The Influence of Sea-Surface Temperature on Surface Wind in the Equatorial Pacific Ocean

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Recent studies suggest that sea surface temperature gradients in the tropics can directly modify surface winds by perturbing the atmospheric sea level pressure field (Lindzen and Nigam, 1987) or by modifying the boundary layer shear profile (Wallace et al., 1989). The latter reference used historical ship data to analyze the seasonal and interannual variability in the eastern Pacific. In this region strong seasonal changes occur and SST gradients are large. During the cold season (July through November) the equatorial cold tongue is well developed and SST cooler than 25°C extends westward to 130°W. Temperature changes of 3°-4°C occur across the equatorial front at the northern edge of the cold tongue. During the warm season (March through June) surface temperatures colder than 25°C are confined to the coast of South America and the equatorial front is weak or non-existent. During El Nino years, SST in the cold tongue is elevated throughout the year; the equatorial front nearly disappears.

Surface winds vary in concert with the changes in the SST distribution in the eastern Pacific. The mean southeasterly winds are strongest during the cold season. As this southerly flow crosses the equatorial front it accelerates, leading to a pronounced horizontal divergence. During the cold season of the colder (i.e. non El Nino) years, when the equatorial cold tongue and the oceanic front are most developed, the southerly surface wind on the equator is anomalously weak, but northerly wind near 5°N is anomalously strong. Hence, the divergence over the equatorial front is enhanced relative to the climatological mean.

Wallace et al., (1989) interpret these correlations in the eastern Pacific as evidence that at least two processes are important in the dynamics of the surface wind field near the equator. The seasonal and interannual variability of the surface wind field is due, in part, to hydrostatic sea-level pressure changes induced by changes in the strength of the associated cold tongue. Such a direct coupling between SST and sea-level pressure anomalies was discussed by Lindzen and Nigam (1987). However, Wallace et al., 1989) note that the sea-level pressure and the surface wind speed are not linearly related to each other or to the underlying SST gradient. They suggest that atmospheric boundary layer dynamics contribute to this discrepancy. As boundary layer flow passes from the cold tongue to the warmer water north of the equatorial front, the

