Intergovernmental Oceanographic Commission

Workshop Report No. 52

SCOR-IOC-Unesco Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere

Paris, 6-10 May 1985

Unesco

IOC Workshop Reports

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No.	Title	Publishing Body	Languages
1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IDOE Workshop on); Bangkok, Thailand 24-29 September 1973 UNDP (CCOP), 138 pp.	Office of the Project Manager UNDP/CCOP c/o ESCAP Sala Santitham Bangkok 2, Thailand	English
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (Unesco Technical Paper in Marine Sciences, No. 20).	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock) Spanish (out of stock)
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean, Monte Carlo, 9-14 September 1974.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish (out of stock)
4	Report of the Workshop on the Phenomenon known as "El Niño", Guayaquil, Ecuador, 4-12 December 1974.	FAO Via delle Terme di Caracalla 00100 Rome, Italy	English (out of stock) Spanish (out of stock)
5	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February 1975.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock) Spanish
6	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific, Suva, Fiji, 1-6 September 1975.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/Unesco/EAC, Nairobi, Kenya, 25 March-2 April 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters, Penang, 7-13 April 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience, Mauritius, 9-13 August 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring, Monaco, 14-18 June 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish (out of stock) Russian
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain Trinidad, 13-17 December 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish (out of stock)
11 Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain, Trinidad, 13-17 December 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects, Fort-de-France, Martinique 28 November-2 December 1977.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area, Port of Spain, Trinidad, 16-18 January 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas, Abidjan, Ivory Coast, 2-9 May 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French
15	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific, Santiago de Chile, 6-10 November 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Russian
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS), Moscow, 9-11 April 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
17 Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System, Moscow, 2-6 April 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
18	IOC/Unesco Workshop on Syllabus for Training Marine Technicians, Miami, 22-26 May 1978 (Unesco reports in marine sciences, No. 4)	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock) French Spanish (out of stock) Russian
19	IOC Workshop on Marine Science Syllabus for Secondary Schools, Llantwit Major, Wales, U.K., 5-9 June 1978 (Unesco reports in marine sciences, No. 5).	Division of Marine Sciences, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian Arabic
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources, Bandung, Indonesia, 17-21 October 1978.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
21	Second IDOE Symposium on Turbulence in the Ocean, Liège, Belgium, 7-18 May 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
22	Third IOC/WMO Workshop on Marine Pollution Monitoring, New Delhi, 11-15 February 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific, Tokyo, 27-31 March 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Russian
24	WESTPAC Workshop on Coastal Transport of Pollutants, Tokyo, 27-31 March 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (out of stock)
25	Workshop on the Intercalibration of Sampling Procedures of the IOC/WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters, Bermuda, 11-26 January 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English (superseded by IOC Technical Series No. 22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region, Mexico City, 24 September-5 October 1979.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific, Nouméa, New Caledonia, 9-15 October 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes Lima, 20 April-5 May 1980.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
29	WESTPAC Workshop on Marine biological methodology Tokyo, 9-14 February 1981.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
30	International Workshop on Marine Pollution in the South-West Atlantic Montevideo, 10-14 November 1980.	IOC, Unesco Place de Fontenoy, 75700 Paris, France	English (out of stock) Spanish
31	Third International Workshop on Marine Geoscience Heidelberg, 19-24 July 1982	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
32	UNU/IOC/Unesco Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime Paris, 27 September - 1 October 1982	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish

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1. INTRODUCTION

Since the last century it has been known that lower sea surface temperature and higher productivity and plankton biomass exist in the mixed layer in a narrow equatorial zone of the world oceans. Because ocean temperature decreases with depth, nutrient-rich water occurs below the mixed layer, and the prevailing zonal direction of the surface winds along the equator is westward, upward motion or upwelling is thought to be the physical mechanism responsible for the near surface temperature and phytoplankton distributions observed in the equatorial zone.

The existence of equatorial upwelling has long been a tenet of faith among oceanographers. Vertical motion in the ocean is extremely difficult to measure because of its low speed. Most often, estimates are computed from physical principles or inferred from variations of conservative and nonconservative parameters.

Equatorial vertical motions have substantial influence upon earth's climate. An example of dynamic interactions within the atmosphere-ocean-biosphere system involving equatorial upwelling is the exchanges of carbon dioxide during the El Niño Southern Oscillation (ENSO) episode of 1982-83. The normal rate of increase in the globally averaged atmospheric carbon dioxide level (due to fossil fuel combustion) was strongly perturbed during this ENSO period. Weakened upwelling, deeper mixed layer, and lower productivity in the equatorial Pacific reduced the fixation of carbon into new primary production from 1.0×10^9 tons of carbon (1.0 GtC) to 0.4 GtC during this period; the change in the amount of carbon penetrating to water depths greater than 500 m where it is unavailable for degassing to the atmosphere for many years is poorly known. The reduction in the flux of upwelled carbon dioxide to the equatorial atmosphere was about 0.6 GtC, roughly balancing the effect of decreased new production.

Since the 1977 formation of the Scientific Committee on Oceanic Research (SCOR) Working Group 56 ("Equatorial Upwelling Processes"), there have been many innovative observational and theorical programmes emphasizing the role of equatorial vertical motions. In 1983 it seemed timely to propose an international meeting to provide an opportunity for researchers in different disciplines to discuss this subject. A SCOR Symposium was organized in 1985 to conduct a multidisciplinary enquiry into processes of equatorial upwelling, including assembling evidence of the spatial and temporal characteristics of equatorial upwelling processes.

2. ORGANIZATION

A multidisciplinary Symposium on Vertical Motion in the Equatorial Upper Ocean and its effects upon Living Resources and the Atmosphere was held during 6-10 May 1985 at Unesco, Paris. This innovative Symposium was sponsored by SCOR Working Group (WG) 56 and co-sponsored by the Intergovernmental Oceanographic Commission (IOC) and Unesco's Division of Marine Sciences (OCE). Attendance at this international meeting was approximately 68 people from 13 countries. The Organizing Committee consisted of: R. Barber (United States of America), O. Guillén (Perú), D. Halpern (United States of America), D. Hu (People's Republic of China), R. Jiménez (Ecuador), A. Longhurst (Canada), H. Rotschi (Ivory Coast), M. Vinogradov (Union of Soviet Socialist Republics), and B. Voituriez (France). Dr. Halpern, Chairman of SCOR WG 56 Physical Panel, was Convenor and Dr. Barber, Chairman of SCOR WG 56 Biological Panel, was Co-convenor. The List of Participants is given in Annex II.

