands to the coast of California. Of particular note is the trend-like increase of rainfall in the CNP from 1990 to 1997. We believe that this is the cause of the freshening of the upper pycnocline observed at ALOHA discussed below.

The time series of nonseasonal salinity departures (relative to the first 10-years HOT climatology) in potential density coordinates shows a pronounced salinity decrease in the upper pycnocline between 1991-97 at ALOHA (Fig. 2c). The range of the variation is 0.3 psu that can be clearly seen in the time series of salinity averaged in the 24.2-25 sq layer (Fig. 2d), with a change in the sign of the trend beginning in 1998. This signal is also observed in the mid-pycnocline (25-26 sq), however the trend reversal occurs later than in the shallower layer, and the magnitude is smaller. The increasing salinity in the upper pycnocline coincided with the ENSO-related drought around Hawaii in 1998.

The salinity anomalies appear to propagate downwards with time (Fig. 2c). This is similar in nature to the downward penetration of decadal thermal anomalies in the central North Pacific Ocean (Deser et al., 1996), suggested to be a manifestation of thermocline ventilation (Luyten et al., 1983).

An outstanding issue related to decadal ocean dynamics is the degree to which subducted thermal anomalies are **not** density-compensated by salinity anomalies of opposite sign, and therefore dynamically active (Liu and Shin, 1999). In potential density coordinates the salinity anomalies described here are **exactly** compensated by temperature anomalies, and the freshening trend corresponds to a 0.5°C cooling on certain isopycnals, comparable to the anomalies estimated by Deser et al. (1996). Thus, we expect this signal to act as a passive tracer, subject to mixing but not to baroclinic wave dispersion. If the freshening trend observed at ALOHA is due to anomalous subduction, the increased rainfall in the CNP subduction zone must be compensated by greater heat losses from the upper ocean. Such coherent variations in the thermal and freshwater forcing over a portion of the central North Pacific may partially explain the dominance of density-compensated fronts there (Rudnick and Ferrari, 1999).

The mixed layer T-S characteristics that are transmitted to the upper pycnocline by subduction are those at the time of deepest mixing. This gives rise to a nonlinear relationship between low frequency variations in upper pycnocline T-S characteristics and the high frequency forcing associated with winter storms (Stommel, 1979). Midlatitude storms are responsible for much of the rainfall over the North Pacific Ocean (Figs. 1&2). Interannual and decadal variations of the storm tracks and intensity result in substantial large-scale changes in precipitation and heat fluxes.

Is the delay between the time history of EOF2 and the appearance of salinity anomalies at ALOHA consistent with this scenario? Subducted mixed layer anomalies, or the impact of anomalous subduction rates, appear first in the upper pycnocline at the HOT site because advection is faster near the surface and because the ventilation location is closer than for deeper isopycnals (Huang and Qiu, 1994; Huang and Russell, 1994). The delay from subduction to arrival at ALOHA is about 1 year for densities between 24 and 24.6 sq, and about 3-4 years for density levels between 25 and 26 sq. The downward penetration lag for the salinity signals at ALOHA is grossly consistent with this estimate, which assumes that the geostrophic gyre circulation and the subduction locations do not vary. It is unlikely that the trajectories for anomalous water parcels follow mean streamlines because low frequency Rossby waves are ubiquitous in the North Pacific, and it is certain that the ventilation region for a particular isopycnal varies from year to year. It is difficult however to take the interaction of Rossby waves and subduction into account without recourse to a very sophisticated model.

These observations of coherent thermohaline forcing of the North Pacific subtropical gyre suggest that it is crucial for testing of hypotheses about decadal climate variability to properly model the coherent decadal variations of heat and freshwater forcing associated with storm track changes. Further, because of extreme nonlinearity of the subduction process, it is necessary to properly model the air-sea fluxes of heat, moisture, and momentum within the relatively few, but very intense, winter storms that affect any one area of the mid-latitude North Pacific during a particular year. Until coupled climate models can reproduce the character of the observations reported here, no strong test of decadal climate hypotheses is possible.

Acknowledgements

Many people have contributed over the past decade to the success of HOT, but the vision and drive of Dave Karl has been critical to starting and sustaining the project. Steve Chiswell, Fred Bingham and Eric Firing have made important contributions to the development, maintenance and analysis of the physical observations. Fernando Santiago-Mandujano, Jefrey Snyder, Craig Nosse, Mark Valenciano and Don Wright made most of the measurements for the physical oceanographic component of HOT. Sharon DeCarlo made critical contributions to design and development of data acquisition and processing systems, and to data management and analysis. The HOT program is supported by the US National Science Foundation and by the State of Hawaii.

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Anatomy of North Pacific Decadal Variability

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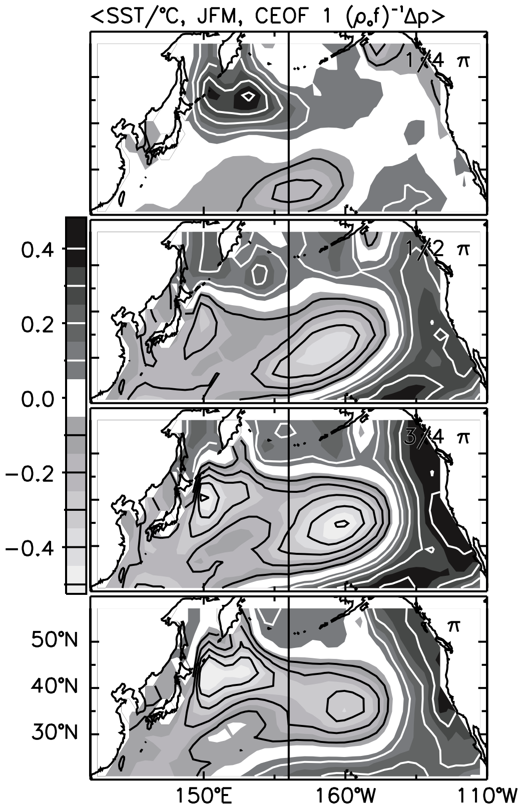
Climate variations on decadal time scales have a profound influence on human activities. The possibility of predicting them requires investigating the underlying physics. This entails establishing (a) the relationships and physical linkages between the different variables and (b) the dynamics that set the decadal time scale. In analogy to a simple oscillator, (a) deals with the multi-variate polarization relation or 'anatomy' of decadal variability, while (b) concerns its dynamics. The purpose of this study is to revisit the coupled model decadal variability investigated by Pierce et al. (2001) and Barnett et al. (1999) in the 128-year ECHO-2 coupled model run. This model is an updated and improved version of the coupled model studied by Latif and Barnett (1994), and hence should contain the 20-year decadal mode whose fundamental physical mechanism has remained uncertain. We seek here to understand the relationships among decadal anomalies of various physical fields in the central Pacific and the Kuroshio-Oyashio Extension (KOE) region, the oceanic heat budgets in the central Pacific and KOE region, possible regional responses of the atmosphere to temperature anomalies caused by ocean dynamics, and the consistency of the evolution of the run with mid-latitude coupled ocean-atmosphere dynamics. In addition, we compare the findings with the available observations. Complete details of our results are given by Schneider et al. (2001).

