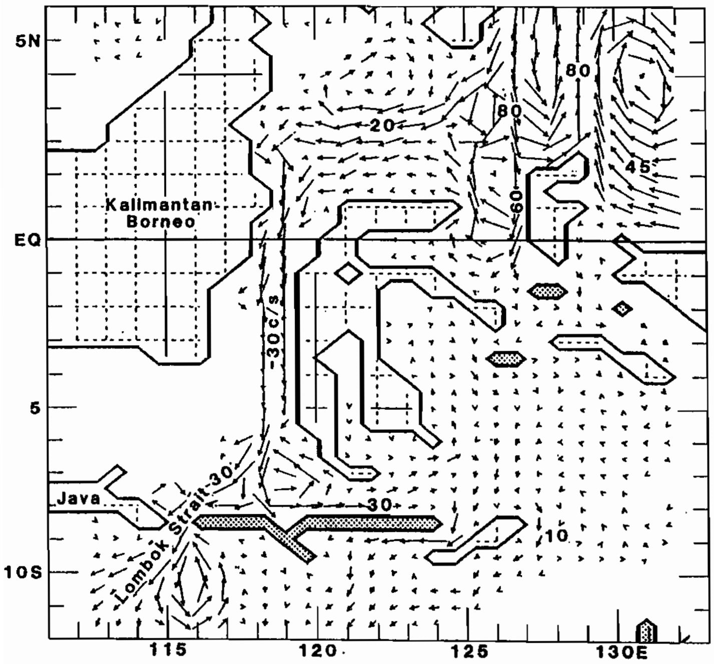

FIG.3. The model velocity field in the study area on May 28, 1985. Representative current speeds (cm/sec) are shown at a few locations.

results for the upper layer velocity field in the throughflow region on May 28, 1985. The strong southward flow in the Makassar Strait (30-60 cm.s^{-1}), fed from the Sulawesi Sea, bifurcates at the archipelago, one branch entering directly into the Indian Ocean through the Lombok Strait and the other branch flowing east through the Flores and Banda seas. The time series of transport predicted by the model for 1985-1986 is compared to our observations in Figure 4.

The computations of observed transport through the Lombok Strait presented in (Murray and Dharma Arief, 1988) are based on monthly block averages of current meter data, which allowed for temporal variation in the vertical current profile. In order to increase temporal resolution for a comparison to the model output, the carefully determined monthly average transports were regressed against monthly average velocity components from various current meters. A best-fit relation ($R^2 = 0.79$) determined over the range of the monthly averages ($5 \leq v \leq 55$ cm.s^{-1}):

$$T = 0.64\, e^{.032\, v}$$

where T is transport in Sv and v is the monthly average north-south component of current speed at the 35-m level (v_{35}) at the site 2 mooring, gave best results. Utilizing this relationship, the v time series from this current meter was passed through a 30-day low-pass filter (v (LP)) and used to compute transport. For the limited amount of data outside the range of the monthly averages where v (LP) < 5 cm.s^{-1}, we let $T \rightarrow 0$ linearly with v (LP). Correspondingly, when v (LP) > 55 cm.s^{-1}, an algorithm where v = constant = v_{35} in the upper 100 m and decreases parabolically to 0 at 200 m gave good results.

Figure 4 shows a comparison between transport through the Lombok Strait calculated from the observations in this manner and from the numerical model. In all figures, eastward- and northward-directed flows are positive; westward- and southward-directed flows are negative. Owing to restrictions on the model grid size, the Lombok opening in the model for the upper active layer is about 2.2 times the actual cross section of the strait above the 200-m depth level, where the net transport is calculated. Note a transport scale adjusted for this discrepancy on the figure. We note the general agreement in phase

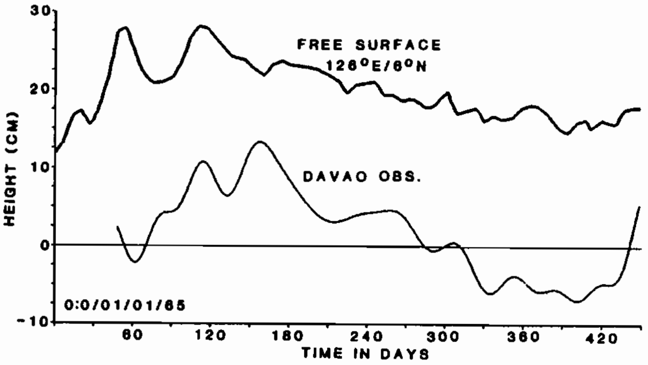

FIG.10. Observed sea level at Davao compared to sea level at the model grid point off the southern Philippines at 126°E, 6°N.

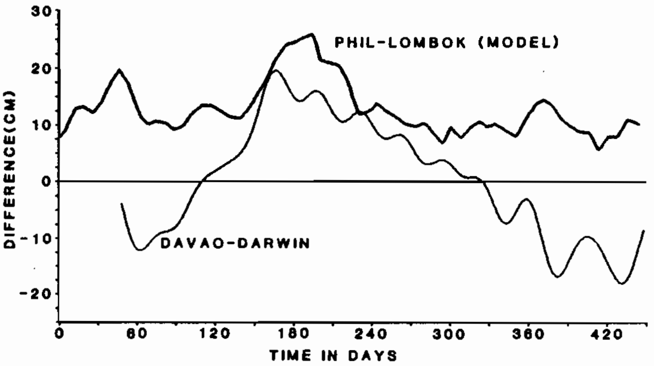

FIG.11. The Davao-Darwin sea level differences, January 1985-March 1986, compared to the sea level difference between the model grid points off the southern Philippines and the Lombok Strait.

