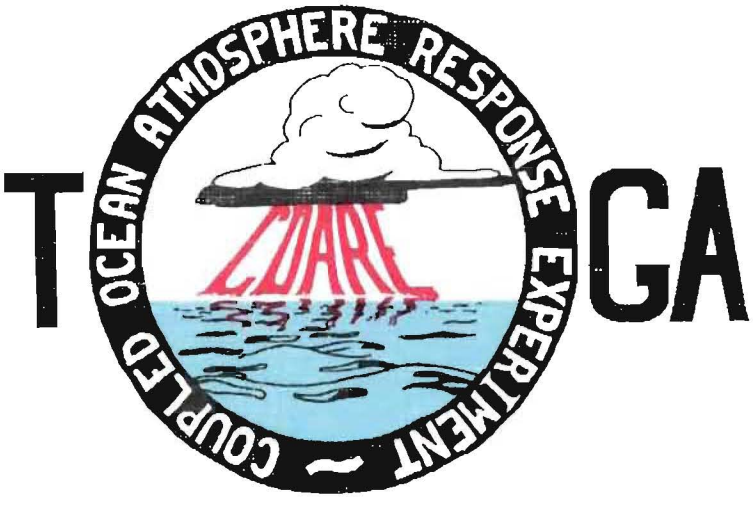
WESTERN PACIFIC INTERNATIONAL MEETING AND WORKSHOP ON TOGA-COARE

Nouméa, New Caledonia
May 24-30, 1989

ABSTRACTS



INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE
POUR LE DÉVELOPPEMENT EN COOPÉRATION

ORSTOM

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JIMAR, University of Hawaii, Honolulu, U.S.A.

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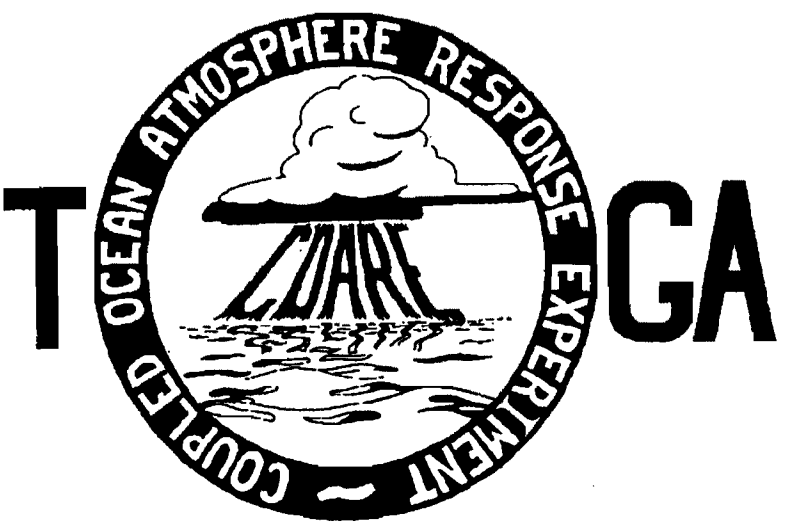

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CENTRE DE NOUMEA

ESTIMATION OF LARGE-SCALE OCEANIC RAINFALL FOR TOGA

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The global Precipitation Climatology Project (GPCP) of the World Climate Research Program has been charged with producing analyses of large-scale monthly rainfall through the use of a mix of satellite algorithms and station data. Over the tropical oceans, the primary information source is to be rainfall estimates derived from geostationary IR digital data using a simple thresholding algorithm. These estimates are now available for the tropics for 5-day periods beginning in January 1986 using data from GOES East and West, Meteosat and GMS. Spatial and temporal gaps in the coverage are being filled by estimates derived similarly from AVHRR observations.

In this paper, we will describe the spatial and temporal variability of tropical rainfall for the period 1986-1988 using these data. This period includes both a warm episode and a cold episode of the El Nino/Southern Oscillation (ENSO) phenomenon, and should provide a good test of the capability of these rainfall estimates to define the features associated with the two poles of ENSO.

While simple IR-based rainfall estimates appear adequate to describe interannual variations in the distribution of planetary scale rainfall, they are less successful on smaller space and shorter time scales. Rainfall estimates for COARE are likely to require better resolution than has so far been obtained for extended time periods and large areas. We will conclude by offering a plan for the production of high spatial and temporal resolution rainfall estimates for the COARE domain for the entire IOP through the use of a hierarchy of algorithms and data sources. The simplest algorithm will be based on thresholded IR histograms, as in the GPCP. This will be complemented by an algorithm which uses spatial textural information and yields a partition of the rainfall into convective and stratiform components (the Convective-Stratiform technique, developed by Adler and Negri). A third algorithm (currently under development) will use observations from a passive microwave radiometer to better define raining areas with an IR-based algorithm. A final algorithm, which might be called a rainfall analysis, will use rainfall forecasts from operational numerical weather prediction models as first guesses and will correct them using a variety of satellite and in-situ observations.

RELEVANCE TO TOGA OF SYSTEMATIC XBT ERRORS

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A series of expendable bathythermograph (XBT) and conductivity temperature-depth (CTD) intercomparisons have been performed to detect errors in XBT temperature and depth. Two commercial digital recorders, which are widely used in ocean/climate programs, were used to collect the XBT data.

Previous studies have documented errors in estimation of depth as the main source of XBT errors. This study examines the applicability of the various proposed depth-correction algorithms, and examines the effect of these depth errors on dynamic height calculations with reference to large-scale ocean/climate programs. The study also examines findings of recorder/processor instrument malfunctions which particularly affect observations in the mixed layer. The implications to TOGA research of these types of errors are also discussed.

SIGNATURE OF A WEST WIND CONVECTIVE EPISODE IN SPECIAL SENSOR MICROWAVE IMAGER (SSM/I) DATA

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Evaporative cooling events in the western equatorial Pacific have been identified as a precursor to anomalous decreases in the local sea surface temperature during the 1982-83 ENSO. It has also been hypothesized that evaporative cooling of the ocean's upper mixed layer may have a significant effect on the rate of entrainment cooling across the bottom of the upper mixed layer. These scenarios suggest that air-sea heat fluxes play a crucial role in the ENSO phenomena of the western equatorial Pacific.

In a pilot study to assess the quality of data from the recently-launched Special Sensor Microwave/Imager (SSM/I), brightness temperature data is used to derive surface wind speed, total water vapor, and rain rate before, during, and after the passage of a west wind convective episode (WWCE) during Northern Hemisphere winter 1988. Since the algorithms used to derive these geophysical variables are simply linear combinations of the brightness temperatures, clustering techniques are used to examine patterns of similar microwave brightness temperature vectors. Wind speed and total water vapor can only be accurately retrieved in the non-precipitating areas. In these areas, the clusters appear to be related qualitatively to different evaporative cooling regimes. The temporal and spatial patterns of the clusters during the passage of a WWCE are discussed.

Estimates of evaporative cooling can be made using SSM/I-derived surface wind speed and total water vapor when combined with independent estimates of sea surface temperature. Quantitative estimates of latent heat release are limited by the lack of quality in situ ground truth, by use of satellite data in the bulk parameterization, and by the uncertain relationship between total water vapor amount and water vapor mixing ratio at a given height in the boundary layer. Suggestions for improvement are offered.

ENSO EVENTS AND CONSEQUENCES ON THE NUTRIENTS, PLANKTONIC BIOMASS AND PRODUCTION IN THE SOUTH WESTERN TROPICAL PACIFIC OCEAN.

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Twelve cruises have been undertaken on the 165°E transect between 20°S to 6°-10°N, from 1985 to 1989, within time frames of 3 to 6 months, under the two ORSTOM programs PROPPAC and SURTROPAC. These occurred during the El Nino event and non-El Nino periods. Data collected in the 200 m upper layer provide an important basis for the study of effects of long-term hydroclimatic variations on the chemical and biological structures in the south western tropical Pacific Ocean.

The first results show; (i) For the nutrients: From January 1985 to April 1987 a thick nutrient depleted mixed layer (under detectable limits) has been observed. Since April 1988, there has been a strong upwelling in the equatorial area due to the westward equatorial current. Surface nitrate, nitrite and phosphate concentrations are higher than 3µM, 0.3µM and 0.3µM, respectively. (ii) For phytoplankton : Increases in abundance and biomass, and changes in depth distribution of cyanobacteria and microalgae are closely related to the upwelling. (iii) For zooplankton : In April and September 1988, between 3°S-2°N, there appeared to be clear increases in mesozooplankton (200-2000µm) biomass, and in the percentage of its relative dry weight to microzooplankton (35-200µm). The vertical structure showed large changes between El Nino and no - El Nino periods; after spring 1988, maxima in zooplankton biomass (70% of dry weight over 0-500m) were observed in the upper 100m. (iv) For primary production : In the upper mixed layer the primary production during the ENSO event was weak. The level of production increased at the beginning of the upwelling and decreased six months later. The integrated values of primary production in the 0-200m for September 1987, April 1988 and September 1988 averaged about 59 $mgC.m^{-2}\,h^{-1}$ 150 $mgC.m^{-2}\,h^{-1}$ and 77 $mgC.m^{-2}\,h^{-1}$, respectively.

MEASUREMENTS OF HEAT AND MOISTURE FLUXES FROM THE WESTERN TROPICAL PACIFIC OCEAN

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During April/May 1988 measurements of heat and moisture fluxes were made from R.V. Franklin operating in the Bismark Sea and between the islands of New Guinea and the equator. A sonic anemometer and Lyman-& humidiometer were mounted at the end of a boom 10 m forward of the bow and 6 m above the water. Psychrometers were mounted at 3, 6 and 10 m. Sea surface temperature was measured with an infra-red radiometer and the individual components of long and short wave radiation with instruments on the masthead. An array of accelerometers was set alongside the sonic to remove the ship's motion from the wind signals; but this paper presents data from 3 days when the wind was light and the sea so calm that eddy-correlation measurement of heat and moisture fluxes was successful without correction. Above about 4 $m.s^{-1}$ bulk transfer coefficients for both entities conformed to the accepted values of 1.2×10^{-3}. Decreasing wind speed, however, saw a corresponding increase in transfer coefficients for both entities conformed to corresponding increase in transfer coefficients, rising sharply below 1 $m.s^{-1}$ in excellent agreement with the model predictions of Liu et al (1979) *. The comparison between covariance and dissipation methods for evaluating scalar fluxes in these light wind conditions will be discussed. Comparison between the infra-red radiometer measurements of SST and the "bucket" temperature of water 2-3 m below the surface indicates a cool skin depression (due to evaporative cooling) of about 0.5°C. These results suggest factors which may lead to systematic errors in the climatology of the region based on ship-of-opportunity reports, and misleading estimates of components of the oceanic heat budget.

* Liu W.T., K. B. Katsaros and J. A. Businger (1979). J. Atm. Sci., 36, 1722-1735

SENSITIVITY OF WIND DRIVEN TROPICAL PACIFIC OCEAN SIMULATIONS ON SEASONAL AND INTERANNUAL TIME SCALES

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The purpose of this study is to characterize differences in the time/space structure present among conventional descriptions of the tropical Pacific surface wind field, and in turn, to quantify the impact of these differences on our ability to model the dominant wind-forced variability of the tropical Pacific Ocean on seasonal and interannual time scales. A linear, multiple vertical mode ocean model is used as a transfer function to determine the influence of three distinct surface wind stress products for the period 1979-1983. This five-year period was chosen for study because it encompasses three years of a fairly regular seasonal cycle leading up to the 1982-83 El Nino for which there are several coincident oceanic and surface wind data sets. The three different wind analyses used are the Florida State University subjective analysis, the University of Hawaii subjective analysis, and the Fleet Numerical Oceanography Center objective analysis. We examine first the three seasonal cycle solutions prior to El Nino which then serve as self-consistent bases for analyzing the significant anomalies about the mean in 1982-83. The model solutions for quantities such as dynamic height, sea level, and heat content are compared with observed variations based on expendable bathythermograph and island tide gauge data. Coherence estimates of 0.5-0.7 are found between the model simulations and the observations for the 1 cycle per year harmonic which dominates the seasonal cycle of sea level over most of the tropical Pacific. In general, the largest modeled and observed interannual anomalies associated with El Nino agree within a few centimeters. The impact of uncertainties in the forcing functions is discussed relative to the dominant seasonal and interannual scales of variability for the oceanic response.

A LAGRANGIAN MODEL OF THE "OCEANIC MONSOON" IN THE WESTERN PACIFIC OCEAN

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A Lagrangian analytical solution for the Monsoonal circulation will be presented in which a meridional pressure gradient drives a cross-equatorial flow.

This solution can be used as a model for the maintenance of the warm pool in the western Pacific Ocean. In the event of an anomalous northward meridional wind, the meridional driving is increased, and the Monsoonal circulation responds by distributing the warm pool eastward as an El Nino event.

Mean sea level and climatic data in support of these ideas will be discussed.

INTERANNUAL VARIABILITY OF THE INDIAN OCEAN SURFACE FIELDS

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The interannual variability of surface fields over the Indian ocean during the period 1930-1986 has been investigated.

First the study of the relationship with the interannual fluctuations of rainfall over East Africa has been performed. Besides the evidence of a strong correlation between surface fields and precipitation, it is shown that the Indian Atmosphere-Ocean system exhibits a mode of fluctuations around 5-6 years. In particular, there is an out of phase correlation between the western and the eastern sectors of the Indian ocean. Analysis of the monthly mean fields of outgoing long wave radiation for the period 1974-84 has confirmed the previous results. These findings are analyzed with reference to the fluctuations of the position and/or intensity of the rising and descending branches of the East-West circulation over the domain.

Second, the interannual variability of the heat budget over the Indian ocean in relationship with the occurrence of El Nino events over the Pacific ocean has been studied for the period 1954-86. The results are showing that warmings are taking place over the Indian ocean due to an increase of the net heating. The maximum SST occurs about 10 months after the maximum of net heating.

DETERMINATION OF BOUNDARY-LAYER FLUXES WITH AN INTEGRATED SOUNDING SYSTEM

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From an atmospheric measurement perspective, TOGA COARE presents a number of significant challenges. To better understand ocean-atmosphere coupling, an important goal is to determine the exchange of momentum, and sensible and latent heat in the western Pacific over the time scales of convective storms, westerly bursts and lower frequency events. TOGA COARE will also require detailed moisture budget studies in support of improved understanding of sub-gridscale processes and the evaluation of model parameterization schemes. Present field-deployable measurement systems do not provide observations on the temporal and spatial scales necessary to properly address these and other issues. We present the concept of the so-called Integrated Sounding System (ISS) as a means to provide these measurements. The ISS would consist of a suite of demonstrated in situ and remote sensing subsystems which together provide the measurements to sense directly or retriave high-resolution profiles of winds, temperature and moisture and associated fluxes. Individual subsystems under consideration for the ISS include : surface meteorological station (winds, state variables and radiation budget); UHF Doppler wind profiling radar; radio acoustic sounder for retrieval of virtual temperature; infrared interferometer-spectrometer (temperature, water vapor, and various trace gases); microwave radiometer (temperature, humidity and liquid water); and an Omega-VLF radiosonde system for in situ but low frequency profiles to - 20mb. Other features of the integral system include a central data acquisition and processing computer, real-time satellite telemetry link, and rugged, easily transported base station. We estimate the cost of individual ISS' to be sufficiently modest to enable deployment of a network of order 10-15 systems in support of TOGA COARE.

ABNORMAL BLOOM OF PHYTOPLANKTON AROUND 7°N IN THE WESTERN PACIFIC DURING THE 1982-1983 ENSO

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The chlorophyll concentration at the surface of the tropical Pacific has been monitored through the 1982-83, owing to the SURTROPAC ships of opportunity network. The event was characterized by a decrease in chlorophyll concentrations at the equator, where a belt of relatively rich water however persisted. The most striking anomaly was observed in the western Pacific between 5°N and 10°N. In this region, the chlorophyll concentration at the surface is generally less than 0.07 mg/m^3, caused by a mixed layer exhausted in nutrient and strong density gradient at the thermocline. From October 1982 to March 1983, higher concentrations up to 0.40 mg/m^3, have been observed by the network. This is consistent with the shallowing of the thermocline which characterizes all ENSO events and was especially well marked in 1982-83. Such a bloom can be explained only if new nutrients have been supplied to the mixed layer. Possible mechanisms are examined.

MECHANISMS OF SUBSURFACE THERMAL STRUCTURE AND SEA SURFACE THERMO-HALINE VARIABILITIES IN THE SOUTH WESTERN TROPICAL PACIFIC OCEAN DURING 1979-85

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Major features of the south western tropical Pacific (SWTP), defined between 160°E-140°W and 24°S-10°S, are brought to light through analysis of surface water samples (23000) and temperature profile observations (8500), both collected by ship of opportunity programs during the 1979-85 period.

Mean vertical thermal structure, sea surface temperature (SST) and salinity (SSS) are first portrayed, to further quantify their 1979-85 respective variability. Is is demonstrated that the observed seasonal and interannual variabilities, the latter being associated with the strong 1982-83 ENSO event, are mostly governed by specific mechanisms involving varying wind field and rainfall regime.

During the non-ENSO period (1979-81+1984-85), SST annual cycle and 0-100 m thermal structure changes are tied to the seasonal variations of the sun position (minimum SST in August). At the mean position of the South Pacific Convergence Zone is a marked seasonal SSS cycle (minimum in March). This minimum occurs 2-3 months after maximum precipitation whose variations suffice to explain SSS changes, assuming a 28±7 m mixed layer depth in agreement with sporadic density profile observations. This suggests that SSS annual cycle is mostly driven by the rainfall regime associated with the SPCZ intensity and meridional migration. The seasonal meridional migration of the SPCZ also causes alternance of cyclonic and anticyclonic wind stress curls, so that west of 175° W and between 13°S-17°S, the thermocline depth seasonal variations are governed by the Ekman pumping mechanism.

During the ENSO period (1982-83), notable changes in the vertical temperature distribution were mostly perceivable within 10°S-15°S and below 100 m, in response to anomalous wind stress field that strongly uplift the thermocline, through local Ekman pumping (as much as 70 m in May 1983). The resulting thermocline shoaling intensified the southern branch of the south equatorial current, and induced a southward shift of the subtropical gyre center, as already observed during the 1957 and 1972 ENSO. In addition, the thermocline shoaling modified the whole water column all the way to the surface, and was thus responsible for the SST coolings anomaly (-0.5°C to -1° C) observed in the northern SWTP (i.e. in the warm pool area). In the southern SWTP, similar SST cooling were concomitant with positive latent heat flux anomaly (>20W/m^2) mostly resulting from an increase in the northward wind component. At the mean SPCZ position, the SSS augmented to as much as +1 in early 1983, in response to a rainfall deficit resulting from the equatorward shift of the SPCZ.

MAJOR GEOSAT SEA LEVEL ANOMALIES IN THE WESTERN TROPICAL PACIFIC DURING THE 1986-87 EL NINO, ELUCIDATED AS EQUATORIAL KELVIN AND ROSSBY WAVES

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The 1986-87 El Nino is the first to be captured by a satellite altimeter, allowing to monitor the total tropical Pacific ocean with reasonably good spatial and temporal resolutions. Thanks to the altimeter data set, information on sea level changes during the 1986-87 El Nino is presented. Special emphasis is placed in the warm pool area, through a detailed description and tentative explanations of the observed sea level changes.