Our study focuses on model streamfunction variability in the North Pacific which exhibits a strong decadal component especially in the KOE and is clearly due to ocean dynamics (Pierce et al., 2000) but can not be explained by spatial resonance (Saravanan and McWilliams, 1998; Pierce et al., 2000). A complex empirical orthogonal function analysis of streamfunction evolution captures the bulk of its decadal variability and provides via the associated patterns clear linkages with SST, atmospheric pressure, Ekman pumping and precipitation. These are shown for a typical magnitude of decadal variability and correspond to half a cycle of the leading CEOF of ocean streamfunction (Fig. 1,



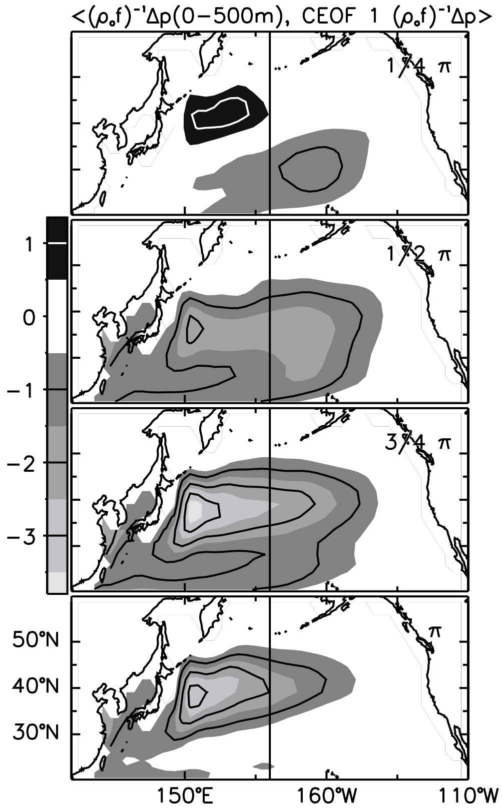


Figure 1 (left): Decadal anomalies of winter sea surface temperature (January through March). The anomalies are scaled to a typical magnitude and are in units of degree K.
Panels are approximately 3 years apart and corresponds to half a cycle of decadal variability.

Figure 2 (right): Decadal anomalies of oceanic stream function, vertically integrated between the surface and a depth of 500m. Units are $10^3 m^2 s^{-1}$. The sequence of panels correspond to Fig. 1.

2). Coupled model decadal variability in the North Pacific evolves in accordance with the schematic of Miller and Schneider (2000). Changes of wintertime atmospheric pressure in the North Pacific, primarily due to intrinsic, low-frequency and global atmospheric variability, alter the surface heat budget in the central North Pacific by changing Ekman advection and vertical mixing. This causes the development of the 'canonical' SST anomaly pattern in the central and eastern North Pacific (Fig. 1) where anomalies of opposing signs occur in those two areas (Zhang et al., 1997). The model central Pacific SST anomalies are then subducted southwestward towards the equator while diffusion extinguishes them. Anomalies of Ekman pumping associated with changes of the North Pacific sea level pressure excite changes of the oceanic stream function. Its anomalies (Fig. 2) are a superposition of a larger-amplitude stationary forced response and a smaller-amplitude westward propagating component associated with long Rossby waves. On average, the KOE region is affected up to five years after anomalies in the central Pacific reach their maximum. In the KOE region, the changes of the geostrophic circulation persist year-round. During summer, subsurface temperature anomalies are insulated from the atmosphere by the seasonal thermocline and attain largest values, while the anomalies at the sea surface are small. During winter, deep mixed-layers bring the subsurface anomalies to the surface and lead to KOE SST anomalies with the same sign as the preceding SST anomalies in the central Pacific (Fig. 1). The associated anomalous heating of the surface layer is vented to the atmosphere by changes of the turbulent surface heat fluxes (mainly latent). These anomalous surface conditions lead to anomalous precipitation in the western boundary region, such that warm SSTs and increased transfer of sensible and latent heat from the ocean to the atmosphere coincide with increased precipitation. Thus the atmosphere responds locally to oceanically induced KOE surface flux anomalies. The response of the wind stress suggests a positive feedback, with anomalies of wind-stress curl over the western North Pacific reinforcing the existing KOE anomalies.

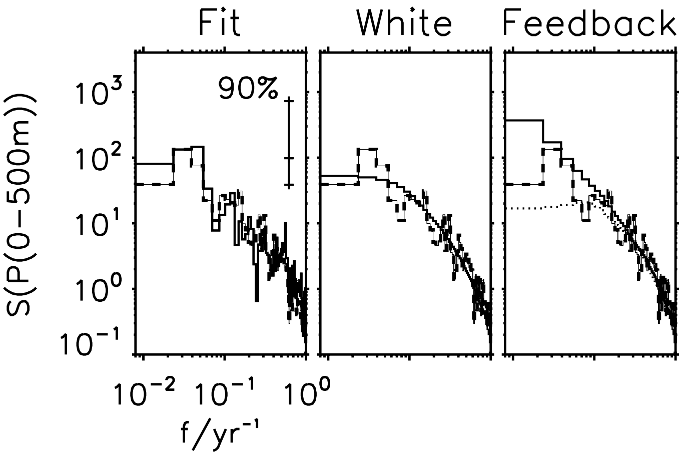


Figure 3: Spectral power of ocean pressure at 151°E, averaged from 34°N to39°N and integrated vertically over the top 500 m of the water column. The left panel shows spectra for results of ECHO-2 (solid line) and from the best solution to an equivalent barotropic Rossby wave forced by ECHO-2's wind stress curl (dashes connected by thin line). This spectra is repeated as a reference on the centre and right panels. The centre panel shows as a solid line the spectrum expected for wind stress curl that has a white frequency spectrum while conserving the spatial coherences and variances of ECHO-2. The right panel displays as a solid line the solution with positive feedback estimated from results of ECHO-2. The dotted line shows results for the same feedback, but with reversed sign.

This result is based on experiments with an equivalent barotropic ocean model that captures the dynamics of linear, forced, mid-latitude Rossby waves and is successful in reproducting the results of the coupled model (Fig. 3, left panel).

Experiments with this simple model suggest that the decadal time scale of the KOE variability results from the integration along Rossby wave trajectories of stochastic forcing due to internal atmospheric dynamics (Fig. 3, centre). The positive feedback of pressure in the KOE region with North Pacific wind stress curl enhances the low frequency variability of the ocean stream function due to a reddening of the spectra of wind stress curl (Fig. 3, right).

It does not, however, select a time scale. The inconsistency of a negative feedback with model results (Fig. 3, right) and the absence of a closed feedback loop are inconsistent with the assumptions often invoked in simple coupled models of North Pacific decadal variability. Instead, the results are consistent with the stochastically forced ocean model of Frankignoul et al. (1997) with a local atmospheric response to SST that may act as a positive feedback.

Comparisons with observations confirm the coupled model results. In both observations and model, decadal anomalies of atmospheric forcing and SST are largest during winter. The SST anomalies occur in two centres of action (c.f.: Deser and Blackmon, 1996; Nakamura et al., 1997): first in the central North Pacific, and then, with like sign and a lag of up-to-five years, in the KOE region.

There, the latent heat flux damps the SST anomalies consistent with an oceanic, rather than an atmospheric, generation (Cayan, 1992; Battisti et al., 1995; Xie et al., 2000). This points to the role of gyre adjustment in linking anomalies in the central Pacific to those in the KOE region with a lag of up-to-five years (Deser et al., 1999; Miller et al., 1998) and implies that observed anomalies in the KOE region can be predicted from the preceding wind stress forcing over the central North Pacific (Schneider and Miller, in preparation, 2001). Prediction of SST anomalies in the KOE region several years in advance could aid the study of sardine fisheries and zooplankton populations which are sensitive to oceanic temperature.

Likewise, if KOE temperature anomalies drive an atmospheric response in nature that is similar to the coupled model, precipitation over the northwestern North Pacific (and perhaps concomitant climate anomalies elsewhere in the Northern Hemisphere) could also be predicted at several-year lead time. Thus, even in the absence of a closed feedback loop, the time horizon of such predictions is several years, and could be of significant value to society.

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Pathway and Propagation of Interdecadal Variability in the Pacific Ocean

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Climate variability on the decadal/interdecadal time scales was evidenced by some dramatic shifts in the climatic conditions. One such shift in the climate system occurred in the Pacific Ocean during 1976-77 (Trenberth and Hurrell, 1994; Latif and Barnett, 1994). In the Pacific Ocean, several different ideas had been proposed to explain some aspects of its extra-tropical interdecadal variability. One of them, which matched well both the observational and theoretical aspects, was that the thermal anomalies in the mid-latitude ocean propagated with subduction in the thermocline and reached the low-latitude ocean by several years (Deser et al., 1996; Schneider et al., 1999).

In pervious researches, it was clear that the thermal anomalies propagated from the central North Pacific (approximately 35°N) to 18°N in the western sub-tropical Pacific. However, a further southward movement of the anomalies from 18°N was not revealed yet. Meanwhile, most of the observational studies focused on the influence of the North Pacific on the tropics on the decadal time-scale (Zhang et al., 1998), less attention was paid to the possible impact caused by the southern tropical Pacific.

