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1. SUMMARY

The European Centre for Medium Range Forecasting (ECMWF) in Reading, England hosted the sixth session of the Tropical Atmosphere Ocean (TAO) Implementation Panel (TIP-6) which was held from 4–6 November 1997.The purposes of TIP-6 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-6, and the reason for holding it at ECMWF, was to foster improved communication between the TAO Project and operational weather and climate prediction centers. Participants from eight nations attended this session.

TIP-6 opened with an update on the strong El Niño/Southern Oscillation (ENSO) event presently underway in the tropical Pacific. TAO data have proven to be extremely valuable in monitoring the evolution of this event which is the strongest of the century. They have also been a key source of data for initializing coupled ocean-atmosphere forecast models, many of which predicted that 1997 would see the development of a warm ENSO event.

The panel then turned to discussing issues of instrumentation, array maintenance, and data dissemination. There are TAO moorings at 64 sites across the equatorial Pacific, including five sites where long-term current measurements are being made and 13 sites where standard ATLAS moorings have been replaced with next generation ATLAS moorings. The next generation ATLAS is based on inductive coupling technology and provides increased temporal resolution, increased accuracy for ocean temperature, and flexibility to add additional sensors such as rainfall, radiation, and ocean conductivity. Discussion topics included ship time requirements, vandalism and damage to the buoys, outreach efforts to the fishing communities, ocean velocity and salinity measurements, and data dissemination updates on the World Wide Web. The throughput of TAO data on the Global Telecommunications System (GTS) was also discussed.

Updates were presented on Japan's TRITON array of moored buoys scheduled to be deployed in the western Pacific starting in March 1998, the PIRATA array which has begun with two moored buoys deployed in September 1997 in the tropical Atlantic (France, Brazil, and US), and Taiwan's mooring in the South China Sea deployed in April 1997 as part of the South China Sea Monsoon Experiment (SCSMEX). India deployed four moored buoys in the Bay of Bengal in 1997 with plans to augment these with six buoys in the Arabian Sea in 1998 as part of the Indian National Data Buoy Programme. Information on a proposed new climate-related mooring program in the tropical Indian Ocean, namely JASMINE (Australia and the United States), was also presented.

Presentations on international and national climate programs included updates on CLIVAR, GOOS, OOPC, NOAA's Office of Global Programs, International Research Institute for Climate Prediction (IRI), Pan American Climate Studies (PACS), Atmospheric Radiation Measurements (ARM) Program, and the Tropical Rainfall Measuring Mission (TRMM). A review of the Data Buoy Cooperation Panel (DBCP) and its functions was also presented. Scientific presentations highlighted the uses of TAO data at several operational weather prediction centers (ECMWF, NCEP, Météo France, and the US Navy). Additional presentations focused on ENSO forecasting and regional impacts, surface flux and salinity variability in the tropical oceans, ocean color, and large-scale current fluctuations.

Several recommendations from TIP-6 emerged during discussions following the presentations. The importance of salinity measurements was recognized for improving ocean general circulation models and for initializing short-term climate forecasts. It was suggested that additional surface and subsurface salinity sensors be added to selected moorings as a contribution to an emerging salinity monitoring effort which includes VOS, S-PALACE, and other platforms. A second recommendation was to measure surface fluxes with the highest possible accuracy at selected sites in order to verify flux climatologies and to improve coupled models. Two other recommendations were made regarding the GTS data stream. Considering the importance of boundary layer moisture in

atmospheric model calculations of surface fluxes, it was recommended that relative humidity measurements from the TAO buoys be placed on the GTS so they could be assimilated and/or used for model validation at operational centers. Due to the sparseness of measurements from the Indian Ocean, it was recommended that an effort be made to make the data from the National Data Buoy Programme of India available on the GTS. Finally, it was recommended that the TAO Implementation Panel become an action group of the DBCP.

2. OPENING OF THE MEETING

Dr. David Anderson welcomed TIP-6 participants and gave a brief overview of activities at ECMWF. The Centre mainly focuses on medium range weather forecasting (out to 10 days), but also is engaged in some efforts related to climate. These efforts include a recent 15-year global atmospheric reanalysis (1979–93) which may soon be extended to 40 years, as well as experimental seasonal climate forecasting. Dr. Anderson noted that both weather and climate analyses and forecasts make use of TAO data for initialization, and he expressed his appreciation for the TAO panel working so diligently to maintain this important data set. Dr. David Burridge, Director of ECMWF, likewise welcomed the TAO Panel, and further drew further attention to the value of TAO data for ECMWF activities.

Dr. Michael McPhaden, Chairman of TIP, expressed his appreciation to ECMWF for agreeing to host TIP-6. He noted that this meeting was special for at least two reasons. First, this was the first TAO Panel meeting held at an operational centre; and second, the meeting was being held in the midst of an intense El Niño event. Dr. McPhaden suggested that data from the array would prove to be extremely valuable in studies of the causes and consequences of this El Niño, and in evaluating the strengths and weaknesses of various seasonal-to-interannual climate forecasting schemes. He then went on to review the purposes of the meeting (as detailed in the summary), and the agenda.

3. SUMMARY OF CURRENT CONDITIONS IN THE TROPICAL PACIFIC

Early 1997 witnessed the rapid development in the tropical Pacific of a significant El Niño/Southern Oscillation (ENSO) warm event. Warm sea surface temperature (SST) anomalies erupted during April–June in the tropical eastern Pacific, and by July SST anomalies were the warmest observed in the past hundred years in that region. SST anomalies in the eastern Pacific subsequently exceeded 5°C*. The Southern Oscillation Index, the difference between surface air pressure at Tahiti minus that at Darwin, Australia, dropped precipitously to negative values March 1997, and remained negative throughout 1997. Wind and SST conditions in the equatorial Pacific at the time of TIP-6 are illustrated in Figure 1.

Surface winds along the equator were punctuated by a series of westerly events of increasing intensity and eastward fetch beginning in early 1997. These westerly episodes excited downwelling equatorial Kelvin waves that propagated eastward, eventually depressing the thermocline by over 90 m in the eastern Pacific. 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 lead to an eastward and equatorward shift in atmospheric deep convection and precipitation in the tropical Pacific. Resultant heating of the atmosphere altered the position of the sub-tropical jet streams and storm tracks, affecting weather patterns worldwide. The coastal ocean regions off both western North and South America were also affected by remote oceanic and atmospheric forcing from the tropics during this event.

The intensity of this El Niño event caught the scientific community by surprise. Though several state-of-the-art prediction models indicated 1997 would witness the development of an El Niño, none

*Editors note: Monthly mean SST anomalies in the Niño3 (5°N–5°S, 150°W–90°W) region of the eastern Pacific in November and December 1997 exceeded those observed at anytime during the 1982–83 El Niño, which up to that time was the strongest of the century.

of them accurately forecast its magnitude, or the timing of its onset which occurred much earlier in the calendar year than for previous events. The Lamont-Doherty coupled ocean-atmosphere forecast model, which uses no ocean data for initialization, failed to predict the event at all.

4. NATIONAL REPORTS

4.1 UNITED STATES (L. Mangum/W. Woodward, NOAA/OAR)

4.1.1 TAO Array

The locations of the present moorings in the TAO array are shown in Figure 2. In addition to the standard ATLAS moorings throughout the array, thirteen sites are instrumented with next generation ATLAS moorings. At three of these sites, reverse catenary next generation moorings were deployed nearby traditional ATLAS moorings for intercomparison. Long-term current measurements are being made at five sites along the equator; one site off the equator (8°N,125°W) was instrumented with a subsurface ADCP by PMEL in April 1997 for a one-year study in support of PACS.

4.1.2 TAO Array Annual Operation Plan

Ship time support for the TAO array in calendar year 1997 is summarized in Figure 3 and the following table. During 1997, three ships were used in support of the array: the NOAA ship *Ka'imimoana*, JAMSTEC's research vessel *Kaiyo*, and Taiwan's research vessel *Ocean Researcher*. NOAA provided 252 days of ship time between 95°W and 165°E with JAMSTEC providing 65 days and Taiwan provided 9 days west of the date line. The new NOAA vessel *Ron Brown* also serviced one of the TAO moorings at 8°N, 125°W during a PACS cruise. In 1998, a major change will be the start of Japan's *Mirai* cruises in March 1998 to deploy TRITON moorings along 156°E. In addition to 1998 TAO cruises on the *Ka'imimoana*, 30 days of time on the *Ron Brown* is anticipated.

Ship Time Summary

	1997	1998	
Western Pacific (137°E–165°E)			
Japan (*Kaiyo*)	65	63	
Japan (*Mirai*)	--	26	(TRITON)
Taiwan (*Fisheries Researcher*)	9	?	
US (*Ka'imimoana*)	15	15	
TOTAL	89	104	(includes TRITON)
East Pacific (95°W–180°W)			
US (*Ka'imimoana*)	237	207	
US (*Ron Brown*)	--	30	
TOTAL	237	237	

4.1.3 Maintenance Requirements

The TAO array has specific scheduling and ship time requirements to ensure continuity of the data and maintenance of equipment. Surface current meter moorings require recovery/deployment every six months, whereas ATLAS and subsurface ADCP moorings require recovery/deployment every twelve months. All sites should be visited at least every six months to check the status of the instruments, verify data quality, and make any necessary repairs. Flexibility in cruise plans is necessary so as to allow for recovery of drifting moorings or unscheduled repairs. On three cruises in 1997, the *Ka'imimoana* diverted from their cruise track, twice to pick up ATLAS moorings that were adrift and also once to recover a malfunctioning LODYC (France) CARIOCA drifter near 110°W. Sufficient time must be build into schedules to allow for unexpected problems with moorings, bad weather, and strong currents.

4.1.4 Vandalism

Vandalism and damage caused by commercial vessels continue to be a significant problem which effect data return and instrument loss. Efforts continued in the past year to work with national and international fishing agencies to find solutions to the problems. Brochures were send to Latin American fishing boats and also to agencies in ten Pacific Rim countries for distribution to local fishing fleets. The TAO Operations Manager, CDR Tim Wright, attended the South Pacific Commission (SOPAC) meeting in Fiji in October 1997 along with JAMSTEC personnel to enlist the assistance of island nations in the region.

Last year at TIP-5, the decision was made to call a moratorium at three sites in the western Pacific until progress has been made in combating vandalism. At 2°N, 147°E, the data return was below 40%, four out of eight moorings were lost, and the remaining four were damaged. At 5°N, 137°E, five out of five moorings were lost and no equipment has ever been recovered at that site. Similar problems were also seen in the short history of 7°N, 137°E, which has also proven to be a difficult site to service by the *Kaiyo* due to bad weather and cruise length restrictions. Two other sites being watched closely include 0°, 147°E and 2°N, 137°E where instrument damage and data return continue to be a problem.

4.1.5 Velocity Measurements

PMEL continued to maintain Acoustic Doppler Current Meter moorings at three sites along the equator at 110°W, 140°W, and 170°W. Additional current measurements were made at 8°N, 125°W by PMEL during the past year as an enhancement to the PACS program. Each subsurface ADCP mooring is deployed for one year. JAMSTEC continued to maintain a subsurface ADCP mooring 0°, 147°E and also took over responsibility for the subsurface current mooring at 0°, 165°E as discussed in the proceedings from TIP-5. Processing has been recently completed for all of PMEL's ADCP data recovered during the past year and these are available on the TAO Web data delivery page. PMEL also continued to maintain traditional surface current meter moorings at 0°, 110°W; 0°, 140°W; and 0°, 165°E.

4.1.6 Salinity Monitoring

At the TIP-4 meeting in September 1995, a revised salinity monitoring plan was adopted for the western Pacific. During the past year, surface SEACATs were in place on 16 TAO moorings between 156°E and 180°W. Instrumentation was provided by ORSTOM and PMEL. Data return from the past year was 85%. These data are being quality-controlled and should be available in early 1998 on the Web. It is planned to continue these surface salinity measurements during the next year.

4.1.7 Next Generation ATLAS Moorings

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

From the standard suite of sensors, the data that are available in real time consist of several values of the surface measurements updated hourly each day as well as the previous day's average of both the surface and subsurface data. Ten minute data is stored onboard for all sensors and will be available after the mooring is recovered. Daily-averaged conductivities can be transmitted in real time from four depths and ten minute samples are also stored in the sensor modules. An RM Young capacitance rain gauge can be interfaced to the data stream; one minute accumulations are stored onboard and the daily mean, standard deviation, maximum rate, and the percent time raining are transmitted back. Radiation measurements can be made using an Eppley PSP radiometer sampled at 1 Hz; 2 minute averages are stored and the transmitted data will consist of a daily mean, maximum, and standard deviation (computed for daylight hours).

In support of the DOE/ARM program, four next generation ATLAS moorings with radiation sensors were deployed along 165°E in June 1997. The TRMM Project Office is supporting rainfall and surface salinity measurements on selected moorings, the first ones of which were also deployed in 1997. Two next generation ATLAS moorings were also deployed as part of PIRATA in the eastern Atlantic and one was deployed in the South China Sea as part of Taiwan's contribution to the SCSMEX experiment. There have been failures with the salinity sensors and PMEL is working with the manufacturer (Sea-Bird) to determine the cause of the problems. Next generation ATLAS moorings will continue to be phased into the TAO array during the next year as funding permits.

Reference:

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

4.1.8 Data Availability

TAO data continues to be available to the international community through anonymous FTP file transfer, the World Wide Web (**http://www.pmel.noaa.gov/toga-tao/**), and the GTS. New Web pages were set up for SCSMEX, PIRATA, TRMM, and DOE/ARM to allow for display of the additional sensors funded by these programs. The TAO Project Office is working with Brazil and France to set up a mirror site for the PIRATA Web pages in each country. With the present El Niño event underway, information from TAO Web pages has been in great demand, with over three million hits each in September and October 1997. The TAO Project will continue to add new displays and data during the next year, including the high resolution data from the next generation ATLAS sensors (10-minute data) and special sensors (rain, radiation, salinity, and currents). An additional area of work during the upcoming year will be a detailed comparison of data from the TAO and TRITON moorings which are scheduled to be co-located along 156°E starting in March 1998. TAO personnel are working with JAMSTEC personnel to set up mirror Web sites in both Japan and at PMEL to coordinate data quality control and processing.

The TAO Project Office continues to work closely with Service Argos and the Buoy Quality Control Network sponsored by the Data Buoy Coordination Panel to ensure high quality real-time GTS data. With a new NOAA satellite available through Service Argos, an approximate increase of 50% was seen the numbers of GTS hourly surface messages starting in late September 1997. During the month of October 1997, over 1800 subsurface temperature profiles and over 7000 surface observations were distributed on the GTS network.

4.1.9 TAO Real-Time Data Monitoring: An Update

Our ability to sustain the long-term operation of components of the ocean observing system depends increasingly on our ability to document applications for the data and to quantify the usage and value of the data in those applications. Previous analyses of the use of TAO data in the global atmospheric models at NCEP indicated that only two-thirds of the real-time data available from the TAO array was being used. One third of the observations was not arriving in time at NCEP to be assimilated into their global system. Because the value and impact of the TAO observations (and other ocean observations) increases as more data is available, it is important to maximize the quantity, quality and timeliness of the real-time data. Consequently the NOAA GOOS Center at AOML is establishing a data tracking capability for the real-time TAO data pipeline. The availability and usage of the TAO observations will be routinely monitored and documented in an effort aimed at maximizing their use and value in the NCEP global models. Results from these monitoring activities will be reported at subsequent TIP meetings.

4.2 JAPAN (M. Hishida and Y. Kuroda, JAMSTEC)

4.2.1 Summary of Frontier Research Program (FRP) for Global Change:

- The FRP's main objective is to accurately predict variations of the earth's system with regards to global change and global warming.
- The science plan of FRP includes process studies and predictions of Asia-Pacific climate change, the hydrological cycle in the Asian region, global warming, and model integrations.
- FRP research sites are located at the University of Hawaii in Honolulu (International Pacific Research Center), University of Alaska in Fairbanks (International Arctic Research Center), and in Mamamatzu-cho, Japan (Tokyo Earth Research Center).
- FRP programs are initiated by US-Japan cooperation which are related to international programs under WCRP-CLIVAR, GEWEX-GAME, and IGBP.
- FRP is closely related to observational research projects using Japan's new vessel *Mirai*, the TRMM project, and the ADEOS-II satellite. The utilization of other important data from the TAO, PIRATA, and TRITON projects is also included.
- FRP will include process studies, model development, and simulations with an earth simulator using a teraflop super parallel computer in the beginning of the 21st century.

4.2.2 Activities of TOCS and TRITON at JAMSTEC

Tropical Ocean Climate Study (TOCS): JAMSTEC begun the Tropical Ocean Climate Study (TOCS) program in 1993 which continued work began in JAPACS (Japanese Pacific Climate Study, 1987–1993). The objective of TOCS is to achieve the better understanding of ocean circulation in the warm pool and its relationship to the ENSO phenomena and global climate change.

- TOCS Cruises: JAMSTEC has conducted two 25-day cruises in a year using the R/V *Kaiyo* to measure the ocean and atmospheric conditions using CTD, shipboard-ADCP, radiosonde, etc. JAMSTEC began the operation of R/V *Mirai* in October 1997, and the first TRITON buoy operation will be done in March 1998.

  1997 Feb.–Mar. R/V *Kaiyo* 37 days from Majuro to Palau
  1997 Aug. R/V *Kaiyo* 28 days from Guam to Palau
  1998 Dec.–Feb. R/V *Kaiyo* 35 days from Majuro to Palau
  1998 Mar. R/V *Mirai* 26 days from Japan to Sydney
  1998 summer R/V *Kaiyo* (Planned similar to boreal summer 1997)
  1998–99 winter R/V *Kaiyo* (Planned similar to boreal winter 1997–98)
  1999 Mar. R/V *Mirai* (Planned)

- Array of Subsurface ADCP Moorings: JAMSTEC has deployed subsurface ADCP moorings to detect the daily, seasonal and year-to-year changes of the equatorial and low latitude western boundary currents. Presently, JAMSTEC has moorings at 7 stations: (0°, 142°E), (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 two sites of (0°, 147°E) and (0°, 165°E) are deployed as a part of TAO current meter array.
- Development of TRIangle Trans Ocean buoy Network (TRITON): The history of development and present implementation schedule in the tropics is as follows:
  FY 1995: Basic design and field test of a prototype mooring in February 1996.
  FY 1996: A new mooring system design was completed

One complete prototype TRITON mooring was constructed and two sea trials near Ogasawara Islands were completed.
International workshop for the buoy network was held in May 1997 in Mutsu city.
TRITON program was acknowledged as one of CLIVAR's observational systems at CLIVAR SSG held in June 1997 in Sapporo.