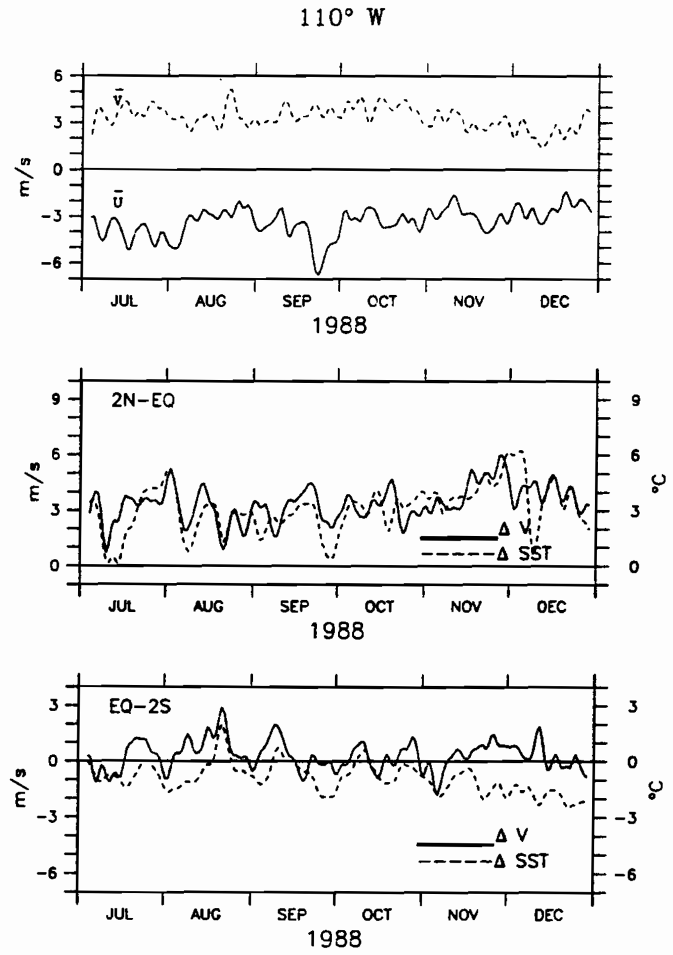

FIG.1. Low-pass filtered near equatorial wind and SST time series along 110°W during the period July through December 1988. Top panel: spatially averaged wind components (U and V) estimated from the measurements at 2°N, 0°, and 2°S. Middle panel: the difference in meridional wind (solid) and SST (dashed) between 2°N and the equator. Bottom panel: the difference in meridional wind (solid) and SST (dashed) between the equator and 2°S.

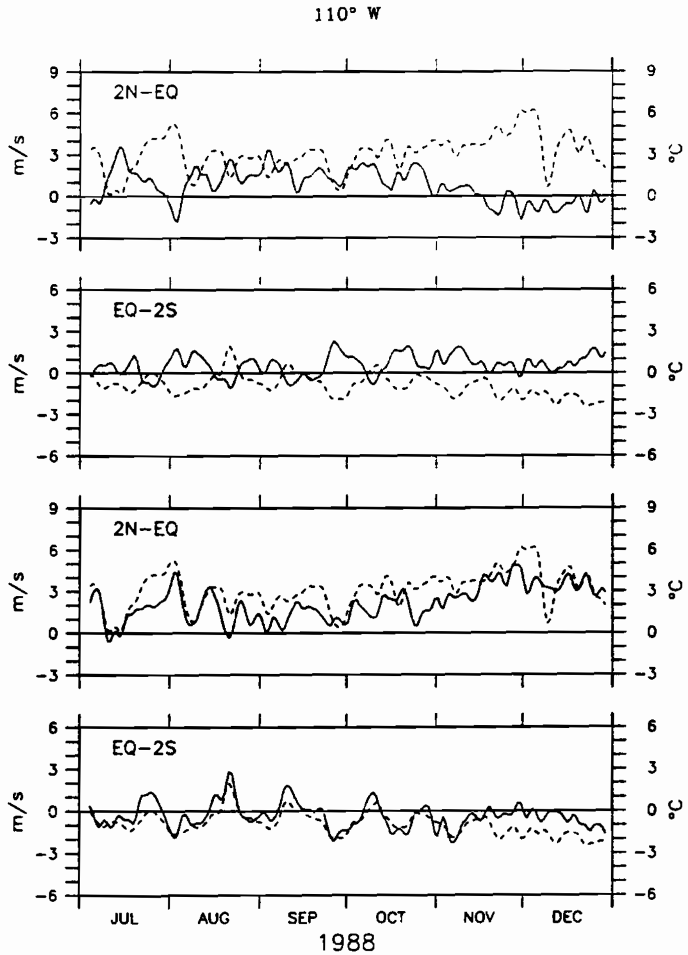

FIG.2. Low-pass filtered near equatorial wind and SST time series along 110°W during the period July through December 1988. Top two panels are the differences in zonal wind (solid) and SST (dashed) between 2°N and the equator and between the equator and 2°S; bottom two panels are the differences in scalar wind speed (solid) and SST (dashed) over the same latitudes.

vertical stratification decreases. Wind shear near the surface is reduced and hence, surface wind speeds increase. This increase is associated with the turbulent transfer of momentum from a low level jet to the surface during unstable boundary layer conditions.