It was worthy to concern about what happened in the western tropical Pacific on the interdecadal time-scales. When the warm signal moved to the northern subtropics north to 18°N after 5 year propagation from the central North Pacific, the warm condition also developed in the western tropical Pacific, as well the signal in the southern tropical Pacific strengthening. The latter signal was traced as northwestward propagating (Wang and Liu, 2000). When it reached around 18°N west to the dateline, it merged with the warm signals which came from the central North Pacific, resulting warm anomalies in most areas of the Pacific Ocean except the coasts off the North and South America.

Since the signals in the central North Pacific propagated southwestward while those in the southern tropical Pacific northwestward, a fixed "<" type pathway can be suggest from the interdecadal variance. Total 20 grids with resolution of 5-degree-by-2-degree were chosen, almost symmetrical about 4°N. Its north branch oriented location of potential vorticity (PV) lines, which lay between the western subtropics and the shadow zone in the eastern subtropics. The pathway changed its direction at 160°E, in order to stand far away from the far western Pacific, where there was an isolated signal (Schneider et al., 1999).

Except five-year running mean, other statistical methods weren't introduced to generate Fig.1 showed the composite temperature anomalies in the chosen "<" type section. With reference to the phases of the interdecadal variability in the central North Pacific, two cases with different signs were formed. Each case was divided into three stages to describe the temporal and spatial evolution of the concerned signals.

The vertical structure of the warm case:

In the first stage (1966-68, see Fig.1a), there were warm anomalies developing in the thermocline (about 200m in this region) at the northern end of the north brand in the section. At the meantime, the warm anomalies occupied the most parts in the southern tropical Pacific whose

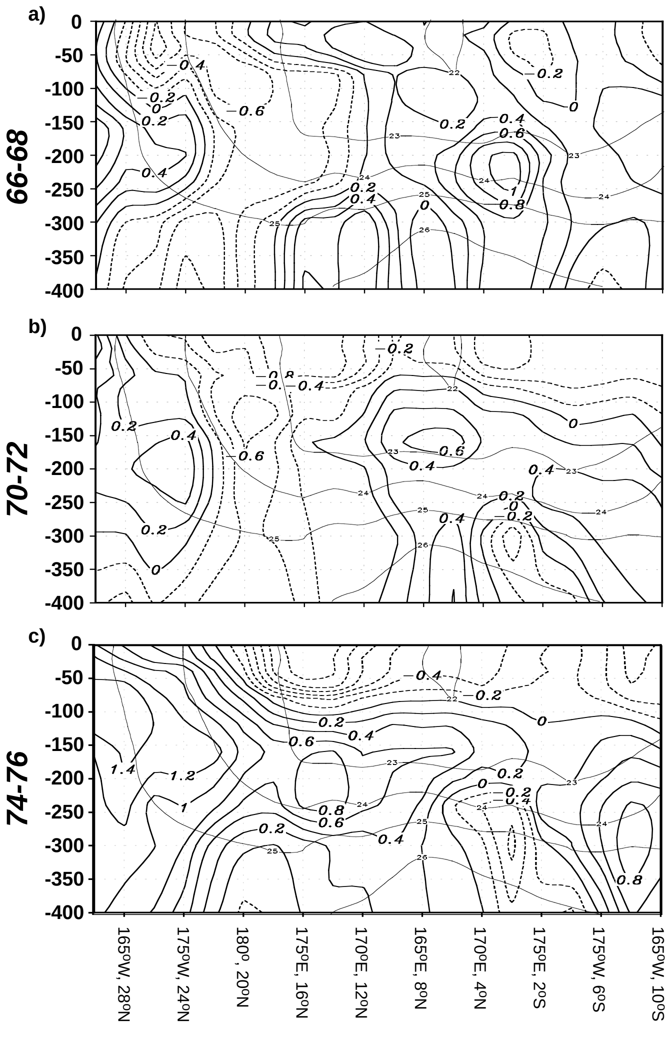

Figure 1: Evolution in temperature anomalies in the vertical sections with location as the so-called pathway. 5-year running mean XBT data at 11 levels from surface to 400m depth used. Each stage is formed from 3 year composite field: upper panel: 1966-68; middle panel: 1970-72; lower panel: 1974-76. Dark contours indicate the density profile at the same section, which is defined from Levitus climatological March data.

vertical core lay in the thermocline also. There was a cold barrier between the two warm areas. In the second stage (1970-72, see Fig.1b), both the two warm signals moved equatorward at the depth of the thermocline due to developing. The anomalies in the western equatorial Pacific could be traced clearly that they were from the southern tropical Pacific. In the third stage (1974-76, see Fig.1c), the warm anomalies in the central North Pacific strengthened quickly and reached the mature phase. Since the cold barrier disappeared, the two warm signals merged at the latitude 18°N.

Two exchanging processes with the interdecadal time scales were documented here, one was the exchange between the North Pacific and the subtropical Pacific, and the other was the connection between the southern tropical Pacific and the western tropical Pacific. In contrast to Zhang et al.'s opinion, diagram in the paper showed some concrete evidences that the signals propagating from the North Pacific couldn't reach the equatorial area. Moreover, the signals detected in the western tropical Pacific came from the southern tropical Pacific.

The southern Pacific is one of the important parts of the pathway for the interdecadal signals. The connection between the southern and western Pacific was proved by the systematic propagation of the interdecadal signals along the thermocline, not only at the warm phase but also at the cold phase. However, research with numerical methods is required.

Acknowledgement

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A new index of El Niño related to decadal variability

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To characterize the nature of El Niño-Southern Oscillation (ENSO), sea surface temperature (SST) anomalies in different regions of the Pacific have been used. We suggest that an optimal description of both the distinct character and the evolution of each El Niño or La Niña event requires at least two indices: (i) SST anomalies in the Niño 3.4 region (referred to as N3.4), and (ii) a new index we call the Trans-Niño Index (TNI), which is given by the difference in normalized anomalies of SST between Niño 1+2 and Niño 4 regions. A formal definition is given by

$$TNI = (\{Niño\ 1{+}2\}_N - \{Niño\ 4\}_N)_N$$

where the subscript "N" indicates normalized. The normalization factors in this case are the standard deviations of the anomalies over the climatological period 1950 to 1979 which amount to 0.92°C for Niño 1+2, 0.75°C for Niño 4, and 0.82 for the smoothed difference of the normalized anomalies. We use a five month running mean to smooth intraseasonal variability.

The N3.4 and TNI indices may be obtained at http://www.cgd.ucar.edu/cas/climind/TNI_N34/ . They are also discussed more fully in Trenberth and Stepaniak (2001). The first index can be thought of as the mean SST throughout the equatorial Pacific east of the dateline, and the second index is the gradient in SST across the same region. Consequently they are approximately orthogonal. This relationship can be explored by computing cross correlations over about 20 year periods as a function of lead and lag up to ±20 months (see Fig. 1). In Fig. 1 the correlations are overall close to zero at zero lag. More revealing is the tendency of TNI to lead N3.4 by 3 to 12 months prior to the climate shift in 1976/77, and also to follow N3.4 but with opposite sign 3 to 12 months later. (A notable exception to this pattern is introduced by the prolonged 1939- 42 El Niño.) However, after the 1976/77 shift, the sign of the TNI leads and lags are reversed, indicating that more recent El Niño events have first developed in the central Pacific and spread eastwards (e.g., Wang 1995). Prior to the 1976/77 shift, El Niño events tended to develop first along the coast of South America and then spread westwards (Rasmusson and Carpenter, 1982).