FY 1997: JAMSTEC started the operation of R/V *Mirai* beginning in October 1997.
Third sea trial of the prototype buoy was conducted in October 1997 at 37.5°E,152°E (east of Japan).
Buoy sensor calibration system and buoy maintenance facilities were completed and equipped in a new buoy maintenance building at JAMSTEC Mutsu-Branch at the home port of R/V *Mirai*.
The TRITON buoy data processing and buoy parts management software has been installed in the buoy maintenance building.
TAO/TRITON data integration and distribution software will be completed by PMEL in February 1998.
The TRITON buoy deployments will start in March 1998 by R/V *Mirai* at the four sites of (8°N,156°E), (5°N,156°E), (2°N,156°E), and (0°,156°E) where intercomparison between ATLAS and TRITON buoys will be carried out. JAMSTEC started a new collaboration program with BPPT (Indonesia) on climate studies with an emphasis on buoy network.
JAMSTEC also started to discuss with SOPAC and FFA how to advertise and provide education regarding the TRITON buoy program to fishermen, in order to avoid conflict with fishing activities in the western tropical Pacific.

FY 1998: Four TRITON buoys will be constructed and four sites will be in operation.
FY 1999: Nine sites will be in operation.
FY 2000: Thirteen sites will be in operation.
FY 2001: Fifteen sites will be in operation.
FY 2002: Eighteen sites will be in operation.

The TRITON buoy array will be started in the western tropical Pacific harmonized with the TAO array and will later be expanded to the Indian Ocean and mid/higher latitudes.

JAMSTEC has already prepared basic facilities to maintain TRITON buoys and some technical staff are employed. The deployment plan, however, has been lengthened because of the difficult financial status in Japan. We need further international support and cooperation to develop and accelerate the TRITON program.

4.3 TAIWAN (D. Tang, National Taiwan University)

In the past year, Taiwan has put most effort into the study of ocean variability in South China Sea (SCS). To monitor the upper ocean thermal variation in the SCS, an ATLAS mooring was deployed at 115.6°E, 18.1°N. It was the first time that an ATLAS mooring was deployed at such high latitude in the western Pacific. Generally speaking, the mooring worked well and survived at least through two typhoons. The wind sensor is presently not working due to a hardware problem. The data are transmitted daily back to PMEL and then to NTU, and is available to the general community. The hourly data will be available after the mooring is recovered in April 1998.

Six current meter moorings, including four self-contained Acoustic Doppler Current Profilers (SC-ADCP), were deployed in the northern SCS, mainly in the Luzon Strait. The new measurements showed quite different features from the early studies which mostly were based upon the ship observations and numerical model results. Since the SCS is a nearly closed basin, the early studies showed that the water circulation was relatively simple. It was mainly driven by the monsoon which was southwesterly (northeasterly) in summer (winter), respectively. The Luzon Strait is the main channel connecting the SCS and Pacific Ocean. The early studies showed that the Kuroshio water intruded into the northern SCS in winter and the SCS water flowed out to the Pacific Ocean in summer. The intruded water did not have much effect on the SCS mainly owing to the insufficient amount of volume transport. Unfortunately, these studies are not supported by the current measurements. The new data shows that Kuroshio current consistently intrudes into the northern SCS. The seasonal variation of current velocity is unclear. The estimated volume transport of intrusion is around 8 Sv. This large amount intruded water should have a significant impact at least on the circulation of northern SCS where the circulation may not be dominated only by the monsoon. Moreover, the data itself is interesting. The observed maximum speed at 1000 m was around 100 cm s^{-1}, which is a rare phenomena. This large speed could be related with the convergence of tidal current in the Strait.

Taiwan also provided assistance for maintaining the TAO array in the western tropical Pacific Ocean last year. From Guam to Taiwan during September 1997, the *Fishery Researcher I* recovered one and deployed two ATLAS moorings. Taiwan will continue to provide the necessary assistance to TAO array.

4.4 INDIA (P. Kumar, NIO)

JGOFS India Arabian Sea Process Study and Current Observational Programmes in the Indian Ocean

4.4.1 JGOFS Arabian Sea Study

Under the Indian JGOFS program, extensive multi-disciplinary field measurements were carried out in the central and eastern Arabian Sea to understand how closely the chemical and biological changes are coupled to the physical forcing. The field measurements started in 1994 and lasted until February 1997, during which two cruises were held during winter (February 1995 and 1997) and during summer (1995 and 1996; July–August) and one during the inter-monsoon (April–May). These cruises were carried out onboard Indian research vessel R/V *Sagar Kanya*. These measurements provided some interesting new insight into the tight coupling between the physical forcing and chemical/biological response during the winter and summer monsoon.

During the summer monsoon (June–September), high biological production was observed in the interior Arabian Sea away from the coastal upwelling zones of Somalia and Arabia. The nutrients which supported the observed high production and biomass resulted from physical processes. Physical data suggested that the lateral advection of fluid in the Ekman layer transports the nutrient rich upwelled waters of Somalia into the interior Arabian Sea which supports the observed high production in the southern regions. In the north, a combination of lateral advection from the Arabian coast as well as upward Ekman pumping, under the influence of cyclonic wind stress curl north of the Findlater Jet, is responsible for the high pigment concentrations.

During the winter monsoon (November–February), a combination of reduced solar insolation and enhanced evaporation under the influence of dry continental air brought into the northern Arabian sea by the north-east trade cools the upper layers. Accordingly, the northern Arabian Sea (north of 15°N), experiences densification and convective mixing, which in turn result in the injection of nutrients from the thermocline region. This nutrient availability into the nutrient depleted upper layers triggers winter bloom.

Thus the Indian JGOFS measurement programme revises our conventional picture of Arabian Sea productivity which stated that a tropical ocean is always nutrient limited, and gives us some new insight into the close coupling between the physical forcing and chemical and biological responses.

4.4.2 Present and Planned Observational Programmes in the Indian Ocean

Considering the importance of the eastern Indian Ocean to climatically critical ocean-atmospheric interaction, a number of observational programmes are in future plan to monitor this region. To start with, as a part of the National Data Buoy Programme, four buoys (Norwegian) are deployed in the Bay of Bengal, measuring the wind speed and direction, air and water temperature, conductivity, wave height and direction, and current speed and direction. These buoys are equipped with global positioning system and communicate with the shore station through Inmarsat-C. Six such buoys are also planned for deployment in the Arabian Sea. As with the Arabian Sea JGOFS study, a Bay of Bengal Process study is planned during 1998–99 and would last for three years during which extensive water column and surface meteorological measurements will be carried out on five cruises. As a part of the Acoustic Thermometry and Ocean Climate (ATOC) program, there are plans to deploy acoustic receivers in the Bay of Bengal. Under the Indian Climate Research Programme (ICRP) as a part of the ocean component, two ATLAS type moorings are projected to be deployed in the eastern equatorial Indian Ocean and the proposal is now with the Department of Science & Technology (DST) for funding consideration. If accepted, it will start off by the year 1999–2000.

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

Since the disappearance of a permanent R/V at Noumea in 1993, the maintenance of the TAO array in the Pacific by France was done through the occasional venues of a French R/V in the Pacific. This was possible in 1994 and 1996 and it is very likely that the R/V *L'Atalante* will return in the Pacific in 1999. Nevertheless, the permanent contribution of France in TAO since 1993 is through the contribution of two dozen of SEACAT thermosalinographs to a pool of instruments handled by NOAA/PMEL, in order to monitor near-surface salinity in the western equatorial Pacific. Over the last years, the ORSTOM and NOAA pool of thermosalinographs has decreased by 40% with the loss of several moorings, and it is expected that the new generation of ATLAS will ensure the continuation, development and, most of all, the data transmission in real time (something not possible with the present thermosalinographs) of near surface salinity in the western equatorial Pacific. Together with the data provided by the ORSTOM-Noumea sea surface salinity merchant ship network, these salinity measurements appear more and more important for understanding the warm pool climate system (see for example section 6.8).

However the French participation in TAO has taken a more global turn since 1997 with the installation of the first PIRATA moorings in the tropical Atlantic, as part of a pilot experiment handled by Brazil, US and France (see PIRATA report in section 5.1). In the same way as the preliminary TOGA-TAO array in the Pacific (installed in 1985–88 by NOAA/PMEL and ORSTOM-Noumea), this pilot array in the tropical Atlantic should be part of a global TAO observing system over the three tropical oceans in the first years of the second millennium.

As stated in the TIP-5 report, the French CLIVAR/GOALS program is building up, with in particular the continuation of the modelling effort in the tropical Pacific and of the XBT and surface salinity merchant networks from ORSTOM-Noumea. However, after being somewhat neglected during the 10 years of TOGA, the tropical Atlantic Ocean will be the focus of several French modelling and field programs, associated in particular with PIRATA.

As shown in section 6.3, the French meteorologists are using the TAO data. With the coupling of the OPA/LODYC OGCM with the Méteo-France ARPEGE AGCM, TAO appears useful in testing the behavior of the coupled system. Process studies from several versions of the OPA OGCM, such as the formation of the barrier layer in the Pacific warm pool, are helped tremendously by the use of TAO data. Other research groups in France are using TAO data, like the Groupe de Méteorologie a Moyenne Echelle at Méteo-France for their own TOGA-COARE research, the Space Oceanographic group at IFREMER for extracting winds from the ERS-1/2 satellites, and the JGOFS group for their analyses of two recent cruises in the equatorial Pacific. Within the ORSTOM Pacific Ocean SURTROPAC group (now spilt in half between Noumea and Toulouse), TAO is used extensively in order to improve the assimilation of TOPEX/Poseidon data in the Gent & Cane model, through a reduce Kalman filter. The combination of salinity measurements from the TAO array of SEACATs and the ORSTOM merchant ship network appears very useful for understanding the behavior of the displacement of the eastern edge of the warm pool during ENSO. Most of all, the TAO data was proved important for the recent discovery of an oceanic zone of convergence on this edge which led to a new concept for the oscillatory nature of ENSO.

5. PROGRAM STATUS REPORTS

5.1 PILOT RESEARCH MOORED ARRAY IN THE TROPICAL ATLANTIC PIRATA (J. Servain, ORSTOM/Brest and M. Vianna, INPE)

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. As for the TAO array, PIRATA will provide time series of surface heat fluxes and surface and subsurface temperatures, salinity, and currents in key regions of the tropical Atlantic. These key regions are chosen to get information about the two main modes of seasonal and interannual variability which occur in the tropical Atlantic, i.e., the El Niño-like equatorial mode and the meridional "dipole" mode. The PIRATA program proposed to install and maintain in the tropical Atlantic and array of 12 moored ATLAS along three lines (Figure 4):

- an equatorial line, with moorings at 35°W, 20°W (with an ADCP measuring currents from 30 to 200 m), 10°W, and 0°;
- a meridional line along 38°W with moorings at 4°N, 8°N, 12°N, and 15°N;
- a meridional line along 10°W, with moorings at 2°N, 0°, 2°S, 6°S, and 10°S.

In addition to the ATLAS mooring array, wind measurements and tide-gauge data will be available in near real-time from St. Peter and St. Paul Rocks, Fernando de Noronha, Atol das Rocas, and Sao Tome Island.

Also as for the TAO Array, the PIRATA measurements are transmitted in near real-time, and are available to all research and operational communities via Internet and GTS.

PIRATA is being coordinated with other national and international programs scheduled for 1997–2000, which will also be taking observations in the tropical Atlantic.

The first two PIRATA moorings were successfully deployed in September 1997 by R/V *Antea* (ORSTOM, France) from Abidjan (Ivory Coast):

- Java site at 0°,10°W (5200 m)
- Gavotte site at 10°S,10°W (3840 m)

Three other ATLAS will be deployed in January 1998 by R/V *Antares* (DHN, Brazil):

- Reggae site at 15°N,38°W
- Lambada site at 8°N,38°W
- Samba site at 0°,35°W

The deployment of these five first moorings represents the first phase of PIRATA deployments. The second and third phase are scheduled for the beginning of 1999 (5 moorings) and mid-1999 (2 moorings).

The PIRATA document is available via the Web (**http://www.ifremer.fr/orstom/pirata /piratus.html**) or directly via anonymous ftp (ftp.ifremer.fr/ifremer /orstom/pirata30.rtf.z). PIRATA information is available at (**http://ifremer. fr./orstm/pirata/piratafr.html**). PIRATA data are available at **http: //www.pmel. Noaa.gov/pirata** and **hppt://www.ifrmer.fr/orstom/pirata/piratafr.html/**.

During 1998, Brazil and France will develop more complete mirror web sites with PMEL.

5.2 JOINT AIR-SEA INTERACTION MONSOON EXPERIMENT (JASMINE) (J. Godfrey, CSIRO/Hobart)

Material was presented relating to a newly-proposed initiative, the Joint Air-Sea Monsoon Investigation (JASMINE). Interannual variability of monsoon rainfall is dominated by intra-seasonal oscillations (ISO), in which rain events typically start on the equator, move northward and die over

Asia. Bands of high/low precipitable water content associated with these ISO's extend from Africa to the dateline with weaker, but quite well-defined, bands in the southern hemisphere from Indonesia to Australia. These latter may affect Australia's winter rain. The long time series of the ISO's may be due to air-sea coupling.

It is hoped that the field phase of JASMINE will begin in May 1999, with the deployment of moorings along a line near 90°E, from 10°N to 5°S. R/V *Ron Brown* will be in the area, for buoy deployment and rain radar measurements. Ship time on the Australian vessel R/V *Franklin* has been allotted for about August 1999 to recover the moorings.

5.3 SOLAR RADIATION MEASUREMENTS FROM THE TAO ARRA (R.M. Reynolds, Brookhaven National Laboratory)

Scientists in the Atmospheric Radiation Measurement (ARM) Program of the US Department of Energy are concerned with decadal measurements of the global heat budget and seek better understanding of processes that control solar and infrared radiative transfer in the atmosphere (especially in clouds) and at the Earth's surface. In a collaborative effort, NOAA/PMEL and ARM are deploying special short-wave radiation sensors as part of the recent upgrade to the ATLAS system. A full description of this effort is presented as an attachment to this TAO Panel report. Four short-wave radiometers were deployed with next-generation ATLAS loggers in 1997 and will be recovered in January 1998. Two-minute continuous averages of solar radiation are stored in the ATLAS and are available after recovery. Daily insolation values, transmitted via Argos, agree qualitatively with satellite outgoing long-wave radiation (OLR) images and indicate that we might expect uncertainties of a few Wm^{-2} between buoys. There are many sources of error in these optical measurements and careful field studies are required to gain confidence in the measurements. (See Appendix 2 for more details)

5.4 TROPICAL RAINFALL MEASURING MISSION (R. Murtugudde, U. Maryland)

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan designed to monitor and study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation shaping both weather and climate around the globe. The TRMM Observatory carries five instruments. It will include the first spaceborne Precipitation Radar (PR), the TRMM Microwave Imager (TMI), a Visible and Infrared Scanner (VIRS), a Cloud and Earth Radiant Energy System (CERES), and a Lightning Imaging Sensor (LIS). The 17 ft tall and 12 ft diameter satellite weighing 3.2 tons was the largest spacecraft ever built at GSFC. The data rate is the highest of any NASA satellite to date.

The ground validation activities have been underway for several years with the primary validation sites are ready with radars, disdrometers, and rain gauges (Darwin, Kwajalein, Texas, and Florida; climatology sites: Israel, Thailand, Guam, Taiwan, Hawaii, and Brazil). The TOGA-COARE composite rainfall data is available from the TRMM office (**http://trmm.gsfc.nasa.gov**). Several TRMM field campaigns are planned to verify individual algorithms, cloud models, etc., with high resolution rain estimates and vertical structure details. Where practical, field campaigns are coordinated other experiments (Texas-Florida Underflights (TEFLUN), South China Sea Monsoon Experiment (SCSMEX), the Large Scale Atmosphere-Biosphere in Amazonia (LBA), and TRMM Kwajalein Ocean Experiment (TKO).

TRMM was scheduled for launch in November 1997 from the Tanegashima Space Center on an H-II expendable launch vehicle, designed and built by Japan**. The circular orbit at an altitude of 350 km at an inclination of 35 degree to the equator with a total orbit period of approximately 96

Editor's note: TRMM was successfully launched successfully on 27 November 1997. The latest TRMM images and other information is available at **http://trmm.gsfc.nasa.gob.

minutes is designed specifically to capture the diurnal cycle of the tropical precipitation. The testing was completed and the satellite was shipped to Japan in August of 1997.

5.5 OCEAN OBSERVATIONS FOR CLIMATE PANEL (OOPC) (R. Weller, WHOI)

The work of the OOPC over the past year was briefly summarized, and two particular issues were brought to the attention of the TIP, a GOOS implementation meeting planned for March 1998 in Sydney, Australia and the Global Ocean Data Assimilation Experiment (GODAE).

OOPC met for the second time in Cape Town in February 1997. Since then, a Long Time Series Workshop was organized and held by OOPC in Baltimore, MD, in March. The workshop clarified the characteristics of long time series needed for understanding ocean climate. Such time series could be exploratory, taken at a location where little is known; laboratory, observing many different variables and processes; phenomenological, observing change or a processes that is key or central to long term variability; and reference, a baseline station. At present, relatively few long time series station exist that have demonstrated merit for ocean climate observing systems, though high latitude North Atlantic time series, such as Bravo and Mike were discussed as candidates. A report from this workshop is being prepared.