The Symposium emphasized the synthesis of multidisciplinary aspects of vertical motion in the equatorial upper ocean, especially the interrelationships of the biological, chemical, physical and living resources parameters. Even though the papers were nearly equally divided between physical and biological aspects, many papers emphasized interrelationships of physics and biology. There were a number of outstanding papers presented in the Symposium. Preprints of papers and several others intended for presentation were distributed at the conference in an unpublished document known as the Blue Report, which greatly aided scientific discussions among the participants. Annex I contains an alphabetical listing by first-author of the titles and abstracts of the papers contained in the Blue Report. Some of the papers and other contributions were then submitted to Oceanologica Acta and appeared in a special issue (Special volume no. 6, May 1987, edited by D. Halpern and T. Barber, published by Gauthier-Villars).

3. SUMMARY OF SCIENTIFIC RESULTS

The average of several quantitative, independent estimates of upwelling in the equatorial zone (remote from a coastline) reported at the Symposium was 2.5×10^{-5} m s^{-1}. Techniques involved: (a) the equation of continuity using (i) drifting buoy trajectories and (ii) moored current measurements; (b) time history of mixed layer depth; (c) equatorial undercurrent core trajectory; (d) flow along isotherms; and (e) mass convervation. The time dependence of equatorial upwelling is still insufficiently known, except perhaps on the annual and inter-annual time scales.

A change in heat storage of the upper ocean not accounted for by net surface heat flux is partially attributed to vertical displacement of the thermocline and to horizontal advection. Upper ocean heat budget studies continue to be made to resolve the role of vertical motion in variations of the thermocline and of the sea surface temperature (SST); it is generally accepted that a downward displacement of the thermocline is associated with an increase in SST, and vice-versa. Studies in the western Indian Ocean indicate downward advection of heat as the southwest monsoon commences and isotherms in the western Pacific deepen when easterly winds occur; however, in the eastern tropical Atlantic the heat content was not significantly related to vertical displacements of the thermocline because of the substantial contribution from horizontal advection.

The horizontal circulation pattern due to a vertical redistribution of the tropical temperature field is complex. Changes in thermocline depth along the equator produce zonal pressure gradient variations and, consequently, disturbances of the east-west ageostrophic current component. The meridional pressure gradient fluctuation near the equator induced by vertical displacement of the thermocline along the equator creates change in the geostrophic zonal current. Thus, vertical motion, though not large in speed, strongly influences the horizontal circulation by its effect upon the position of the thermocline.

Chlorophyll-a is a measure of phytoplankton abundance. In tropical waters a subsurface chlorophyll-a maximum is associated with the upper portion of the nitrate gradient, and the depth of primary production maximum occurs closer to the surface than the chlorophyll-a maximum or the nitrate gradient. In tropical regions a strong thermocline separates a mixed layer low in chlorophyll-a and nutrients from nutrient-rich water below. Because of spotty and intermittent observations over short durations in a biologically active environment where the doubling time of phytoplankton is about 1 day, the relative contributions of upwelling (an upward current), and vertical mixing (turbulent exchange of momentum, heat and nutrients) to the chlorophyll-a and primary production patterns remain elusive. Turbulent mixing along the equator has several time scales, including the diurnal period produced by nocturnal surface heat flux and 5- to 30-day periods produced by vertical shear betzeen the swiftly flowing currents (e.g. westward flowing South Equatorial Current and eastward flowing Equatorial Undercurrent). Double diffusive heat and salt fluxes in the strongly stratified waters also contributes significantly to ocean mixing.

Upwelling strongly influences biological processes in the tropical zone. Vertical motion not only uplifts nutrients into the euphotic zone where light intensity decreases exponentially with depth, it also determines the net sinking rate of phytoplankton which, consequently, contributes to the growth rate, concentration, and size distribution of the primary productivity. Upwelling allows nonmobile phytoplankton to be

entrained for increased intervals in the biologically active near surface zone. Along the equator, phytoplankton would be carried eastward and toward the surface by the Equatorial Undercurrent. In the coastal zone, horizontal currents frequently re-introduce phytoplankton into the region of upward motion, producing rapid growth cycles.

Irradiance absorption by biological constituents (e.g. phytoplankton) can produce localized heating at depth and effect the thermal structure of the upper ocean. The radiation absorption might be large enough for a thermal inversion and, possibly a static instability, to develop. The consequences of this physical-biological interaction upon modelling SST dynamics requires elaboration.

While temporal sampling of chlorophyll-a and primary production will continue to be aliased until in-situ time series observations are recorded, satellite-borne instrumentation will reduce the spatial aliasing of surface chlorophyll-a data. The potential for global primary productivity estimates is exciting, though much basic research needs to be done because the correlation between surface chlorophyll-a and primary production has substantial regional differences due to characteristics of static and dynamic stabilities, mixed layer depth, light penetration intensity, advective effects, nutrient supply, etc. Most likely, in-situ measurements of intensity of mixing or of photosynthetic parameters such as the depth of the chlorophyll-a maximum will be an integral component of global estimates of primary production from satellite data.

One of the factors contributing to the high fisheries yield in upwelling regions is the relatively short food chain, i.e. fewer trophic levels are required to convert organic matter to useful form for society. Thus, the size of photosynthetic organisms or of the chlorophyll-a, which are the intitial elements in the food chain, may be indicators of the ultimate fisheries yield. For instance, in highly productive coastal upwelling environments the size of the diatoms and dinoflagellates are about 10-20 um (i.e. nanoplankton). In contrast, picoplankton (2 um) predominate in the tropical open ocean, e.g. in the eastern Atlantic where picoplankton associated with the chlorophyll-a maximum are upwelled without much increase in cell size.

4. RECOMMENDATIONS

The scope of results presented at the Symposium was far ranging, from 10^{-6} m for plankton cell size to 10^{8} seconds) of wind and current variations. These large characteristic space and time scales sometime hamper effective communications among participants specialized in a portion of the scale range. however, studies of interactions between processes within these scales must be encouraged to achieve answers to some of society's most pressing environmental concerns, e.g. the role of the marine

biosphere upon atmospheric carbon dioxide variations. The Symposium format, with its lengthy lectures and ample time for scientific discussions, contributed greatly towards multidisciplinary interactions among participants; attendees' remarks indicated appreciation of this type of Symposium structure. One of the strongest lessons of the Symposium was the need for cooperation among countries in order to develop an accurate global understanding of equatorial processes.