The correlations of SST and surface wind observed in the seasonal and interannual changes can also be seen in the weekly to monthly variability using buoy measurements (Hayes et al., 1989). Figure 1 shows the average wind from buoy measurements along 110°W at 2°N, 0° and 2°S for the cold season of 1988 (July through December). During this season the southeast trades were persistent; equatorial SST was anomalously cold, and the equatorial front was well developed. Tropical instability waves, caused by instabilities of the zonal currents near the equator, were pronounced in the SST field. These waves have periods of about 20 days and contribute much of the SST variability in the week to month time period. Their properties are reviewed by Legeckis (1986) and Halpern et al., (1988). Since these waves are a feature of the ocean dynamics and are not directly wind forced, they are a convenient probe for examining the influence of the ocean on the atmosphere. Evidence of the instability waves can be seen in the differences of SST between 2°N and the equator and between the equator and 2°S (figure 1). North of the equator this difference is about 3°C on average and varies from 0° to 6°C. South of the equator the mean SST gradient is near zero but differences of more than 2°C are observed. These fluctuations of SST gradient are clearly correlated with changes in the meridional wind gradient shown by the solid lines in figure 1. Wind gradients rather than the wind itself are used in this analysis as a means of isolating the smaller spatial scale features of the wind field. Both north and south of the equator the meridional wind and SST gradients are significantly correlated ($R = 0.6$) at the 95% confidence level. Zonal wind gradients were also correlated with SST gradients during this period (fig.2, upper panels). In this case correlations were negative ($R = -0.66$ from 2°N to the equator and $R = -0.73$ from the equator to 2°S). The sign of the correlations indicates that the southeast tradewinds at the surface are stronger over the warm water. Indeed, the best correlations observed were between meridional gradients of wind speed and SST (fig.2, lower panels). The correlation coefficients are 0.75 north and 0.83 south of the equator. Fluctuations of the wind speed associated with the passage of instability waves were 1-2 m s^{-1}.

The high correlation between wind speed and SST gradient suggests that boundary layer stability is a key factor in causing the fluctuations in surface wind. If so, then one expects that the surface wind speed will correlate with the difference between air and sea surface temperature. In order to investigate this correlation the wind records at each buoy were demeaned by removing the spatially averaged wind between 2°N and 2°S. This subtraction again tended to remove the large scale wind variability and focused on the small scale changes. Figure 3 shows the demeaned wind speed at 2°S plotted as a function of air-sea temperature difference. The correlation is significant ($R = 0.7$) and the highest wind speeds are associated with SST warmer than air temperature. These results support the hypothesis that modification of the boundary layer stratification plays a key role in determining surface winds in the eastern Pacific.

The clear correlation between SST and surface wind gradients may only be a feature of the eastern equatorial Pacific where the southerly winds are strong and blow across the strong SST front. In the central Pacific surface winds are more nearly zonal and the strength of the equatorial front is reduced. West of the dateline surface winds are more variable and SST gradients are very weak. Correlations in these regimes were briefly examined using buoy measurements at 140°W and 165°E. At the former location significant correlation between surface wind speed and SST gradients were again observed (fig.4); however correlations between wind speed and air-sea temperature

