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1. EXECUTIVE SUMMARY

The seventh session of the Tropical Atmosphere-Ocean Array (TAO) Implementation Panel (TIP-7) was held at the Hotel Golf Intercontinental in Abidjan, Côte d'Ivoire, on 11-13 November 1998. The meeting was held in conjunction with the fifth session of the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) which took place at the same location on 9-10 November 1998. The meetings were hosted by "L'Institut Francais de Recherche pour le Developpement (IRD/ORSTOM)", and by the "Centre Ivorien de Recherche Océanographique (CRO)". The purposes of TIP-7 were to review the present status of the TAO array; to address technical and logistic issues related to its maintenance; to provide a forum for discussion of enhancements and expansions of the array to other tropical oceans; and to promote the use of the TAO data for research and operational activities. An additional purpose of TIP-7 was to examine the dual themes of the hydrologic cycle over the ocean, and the importance of salinity variability in the climate system. Over 40 participants from 14 nations attended TIP-7.

The meeting opened with a review of variations in the tropical Pacific since TIP-6 (held in November 1997). In the past year, the tropical Pacific has switched from extreme warm El Niño conditions to cold La Niña conditions. Data from the TAO array captured the dramatic termination of the 1997-98 El Niño in May-June 1998, when an unprecedented 8 °C drop occurred in 30 days in the equatorial cold tongue. ENSO Forecast models suggest cold La Niña conditions will persist through boreal spring 1999.

The panel discussed issues of instrumentation, array maintenance, ship-time requirements, vandalism and damage to the buoys, outreach efforts to fishing communities, ocean velocity and salinity measurements, TAO enhancements and expansions, and data dissemination *via* the World Wide Web and the Global Telecommunications System (GTS). Updates were presented on Japan's TRITON array of moored buoys, the first four of which were deployed in the western Pacific in March 1998; on the PIRATA array (supported by France, Brazil, and the U.S.) with 5 of 12 planned sites occupied in the tropical Atlantic during 1998; and on Taiwan's moored buoy programme as part of the South China Sea Monsoon Experiment (SCSMEX). The panel was also briefed on a multi-year mooring programme along the Pacific Coast of Chile, and on the status of Indian National Data Buoy Programme. In response to a recommendation from the sixth session of the TAO Implementation Panel (TIP-6), it was reported that surface meteorological data from Indian moored buoys in the Bay of Bengal and the Arabian Sea will be available on the GTS by the end of 1998.

Presentations on national and international climate programmes included CLIVAR, GOOS, and the Tropical Rainfall Measuring Mission (TRMM). Science presentations addressed variability associated with the 1997-98 ENSO cycle, ENSO forecasting, the Madden-Julian Oscillation, salinity variability in all three tropical oceans, satellite and *in situ* rainfall measurements in the tropical Pacific, model development and validation using TAO data, and large scale ocean current dynamics.

Two recommendations emerged from TIP-7 regarding salinity. One dealt with a pilot project for assembling all available ship-based thermosalinograph data in the tropical Pacific for 1991-98 at ORSTOM/Noumea. The other is for GOOS, GCOS, and CLIVAR to endorse proposed surface salinity satellite missions. These recommendations built on similar recommendations from TIP-6 calling for additional surface and subsurface salinity sensors be added to selected moorings as a contribution to emerging salinity monitoring effort which includes Volunteer Observing Ships (VOS), Salinity/Profiling Autonomous LAgrangion Circulation Explorer (S-PALACE), and other platforms. A third recommendation called for a UN resolution to help alleviate the serious loss of mooring data and equipment that is plaguing TAO, PIRATA and other climate-oriented mooring programmes.

2. SUMMARY OF CURRENT CONDITIONS

At the time of TIP-7, cold La Niña conditions characterized the tropical Pacific (Figure 1). Temperatures were as much as 2 °C below normal in areas of the central Pacific, and the trade winds were significantly stronger than normal in the western Pacific. Likewise, across nearly the entire range of longitudes shown in Figure 1, the thermoline (as measured by the 20 °C depth) was shallower than normal by as much as 40 m. The transition from warm El Niño to cold La Niña conditions occurred abruptly with an 8 °C drop in SST over a 30-day period in May-June 1998. Since then, the area of below normal SST's has continued to expand, although warm surface anomalies persist in the eastern and western Pacific, and to the north and south of the cold equatorial strip. Most ENSO forecast models suggest that cold equatorial SST's will persist through boreal spring, after which near normal conditions are expected to return.

3. NATIONAL REPORTS

3.1 UNITED STATES OF AMERICA (M. McPhaden, NOAA/PMEL)

3.1.1 TAO Array Configuration

The locations of present moorings in the TAO array are shown in Figure 2. In addition to the standard ATLAS moorings, nineteen sites are instrumented with next generation ATLAS moorings. At three of these sites, reverse catenary next generation moorings are deployed nearby traditional ATLAS moorings for intercomparison. Long-term current measurements are being made at five sites along the equator. Three sites at present are unoccupied in the western Pacific under a moratorium imposed in response to fishing vandalism.

3.1.2 TAO Array Annual Operation Plan

Ship-time support for the TAO array in calendar year 1998 is summarized in Figure 3 and the following table. During 1998, three ships were used to support the array: the NOAA ships *Ka'imimoana* and *Ron Brown,* and JAMSTEC's research vessel *Kaiyo*. NOAA provided 273 days of ship-time between 95 °W and 165 °E with JAMSTEC providing 57 days west of the date line. In 1998, 228 days on the *Ka'imimoana*, 39 days of on the *Ron Brown* are anticipated. Also, TAO buoy operations are scheduled in 1999 on both of JAMSTEC's *Kaiyo* and *Mirai* research vessels west of the date line.

Ship-time Summary

	1998	1999
Western Pacific (137 °E–165 °E)		
Japan (*Kaiyo*)	57	48
Japan (*Mirai*)	--	11
U.S. (*Ka'imimoana*)	15	15
Subtotal–West Pacific	72	74
East Pacific (95 °W–180 °W)		
U.S. (*Ka'imimoana*)	224	213
U.S. (*Ron Brown*)	34	39
Subtotal–East Pacific	258	252
TOTAL	330	326

3.1.3 Transition to TRITON

The TRITON buoy programme plans an accelerated schedule of deployments such that all sites along 156 °E, 147 °E and 137 °E will be occupied by TRITON buoys by the end of 1999. Initial comparisons of TAO and TRITON buoy data for TRITON deployments along 156 °E in March-June 1998 have been encouraging. Additional overlapping data for nearby TAO and TRITON moorings will be obtained in 1999. Assuming that TRITON implementation proceeds smoothly, TAO will recover all ATLAS moorings without redeployment between 156 °E and 137 °E by late 1999. Both TAO and TRITON are working to seamlessly integrate the two data streams so that the transition to a combined TAO/TRITON array will be transparent to users.

3.1.4 Fishing Vandalism and Data Return

Fishing vandalism continues to plague the TAO array with particularly low data (and equipment) return at the eastern and western margins of the array. A resolution has been drafted to the IOC (see Section 6) which addresses the need for help from UNESCO to mitigate against this vandalism.

Data return at some sites at the equator and 2°N in the eastern and central Pacific was also affected by moorings being pulled under due to extremely strong (in some cases >4 knot) zonal currents associated with the developing La Niña in 1998.

3.1.5 Velocity Measurements

The Pacific Marine Environmental Laboratory (PMEL) continued to maintain Acoustic Doppler Current Profiler (ADCP) moorings at three sites along the equator at 110°W, 140°W, and 170°W. JAMSTEC continued to maintain subsurface ADCP moorings 0°, 147°E and 0°, 165°E. Each subsurface ADCP mooring is deployed for one year.

PMEL also continued to maintain surface current meter moorings at 0°, 110°W; 0°, 140°W; and 0°, 165°E. These surface current meter moorings, beginning in late 1998, are being configured as a Next Generation ATLAS with SonTek Argonaut current meters attached to the line. The SonTek current meters at present only internally record data. We anticipate though that by the end of 1999 the three sites at 110°W, 140°W and 165°W will be telemetering SonTek data *via* Argos Service. These engineering developments will allow us to retire the aging and obsolete inventory of Vecta Averaging and Vector Measuring (VACM and VMCM) current meters.

3.1.6 ORSTOM /PMEL Salinity Measurements

During the past year, internally recording SEACATs were placed at the surface on 17 TAO moorings between 156°E and 180°W. Instrumentation was provided by ORSTOM and PMEL. Data return from the past year was 85% and no instruments were lost. These surface salinity measurements will be continued during the next year.

3.1.7 TAO/ARM Shortwave Radiation Measurements

The TAO/ARM array of shortwave radiation measurements presently consists of seven instrumented sites along 165°E. Measurements were begun in June 1997 at four sites, expanding to another three sites in January 1998. Each site is occupied by a Next Generation ATLAS mooring instrumented with an Eppley Precisior Spectral Pyranometer (PSP). Data are internally recorded at 2-minute intervals and transmitted to shore in real-time *via* Service Argos as daytime (06h00 to 18h00 local time) averages. Data return has been about 85% since the beginning of the project. The TAO project intends to continue these shortwave radiation measurements for the next year with support from the Department of Energy (DOE).

3.1.8 TAO/TRMM Rainrate Measurements

With support from the NASA/TRMM Project Office, 13 NextGeneration ATLAS moorings of the TAO Array are presently instrumented with RM Young siphon rain gauges to provide estimates of rainrate over the tropical Pacific Ocean. Rainfall accumulations are internally recorded at 1-minute intervals, and daily statistics (mean rainrate, rainrate standard deviation, and percent time raining) are transmitted to shore in real-time *via* Service Argos. Each TAO/TRMM site is also equipped with a surface temperature/conductivity sensor for determination of surface salinity. It is expected that this rainrate/surface salinity array will expand by about another six sites in 1999 with continued support from TRMM. The present status and plans for the TAO/TRMM rainrate array can be found on the World Wide Web at:
http://www.pmel.noaa.gov/toga-tao/.trmm/. Data can be displayed and accessed from this page.

In a related study, TRMM has provided support to the TAO Project Office for two fully equipped NextGeneration ATLAS moorings with rainrate sensors to be deployed near Kwajalein in mid-1999 as part of the TRMM KWAJEX experiment. These buoys will be deployed for approximately one month within view of a shipboard rain radar system on the NOAA Ship *Ron Brown*.

3.1.9 Moored Bio-Optical and Chemical Measurements

Two TAO moorings (0°, 155°W and 2°S, 170°W) have been instrumented with biogeochemical sensors as part of a collaborative study between PMEL and the Monterey Bay Aquarium Research Institute (MBARI). This effort was developed under auspices of NOAA's Ocean Atmosphere Carbon Exchange Studies (OACES), a primary goal of which is to determine the spatial/temporal variability of primary production, carbon dioxide, and their relation to variations in the physical environment. Measurements on the two TAO moorings include downwelling irradiance from the buoy tower, downwelling and upwelling irradiance in the upper 30 m of the ocean, oceanic pCO_2, and chlorophyll fluorescence. Data are telemetered to shore *via* Service Argos. Moorings are recovered and redeployed on a 1-year schedule with visits every 6 months for sensor replacements and data retrieval. The first OACES moorings in the TAO array were deployed in November 1996, and the most recent deployments were in October/November 1998.

In addition to these two sites, four other TAO sites at 2°N, 110°W, 2°N, 140° W, 2°S, 140°W, and 2°N, 180° have been instrumented by MBARI to measure downwelling irradiance from the buoy tower, upwelling radiance at 1.5 m depth, and chlorophyll fluorescence at 1.5 m depth. Data are telemetered to shore *via* Service Argos. These systems are serviced on a 6-month schedule and were last visited between September and December 1998.

Additional underway measurements are made from the TAO support vessel *Ka'imimoana* in support of OACES objectives during some or all mooring cruises. These measurements include photosynthetically available radiation (PAR), stimulated fluorescence, chlorophyll and nutrient extractions from CTD samples, primary productivity measurements, and pCO_2 measurements in surface water and air.

3.1.10 Data and Information Dissemination

TAO data are telemetered in real-time to PMEL *via* Service Argos. Calibration coefficients and quality control checks are applied at PMEL. The data are then made available to the research community, to other governmental agencies, and to the public *via* ftp (ftp.pmel.noaa.gov/taodata) and the World Wide Web (http://www.pmel.noaa.gov/toga-tao/).

Data are also placed on the Global Telecommunications System (GTS) by Service Argos for distribution to operational centres where the data are assimilated into weather and climate forecast models. PMEL monitors TAO data transmissions on the GTS for quality control purposes. About 80 - 90% of surface and subsurface data which reaches PMEL on a daily basis *via* Service Argos is available on the GTS (Figure 4). It is thought that much of the missing GTS data is due to messages with transmission errors, which eventually reach PMEL in corrected form, but which in the interim are declared as bad by Service Argos.

To reduce both battery and Service Argos costs, TAO moorings transmit only 8 hours *per* day. This transmission schedule returns daily averaged surface and subsurface data, plus about 3 surface hourly observations *per* day. These hourly observations are clustered around daylight satellite passes, and thus users will notice a lack of real-time hourly data at most sites between 0600 UTC and 1200 UTC. Lags between the time of measurement and the time of data arrival at operational centres are typically about 2-3 hours, but can be significantly longer because of inherent delays in the satellite data delivery system. These delays may cause a reduction in the amount of data which are usable by some weather forecast models.

TAO Web pages provide not only for dissemination of the data (both real-time and delayed mode), but also for graphical displays, for general information on El Niño and La Niña, and for links to climate analysis and forecasting centres. These Web pages served as a very effective means of informing the scientific community and general public about the evolving climate conditions in the tropical Pacific during the 1997-98

El Niño event. From January 1997 to October 1998, TAO Web pages received over 25,000,000 hits, with a peak of over 3,500,000 hits in October 1997 (Figure 5).

