References

Bennett, A.F., Poleward heat fluxes in Southern Hemisphere oceans, J. Phys. Oceanogr., 8, 785-798, 1978.

Bernstein, R.L., and W.B. White, Meridional eddy heat flux in the Kuroshio Extension Current, J. Phys. Oceanogr., 12, 154-159, 1982.

Bryan, K., Measurements of meridional heat transport by ocean currents, J. Geophys. Res. 67, 3403-3414, 1962.

Bryan, K., Poleward heat transport by the ocean: observations and models, Ann. Rev. Earth Planet. Sci., 10, 15-38, 1982a.

Bryan, K., Seasonal variation in meridional overturning and poleward heat transport in the Atlantic and Pacific Oceans: A model study, J. Mar. Res., 40 (Supl. Vol.) 39-53, 1982b.

Bryan, K. and L.J. Lewis, A water mass model of the World Ocean, J. Geophys. Res., 84(C5) 2503-2517, 1979.

Bryden, H.L., Poleward heat flux and conversion of available potential energy in Drake Passage, J. Mar. Res., 37, 1-22, 1979.

Bryden, H.L., Ocean heat transport, Papers of the JSC/CCCO Meeting on Time Series of Ocean Measurements, Tokyo, May, 1981, World Climate Program, Publ. 21, IOC, Paris, WMO, Geneva, 1982.

Bryden, H.L., and M.M. Hall, Heat transport by currents across 25°N latitude in the Atlantic Ocean. Science, 207, 884-886, 1980.

Bunker, A., Computations of surface energy flux and annual air-sea interaction cycles of the North Atlantic Ocean, Mon. Weather Rev., 104, 1122-1140, 1976.

Campbell, G.G., Energy transport within the earth's atmosphere-ocean system from a climate point of view, Ph.D. Thesis, Colorado State University, Fort Collins, CO., 1981.

De Szoeke, R.A. and M.D. Levine. The advective flux of heat by mean geostrophic motions in the Southern Ocean, Deep-Sea Res. 28, 1057-1085, 1981.

Dobson, F., F.P. Bretherton, D.M. Burridge, J. Crease, E.B. Kraus, and T.H. Vonder Haar, The 'Cage' Experiment: A Feasibility Study, World Climate Program, 22, World Meteor. Org. Geneva, 95 pp. 1982.

Fu, L.L., The general circulation and meridional heat transport of the subtropical South Atlantic determined by inverse methods, J. Phys. Oceanogr., 11, 1171-1193, 1981.

Fuglister, F.C., Atlantic Ocean Atlas of Temperature and Salinity Profiles and Data from the International Geophysical Year of 1957-58, Woods Hole Oceanographic Inst., Atlas Series 1, 209 pp. 1960.

Georgi, D.T., and J.M. Toole, The Antarctic Circumpolar Current and the oceanic heat and fresh water budgets, J. Mar. Res., (Vol.40, Suppl.), 183-197, 1982.

Godfrey, J.S., and T.J. Golding, The Sverdrup relation in the Indian Ocean, and the effect of the Pacific. Indian Ocean through-flow on Indian Ocean circulation and on the East Australian Current, J. Phys. Oceanogr., 11, (6): 771-79, 1981.

Hall, M.M., and H.L. Bryden, Direct estimates and mechanisms of ocean heat transport, Deep-Sea Res., 29, 339-360, 1982.

Hastenrath, S., Heat budget of tropical ocean and atmosphere, J. Phys. Oceanogr., 10, 157-170, 1980

Hastenrath, S., On meridional heat transports in the World Ocean, J. Phys. Oceanogr., 12, 922-927, 1982.

Hastenrath, S. and P. Lamb, Climatic Atlas of the Tropical Atlantic and Eastern Pacific Oceans, Madison: University of Wisconsin Press, 105 pp, 1977.

Jung, G.H., Energy transport by air and sea. Section XIV of The Dynamic North, Book I, published by Technical Assistant to Chief of Naval Operations for Polar Projects, 19 pp, 1956.

Luyten, J. and H. Stommel, Recirculation reconsidered. J. Mar. Res., 40, (Suppl. Vol.) 407-426, 1982.

Meehl, G.A., W.M. Washington, and A.J. Semtner, Experiments with a global ocean model driven by observed atmospheric forcing, J. Phys. Oceanogr., 12, 301-312, 1982.

Miller, J.R., G.L. Russell, and L-C Tsang, Annual oceanic heat transports computed from an atmospheric model, Dyn. Atmos. Oceans, 1982, in press.

Niiler, P.P., and W.S. Richardson, Seasonal variability of the Florida Current, J. Mar. Res., 31, 144-167, 1973.

Oort, A.H., Global Atmosphere Circulation Statistics, 1958-1973, NOAA Prof. Paper, 14, U.S. Gov't. Printing Office, Washington, DC, 323 pp, 1982.

Roemmich, D., Estimation of meridional heat flux in the North Atlantic by inverse methods, J. Phys. Ocean., 10, 1972-83, 1980.

Sarmiento, J.L., and K. Bryan, An ocean transport model for the North Atlantic. J. Geophys. Res., 87(C1), 394-408, 1982.

Sciremammano, F. Jr., The nature of the poleward heat flux due to low-frequency current fluctuations in the Drake Passage, J. Phys. Oceanogr., 10, 843-852, 1980.

Stommel, H., Asymmetry of interoceanic fresh-water and heat fluxes, Proc. Nat. Acad. Sci. USA, 77(5) 2377-2381, 1980.

Stommel, H., and G.T. Csanady, Relation between the T-S curve and global heat and atmospheric water transports, J. Geophys. Res., 85, (C1) 495-501, 1980.

Stommel, H., and G. Veronis, Variational inverse method for study of ocean circulation, Deep Sea Res., 28A, 1147-1160, 1981.

Trenberth, K.E., Mean annual poleward energy transports by the oceans in the southern hemisphere, Dyn. Atmos. Oceans, 4, 57-64, 1979.

Vonder Haar, T.H., and A. Oort, New estimate of annual poleward energy transport by northern hemisphere oceans, J. Phys. Oceanogr. 3, 169-172, 1973.

Weare, B., P.T. Strub, and M.D. Samuel, Annual mean surface heat fluxes in the tropical Pacific Ocean, J. Phys. Oceanogr., 11, 705-717, 1981.

Wunsch, C., Meridional heat flux of the North Atlantic Ocean, Proc. Nat. Acad. of Sciences, USA, 77, 5043-5047, 1980.

Wunsch, C., The North Atlantic general circulation west of 50°W determined by inverse methods, Rev. Geophys. and Space Phys., 16, 583-620, 1978.

Wunsch, C., D. Hu, and B. Grant, Mass, heat, salt and nutrient fluxes in the South Pacific Ocean, J. Phys. Oceanogr., (in press) 1983.

Wüst, G., and A. Defant, Scientific Results of the German Atlantic of the Research Vessel "Meteor" 1925-27, 6, Atlas, Walter de Gruyter, Berlin Leipzig, 1936.

(Received October 29, 1982;
accepted January 6, 1983.)

REVIEWS OF GEOPHYSICS AND SPACE PHYSICS, VOL. 21, NO. 5, PAGES 1137-1148, JUNE 1983
U.S. NATIONAL REPORT TO INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS 1979-1982

EQUATORIAL OCEANOGRAPHY

Mark A. Cane

Dept. of Meteorology and Physical Oceanography, MIT, Cambridge, MA 02139

E.S. Sarachik

Center for Earth and Planetary Physics, Harvard Univ., Cambridge, MA 02138

Introduction

Interest and activity in the equatorial oceans (defined arbitrarily as that part of the oceans within ten degrees of the equator) have undergone a remarkable expansion in the last four years. The previous IUGG report (O'Brien, 1979) listed about one hundred references - the present one lists over two hundred and fifty. Among the many reasons for this growth, a primary one is the realization of the rapid nature of equatorial responses. The vanishing of the Coriolis parameter in the presence of density stratification means that the ocean can respond strongly to basinwide winds on the climatically important, and observationally accessible, annual and interannual time scales. This realization has taken hold as the result of an interplay among theory, modelling and observation.

Linear wave ideas have provided a simple framework and common language to discuss a wide range of equatorial phenomena. In particular, the equatorial Kelvin wave, which allows locally forced wind changes to be rapidly communicated to the east of the forcing region, has been a particularly fruitful concept in equatorial oceanography. Linear and nonlinear numerical models ranging from single layer shallow water models to full general circulation models have built upon these linear wave concepts to elucidate the roles of stratification, mixing, and

Paper number 3R0051.
0034-6853/83/003R-0051$15.00

non-linearity in the dynamics of a wide variety of phenomena in the equatorial oceans. In addition, extensive observations taken during field programs in all three oceans have become available in the last four years: the GARP Atlantic Tropical Experiment (GATE) in the Atlantic (see the GATE Atlas: Duing, Ostapoff and Merle, 1980 and the GATE Supplements to Deep-Sea Research; Duing, 1980, and Siedler and Woods, 1980), the Indian Ocean Experiment (INDEX, see the August 1, 1980 issue of Science); and the intensive year 1979-1980 of the First GARP Global Experiment (FGGE, see McCreary, Moore and Witte, 1981). In addition, preliminary theoretical and observational work is regularly and efficiently transmitted by the Tropical Ocean-Atmosphere Newsletter (edited by D. Halpern, JISAO, University of Washington, Seattle).

Interest in equatorial oceanography has also intensified outside the oceanographic community. All available data shows that the tropical ocean dominates ocean heat transport both in the mean and in annual variations (see Bryan, 1982, for a recent review) and is therefore a major component of the climate system. It is only within the last few years that a major role for the equatorial ocean in interannual global climate variability has been more than simply suggested. Horel and Wallace (1981) showed that periods of low Southern Oscillation, known to coincide with those periods of anomalous warmings of the equatorial Pacific called El Nino, show correlation with anomalous winter climate over the United States and that this anomalous mid-latitude winter response is consistent in its geographical pattern with having been forced by atmospheric thermal anomalies associated with the warm Pacific. While the correlations are not large, and the atmospheric forcing mechanisms by no means completely understood, the possibility of predicting anomalous conditions over the U.S. during the winter following the onset of El Nino (e.g. Barnett, 1981a) seems to have galvanized both the meteorological and oceanographic communities into a burst of research into the origins of interannual sea surface temperature (SST) variability in the Pacific and into the mechanisms of atmospheric telecommunications from equatorial to midlatitude regions.

In order to usefully review U.S. progress in equatorial oceanography in the limited space available to us, we focus our primarily on the low frequency response of upper equatorial oceans to forcing by the wind. We perceive this as the unifying theme of equatorial oceanography during the previous four years. A major development in this vein, unprecedented in large-scale oceanography, is the attempt to simulate ocean variability by forcing ocean models with real winds and verifying the model response by comparing to oceanographic data records at selected points. While the ocean models used in these attempts have been highly idealized and the quality of wind data dubious at best, the initial results have been encouraging. This attempt at simulation brings observation and theory into an intimacy rare in oceanography and will, we hope, provide a continuing arena for testing our understanding of dynamic and thermodynamic processes.