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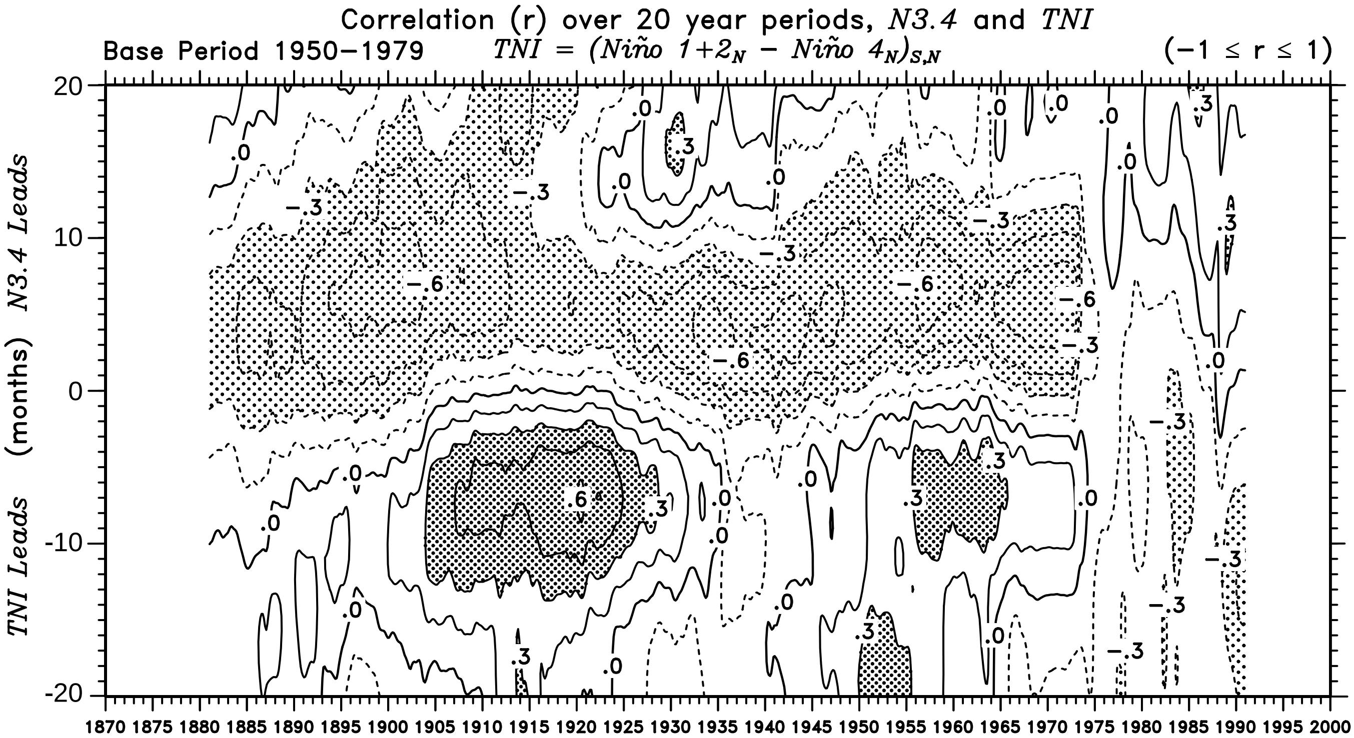

Figure 1*: Moving cross correlations of TNI with N3.4 as 241 month running means (about 20 years). Negative lag means TNI leads, and positive lag means N3.4 leads. Values exceeding 0.3 in magnitude are shaded.*

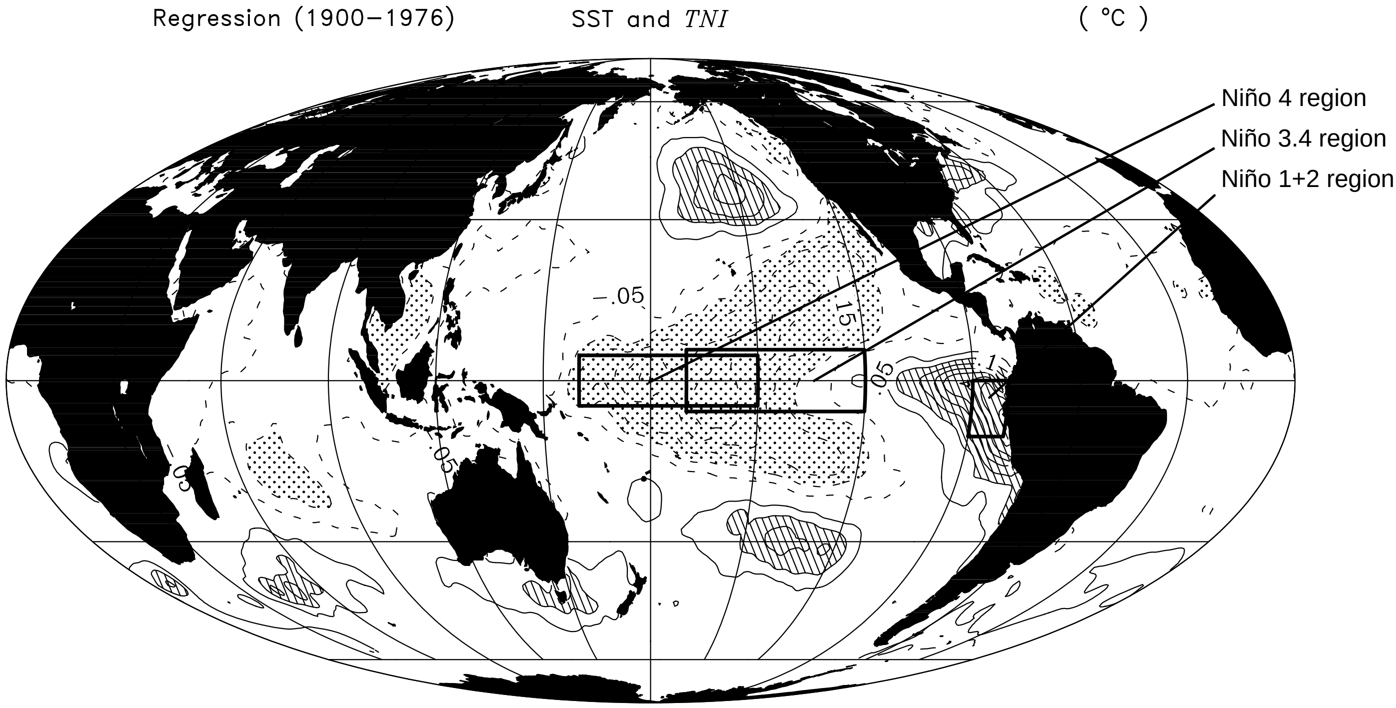

Figure 2*: Regression of global SST anomalies with TNI for 1900-1976 in °C. Values exceeding 0.10°C are hatched and less than -0.10°C are stippled. The contours are ±0.05°C, ±0.10°C, ±0.15°C, and so on.*

A sample of the type of SST patterns implied by these indices is shown in Fig. 2 which is a regression of global SST anomalies with TNI for 1900-1976. A negative boomerang shaped regression pattern of magnitude 0.2°C per unit standard deviation of TNI occupies the central tropical Pacific just east of the International Dateline, while a more localized positive regression of magnitude 0.8°C is centred on the Niño 1+2 region off the coast of Ecuador and Peru. Also present are regions of positive regression (up to +0.2°C) centred in the midlatitudes of the eastern Pacific in both hemispheres. For 1977-2000 (not shown) the centres of the two dominant structures occupying the tropical Pacific are shifted westward, and the sign of the patterns centred in the midlatitudes of the eastern Pacific are reversed. A secondary boomerang shaped region of positive regression also develops along the western edge of the Pacific rim during this period.

The TNI index is clearly involved in low frequency behaviour of ENSO and the pattern is closely related to the so-called Pacific Decadal Oscillation. It has an advantage in that it is approximately orthogonal to N3.4 and applies on all time scales, and so does not require filtering of data to determine what is happening. Therefore, we suggest that it is essential to have at least two indices to describe the character and evolution of ENSO events, especially in studies which attempt to linearly remove the influence of ENSO using only a single index.

Climate models have difficulty in realistically simulating ENSO and a primary measure of success has been the magnitude of SST anomalies in the Niño 3.4 region. However, a realistic simulation of TNI also seems to be required to capture the different flavours of ENSO.