3.1.11 NOAA Perspectives on the ENSO Observing System (Contributed by S. Piotrowicz, NOAA/Office of Oceanic and Atmospheric Research)

NOAA received $4.9 million in its 1998 budget for an "Operational ENSO Observing System" to support the operational ENSO prediction mission of NOAA. The major components of the observing system supported in 1998 were the TAO array, the Voluntary Observing Ship programme operated by NOAA which includes XBT observations and surface meteorological observations, NOAA's surface drifter programme, and the Indo-Pacific Sea Level programme operated by the University of Hawaii. Included in this budget are the satellite data transmission costs. The justification for obtaining this funding was based on providing observations for the ENSO prediction mission and not the long-term support of any particular observational programme. For the foreseeable future, the major components of the ENSO Observing System, however, will remain basically the same.

The 1998 programme was supported as a basic continuation of the research-funded, 1997 programme. For 1999, NOAA solicited proposals from the above programmes to cover a three-year period. The invitation message for those proposals stated that 10% of the total funding may be reprogrammed annually but 75% of each programme's Fiscal Year 1999 funding is guaranteed for three years. This was to allow for changes in the present configuration of the Observing System and/or the components of the system that might be dictated by the operational requirements or a quantitative evaluation programme, while still preserving operational continuity for the implementing organizations.

A quantitative evaluation programme for the ENSO observing system is being implemented through NOAA's Virtual Laboratory for Observing System Evaluation that has been established. It has begun some analyses, and will continue to conduct analyses throughout the duration of the existing proposals. The results of those activities will be made available to the NOAA ENSO Systems Council. Even though the results of Virtual Laboratory activities will likely be intermittent, and probably, result in only minor recommendations early in their evolution, the above funding guidelines will allow for the implementation of significant Virtual Laboratory findings by the ENSO Observing System Director and Council. The development and inclusion of major, new observing systems (e.g., profiling floats) will probably require new funding which generally takes several years to develop. In the meantime, inflationary considerations alone imply that the ENSO prediction mission will have to be accomplished with declining resources. The above guidelines also allow adjustments due to increasing costs to maintain the existing system as well as changes in the system.

Support for ship-time is not included in the 1998 appropriation for the ENSO Observing System. Platform support is included in another item in NOAA's budget. Platform time in support of the TAO array presently amounts to a full ship-year on the *Ka'imimoana* and three additional 30 to 35 days cruises every two years on a NOAA Class I ship. This basically supports visiting the moorings in PMEL's purview semiannually. Ship support costs for TAO amount to something around $5 million annually and this budget item, like the ENSO Observing System, is not likely to increase in the near future either. In 1999, the funding that supports ship-time for TAO and all of NOAA research was reduced by 14% for its 1998 level. The ship-time supporting TAO was not decreased as a result of this budget reduction. Other programmes were reduced. It is likely that any new funding obtained for platforms in the future will be directly tied to programmes whereby, if the programme is not supported, increases in support for ship-time are not granted. This will not affect the base budget that supports the *Ka'imimoana*, however, funding to support additional time on a NOAA or other vessel could, in the long-term, be impacted. Presently, support of the TAO array is one of NOAA's highest priorities for allocation of ship-time. It would, however, be prudent to attempt to reduce the dependency on ship-time beyond what is available on the *Ka'imimoana* . This must be done without compromising the ENSO prediction mission such as new technologies reducing the frequency of visiting moorings, replacing some moorings with other observing systems (floats, remote sensing, etc.) as determined by the Virtual Laboratory, and/or increasing the number of nations providing ship-time in support of the ENSO prediction mission.

3.2 JAPAN (Y. Kuroda/M. Endoh, JAMSTEC)

3.2.1 Tropical Ocean Climate Study (TOCS)

JAMSTEC began the Tropical Ocean Climate Study (TOCS) programme in 1993 following on the previous programme JAPACS (Japanese Pacific Climate Study, 1987-1993). The objective of TOCS is to achieve the better understanding of ocean circulation in the warm pool affecting the ENSO phenomena and global climate change.

As part of TOCS, JAMSTEC has deployed subsurface Acoustic Doppler Current Profiler (ADCP) moorings to detect daily, seasonal and year-to-year changes of the equatorial and low latitude western boundary currents. Seven sites have been occupied: 0°, 142°E and 0°, 147°E since May 1994; 0°, 138°E, 2.5°S, 142°E, 2°S, 142°E, 0°, 156°E since July 1995 and 0°, 165°E since February 1997. The 2°S, 142°E site was discontinued in summer 1998. Two sites at 0°, 147°E and 0°, 165°E are deployed as part of the TAO current meter array.

JAMSTEC has conducted two cruises *per* year since Japanese Fiscal Year 1993 (April 1993-March 1994) using R/V *Kaiyo*, and increased to three cruises *per* year since FY 97 using the R/V *Kaiyo* and R/V *Mirai*. Hydrographic and atmospheric measurements have been carried out using CTD, shipboard-ADCP, and radiosondes. These cruises also maintain the JAMSTEC subsurface ADCP array and TAO array in the western Pacific. Operation of R/V *Mirai* started in October 1997, and the first TRITON buoy operations were carried out in March 1998.

* Cruises in FY 97

1998 Jan-Feb	R/V *Kaiyo* 29 days from Majuro to Palau
1998 Mar	R/V *Mirai* 26 days from Hachinohe, Japan to Sydney

* Cruises in FY 98

1998 Aug	R/V *Kaiyo* 26 days from Guam to Palau
1999 Jan-Feb	R/V *Kaiyo* 30 days from Majuro to Palau (Planned)
1999 Feb-Mar (Planned)	R/V *Mirai* 44 days from Hachinohe, Japan to Majuro

* Cruises in FY 99

1999 Summer	R/V *Kaiyo* (Planned similar to summer 1998)
1999 Oct-Nov	R/V *Mirai* (Planned)
2000 Feb-Mar	R/V *Mirai* (Planned)

3.2.2 Status of TRITON

JAMSTEC is developing a surface moored-buoy network named TRITON (TRIangle Trans-Ocean Buoy Network) for observing oceanic and atmospheric variability in the Pacific Ocean and its adjacent seas in co-operation with interested Japanese and foreign agencies and institutions. The principal scientific objective is to understand variations of ocean circulation and heat/salt transports with emphasis on ENSO, the Asian monsoon, and decadal scale variability that influences climate change in the Pacific and its adjacent seas. In its first phase, the buoy network will be established mainly in the western tropical Pacific Ocean between 8°S and 8°N, and harmonized with TAO-ATLAS buoys which are presently maintained by NOAA's Pacific Marine Environmental Laboratory.

The fundamental functions of TRITON are (i) basin scale ENSO monitoring, and (ii) measurements of heat, freshwater, momentum fluxes for improving modelling capability. A subsurface ADCP current meter array will be maintained along the equator by the Tropical Ocean Climate Study in conjunction with TRITON to measure the variability of equatorial currents. After establishing the TRITON network in the western tropical Pacific, two of buoys will be deployed in the eastern Indian Ocean as a pilot study focusing on intraseasonal ocean and atmosphere change associated with the MJO, monsoon variability, and ENSO scale variability.

JAMSTEC deployed four TRITON buoys at 8°N, 5°N, 2°N and 0°, 156°E from the R/V *MIRAI* in March 1998. These buoys were intended for a year long deployments. However, the buoys were recovered due to technological problems (unexpected corrosion between stainless buoy structure and galvanized steel parts, data transmission problems on a TRITON buoy caused by water intrusion into an Argos antenna tube, and some mechanical failures on CT/CTD sensors). The TRITON data collecting system worked well during the first deployments and took useful data during the recovery stage of the 1997-98 El Niño.

The TRITON buoys were deployed close to ATLAS buoys within 10-15 miles for intercomparison. The 3-month TRITON data were cross validated well with ATLAS data intercomparison, although the capability for year long TRITON deployments needs to be verified.

3.2.3 Future TRITON Plans

- Construction of TRITON buoys. JAMSTEC will have total 18 TRITON buoys by the end of FY 98, after addressing the technological problems found during the first deployment.

- *Deployment schedule.* The TRITON buoys at 8°N, 5°N, 2°N, 0°, 2°S, 5°S along 156°E, and 5°N, 2°N, 0° along 147°E will be deployed during the February-March 1999 R/V *MIRAI* cruise. The array along 138°E will be deployed during the October-November 1999. The present TAO-ATLAS buoys in these sites will be replaced with TRITON buoys. Therefore, the combined TAO/TRITON array will continually cover the Pacific basin. Afterwards, the TRITON array will be expanded to 130°E.

JAMSTEC has plans to go into the Indian Ocean in October 2000 if the deployments in the western tropical Pacific Ocean go well. Buoy deployments will be started as a pilot study for three years and be co-ordinated with other programme like JASMINE, the Indian National Data Buoy programme, the Indonesian climate studies, etc.

3.2.4 Data Dissemination

TRITON data will be distributed the same as TAO data. The display and distribution software for the combined TAO/TRITON data sets has been developed based upon the TAO software. These data will be distributed from both JAMSTEC and PMEL/TAO homepages.

3.2.5. JAMSTEC Outreach in 1997-1998 Related to Fishing Activity

In 1998, JAMSTEC contacted to some Japanese fishing associations and the Japan Shipowners' Association, and asked them to distribute TRITON brochures to ship operating companies. JAMSTEC also asked the Maritime Safety Agency of Japan to announce the exact TRITON buoy locations in the World Cruise Warning System. Similarly, JAMSTEC sent TRITON brochures to fishing associations in the Republic of Korea, Taiwan, and the United States of America to distribute to ship operating companies.

JAMSTEC sent representatives to attend the annual SOPAC (South Pacific Applied Geoscience Commission) meeting where TRITON activities were described. The participants understood well the purpose and importance of the TAO/TRITON array and recommended that member countries support efforts to mitigate against fishing related mooring equipment and data loss. SOPAC has also helped to co-ordinate a number of activities, as described below.

JAMSTEC sent representatives to the FFA (Forum Fisheries Agencies) in 1997. FFA understood well the importance of TAO/TRITON data for research not only on climate change but also fisheries. JAMSTEC requested that FFA distribute TRITON brochures to ship operators when ships register with FFA before getting fishing licenses from each Member State. FFA agreed to distribute the brochures, and also posted the exact locations of TRITON buoys in the FFA Newsletter.

JAMSTEC sent representatives to the Federated States of Micronesia (FSM) in 1997 to ask permission for year long clearance for JAMSTEC research vessels in order to maintain TRITON array. This permission was granted. JAMSTEC also asked to charter FSM cargo-passenger vessels for the emergency TRITON operations. We expect emergency charters to be possible in 1999, if necessary. Finally, JAMSTEC sent representatives to Papau New Guinea, in 1998 to inform officials there of TRITON activities, and to request help in distributing TRITON brochures.

3.2.6 International Co-ordination

International co-ordination is vital to enable sustainable measurements by the TRITON and TOCS buoy arrays. Therefore, JAMSTEC plans the following:

(i) exchange of scientific, technological and logistical information among the various moored buoy programmes;
(ii) sharing logistics support for buoy maintenance, ship-time, security, buoy rescue, etc.;
(iii) education of fishing communities; and
(iv) buoy data distribution and utilization from various moored buoy programmes.

3.3 FRANCE (J. Picaut, IRD/ORSTOM and NASA/GSFC)

The French R/V *L'Atalante* will be back in the Pacific in 1999. After some discussions with the TAO Project Office, it appears that there should be enough ship-time from the U.S. and Japan to maintain the TAO array in 1999. Hence, it was decided not to request any ship-time from the R/V *L'Atalante* for the replacement of TAO moorings. However, knowing that some instruments in the TAO array can fail at any time, it should be kept in mind that the R/V *L'Atalante* may be able to help. In particular, it may be possible to use this research vessel during the transits between specific ports of call. The transits of interest for TAO moorings are so far the following: Manzanillo-Papeete in March, Papeete-Noumea in June, and Noumea-Rabaul in December 1999.

In addition to some transits planned with the R/V *L'Atalante*, two cruises with the IRD/ORSTOM R/V *L'Alis* have been proposed by the physical oceanographic SURTROPAC group in Noumea. These two cruises intend to study the oceanic response of the South Pacific Convergence Zone during two different seasons (around April and October). These cruises should run from Noumea, along 165°E up to the equator, then along the equator to the date line, then down to Wallis Island and back to Noumea. During these cruises, one or two TAO moorings along 165°E and the date line may be replaced or at least all the surface instruments along these two meridians could be checked and eventually replaced. The first cruise has been accepted and the tentative date is from 10 October to 10 November 1999. The second cruise is requested for April 2000.

The remaining pool of SEACAT thermosalinographs from ORSTOM and NOAA/PMEL is still in use on several TAO moorings for the necessary measurement of salinity in the western equatorial Pacific. They are going to be progressively replaced by the thermosalinographs that are now part of the new generation of ATLAS, which transmits salinity data in real-time, something not routinely done with the standard SEACAT.

Due to research ship limitations in the Pacific and the interest of the Euro-CLIVAR community in the Atlantic, the French participation in TAO has mostly shifted into the Atlantic Ocean with the successful deployment of several ATLAS moorings. These moorings are part of the PIRATA pilot experiment developed by Brazil, France and the U.S. This project was made possible in part by the presence of the IRD/ORSTOM R/V *Antea* in Abidjan,Côte d'Ivoire. As with the very successful TAO project in the Pacific, discussions are underway to maintain PIRATA after its pilot period expires.

As stated in previous TIP reports, the French community of oceanographers and meteorologists are using TAO data for research, validation, and operational purposes. In particular the ENSO migration of the western equatorial Pacific warm and fresh pool has been extensively analyzed with TAO data, other *in situ* data, and satellite data. Improvement of Pacific OGCMs (with and without data assimilation) and coupled models could not have been done without TAO data, which by far is the best set of data ever collected from the air-sea interface down to 500 m.

3.4 TAIWAN (D. Tang and H. H. Hsu, National Taiwan University)

Taiwan's primary national contribution to the TAO array in 1998 was to extend the array into the South China Sea. Since ship-time for the TAO project was sufficient in the western Pacific Ocean, Taiwan did not provide ship-time required to maintain TAO moorings there in 1998. In co-operation with PMEL, Taiwan deployed three ATLAS moorings accompanied by three sub-surface ADCP moorings in the centre of South China Sea in April of 1998. This work is related to the South China Sea Monsoon Experiment (SCSMEX). One of the three ATLAS sites has been occupied since April 1997. Like the other ATLAS moorings in the tropical Pacific Ocean, the data are transmitted in real-time back to the PMEL, where they are made available to the research and operational communities.