We begin this review by discussing variations of thermocline depth, mid-ocean currents, and boundary currents. We will then review a problem which has just begun to receive serious attention, namely the factors that determine SST variability in equatorial oceans. We then discuss the status of our understanding of the most spectacular manifestation of SST variability, the El Nino - Southern Oscillation phenomenon. We proceed to discuss the problem of observing the surface winds, which we regard as a fundamental factor limiting our understanding of the equatorial oceans. Finally, we will try to identify those current trends that we expect to bear fruit by the time of the next IUGG report, and some directions for the more distant future.

Thermocline Variations

The thermocline in equatorial oceans tends to be quite shallow, with an average depth of about 100 m. Because of the action of the easterly trade winds, the mean thermocline tends to be deeper in the western parts of the ocean and shallower in the east. It has proved illuminating, over the last decade, to consider a model of the equatorial ocean consisting of a homogeneous light fluid, of mean depth of order 100m, overlaying a heavier fluid. The interface between these fluids then represented the thermocline, and to the extent that motions in the fluid below the interface are small, the motion of the upper fluid satisfies the shallow water equations. In the presence of steady zonal winds, a no motion solution to the shallow water equations is $\frac{1}{2}g' (h^2)_x = \tau(x)$ where h is the depth to the interface and $\tau(x)$ is the wind stress. The long-term mean Pacific thermocline does indeed seem to agree with this simple formula, even though the Pacific in the mean has a wind-driven surface current and an equatorial undercurrent, and therefore is far from motionless. The success of the simple shallow water model at modelling variations of thermocline depth has been quite striking, but there is no consensus on why it works as well as it does. Certainly the currents that the shallow water models predict are at odds with observations of equatorial currents (see next section for more details).

Equatorial subsurface measurements have been taken infrequently in the Atlantic and Pacific, and hardly at all in the Indian Ocean. There is, however, enough climatological data in the Pacific and Atlantic to at least give the broad outline of seasonal variability. Meyers (1979b) examined the climatological monthly variation of the 14°C isotherm on the equator, which is near the bottom of the thermocline in the Pacific. He finds that the variability with respect to the mean is relatively small and that the largest seasonal variability is in the eastern Pacific. Tsuchiya (1979) examined the geopotential gradient in the eastern Pacific and found it to be roughly in phase with the seasonal zonal winds. Both of these results are complementary to Horel's (1982) results which shows most of the seasonal variability of SST to be confined to the eastern Pacific. In the Atlantic, Merle (1980b, 1980c) finds that the seasonal variation of the 23°C isotherm (marking the upper part of the equatorial thermocline) is not small compared to the mean and that when the mean zonal winds across the equatorial Atlantic are weak (in February-March), the thermocline becomes almost flat. These results are in agreement with the previous results of Katz et al (1977) for the zonal pressure gradient in the equatorial Atlantic. Merle also finds that the variations in heat content are in phase with the thermocline variations and that they are an order of magnitude larger than, and out of phase with, the vertical heat fluxes through the sea surface. This implies that on a seasonal time scale at least, heat content variations are dynamically forced and that the surface heat flux does not cause these heat content variations but, rather, responds to the dynamically induced SST variations accompanying the heat content changes. Further, by taking zonal averages across the entire Atlantic, Merle finds that there are annual heat content variations in the zonal average implying that heat is not simply sloshed east-west, but must also be redistributed meridionally. This latter result is consistent with a study by Katz (1981) of dynamic topography in the western Atlantic showing that the entire dynamic topography pattern (consisting of a mean equatorial ridge at 4N and a trough at 10N between which geostrophically flows the North Equatorial Counter Current) flattens out in early spring and deepens in late summer.

Theoretical approaches to understanding thermocline variations have been of two major types: those using idealized winds blowing over shallow water models and those using approximations to the real winds blowing over shallow water models. The first type of calculation is done to understand the basic dynamics of forced response, while the second type is done to compare response to observations.

An illustration of the first type of calculation is Cane and Sarachik (1981) who forced a linear equatorial shallow water model with periodically varying zonal winds of Gaussian form in the meridional direction, and independent of zonal coordinate. They solved for the response analytically over a wide range of parameters. The response for parameters characteristic of annual forcing over the Atlantic showed a remarkable (and perhaps fortuitous) agreement with many of the features of the annual Atlantic response as described by Merle (1980c). But more important, the calculation showed that response to periodic forcing differed in fundamental ways from response to impulsive forcing. In particular, the response to periodic forcing may be considered the standing sum of local and boundary responses, all at the forcing frequency, and illustrated many of the interference effects first predicted by Schopf, Anderson and Smith (1981). Furthermore, it showed that the greater seasonality of response of the Atlantic versus the Pacific could not be attributed to the smaller size or greater memory of the Atlantic (Philander, 1979) since "memory" is a concept concept valid only in initial value problems, not in periodic response problems. The difference in the response of the two oceans is attributable to the greater seasonality of the winds over the Atlantic. The calculations also indicated that periodic response of the thermocline depends strongly on the winds within ten degrees of the equator and only weakly on winds beyond ten degrees.

Kindle (1979) and Busalacchi and O'Brien (1980) force a shallow water model of the Pacific with an approximation to the annual and semi-annual winds. They both find that the semi-annual response of the thermocline in the eastern Pacific is forced by the semi-annual winds in the central Pacific. Kindle (1979) achieves a better overall simulation of equatorial thermocline variability in the east primarily, we believe, because Busalacchi and O'Brien (1980) extended the winds observed between ± 3 degrees and uniformly extended poleward; as indicated earlier, the winds between 3 and 10 degrees do affect the equatorial response. On the other hand, using mean monthly winds over the entire Pacific, Busalacchi and O'Brien achieve impressive agreement of the meridional topography of the thermocline and its observed annual variation with observation.

In the Atlantic, Busalacchi and Picaut (1982) and Cane and Patton (1982) force with climatological monthly winds and compare with observations at Abijan on the northern coast of the Gulf of Guinea. Both are able to simulate the annual variation well and both conclude, by dividing up the wind field geographically, that the response is due to the wind field across the entire ocean and not just to wind changes in the Western Atlantic as had been previously suggested. There is no special contribution from the local winds at the Guinea coast.

Finally, Busalacchi and O'Brien (1981) force the linear shallow water model of the Pacific with a decade of observed winds subjectively analyzed to fill gaps (Goldenberg and O'Brien, 1981), and compare to a decade of tide gauge observations of sea surface taken in the Galapagos. To the extent that motion is confined to a single baroclinic mode, sea surface variability is a proxy for themocline variability. The results show broad agreement with the sea surface interannual variability in that the model broadly reproduces the interannual cold and warm periods. There are obvious differences however: the simulated variability seems to have shorter time scales than observed and there are epochs of cold or warm water that the simulation misses completely. Considering that the winds are of low quality, that the model uses a single vertical mode where perhaps two or more are called for, and that the verification data for themocline displacement is a proxy, we take the results to be encouraging.

These attempts at simulation point to two important needs that currently exist, and have to be met before any further progress can take place. First, an accurate wind data set over the surface of the ocean over at least an annual cycle, and second, a complete thermocline depth data set simultaneous with the winds. Until both of these data sets are available, the confrontation between theory and experiment must necessarily be incomplete. It should be noted that two field programs are due to be performed in 1983, the U.S. Program SEQUAL (Seasonal Equatorial Atlantic Experiment) and the French program FOCAL (French Ocean Climate Atlantic experiment) which have, as one of their goals, the acquisition of simultaneous wind and thermocline data set for the equatorial Atlantic over a complete annual cycle.

Equatorial Currents

McCreary (1981a,b) has proposed an interesting conceptual model for the steady equatorial undercurrent. The response of a linear inviscid ocean to a zonal wind independent of the meriodional coordinate would be a motionless Sverdrup balance in which the wind stress is opposed by the pressure gradient force. In McCreary's model the graver vertical modes are in such a Sverdrup balance, while for the higher modes the driving is balanced by the dissipation of heat and momentum. The result is a zonal jet -- an undercurrent -- centered in the model thermocline. This work shows how friction and stratification can act in concert to determine the characteristics of the undercurrent. The form chosen for the vertical viscosity and diffusion, however, is a function of the stratification, making the two influences inseparable. McPhaden (1981) has proposed a linear model that uncouples the friction from the stratification, though not the thermal diffusion.

The models mentioned in the preceding paragraph both neglect nonlinear terms, which are easily shown to be order one near the equator. The nonlinear studies of Cane (1979,1980) and Philander and Pacanowski (1979,1981) have emphasized the role of the meriodional circulation, especially the vertical advection of momentum. In a model with two homogeneous levels above the thermocline, Cane (1980) pointed out the differing effects of this term with easterlies and westerlies and used the results to explain the observed behavior of equatorial currents in the Indian Ocean (also see McPhaden, 1982b). Philander and Pacanowski (1979,1981) extended these results to a multilevel stratified model. The papers referenced in this paragraph combine these nonlinear ideas with linear wave theory to explain the temporal behavior of the undercurrent and associated equatorial circulation. Cane (1979) showed that the linear ideas explained the establishment of the pressure gradient, which is crucial for establishing the meridional circulation and the undercurrent.

In the nonlinear meridional wind case the meridional advection of momentum destroys the symmetry of the linear solution and results in a strong eastward jet downwind of the equator. As a parcel of fluid moves meriodionally it picks up energy from the wind and as it moves away from the equator its relative vorticity changes to compensate the change in planetary vorticity. The result is an eastward jet downwind of the equator and strong upwelling on the upwind side (Cane, 1979; also see Philander and Pacanowski, 1981b). The multilevel model of Philander and Pacanowski (1979) allows the vertical structure of modes and currents to differ. They added the important result that the adjustment of the upper ocean is via the second baroclinic mode, the gravest mode which is very nearly trapped above the thermocline.

In Philander and Pacanowski (1981a) the response to periodic winds was explored systematically. For periods shorter than 10 days there is little rectified motion, but as the period approaches 50 days intense eastward surface currents can develop. For periods up to 150 days there is great variability above the main thermocline (though not below) and an intense undercurrent develops. For still longer periods the model ocean response is a succession of equilibrium states. (The numbers given are for a 5000 km basin and would increase linearly with basin size.) Katz and Garzoli (1982) used these theoretical results to explain the observed seasonal variations of equatorial currents in the Atlantic. The most striking result is that most of the variation in transport is due to the reversal of the surface currents rather than an increase in undercurrent speed.

As is true for their linear counterparts, nonlinear models show current structure and amplitude to be highly dependent on vertical mixing processes. The calculation of Semtner and Holland (1980) provides an interesting example. It used a very low value for vertical eddy viscosity and generated a great deal of horizontal mixing due to turbulent eddies. In fact, the eddy activity in this model appears to exceed what is observed in the real oceans while the value used for vertical viscosity appears to be much lower than observations suggest (e.g. Crawford and Osborn, 1981a). Pacanowski and Philander (1982) incorporated a more realistic, Richardson number dependent parameterization of vertical mixing. They found that the vertical circulation and mixing at the equator are so vigorous that surface heating is essential for maintaining the stratification on timescales of 100 days. Without this stratification a mixing model will wipe out the shear between the surface and the undercurrent. Schopf and Cane (1982) found a similar result in a model that explicitly parameterizes the physics of the surface layer. Our lack of understanding of vertical mixing processes remains a significant limitation on our ability to model the equatorial circulation.

