TAO IMPLEMENTATION PANEL

REPORT OF THE FIFTH MEETING

Goa, India

18-21 November 1996

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PROCEEDINGS OF THE FIFTH MEETING OF THE

TAO IMPLEMENTATION PANEL

National Institute of Oceanography
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1. SUMMARY

The fifth session of the TAO Implementation Panel (TIP-5) was held in Goa, India during 18-21 November 1996. The meeting was hosted by the National Institute of Oceanography. The purposes of TIP-5 were to review the present status of TAO array; to address technical and logistic issues related to its maintenance; to provide a forum for discussion of possible enhancements and/or expansions of the array to other tropical oceans and to higher latitudes; and to promote the scientific utilization of TAO data.

TIP-5 was coordinated with the first meeting of the CLIVAR Monsoon Panel, which was held during 19-22 November at the same location. Several sessions of the CLIVAR Monsoon Panel and TAO panel were conducted jointly, with a combined attendance of about 50 participants. An important objective of the CLIVAR Monsoon Panel meeting was to review scientific issues related to variability and predictability of the Austral-Asian monsoon system, and to formulate an implementation strategy for observational, empirical and modeling studies needed to address those issues. The overlapping themes of the TAO Panel and the CLIVAR Monsoon Panel meetings (specifically related to possible extensions of the TOGA observing system into regions influenced by the Austral-Asian monsoon) made it advantageous to closely coordinate the scheduling of these two panel meetings.

TIP-5 opened with a review of recent conditions in the equatorial Pacific, characterized by a lingering weak La Niña. The panel then turned to discussing issues of instrumentation, array maintenance, and data dissemination. Topics included ship time requirements; the commissioning of the new NOAA ship *Ka 'imimoana*, dedicated to servicing the TAO array primarily east of the date line; progress in developing a new generation ATLAS mooring (with nine systems deployed already in the equatorial Pacific); updates of the World Wide Web TAO pages, including new Java applications; Web access to a new COARE moored data archive at NOAA/PMEL; the status of TAO ocean velocity and salinity measurements; and TAO data throughput on the GTS. Fishing-related mooring and data losses (most severe in the western Pacific), and strategies to alleviate these losses, were also discussed.

Presentations were made on several proposed and, in some cases already funded, enhancements and expansions to the TAO array. These included shortwave radiation measurements along 165°E beginning in 1997 with support from the U.S. Department of Energy Atmospheric Radiation Measurements program; bio-optical, pCO_2, and nutrient measurements for studies of biogeochemical cycling in the equatorial Pacific beginning in November 1996; and moorings in the South China Sea coordinated with the South China Sea Monsoon Experiment (SCSMEX) in 1997-98. A proposed enhancement of the TAO array for moored measurements of *in situ* rainfall rates in support of the Tropical Rainfall Measuring Mission (TRMM) was described. Progress in planning two new TAO-related mooring programs, the Japanese Indo-Pacific Triangle Trans Ocean Buoy Network (TRITON) program and the Brazilian-French-U.S. Pilot Research Moored Array in the Tropical Atlantic (PIRATA) was also reviewed.

Scientific presentations highlighted large scale ocean dynamics and ocean-atmosphere interactions in all three tropical ocean basins. Several of these presentations served as background for discussion of implementation strategies directed at the Austral-Asian monsoon for which the following set of priority goals were identified:

- To determine the limits of predictability of the monsoon climate system.
- To assess the relative contributions of the slowly varying boundary conditions and the internal dynamics to the predictability of the monsoon.
- To evaluate the impact of the monsoon on the predictability of the global climate system.

Given the enormous societal consequences of monsoon rainfall variability in the Indo-Pacific region, and the potential for global impacts of that variability, there are compelling reasons to develop coordinated field, modeling and analysis programs to address these questions. The Panel recognized, however, that present *in situ* data bases are inadequate to address many of the outstanding scientific issues related to monsoon dynamics. Hence, the Panel recommended that consideration be given to pilot studies designed to enhance the climate data base in the region. It was noted, furthermore, that pilot scale moored measurement programs, appropriately designed, could provide high accuracy time series data of crucial variables needed for studies of large scale tropical ocean-atmosphere interactions. Regions of identified as urgently in need of study were the Bay of Bengal and the equatorial/southern tropical Indian Ocean. Following the close of the TAO Panel meeting, the CLIVAR Monsoon Panel established an ad hoc task group to define specific implementation strategies for pilot studies in the Indian Ocean. The TAO Panel will coordinate with the CLIVAR Monsoon Panel (and also the CLIVAR Upper Ocean Panel which has overlapping responsibilities) in developing these strategies for monsoon related research.

2. OPENING AND PURPOSE OF THE MEETING

Dr. M. R. Nayak, chairman of the TIP-5 local organizing committee, opened the meeting with a brief welcoming address, and then introduced Dr. E. Desa, Director of NIO, Dr. M.J. McPhaden, chairman of the TAO Implementation Panel, and Dr. A. Sumi, co-chairman of both the TAO Implementation Panel and the CLIVAR Monsoon Panel.

Dr. Desa welcomed the participants to Goa, and wished them success in their deliberations. He pointed out that NIO has a tradition of over 30 years of research in the Indian Ocean, and welcomed further involvement of NIO in climate related studies as part of international programs such as CLIVAR. NIO would in particular welcome an expansion of the TAO array into the Indian Ocean, noting that the institute has a very capable deep ocean going vessel (the RV *Sagar Kanya*) at its disposal.

Dr. McPhaden gave a brief historical overview of the development of the TAO array as a background to the meeting. He then stated the purposes of TIP-5 which were to review the present status of TAO array; to address technical and logistic issues related to its maintenance: to provide a forum for discussion of possible enhancements and/or expansions of the array to other into other regions of the world ocean; and to promote the scientific utilization of TAO data. In addition, some sessions at TIP-5 would be organized around the science theme of short term climate variability and predictability related to the monsoons.

Dr. McPhaden noted that, while planning for TIP-5 was underway with NIO, the International CLIVAR Office recommended that the first session of CLIVAR Monsoon Panel be held in conjunction with TIP-5. The intent in overlapping the CLIVAR Monsoon Panel meeting with TIP-5 was to engage a broad segment of the international community in focussed discussions of monsoon dynamics. The expectation was that these discussions would contribute to defining the scientific rationale for possible development of future observational networks in oceanic regions affected by, or exerting an influence upon, monsoon circulations in the atmosphere.

Dr. McPhaden concluded by thanking the meeting participants for persevering in their efforts to reach Goa for TIP-5 and the CLIVAR Monsoon Panel meeting. Several participants were indisposed by the sudden failure of Modiluft Airlines, complicating travel within India during the busy tourist season. Nonetheless, nearly everyone who planned to be at the meetings was able to attend.

Dr. Sumi pointed out that the CLIVAR Monsoon Panel was responsible for developing an implementation plan to address the Austral-Asian monsoon. This plan was necessary to continue the progress begun during the TOGA program, and to enhance our understanding and ability to predict monsoon related variations in the coupled ocean-atmosphere system. He observed that Indian Ocean region is very important for monsoon dynamics, and that India had a long history of leadership in monsoon studies. He looked forward to a week of successful meetings hosted by NIO.

3. SUMMARY OF CURRENT CONDITIONS IN THE TROPICAL PACIFIC

The tropical Pacific at the time of TIP-S was characterized by weak La Niña conditions. These conditions were the continuation of a cold phase of the ENS0 cycle that developed in mid-1995 and persisted, albeit with diminishing intensity, into 1996. Specific manifestations of the La Niña in November 1996 included weak (generally less than 1 "C) cold SST anomalies in the equatorial cold tongue, weak warm SST anomalies in the western equatorial Pacific warm pool, and easterly trade winds near to or slightly stronger than normal east of the date line (Figure 1). Subsurface TAO temperature data, and the NCEP ocean analysis system that assimilates these data, indicated that the equatorial thermocline was deeper than normal in the western Pacific and shallower than normal in the eastern Pacific. Consistent with these cold La Niña conditions, convection was reduced over the central equatorial Pacific and enhanced in the far western Pacific in November 1996 (Climate Prediction Center, 1996). The Southern Oscillation Index was slightly negative (-0.2), although it had been positive for nearly all of 1996 beforehand.

A westerly wind burst occurred during the latter half of November 1996 with anomalies of 3-4 m s^{-1} west of the date line (Fig. 1). However, winds returned to normal by the end of the month. Whether this westerly wind burst and subsequent oceanic response are the harbingers of a switch from La Niiia to El Niño conditions in 1997 is uncertain. The role of westerly wind bursts in the ENS0 cycle remains a controversial topic, one which will perhaps be clarified by analyses of TOGA-COARE data sets.

According to Climate Diagnostics Bulletin (Climate Prediction Center, 1996), there was no consensus among ENS0 forecasting schemes in November 1996 as to the evolution of the coupled ocean-atmosphere system over the next few seasons (although all schemes, to the extent they are initialized by Pacific ocean temperature and/or wind data, make use of TAO data in some form). The NCEP coupled ocean-atmosphere general circulation model system and the NCEP canonical correlation statistical model both predicted warming trends into the

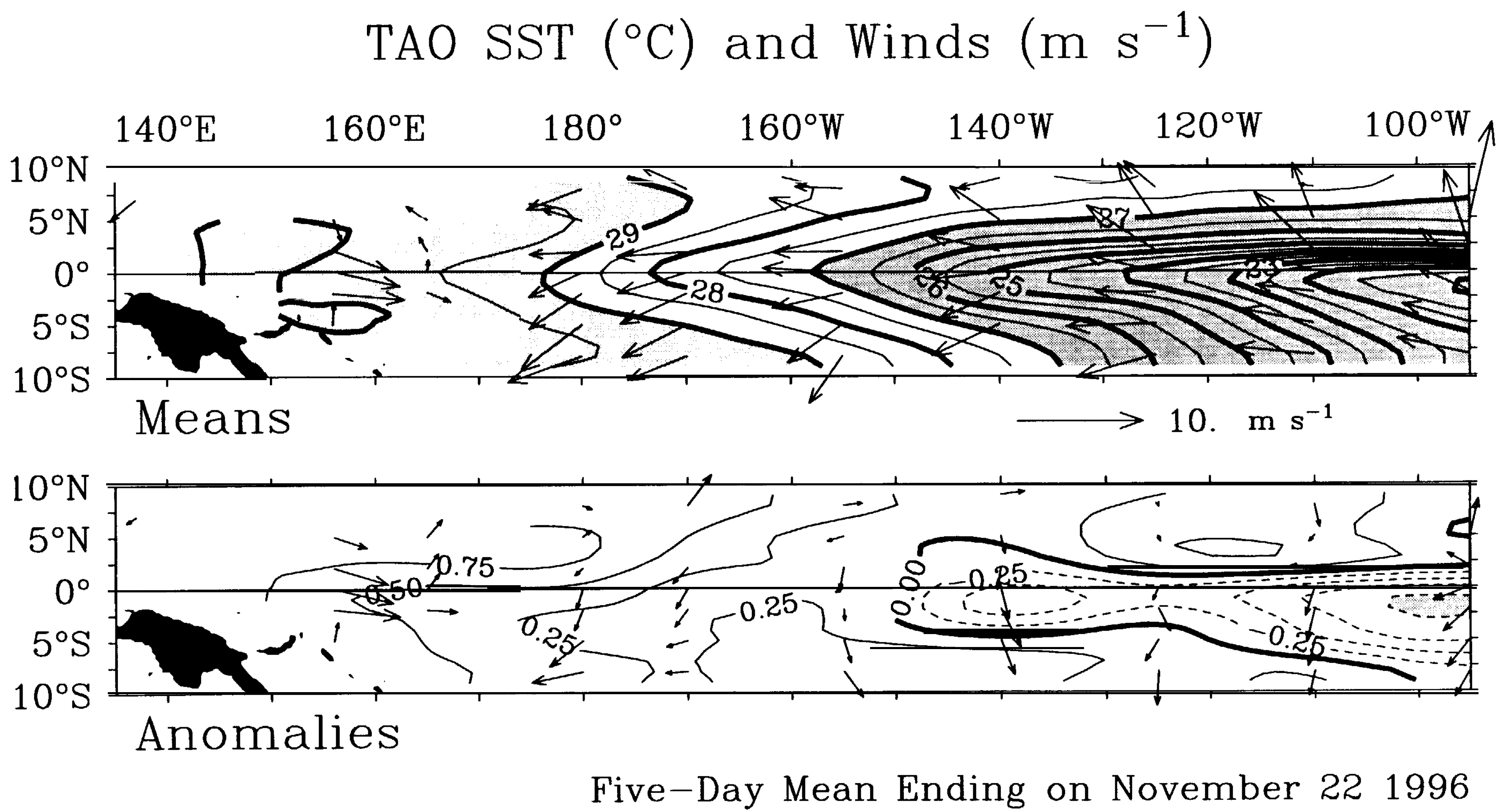
TAO SST (°C) and Winds (m s⁻¹)
140°E
160°E
180°
160°W
140°W
120°W
100°W
10°N
5°N
0°
5°S
10°S
29
28
26
25
23
27
Means
10. m s⁻¹
Anomalies
0.75
0.50
0.25
0.00
-0.25
Five-Day Mean Ending on November 22 1996

Figure 1

first half of 1997. Conversely, the Cane and Zebiak dynamical model forecasting scheme predicted a continuation of cold La Niña conditions into 1997. The Penland and Magorian statistical method predicted near normal conditions in the first half of 1997. It is unclear which of these model forecasts is correct, or what accounts for the spread of the forecasts.

Reference:
Climate Prediction Center, 1996: Climate Diagnostics Bulletin, November 1996. U.S. Dept. of Commerce, Washington, DC, 78 pp.

4. NATIONAL REPORTS

*4.1 United States **(L. Mangum/T.** Wright, **NOAA/PMEL)***

4. I. *1 TAO Array.* The locations of the present moorings in the TAO array are shown in Figure 2. In addition to the ATLAS moorings throughout the array, there are 5 sites where current measurements are being made. During the past year, nine next generation ATLAS moorings were deployed, with six of those replacing traditional ATLAS moorings. At three sites, reverse catenary next generation moorings were deployed nearby traditional ATLAS moorings for intercomparison.

4. I.2 Velocity Measurements. During the past year, upward looking Doppler current profilers placed on subsurface moorings replaced the surface PROTEUS moorings at the three PMEL current sites (0°,110°W; 0", 140°W, 0°,165°E). At these sites, traditional surface current meter moorings are also deployed to provide surface measurements as well as current comparisons. JAMSTEC will take over ADCP measurements at 0°, 165°E in 1997. PMEL will continue the current measurements at 0°, 170°W which were begun by R. Weisberg (University of South Florida) in 1988, with a deployment of a subsurface mooring in August 1996. The complete current record from 0", 170°W between 1988 and 1994 is now available as part of the TAO data base at PMEL .

4.1.3 Salinity Monitoring. At the TIP-4 meeting in September 1995, a revised salinity monitoring plan was adopted for the western Pacific. During the past year, surface SEACATs were in place on 16 TAO moorings between 156°E and 180°W. Instrumentation was provided by ORSTOM and PMEL. Data return from 1996 was approximately 85 % for the past year. It is planned to continue surface salinity measurements during the next year.

4.1.4 Next Generation ATLAS Moorings. Next generation ATLAS moorings use inductive coupling technology to transmit the subsurface data to the surface electronics package, eliminating the need for the thermistor cable. These moorings are described in Milburn et al. (1996). Standard sensors on the next generation ATLAS buoys include wind speed and direction, air temperature, relative humidity, sea surface temperature, ten subsurface temperatures and three subsurface pressures to monitor vertical excursions of the subsurface modules. Additional sensors such as conductivity, rainfall, and radiation can be added as special projects require.