It was noted that the penetration depth of anthropogenic carbon dioxide in the equatorial ocean was 1000 m in the Atlantic and 400 m in the Pacific. Future studies need to determine whether this feature was the result of increased downwelling in the Atlantic or some other process. The size of the global carbon flux to the deep sea and the biochemical processes in the euphotic zone regulating this flux are poorly characterized; this is a subject of the International Global Ocean Flux Studies (GOFS) Programme. Much work needs to be done on the new to total production ratio, such as descriptions of its mean and variance.

While the climatological-mean value of equatorial upwelling is fairly well established, temporal and spatial variations are poorly known. Projects should be initiated to determine the wavenumber-frequency variations of vertical motion in the equatorial upper ocean for scales less than about 2 months and 1000 km. Simultaneous observations of plankton communities, primary production, solar irradiance, mixed layer depth, and other parameters should be made to quantify the relationship between these types of data. Emphasis must be given to the difficult problem of parameterization of small scale processes involved in primary production in terms of easily and routinely measureable quantities. These results would be extremely useful in model development of mesoscale variations of near surface primary production. Eventually, this type of model would be imbedded in models of global variations of marine primary production.

Satellite estimation of global distributions of surface pigment concentration was one of the new, innovative techniques described at the Symposium. Further research is encouraged to learn about its representativeness of chlorophyll-a and its use as an indicator of primary productivity. It is anticipated that analysis of satellite ocean color measurements will determine the mean and fluctuating components of oceanic phytoplankton abundance and the empirical relationships between patterns of phytoplankton variability and physical oceanographic processes. Satellite observations of ocean color have the potential to revolutionize current dogma about global estimates of primary productivity, which have been assembled from instantaneous estimates made at isolated sites throughout the world over many decades.

Laboratory experiments of geophysical flows are a useful method to study coastal circulation processes, and may likewise be applicable to equatorial circulation, especially for descriptions of the current platform induced by different forcing regimes.

In summary, the Symposium recommendations are:

- Description of vertical motion with time and space scales less than 2 months and 1000 km with minimum amount of aliasing;

- Description of the carbon cycle in the near-equatorial region of the world oceans;

- Development of physical-biological-chemical model of mesoscale variations of near surface equatorial productivity;

- Improvement of interpretation of satellite observations of surface pigment concentration and primary productivity;

- Description of temporal variations of chlorophyll-a maximum and surface chlorophyll-a for time scale less than 2 months with a minimum amount of aliasing;

- Description of horizontal and vertical advective influences upon thermocline variations.

5. ACKNOWLEDGEMENTS

The Symposium was well organized, due in large part to Ms. Elizabeth Tidmarsh (SCOR) without whose contribution this work would have suffered.

This Report was prepared by Dr. David Halpern and Dr. Richard T. Barber, Convenor and Co-Convenor of the Symposium, respectively.

The co-sponsoring organizations wish to thank these, and the numerous other persons involved in the preparation of the Symposium, as well as the participants, for their generous contributions to the success of the Symposium.

ANNEX I

ABSTRACTS OF THE SCIENTIFIC PAPERS

Inference of Vertical Processes in the Equatorial Indian Ocean Using Satellite Data

by
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Vertical processes in the equatorial Indian Ocean, around the onset of the southwest monsoon, are said to be dominated by the vertical displacements of the thermocline associated with the jet-like response to the zonal wind-stress changes. Thus, a knowledge of the surface wind-stress distribution, particularly the zonal component along the equatorial belt, could help infer vertical motion.

Geosynchronous satellite low-cloud motion winds, with suitable collatoral data, could be approximately extended to the ocean surface to obtain this pattern. In this paper, such an attempt is made using MONEX-79 GOES winds; the expected nature of the resulting thermocline vertical displacements is verified qualitatively by using mixed-layer-depth estimates from research ships' TESAC data and TIROS-N Sea-Surface-Temperature (SST) fields.

A more complete experiment, involving INSAT, NOAA, Microwave satellites, in-situ data, numerical model runs and biological component is proposed, conveniently names as Equatorial Indian Ocean Experiment (EQUINOX), signifying transition season response.

Variations in Biological Productivity in the Eastern equatorial Pacific: The 1976 Dinoflagellate Bloom

by
Richard Barber

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Roberto Jimenez

Instituto Nacional de Pesca Guayaquil, ECUADOR

Changes in the physical dynamics of the surface layer can affect the productivity of the equatorial and coastal ecosystems even though upwelling does not cease. Increased stability in March 1976 was the initial condition that allowed the motile and phototactic but slow growing dinoflagellate, Gymnodinium splendens, to predominate in the euphotic layer along the coast of South America off Ecuador, Peru and northern Chile. This change in phytoplankton composition affected anchovy recruitment more severely than the 1972 El Niño.

Primary Production and Phytoplankton Biomass In the Equatorial Region of the Atlantic at 22 °West

by
Eduard Bauerfeind
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Biological and chemical measurements were carried out in the equatorial Atlantic at 22 °W, at ten sections between 3 °N and 2 °S, from February to June 1979. During this time two periods with low sea-surface timperatures, due to upwelling, were observed. One period in february, the other in June. An increase in chlorophyll concentrations was measured during these periods, whereas an increase in primary production was observed only during the upwelling event in June. Small organisms dominated the phytoplankton composition in numbers as well as in biomass. Primary production was also highest in the small fraction (<20 um). Primary production values as estimated from the input of new nutrients into the productive zone showed the importance of regenerated production during the times without upwelling.

Double Diffusive Heat and Salt Fluxes in the Northwestern Tropical Atlantic

by
Janice Dinegar Boyd and Henry Perkins
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Measurements in the northwest tropical Atlantic off the coast of of South America have revealed an extensive and apparently permanent region of well-developed thermohaline steps presumed caused by particularly vigorous salt finger activity. Estimates of vertical fluxes of heat and salt through the staircases are large enough to suggest that the process is playing a major role in vertical exchange across the thermocline.