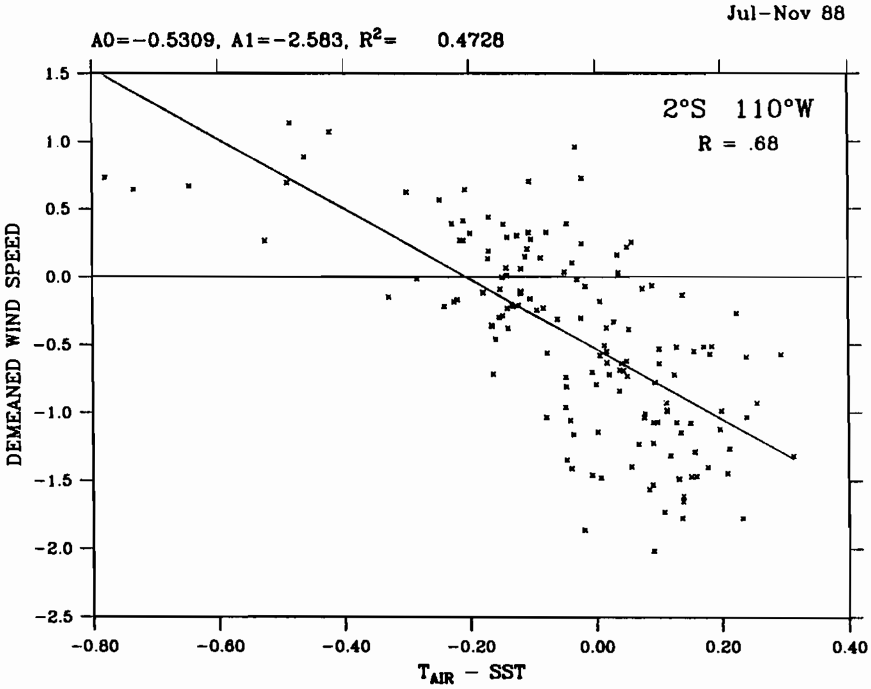

FIG.3. Scatter plot of demeaned wind speed versus air-sea temperature difference for 2°S, 110°W. Period of the observations is the same as figure 2. Regression line is least squares fit to the observations.

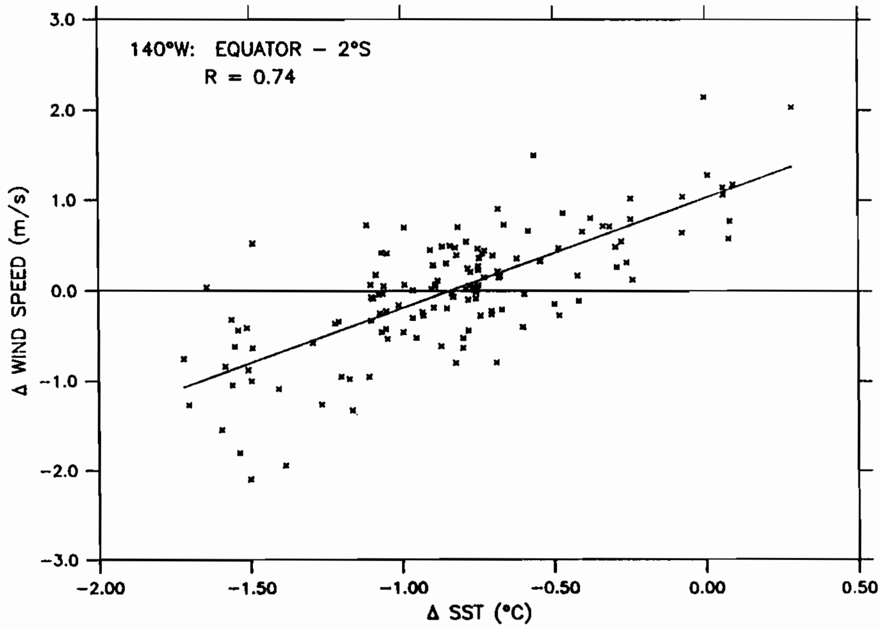

FIG.4. Scatter plot of change in wind speed between the equator and 2°S versus the change in SST between these latitudes at 140°W for the period September 1987 to February 1988. Regression line is least squares fit to the observations.

difference were lower than at 110°W. In the western Pacific, measurements at 165°E failed to show significant correlations between surface wind speed and SST gradients for any of the periods considered.

The structure of the boundary layer winds in the eastern Pacific need to be more fully examined before the processes responsible for the observed correlations can be clearly defined. However, based on the limited data available, it appears that the existence of a low level southeasterly jet and the strong SST gradients over which this boundary layer passes are crucial parameters in determining the surface wind field. Further investigations using shipboard profiling as well as the surface measurements are needed to understand the dynamics involved.