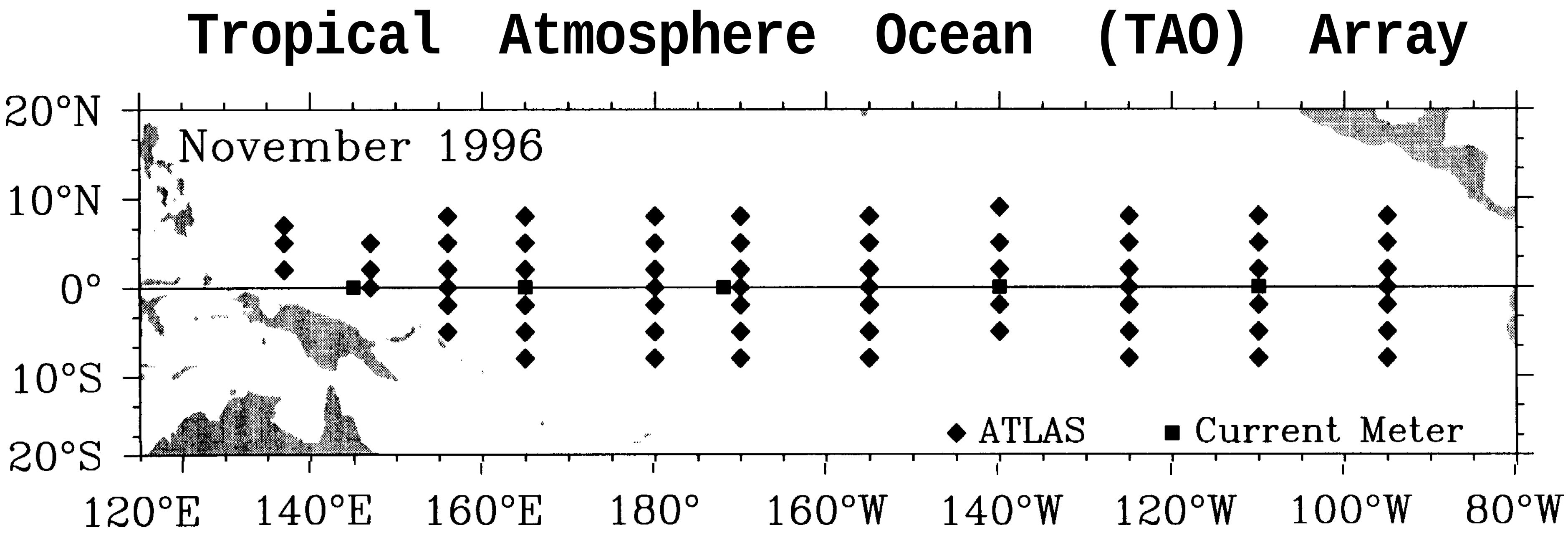
Tropical Atmosphere Ocean (TAO) Array
November 1996
20°N
10°N
0°
10°S
20°S
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
ATLAS
Current Meter

Figure 2

From the standard suite of sensors, the data that are available in real time will consist of several spot values of the surface measurements each day as well as the previous day's average of both the surface and subsurface data. Ten-minute data is stored onboard for all sensors and will be available after the mooring is recovered. Four daily-averaged conductivities can be transmitted in real time and ten minute samples are also stored in the sensor modules. An R.M. Young capacitance rain gauge is presently being tested; one minute accumulations will be stored onboard and the daily mean, standard deviation, maximum rate, and the percent time raining will be transmitted back. Radiation measurements will be made using an Eppley PSP radiometer sampled at 5 Hz; 2 minute averages will be stored and the transmitted data will consist of a daily mean, maximum, and standard deviation (computed for daylight hours).

During the next year 10-15 new next generation systems will be deployed in the TAO array. ARM has funded incoming shortwave radiation measurements along 165 °E and next generation ATLAS moorings with radiation sensors will be deployed there in the next year. Discussions regarding possible rainfall and conductivity measurements are also underway with the TRMM project office.

Reference:

Milburn, H.B., P.D. McLain, C. Meinig, 1996: ATLAS Buoy - Reengineered for the Next Decade, In: ***Proceedings of the IEEE/MTS OCEANS 96 Conference,*** Ft. Lauderdale, FL, Sept 1996, 698-702.

4.1.5 Data Availability. TAO data continues to be available to the international community through anonymous FTP file transfer, the World Wide Web, and the GTS. New Java applets on the Web allow interactive displays of surface meteorological data, interactive browsing of TAO time series, and animations of monthly SST and surface wind anomalies (http://www.epic.noaa.gov/tao/select/timeselect.html). Another new page displays the BMRC ocean analysis data provided by N. Smith based on temperature profile data from XBTs and TAO moorings (http://www.pmel.noaa.gov/bmrc-display.html).

The COARE Moored Data Archive was established this year at PMEL for dissemination of all moored measurements taken during the COARE field program. Data provided from various principal investigators and institutions are available for downloading (http://ww.pmel.noaa.gov/coare/ coare-data.html).

The TAO Project Office works closely with Service Argos and the Buoy Quality Control Network sponsored by the Data Buoy Coordination Panel (DBCP) to ensure high quality realtime GTS data. During the month of October 1996, over 1500 subsurface temperature profiles and over 4500 surface observations were distributed on the GTS network. During the past year, PMEL has received GTS statistics on data availability from the MEDS office in Canada. For an eight month period between March and November 1996, 50% of the GTS surface messages were received at MEDS within three hours of the observation time; 90% of all messages received within seven hours.

4.1.6 Ocean-Atmosphere Carbon Exchange Studies (OACES). Two TAO moorings equipped with biological/chemical sensors developed by the Monterey Bay Aquarium Research Institute (MBARI) and PMEL's CO_2 group were deployed in November 1996 at 0" ,155" W and 2°S, 170°W. Sensors include pCO_2, NO_3, spectroradiometer, transmissometer, absorption meter, fluorometer, and PAR. The goals of the OACES project are to determine the spatial/temporal variability of primary production, carbon dioxide and nutrient concentrations, and their relation to variations in the physical environment; to determine the biological and chemical responses to climatic forcing; to provide data for calibration/validation of satellite ocean color measurements.

4.1.7 TAO Array Support Vessel. Though delivery of the vessel was delayed by several months, the NOAA Ship ***Ka'imimoana*** entered service to support the TAO Array in June 1996. NOAA provided the use of the NOAA Ship ***Malcolm Baldrige*** to cover the delay period. ***Ku'imimoana*** has been modified to support the TAO Project as her primary task. In 1996, she made 5 cruises. The vessel recovered and deployed 38 TAO moorings and serviced or visited 33 moorings during this period. ***Ka 'imimoana*** will service the array from 95° W to 180" W and it will share the servicing of moorings along 165°E with JAMSTEC vessels.

4.1.8 Ka'imimoana Home Page. A new Web page was developed with the help of TAO personnel to provide information from NOAA's new research ***vessel Ka'imimoana*** which is dedicated to servicing the TAO array. Digital pictures and information from the ship are updated daily while the ship is at sea. Preliminary CTD section plots are also displayed from plots made onboard the ship and transmitted back to PMEL. More information about the ***Ka'imimoana*** can be found at http://rho.pmel.noaa.gov/atlasrt/kaimi.html.

4. I.9 TAO Array Annual Operating Plan. Ship time support for the TAO array in 1996 is summarized in Figure 3 and the following table. During 1996, four ships were used in support of the array: the NOAA ships ***Ka'imimoana*** and ***Malcolm Baldrige*** (USA), the IFREMER ship R/V ***Atalante*** (France) and the JAMSTEC ship R/V ***Kaiyo*** (Japan). NOAA provided 23 1 days of ship time between 95° W and 165 ° E and JAMSTEC provided 65 days of ship time west of the date line. Four days of TAO mooring work on ***the Atalante*** was included as part of an ORSTOM JGOFS cruise along 180" (see section 4.5).

Three ships of opportunity recovered drifting TAO buoys or serviced moored instrumentation during this period. These ships were ***Moana Wave*** (U. of Hawaii), Thomas ***Thompson*** (U. of Washington), and ***Discoverer*** (NOAA).

In 1997, JAMSTEC will provide 65 days of ship time in the western Pacific, and NOAA will provide 249 days (236 in the eastern/central Pacific and 13 days in the western Pacific). In addition, Taiwan may be able to provide ship time in October 1997 to support the array.

1996 TAO Cruises

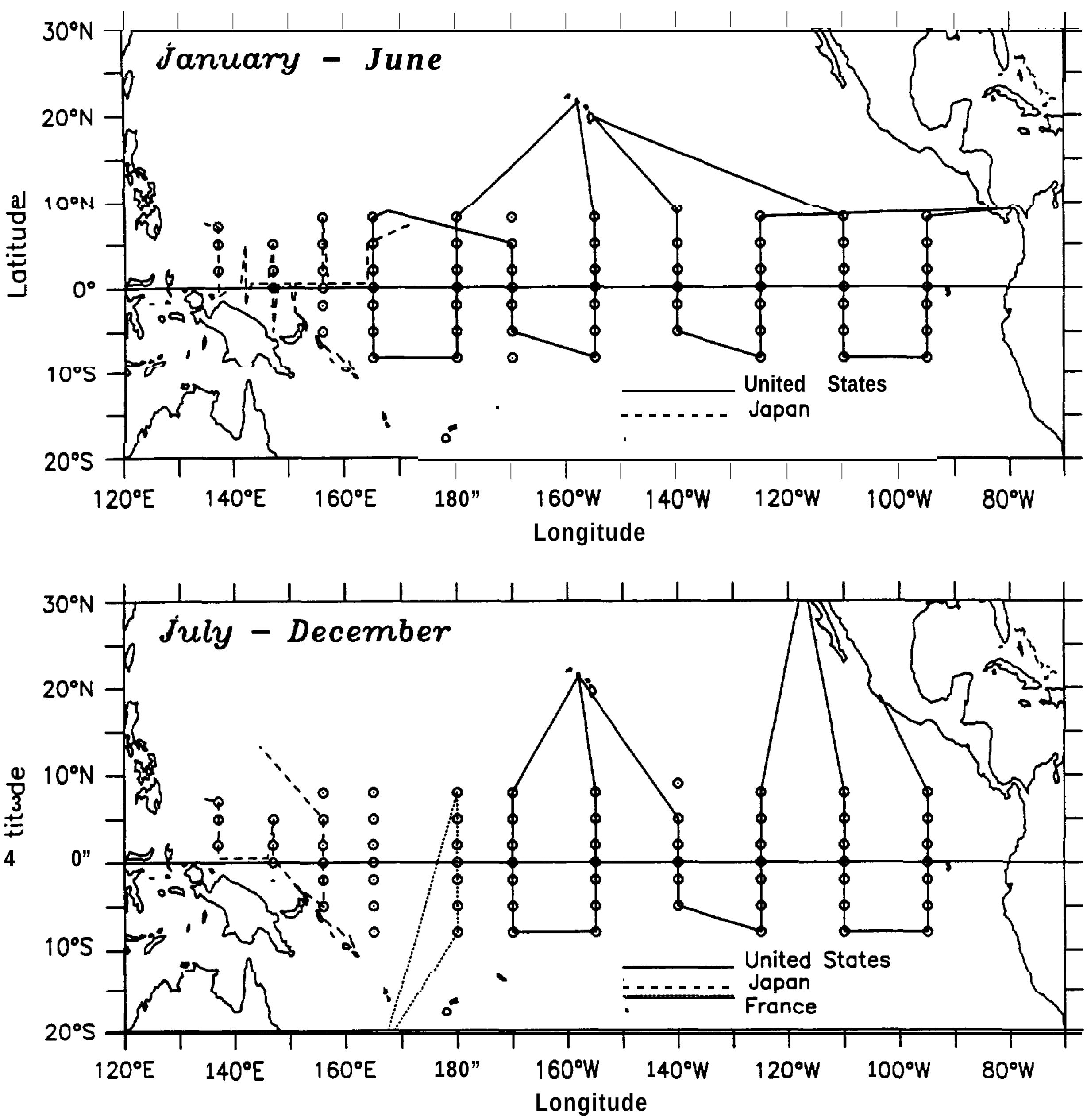

Figure 3

Ship Time Summary

	Western Pacific (137°E–165°E)	Central/Eastern Pacific (180" -95 ° W)
1996	*Kaiyo* (Japan) - 65 *Ka'imimoana* (USA) - 15 Total - 80	*Malcolm Baldrige* (USA) - 57 *Ka'imimoana* (USA) - 159 *Atalante* (France) - 4 Total - 220
1997	*Kaiyo* (Japan) - 65 *Ka'imimoana* (USA) - 13 *Fisheries Researcher* (Taiwan) - ? Total - 78	*Ka'imimoana* (USA) - 236 Total - 236

4.1 .10 Maintenance Requirements. The TAO array has specific scheduling and ship time requirements to ensure continuity of the data and maintenance of equipment. Surface current meter moorings require recovery/deployment every six months, whereas thermistor chain and ADCP moorings require recovery/deployment every twelve months. All sites should be visited at least every six months to check the status of the equipment, verify data quality, and make any necessary repairs.

To meet these requirements, approximately 235 days of ship time per year are needed to service moorings between 95°W and 180°, and approximately 90 days of ship time per year are needed to service moorings between 165°E and 137°E. These requirements were not met in 1996. Only 220 days of ship time were available in the eastern Pacific and 80 days of shiptime in the western Pacific. Requirements east of the date line would have been met had the *Ka'imimoana* used all its available ship time in the eastern and central Pacific. However, faced with a major shortfall of ship time along 165 "E, *the Ka 'imimoana* was diverted to that meridian in June 1996.

The result of these ship time shortfalls was that several mooring sites, most notably along 165°E and 156°E, were not serviced twice during the year. For those sites visited less frequently than about once every six months, both the quantity and the quality of the data are potentially compromised. Irregular servicing in the western Pacific compounds the problems of fishing vandalism, since data gaps can be longer than would otherwise be the case for want of replacement or repair of damaged instrumentation.

With an increased *Ka'imimoana* work schedule in 1997, ship time requirements will be satisfied between 95°W and *180"*. However, even with a *Ka'imimoana* leg along 165 °E scheduled for mid-1997, there will be a shortfall of 12 days of ship time in the western Pacific without further commitments.

4.1.11 Vandalism. Vandalism remains a serious concern especially in the western and eastern boundaries of the array. The informational brochure discussed at TIP-4 has been completed and is available in five languages: English, Japanese, Spanish, Chinese, and Korean. The brochure has been widely distributed through government agencies and the fishing industry in the Pacific. Panel members were asked to assist in distribution of the brochures.

Engineering attempts to minimize impact of vandalism consists of hardware modifications such as a cage around the top part of the electronics to protect connectors, as well as modification to the connectors to prevent damage.

4.2 Japan (A. Sumi, University of Tokyo, Y. Kuroda and M. Hishida, Japan Marine Science and Technology Center)

4.2.1 Japan (A. Sumi, University** of **Tokyo): During May 1996, the Mutsu Workshop was held at Mutsu-city where the TRITON Buoy Network was proposed and its relationship to existing international program was discussed. The summary of discussions was conveyed to the CLIVAR SSG meeting held at Sapporo. CLIVAR SSG admitted that it is a great contribution to CLIVAR implementation and recommended further development of the plan.