Coastal Currents

The Somali Current has long held a particular fascination for those who work in equatorial oceanography. The observations taken during FGGE have provided us with a clear description of the response of this current to the Southwest Monsoon (cf. Schott and Quadfasel, 1980,1982; Smith and Codispoti, 1980; Brown, Bruce and Evans, 1980; Bruce, Quadfasel and Swallow, 1980; Bruce, Fieux and Gonella, 1982; Evans and Brown, 1981). The picture that emerges shows two anticyclonic gyres, one turning offshore at about 10N and the other at about 4N. The latter is observed to migrate northward beginning in the late summer, eventually coalescing with the more northerly gyre which remains approximately fixed in space. (This behavior is shown most clearly in the sequence of pictures of the thermal front at the northern edge of the gyres given in Brown, Bruce and Evans, 1980). Explanations for various aspects of the observed behavior have appeared in the literature, but there is no coherent synthesis as yet. The more northerly gyre has been attributed to the local wind stress curl (which is unusually intense at this location; cf. Wylie and Hinton, 1982 or Schott and Fernandez-Partagas, 1981). The calculations of Cox (1979) indicate that such a gyre will form in response to the northward strengthening of the longshore winds. Philander and Delacluse (1982) propose that the turn-off latitude of the southerly gyre is set by the interior flow: in response to a northerly wind an eastward jet will develop at about 4N (cf. Cane, 1979) and the western boundary current will adjust to supply the needed mass flux. Another possible (and somewhat similar) explanation is contained in the study of cross equatorial flows given by Anderson and Moore (1980). Neither study explains the northward migration of this feature. However, Cox (1979) was able to simulate such behavior in a numerical experiment in which the wind along the coast was relaxed.

Philander and Delacluse (1982) contrasted the behavior at the western boundary in response to southerly winds (viz. the Somali Current) with that at an eastern boundary. At both boundaries the surface flow is in the direction of the wind, but at the eastern side the sea surface sets up so that the pressure gradient opposes the wind stress, driving a poleward undercurrent (also see McCreary, 1981b and Philander and Yoon, 1982). This is clearly evident in observations taken off the coast of Peru (Brockmann et al, 1980; Brink, Halpern, and Smith, 1980). Theory implies that the eastern boundary is an extension of the equatorial waveguide, and that the reflection of a Kelvin wave incident on the boundary at the equator should be evident at all latitudes along the coast. The observational study of Enfield and Allen (1980) suggests that this indeed the case. Allen and Romea (1980) and Romea and Allen (1982) have considered the modification of the coastal response due to the presence of the continental shelf.

Equatorial Waves and Deep Jets

Given their central role in theoretical equatorial oceanography, it is natural that observationalists would seek evidence for the existence of equatorial waves in the data record. As an overall characterization of these efforts it may be said that a number of papers have made a strong case, but that no data set is complete enough to identify more than a very few of the characteristic signatures of such waves. An early effort is that of Weisberg, Horigan and Colin (1979), who present evidence for the existence of a mixed Rossby-gravity wave in the Atlantic. The most striking example is the Kelvin wave event observed in the Pacific in 1980 (Knox and Halpern, 1982). A disturbance in sea level crossed the Pacific from the dateline to the Galapagos at a speed of 2.9 m/s without dispersing. These characteristics imply that it should be identified as a packet of first baroclinic mode Kelvin waves. Most of the work on equatorial waves has ignored the effects of mean currents, but there are a few exceptions. Hallock (1980) and Weisberg (1980) attempted to account for mean flow influences in GATE data; Philander (1979) and McPhaden and Knox (1979) did theoretical studies of the influence of an undercurrent-like mean flow on a shallow water system. There have been no studies which considered the influence of a current system with a complex vertical structure.

Among the interesting observations reported over the past four years are those of deep equatorial jets. Beneath the thermocline in all three tropical oceans there are equatorially confined currents with vertical scales of several hundred meters and speeds of several tens of cm/sec down to depths of several thousand meters. (For examples in the Atlantic see Horigan and Weisberg, 1981, or Weisberg and Horigan, 1981; for the Indian Ocean, Eriksen, 1980 or Luyten, 1982; for the Pacific, Leetmaa and Spain, 1981, or Eriksen, 1981). The data presently available is not sufficient to permit a conclusive characterization of the suite of equatorial motions, but a speculative picture is beginning to emerge. Equatorial waves exist at all frequencies: there is no cutoff at a nonzero inertial frequency. It appears that the deeper motions exhibit spectral peaks at annual (Eriksen, 1981) and/or semiannual periods (Luyten and Roemmich, 1982), periods for which there is an obvious source. (At present, it is not clear how much of the deep motions are quasi-steady). There is also evidence, especially in the upper 500m or so, for peaks at periods in the range from 16 to 30 days (e.g. Duing and Hallock, 1980). The most likely explanation is that these motions result from instabilities of the mean currents (Philander, 1978; Cox, 1980). It is possible that some smooth spectral form will characterize motions at shorter periods, but it is also likely that significant peaks related to peaks in the winds will appear (Garzoli and Katz, 1981).

It would be a helpful simplification if the deep jets could all be described as a sum of just a few types of wave motions; e.g. Kelvin waves, mixed Rossby-gravity waves and the gravest Rossby waves. Eriksen's analyses (1980,1981) indicate that this is not the case: the observations can only be described by a sum over many wave types.

Sea Surface Temperature Variability

The equilibrium temperature at the tropical sea surface is determined by a complicated interaction between solar radiation, infrared radiation and evaporation and is basically determined by atmospheric processes (Sarachik, 1978). There are now only three ways to change SST at a point: by changing the vertical heat flux into into the ocean across the sea surface by purely atmospheric processes; by changing advection of heat into that point by a variety of purely oceanic processes; and by increases in mixed layer depth (on an ocean whose temperature decreases with depth) forced by increased wind stirring. A fundamental distinction among these three methods of changing SST is that in the first method vertical heat fluxes through the sea surface cause the SST change while in the second and third method, all else being equal, the SST change is dynamically caused in such a way that the vertical heat fluxes through the surface tend to restore the equilibrium and therefore oppose the SST change. Sometimes all things are not equal - positive feedbacks can arise, for example, in eastern oceans when cooling of the SST by ocean dynamics leads to stratus cloud formation by advective atmospheric processes thereby reducing the solar radiation reaching the surface and reducing rather than increasing the vertical heat flux into the ocean. All three methods of changing SST act in various places in equatorial oceans. We will discuss the observations of SST changes and the status of the models recently developed to address the processes that change SST.

In the central Indian Ocean, where temperature gradients are weak, advective temperature changes are small and SST changes are caused almost entirely by heat fluxes through the sea surface: simple one dimensional mixed layer models driven by fluxes of heat and momentum at the surface seem adequate for describing SST variability on time scales up to the annual (McPhaden, 1982). In the central Pacific, Stevenson and Niiler (1982) find that two-thirds of the heat storage in the mixed layer can be explained by heat fluxes through the sea surface, the remaining third presumably accountd for by advective affects. The eastern Pacific exhibits a large and complex annual cycle with cold water appearing in northern summer and propagating westward with time (Horel, 1982). Niiler indicates that 60% of the variance of storage in a very large area (encompassing that part of the Pacific showing large annual variation, 6 N-6 S, 76 W-140 W) can be accounted for by vertical heat fluxes through the surface although finer spatial scale budgets have not yeat been made. In the eastern Atlantic, the annual signal is dominated by a cold summer tongue of water that seems dynamical in origin in that the coldest SST's appear at times of smallest heat content (i.e. shallowest thermocline) and are marked by <u>increases</u> of the heat flux into the cold tongue (Merle, 1980).

A numerical model that has the capacity to deal with all three types of SST change must have enough vertical resolution to resolve the mixed layer, adequate dynamics so as to be able to model the wave, advective, and diffusive processes that affect SST, and an adequate enough representation of the atmosphere so as to get reasonable heat fluxes through the sea surface. One layer models, which may work well at simulating thermocline depth changes, are totally inappropriate for simulating SST changes, except in those places and on those time scales where thermocline variability is a suitable proxy for SST variability.

Philander has been using a sixteen layer general circulation type ocean model forced by wind stresses, but not heat fluxes, at the sea surface (Philander and Pacanowski 1980, 1981). While carrying no explicit mixed layer, the non-uniform vertical resolution is chosen to be finest near the surface and since there are no surface heat fluxes, temperature changes are dynamically determined. In a study of reponse to meridional wind variations, Philander and Pacanowski, 1981, find patterns of SST distribution remarkably like those in the eastern Atlantic where SST is believed to be dynamically determined. In an investigation concentrating on improving the temperature structure in this model, Pacanowski and Philander (1981), find that a Richardson number dependent vertical mixing of momentum, and a vertical heat flux into the ocean are both necessary factors in obtaining realistic thermocline temperatures.

A recent numerical model by Schopf and Cane (1982) has explicitly coupled a mixed layer to a low vertical resolution dynamical model. This model effectively replaces the directly wind driven, but fixed depth, upper layer in the model of Cane (1979) with a thermally active and variable depth mixed layer: it therefore constitutes the simplest model that not only contains enough dynamics to simulate the equatorial undercurrent but also has all the basic mechanisms (albeit in simplified form) that affect SST variability. Initial tests with this model indicate a strong assymmetry between upwelling and downwelling: upwelling lowers SST directly by vertical advection while downwelling leads to no direct SST change but does make it possible for SST to slowly change by entrainment at the base of the mixed layer. This assymmetry clearly indicates that on short time scales there need be no relation between thermocline variability and SST variability. Further experiments with the model (Schopf and Harrison, 1982) indicate that the existence of SST signatures associated with downwelling Kelvin signals are advectively produced, and are therefore very much a function of the pre-existing mean state of the ocean. For some mean wind conditions, they showed that a downwelling Kelvin wave was able to induce SST changes similar in amplitude and form to the initial coastal and equatorial warming occurring during El Nino episodes in the Pacific. While these initial results are encouraging, deficiencies in the parameterization of vertical surface heat fluxes, taken proportional to the difference of SST and a fixed atmospheric temperature, are clearly apparent.

As thermally active equatorial ocean models begin to be developed, it appears as though the most difficult issue remaining to be addressed is that of the surface boundary condition for vertical heat fluxes. The heat flux into the ocean is influenced in an essential way by advective and convective processes in the atmosphere which are in turn influenced by sea surface temperature. The usual type of boundary condition that parameterizes heat flux by the difference between some fixed atmospheric temperature and the calculated SST is inadequate in that it takes no account of the role of the ocean in determining the atmospheric temperature. Perhaps a correct surface condition can only be applied by coupling a full atmospheric model to the ocean. In any case, it appears that progress in modelling SST variations may require a deeper appreciation by oceanographers of the nature of the interaction between the ocean and the atmosphere.