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Letters to the Editor

Comments on an article entitled "Are we seeing human-induced Warming of the deep Layers in the north subtropical Atlantic?" by A. B. Polonsky

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In a recent article in Exchanges, Polonsky (2001a) discusses the possibility of observing human-induced changes amid the decadal variability in the subtropical N. Atlantic. He cites a paper by Parrilla et al. (1994) as an example where the former is obscured by the latter because of a shift or an intensification of the subtropical gyre at the latitude of their hydrographic section (24ºN). While this was certainly a possibility when the Parrilla et al. paper was written, more recent papers (Joyce and Robbins, 1996; Bryden et al., 1996; Joyce et al., 1999) argue against Polonsky's conclusion. Since none of these were cited by Polonsky, we take the opportunity here to review them with relevance to the issue of gyre shift/spin-up as inducing the observed changes at 24ºN in the Atlantic.

Joyce and Robbins (1996), examined long-term changes within the thermocline and the intermediate waters at Bermuda. At intermediate depths of 1500-2500m, a long-term temperature increase was observed extending back before the IGY period which clearly emerged from the decadal variability signals at Bermuda. In the same paper, the authors compared two hydrographic sections taken meridionally at a nominal longitude near Bermuda in the 1980s and during the IGY and found confirmation of comparably sized, large-scale temperature (and salinity) changes throughout the subtropics at all latitudes of the subtropical gyre in the depth range of 1000-2500m, not just at the southern edge of the gyre where a meridional shift of the southern boundary of the gyre might give rise to a temporal change near 24ºN. In a subsequent paper, Joyce et al. (1999) added two new sections made during WOCE in 1997 at 52ºW and 66ºW and the story of a warming of subtropical waters at these depths throughout the western part of the subtropical gyre remained the same (see their Fig. 5). There was some evidence that, in addition to T/S changes due to vertical heaving of density surfaces, there were significant T/S changes on constant density surfaces (see their Fig. 10). From the zonal section at 24ºN repeated in 1992 during WOCE, Bryden et al. (1996) found the waters at depths of 1000-2500m continued to warm up from both the IGY and the 1980s. They noted that in the main pycnocline and below, T/S changes on density surfaces occurred over time that could not be explained by either vertical motion of density surfaces or meridional shifts in the gyre. The latter assertion was based on the small T/S variation meridionally in the pycnocline. At depths of the Mediterranean salt tongue, temporal changes in dissolved oxygen showed a decrease in intermediate waters from 1981 to 1992, whereas a southward shift of the gyre (which Polonsky invokes) would produce an oxygen increase in time.

Thus, none of the more recent references of subtropical changes support the hypothesis of Polonsky that they are due to a southward shift of the gyre by 2 degrees of latitude at 24ºN. While his contention that the NAO phase during WOCE was higher than in the past (his reference to changes in the Azores high in his Fig. 3) is plausible as is a spin-up of the gyre during recent decades, the evidence presented in the above recent references argues against this as the principal agent behind the observed changes. Since substantial changes in depth of isopycnals did happen between the IGY and WOCE, Polonsky's hypothesis cannot be entirely discounted. And we are in complete agreement with his call for a global observation network for the next decades so that changes at a single location or single latitude can be put into a larger context which can resolve the proximate causes of the observed variability. Yet a simple deepening or meridional shift of the gyre cannot explain the observed changes at depths of 1000-2500m in the N. Atlantic subtropical gyre at 24°N. Whether human-induced changes can be attributed to our observations is another question, which we do not intend to expound on. We are aware that a manuscript is in press at JPO by Polonsky (2001b), which is referenced in the Exchanges article and presumably goes into more detail about the justification for his hypothesis. We have not seen this article and look foreward to seeing more arguments in favour of his hypothesis. However, we anticipate that further comments along the lines above may be necessary.

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Reply to Joyce et al.

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A principal goal of my note (Polonsky, 2001) was to discuss briefly a problem of detection of the climatic signal in intermediate and deep-ocean layers due to a lack of oceanographic observations and to call once more for the persistent global observations for the next decades. I have used the result published by Parrilla et al. (1994) as an example to demonstrate that sparse deep-ocean observations permit different interpretations. I did not intend to discuss in details the problem of long-term T/S changes in the entire North Atlantic. That is why I did not cite the papers by Bryden et al. (1996), Joyce et al. (1996; 1999) and very many others. However, in response to the comment I would like to extend some points concerning the issue of gyre shift/ spin-up as a possible mechanism of the changes observed in the subtropical Atlantic Ocean.

1. The assumption that the observed (along 24°N) changes are due to a southward shift of a gyre is not my hypothesis (see p.18 in my note or p.69 in (WCRP, 1995) for the original citation). I only checked this assumption using NODC climatology and found that if subtropical gyre has shifted to the South by about 2 degrees from 1957 to 1992 even without any other changes, it results in the deep-ocean temperature change along 24°N resembling the warming described by Parrilla et al. (1994). The argument from (Bryden et al., 1996) that T/S changes alone 24°N could not be explained by meridional shifts in the gyre because of the small T/S variation meridionally is not clear. In fact at least the temperature changes can be explained so. Another question is: has a gyre shifted to the South by about 2 degrees from 1957 to 1992? I do not think so because the r.m.s. interdecadal meridional variations of Azores high is about 2 degrees (Polonsky, 1997) and taken into account that the oceanic subtropical gyre is much more inertial component of the coupled system than the atmosphere. In addition as noted by the comment's authors, there is a warming of the intermittent layer in the other parts of the subtropical gyre not only at its southern edge. Thus I agree with the author's comments. I do not think that the gyre shift accounts for a principal portion of the observed (along 24°N) changes.

2. I mentioned the second possible reason for the observed changes. This is the subtropical gyre intensification due to the wind field change. The Azores high deepening occurred not only from 60s to 90s of 20th century but also between 1900 and 1930. Moreover the long-term century-scale positive trend of SLP in Azores high occurs and it could be one of the reasons for a long-term temperature increase observed by Joyce and Robbins (1996) at Bermuda. We assessed the temperature change in the subtropical thermocline due to decadal variations of Ekman pumping at 36°N (Polonsky and Kuzmin, 2000). According to our results it is more than 0.5°C per 10 year in the upper main thermocline and it decreases to the depth. In fact this change should be larger in the western and smaller in eastern part of the subtropical gyre because of the effect and variations of thermocline slope in a zonal direction (see e.g., Polonsky et al., 1992). Associated vertical shift of the isoterms at 1000m depth is about 2.5m/year. Concurrently we found that one-dimensional heat balance is not realized within the upper thermocline. Horizontal advection prevails there on the decadal scale. This may be a principal reason for the absence of strong warming in the upper thermocline as a result of gyre intensification.

3. There are a lot of other recent results (e.g., presented at the WOCE and OCEANOBS'99 conferences and published in (WOCE, 1998; OCEANOBS'99, 1999) or mentioned in the comment). They argue that quite strong exchange between subpolar and subtropical gyres in mid-depth ocean layers and warming of the intermediate layers of the subtropical gyre are observed in reality for a few recent decades. I do not reject these results. However, I would like to draw attention to the fact that the relative importance of the different terms in the

equations of heat and salt balance in different part of the subtropical gyre at the decadal-to-interdecadal scale (and hence, an importance of different mechanisms) is not clear. In fact results by Joyce et al. (1999) confirm that. On the one hand the authors of this note argued that the mid-depth increase in temperature and salinity along 52°W and 66°W between IGY and the present is dominantly due to heaving. The depth variation of the "heave" signal indicates a maximum shift of 112 m at the depth 1800m giving a downward vertical velocity of the density surface of 2.7m/year (by the way this is close to our assessment of a downward vertical velocity at 36°N due to gyre spin-up). On the other hand Joyce et al. (1999) pointed out to the following difference between 52°W and 66°W: from IGY-80s, the change indicates a T/S shift along the mean curve for 52°W but more of a combined contribution due to vertical sinking of properties as well as a salinity increase for 66°W. They also mention that between the 80s and the present, temperature has changed little, but salinity has decreased on both sections. This means that a relative importance of different mechanisms regulating the observed changes varies from one decadal-scale period to another.

In conclusion, there are trend-like (century-scale) and decadal-to-interdecadal changes of the meridional transport in the North Atlantic and spin-up/shift of subpolar and subtropical gyres for recent decades. Long-term observations at Bermuda and OWS Mike (Joyce and Robhins, 1996; Østerhus et al., 1996) do not contradict this statement in principle. However, the relative importance of different mechanisms regulating the observed decadal-to-multidecadal changes in the entire North Atlantic is not clear. And a lack of adequate long-term observations is a principal reason for that.