During August 1996, NASDA successfully launched ADEOS, which is called "Midori." It has eight sensors, among which NSCAT, OCTS, and IMG are expected to contribute to oceanography. OCTS gives ocean color data, which has been awaited for a long time (since CZCS). It is expected that ZMG will give SST to within 0.5°C accuracy.

STA has defined and submitted a new proposal which is called "Frontier Research Program." It is a 20 year plan, and has six research topics. In the next fiscal year, the first three topics, namely climate change prediction, hydrological cycle prediction, and global warming prediction will be initiated. TAO activity is strongly related to the climate change prediction topic.

4.2.2 Japan (Y. Kuroda and M. Hishida, Japan Marine Science and Technology Center): The status and plans of the TRITON buoy program at JAMSTEC were reported. The principal scientific objective is to understand heat transports focusing on ENSO, Asian Monsoon and decadal scale oceanic variations that influence climate change in the Pacific rim and around the world. The first deployment of four buoys is planned in March 1998 in conjunction with ATLAS buoys to carry out an intercomparison and to ensure the data compatibility. It will be extended to mid-latitude sea in FY 1999 and the Indian Ocean in FY 2000[1].

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TRITON Develop-

FY 1994: Conceptual buoy design.

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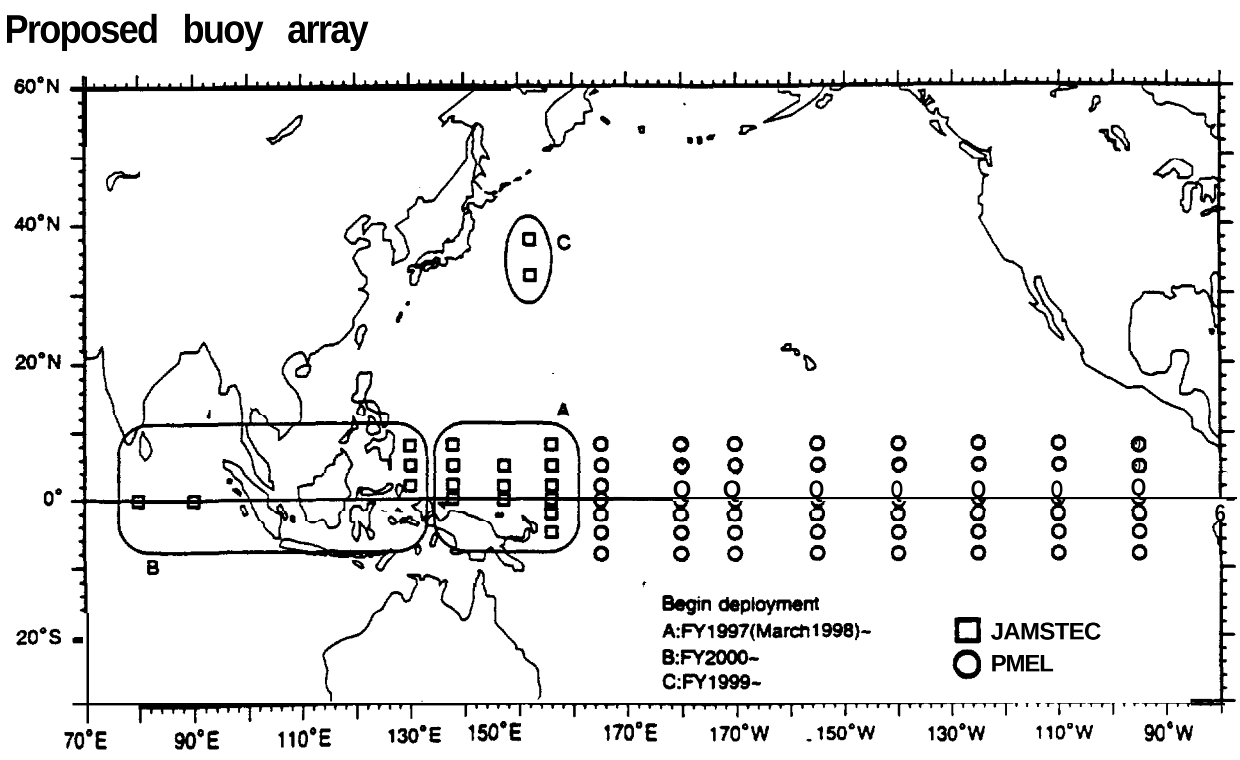
[1]"FY" in this section refers to the Japanese fiscal year, which runs from 1 April to 3 1 March.



Proposed buoy array
60°N
40°N
20°N
0°
20°S
70°E
90°E
110°E
130°E
150°E
170°E
170°W
150°W
130°W
110°W
90°W
A
B
C
Begin deployment
A:FY1997(March1998)~
B:FY2000~
C:FY1999~
JAMSTEC
PMEL

Figure 4

FY 1995: Basic buoy design and construction of a prototype buoy. Open sea trial of the low-latitude prototype buoy.

FY 1996: "International Workshop on Ocean Climate Variations from Seasons to Decades with Special Emphasis on Pacific Ocean Buoy Network," in May 1996 in Mutsu. Continuation of the open sea trial of the low-latitude prototype buoy. Construction a buoy maintenance building at the mother port of R/V *Mirai* in Mutsu.

FY 1997: Launching R/V *Mirai*.
Open sea trial of mid- and high- latitude prototype buoy.

Deployment Schedule

Region A: Begin deployment in FY 1997 (March 1998) harmonized with TAO array and completed within a few years.
TRITON buoys will enhance the capability of TAO buoys in the warm pool region by carrying salinity sensors and full meteorological sensors, and be deployed in order to obtain long-term data for process studies on ENSO.

Region B: Begin deployment in FY 2000.
TRITON buoys focusing on oceanic change and air-sea interaction associated with Asian monsoon in the far western Pacific Ocean and the eastern Indian Ocean.

Region C: Begin deployment in FY 1999.
TRITON buoys focusing on intermediate water formation and air-sea interaction in the frontal region between the subtropical gyre and the subpolar gyre.

JAMSTEC provided 65 days of ship time in FY 1996 and will provide 65 days of ship time in FY 1997 for servicing moorings of the TOCS (Tropical Ocean Climate Study) program. Some of this ship time has been and will continue to be available to recover and deploy ATLAS moorings west of 156°E and a few ATLAS buoys along 165°E.

4.3 Korea (I.-S. Kang, Seoul National University)

Korea has provided three ATLAS buoys along the 137°E line in the western Pacific in previous years. However, in 1995-96, Korea did not contribute any further resources to TAO. The three-year TAO related project at Seoul National University ended in November 1994 with the end of TOGA. But the Meteorological Research Institute supported one more year (1994-95) by providing funds for replacing the sensors on three ATLAS buoys.

At present, Korea has no definitive plan for further involvement in the TAO program. Until now, meteorologists have led the Korean contribution to TAO. But, it is hoped that Korean oceanographers and Korean Ocean Research and Development Institute (KORDI) involve more actively in the international activities related to TAO in near future. Recently, in July 1996, Korean government established a new Ministry, the Ministry of Ocean and Fishery, and KORDI is now belong to the new ministry. We hope that the new ministry recognize the importance of the international contribution to the TAO program and KORDI can involve in TAO with sufficient resources in very near future.

4.4 Taiwan (D. Tang, National Taiwan University)

Taiwanese national contributions to the TAO array include: maintaining an ATLAS buoy in the western Pacific ocean; providing ship time; and analyzing and studying the collected data. Presently, our ATLAS buoy, which is deployed at 8°N, 156” E is maintained by the PMEL/NOAA through the contract between the PMEL and NTU. The ship time to be provided by Taiwan in 1996 was canceled due cost/benefit considerations, stemming from the fact that there were only two ATLAS buoys in need of repairs at the time the ship was scheduled to sail. For research, basinwide upper ocean thermal variations related to various time-scales in zonal wind stress were studied. Results are described in “Basinwide zonal wind stress and upper ocean thermal variations in the equatorial Pacific Ocean” which will soon be published in *J. Geophys. Res.-Oceans*. Westerly wind bursts related to the reversal of surface zonal currents and their vertical gradients have been investigated. Current velocities collected at 165°E, 170°W, 140°W, and 110°W along the equator have also been analyzed. The importance of upper ocean current variation in the west-central Pacific Ocean has been addressed. The results have been included in a refereed journal article which is currently under reviewed.

In additional to the work in the tropical equatorial Pacific Ocean, we plan to deploy three newest generation ATLAS buoys in the South China Sea. This is a joint research project between the PMEL and NTU. The data collected by these three buoys will be transmitted back to the PMEL on a daily basis and be available to the public. The first buoy will be in the water by April 1997 while the other two buoys are scheduled for April 1998. Within approximately 10 miles of each ATLAS buoy, a subsurface ADCP (Acoustic Doppler Current Profiler) buoy will be deployed to monitor the upper ocean current velocity variations. In addition, an array of current meters will be deployed across the Luzon Strait to study the water exchange between the South China Sea and the Kuroshio. Although the above are part of regional work of South China Sea Monsoon Experiment (SCSMEX), they will be able to provide new information on the global impact of ENSO. Specifically, one of our governmental agents will possibly take over these three ATLAS buoys after the SCSMEX program and keep them in the South China Sea as long-term observing stations, so that, the ENS0 effects on the South China Sea can be studied over a long period of time.

4.5 France (J. Picaut, ORSTOM/Noumea)

From October 21 to November 20, 1996, the EBENE cruise was conducted onboard the French R/V ***L 'Atalante*** from Noumea by the ORSTOM FLUPAC group. The main purpose of this JGOFS cruise along 180” was to study grazing of phytoplankton by planktonic herbivores in order to better understand the oceanic carbon cycle. Four days of ship time were devoted for the maintenance of the TAO array along 180”. Two PMEL technicians and one technician from the SURTROPAC group at ORSTOM-Noumea participated in this cruise, and the following instruments were replaced: four complete moorings at 8°S, 2°S, Equator, and 8°N, an electronic tube at 5 °S and an air temperature sensor at 2° N.

Over the next three years, except for occasional mooring replacement with the possible venue of a French R/V in the Pacific, the French participation in the TAO array will be centered in the tropical Atlantic, with the launch in 1997 of the PIRATA experiment. This pilot experiment will be implemented as a collaborative multinational effort issued from Brazil, France and USA (see Jacques Servain's report).

The French CLIVAR program is building up, with the submission in November 1996 to the PNEDC (Programme National d'Etude de la Dynamique du Climat) Scientific Committee of a common set of proposals from various French research groups. In particular, the CLIVAR/GOALS contribution will be composed of an Indo-Pacific program and a tropical Atlantic program. The Indo-Pacific program is the continuation of the French effort in the tropical Pacific during TOGA (now named ECOP for Etudes Climatiques de l'Ocean Pacifique) and of the JADE throughflow experiment; a better coordination and use of observations at sea and modeling activities will be the center piece of this Indo-Pacific program. The tropical Atlantic program (named ECLAT for Etudes Climatiques dans 1' Atlantique Tropical) will deal with the coupled ocean-atmosphere system together with its role in the climate of the surrounding continents. New observations at sea will be proposed with in particular the French participation in the PIRATA experiment.

The cooperative western Pacific salinity monitoring TAO project is maintained by NOAA/PMEL and ORSTOM/Noumea. Only one SEACAT instrument has been lost in 1996; 35 instruments are still in use, with 23 right now deployed at sea. This cooperative effort results in the instrumentation of three meridians in the western and central Pacific along 156°E, 165°E, and 180". The corresponding TAO salinity data bank is assembled under the supervision of Paul Freitag at NOAA/PMEL. This salinity project together with the ORSTOM-Noumea Ship-of-Opportunity surface salinity program appear increasingly important for process studies in the warm pool, such as the formation of the barrier layer.

Many scientists from mainland France and ORSTOM-Noumea have used the TAO data in 1996 for various and complementary scientific purposes. Several types of models (OPA/LODYC and Gent and Cane OGCMs, long-wave linear model) were validated with TAO data. Algorithms for extracting wind stress field from ERS-1 and ERS-2 data were improved by the Space Oceanographic group at IFREMER-Brest through the comparison with TAO data. The Groupe de Meteorologie a Moyenne Echelle at Meteo-France is using the TAO data for their own TOGA-COARE research. Hourly heat fluxes along surface drifter trajectory in the COARE domain were determined with the help of TAO data. The dominance of zonal advection in the ENS0 displacement of the eastern edge of the warm pool was demonstrated with the outputs from three models and four types of near-surface currents, including the TAO current meter data. This demonstration was made possible through the evidence of a convergence of water masses in the equatorial band, resulting in a salinity front that was observed in particular from salinity data taken on some of the TAO moorings. During La Niña, the zonal displacement of saltier water from the eastern Pacific into the fresh water of the warm pool results in saltier water in the surface layer of the western Pacific. Together with the presence of a salinity maximum around 150-200 m, this suggests an apparent upward motion into the surface layer at the equator. The question about the importance or existence of an equatorial upwelling in the warm pool during La Niña was therefore considered in view of TAO temperature series at the equator. An open-ocean validation of the TOPEX/Poseidon altimeters, using two TAO moorings at 2°S, 164°E and 2°S, 156°E outfitted with additional sensors from surface-to-bottom led to the discovery of strong semi-diurnal internal tide in the middle of the COARE domain. Additional analyses, using these TAO data and high-frequency TOPEX/Poseidon data, resulted in a better understanding on the formation and propagation of these internal tides. A project to build bimonthly temperature fields over the whole tropical Pacific during 1979 to 1996 from XBT and CTDs data, through objective analysis requires an estimate of the error field. The longest TAO temperature time series were used to estimate the high frequency noise that cannot be resolved from XBT data. Finally, the relationship between biological and physical processes, as observed during the French JGOFS FLUPAC cruise along the equator in October 1994, was determined in view of the large space-time scale determined through the TAO array.

4.6 India (L. V.G. Rao, NIO)

The tropical region of the Indian Ocean is of special interest to oceanographers and meteorologists due to seasonally reversing monsoon winds, inflow of warm high saline waters from the Persian Gulf and the Red Sea, influx of large quantities of fresh water from the Indian peninsula and the cyclonic storms of the Bay of Bengal. Recognizing the importance of generating a large set of oceanographic data needed to determine the circulation and heat storage and to characterize their response to atmospheric forcing, India has initiated systematic and long-term measurements of oceanographic parameters.

4.6. *1* Sea ***Level*** Measurements. The existing 13 functional tidal observatories along the Indian coast and islands, maintained by the Survey of India, are being equipped with modern tide gauges (with accuracy of 3 mm) under the Sea Level Monitoring and Modelling (SELMAM) Programme and GLOSS Programme with the support of Department of Ocean Development (DOD) and Department of Science and Technology (DST), respectively. Acoustic tide gauges with higher accuracy are being installed at selected stations.

A National Tidal Data Center has been established for archiving and disseminating data to the user community. Historical data are being analysed and interpreted with dynamical models, with National Institute of Oceanography (NIO) as the nodal agency.

4.6.2 XBT Observations. A long term programme of XBT observations for routine monitoring of the upper ocean thermal structure along a few selected shipping lanes in the tropical Indian Ocean was launched by NIO in 1990 with the support of DST. To start with, observations were carried out along Madras-Port Blair (Andamans)-Calcutta route in the Bay of Bengal and subsequently extended to Bombay-Mauritius route (in 1992) and to Visakhapatnam-Singapore route (in 1995). Temperature data in the upper 800 meters (using the standard Deep Blue XBT probes) together with surface meteorological data are being collected at one degree (100 km) intervals along these routes, atleast once in two months, depending on availability of merchant ships. It is planned to use XCTD probes and extend the observations to two additional routes (Cochin-Muscat and Bombay-Mombasa) during the next ***5*** years.