Estimating Vertical velocity on the Equator

by
Esther C. Brady and Harry L. Bryden
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Woods Hole, MA 02543

The equatorial upwelling rate for the Central Pacific is estimated in four ways using mean CTD measurements assuming the following: (1) that the Equatorial Undercurrent core is a trajectory of flow, (2) that the flow is along isotherms, (3) that mass is conserved in the meridional-vertical plane, and (4) that mass is conserved three-dimensionally. It is remarkable that by using such simple and independent methods, all results agree so well, exhibiting an average vertical velocity at 90m of 1.9×10^{-3} cm s^{-1}, with a standard deviation of only 0.3×10^{-3} cm s^{-1}. The results reported here demonstrate the ease with which reliable estimates of vertical velocity may be obtained on the equator, which should be useful in studies of the effects of upwelling on productivity and chemical nutrient renewal in the equatorial surface layer.

Seasonal Heat Content Variations in the Northwestern Indian Ocean

by
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The changes of heat storage of the Somali Basin in the western Indian Ocean as shown from 55 detailed temperature sections along the western sea lane (tanker XBT program 1975-1979) are only partly accounted for by the net heat gain at the sea surface. Vertical and horizontal advection appear to be the cause of major changes both between and during the monsoons. During the southwest monsoon the large amount of heat stored in the 0-400m layer during northern spring (up to 31×10^8 Jm^{-2}) is redistributed with a heat loss of approximately 13×10^8 Jm^{-2} in the upper 0-100m layer and the gain of a similar amount in the 100-400m layer, caused to a large extent by the dynamic response of these layers to the monsoon wind stress. In late autumn this heat is then advected from the region.

Vertical Motions in the Central Equatorial Pacific

by
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of the USSR Academy of Sciences, Kaliningrad 236000, USSR

Using the long term current observations from 10 moorings in the Central Pacific (1°30' N - 1°30' S, 163°15' W - 167° W) in February-March 1980 estimations of vertical velocities are made from the continuity equation and on the basis of box model. Vertical motion in the upper 300-m layer is directed upwards, and its velocity ranges from 1.0 to 8.0 x 10^{-3} cm/sec^{-1}.

Numerical Study of Vertical Motion in Tropical Oceans Induced by Atmospheric Mesoscale Vortices

by
Simon W. Chang
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A nonlinear primitive equation, hydrostatic ocean model with a rigid bottom and a free surface is constructed to study the ocean's barotropic and baroclinic response to wind stress of tropical cyclones.

With an axisymmetric, stationary wind stress, induced mixing and upwelling create deep ocean circulations. The divergence in the upper ocean is compensated by an inflow which extends from the thermocline to the ocean floor at 2000 m. Upwelling, with a maximum of 0.1 cm/s at 50-75 m near the center, and downwelling at large radii also extend to the ocean bottom.

Moving tropical cyclones leave the ocean with a barotropic trough and a baroclinic ridge in the wake. The vertical motion field in the wake is wave-like with typical half-wavelength of 300 km. The vertical motion is the strongest at the depth 80-150 m, but still considerable at 500-700 m below the surface. In the x-z plane the vertical motion field has a phase shift that the vertical motion below the depth of 1000 m is out of phase with that above 500 m.

These numerical simulations suggest that tropical cyclones can induce ocean vertical motion at greater depths than previously believed. This may have significant biological and chemical implications.

Ocean Variability and Phytoplankton Community Structure: Onset of The 1982-83 El Nino in the Peruvian Upwelling Region

by
Francisco P. Chavez
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Beaufort, NC 28516 USA

A time series of phytoplankton species abundances, based on triweekly sampling at a coastal station off Paita, Peru (5°S) between June 1982 and January 1983, is compared to parallel series of physical (temperature, salinity, wind, sea level) and chemical (primary nutrients and chlorophyll) parameters to investigate the processes structuring phytoplankton communities in the Peruvian upwelling region. Onset of El Nino in September 1982 reduced all the major phytoplankton groups, but this reduction was temporary and high levels of phytoplankton are maintained in a narrow coastal zone in the face of El Nino.

On the Distribution of Anthropogenic CO_2 in the Equatorial Atlantic And Pacific Oceans

by
Chen-Tung Arthur Chen
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National Sun Yat-sen University
Kaohsiung, Taiwan Republic of China

The lower boundary of anthropogenic CO_2 penetration is shown for the equatorial regions in the Atlantic and Pacific Oceans based on carbonate data in the literature. The results indicate that the excess CO_2 has penetrated to roughly 1200 m in the equatorial Atlantic Ocean but to only 400 m in the equatorial Pacific Ocean during the past 130 years.

Small Pelagics Abundance and Upwelling in Ivory Coast

by
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A model using fishing effort and a measure of upwelling intensity is proposed to analyze fluctuations of aboundance of Ivory Coast coastal pelagic species.

It is shown that fishing effort alone is not able to explain observed variations of abundance. The model fits much better when integrating a measure of the upwelling intensity, not only for the time of catches but also for the year before, so as to take into account reproduction and recruitment. Using annual upwelling index at year i and i-1 and fishing effort, the model explains 75% of the variance of the abundance index.

Adjustment to Wind Forcing in the Western Equatorial Pacific

by
Jean-René Donguy and Jean-Paul Rebert
Groupe SURTROPAC, Centre ORSTOM de Nouméa
B.P. A5 - NOUMEA - Nouvelle Calédonie

In the Western Equatorial Pacific, the effects of the prevailing winds are due to the baroclinic adjustment induced by the changes of sea level. When easterlies blow, isotherms deepen; when westerlies blow, isotherms lift up. The effects of the wind bursts are different. With easterly wind, upwelling and spreading of the 15°-25°C isotherms occur. With westerly wind, downwelling and pinching of the 20°-25°C isotherms are observed. Each thermal pattern is associated with a current pattern.

Changes in Nutrients, PH, Light Penetration and Heat Budget Due to Vertical Movements of Photosynthetic Organisms in Peru Coastal Waters

by

R. C. Dugdale[1], F. P. Wilkerson[1], R. T. Barber[2], D. Blasco[3], T. T. Packard[3].

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The impact of red tide organisms; Gymnodinium splendens in 1976 and Mesodinium rubrum in 1977, on the oceanography of Peru coastal waters is described. In the upper 1m of the ocean they control up to 99% of the absorption and transport of incoming radiation. The key role of these vertically migrating organisms in heat transport in eastern boundary systems is revealed.

Estimating Ocean Production from Satellite-derived Chlorophyll: Insights Eastropac Data Set

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The EASTROPAC expedition took place in 1967-68 in the eastern tropical Pacific Ocean. Primary production was related to near-surface chlorophyll in these data. Much of the variability in the relation was due to the light-history of the phytoplankton and its photoadaptive state. This was due to changes in the depth of mixing of the surface waters more than changes in insolation. Accurate estimates of production from satellite chlorophyll measurements may require knowledge of the temporal and spatial variation in mixing of this region.