The GEOSAT Sea Level Anomalies (SLAs) are first evaluated near the 165°E longitude, with independent data sets including meridional CTD sections made during seven cruises, continuous vertical temperature measurements from thermistor chain moorings, and island sea level observations. It is shown that the altimetric time series have an RMS accuracy of approximately 4 cm. Hence, only SLAs over +/- 8 cm (signal to noise = 2) are analysed.

Near the 165°E longitude (which crosses the middle of the warm pool), the onset of the 1986-87 El Nino is characterized by a rapid development of a positive (>14 cm) equatorial SLA in November/December 1986. This feature occurs in response to eastward wind anomaly which appears between 140°E-170°W along the equator. The wind induces an equatorial downwelling Kelvin waves with phase speed of about 2.8 $m.s^{-1}$, as deduced from time-lag correlation analysis and Gaussian fit of the meridional SLA structures. Then, equatorial SLAs remain quite constant (i.e., < 8 cm) from January to April/May 1987. In June 1987, equatorial SLA decreases to a minimum value, just after an abrupt change of the zonal wind stress anomaly west of 165°E (+20 $m^2.s^{-2}$ down to -20 $m^2.s^{-2}$). A Gaussian fit of the meridional SLA structure, together with a time-lag correlation analysis evidence that the June 1987 SLA results from propagation of an upwelling Kelvin wave at about 2.8 $m.s^{-1}$. Two patches of negative SLAs then appear in September 1987 at 4°N and 4°S, symmetrical about the equator. These are the signature of a first meridional mode equatorial upwelling Rossby wave arising from the eastern boundary as a reflexion of an equatorial upwelling Kelvin wave generated in January 1987, east of 165°E. The Rossby wave phase speed of about 0.9 $m.s^{-1}$ is deduced from both time-lag correlation analysis and a fit of the SLA meridional structure to Rossby wave. These calculations reveal that first baroclinic Kelvin waves and reflected Rossby waves were the dominant sources of sea level changes in the equatorial band, all over the November 1986-November 1987 El Nino period.

COMPARISON OF RESULTS OF TWO PRE-COARE CRUISES: FOC (1971) and WEPOCS (1985-86)

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Where the program COARE will take place, in the equatorial area located north of New Guinea, two similar series of cruises have been carried out at the same seasons: FOC (Jan-Feb and June-July 1971), WEPOCS (June-July 1985 and Jan-Feb 1986). Both are including hydrographical and current measurements but the techniques used are of course different: discrete sampling and current profiling for FOC, CTD and acoustic Doppler measurements for WEPOCS. However main features newly discovered are the same:

1) The New Guinea Coastal Undercurrent (NGCU) flowing westward at 250 m depth, is obvious during all the cruises. It is characterized by the spreading of the isotherms at the shore and it transports salted and oxygenated water.

2) This water probably feeds the equatorial undercurrent but the retroflection is out of the studied area.

3) A Pacific Equatorial Monsoon Jet appeared not only in January 1971 and January 1986 but also in June-July 1985 and during only one leg in June-July 1971. The occurrence of such jet is probably connected to local meteorological conditions. Moreover, Pacific Equatorial Monsoon Jet is usually associated to a vein of westward flow embedded between the eastward surface jet and the eastward undercurrent. This feature may be due to a transient response of the upper ocean to a sudden relaxation of the easterly winds.

Isopycnal analysis points out some discrepancies:

- at 300 cl/t, the salinity maximum extends westward north of New Ireland during the FOC cruises.It extends close to New Guinea shore during WEPOCS.
- at 160 cl/t, the oxygen maximum flowing eastward in the NGCU is more extended during FOC than during WEPOCS.

The heat content and the salt quantity from the surface to 100 m depth are similar during all the cruises. Heat content from the surface to 300 m is the same during FOC1, FOC2 and WEPOCS1 but smaller during WEPOCS2 (Jan-Fev 1986). This feature may be connected to the onset of the 1986-87 El-Nino.

EFFECT OF LOW LATITUDE WESTERN BOUNDARY GAPS ON THE REFLECTION OF EQUATORIAL MOTIONS

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The western tropical Pacific is thought to be an important zone for generating El Nino : reflections at the boundary make it a source region of equatorial Kelvin waves. Calculations of the effect of a gappy western boundary on the reflection process are carried out in the framework of the low frequency limit of the shallow water equations and are highly idealized. The method is also applied to a schematic version of the flow through the Indonesian seas from the western Pacific to the Indian oceans.

The results indicate some strong sensitivities to the location of the gap and to the structure of the incoming flows. In addition, the results can be quite different depending on whether the zonal extent of the gap is assumed to be infinite or finite. (More precisely, the latter means that the extent of the gap is short compared with the zonal wavelength of the relevant free waves at that frequency.)

Due to the complexity of the results for even such a simplified model, it will be very difficult to be confident of any modeling study of the Indonesian throughflow short of a highly resolved numerical calculation with a detailed representation of the geometry and bathymetry. Nonetheless, we offer tentative conclusions concerning the efficiency of the western Pacific boundary as a reflector. Our results suggest that the realistic boundary will not greatly alter expectations on a simple solid boundary if the reflections important for El Nino are primarily in motion represented by low order Rossby modes. This is also consistent with observational evidence which tends to support that there is no anomalous throughflow during El Nino events.

SEA SURFACE CHLOROPHYLL CONCENTRATION IN THE SOUTH WESTERN TROPICAL PACIFIC AS SEEN BY NIMBUS CZCS FROM 1978 TO 1984

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Surface oligotrophy is the rule in the South Western Tropical Pacific due to the generalization of the deep chlorophyll maximum at the nutricline depth. Then, the phytoplankton content of the upper layer is an indicator of nutrient inputs in the euphotic zone due to diverse physical processes.

The Coastal Zone Color Scanner (CZCS) on board the NIMBUS-7 NASA satellite measured the ocean color variation of the sea during the 1978-1984 period. The sea surface chlorophyll variations were followed during 6 years in the Coral Sea around New Caledonia and Vanuatu by analyzing 40 images of this archive.

Major phytoplankton enrichment effects were then detected from the CZCS chlorophyll increases linked to the main circulation patterns related to the position of the tropical convergence zone of winds, and in accordance with the merchant ships survey and cruises observations (Dandonneau and Gohin, 1984). They are :

- enrichment due to trade mixing events in the southern waters (south of 22° S)
- convergence zone at 25° S
- bathymetric and island mass effects around New Caledonia, Loyalty Islands and Vanuatu
- discolored cyanobacteria extensive blooms along 800 miles to the east of New Caledonia during the calm period.

At each season, the upper layer phytoplankton (30 meters) reveals the complexity of the mesoscale circulation which is hardly detected by sea measurements. Mesoscale gyres (100 miles of diameter) are trapped at the western coast of New Caledonia, frontal structures are indented by small eddies, light island effects are detected at reefs and south or north of islands (narrow meanders of 50 miles).

To perform a large-scale description of the superficial phytoplankton enrichment processes, mosaics of all these CZCS data would be necessary. A modeling of the potential primary production related to the satellite-measured biomass is in progress at the Center ORSTOM of Nouméa.

RELATIONSHIPS BETWEEN THE 30-60 DAY OSCILLATION IN THE TROPICS AND THE VARYING FREQUENCY OF ATMOSPHERIC ANGULAR MOMENTUM OSCILLATIONS

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Modeling and observational studies have suggested that the 30-60 day oscillation, manifest primarily as eastward propagation of convection and circulation anomalies, is coupled with a zonally symmetric oscillation Hadley circulation responding to changes in tropical convection. We have found that the frequency of the zonally symmetric oscillation, measured as total atmospheric angular momentum (AAM), has a large interannual variability. In this study we compare and contrast the convection and circulation characteristics of two November-March seasons with markedly different oscillation frequencies in AAM.

Results suggest that variations in the frequency of AAM oscillations are related to differences in the basic state for each season. The relationship of these oscillations to tropical (5°N-5°S) convection anomalies also varies interannually. During 1984-85 (low frequency AAM oscillations) a large sea surface temperature (SST) gradient existed across the Pacific basin as below normal SST's extend from the South American coast to the dateline in conjunction with anomalous low level easterlies from 160°E-90°W. In contrast, the 1979-80 (high frequency AAM oscillations) season shows SST's to be slightly above normal in the same region with low level westerlies (strongest from 150°E-180°) along the equator. The onset of anomalous convection in the tropics during 1984-85 is centered at 60°E-90°E and leads minima in AAM. As AAM decreases, convection propagates eastward and AAM reaches a relative maximum approximately 10 days after OLR crosses the dateline (minimum AAM). Low level westerly wind anomalies are observed in eastward propagating phase, low level easterlies were manifest east of the convection. At the maximum phase of AAM convection is suppressed over Indonesia and is generally enhanced over South America and Africa.

The 1979-80 high frequency season displays a distinctly different pattern of variation; the onset of convection is shifted eastward to 120°E-150°E, covers less geographical area, and is coincident with a minimum of AAM (versus leading minimum AAM in 1984-85). Additionally, low level northerlies, possibly associated with cold air surges, occur in conjunction with the onset of convection. Eastward propagation of convection is not as well defined as during 1984-85 and may be indicative of a standing wave. These "convective pulses" exhibit low level westerlies immediately east of the convection just prior to a maximum in AAM. As with 1984-85, relative maxima in AAM are associated with suppressed convection over Indonesia and enhanced convection over South America and Africa.

VERTICAL THERMAL STRUCTURE VARIABILITY ALONG 165°E DURING THE 1986-87 ENSO EVENT

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Modifications of the intertropical thermal structure along the 165°E meridian linked to the 1986-87 ENSO are described and analyzed from results of a series of cruises carried out by ORSTOM from Nouméa, and additional data from the US-PRC Western Pacific program cruises.

During the evolution of the ENSO event, changes in the vertical distribution of temperature are found to be restricted mostly to the upper 400 m. Therefore, temperature anomalies and vertical displacements of isotherms can be computed in relation to a climatology deduced from XBT data available in the region.

Warming and deepening of surface layers are apparent before the onset of the ENSO event, more important in the southern hemisphere warm pool ; then, a cooling of thermocline layers appears close to the Equator at the beginning of 1987. The corresponding equatorial shoaling of isotherms extends progressively poleward in both hemispheres to 10° of latitude, while reaching sub-thermocline layers. This anomalous temperature pattern persists until the first half of 1988. In June 1988 temperature anomalies have lowered or changed sign, returning to a configuration close to that observed prior to the onset of ENSO.

Heat content and thermocline depth anomalies are shown to be correlated to large scale sea level anomalies from GEOSAT altimeter data. Differences emphasize the smoothing of structures by satellite measurements. Mechanisms for large scale evolutions are searched for in the effects of local and remote wind stress forcing.

VARIABLE CURRENTS IN THE WESTERN PACIFIC MEASURED DURING THE USA-PRC BILATERAL TOGA PROJECT

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Acoustic Doppler current profile sections from USA-PRC TOGA project show strong variability associated with the 1986-87 El Nino event. Currents along 165°E could hardly be more different than among cruises 2,3 and 4. In cruise 2, December 1986, flow was predominantly eastward within 9° of equator, with a strong North Equatorial Countercurrent (NECC) reaching 80 $cm.s^{-1}$ at 5°N, an equatorial jet in the mixed layer exceeding 120 $cm.s^{-1}$, and a South Equatorial Countercurrent reaching 50 $cm.s^{-1}$ at 5°S. The equatorial jet is remarkably similar to that observed at 159°W in November and December of 1982, during the 1982 El Nino. An equatorial undercurrent (EUC) is evident below 150 m, a depth at which the flow is near zero or weakly westward. Nearly a year later, on cruise 3 in October 1987, the EUC was utterly absent. All currents below 100 m within about 2° of the equator were westward. This was a more thorough reversal of the EUC than any other of which we are aware. The westward flow on the equator was symmetrically flanked by eastward currents in the range 3-7° or either side of the equator. This velocity field is suggestive of an equatorial Rossby wave, but a detailed analysis, including the density as well as the velocity fields, remains to be done. The following spring, on cruise 4 in May 1988, the EUC was exceptionally strong for this longitude and was flanked by strong westward flows, suggestive of a Rossby wave of opposite sign. It is clear that more than a single vertical mode is involved in these velocity changes, and almost certainly more than a single equatorial wave type as well. Nevertheless, the strength of the signals encourages one to think that a fairly simple description in terms of a few modes and waves may be successful.

The contrasts between the 141.5°E and the 165°E sections are also striking. The 141.5°E section is missing from cruise 2 because of computer failures, but in cruises 3 and 4 we find the New Guinea Coastal Undercurrent, the EUC, and a deeper undercurrent at 3.5°N that can probably be identified as the North Subsurface Countercurrent, or Tsuchiya jet. The currents below 200 m were quite similar between cruises 3 and 4 at 141.5°E, in spite of the great differences between these cruises at 165°E. Above 200 m there were major differences at 141.5°E as well. The cruise 3 section is notable for its strong shear between the westward South Equatorial Current along the coast, which reached a maximum of 100 cm/s, and the eastward jet on and north of the equator. The eastward flow might be described as a combination of the North Equatorial Countercurrent and the EUC. During cruise 4 the New Guinea Coastal Undercurrent was overlain by a strong westward South Equatorial Current. The North Equatorial countercurrent was weak but spanned a fairly large range of latitudes, from 3°N to 8°N.

EUROPEAN GROSSWETTER DURING THE WARM AND COLD EXTREMES OF THE EL NINO/SOUTHERN OSCILLATION

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El Nino/Southern Oscillation (ENSO) warm and cold events affect the synoptic climatology of the north-eastern Atlantic-European sector. The classification of cyclonic and anticyclonic European Grosswetter (1881-1987) is analyzed for its response on 26 warm and 21 cold ENSO episodes. Bimonthly ranked composites computed over idealized 2-year ENSO warm (cold) episodes show more days of cyclonic (anticyclonic) steering over Europe. This signal is largest in the winter months of January and February following the year of a warm or cold event. The distributions of the occurrence of cyclonic and anticyclonic Grosswetter days are significantly different for warm and cold event winters : (i) There is more variability between individual warm event winter months, whereas the response on cold episodes is relatively uniform; (ii) On average, cyclonic Grosswetter days are experienced on 60% (46%) of the 58 warm (cold) event winter days; about 70% (90%) of the warm (cold) event winters realize more than 30 (less than 36) days of cyclonic steering. Qualitatively corresponding results are obtained at a representative central European location for sunshine duration and the sum of daily negative temperatures, which characterize the winter strength.

WIND PROFILER RELATED RESEARCH IN THE TROPICAL PACIFIC

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Since 1984 the Aeronomy Laboratory of NOAA's Environmental Research Laboratories has been engaged in a research program in tropical dynamics. A principal tool employed in this research has been the wind-profiling Doppler radar. The Aeronomy Laboratory played a pioneering role in the development of wind profiler technology and has been the first group to deploy wind profilers in the equatorial region to study the tropical atmosphere. The Pohnpei radar was constructed in 1984 and the Christmas Island radar became operational in 1986.

Vertical velocities observed at Pohnpei have been analyzed to obtain average vertical velocity profiles under convective, stratiform and relatively clear conditions at Pohnpei. These observations constitute the first direct measurements of vertical motions in the tropics. In addition individual "hot towers" are clearly seen in the short-term observations. For the past two years wind profiler observations from Christmas Island have been input via GOES into the GTS. They have been used routinely by the NMC and ECMWF for their analysis and forecast products. A comparison of the quality of the analyses at Christmas Island compared to the wind profiler observations shows considerable improvement after the wind profiler observations were used in the analyses. Christmas Island winds are archived at the Aeronomy Laboratory and summaries of the data are published in the Climate Diagnostics Bulletin. Comparisons of the winds observed in 1987 and 1988 reveal considerable interannual variability that seems to be related to the changing phase of the Southern Oscillation between the two years.

The Christmas Island wind profiler serves as a prototype of wind profilers that can be used even in fairly remote locations to obtain reliable tropospheric winds in the tropics; The VHF radars used in the tropics do not observe winds below 1-2 km. To address this problem the Aeronomy Laboratory has developed a 915 MHz lower tropospheric wind profiler capable of observing winds from about 100 m above the surface to 3 to 4 km with good height resolution.

With support from the National Science Foundation we are expanding our tropical research. Specifically, we are constructing a Transpacific Profiler Network that will extend from Peru to Indonesia. In addition to the Christmas island facility that is supported by TOGA, the Pohnpei radar will be upgraded to measure horizontal winds and new wind profilers will be constructed in Piura, Peru and Biak, Indonesia.

THE EQUATORIAL MIXED LAYER SYSTEM : MEAN STATE AND DIURNAL MODULATION

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The mechanics of the equatorial mixed layer system are explained. On the equator, the mean state of the mechanical energy budget is explained by a balance between downward fluxes of buoyancy and kinetic energy (KE) at the surface and the upwelling-induced conversion of mean KE to turbulent kinetic energy (TKE) at depth, below the well-mixed layer. In the mean state, with steady surface forcing, the vertical profile of the dissipation of TKE penetrates into the pycnocline, well below the mixed layer and down to the depth of maximum upwelling velocity. Below the depth of maximum vertical velocity, the conversion of mean KE to TKE ceases, and turbulent fluxes of all properties as well as the rate of dissipation of TKE and property variances would be expected to be relatively low compared with the respective values above the depth of maximum upwelling velocity. This turbulent bu not-so-well-mixed zone is expected to limited by planetary rotation to something less than u*/f at higher latitudes and has been approximated frequently as a discontinuity. However, the thickness of the entrainment zone at the equator is not limited by f, but by upwelling which opposes the downward penetration of mixed-layer turbulence. The mean vertical motion, while limiting vertical transport of turbulence, actually enhances local dynamic instability down to the depth of maximum upwelling speed.

For upwelling that is attributable to the horizontal divergence of the wind-driven current, the depth of the maximum vertical velocity will coincide with the depth of penetration of the wind-driven transport. This depth will include the well-mixed part of the turbulent boundary layer and the thick underlying entrainment zone. The diurnal surface buoyancy flux cycle will modulate the TKE budget in the well-mixed surface layer, but perhaps even more significantly it will modulate the production of turbulence in the underlying entrainment zone. When the surface layer turbulence is caused to shallow, the entrainment process stops (in fact there is temporarily no entrainment zone). Then the wind-driven transport is entirely contained above the depth of shallowing which is proportional to the Obukhov depth modified by rotation (Garwood, Muller and Gallacher, 1985). Thus the maximum upwelling velocity is relatively shallow, at the Obukhov depth. Below this depth the vertical flow is divergent and the dynamic instability of the mean state ceases, and the earlier zone of strong dissipation and turbulent fluxes becomes quiescent; As the diurnal surface heating reduces and

entrainment again begins, the depth of the wind-driven transport grows. Trough the night, the thickness of the well-mixed layer grows somewhat, and at the same time the entrainment zone grows to its earlier depth.