The data are screened for quality, processed for archiving in standard formats and disseminated to user community including TOGA subsurface Data Centre at Brest (France). The data have been analysed to study the evolution of the upper ocean thermal structure on annual time scales and its year to year variability. Relationship between upper ocean heat content and cyclogenesis (in the Bay of Bengal) and monsoon activity are also being investigated.

4.6.3 Drifting Buoy Programme. A drifting buoy programme was launched by NIO in 1991 with the support of DOD. It forms an important component of the seatruth collection effort for the National Ocean Remote Sensing Programme aimed at developing a Marine Satellite Information Service (MARSIS) for the Indian seas. During the last 6 years more than 40 drifters were deployed by the Indian Research Vessels *Gaveshani* and ***Sugar Kanya*** in the Arabian Sea, Bay of Bengal and the equatorial Indian Ocean and the data on surface meteorological and oceanographic parameters were acquired through Argos System. Besides WOCE drifters with SST and pressure sensors, a few multiparameter TOGA drifters with sensors for air temperature and winds were also used. Since July 1995, the data from these drifters are being disseminated on GTS. A few prototype drifters developed indigenously at NIO were also deployed and their performance is being evaluated. The drifters worked for periods ranging from six months to one and half years. It is planned to intensify this programme through deployment of 20-30 drifters per year in a phased manner during the next 5 years (1997-2002).

A collaborative programme with Global Drifter Centre at AOML/NOAA has been initiated in 1996 and a few GDC drifters have been deployed by NIO in the equatorial Indian Ocean. A few drifters are being assembled/fabricated at NIO for deployment under this programme. It is planned to initiate such collaborative programmes with other organizations also, for mutual benefit.

The drifter data collected to date have been screened for quality and processed for archival in standard formats. Analysis of these data for description of diurnal variations of SST and inertial oscillations/circulations and construction of climatologies of surface drifts on different time scales is in progress. It is planned to construct surface circulation patterns from satellite altimetry and scatterometry and compare the same with those derived from drifting buoys.

4.6.4 Deep Sea Moorings & Moored Buoy Programme. Under the Indo-German collaborative programme on Particle Flux Studies in the north Indian Ocean initiated in 1986, NIO has deployed and maintained deep sea moorings (with sediment traps and current meters) at 9 locations in the Arabian Sea and the Bay of Bengal. At 3 of these locations in the central Arabian Sea, six current meters were moored under the Indian JGOFS Programme. Two moorings with acoustic transceivers, tilt meters and current meters were deployed in the Arabian Sea during May 1993 under the Ocean Acoustic Tomography Programme, from ***Sugar Kanya*** .

A National Data Buoy Programme sponsored by DOD has been initiated in 1996. It envisages deployment of twelve met-ocean moored data buoys at selected locations in the seas around India, over a period of 3 years (at a rate of four buoys per year). Eight of these buoys will be moored in the shallow water regions along the Indian coast and the remaining four in the deeper waters (two each in the Arabian Sea and the Bay of Bengal). All the buoys will be equipped with sensors for measurement of various meteorological and oceanographic parameters viz. atmospheric pressure, air temperature, wind speed and direction, SST, wave height and period, current speed and direction, salinity, dissolved oxygen, etc. Besides these four buoys, deployment of another ten moored met-ocean data buoys in the deeper waters of the Bay of Bengal, Arabian Sea and equatorial Indian Ocean is planned during the next 10 years under the Indian Climate Research Programme.

4.6.5 ***TAO Moorings.*** A proposal on a long term collaborative programme between India, Australia and USA for operating/monitoring a line of three TAO moorings (with temperature recorders and current meter arrays) in the eastern Indian Ocean was mooted by the Chairmen of the Indian Ocean Panel of CCCO and TOGA-TAO Implementation Panel in 1993. NIO responded positively to this proposal and is looking forward to actively participate in this programme. NIO can provide the technical and logistic support for deployment and recovery of the instrumented moorings using ***Sagar Kanya***. Following this initiative, it is planned to extend the TAO array in the Indian Ocean further during the next 10 years under the Indian Climate Research Programme.

4.7 Indonesia (T. Sribimawati BPPT)

Climate research activities in Indonesia are increasing compared to only a few years ago. However, comprehensive interagency efforts have only been coordinated seriously in the last two years, since the establishment of the Indonesian Scientific Community of Atmospheric Dynamics (SCAR). In its gatherings, scientists from different institutions discuss their activities, their facilities, try to find out how to integrate their activities to solve our national problems (in particular like how to improve climate prediction capabilities) and to contribute to global issues such as global climate change.

Operational climate activities in Indonesia are conducted by the Meteorology and Geophysics Agency (BMG), while research activities are conducted by different research institutes, Agency for the Assessment and Application of Technology (BPPT), National Institute of Aeronautics and Space (LAPAN), Indonesian Institute of Science (LIPI), National Coordination Agency for Surveying and Mapping, Dishidros-Al, and universities. The Scientific Community on Atmospheric Dynamics is comprised of researchers from these institutions.

Available resources, including facilities and funding, are coordinated by scientific meetings.

Within the Indonesian development program scheme, improving climate prediction capabilities is one priority. This is due to the fact that agriculture is an important sector in Indonesia. Strategic and tactical planning for agriculture require a better climate prediction. The strategy to deal with climate research is to converge research activities. The avenues are through the Integrated Excellence Research (RUT) program, the National Strategic Excellence Research (RUSNAS) program, through the International Integrated Excellence Research (RUTI) program, through international collaborative projects, and through research assessment projects in each institution.

As an ongoing climate project, LAPAN has started to install the CSIRO nine-level atmospheric general circulation model and Langrangian atmospheric dispersion model on a parallel processor computer. A similar machine will be installed in BPPT. SCAR has started to develop climate data base in cooperation with Japanese scientists. SCAR will start to study ocean climate through cooperative work between BPPT and JAMSTEC in order to extend TAO array (18 buoys will be installed within and around the Indonesian region). ARLINDO data and TAO array data will be used in this study. It is hoped through this collaborative work, SCAR could actively participate in the CLIVAR program. Modelling studies will be developed through RUSNAS (proposed for FY 1997-2000)

Through RUT, the impact of monsoon-ENS0 on mesoscale atmospheric circulation will be studied. Available atmospheric radars (Serpong and Biak) and intensive atmospheric sounding data will be used to observe tropical atmospheric waves. This study will start in FY 1997- 1998, and last for three years.

In line with its main task, SCAR will facilitate international cooperative work with Indonesian scientific communities working on climate. SCAR also seek the opportunities to collaborate with other international program, such as SCSMEX, GAME, and the GAME-T program.

5. PROGRAM STATUS REPORTS

*5.1 The PIRATA Program: An Extenstion of the TAO Array in the Atlantic (J. Servain, **ORSTOM/Brest**)*

It is well recognized that atmosphere-ocean interactions throughout the global tropics are potentially important to the earth's climate system on time scales of years to decades. Among the regions of particular interest is the tropical Atlantic where two main modes of interannual and longer-term variability are observed: (i) an "equatorial" mode, operating preferentially at seasonal and interannual time scales, has many similarities to the ENS0 phenomenon in the Pacific, and involves trade wind variations and the excitation of equatorial Kelvin and Rossby waves; (ii) the so-called "dipole" mode, which operates primarily at decadal and longer time scales, involving north-south interhemispheric variations in sea surface temperature.

Unfortunately, the *in-situ* observational system that exists in the tropical Atlantic is relatively poorly developed. It relies mainly on volunteer observing ships and occasional research vessels that pass through the area. The generally infrequent sampling provided shipboard data limit our ability to better describe and understand climatically relevant ocean-atmosphere interactions in this region.

The Pilot Research Moored Array in the Tropical Atlantic (PIRATA) is an initiative put forward by a group of scientists from Brazil, France, and the USA involved in tropical climatic studies. The PIRATA program, which will be implemented as a collaborative multinational effort, proposes to install and maintain in the tropical Atlantic an array of 14 moored ATLAS buoys in the region 15°N-10°S, 0°-35°W during the years 1997 to 2000. In addition to the ATLAS mooring array, wind measurements and tide-gauge data will be available in real-time from St. Peter and St. Paul Rocks, Atol das Rocas, and Sao Tom Island. Brazil will also instrument 0°,44°W with a coastal meteorological buoy.

There are several specific scientific and technical goals of PIRATA:

- To provide an improved description of the seasonal-to-interannual variability in the upper ocean and at the air-sea interface in the tropical Atlantic.

- To improve our understanding of the relative contributions of the different components of the surface heat flux and ocean dynamics to the seasonal and interannual variability of SST within the tropical Atlantic basin.
- To provide a data set that can be used to develop and improve predictive models of the coupled Atlantic climate system.
- To design, deploy and operate a pilot array of moored buoys, similar to the ones used during the TOGA program (the TOGA-TAO array) in the tropical Pacific.
- To collect and transmit via satellite in real-time a set of oceanic and atmospheric data to monitor and study the upper ocean and atmosphere of the tropical Atlantic. These measurements will be available to all interested users in the research and operational communities.

Three years of measurements will only barely touch on the issues of seasonal to interannual variations in the tropical Atlantic, and will not resolve decadal scale variability. Yet PIRATA has the potential to establish the foundation for a longer term monitoring network that will address more completely a broad range scientific problems under auspices of CLIVAR, GOOS and GCOS.

The PIRATA document is available via World-Wide-Web (http://www. ifremer.fr/orstom/pirata/pirataus.html) or directly via anonymous ftp (ftp.ifremer.fr/ifremer/orstom/pirata30.rtf.Z).

5.2 Observations, Analyses, and Forecasts for Climate in the Japan Meteorological Agency (T. Manabe, JMA)

The Japan Meteorological Agency (JMA) has been making comprehensive oceanographic observations using its six research vessels in the western Pacific, three ocean data buoys in the seas adjacent to Japan, and tidal stations for many years. In particular, marine meteorological and oceanographic observations have been carried out by two vessels from south of Japan to the equator along 137°E for about thirty years and have contributed to understanding the roles of the western North Pacific in the climate system. In 1994, R/V *Ryofu Maru*, one of the JMA vessels, made a highly precise oceanographic survey as a part of the WOCE Hydrographic Programme (WHP) one-time survey along 137°E (P9). A new R/V *Ryofu Maru* built in 1995 is equipped with a greenhouse gases (CO,, CH,, CFCs, N_2O) measuring system among others and commenced making observations along 165°E up to 50" N twice a year (once a year in the equatorial region). JMA will also continue the observations along 137" E four times a year.

In addition to the observations by research vessels, JMA is making an effort to promote subsurface observations by Voluntary Observing Ships along the routes of Japan - Persian Gulf and Hong Kong - New Zealand - Japan and in the TRANSPAC region.

JMA has been providing oceanographic information services for more than fifty years. Based on ***in situ*** data from ships and buoys including TAO array and satellite data, in addition to the observations made by JMA itself, the Agency has been making a variety of oceanographic products. These include analyses and forecasts of 10-day and/or monthly mean sea surface temperature, subsurface temperature and sea surface current. Some of these products are broadcast on an operational basis through meteorological radio facsimile to the ships and JMA also publishes the Monthly Ocean Report which is distributed to interested institutes and agencies. JMA also disseminates information on the latest states of El Niño events to the domestic public.

For the purpose of monitoring the climate, especially ocean variability related to ENSO, JMA has developed an Ocean Data Assimilation System (ODAS) and started to use it operationally in February 1995. The system consists of an ocean general circulation model (OGCM) and a subsurface temperature analysis scheme using optimum interpolation. The analysed temperatures are continuously assimilated into the wind-driven OGCM. Only data that arrive via the GTS are used in the ocean temperature analysis, some TAO array data are available this way. Other TAO data, from the current meter moorings along the equator, do not come via the GTS. Because these data are not incorporated in the temperature analysis, they provide a valuable source of verification of the fields produced by the ODAS. We find that the subsurface thermal field produced by the ODAS is more closely correlated with the subsurface temperature data from TAO than with the same field derived from the wind-driven OGCM, thus the TAO data are clearly having a major impact on the JMA ocean temperature product. We find also that the intra-seasonal variation of the currents produced by the ODAS compare well with the observed sea surface current. At present, JMA is developing a new objective analysis method for the current field, using current observations obtained through traces of drifting buoys and geostrophic current data obtained through dynamic height observed by TOPEX/Poseidon altimeter. The verification of this new method also needs current data of TAO array. Aiming at operational forecasting of ENSO, JMA is developing a coupled ocean-atmosphere general circulation model. The oceanic field obtained by the ODAS is supposed to serve as the initial condition for the prediction. Impacts of TAO data on the prediction will be examined.

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Kirnoto, M., I. Yoshikawa and M. Ishii, 1996: An Ocean Data Assimilation System for Climate Monitoring , J. Meteor. Soc. Japan, special issue (in press).

5.3 U.S. Global Ocean Atmosphere Land System/Pan American Climate Studies (GOALS/PACS) (S. Piotrowicz, A. J. Ray, and M. J. Patterson, NOAA/OAR; M. J. McPhaden, NOAA/PMEL)

The Global Ocean-Atmosphere-Land System program began in 1995 in order to build on the successes of the Tropical Ocean-Global Atmosphere (TOGA) program by broadening' the geographic scope from the tropical Pacific to the global tropics, and eventually the entire globe. The scientific objectives of the GOALS program are to (1) understand global climate variability on seasonal-to-interannual time scales; (2) determine the spatial and temporal extent to which this variability is predictable; (3) develop the observational, theoretical, and computational means to predict this variability; and (4) make enhanced climate predictions on seasonal-to-interannual time scales. The GOALS program has three regional foci: (1) El Niño-Southern Oscillation focusing on the tropical Pacific building upon the TOGA program in that region; (2) Asian-Australian Monsoon covering the western Pacific and Indian Oceans and extending into the midlatitudes; and Pan American Climate Studies (PACS) with a domain of the eastern Pacific, western Atlantic and the continents of North and South America. The El Niiio-Southern Oscillation and Pan American Climate Studies programs are underway while the Asian-Australian Monsoon program is in its planning stages.

The scientific objectives of PACS are to understand and more realistically model (1) the seasonally varying mean climate of the Americas and adjacent ocean regions; (2) the role of boundary processes in forcing seasonal-to-interannual climate variability over the Americas; (3) the coupling between the oceanic mixed layer in the tropical Atlantic and eastern Pacific; and (4) the processes that determine the structure and evolution of the tropical sea-surface temperature field. As a result of the first two proposal cycles for PACS, three studies requiring observations beyond those provided by the TAO array will be deploying into the field in 1997 and 1998:

- A study of the relative importance between ocean dynamics and surface heat fluxes in determining the evolution of cold tongue SST will deploy on the equator, near an existing ATLAS mooring, a downward looking 600 kHz ADCP to obtain, with high vertical resolution, upper ocean currents over a 6 month to 1 year period (Figure 5). Together with data from the TAO Array, this will allow detailed investigations of the nature of the near surface shear and its relationship to the local wind stress.

- The temporal and spatial variability of the air-sea fluxes and the upper ocean will be examined by collecting one-year long time series of fluxes of momentum, heat, fresh water, upper ocean temperatures, velocities, and salinities using IMET moorings deployed along 125°W (Figure 5). One mooring will be at 10°N, which places it in the ITCZ for much of the year, a region characterized by high precipitation rates and warm sea surface temperatures. The second mooring will be in the equatorial cold tongue (0°-2°N), a region of clear skies and very little precipitation except during strong ENS0 episodes.