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Meeting Reports

CLIVAR Pacific Implementation Workshop

An international coordinated effort to implement projects with the Pacific sector is now moving forward. As a first step CLIVAR organized an international implementation workshop that was held at the IPRC in Hawaii on February 5 to 8, 2001. This was the first meeting in which scientists from the many nations interested in CLIVAR research in the Pacific were brought together to begin the process of developing a coordinated implementation plan. In bringing the group together, an emphasis was placed on participation by atmospheric scientists as well as oceanographers and on engaging as many Pacific rim nations as possible. More information can be obtained through the new CLIVAR Pacific web pages accessible under: http://www.clivar.org/organization/pacific/index.htm.

The workshop was organized around invited talks, plenary discussions, and working group meetings. The invited speakers were charged with pointing to the challenges of implementing work in the Pacific that would successfully address the objectives in the Principal Research Areas in the Pacific laid out in the CLIVAR science documents. Their talks were focused on: Pacific CLIVAR science, broad-scale ocean and atmospheric sampling, regionally enhanced observations, atmospheric and ocean data assimilation, model development)atmosphere, ocean, coupled models), ocean and atmosphere process studies. Working group and plenary discussions were aimed at integrating these topics but were provided initial foci on broad-scale atmospheric and ocean sampling and on regional and process studies. Within the working groups and in the plenary discussions many national and individual reports were also provided.

The discussions of basin-scale ocean sampling reaffirmed the approach that has developed to date of combining remote sensing, ARGO profiling floats, basin-scale surface flux fields, surface drifters, time series stations including surface reference sites for improved flux estimations, the high density XBT lines with additional meteorological sensors, and repeat hydrography. A particular success of the workshop was the participation by a number of atmospheric scientists who initiated discussion of how CLIVAR, in conjunction with other programs such as the World Weather Research Program and elements such as THORPEX, can most effectively sustain and add to the atmospheric observations made across the Pacific Basin. In addition to the need for radiosondes, a need for more in-situ data about aerosols was pointed to by the atmospheric modellers. It was felt that the momentum achieved here should be sustained through workshops that increase the international participation and engagement of atmospheric scientists in Pacific CLIVAR.

Discussion quickly broke down the distinction initially perceived between regional and process studies. While the duration and domain of these studies may vary, they have in common the goals of improving understanding of the processes involved in storage, transport, exchange, and mixing of heat and other properties in the coupled air-sea system and of using that knowledge to improve predictive capability. Identified as of high interest to Pacific CLIVAR were studies of the western boundary and equatorial current regions, of vertical exchange, transport, and mixing processes in the ocean, of atmosphere-ocean links in the eastern tropical Pacific and in the Kuroshio extension regions, of cloud process in key regions of the Pacific, and of pathways to the equator from the subtropics with the Pacific ocean.

Good agreement was reached in many discussions and constructive comments offered on national plans. It was felt that further progress would be fostered by holding small, international workshops focused on particular elements of Pacific CLIVAR, such as the Kuroshio Extension System Study (KESS). These workshops are seen as a means to increase international participation and a balance of atmospheric and oceanographic studies. It was also recognized that continued progress in planning the Pacific will require support by the ICPO, particularly to develop permissions from the many Pacific nations to sample in and around these countries, strong links to the VAMOS and Austral-Asian elements of CLIVAR, and a standing Pacific panel.

Recommendations and action items:

The workshop recommended the formation of an international Pacific sector panel (hereafter Pacific Panel) with the following terms of reference

- To oversee and facilitate the implementation of CLIVAR in the Pacific sector in order to meet the objectives outlined in the Science and Initial Implementation Plans particularly with respect to:
  – Expanding and Improving ENSO predictions
  – Indo-Pacific Decadal Variability
  and also on Pacific impacts on:
  – Variability and predictability of the American Monsoon system
  – Southern Ocean Climate variability
  – Climate change prediction/detection and attribution
- To develop broad-scale atmospheric sampling plans and processes studies to complement the oceanic observations planned for the Pacific and as an integral component of the strategy to improve atmospheric and coupled models. To work with agencies and nations to sustain broad-scale atmospheric sampling in the Pacific.
- To coordinate the activities of the Pacific nations, facilitating cooperative efforts and coordinating work within the boundaries of the various nations as well as outside those boundaries. To provide a forum for exchange and discussion of national plans in the Pacific.
- To organize and conduct workshops that will entrain oceanographers, atmospheric scientists, and other investigators from the Pacific nations, that will lead to formulation of plans for broad-scale sampling and for sampling locations of high interest (such as boundary currents), and will coordinate not only the field activities but also the modelling, empirical, and paleo studies in the Pacific.
- To collaborate with WCRP WG on Coupled Modelling, the CLIVAR WG on Seasonal-Interannual Prediction and the WG on Ocean model development in order to design appropriate numerical experiments. To be aware of the requirements of these groups for data sets needed to validate models.
- To liaise with the Ocean Observation Panel for Climate (OOPC), with the Joint Commission for Oceanography and Marine Meteorology (JCOMM), with the Atmospheric Observations Panel for Climate (AOPC), and other relevant groups to ensure that CLIVAR benefits from and contributes to observations in GOOS and GCOS
- To advise the CLIVAR SSG of progress and obstacles toward successful implementation of CLIVAR in the Pacific.

It was felt that the ARGO Science Team should be informed that ARGO is essential for the implementation of Pacific CLIVAR and that, should the completion of basin-wide ARGO in the Pacific be done in phases, that coordination of this phased deployment with regional foci within the Pacific would greatly assist Pacific CLIVAR.

Broad-scale sampling methods, strategies, and plans need to be more fully developed for the following elements:

- Surface fluxes
- Time series stations
- Boundary currents
- Remotely sensed (satellite) fields

- Surface drifters
- Atmospheric aerosols

a) The central issue is how to best develop accurate surface flux fields over the Pacific basin. CLIVAR Pacific plans outline the strategy of making high quality in-situ observations, using those observations to correct biases and errors in remotely-sensed and NWP-produced fields, and then using a combination of the best of the NWP and satellite fields in an assimilative model to produce surface flux fields. This strategy will require cooperation and collaboration among in-situ and satellite observationalists, the NWP centres, and modellers. It is recommended that a CLIVAR Surface Flux Working Group be established to bring together the different, requisite expertise, forge collaborations, and advance the process of producing the surface flux fields that CLIVAR requires.

b) Time series stations are seen as a key element of Pacific CLIVAR, able to provide high vertical and temporal resolution, and offering platforms for multidisciplinary measurements. They have been proposed for boundary current and open ocean observations. It is recommended that the choice of sites and rationale for these time series stations in the Pacific be further developed in the context of the Pacific of the CLIVAR Pacific implementation plans advanced at this workshop.

c) Observations in the western and eastern boundary currents and their bifurcations and recirculations are identified as key elements of the effort to quantify tropical-extra-tropical exchanges. Two actions need to be taken on boundary currents. First, small workshops should be held to develop detailed plans approaches to sampling the boundary currents. It is anticipated that these workshops may recommend pilot studies to test the recommendations in addition to providing the more comprehensive plans needed in advance of ongoing measurement campaigns to be done as part of Pacific CLIVAR. Second, work toward addressing the practical challenges of doing these field measurements, such as identifying national contacts, initiating clearance requests, and finding vessels, should begin with support by the ICPO staff.

d) The initial implementation workshop did not explicitly involve providers of the satellite data sets required by Pacific CLIVAR. It is recommended that the links to the satellite data providers and satellite remote sensing community be strengthened by entraining members of those communities into the process of implementing Pacific CLIVAR.

e) Surface drifters provide velocity at 15 m and a platform for observing SST, barometric pressure, and additional variables. A recommendation for the density of surface drifters needed in the Pacific to support CLIVAR should be developed, and that recommendation should explain the need for these drifters.

f) The atmospheric modellers requested that the broad-scale atmospheric sampling plan under development include efforts to provide information about atmospheric aerosols.