The El Nino - Southern Oscillation Phenomenon

The Southern Oscillation is an oscillation of surface pressure primarily between the broad low pressure area over the "maritime continent" centered on Indonesia and the center of the South Pacific high in the southeast Pacific, but also with global manifestations. A convenient index of the SO is the anomalous pressure difference (seasonal cycle removed) between the Southern Pacific high and the Indonesian low. It is known that this index, the SOI, oscillates irregularly with periods roughly from 3 to 5 years and that periods of lowest SOI coincide with anomalously warm water across the equatorial Pacific from the coast of South America to beyond the dateline, a distance comprising of more than a quarter of the circumference of the earth. This phenomenon of the interannual variation of Pacific SST, the anomalies beginning at the coast of Peru in phase with the normal seasonally warm water in March but then propagating westward into the open Pacific, is called El Nino. Because the causal relationship between the pressure fluctuations of the SO and the warm water anomalies of El Nino remains unclear, we will sometimes lump both phenomena together into a single acronym, ENSO.

While scenarios for ENSO due to Bjerknes and Wyrtki have been in existence for many years, the lack of data over vast regions of the Pacific have required so much averaging over space and time in order to obtain smooth results, that spatial and temporal relationships have become obscured. While still plagued by a sparsity of data, Rasmussen and Carpenter (1982) assembled new SST and wind sets and composited the data for six El Nino periods, those of 1951, 1953, 1957, 1965, 1969 and 1972. Because the sequence of events for each individual El Nino was so tightly coupled to the seasonal cycle, it was found possible to composite the data by months during the El Nino years but even here, data sparsity first required that 3 month averages be taken. This paper gives the first detailed description of the sequence of events in the ENSO phenomenon over the entire tropical Pacific basin and therefore is a major milestone on our road to understanding it.

We may summarize their description of the composite El Nino as follows. As early as the May of the year preceding El Nino, the South Pacific high begins its anomalous weakening and, since the low pressure region over Indonesia exhibits no anomally until several months later, the weakening of the SOI is initially affected only by the South Pacific high. By September of the year preceeding El Nino, the most striking anomalies seem to be connected to the South Pacific high with slightly warmer SST everywhere South of 20 S (the analyzed region extends only to 30 S), anomalously warm SST and anomalous convergence to the south of the normal position of the South Pacific convergence zone (SPCZ), and some weak indication of anomalously strong equatorial easterlies to the west of the dateline. Thus, in this antecedent September, it appears as if the SPCZ, that convergence zone extending from Indonesia southeastward across the Pacific, has moved anomalously far south. By contrast, in the antecedent December, the SPCZ has moved anomalously far north, warm SST anomalies remaining everywhere south of 20 S accompanied by anomalous westerlies, but now a warm anomally has appeared on the equator at the dateline with indications of slight anomalous westerlies in this warm patch. On the coast of Peru, warm anomalies are still small but have begun to grow. By the April of the El Nino year, the anomalies are large at Peru (in phase with the normal seasonal cycle), warm water has propagated westward halfway across the Pacific, and the warm patch on the dateline seems to have expanded eastward. In this April of the EN year, the SPCZ is anomalously far north, the ITCZ moves southward onto the equator to lie over warm water, and positive precipitation anomalies and westerly wind anomalies appear over the equatorial warm water. By September of the EN year, the warm dateline anomaly and the westward propagative warm anomaly have merged to give warm SST anomalies across the entire equatorial Pacific all the way to Indonesia. There are now very large westerly anomalies in the wind all across the Pacific but strongest in the western Pacific west of 160W. The SPCZ has stayed far north, the ITCZ has stayed far south and they meet roughly at the dateline rather than near Indonesia. Precipitation shows large increases near the dateline with decreases over Indonesia, all indicating that the vast thermal heat source, that would usually be over the maritime continent centered about Indonesia has moved eastward to the dateline. By January of the year following El Nino, these trends have reached their peak and a return to normal is indicated by anomalously cold water everywhere to the south of 20 S. Cold anomalies then appear at the coast of Peru and begin propagating westward along the equator, and the El Nino cycle has come to a close.

The scenario presented is indeed complicated and we have gone into it in some detail because at our present level of understanding, it is not clear which parts are essential and which are not. Wyrtki (1975,1979,1982) has offered hypotheses as to which elements are essential to El Nino. He notes that in the year preceding an El Nino event the easterlies over the Pacific are anomolously strong, raising sea level in the western Pacific and lowering it in the east (see especially Wyrtki, 1979). He proposes that the weakening of these winds generates downwelling equatorial Kelvin waves that propagate to the coast of South America and depress the thermocline there. Enfield (1981c) shows that during the 1972 El Nino the thermocline off Peru was normal in November-December 1971, but had lowered substantially by February-March 1972. In the 1975 paper Wyrtki indicates that the weakening of the winds in the central Pacific is the critical initiator of these events. However, the data presented by Rasmussen and Carpenter makes it clear that the winds in this region do not relax until <u>after</u> the warming at the coast has already begun to spread westward. Busalacchi and O'Brien (1981), in the simulation using real winds referred to earlier, identified the relaxation of the winds <u>west</u> of the dateline as the precursor to the coastal warming and suggested that the subsequent collapse of the easterlies in the central Pacific helps maintain the deep thermocline at the coast throughout the El Nino year.

In summary, Wyrtki (1982) views El Nino as a vast sea-saw. The ocean is preconditioned by the stronger, high SOI easterlies, causing warm water to pile up in the west. Their subsequent relaxation generates Kelvin waves that carry the water back to the east. Wyrtki regards the preconditioning as essential; this is a bit puzzeling because according to theory the ocean dynamics should respond to the any changes in the winds.

There are as yet no theories that account for the entire sequence of events that comprise ENSO. It is generally felt that only the ocean has inherent timescales long enough to account for the four year quasi-periodicity of the cycle. McCreary (1982) has constructed the first model to make this idea concrete. It produces a periodic ENSO signal with the period set by the cross Pacific travel times of an eastward Kelvin wave plus a westward higher order Rossby wave. In its present form the model does not account for the variable spacing of El Nino occurrences or the apparent relation of El Nino to the seasonal cycle, but its most serious shortcoming is the schematic nature of the atmospheric component and its unrealistic response to changes in the model ocean.

That the locking of ENSO to the seasonal cycle may be a clue to the entire sequence of ENSO was suggested by Philander (1983). Based on a complete documentation of the seasonal cycle of SST and winds over the Pacific by Horel (1982), Philander argues that the warm water that normally appears near Peru early in the year is particularly susceptible to positive feedback due to air-sea interactions. He argues that a warm anomaly off Peru produces enhanced westerlies at the western edge of the westward propagating normal seasonal warming which in turn enhances the warm water. While this is an argument, rather than a model, it contains the intriguing suggestion that it is El Nino that causes the SO rather than the other way around.

As we see it, the current situation is as follows. There is an indication that the EN response is in the winds (Busalacchi and O'Brien, 1981) and that the precursors to the Peruvian warm water is the relaxation of the easterlies west of the dateline. Further, this relaxation is connected to the appearance of a pool of warm water near the dateline (Rasmussen and Carpenter, 1982), but no one has yet explained where this pool of warm water came from, or why so much of the antecedent warm anomalies appear south of 20 S or why the South Pacific High starts weakening. The ability to continuously monitor SST and winds over the entire South Pacific, presumably by satellite, seems a prerequisite to answering these questions.

Surface Winds

Since the equatorial thermocline and the equatorial currents respond primarily to changes in the surface wind stress, and since SST variability can additionally depend on the heat flux into the ocean which in turn depends in an essential way on the surface wind, it is clear that in order to understand the forced response we must know the surface winds to some degree of accuracy. Ideally, we would like to know the winds to an accuracy such that errors in the wind field would force errors in the response no larger than the measurement errors. Even when this accuracy can not be obtained, useful results are still assured if the errors in the wind field force errors in the response small compared to the amplitude of the response. The required accuracy of the wind field varies from problem to problem and has not as yet been quantified - an obvious way to do this would be by series of numerical simulations.

Currently, surface winds over the ocean are routinely collected only by selected island stations, by ships of opportunity, and by satellite measurements of the motion of low level clouds and interpolating down to the surface. All of these methods suffer from inherent inaccuracies and from spatial inhomogenieties that render it impractical to construct a basin-wide surface wind field by any single technique. On rare occasions, enough research platforms are placed in the ocean to enable the construction of a limited area surface wind field directly from measurements; this was accomplished during the GATE experiment, for example Krishnamurti and Krishnamurti, 1980.

Ship of opportunity measurements of the surface wind have been archived for over sixty years and this makes it possible to construct climatological monthly wind fields over entire ocean basins (e.g. Hastenrath and Lamb, 1979; Hellerman, 1980) but even here, coverage is adequate only in limited regions. Since the quality of the individual wind measurements that go into the climatological average is not high, errors rapidly accumulate in those regions where ships rarely venture. Furthermore, the representativeness of the monthly wind field depends on the degree of interannual variability present in the wind field and on possible high frequency aliasing (Harrison and Luther, 1982). Only recently has any attempt been made to estimate the errors inherent in the construction of climatological monthly wind fields (Hellerman, 1982).

The situation with respect to the construction of actual, rather than climatological, surface wind fields is still more unsatisfactory since the number of data available during any particular month is very limited. Subjective analysis by meteorologists trained to recognize wind patterns has been used (Goldenberg and O'Brien, 1981) to spatially interpolate the monthly Pacific ship wind field onto a regular grid for the years 1961-1970 but the quality of the resultant wind field remains unknown. Cloud winds have been show to give reasonable time averaged surface winds (Halpern, 1979) in some regions but seem to fail in others (Garzoli, et al., 1982). Perhaps the best that can be done at the moment is to use all the sources of surface winds real-time assimilated into numerical weather forecast models which are then corrected afterwards when additional data, too late to have been included in the real time assimilations, become available. This method is still limited by the relatively small amount of data available and by their spatial inhomogeneity but would improve slowly as the forecast models improve. Lacking detailed comparisons with *in situ* measurements, it is at present impossible to assess the accuracy that even this best method can provide.

The capability for almost synoptic surface wind measurements that satellite instruments could provide, especially the scatterometer (see the papers in Gower, 1981 and the Vol. 87, April 30, 1982 issue of J. Geophys. Res.)is an exciting possibility for the future. A basin-wide surface wind field of known accuracy would be a major boon to equatorial oceanographers.

Summary and Outlook

The previous four years have seen notable progress in the use of simple shallow water models for describing the response of the thermocline (and, by proxy, sea level) to the forcing by large scale wind stresses (e.g. Busalacchi and O'Brien, 1980, 1981). We noted that these models are not adequate to describe equatorial currents because the averaging above the thermocline is too severe to allow the appropriate non-linearities to develop. A simple division of the homogeneous layer above the thermocline into two levels, one communicating directly with the wind stress and one responding to the pressure changes induced by thermocline tilt, provides a model that describes much of the variability of both thermocline and currents in equatorial regions. We are aware of no case where upper ocean current variations described by such a simple model disagree qualitatively with those simulated by ocean general circulation models containing many levels in the vertical.