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TABLE OF CONTENTS

ABSTRACT i

RESUME iii

ACKNOWLEDGMENTS vi

INTRODUCTION

1. Motivation 1
2. Structure 2

LIST OF PARTICIPANTS 5

AGENDA 7

WORKSHOP REPORT

1. Introduction 19
2. Working group discussions, recommendations, and plans 20
   a. Air-Sea Fluxes and Boundary Layer Processes 20
   b. Regional Scale Atmospheric Circulation and Waves 24
   c. Regional Scale Oceanic Circulation and Waves 30
3. Related programs 35
   a. NASA Ocean Processes and Satellite Missions 35
   b. Tropical Rainfall Measuring Mission 37
   c. Typhoon Motion Program 39
   d. World Ocean Circulation Experiment 39
4. Presentations on related technology 40
5. National reports 40
6. Meeting of the International Ad Hoc Committee on TOGA COARE 40

APPENDIX: WORKSHOP RELATED PAPERS

Robert A. Weller and David S. Hosom: Improved Meteorological Measurements from Buoys and Ships for the World Ocean Circulation Experiment 45

Peter H. Hildebrand: Flux Measurement using Aircraft and Radars 57

Walter F. Dabberdt, Hale Cole, K. Gage, W. Ecklund and W.L. Smith: Determination of Boundary-Layer Fluxes with an Integrated Sounding System 81

MEETING COLLECTED PAPERS

WATER MASSES, SEA SURFACE TOPOGRAPHY, AND CIRCULATION

Klaus Wyrtki: Some Thoughts about the West Pacific Warm Pool 99
Jean René Donguy, Gary Meyers, and Eric Lindstrom: Comparison of the Results of two West Pacific Oceanographic Expeditions FOC (1971) and WEPOCS (1985-86) 111
Dunxin Hu, and Maochang Cui: The Western Boundary Current in the Far Western Pacific Ocean 123
Peter Hacker, Eric Firing, Roger Lukas, Philipp L. Richardson, and Curtis A. Collins: Observations of the Low-latitude Western Boundary Circulation in the Pacific during WEPOCS III 135
Stephen P. Murray, John Kindle, Dharma Arief, and Harley Hurlburt: Comparison of Observations and Numerical Model Results in the Indonesian Throughflow Region 145
Christian Henin: Thermohaline Structure Variability along 165°E in the Western Tropical Pacific Ocean (January 1984 - January 1989) 155
David J. Webb, and Brian A. King: Preliminary Results from Charles Darwin Cruise 34A in the Western Equatorial Pacific 165
Warren B. White, Nicholas Graham, and Chang-Kou Tai: Reflection of Annual Rossby Waves at The Maritime Western Boundary of the Tropical Pacific 173
William S. Kessler: Observations of Long Rossby Waves in the Northern Tropical Pacific 185
Eric Firing, and Jiang Songnian: Variable Currents in the Western Pacific Measured During the US/PRC Bilateral Air-Sea Interaction Program and WEPOCS 205
John S. Godfrey, and A. Weaver: Why are there Such Strong Steric Height Gradients off Western Australia ? 215
John M. Toole, R.C. Millard, Z. Wang, and S. Pu: Observations of the Pacific North Equatorial Current Bifurcation at the Philippine Coast 223

EL NINO/SOUTHERN OSCILLATION 1986-87

Gary Meyers, Rick Bailey, Eric Lindstrom, and Helen Phillips: Air/Sea Interaction in the Western Tropical Pacific Ocean during 1982/83 and 1986/87 229
Laury Miller, and Robert Cheney: GEOSAT Observations of Sea Level in the Tropical Pacific and Indian Oceans during the 1986-87 El Nino Event 247
Thierry Delcroix, Gérard Eldin, and Joël Picaut: GEOSAT Sea Level Anomalies in the Western Equatorial Pacific during the 1986-87 El Nino, Elucidated as Equatorial Kelvin and Rossby Waves 259
Gérard Eldin, and Thierry Delcroix: Vertical Thermal Structure Variability along 165°E during the 1986-87 ENSO Event 269
Michael J. McPhaden: On the Relationship between Winds and Upper Ocean Temperature Variability in the Western Equatorial Pacific 283