4. Summary

Observations of currents, transport, sea level, and sea level slope in Lombok Strait and west Flores Sea in 1985 and 1986 have been compared to a simulation of the NORDA global ocean model in the Indonesian throughflow region. Despite the relatively coarse grid scale of the model compared to topographic length scales in the region, the model appears to be realistically reproducing many of the observed features. The predicted transport through the Lombok Strait, for example, agrees with detailed observations of phase and magnitude, especially when corrected for grid size limitations. The sea surface fluctuations and sea surface slopes predicted by the model agree within less than a factor of 1.5 with sea level changes and slopes observed on tide gauges. There do appear to be several cases of phase difference of several months between model and observations that require further investigation.

REFERENCES

Cox, M., 1982: Numerical Models of Ocean Circulation. National Academy of Science Press, Washington, D.C.

Fine, R. A., 1985: Direct evidence using tritium data for throughflow from the Pacific into the Indian Ocean, *Nature*, **315**, 478-480.

Fu, L., 1986: Mass, heat and freshwater fluxes in the south Indian Ocean, *J. Phys. Oceanogr.*, **16**, 1683-1693.

Godfrey, J. S., and T. J. Golding, 1981: The Sverdrup relation in the Indian Ocean, and the effect of Pacific-Indian Ocean through flow on Indian Ocean circulation and on the East Australian Current, *J. Phys. Oceanogr.*, **11**, 771-779.

Gordon, A. L., 1986: Interocean exchange of thermocline water, *J. Geophys. Res.*, **91**, 5037-5046.

Hurlburt, H. E., J. C. Kindle, and E. J. Metzger, Results from a global ocean model in the western tropical Pacific, 1989.

Kindle, J. C., G. Heburn, and R. Rhodes, 1987: An estimate of the Pacific to Indian Ocean throughflow from a global numerical model, Interannual variability of the Pacific to Indian throughflow, I : Further progress in equatorial oceanography (E. Katz and J. Witte, eds.), *Nova University*, In: Further progress in equatorial oceanography (E. Katz and J. Witte, eds.), *Nova University Press*, Ft. Lauderdale, FL, 317-321.

Kindle, J. C., H. E. Hurlburt, and E. J. Metzger, On the seasonal and interannual variability of the Pacific to Indian Ocean throughflow, 1989.

Murray, S. P., and Dharma Arief, 1986: Effect of Indian Ocean cyclones on net flow through the Lombok Strait, Indonesia (abs.), *EOS*, **67**, 1017, *AGU Fall Meeting*, December 1986.

Murray, S. P., and Dharma Arief, 1988: Throughflow into the Indian Ocean through the Lombok Strait, January 1985-January 1986, *Nature*, **333**, 444-447.

Piola, A. R., and A. L. Gordon, 1984: Pacific and Indian Ocean upper-layer salinity budget, *J. Phys. Oceanogr.*, **14**, 747-753.

Wyrtki, K., 1961: Physical oceanography of the Southeast Asian waters, Scientific Results of Maritime Investigations of the South China Sea and Gulf of Thailand 1959-1961, *NAGA Rep.*, **2**, 195 pp., Scripps Inst. Oceanogr., La Jolla, California, U.S.A.

Wyrtki, K., 1987: Indonesia throughflow and the associated pressure gradient, *J. Geophys. Res.*, **92**, 12941-12946.

WESTERN PACIFIC INTERNATIONAL MEETING AND WORKSHOP ON TOGA COARE

Nouméa, New Caledonia
May 24-30, 1989

PROCEEDINGS

edited by

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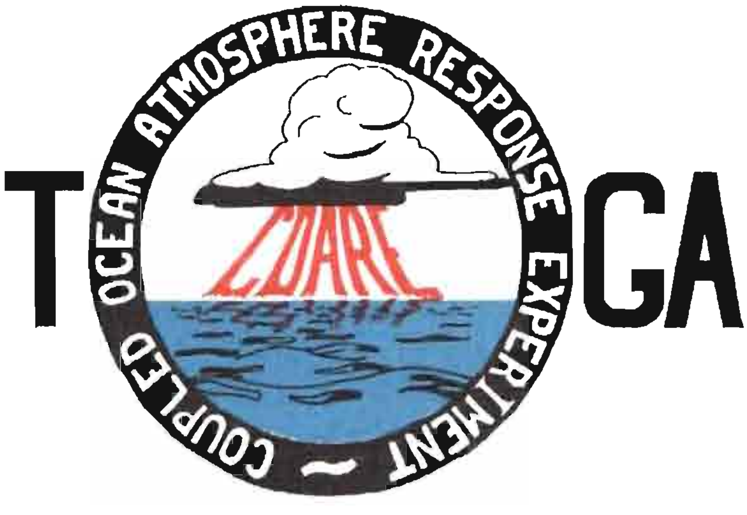

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TABLE OF CONTENTS

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

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, and **John 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