OOPC also participated in a NOAA Sea Level Workshop to help better define the observational system needed to measure sea level. A long-term system based on satellite altimetry and 30 *in-situ* sites was discussed; more detail is given in a workshop report and in a document, "Climate Sea Level Network Report," to be published by OOPC.

WMO, GOOS, and CMM have developed a plan for an implementation workshop to push toward improved mechanisms and lines of responsibility, consistency of approach, development of rationales, and clarification of the foci of the many groups working toward GOOS. This workshop will be in Sydney in March 1998. TIP will be one of the implementation groups asked to attend.

Over the past year, concerns for developing the justification for the continuation of existing global observations, especially remote sensing tools which have to date been flown as research instruments, has led OOPC to take a lead role in developing the idea of a Global Data Assimilation Experiment. A first GODAE Workshop was help in Martinique of July (and was reported on by Billy Kessler at this TIP meeting). It was noted that as GODAE got started, the tropical Pacific would likely serve as a testing ground for data assimilation and analysis methods. Thus, TIP may want to develop a liaison with GODAE.

5.6 CLIVAR UPPER OCEAN PANEL/GODAE (W. Kessler, NOAA/PMEL)

The Global Ocean Data Assimilation Experiment (GODAE) held its first workshop in Martinique on 24–29 July 1997. GODAE is driven by the desire of the remote sensing community to make the best use of its products (altimetric sea surface height, scatterometer winds, and blended AVHRR/*in situ* SST) through assimilation. The aim of GODAE is to have a 3-year demonstration during 2003–2005 in which a global ocean fields (density and currents) would be constructed, based on the satellite data assimilated in models and constrained by *in situ* data. The fields would be used as integrated analyses for research, as initial conditions for climate models and boundary conditions for regional or coastal models, and for short timescale nowcasts and forecasts (for shipping and pollution monitoring). There will be several groups focusing at first on specific oceans, without a single operational center. French groups, particularly those associated with the satellite centers, are prominent supporters of GODAE.

The weakest link in the GODAE project appears to be the sparsity of *in situ* subsurface ocean observations, and it remains unclear to what degree the models will be sufficiently constrained by the existing data. The problem of how to distribute observed anomalies of sea surface height from altimeters through the water column is a difficult challenge. GODAE does not plan to seek support for any additional observations, but the results may provide clearer justification for *in situ* observations (or possibly show which are redundant).

The tropical Pacific is an important region for GODAE, since its relatively well-sampled in situ network makes it a good place to test assimilation strategies and the ability of observations to constrain models.

5.7 NEWS FROM THE CLIVAR INTERNATIONAL PROJECT OFFICE (CLIVAR IPO) (A. Villwock, International CLIVAR Office)

Since September 1997 the CLIVAR IPO has a new director. Dr. Michael Coughlan left the IPO to take over the director's position of the World Climate Programme in Geneva. His successor is Dr. Lydia Dümenil from the Max-Planck-Institut fur Meteorologie in Hamburg who will serve as acting director until the end of May 1998. In the meantime the director's position has been advertised widely seeking for a permanent director to take over on 1 May 1998.

CLIVAR is currently finishing its Initial Implementation Plan. An executive summary has already been published in the form of a brochure in time for the WCRP conference in August 1997. Until end of 1997 the Initial Implementation Plan will undergo a final revision, edited by Dr. George Needler. Dr. Needler, bringing in his experience from WOCE, kindly agreed to serve as an editor for the CLIVAR Implementation Plan. The CLIVAR IPO expects to publish the plan early 1998. The plan will serve as the main background document for the first CLIVAR conference scheduled for 1–3 December 1998 at UNESCO in Paris. This conference will be held as an intergovernmental meeting seeking for commitments for the initial phase of CLIVAR.

In the Initial Implementation Plan, the important role of the ocean observations provided by moored buoys, such as TAO, TRITON, or PIRATA is highlighted several times. These observations have been identified by a number of the CLIVAR core projects to be essential for the overall success of the programme. In particular recommendations to maintain and/or extend the moored buoy arrays are made within the following Principal Research Areas:

G1: Extending and Improving the Predictions
G2: Interannual Variability of the Asian-Australian Monsoon
G3: Variability of the American Monsoon System
G4: African Climate Variability
D2: Tropical Atlantic Variability
D4: Indo-Pacific Decadal Variability and in the integrating section on global ocean observations.

5.8 GLOBAL OCEAN OBSERVING SYSTEM (GOOS) (J. Trotte, GOOS Project Office)

The Global Ocean Observing System (GOOS) is presently moving quite rapidly towards implementation, according to its five overlapping phases:

(1) planning, including design and technical definition;
(2) operational demonstrations and pilot experiments;
(3) incorporation of suitable existing observing and related activities and new activities that can be immediately implemented within the GOOS framework;
(4) gradual operational implementation of the "permanent" or ongoing Global Ocean Observing System; and
(5) continued assessment and improvement in individual aspects and in the entire system.

The extensive work carried out by the GOOS Project Office (GPO) during this year has been presented, with emphasis to the considerable progress that has been made, as phase 1 (planning) reaches its culmination. A set of Principles has been devised, a Strategic Plan is to be published early in 1998 and implementation starts taking place in several different ways, but mainly through pilot projects and incorporation of existing national or international operational systems.

A brief review of international GOOS activities has been made. On the development of the GOOS Panels, it was noted in particular the recent establishment of the Living Marine Resources and Coastal Panels, expected to have their first meetings in March 1998.

The implementation of GOOS will also be very largely dependent upon the commitments made by the participating nations to support the observational systems through their national observing agencies, and by providing elements such as data centres and distribution networks, scientific and technical research, development and installation. Much of the implementation will be accomplished using regional alliances, but a global approach is needed to address the ocean's role in the climate system.

In the US, NOAA has agreed that the TAO array of buoys in the Pacific forms a contribution to GOOS. Similarly, the SOOP Implementation Panel decided that the SOOP network formed a contribution to GOOS. In addition, several nations continued the development of GOOS within their own countries, forming national GOOS committees and considering which parts of their present systems might form contributions to GOOS. It is much hoped that the Indian Ocean nations will also consider starting a GOOS Pilot Project in the near future.

The mangers of GOOS and GCOS will meet with managers of existing systems in Sydney, Australia, March 1998 when the continuation of TAO with international support will be considered, taking into account the fact that the US has already provided support for considering TAO as a contribution to GOOS.

A guide on GOOS implementation is due to be published in June 1998, where the GOOS vision will be presented, as a global network to cope with critical marine-related issues including the ocean's effects on climate.

The TAO array remains a source of high priority observations for the climate module of GOOS (the ocean component of GCOS). The expansion of the tropical atmosphere ocean observing array to include the tropical Atlantic has already started, with the launching of PIRATA and its latest developments. Those two systems and eventually a similar one in the Indian Ocean are regarded by IOC as a milestone of GOOS and an excellent opportunity to the build up of technical and educational capacity in less-developed and smaller countries, enabling them to forecast their own possibilities to acquire, have access and use marine and oceanic data and products for their own particular needs.

5.9 DATA BUOY COORDINATION PANEL (E. Charpentier, DBCP)

- DBCP-13 session was held in La Reunion island, 13-17 October 1997. A scientific and technical workshop was associated with the DBCP session, stressing applications of buoy data in both meteorology and oceanography. Workshop presentations will be published within the DBCP document series. The Panel decided to organize a similar workshop in association with the next DBCP session, Miami, 12–16 October 1998. The workshop will stress scientific and operational applications of buoy data; moored buoy technology and data applications.

- Some of the requirements expressed by the users which had been presented and discussed at the previous DBCP session, and then included within the Argos development program (JTA-16) have been developed and implemented: Argos data bank extended from 4 to 10 days, remote and automatic technical file access for GTS platforms (via Email), and connection of Local User Terminals in Cape Town and La Réunion (to substantially decrease delays in the South Atlantic and Indian oceans respectively). The Panel decided that providing Argos users with data on CD ROM should be a top priority and urged Service Argos to propose and implement a solution as soon as possible

- Data flow monitoring tools are being developed in the context of the DBCP server in co-operation with Météo France, NWS and MEDS. Basically, users will be able to access GTS data of the preceding week via the web. Most recent data will be yesterday's data. Only GTS Bulletin header, WMO number, date of observation, delay, and presence of sensors will be indicated (for confidentiality reasons, we cannot provide location & sensor data on the web). These tools will make it easy for a user with no GTS access to rapidly check that a buoy is actually reporting on GTS and how many reports are being received.

- The panel is developing a comprehensive implementation strategy plan for itself and its action groups, in support of the requirements of both global programs and also national/regional projects. Such an implementation strategy would be essential input to the development of a comprehensive GOOS/GCOS implementation strategy. A draft implementation strategy plan was discussed at the Panel session and the following comments were proposed:

  (a) The strategy needed to stress importance of optimizing deployments in the light of limited available resources;
  (b) A climatology of drifter tracks would be very valuable as a tool for future reseeding of networks, and panel members should be encouraged to develop such a tool;
  (c) Better contacts were required among the action groups, to allow cross-fertilization of deployments;
  (d) GTS data flow monitoring should be included;
  (e) The strategy should be expanded to cover also moored buoy networks, stressing their importance, requirements and complementarity to drifters, with the title adjusted accordingly;
  (f) References to buoy hardware should be more comprehensive;
  (g) The value of meteorological/oceanographic coordination to optimize deployments should be emphasized, as well as the role of the DBCP as a link between observing network managers and data users;
  (h) Section 7 should be divided, to show separately summary and action items;
  (I) The action items should underline the direct participation of action group members in GOOS/GCOS; and the role of the DBCP in providing buoy data for GODAE; and the value of the action groups adopting mechanisms to identify primary applications of buoy data in their region and subsequently monitoring the use of the data in these applications; and
  (j) The strategy should clearly show its relationship to the panel's terms of reference.

The Panel agreed that the second draft of the strategy plan, to include these and other comments received from members up to mid-November 1997, should be finalized by the end of December 1997, for further discussion to members and also for submission to the planned GOOS/GCOS implementation strategy workshop in March 1998. The final draft of the strategy should be prepared for adoption at the 14th DBCP session.

- The Panel decided to submit the document reflecting DBCP views on encoding buoy data in BUFR to CBS in 1998 as a formal DBCP request. Copies of the document can be obtained from the Technical Co-ordinator of the DBCP.

- DBCP Technical Document No. 8 "Guide to moored buoys and other ocean data acquisition systems" (by Eric Meindl) is now available and can be obtained via the Technical Coordinator of the DBCP.

5.10 STATUS OF NOAA CLIMATE OBSERVATIONS IN THE US (M. Johnson, NOAA/OGP)

In order to improve climate forecasts, NOAA's Office of Global Programs has set three strategic priorities for observations: 1) observe ENSO; 2) learn how to observe Atlantic modes of variability; and 3) learn how to observe Indo-Pacific modes of variability beyond ENSO. NOAA's first priority has been, and will remain, to support the successful observing system in the tropical Pacific that was developed during TOGA for monitoring ENSO. The TAO array is the cornerstone of this ENSO Observing System. Other components include the island tide gauge network, the VOS XBT network, and the surface drifter network. The President's FY 1998 budget presently before the US Congress includes $4.9 million to "operationalize" the ENSO Observing System. This initiative will transfer responsibility for the TAO array (and the other existing networks) to NOAA's base budget and will free up climate research program funding for expansion of observations in pursuit of the other two priorities - Atlantic modes, and Indo-Pacific modes beyond ENSO. Although the US Congress has not yet acted on this 1998 budget, we are optimistic that the initiative will be successful and are planning accordingly***.

Assuming congressional appropriation of the operational funding in 1998, NOAA's climate research program will support implementation of new pilot projects in the Atlantic to contribute to building a basin-scale composite observing system in support of improved weather/climate prediction. The PIRATA moorings will anchor the Atlantic observing system in the tropics; the other three complementary networks (tide gauges, drifters, VOS) plus a fourth network - autonomous profiling floats - will be used to extend observations into the higher latitudes. The hurricane genesis area of the Atlantic will also be targeted for observation to improve forecasts of intensity and landfall tracks of tropical cyclones. Simultaneously, NOAA will support expansion of the observing system in the Pacific with additional surface drifters, profiling floats, and high density VOS XBT lines (including automated surface meteorological observations from VOS). NOAA looks forward to the Indo Pacific expansions of the moored array by our international partners which, along with PIRATA, will advance the moored array toward becoming a truly global network.

The five complementary networks to which NOAA contributes - moorings, drifters, tide gauges, VOS, profilers - are all international efforts and global in scope. These five international networks provide a significant proportion of the elements of the ocean observing system called for by the draft CLIVAR Implementation Plan. NOAA considers the networks to be "building blocks" of a composite Global Ocean Observing System for climate. Each building block contributes its unique capabilities in concert with the others, and together they form a global observing system that serves both research and operational programs. In concept, each building block is made up of three elements - an international implementation panel, ocean platforms, and a global data center. The TAO Implementation Panel's coordination of the expanding moored array and its global data center provides an excellent model for this global observing network concept.

5.11 PAN AMERICAN CLIMATE STUDIES (PACS) (S. Piotrowicz, NOAA/OAR)

The Pan American Climate Studies Implementation Plan is in the process of being drafted and is expected to be completed in March. The overall plan, covering through 2005, will be available in hard copy. A more detailed version will be a "living document" continuously updated and available on the PACS web site at **http://tao.atmos. washington.edu/PACS/**. Presentations at TIP-4 and TIP-5 presented the pilot projects that were supported as part of the FY 1995 Program Announcement. Those projects are being implemented along, nominally, 125°W, from 3°S to 10°N. Though not complete at this time, it is expected that the region of emphasis for the field programs for PACS will be east of this area and extend both further north and further south.

Some areas of consideration are the stratus decks off the coast of South America, the ITCZ-cold tongue complex in the vicinity of 110°W, and the extreme convection region along the equator at and east of 95°W. Regardless of exact location, studies of the ITCZ-cold tongue complex and the convection, i.e., studies along the equator, will be conducted in regions where southerly air flow exists for major portions of the year. Please refer to the Implementation Plan at the above URL for the most recent information regarding PACS.

***Editor's note: The US Congress passed the $4.9M budget initiative referred to in this presentation subsequent to the TAO Panel Meeting.

5.12 IMPLEMENTING OBSERVATIONS FOR PREDICTION AND ASSESSMENT PURPOSES WITH AN EMPHASIS ON THE ENSO OBSERVING SYSTEM (S. Piotrowicz, NOAA/OAR)

The requirements of NOAA to provide useful forecasts of weather and climate variability in the United States on seasonal to interannual time scales has justified the implementation and long-term maintenance of an observing system of the coupled ocean-atmosphere system in the equatorial Pacific for the ENSO (El Niño-Southern Oscillation) phenomenon. This ENSO Observing System consists of those components of the TOGA Observing System which have been shown to provide measurements essential for skillful forecasts of the ENSO phenomenon. As of today, those components are the TAO Array, a network of in situ sea level observing systems in and around the Pacific, the Volunteer Observing Ship (VOS) Program, and the Drifting Buoy Program. Fundamental to this observational program is the expectation that the observing system will evolve as required by the forecast products, and in response to analyses and scientific results.

The design and implementation of the ENSO Observing System is an example of a systematic approach to the development of an observing system to meet a particular objective - improving our ability to forecast ENSO events. The design of the system was based on the known space and time scales of tropical ocean and atmosphere variability, with the preliminary objective of improving our ability to produce, operationally, fields of the air-sea quantities of interest. The next step is to implement an on-going activity to assess the effectiveness of the observing system in meeting its goal of improved forecasting skill, and to guide the evolution of the observing system in order to optimize future forecast skill.

Our ENSO forecast skill is developing all the time because: new ideas about the mechanisms of ENSO are being uncovered; better ocean-atmosphere models are being implemented; and improved procedures for data assimilation are being adopted. The situation bears many similarities to operational weather forecasting - a never-ending process of model improvement, observing system re-evaluation and data assimilation system evolution is fundamental to our increasing weather forecasting skill. This means that assessment of the observing system will be an interactive process, that goes hand-in-hand with our developing ENSO forecast capability. At this time we cannot specify the forecast skill improvement that will result from a given improvement in our ability to observe and map any particular air-sea variable. Perhaps it is particular combinations of variables that must be observed in particular regions. Nor are we confident that we understand which aspects of the processes that cause ENSO must be observed to improve our forecasts.

ENSO forecasting development requires close interaction between the different elements of the ENSO community. Operational and experimental forecasters, ocean-atmosphere data assimilation technique developers, engineers and observational oceanographers, satellite remote sensing personnel and ENSO science researchers must all interact closely in the coming years to bring about the best development of our ENSO forecast skill. The ENSO observing system assessment activity, properly configured, will be an essential element that keeps all of these groups interacting productively with each other.

It is quite possible that new observations, new coupled models and new air-sea interaction process experiments will be needed to keep our forecast skill increasing. In a time of very tight governmental budget constraints, an integrated assessment activity - with forecast skill evaluation as its fundamental measure of success - offers the best hope of raising the resources required to support the needed observations and model development.

5.13 INTERNATIONAL RESEARCH INSTITUTE FOR CLIMATE PREDICTION (R. Kleeman, IRI)

The philosophy and current status of the International Research Institute (IRI) was outlined. The organization is intended to be a so-called "end to end" prediction system. This involves the development of a seamless integration of climate model outputs (e.g., ENSO prediction) with societal applications. A pilot project demonstrating this involving Peruvian fisheries was outlined. The proposed international funding and management structure of the organization was outlined and the hiring strategy for the next three years was discussed. It is expected that there will be significant secondment of staff from interested international parties.