Unfortunately, ATLAS moorings in the South China Sea were vandalized seriously by fishing boats. Two months after deployment in April 1998, only one surface mooring survived. However, the data collected so far show some very interesting features, some of which are quite different from what we expected based on climatology. The time series of upper ocean heat content displayed a marked semi-annual variation even though the wind is dominated by an annual cycle. Downwelling followed by upwelling was observed in the late boreal spring 1997 when the southwesterly monsoon intensified. This sequence was also seen in October 1997 when the northeasterly monsoon strengthened. The upwelling generally weakened but had a longer duration than the downwelling. The coherence between the upper ocean heat content and local wind stress (or wind stress curl) was low. The vorticity analysis indicates that remote effects (e. g. propagating planetary waves) on the upper ocean thermal structure could be important.

Sea Surface Temperature (SST) variations were poorly correlated with variations in subsurface thermal structure. SST was dominated by an annual variation, high in summer and low in winter. The ENSO influence is also clearly seen in the SST, with observed temperatures 1-3 °C higher than the climatological SST starting in December 1997. This high SST persists even to the present. The high-resolution thermal data shows that the internal tide is persistently large at least in the northern South China Sea.

The subsurface ADCP moorings were retrieved in October of 1998. The observed current velocity did not agree with the surface velocity derived from ship drift. Current velocities obtained from the three moorings varied significantly when the southwesterly wind intensified, but they generally were marginally coherent with the local wind stress over the 6-month observation period. Further study is required.

3.5 INDIA (S. Prasanna Kumar, NIO)

India has three major ongoing ocean observation programmes: a National Data Buoy Programme (NDBP), an Expandable Bathythermography Tree (XBT) programme, and a drifting buoy programme. The NDBP is implemented from the National Institute of Ocean Technology (NIOT) in Chennai while the other two are carried out by NIO in Goa. Under the NDBP three deep ocean and four shallow ocean data buoys have been deployed (6 in Bay of Bengal and 1 in the Arabian Sea) since September 1997. NDBP is a joint project between India and Norway.

Under the XBT programme 4 lines are being monitored. The Madras-Andaman and Calcutta-Andama lines are covered bi-monthly since 1990 while the Bombay-Mauritius line is covered once every three months. The Vizag-Singapore line started in 1994 is irregularly sample due to the irregular availability of ships along this route. The drifting buoy programme was started in 1991 and every year, on an average, 7 to 8 buoys are deployed. Apart from these ongoing programmes, two programmes that will start next year are deep ocean moored buoys and Bay of Bengal Process Study (BOBPS). Under the moored buoy programme, 3 subsurface moorings with 5 current meters on each mooring will be deployed along the equator at 73°E, 83°E, and 93°E. Under the BOBPS programme, the Bay of Bengal will be sampled from 3°N to 20°N along 87°E as well as long the east coast of India five times during 1999 to 2001. Physics, chemistry, biology, geology and radiochemistry will be studied from shipboard measurements.

In response to a recommendation made at TIP-6 in 1997, there were several efforts at the national level within India by the Department of Ocean Development and National Institute of Oceanography to make data from the NDBP accessible in real-time. This will now be possible by the end of 1998 when the surface met data from NDBP buoys will be put on to GTS.

4. PROGRAMME STATUS REPORTS

4.1 PIRATA STATUS REPORT (J. Servain, IRD/ORSTOM, Brest)

The Pilot Research Moored Array in the Tropical Atlantic (PIRATA) is an extension of the TAO array in the Atlantic. Twelve ATLAS moorings will be deployed during 1997-2000 as part of a multinational effort involving Brazil, France and the United States of America (Figure 6). Like TAO, PIRATA is designed to monitor surface meteorological variables and upper ocean thermal structure at key locations in the tropical Atlantic, with data transmitted to shore in real-time *via* satellite (Service Argos). These key locations are chosen to obtain information on the two main modes of seasonal-to-interannual and longer time scale variability which occur in the tropical Atlantic, i.e. the El Niño-like equatorial mode and the meridional "dipole" mode (Servain *et al.*, 1998). PIRATA data are available to all interested users from the research or operational communities in the Web sites www.pmel.noaa.gov/pirata and www.ifremer/orstom/pirata/pirataus.ht.

Five deployments were made during the first phase of PIRATA experiment (late 1997 to early 1998) (see Figure 6). One mooring failed after two months (0°N, 10°W). Therefore, an additional deployment was made at 0°N, 0°W, which also failed after ten months. These losses, both along the equator in the Gulf of Guinea, were due to vandalism associated with tuna fisheries. Vandalism issues were discussed during the PIRATA-5 meeting (held in Abidjan just before the TIP-7 meeting) and the idea of a United Nations resolution to help mitigate against vandalism was proposed (see Annex I).

At the time of TIP-7 (November 1998), the PIRATA array was operational as follows:

- Gavotte (10°S, 10°W) maintained by R/V *Antea* (IRD) in October 1998
- Soul (0°N, 0°W) maintained by R/V *Antea* (IRD) in November 1998
- Reggae (15°N, 38°W) deployed by R/V *Antares* (DHN) in February 1998
- Lambada (8°N, 38°W) deployed by R/V *Antares* (DHN) in February 1998
- Samba (0°N, 35°W) deployed by R/V *Antares* (DHN) in February 1998

The second and third (final) deployment phases are scheduled in early 1999 (by the R/V *Antea* and R/V *Antares*), and in July 1999 (by the R/V *Antea*) respectively. Intensive air-sea flux measurements are planned with an instrumented masts aboard the R/V *La Thalassa* in summer 1999 during the French EQUALANT-99 experiment, from Salvador de Bahia, Brazil, to Abidjan, Côte d'Ivoire. These meteorological measurements, especially those which will be made in the vicinity of three PIRATA equatorial sites (one in the western basin, two others in the eastern basin), will be useful for calibrating turbulent air-sea fluxes estimated from the PIRATA observations *via* the bulk formula. During EQUALANT-99, a complex current measurement system (internally recorded data only) will be deployed close to 0°N, 10°W (Java), with an ADCP (0-250 m), a "Yoyo" system (150-1000 m daily current profiles), and conventional current measurements (1000-4000 m). An ADCP mooring (with 0-300 m measurements) is also scheduled for deployment by Brazil at the PIRATA Jazz site (0°N, 20°W) in mid-1999, as well as a meteorological buoy at 0°N, 44°W. Complementing these *in situ* observations, tide-gauge data on islands located close to the equator (St Peter and St Paul Rocks, Atol das Rocas, Sao Tome) will provide information about sea level variability. Thus, a complete integrated ocean observing system (full PIRATA array, current measurements, sea level data, and meteorological observations) will be operational for at least one year (mid-1999 to mid-2000).

It is expected that at the end of the pilot phase of PIRATA (late 2000 to early 2001), other nations may join in the maintenance and possible expansion of the array (and other types of *in situ* oceanic observations) to constitute a tropical Atlantic Ocean Observing System. A meeting is now scheduled in Miami for May 1999 to discuss that possibility.

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4.2 TROPICAL RAINFALL MEASURING MISSION (TRMM) PROGRAMME STATUS REPORT (T. Rickenbach, NASA/Goddard Space Flight Centre)

The Tropical Rainfall Measuring Mission (TRMM) is a joint programme between the National Air and Space Administration (NASA, United States of America) and the National Space Development Agency (NASDA, Japan) to provide unprecedented, high resolution precipitation measurements over the global Tropics. The fundamental goal of TRMM is to produce four-dimensional estimates of the vertical profile of latent heating in the tropical atmosphere. This will greatly enhance our ability to model the interaction between convective scale processes (which produce rainfall) and global circulation patterns. The TRMM satellite was launched successfully from Tanegashima Space Centre, Japan on 27 November 1997.

TRMM has three main components: satellite measurements, ground validation, and field campaigns. Monthly 5° rainfall maps are the end product of the satellite measurements, provided by the Precipitation Radar (PR), the TRMM Microwave Imager (TMI), and the Visible and Infrared Radiometer System (VIRS). The PR and TMI also measure the vertical structure of precipitating systems. Coincident data from the VIRS, which measures the cloud top temperature and albedo, may be compared to the more physically direct measurements of the PR and TMI to improve ongoing climatological estimates of global rainfall from geostationary satellites. TRMM data has been approved for public release on September 1, 1998. Agreement to within 25% in global rainfall estimates was found among the different instruments on TRMM.

The ground validation (GV) component provides an independent estimate of precipitation at ten tropical GV sites, derived from surface-based radars, rain gages, and disdrometers. Radar reflectivity fields are partitioned into convective and stratiform components (as is done with the PR data), which are regions of distinct vertical heating profiles. High resolution vertical structure information is also given by the GV radars. The four primary GV sites are located at Darwin (Australia), Kwajalein (Republic of the Marshall Islands), Houston (Texas, United States of America), and Melbourne (Florida, United States of America).

The TRMM field campaigns provide extensive measurements by ground based and airborne radar, rain gages, soundings, and profilers at key locations in the tropics during the mission. The main purpose of the TRMM field campaigns is to obtain vertical profiles of latent heating (through divergence measurements from radiosondes and profilers) at several tropical land and oceanic sites. In addition, Doppler-derived vertical motion fields will assess the performance of GV and satellite convective - stratiform partitioning algorithms. Preliminary campaigns have been carried out as part of the South China Sea Monsoon Experiment (SCSMEX) and the Texas-Florida Underflights (TEFLUN) programme earlier this year. The main TRMM field campaigns (one land and one ocean) will occur in early and mid 1999. The LBA-TRMM campaign will be held in Rondonia, Brazil, in the Amazon region. The Kwajalein Experiment (KWAJEX) will take place at Kwajalein Atoll in the central Pacific Ocean.

4.3 RECENT DEVELOPMENTS RELEVANT TO TAO AT MEETINGS OF THE CLIVAR UPPER OCEAN PANEL AND U.S. CLIVAR SCIENTIFIC STEERING COMMITTEE (W.S. Kessler, NOAA/PMEL)

The CLIVAR Upper Ocean Panel (UOP) met in Toulouse, France in April 1998. The major new development is the prospect of a global array of profiling floats (PALACE) that are likely to be deployed over the next few years (the array is known as Argo, the Array for Geostrophic Oceanography). The plan is for roughly 3,000 floats making bi-weekly profiles of T(z) and S(z) globally. It is likely that the tropical-subtropical Pacific will be one of the early areas of concentration. This programme has a large constituency, especially driven by the satellite community which is seeking to better interpret altimetre data in the light of subsurface information. Also involved are groups that assimilate XBT profiles for forecast initialization. A third community is looking at decadal modulation of the ENSO cycle and would like to study the processes of the subtropical cells and shallow overturning circulation in the Pacific.

The TAO array is well-positioned with respect to Argo for two reasons. First, the excellent time resolution of TAO is invaluable for estimation of unsampled variability in the tropics; second, Argo cannot properly sample the vital boundary current and equatorial regimes because of float motion. The Argo concept works best where the floats stay put and act as virtual moorings; that is, where the flows at 1500 m are weak. PALACE floats in the equatorial Pacific tend to move thousands of kilometres, and therefore cannot be relied upon to provide a near-grid-like sampling pattern.

The UOP also had extensive discussion of salinity observations, and there is widespread agreement that subsurface salinity is a necessary parameter for interpretation and assimilation. Extensive effort is going into developing longterm salinity sensors, and we can expect cross-fertilization with similiar TAO work. The UOP also encourages and endorses the TAO subsurface salinity programme.

The U.S. CLIVAR Scientific Steering Committee (SSC) met in Washington in September 1998. SSC actions are of direct relevance only to U.S. funding decisions, but will probably be influential in determining the future evolution of the TAO array and PIRATA.

The SSC recommends as U.S. CLIVAR focies (among other things):

- The United States of America should continue to strongly support research and monitoring for ENSO prediction, and expand this effort to the decadal modulation of the ENSO cycle. For TAO, this means that the U. S. is committed to continuing support of TAO, and that the U. S. work in the Pacific will extend through both subtropical gyres.

- The SSC also recommended that the United States of America should take a major interest in Atlantic climate variability, especially tropical Atlantic interannual variability. Therefore, PIRATA will probably continue to be supported as a key element of this effort beyond the pilot programme. There will also likely be support for additional the U. S. observational (ocean+atmosphere) efforts in the Atlantic.

- Data assimilation is seen as crucial to gaining the full benefit from observations. To some extent, the usefulness of observing systems will be judged on the basis of their impact on assimilation.

The SSC will note the need to study sampling strategies of the various elements of the observing system, including TAO. Refinement and evolutionary improvement of the elements of the observing system will be promoted.

4.4 PROGRESS WITH THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS) (Janice Trotte, IOC/UNESCO)

A presentation on the basic principles and recent developments of GOOS was made, on behalf of the

GOOS Project Office, one of the Tropical Atmosphere Ocean Array (TAO) co-sponsors.

GOOS is a global project co-sponsored by IOC, WMO, UNEP and ICSU. It is supported by governments and implemented according to a set of principles to which all participants adhere. There is no single model to follow and its implementation is to be fully based on the regional approach. Individual countries are free to participate, provided they accept those principles and their proposed activities fit in the GOOS Agenda.

The Capacity Building component is highly important to promote GOOS in developing States, some of them located in the African continent, and which present some level of diversity in terms of the available logistic, operational and human resources to carry out the required GOOS tasks.

Several examples of benefits in participating in GOOS were also presented, such as the laying of the foundations for the creation of an early warning storm surge system, ships meteorological routing, management of ports and harbours, forecasting of sea ice, climate forecasts, preparing for epidemics, etc. The examples provided suggest that the benefits of GOOS outweight its costs and show how governments and society as a whole could benefit from the utilization of operational oceanographic data.

Demonstrations of how much natural forcings can impact on the economics and social welfare of coastal nations were presented, with emphasis of the use of ENSO forecasting on planning crop production. Examples of the use of operational data for forecasting malaria epidemics in Colombia, and maize yield in Zimbabwe were also shown.