These simple models are clearly inapplicable to the description of the complicated motions observed below the thermocline. If these deep motions are forced from the surface, a crucial issue that needs to be addressed is the rate of energy leakage through the thermocline down into the deeper ocean. Current estimates are that dissipation rates below the thermocline are small, implying that the energy flux through the thermocline is also small. Hence most of the energetic motion forced at the surface is trapped above the thermocline. This leads us to believe that we can model the essential features of upper ocean variability without considering the coupling to the deeper ocean below. Just why this is so is not altogether clear. There has been some work related to this issue by Philander (1978) and McCreary (see McCreary, Moore and Picaut, 1982), but much remains to be done on the influence of variable stratification and realistic dissipation. The effects of mean currents, notably the equatorial undercurrent and the vigorous meridional circulation associated with it, on the vertical propagation of waves has not yet been considered.

Additional questions remain about the degree of realism needed in modelling the stratification in and above the thermocline. Preliminary results already indicate that the description of sea level variability requires more than a single baroclinic mode and that the thickness of the thermocline itself undergoes variations on seasonal time scales. McCreary (1981a,b,) has long emphasized the need to consider high order modes in order to model the vertical structure of the current system. As more ocean data are collected, and as climatological data undergo more detailed and searching analyses, we expect that these models containing a single homogeneous layer above a delta function themocline will no longer prove adequate and that models with more resolution in the vertical will have to be invoked.

In emphasizing purely equatorial processes, we have not given enough attention to some basic larger scale questions which we expect to begin to be addressed during the next four years. In particular the entire question of the connection of equatorial circulations with the gyre scale circulation of the major ocean basins remains obscure. Sub-categories of this question involve the relation of the eastern boundary currents to the equatorial current-countercurrent system, the role of upwelling in eastern boundary current dynamics and thermodynamics, and the sources of water and salinity for each component of the equatorial current-countercurrent system and the eastern and western boundary currents that connect to them. In addition, some very basic descriptive equatorial oceanography still remains to be done. For example, we still lack a climatology of the South Equatorial Countercurrent and of the subsurface countercurrents and the seasonal variations of most components of the equatorial current-contercurrent system still remains to be described in all three oceans.

During the next four years, we expect much emphasis on theoretical investigations of the mechanisms responsible for SST variability, and on field investigations of SST variability on annual and interannual time scales. A variety of models will be developed, both linear and non-linear, having increased resolution in the vertical and containing thermodynamically active upper levels. We expect to see these models used for simulations of not only thermocline depth and structure and the associated currents, but also of the concommitent SST variations.

Many new data sets will become available from ongoing and planned field programs in the equatorial oceans: EPOCS (Equatorial Pacific Ocean Climate Studies) in the eastern Pacific; Tropic Heat in the central Pacific; SEQUAL (Seasonal Equatorial Atlantic Experiment) and FOCAL (French Ocean Climate Atlantic Experiment) in the Atlantic. We expect a continuing and deepening interest in the problem of the El Nino phenomenon theough the ENSO (El Nino - Southern Oscillation) program and the El Nino Rapid Response experiment, both under the overall aegis of TOGA (Tropical Ocean - Global Atmosphere). We expect that satellite remote sensing and telemetry will play an increasingly important role in the execution and design of these and future field programs.

Finally, we expect oceanographers to become more and more interested in the general role of the ocean in climate and increasingly aware of the problems of heat transport in the oceans. This will require additional study of the general nature of couplings at the air-sea interface and the particular question of how to parameterize vertical heat fluxes through the ocean surface. As our capacity to make measurements in the equatorial oceans increases, the requirement for more accurate surface winds becomes more pressing.

We close by noting that the three major oceans differ in size, geography, and wind forcing. It will be through the comparative study of equatorial processes in all three oceans that our understanding of equatorial oceanography will be most profoundly increased.

Acknowledgements: This work was supported by NASA Grant NGR 22-009-727 and NSF Grant OCE-7922046 at MIT and by NASA Grant NGL 22-007-228 at Harvard. We wish to thank Dr. D.E. Harrison for critically reading the paper and D.F. Franzosa for carefully preparing the manuscript.

References

Allen, J.S. and R.D. Romea, On coastal trapped waves at low latitudes in a stratified ocean, J. Fluid Mech., 98, 555-585, 1980.

Anderson, D.L.T. and D.W. Moore, Cross-equatorial inertial jets with special relevance to very remote forcing of the Somali current, Deep-Sea Res., 26A, 1-22, 1979.

Angell, J.K., Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial eastern Pacific, Mon. Wea. Rev., 109, 230-243, 1981.

Bacastow, J.A., J.A. Adams, C.D. Keeling, D.J. Moss, T.P. Whorf and C.S. Wong, Atmospheric carbon dioxide, the Southern Oscillation, and the weak 1975 El Nino, Science, 210, 66-68, 1980.

Barnett, T.P. and W.C. Patzert, Scales of thermal variability in the tropical Pacific, J. Phys. Oceanogr., 10, 529-540, 1980.

Barnett, T.P., Statistical prediction of North American air temperatures from Pacific predictors, Mon. Wea. Rev., 109, 1021-1040, 1981.

Barnett, T.P., Statistical relations between ocean/atmosphere fluctuations in the tropical Pacific, J. Phys. Oceanogr., 11, 1043-1058, 1981.

Behringer, D.W. and H. Stommel, Annual heat gain of the tropical Atlantic computed from subsurface ocean data, J. Phys. Oceanogr., 11, 1393-1398, 1981.

Boyd, J.P., The nonlinear equatorial Kelvin wave, J. Phys. Oceanogr., 10, 1-11, 1980.

Boyd, J.P., Equatorial solitary Waves. Part I: Rossby solitons, J. Phys. Oceanogr., 10, 1699-1718, 1980.

Boyd, J.P. and Z.D. Christidis, Low wavenumber instability on the equatorial beta-plane, Geophys. Res. Let., 9, 769-772, 1982.

Brink, J.H., D. Halpern and R.L. Smith, Circulation in the Peruvian upwelling system Near 15 S, J. Geophys. Res., 85, 4036-4048, 1980.

Brink, K.H., A comparison of long coastal trapped wave theory with observations off Peru, J. Phys. Oceanogr., 12, 897-913, 1982.

Brockmann, C., E. Fahrbach, A. Huyer and R.L. Smith, The poleward undercurrent along the Peru coast: 5 to 15 S, Deep-Sea Res., 27A, 847-856, 1980.

Brown, O.B., J.G. Bruce and R.H. Evans, Evolution of sea surface temperature in the Somali basin during the southwest monsoon of 1979, Science, 209, 595-597, 1980.

Brown, O.B., Observation of long period sea surface temperature variability during GATE, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 103-124, 1978.

Bruce, J.G., Eddies off the Somali coast during the southwest monsoon, J. Geophys. Res., 84 7742-7748, 1979.

Bruce, J.G., D.R. Quadfasel and J.C. Swallow, Somali eddy formation during the commencement of the southwest monsoon, 1978, J. Geophys. Res., 85 6654-6660, 1980.

Bruce, J.G., M. Fieux and J. Gonella, A note on the continuance of the Somali eddy after the cessation of the Southwest monsoon, Oceanologica Acta, 4, 7-9, 1982.

Bruce, J.G. and W.H. Beatty, III, Observations of the diurnal heating in the western equatorial Indian Ocean, Oceanologica Acta, 5. 137-139, 1982.

Bryan, K., Poleward heat transport by the ocean: Observations and models. Ann. Rev. Earth Planet. Sci., 15-38, 1982.

Bunker, A.F., Trends of variables and energy fluxes over the Atlantic Ocean from 1948 to 1972, Mon. Wea. Rev., 108, 720-732, 1980.

Busalacchi, A.J. and J.J. O'Brien, The seasonal variability of the tropical Pacific, J. Phys. Oceanogr., 10, 1929-1952, 1980.

Busalacchi, A.J. and J.J. O'Brien, Interannual variability of the equatorial Pacific in the 1960's, J. Geophys. Res., 86, 10901-10907, 1981.

Busalacchi, A.J. and J. Picaut, Seasonal variability from a model of the tropical Atlantic, J. Phys. Oceanogr., 1982.

Cane, M.A., The response of an equatorial ocean to simple wind stress patterns: I. Model formulation and analytic results, J. Mar. Res., 37, 233-252, 1979.

Cane, M.A., The response of an equatorial ocean to simple wind stress patterns: II. Numerical results., J. Mar. Res.,37, 253-299, 1979.

Cane, M.A. and E.S. Sarachik, Forced baroclinic ocean motions, III: The linear equatorial basin case,J. Mar. Res., 37, 355-398, 1979.

Cane, M.A., On the dynamics of equatorial currents, with application to the Indian Ocean, Deep-Sea Res., 27A, 525-544, 1980.

Cane, M.A. and D.W. Moore, A note on low-frequency equatorial basin modes, J. Phys. Oceanogr., 11, 1578-1585, 1981.

Cane, M.A. and E.S. Sarachik, The response of a linear baroclinic equatorial ocean to periodic forcing, J. Mar. Res., 39, 651-693, 1981.

Cane, M.A. and Y. DuPenhoat, The effect of islands on low frequency equatorial motions, J. Mar. Res., 40 1981.

Cane, M.A. and R.J. Patton, A numerical model for low frequency equatorial dynamics, 1982.

Cane, M.A. and R.J. Patton, Sources of coastal upwelling in the Gulf of Guinea, 1982.

Cane, M.A. and E.S. Sarachik, Seasonal heat transport in a forced equatorial baroclinic model, J. Phys. Oceanogr., 1983.

Chiu, W-C. and A. Lo, A preliminary study of the possible statistical relationship between the tropical Pacific sea surface temperature and the atmospheric circulation, Mon. Wea. Rev., 107, 18-25, 1979.

Chiu, W-C., A. Lo, D.H. Weidler, Jr., and D. Fulker, A study of the possible statistical relationship between the tropical Pacific sea surface temperature and atmospheric circulation, Mon. Wea. Rev., 109, 1013-1020, 1981.

Clarke, A.J., On the generation of the seasonal coastal upwelling in the Gulf of Guinea, J. Geophys. Res., 84., 3743-3751, 1979.

Clarke, A.J., The reflection of equatorial waves from oceanic boundaries, submitted to J. Phys. Oceanogr., 1982.

Clarke, R.A., Changes in the upper ocean within the C-scale array during Phase III, GATE-1 Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res. 26A, eds. G. Siedler and J.D.Woods, Pergamon Press, 115-127, 1980.

Cochrane, J.D., F.J. Kelley, Jr., and C.R. Olling, Subthermocline countercurrents in the western equatorial Atlantic Ocean, J. Phys. Oceanogr., 9, 724-738, 1979.

Cox, M.D., A numerical study of Somali current eddies, J. Phys. Oceanogr., 9, 311-326, 1979.