6. SCIENCE REPORTS

6.1 THE ENSO OBSERVING SYSTEM AND ITS IMPACT ON ECMWF SEASONAL FORECASTING (D. Anderson, T. Stockdale, and O. Alves ECMWF)

At ECMWF a comprehensive coupled atmosphere-ocean model has been developed which is used to make seasonal forecasts on a global basis, where appropriate. Both the atmospheric and oceanic components of the coupled model are global. The atmospheric resolution is T63 in spectral space (approx 2 degrees in physical space). The ocean model resolution varies, being quite highly resolved in the meridional direction near the equator but less well resolved at high latitudes. Initial conditions for coupled integrations are obtained by forcing the ocean with the fluxes of momentum heat and fresh water from the ECMWF operational atmospheric analysis system, and relaxing strongly to the Reynold's SST fields. All subsurface ocean data are assimilated in order to produce an ocean analysis. This is done weekly in a 'quasi-operational' environment. From the ocean analysis, three coupled forecasts are made out to 6 months every week. A parallel analysis is also performed which is similar to the first except that sub-surface ocean data are not assimilated and three forecasts are made from that analysis too. It is necessary to have a significant ensemble size in order to sample the chaotic behavior of the coupled system. By having two sets of forecasts, from two differently produced ocean analyses, it is possible to sample uncertainty in ocean initial conditions to some degree and to assess the impact of the ocean observing system on forecasts. For the 1997 event the presence of TAO data has been very beneficial, both for analyses and for forecasts.

Forecasts of the current 1997 event were shown. The research version of the model for which the forecast period was one year, predicted a warming of ~2K in the NINO-3 region from as early as Oct 96 but did not indicate the major El Niño which was to follow. However, the 'quasi-operational' version of the model with a 6 month forecast lead time correctly predicted the timing of the onset of the 97 ENSO from November 96. Although the model results are encouraging, there are also well-known deficiencies. Full, as opposed to anomaly, coupling is employed between the two components which allows some model drift. This is corrected a posteriori. Developments to the coupled system to improve the resolution in both atmosphere and ocean and to improve the atmospheric physics are in hand.

Because of the large amplitude of the present El Niño, there is the possibility of making useful forecasts for mid latitudes and other parts of the world in which chaotic processes play a significant role. To extract a coherent signal from the chaotic background requires a significant ensemble size and so the ensemble size has recently been increased to one six month forecast per day, giving an ensemble size of around 30 per month.

An assessment of the realism of the atmospheric response predicted by the coupled system is made difficult by the small number of years for which good quality initialization of the forecast system is possible (primarily because TAO has not been deployed for very long). Much more is known about the ability of uncoupled atmospheric models driven by observed SST. To try to relate our knowledge of uncoupled integrations to the coupled system, a parallel set of experiments has been run. In one set, a 19 member ensemble of coupled integrations was run four times a year in the period 1991–96. In a second set, a 19 member ensemble with an identical atmosphere model was run, with the same atmosphere initial conditions but using prescribed observed SST. Comparisons were shown of rainfall anomaly distributions predicted by the two model ensembles. Perhaps surprisingly, many aspects of the distributions were the same, suggesting that coupled model drift and anomaly forecast error were not excessively disrupting the predictable signals. Nonetheless, some of the differences could be highly significant on a regional scale, suggesting that the coupled system still needs substantial development. The relative importance of model drift and errors in the forecast SST anomalies has yet to be established.

6.2 IMPACT OF THE TOGA OBSERVING SYSTEM ON OCEAN INITIALIZATION AND ENSO PREDICTION (M. Ji, NCEP)

Prediction of seasonal to interannual sea surface temperature (SST) variability in the tropical Pacific, primarily variations associated with the El Niño-Southern Oscillation (ENSO) phenomenon, has been a major objective of the climate research community. A major achievement from the recently completed 10-year international research program, tropical ocean global atmosphere (TOGA, 1985–1994) is the development of prediction capability for ENSO using dynamical coupled models and the deployment of the TOGA observing system to support the prediction efforts (McPhaden et al. 1997; National Research Council, 1996). The NCEP coupled model is a coupled general circulation model. It attempts to takes full advantage of the availability of real-time *in situ* and remotely sensed observations for the tropical Pacific to initialize the ocean component of the coupled system in order to achieve useful skill for El Niño forecasts.

In this study, we carried out three parallel hindcasting experiments using the NCEP coupled ocean-atmosphere forecast model. The three experiments differ in the method used for ocean initialization. The initialization for the first experiment, denoted as SST, is accomplished by running the coupled model in a simulation mode for 1981–1996. Only observed SST are inserted into the model during the simulation. The initialization for the second experiment, denoted as XBT, is similar to the SST experiment, however, observed subsurface temperature data from XBTs and TAO moorings are assimilated into the coupled model during the simulation. In both cases, no observed surface wind stress is needed because the coupled model predicts the wind stress forcing for itself during the simulation. The third experiment, we denote it as ASM, uses the standard NCEP ocean data assimilation system which assimilates observed temperature data into an ocean GCM driven by observed wind stress forcing for ocean initialization.

One year hindcast experiments are carried out using the same coupled forecast model with the three different sets of ocean initial conditions. Due to the computational intensive nature of the coupled general circulation model, only four hindcasts for each year are run for the period of 1981–1996. The hindcasts are initiated in January, April, July and October in order to take into account of some seasonal dependency of prediction skill.

The skills for hindcasts are evaluated for two separate period: 1981–1989 and 1990–1996. Since the hindcasts are one year in length, the corresponding two periods for validating the predictions are 1981–1990 and 1990–1997. Evidence from comparison of skills for the two periods (Figure 5) suggests that for the 1980s, comprehensive ocean data assimilation provided very little improvement to the prediction skill. However, for the 1990s, with the full ocean data assimilation, i.e., utilizing observed winds, SST and subsurface temperature data, the prediction skill achieved by the ASM is much higher than that for just SST.

The 1980s is dominated by several strong ENSO episodes (The warm episodes of 1982–83, 1986–87, and the cold episode of 1988–89). During this period, the strong oscillatory ENSO mode prevailed. A coupled model that captures the dominant quasi-periodic oscillation of the coupled climate system such as the quasi-biennial and quasi-quadrennial mode (Jiang et al. 1995) potentially is capable of making skillful predictions. This is probably the reason for many simple coupled models to be successful in hindcasting ENSO episodes of the 1980s (Ghil and Jiang, 1997).

However, in the present decade, obvious changes in characteristic of ENSO development have been observed (Ji et al. 1996; Trenberth and Hoar 1996; Goddard and Graham 1997). The change in ENSO characteristics can be linked to the weakening of the dominant quasi-oscillatory interannual mode represented by the leading two sea level anomaly EOFs during the 1990s (not shown). Therefore, impact of additional modes of variability in the coupled climate system such as interdecadal mode (Zhang and Wallace 1997; Latif et al. 1997), and their interaction with the ENSO mode may be significant, and need to be taken into account in order to achieve skillful ENSO forecast. What's needed are forecast models with complex physics and dynamics coupled with an observing system and ocean initialization scheme capable of capturing all relevant scales of variability.

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6.3 ACTUAL AND POTENTIAL USE OF TAO DATA AT MÉTÉO-FRANCE (S. Planton, Météo France)

The TAO data are currently or have recently been used by the Météo-France operational and research services. From the operational side, the buoy wind and sea surface temperature are both accounted for in the data assimilation system for weather forecasting but with various sampling according to the network time. The TAO and meteorological data have also been used in conjunction with drifting buoy measurements and satellite data collected during the TOGA-COARE experiment. The objective was to evaluate the surface heat budget along the drifting buoy trajectory through the assimilation of the oceanic data in a one-dimensional ocean model (Roquet et al., 1993).

In the near future, the PIRATA data completing the network for the tropical Atlantic are also expected to be incorporated in the operational data processing for weather forecasting. They will also be used to validate the operational oceanic simulation performed in the tropical Atlantic (OPERA) with a version of the LODYC model. The SSTs will also be used to validate the products of the "Satellite Application Facility" of ocean, initiated by EUMETSAT and piloted by Météo-France. Another application will be the validation of oceanic temperatures and currents of oceanic models integrated for climate studies or seasonal forecasting. An important component of the moored array network will also be the evaluation of the ocean-air heat and momentum exchanges. After validation through a dedicated ocean field experiments (Equalant 1999), this data set will be incomparable to validate the fluxes at different scales. At the larger scale coupled or uncoupled atmospheric model surface fluxes will be evaluated, as well as products from the ECMWF reanalysis. At the mesoscale, the variability of the fluxes in relation to boundary layer variability both in the ocean and atmosphere will be investigated.

As an illustration, the Figure 6 reproduces the sensible heat flux, latent heat flux and friction velocity along the trajectory of the research ship *Le Suroit*, during the Intensive Observing Phase of the SEMAPHORE ocean field experiment (Eymard et al, 1996). It compares the evaluation of the fluxes through the inertial dissipation method (star symbol) and through adjusted bulk formulae applied to the ship observations (Dupuis et al, 1997). Fluxes from a reanalysis performed with a stretched version of the ARPEGE operational model centred on the experiment domain are also shown.

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6.4 TOWARD DETERMINING THE SENSITIVITY OF THE ENSO COUPLED SYSTEM TO PERTURBATIONS (R. Kleeman, BMRC/IRI)

A mathematical formalism (currently being widely applied to intermediate ENSO models) to determine the sensitivity of the tropical Pacific coupled system to perturbations was outlined (singular vectors). It was shown that results are currently highly model dependent and it was suggested that this was mainly due to the differences in the atmospheric components used. Using a particular model it was shown that perturbations resembling aspects of the Madden Julian Oscillation were highly efficient in perturbing the system. The observed irregularity of ENSO was very well reproduced by such a stochastic model. It was argued using operational predictions from a coupled model that the amplitude (but not phasing) of the current very large warm event could be accounted for by a stochastic input from two very strong westerly wind bursts in the March–April 1997 time period. Many coupled models were able to predict that a warming would occur in 1997 at lead times of 9–12 months but were unable to predict its extreme magnitude. This analysis provides a possible explanation for this.

6.5 USE OF THE TAO BUOY DATA BY THE US NAVY (P. Phoebus, FNOC)

Marine Meteorology Division Naval Research Laboratory Monterey California

Observations from the TAO buoy array in the equatorial Pacific are used by the US Navy for both operational meteorology and oceanography and for research purposes. The Navy has a high interest in accurate analyses and forecasts of marine surface winds around the globe, since many Navy operations take place near the air-sea interface. Furthermore, many areas of tactical or operational exercises take place in the tropics or sub-tropics, and the Navy centers in Guam and Hawaii have forecast responsibility for Northern Hemisphere tropical cyclones in the Pacific that often pose a threat to Navy assets.

TAO data have been used by the Navy for a number of validation studies. Data denial studies have identified systematic biases in the Navy's global atmospheric prediction system, and the impact of the TAO wind observations compared to the SSM/I wind observations have pointed to likely problems with the SSM/I data in the tropics due to water vapor contamination. TAO data have been used to substantiate the skill of the global atmospheric prediction system in analyzing and forecasting the development of tropical cyclones near the equator, thereby increasing the Navy's confidence in the global model as a tropical forecasting aid.

The Navy also routinely produces a number of oceanographic products. Accurate wind forcing is needed for a variety of ocean models, including dynamical and mixed-layer models, ice, and wave models. Buoy measurements of ocean temperature provide a valuable source of data for the Navy's twice-daily, three dimensional global ocean temperature analysis, which in turn provides a timely and accurate lower boundary condition for the Navy's global and regional atmospheric models. This analysis can be critical to the Navy model's tropical cyclone forecasting skill, and the TAO buoys are a valuable additional data source in the Pacific, where tropical cyclones frequently develop within 5 or 10 degrees of the equator. Because of the Navy's high interest in the tropical Pacific, there have been a number of research projects that have used the TAO data. These projects encompass both observational studies, which increase our understanding of tropical air-sea interactions, and modelling studies, where the TAO data are most often used for verification of the modelling results. Several of these research projects will be discussed.

6.6 COMPARISON OF NCEP/NCAR AND ECMWF REANALYZED FIELDS WITH TOGA-TAO BUOY OBSERVATION (B. Smull, U. of Washington)

This study seeks to assess the quality of reanalyzed surface fields (especially winds) compiled over the TAO array during the period 1991–1993. Our broader objective is to quantify these differences in conjunction with other observed quantities (e.g., temperature and humidity) as a function of season and climatic regime, and moreover to point toward needed improvements in operational global data assimilation and modelling systems as applied over the tropical oceans. This evaluation is performed through comparison of pentad-, monthly- and annual-mean surface observations derived at each of ~65 sites comprised by the TAO array to corresponding mean conditions derived from both the NCEP/NCAR and ECMWF reanalyses, which are available at a frequency of 4 per day and spatial resolution of T62/L28 and T106/L31, respectively. NCEP/NCAR zonal and meridional wind components were obtained from the "Gauss Grid" (effective equatorial resolution ~2° x 2°) obtained from NOAA/CDC, while analogous ECMWF quantities at a resolution of 1.25° x 1.235° were provided courtesy Dr. David Anderson of ECMWF.

Figure 7 summarizes annual-mean winds and TAO-reanalysis wind differences for 1993; largely similar results were evident in 1991–1992 (not shown) but were restricted spatially owing to the reduced coverage of the TAO array during those earlier years. NCEP reanalyzed and TAO observed wind vectors are overplotted in panel (a), while corresponding vector differences are shown in (b). In (a) we see that directional differences of 20–30 deg are common, though these reach nearly 90° near the ITCZ. In general, NCEP winds are weaker and more zonal (i.e., less divergent) than those observed by TAO. Vector differences in (b) form a pronounced divergence/convergence pattern in association with the ITCZ/cold tongue complex in the east Pacific basin. Magnitudes of these differences were generally 1–2 m s^{-1} (peaking near 3 m s^{-1}) in the annual mean, but locally exceeded 5 m s^{-1} in monthly means (not shown). In the west Pacific, NCEP is on the whole too easterly, but behavior in this region is more complex, likely reflecting far-field influences of the Austral-Asian monsoon. Respective patterns for ECMWF shown in panels © and (d) are largely similar to those for NCEP, but agree slightly better with the TAO observations (~10–20% mean reduction in overall wind differences). Much of the ECMWF reanalysis' strength appears to rest at shorter (intraseasonal) time scales. Future work will focus on quantifying the effect of these errors on modelled vs. observationally-derived surface fluxes and tracing such difference back to component kinematic and thermodynamic quantities.

6.7 THE VALUE OF WELL-INSTRUMENTED SURFACE MOORINGS (R. Weller, WHOI)

Data from the recent deployment (October 1994–October 1995) of a surface mooring in the northwestern Arabian Sea (15.5°N,61.5°E) is used to illustrate the value of deploying a well-equipped surface mooring. This mooring was equipped with both a Vector Averaging Wind-Recorder (VAWR), sampling every 7.5 minutes, and an Improved Meteorological Recorder (IMET), sampling every 1 minute. Wind speed and direction, air temperature (aspirated and non-aspirated), relative humidity, incoming shortwave radiation, incoming longwave radiation, sea surface temperature (floating sensor), barometric pressure, and precipitation were measured. Pre- and post-deployment calibrations and *in-situ* intercomparisons between shipboard and buoy sensors conducted for a day just after and just before deployment were used to ensure the quality of the meteorological measurements; and the air-sea fluxes were computed using the COARE flux algorithm. These high sampling rate, high quality surface meteorological and air-sea flux time series have allowed us to: 1) examine the validity in the Arabian Sea of the available climatological fields of the surface meteorology and air-sea fluxes, 2) investigate the extent to which numerical weather prediction models including NCEP, ECMWF, and FNOC, fluxes in the Arabian Sea, 3) demonstrate the improvements made by Josey and Taylor in developing the new Southampton Oceanography Center (SOC) climatology, 4) select (in collaboration with Dave Halpern) coincident, collocated data from satellite wind sensors and examine the validity of that data as processed by several algorithms, and 5) develop a new understanding of the physics of the atmosphere-ocean coupling during the monsoons.

The buoy observations have an annual mean heat flux of 60.3 W m^{-2}, while the Hastenrath and Oberhuber climatological means at the buoy site are 29.0 and 37.9 W m^{-2}, respectively. ECMWF and NCEP annual mean net heat fluxes at the grid points nearest to the buoy are 9.4 and -4.5 W m^{-2}, respectively. In contrast, the SOC was in good agreement with the observations and has an annual mean of 61.3 W m^{-2}. The differences during the Southwest Monsoon are particularly striking, as the Oberhuber and Hastenrath climatologies indicate heat loss (-12.0 and -3.3 W m^{-2}, respectively) while the buoy and SOC show 84.3 and 87.3 W m^{-2} gain, respectively. As a result of the strong observed heating, the upper ocean response during the Southwest Monsoon was dominated by wind-driven mixing rather than by convective mixing as seen during the Northeast Monsoon and as previously postulated by some to be a dominant mechanism during the Southwest Monsoon as well. ECMWF and NCEP net heat fluxes during the Southwest Monsoon were too small (not enough ocean heat gain) by 40 to 80 W m^{-2}.

Comparison of concurrent (1994–1995) data from the SOC climatology and the buoy shows good agreement, substantiates the improvements made to that ship-based climatology, and supports wider use of the SOC climatology in the Arabian Sea as a better choice for forcing fields than either previous climatologies or fields from numerical weather prediction models. This allows us to use the SOC climatology to provide spatial coverage over the Arabian Sea during the ONR/JGOFS projects in 1994–1995. It also allows us to use the SOC data set from 1980–1995 to establish that 1994–1995 was a typical year.

Further comparisons of well-instrumented surface moorings (the Subduction Experiment, TOGA COARE, the Pan American Climate Study) with climatological and model fields have been and are being carried out. These studies show that the present generation of modern buoy sensors, which can also be deployed on Volunteer Observing Ships, obtain surface meteorological and air-sea flux data of high quality that clearly identify the shortcomings of the climatologies and model flux fields and provide an accurate record of local air-sea coupling. Thus, it is suggested that the TIP consider deploying a number of well-instrumented moorings for surface fluxes within the TAO array.