For upwelling caused by internal wave motion and circulation not related directly to the divergence of the Ekman transport, turbulent mixing and dissipation at depth could persist and be independent of the diurnal shallowing of the surface well-mixed layer. However, the depth of maximum vertical velocity should still be a limiting depth for strong vertical mixing and dissipation. In general, the depth of the maximum upwelling velocity is predicted to have a strong diurnal cycle, and significant vertical fluxes of nutrients and deep mixing of all properties is most likely to occur in the early morning hours preceding sunrise.

HYDROLOGICAL EFFECTS ON THE AIR-OCEAN COUPLED SYSTEM

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The ocean and atmosphere are driven by the fluxes of momentum, heat, and water mass across the air-sea interface. The importance of the fluxes of momentum and heat are well recognized by both meteorologists and oceanographers. The hydrological cycle is, however, only given considerable attention in atmospheric models since the moisture flux from the ocean surface is an important source of the atmospheric general circulation. The hydrological cycle is given less attention in ocean models although it is realized that evaporation and precipitation are contributors to the surface buoyancy flux which determines the depth of mixing and drives the thermohaline circulation.

Based on hydrological effects we present and discuss a positive-negative feedback mechanism between cloud and ocean mixed layer. Water vapor, evaporated from the ocean surface or transported by the large-scale air flow, often forms convective clouds under a conditionally unstable lapse rate. First, clouds reduce the incoming solar radiation at the ocean surface by scattering and absorption, which cools (relatively) the ocean surface layer. The cooling of the ocean mixed layer lowers the evaporation rate, which will diminish the clouds. This is the negative feed back mechanism. Second, precipitation dilutes the surface salinity, stabilizing the upper ocean and reducing mixed layer deepening. The mixed layer may even be caused to shallow if the downward surface buoyancy flux is sufficiently enhanced by the precipitation. The reduction in mixed layer depth will increase the sea surface temperature (SST) by concentrating the net radiation plus heat fluxed downward across the sea surface into a thinner layer. The increase of SST augments the surface evaporation, which in turn produces more clouds. This is a positive feedback mechanism.

In this paper we show new modes with interannual frequency that are generated by this feedback mechanism. We also show that temperature changes in the ocean should not be assumed generally to be in phase with salinity changes, and no constant T-S relationship exists for a non-stationary ocean, even at a fixed location. Furthermore, in the atmospheric part of the coupled system, a realistic cloud model is required to separately predict precipitation, evaporation, heat fluxes, and radiation. Thus heat storage and density structure in the atmosphere and in the upper ocean need to be independent.

This independence has important implications for two-component air-sea interaction. The exchanges of water mass and heat between the ocean and atmosphere may be strongly coupled, but these processes must be allowed to have different phases and different time and space scales of variability.

The importance of phase difference between the respective heat and water budgets are explored first. A simple linear approximation of the two component thermodynamic system demonstrates a coupling of the exchanges of heat and water

fluxes across the sea surface which leads to both growing and decaying modes of oscillation on interannual time scales. These oscillatory solutions are entirely thermodynamic and do not require wave dynamics for their existence.

SURFACE RADIATION PROCESSES IN THE TROPICAL PACIFIC

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Solar irradiance at the surface has been estimated from GOES satellite data for the tropical Pacific east of the date line for the period 1981-1985. This period covers the 1982-1983 El Nino event during which major changes took place in the coupled atmosphere-ocean system. These satellite estimations provide an unprecedented accurate description of the spatial and temporal variability of the surface solar radiation on a daily (to monthly) basis and a 50 km spatial scale.

The first result of this study was a preliminary assessment of existing climatologies by comparing them with the annual mean satellite estimates (over the October 1983 to September 1985 period), which are expected to be accurate to better than 15 Wm^{-2}. The climatological values at the equator computed by Budyko (1963), Chou (1985), Esbensen and Kushnir (1981), and Wyrtki (1965) all appear to underestimate solar irradiance at the surface by about 20 to 40 Wm^{-2}, whereas those computed by Weare et al.(1981) are very close (within 1 to 2 Wm^{-2}) to the satellite estimations. When the annual mean is computed by including the El Nino conditions, the satellite estimations are reduced by only 8 Wm^{-2}, suggesting that most climatologies underestimate solar irradiance at the surface.

The spatial variability of the annual solar irradiance depicted from the satellite data during non El Nino years is dominated by very weak zonal gradients (1 to 2 Wm^{-2} over 200 km) but by stronger meridional ones (up to 20 Wm^{-2} over 200 km) in the region of the ITCZ. These gradients are even more noticeable in the monthly fields. During the El Nino period, the zonal variability becomes as large as the meridional variability, particularly in the central pacific, where intense convection dominates the atmospheric state; The standard deviation from the annual mean reaches 40 Wm^{-2} in that region, much larger than that observed within the ITCZ region during non-El Nino years. A difference of more than 150 Wm^{-2} in surface solar irradiance takes place in the equatorial region between 140° and 180°W between January 1981 and January 1983, where the largest SST anomaly is observed. Such a dramatic decrease of solar irradiance in 1983 will induce changes in the ocean heating and possibly affect the evolution of the SST anomalies.

A preliminary study of the entire tropical Pacific solar irradiance has been started using data from two geostationary satellites to cover the entire width of the basin. The GMS satellite data have been used to complement the GOES data and compute solar irradiance in the eastern Pacific. The region of the warm pool is found to be dominated by deep convection of a similar nature to that observed in the central Pacific during El Nino. The east to west gradient of solar irradiance will be quantified and presented for this first month (July 1983) of data analyzed.

THE SENSITIVITY OF THE ANNUAL CYCLE IN THE TROPICAL PACIFIC OCEAN TO VERTICAL MIXING PARAMETRIZATIONS

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A new reduced gravity, primitive equation model of the upper equatorial ocean has been developed. It has been configured to simulate the annual cycle in the tropical Pacific Ocean. It is forced by the winds from Rasmusson and Carpenter (1982) and the heat flux formulation from Seager et al. (1988). The coefficients of vertical eddy viscosity and conductivity depend upon the Richardson number of the flow. With this mixing a deep warm pool forms in the Western Pacific, increasing the west-east gradient of the thermocline and equatorial undercurrent. The model can be diagnosed as to what factors maintain this deep warm pool.

SEA LEVEL AND THERMAL RESPONSE TO THE 1986-87 ENSO EVENT IN THE FAR WESTERN PACIFIC

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Sea levels at the Papua-New-Guinea coast responded to the 1986-87 ENSO event much as would be expected for points on the inshore edge of a western boundary current, driven by remote Rossby waves rather than by local winds. The first EOF of sea level in the region accounts for 60% of the variance, and shows a clear western boundary current signal. Sea level estimates from tide gauges and adjacent XBT's are in good agreement, so XBT data are used to supplement sea level results; specifically, we obtain an estimate of the western boundary current as a function of depth. The anomalous transport varied by about 15 Sverdrups during the event. The boundary current followed the Trobriand Island ridge, rather than the main Papua-New-Guinea coastline. A maximum response to the ENSO occurred south of New Ireland, where steric sea level varied 45 cm due to the ENSO event.

STERIC HEIGHT GRADIENTS, THE INDONESIAN THROUGHFLOW AND THE LEEUWIN CURRENT

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The Indonesian channel permits equatorial Pacific winds to maintain a bank of very warm (28°C) water along Australia's Northwest Shelf. This leads to net ocean cooling south of 20°S off Western Australia (compared to 40° or 50°S, in the eastern Atlantic or Pacific). This convective cooling in turn generates meridional pressure gradients and the onshore geostrophic flows that feed the Leeuwin Current; in this sense equatorial Pacific winds drive the Leeuwin Current. Recent low estimates of the Indonesian throughflow are shown to contain errors; direct geostrophic estimates are closer to 12-16 Sverdrups.

THE WEST PACIFIC WARM POOL IN A COUPLED GENERAL CIRCULATION MODEL

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In coupled models, as in reality, the west Pacific warm pool region is particularly important because it is one of the major forcing centers of the atmospheric general circulation. The coupled model simulation indicates that the oceanic heat budget of the warm pool is dominated by local processes. At the ocean surface both evaporation, short wave feedbacks and wind variations on scales less than the model resolution are found to be important. There is a significant climate drift within the coupled model, with the warm pool migrating from its climatological position in the far west Pacific. This drift is most likely associated with the surface heat fluxes simulated by the model (which are, however, within the uncertainty in the climatological estimates).

The simulation of the oceanic mixed layer structure in the low wind, heavy precipitation. The dominant physical mechanisms in the atmosphere and ocean models over the warm pool will be described in detail and the areas in which the coupled model simulation suggests physical parametrizations need to be most improved will be discussed.

A SIMPLE 2 DIMENSIONAL COUPLED MODEL OF THE EQUATORIAL PACIFIC

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Gill (1983) noted three aspects of the evolution of El Nino episodes that are relevant to recent research on that topic. First, Gill proposed that the slow eastward propagation of ocean and atmosphere anomalies sometimes observed in association with El Nino activity might be explained by the advection of the mean SST gradient by perturbation zonal currents associated with baroclinic Kelvin wave activity. Second, in reconstructing the baroclinic wave field on the basis of wind stress data and observed sea level data, Gill found that the zonal wind stress forcing on the equator could not account for the magnitude of the Kelvin wave activity observed at the eastern boundary. While acknowledging that this effect might be due in part to flaws in the wind stress data, Gill proposed that significant Kelvin wave energy is, in fact, emitted from the western equatorial boundary. Finally, Gill conjectured that this Kelvin wave activity emanating from the western boundary might result in a coupled wave in the ocean/atmosphere system involving changes in the zonal SST gradients due to zonal advection associated with the Kelvin wave activity, consequent changes in the zonal wind stress field, and a resulting amplification of the Kelvin wave field. Of course, these ideas relate to the hypothesized role of internal baroclinic wave reflections in modulating phase changes in the El Nino cycle.

Since that time, several workers (e.g., Philander et al., 1984; Hirst 1986; and Rennick and Haney, 1986) have performed linear stability analyses on various simple, but realistic, models of tropical ocean-atmosphere systems in an attempt to reproduce and understand the observed slowly eastward propagating mode in the coupled system. These studies, although notable for their elegance, have not produced results that convincingly resemble the rather consistent and robust behavior of the actual system. Despite the lack of success of these linear analyses, slow eastward propagation and amplification does appear in some uncoupled ocean and atmosphere model simulations in which observed surface wind or SST forcing data is prescribed (e.g., Fenessey and Shukla, 1988; Latif, et al., 1988). Further, at least one coupled model of the tropical Pacific (Anderson and McCreary, 1985) has produced slow eastward motion of coupled anomalies, although at a speed much slower than observed.

We present results from a very simple 2-dimensional model of the equatorial Pacific that reproduces the basic mechanisms proposed by Gill, i.e., a slowly eastward propagating, amplifying wave in the coupled system that is excited by western boundary forcing in the upper level thickness. The model ocean includes only first baroclinic mode Kelvin wave dynamics. SST anomalies are due to advection by perturbation zonal currents associated with Kelvin wave activity. Zonal wind stress anomalies are proportional to the anomalous SST gradient, with a modification which is a function of total SST. The zonal wind stress anomalies, in turn, drive the Kelvin wave activity. A realistic zonal mean SST profile is prescribed.

In the model, the amplification of coupled ocean-atmosphere anomalies is due to positive feedback involving zonal currents, zonal advection of the mean SST field, and the resulting changes in the zonal wind stress. Linear stability analysis of the model reveals that in the absence of non-linear advection, a mean zonal current to the east is required to produce an energetic propagating signal. This linear analysis also shows that the propagating behavior is due primarily to the excitation of two large scale, lightly damped, stationary models in the system. Other, more highly damped, propagating modes, also contribute to the solution. Thus the energetic propagating mode that characterizes the model's behavior is due to the excitation of preferred, rather than unstable, modes. Without the inclusion of an eastward current in the linear advection case, an unstable mode does appear and dominates the solution.

With non-linear advection, the model does not require a zonal current to reproduce the propagating mode, which in this case travels somewhat faster than in the linear advection model. Both the linear and non-linear advection models require a non-linear (that is, is not constant) zonal mean SST profile to produce an amplifying response.

The results described above will be presented, along with some results from experiments in which the model is forced with realistic western boundary upper level thickness data. These results support the role of Kelvin wave activity emitted from the western boundary as an integral link in the coupled feedback loop that tends to perpetuate a broad-banded, somewhat periodic El Nino cycle. At the same time, such tests indicate that physical processes not included in the model probably have significant effects on the timing of the evolution of coupled anomalies, and that external influences may occasionally introduce major disturbances into the coupled system.

SEASONAL AND INTERANNUAL VARIABILITY OF THE MADDEN-JULIAN OSCILLATION

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Daily time series of near-equatorial wind observations from rawinsonde and island surface stations are used to examine the low-frequency variability of the "40-50 day" or "Madden-Julian" oscillation (MJO). Seasonal variations in the variance of intraseasonal zonal wind fluctuations are most pronounced in the upper troposphere and have a distinct geographical distribution. Over the western near-equatorial Pacific, intraseasonal variance is greatest during the equinoctial seasons (spring and autumn), whereas at other longitudes the variance is by far the greatest during the boreal winter season. Coherent intraseasonal variance of zonal wind in the lower troposphere is found only across the western Pacific. These results, and consideration of the longitudinal phase lags between intraseasonally-filtered time series from different stations, suggest the presence of two geographical regimes : a "convective regime" across the near-equatorial western Pacific and a "dry regime" elsewhere.

Data from stations in the western Pacific "convective regime" are examined further for evidence of interannual variability of the MJO that is associated with the Southern Oscillation. Seasonal time series of intraseasonal zonal wind variance are correlated with a standard Southern Oscillation Index. These correlations are most pronounced in the lower troposphere (including the surface wind) and are highly season-dependent. Implications of these results for theories of the MJO and for wind-stress forcing of ocean models are discussed.

OBSERVED STRUCTURE OF CONVECTIVE ANOMALIES

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Geographical variations in the variance and cross-correlation of monthly mean sea surface temperature (SST), outgoing longwave radiation (OLR, a proxy for deep convection and vertical motion), and convergence of winds at the surface and at 850 mb across the tropical Indian and Pacific Oceans are examined. Largest variances in the SST and surface convergence data occur across the eastern near-equatorial Pacific, whereas OLR and 850 mb convergence variances are largest across the western Pacific. OLR anomalies are significantly correlated with collocated SST and surface convergence anomalies from the date line eastward to the South American coast, but are uncorrelated west of the date line. On the other hand, OLR and 850 mb convergence anomalies are significantly correlated from about 120°W westward but uncorrelated east of that longitude. These calculations provide the basis for a comparative evaluation of several mechanisms invoked in recent efforts to simulate large-scale ocean-atmosphere coupling in simplified models. direct thermodynamic linkage between SST and convection anomalies is consistent with the results only across the eastern near-equatorial Pacific. Similarly, surface gradients of SST may play an important role in kinematically forcing low-level atmospheric circulation anomalies over the eastern Pacific, where SST and surface convergence have large variances and OLR and 850 mb convergence anomalies are small and not well-correlated. West of the date line, however, forcing by mid-tropospheric latent heating seems more consistent with the observed relationships than the thermodynamic or surface gradient mechanisms. It is suggested that the relative effectiveness of these mechanisms varies considerably across the near-equatorial oceans, with different mechanisms predominant in different regions. These deductions are reinforced by comparing the contributions of zonal and meridional convergence to the total convergence at the surface and 850 mb. Zonal convergence, which is emphasized in models forced by equatorially-centered interior heating, dominates the 850 mb convergence field, whereas meridional convergence tends to dominate at the surface. The near-surface convergence field thus contains a complicated vertical structure that is not adequately represented by models with a single lower layer.

OBSERVATIONS OF THE LOW-LATITUDE WESTERN BOUNDARY CIRCULATION IN THE PACIFIC DURING WEPOCS III

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Two of the goals of the third U.S. cruise of the Western Equatorial Pacific Ocean Circulation Study (WEPOCS) are to define the circulation of the low-latitude western boundary currents of the Pacific, and to determine the circulation patterns which supply the North Equatorial Countercurrent near its origin. The cruise was conducted aboard the R/V MOANA WAVE during June and July 1988. A 150 kHz RD Instruments Acoustic Doppler Current Profiler was used to observe the vertical and horizontal (along track) structure of currents from the ship. The data were taken within the region bordered by 124°E-145°E and 4°S-14°N and provide a quasisynoptic view of the upper ocean circulation within the region. The focus of this paper is on the horizontal and vertical structure of the currents, and the interconnections between the Mindanao Current, the North Equatorial Current and the North Equatorial Countercurrent.

Thirteen onshore-offshore sections made along the eastern coast of the Philippines from 14°N to the southern tip of Mindanao Island show that the Mindanao current was a continuous feature over the entire region. The velocities and transports are weaker at the northern sections and increase to the south. Transports of the Mindanao current (over the depth range 18-300 m) are 10 Sv (+ or -20%) north of 10°N and 20 Sv (+ or - 20 %) from 8°N to the southern tip of Mindanao Island. In all sections the velocity core was subsurface, in the depth range 50-100 m. At all observed depths the Mindanao current closely follows the topography of the Philippine islands until the current separates from the coast off the southern tip of Mindanao Island as it enters the Celebes Sea. Peak velocities observed at this location are 160 $cm.s^{-1}$. Within the celebes Sea a strong, clockwise flowing recirculation is observed between the northern edge of the Mindanao current and the southwestern coast of Mindanao Island.

To the east of the Mindanao Current in the region between 8°N and 14°N, the westward flow of the North Equatorial Current is observed. This flow feeds into the southward-flowing Mindanao Current; In this region a banded structure in the meridional velocity is observed in the offshore direction. To the southeast of the Mindanao current (in the region east of Talaud island) a strong outflow from the Malukka Passage is observed with peak velocities of somewhat over 100 $cm.s^{-1}$. Two velocity cores are observed, one at a depth of 60 m, the second at 160 m. Waters from the South Equatorial Current, flowing to the northwest, join the outflow from the Malukka passage (primarily Mindanao current water) to feed into the North Equatorial Countercurrent. The northern

edge of this combined flow is observed to turn to the east at 7°N, 130°E with peak eastward velocities of 110 cm/s near the surface. Recirculation is observed both in the Mindanao Eddy and the Halmahera Eddy.

To the east of the Mindanao current, large vertical shears in the currents are observed in the upper 400 m of the ocean. To describe this vertical current structure, maps of velocity at different levels are presented.

THE STEADY STATE RESPONSE OF INDONESIAN SEA TO A STEADY WIND FIELD

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A Barotropic fluid model based on the vertically integrated equations of motion was used for studying the steady-state response of Indonesian sea to a steady wind field.

Using Climatological wind field in Indonesia, the model results yield reasonable direction of water transport due to wind in Indonesia.

It was also found that direction of water transport vary according to the direction of the wind and the water movement is generally with the wind in shallow portions of the sea and against the wind in deeper areas.

WESTERLY WIND ANOMALIES FROM CENTRAL PACIFIC ISLANDS 1950-1980

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Thirty years of surface wind data from New Zealand-supervised observers on islands near the Dateline are used to summarize the characteristics of westerly wind anomalies as they are sampled in this data set.