- The establishment of an enhanced atmospheric sounding and monitoring network over the eastern tropical Pacific Ocean and bordering regions. This program will begin with the establishment of a radiosonde station at Cocos Island and pilot balloon observations at selected sites and is intended to operate for a period of up to 18 months. At the end of this period, it is believed that enough data (both meteorological and operational experience) will have been collected to determine the desirability and feasibility of sustaining the network.

These three programs are best classified as focussed process studies. Understanding the coupled ocean-atmosphere system requires a suite of observations beyond what is presently provided by the TAO Array and these process studies. The major requirement is for long time series of atmospheric observations in the extreme eastern portion of the equatorial Pacific and extending south to include the stratus deck west of Peru. Implementing monthly or bi-monthly soundings over several years from ships, aircraft, etc., will be a near term focus of PACS.

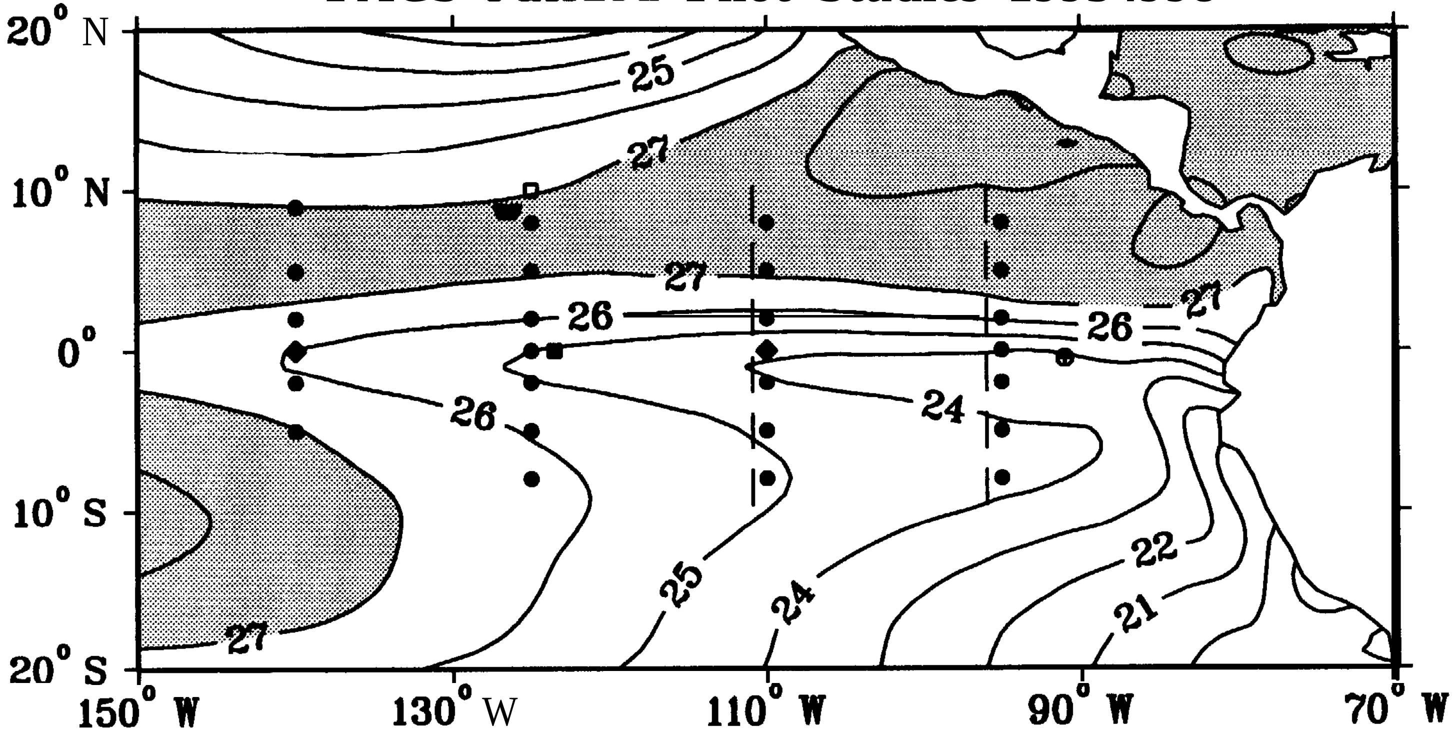

Figure 5. PACS funded pilot studies for the period 1995–1988 superimposed on annual mean sea surface temperature contours from Reynolds and Smith (1995). Also shown are pre-existing TAO Array ATLAS and current meter mooring sites, and a wind profiler site in the Galapagos Islands. The location of pilot study activities is offset from TAO mooring locations for clarity. Soundings will be made along 95°W and 110°W; IMET mooring at 10°N, 125°W and ATLAS mooring at 8°N, 125°W will be within range of the shipboard Doppler Weather radar.

The PACS Implementation Plan is, and will be, maintained as an electronic version at http://tao.atmos.washington.edu because it is meant to be a dynamic document to be updated as programs as detailed plans for studies are developed, studies implemented, and new foci developed. The period immediately after the above programs (e.g., 1998-2000) will include a major observational program focussed on the ITCZ/Cold Tongue complex in the extreme eastern Pacific and will utilize the *in situ* observations provided by the TAO Array along 95°W, supplemented by shipboard observations and aircraft (manned and, possibly, unmanned) based out of the Galapagos Islands, southern Mexico and/or Costa Rica. Included within this study is the region of extreme deep convection centered over the Panama Basin, southern Central America, and northwest South America. Plans under consideration include augmenting the existing radiosonde network in the region and establishing two sounding stations on islands in the region. This program may be further augmented with periodic dropsonde missions flown by the NOAA Gulfstream IV aircraft out of Tampa, Florida.

Plans are also under consideration to extend the proposed Atlantic Circulation and Climate Experiment with PACS support for some observations from 5 °N to 5 °S. Longer range proposals include more comprehensive atmospheric observations in the extreme western tropical Atlantic.

5.4 Use of TAO Data in the NCEP Operational Model (W. Woodward, NOAA/NOS)[2]

A first step in assessing the impact of TAO data on operational models is to determine what percentage of the available data is actually being used in the models. The atmospheric models at NOAA's National Centers for Environmental Prediction (NCEP) have well-defined observation time and data receipt time cut-off windows within which the data must arrive to be assimilated. Analysis of the wind observations from the TAO Array indicates that only 56% of the data set available to the models is being assimilated into the global atmospheric model suite at NCEP. The time of the observation, the on-off cycle times of the buoys, and the time between when the satellite is visible to the buoy and when it is visible to the ground station are the primary controlling factors of that percentage. The low percentage suggests that the method for real-time relay of data from the TAO array may not be optimum for operational applications. In this presentation the suite of global atmospheric models at NCEP, their data acceptance windows and how they differ among the models are described briefly. The quantity of TAO wind observations actually used in the models is shown for the period July/August 1996 and is compared to the total number of observations collected by the array during that same period. Illustrations are provided showing the number of observations used in the models displayed against several variables, including the time of the observation, the difference between the time of the observation and its time of arrival at NCEP, and the cycle times of the model. Recommendations are made on ways to increase the percentage of TAO observations used in the NCEP models.

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[2]Abstract was submitted prior to the meeting but author was unable to attend.

5.5 CLIVAR Upper Ocean Panel Report **(W.** *Kessler,* ***NOAA/PMEL)***

The CLIVAR Upper Ocean Panel held its 2nd session on 2 l-24 October 1996, in Villefranche-sur-mer, France. The focus of the meeting this year was “Assessment of the Pacific Observing system for Analyses, Model-Testing, and El Niño Forecasts.”

Perhaps the most important conclusion of the UOP meeting was that despite the many advances that have been made in modeling Pacific dynamics and thermodynamics, and the increased quantity and quality of wind observations, there remains a strong need for *in situ* sub-surface observations to correct wind-forced GCMs by assimilation. Several talks focused on the NCEP GCM runs and reanalysis product, comparing the output to observations of various types, and evaluating this model’s ability to hindcast features of the Pacific climate such as ENSO. There was discussion of how to best use the *in situ* observations for assimilation. At present, an observed temperature profile (from TAO or XBT), is assimilated directly. In regions where the model has significant mean errors (for example the wrong depth of the mean thermocline), most of the information content of an observed profile serves to correct the mean error, and observed anomalies may not have much influence. On the other hand, one might try to assimilate observed anomalies. However, evidence was shown of significant decadal changes which make definition of anomalies problematic, particularly when the time range of data available to compute climatologies is not consistent from region to region. Another unsolved problem is how to make use of altimetric sea level from the TOPEX/Poseidon satellite. It is not obvious how one would use sea level as a constraint in the GFDL model formulation. One group at GFDL has developed a regression technique to make “synthetic XBTs” from the altimeter values. Unfortunately this produces some quite odd profiles on occasion. Another method attempts to use sea level as an integral constraint on the model; this work is still in progress. Overall, it is clear that to date, even in the relatively well-studied tropical Pacific, large amounts of *in situ* data will continue to be necessary for the foreseeable future.

Another subject of discussion at the meeting was the Pacific wind products (NCEP, ECMWF, FNOC, and FSU). Although TAO winds flow to all these centers, large differences remain among the wind fields and between TAO and the wind products, indicating that the observed winds may not be constraining the fields appropriately. Reasons for this might be problems in the model planetary boundary layer physics or surface pressure fields that result in observed winds appearing too anomalous and being rejected.

Salinity was discussed, and evidence was shown for the need for *in situ* salinity profiles for the computation of dynamic height and geostrophic currents, Salinity will be investigated for next years’ meeting, including questions of where the need for *in situ* salinity is most important, to what extent surface salinity alone is useful, and how densely salinity must be sampled to be useful.

Other regions of the world ocean were briefly discussed with an eye towards choosing a focus for next year’s meeting. Possible topics include the subtropical-tropical connection, which is seen to be important in regards to decadal changes; the Southern Ocean, where observations of barometric pressure that can be collected by drifting buoys might have a large influence on the AGCMs; the Atlantic, which is of interest in connection with climate over the Americas; and the Indian Ocean and monsoon variability.

5.6 Ocean Rain Measurements for TRMM Validation (O. Thiele, NASA/GSFC)

The TRMM Global Validation Program has been concerned with methods to validate TRMM satellite observations over the oceans since the earliest concepts of the mission. As a result, several techniques that would overcome some of the problems associated with ship and buoy motions were investigated. The most promising system for this purpose at the time was a newly developed miniature version of an optical rain gauge (ORG) manufactured by STI, Inc. Although substantial success was achieved during TOGA-COARE with approximately 25 of these experimental ORG's deployed on ships, buoy and nearby islands, their maximum potential was not realized for several reasons. The key problems that have been encountered with the mini-ORG relates to design of the optical transmitter support, directional wind effect, manufacturing quality control and non-linearity of the standard rain (R) calibration, i.e., $R = 100V^2$ (V = sensor output voltage). With careful attention, all of these problems can be reasonably overcome with independent calibration of each instrument. However, even assuming a reliable manufacturing quality, the fairly high cost of these instruments do not make them economically feasible for large-scale network type deployment.

Another line of investigation centers around a low cost disdrometer that can be used on ships and buoys as well as on land. The current development approach is based on an early Johns Hopkins' Applied Physics Laboratory design. The disdrometer instrument has the advantage of measuring rain drop size distribution (in addition to rain-rate and amount) which is highly important for quantifying latent heat release in convective/cumulus cloud models, and for developing reliable radar reflectivity to rain (i.e., Z-R) relationships. Although this type disdrometer is an order of magnitude less expensive than the one commercially available Swiss disdrometer, it, like the ORG of similar cost, is not suitable for large scale deployment. However, a number of these on buoys located in a few representative regions in the tropics could provide invaluable information on variable rain systems. Approximately 50 of these units will be completed by the Summer of 1997 and deployed at the several TRMM ground validation sites and at various experimental locations.

While both of these systems, especially the disdrometer, can contribute significantly to important and specialized ocean measurements of rainfall, a simpler and less expensive rain measuring system is needed for wide spread ocean buoy deployment such as the TAO Array. The most promising solution at this time for extending Pacific Ocean rain measurements at this time would appear to be the R.M. Young syphon gauge. A significantly large deployment of these gauges on ATLAS moorings in the Pacific would be of great benefit to TRMM.

6. SCIENCE REPORTS

6.1 Surface and Subsurface Low-Frequency Variability in the Tropical Atlantic: One Necessity for Implementing the PIRATA Array (J. Servain, ORSTOM/Brest and I. Wainer, IOUSP/Brazil)

Though some aspects of the interannual variability in the upper tropical Atlantic Ocean were previously tackled, we do not have any conclusive idea about the time-scale of such variability. Our attention was to focus on the monthly deviations from the seasonal cycle of the vertical displacement of the 20°C isotherm (Z20), which is commonly associated in the tropical regions with the vertical displacement of the thermocline depth. Until now, the TOGA-WOCE XBT data set remains the only candidate to provide such type of information, even if opportunities to construct Z20 long-term series in the tropical Atlantic from XBT probes are exceedingly limited. Our alternative was to look at the Z20 long-term series simulated by an OGCM, after testing primarily the accuracy of the model results vs. the observed data fields, where and when that was possible. In the present experiment, the OGCM OPA7 developed at LODYC is forced during 1985-1994 by the outputs (momentum, heat and fresh water fluxes) from the AGCM ARPEGE developed by Meteo-France. Only the oceanic results between 20°N and 20°S can be used in the validation analyses because OPA7 is partially relaxed to the climatology (temperature and salinity) outside the subtropical latitudes.

A first series of tests were made to look at surface variability, especially SST anomalies. The OGCM reproduces pretty well the observed interannual variability of SST in the whole tropical Atlantic, either at shorter time-scales (a few months), or at longer scale-times (many years). That is an important improvement in comparison with what was noted in previous experiments. Furthermore, it was determined that the model is able to reproduce properly low-frequency (decadal time-scale) interhemispheric variability in the surface layer which is evident from SST observations (the "SST dipole mode").

6.2 An Optimized Design for a Moored Instrument Array in the Tropical Atlantic Ocean (T. Busalacchi, NASA/GSFC)

Recently, a joint Brazil-France-U.S. program, known as PIRATA (Pilot Research moored Array in the Tropical Atlantic), was proposed to begin the deployment of moored measurement platforms in the tropical Atlantic in order to enhance the existing observational data base and subsequent understanding of the processes by which the ocean and atmosphere couple in key regions of the tropical Atlantic Ocean. Empirical studies have suggested that there are strong relationships between tropical Atlantic upper ocean variability, SST, ocean-atmosphere coupling and regional climate variability. During the early 1980's a coordinated set of surface wind, subsurface thermal structure, and subsurface current observations were obtained as part of the U.S.-France SEQUAL-FOCAL process experiment designed to observe the seasonal response of the tropical Atlantic Ocean to surface forcing. Since that time, however, the observational data base for the tropical Atlantic Ocean has disintegrated to a few XBT lines and a small collection of tide gauge stations. A more comprehensive set of observations, modeling and empirical studies is now in order to make progress on understanding the regional climate variability. The proposed PIRATA program will use mooring platforms similar to the tropical Pacific Ocean TAO array to measure surface fluxes of momentum and heat and the corresponding changes in the upper ocean thermal structure. It is anticipated that the oceanic data from this monitoring array will also be used in a predictive mode for initialization studies of regional coupled climate models. Of particular interest are zonal and meridional modes of ocean-atmosphere variability within the tropical Atlantic basin that have significant impacts on the regional climate of the bordering continents.