Significant progress was made at the meeting to develop the atmospheric broad-scale and process study elements of Pacific CLIVAR. To advance the state of maturity of the planning of these elements and to engage additional atmospheric scientists in Pacific CLIVAR, it is recommended that within the next 6 to 8 months, one or more small workshops on the atmospheric elements of Pacific CLIVAR be supported. These would be attended also by several of the Pacific CLIVAR oceanographers and would continue the integration of modellers and observationalists established at the Hawaii meeting. A goal of these workshops will be to increase international participation and the breadth and completeness of the atmospheric science community engaged in Pacific CLIVAR.

Process studies in several regions of the Pacific are planned to quantify mechanisms involved in the transport, exchange, and storage of heat, freshwater, and mass. The scientific needs and rationale for these process studies were identified at the workshop. Because developing more detailed plans for these process studies will greatly benefit from the inputs, exchanges, and deliberations of larger groups of investigators, it is recommended that the next stage of planning these process studies be built around a series of focused workshops, with each workshop charged with developing the plans for a specific process study, identifying how that process study addresses the Pacific CLIVAR science objectives, and knitting that process study together with the modelling and broad-scale sampling programs of Pacific CLIVAR.

The Kuroshio Extension System Study (KESS) provides an excellent opportunity to investigate and better understand the impact on the atmosphere of the poleward transport and release at mid-latitude of heat by this strong western boundary current. For this process study, the workshop made the specific recommendation that the investigators planning KESS more fully develop studies of air-sea interaction and atmospheric dynamics. The workshop suggested a winter study looking at the outbreak of cold air over the Kuroshio extension and a summer study of cloud processes over the Kuroshio extension.

The process of developing and maintaining the formal dialogue with each of the Pacific nations that is required for international sampling within each of these nations and in their surrounding waters must be initiated and then carried forward. Staffing at the ICPO should be identified to do this. The recent effort by the ARGO Science Team to work with SOPAC and SPREP should be built upon; liaison with PICES should be pursued; and the past effort of the CCCO Pacific Panel should be taken into account. This effort is seen as critical for the implementation of the boundary current sampling recommended by Pacific CLIVAR.

The possibility that additional meteorological observations can be obtained using the surface buoys deployed in the Pacific by the various national weather services should be investigated.

The western maritime continent plays a prominent role in Pacific as well as Austral-Asian climate variability. Coordination with the Austral-Asian Panel is recommended to maintain a focus on this region and its role in climate variability.

Co-ordination with plans for VAMOS activities in the eastern Pacific should be maintained. This has started well with EPIC and VEPIC. As NAME develops, joint interests in the eastern Pacific west of Central America and in the Gulf of California should be identified and pursued.

To maintain an the International Pacific CLIVAR website established for the Workshop an use it to facilitate exchange of national and other plans, to coordinate implementation, to catalog data collected, being collected, or to be collected in the Pacific basin, to provide pointers to modelling and empirical studies, and to allow exchange of results and graphics relevant to Pacific CLIVAR science.

CLIVAR VAMOS Panel Report from the 4th Session

1. Introduction

The 4th session of the CLIVAR VAMOS panel was held in Montevideo, Uruguay, March 26-30. The panel meeting was combined with a scientific workshop on the 'Climatology and Hydrology of the La Plata Basin' with special emphasis on the development of an application component for this project. The meeting, which was attended by more than 50 scientists from various disciplines, was organized around three main topics:

1. The development of a La Plata Basin Programme (PLATIN)
2. Development of a Science Plan for a field program on marine stratocumulus along the coasts of Peru and Chile (VEPIC)
3. Finalisation of the implementation plan for the South American Low Level Jet Experiment (SALLJ).

In addition, updates on programmes that contribute to VAMOS, particularly NAME were provided.

The first three days of the meeting were dedicated to the workshop on the Climatology and Hydrology of the La Plata Basin. After a series of scientific presentations, working groups for SALLJ/PLATIN, VEPIC and applications/human dimensions met.

Prof. Dr. Carlos Roberto Mechoso, chairman of the VAMOS panel, welcomed the participants, reviewed the progress of the VAMOS programme and gave an introduction to the La Plata Basin study (PLATIN). He stated that VAMOS has completed a science study phase and selected its first targets, and is now entering an implementation phase. This phase is organized 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.

2. Monsoon Experiment in South American (MESA)

The major VAMOS initiative MESA is organized as a sequence of three stages to be developed sequentially. The flag bearer of the first stage is the South American Low-Level Jet Program (SALLJ). A two-month field campaign is planned for the southern summer of 2003. Research proposals have been funded in Argentina, and are being written/submitted in Brazil and the US.

The second stage of MESA will consist of a research programme on the Climatology and Hydrology of La Plata Basin (PLATIN). PLATIN may become a major end-to-end international programme with support from international funding organizations. Although VAMOS has appointed a PLATIN Science Study Group (SSG), members are primarily physical scientists and its scope will gradually broaden to include applications and "human impacts". In addition, governments and international institutions will have to be involved. The VAMOS Panel felt that guidance from the highest levels of WMO and WCRP will help PLATIN to develop at a "CLIVAR showcase level."

The other component of MESA Stage 2 will be VEPIC (VAMOS Eastern Pacific Investigation of Climate), which has been provisionally defined as "a program of data analysis, monitoring, and modelling activities together with pilot observational studies on the climate variability in the Eastern Pacific." Some preparatory activities are already taking place. The VAMOS Panel strongly feels that it should continue hosting this activity within CLIVAR, since it provides motivation for involvement from countries along the western coasts of the Americas.

2.1 Low Level Jet Experiment (LLJ)

The low level jet experiment planning is now well under way. The working group sharpened the focus for the experiment and presented a draft for a budget. The working group will continue their efforts and complete the document until early summer.

A scientific workshop and a training meeting are being planned for early 2002 in Santa Cruz, Bolivia. It was pointed out that the cooperation with Bolivian scientists has to be strengthened in preparation to the field phase. Concerning the data of the field experiment and the management of the field project UCAR JOSS will be involved. The expertise of this group will be extremely helpful for the field study.

In this context, the panel endorsed the satellite archiving activity at UCAR. The data base for South America will become available to the community and provide a useful resource of information.

2.2 PLATIN

The La Plata Experiment was the main focus of VPM4. VAMOS will try to design this experiment as an end-to-end study (i.e. with an application component). The presentations of application components for a PLATIN study at the meeting have shown the strong interest of the hydropower and agriculture community to interact with the physical climate science community in this project. The application link will be revisited at VPM5.

The PLATIN project will likely to be a joint CLIVAR/GEWEX enterprise. A joint CLIVAR/VAMOS – GEWEX/GHP SSG Science Study Group for this project has appointed chaired by Professor Mechoso and Pedro Silva Dias. As a first step, the PLATIN SSG will prepare a more comprehensive scientific prospectus for this project. The group will start to work based on the document prepared in a workshop held in Montevideo , December 1999 (http://www.meto.umd.edu/~berbery/lpb/laplata.html).

2.3 PROSUR

The panel recognized that this IAI project is already very much contributing to further the goals of VAMOS. PROSUR will be invited to nominate a representative to the VAMOS panel meetings.

2.4 VEPIC

The VEPIC working group made very good progress during the meeting. It was reported that scientists from Chile and Peru have already started the implementation of a buoy network in the eastern subtropical Pacific and will participate in the upcoming EPIC field phase. In addition Science Workshop related to VEPIC will be planned for 2003. Peru has offered to host such a meeting. An international field experiment would be planned after 2005 but there will be some activity through the next years mainly by Peru and Chile that might also provide valuable information on a potential link between subsidence area in the Pacific and the LLJ / convection over the Amazon.

In view of the upcoming planning activities for an international CLIVAR Pacific programme, the panel recommended to keep the VEPIC project under the auspices of VAMOS, because a) of its important scientific linkages to the South American Monsoon Experiment and b) because of the opportunity of the countries at the South American coast to participate in VAMOS.