The character of monthly mean anomalies during ENSO periods has been described by Harrison (1987; Monthly Weather Review 115, 12); here daily average wind and pseudostress data are used to examine the variability during ENSO and non-ENSO periods. Typical frequency of occurrence, by months, magnitude of anomaly, and geographical location will be presented. Some case histories showing a possible relationship between, the appearance of equatorial westerly anomalies and the subsequent development of tropical depressions also will be presented.

SOME OGCM STUDIES OF THE OCEANIC RESPONSE TO WESTERLY WIND EPISODES

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The Philander and Pacanowski version of the GFDL ocean circulation model has been used, in a series of experiments, to explore the oceanic response to idealized episodes of surface westerly wind in the western Pacific. Some preliminary results were published by Harrison and Giese (1988; Geophys. Res. Lett., 15,8). Additional experiments, and comparison of model results with central and eastern Pacific observations subsequent to the May 1986 tropical cyclone pair event have been carried out. Model results and observations are generally consistent, and non trivial ocean surface warming can take place. However, nonlinear processes and the presence of instability waves can make interpretation of the observations tricky. Both the first and second baroclinic mode response are important for understanding the remote response to such wind events; this provides a simple mechanism for how a short duration event in the western Pacific can produce substantial perturbations in the east over a much longer period of time. In fact, only a few wind events like the May 1986 event would be need to account for most of the warming, and for the typical duration of an ENSO event.

THE INFLUENCE OF SEA SURFACE TEMPERATURE ON SURFACE WIND IN THE EQUATORIAL PACIFIC OCEAN

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Recent studies suggest that sea surface temperature gradients in the tropics can directly modify surface winds by perturbing the atmospheric sea level pressure field (Lindzen and Nigam, J. Atmosph. Sci. 1987) or by modifying the boundary layer shear profile (Wallace et al, submitted to J. Cli. 1989). Historical ship data analyses of seasonal and interannual variability reported in the latter reference indicate that in the eastern tropical Pacific both processes are important.

In this paper, we investigate the correlation between near equatorial wind and SST using data from moored buoys which have been installed by the EPOCS and TOGA programs as part of a Pacific-wide thin observing system. Data within 5° latitude of the equator at 110°W, and 165°E are examined. These measurements span the major climatic zones of the equatorial Pacific. In the eastern Pacific, near equatorial winds have a large meridional component and the SST field is dominated by a strong frontal region north of the equator. Near 140°W, the winds are more nearly zonal and the SST cold tongue associated with the equatorial upwelling is nearly symmetric about the equator. In the western Pacific, mean winds are near zero and there is considerable synoptic variability; SST gradients are weak. Correlations between SST and wind fluctuations are particularly striking in the eastern Pacific. A pronounced signal in the SST field in this region is the 20-30 day fluctuations associated with the tropical instability waves. Since these waves are not directly forced by local wind fluctuations and since the SST perturbations associated with them are large (2-3° C), these waves are a convenient probe of the atmospheric response. Strong correlations between wind speed and SST fluctuations were observed; southeast tradewinds were enhanced when flowing over warmer water. Correlation coefficients between small scale wind speed and SST perturbations were significant at the 99% confidence level and the wind fluctuations associated with the tropical instability waves were on the order of 1-2 m/s. It is suggested that the principal coupling mechanism is the modification of the atmospheric boundary layer stratification. Unstable stratification associated with cool air flowing over warm water leads to reduced boundary layer shear and larger surface winds in regions influenced by the prevailing southeasterlies. Correlations throughout the basin are compared.

THERMOHALINE STRUCTURES VARIABILITY ALONG 165°E IN THE WESTERN TROPICAL PACIFIC OCEAN (JANUARY 1984-JANUARY 1989)

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Variability of temperature, salinity and dynamic topography distribution is examined using data from the eleven SURTROPAC and three PROPPAC cruises of the R.V.Coriolis (IFREMER) undertaken by the ORSTOM Center of Nouméa between January 1984 and January 1989.

Long term changes of heat content and dynamic topography give a new glance on variability in the western equatorial Pacific ocean between 5°N and 5°S :

a) After the 1982-83 El Nino event a drastic change occurs between 1984 and 1985 with a sudden accumulation of warm waters

b) A continuous loss of heat with a shallowing of the thermocline culminating in 1986-87 during the associated El Nino episode

c) A quite abrupt change in 1988-89 like in 1985.

Continuous temperature data from ATLAS moorings confirm the slow tendency between 1985 and 1987 as well as the sharp change in 1988-89 giving a new insight of El Nino scenario in the western Pacific.

These cruises have given also a more precise temperature/salinity relationship along 165°E and have permitted therefore to determine the accuracy of dynamic topography given by ATLAS temperature data set and Levitus T/S climatology.

In addition, the meridional surface dynamic topography relative to 1000 db suggests a global seasonal displacement of the equatorial surface current system composed of NECC, SEC and SECC while individual cruises show that SECC related to the SPCZ (South Pacific Convergence Zone) which was neglected up to date might present sometimes a very strong eastward flow, larger than NECC flow, and should be carefully considered in the COARE project as a major current in the western south Pacific ocean.

FLUX MEASUREMENTS USING AIRCRAFT AND RADARS

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This paper will discuss the use of intrumented aircraft to measure bulk and turbulent fluxes of heat, moisture and momentum over large distances. The paper will cover the techniques of aircraft measurement, the design of aircraft flight patterns and the likely measurement accuracies which can result from these measurement techniques. The measurement techniques include the use of in-situ and remote sensors.

The in-situ sensing techniques involve direct measurement of winds, temperature and humidity along long straight flight paths. These measurements are then used with the so-called eddy correlation technique to provide measurements of turbulent fluxes of heat, moisture and momentum along the aircraft's flight path. The accuracy of such measurements typically depends more on the path length of the measurement than on instrument accuracy. While the individual sensors can be accurately calibrated, the measurements along the aircraft flight path may not be representative of the state of the atmospheric boundary layer as a whole. Due to limitations on the sensitivity and accuracy of the measurements, the measurements of turbulent transport are typically limited to the convective boundary layer. Measurements of bulk transport can similarly be carried out using aircraft measurements of the mean structure and gradients. These measurements can be successfully made at all altitudes within the aircraft's flight range.

Remote probing using radar can significantly extend the bulk and turbulent flux measurements. The remote probing measurements can extend the measurements away from the aircraft flight path to include surface stress and wind measurements over the ocean, and to include measurements of transport within areas of convective activity.

"VINGT ANS APRES" : THE 170° E EQUATORIAL SECTION REVISITED.

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From December 1964 until April 1966, an extended rainy period was observed at Nauru Island (0°34'S-166°55'E) at the climatic boundary between the Western and the Central Equatorial Pacific (Junk, 1984) : nearly all the 17 monthly records exceeded 250 mm. Then, a long dry period developed until November 1967 : all the monthly records being lower than 100 mm with the exception of April 1967 which amounted to 400 mm. The usual seasonal cycle, wet northern winter, dry summer and fall, characterized the succeeding years.

From the wind record at Ocean island (0°54'S-169° 32'E) the period from November 1964 to April 1966 was clearly dominated by a "Clash of the Trades" (Luther et al., 1983; Brooks and Barby, 1921).

Westerlies prevailed except during March and April 1965. The period that followed was dominated by nearly permanent Trades. During April 1967, however, a sharp westerly burst was observed.

The ORSTOM oceanographers from Noumea were unaware of this climatic scenario as they were just planning to describe for the first time the presumed seasonal cycle of the equatorial structure at 170° E. They were unaware of an ENSO phenomenon that was "en route" during the 1964-65 winter. It was the very period for the maiden trip of the N.O. "Coriolis" which achieved a temperature profile along the whole Pacific Equator from the Galapagos to the Salomon islands. This section, however biased, would be used as a reference for a large number of publications since then.

The most dramatic feature evidenced during the 12 equatorial cruises at 170° E during 1966 and 1967 was a nearly complete and rapid reversal of the vertical current structure that occurred between March and April 1967 when a westerly burst substituted to the trades. It was the subject for one of the first paper devoted to westerly burst forcing on equatorial structure (Hisard et al., 1970).

"Vingt ans après" we would like to give a new glance to this historical two-years-survey.

OBSERVATIONS FROM THE MARITIME CONTINENT : DARWIN, AUSTRALIA

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A major observational and research program has commenced in Darwin, Australia as part of the interannual variability of the Tropical Oceans and Global Atmosphere (TOGA) and the National Aeronautics and Space Administration (NASA) Tropical rainfall Measuring Mission (TRMM). Darwin is situated in northern Australia and experiences a monsoon environment typical of the Maritime continent region, together with break and transition periods when continental systems are predominant. The Darwin initiative follows the recent Australian Monsoon Experiment (AMEX)/Equatorial Mesoscale Experiment (EMEX) and represent a continuing effort to gather convective, to mesoscale research data in this important tropical location.

The Darwin station obtains primary data from the National Oceanic and Atmospheric Administration (NOAA)/TOGA Doppler radar, full tropospheric soundings every 12h and wind soundings every 6h, a mesoscale network of raingauges, a distrometer and a surface observing network. At present the network also includes the Massachusetts Institute of Technology Doppler radar for dual Doppler studies, together with a network of corona point instruments and a cloud-to-ground lightning network. Future upgrades of the network for 1989/90 will include a BMRC/NOAA 50Mhz wind profiler, a mesonet of automatic weather stations concentrated in the zones of dual Doppler coverage, a surface energy budget and radiation monitoring station and, for limited periods, a 100 km scale rawinsonde network.

Specific observational programs include the Island Thunderstorm Experiment undertaken during November/December 1988. This experiment collected detailed observations from the NOAA/TOGA Doppler radar, a network of rawinsonde stations, an aircraft and a surface network on the development and evolution of maritime continent thunderstorms. Initial results show the importance of sea breeze circulations, a definite lifecycle including merging processes, mesocyclonic rotation about updraughts and squall like stages within the lifecycle.

A morphology of convective systems in the context of a bulk Richardson number classification has indicated considerable variability. Monsoon systems seem to be best characterized by low shear rather than CAPE, continental squalls in the dynamic range of severe and supercell storms are observed and various propagation mechanisms are apparent. The representiveness of GATE data for the tropics is also questionable, given the modes observed.

Nowcasting experiments are continuing looking at the problems related to forecasting the initiation and motion of tropical convective activity. Results indicate a significant microburst problem and an important interactions between sea breeze circulations and outflow boundaries prior to the initiation. The need for a highly sensitive radars for detection of clear air boundaries for the forecasting of convective initiation.

The presentation will summarise the observing program and describe some of the scientific results.

INTERANNUAL VARIABILITY OF THE WESTERN BOUNDARY CURRENT IN THE PACIFIC OCEAN

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Based on CTD Data gathered from three cruises carried out with R/V Science 1 in the Western Pacific Ocean every September-October from 1986 through 1988, interannual variability of the western boundary current (the Kuroshio and the Mindanao current) is examined with inversion calculation. The division of the North Equatorial current (NEC) into the Kuroshio and the Mindanao current is discussed and also the cause of the interannual variability, its relationship with 1986-87 ENSO event and its effect upon the climate change in China are reviewed.

RESULTS FROM A GLOBAL OCEAN MODEL IN THE WESTERN TROPICAL PACIFIC

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The circulation of the western equatorial Pacific is examined using the NORDA global ocean model on a .5°x.7° grid (lat,long). The model uses detailed coastline geometry including the islands resolved by the grid. The model is reduced gravity and includes thermodynamics and mixing. The model has been forced by the Hellerman-Rosenstein wind climatology and by winds from ECMWF (1980-1987). The discussion will focus on the Pacific west of the dateline and +/-20° latitude, including the Indonesian archipelago.

The model is able to represent detailed aspects of the circulation in the region. Results include 45-50 day oscillations with onset in the early spring. Annual migration of the trough in the sea surface height (SSH) between the North Equatorial Current (NEC) and the North Equatorial Countercurrent (NECC) reaches the highest latitude during the spring (8°-9°N). This trough is gradually replaced by one at a lower latitude (4°-6°N) that propagates westward across the region during June - Sept.

The split of the NEC at the Philippine coast into the Mindanao current and the beginning of the Kuroshio current shows an annual variation of only 12.75° to 13.75° N. At 8° N the model Mindanao current has a mean transport of 24 Sv with an opening in the S.Sulu Sea and 36 Sv with it closed. At 18°N the Kuroshio has a mean transport of 28 (18) Sv with the S. Sulu Sea open (closed). This indicates a net cyclonic flow around the Philippines, a flow which has little effect on the transports south of the Celebes Sea, east of 130°E, and north of the Luzon Strait.

The Mindanao current exhibits a 3-way split near the south end of the Philippines with one branch recirculating in the Mindanao Eddy and a second (strongest) branch heading southward between Talaud and Sangihe Islands (126.5°E at 4°N) before joining the NECC. The islands and the topography play no role in this placement in the model. The 3rd branch proceeds westward through the Celebes Sea where some flow returns eastward north of Celebes Island, and some proceeds southward through the Makassar Strait. This flow again divides into Pacific-Indian Ocean throughflow and flow that returns northward east of Celebes and Halmahera Islands where it joins the NECC. In the annual mean there is a westward coastal current along the New Guinea coast.

The region also exhibits several prominent eddies in the annual mean, the cyclonic Mindanao eddy centered at 7°N, 130°E with a secondary center north of Halmahera Island at 5°N, 127°-127.5° E, a cyclonic eddy at 137°E, 6.5°N, 770 km east of the Mindanao eddy, an anticyclonic eddy at 3°N, 132.5°E, ENE of Halmahera, and a

cyclonic (clockwise) eddy centered on Manus Island at 2°S, 147°E that is present in summer and fall. Cyclonic eddies are also prominent in the Solomon Sea and the Coral Sea. There are many more transient eddies.

These features tend to be present in all seasons but there is a great deal of variation in the location and amplitude (or even presence) of these features and in general temporal variability throughout most of the region, especially within 5° of the equator from within the Celebes Sea to about 150°E. The preceding results are for the upper ocean and were obtained using wind forcing from the Hellerman-Rosenstein monthly climatology.

A ONE-DIMENSIONAL COUPLED AIR-SEA MODEL FOR DIAGNOSTIC STUDIES DURING TOGA COARE

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A one-dimensional diagnostic model of an atmospheric column coupled to an upper ocean has been developed; The essential time-dependent input to the model is the observed large-scale wind field, together with observed horizontal gradients of temperature and moisture. From these data, the model then computes the time evolution of variables such as precipitation, surface fluxes and the vertical profiles of temperature, humidity, cloudiness, and diabatic heating rate components. These results may be verified against detailed local measurements.

The atmospheric component of the model is a generalization of a typical radiative-convective model, which has been supplemented by additional parametrizations of diabatic processes and subgrid transports. This portion of the model thus closely resembles a single column of a modern atmospheric general circulation model. The physical parameterizations include shallow and deep moist convection, solar and terrestrial radiative transfer with interactive prognostic clouds, vertical mixing in both atmosphere and ocean, and a surface energy budget computation.

The principal role of such a process-oriented model is not as a predictive tool, but as a test environment for parameterization development and as a means of gaining physical insight. The diagnostic model can also be a valuable aid in explaining the behavior of multidimensional forecasting models. The restriction to one space dimension makes the model computationally efficient and relatively easy to interpret. At each atmospheric level, the model produces budgets of heat, moisture and momentum which are consistent with the observationally derived estimates of horizontal advection. In TOGA COARE, potential applications of this model include assessments of the role of cloud-radiation interactions, validation of model surface flux data, estimating sensitivity of multidimensional models to alternative physical parameterizations, and observing system simulation experiments to aid in the design of the intensive field phase.

SMALL SCALE (LOCAL) RESPONSE TO EL NINO IN THE MALAKU SEA

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Four oceanographic cruises have been carried out by the Center for Oceanographical Research and Development (CORD) in the Maluku Sea in the period 1971 to 1977, respectively in September 1971, May 1972, March 1973 and September 1977. The results show that in September 1977, quite an upwelling have occurred along the eastern coast of the North Sulawesi. The upwelling is indicated by the drop of about 3° C in the temperature of the near-surface (29 to 26° C), and the increase of nutrients layer (1 to 2 μm for silicate, 0.1 to 0.2 μm for phosphate, 0.5 to slightly below 2 μm for nitrate) in the homogeneous layer.

The effect of upwelling is seen in the concentrations of chlorophyll, phytoplankton and zooplankton, which in September 1977, vary between 0.3 to 0.9 mg/m^3 respectively. For the months September 1971, May 1972, and March 1973, these values generally vary between : 0.1 to 0.5 mg/m^3 for chlorophyll, 2 to 5 ml/m^3 for phytoplankton and 0.08 to 0.16 ml/m^3 for zooplankton density.

The surface current in the Maluku Sea is mostly directed in a NE direction to the Pacific Ocean the whole year, forming the root of the Pacific North Equatorial Counter Current (NECC). An abnormally strong NECC, like the one during the El Nino period, could induce an upwelling process in this region. It is thought that the upwelling of September 1977 was probably associated with the El Nino of 1976-77.

THE HYDROPHYSICAL EXPERIMENT MEGAPOLYGON

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The national experiment Megapolygon was carried out in the region of the Subarctic front of the North-West Pacific (38°-42°N, 150°-160°W) since July through October 1987. The experiment was aimed at the investigation of the structure and dynamics of jet streams and frontal rings; the estimation of transfrontal transport of heat, salt and momentum by rings and transport of these characteristics through the upper boundary layer; the investigation of intrusions of the main front and fronts of rings and meanders.

The Megapolygon data were obtained through 6 repeated T, S - surveys and deployment of 178 moorings consisting of self-recording current meters "POTOK" at 120, 400, 1200 and 4500 m depth. The hydrochemical and meteorological measurements were also carried out; The data are expected to be of great importance, in particular, to check the validity of various versions of four-dimensional analysis and eddy-resolving models. Intensive processing of the data is now under way. Some main preliminary results are :

1) The positions of the areas of cyclonic and anticyclonic movements in the upper layer were stable during the experiment span. The Megapolygon central and southwestern parts were occupied by a large-scale meander of the Kuroshio. Cyclonic meanders of the Subarctic current settled in the northwestern and northeastern parts of the region.

2) Relatively small rings were periodically formed in the upper layer. The rings were 100 to 150 km across and provided transfrontal transport due to the movement of the chain of warm anticyclonic rings northward in the central part and the movement of cold cyclonic rings southward in the eastern part of the region.

3) Bigger scale highly variable rings having absolutely different configuration in comparison with 120 m depth were discovered at 1200 m depth. The local signs of circulation at 120 m and 1200 m depth were opposite as a rule. The usual speed of currents was about 50 $cm.sec^{-1}$.

4) Circulation pattern at 4500 m depth had close resemblance with one at 1200 m depth. The average speed of currents was about 25 $cm.sec^{-1}$. The deeper layers peculiarities moved westward that could be explained in the light of the barotropic Rossby wave theory.

AIR-SEA INTERACTIONS IN THE TROPICAL WESTERN PACIFIC ON INTERANNUAL AND INTRASEASONAL TIME SCALES

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The interrelationships among the 700 mb zonal wind in the tropics, the sea surface temperature (SST) in the tropical Indian and Pacific Oceans, and the sea water temperature (SWT) in the tropical western Pacific are discussed on a characteristic interannual time scale. The intraseasonal variability of SST is also discussed.