GOOS will capitalize on the already existing observing activities in the world's oceans, converting them into products of beneficial use by society and governments, to the extent possible. Initiatives such as the TAO array and the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) are essential components of GOOS.

No one country or agency could perform the whole suite of activities required to permanently observe the state of the oceans, GOOS involve concerted actions between all observing systems, satellite agencies, existing strategies, and others, for the benefit of all potential users of GOOS products.

The GOOS Web site (http://ioc.unesco.org/goos/goos.htm) a useful source of information on GOOS, and links to related sites.

5. SCIENCE REPORTS

5.1 SEASONAL FORECASTING AT ECMWF
(D. L. T. Anderson, ECMWF)

The European Centre for Medium Range Weather Forecasting (ECMWF) has set up an operational coupled model system to produce global seasonal forecasts. One of the main contributors to predictability on these timescales is ENSO. The 97/98 El Niño, in particular its onset, was well predicted. Because the coupled model is global, it can also represent the impact of ENSO outside the tropical Pacific, for example, on the high latitudes and the Asian Monsoon.

Errors in the forecasts can arise from uncertainties in the atmosphere model, ocean model and initial conditions (ocean, atmosphere, land). Some deficiencies in the coupled model forecasts of equatorial Pacific SSTs over the 90s are discussed. Errors in the forecasts due to uncertainties in the ocean initial conditions are examined using coupled forecasts starting from different initialization methods (with and without ocean data assimilation and different assimilation set-ups). Results show the ocean data assimilation can have a large positive impact on the coupled model forecasts of ENSO. Links are found between these forecasts and uncertainties in the ocean initial state in the central and western equatorial Pacific, as well as the north western tropical Pacific, outside the TOGA-TAO array region. The lack of salinity observations means that errors in the salinity field cannot be corrected. Assimilating temperature but not salinity can lead to dynamical imbalances along the equator.

5.2 BASIN-WIDE ADJUSTMENT OF MASS AND WARM POOL DISPLACEMENT DURING THE 1997-98 EL NIÑO-LA NIÑA (J. Picaut, IRD/ORSTOM and NASA/ Goddard Space Flight Centre)

An intriguing feature of the successive 1997-98 El Niño-La Niña events is their appearance at depth months before their signature in sea surface temperature. The subsurface TAO data showed that the anomalous downward movement of the thermocline in the central-eastern Equatorial Pacific was underway several months before the appearance of the 1997 El Niño warming in sea surface temperature. Similar feature, associated with an upward movement of the thermocline, was also evident prior to the sea surface cooling associated with the onset of the 1998 La Niña. *In situ* and TOPEX/Poseidon derived currents indicate that strong mass transport within the equatorial wave guide was already pushing the warm pool toward the east (west) as early as February 1997 (January 1998). Possible mechanisms for these original features are explored through the readjustment of water masses in the equatorial wave guide associated with the displacements of the eastern edge of the warm pool. The role of horizontal and vertical advection, of equatorial waves and their reflection on both ocean boundaries in this readjustment of mass and of thermocline depth all along the equatorial band is investigated. This is done through the use of TOPEX/Poseidon and TAO data, the Gent and Cane oceanic general circulation model forced by observed winds and a simplified coupled ocean-atmosphere model. In particular it was found that the strong westerly winds bursts end of 1996 - early 1997 (much probably originating from the Indian Ocean and the North/Pacific) acting in phase with the basic ENSO oscillation, were the main reason for the 1997 El Niño to be so powerful. As for the basic ENSO oscillation, it appears to be due to equatorial wave reflections on both ocean boundaries, in accord with the delayed action oscillator and the revised advective/reflective mechanisms. Similarly, the sudden shift into La Niña appeared to be due to equatorial wave reflection on both ocean boundaries together with the remote effect of weak easterly winds in the far western Pacific.

5.3 IMPACT OF TAO vs. ERS WIND STRESSES ON SIMULATIONS OF THE TROPICAL PACIFIC OCEAN DURING THE 1993-1998 SIMULATED BY THE OPA OGCM (C. Menkes, LODYC and IRD/ORSTOM)

A simulation of the 1993-1998 period is performed with the OPA Oceanic General Circulation Model (OGCM) forced by weekly ERS 1-2 wind stress data from IFREMER/CERSAT extending the work of Grima *et al.* (1998) for the 1992-1995 period in which the quality of the ERS-1 forcing fields proved to give high quality OPA simulations of the tropical Pacific. Heat and fresh water fluxes used in this simulation are climatological, computed from the ECMWF 1979-1993 reanalysis. First, SSTs are restored to Reynold's weekly SSTs with a restoring term of 40 W m^{-2} °K^{-1}. The implied heat flux by this restoring term is stored during the simulation. Second, this heat flux is added to the forcing flux and the model is rerun using this fluxes without any restoring terms. This results in simulations in which SST is now a free parameter (Vialard *et al.*, 1998).

The simulation is evaluated relative to different data sets. First, a comparison to TOPEX/Poseidon sea level anomalies shows a mean correlation of 0.84 in the 5°N-5°S band and a mean rms difference of 4.3 cm. The mean rms of the model and data sea level anomalies are respectively 5.3 cm and 7.9 cm. That suggests that the ERS wind stresses may be too weak in the equatorial Pacific band. Second, comparisons with TAO equatorial currents are performed. At the surface (-15 m depth), correlations and rms differences between model and TAO currents at 0°, 156°E, 0°, 170°W, 0°, 140°W and 0°, 110°W average to 0.72 and 22.4 cm^{-1}. However, simulated zonal current display a well-marked bias at 140°W and 110°W in the vertical. This bias is characterized by too weak and too shallow an equatorial undercurrent, and variability of the current structure that is too weak in the vertical. Comparisons between ERS and TAO winds at 10 m reveal that the ERS wind zonal gradient along the equator is weaker than observed in the *in situ* data. Secondly, the ERS stress variability is weaker than observed variability at TAO moorings by 10-20%. These results are consistent with the findings of Graber *et al.* (1996) who found such systematic biases when comparing 10 m neutral winds from different ERS products to TAO buoys. However, among those ERS products, the

IFREMER/CERSAT product was the least biased. In any case, such biases in the ERS products are also consistent with the lack of variability observed in the simulation.

We aim at improving the model simulation by including the information contained in the TAO wind data. To do so stresses are computed at each TAO mooring using stability-dependent formulae based on Liu *et al.* (1979) and Smith (1988). A combined data set ERS+TAO is constructed by optimally inserting weekly TAO stresses into the ERS baseline forcing. A new simulation is performed using the ERS+TAO stresses. Significant improvements are observed. First, in terms of simulated sea level amplitudes, the mean rms of the model sea level anomalies are now 7 cm while mean correlation and rms difference are unchanged. Second, correlation with zonal currents are improved above the thermocline. For example, simulated surface current correlations and rms differences with TAO zonal currents amount to 0.79 and 22.6 cm. In the east, the EUC core is now well located, and the variability of the current structure in the vertical is much improved at 140°W and 110°W. Among the model parameters, SST is quite dramatically affected by such changes. In the ERS+TAO run, there can be changes greater than 2°C in the eastern Pacific compared to the ERS run, during the 1997-1998 El Niño. Such changes are achieved and dominated by enhanced vertical processes such as enhanced entrainment of cold water at the mixed layer base and enhanced vertical diffusion processes.

To this day, ERS 1-2 IFREMER wind products are possibly among the best observed winds available on a long time period. However, these results tend to show that there are still unresolved biases when comparing to TAO buoys that need to be understood. In particular, Graber *et al.* (1996) show that other comparisons with buoy networks outside the equatorial band seem less biased. This point is being investigated. However, if such biases in the equatorial band are proven to be true, as these simulations suggest, this could have several implications for ocean atmosphere climate predictions in models that assimilate such remotely sensed data. Finally, these results point out how crucial it is to have synoptic observations of *in situ* data such as those provided by the TAO array and the developing PIRATA array.

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5.4 GENESIS AND EVOLUTION OF THE 1997-98 EL NIÑO
(M. J. McPhaden, NOAA/Pacific Marine Environmental Laboratory)

This presentation describes the onset, development, and sudden end of the 1997-98 El Niño, using data from the Tropical Atmosphere Ocean (TAO) array of moored buoys and other data sets of the ENSO observing system. Warm sea surface temperature (SST) anomalies erupted in the tropical eastern Pacific during April-June 1997, and by July 1997 SST anomalies were the highest observed in the past hundred years. SST anomalies in the eastern Pacific subsequently exceeded 5°C, making this the strongest El Niños on record. The onset of the El Niño was characterized by surface winds along the equator that were punctuated by a series of westerly events of increasing intensity and eastward fetch. These westerly episodes, associated with enhanced Madden and Julian Oscillations in the atmosphere, locally drove warm water eastward near the equator. These westerly events also excited downwelling equatorial Kelvin waves that propagated into the eastern Pacific, depressing the thermocline by over 90 m in late 1997. At the same time, the thermocline in the western Pacific shoaled by 20-40 m in response to anomalous upwelling Rossby wave generation. Changes in SST due to ocean dynamical effects and anomalous air-sea heat exchanges led to changes in the location and intensity of atmospheric deep convection and precipitation in the tropics. Resultant anomalous heating of the atmosphere altered the position of the sub-tropical jet streams and storm tracks, affecting weather patterns worldwide. The event ended abruptly with the return of normal trade winds in May-June 1998, which upwelled thermocline water to cool the surface in the eastern and central equatorial Pacific. These observations will be used to test the delayed oscillator theory for ENSO, and the implications for the predictability of ENSO will be discussed.

5.5 RECTIFICATION OF THE MADDEN-JULIAN OSCILLATION (MJO) INTO THE ENSO CYCLE (W.S. Kessler, NOAA/PMEL and R. Kleeman, BMRC)

An ocean general circulation model, forced with idealized, purely oscillating winds over the western equatorial Pacific similar to those observed during the Madden-Julian Oscillation, developed rectified low-frequency anomalies in SST and zonal currents, compared to a run in which the forcing was climatological. The rectification in SST resulted from increased evaporation under stronger-than-normal winds of either sign, from changes in the vertical temperature gradient that were correlated with oscillations of upwelling speed at the intraseasonal frequency, and from zonal advection due to nonlinearly-generated equatorial currents. The net rectified signature produced by the MJO-like winds was SST cooling (about 1°C) in the west Pacific, and warming (about 0.3°C) in the central Pacific, thereby flattening or reversing the background zonal SST gradient. It is hypothesized that, in a coupled system, such a pattern of SST anomalies would tend to spawn additional westerly wind anomalies as a result of SST-induced changes in the low-level pressure gradient. This was tested in an intermediate coupled model initialized to 1 January 1997, preceding the 1997-98 El Niño. On its own, the model hindcast a (relatively weak) warm event, but when the effect of the rectified SST pattern was added, the hindcast El Niño became about 30% stronger due to the hypothesized additional westerlies. The results suggest that the MJO can interact constructively with the ENSO cycle, and therefore is more than just "weather noise" that introduces irregularity to the cycle. This implies that developing the capacity to predict, if not individual MJO events, then the conditions that affect their amplitude, would enhance predictability of the strength of oncoming El Niños over present abilities as demonstrated in 1996-97.

5.6 YOSHIDA JET DETECTED IN JAMSTEC SUBSURFACE CURRENT MOORINGS (K. Kutsuwada, Tokai University)

Long-term measurements of oceanic currents in the subsurface layers by upward-looking acoustic Doppler current profilers (ADCP) at three stations (142°E, 147°E and 165°E) on the equator have been performed as a part of the Tropical Ocean Climate Study (TOCS) by the Japan Marine Science and Technology Centre (JAMSTEC). Time series of the current data are analyzed to examine variations which are related to the onset of El Niño events. Some episodes in which strong eastward flow covers the upper layer above about 100 m are recognized during the period from December 1996 to November 1997, corresponding to the onset and mature phases of the 1997-98 El Niño event. In these episodes of surface eastward jet, the vertically-averaged (0-100m) eastward flow was larger than 0.5 m s^{-1} and attained to 1.3 m s^{-1} at the westernmost station (142°E) during the strongest episode occurring in December 1996. The surface eastward jet in the onset phase of the El Niño event (December 1996 and March 1997) occurred in the western Pacific at all the three stations, while in the mature phase (from April to November 1997) it was recognized only at the easternmost station (165°E). To investigate variations of the wind stress during these episodes, we construct data sets of daily surface wind-stress vectors on a 1° x 1° grid in the tropical Pacific using satellite scatterometer data (ADEOS/NSCAT and ERS-2 supplied by JPL and IFREMER, respectively).

In all the episodes, westerly winds (bursts) stronger than 5 m s^{-1} are predominant over the western equatorial Pacific covering our mooring stations. Dominance of the westerly wind bursts (WWB) is confined to the west of 160°E in the onset phase of the El Niño event, while the WWBs migrate eastward to an area east of the dateline in the mature phase after May 1997. We attempt to interpret the occurrence of surface eastward jets as Yoshida jets in response to local wind forcing. Results reveal that in some episodes such as the strongest one in December 1996, the enhancement of the surface eastward current estimated from NASA Advanced Scatterometers (NSCAT), wind data is almost identical to that observed in the mooring data. This means that the onset of this episode is interpretable in terms of Yoshida jet dynamics.

On the other hand, in the termination as well as in the onset of other episodes, significant discrepancies are found between the estimated and observed enhancements of the surface eastward currents. These results suggest that the effect of remote wind forcing plays an important role during these periods, indicating the necessity for information on the zonal pressure gradient along the equator.

5.7 REMOTELY-FORCED EFFECTS ON CURRENTS AND WATER PROPERTIES IN THE COASTAL UPWELLING SYSTEM OFF NORTHERN AND CENTRAL CHILE

(S. Hormazabal Fritz, Regional Programme for Physical Oceanography and Climate, U. Concepción)

A recent seven-year (1991-1998) continuous record of currents over the continental slope at 30°S off Chile, at 220 m, 485 m, 750 m depths in 850 m of water, is used to show interannual modulation of intraseasonal coastal trapped waves in the eastern South Pacific ocean. The first six years of the continuous records correspond to the physical oceanography component of the bilateral research programme "Marine Natural Resources - SAREC contribution to the international JGOFS Eastern Boundary Current Study off Chile" (1991-1997). This study is jointly sponsored by SAREC/SIDA (Sweden) and CONICYT (Chile). The last nine months of data are from the continuation of the observations within the Chilean research programme FONDAP-Humboldt (1997-2000), which is a study of the circulation and physical-biological interactions in the Humboldt current system, and their impacts on regional bio-geochemical cycling.