Variability of the Productive Habitat in the Eastern Equatorial Pacific

by
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Satellite ocean color data was used to assess the area of enhanced biological production in the Eastern Equatorial Pacific. The mean pigment concentration (an index of phytoplankton biomass) for the entire region increased by a factor of 3.5 from late 1978 to late 1979. The area of the productive habitat (defined as the region in which satellite derived pigment concentrations exceeded 1.0 mg/m3) increased 14-fold ober the same period and covered nearly 0.5 x 10^5 km^2. The 1982-83 El Niño reduced the size of the productive habitat and the levels of primary production when compared with the Dec 79-Jan 80 period, but surprisingly showed higher values of both parameters when compared with the Dec 78 - Jan 79 ½eriod. Although significant mesoscale variability was observed over short time scales (daily to weekly), monthly composites retained the major mesoscale structures and dominant features of the region and were found to be the best means for quantifying the large-scale interannual variability.

Upwelling in the Equatorial Pacific Using Tritium Data

by
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Tritium data collected over ten years in the tropical Pacific are used to show that equatorward penetration of higher latitude thermocline water is the source for the equatorial upwelling in the Pacific Ocean. Observations of subsurface tritium maxima from the dateline to 125W show that the entire thermocline down to 16C participates in the equatorward geostrophic convergence. A combination of convergence and advection manifests itself on the equator both as a subserface maximum between 145 and 125W showing that region has received the greatest input of high latitude water; and as a surface maximum on and north of the equator. The high surface tritium is roughly coincident with the cold tongue suggesting the importance of geostrophic convergence in feeding the upwelling, which is shown to occur at temperatures above 16C. Ekman divergence at the equator fed by upwelling and southward recirculation of the major eastward flowing zonal currents in the eastern Pacific have resulted in a small cross equatorial flux of northern hemisphere tritium.

Biomass and Composition of Zooplankton and Ichthyoplankton in the Upwelling System of the Galápagos Islands

by
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Collections of zooplankton were obtained from oblique tows, taken during various oceanographic research cruises designed to study the ocean variability and productivity in the equatorial waters of the Eastern Pacific around Galapagos Islands. The cruises were carried out on March, November, December, 1983 and April, 1984.

This work describes the patterns of distribution of total zooplankton biomass and abundance in numbers of the following groups: Copepoda, Ostracoda, Euphausiacea, Pteropoda, Chaetognatha, Thaliacea, Larvacea, and Fish Eggs and Larvae, and the abundance of fish eggs and larvae of the families Bathylagidae, Gonostomatidae, Myctophidae and Clupeidae.

Zooplankton biomass was lower (<100 ml/1000 m^3) during March 1983, when the event of "El Niño" occurred at this region.

During periods of post "El Niño" the zooplankton and Ichthyoplankton groups were related to advective processes caused by the upwelling of the equatorial undercurrent or with the frontal zones between the Surface Tropical and Subtropical Waters Masses.

In November 1983, when more stations were surveyed within the Island system, it was evident that the greatest abundances of fish eggs were located eastward from the main upwelling area, but in the same equatorial band bounded by the 0°00' and 1°00' of Latitude south.

Higher densities of sardine larvae, Sardine sagax sagax, (365-1400 larvae per standard haul) were recorded for the same month, compared with those that have been reported Ahlstrom during February-March, 1967.

Chemical Characteristics and Productivity off Peru During El Niño 1982-83

by
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The 1982-83 El Niño presented and characteristics affects with great differences respect to previous events. During the summer and early autumn of 1983 a weak coastal upwelling was present in a coastal band near to shore, particulary off Pimentel and Chimbote; but the upwelled waters were warm and poor in nutrients and consequently there was a declay in phytoplankton production, and negative effects in the

zooplankton, fishes, et; the exception was a relative high concentration of chlorophyll "a" at the coastal band. The highly productive condition had returned by July 1983. The unsual case was the higher defficiency in nitrates than in silicates, mainly due to a predominance in dinoflagellates. Comparisions are made of 1982-83 El Niño with 1972-73 event, as well with normal and cold periods; it is fininished with a discussion of its effects on the upwelling and the fertility of the coastal waters.

Eddy-like Features with Trapped Sacw Northwest off cape Verde Islands

by
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Examples are presented for eddy-like features in the region northwest offf Cape Verde Islands. These events were observed in the layer between 100 m and 300 m where a strong correspondence between the local level of potential energy and the percentage of trapped South Atlantic Central Water was established. The local potential "eddy-energy" was higher by a factor of two up to a factor of four than the mean values which were presented by Danzler (1977) for the investigation area and moreover, values of the same order as in the Gulf stream region were locally estimated. We conclude the baroclinic instability is mainly the energy source of such eddy-like phenomena within intermediate layers off cape Verde Islands.

On the Zonal Distribution of Sacw off Cape Blanc-Northwest Africa

by
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The hypothesis of isopycnal mixing is used in order to calculate the percentages of South Atlantic Central Water (SACW) with respect to North Atlantic Central Water (NACW) what surrounding it in the intermediate layer between density surfaces of 6_t = 26.5/27.2 along a zonal section at 20°10' N. Here, the SACW distribution was "conserved" within an offshore distance of about 370 km from the shore during two observation periods with a time lag of 10 months. The zonal SACW structure corresponds well to the zonal energy distribution of geostrophic meridional flow within this layer.

It is concluded the intermediate geostrophic meridional motions are adjusted to the local shelf profile H(x). Caused by this, a nearslope zone is formed by the condition $(f/H)\ (dH/dx)/B > 1$ where the "freezing" of the inner zonal structures was observed.

Vertical Motion in the Eastern Equatorial Pacific Inferred from Drifting Buoys

by
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Surface current measurements have been obtained from the eastern tropical Pacific Ocean by means of drifting buoys tracked by the NIMBUS and ARGOS satellite systems since 1977. Upwelling velocity and transport were estimated from the horizontal divergence of surface current fields obtained by optimum interpolation of overall and monthly composite data. Average upwelling velocity and transport in the region 1.5°N-1.5°S, 80°W-130°W are estimated to be 1.5 m da^{-1} and 32 x 10^6 m^3 s^{-1}.