The interannual variability of the main thermocline in low latitudes along 137°E longitude line is reflected primarily on the quasi-biennial oscillation (QBO) time scale. To investigate its physical process, each dominant QBO mode propagating eastward is deduced by applying the complex EOF analysis to monthly mean SST and 700 mb zonal wind data over tropical Indian and Pacific Oceans. The QBO mode of SST does not propagate with uniform phase speed and a marked phase difference is observed at the area around 150°-160°E, where the zonal wind anomalies at 700 mb level have the largest amplitudes. Thus, the QBO mode of tropical SST does not always propagate in parallel with that of the tropical troposphere and it is suggested that the tropical tropospheric QBO phase shift of SST anomalies around 150°-160°E. Since the SWT anomalies located in the main thermocline fluctuate in phase with those in the near surface layer (0-50m depth), it is inferred that these variations, which are influenced by the accumulation and release of warm water east of the Philippines, result from the dynamic response of the ocean to the wind stress with the QBO variability.

On the other hand, the SST in the tropical western Pacific displays a marked intraseasonal (30-60 days) variability and fluctuates, exhibiting a coupling with tropical convective activity on the same time scale with a phase difference of 10-12 days. The SSTs are above normal to the east of the eastward-propagating 30-60 day mode disturbances. An air-sea feedback system appears to be rather significant for the 30-60 day oscillation.

Phase relationships among the SST, OLR and 850 mb zonal wind over tropical western Pacific are extracted on intraseasonal and interannual time scales, using the complex EOF analysis. It is found that there are some characteristic differences of the phase relationship among them on two time scales. This finding may play an important role in understanding the mechanism of triggering ENSO.

A PRELIMINARY MORPHOLOGY OF CONVECTIVE SYSTEMS IN TROPICAL NORTHERN AUSTRALIA

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The US TOGA (Tropical Ocean Global Atmosphere) Doppler radar is presently located near Darwin, Australia (12°S-131°E) under the joint sponsorship of the National Aeronautics and Space Administration and the Australian Bureau of Meteorology.

The area is situated in the "maritime continent" and has pronounced wet and dry seasons. The wet season, extends from December through March and is characterized by low level equatorial westerly flow as the monsoon trough moves to the south of Darwin. Transition season flow, at the start and end of the wet season and break periods during the wet season, have dry continental easterly flow.

The monsoon is characterized by precipitation structures reminiscent of weaker imbedded convection observed during the GARP Atlantic Tropical Experiment (GATE). Reflectivity gradients are typically small with stratiform echo strength from 14 to 30 dBZ being typical. However, convective areas are embedded within the larger stratiform region and these can form significant line structures with echo strengths >55dBZ. Peak reflectivities are constrained typically to below the freezing level.

Continental convection assumes several forms ranging from isolated showers to large mesoscale convective systems. Some showers clearly result from small instability and weaker updrafts, extending to only 4-7 km. Often, such showers do not include the ice phase and do not exhibit electrical activity.

Squall lines are a dominant form of precipitation system. The depth of convection is regularly 15 km and can exceed 18 km. Reflectivities are regularly >55 dBZ in the convective lines.

Trailing stratiform regions are also evident. It is common to experience more than one squall line per day in the continental regime. Different types of squall lines are observed to propagate in various directions with respect to the mean wind. In some instances, it may be the case that convective lines propagate with respect to the winds at all levels. Boundary layer outflow strutures are observed to propagate ahead of some convective lines and initiate new convection.

Analyses of the 1987-1988 wet season data have just begun. It is our intention to compare these data with other conventional and Doppler data from the tropics and mid-latitudes. Of particular interest are the types of dynamical structures which may be inferred from the reflectivity and mean radial velocity fields. These will be examined in the general context of bulk Richardson number (i.e., the ratio buoyancy to the kinetic energy of environmental shear).

The stratification and classification of environments will be accomplished through examination of darwin soundings.

OBSERVATIONS OF LONG ROSSBY WAVES IN THE NORTHERN TROPICAL PACIFIC

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Long baroclinic Rossby waves are potentially important in the adjustment of the tropical Pacific pycnocline to both annual and interannual wind stress curl fluctuations. Evidence for such waves is found in variations of the depth of the 20° C isotherm in the northern tropical Pacific during 1970 through 1987. 190,000 bathythermograph profiles have been compiled from the archives of several countries; the data coverage is dense enough that westward-propagating events may be observed with a minimum of zonal interpolation. After extensive quality control, 20° C depths were gridded with a resolution of 2° latitude, 5° longitude and bimonths; statistical parameters of the data were estimated. A simple model of low-frequency pynocline variability allows the physical processes of Ekman pumping, the radiation of long Rossby waves due to such pumping in mid-basin, and the radiation of long Rossby waves from the observed eastern boundary pynocline depth fluctuations. Although the wind stress curl has very little zonal variability at the annual period in the northern tropical Pacific, an annual fluctuation of 20° C depth propagates westward as a long Rossby wave near 4°-6° N and 14°-18° N in agreement with the model hindcast. Near the thermocline ridge at 10°N, however, the annual cycle is dominated by Ekman pumping. The wave-dominated annual variations at 4°-6°N in the western Pacific are out of phase with the local Ekman pumping, so the annual cycle of NECC geostrophic transport is much weaker in the west than in the eastern of central Pacific. El Nino events are associated with westerly wind anomalies concentrated in the central equatorial Pacific; an upwelling wind stress curl pattern is generated in the extra-equatorial tropics by these westerlies. Long upwelling Rossby waves were observed to raise the western Pacific thermocline well outside the equatorial waveguide in the later stages of several El Ninos, consistent with the simple model. It has been suggested that El Nino events are initiated by downwelling long Rossby waves in the extra-equatorial region reflecting off the western boundary as equatorial Kelvin waves. The bathythermograph observations show that although such downwelling waves commonly arrive at the western boundary (the Philippines coast), there is a low correlation between these occurrences and the subsequent initiation of El Ninos.

REMOTE SENSING OF ATMOSPHERIC THERMODYNAMICS IN THE TROPICS

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Successful diagnosis of the processes coupling the tropical oceans and global atmosphere requires knowledge of the thermodynamic state of the atmosphere. The horizontal and vertical distribution of heat and moisture both influences the onset of convection and is altered by it. Low-level heat and moisture also determines in part the magnitude of the fluxes across the air-sea interface. Remote sensing from space is the only practical means of obtaining this information over the broad regions of the tropical oceans.

I will discuss applications of remotely sensed thermodynamic information to tropical studies, based mostly on the work we have done with an eight year data set derived from TOVS. TOVS has provided information on low level moisture and static stability of the tropical atmosphere for a number of studies including investigations of the Indian and Mexican winter monsoons (Prabhakara) and studies of the 30-60 day oscillation (see Weickmann and Eischeid abstracts). Work with data from the DMSP microwave temperature sounder, SSM/I will also be described. The accuracy and resolution of current and future sensors that provide thermodynamic information will be reviewed.

Current schemes to estimate surface latent heat flux from space rely on an empirical relationship between total column water vapor and specific humidity at some level near the surface. This relationship is based on monthly or longer term means and is probably not valid for disturbed conditions. I will describe attempts that are being made to define characteristic atmospheric profiles for disturbed atmospheric states using island rawinsonde data. These atmospheric state could then be matched with observed microwave and infrared brightness temperatures. By this method it may be possible to estimate for a variety of convective conditions a boundary layer moisture value that could be used in a bulk parameterization of latent heat flux across the air-sea interface.

THE DYNAMICS OF THE PACIFIC TO INDIAN OCEAN THROUGHFLOW

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The Indonesian throughflow is examined using the NORDA one-active layer reduced-gravity global model on a .5° by .7° grid. The model, which includes the effects of realistic coastline geometry, thermodynamics and mixing, is forced by the Hellerman-Rosenstein wind stress climatology and the ECMWF 1000 mb winds from 1980 to 1988. Empirical Orthogonal Function and Principal Estimator Pattern analyses of the wind stress curl and model sea level are utilized to examine the dynamics of the mean throughflow as well as the seasonal and interannual variability. A suite of experiments designed to determine the relative importance of remote and local forcing and the reflection of Rossby waves from the irregular, porous western Pacific boundary are discussed.

DYNAMICS OF MULTI-SCALE ATMOSPHERE-OCEAN INTERACTIONS OVER THE TROPICAL WESTERN PACIFIC

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In this paper we present results of several numerical experiments to study the mechanism of the observed variabilities in wind and convection associated with super cloud clusters (SCC), westerly wind bursts and 30-60 day oscillations in the western Pacific region and their relationship with ENSO. Using the Lau and Peng (1987) model, we show that the generation of a 30-60 day eastward propagating precipitation pattern associated with the 30-60 day oscillation can be identified as a SSC. During its development stage, the SCC is accompanied by convective clusters moving in opposite direction (westward) to that of the SCC. The results suggest that these westward propagating cloud cells are associated with Rossby waves produced at the development stage of the 30-60 day disturbance due to mutual adjustment of the large scale flow and heating. If the boundary forcing is zonally symmetric and in the absence of other external forcings, the SCC eventually settles down to an organized eastward propagating precipitation pattern accompanied by a planetary east-west circulation cell in the equatorial zonal plane.

Model results further suggest that intraseasonal oscillation in the tropical atmosphere is a multi-scale process. Three basic spatial scales are identified, i.e., synoptic scale motion associated with cloud cluster (1000-2000 km), size of the SCC complex (2000-4000 km) and planetary scale circulation (wavenumber 1 and 2). The first is associated with westerly wind burst, double cyclone formation and high-frequency fluctuations of the order of several days. It appears that the westerly wind burst at the surface is produced by the high-frequency (2-3 days) "shedding" of Rossby waves from the developing supercluster. As a result of the separation of the waves, the region of low level westerly expanded abruptly.

The relationship between SSC and westerly wind burst is studied by examining the detailed spatial and temporal variation of the model SCCs as they propagate over zonally varying sea surface temperature. It is found that wave-CISK heating in the lower troposphere as well as surface heating are crucial in leading to the strongly asymmetric low level westerly wind bursts similar to those observed in the real atmosphere. The present results suggest that the western Pacific (perhaps also the Indian Ocean) is a unique region where multi-scale interactions between atmosphere and ocean are most important. Based on the results of these experiments, it is tentatively concluded that there are two basic causes of westerly wind burst :

(1) a direct response of the surface wind to the passage of eastward propagating main SSC heat source associated with the 30-60 day oscillation in the near-equatorial regions and/or

(2) zonal wind fluctuations on the equatorial side of the twin cyclonic vortices emanating westward from the main SSC heat source.

Based on the above and other theoretical considerations of unstable air-sea interactions, a unified theory of the multi-scale interactions involving onset mechanisms for ENSO will discussed.

THE ROLES OF TROPICAL OCEANIC EVAPORATION IN ATMOSPHERIC ORGANIZED CONVECTION AND UPPER OCEAN HEAT BALANCE

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Monthly-mean fields of evaporation and latent heat flux over the tropical Pacific from 1980 to 1983 were computed using observations from the microwave radiometer on Nimbus-7, including an intense El Nino Southern Oscillation episode. The dislocation of the organized convection from the western to the central tropical Pacific, envisioned by anomalous atmospheric water content was found not to be driven by an increase in local evaporation but forced by surface moisture convergence.

By combining the latent heat flux with surface insolation computed using data from the visible/infrared sensor on GOES-W, the correlation between surface thermal forcing and sea surface temperature change was examined. Surface thermal forcing was found to be the dominant factor in sea surface temperature change outside of the equatorial wave guide. In the narrow equatorial wave guide, ocean dynamics play a stronger role, and surface heat flux is a consequence rather than the cause of sea surface temperature change.

OBSERVATIONS OF AIR-SEA INTERACTION IN THE WESTERN PACIFIC WARM POOL DURING WEPOCS

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The winds in the core of the western Pacific warm pool are usually light, and air-sea interaction there is controlled by local convective processes. During low mean wind speed conditions, a radiative-convective equilibrium seems to hold in which the strong coupling between atmosphere and ocean provides a negative feedback that stabilizes the system (cf. Sarachik, 1978). (This feedback is not able to damp out the diurnal cycle however, and on this time scale the waxing and waning of convection in response to diurnal radiative heating of the sea surface was observed during WEPOCS III.) Recently, the importance of the hydrological cycle in this coupling has become apparent, both in observations and in simple models.

Precipitation, through its influence on the buoyancy profile of the upper ocean, can have an important impact on the evolution of the mixed layer, and ultimately on the evolution of SST. The effect of a typical individual convective cell on the near-surface (4 m depth) temperature and salinity was observed during the recent WEPOCS III expedition in the western Pacific warm pool, with freshening of 0.6 psu and cooling of 0.3°C over 20 km. Freshening of as much as 2.5 psu was observed in some cases. The general correlation of SST and sea surface salinity due to the heavy convection in this region is quite robust. A piece of the thermosalinograph record shows several of these cold/fresh events with widths of 5-20 km. A larger scale depression of sea surface salinity is seen between 50 and 550 km along the ship track, suggesting that a group of convective cells (mesoscale convective complex) existed in this region.

The incoming solar radiation is primarily modulated by the diurnal cycle, and by the clouds associated with mesoscale convection. When the winds are light, and the skies are relatively clear, the SST responds rapidly to the heating as does the overlying atmosphere. This can be seen in WEPOCS observations where the diurnal cycle of SST is as large as 1°C, and the diurnal cycle of air temperature is about 2°C.

The sensible heat flux is proportional to the air-sea temperature difference, which varied diurnally but not much from day to day. The mean air-sea temperature difference for the data from Leg 1 of WEPOCS III is 1.6°C, three times larger than climatological estimates for this region (Weare et al., 1981; Esbensen and Kushnir, 1981). This is probably due to biases in merchant ship temperature observations; large air-sea temperature differences have been observed on all three WEPOCS expeditions and from the WEPOCS moored buoy in the warm pool (Lukas, 1987).

Large negative excursions of dry air temperature are associated with convective gust fronts (squall lines) in which the air is cold and saturated. This air is brought rapidly to the surface in downdrafts inside the convective towers, which points to the conclusion that the relatively steady wet bulb temperatures are indicative of the nearly constant level at which precipitation is occurring in this region. (Without soundings, it is

not possible to say what the pressure level is, however.) Because of the large air-sea temperature difference at these times, a considerable sensible heat flux from the ocean to the atmosphere is occurring in the region of such downdrafts, and the SST cooling pointed to earlier may be partly related to this (Gautier, 1978; Greenhut, 1978).

Both wind and humidity changes were responsible for modulating the daily mean latent heat fluxes during leg 1 of WEPOCS III, where the mean wind speed was less than 4 $m.s^{-1}$. The net heat flux over 11 days was -11 $W.m^{-2}$, with excursions between +20 and -30 $W.m^{-2}$ for the daily values. During leg 2, several surges of the Southwest Monsoon resulted in winds of 8-14 $m.s^{-1}$ for 2-3 days at a time, and an average wind speed of about 6 $m.s^{-1}$. The large latent heat losses during the monsoon surges (200-250 $W.m^{-2}$) resulted in net heat losses from the ocean of 100-150 $W.m^{-2}$, and an average over 23 days of -50 $W.m^{-2}$.

ZONAL SCALES OF THERMOHALINE VARIABILITY IN THE WESTERN EQUATORIAL PACIFIC

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Zonal variability of temperature, salinity, and dynamic topography along the equator in the western Pacific from 165° E to 141° E is examined using data from the five cruises of the US/PRC Bilateral Study of air-sea interaction in the western Pacific. Zonal spacing of NBIS CTD casts on recent cruises was every 2.5° of longitude; on the first few cruises this spacing was 5° of longitude. These sections obtained in January-February 1986, November-December 1986, October 1987, May 1988, and October 1988 span the evolution of the of 1986-87 El Nino and the subsequent cool period.

The upper ocean thermohaline field in the western Pacific exhibits considerable small scale variability principally associated with the salinity and with variations in thermocline depth; the near surface SST is rather uniform. The surface dynamic topography (relative to 500 dbar) was not generally uniform across the region; the zonal pressure gradient often reversed sign between 165°E and 140°E. The zonally averaged surface pressure gradient varied from -0.0055 $N.m^{-3}$ (eastward force) in May 1988 to 0.004 $N.m^{-3}$ in November-December 1986. In the first case the eastward force appeared to extend from 165°E to 145°E; it reversed west of this longitude. In the second case, the westward force extended from 140° E to 160° E and then appeared to reverse east of this longitude. These structures and the associated thermohaline perturbations are used to suggest the zonal resolution required in order to understand the response of the western Pacific to variable forcing.

COUPLED OCEAN-ATMOSPHERE MODELS OF EL NINO AND THE SOUTHERN OSCILLATION

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The phenomenon of El Nino and the Southern Oscillation (ENSO) exhibits a time scale of the order of 2-9 years. An intriguing hypothesis, for which there is an increasing body of supportive observational evidence, is that ENSO is the result of strong coupling between the ocean and the atmosphere in the tropics. A number of coupled models have been developed over the past few years to explore this idea. Specifically, the models address the question: How can the ocean and atmosphere interact to produce oscillations with the long ENSO time scale?

The models range in dynamical complexity from highly simplified systems (consisting, for example, of only one or two equations) to coupled oceanic and atmospheric GCM's. The advantage of the simpler models is that it is easier to isolate their fundamental dynamics. Their obvious limitation is that, due to the many simplifying assumptions built into them, it is often difficult or impossible to compare solutions closely with observations; hence, the models are untestable. In contrast, solutions to the coupled GCM's can be closely compared to observations, but the important processes at work in them are not always easy to determine.

The simpler models illustrate three types of possible interaction mechanisms for generating ENSO time scales. In the first type, it is the slow propagation speed of oceanic Rossby waves across the basin that sets the oscillation period. In the second, the coupled system has two equilibrium states for the same forcing, and a "trigger" causes the system to jump from being near one state to being near the other. In the third, slowly propagating, unstable disturbances develop and propagate eastward. The coupled GCM's clearly develop unstable disturbances, similar to those present in simpler models. It is not yet clear what other interaction mechanisms, if any, are also present in them.

WESTERLY WIND FORCING AND SST VARIATIONS IN THE WESTERN PACIFIC DURING THE 1986-87 EVENT

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It has been suggested that the frequent occurrence of westerly winds of 0(days to weeks) duration plays a crucial role in ocean-atmosphere coupling on ENSO time scales by cooling the western Pacific warm pool. The mechanisms responsible for this cooling are presumed to be evaporation, entrainment mixing, and/or eastward advection due to wind-driven current variations. Data from the US/PRC bilateral mooring at 0, 165° E and ATLAS thermistor chain moorings at 2°N and 2° S, 165° E are used to examine this hypothesis. Emphasis is on 1986-87 during which a significant amount of overlapping ocean current, temperature and wind data are available. Winds at this time in the western Pacific were more westerly than normal by 2-3 $m.s^{-1}$ in association with the 1986-87 ENSO event.