3. NAME

NAME is organized in three tiers that overlap in time. The two-year period 2003-2004 has been identified as providing an excellent opportunity to carry out NAME data collection activities. At the present time NAME has been endorsed by the US CLIVAR Pan American panel as a U.S. national process study, and by the CLIVAR/VAMOS panel as the North American component of VAMOS implementation. In addition, NAME is included as a chapter in the emerging GAPP Science Plan and Implementation Strategy. The VAMOS panel believes that recognition of the complex base of NAME by WCRP will be helpful to the programme. A joint CLIVAR-GEWEX NAME Science working group is in the process of starting its activity. A very comprehensive draft of a science and implementation plan has been written and is available to the community. The VAMOS panel decided that NAME will be a major focus in VPM5. This was one of the motivations for selecting a location in the Northern Hemisphere for VPM5.

4. VAMOS Legacy

The following proposal was endorsed by the VAMOS panel:

The VAMOS panel requires that its subsidiary projects actively seek to create a legacy from VAMOS, in the form of:

a) A project data base (that might become ongoing after the project) with established data exchange policies consistent with CLIVAR.

b) Education and Training for regional scientists involved in the project.

c) Any observational systems that may have been proven by the project to be of value for improved climate and hydrological prediction.

d) Any implemented upgrades to the operational systems used by interested stakeholders that may have been developed during the project.

e) Published records of progress that reflect the international framework of the project.

In the context of the last point, the panel recommended the preparation of an article emphasizing the VAMOS contribution to the understanding of the South American Monsoon System. The article will be authored by the VAMOS panel and preferably submitted to an international journal.

A. Villlwock and C.R. Mechoso

The Caribbean Climate Data Workshop
"A workshop on Enhancing Caribbean Climate Data Collection and Processing Capability and the Dissemination of Derived Global Climate Change Information for the Region."

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The view has long been held that within the Caribbean region substantial datasets of daily climate parameters exist, which could shed light on climate change trends within the region. However a number of factors prevented their being made available, even to researchers within the region, which include: (i) the less than convenient (non-electronic) format in which data are currently stored (ii) the need for quality checking and homogenization of the data (iii) a genuine fear that the data once exchanged will be used without benefit to the region (i.e., without the accompanying capacity building through the development of regional experts in data analysis and treatment), and (iv) the view that data is an income generator which must not be easily dispensed without discretion. To address these issues, and to initiate the examination of Caribbean climate data for evidence of change in climatic extremes, the Caribbean Climate Data workshop was held in Kingston, Jamaica from January 8-12, 2001.

The workshop was hosted by the Department of Physics of the University of the West Indies (Mona) and organized by Michael Taylor, researcher in the Climate Studies Group Mona and Thomas Peterson of the National Climatic Data Center (U.S.A.). The workshop brought together data managers from 18 meteorological services across the Caribbean region, representatives of four regional entities with interest in Caribbean climate, and experts in Caribbean climate, data quality assessment, and climate change. Given the perceived needs, the workshop had overall aims of enhancing climate data collection and processing capability within the Caribbean, and eliciting climate change information relevant to the region. Specifically the workshop was an attempt to 1) assess daily station climate data stores within the region 2) promote dialogue between Caribbean data managers and data users 3) train Caribbean data managers in appropriate techniques for data quality management and homogenization 4) disseminate software to facilitate data management in individual Caribbean territories 5) adopt and examine a list of easily calculable and meaningful indices for evidence of climate change in the region, and 6) create an electronic dataset of Caribbean precipitation and temperature records for use within the workshop and for subsequent dissemination to workshop participants and/or their sponsoring institutions.

The week began by putting in perspective for the region the issue of climate change. Plenary talks covered Caribbean climate variability with an examination of observed global influences such as ENSO and NAO (Alessandra Giannini, NCAR); an overview of Atlantic hurricanes of the 21st century (Hugh Willoughby, AOML/NOAA); projections of climate change in the Caribbean basin from global models and the extent to which the results are believable (Ben Santer, Lawrence Livermore National Laboratory); and a review of a similar workshop held in the Asia-Pacific region (Neville Nicholls, Australian Bureau of Meteorology Research Centre).

Armed with a contextual overview of the climate of the region and the importance of data for research, participants were then introduced to science on the data, i.e. quality control (Tom Peterson) and homogeneity (Albert Klein Tank, KNMI), as well as to climate indices as a mechanism for extracting climate change information. The necessity of and common techniques for carrying out these procedures were discussed and a common set of 15 indices which might prove indicative of climate change in the region decided upon. The set of indices used was coordinated with other research through the joint WMO CCl/CLIVAR Working Group on Climate Change Detection.

The following three days of the workshop saw participants engaged in hands-on exercises related to the data issues discussed. Participants had previously been asked to carry daily temperature and precipitation data of appreciable length (40 or more years) from their respective territories. Utilising computers provided by the host institution and software developed and provided by and provided by Byron Gleason of NCDC, participants initially logged many hours processing the data which they had brought to determine their suitability for the climate change analysis which was to be subsequently performed. Once the reliability of the data was ascertained the 15 climate change indices were calculated, again via the easy to use and multi-purposed software provided by the NCDC. These latter activities were under the direction and guidance of Tom Peterson, Albert Klein Tank and Lisa Alexander (Hadley Centre). The latter stages of the hands-on portion of the workshop involved the visualization of the results on suitable plots for use in the discussions of climate change in the region (as revealed by the data) that ensued.

Whereas all of the calculated indices revealed valuable information about climate trends in individual countries, some clearly highlighted dramatic changes in the climate of the region as a whole or parts of the region. For example, since the late 1970s, stations from the southern Caribbean showed strong, nearly linear increases in the number of warm nights (90th percentile of minimum temperature). The additional benefit realised by plotting on the same graph time series of indices from stations from different countries, was the clear understanding of how cooperative regional analyses can increase confidence in the results.

The final day of the workshop was devoted to discussion of the issues surrounding data availability. It became clear to all participants that there was urgent need for data to be digitised as only half of the countries had daily data time series digitised back before the mid-1970's. Additionally, through often impassioned discussion, the need for such quality checked data by end users (e.g. researchers in agriculture, health, and disaster mitigation) was presented. Indeed one of the problems in the region has been getting access to the climate data in whatever form it existed.

By the end of the workshop there was renewed determination on the part of the participants to digitise additional data which existed in their respective countries and to use the digitised data in conjunction with the software (which was made freely available to all participants) to ascertain how the climate of their country was changing. By so doing the capacity for future research would be increased. There was also agreement to make the data and the indices available for the purpose of further analysis on a regional basis and the authoring of a journal article on changes in climate extremes in the Caribbean region. The University of the West Indies (through M. Taylor) agreed to undertake the collation of the data and indices into a database freely accessible to all the participating institutions, whilst Tom Peterson undertook the coordination of the article with assistance from Michael Taylor and Lisa Alexander. As the workshop was also the first of a series of regional workshops coordinated by the WMO CCl/CLIVAR Working Group on Climate Change Detection, recommendations were also offered on ways to improve future workshops, including ways to improve the software.

CLIVAR Calendar

2001	Meeting	Location	Attendance
July 14	PAGES/CLIVAR Working Group	Amsterdam, NL	Invitation
July 10-18	IAMAS General Assembly	Innsbruck, Austria	Open
Aug-19-24	First International Conference on Global Warming and The Next Ice Age	Halifax, Canada	Open
Aug. 20-24	Climate Conference 2001	Utrecht, NL	Open
Aug. 29-31	CLIVAR Asian-Australian Monsoon Panel, 4th Session	Reading, UK	Invitation
Aug. 29-31	PIRATA-8	Paris, France	Invitation
September 3-7	CLIVAR Tropical Atlantic Workshop	Paris, France	Open
September 7-8	CLIVAR Atlantic Panel, 3rd Session	Paris, France	Invitation
September 10-12	New TAO Implementation Panel (TIP) First Meeting	Seattle, USA	Invitation
September 10-14	4th International GEWEX Conference	Paris, France	Open
September 18-21	Workshop on Advances in the Use of Historical Marine Data: Sea Surface Temperature and Other Key Climate Variables	Boulder, USA	Invitation
October 21-28	IAPSO - IABO 2001: An Ocean Odyssey	Mar del Plata, Argentina	Open
Nov. 10-15	Abrupt Climate Change Dynamics	Il Ciocco, Italy	Open

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

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