Permanence of an Eastward Surface Flow Near 2-3°S In the Equatorial Atlantic Ocean

by
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Direct current measurements made during the nine cruises of the FOCAL program evidence an eastward surface flow located near 2-3°S in the central and eastern Atlantic Ocean. It is related with a southward rise of the thermocline and agrees well with geostrophy. It is linked with the Equatorial Undercurrent but generally the two flows are distinct except during February 1984 when a general eastward drift occurred in the equatorial area.

Similar eastward flows were already observed in the equatorial Atlantic Ocean during GATE (Bubnov, 1980) and CIPREA (Voituriez, 1983) experiment and in the eastern equatorial Pacific Ocean (Leetmaa, 1982). Historical ship drifts also suggest such an eastward surface flow which seems to be a characteristic feature of the equatorial current system.

Size structure of Phytoplankton and Nutrient Enrichment in the Equatorial Atlantic Ocean

by
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A study of the size structure of chlorophyll a (Chla) covering the major part of the equatorial Atlantic ocean from 5°N to 5°S leads to the conclusion that the seasonal nutrient enrichment in the open eastern equatorial Atlantic does not drastically affect the size distribution of the primary producers. 90% of the total Chla are everywhere contained in the <10 um fraction on the average.

These new results confirm the previous suggestion that the structure of the food web would not change with the seasonal and geographical variations in oceanic regimes. Therefore, from an ecological point of view, the term "upwelling" is misleading and the open equatorial (and probably tropical) Atlantic ocean can be considered as a unique ecosystem.

Zonal Pressure Gradient Variabiltiy along the Equatorial Atlantic From October 1982 to August 1984

by
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Seven equatorial sections, overlapping the equatorial Atlantic (35°W, 28°W, 23°W, 4°W, 1°E and 6°30'E), were occupied during eight surveys, from October 1982 to August 1984, on a three-month basis, as part of the FOCAL experiment. The CTD and Current-profiler data sets (from 0 to 500 m depth) allow us to address the question of the seasonal variations of the Zonal Pressure Gradient (ZPG) along the equator and that one of the related field of currents, giving to us also some elements about interannual variability.

A Theory of Wind-Driven Equatorial Upwelling and Undercurrent

by
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A 3-D, 2-layer model with vertical and lateral diffusion taken into account is proposed to describe the upwelling and undercurrent which take place in the equatorial oceans driven by trade winds.

Analytical solution for the model has been obtained. The results calculated show some main features analogous to those observed in the equatorial ocens, such as the following.

(1) The surface layer water is piled up in the western part of the equatorial ocean, which results in sea surface tilting up from the east to the west.

(2) The pycnocline in the equatorial ocean tends to get much shallower when it goes eastward.

(3) A westward current is formed in the uppermost layer and a jet-like eastward undercurrent lies in the pycnocline.

(4) Upwelling occurs along the equator, much stronger in the east in concert with the pycnocline shallowing eastward.

The Association of Mesodinium Rubrum Blooms with the Upwelling area Off Ecuador

by
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During January 1984, some upwelling water was found in the euphotic zone along the coast of Ecuador from 1°20'S to 2°30'S.

This water was characterized by a relative low surface temperature of 23°C and the presence of Mesodinium rubrum. The concentration of chlorophyll a was between 0.50 and 1.37 ugél. The levels of phosphate, nitrate, ammonia and silicate fluctuated between 0.03 to 0.35 ug-atél PO_4-Pél, 0.6 to 3.5 ug-at NO_3-Nél, 1.0 to 6.0 ug-at NH_4-Nél, and 4.0 to 10.3 ug-at SiO_4-Siél respectively.

In February-March of the same year a large scale "red tide" bloom of M. rubrum had developed, with dense patches, covering an area of one hundred miles, though the organism was spread over more than two hundred miles along the coast. The maximum number of cells within the patches was 7.6×10^6 cells/l, and outside of them 100×10^3 cells/l. The sea surface temperature was 26°C. The concentration of chlorophyll a varied between 0.5 and 140 ug/l. The nutrient content was almost similar to the previous month. It was also found large concentration of small Gymnodinium sp., diatoms and dinoflagellates being the maximum of 900×100^3 cells/l, 700×100^3 cells/l and 950×100^3 cells/l, respectively. Microflagellates were an important component of the phytoplankton community, in concentration of 100×100^3 cells/s, respectively. Microflagellates were an important component of the phytoplan ton community in concentration of 100×100^3 cells/l extending along the coast from 0° to 3°20'S.

A distribution and abundance of the phytoplankton species composition was recorded in January and February-March, 1984.

Linkage of Mudbank (Chakara) and Upwelling Off the Southwest Coast of India

by
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Coastal upwelling off south-west coast of India and the mudbank formation at few coastal locations at southern tip of India take place during the southwest monsoon season. As the mudbank formation is present only in this part of the world and it is associated with high fishery potentiality, a study of the possible interlink of the geographical distribution and fluctuations in the life span of mudbanks with the upwelling activity is conducted using historical evidences of these two processes. Though the studies revealed no concrete relationships between these two natural processes, the result hints towards some relationship between these two processes and the present result can be taken as a first step in this line.

Phytoplankton and Thermal Structure in the Tropical Ocean

by
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Variation in the absorption of solar irradiance in the upper ocean is strongly influenced by variation in the concentration of phytoplankton. In optically clear tropical regions, where the climatological mixed layer depth is shallow relative to the depth of significant penetration of irradiance ($\lambda \leq 700$mm) all year, such variation is particularly important for upper ocean thermal structure and dynamics. The nonuniformities in vertical chlorophyll distribution associated with "Typical Tropical Structure" can give rise to local heating rates that increase with depth; the vertical motions that may result are discussed. The penetration of irradiance through the mixed layer is a downward energy flux which is shown to be of the same order as that thought to be transported vertically by turbulent fluid motions. Variability in sea-surface chlorophyll in time and horizontally will result in variation in the vertical radiative energy flux out of the base of the upper mixed layer; it is suggested that this variability may be important for tropical and global heat budgets.

A Time-Dependent Model of Coastal Upwelling

by
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A 2-D time-dependent upwelling model in a coastal ocean with inclined bottom slope, driven by wind is proposed with vertical and horizontal viscous terms, and sea surface topography taken into consideration. For certain inclined bottom slopes in order of magnitude of thousandths, analytical solutions have been gained, making use of Laplace transform and Green function method. Usually observed and generally recognized vertical circulation pattern in a cross-shore section can be well simulated by the solution obtained in the present paper.