Wind data are processed to time series of speed, pseudostress and wind work which are related to evaporative cooling, advection (vertical and horizontal) and turbulent entrainment cooling, respectively. Coherence analysis shows that wind speed and wind work variations lead to cooling on time scales of several days to several weeks. The magnitude of this cooling is 0(0.1°C) rms and is generally confined to the upper 10m. Variations in wind pseudostress on the same time scales lead to changes in thermocline temperature which are most likely due to Ekman pumping. These changes are out of phase with sea surface temperature variations however, suggesting that vertical advection is not important in cooling the surface. The relevance of these short period variations in winds and temperature to the low frequency evolution of the 1986-87 ENSO event is discussed.

AIR-SEA INTERACTION IN THE TROPICAL PACIFIC OCEAN DURING 1982-83 AND 1986-87

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The southern oscillation index (SOI), equatorial zonal wind, sea level anomalies at islands, sea surface temperature at Puerto Chicama Peru, and mixed layer temperature and depth from the expendable bathythermograph ship of opportunity network are used to describe conditions during the past two ENSO episodes. Onset of sustained ENSO anomalies in the 1986-87 episode was in July 1986, one month later in the year than onset of the 1982-83 episode in June 1982. Both episodes of the 1980's developed later in the year than episodes of the 1970's.

The XBT data show that the usual surface temperature difference along the equator between 165°W and 160°E reversed during the episodes of the 1980's. ENSO warming of the central Pacific tends to be confined to the region 10°N to 10°S whereas cooling of the western pacific occurs in a broader region from 19°N to 19°S, and extends westward into the eastern Indian Ocean. Evaluation of terms in the surface heat budget (for 1982-83 only) shows that the dominant mechanism of cooling surface temperature in the western Pacific is latent heat flux.

GEOSAT OBSERVATIONS OF SEA LEVEL IN THE TROPICAL PACIFIC AND INDIAN OCEANS DURING THE 1986-87 EL NINO EVENT.

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Using a combination of crossover and colinear techniques, we have derived times series of sea level anomalies throughout the tropical Pacific and Indian Oceans for the first 3.5 years of the GEOSAT mission (1985-88). This time interval is particularly valuable because it provides the first complete, multi-ocean picture of sea level variability during an El Nino event (1986-87). An analysis of sea level averaged over the entire tropical Pacific (20°N to 20°S) shows no evidence of an anomalous rise (increase in upper layer volume) prior to the warm phase of El Nino. However, sea level anomalies (relative to observations between April 1985 and March 1986) can be seen when averaging is performed over certain sub-regions. Beginning in April 1987, the zonally averaged region 8°N to 20°N exhibits a nearly constant positive anomaly of +5.0 cm, while the region 7°S to 7°N exhibits a negative anomaly of -3.5 cm. This indicates that most of the water which entered the north equatorial region at the end of the warm phase came from the equator.

In addition to these El Nino signals, large annual signals are evident over much of the tropical Pacific and Indian Oceans. In the Pacific, the annual signals are clearly organized in large zonal bands. The equatorial region (7°S to 7°N) is lowest in May and highest in November. Conversely, the north equatorial region (8°N to 20°N) is highest in May and lowest in November. The average annual amplitude in each region is approximately 10 cm.

In the Indian Ocean, large scale annual signals occur predominately along the equator (where sea level is highest in June and lowest in December), and along 10°S (where sea level is highest in December and lowest in June). In addition to these basin-wide features, a strong (20 cm) southeast-northwest oriented positive anomaly appears in the eastern half of the Indian Ocean (20°S to 5°N) in September-October.

ABSOLUTE DYNAMIC HEIGHT VARIABILITY ACROSS THE EQUATORIAL PACIFIC CURRENT SYSTEM FROM GEOSAT-ERM ALTIMETRY

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Gleaning relatively weak absolute surface topographic signatures, such as those associated with the equatorial Pacific current system, from GEOSAT-Exact Repeat Mission (GEOSAT-ERM) altimetry requires simultaneous in situ observations. Our procedure applied to data near 110°W is to :

a) compute a mean sea surface height profile from an ensemble of GEOSAT-ERM altimetric passes,

b) least squares remove a tilt and bias from demeaned individual passes,

c) determine a mean dynamic height profile from hydrographic data along the selected pass segment of approximately 1000 km length,

d) demean the tilt/bias-adjusted individual passes and substract the mean dynamic height, and

e) employ inverted echo sounders (IES's) to correct for the observed dynamic height at two or more suborbital points during the satellite pass.

Comparison of this procedure with in situ data shows differences in surface topography of +/- 2-3 cm, while analysis of the procedure suggests RMS errors of +/- 5 cm. Comparison with the National Meteorological Center's Climate Analysis Center (NMC/CAC) oceanographic model shows good agreement in amplitude and phase of the variability in surface topography associated with the South Equatorial Current/North Equatorial Counter Current System in the eastern Pacific.

TROPICAL OCEAN DATA ASSIMILATION AND INITIALIZATION

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The problem of data assimilation in numerical models of the tropical oceans will be discussed and the results of experiments using a simple model of the tropical Pacific ocean are presented.

XBT data from the TOGA ship of opportunity program in the tropical Pacific was assimilated into a reduced gravity model of the same region. The data were periodically combined with the model first-guess field using simple objective analysis techniques. Away from the equator, the model was found to retain information about the ocean temperature field for up to 12 months. In the equatorial region, planetary waves are excited as a result of biases which exist in the model and so temperature information is lost from this region after only 2 or 3 months.

Comparisons will also be made between the model predicted equatorial currents and those inferred from observation. During data assimilation runs, the model recaptures the relative positions and strengths of the major equatorial currents in the central Pacific. In general, these currents take around 6-12 months to spin-up to full strength.

Following data insertion into the model, an imbalance exists between the temperature field and velocity field of the model. The geostrophic adjustment process which ensures results in the generation of spurious, large amplitude, equatorial Kelvin waves and Yanai waves. The presence of the equatorial wave guide means that such waves, if left unchecked, may be potentially damaging to the model first-guess fields in areas remote from their point of origin. Methods for suppressing or reducing the detrimental effects of the spurious wave modes will be discussed.

ON THE MEGAPOLYGON SPATIAL SPECTRA OF TEMPERATURE

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The Megapolygon moored data provide a unique opportunity for estimation of currents and temperature spatial spectra. At present stage the main attention has been paid to the calculation of spatial temperature spectrum estimations (STSE) at semi-diurnal frequency by means of traditional Barber's method.

The temperature spectral estimations at this frequency possess an advantage over current spectral estimations for they aren't contaminated by barotropic tide and, therefore, provide a better picture of the internal waves spatial energy distribution.

The analysis has been carried out by considering the results of STSE computations at 1200 m depth for two clusters of moored current and temperature meters "POTOK". Four statistically independent synchronous sets of temperature time series from 14 moorings and two independent synchronous sets from 15 moorings have been chosen from the northwestern and southeastern clusters respectively to study temporal and spatial variability of STSE. The length of each set of thoroughly checked and filtered out time series is about 13 days.

The analysis shows that STSE have quite a lot of resemblance in their configuration. For both clusters and all temporal variants the main peak has stable location at a wavelength of approximately 130 km in the direction of 270°. These results indicate that a stable system of semi-diurnal internal waves exists in the Megapolygon region and confirm some of our earlier investigations carried out in the vicinity of the region.

INFLUENCE OF SOUTHERN OSCILLATION ON NEW ZEALAND WEATHER

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The Southern Oscillation is known to have a significant effect on New Zealand weather. In general, during the negative (El Nino) phase of the oscillation, New Zealand experiences an increased frequency of cold southwesterly airstreams that result in more rain in the southwest of the country, and dry conditions in the north and east. During the positive (La Nina) phase, there is a tendency for increased cyclonic activity in the North Tasman and more slow-moving or blocking anticyclones to the southeast of New Zealand. This results in frequent warm moist northerly or northeasterly airstreams over the country, with warmer than normal temperature nationwide and wetter conditions in parts of the North island exposed to these prevailing winds.

The pressure anomalies in the New Zealand region associated with extremes of Southern Oscillation Index show some seasonal variation. The anomalies are also not entirely symmetrical with respect to change of sign of the SOI. This paper discusses these aspects, and then concentrates on the predicted and observed anomalies in New Zealand weather associated with 1988/89 La Nina episode.

THROUGHFLOW BETWEEN THE WESTERN PACIFIC AND THE INDIAN OCEAN : COMPARISON BETWEEN MODEL AND OBSERVATIONS

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Previous estimates of the Indonesian throughflow all by indirect means vary greatly between 1.5 and 20 Sverdrups (Sv). The deep and wide passages bracketing Timor have been generally believed to the sole throughflow pathways. The second strait of potential throughflow importance, the Lombok Strait, has only about 1/5 of the cross-sectional area above 200m of the Timor passages but does have a direct bathymetric link to the Makassar Strait. Recent direct observations of net currents in the Lombok Strait during Jan 1985-March 1986 (Murray and Arief,1988) revealed strong net southward currents reaching 90 $cm.s^{-1}$. Transport computations show a distinct annual cycle with minimum southward transport of 1 Sv during February-May followed by a maximum of 3.8-4.0 Sv in July and August during the east monsoon. The 1985 average is 1.7 Sv which supports the idea of a large throughflow including the Timor Passages. To investigate interannual and geographic variability in the throughflow numerical simulations using the NORDA reduced gravity (one active layer) global ocean model forced by the ECMWF 1000mb winds were run for the region for 1980-1988. The model includes effects of realistic coastline geometry, thermodynamics, and mixing. Grid resolution is 0.5° by 0.7°. Initial model results indicate the Makassar strait is a primary passage for the throughflow with a significant portion entering the Indian Ocean through the Lombok strait. This study will compare observations of transport through the Lombok Strait for the year 1985 to the numerical solutions in order to both calibrate the model and examine the temporal variability of the flow patterns in the Lombok Strait-Banda Sea region. Hydrographic observations of core layer movements are also factored into the model results.

SATELLITE DERIVATION OF OCEAN-ATMOSPHERE HEAT FLUXES IN TROPICAL ENVIRONMENT

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Satellite estimates of ocean-atmosphere heat fluxes are compared with surface measurements taken at a meteorological platform on John Brewer Teef, located 80 km NNE of Townsville, Australia. A combination of data from the geostationary meteorological satellite (GMS), soundings from NOAA-9/TOVS and a blend of ship observations and NOAA-9 determined surface temperatures were obtained on a daily basis for ten months period. The data enabled estimation of all the components of the ocean/atmosphere heat fluxes. Weekly averaged RMS differences were calculated between satellite and surface estimates of various component fluxes.

These RMS differences were 19 $W.m^{-2}$, 40 $W.m^{-2}$ and 50 $W.m^{-2}$ ocean-atmosphere heat flux respectively.

30 DAY OSCILLATIONS IN THE TROPICAL PACIFIC OCEAN OBSERVED WITH GEOSAT ALTIMETER

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Weekly fields of sea level are derived from Geosat altimeter data from November 1986 to December 1987 in the 20° tropical Pacific band. Patterns similar to "Legeckis-waves" clearly show up in November 1986 and in autumn 1987. They present anticyclonic eddies (10 to 15 cm high, 800 km extent) regularly spaced every 1300 km in the 3°N to 8°N band. Though the strongest eddies appear between 100°W and 160°W, similar patterns extend although the Pacific ocean past the dateline.

On the 5 tide-gage locations examined in this band, GEOSAT sea level time series agree with weekly averaged tide gage data with a RMS of 3.6 cm and a correlation ranging from .4 to .8. The power spectra of both time series present similar peaks at periods between 26 and 33 days.

Hovmoeller diagrams are derived from the GEOSAT analyzed fields. Frequency and wavenumber power spectra of sea level are averaged for the Eastern and Western Pacific and given as a function of latitude. The strongest energy appears in the Northeastern band (33 days, 1300 km). In the northwestern band, wavelength peak is the same but energy is less and peak periods higher (40 days). The equatorial band presents low energy at periods between 25 days to 50 days. The whole southern band energy level is similar to the northwestern one, with peak periods ranging from 40 to 50 days depending on the latitude. These results are being investigated to examine if the energy propagation from the generation location is compatible with wave mechanisms.

Preliminary results, like the time and space characteristics of the peak energy in the Northeastern band with a minimum energy at these frequencies on the equator, are consistent with free equatorial waves like the Yanai-wave. However, the signal south of the equator is very seldom antisymetric and the axis of the wavelike patterns in the sea level fields is not zonal, but tilted as the axis of maximum shear strength between the SEC and NECC. The energy spectrum peak varies significantly from November 1986 to December 1987. It is maximum in autumn when the observed meridional sea level slope corresponds to a maximum of the shear strength between the SEC and the NECC. Indeed, the seasonal modulation is as strong as the interannual one. In autumn 1986, "waves" disappear as early as mid-December and in September 1987, observed "waves" are weaker than those detected with SEASAT altimeter in September 1978. In 1986 and 1987, it is possible that the waves were weaker than usual because of the El Nino event.

SURFACE EQUATORIAL FLOW ANOMALIES IN THE PACIFIC OCEAN DURING THE 1986-87 ENSO USING GEOSAT ALTIMETER DATA

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Estimates of geostrophic zonal flow in the equatorial Pacific have been deduced from the 17-day exact repeat orbit GEOSAT measurements for the period November 1986-November 1987. This period coincided with the height of the 1986-87 ENSO. Along-track altimeter data anomalies were first smoothed using a combination of linear and nonlinear filters. Currents were then calculated from the differentiated form of the meridional momentum equation at the equator and from the classical first derivative of the meridional pressure field away from the equator. By combining several tracks in the zonal direction and filtering in time, we were able to obtain low frequency surface currents (less than 1 cycle per month) at any point of the tropical Pacific. Comparison of low frequency near-surface zonal current directly measured from equatorial moorings at 165°E, 140°W and 110°W yield a correlation of 0.83, 0.84 and 0.50 respectively with a mean RMS difference of 23 $cm.s^{-1}$. Sea level and zonal velocity solutions from a tropical Pacific numerical model were used as proxy data sets in order to quantify errors induced into the geostrophic calculation by the GEOSAT space-time sampling.

In December 1986, strong equatorial westerly winds west of the date line generated an intense local 100 cm/s eastward surface flow anomaly and a downwelling equatorial Kelvin wave. This Kelvin wave propagated into the eastern equatorial Pacific with a phase speed of 2.8 $m.s^{-1}$ and was associated with eastward current anomalies of 25-50 $cm.s^{-1}$. In January 1987, stronger than normal easterlies over most of the equatorial Pacific forced an upwelling equatorial Kelvin wave which propagates eastward at 2.8 $m.s^{-1}$. This wave, with westward flow anomalies of 25-80 $cm.s^{-1}$, reached the eastern Pacific boundary in March 1987 where it forced an upwelling first meridional mode equatorial Rossby wave. This Rossby wave propagated westward in the ocean interior at about 0.9 $m.s^{-1}$ as a patch of equatorially trapped eastward flow (60-80 cm/s maximum) flanked, in both hemispheres, by 20-40 $cm.s^{-1}$ westward flow anomalies which decreased the North and South Equatorial Countercurrents. This patch could be traced sequentially through the eastern, central and western Pacific from April to September 1987. Thus GEOSAT altimeter data indicate that wind-forced equatorial Kelvin waves and their eastern reflection as Rossby waves were an important component of basin scale current variability during the 1986-87 ENSO.

FINE STRUCTURE VARIABILITY IN THE EQUATORIAL WESTERN PACIFIC OCEAN

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Twice a year, as part of the PROPPAC program, a transect along 165°E is carried out. Afterward, an eight-day long station is undertaken in order to examine a specific situation.

Following the 1986-1987 El Niño, results of the 165°E leg in April 1988 pointed out an unusually strong equatorial upwelling (since 1984, only a weak upwelling has been perceptible along this track during January and August 1984 SURTROPAC cruises) and a strong south equatorial current (SEC). To study fine scale variability of this particular situation, CTD data and velocity vertical profiles have been collected every six hours at the equator .

Large scale features are first described along the 165°E meridian. Then, hydrographic and velocity data are compared during the long term station. Preliminary results indicate that high variability appears in the velocity shear zone between SEC and equatorial undercurrent (EUC), as well as under EUC despite a weak equatorial intermediate current during this cruise.

THE CLIMATOLOGY OF THE WESTERN TROPICAL PACIFIC ANALYSIS OF RADIOSONDE DATA BASE

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Several radiosonde stations in the western tropical Pacific have been in more or less continuous operation for nearly 40 years. Analysis of the archived data is being carried out as an ongoing project, with the main emphasis on determining the low-frequency response of the atmosphere at all levels to the ENSO cycle.

Specific studies that have been carried out to date have centered on the thermal response of the atmosphere at all levels from the surface to the lower stratosphere to ENSO-related SST anomalies, and on there behavior of the tropopause region in response to the variations in the location and intensity of convective activity associated with the ENSO cycle. The results have a direct bearing on our understanding of ocean-atmosphere coupling in this region, and will be described. Studies of the variations in the wind field are now under way, and the preliminary results will be reported.

EVALUATION OF NMC'S OPERATIONAL SURFACE FLUXES IN THE TROPICAL PACIFIC

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A major part of our effort at the Climate Analysis Center (CAC) consists of the evaluation of surface fields from the data assimilation/forecast cycle of the NMC medium range forecast model. This is done using direct comparison of the NMC fields with independent data and by comparing the response of the CAC tropical ocean model to different forcing fields. Here, we evaluate the accuracy of the NMC surface winds and surface heat flux fields. Because sea surface temperature (SST) is an important parameter in the coupling of atmospheric and oceanic models, a high resolution SST product is also presented.

Daily surface winds from the NMC data assimilation system are compared with daily wind observations from Pacific Marine Environmental Laboratory (PMEL) meteorological buoys for a one year period (September 1987 to August 1988). These results show that the level of agreement between the assimilated winds and the independent buoy winds is mixed. The long-term mean differences between the buoy and the assimilated winds varies from less than 0.1 $m.s^{-1}$ to as large as 3 $m.s^{-1}$ (which is comparable to the size of the means themselves). Comparisons of the correlations and long-term means are better for the zonal than for the meridional wind components.

The boundary layer physics of the NMC medium range forecast model, generates a complete set of surface heat fluxes in the data assimilation/forecast cycle. Because conventional in situ data are so sparse in the tropical Pacific, these NMC fields could be very useful because of their high spatial and temporal resolution. To test their accuracy, the NMC fields are compared with in situ climatologies. Furthermore, the fields are used to force the CAC tropical ocean model; the heat content of the model upper ocean is compared with a control run.

The present TOGA SST product was designed to use both in situ and satellite data. The in situ data were used to define ground truth and the satellite data were used to fill in the field in regions without adequate in situ data. In this method, spatial and temporal smoothing eliminates much of the finer scale features in the satellite data. A higher resolution SST analysis is presented which uses optimum interpolation with a first guess generated by the CAC tropical ocean model. This technique must use careful quality control because the higher resolution results in fewer observations per grid interval and because the optimum interpolation method doesn't automatically eliminate satellite biases. Comparisons are presented to show the advantages and disadvantages of the two techniques.