Cox, M.D., Generation and propagation of 30-day waves in a numerical model of the Pacific, J. Phys. Oceanogr., 10, 1168-1186, 1980.

Cox, M.D., A numerical study of surface cooling processes during summer in the Arabian Sea. in Monsoon Dynamics, eds. J. Lighthill & R. P. Pearce, Cambridge University Press, 529-540, 1981.

Crawford, W.R., Pacific equatorial turbulence, J. Phys. Oceanogr. 12, 1137-1149, 1982.

Crawford, W.R. and T. R. Osborn, Microstructure measurements in the Atlantic equatorial undercurrent during GATE, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. Walter Duing, Pergamon Press, 285-308, 1980.

Crawford, W.R. and T. R. Osborn, Energetics of the Atlantic equatorial undercurrent, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res.,26A, ed. Walter Duing, Pergamon Press, 309-323, 1980.

Crawford, W.R. and T.R. Osborn, The control of equatorial ocean currents by turbulent dissipation, Science, 212, 539-540, 1981.

Duing, W. and Z. Hallock, Equatorial waves in the upper central Atlantic, GATE-2, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res. 26A, 26, ed. W. Duing, Pergamon Press, 161-178, 1980.

Duing, W., R. L. Molinari and J. C. Swallow, Somali current: evolution of surface flow, Science, 209, 588-589, 1980.

Duing, W., and A. Leetmaa, Arabian Sea cooling: A preliminary heat budget, J. Phys. Oceanogr., 10, 307-312, 1980.

Duing, W., F. Ostapoff and J. Merle, eds. Physical Oceanography of the Tropical Atlantic During GATE, University of Miami Press, 117 p., 1980.

Duing, W., ed., Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res.,26A, Pergamon Press, pp. 356, 1980.

Elliott J.A. and N.S. Oakey, Average microstructure levels and vertical diffusion for Phase III, GATE, Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, eds. G. Siedler and J.D. Woods, Pergamon Press, 273-294, 1980.

Egger, J., G. Meyers and P. B. Wright, Pressure, wind and cloudiness in the tropical Pacific related to the southern oscillation, Mon. Wea. Rev., 109, 1139-1149, 1981.

Enfield, D.B. and J.S. Allen, On the structure and dynamics of monthly mean sea level anomalies along the Pacific coast of North and South America, J. Phys. Oceanogr., 10, 557-588, 1980.

Enfield, D.B., Thermally driven wind variability in the planetary boundary layer above Lima, Peru, J. Geophys. Res., 86, 2005-2016, 1981.

Enfield, D. B., Annual and nonseasonal variability of monthly low-level wind fields over the southeastern tropical Pacific, Mon. Wea. Rev., 109, 2177-2190, 1981.

Enfield, D.B., El Nino Pacific eastern boundary response to interannual forcing, in Resource Management and Environmental Uncertainty, eds. M.H. Glantz and J.D. Thompson, John Wiley & Sons, Inc., 213-254, 1981.

Eriksen, C.C., An equatorial transect of the Indian Ocean, J. Mar. Res., 37, 215-232, 1979.

Eriksen, C.C., Evidence for a continuous spectrum of equatorial waves in the Indian Ocean, J. Geophys. Res., 85, 3285-3303, 1980.

Eriksen, C.C., Deep currents and their interpretation as equatorial waves in the western Pacific Ocean, J. Phys. Oceanogr., 11, 48-70, 1981.

Eriksen, C.C., Equatorial wave vertical modes observed in a western Pacific island array, J. Geophys. Res., 87, 1982.

Ericksen, C.C., Geostrophic equatorial deep jets, J. Mar. Res., 40, Supp, 143-157, 1982.

Evans, R.H. and O.B. Brown, Propagation of thermal fronts in the Somali current system, Deep-Sea Res., 28A. 521-527, 1981.

Flohn, H., Oceanic upwelling as a key for abrupt climatic change, J. Met. Soc. Japan, 60, 268-273, 1982.

Garzoli, S. and E.J. Katz, Observations of inertia-gravity waves in the Atlantic from inverted echo sounders during FGGE, J. Phys. Oceanogr. 11, 1463-1473, 1981.

Garzoli, S.L., E.J. Katz, H.-J, Panitz and P. Speth, In situ wind measurements in the equatorial Atlantic during 1979, Oceanologica Acta, 5, 281-288, 1982.

Gent, P., Standing equatorial wave modes in bounded ocean basins, J. Phys. Oceanogr., 9, 653-662, 1979.

Gent, P.R. and A.J. Semtner, Jr., Energy trapping near the equator in a numerical ocean model, J. Phys. Oceanogr., 10, 823-842, 1980.

Gent, P.R., Forced standing equatorial ocean wave modes, J. Mar. Res., 39, 695-709, 1981.

Gibbs, R.J., Wind-controlled coastal upwelling in the western Atlantic, Deep-Sea Res., 27, 857-866, 1980.

Goldenberg, S.B., and J.J. O'Brien, Time and space variability of tropical Pacific wind stress, Mon. Wea. Rev., 109, 1190-1207, 1981.

Gower, J.F.R., ed., Oceanography from Space, Plenum Press, pp. 978, 1981.

Green, K. and V.T. Buchwald, Interior shelf waves on an equatorial - plane, J. Phys. Oceanogr., 9, 1299-1304, 1979.

Grose, P.L., Transition in water mass properties between 200 and 500 meters depth in the GATE B-array, in Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, eds. G. Siedler and J.D. Woods, Pergamon Press, 147-160, 1980.