The analysis of these records of currents confirms earlier results (Shaffer *et al.*, 1997) that show a remarkably efficient transmission through the ocean of strong 40-70 day waves, driven by equatorial wind events. These waves travel first as equatorial Kelvin waves, along to equator and later as coastal-trapped waves along the coasts of South America. Wavelet analysis of along-shore currents shows that intraseasonal time scale variability associated with coastal trapped waves is seasonally stronger during the austral summer. It is also stronger during El Niño events (1991-1992, 1994 and 1997-1998) and weaker during La Nina events (1995-1996). Currents observations at 750 m depth show clearly an enhanced equatorward flow near the bottom during warm ENSO events.

The analysis of records of sea level, sea surface temperature and coastal wind collected during five years (1991-1995), and sea-surface temperatures obtained through remote sensing in the austral summers (1991 and 1992), show that sea surface temperature is controlled by local wind through coastal upwelling and strongly modulated by coastal trapped waves in the coastal area of northern Chile (18°-33°S). In the intraseasonal band, the sea surface temperature signal does not propagate alongshore, and is not related to the wind stress, particularly off Iquique (20°S), but sea level perturbations are followed by sea surface temperature anomalies with an 11-12 day lag-time. These relations are explained by changes in the depth of the thermocline due to coastal trapped waves that generate differences in water temperature entering the upper mixed surface layer due to coastal upwelling, modifying its heat budget and the sea surface temperature. In this way, the sea surface temperature is being strongly modulated by coastal trapped waves.

Reference:

Shaffer, G., O. Pizarro, L. Djurfeldt, S. Salinas, and J. Rutlant (1997): Circulation and low-frequency variability near the Chilean coast: Remotely forced fluctuations during the 1991-1992 El Niño, *J. Phys. Oceanogr.*, *27*, 217-235.

5.8 TRITON SALINITY MEASUREMENTS

(K. Ando and Y. Kuroda, JAMSTEC)

The surface layer in the western equatorial Pacific is characterized by a warm and fresh water pool of surface water. The zonal displacement of this pool is strongly related to the ENSO phenomena. The surface fresh water is formed by the heavy rainfall over the area, and to this area high salinity surface water from the east is transported and subducted below the surface fresh water by the westward South Equatorial Current. The contribution of salinity to density change in this warm fresh pool cannot be neglected. For example, lack of salinity data will cause errors in estimation of dynamic height and buoyancy in the mixed layer. The measurement of salinity is therefore crucial to understanding the western tropical Pacific. Twelve conductivity/temperature (CT) sensors are attached to each TRITON buoy, and more than 140 CT sensors are planned in the upper (0-750 m) western tropical Pacific as part of the TRITON project. A necessary first step is to verify the quality of our salinity data for meeting TRITON scientific goals.

The current status of the Triangle Trans-Ocean Buoy Network-Japan (TRITON) salinity measurement project is the validation of salinity data from four buoys (48 sensors) in March-June 1998 along 156°E, as well as comparing laboratory pre- and post-calibrations of each sensor. The temperature calibration by JAMSTEC shows good agreement (within 2 mK difference for all sensors) with that by the manufacturer (SeaBird Electronics). The conductivity calibration by JAMSTEC shows a 0.8 mS m^{-1} difference on average (equivalent to about 0.004-0.008 psu in salinity). The drift of the temperature sensors is very small (within 2 mK *per* year) on average, and the drift of the conductivity sensor is 0.002 psu *per* month (0.024 psu *per* year) on average. Salinity data from the buoys are sometimes missing because of hardware or electrical problems, and there are occasional unrealistic values. However, data return was about 80% in real-time. In the mixed layer, temperature data shows strong diurnal cycles, and salinity data seem to show realistic variability related to local rainfall events.

5.9 SEA-SURFACE SALINITY CHANGES IN THE WESTERN TROPICAL PACIFIC DURING THE 1996 LA NIÑA AND 1997 EL NIÑO PERIOD: THE PRESENT ORSTOM-TSG NETWORK IN THE PACIFIC. (T. Delcroix, ORSTOM/Noumea)

Sea-surface salinity (SSS) changes during the 1996 La Niña and 1997 El Niño events are analysed along the Fiji-Japan shipping track, based on 20 thermosalinograph sections. In the equatorial band, above-average SSS (35.2 - 35.4 psu instead of 35 psu) were observed in 1996, consistent with a well-marked south equatorial current, an unusually-strong equatorial upwelling, and below-average precipitation. From January to August 1997, the SSS decreased sharply from 35.2 - 33.8 psu (lowest recorded monthly value over the last 20 years), compatible with a reversal of zonal current, the occurrence of equatorial downwelling, and above-average precipitation. From September to November 1997, the SSS remained almost constant (34.2 psu), consistent with the opposite effects of eastward current, likely bringing low saline water from the Pacific warm pool, and of evaporative cooling, vertical mixing and below-average precipitation which all tend to increase SSS. The impacts of the SSS changes on sea level are discussed. The present status of the ORSTOM thermosalinograph network in the Tropical Pacific is also presented together with scheduled studies for assimilating SSS data in numerical models.

5.10 OBSERVING TROPICAL SEA-SURFACE SALINITY IN THE FUTURE BY INTEGRATING TAO AND SATELLITE DATA (G. Lagerloef, Earth and Space Research, Seattle)

The ability to measure surface ocean salinity by passive microwave (L-band) remote sensing has been known for several decades and demonstrated with airborne instruments. Satellite mission designs in the United States of America and in Europe are presently being considered by cognizant space agencies. Because requirements for salinity are very similar to requirements for measuring soil moisture, these missions will measure both parameters, although the radiometric signal over the ocean is much smaller than over land.

This presentation first outlined the basic considerations for tropical dynamics with the following points:

1. Interannual SSS variations of ±1 psu are observed in the tropics, caused mainly by variations in rainfall and advection.

2. SSS fields are needed to balance the upper ocean freshwater budget, initialize coupled climate models and validate freshwater flux parameterizations.

3. It is possible to improve the initialization of tropical ocean climate models with SSS data by adjusting T-S curves with SSS and altimeter sea level data (e.g,. recent work by Reynolds, Ji, Vossepol).

4. Tropical SSS retrievals likely will be more precise than those in temperate and polar latitudes because of brightness temperature sensitivity to salinity increases with SST.

5. TAO/PIRATA SSS data will be essential to improving and validating satellite SSS measurements. Satellite SSS error covariances can be estimated.

6. Optimal interpolation of satellite, TAO/PIRATA and other *in situ* SSS (similar to Reynolds SST) will provide the best estimate of SSS fields in the tropics. This will yield high-resolution SSS fields with known errors which are essential for coupled model development.

The physical principles governing salinity remote sensing then were presented, along with the various errors and corrections that must be applied. The satellite mission concepts were then be described, along with their approval status within agency programmes. These include the HYDROSTAR mission proposed to NASA earlier in 1998 with selections to be announced before the end of the year, and the European MIRAS/RAMSES/SMOS sensor which will be proposed to ESA on 30 November 1998 with selections to be announced mid-1999*. If approved, these satellites may be launched in the 2002-2003 time frame, and could be planned in sequence to extend the potential time series to more than five years. The relative salinity retrieval aspects were addressed, and it is apparent that large-scale climatological variability in the tropics will be resolved. Accuracies may be <0.5 psu at 1° x 1° resolution and ~1 week time scales, and perhaps ~0.2 psu on monthly time scales. Accuracies ~0.1 psu appear possible in the future with more precise radiometer systems under study. For additional reference, the draft of the First Workshop Report, Salinity Sea Ice Working Group (SSIWG), held at La Jolla, CA, United States of America, 7-8 February 1998, can be found at http://www.esr.org/lagerloef/ssiwg/ssiwgrep1.v2.html.

5.11 ESTIMATING RAINFALL IN THE TROPICS USING THE FRACTIONAL TIME RAINING AND NEW EFFORTS AT OBTAINING MINUTE RESOLUTION RAINFALL DATA IN THE PACIFIC (J. Ensworth, University of Oklahoma)

The relationship between the fractional time raining and tropical rainfall amount is investigated using rain gauge data and a point process model of tropical rainfall, building upon the work originally published by Morressey *et al.* (1994). Both the strength and the nature of the relationship are dependent upon the resolution of the data used to estimate the fractional time raining. It is found that highly accurate estimates of rainfall amounts over periods of one month or greater can be obtained from the fractional time raining as long as high-time resolution (minute) data are used. It is demonstrated that the relationship between the fractional time raining and monthly atoll rainfall is quasi-homogeneous within the monsoon through region of the equatorial western Pacific.

Optical rain gauges also reflect this homogeneity but with an overall offset/overcatch indicated. Programmes have been implemented to make these minute resolution rainfall measurements through the University of Oklahoma's Environmental Verification and Analysis Centre (EVAC). SPaRCE (South Pacific Rainfall Climate Experiment), GLOBE and the DOE/ARM projects involve school participation in rainfall collection using automated weather stations.

Reference:

Morrissey, M., W.F. Krajewski, and M.J. McPhaden (1994): Estimating rainfall in the tropics using the fractional time raining. *J. Appl. Met., 33,* 387-393.

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*It was learned in late December 1998 that the HYDROSTAR mission, proposed to the NASA ESSP-2 announcement in 1998, was not selected. The SMOS proposal was submitted to ESA on 30 November 1998 and can be viewed at the Web site http://www-sv.cict.fr/cesbio/smos.

5.12 EASTERLY WAVES AND CONVECTIVE ORGANIZATION IN THE EASTERN EQUATORIAL PACIFIC ITCZ (Y. Serra, University of Washington)

Atmospheric sounding data are used to identify easterly wave activity in the East Pacific Intertropical Convergence Zone (ITCZ) during the Tropical East Pacific Process Study (TEPPS). TEPPS collected surface meteorological data, Doppler radar volumes, atmospheric soundings and rainfall data from the NOAA ship *Ronald H. Brown* while on station at 7.8°N, 125°W from 08-23 August 1997. The main objective of the experiment was to understand the discrepancies between satellite microwave and infrared radiometer estimates of rainfall in this data poor region of the Pacific. In addition to results related to this objective, easterly wave activity was discovered as a prominent time scale of variability in the meridional wind and humidity data.

The meridional wind shows variability on the order of 4 days, with a amplitudes of -5 to 12 m s^{-1} from the surface to 2 or 4 km. Maximum amplitudes in moisture variance are >±1 g kg^{-1} from the surface to 4 or 6 km. There were three cycles of the wave observed in the data. The maxima in the moisture occurred about a day before the maxima in the southerlies for two of these three events. An *in situ* convective indicator, calculated from the radar data, confirms a connection between convection over the ship and the meridional wind variance, with the convection occurring in the enhanced southerlies. As the ship provides just a point measurement of the winds, the location of the convection with respect to the surface convergence related to any wave passage cannot be determined. Satellite infrared radiometer (IR) data were also examined for 4-day activity. However, comparisons between IR cold cloud tops (<235°K) and the radar convective activity index indicate that IR data are not a reliable indicator of convection in the east Pacific (S. Yuter, personal communication). Only cloud systems >100 km and longer than 24 hrs in duration were consistently detected as IR cold cloudiness. Nevertheless, these data reveal non-propagating variability in IR temperatures on the scale of 4-5 days. The lack of propagation may be related to the failure of IR to detect all stages of the cloud systems and the use of daily averaged data, currently the highest time resolution available for the preliminary data set. Continued work in this area will include a closer look at the IR temperature data, using warmer cloud top temperatures and higher time resolution, as well as analysis of surface mooring data and NCEP and ECMWF model analyses.

5.13 RELATIONSHIPS BETWEEN THE ATLANTIC AND INDO-PACIFIC EL NIÑO: PREDICTABILITY OF AFRICAN CLIMATE (M. Jury, University of Zululand)

Links between the oceans and the atmospheric circulation over Africa prior to and during historical El Niño events were revealed through empirical studies using National Centre for Environmental Prediction NOAA/USA (NCEP) reanalysis composites and numerical studies using Global Simulation Models (GCM) simulations. Anti-phase relationships of tropical SST on either side of Africa were outlined. Warming of the tropical eastern Pacific increases upper level westerly winds downstream over tropical Africa. Cooling occurs in the eastern Atlantic as surface easterlies drive equatorial upwelling prior to an Indo-Pacific El Niño event. The sub-tropical jet decelerates over southern Africa, creating a high pressure cell which blocks the supply of moisture during austral summer. Warmer sea temperatures in the western Indian Ocean attract convection away from southern Africa.

It is concluded that the atmospheric circulation generated by warm El Niño conditions in the Indo-Pacific Oceans opposes that which develops over the Atlantic Ocean during a warm event there. Coupling of the ENSO circulation over Africa is dependent on the response of the Atlantic Walker Cell and underlying ocean. The PIRATA array is ideally placed to assist our understanding of the uptake of ENSO signals at seasonal lead times. PIRATA has already proved its worth in long-range predictions for Africa. During a December 1997 forecast meeting in Windhoek it was pointed out that the El Niño situation was unusual for southern Africa with warming in the tropical eastern Atlantic Ocean reducing the potential for drought. In hindsight, this was indeed the case. Further dynamical analysis of ocean-atmosphere interactions is proposed as part of the CLIVAR Africa project, and this could ensure continued involvement by African scientists in TIP activities.