John S. Godfrey, K. Ridgway, Gary Meyers, and Rick Bailey: Sea Level and Thermal Response to the 1986-87 ENSO Event in the Far Western Pacific 291
Joël Picaut, Bruno Camusat, Thierry Delcroix, Michael J. McPhaden, and Antonio J. Busalacchi: Surface Equatorial Flow Anomalies in the Pacific Ocean during the 1986-87 ENSO using GEOSAT Altimeter Data 301

THEORETICAL AND MODELING STUDIES OF ENSO AND RELATED PROCESSES

Julian P. McCreary, Jr.: An Overview of Coupled Ocean-Atmosphere Models of El Nino and the Southern Oscillation 313
Kensuke Takeuchi: On Warm Rossby Waves and their Relations to ENSO Events 329
Yves du Penhoat, and Mark A. Cane: Effect of Low Latitude Western Boundary Gaps on the Reflection of Equatorial Motions 335
Harley Hurlburt, John Kindle, E. Joseph Metzger, and Alan Wallcraft: Results from a Global Ocean Model in the Western Tropical Pacific 343
John C. Kindle, Harley E. Hurlburt, and E. Joseph Metzger: On the Seasonal and Interannual Variability of the Pacific to Indian Ocean Throughflow 355
Antonio J. Busalacchi, Michael J. McPhaden, Joël Picaut, and Scott Springer: Uncertainties in Tropical Pacific Ocean Simulations: The Seasonal and Interannual Sea Level Response to Three Analyses of the Surface Wind Field 367
Stephen E. Zebiak: Intraseasonal Variability - A Critical Component of ENSO ? 379
Akimasa Sumi: Behavior of Convective Activity over the "Jovian-type" Aqua-Planet Experiments 389
Ka-Ming Lau: Dynamics of Multi-Scale Interactions Relevant to ENSO 397
Pecheng C. Chu and Roland W. Garwood, Jr.: Hydrological Effects on the Air-Ocean Coupled System 407
Sam F. Iacobellis, and Richard C.J. Somerville: A one Dimensional Coupled Air-Sea Model for Diagnostic Studies during TOGA-COARE 419
Allan J. Clarke: On the Reflection and Transmission of Low Frequency Energy at the Irregular Western Pacific Ocean Boundary - a Preliminary Report 423
Roland W. Garwood, Jr., Pecheng C. Chu, Peter Muller, and Niklas Schneider: Equatorial Entrainment Zone : the Diurnal Cycle 435
Peter R. Gent: A New Ocean GCM for Tropical Ocean and ENSO Studies 445
Wasito Hadi, and Nuraini: The Steady State Response of Indonesian Sea to a Steady Wind Field 451
Pedro Ripa: Instability Conditions and Energetics in the Equatorial Pacific 457
Lewis M. Rothstein: Mixed Layer Modelling in the Western Equatorial Pacific Ocean 465
Neville R. Smith: An Oceanic Subsurface Thermal Analysis Scheme with Objective Quality Control 475
Duane E. Stevens, Qi Hu, Graeme Stephens, and David Randall: The hydrological Cycle of the Intraseasonal Oscillation 485
Peter J. Webster, Hai-Ru Chang, and Chidong Zhang: Transmission Characteristics of the Dynamic Response to Episodic Forcing in the Warm Pool Regions of the Tropical Oceans 493