Hallock, Z., On wind-excited, equatorially trapped waves in the presence of mean

currents, in Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 261-284, 1980.
Halpern, D., Surface wind measurements and low-level cloud motion vectors near the intertropical convergence zone in the central Pacific Ocean from November 1977 to March 1978, Mon. Wea. Rev., 107, 1524-1534, 1979.
Halpern, D., A Pacific equatorial temperature section from 172 E to 110 W during winter and spring 1979, Deep-Sea Res., 27A, 931-940, 1980.
Halpern, D., Variability of near-surface currents in the Atlantic north equatorial countercurrent during GATE, J. Phys. Ocean., 10, 1213-1220, 1980.
Harrison, D.E. and D.S. Luther, Observing long-period fluctuations of surface winds in the tropical Pacific: Preliminary results from Island data, submitted Mon. Wea. Rev., 1982.
Hastenrath, S. and P.J. Lamb, Climatic Atlas of the Indian Ocean, Part I: Surface climate and atmospheric circulation, The University of Wisconsin Press, 1979.
Hastenrath, S. and P.J. Lamb, Climatic Atlas of the Indian Ocean - Part II: The oceanic heat budget, The University of Wisconsin Press, 1979.
Hastenrath, S., Heat budget of tropical ocean and atmosphere, J. Phys. Oceanogr., 10, 159-170, 1980.
Hastenrath, S. and P.J. Lamb, On the heat budget of hydrosphere and atmosphere in the Indian Ocean, J. Phys. Oceanogr., 10, 694-708, 1980.
Hayes, S.P. and H.B. Milburn, On the vertical structure of velocity in the eastern equatorial Pacific, J. Phys. Oceanogr., 10, 633-635, 1980.
Hayes, S.P. and C.J. Powell, Vertical wave number spectra of temperature fine structure in the Equatorial Pacific, J. Geophys. Res., 85, 4029-4035, 1980.
Hayes, S.P., Vertical fine structure observations in the eastern equatorial Pacific, J. Geophys. Res., 86, 10983-10999, 1981.
Hayes, S.P., J.M. Toole and L.J. Mangum, Water mass and transport variability at 100 W in the equatorial Pacific, 1982.
Hayes, S.P., A comparison of geostrophic and measured velocities in the Equatorial Undercurrent, J. Mar. Res., 40, Supp., 219-229, 1982.
Hellerman, S., Charts of the variability of the wind stress over the tropical Atlantic, in Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res. 26A, ed. W. Duing, Pergamon Press, 63-75, 1980.
Hellerman, S., Normal monthly windstress over the world ocean with error estimates, J. Phys. Oceanogr., 1982.
Hisard, P., Observation de responses de type <<El Nino>> dans l'Atlantique tropical oriental Golfe de Guinea, Oceanologica Acta, 3, 69-78, 1980.
Hisard, P. and J. Merle, Onset of summer surface cooling in the Gulf of Guinea during GATE, in Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 325-341, 1980.
Horel, J.D. and J.M. Wallace, Planetary-scale atmospheric phenomena associated with the Southern Oscillation, Mon. Wea. Rev. 109, 813-829, 1981.
Horel, J.D., On the annual cycle of the tropical Pacific atmosphere and ocean, Mon. Wea. Rev.,110, - , 1982.
Horigan, A.M. and R.H. Weisberg, A systematic search for trapped equatorial waves in the GATE velocity data, J. Phys. Oceanogr., 11, 497-509, 1981.
Huyer, A., The offshore structure and subsurface expression of sea level variations off Peru, 1976-1977, J. Phys. Oceanogr., 10, 1755-1769, 1980.
Jacobs, C.A., Mean diurnal and shorter period variations in the air-sea fluxes and related parameters during GATE, Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res. 26A, eds. G. Seidler and J.D. Woods, 65-85, 1980.
Johnson, Donald R., M. Mutua Nguli and E.J. Kimani, Response to annual reversing monsoon winds at the southern boundary of the Somali Current, Deep-Sea Res., 29, 1217-1228, 1982.
Judkin, D.C., Vertical distribution of zooplankton in relation to the oxygen minimum off Peru, Deep-Sea Res., 27A, 475-487, 1980.
Katz, E.J., and collaborators, Zonal pressure gradient along the equatorial Atlantic, J. Mar. Res., 35, 293-307, 1977.
Katz, E.J., J.G. Bruce and B.D. Petrie, Salt and mass flux in the atlantic equatorial undercurrent, in Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea. Res., 26A, ed. W. Duing, 137-160, 1980.
Katz, E.J., R.L. Molinari, D.E. Cartwright, P. Hisard, H.U. Lass, A. deMesquita, The seasonal transport of the equatorial undercurrent in the western Atlantic (during the global weather experiment), Oceanologica Acta, 4, 445-450, 1981.
Katz, E.J., Dynamic topography of the sea surface in the equatorial Atlantic, J. Mar. Res., 39, 53-63, 1981.
Katz, E.J. and S. Garzoli, Response of the western equatorial Atlantic ocean to an annual wind cycle, J. Mar. Res., 40, Supp., 307-327, 1982.
Keshavamurty, R.N., Response of the atmosphere to sea surface temperature anomalies over the equatorial Pacific and the teleconnections of the southern oscillation, J. Atmos. Sci., 39, 1241-1259, 1982.
Kindle, J.C., Equatorial Pacific ocean variability - seasonal and El Nino time scales, Ph.D. Dissertation, Dept. of Oceanography, Florida State University, pp. 139, 1979.
Knox, R.A., Time variability of Indian Ocean equatorial currents, Deep-Sea Res., 28A, 291-295, 1981.
Knox, R.A. and D. Halpern, Long range Kelvin wave propagation of transport variations in Pacific ocean equatorial currents, J. Mar. Res., 40, Supp., 329-339, 1982.
Kraus, E.B. and H.P. Hanson, Air-Sea interaction as a propagator of equatorial ocean surface temperature anomalies, J. Phys. Oceanogr., 1982.
Krishnamurti, T.N., and R. Krishnamurti, Surface meteorology over the GATE A-scale, in Equatorial and A-Scale Oceanography, Supp II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 29-61, 1980.
Lamb, P.J. and A.F. Bunker, The annual march of the heat budget of the north and tropical Atlantic Oceans, J. Phys. Oceanogr., 1982.
Lass, H.U., V. Bubnov, J.M. Huthnance, E.J. Katz, J. Meinke, A.deMesquita, F. Ostapoff and B. Voituret, Seasonal changes of the zonal pressure gradient in the equatorial Atlantic during the FGGE year, Oceanologica Acta, 1982.
Lau, K-M.W., A numerical study of tropical large-scale air-sea interaction, J. Atmos. Sci., 36, 1467-1489, 1979.
Lau, K-M.W., Oscillations in a simple equatorial climate system, J. Atmos. Sci., 38, 248-261, 1981.
Leetmaa, A. and H. Stommel, Equatorial current observations in the western Indian ocean in 1975 and 1976, J. Phys. Oceanogr., 10, 258-269, 1980.
Leetmaa, A., H.T. Rossby, P.M. Saunders and P. Wilson, Subsurface circulation in the Somali current, Science, 209, 590-592, 1980.
Leetmaa, A., J.P. McCreary, Jr., and D.W. Moore, Equatorial currents; observations and theory, in Evolution of Physical Oceanography, eds. B.A. Warren and C. Wunsch, 184-196, MIT Press, 1981.
Leetmaa, A. and P.F. Spain, Results from a velocity transect along the equator from 125 to 159 W, J. Phys. Oceanogr., 11, 1030-1032, 1981.
Leetmaa, A., The role of local heating in producing temperature variations in the eastern tropical Pacific.
Leetmaa, A, Observations of near-equatorial flows in the eastern Pacific, J. Mar. Res., 40, Supp., 357-370, 1982.
Leetmaa, A., D.R. Quadfasel and D. Wilson, Development of the flow field during the onset of the Somali Current, 1979. J. Phys. Oceanogr., 1982.
Lighthill, Sir James, and R.P. Pearce, Monsoon Dynamics, Cambridge University Press, pp. 735, 1981.
Lin, L.B., and H.E. Hurlburt, Maximum simplification of nonlinear Somali current dynamics, in Monsoon Dynamics, eds. J. Lighthill and R.P. Pearce, Cambridge University Press, 541-555, 1981.
Lukas, R., The termination of the equatorial undercurrent in the eastern Pacific, Ph.D. Thesis, University of Hawaii, 127 pp., 1981.
Luther, D.S., Observations of long period waves in the tropical oceans and atmosphere, Ph.D. Thesis, Mass. Institute of Technology, 210 pp., 1980.
Luyten, J.R., M. Fieux and J. Gonella, Equatorial currents in the western Indian Ocean, Science, 209, 600-602, 1980.
Luyten, J.R., Recent observations in the equatorial Indian Ocean, Monsoon Dynamics, eds. J. Lighthill and R.P. Pearce, Cambridge University Press, 465-480, 1981.
Luyten, J.R., Equatorial current measurements, I. Moored observations, J. Mar. Res., 40, 19-40, 1982.
Luyten, J.R. and D. H. Roemmich, Equatorial currents at semi-annual period in the Indian Ocean, J. Phys. Oceanogr, 12, 406-413, 1982.
McCreary, J., A linear stratified ocean model of the equatorial undercurrent, Phil. Trans. of the Roy. Soc. of London, 603-635, 1981a.
McCreary, J.P., Jr., A linear stratified ocean model of the coastal undercurrent, undercurrent Phil. Trans. of the Roy. Soc. of London, 385-413, 1981b.
McCreary, J.P., Jr., D.W. Moore and J.M.Witte, Recent Progress in Equatorial Oceanography: A Report of the Final Meeting of SCOR Working Group 47 in Venice, Italy, April 27-30, 1981, Nova University-N.Y.I.T. Press, 466 pp., 1982.
McCreary, J.P., Jr., A model of tropical ocean-atmosphere interaction, Mon. Wea. Rev., 110, 1982.
McCreary, J.P., J. Picaut and D.W. Moore, Effect of annual remote forcing in the eastern tropical Atlantic, J. Phys. Oceanogr., 1982.
McPhaden, J. and R.A. Knox, Equatorial Kelvin and inertio-gravity waves in zonal shear flow., J. Phys. Oceanogr., 9, 263-277, 1979.
McPhaden, M.J., Continuously stratified models of the steady-state equatorial ocean, J. Phys. Oceanogr., 11, 337-354, 1981.
McPhaden, M.J., Variability in the central equatorial Indian Ocean - Part I: Ocean dynamics, J. Mar. Res., 40, 157-176, 1982.
McPhaden, M.J., Variability in the central equatorial Indian Ocean, Part II: Oceanic heat and turbulent energy balances, J. Mar. Res., 40, 403-419, 1982.
McPhaden, M.J. and A.J. Semtner, The effects of mean shear flow on equatorial basin modes, J. Phys. Oceanogr., 12, 795-804, 1982.
Meehl, G.A., Characteristics of surface current flow inferred from a global ocean current data set, J. Phys. Oceanogr., 12, 538-555, 1982.
Merle, J. and J.Le Floch, Cycle annuel moyen de la temperature dans les couches superieures de l'Ocean Atlantique intertropical, Oceanolgica Acta, 1, 271-276, 1978.
Merle, J., M. Fieux and P. Hisard, Annual Signal and interannual anomalies of sea surface temperature in the eastern equatorial Atlantic Ocean, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing Pergamon Press, 77-101, 1980.
Merle, J., Variabilite thermique annuelle et interannuelle de l'ocean Atlantique equatorial Est. L'hypothese d'un <<El Nino>> Atlantique, Oceanologica Acta, 3, 209-220, 1980a.
Merle, J., Seasonal variation of heat-storage in the tropical Atlantic Ocean, Oceanoligica Acta, 1980, 3., 455-463, 1980b.
Merle, J. Seasonal heat budget in the equatorial Atlantic Ocean, J. Phys. Oceanogr., 10, 464-469, 1980c.
Meyers, G., On the annual Rossby wave in the tropical North Pacific Ocean, J. Phys. Oceanogr., 9, 663-674, 1979.
Meyers, G., Annual variation in the slope of the 14 C isotherm along the Equator in the Pacific Ocean, J. Phys. Oceanogr, 9, 885-891, 1979.
Meyers, G., Do Sverdrup transports account for the Pacific north equatorial countercurrent?, J. Geophys. Res., 85, 1073-1075, 1980.
Meyers, G., Interannual variation in sea level near Truk Island - A bimodal seasonal cycle, J. Phys. Oceanogr., 12, 1982.
Meyers, G., W. White and K. Hasunuma, Annual variation in baroclinic structure of the northwestern tropical Pacific, Oceanogr. trop. 1, 59-69, 1982.
Mofjeld, H.O., Effects of vertical viscosity on Kelvin waves., J. Phys. Oceanogr., 10, 1039-1050, 1980.
Mofjeld, H.O., An analytic theory on how friction affects free internal waves in the equatorial waveguide, J. Phys. Oceanogr., 11, 1585-1590, 1981.
Molinari, R., Satellite tracked drifting buoy observations of near surface currents and temperature in the Central and Western tropical Atlantic ocean, submitted J. Geophys. Res., 1982.
Molinari, R.L., B. Voituriez and P. Duncan, Observations in the subthermocline undercurrent of the equatorial south Atlantic ocean: 1978-1979, Oceanolgica Acta, 4, 451-456, 1981.
Molinari, R.L., Observations of eastward currents in the tropical South Atlantic Ocean: 1978-1980, J. Geophys. Res., 87, 9707-9714, 1982.
Moura, A.D. and J. Shukla, On the dynamics of droughts in northeast Brazil: Observations, theory and numerical experiments with a general circulation model, J. Atmos. Sci., 38, 2653-2675, 1981.
Niiler, P. and J. Stevenson, The heat budget of tropical ocean warm water pools, J. Mar. Res., 40, Supp. 465-480, 1982.
Nof, D., On the dynamics of equatorial outflows with application to the Amazon's basin, J. Mar. Res., 39, 1-29, 1981.
O'Brien, J.J., Equatorial Oceanography, Rev. of Geophys. and Space Physics, 17, 1569-1575, 1979.
O'Brien, J.J., A. Busalacchi and J. Kindle, Ocean models of El Nino, Resources Management and Environmental Uncertainty, ed. M. H. Glantz, John Wiley and Sons, 159-212, 1980.
O'Neill, K., Observations of vertical propagating equatorially-trapped waves in the deep western Indian Ocean, Ph.D. Thesis, Johns Hopkins University, pp.161, 1982.
Osborn, T.R., and L.E. Bilodeau, Temperature microstructure in the equatorial Atlantic, J. Phys. Oceanogr. 10, 66-82, 1980.
Ostapoff, F., More on the zonal pressure gradients in the equatorial Atlantic, Oceanologica Acta, 5, 265-276, 1982.
Pacanowski, R.C. and S.G.H. Philander, Parame-