In this investigation a series of observing system simulation experiments (OSSE's) is performed as part of a design study for the proposed PIRATA array of instrumented moorings in the tropical Atlantic. In most OSSE's, a model is used to construct synthetic fields of ocean data, which are then subsampled according to the observing pattern being simulated. The challenge of these experiments is the reconstruction of the reference field from the restricted data set. Such experiments in which the same model is used for construction of the synthetic data set and for its reconstruction for simulated observations are often referred to as "identical twin" experiments. In contrast, here we subsample fields of sea surface height anomalies observed by the TOPEX/Poseidon satellite altimeter, and attempt to reconstruct the full TOPEX/Poseidon height anomaly field through the use of assimilation of data at a restricted number of locations.

A modified Kalman filter is used to assimilate surface height anomaly data into a simple ocean model of the tropical Atlantic. In the past, limitations of computer resources have kept researchers from using the full Kalman filter for assimilation of data into ocean models. Our approach to implementing the Kalman filter eliminates the large memory requirement since the forecast error covariance is calculated and maintained on a grid which is much coarser than that used in the model. This is acceptable since the primary interest is in the large scale characteristics of the error.

With the reduced-space Kalman filter, several data assimilation runs are performed in order to optimize the location of a limited number of moorings for the PIRATA deployment. The OSSE begins by establishing bounds for the suite of experiments. The lower bound is an experiment without assimilation which demonstrates the ocean model errors. Another experiment, in which data are assimilated in an unrealistically dense array configuration, serves as an upper bound to any proposed pilot mooring array. A suite of experiments was then conducted by assimilating altimeter data at three mooring locations along a meridian at 2°N, 2 °S, and the Equator, while the longitude was varied sequentially by 5° for each run. Results of these experiments show the biggest impact of the assimilated data occurs when the observations are taken between 15°W and 30°W. For example, assimilation of sea level observations at 20°W shows that a limited number of assimilation sites can improve the temporal signal throughout the equatorial waveguide, however, the amplitude of the sea level signal is poorly reconstructed.

Next, a more theoretical approach is used to determine optimal mooring locations. Optimal points are determined in a more objective fashion using a Monte-Carlo sampling of the model forecast error structure. Using this technique, the optimal mooring locations were found to be along the Equator at 35°W, 20°W, and 10°W. Assimilation at these three locations shows that not only the temporal signal, but also the amplitude is transmitted throughout the equatorial waveguide.

These OSSE results were used to guide the decision for the initial deployment of three equatorial moorings during the first year of PIRATA. In subsequent years, the PIRATA plan calls for additional moorings (approximately 14 in total) to be deployed to enhance the sampling within the equatorial waveguide and off the equator in the vicinity of the dipole SST variability maxima. Additional experiments were performed to demonstrate the efficacy of the full PIRATA deployment and the added value that can be expected from PIRATA observations above and beyond existing XBT observations.

*6.3 On the Physics of **ENSO** Displacement of the Pacific Warm Pool (J. Picaut, **ORSTOM/Noumea)***

The Pacific warm pool is peculiar with a relatively deep upper layer of well-mixed warm and low-salinity waters which cover one-third of the equatorial Pacific. Furthermore, this pool is subject to strong interannual migration along the equator, in phase with the Southern Oscillation Index. In the scientific plan for TOGA-COARE, it has been suggested that the Warm Pool may be associated with the zonal convergence of the oceanic circulation in the western tropical Pacific, and that low surface salinity contributes to its insulation from colder and saltier water below. In the present study, with the use of four datasets and three classes of ocean model, we demonstrate the dominance of zonal advection in the zonal migration of the eastern edge of the warm pool. This is evidenced through the discovery of a zonal convergence of water masses and a well-defined salinity front at the eastern edge of the warm pool, which together move along the equator in phase with the Southern Oscillation.

Most data presented in this study was collected during the 1985-94 TOGA decade. They consist mainly of surface current fields collected from four equatorial TAO moorings and drifters, as well as currents derived from satellite altimetry measurements (GEOSAT and TOPEX/Poseidon). Three different model outputs were used: the Cane and Patton linear multimode model over the 1961-94 period, the Gent and Cane OGCM and the three tropical oceans LODYC high resolution OGCM over the 1982-94 period. Following previous studies suggesting the importance of zonal advection in the zonal migration of the warm pool, all surface-current fields were used to compute the zonal displacements of hypothetical drifters transported by the 4°N-4°S averaged current. Such hypothetical drifters, launched on the eastern edge of the warm pool and moved by the observed and simulated surface currents, remain close to this edge all the way to the end of the studied period. This stresses the dominance of zonal advection in the zonal displacement of the eastern edge of the warm pool. The trajectories of different hypothetical drifters launched in each current field a little west or east of the eastern edge of the warm pool converge into a single trajectory after 2-3 years. The 4°N-4°S drifter trajectories integrating the eastward and westward surface currents in the equatorial band, this provides evidence for the zonal convergence of water masses towards the eastern edge of the warm pool. Given the presence of rainfall-induced fresh water in the warm pool and saltier water to the east, the zonal convergence of water masses within the equatorial band results in a well-defined salinity front and therefore in a density front, as indicated by salinity observations and LODYC model simulation. Because the salinity front is induced by current convergence, it is situated in a region of very weak or null zonal currents, which together with the corresponding density front restrain the heat exchange between the warm pool and the equatorial region further east. The convergence of surface currents and water masses not only results in the formation of the salinity front but also in the subduction of salty water from the central equatorial Pacific below the fresh water of the western Pacific. This creates the underlying barrier layer in the equatorial band which obstructs entrainment of the colder and saltier water into the surface layer. The warm pool, which is composed of low-density fresh and warm water, floats above the high-density cold and salty water; therefore it can be easily displaced zonally by wind-driven currents, as the momentum is trapped in a shallow mixed layer. All of this explains why the warm pool is somewhat isolated from the remaining equatorial Pacific, and why there is such a good agreement between the ENS0 displacements of the eastern edge of the warm pool, of the zonal convergence of water masses, and of the zonal salinity front.

6.4 The Annual Cycle of SST in the Eastern Tropical Pacific, diagnosed in an ocean GCM (W. Kessler, NOAA/PMEL, L.M. Rothstein, University of Rhode Island, and D. Chen, Columbia University)

The annual onset of the east Pacific cold tongue is diagnosed in a ocean GCM simulation of the tropical Pacific, with particular reference to the role of the cross-equatorial wind associated with continental heating over the Americas. The model uses a recently-developed mixed layer scheme that explicitly simulates the processes of vertical exchange of heat and momentum with the deeper layers of the ocean; comparison with observations of temperature and currents shows that many important aspects of the model fields are realistic. As previous studies have found, the heat balance in the eastern tropical Pacific is notoriously complicated, and virtually every term in the balance plays a significant role at one time or another. However, despite many complications, the three-dimensional ocean advection terms tend to cancel each other in the annual cycle, and to zeroth order the variation of upper layer heat content can be described as simply following the variation of net solar radiation at the sea surface (sun minus clouds). Even near the equator where the ocean advection terms are relatively intense, the heat balance terms associated with cloudiness variations are among the largest signals. The annual cycle of cloudiness transforms the semi-annual solar cycle at the top of the atmosphere into a largely one cycle per year variation of insolation at the sea surface. However, the annual cycle of cloudiness appears closely tied to SST in coupled feedbacks (positive for low stratus decks and negative for deep cumulus convection), so the annual cycle of SST cannot be satisfactorily diagnosed in an ocean-only modeling context as in the present study. Meridional advection driven by cross- equatorial winds has been conjectured as a key factor leading to the onset of the cold tongue. Our results suggest that the SST changes due to this process are modest, and if meridional advection is in fact a major factor then it must be through feedback with the stratus decks. At present, it is not possible to evaluate such a feedback quantitatively.

6.5 Variability of Surface Equatorial Currents in the Warm Pool Region: A Quasi-2-Day Oscillation (K. Kutsuwada and I. Ueki, Tokai University; Y. Kuroda, JAMSTEC)

Current measurements in the warm pool region of the western equatorial Pacific were made by upward-looking moored Acoustic Doppler Current Profiler (ADCP) at two sites (0", 142°E and 0°, 147°E). Time series of daily and hourly current data between the near-surface layer (30-40 m) and the lower part of the Equatorial Undercurrent (EUC) (200-240 m) were constructed for two periods from April to December in 1994 and from January 1995 to February 1996 to examine variability in surface equatorial currents.

Events in which strong eastward current exceeding 0.5 m s^{-1} covers a surface layer above about 100 m were observed at the eastern station (147°E) in May, September, and December 1994. Timings of similar events at the western station (142°E) are different among the events.

The event in May occurred at the western station prior to that at the eastern one suggesting eastward propagation of a disturbance, while for the event in December the western station lagged the eastern one. In September, no event was observed at the western station. Surface wind data based on the ECMWF Basic level III were used to examine a forcing mechanism of the events. Enhancements (bursts) of the westerly winds in the western Pacific on the equator occurred all in these events. Areas where the westerly wind burst (WWB) are dominant are found at different longitudes among the events. Thus, it seems that the timing for the occurrence of the surface eastward jet at the equatorial stations is related to the dominant areas of the WWB.

A signal with the period of about two days was often observed in the hourly time series of the zonal and meridional currents at both stations. In the time series of surface wind obtained from the ATLAS buoy at 0°, 147°E, no similar signals are detected, which gives no evidence of surface forcing for the oceanic signal. The quasi-two-day signal has a tendency of being active at the surface layer above about 150 m, and little phase difference in the vertical direction. In some periods, the signal is confined at the subsurface layer between 50 and 150 m, and its large vertical phase shift was found at a layer in which time-averaged zonal current has a large vertical shear. It is suggested that the occurrence of the signal may be caused by shear instability of the mean currents.

6.6 Observational Study on the New Guinea Coastal Current and Its Undercurrent (Y. Kuroda, JAMSTEC)

One-year time series current data from subsurface ADCP moorings were examined to detect the variability of the New Guinea Coastal Current (NGCC) and New Guinea Coastal Undercurrent (NGCUC). These moorings were deployed at 2°S,142°E and 2.5°S,142°E in the core region of these currents from July 1995 to July 1996. Knowing the characteristics of the NGCC and NGCUC are important for understanding mechanisms that maintain the warm pool in the western tropical Pacific because they are major inflows, particularly NGCUC carrying high salinity water from southern hemisphere to northern hemisphere. Seasonal reversal of the NGCC was clearly observed. Flow in the surface layer was dominant to the northwest along the direction of the New Guinea coast at maximum speeds of 80-100 cm s^{-1} down to 100 m depth in the boreal winter; conversely in summer, it flowed southeastward at maximum speeds of 50-60 cm s^{-1}. The time change of zonal volume transport in the upper 50 m layer between 2.5°S and 2°S at 142°E in the NGCC was coincided with the time change of local zonal wind speeds. The NGCUC below the surface layer flowed northwestward all'the year. From the annual mean profile at 2.5 °S, 142 ° E , the core speed of NGCUC was 50 cm s^{-1} at 230 m depth with standard deviation of 15 cm s^{-1}. In the NGCUC core layer of 150-250 m depth, 20-30 day perturbations were evident all year. The westward volume transport across the 142°E line between 2.5°S and 2°S in the O-200 m layer increased up to 6.5 Sv in boreal summer and decreased to zero in boreal winter.

6.7 Large Scale Sea Surface Height Variations of the India Ocean from TOPEX/Poseidon Altimeter (P. Kumar, NIO)

TOPEX/Poseidon altimeter data, during November 1992 to August 1995, pertaining to the Indian Ocean region bounded by longitudes 40°E to 100°E and latitudes 10°S to 30°N were extracted from merged geophysical data records (MGDR) available on AVIS0 CD-ROM. Apart from applying standard corrections, a gradient reduction correction was also applied to minimize the errors in the sea surface height (SSH) estimation due to cross track variations in sampling positions. This was found to be most effective in the region where the Ninety East Ridge is located and the topography presents large variability. Finally, the ten-day snap shot of SSH anomaly was obtained from the gradient reduced collocated data by subtracting the mean.

The time-longitude plots of SSH reveal the signatures of Kelvin wave propagation along the equator: one during mid-February and the other during mid-August, both associated with the collapse of the monsoonal winds. The computed speed is about 1.25 m s^{-1}. This Kelvin wave hits the eastern boundary in November, as evident by the high SSH in the ten-day snapshots. On hitting the eastern boundary, the high sea level propagates northwards along the eastern boundary and southward along the east coast of India (coastally trapped Kelvin wave). The northward coastal current along the west coast of India is seen developing during November and becomes fully developed by January. The offshore movement of high sea level seen in mid-January, off the southern tip of India is the westward propagation of the downwelling Rossby wave radiated by the coastally trapped Kelvin wave. During this period the circulation in the interior Arabian Sea is zonal and westward and in the Bay of Bengal it is cyclonic. By July, the Somali current is fully developed and the formation of Great Whirl is seen in all the three years. Signatures of upwelling is inferred along the coast of Somalia, Arabia, and the south west coast of India. The upwelling front along the west coast of India, where the SSH shallows markedly, appears to propagate westward.

Along 5°N, 10°N, and 15°N the time-longitude plots show dominant westward propagating Rossby waves, the speed of which decreases from 2 1.98 cm s^{-1} at 5 °N to about 7.5 cm s^{-1} at 15°N. The westward propagation at 10°N in the Bay of Bengal starts during January, while in the Arabian Sea it starts from the eastern boundary (west coast of India) during mid-May. The two-dimensional fast Fourier transform along 15°N shows a dominant westward propagation in the Bay of Bengal, while in the Arabian Sea there are signatures of both westward as well as eastward propagation. The eastward propagation at the western boundary in the Arabian Sea is associated with the offshore advection of the Somali current and upwelling.

6.8 Dynamics of the Lakshadweep High and Low (S. Shetye, NIO)

A "high" in sea surface topography forms off southwest India, in the vicinity of the Lakshadweep Islands, during the northeast monsoon, and a "low" forms during the southwest monsoon. The high and the low propagate westward, extending across the southern Arabian Sea a few months after formation. Our studies on the dynamics of the high and the low suggest that, unlike eddies often observed in the world oceans, the high and the low do not owe their existence to nonlinearity. They are a consequence of westward propagating Rossby waves radiated by Kelvin waves propagating poleward along the western margin of the Indian subcontinent. The formation of the high/low provides a mechanism for the early onset of upwelling off southwest India, and hence for formation of SST gradient before onset of the southwest monsoon.

6.9 Upper-Ocean Circulation in the Indian Ocean, and Possible Feedbacks to the Atmosphere (J. McCreary, NOVA University)

What mechanisms of ocean-atmosphere interaction might cause climate variations in the Indian Ocean and elsewhere? More specifically, what processes might cause interannual variability of sea-surface temperature (SST) and surface heat flux (Q)? Three categories of possible mechanisms are: ocean dynamics, mixed-layer thickness, and variability in the Indonesian Throughflow.