6.8 INTERANNUAL VARIABILITY OF THE HIGH-SALINITY TONGUE SOUTH OF THE EQUATOR AT 165°E (W. Kessler, NOAA/PMEL)

In 1996, the ENSO forecast group at NCEP noticed an apparent contradiction between the west Pacific sea surface height found in their model assimilating TAO data and that found from the TOPEX altimeter. The difference was as large as 9 dyn-cm, a significant fraction of the total variability. It turns out that the difference was largely due to salinity changes extending over the upper 200 m of the water column, and these were not accounted for by the model assimilation of TAO temperature-only data. A nearly 1 psu increase in salinity between 1995 and 1996 occurred in the upper 50 m, which was not surprising due to the change in rainfall associated with the waning of the El Niño of 1994–95, but there was also a 0.4 psu increase of salinity in the high-salinity tongue at about 150 m depth. The high-salinity tongue is a layer of water moving westward and equatorward from the surface near 10–20°S in the eastern Pacific as part of the southern subtropical gyre circulation.

165°E is one of the few places in the Pacific where time series of subsurface salinity can be reasonably constructed back to about 1984, based primarily on CTDs taken during the France-US and US-PRC hydrographic programs, and TAO deployment cruises. Time series at the level of the salinity maximum south of the equator showed low-frequency variability with fluctuations of 0.2 to 0.4 psu, most strongly near 4°S–8°S. This variability was not well correlated with vertical motion of the thermocline or with the ENSO cycle. Instead, the variations of salinity in the high-salinity tongue at 165°E appear to be controlled by zonal advection in the SEC, and variations of both zonal current and zonal salinity gradient contribute to the signal.

The changes described here show that subsurface salinity can be an important element in the variability of dynamic height. While the TOPEX altimeter can be used to correct the model dynamic height through assimilation, without salinity observations it is not straightforward to know how to distribute the differences in the vertical. However, those choices impact the assimilated product current and density fields. Therefore it would be desirable to improve our understanding of the relation between surface and subsurface salinity. Since CTD sampling in this region has fallen off with the termination of the French New Caledonia deep-sea research effort, the present level of cruises (now essentially just the TAO deployment cruises) this can only be accomplished through subsurface salinity sampling on TAO moorings. The variability described here suggest that 5°S, 165°E would be a good location to sample this signal, and that instruments need to be placed down to 200 m and include a sample at 150 m.

6.9 EFFECTS OF SALINITY AND THE INDONESIAN THROUGHFLOW ON THE TROPICAL INDO-PACIFIC BASIN (R. Murtugudde, U. Maryland)

State of the art heat flux formulations have reduced the errors in SST simulations by OGCMs to an extent where the remaining errors that can not be explained by uncertainties in the surface fluxes must be attributed to model errors. However, the discrepancies between various precipitation products are too large which makes it difficult to blame OGCMs for poor simulations of salinity fields. With the high accuracy precipitation products on the horizon, need for salinity data for validation of OGCMs is evident. Salinity contributes to large scale dynamics and thermodynamics through density and pressure gradients. Even a small bias in precipitation of 1 m yr^{-1} is seen to produce SST errors of up to 0.5°C and errors in the Equatorial Undercurrent of over 10 cm s^{-1}. Extensive comparisons between an OGCM with active salinity and with salinity held constant show a substantial improvement in the cold tongue region of the equatorial Pacific. These experiments clearly demonstrate that even in the tropics, salinity plays a very important role in large scale processes on seasonal-to-interannual and longer time-scales.

Seasonal-to-interannual (1980–1995) Indonesian throughflow (ITF) simulations are performed with a primitive equation, reduced gravity, sigma-coordinate model. An ENSO related reduction in the ITF is clearly evident which is driven by winds over the Pacific. However, winds over the Indian Ocean generate a significant non-ENSO related signal. The ITF cools the Pacific and warms the Indian Ocean. The seasonal cycle of SST in certain regions such as the equatorial Pacific and the Leeuwin Current are shifted whereas in other regions such as coasts of Java and Somalia, the ITF signature is prominent during the upwelling season. The winter rainfall deficit over Australia may be enhanced by the ITF as seen be its influence over the central Indian SST gradient. Difference of sea level across the Indonesian channel shows a high correlation with ITF indicating that an index may be defined based on TOPEX.

6.10 SHORT-TERM CLIMATE VARIABILITY IN TAIWAN AND THE TROPICAL ATMOSPHERE-OCEAN (H.-H. Hsu, National Taiwan University)

This study calculates EOFs of SST in the Pacific, Indian, and Atlantic Oceans, separately. The first EOF of the three oceans, which exhibit the characteristics of the El-Niño/Southern Oscillation (ENSO), are closely correlated, with the Pacific leading the Indian Ocean and the Atlantic by 4 months and 6 months, respectively. The first EOF in the Indian Ocean appears to have the strongest correlation with the monthly-mean temperature and precipitation in Taiwan. The major features are the above-normal (below-normal) precipitation in March and the above-normal (below-normal) temperature in September following the warm (cold) years.

The increase of precipitation in March following the warm years is associated with a deepened trough and strong baroclinic wave activity in East Asia. The case of March 1983 was investigated using a GCM. Results of the simulation suggest that the warm SST may have caused the abnormal circulation and precipitation.

The above-normal temperature in September is apparently associated with the anomalous anticyclone in South Asia that expands more eastward than normal to cover the east coast of East Asia. The reason for the displacement of the anticyclone is not clear. However, it is strongly correlated with the warm SST in the Indian Ocean several months before.

In addition to the influences of the tropical ocean-atmosphere, the interannual variations of the summer temperature and precipitation in Taiwan are also associated with the variations of the SST in the extra-tropical Pacific. Anomalous circulation, precipitation, and SST of the 1993 and 1994 summers were investigated to identify the relationship.

6.11 SURFACE OCEANIC EASTWARD JET AND ITS RELATION WITH THE WESTERLY WIND BURSTS IN THE WESTERN EQUATORIAL PACIFIC: USE OF SATELLITE SCATTEROMETER DATA (Y. Kuroda, JAMSTEC and K. Kutsuwada, Tokai University)

Current data obtained by upward-looking moored Acoustic Doppler Current Profilers at two equatorial stations (142°E and 147°E) since 1994 are used to detect events in which eastward flow stronger than 50 cm s^{-1} in the near-surface layer. Such events are recognized in May 1994, December 1994 to January 1995, April 1995 and December 1996. In these events, the strong eastward flow is confined to the surface layer above about 100 m, which suggests that the surface wind is an important factor driving these surface jets.

Data sets of daily surface wind on 1° x 1° grid in the tropical Pacific region are constructed using data of satellite scatterometers (NSCAT and ERS-1). In all the periods in which the surface eastward jet occurred, the westerly winds stronger than 5 m s^{-1} are found over the western equatorial Pacific. Areas covered by the strong westerly wind bursts have different zonal expanse among the events, which suggests that they affect the zonal propagation of oceanic signals. For example, during the event of May 1994 in which the dominance of the westerly wind burst was confined to the equatorial area west of 150°–160°E, the surface eastward jet occurred with eastward phase lag, corresponding to zonal propagation speed of internal equatorial Kelvin waves. On the other hand, during the event of December 1994 in which the westerly wind burst had a large zonal expanse between 130°E and 180°, the eastward jet occurred almost simultaneously in the two equatorial stations. Noticeable features are found in a period from December 1996 to June 1997 constructed by NSCAT wind data. In December 1996, the strong westerly wind on the equator is confined to areas west of 150°E, associated with a twin cyclone having a symmetric feature of the equator. Similar westerly wind bursts are found also in March–April and May–June 1997. It is suggested that these events played an important role for the trigger and/or evolution of 1997 El Niño event.

6.12 PENETRATION OF VISIBLE LIGHT IN THE UPPER OCEAN HEAT BUDGET (M. Lewis, Dalhousie University)

Solar radiation in the visible portion of the spectrum, which represents approximately half of the global downwelling flux, penetrates to a varying degree to heat the ocean interior by absorption. The degree to which these visible wavelengths penetrate depends on the optical properties of the water itself, and the particulate and dissolved constituents; most of the variability is due to variations in the concentration of phytoplankton or algae in the upper ocean.

For the tropical Pacific, and for the western Warm Pool in particular, a significant energy flux is represented by the penetration of visible radiation through the shallow mixed layer which actively interacts with the atmosphere. On a climatological basis, Lewis et al. (1990) demonstrated that most of the computed net surface heat flux of order 20–40 Wm^{-2} could be accounted for by a downward irradiance flux through the base of the mixed layer such that the surface layer received a net input of zero, as required by many circulation models. Furthermore, they speculated that if phytoplankton concentrations in the western Pacific attained values similar to those in the Eastern Pacific, most of this energy would be trapped in the upper ocean leading to enhanced surface heating rates.

Over the last six years, such a situation has been observed twice. Siegel et al. (1995) observed high pigment blooms in the western Pacific during TOGA-COARE, and Lewis et al. observed such high concentrations in early 1997. The coincidence with the El Niño may not be fortuitous. Pigment concentrations also vary strongly in the eastern Pacific and in general are depressed during El Niño, permitting greater penetrative irradiance fluxes.

Given this strong variability, and given the magnitude of the heat fluxes, it will be useful to monitor the ocean optical properties more closely, on time and space scales consistent with the other important contributors to the upper ocean heat budget. Recently, a buoy deployment has been carried out by MBARI and PMEL where optical sensors were placed on TAO buoys with independent data transmission. Initial results from these deployments in the eastern Pacific in 1997 show derived pigment concentrations approximately half of those seen in climatology, with a consequent increase in the penetration depth of visible irradiance. Future deployments of such sensors, particularly in the sensitive western Pacific, should be strongly encouraged, in order to provide constraints on the magnitude of the upper ocean heat budget, as well as for critical biogeochemical investigations.

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7. RECOMMENDATIONS

7.1 SURFACE FLUXES

TIP presentations emphasized the need for more systematic verification of surface flux climatologies, and verification of surface fluxes from atmospheric and coupled ocean-atmosphere models used in climate studies. It was therefore recommended that a few moorings be dedicated to measurement of surface fluxes with the highest possible accuracy. Initial mooring sites to be equipped with specialized instrumentation were recommended along 95°W, 140°W, 165°E, and 156°E, and one in the tropical Atlantic. Quality assurance would need to be maintained with (I) a shore-based set of primary standards, (ii) frequent calibration of shipboard transfer standards, and (iii) adequate time allowances for ship/buoy comparisons on deployment and recovery.

It was recommended that buoy flux data at these sites not be assimilated into standard operational products; and that, to facilitate comparisons, model products be stored at the verification buoy locations at finest temporal resolution.

7.2 SALINITY MEASUREMENTS

Recent evidence from forecast models suggests that initialization errors due to lack of ocean salinity can negatively impact the skill of El Niño SST predictions in the tropical Pacific.

Analyses show that lack of surface and subsurface salinity observations can sometimes lead to errors in dynamic height that are a comparable in size to the ENSO signal in the western Pacific. These errors affect the pressure field and large-scale ocean circulation. Unfortunately, attempts to correct errors in surface height using altimetry data can produce errors in the upper ocean temperature field if salinity effects are not accounted for. Salinity simulations in present OGCMs are unrealistic. Salinity data are needed for understanding model shortcomings and improving model physics. Salinity observations in key areas such as the western Pacific would be very valuable for improved assimilation of altimetry data for ocean initialization. Salinity is also a useful tracer of the meridional overturning circulation in the tropical and subtropical oceans.

Existing salinity time series show substantial high-frequency variations that potentially can alias into low frequencies of greatest interest for climate. It was recommended that a cost-effective strategy for increasing the salinity data base in the tropical Pacific would be to increase the number surface and subsurface salinity sensors on selected TAO and TRITON moorings. At present, surface salinity is measured systematically only from ATLAS moorings along 156°E, 165°E, and 180°E. An enhanced moored salinity array in the tropical Pacific would contribute to an emerging salinity monitoring effort which includes VOS/XCTDs, S-PALACE and research vessel measurements.

7.3 INDIAN OCEAN MOORING DATA ON THE GTS

Presently, India has four moored buoys deployed in the Bay of Bengal and plans to augment these with a further six in the Arabian Sea as part of its National Data Buoy Programme. These buoys measure important surface oceanographic and meteorological parameters such as wind speed and direction, air temperature, and upper ocean temperature profiles. Since the Indian Ocean region is presently so poorly observed, these data are potentially important both for climate studies and for assimilation into global weather prediction models. With proposed new experiments in the Indian Ocean such as JASMINE, ATOC, and the proposed deployment of TRITON moorings in the Indian Ocean, moorings of the Indian National Data Buoy Programme could represent an important beginning of an Indian Ocean observing system.

The TAO Panel therefore recommended that data from Indian National Data Buoy Programme should be transmitted in real-time over the GTS to maximize their benefit for weather and climate forecasting and analysis. A letter to Dr. E. Desa, head of NIO, urging him to act on this recommendation, is contained in Appendix 1. The letter was sent by Dr. Gunnar Kullenburg, Executive Secretary of IOC, on behalf of the TAO Implementation Panel and its three sponsoring organizations (GOOS/GCOS/CLIVAR).

7.4 TRANSMISSION OF TAO RELATIVE HUMIDITY DATA ON THE GTS

Data from ATLAS moorings of the TAO array have been transmitted on the GTS since 1987. These data consist of surface wind speed and direction, air temperature, sea surface temperature, and subsurface temperature profiles. Relative humidity measurements have been collected since 1988 on the majority of TAO moorings. However, these data have not been distributed on GTS because of early concerns about data quality. Recent modelling studies have shown that relatively small changes in boundary layer moisture can have a large impact on model based flux determinations and deep convection. In order to improve the model boundary layer analyses in the operational atmospheric models, it is recommended that the humidity measurements from the TAO moorings be added to the surface messages that are distributed on GTS. Present accuracy for humidity measurements from the TAO moorings are estimated at 4% or better, which is well within the range considered useful for present modelling efforts.

7.5 DATA BUOY COOPERATION PANEL ACTION GROUP

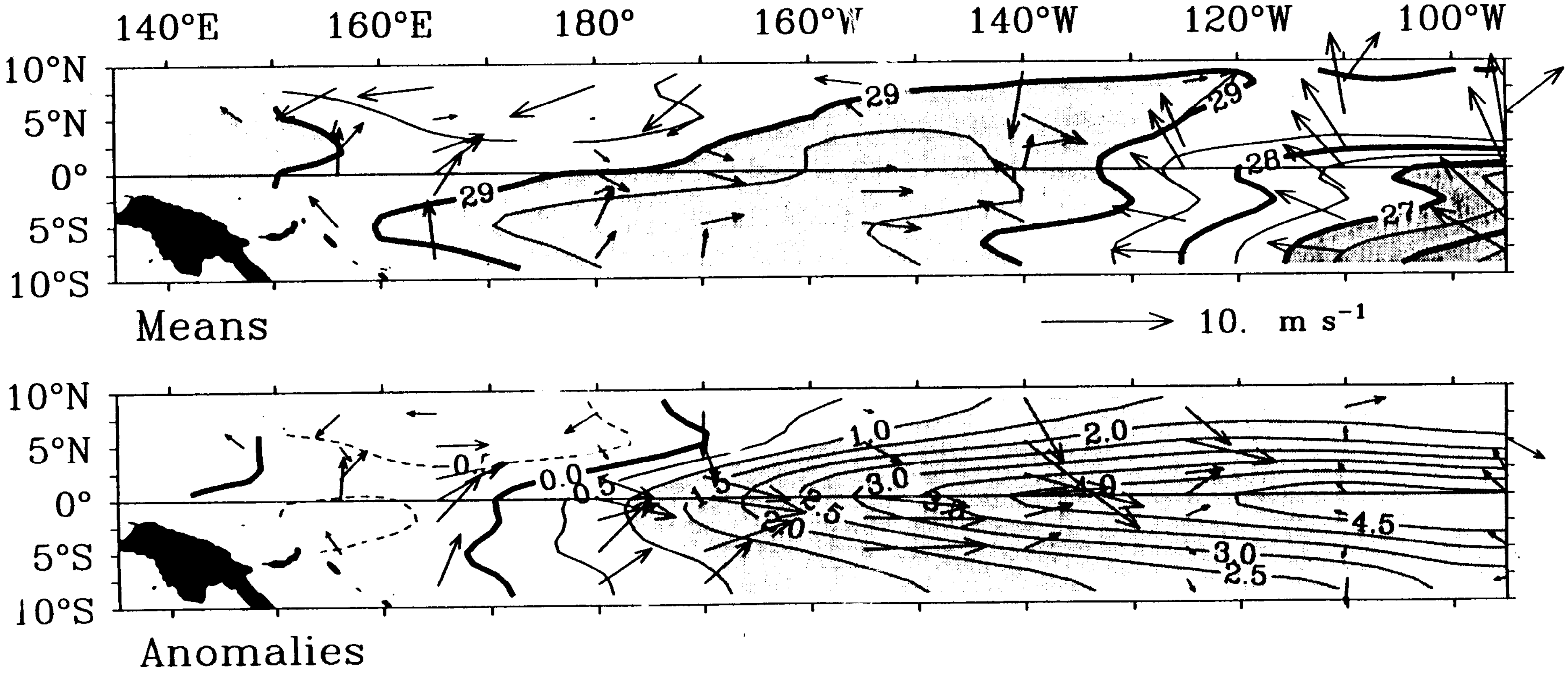
Motivated by a history of effective informal collaboration between the TAO Implementation Panel (TIP) and the WMO/IOC Data Buoy Cooperation Panel (DBCP), the suggestion was made at TIP-6 that the TIP become an Action Group of the DBCP. The benefits of becoming an Action Group are immediate and include, among other things, direct participation in a most effective international mechanism for coordinating the implementation of the global array of research and operational ocean buoy programs and for speaking with a united voice on real-time data transmission and usage issues affecting all programs. Membership also permits full access to the resources of the DBCP Technical Coordinator, Mr. Etienne Charpentier, to assist in solving real-time data retrieval and dissemination problems. Although the TIP has functioned well as a virtual member of the DBCP, a formal association between the two bodies would enhance the effectiveness of the TIP in the international operational buoy community. It is therefore recommended that Dr. McPhaden send a letter to the DBCP Chairman requesting formal recognition of the TIP as an Action Group of the DBCP[****].