5.14 UPPER LAYER HYDROLOGY AND CIRCULATION VARIABILITY IN THE WESTERN EQUATORIAL ATLANTIC (B. Bourles, IRD/ORSTOM, K. Pailler, University of Brest, and Y. Gouriou, IRD/ORSTOM)

The western Tropical Atlantic is an area of crucial interest with regard to the thermohaline circulation and associated mass, heat, and salt transports. There, the North Brazil Current (NBC) and the North Brazil Undercurrent (NBUC) transport warm upper ocean waters toward the northern hemisphere, contributing to balance the southward flow of cold North Atlantic Deep Water, and closing the meridional overturning cell of the global thermohaline circulation. The NBC and NBUC feed surface and subsurface eastward flows at different depths and different latitudes. Namely, from south to north, the NBUC feeds the South Equatorial Undercurrent, whereas the NBC feeds the Equatorial Undercurrent, the North Equatorial Undercurrent and the North Equatorial Countercurrent (NECC).

The quantification of mean and seasonal transports and water mass contents of these different currents is made very difficult due to a large spatial and time variability encountered in this region, and to eddies that detach from the NBC retroflection from boreal summer to winter. Four surveys, carried out in the western Tropical Atlantic, in January-March 1993, January-March 1994, September-October 1995 and April-May 1996 as part of the World Ocean Circulation Experiment Hydrographic Programme, allowed to improve our knowledge of some main aspects of the circulation. Off the continental shelf, while the NBC retroflection is total from June to January, the continuity of the NBC along the American continent toward the Caribbean Sea is confirmed in boreal spring in the upper layer. The southeastward flowing current, observed around 3°N, 45°W and supplied by the NBC retroflection (but also by a North Equatorial Current recirculation) feeds, in the upper layer, the EUC and the NECC, and in the subthermocline layer, the EUC and the Northern Subsurface Countercurrent. Over the continental shelf, estimates of the transport off French Guiana indicate an annual mean coastal flow as high as 3.9±1.2 Sv from the coastline to the 200 m isobath (located 200 km offshore). There is no clear-cut seasonal variability of this coastal flow, which is strongly modulated by the offshore mesoscale eddies shed from the NBC retroflection loop.

The western Tropical Atlantic is also a region where different water masses are present. The waters formed within the subtropical region of both hemispheres exhibit salinity values up to 37 psu just above the thermocline. At the surface, the Amazon discharge is responsible for the presence of large fresh ($S<34$ psu) water lenses of about 30 m thickness, extending eastward as far as 30°W in boreal fall, when entrained by the NECC. Such different water masses superimposition implies significant vertical salinity gradients, largely superior to those observed in the western Pacific Ocean, that induce strong haloclines, and thus marked pycnoclines, yielding to the presence of "barrier layers". It is noticeable that fresh surface waters are generally associated to positive sea surface temperature anomalies, that may be the consequence of barrier layer effects. Furthermore, the determination of the mixed layer depth, by applying the commonly used criteria, indicates values of 3-5 m within the Amazon water lenses.

5.15 THE BARRIER LAYER IN THE ATLANTIC OCEAN (S. Masson, LODYC/University of Paris)

Many papers highlight the importance of the barrier layer in the vertical structure of the western Pacific ocean. The barrier layer is defined as a salinity stratified layer separating the warm surface layer from the thermocline. More recently, a barrier layer has been observed in the west Atlantic. However, this barrier layer does not seem to be created by a maximum of precipitation like in Pacific ocean. An ocean general circulation model forced by the 15-year ECMWF reanalysis fluxes (1979-1993) is therefore used to investigate the barrier layer formation mechanisms and to evaluate its impact on the vertical structure of Atlantic Ocean. Each year, this simulation generates a 40 m thick barrier layer between July and September offshore of the mouth of the Amazon.

The seasonal variation of the barrier layer is mainly caused by the current dynamics. In the surface layer, the North Brazilian Current (NBC) and the North Equatorial Counter Current system bring offshore fresh water from the Amazon, while in the subsurface, salty water from the south Atlantic is advected by the North Brazilian Undercurrent and the North Equatorial Undercurrent system. Our results do not show that input of fresh water by precipitation or by river runoff affect significantly the seasonal variation of the barrier layer.

In this study, interannual variations of the barrier layer are also investigated. The results of the simulation show a minimum barrier layer thickness in 1983 and 1987. In these two years, a strong NBC seems to advect the Amazon water along the coast, limiting the decrease of sea surface salinity offshore. Presence of a robust barrier layer in the simulations encourages us to investigate the effect of the hyaline stratification on vertical mixing. By running an experiment in which the mixed layer is computed only as a function of temperature, we establish the increase of the NBC retroflection by trapping the current in the shallow pycnoclines that result from barrier layer formation.

5.16 FORMATION AND SPREADING OF ARABIAN SEA HIGH-SALINITY WATER MASS (S. Prasanna Kumar, NIO)

The formation and seasonal spreading of Arabian Sea high-salinity water (ASHSW) were studied based on the monthly mean climatology of temperature and salinity in the Arabian Sea, north of the equator and west of 80°E, on a 2° x 2° grid. The ASHSW forms in the northern Arabian Sea during winter and spreads southwards along the 24 sigma-t surface against the prevailing weak zonal currents. The eastern extent of the core is limited by the strong northward coastal current flowing along the west coast of India. During the southwest monsoon, the northern part of the core shoals under the influence of the Findlater jet, while the southern extent deepens. Throughout the year, the southward extent of the ASHSW is inhibited by the equatorial currents.

The atmospheric forcing that leads to the formation of ASHSW was delineated using the monthly mean climatology of heat and fresh water fluxes. Monsoon winds dominate all the flux fields during summer (June-September) while latent heat release during the relative calm of the winter (November-February) monsoon, driven by cool, dry continental air from the north, results in an increased density of the surface layer. Thus, excess evaporation over precipitation, and turbulent heat loss exceeding the radiative heat gain, cool the surface waters of the northern Arabian Sea during winter and drive convective formation of ASHSW.

6. RECOMMENDATIONS

6.1 IOC SUPPORT OF EFFORTS TO REDUCE VANDALISM OF OCEANOGRAPHIC EQUIPMENT AT SEA

Recognizing that vandalism by fishing vessels continues to be a major threat to the viability of maintaining the TAO and PIRATA arrays, and that at some sites data and equipment return have been reduced to significantly less than 50%, the TAO panel recommended that the IOC adopt a resolution to address the problems of vandalism of oceanographic equipment by fishing vessels. Based on this recommendation, the TAO panel chairman and the GOOS representative to the TAO panel produced a draft resolution for presentation to the IOC. The full resolution endorsed by the IOC Executive Council in Paris on 27 November 1998 appears in Appendix I of this report.

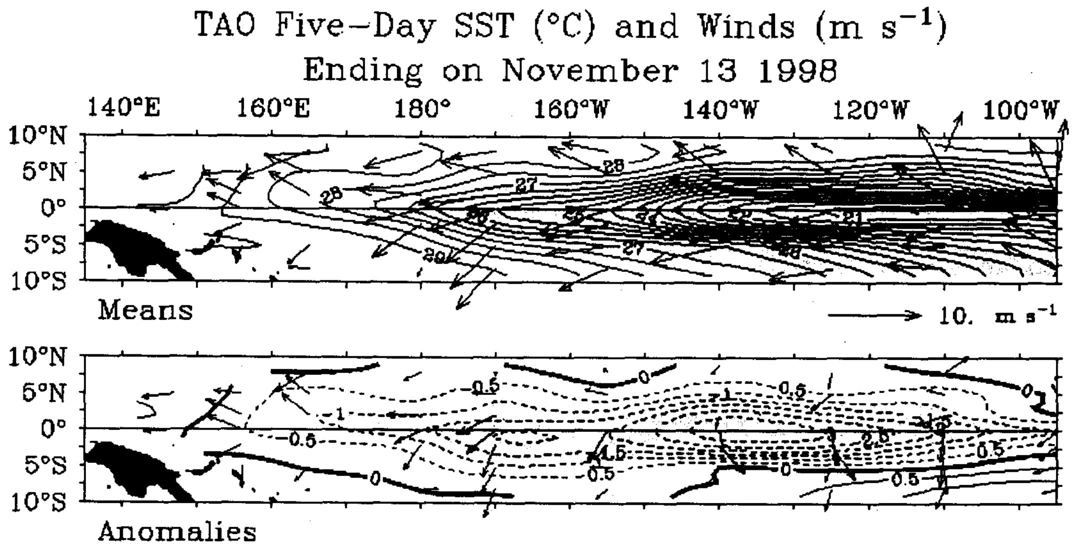
6.2 THERMOSALINOGRAPH PILOT PROJECT

The importance of salinity measurements for describing and understanding climate variability, and for improving ocean general circulation models, is well established. Salinity measurements are also potentially important for improving initial conditions and forecast skill of coupled ocean-atmosphere ENSO prediction models. Recognizing that ORSTOM/Noumea has operated a network of Volunteer Observing Ship (VOS), Thermosalinograph (TSG) measurements since 1991, and that TAO and TRITON cruises to maintain moorings in the Tropical Pacific also provide TSG measurements on a regular basis, the TAO Implementation Panel recommends that a pilot project be conducted to assemble a quality-controlled, unified TSG data base for the tropical Pacific over the period 1991-98. This period encompasses the unique 1991-95 ENSO warm event(s) and the 1997-98 El Niño/La Niña cycle. The Panel further recommends that the IRD/ORSTOM laboratory in Noumea co-ordinate this project and maintain a 1991-98 TSG archive for the benefit of ENSO-related climate research.

6.3 SALINITY REMOTE SENSING FROM SATELLITE

Satellite missions are presently being proposed to space agencies for remote sensing of soil moisture and ocean surface salinity. If approved, launch would be in approximately the 2002-2003 time frame. These missions are expected to resolve large scale climatological sea-surface salinity (SSS) variations in the tropics. Calibration and validation of the satellite measurements will require *in situ* data, such as provided by SSS measurements from the TAO and PIRATA arrays, drifting buoys, and VOS. The combination of *in situ* and satellite data in turn will yield large scale surface analyses that will significantly enhance the value of expanded ocean salinity observations called for in the Proceedings of the Sixth Session of the TAO Implementation Panel (TIP-6, Section 7.2).

It is recommended that (i) these satellite missions be strongly endorsed by the sponsors of TIP, namely CLIVAR, GOOS, and GCOS; and (ii) the number of surface and subsurface salinity observations on moored buoy, drifting buoy and ship arrays be substantially enhanced by launch time.



Wind vectors and sea surface temperatures (SSTs) from the TAO array of current meter moorings and ATLAS thermistor chain moorings for November 9–13 1998. Top panel shows 5–Day means; bottom panel shows 5–Day anomalies from the COADS wind climatology and Reynolds SST climatology (1950–1979). SSTs warmer than 29°C and colder than 27°C are shaded; SST anomalies greater than 1°C and less than −1°C are shaded. The TAO array is presently supported by the United States (NOAA), France (IRD/ORSTOM), Japan (STA), and Taiwan (NSC).

Figure 1

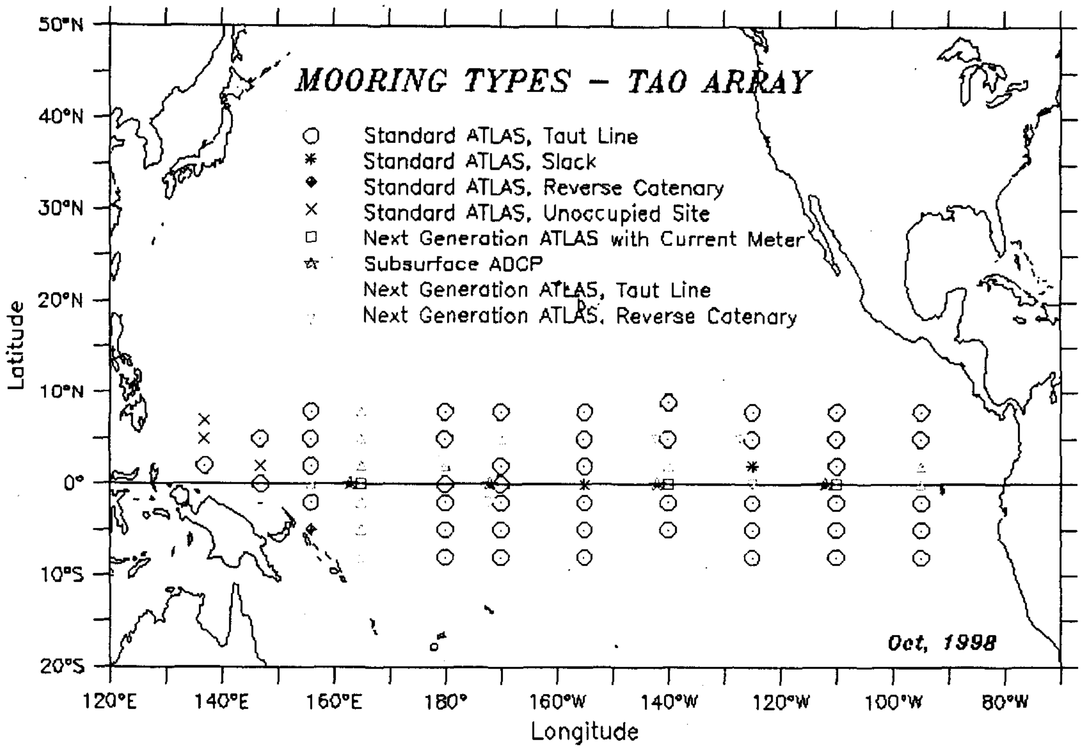

MOORING TYPES – TAO ARRAY
Standard ATLAS, Taut Line
Standard ATLAS, Slack
Standard ATLAS, Reverse Catenary
Standard ATLAS, Unoccupied Site
Next Generation ATLAS with Current Meter
Subsurface ADCP
Next Generation ATLAS, Taut Line
Next Generation ATLAS, Reverse Catenary
Oct, 1998
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
Latitude
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
Longitude