Experiments and Observations on the Effects of Bottom Topography on Coastal Upwelling

by
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We present new experimental data on the effects of bottom topography on stress-driven, coastal upwelling. These results are then compared to a number of examples revealed by satellite or field observations. It appears that the experiments may be useful in determining the characteristics of actual upwelling phenomena.

Modelling of the Equatorial Mixed Layer

by
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The three-deimensional structure of the equatorial mixed layer is modelled by a bulk mixed layer model that describes the penetration of turbulence generated by local atmospheric forcing and other processes. The model is driven by the surface wind stress and heat flux and by upwelling and horizontal advention. The model includes a previously overlooked interaction between planetary rotation and the zonal wind stress which makes the mixed layer dynamics dependent on the wind direction. Steady state results describe well the observed zonal and meridional structure of the equilibrium mixed layer in the equatorial Pacific. The rotation-stress interaction is crucial for explaining the zonal structure with deep mixed layers in the central and western equatorial Pacific. Upwelling is crucial for explaining the meridional structure.

Forced Annual Response in the Equatorial Pacific Ocean

by
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el Nino events appear to be an amplification of the seasonal cycle in the Pacific Ocean, particularly in the eastern Pacific. The response of the equatorial Pacific to the annual component of the zonal wind stress field is examined using a linear forced periodic model. Responses to annual forcing are compared to sea level, velocity components and temperature (vertical displacement), where available.

Physical Control of Equatorial Productivity

by
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Measurements of productivity and nutrient concentration in the equatorial region at 110° W show variable productivity but consistently high nutrient levels. The relatively high productivity is associated with a diatom rich collection. During the times of low productivity, the diatoms are absent and microdiagellates are dominant. We examine the role of mixing and upwelling in population growth with a one-dimensional model. The vertical eddy coefficent is estimated from velocity microstructure measurements. The result indicate that the change in species composition to the lower productivity is due to a substantial decrease in both the upwelling and the mixing. The changed environment probably is associated with a weakening of the trace winds and a surfacing of the undercurrent.

The Distribution of Nutrients in Equatorial Atlantic: Vertical Motion, Vertical Turbulent Mixing and Zonal Advection

by
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In the Gulf of Guinea (4°W), the equatorial upwelling, generated by the divergence of surface current meridional components, appears only in northern summer (June to September) south of the equator and exhibits a respectable enrichment in nitrate and phosphate at the sea surface. But at the equator properly so-called, the surface layer is enriched also in nutrients by the vertical mixing by vertical shear between the Equatorial Undercurrent and the surface Equatorial Current. The zonal advection from the African coastal zone, put forward to explain the equatorial fertility, does not agree with the observed surface distributions of nitrate.

In the western equatorial Atlantic (35°W), the seasonal surface nutrient enrichment does not appear in July and the surface layer seems to stay impoverished in nutrients throughout the year. There the thermocline is deeper and the upwelling does not seem sufficiently strong to bring up the nutrients to the lighted surface layer: then the activity of the primary biological producers is reduced. The deepening of the thermocline occurs between 22 and 24°W.

Carbon and Oxygen Fluxes in the Open Ocean

by
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Some of the problems associated with quantifying the biogenic fluxes of oxygen and carbon in the open ocean are reviewed.

Seasonal Variation of Potential Energy Indices Along the Southwest Coast of India

by
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The orientation of the coastline and prevailing wind system coupled with the surface circulation are favourable for upwelling along the southwest coast of India during southwest monsoon season. The changes in the potential energies from month to month during upwelling season are calculated for five sections along southwest coast of India. The potential energy indices show a slight decrease from March to April. They show a marked steepness from May to June for all sections, except the southern most one, indicating that even though upwelling starts as early as March in deeper layers, the maximum changes take place from May to June. From June onwards the indices do not show much variation. Double maxima of the indices along 10^0N and $8^0$50'N is noticed. The change in the PE indices from April to May itself along 8^o10'N indicates early commencement of upwelling on the southern side. Based on the gaps in the earlier studies along the west coast of India, some suggestions for future studies are made.

Effects of El Nino on the Phytoplankton of the Eastern Tropical Pacific

by
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The eastern tropical Pacific is among the most productive regions in the world oceans, however, periodically this high productivity is disrupted during El Nino Southern Oscillation episodes. The high productivity results from high rates of phytoplankton photosynthesis due to upwelling of primary plant nutrients into the euphotic zone. During El Nino there are dramatic changes in the physical, chemical and biological conditions in the eastern tropical Pacific and results from cruises in March 1983 during the peak of the event and April 1984 when conditions had returned to normal, allow us to describe these changes. Time series observations from a coastal station and sampling operations before and during El Nino provide additional information on the changes which occur in the phytoplankton of the eastern tropical Pacific during these climatic episodes.

A Non-Linear System of Ocean-Atmosphere Coupling

by
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The object of this paper is to study the relationahip of El Nino/ Southern Oscillation (ENSO) and monthly mean circulation at 500 mb over Northern Hemisphere. Besides the utilizing the spectral analysis methods, a non-linear model--threshold auto-regressive model (TAR) in discrete time is used. The essential idea underlying the class of TAR is the piece-wise linearization of non-linear models over the state space by the introduction of the thresholds. These models are locally linear.

TAR model for real data to analyse ocean-atmosphere interaction. The results are interesting.

The Influence of Vertical Displacements on Biological Processes in Tropical Upwelling Systems

by
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The mechanisms by which biological processes are regulated in physically dynamic environments have only recently begun to be elucidated. Regulation operates on different scales, from the small scale (e.g., patch formation) to the large scale (e.g., migration of fishes over basin-wide areas). Phytoplankton communities in upwelling regions are not only influenced by chemical and biological interactions, but are dramatically impacted by a three-dimensional advective regime. The "success" of a populations, as defined by its growth and persistence through time, is often primarily controlled by the combined effects of particle sinking and its interaction with the physical field. Examples are from a coastal upwelling system will be used to illustrate the interaction, and the possible operation of this interrelationship during ENSO events will be discussed.

The Seasonal Heat Content in the Eastern Tropical Atlantic

by
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The upper ocean heat content and sea level seasonal changes in the eastern tropical Atlantic do not depend only upon the vertical displacements of the shallow tropical thermocline and changes in temperature and thickness of the tropical surface waters. These seasonal changes depend also heavily upon the changes in thickness of the South Atlantic central waters, advected to the east into the Gulf of Guinea through the three equatorial countercurrents, and polewards from the equator along the African shelf edge through the coastal countercurrents. The seasonal vertical expansion of the south Atlantic central waters is particularly studied off Abidjan; heat contents in the tropical surface waters and the south Atlantic central waters are compared: Heat gain and loss between these two water masses seem to be in balance.