MOMENTUM, HEAT, AND MOISTURE FLUXES BETWEEN ATMOSPHERE AND OCEAN

W. Timothy Liu: An Overview of Bulk Parametrization and Remote Sensing of Latent Heat Flux in the Tropical Ocean 513
E. Frank Bradley, Peter A. Coppin, and **John S. Godfrey**: Measurements of Heat and Moisture Fluxes from the Western Tropical Pacific Ocean 523
Richard W. Reynolds, and **Ants Leetmaa**: Evaluation of NMC's Operational Surface Fluxes in the Tropical Pacific 535
Stanley P. Hayes, Michael J. McPhaden, John M. Wallace, and **Joël Picaut**: The Influence of Sea-Surface Temperature on Surface Wind in the Equatorial Pacific Ocean 543
T.D. Keenan, and **Richard E. Carbone**: A Preliminary Morphology of Precipitation Systems In Tropical Northern Australia 549
Phillip A. Arkin: Estimation of Large-Scale Oceanic Rainfall for TOGA 561
Catherine Gautier, and **Robert Frouin**: Surface Radiation Processes in the Tropical Pacific 571
Thierry Delcroix, and **Christian Henin**: Mechanisms of Subsurface Thermal Structure and Sea Surface Thermo-Haline Variabilities in the South Western Tropical Pacific during 1979-85 - A Preliminary Report 581
Greg. J. Holland, T.D. Keenan, and **M.J. Manton**: Observations from the Maritime Continent : Darwin, Australia 591
Roger Lukas: Observations of Air-Sea Interactions in the Western Pacific Warm Pool during WEPOCS 599
M. Nunez, and **K. Michael**: Satellite Derivation of Ocean-Atmosphere Heat Fluxes in a Tropical Environment 611

EMPIRICAL STUDIES OF ENSO AND SHORT-TERM CLIMATE VARIABILITY

Klaus M. Weickmann: Convection and Circulation Anomalies over the Oceanic Warm Pool during 1981-1982 623
Claire Perigaud: Instability Waves in the Tropical Pacific Observed with GEOSAT 637
Ryuichi Kawamura: Intraseasonal and Interannual Modes of Atmosphere-Ocean System Over the Tropical Western Pacific 649
David Gutzler, and **Tamara M. Wood**: Observed Structure of Convective Anomalies 659
Siri Jodha Khalsa: Remote Sensing of Atmospheric Thermodynamics in the Tropics 665
Bingrong Xu: Some Features of the Western Tropical Pacific: Surface Wind Field and its Influence on the Upper Ocean Thermal Structure 677
Bret A. Mullan: Influence of Southern Oscillation on New Zealand Weather 687
Kenneth S. Gage, Ben Basley, Warner Ecklund, D.A. Carter, andJohn R. McAfee: Wind Profiler Related Research in the Tropical Pacific 699
John Joseph Bates: Signature of a West Wind Convective Event in SSM/I Data 711
David S. Gutzler: Seasonal and Interannual Variability of the Madden-Julian Oscillation 723
Marie-Hélène Radenac: Fine Structure Variability in the Equatorial Western Pacific Ocean 735
George C. Reid, Kenneth S. Gage, and **John R. McAfee**: The Climatology of the Western Tropical Pacific: Analysis of the Radiosonde Data Base 741

Chung-Hsiung Sui, and Ka-Ming Lau: Multi-Scale Processes in the Equatorial Western Pacific 747
Stephen E. Zebiak: Diagnostic Studies of Pacific Surface Winds 757

MISCELLANEOUS

Rick J. Bailey, Helene E. Phillips, and Gary Meyers: Relevance to TOGA of Systematic XBT Errors 775
Jean Blanchot, Robert Le Borgne, Aubert Le Bouteiller, and Martine Rodier: ENSO Events and Consequences on Nutrient, Planktonic Biomass, and Production in the Western Tropical Pacific Ocean 785
Yves Dandonneau: Abnormal Bloom of Phytoplankton around 10°N in the Western Pacific during the 1982-83 ENSO 791
Cécile Dupouy: Sea Surface Chlorophyll Concentration in the South Western Tropical Pacific, as seen from NIMBUS Coastal Zone Color Scanner from 1979 to 1984 (New Caledonia and Vanuatu) 803
Michael Szabados, and Darren Wright: Field Evaluation of Real-Time XBT Systems 811
Pierre Rual: For a Better XBT Bathy-Message: Onboard Quality Control, plus a New Data Reduction Method 823