Figure 2

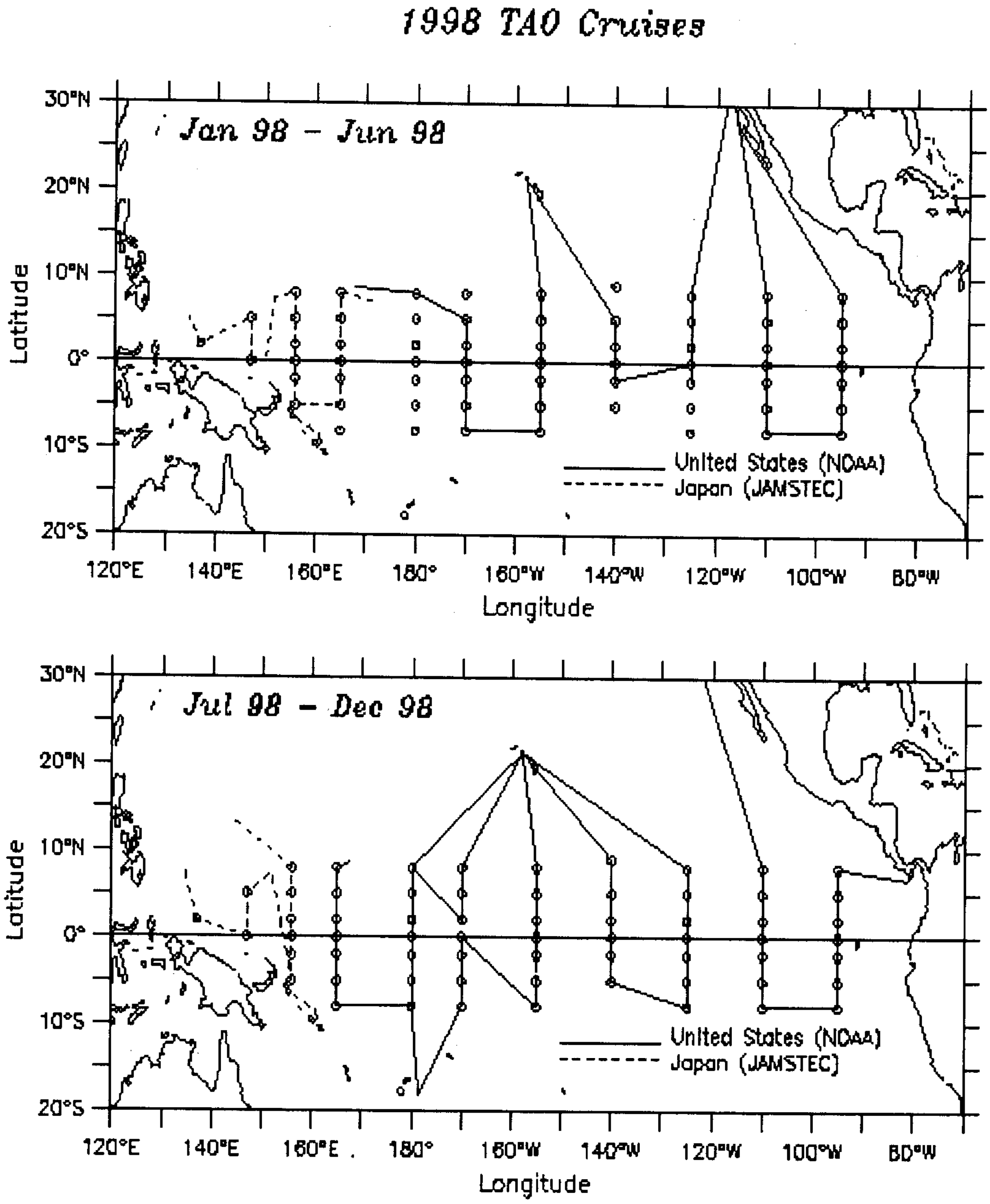

1998 TAO Cruises
Jan 98 - Jun 98
Jul 98 - Dec 98
30°N
20°N
10°N
0°
10°S
20°S
Latitude
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
Longitude
United States (NOAA)
Japan (JAMSTEC)

Figure 3

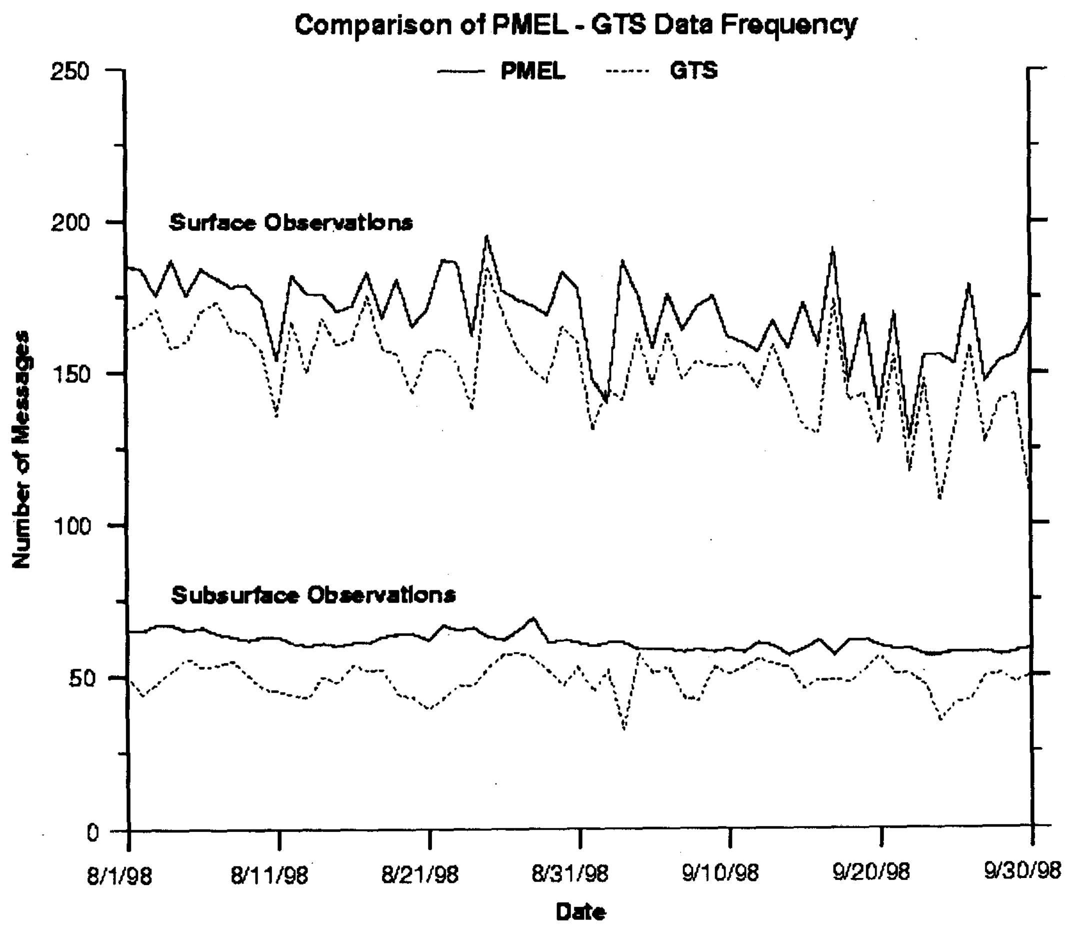

Comparison of PMEL - GTS Data Frequency
PMEL
GTS
Surface Observations
Subsurface Observations
Number of Messages
Date
250
200
150
100
50
0
8/1/98
8/11/98
8/21/98
8/31/98
9/10/98
9/20/98
9/30/98

Figure 4

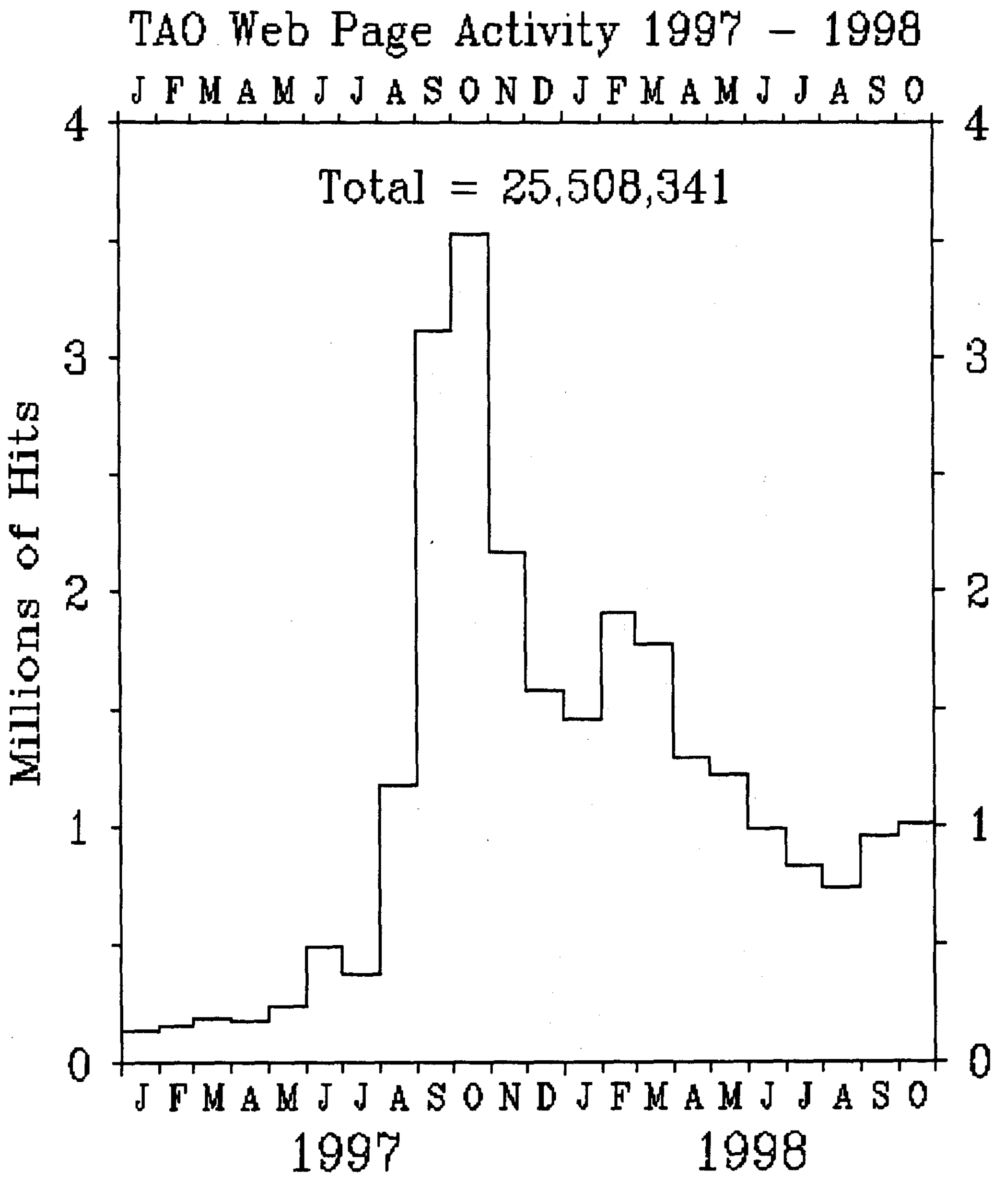

TAO Web Page Activity 1997 - 1998
J F M A M J J A S O N D J F M A M J J A S O
Total = 25,508,341
Millions of Hits
0
1
2
3
4
1997
1998

Figure 5

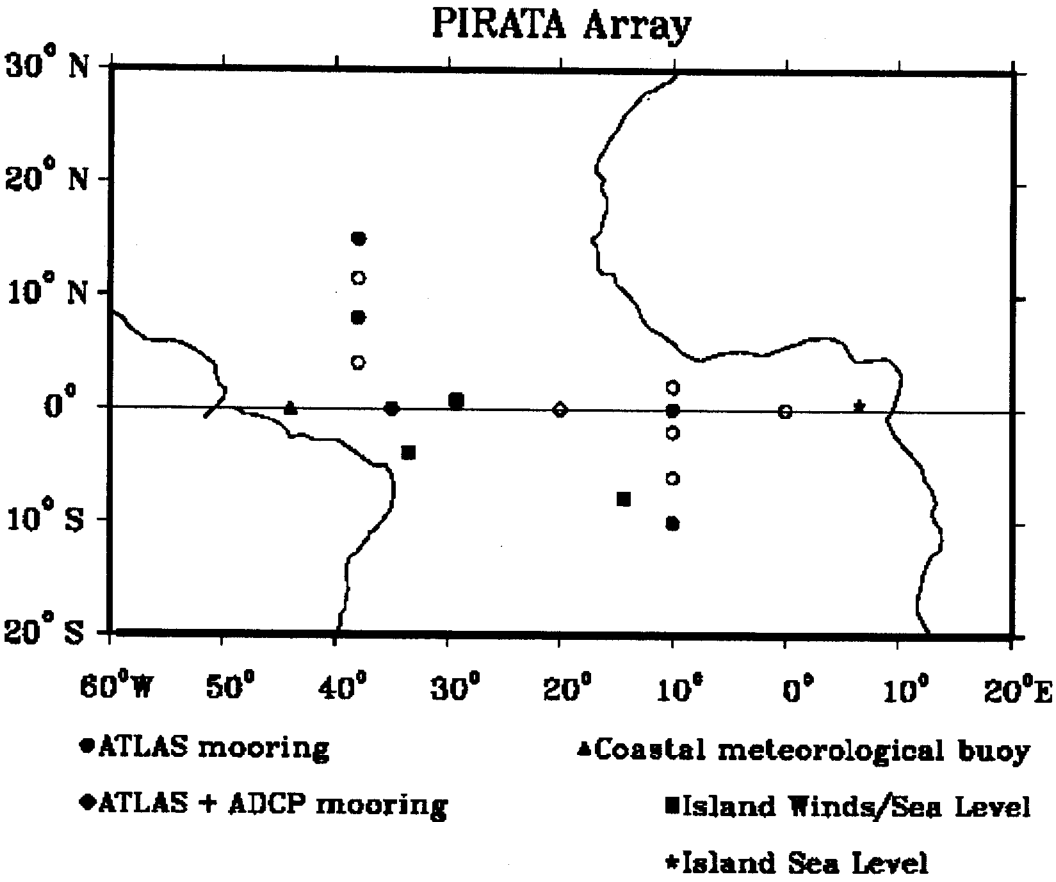

PIRATA Array
30° N
20° N
10° N
0°
10° S
20° S
60°W
50°
40°
30°
20°
10°
0°
10°
20°E
•ATLAS mooring
◆ATLAS + ADCP mooring
▲Coastal meteorological buoy
■Island Winds/Sea Level
*Island Sea Level

Figure 6

ANNEX I

RESOLUTION TO IOC/FISHING VANDALISM

Paris, Friday November 27, 1998
Submitted by the IOC Secretariat

Resolution EC-XXXI.4

IOC SUPPORT OF EFFORTS TO REDUCE VANDALISM OF OCEANOGRAPHIC EQUIPMENT AT SEA

The Executive Council,

1. **Recognizing:**

   (i) the importance of operational systems to the development of GOOS, which is highly dependent on establishing instrumented moorings for permanent observations of the oceans,

   (ii) that vandalism by vessels, in particular fishing vessels, has been a major threat to the viability of maintaining such arrays, since at some sites data and equipment return have been reduced to significantly less than 50%;

2. **Emphasizing** the great value of:

   (i) TAO and PIRATA for improving marine weather and surface wave forecasts, which facilitate efficient ship routing, provide early warning of natural hazards such as storms and hurricanes, and support search and rescue efforts at sea,

   (ii) TAO and PIRATA data for improving climate forecasts of El Niño, La Niña, and related phenomena which affect the lives of hundreds of millions of people around the globe through droughts, floods, fires, and their socio-economic impacts;

3. **Appreciating** the degree of financial commitment already made by those governments involved in setting up the TAO and PIRATA moored arrays that constitute important demonstration projects for GOOS;

4. **Encourages** Member States to protect moored drifting and other unattended equipment at sea;

5. **Instructs** the Executive Secretary IOC to prepare a proposal that the Director-General of UNESCO would present at the appropriate UN level which:

   (i) addresses the problems of the vandalization of oceanographic equipment by vessels, in particular by fishing vessels;

   (ii) encourages appropriate action by the competent international organizations, taking into account the relevant provisions of the UN Convention on the Law of the Sea (UNCLOS), as well as national legislation of Member States on unattended equipment in their respective EEZs and international waters.