terization of vertical mixing in numerical models of tropical oceans, J. Phys. Oceanogr., 11, 1443-1451, 1981.
Pazan, S.E., and G. Meyers, Interannual fluctuations of the tropical Pacific wind field and the southern oscillation, Mon. Wea. Rev., 110, 587-600, 1982.
Perkins, H., Low-frequency forcing of the tropical atlantic ocean under ITCZ during GATE, in Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, eds. G. Siedler and J.D.Woods, Pergamon Press, 225-236, 1980.
Philander, S.G.H., Instabilities of equatorial zonal currents II, J. Geophys. Res., 83, 3679-3682, 1978.
Philander, S.G.H., Nonlinear coastal and equatorial jets, J. Phys. Oceanogr., 9, 739-747, 1979.
Philander, S.G.H., Upwelling in the Gulf of Guinea, J. Mar. Res., 37, 23-33, 1979.
Philander, S.G.H., Equatorial waves in the presence of the equatorial undercurrent, J. Phys. Oceanogr., 9, 254-262, 1979.
Philander, S.G.H., Variability of the tropical oceans, Dyn. of Atmos. and Oceans, 3, 191-208, 1979.
Philander S.G.H., and R.C. Pacanowski, The generation of equatorial currents, J. Geophys. Res., 85, 1123-1136, 1980.
Philander, G. and Walter Duing, The oceanic circulation of the tropical Atlantic and its variability, as observed during GATE, in Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res.,26A, ed. Walter Duing, Pergamon Press, 1-27, 1980.
Philander, S.G.H., The equatorial undercurrent revisited, Ann. Rev. Earth Planet. Sci., 8, 191-204, 1980.
Philander S.G.H., The response of equatorial oceans to a relaxation of the trade winds, J. of Phys. Oceanogr., 11, 176-189, 1981.
Philander, S.G.H. and R.C. Pacanowski, The oceanic response to cross-equatorial winds (with application to coastal upwelling in low latitudes), Tellus, 33, 201-210, 1981.
Philander, S.G.H. and R.C. Pacanowski, Response of equatorial oceans to periodic forcing, J. Geophys. Res., 86, 1903-1916, 1981.
Philander, S.G.H., and J.-H. Yoon, Eastern boundary currents and coastal upwelling, J. Phys. Oceanogr. 12, 862-879, 1982.
Philander, S.G.H., and P. Delecluse, Coastal currents in low latitudes (with application to the Somali and El Nino currents), Deep Sea Res., to appear, 1982
Philander, S.G.H., El Nino - Southern Oscillation phenomena, Nature, 1983.
Preller, R. and J.J. O'Brien, The influence of bottom topography on upwelling off Peru, J. Phys. Oceanogr., 10, 1377-1398, 1980.
Quadfasel, D.R., Low frequency variability of the 20 C isotherm topography in the western equatorial Indian Ocean, J. Geophys Res., 87, 1990-1996, 1982.
Quadfasel, D.R. and F. Schott, Water-mass distributions at intermediate layers off the Somali coase during the onset of the southwest monsoon, 1979, J. Phys. Oceanogr., 1982.
Ramage, C.S., S.J.S. Khalsa and B.N. Meisner, The central Pacific near-equatorial convergence zone, J. Geophys Res., 86, 6580-6598, 1981.
Ramage, C.S. and A.M. Hori, Meteorological aspects of El Nino, Mon. Wea. Rev., 109, 1827-1835, 1981.
Rasmusson, E.M. and T.H. Carpenter, Variations in tropical sea surface temperature and surface wind fields associated with the southern oscillation/El Nino, Mon. Wea. Rev., 110, 354-384, 1982.
Rasmusson, E.M., and T.H. Carpenter, The relationship between eastern equatorial Pacific sea surface temperatures and summer monsoon rainfall over India, May, 1982.
Reed, R.J. and R.M. Lewis, Response of upper ocean temperatures to diurnal and synoptic-scale variations of meteorological parameters in the GATE B-Scale area, Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res.26A, eds. G. Siedler and J.D. Woods, Pergamon Press, 99-114, 1982.
Ripa, P. and S.P. Hayes, Evidence for equatorial trapped waves at the Galapagos Islands, J. Geophys. Res., 86, 6509-6516, 1981.
Ripa, P., Nonlinear wave-wave interactions in a one-layer reduced-gravity model of the equatorial β-plane, J. Phys. Oceanogr., 12, 97-111, 1982.
Ripa, P., Resonant interactions of equatorial waves in a one layer model I. Non local triads and triads of waves with the same speed, 1982.
Ripa, P., Resonant interactions of equatorial waves in a one layer model II. General classification of resonant triads and double triads, 1982.
Roemmich, D., The balance of geostrophis and Ekman transports in the tropical Atlantic, J. Phys. Oceanogr., 1982.
Romea, R.D., and J.S. Allen, On forced coastal trapped waves at low latitudes in a stratified ocean, J. Mar. Res., 40, 369-401, 1982.
Romea, R.D., and J.S. Allen, On vertically propagating coastal Kelvin waves at low latitudes, J. Phys. Oceanogr. submitted, 1982.
Sarachik, E.S., Tropical sea-surface temperature: An interactive one-dimensional atmosphere-ocean model, Dyn. Atmos. and Oceans, 2, 455,469, 1978.
Siedler, G. and J.D. Woods, eds., Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, Pergamon Press, pp. 294, 1980.
Schopf, P.S., The role of Ekman flow and planetary waves in the oceanic cross-equatorial heat transport, J. Phys. Oceanogr., 10, 330-341, 1980.
Schopf, P.S., D.L.T. Anderson and R. Smith, Beta-dispersion of low-frequency Rossby Waves, Dyn. of Atmos. and Oceans, 5, 187-214, 1981.
Schopf, P.S. and M.A. Cane, On equatorial dynamics, mixed layer physics and sea surface temperature, J. Phys. Oceanogr. submitted, 1982.
Schopf, P.S. and D.E. Harrison, On equatorial Kelvin waves and El Nino: I. Effects of simple mean wind fields, 1982.
Schott, F. and D.R. Quadfasel, Development of the subsurface currents of the northern Somali current gyre from March to July 1979, Science, 209, 593-595, 1980.
Schott, F. and J. Fernandez-Partagas, The onset of the summer monsoon during the FGGE 1979 experiment off the East African coast: A comparison of wind data collected by different means, J. Geophys. Res., 86, 4173-4180, 1981.
Schott, F. and D.R. Quadfasel, Low frequency fluctuations off Somalia during the 1979 summer monsoons, J. Phys. Oceanogr., 1982.
Schott, F. and D.R. Quadfasel, Variability of the Somali current system during the onset of the southwest monsoon, 1979, J. Phys. Ocenogr., 1982.
Semtner, A.J., Jr., and W.R. Holland, Numerical simulation of equatorial ocean circulation. Part I: A basic case in turbulent equilibrium, J. Phys. Oceanogr., 10, 667-693, 1980.
Schaffer, G., On the upwelling circulation over the wide shelf off Peru: 1. Circulation, J. Mar. Res., 40 293-314, 1982.
Smith, S.L. and L.A. Codispoti, Southwest monsoon of 1979: Chemical and biological response of Somali coastal waters, Science, 209, 597-600, 1980.
Stevenson, J.P. and P. Niiler, Tropical heat flux and storage during the FGGE shuttle experiment, 1982.
Swallow, J.C., Observations of the Somali current and its relationship to the monsoon winds, Moonsoon Dynamics, eds. J. Lighthill and R.P. Pearce, Cambridge University Press, 444-452, 1981.
Toole, J.M., Anomalous characteristics of equatorial thermohaline finestructure, J. Phys. Oceanogr., 11, 871-876, 1981.
Tsuchiya, M., Seasonal variation of the equatorial zonal geopotential gradient in the eastern Pacific Ocean, J. Mar. Res., 37, 399-407, 1979.
Tsuchiya, M., The origin of the Pacific equatorial 13 C water, J. Phys. Oceanogr., 11, 794-812, 1981.
Verstraete H-M., J. Picaut and A. Morliere, Atmospheric and tidal observations along the shelf of the Guinea Gulf, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 343-356, 1980.
Walsh, J.J., R.W. Whitledge, W.E. Esaias, R.L. Smith, S.A. Huntsmans, H. Santander and B.R. De Mendiola, The spawning habitat of the Peruvian anchovy, Engraulis ringens, Deep-Sea Res. 27A, 1-27, 1980.
Weare, B.C., A statistical study of the relationships between ocean surface temperatures and the Indian monsoon., J. Atmos. Sci., 36, 2279-2292, 1979.
Weare, B.C., P.T.Strub and M.D. Samuel, Annual mean surface heat fluxes in the tropical Pacific ocean, J. Phys. Oceanogr., 11, 705-717, 1981.
Weare, B.C. and P. Ted Strub, Annual mean atmospheric statistics at the surface of the tropical Pacific ocean, Mon. Wea. Rev., 109, 1002-1012, 1981.
Weare, B.C., El Nino and tropical Pacific ocean surface temperatures, J. Phys. Oceanogr., 12, 17-27, 1982.
Weare, B.C. and J.S. Nasstrom, Examples of extended empirical orthogonal function analyses, Mon. Wea. Rev., 110, 481-504, 1982.
Weisberg, R.H., A. Horigan and C. Colin, Equatorially trapped Rossby-gravity wave propagation in the Gulf of Guinea, J. Mar. Res., 37, 67-86, 1979.
Weisberg, R.H. and A.M. Horigan, Low-frequency variability in the equatorial Atlantic, J. Phys. Oceanogr., 11, 913-920, 1981.
Weisberg, R.H., Equatorial waves during GATE and their relation to the mean zonal circulation, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 179-198, 1982.
Weisberg, R.H., L. Miller, A. Horigan and J.A. Knauss, Velocity observations in the equatorial thermocline during GATE, Equatorial and A-Scale Oceanography, Supp. II to Deep-Sea Res., 26A, ed. W. Duing, Pergamon Press, 217-248, 1980.
Williams, R.G. and R.E. Dennis, Variability of the upper ocean mass field in the eastern tropical Atlantic during GATE, Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, eds. G. Siedler and J.D. Woods, Pergamon Press, 129-146, 1980.
Witte, J., Physical processes in the equatorial regions of the oceans: A bibliography, Nova/NYIT Press, pp. 73, 1980.
Worthem, A. and G. Mellor, Turbulence closure model applied to the upper tropical ocean, Oceanography and Surface Layer Meteorology in the B/C Scale, Supp. I to Deep-Sea Res., 26A, eds. G. Siedler and J.D. Woods, Pergamon Press, 237-272, 1980.
Wylie, D.P. and B.B. Hinton, Some statistical characteristics of cloud motion winds measured over the Indian ocean during the summer monsoon, Mon. Wea. Rev., 109, 1810-1812, 1981.
Wylie, D.P. and B.B. Hinton, The feasibility of estimating large-scale surface wind fields for the summer MONEX using cloud motion and ship data, Bound-Layer Met., 21, 357-367, 1981.
Wylie, D.P., B.B. Hinton and K.M. Millett, A comparison of three satellite based methods for estimating surface winds over oceans, J. Appl. Met., 20, 438-449, 1981.
Wylie, D.P. and B.B. Hinton, The wind stress patterns over the Indian Oceans during the summer monsoon of 1979., J. Phys. Oceanogr., 12, 186-199, 1982.
Wyrtki, K., El Nino - The dynamic response of the equatorial Pacific ocean to atmospheric forcing, J. Phys. Oceanogr., 5, 572-584, 1975.
Wyrtki, K., The response of sea surface topography to the 1976 El Nino, J. Phys. Oceanogr., 9, 1223-1231, 1979.
Wyrtki, K., E. Firing, D. Halpern, R. Knox, G.J. McNally, W.C. Patzert, E.D. Stroup, B.A. Taft and R. Williams, The Hawaii to Tahiti shuttle experiment, Science, 211, 22-28, 1981.
Wyrtki, K., An estimate of equatorial upwelling in the Pacific, J. Phys. Oceanogr., 11, 1205-1214, 1981.
Wyrtki, K., Eddies in the Pacific north equatorial current, J. Phys. Oceanogr., 12, 746-749, 1982.
Wyrtki, K, The southern oscillation, ocean-atmosphere interaction and El Nino, Mar. Tech. Soc. J., 16, 3-10, 1982.
Wyrtki, K. and G. Eldin, Equatorial upwelling events in the central Pacific, J. Phys. Oceanogr., 12, 984-988, 1982.
Yoon, H-G., Effects of islands on equatorial waves, J. Geophys. Res., 86, 10913-10920, 1981.
Yoon, J-H. and S.G.H. Philander, The generation of coastal undercurrents, J. Oceanogr. Soc. Japan, in press, 1982.

(Received October 29, 1982;
accepted January 10, 1983.)