8. ACKNOWLEDGEMENTS

The TAO Panel would like to thank Dr. David Burridge, Director of the European Centre for Medium-Range Weather Forecasts, for the opportunity to hold TIP-6 at ECMWF in Reading, England. We are likewise grateful to Dr. David Anderson, head of the local TIP-6 organizing committee, for the time and effort he and his staff put into the making the meeting a success. The Panel acknowledges the financial support of the Intergovernmental Oceanographic Commission Global Ocean Observing System Project Office directed by Dr. Colin Summerhayes. The TAO Panel is co-sponsored by IOC/GOOS, the Global Climate Observing System Project Office directed by Dr. Thomas Spence, and the International CLIVAR Office directed by Dr. Lydia Dümenil. These proceedings were prepared with the assistance of Ms. Vallapha Cass of NOAA/PMEL.

[****]Editor's note: A letter of request was sent to the DBCP chairman Mr. Graeme Brough by Dr. McPhaden on 5 February 1998. Mr. Brough responded on 25 February 1998 that TAO would be recognized as an Action Group of the DBCP.

Five–Day TAO SST (°C) and Winds (m s^{-1}) November 2 to 6 1997



Wind vectors and sea surface temperatures (SSTs) from the TAO array of current meter moorings and ATLAS thermistor chain moorings. Top panel shows means; bottom panel shows 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 Office of Global Programs), France (ORSTOM), Japan (STA), Korea (STA), and Taiwan (NSC).

Figure 1

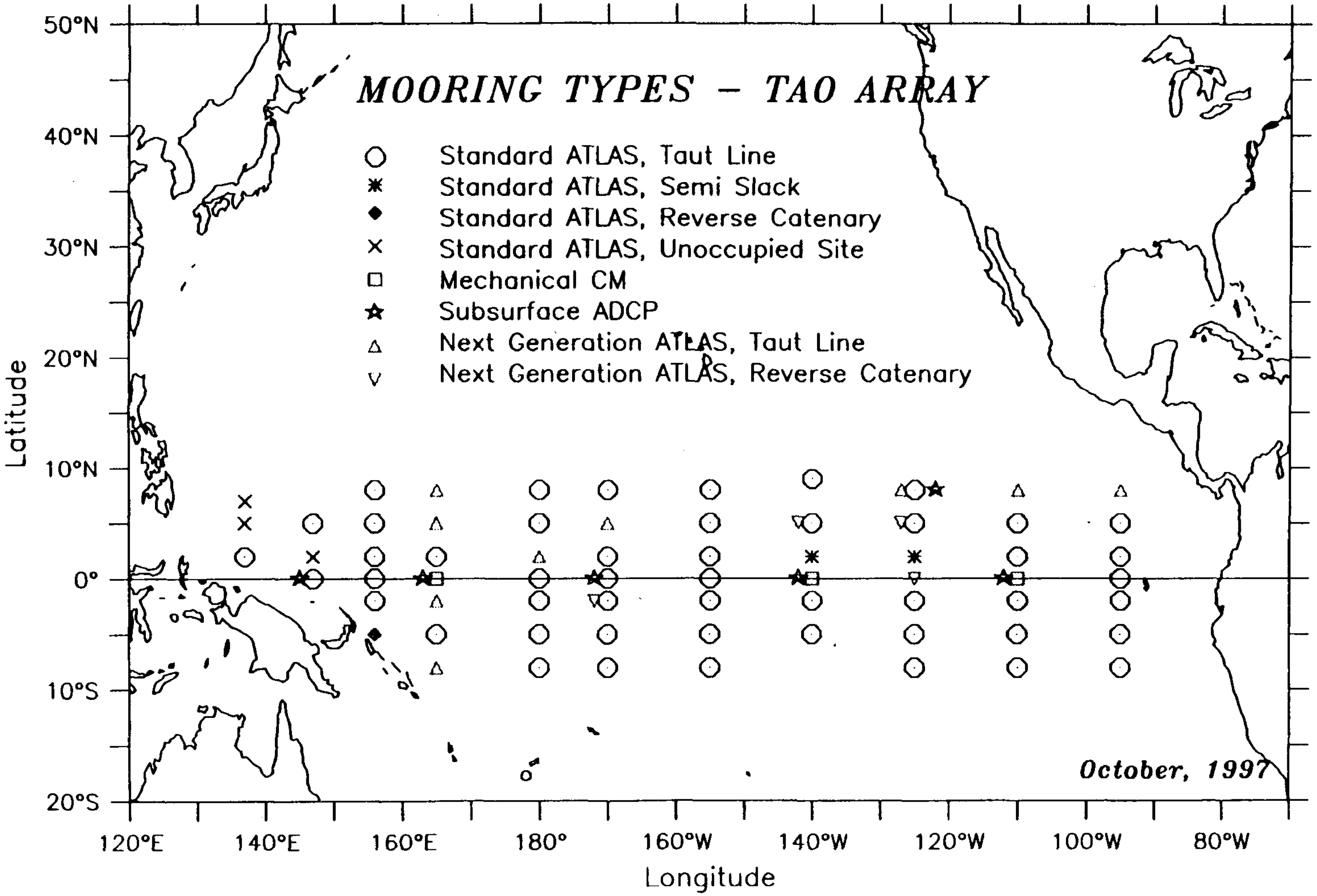

MOORING TYPES – TAO ARRAY
Standard ATLAS, Taut Line
Standard ATLAS, Semi Slack
Standard ATLAS, Reverse Catenary
Standard ATLAS, Unoccupied Site
Mechanical CM
Subsurface ADCP
Next Generation ATLAS, Taut Line
Next Generation ATLAS, Reverse Catenary
October, 1997
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
Latitude
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
Longitude

Figure 2

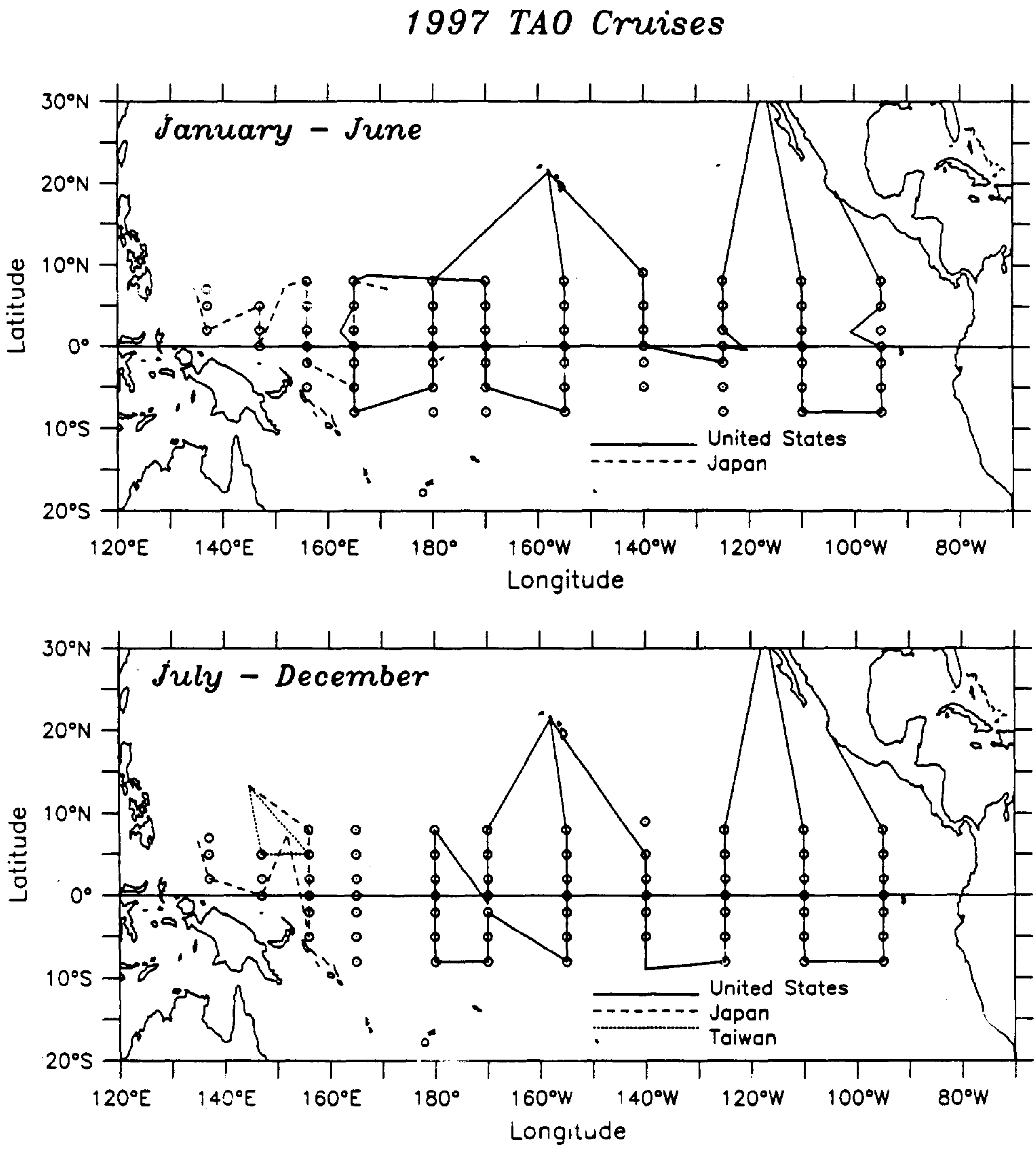

1997 TAO Cruises
January - June
30°N
20°N
10°N
0°
10°S
20°S
Latitude
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
Longitude
United States
Japan
July - December
30°N
20°N
10°N
0°
10°S
20°S
Latitude
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
Longitude
United States
Japan
Taiwan

Figure 3

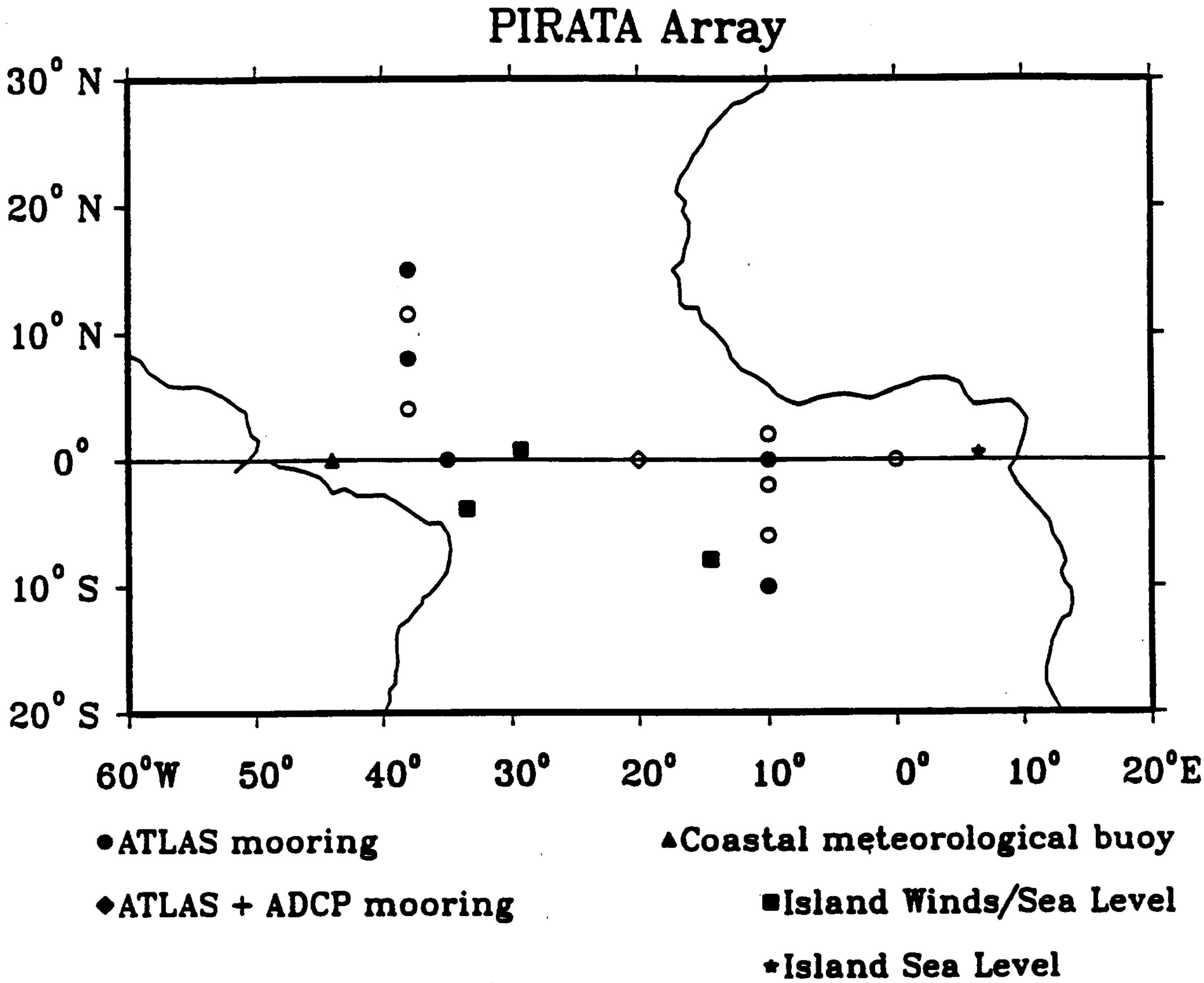


Figure 4. Schematic of PIRATA array. Solid symbols indicate first phase of deployment, September 1997–January 1998. (J. Servain)

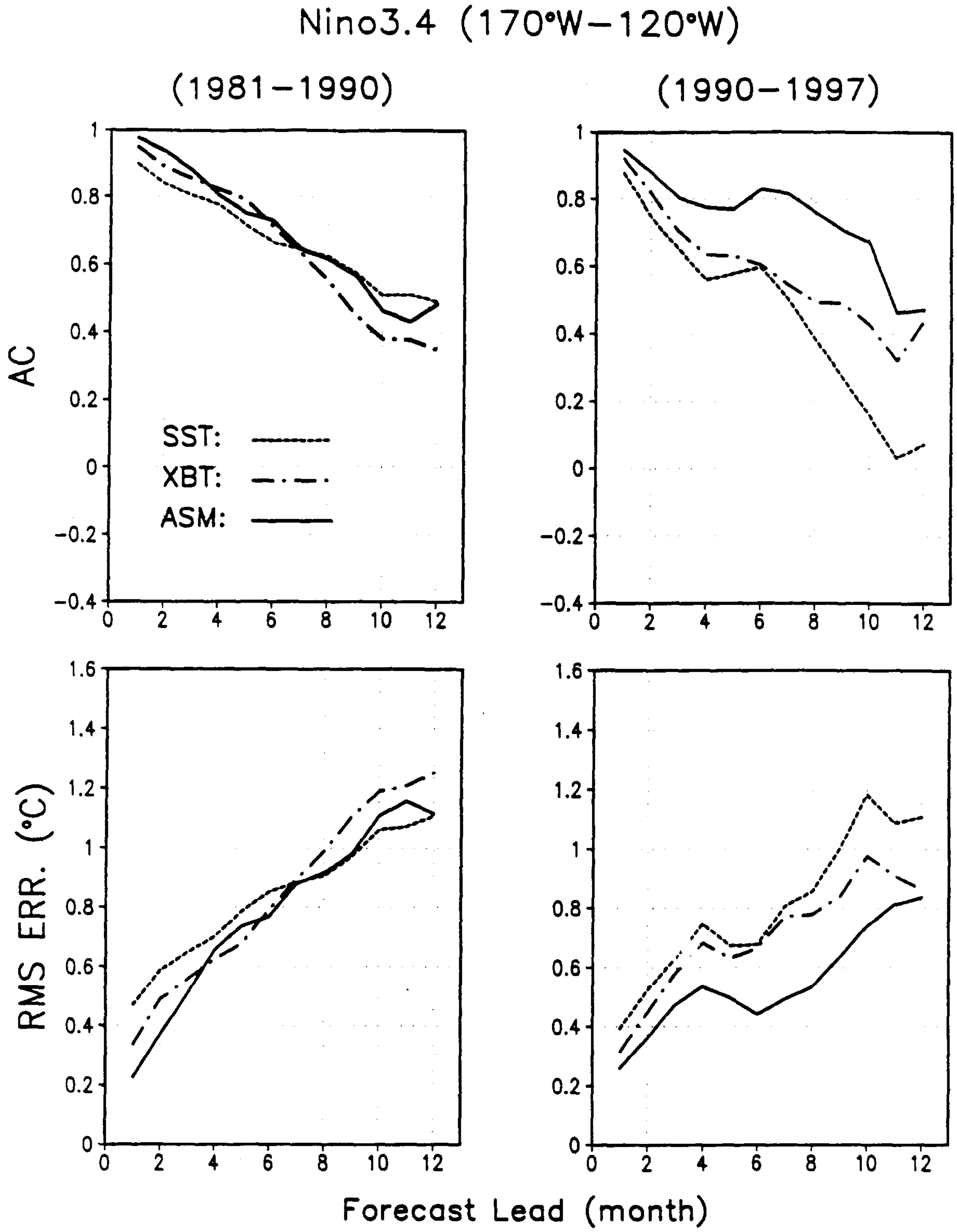


Figure 5. Hindcast skill verified for 1980–1990 (left) and 1990–1997 (right). Skills are measured as AC (upper) and RMS errors (lower) for the NINO3.4 region between observed and predicted SST anomalies. Skills for the three hindcasting experiments, i.e., ASM, SST, and XBT, are shown in solid, dash, and dot-dash curves, respectively. (M. Ji)