Large-Scale Aspects of Equatorial Upwelling

by
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Equatorial upwelling is an oceanographic feature of large scale and consequently has a pronounced influence on ocean circulation and ocean-atmosphere interation. Our knowledge of its mechanism, its mass and heat balance will be critically reviewed. The contributions of advection and of the equatorial undercurrent to these balances will be discussed. Differences of equatorial upwelling in the eastern, central, and western Pacific will be outlined. The time dependence of equatorial upwelling is still insufficiently known, except on the annual and interannual time scale. Is equatorial upwelling spotty and intermittent?

The consequences of equatorial upwelling are most pronounced in its interaction with the atmosphere, leading to an asymmetry of atmospheric and oceanic circulation.

Cross-equatorial heat transport is critically linked to equatorial upwelling, and is consequently dependent on the fluctuations of the wind field. There are many remaining unresolved problems about equatorial upwelling.

The Diagnostic Calculation of Equatorial Flows in the Eastern Part of the Western Pacific Ocean

by
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On the basis of observational data of the eastern part of the western Pacific Ocean between 160°E and 165°E in the west-east direction and from 0° to 5°N in the north-south direction (R/V Xiang Hong 09, January 3-March 4, and April 22-May 26, 1979), the diagnostic calculation of equatorial flow for this region are performed by using our model equations and computing scheme and methods. The diagnostic model reflects the following important features: 1) An important driving force for the Cromwell Current is the pressure gradient. 2) The nonlinear terms are essential in the dynamics of equatorial flows, thus they must be considered. 3) If the coefficient of vertical eddy viscosity Az = const., A_2 must be equal or less than 10^8 cm^2/sec, then the orders of magnitude of the nonlinear terms are greater than orders of magnitude of the horizontal eddy viscosity terms. In such a case, the numerical solution depends weakly on the boundary conditions. We suggest that $A_2 = 5 \times 10^7$ cm^2/sec may be better.

For the first cruise (January 3 - March 4 1979), the calculated results show: 1) The primary driving force of the equatorial surface flows is the prevailing northeasterly wind field, an average uniform wind speed Vw = 6.3 m/sec. The steady westward wind produces the divergent westward flows in the surface layers which cause upwelling near the equator. The importance of the steady wind stress in the upper layer (120m) decreases with depth and it becomes unimportant at the level of Z = 75 m or Z = 100 m. 2) The equatorial undercurrent is a strong eastward and equatorward flow; the eastward component of the undercurrent is larger than its meridional component. The core of the undercurrent is in the thermocline and the maximum velocity of the undercurrent is 88-90 cm/sec at the level of Z □ 200 m. The core of the undercurrent shifts northward, because the wind with a southward component causes the northward displacement of the core of the undercurrent. We discuss briefly the deeper flows in this region. Finally, we empasize that the dolution of equatorial flows at each level will depend strongly on the density field, thus the density field, especially the density fieldin the deep layer, must be sufficiently exact.

ANNEX II

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ANNEX III

LIST OF ACRONYMS

ENSO	El Niño Southern Oscillation.
EQUINOX	Equatorial Indian Ocean Experiment.
GOFS	International Global Ocean Flux Studies.
IOC	Intergovernmental Oceanographic Commission.
ISRO	Space Applications Centre.
NACW	North Atlantic Central Water.
OCE	UNESCO'S Division of Marine Sciences.
SACW	South Atlantic Central Water.
SCOR	Scientific Committee on Oceanic Research.
UNESCO	United Nations Educational, Scientific and Cultural Organization.

No.	Title	Publishing Body	Languages
32 Suppl.	Papers submitted to the UNU/IOC/Unesco Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime Paris, 27 September-1 October 1982	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR) Halifax, 26-30 September 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa) Tenerife 12-17 December 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific Suva, Fiji, 3-7 October 1983	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
36	IOC/FAO Workshop on the Improved Uses of Research Vessels Lisbon, 28 May - 2 June 1984	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
36 Suppl.	Papers submitted to the IOC-FAO Workshop on Inproved Uses of Research Vessels Lisbon, 28 May-2 June 1984	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
37	IOC/Unesco Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs Colombo, 8-13 July 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
37 Suppl.	Papers submitted to the IOC/Unesco Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs Colombo, 8-13 July 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region Basrah, Iraq, 8-12 January 1984	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
39	CCOP (SOPAC)-IOC-IFREMER-ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific Suva, Fiji, 24-29 September 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
40	IOC Workshop on the Technical Aspects of Tsunami Analyses, Prediction and Communications Sidney, B.C., Canada, 29-31 July 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
40 Suppl.	Submitted papers to the First International Workshop on Tsunami Analyses, Prediction and Communications Sidney, B.C., Canada, 29 July - 1 August 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2) Dakar, Senegal, 28 October - 1 November 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
42	IOC/UNEP Intercalibration Workshop on Dissolved/Dispersed Hydrocarbons in Seawater Bermuda, USA, 3-14 December 1984 (in press)	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean Venice, Italy, 23-25 October 1985	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
44	IOC/FAO Workshop on Recruitment in Tropical Coastal Demersal Communities Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
44 Suppl.	IOC/FAO Workshop on Recruitment in Tropical Coastal Demersal Communities - *Submitted Papers* Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
45	IOCARIBE Workshop on Physical Oceanography and Climate Cartagena, Colombia, 19-22 August 1986	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
46	Reunión de Trabajo para Desarroilo del Programa «Ciencia Oceanica en Relación a los Recursos No vivos en la Región del Atlantico Sudoccidental Porto Alegre, Brazil 7-11 de Abril de 1986 (in press)	IOC, Unesco Place de Fontenoy 75700 Paris, France	Spanish
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence Townsville, 1-6 December 1986 (in press)	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on "Ocean Science in Relation to Non-Living Resources (OSNLR)"	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on "El Niño" Guyaquil, Ecuador, 27-31 October 1986	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
50	CCAMLR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR) Paris, France, 2-6 June 1987	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations, Lae, Papua-New Guinea, 1-8 October 1987	IOC, Unesco Place de Fontenoy 75700 Paris, France	English