6. **Further instructs** the Executive Secretary IOC to bring this item to the attention of the XXth session of the IOC Assembly.

ANNEX II

MEETING AGENDA

SEVENTH SESSION OF THE TAO IMPLEMENTATION PANEL
Hotel Golf Detercontinental
Abidjan,Côte d'Ivoire
11-13 November 1998

NOVEMBER 11 - Wednesday, 8:30 a.m. – 5:30 p.m.

*OPENING CEREMONY (Session Chair, J. Servain/ORSTOM)
*STATUS OF THE ARRAY (M. J. McPhaden, NOAA/PMEL)
*NATIONAL REPORTS
United States: S.Piotrowicz (NOAA/OAR)
Japan: M. Endoh (JAMSTEC)/Y. Kuroda (JAMSTEC)
France: J. Picaut (ORSTOM)
Taiwan: H. Hsu (National Taiwan University)
India: P. Kumar (NIO)

*PROGRAMME STATUS REPORTS
Pilot Research Moored Array in the Tropical Atlantic (PIRATA)
J. Servain (ORSTOM/Brest)
Tropical Rainfall Measuring Mission
Thomas Rickenbach (University of Maryland)
CLIVAR Upper Ocean Panel
W. Kessler (NOAA/PMEL)
Global Ocean Observing System
J. Trotte (GOOS Project Office)

* SCIENCE REPORTS
Seasonal Climate Forecasting at ECMWF
D. Anderson (ECMWF)
Basin-Wide Adjustment of Mass and Warm Pool Displacement During the 1997–98 El Niño-La Niña
J. Picaut (ORSTOM)
Impact of TAO vs. ERS Wind Stresses onto Simulations of the Tropical Pacific Ocean During the 1993–1998 Period by the OPA OGCM
C. Menkes (LODYC)

NOVEMBER 12 - Thursday, 8:30 a.m. – 5:30 p.m.

* SCIENCE REPORTS (continued)
The Delayed Oscillator and the Onset of the 1997–98 El Niño
M. McPhaden (NOAA/PMEL)
Predictability of ENSO and the MJO
W. Kessler (NOAA/PMEL)
Yoshida Jet Detected in JAMSTEC Subsurface Current Moorings
K. Kutsuwada (Tokai University)
Remotely-forced Effects on Currents and Water Properties in the Coastal Upwelling System off Northern and Central Chile
Samuel Hormazabal (University of Concepcion, Chile)
TRITON Salinity Measurements
K. Ando (JAMSTEC)

SSS Changes in the Western Tropical Pacific During the 1996–98 ENSO
T. Delcroix (ORSTOM/Noumea)
Observing Tropical SSS in the Future by Integrating TAO and Satellite Data
G. Lagerloef (Earth and Space Research)
Rainfall Variability in the Tropical Pacific
John Ensworth (University of Oklahoma)
Convective Structure over Equatorial Oceans
Y. Serra (University of Washington)
Relationships Between the Atlantic and Indo-Pacific El Niño and Predictability Over Africa
M. Jury (University of Zululand, South Africa)
Upper Layer Hydrology and Circulation Variability in the Western Equatorial Atlantic
Bernard Bourles (ORSTOM)
The Barrier Layer in the Atlantic Ocean
Sebastien Masson (LODYC)
Formation and Spreading of Arabian Sea High-Salinity Water Mass
P. Kumar (National Institute of Oceanography, India)

NOVEMBER 13 - Friday, 8:30 a.m. – 12:30 p.m.

* DISCUSSION AND RECOMMENDATIONS
* EXECUTIVE SESSION (TIP Members only)

EACH DAY THERE WILL BE A LUNCH BREAK, AND A 30 MINUTE COFFEE BREAK DURING THE MORNING SESSION AND AFTERNOON SESSION. THERE WILL ALSO BE AN ICEBREAKER ON WEDNESDAY EVENING.

ANNEX III

LIST OF PARTICIPANTS

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ANNEX IV

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 co-ordinate 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 programmes.
- To cooperate with organizations such as CLIVAR Upper Ocean Panel and the GOOS/GCOS/WCRP Ocean Observations Panel for Climate (OOPC) 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.

ANNEX V

TAO PANEL MEMBERSHIP

Executive Committee:

M. McPhaden (NOAA/PMEL, Chairman)
Y. Kuroda (JAMSTEC)
J. Picaut (IRD/ORSTOM)

Members:

A. Busalacchi United States of America (NASA/Goddard Space Flight Centre)
H. Hsu (National Taiwan University)
M. Ji (NOAA/NCEP)
W. Kessler (NOAA/PMEL)
P. Kumar (National Institute of Oceanography, India)
K. Kutsuwada (Tokai University)
J. Servain (IRD/ORSTOM)
O. Thiele (NASA/Goddard Space Flight Centre)
M. Vianna (INPE)

CATEGORIES OF PANEL MEMBERSHIP

Panel Membership

Membership of the TAO Implementation Panel will be by invitation of the Global Ocean Observing System Project Office, based on recommendations made by the TAO Panel or its sponsors (GOOS/GCOS/CLIVAR). Categories of membership are:

Executive Committee.

One representative from each nation actively supporting the TAO Array. The TAO Panel chairman will serve as national representatives on the executive committee. Responsibilities of the executive committee include: co-ordinating intersessional activities, recommending membership changes, organizing panel meetings, reporting to parent bodies, etc.

Members

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

ANNEX VI

DEFINITION OF TAO SUPPORT

Support for TAO implies multi-year contributions of critical resources to the maintenance and/or expansion of the moored array.

"Critical resources" are defined as:

1. ship-time
2. specialized mooring hardware and/or instrumentation
3. grant money for operations

"Multi-year" means ongoing rather than one-time support. Multi-year does not necessarily mean each and every year, however. It is expected that there may be political and/or economic downturns that can affect a particular country's ability to contribute on a consistent annual basis. A maximum of three years may pass with no critical contributions before a country slips off the "supporters" list.

By the above definition, the United States of America, Japan, Taiwan, and France are all presently supporters.

ANNEX VII

LIST OF ACRONYMS

ADCP:	Acoustic Doppler Current Profiler
ADEOS:	Advanced Earth Observing Satellite
Argo:	Array for Geostrophic Oceanography
ARM:	Atmospheric Radiation Measurement (Programme)
ASHSW:	Arabian Sea High-Salinity Water (Mass)
ATLAS:	Autonomous Temperature Line Acquisition System
BOBPS:	Bay of Bengal Process Study
BMRC:	Bureau of Meteorology Research Centre (Australia)
CERSAT:	Centre ERS d'Archivage et de Traitement
CLIVAR:	Climate variability and Predictability (WCRP)
CONICYT:	Comision Nacional de Investigacisn Cientifica y Tecnologica
CRO:	Centre Ivorien de Recherche Océanographique
CT:	Conductivity-Temperature
CTD:	Conductivity-Temperature-Depth (Profiler)
DOE:	Department of Energy (USA)
ECMWF:	European Centre for Medium Range Weather Forecasting
ENSO:	El Niño-Southern Oscillation
ERS:	Earth Remote Sensing Satellite
EUC:	Equatorial Undercurrent
EVAC:	Environmental Verification and Analysis Centre
FFA:	Forum Fisheries Agencies
FONDAP:	Fondo Nacional para el Desarrollo de Areas Prioritarias
FY:	Fiscal Year
GAME:	GEWEX Asian Monsoon Experiment
GCM:	Global Circulation Models
GCOS:	Global Climate Observing System
GEWEX:	Global Energy and Water Cycle Experiment (WCRP)
GLOBE:	Global Learning and Observations to Benefit the Environment
GOOS:	Global Ocean Observing System
GSFC:	Goddard Space Flight Centre (NASA/USA)
GTS:	Global Telecommunication System
GV:	Ground Validation
HYDROSTAR:	Hydro Scanning Thinned Array Radiometer
ICPO	International CLIVAR Project Office
IFREMER:	Institut Francais de Recherche pour l'Exploitation de la Mer (France)
INPE:	Instituto Nacional de Pesquisas Espaciais (Brazil)
IOC:	Intergovernmental Oceanographic Commission
IR:	Infrared Radiometer
IRD:	Institut de Recherche pour le Développement
IRI:	International Research Institute
ITCZ:	Intertropical Convergence Zone
JAMSTEC:	Japan Marine Science and Technology Centre (Japan)
JAPACS:	Japanese Pacific Climate Study
JASMINE:	Joint Air-Sea Interaction Monsoon Experiment
JGOFS:	Joint Global Ocean Flux Study
JPL:	Jet Propulsion Laboratory
KWAJEX:	(The) Kwajalein Experiment
LBA:	Large-scale Biosphere Atmosphere (Experiment)
LODYC:	Laboratoire d'Océanographie Dynamique et de Climatologie (France)
MBARI:	Monterey Bay Aquarium Research Institute (USA)
MJO:	Madden-Julian Oscillation

MIRAS	Microwave Imaging Radiometer with Aperture Synthesis
NASA:	National Aeronautics and Space Administration (USA)
NASDA:	National Space Development Agency of Japan (Japan)
NBC:	North Brazil Current
NBUC:	North Brazil Undercurrent
NCEP:	National Centre for Environmental Prediction (NOAA/USA)
NECC:	North Equatorial Countercurrent
NDBP:	National Data Buoy Programme
NIO:	National Institute of Oceanography (India)
NIOT:	National Institute of Ocean Technology
NOAA:	National Oceanic and Atmospheric Administration (USA)
NSCAT:	NASA Advanced Scatterometer (USA)
NTU:	National Taiwan University (Taiwan)
OAR:	Oceanic and Atmospheric Research Agency (USA)
OGCM:	Oceanic General Circulation Model
OOPC:	Ocean Observations for Climate Panel
ORSTOM:	Institut Francais de Recherche pour le Développment en Cooperation (The old name of IRD)
PALACE:	Profiling Autonomous LAgrangian Circulation Explorer
PAR:	Photosynthetically Available Radiation
PIRATA:	Pilot Moored Array in the Tropical Atlantic
PMEL:	Pacific Marine Environmental Laboratory (NOAA/USA)
PR:	Precipitation Radar
PSP:	Precision Spectral Pyranometer
RAMSES:	Radiomitrie Appliquée à la Measure de la Salinité et de l'Eau du Sol
SAREC/SIDA:	Department of Research Cooperation of the Swedish International Development Cooperation Agency
SCSMEX:	South China Sea Monsoon Experiment
SEACAT:	Sea-Bird Conductivity and Temperature Recorder
SMOS:	Soil Moisture Ocean Salinity
SOPAC:	South Pacific Commission
S-PALACE:	Salinity/Profiling Autonomous LAgrangian Circulation Explorer
SPaRCE:	South Pacific Rainfall Climate Experiment
SSC:	Scientific Steering Committee
SSIWG:	Salinity Sea Ice Working Group
SSS:	Sea-Surface Salinity
SST:	Sea-Surface Temperature
STA:	Science and Technology Agency (Japan)
SURTROPAC:	Survey of the Tropical Pacific (SURveillance TRans-Océanique du PACifique) ORSTOM, France
TAO:	Tropical Atmosphere-Ocean Array
TEFLUN:	Texas-Florida Underflights
TEPPS:	Tropical East Pacific Process Study
TIP:	TAO Implementation Panel
TMI:	TRMM Microwave Imager
TOCS:	Tropical Ocean Climate Study (Japan)
TOGA:	Tropical Ocean-Global Atmosphere
TOPEX/Poseidon:	Ocean Topography Experiment
TRITON:	Triangle Trans-Ocean Buoy Network (Japan)
TRMM:	Tropical Rainfall Measuring Mission (NASA/USA)
TSG:	Thermosalinograph
UNESCO:	United Nations Educational, Scientific, and Cultural Organization
UOP:	Upper Ocean Panel
VACM:	Vector Averaging Current Meter

VIRS:	Visible Infrared Radiometer System
VMCM:	Vector Measuring Current Meter
VOS:	Volunteer Observing Ships
WCRP:	World Climate Research Programme
WWB:	Westerly Wind Burst
XBT:	Expendable Bathythermography