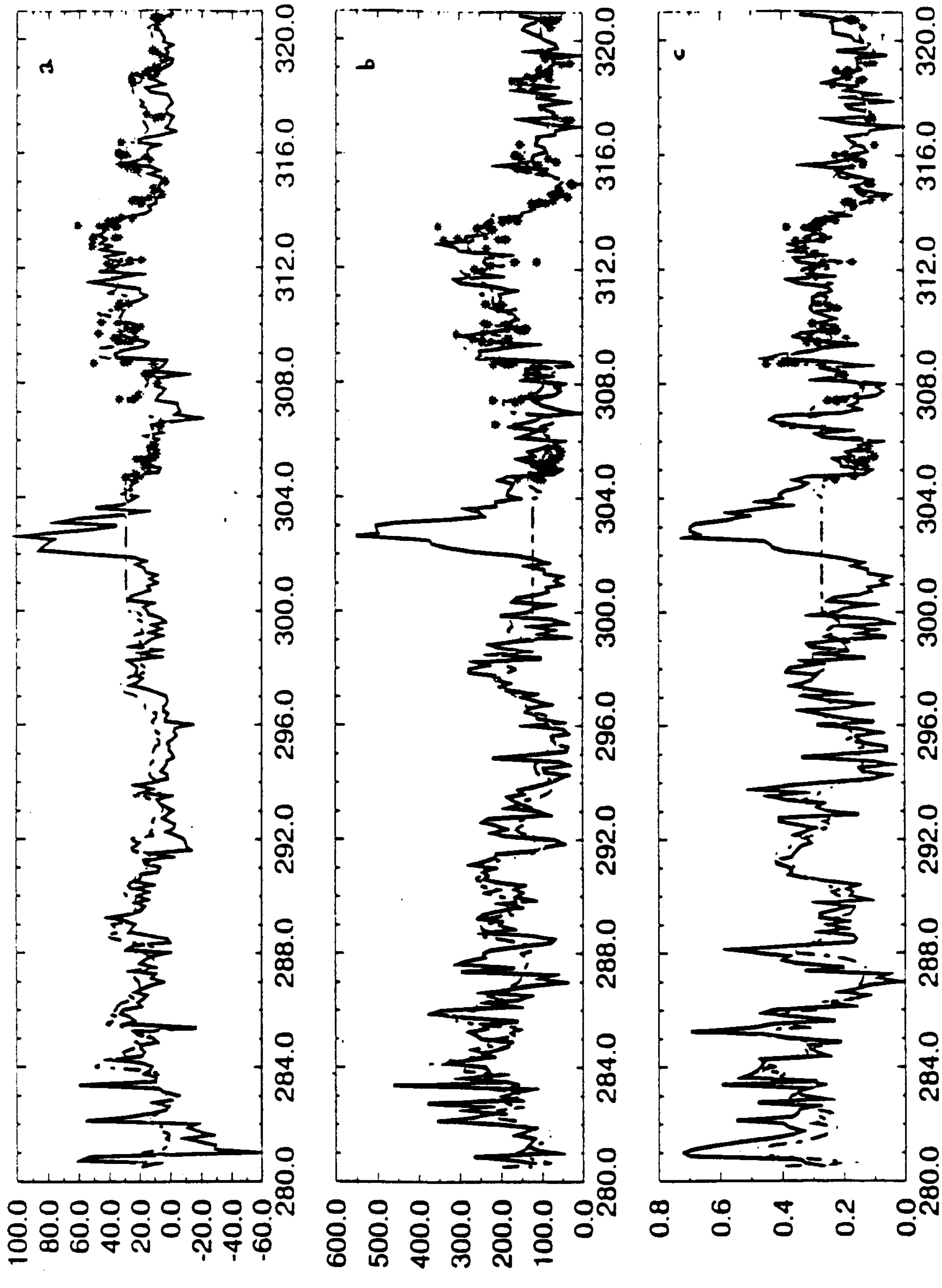


Figure 6. (a) Sensible heat flux in W m^{-2}, (b) latent heat flux in W m^{-2}, and (c) friction velocity in m s^{-1} along the trajectory of *Le Suroit* from 7 October to 17 November 1993. The fluxes are calculated through the inertial dissipation method (star symbol), through adjusted bulk formulae (dotted line) or derived from the ARPEGE reanalysis (solid line). (S. Planton)

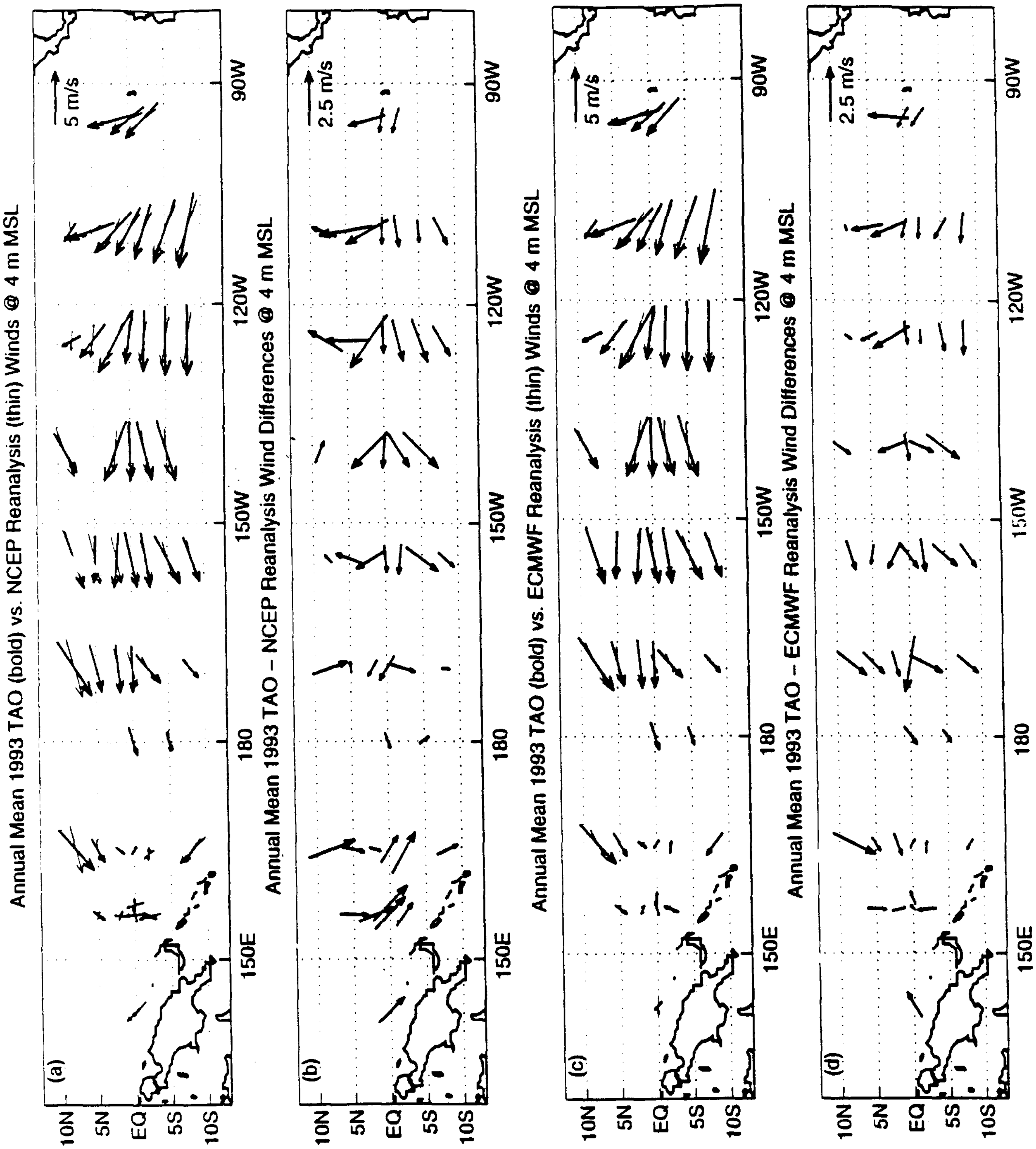


Figure 7. Annual mean vector plots at 4 m MSL for 1993 depicting (a) TAO observed (bold) vs. NCEP reanalyzed (thin) winds; (b) TAO-NCEP wind differences; (c) TAO observed (bold) vs. ECMWF reanalyzed (thin) winds; and (d) TAO-ECMWF wind differences. Vector key at upper-right of each panel. (B. Smull)

APPENDIX 1.

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
COMMISSION OCEANOGRAPHIQUE INTERGOUVERNEMENTALE
COMISIÓN OCEANOGRAFICA INTERGUBERNAMENTAL
МЕЖПРАВИТЕЛЬСТВЕННАЯ ОКЕАНОГРАФИЧЕСКАЯ КОМИССИЯ
اللجنة الدولية الحكومية لعلوم المحيطات
政府间海洋学委员会

UNESCO

UNESCO - 1, rue Miollis - 75732 Paris cedex 15
cable address: UNESCO Paris - telex: 204461 Paris-fax: (33) (1) 45 68 58 12 - contact phone: (33) (1)

Reference: IOC/GOOS/TAO/JT/jt

16 December 1997

Subject/Objet: Data distribution from the Indian Data Buoy Programme

Dear Dr. Desa,

I am writing to you on behalf of the three co-sponsoring bodies (GOOS/GCOS/CLIVAR) of the TAO Implementation Panel.

As you may know, the Sixth Session of the TAO Implementation Panel was held in Reading (UK), 4-6 November 1997, with the attendance of participants from eight nations, including India. In response to the national report from India, the TAO Panel has recommended that data from the Indian National Data Buoy Programme be placed in the Global Telecommunications System (GTS), as soon as possible.

The final report of the Reading meeting will be published by IOC/UNESCO and available early next year, but I thought the issue could be immediately brought to your attention.

Presently, India has four moored buoys in the Bay of Bengal with plans to augment this by a further 6 buoys in the Arabian Sea as part of the Indian National Data Buoy Programme. Those buoys measure important surface meteorological parameters, such as wind speed and direction, air temperature, as well as upper ocean temperature profiles. At present, few oceanographic and meteorological observations are available in the Indian Ocean, so the data are potentially important both for purposes of climate research and for operational use in weather prediction models.

Together with proposed new experiments such as CLIVAR/JASMINE, ATOC and the proposed extension of TRITON moorings into the Indian Ocean, these moorings could represent an important beginning of an Indian Ocean observing array, as envisaged by the existing global systems.

To gain maximum impact of the data, they should be transmitted in near real-time on the GTS so that it can be assimilated into the weather centres' observational data bases. It can then be used for present operational atmospheric and oceanic analyses as well as for any subsequent reanalyses.

Due to the benefit of these data for weather forecasting as well as for climate research, GCOS, GOOS and CLIVAR strongly endorse the recommendation made by the TAO panel. We would very much appreciate the support of the Indian National Data Buoy Programme and all the agencies and institutes involved.

Yours sincerely,

Gunnar Kullenberg
Executive Secretary IOC

Dr. Ehrlich Desa
Director
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Dona Paula, Goa 403004
India

cc: WMO Secretary General
GCOS Project Office
GOOS Project Office
International CLIVAR Project Office
Chairman IBPIO

APPENDIX 2.

The Atmospheric Radiation Measurement (ARM) Program and Radiation Measurements from the TAO Array.[1]

R. Michael Reynolds
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Sun, Nov 2, 1997

Introduction: There is a strong relationship between climatic variability in the tropical western Pacific (TWP) and variability in other portions of the globe. These connections are well documented in the meteorological and oceanographic literature (e.g., United States CLIVAR Implementation Planning Report, as well as the extensive TOGA literature).

The Atmospheric Radiation Measurement (ARM) Program[2] (Stokes and Schwartz, 1994) is the largest global change research program supported by the Environmental Sciences Division of the U.S. Department of Energy (DOE). ARM scientists focus on obtaining field measurements and developing models to better understand the processes that control solar and thermal infrared radiative transfer in the atmosphere (especially in clouds) and at the earth's surface. The ARM Science Plan (DOE, 1996) lists three primary research objectives for the TWP:

1. Surface radiation budget and cloud forcing.
2. Water and energy budgets of clouds and cloud systems.
3. Ocean-atmosphere interactions.

The Science Plan also gives three critical elements for the TWP observing strategy:

A. A long time series of basic observations at several locations.

B. Intensive field campaigns to augment the long-term measurement sets.

C. Long-term measurements of properties and fluxes at the ocean-atmosphere interface.

The TWP program[3], in response to item A, has developed the Atmospheric and Cloud Radiation Station (ARCS) to provide long-term, basic climatological observations. An ARCS consists of an integrated instrument set that measures the surface radiation balance, surface meteorology, cloud properties, and some limited atmospheric quantities. The first ARCS was installed at Manus Island, Papua New Guinea in October 1996 (Mather *et al.*, 1997). A second ARCS will be installed on Nauru in 1998, and others will be installed at additional tropical sites in the future.

TAO-PSP Radiation Sensors: As a first step toward satisfying item C, above, an array of high-quality short-wave radiation measurements will be deployed in the TAO buoy array along the 165°E longitude line. The NOAA Pacific Marine Environmental Laboratory (PMEL), with support from ARM, has developed new ATLAS data loggers with precipitation sensors and shortwave radiometers that will substantially upgrade insolation measurements in the tropical Pacific. (Heretofore, radiation and rain measurements were not part of the standard ATLAS package but were collected by a separate data logger.) Eight ATLAS buoys along the 165°E meridian will be instrumented by early 1998. These solar measurements will provide a limited but continuous data set to compare to the ARCS measurements made on Nauru. Questions regarding the accuracy and utility of these buoy measurements need to be addressed as part of an intensive operating period.

The TAO-PSP short-wave radiation sensor (Figure 1) was developed by the Eppley Laboratories in collaboration with PMEL. The sensor is completely sealed in a special non-metallic case and electronic access is via a small wet-pluggable oceanographic connecter mounted in the bottom plate of the sensor. PMEL engineers install a micropower processor circuit inside the TAO-PSP case. A low-noise preamplifier with gain of approximately 276 drives an analog-digital-converter with a final resolution of 0.4 $W m^{-2} bit^{-1}$.

The TAO-PSP circuit samples continuously at 1 Hz and accumulates a sum of the samples and a sum of the squares of the samples. On command from

[1] Presented at the Sixth TAO Implementation Panel, Reading Great Briton, 4-7 November 1997
[2] www.arm.gov
[3] www.arm.gov/docs/sites/twp/twp.html

the data logger, three numbers are transmitted by serial data transfer: the number of samples, the sum, and the sum of squares. With these numbers the mean and standard deviation of the short-wave global flux can be computed. In the present configuration, 2-minute averages are accumulated and stored.

Daily averages of insolation are telemetered by the buoy ARGOS telemetry system. The daily averages are summed over the 24-hour period based on UTC time. The radiometers are sampled only from 0600 to 1800 hours local time. Thus a transmitted daily average includes, in local time, the previous afternoon and the current morning.

Sensor Calibration: The TAO-PSP sensor transmits the direct digital counts from the analog-to-digital converter circuit. Because each sensor comes from the factory with different calibration values, and because the analog circuitry can have minor differences, a direct in-field calibration of the sensors is the best method for quality assurance. A special calibration interface (Figure 1) capable of supporting sixteen TAO-PSP sensors was developed at PMEL for calibration. The calibration box is provided to the National Renewable Energy Laboratory in Golden CO where it will be installed on the NREL calibration platform. The plan is to calibrate each TAO-PSP sensor before and after its deployment.

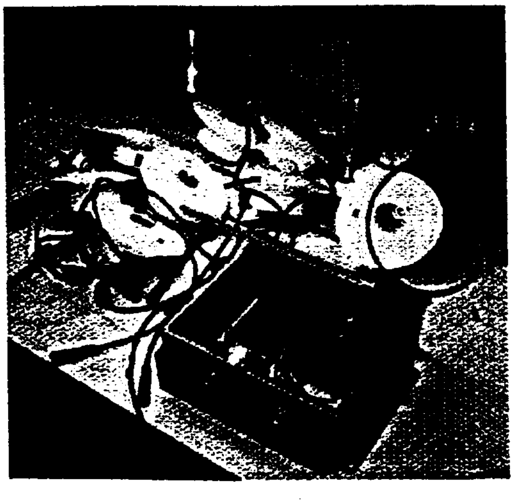

Figure 1. Sensors and calibration test set just prior to the first calibration.

Expected Performance: There are considerable questions concerning the uncertainty in short-wave radiation measurements taken from a moving platform, especially from a surface-following buoy such as the ATLAS. Based on tilting-table studies by MacWhorter and Weller (1991), we know that rocking in waves is reduced by the time constant in the Eppley sensor (4 sec) but mean tilt can cause error of up to 1-3% for typical tilt from moored buoys in the deep ocean. Figure 2 below shows results from a 30-day comparison of shortwave radiometer measurements from a ship and a TAO buoy (Fairall and McPhaden, 1993). These results are encouraging and suggest that with care and calibration we can expect solar insolation measurement uncertainties of less than 5 $W m^{-2}$ on a continuing basis. This estimate is in agreement with the review by Weller (1996).

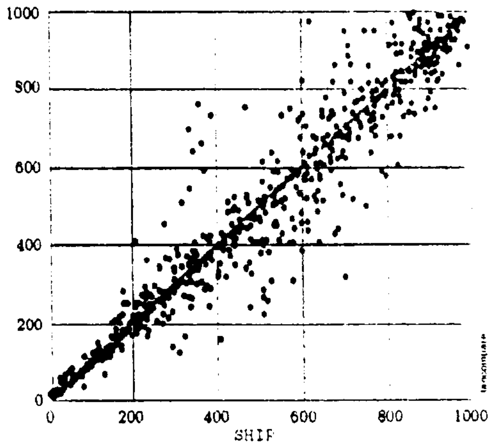

Figure 2. The standard deviation for the 20-minute averages, shown above, was 7 $W m^{-2}$ and for daily averages the deviation was 4 $W m^{-2}$.

Current Schedule: The following are the expected milestones for this project.

June 97	Pilot deployments 165E and 8N, 5N, 2S, 8S.
27 Oct 97	Start NREL calibration.
Jan 98	Recover 4 pilot deployments from 165E line.
Jan 98	Deploy eight next-gen systems on 165E line.