Ocean dynamics affect SST and Q most strongly by their influence on upwelling. In contrast to the Pacific, the primary upwelling regions in the Indian Ocean are located in the northern basin; moreover, the meridional circulation cells that carry cool water to the upwelling regions are estimated by models to be 4-5 times weaker than they are in the Pacific (5 Sv as compared to 22 Sv). Thus, mechanisms of ocean-atmosphere interaction thought to be important in ENS0 are not likely to be active in the Indian Ocean. On the other hand, due to Ekman suction the thermocline is shallow in a band that extends across the eastern and central Indian Ocean from about 5 °S to 15°S. In several Indian Ocean models, the thermocline surfaces in this band thereby cooling SST, but there is little indication in climatological SST data that this surfacing actually occurs. Nevertheless, interannual variability in the strength of Ekman suction, could allow the thermocline to surface there, and so provide a dynamical mechanism for altering SST and Q significantly.

Mixed-layer thickness affects SST and Q through its influence on the ocean's ability to absorb heat. In the southern Indian Ocean, the annual cycle of mixed-layer thickness is large in locations where the Southwest Monsoon gains moisture; hence, interannual variability that affects this cycle may impact monsoon rainfall. In the eastern equatorial Indian Ocean and Bay of Bengal, the mixed-layer thickness is strongly influenced by fresh-water flux, and during the winter, barrier layers with temperature inversions are prominent, just as they are in the western Pacific warm pool. It may be that mixed-layer processes in these regions are involved in the generation of the both ENS0 and the biennial oscillation.

The Indonesian Throughflow carries warm, fresh water into the Indian Ocean. Its interannual variability is dominated by the ENS0 signal. It is likely that this variability is simply a reaction to ENSO, but one model suggests that Throughflow variability may feedback to affect SST and Q in the eastern Pacific.

6.10 Seasonal-to-Interannual Variability in the Indian Ocean (R. Murtugudde, University of Maryland)

A reduced gravity, primitive equation, sigma-coordinate ocean GCM was used to study the Indo-Pacific domain. The GCM is coupled to an advective atmospheric mixed layer model which allows the computation of accurate SST without resorting to feedbacks to observed SST. The model SST errors are typically of the order 0.5°C. Seasonal variability of the Indian Ocean is dominated by the reversal of the Somali Current driven by the monsoon winds. Annual cycle in the wind-stress curl drives a pair of upwelling and a pair of downwelling Rossby waves which are ubiquitous in the southern tropical Indian Ocean (STIO). The thermocline between 8°S and 10°S has a significant east-west slope similar to the equatorial Pacific albeit in the opposite direction (shallow in the west and deep in the east).

The interannual variability is reproduced well by the model as seen by comparisons to data such as NMC Reanalysis and TOPEX/Poseidon. The SST anomalies in the Arabian Sea and the Bay of Bengal are less than a degree C and are mainly determined by radiation anomalies associated with the cloudiness and convection anomalies. The thermocline close to the surface in the western part of STIO mentioned above results in the largest interannual anomalies in SST (~ 1 "C) and sea-level (~ 10 cm). The thermocline in the eastern Indian Ocean at the same latitudes is deep and typically has anomalies of opposite sign in both SST and sea-level. A perturbation to the pressure center in the Indonesian region on a quasi-biennial time-scale (associated with the SO) leads to basin scale wind anomalies between 5°S and 15°S which appear to be modulations of the annual cycle. These wind-anomalies produce anomalies of opposite sign in SST and sea-level in the western and eastern STIO in this latitude-band due to the sloping thermocline. Analysis of heat budgets shows that upwelling anomalies in the west (where the thermocline is close to the surface) and advection anomalies in the east determine the SST anomalies. Thus a quasi-biennial oscillation involving the thermocline tilt exists in the STIO. This oscillation may play an important role in the Indian monsoon and also the heat balance of the Indo-Pacific warm pool and is being investigated further.

6.11 Uncertainties of ERS-1 Surface Winds Over the Arabian Sea (D. Halpern, JPL)

Spatial variations of the east-west and north-south components of surface wind stress are critical in studies of ocean circulation and biological-physical interactions because surface wind stress curl produces a vertical velocity (W,) in the upper ocean at the bottom of the Ekman layer. The wind forced W_e acts as a "pump," causing water to upwell and sink. The ERS-1 scatterometer provides reasonable coverage and unique direct measurements of vector of winds. However, empirical schemes must be used to generate wind velocity from ERS-1 radar measurements. Three schemes (ESA, IFREMER, and JPL) are evaluated relative to high-quality moored-buoy wind observations recorded in the central Arabian Sea, where high surface waves and high atmospheric water content during the southeast monsoon adversely affect the estimation of satellite-derived winds. The sensitivities of W_e and other wind-driven characteristics of ocean circulation (such as Ekman transport and Sverdrup transport) to different ERS-1 surface wind velocity data products are discussed.

6.12 *Atmospheric Forcing and Upper Ocean Response to Monsoonal Forcing in the Arabian Sea (R. Weller, WHOI)*[3]

The atmospheric forcing and variability of the upper ocean observed for one year at a site in the Arabian Sea are described. Meteorological observations and the air-sea fluxes of momentum, heat, and freshwater computed from them are compared to climatologies and to the output of numerical weather prediction models. Temperature, salinity, and velocity variability in the upper 300 m of the ocean are described, and the ability of a one-dimensional ocean model forced with the observed fluxes to predict the observed variability is investigated.

From October 1994 to October 1995, a surface mooring was maintained at 15 °N, 61 °E, some 500 km off the coast of Oman. The mooring line carried oceanographic instruments from Lamont-Doherty Earth Observatory (Dr. John Marra) and the University of California, Santa Barbara (Dr. Tom Dickey) as well as those deployed by the Woods Hole Oceanographic Institution. The mooring was recovered and redeployed with fresh instrumentation in April 1995.

The winds of the northeast monsoon were moderate, typically 6 m s^{-1}, dropped to 3 to 4 m s^{-1} in the intermonsoon, and then increased to monthly averages of between 9 and 13 m s^{-1} in the southwest monsoon, when they were particularly steady in direction and peaked in July when the highest daily average reached 15.7 m s^{-1} . The air during the southwest monsoon was more humid than during the winter, and in July and August sea surface temperatures were cooler than air temperatures. As a result, during the southwest monsoon sensible heat flux was positive (ocean heat gain) and latent heat loss reduced, so that in contrast with the northeast monsoon (when monthly net heat fluxes were for two months an average of -45 W m^{-2}), the ocean typically gained heat (50 to 100 W m^{-2} monthly averages). The observed summer heat gain contrasts with the Hastenrath climatology (Hastenrath and Lamb, 1979 a,b) that suggests significant heat loss to the atmosphere during both the northeast and southwest monsoons but is close to the present COADS climatology (da Silva et al., 1994) that also shows heat gain by the ocean through the southwest monsoon. Observed meteorological variability and air-sea fluxes were also compared with those fields from numerical weather prediction models. Net heat fluxes from NCEP were typically 100 W m^{-2} less (and thus negative during the southwest monsoon) than observed, due largely to greater latent heat loss and less net shortwave radiation than observed. ECMWF net heat fluxes were also lower than observed (though not negative during the southwest monsoon) but the source of the difference varied. In the northeast monsoon, ECMWF had less than observed shortwave radiation and larger negative sensible heat loss; in the southwest monsoon, ECMWF, the net shortwave was in good agreement, and the difference came from the model's more negative latent heat flux.

The mixed layer depth (defined as the depth that was 0.1 °C cooler than the surface temperature) was shallow initially, in October 1994, with a depth of 10 to 20 m. It deepened to over 100 m in early January 1995 and cooled 1 °C during the northeast monsoon. From early January it shoaled steadily and warmed until late March 1995. Then it continued to warm and remained shallow through early June, when sea surface temperature was in excess of 30°C. With the onset of the southwest monsoon, the mixed layer cooled and deepened to

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'Abstract was submitted prior to the meeting but the author was unable to attend.

reach 80 m by early July 1995, warmed and shoaled to 30 to 40 m through early August, and continued to warm and shoaled to 20 m through the end of the deployment in October 1995. Some of this variability can be replicated by a one-dimensional mixed layer model (Price et al., 1986) forced with the observed fluxes and initialized with a CTD profile taken in October 1994. The predicted mixed layer deepens and cools with both the northeast and southwest monsoons. However, the predicted mixed layer depths are too shallow during both monsoons; and the model mixed layer's temperature and salinity increase beyond those observed during the southwest monsoon.

Other processes that contribute to the local heat and salt budgets are being investigated. Estimates of the magnitude of Ekman pumping based on the ECMWF winds suggest that local pumping does not play a major role in balancing surface heating and evaporation. Two effects of horizontal advection, change in the vertical structure of the temperature and salinity fields and heat and salt transport within the mixed layer appear to be more important. Large velocities, in excess of 70 cm s^{-1} in the mixed layer, were observed that were related to mesoscale variability in the ocean, particularly in October through December, 1994. Associated with these events is a change in water properties, with cooler temperature found below the mixed layer and intensification of the pycnocline. Experiments in which the one-dimensional model is re-initialized often throughout the year suggest that the temporal change in upper ocean stability associated with the mesoscale flows modulates the mixed layer response to local forcing. In addition, and particularly during the latter half of the southwest monsoon, the eastward flow in the upper advects in cooler water upwelled along the coast of Arabia.

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6.13 Ocean-Atmosphere Interaction During the First Transition of Asian Summer Monsoon (H. -H. Hsu/C.-T. Chen, National Taiwan University)

Climatologically, the Asian summer monsoon goes through two major transitions. The first one occurs in mid-May and marks the onset of East Asian summer monsoon, and the second one occurs in early June marking the onset of Indian summer monsoon. The characteristics of large-scale circulation during the first transition were investigated by a cornpositing technique. The major changes are the sudden development of the low-level cyclonic circulation in South Asia and the convection in the Bay of Bengal, the Indochina peninsula and the South China Sea.

The sea surface temperature in the Bay of Bengal continues to rise before the occurrence of the first transition and drops quickly after. Before the transition, the atmospheric conditions in the Bay of Bengal are characterized by low surface winds, low cloud cover, and small optical thickness. Such condition favors the rising of the sea surface temperature through increasing shortwave radiation and low latent heat flux. During and after the transition, strong low-level winds and convection result in the drop of sea surface temperature by decreasing shortwave radiation and increasing latent heat flux. The ocean seems to contribute to the abrupt change of the atmospheric circulation during the transition. Before the transition, the warm sea surface in the Bay of Bengal, that is located to the north of the convective region, helps to destabilize the lower troposphere and leads to the northward shift of the convection. The large latent heat fluxes that the ocean supplies to the atmosphere during and after the transition help to sustain the convection and the large-scale circulation.

It is proposed that the interaction between large-scale atmospheric circulation, convection, and lower-boundary forcing leads to the abrupt change of the atmospheric circulation during the first transition. The ocean-atmosphere interaction occurring in the Bay of Bengal, that contributes to the lower-boundary forcing, could be one of the important factor.

7. DISCUSSION AND RECOMMENDATIONS

7.1 JMA Involvement in TAO

The TAO Panel was briefed on JMA's observational, analysis, and prediction activities at TIP-5. JMA is a user of TAO data, both from the GTS and directly from NOAA/PMEL via Internet anonymous ftp data transfers. JMA also runs quarterly cruises along 137°E and yearly cruises along 165°E, meridians presently instrumented with TAO moorings. The 165°E line is particularly difficult to service regularly with dedicated mooring cruises, so that damaged or otherwise inoperable buoys may go unattended for unnecessarily long periods of time. The JMA ship *Ryofu Maru #3* could assist in the repair of buoys along 165°E and 137°E, thereby improving the quantity and quality of data available for operational weather and climate analysis and prediction products. It is therefore recommended that JMA consider an active participation in moored buoy maintenance along 137°E and 165 °E in cooperation with the TAO Implementation Panel.

7.2 Fishing Vandalism

Damage and loss of mooring equipment associated with fishing activity continues to be a problem affecting performance of the array. At three especially hard hit sites in the western Pacific (0°,147°E; 2°N,147°E; 5°N,137°E), data return has been limited in 1993-1995 to 35-50%, and 9 out of 16 most recently deployed moorings have been lost. It is not clear why these three sites in particular should be so severely affected. However, given the present level of resources available to maintain the array, the panel recognizes that a moratorium on measurements at one or more of these sites may be necessary until progress can be made on reducing fishing related losses of data and equipment. Progress will be measured by tracking data and equipment return of neighboring western Pacific sites where losses, though not as severe, are still evident. Data return approaching that of the central Pacific (75-90%), and a downward trend in mooring losses, will be criteria used to evaluate progress.

The panel also established a team of two individuals, one from PMEL (T. Wright) and one from JAMSTEC (Y. Kuroda) to formulate and implement a coordinated strategy to mitigate against the adverse impacts of fishing related mooring damage and losses. The team will report yearly to the TAO Panel on its efforts.

7.3 TAO Terms of Reference

The question was raised about whether the Panel might need to modify its terms of reference in view of new mooring programs being planned in all three tropical oceans and in the extratropical North Pacific, such as PIRATA, TRITON, and work in the South China Sea (SCSMEX). The Panel agreed that there was merit to considering this issue further, since these new programs address the objectives of TIP sponsors (CLIVAR, GCOS, and GOOS). However, the Panel recommended that discussion of this topic be deferred until such time as some or all of these programs have progressed further in their implementation.

7.4 Indian Ocean Pilot Studies

The TAO Panel, in joint sessions with the CLIVAR Monsoon Panel, reviewed scientific issues regarding ocean-atmosphere-land interactions of relevance to variability and predictability of the Austral-Asian monsoon. Presentations and discussions lead to indentification of the following set of priority goals:

- To determine the limits of predictability of the monsoon climate system.
- To assess the relative contributions of the slowly varying boundary conditions and the internal dynamics to the predictability of the monsoon.
- To evaluate the impact of the monsoon on the predictability of the global climate system.

To achieve these goals, it will be necessary to address a set of specific questions, namely:

- What is the spatial and temporal variability of the monsoon system for intraseasonal, interannual and decadal time scales?
- What are the specific mechanisms of the annual cycle in the coupled ocean-atmosphere-land system in the monsoon regions?
- What are the mechanisms of the intraseasonal oscillations affecting the monsoon regions?
- What are the fundamental roles and mechanisms in ENSO-monsoon coupling, including the tropical biennial oscillation and interdecadal modulations?
- What are the relative roles of ocean processes in different oceans, and land surface processes in determining monsoon variability?
- What are the relative contributions of “chaotic” (local, internal atmosphere) versus deterministic (lower boundary conditions) processes in monsoon predictability?

- How do tropical - extratropical, tropospheric - stratospheric interactions influence monsoon variations?

Given the enormous societal impacts of monsoon rainfall variability in the Indo-Pacific region, there are compelling reasons to develop coordinated field modeling and analysis programs to address these questions. The Panel recognized however that present in *situ* data bases are inadequate to address many of the outstanding issues related to monsoons. Hence, it recommended that consideration be given to pilot studies designed to enhance the climate data base in the tropical Indian Ocean. It furthermore noted that a pilot scale moored measurement program, appropriately designed, could provide high accuracy time series data capable of addressing some of the unanswered questions about ocean-atmosphere interactions in this part of the world oceans. Regions identified as urgently in need of study from an ocean-atmosphere interaction perspective included the Bay of Bengal and the eastern equatorial/south tropical Indian Ocean. The TAO Panel will coordinate with the CLIVAR Monsoon Panel and the CLIVAR Upper Ocean Panel in developing implementation strategies for monsoon related research.