PRELIMINARY RESULTS FROM WEPOCS DRIFTERS

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Thirty-five freely drifting buoys were launched in the western tropical equatorial Pacific in June and July 1988. During the first three months (July-September) they provide for the first time a quasi-synoptic picture of the surface flow in the region. Preliminary trajectories show that the South Equatorial Current runs northwestward along the coast of New Guinea, retroflects or turns eastward around the quasi-stationary Halmahera Eddy centered near 4°N 130°E, and flows eastward in the North Equatorial Countercurrent which is centered near 4.5°N. Buoys in the countercurrent meandered swiftly eastward with meridional displacements of 300 km and wavelengths of 600-700 km. Of eleven buoys in the Mindanao Current, two continued through the Makassar Strait, five peeled off eastward into the countercurrent joining the retroflecting buoys, and the rest grounded or were stolen. Three buoys looped cyclonically around the Mindanao Eddy centered near 7.5°N-129°E. The buoy velocities were grouped into 1° x 1° bins and average velocity for each bin was calculated. The resulting velocity field agrees to a large extent with the field of historical shipdrift velocities for the same time of year.

MODELING THE WARM POOL OF THE WESTERN EQUATORIAL PACIFIC OCEAN

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Designing a process-oriented model of the warm water region of the Western Equatorial Pacific Ocean presents difficult choices for the scientist interested in numerically representing the various physical processes associated with the maintenance of the SST. One would clearly like to include the effects of buoyancy forcing on equatorial mixed layer evolution as well as including the vigorous three-dimensional circulation of the region. The unique nature of the mixed layer in this region demands that the model should resolve (at least) all of the following : the SEC-EUC current system, the thermocline and the distinct isothermal and isohaline layers. Clearly the problem calls for a model that can incorporate the exchanges that take place among these very different physical regimes. This talk will review the issues that one must contend with in order to design a successful process-oriented model of the mixed layer of the Western Equatorial Pacific. Questions such as how many degrees of freedom in the vertical is minimal and what kind of turbulent mixing parameterization (i.e. Kraus-Turner, Mellor-Yamada, Richardson #, etc.) is appropriate for the region will be discussed. Finally issues related to basin configuration (westerly boundaries) and the dynamical connections to the western boundary currents in the region will be mentioned. A new "minimal" model of the mixed layer of this region will be presented.

A BETTER DATA REDUCTION METHOD FOR XBT BATHYMESSAGE

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On the Global Transmission System (GTS) of the World Weather Watch (WWW) the XBT temperature profiles are limited to 20 temperature depth couples, but theses profiles are currently recorded every 60 cm (500 to 1000 data points). So, some linear data reduction method is to be used. On the older XBT strip chart recorders, it was done by hand, by experienced officers. On the computer based XBT systems, iterative methods are generally used, based on the "pipe" or the "conus" methods. Theses methods use a fixed temperature tolerance and are rather slow to converge to the required number of characteristic points, and sometime oscillate between two poles, without converging any further.

A more accurate and faster solution is to use the "broken stick" method which give directly the required number of data points.

Then each approximately linear segment of the profile between two characteristic points is replaced by its regression line, and the characteristic points are replaced by the intersection of these regression lines. The improvement is surprising : the rms temperature error is reduced by a factor of 2-3 and the heat content error by a factor of 10.

Further improvement may be added by, in the first place, filtering the profile, using a non linear median filter to eliminate any spike and a linear Hanning filter to low-pass the data. This leads to a better distribution of the characteristic points and to deeper bathymessages, (as the greatest depth of a bathymessage is determined by the first unrealistic temperature).

VARIATIONAL DATA ASSIMILATION IN A MODEL OF THE PACIFIC OCEAN

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XBT data from the Pacific Ocean have been assimilated in a reduced gravity model. A variational technique was used to find the best space time trajectory of the model through the data. This is preferable to assimilating data at discrete (monthly) intervals as used by techniques such as successive correction or optimum interpolation. By finding the space-time trajectory, inconsistencies between the data and the model (and its forcing) can be clearly identified. The data are not sufficient to define the model trajectory uniquely. The data null space is identified, together with an assessment of methods to impose prior information.

AN OCEANIC SUBSURFACE THERMAL ANALYSIS SCHEME. WITH OBJECTIVE QUALITY CONTROL

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In view of the strong impact of interannual climate fluctuations in the Australian region, and of the strategic proximity of Australia to climatically sensitive regions of the tropical oceans, the Bureau of Meteorology and CSIRO Division of Oceanography jointly initiated the development of an oceanic analysis program for the Indian and Pacific regions.

The analysis scheme is based on the multivariate schemes employed for routine numerical analysis of meteorological observations. It incorporates methods for eliminating redundancies in the observation data base (super-observation formation), objective quality control through comparisons with climatology, first-guess (forecast) fields and near-by observations, and cross-validation of data against the analysis.

This paper discusses the implementation of the scheme with emphasis on the application of objective quality controls. The scheme currently operates for the tropical regions of the Indian and Pacific oceans producing bimonthly analyses of specific derived thermal variables and analyses at the standard NODC depth levels to 500 m. Examples include real-time analyses derived from the BATHY message data base, and analyses of observations obtained from the TOGA Sub-surface Data Center.

THE HYDROLOGIC CYCLE OF THE INTRASEASONAL OSCILLATION

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We propose a new theory for intraseasonal oscillations in which the hydrologic cycle plays a fundamental role in the initiation of oscillations in the tropical atmosphere and ocean. Our thermodynamic models involve a mechanically mixed layer in the ocean, with either a fixed or a time varying sea surface temperature (SST), and a moist convectively mixed layer in the atmosphere; these layers are coupled through hydrologic and energetic exchanges. Characterized by thermodynamic properties of this coupled atmosphere-ocean system, the models feature a critical atmospheric moisture capacity which drives a hydrologic circulation, essentially independent of the detailed low level wind structure. This hydrologic circulation and the surface energy budget, along with the associated exchanges of energy and momentum between atmosphere and ocean, are crucial components in the determination of intraseasonal oscillations in the tropics.

Since the atmospheric moisture content and its variability in time are key aspects of this hypothesis, we have examined relationships between water vapor amount and other parameters using observational data sets. We present results that explore the relationship between monthly averaged precipitable water and sea surface temperature. We develop water vapor retrieval methods to obtain precipitable water vapor from SSMI data on a higher space and time resolution than was previously possible.

MULTI-SCALE PROCESSES IN THE EQUATORIAL WESTERN PACIFIC

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A wide range of phenomena exists in the equatorial western Pacific. The El Nino/Southern Oscillation (ENSO) and the 30-60 day (intraseasonal) oscillation dominates the tropical climate variability in the interannual and intraseasonal time scale respectively. Convection associated with the intraseasonal oscillation tends to appear in a series of large-scale complex systems (so called super cloud clusters, SCC's). It is also known that the easterly trade winds over the western and central Pacific are often interrupted by transient outbreaks of strong surface westerlies. These energetic fluctuations are known as "westerly wind bursts". The purpose of this study is to seek a better understanding of the family of phenomena. Particularly, we want to identify the relationship among SCC's, westerly bursts, ISOs and the seasonal variation in the western Pacific region.

We analyze the circulation and other related fields during the period from December 1, 1978 to February 28, 1979. This period corresponds to the first Special Observing Period (5 January to 4 March 1979) of the First GARP Global Experiment (FGGE). The data set collected during the FGGE year (December 1978 to November 1979) especially during the SOPs contain a much greater quantity of tropical observations (e.g. tropical wind, temperature, moisture, etc.) than what can be normally achieved by the existing World Weather Watch System.

The following data sets are used :i) the convection index (Ic) for deep convectivity derived by Dr. Murakami of Meteorological Research Institute of Japan using IR irradiance obtained by the Japanese GMS-1 gesostationary satellite (Murakami, 1983); ii) FGGE-IIb wind data produced by the Goddard Laboratory for Atmospheres assimilation/forecast system (Baker, 1983); iii) monthly mean sea surface temperature analyzed by Climate Analysis Center; and iv) FGGE-IIc surface based precipitation data.

We found that the deepest convection forms in the equatorial belt and is generally found over the areas of warmest SST. Corresponding to the strong convective heating, centers of equatorial cyclonic flow are formed. These well defined ITCZ and warm SST expanded eastward near the date line from December to January and shift westward from January to February. A slight southward shift and development of cyclonic flow was also apparent during the Australian monsoon period. The onset and break of the monsoon was associated with the passage of two eastward-moving intraseasonal disturbances. These two intraseasonal disturbances consist of a series of eastward moving "super cloud clusters" (SCC) which have a vertical structure of the first baroclinic mode and longitudinal extent of 10° to 20° and can last up to 10 days. There are distinct westerly wind bursts associated with the generation of SCC over the warm western Pacific. While the eastward propagating disturbances are characterized by strong low-level

convergence, we also found some westward moving disturbances associated with strong low-level cyclonic vorticity. This east-west asymmetry is likely caused by the Kelvin and Rossby wave dynamics and their interaction with convection.

Examination of high-resolution GMS data reveals that each SCC consists of many individual cloud clusters which have strong diurnal variations and a typical life span of 1-2 days and a spatial extent of 100-500 km. Most of strong convection and westerly events occur in phase with ISO and coincide with warm SST in the western Pacific region. The warm pool in the western Pacific appears to be crucial for organizing the multi-scale family phenomena.

BEHAVIOR OF CONVECTIVE ACTIVITY OVER THE "JOVIAN-TYPE" AQUA-PLANET MODEL

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In order to investigate the behavior of convective activity over the uniform tropical ocean, several numerical experiments have been conducted. To exclude the influence of baroclinic waves, Sea Surface Temperature is assumed to be uniform from pole to equator ("Jovean-type" Aqua Planet).

The results are summarized as below;

1) Once evaporation rate is lower than a critical value, organization of convective activity emerges in the equatorial region.

2) There exist two kinds of organization. The one is for a longitudinal direction (super cluster) and the other is for a meridional direction (double ITCZ structure).

These results are closely related to the Earth rotation effect. Its dependence for an organization of convective activity is also obtained.

ON WARM ROSSBY WAVES AND THEIR RELATIONS TO ENSO EVENTS

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The hypothesis suggested by several simple air-sea coupled models is examined by a numerical ocean model driven by FSU wind stress for the period from 1963 to 1987. The hypothesis examined is that warm Rossby waves generated by stronger trades associating with cold events following warm episodes are responsible for triggering the next warm events. As the results, followings are found.

1) Warm Rossby waves are always found approaching the western boundary of the tropical Pacific in the preceding winters of the warm events.

2) However, there are some winters not followed by warm episode even though warm Rossby waves are found near the western boundary.

3) The warm Rossby waves are mostly generated in the central and western tropical Pacific in the preceding years and clear relations are not found between the previous warm events.

ON THE BIFURCATION OF THE NORTH EQUATORIAL CURRENT AT THE PHILIPPINE COAST

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The westward directed North Equatorial Current (NEC) of the Pacific Ocean bifurcates upon reaching the western boundary of the basin at the Philippine Islands. Two boundary currents result; the northward branch forms the root of the Kuroshio, while the southward limb of the circulation is the Mindanao Current. A series of five cruises have been made to the western equatorial Pacific, under the auspices of the US/PRC cooperative program, during which observations of these currents were obtained (Table I). Conducticity-Temperature-Depth-Dissolved-Oxygen (CTD/O2) data from the cooperative cruises constitute the focus of the present work. The sampling plan that has evolved includes a near synoptic occupation of a closed box of stations which encompass the NEC bifurcation region. A section across the Kuroshio between the Philippine coast and 130°E is occupied at 18.3°N, close to the northern tip of Luzon Island. Similarly, a Mindanao Current section is made along 8°N from the coast of Mindanao Island to 130°E. The box is closed with stations along 130°E across the NEC. The requirement of mass conservation within this box was utilized to estimate absolute transport of the three currents.

Considerable transport variations in the NEC, Kuroshio and Mindanao Current were observed. Most dramatic were the differences between cruises 3 and 4; the upper ocean transport field was twice as intense in fall 1988 as in spring 1987. However, the patterns of circulation in both cases were similar.

Net absolute transports of the three currents, based on geophysical inverse calculations, appear in Table II along with an estimate of the latitude of the NEC bifurcation point. Total mass transport into the boxes balanced to better than 2 Sv. Note however, that on cruise 3 there was a net accumulation of surface waters at a rate of 7 Sv. Divergence of water colder than 10°C was at a comparable rate, resulting in near zero net mass convergence. This pattern of near surface convergence and deep convergence is thought to be balanced by time dependent vertical motion of the thermocline within the box. The required downward velocity is order 1 m/day with a vertical distribution consistent with a low vertical mode/long vertical wavelength disturbance.

Table I

Observations of the NEC Bifurcation in the US/PRC Program

	dates	comments
cruise 1	Feb 14-18 1986	Kuroshio section ends 290km from coast, no Mindanao section
cruise 2	Nov 18-25 1986	Kuroshio and Mindanao sections end 65 km from coast Mindanao section at 10°N
cruise 3	Oct 23-30 1987	full occupation of sampling grid
cruise 4	Apr 23-30 1988	full occupation of sampling grid
cruise 5	Oct 17-24 1988	offshore sampling in NEC and Mindanao restricted by bad weather

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Table II
Comparison of Current Transports
Observed in Fall 1987 and Spring 1988.

Transport in Sv for water with potential temperature above 10°C

	cruise 3	cruise 4	
NEC (130°E) 18.3°-8°N	33.3	60.3	(westward)
Kuroshio (18.3°N) coast to 130°E	12.4	28.0	(northward)
Mindanao (8°N)	13.9	31.4	(southward)
NEC Bifurcation latitude	12.8°N	14.2°N	

THERMAL AND CURRENT STRUCTURE VARIABILITIES IN THE WESTERN AND CENTRAL TROPICAL PACIFIC DURING 1979-85

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Monthly meridional time series of temperature and geostrophic currents, from 0-400m and over the 1979-85 period, were built, in the western and central tropical Pacific (20°N-20°S), from an important update of the original XBT data set of the ORSTOM-Scripps Ship-of-Opportunity Program. This was possible thanks to a tremendous validation effort and to a specific technique, which combines filtering in time and space and ensures the continuity between the currents at and nearby the equator, deduced from the second and first derivative of the meridional pressure field. The significance of these geostrophic currents, all the way to the equator, was positively tested through an intercomparison with direct current measurements taken, in the central equatorial Pacific, during the NORPAX Hawaii-to-Tahiti Shuttle and PEQUOD-LIPP experiments.

EOF analyses reveal that the variability associated with the regular seasonal cycle and the 1982-83 El Nino, is restricted, for the thermal structure, to a relatively large 10°N-10°S area whereas it is mostly trapped within the 3°N-3°S equatorial band for the current structure. Outside this equatorial band, Ekman pumping appears to be the dominant mechanism which induced, during El Nino and at different timing, 30 to 90m thermocline displacement in the north and south side of the western and central equatorial Pacific. The different timing of these extra-equatorial thermocline displacement along with the equatorial thermocline movement, is responsible for strong variations in the North and South Equatorial Countercurrents and in the South Equatorial Current. In the equatorial band, strong westerly winds from June to September 1982 induced a reversal of the zonal slope along the equator, between the western and central regions. This slope reversal induces, a few months later (October 1982), the simultaneous disappearance of the Equatorial Undercurrent in both regions, and is followed by a strong uplifting of the equatorial thermocline. More generally there is a relationship, on seasonal and interannual time scales, between the average of the western and central Equatorial Undercurrent transports and the equatorial mean slope at the Undercurrent level. A box model study, within the 3°N-3°S equatorial band and between the western and central Pacific regions, evidences an exact compensation between an Ekman equatorial convergence and a meridional geostrophic divergence, during the Fall of 1982. This El Nino scheme is exactly opposite to the non El Nino balanced meridional Ekman divergence-geostrophic convergence. This box model study also reveals that, over the 1979-84 period, all the meridional and zonal Ekman and geostrophic volume transport variabilities, within the two regions, are dominated by the zonal geostrophic transport variability in the Western Equatorial Pacific.

A SURVEY OF THE WESTERN EQUATORIAL PACIFIC IN SEPTEMBER 1988

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In September 1988 a survey was made from the RRS Charles Darwin, of the surface meteorology and upper ocean physical oceanography of the Western Equatorial Pacific between 127°E and 160°E and between 7°N and 3°S. Oceanographic instruments included an Acoustic Doppler, Current Profiler and a towed undulating CTD system (SeaSoar) which sampled to a depth of 250m.

The preliminary results show that a major feature during the period was a strong front between the waters of the South Equatorial Current and the relatively fresh North Equatorial Countercurrent. The surface temperatures of the two water masses were similar.

The major surface currents were found in the vicinity of the front which also formed mesoscale size eddies and, near the equator, extended down into the undercurrent.

Near New Guinea, the deep coastal jet was observed flowing to the north-west. Offshore a flow of well mixed water with a strong easterly component was observed with a core at 60m. Other measurements showed the development of surface temperatures of above 33°C with strong stabilization in the upper few meters, and the cooling of the surface and the warming of the ocean at a depth of 5m during periods of rain. Downdraughts associated with rain also produced winds of up to 12 $m.s^{-1}$.

THE HYDROLOGY CYCLE: INTERLOCKING PROCESSES BETWEEN THE OCEAN AND THE ATMOSPHERE

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In the traditional view of the coupled ocean-atmosphere system, the ocean is driven by a momentum flux from the atmosphere and by a latitudinally dependent radiation gradient of the upper ocean. In turn, the atmosphere is driven by gradients of surface heat fluxes, in particular those from the ocean, and by the gradient of latent heating in the atmosphere. The latent heating is a result, in part, of the gradient of the fluxes. Within this scheme, the hydrology cycle plays a relatively passive role in the linkage between the two spheres.

We suggest a more active and significant role for the hydrology cycle, especially in the warm pool regions of the tropical oceans. It is proposed that the hydrology cycle, in tandem with the radiational forcing associated with attendant cloudiness, are first order quantities in the interaction of the two spheres. In particular, we emphasize coupled ocean-atmosphere processes associated with:

(i) Variations introduced into atmospheric heating gradients by cloud,

(ii) Variations of the magnitude of the net radiation at the surface of the ocean,

(iii) Variations in the spectral distribution of radiation at the ocean surface by cloudiness and thus the vertical heating distribution of the upper layers of the atmosphere,

(iv) Variations of the stability of the upper ocean by the strong flux of fresh water during pluvial periods in the warm pool.

An attempt is made to relate these aspects of the hydrology cycle to the observed convection in the warm pool regions of the tropics. With the proposed TOGA COARE in mind, the ramifications of these processes for the planning of the field phase is discussed.

SOME NEW INSIGHTS ON THE JOINT INTERACTION OF THE TROPICS AND THE EXTRATROPICS

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During the last decade there has been an emphasis on observational and theoretical studies regarding the role of anomalous forcing within the tropics on the state of the climate in other regions of the globe.

Early theories suggested that the teleconnection route was unidirectional with a wavetrain emanating from the source of the perturbation forcing. Whereas the simple theory was able to explain some features of the observations, there were many missing elements. For example, the theory did not explain the relative insensitivity of the location of the middle latitude response to the location of the forcing, it did not account for the strong low frequency variance or episodic nature of the forcing or predict the reverse influence, the impact of extratropical variance on the structure of the tropics.