A pilot deployment of next-generation data systems was made in June 1997 at 165°E and 8°N, 5°N, 2°S, and 8°S. These units are transmitting their daily data and are apparently operating correctly. The pilot units will be recovered during the January 1998 cruise of the R/V *KAIYO*[4]. During this cruise, the entire line of eight moorings on the 165°E line will be deployed as the official beginning of the

[4] Scientists from BNL will be on board to observe and participate in the first recovery.

ARM shortwave measurement program in the TWP ocean.

Early Results: Figure 3 shows daily averages from buoys located at 165°E and 8°N, 5°N, 2°S, and 8°S. Daily averages are transmitted via the ARGOS satellite system and are available in near-real time. Daily averages, in this case, are computed from the two-minute averages over the time interval of 0600 to 1800 local standard time. However, because times are all maintained in UTC, a daily average includes data from 1100–1800 LST from the previous day and 0600–1100 LST on the current day.

The dashed line in Figure 3 shows the theoretical clear-sky insolation at the surface with an integrated water vapor of 4 cm, typical of the tropics, and no aerosols. The solid blue lines are the measured daily averages for each buoy. There are no clear days, as is expected, and there are many days with extremely low means, especially at 8°S where means dropped to as low as 20 W m^{-2} on two occasions. The numbers in the upper right-hand corners of the plots show the mean clear-sky insolation for the time period and the measured insolation. The number below these is the percent reduction in sunlight between the observed and clear sky averages.

A latitudinal difference is apparent. The percent insolation reduction at 2°S is 30%, while the other buoys were 38–40%. Also, the variance at 2°S is markedly less than the other positions. The data indicate that conditions at 2°S were sunnier than at the other sites, and there is a reasonable physical argument for this. If one looks at maps of long-term mean outgoing longwave radiation (OLR) over the tropical Pacific, a large area of low radiation, indicative of deep convection and precipitation, is evident over the western Pacific. The OLR minimum, coinciding with both SST and the ITCZ, separates into two distinct branches at approximately the longitude of 160°E. The TAO buoys along 165°E cross both the northern and southern arms of the ITCZ and the buoy at 2°S lies approximately between. This result will be confirmed by longer time series, but the argument is intriguing, and it appears that theTAO radiation measurement uncertainty is small enough to identify such features.

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Fairall, C.W. and M.J. McPhaden (1993) A ship-buoy comparison of bulk meteorological measurements and implications for surface heat flux measurements. In: *Abstracts of the third Scientific Meeting of the Oceanographic Society, April 13-16, 1993, Seattle, WA*, p. 104

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Weller, R.A., In Situ Observations of Surface Meteorology and Air-Sea Fluxes, *U.S. WOCE Report, 8*, 17–20, 1996.

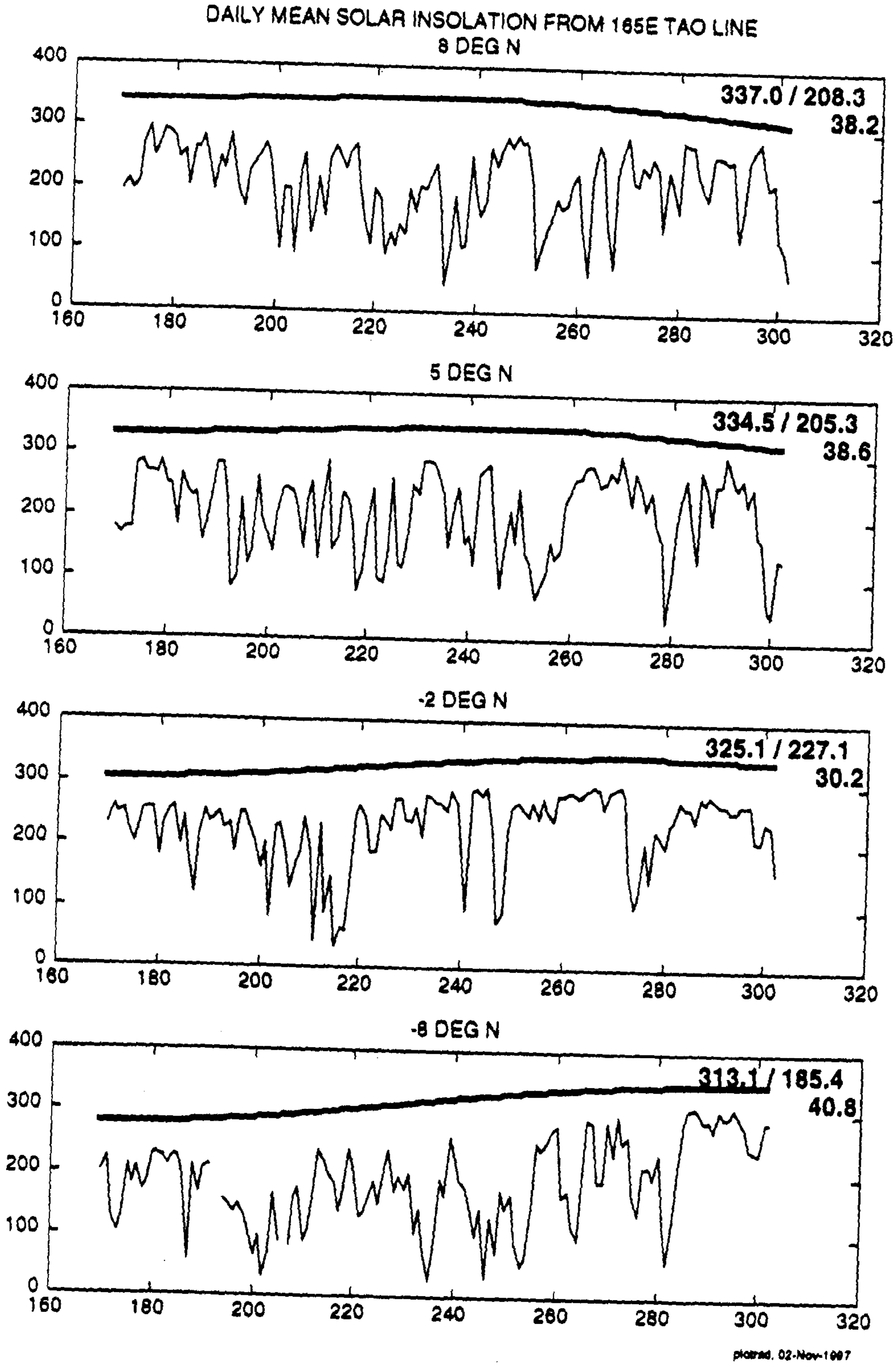

Figure 3. A quick look at daily averages from the first four (prototype) buoys on the 165°E buoy line. The thin line shows measured, daily insolation for the four TAO buoy locations along the 165°E longitude. The thick line is the expected clear sky surface insolation. Mean clear sky and measured insolation for the series and the percent solar reduction are shown in the upper right-hand corners of each plot.

 Appendix 3

APPENDIX 3.

Meeting Agenda

SIXTH SESSION OF THE TAO IMPLEMENTATION PANEL
European Centre for Medium Range Forecasting
Reading, England
4–6 November 1997

NOVEMBER 4 - Tuesday

8:30 a.m.	OPENING CEREMONY (Session Chair: Dr. David Anderson)
9:00 a.m.	STATUS OF THE ARRAY (M. J. McPhaden, NOAA/PMEL)
10:00 a.m.	NATIONAL REPORTS (Session Chair: J. Servain/ORSTOM) United States: L. Mangum (PMEL)/W. Woodward (NOAA/OAR) Japan: M. Hishida (JAMSTEC)/Y. Kuroda (JAMSTEC) Taiwan: D. Tang (National Taiwan University) India: P. Kumar (NIO)
12:30–2:00 p.m.	Lunch
2:00 p.m.	PROGRAM STATUS REPORTS (Session Chair: W. Woodward, NOAA/OAR) Pilot Research Moored Array in the Tropical Atlantic (PIRATA) J. Servain (ORSTOM/Brest) and M. Vianna (INPE) Joint Air-Sea Interaction Monsoon Experiment (JASMINE) J. Godfery (CSIRO/Hobart) Atmospheric Radiation Measurements Program M. Reynolds (Brookhaven National Laboratory) Tropical Rainfall Measuring Mission R. Murtugudde (U. Maryland) Ocean Observations for Climate Panel (OOPC) R. Weller (WHOI) CLIVAR Upper Ocean Panel W. Kessler (NOAA/PMEL) CLIVAR A. Villwock (International CLIVAR Office) Global Ocean Observing System J. Trotte (GOOS Project Office) Data Buoy Coordination Panel E. Charpentier (DBCP)
5:30 p.m.	ADJOURN
6:30 p.m.	RECEPTION

NOVEMBER 5 - Wednesday

8:30 a.m. PROGRAM STATUS REPORTS (continued)

Climate Observations in the US
M. Johnson (NOAA/OGP)

Pan American Climate Studies (PACS)
S. Piotrowicz (NOAA/OAR)

International Research Institute for Climate Prediction.
R. Kleeman (IRI)

SCIENCE REPORTS (Session Chair: W. Kessler, PMEL)

ECMWF climate forecasting system and results.
D. Anderson (ECMWF)

ECMWF data assimilation system for climate forecasting.
T. Stockdale (ECMWF)

Operational weather forecasting at ECMWF, with emphasis on analysis and assimilation of low level data.
T. Hollingworth (ECMWF)

TBA
O. Alves, (ECMWF)

The Coupled Modelling Project at NCEP.
M. Ji (NCEP)

12:30–2:00 p.m.LUNCH

2:00 p.m. SCIENCE REPORTS (Session Chair: K. Kutsuwada/Tokai U.)

Actual and potential use of TAO data at Méteo-France.
S. Planton (Méteo France)

Reliability measures for ENSO predictions: Implications for the observing network.
R. Kleeman (BMRC/IRI)

Use of the TAO buoy data by the US Navy
P. Phoebus (FNOC)

Comparison of NCEP/NCAR and ECMWF reanalyzed fields with TAO buoy observations over the tropical Pacific.
B. Smull (Univ. Washington)

The value of good surface meteorology from moorings: Results from the Arabian Sea.
R. Weller (WHOI)

Salinity variations in the western tropical Pacific.
W. Kessler (NOAA/PMEL)

5:30 p.m. ADJOURN

NOVEMBER 6 - Thursday

8: 30 a.m.	SCIENCE REPORTS (Session Chair: D. Tang, NTU) Impacts of salinity and Indonesian throughflow on the Indo-Pacific basin. R. Murtugudde (U. Maryland) Short-term climate variability in Taiwan and the tropical atmosphere-ocean. H.-H. Hsu (National Taiwan University) Analyses of JAMSTEC subsurface ADCP mooring data. Y. Kuroda (JAMSTEC) and K. Kutsuwada (Tokai University) TBA--J. Servain (ORSTOM/Brest) Effects of ocean transparency on the upper ocean heat balance. M. Lewis (Dalhousie University)
11:00 a.m.	DISCUSSION AND RECOMMENDATIONS
12:30–2:00 p.m.	LUNCH
2:00–4:00 p.m.	DISCUSSION AND RECOMMENDATIONS (continued)
4:00–5:00 p.m.	EXECUTIVE SESSION (TIP Members only)
5:00 p.m.	ADJOURN

APPENDIX 4.

List of Participants

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APPENDIX 5.

Terms of Reference

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

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

APPENDIX 6.

TAO Panel Membership

Executive Committee:

M. McPhaden (NOAA/PMEL, Chairman)
A. Sumi (University of Tokyo, Vice-Chairman)
J. Picaut (ORSTOM)

Members:

A. Busalacchi (National Aeronautics and Space Administration)
S. Godfrey (Commonwealth Scientific and Industrial Research Organization, Australia)
M. Hishida (Japanese Marine Science and Technology Center)
H.-H. Hsu (National Taiwan University)
W. Kessler (Pacific Marine Environmental Laboratory)
P. Kumar (National Institute of Oceanography, India)
K. Kutsuwada (Tokai University)
M.-S. Suk (Korean Ocean Research and Development Institute)
O. Thiele (NASA/Goddard Space Flight Center, USA)
W. Woodward (National Ocean Service)

CATEGORIES OF PANEL MEMBERSHIP

Panel Membership:

Membership of the TAO Implementation Panel will be by invitation of the Global Ocean Observing System Planning 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 and vice-chairman will serve as national representatives on the executive committee. Responsibilities of the executive committee include: coordinating 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 and other ocean-climate data sets.

APPENDIX 7.

List of Acronyms

ADCP:	Acoustic Doppler Current Profiler
ADEOS:	Advanced Earth Observing Satellite
AGCM:	Atmospheric General Circulation Model
AOML:	Atlantic Oceanographic and Meteorological Laboratory (NOAA/USA)
ARM:	Atmospheric Radiation Measurement
ARPEGE:	Action de Recherche Petite Echelle Grande Echelle
ATLAS:	Autonomous Temperature Line Acquisition System
ATOC:	Acoustic Thermometry and Ocean Climate
BMRC:	Bureau of Meteorology Research Centre (Australia)
BPPT:	Agency for the Assessment and Application of Technology (Indonesia)
CBS:	Commission for Basic Systems (WMO)
CDC:	Climate Diagnostics Center
CLIVAR:	Climate variability and Predictability (WCRP)
CMM:	Centre de Meteorologie Marine (France)
COARE:	Coupled Ocean-Atmosphere Response Experiment (TOGA)
CSIRO:	Commonwealth Scientific and Industrial Research Organization
CTD:	Conductivity Temperature Depth Profiler
DBCP:	Data Buoy Cooperation Panel
DHN:	Diretoria de Hidrografia e Navegacao (Brazil)
DOE:	Department of Energy (USA)
DST:	Department of Science and Technology (India)
ECMWF:	European Centre for Medium Range Weather Forecasting
ENSO:	El Niño-Southern Oscillation
EOF:	Empirical Orthogonal Function
ERS:	Earth Remote Sensing Satellite
FFA:	Foreign Fishing Agency
FNOC:	Fleet Numerical Center (Navy/USA)
FRP:	Frontier Research Programs
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)
GOALS:	Global Ocean-Atmosphere-Land System
GODAE:	Global Observational Data Assimilation Experiment
GOOS:	Global Ocean Observing System
GSFC:	Goddard Space Flight Center (NASA/USA)
GTS:	Global Telecommunication System
ICRP:	Indian Climate Research Programme
IFREMER	Institut Francais de Recherche pour l'Exploitation de la Mer (France)
IGBP:	International Geosphere-Biosphere Program
IMET:	Improved Meteorological Package (WHOI/USA)
INPE:	Instituto Nacional de Pesquisas Espaciais (Brazil)
IOC:	International Oceanographic Commission
IPO:	International Project Office
IRI:	International Research Institute
ISO:	Intra-Seasonal Oscillations
ITCZ:	Intertropical Convergence Zone
ITF:	Indonesian ThroughFlow
JAMSTEC:	Japan Marine Science and Technology Center (Japan)

JAPACS:	Japanese Pacific Climate Study
JASMINE:	Joint Air-Sea Interaction Monsoon Experiment
JGOFS:	Joint Global Ocean Flux Study
JTA:	Joint Tariff Agreement
LODYC:	Laboratoire D'Oceanographie Dynamique et de Climatologie (France)
MBARI:	Monterey Bay Aquarium Research Institute (USA)
MEDS:	Marine Environmental Data Service (Canada)
NASA:	National Aeronautics and Space Administration (USA)
NASDA:	National Space Development Agency of Japan (Japan)
NCAR:	National Center for Atmospheric Research
NCEP:	National Center for Environmental Prediction (NOAA/USA)
NIO:	National Institute of Oceanography (India)
NOAA:	National Oceanic and Atmospheric Administration (USA)
NSCAT:	NASA Advanced Scatterometer (USA)
NTU:	National Taiwan University (Taiwan)
NWS:	National Weather Service (NOAA)
OAR:	Oceanic and Atmospheric Research Agency (NOAA/USA)
OGCM:	Oceanic General Circulation Model
OGP:	Office of Global Programs (NOAA)
OLR:	Outgoing Longwave Radiation
ONR:	Office of Naval Research
OOPC	Ocean Observations for Climate Panel
ORSTOM:	Office de la Recherche Scientifique et Technique Outre-Mer (France)
PACS:	Pan American Climate Studies
PIRATA:	Pilot Moored Array in the Tropical Atlantic
PMEL:	Pacific Marine Environmental Laboratory (NOAA/USA)
PRC:	People's Republic of China
SCSMEX:	South China Sea Monsoon Experiment
SEACAT:	Sea-Bird Conductivity and Temperature Recorder
SCS:	South China Sea
SOC:	Southampton Oceanography Center
SOPAC:	South Pacific Commission
S-PALACE:	Salinity/Profiling Autonomous Lagrangian Circulation Explorer
SSG:	Scientific Steering Group
SST:	Sea surface temperature
STA:	Science and Technology Agency (Japan)
SURTROPAC:	Survey of the Tropical Pacific (SURveillance TRans-Oceanique du PACifique) ORSTOM, France
TAO:	Tropical Atmosphere-Ocean Array
TIP:	TAO Implementation Panel
TOCS:	Tropical Ocean Climate Study (Japan)
TOGA.	Tropical Ocean-Global Atmosphere
TOPEX/Poseidon:	Ocean Topography Experiment
TRITON:	Triangle Trans-Ocean Buoy Network (Japan)
TRMM:	Tropical Rainfall Measuring Mission (NASA/USA)
UNESCO:	United Nations Educational, Scientific, and Cultural Organization
VOS:	Volunteer Observing Ships
WHOI:	Woods Hole Oceanographic Institution (USA)
WHP:	WOCE Hydrographic Program
WCRP:	World Climate Research Programme
WMO:	World Meteorological Organization
WOCE:	World Ocean Circulation Experiment
WWB:	Westerly wind burst
XBT:	Expendable Bathythermography
XCTD:	Expendable Conductivity, Temperature and Depth