8. ACKNOWLEDGMENTS

The TAO Panel would like to thank Dr. E. Desa, Director of the National Institute of Oceanography, for the opportunity to hold TIP-5 in Goa. We are especially grateful to Dr. M. R. Nayak, head of the local organizing committee for the time and effort he put into the making the meeting a success. The Panel also acknowledges the financial support of the Joint Planning Office of the Global Climate Observing System directed by Dr. Thomas Spence, the International CLIVAR Office directed by Dr. Michael Coughlan, and the Intergovernmental Oceanographic Commission Global Ocean Observing System Office directed by Jean-Paul Rebert. These proceedings were prepared with the assistance of Ms. Vallapha Cass of NOAA/PMEL.

Appendix 1.
Meeting Agenda

FIFTH SESSION OF THE TAO IMPLEMENTATION PANEL
National Institute of Oceanography
Goa, India

18-21 November 1996

NOVEMBER 18 - Monday — Lunch: 12:30-1:30 p.m.

9:00 a.m.	OPENING CEREMONY (Session Chair: Dr. E. Desa, Director, NIO)
9:30 a.m.	STATUS OF THE ARRAY (M. J. McPhaden, NOAA/PMEL)
10: 15 a.m.	NATIONAL REPORTS (Session Chair: M.R. Nayak, NIO) United States: L. Mangum/T. Wright (NOAA/PMEL) Japan: A. Sumi (U. Tokyo)/Y. Kuroda (JAMSTEC) M. Hishida (JAMSTEC)
1:30 p.m.	NATIONAL REPORTS (Session Chair: K. Takeuchi, Hokkaido U.) Korea: I.-S. Kang (Seoul National University) Taiwan: D. Tang (National Taiwan University) France: J. Picaut (ORSTOM/Noumea) India: L.V.G. Rao (NIO) Indonesia: T. Sribimawati (BPPT) PROGRAM STATUS REPORTS (Session Chair: J. Picaut, ORSTOM/Noumea) Pilot Research Moored Array in the Tropical Atlantic (PIRATA) J. Servain (ORSTOM/Brest) JMA Climate Observations, Analyses and Forecasts T. Manabe (JMA) The U.S. GOALS/PACS Program S. Piotrowicz (NOAA/OAR)
5:30 p.m.	ADJOURN

NOVEMBER 19 - Tuesday Lunch: 12:30-1:30 p.m.

9:30 a.m. JOINT WITH CLIVAR

SCIENCE REPORTS (Session Chair: D. Tang, NTU;
Rapporteur: S. Godfrey, CSIRO/Australia

Surface and subsurface low-frequency variability in the tropical Atlantic: One necessity for implementing the PIRATA array
J. Servain (ORSTOM/Brest)

An optimized design for a moored instrument array in the tropical Atlantic Ocean
T. Busalacchi (NASA/GSCF)

On the physics of ENS0 displacement of the Pacific warm pool
J. Picaut (ORSTOM/Noumea)

The mean seasonal cycle in the eastern equatorial Pacific Ocean
W. Kessler (NOAA/PMEL)

Variability of surface equatorial currents in the warm pool region: a quasi-2-day oscillation
K. Kutsuwada (Tokai U.)

Observational Study on the New Guinea Coastal Current and its Undercurrent
Y. Kuroda (JAMSTEC)

SCIENCE REPORTS (Session Chair: A. Sumi, U. Tokyo;
Rapporteur: W. Kessler, NOAA/PMEL)

Large scale sea surface height variations of the Indian Ocean from TOPEX/Poseidon altimeter
P. Kumar (NIO)

Dynamics of the Lakshdweep High and Low
S. Shetye (NIO)

Upper-ocean circulation in the Indian Ocean, and possible feedbacks to the atmosphere
J. McCreary (Nova University)

Seasonal-to-Interannual Variability in the Indian Ocean
R. Murtugudde (U. Maryland)

Uncertainties of ERS-1 Surface Winds Over the Arabian Sea
D. Halpern (JPL)

Ocean-atmosphere interaction during the first transition of Asian summer monsoon
H.-H. Hsu (National Taiwan University)

5:30 p.m. ADJOURN

7:30 p.m. DINNER

NOVEMBER 20 - Wednesday Lunch: 12:30-1:30 p.m.

8:30 a.m. JOINT WITH CLIVAR

Session Chair: W. Lau, NASA/GSFC
Rapporteur: McBride

Review talks on empirical studies, monsoon processes and hypotheses (20 minutes talk, 10 minutes discussion)
W. Lau (NASA/GSFC)
Thiele/Kakar (NASA/GSFC)

Short topical presentations on empirical and process studies (strictly limited to 10 minutes each)
Summary Discussions

1:30 p.m. Session Chair: S. Godfrey, CSIRO/Australia
Rapporteur: Goswami

Review talks on monsoon related modeling and predictions (20 minutes talk, 10 minutes discussion)
Goswami (IIS Bangalore)
J. Shukla (COLA)
Sumi (CCSR/Japan)

Short topical presentations on monsoon modeling and predictions (strictly limited to 10 minutes each)
Summary Discussions

NOVEMBER 21 - Thursday Lunch: 12:30-1:30 p.m.

8:30 a.m. JOINT WITH CLIVAR

CLIVAR Upper-Ocean Panel Update
W. Kessler, NOAA/PMEL

CLIVAR NEG-1 Panel Update
J. Shukla, COLA

Monsoon Field Campaigns and Related Programs
GAME (T. Yasunari, University of Tsukuba)
SCSMEX (W. Lau, NASA/GSFC)
Others
TIP-5 Recommendations
Adjourn

1:30 p.m. Tour of NIO

Appendix 2
List of Participants

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Appendix 3
List of Acronyms

ADCP:	Acoustic Doppler Current Profiler
ADEOS:	Advanced Earth Observing Satellite
AGCM:	Atmospheric general circulation mode1
AOML:	Atlantic Oceanographic and Meteorological Laboratory (NOAA/USA)
ARLINDO:	Arus Lintas Indonesia (Indonesia)
ARM:	Atmospheric Radiation Measurement
ARPEGE:	Action de Recherche Petite Echelle Grande Echelle
ATLAS:	Autonomous Temperature Line Acquisition System
AVISO:	Analysis and Validation of Satellite Oceanographic Data
BMG:	Meteorology and Geophysics Agency (Indonesia)
BMRC:	Bureau of Meteorology Research Centre (Australia)
BPPT:	Agency for the Assessment and Application of Technology (Indonesia)
CCCO:	Committe on Climatic Changes and the OCean (SCOR-IOC)
CCSR:	Center for Climate System Research
CFC:	Cloroflurocarbon
CLIVAR:	Climate variability and Predictability (WCRP)
COAD:	Comprehensive Ocean-Atmosphere Data Set
COARE:	Coupled Ocean-Atmosphere Response Experiment (TOGA)
COLAS:	Center for Ocean-Land-Atmosphere Studies
CSIRO:	Commonwealth Scientific and Industrial Research Organization
CTD:	Conductivity-Temperature-Depth profiler
czcs:	Coastal Zone Color Scanner
DBCP:	Data Buoy Co-operation Panel
DOD:	Department of Ocean Development (India)
DST:	Department of Science and Technology (India)
EBENE:	Etude du broutage en zone equatoriale (France)
ECLAT:	Etudes Climatiques dans l'Atlantique Tropical (France)
ECMWF:	European Center for Medium Range Weather Forecasting
ECOP:	Etudes Climatiques de l'Ocean Pacifique (France)
ENSO:	El Niño-Southern Oscillation
ERS:	Earth Remote Sensing Satellite
ESA:	European Space Agency
EUC:	Equatorial Undercurrent
FFT:	Fast Fourier transform
FLUPAC:	Flux de carbone dans le Pacifique (JGOFS/France)
FNOC:	Fleet Numerical Center (Navy/USA)
FOCAL:	Français Ocean Climat Atlantique Tropical
FSU:	Florida State University (USA)
FY:	Fiscal Year
GAME-T:	GEWEX Asian Monsoon Experiment - Tropics

GAME:	GEWEX Asian Monsoon Experiment
GCM:	Global Circulation Models
GCOS:	Global Climate Observing System
GDC:	Global Drifter Center (NOAA/USA)
GEOSAT:	Geodetic Satellite Mission
GEWEX:	Global Energy and Water Cycle Experiment (WCRP)
GFDL:	Geophysical Fluid Dynamics Laboratory (NOAA/USA)
GLOSS:	Global Sea-level Observing System (IOC)
GOALS:	Global Ocean-Atmosphere-Land System
GOOS:	Global Ocean Observing System
GSFC:	Goddard Space Flight Center (NASA/USA)
GTS:	Global Telecommunication System
ICPO:	International CLIVAR Project Office
IFREMER:	Institut Francais de Recherche pour l'Exploitation de la Mer (France)
IMET:	Improved Meteorological Package (WHOI/USA)
IMG:	Interterometric Monitor for Greenhouse Gases
IOUSP:	Instituto Oceanografico da Universidade de Sao Paulo (Brazil)
ITCZ:	Intertropical Convergence Zone
JADE:	Java-Australia Dynamics Experiment
JAMSTEC:	Japan Marine Science and Technology Center (Japan)
JGOFS:	Joint Global Ocean Flux Study
JGR:	Journal of Geophysical Research
JMA:	Japan Meteorological Agency (Japan)
JPL:	Jet Propulsion Laboratory (USA)
KORDI:	Korean Ocean Research and Development Institute (Korea)
LAPAN:	NationalInstitute of Aeronautics and Space (Indonesia)
LIPI:	Indonesia Institute of Sciences (Indonesia)
LODYC:	Laboratoire D'Oceanographie Dynamique et de Climatologie (France)
MARSIS:	Marine Satellite Information Service (India)
MBARI:	Monterey Bay Aquarium Research Institute (USA)
MEDS:	Marine Environmental Data Service (Canada)
MGDR:	Merged geophysical data records
NASA:	National Aeronautics and Space Administration (USA)
NASDA:	National Space Development Agency of Japan (Japan)
NCEP:	National Center for Environmental Prediction (NOAA/USA)
NGCC:	New Guinea Coastal Current
NGCUC:	New Guinea Coastal Undercurrent
NIO:	National Institute of Oceanography (India)
NOAA:	National Oceanic and Atmospheric Administration (USA)
NSCAT:	NASA Advanced Scatterometer (USA)
NTU:	National Taiwan University (Taiwan)
OACES:	Ocean-Atmosphere Carbon Exchange Studies (USA)
OAR:	Oceanic and Atmospheric Research Agency (NOAA/USA)
OCTS:	Ocean Color and Temperature Scanner
ODAS:	Ocean Data Assimilation System

OGCM:	Oceanic General Circulation Model
OPA:	LODYC's OGCM
ORG:	Optical Rain Gauge
ORSTOM:	Office de la Recherche Scientifique et Technique Outre-Mer (France)
OSSE:	Observation System Simulation Experiment
PACS:	Pan American Climate Studies
PAR:	Photosynthetic active radiation
PIRATA:	Pilot Moored Array in the Tropical Atlantic
PMEL:	Pacific Marine Environmental Laboratory (NOAA/USA)
PNEDC:	Programme National d'Etude de la Dynamique du Climat (France)
PROTEUS:	Profile Telemetry of Upper Ocean Currents
PSP:	Eppley Precision Pyranometer
RUSNAS:	National Stretegic Excellence Research Program (Indonesia)
RUT:	Ingerated Excellence Research Program (Indonesia)
RUTI:	International Integrated Excellence Research Program (Indonesia)
SCAR:	Scientific Community of Atmospheric Dynamics (Indonesia)
SCSMEX:	South China Sea Monsoon Experiment
SEACAT:	SeaBird Conductivity and Temperature Recorder
SEQUAL:	Seasonal Equatorial Atlantic Experiment (USA)
SELMAM:	Sea Level Monitoring and Modelling (India)
SSG:	Scientific Steering Group
SSH:	Sea surface height
SST:	Sea surface temperature
STA:	Science and Technology Agency (Japan)
STIO:	Southern tropical Indian Ocean
SURTROPAC:	Survey of the Tropical Pacific (SURveillance Trans-Oceanique du PACifique) ORSTOM/France
TAO:	Tropical Atmosphere-Ocean Array
TIP:	TAO Implementation Panel
TOCS:	Tropical Ocean Climate Study (Japan)
TOGA:	Tropical Ocean-Global Atmosphere
TOPEX/Poseidon:	Ocean Topography Experiment
TRANSPAC:	North Pacific Ocean Monitoring (XBT) for Climate Research (Japan-USA)
TRITON:	Triangle Trans-Ocean Buoy Network (Japan)
TRMM:	Tropical Rainfall Measuring Mission (NASA/USA)
UOP:	Upper Ocean Panel (CLIVAR)
WHOI:	Woods Hole Oceanographic Institution (USA)
WHP:	Woce Hydrographic Program
WCRP:	World Climate Research Programme
WOCE:	World Ocean Circulation Experiment
WWB:	Westerly wind burst
XBT:	Expendable Bathythermography
XCTD:	Expendable Conductivity, Temperature and Depth

Appendix 4

TERMS OF REFERENCE

The following terms of reference apply to the TAO Implementation Panel:

* To prepare an annual operating plan and budget for the TAO array.
* To coordinate the technical and logistic support of institutions participating in the maintenance of the array.
* To ensure the rapid dissemination of TAO data (in real-time where possible) to serve both research and operational applications.
* To promote the utilization of TAO data in national and international climate research and prediction programs.
* To cooperate with organizations such as the WOCE/CLIVAR XBT/XCTD Programme Planning Committee and the WOCE/CLIVAR Surface Velocity Programme Planning Committee to ensure an integrated approach to observing the climate system in the tropics.
* To report regularly to the GCOS/GOOS Planning Offices and to the CLIVAR Scientific Steering Group on the status of the TAO array.

CATEGORIES OF PANEL MEMBERSHIP

Membership of the TAO Implementation Panel will be by invitation of the Global Climate Observing System Office, based on recommendations made by the Implementation Panel. Categories of membership are:

Executive Committee:

One representative from each nation actively supporting the TAO Array (as of 1995: the United States, France, Japan, Korea, and Taiwan). The TAO Panel chairman and vice-chairman will serve as national representatives on the executive committee. Responsibilities of the executive committee include: coordinating intercessional activities, recommending membership changes, organizing panel meetings, reporting to parent bodies, etc.

Institutional Representatives:

Individuals representing institutions (or agencies) that provide resources such as ships, mooring hardware and/or technician time to maintain the TAO array; or individuals representing institutions having special expertise in analysis and interpretation of TAO data.

Observers:

The sponsoring organizations may invite those associated with the maintenance of the TAO array, or with a potential to provide future support for the maintenance of the TAO array who do not fall into either of the above categories, to participate in meetings as observers.

Appendix 5

TAO PANEL MEMBERSHIP

Executive Committee:

M. McPhaden (NOAA/PMEL, chairman)
A. Sumi (University of Tokyo, vice-chairman)
J. Picaut (ORSTOM)
D. Tang (National Taiwan University).

Institutional Representatives:

Japanese Marine Science and Technology Center (M. Hishida)
Korean Ocean Research and Development Institute (M.-S. Suk)
National Ocean Service (W. Woodward)
Pacific Marine Environmental Laboratory (W. Kessler)
Tokai University (K. Kutsuwada)
University of Hawaii (R. Lukas)
National Aeronautics and Space Administration (A. Busalacchi)

Observers:

S. Godfrey (Commonwealth Scientific and Industrial Research Organization, Australia)
P. Kumar (National Institute of Oceanography, India)
0. Thiele (NASA/Goddard Space Flight Center, U.S.A.).

Appendix 6

Bibliography of Refereed TAO Publications

19951997

(As of March 27, 1997)

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