We present a nest of theories which appears to account for many aspects of the observational record and which relates the warm pool regions of the tropics with the global atmosphere. We show that the structure of equatorial and extratropical modes depend crucially on the state of the basic state within the tropics. This has three major ramifications:

(i) Remote energy accumulations to transient

Forcing : Within observed physical ranges, transient equatorially trapped Rossby waves forced by the episodic convection of the warm pool regions of the tropics may posses doppler-shifted group speed zeros in regions of negative stretching deformation which would result in local energy accumulation or the production of equatorial centers of action such as in the eastern Pacific and Atlantic Oceans.

(ii) Trapping characteristics as a function of the character of the basic state:

The longitudinal structure of the forced modes depends on the longitudinal structure of the flow. The latitudinal structure, or degree of trapping, of the forced modes depends on both the sign and the latitudinal shear of the basic state. Regions of easterlies and strong shear (such as characterizes the eastern hemisphere) severely trap equatorial modes. In westerly and weak shear regions (western hemisphere) the modes are weakly trapped. Modes which possess turning latitudes of 10° about the equator in the easterly forcing latitudes may swell beyond 40° in the equatorial westerlies. That is, from the regions of energy accumulation, the equatorial modes increase their regions of influence well into the extratropics. In that manner, the response to time dependent forcing is phase locked in middle latitudes by the extended equatorial modes.

(iii) Influence of extratropical modes on the structure of the tropics:

Earlier theories emphasized the importance of the location of equatorial forcing relative to the position of the "westerly duct". This may still be true, but whether the extratropical forcing will force an equatorially trapped mode depends on whether the forcing is located within the influence defined by the turning latitudes of the equatorial free modes. Given that this region is excessively broad about the equatorial westerlies, the Pacific Ocean of both hemispheres appears to be a critical region for the overlap of extratropical and tropical domains of influence.

In this study we emphasize the role the various processes play in the interaction between the tropics and the extratropics and between the hemispheres on transient and interannual timescales. Finally, we comment on the requirements of near and far field atmospheric observation strategy suggested by the theories.

FLUCTUATIONS OF CONVECTION AND CIRCULATION OVER THE OCEANIC WARM POOL DURING SEPTEMBER-DECEMBER 1981

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The convection associated with the 30-60 day oscillation can be described as an eastward-propagating ensemble or envelope of convective activity focused in the region of warmest sea surface temperature (SST). The activity is linked to the planetary scale circulation through fluctuations in atmospheric angular momentum (wavenumber 0) and asymmetric (wavenumber 1) subtropical waves. Previous research has documented composite features of the oscillation but has also emphasized the higher frequency structure within the envelope of convective activity. In this case study, we investigate the higher frequency structure and a major eastward shift in convection that accompanies a 30-60 day oscillation.

The time period of the study (September-December 1981) coincides with beginning of the 1982-83 ENSO event. Warm SST anomalies extend from the Indian ocean to 140°E during northern fall and shift eastward past the dateline during the course of the 1981-82 winter. Three 30-60 day oscillation events occur during the period with the last event coinciding with the major eastward shift in convection. South China Sea cold surges were observed during each event although their number and intensity varied considerably. Details of the eastward propagating component also showed little similarity, being more closely related to the cold surges than to the large scale forcing implied by upper level velocity potential. After mid-October 1981 the 30-60 day oscillations consisted of three to four convective flare-ups at approximately 10-day intervals, prominent over the Indian Ocean. As the season progressed, these flare-ups showed more of a tendency to propagate east along the equator.

On November 26, 1981 a cold surge followed an equatorial convective flare-up that subsequently developed eastward along and south of the equator. This surge was the strongest and most persistent of the season and convection intensified dramatically near 105°E in response to the surge. Simultaneously, 850 mb westerlies and convergence started to shift east along the equator (5°N-5°S) well ahead of the convection near 105°E. Anomalous subtropical anticyclones and downstream troughs developed in response to the eastern Indian Ocean convection (105°E). A wavetrain arced toward North America from the region of the downstream trough while enhanced trade winds developed east of the dateline below upper level equatorial westerlies. The combination of strong trades and eastward shifting westerlies produced large moisture convergence near 160°E and may have been a key component in a moisture redistribution that favored an eastward shift in convection. The eastward shift of convection was followed by two westerly wind bursts on 5-10 and 13-21 December 1981 and a reversal in the anomalous circulation over the subtropics and the North Pacific. Convection subsequently shifted into the SPCZ region during late December 1981.

Our study demonstrates the complex nature of the multi-scale interactions of convection and circulation over the Indian and western Pacific oceans. While the 30-60 day oscillation coincides with increased convective activity over the oceanic warm pool, the degree to which convection propagates east varies from event to event. Other factors appear to control this feature including interaction with both higher and lower frequency fluctuations. In addition, we speculate that the time of year (i.e., seasonal cycle) is an important factor determining the occurrence of a major eastward shift in convection.

THE STUDY OF THERMOCLINE DEVELOPMENT IN THE WESTERN TROPICAL PACIFIC DURING EL NINO USING TOGA XBT'S, GEOSAT ALTIMETRY, AND THE FSU TROPICAL PACIFIC MODEL.

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At issue are the processes in the western tropical Pacific that allow off-equatorial thermocline influences to affect the equatorial Pacific thermocline during El Nino occurrences. The FSU and NORDA 1-1/2 layer models indicate equatorial baroclinic Kelvin wave activity to be generated both by baroclinic Kelvin/Munk wave activity along the western boundary (in response to incident off-equatorial baroclinic long wave activity) and by Beta refraction of baroclinic long wave activity east of there, suggesting a significant off-equatorial influence (on the equatorial thermocline) in the western tropical Pacific during El Nino occurrences. Analysis of in situ XBT observations indirectly support the existence of this influence through a successful verification of model results both on and off the equator east of the western boundary. However, what has been lacking in this verification effort is the ability to observe oceanic variability at the maritime western boundary itself during El Nino occurrences (i.e., XBT observational activity is particularly sparse in this region). This problem is compounded by the inability of the models to simulate, at this time, an oceanic response to a realistic configuration of the maritime coast of Asia in the tropical Pacific. The observational difficulties of this western boundary influence have been partially overcome by the analysis of GEOSAT altimetric sea level differences (taken during the Exact Repeat Mission), which has allowed sea level fluctuations to be observed over the entire tropical Pacific to within 100 km of the maritime coast of Asia from 20°N-20°S. Results of this analysis will be presented at the meeting.

FIELD EVALUATION OF REAL-TIME XBT SYSTEMS

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The use of XBT's to measure the ocean subsurface temperature and the ability to report this information to users via satellite has significantly increased over the past decade. NOAA is actively participating in an international effort to increase the number of subsurface temperature observations world wide in support of global oceanographic and climate studies. NOAA's XBT program currently supports more than one hundred voluntary ships. Determining the field performance of XBT data systems, including the satellite data link, is an important step in the quality control of these data. This poster paper summarizes the results of a field test NOAA conducted to evaluate the field performance of four XBT system during a Subtropical Atlantic Climate Study (STACS) cruise in July 1988. The systems evaluated included: Argos XBT System; a Shipboard Environmental data Acquisition System (SEAS) using a Sippican MK-9; a Bathy Systems XBT controller; and a XBT Data Box developed at Oregon State University. All XBT's were evaluated relative to a field standard, a Neil-Brown CTD. During the field test a total of 33 CTD and 250 XBT profiles were evaluated.

EXPERIMENTAL RESEARCH ON THE QUASI-BIWEEKLY OSCILLATION OF THE TROPICAL ATMOSPHERE

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The quasi-biweekly oscillation of the tropical atmosphere is examined in terms of P-6 mixed coordinate primitive equation global band model with the surface temperature governed by the heat-balance equation. Simulated results are summarized as follows :

1) The quasi-biweekly oscillation of SST and rainfall is obvious if the interaction between the cloud and radiation is considered. The phase of SST is ahead of the rainfall about one third period.

2) The anomalies of the oscillation system associated with the interaction between the cloud and radiation, such as the cross-equatorial flow moving northward in the upper level and southward in the lower level; the subtropic westerlies in the upper level of northern hemisphere and the convergence zone in the lower level of southern hemisphere; the Walker and anti-Walker circulations located on the east and west side of the intense disturbance respectively are observed when the anomalously warm SST is superimposed at somewhere on the southern hemisphere Pacific region.

3) The higher the anomaly in the initial SST warmth, the stronger the resulting oscillation and the oscillation is decayed with propagation of the disturbance from higher SST region in the western Pacific to lower SST region in the eastern Pacific.

4) The circulation system are larger in scale and bigger in strength when the anomaly of SST is at the central Pacific region than at the Eastern Pacific region.

SOME THOUGHTS ABOUT THE WEST PACIFIC WARM POOL

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Large scale aspects of the West Pacific warm pool will be discussed on the basis of existing data and information. A definition of the warm pool in terms of an isothermal layer is relatively easy and definitive in the vertical, but difficult with regard to its horizontal extent. Even if narrowly defined by the 28°C isotherm, the pool undergoes large annual variations in its horizontal extent. The region of overlap is only about one half of the size of the pool. The pool is persistent only between 10°N and 10°S with its center at 170°E. An inspection of the circulation of upper layer water indicates that the pool gains water from the two anticyclonic gyres, and discharges warm water by means of the countercurrent and the Indonesian throughflow. The residence time of water in the pool is of the order of two years and makes the pool sensitive to interannual variations of heat advection and heat input. There seems to be little interhemispheric exchange of water through the pool.

The role of the countercurrent as a boundary current between the two gyres will be discussed, and its response to variations in the intensity of the two subtropical gyres. A strong south Pacific gyre will lead to a weak countercurrent and to an accumulation of warm water in the warm pool. This situation persists during the build-up phase before El Nino. In contrast, a strong North Pacific gyre will lead to a strong countercurrent and a drain of warm water from the warm pool as is occurring during El Nino. As a consequence, the variations of the volume of warm water in the warm pool and the occurrence of El Nino may well be linked to pulsations of the subtropical gyres in the two hemispheres.

SOME FEATURES OF THE WESTERN TROPICAL PACIFIC : SURFACE WIND FIELD AND ITS INFLUENCE ON THE UPPER OCEAN THERMAL STRUCTURE

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Monthly mean sea surface pseudo wind stress data during the period from Jan. 1962 to Jan. 1980 are used to examine annual and interannual variation of surface wind field over the Western Pacific Ocean by harmonic and spectral analyses. The surface wind over the tropical and equatorial western Pacific ocean have clearly annual and semiannual variations respectively and are consistent with seasonal shift of the Intertropical Convergence Zone of the wind (ITCZ) over the same area. The interannual variation of the surface wind is associated with the El Nino-Southern Oscillation phenomenon (ENSO) and has anomalous variations preceding ENSO. The westerly wind anomalies, which correspond to ENSO, occurred over the western equatorial Pacific at first and then eastward migrated gradually. The monthly mean zonal wind stress over the western equatorial Pacific Ocean is closely related to the Southern oscillation Index (SOI). Monthly correlation coefficient of these two time series is 0.86 (n=207 months).

The effect of the wind field on the thermal structure of the upper layer ocean is primarily analyzed too. The seasonal displacement of the depth of thermocline are computed from the surface wind stress curl using the method derived by Meyers (1979). The mean seasonal variations of the depth of 20°C isotherm which obtained from the subsurface temperature data during the period from Jan. 1964 to Dec. 1980, are consistent with the seasonal displacement of the depth of thermocline from computation. Zonal wind stress over the central and western equatorial Pacific play an important role in change of the volume of the Western Pacific Warm Pool (In this paper, the volume of the Western Pacific Warm Pool is defined as the number of gridpoint at which the average temperature from sea surface to 100 m depth are higher or equal 28° C). Correlation coefficient between the seasonal mean zonal wind stress and the volume of the Western Pacific Warm Pool is 0.70 (n=52 seasons).

MEGAPOLYGON CURRENT METER DATA ANALYSIS

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The autonomous buoy stations (ABS), or moorings, covered the area 510x510 km with its center at 40°20'N, 154°30'E. Currents were measured at depths 120 m, 400 m, 1200 m and 4500 m. Temperature measurements were carried out at 120 m and 1200 m. The data has been separated into "geostrophic" and "ageostrophic" components by low-pass filtering, which eliminated tidal and inertial oscillations with time scales less than 24 hours.

Available potential and kinetic (KE) energy fluxes between mesoscale and large-scale geostrophic currents have been obtained via estimation of corresponding terms in Reynolds energy balance equations :

$$(P->P')=-(g^2/N^2.\rho_0).\langle u'_i.\rho'\rangle.\partial_i\rho$$
$$(K->K')=-\rho_0.\langle u'_i.u'_k\rangle.\partial_i u_k$$

Two methods were used for determination of large-scale fields : space-time averaging of Megapolygon data, and analysis of hydrological data from Levitus Climatological Atlas of World Oceans. Both methods gave compatible estimates : (P->P')=.8 erg/g.day and (K->K') = -.2 erg/g.day at 120 m, horizontal eddy heat fluxes being about $\langle U'.T'\rangle=0.3°C.cm.s^{-1}$, $\langle V'.T'\rangle=3.2°C.cm.s^{-1}$ at the same level. Geostrophic KE spectra were found to be similar to unstable disturbances ' e - folding times distribution over wavenumber space in the linear stability problem for Megapolygon mean current.

Temperature data analysis at 120 and 1200 m gave a stable estimate of Ekman upwelling caused by atmospheric cyclones which had been passing over the region.

High correlation (0.5 to 0.7) have been obtained between KE of geostrophic, ageostrophic currents at all levels and atmosphere pressure disturbances.

Correlation between geostrophic deformation rates $\partial_i u'_k+\partial u'_i$ and ageostrophic Reynolds stresses $\langle u''_i.u''_k\rangle-0.5\delta_{ik}\langle u''_n.u''_n\rangle$ was found to be zero within 70% confidence limits. Reynolds estimate of geostrophic currents dissipation rate $-\rho.\langle u''_i.u''_k\rangle.\partial_i u'_k$ is close to 0.8 erg/g.day and depth-independant.

DIAGNOSTIC STUDIES OF PACIFIC SURFACE WINDS

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Analyses are performed using surface winds derived from the FSU Pacific pseudo-stress fields. Vorticity budget calculations reveal the relative contributions of various terms, and allow simplification of the full momentum equations. Based on the simplified equations, a procedure is developed for estimating surface pressure. Finally, the winds and pressure are used to infer boundary layer and upper level heating fields, within the context of particular model formulations.

The results suggest that the structure of convective heating differs considerably from what is usually assumed.

INTERSEASONAL VARIABILITY - A CRITICAL COMPONENT OF ENSO?

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The role of intraseasonal variability in modulating the ENSO cycle is investigated using the coupled model of Zebiak and Cane (1987). Based on observations of 30-60 day oscillations and westerly wind burst activity in the west Pacific, a stochastic external forcing in zonal wind stress is applied to the model, and the resulting behavior compared to unforced variability, in both simulation mode and forecast mode. Despite very energetic forcing at intraseasonal timescales, only small changes are detectable in the model behavior.

Forecast results suggest that initial conditions have a greater impact than intraseasonal variability in determining the subsequent evolution of the system over a period of several years.

AN INTRODUCTION OF THE FOUR YEAR EXPEDITION ON WEST PACIFIC CONDUCTED BY CHINA ACADEMY OF SCIENCES

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Since 1985, two vessels (both 3,000 ton Institutes of Oceanography in Qingdao and Canton) carried out seven cruises in Western Pacific area with, especially, equipments measuring the parameters of air-sea interaction. An overview will be given about the results obtained from the expeditions.

A four-layer version of the IAP OGGM has been tested towards the response study of climatological surface wind stress, heat flux and sea level air pressure in the Pacific. The model was span-up for more than 60 years and shows most of the large-scale features of annual mean and seasonal variations of observed temperature, currents and sea surface elevation.

ON THE REFLECTION AND TRANSMISSION OF LOW FREQUENCY ENERGY AT THE IRREGULAR PACIFIC OCEAN BOUNDARY

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The western boundary of the tropical Pacific is not continuous and leakage of low frequency energy from the Pacific to the Indian Ocean is possible. At low frequencies equatorial Kelvin and Rossby waves have very large east-west scales compared with the east-west scale of the land masses in the region. Consequently, these land masses may be treated as islands that are infinitesimally thin in the east-west direction. By generalizing previous theory for a single island, the leakage of low frequency energy through the seven major "islands" forming the boundary of the western Pacific can be studied. The major results are as follows.

1) When a mode 1 low frenquency Rossby wave is reflected at the discontinuous western Pacific boundary, the eastward Kelvin wave energy flux is considerably reduced compared with reflection from a solid wall.

2) Some Pacific Rossby wave energy is transmitted into the Southern Indian Ocean and in phase interannual sea levels should occur along Australia's western coast. The latter prediction is in agreement with observation.

3) Negligible low frequency Kelvin wave energy from the Indian Ocean is transmitted into the Pacific.

4) Strong narrow currents are predicted to occur westward of some island tips.

A BRIEF REVIEW ON THE BULK PARAMETERIZATION AND REMOTE SENSING OF LATENT HEAT FLUX IN TROPICAL OCEANS

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Over the warm water pool in the western tropical Pacific and under the tropical convergence zones, the winds are weak and the humidity is high most of the time. The most commonly used bulk aerodynamic transfer coefficients may not apply under these conditions. The constraint on turbulence transfer near the surface and the difference between aerodynamic rough and smooth flows will be examined with respect to the behavior of the transfer coefficients. The effect of humidity driven instability on the transfer coefficient will be described. Parameterization schemes in the extreme case of free convection with vanishing mean-winds will be postulated.

Monthly-mean fields of surface latent heat flux over the tropical Pacific were computed from January 1980 to October 1983, including an intense El Nino Southern Oscillation episode. The method is based on a surface layer turbulence transfer model and an empirical relation between the atmospheric columnar water vapor and surface humidity. Observations by the microwave radiometer on Nimbus-7 were used. The results were compared with in situ measurements from volunteer ship, research buoys, and operational weather stations. The methodology and the evaluation will be briefly described. The seasonal variation and ENSO anomalies of latent heat flux will be compared with those of the related parameters. The correlation between the temporal variation of latent heat flux and the time change of sea surface temperature is significantly high outside the area covered by the migration of the Intertropical Conversion Zone (ITCZ) and outside of the equatorial wave guide. At the ITCZ, the variation of cloud cover and radiation may govern the change of sea surface temperature and, in the wave guide, ocean dynamics play a more dominant role in the upper ocean heat balance.

Combination with shortwave radiation fields is in progress and the significance of these results in the planning of TOGA/COARE will be examined.

INSTABILITY CONDITIONS AND ENERGETICS IN THE EQUATORIAL PACIFIC

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Instability conditions applicable to zonal flows in the equatorial oceans will be reviewed. Multi-layer and continuously stratified models, with either rigid bottom (including the effects of topography) or "reduced gravity" bottom boundary, will be discussed. The use of these theoretical results will be illustrated with the zonal geostrophic velocity profiles calculated from the Hawaii-Tahiti Shuttle Data (Wyrtki and Kilonsky 1984).

The energetics of the instability will also be presented, with a particular discussion on the differences between using the Eulerian framework or the mixed Lagrangian-Eulerian one (in which a function of potential density is used as "vertical" coordinate). As far as possible, the results will be presented in a form useful for the analysis of observational data.

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