The Climatology of the Western Tropical Pacific: Analysis of the Radiosonde Data Base

G.C. REID, K.S. GAGE and J.R. McAFEE

Aeronomy Laboratory
National Oceanic and Atmospheric Administration
Boulder, CO 80303 - U.S.A.

INTRODUCTION

Upper air data are available from several radiosonde stations in the western tropical Pacific at daily or twice-daily intervals for a period of over 30 years, beginning in the early 1950s. Three of these stations (Ponape, Truk, and Majuro) lie within the TOGA COARE domain, and several others (Koror, Yap, Guam, Eniwetok, and Pago Pago) are closely adjacent. Analysis of this data base is in principle capable of providing important information on the height and time structure of atmospheric variability over the warm pool region.

As a preliminary study, we have used the temperature records from three of these stations (Yap, Majuro, and Pago Pago), together with two more distant stations (Wake Island and Curacao) to examine the development in time of the ENSO-related anomalies at 30 pressure levels from 1000 hPa to 15 hPa (about 28 km) during the 17-year period 1966-1982. The analysis is described in detail in Reid et al. (1989).

THE RELATIONSHIP OF OCEANIC AND ATMOSPHERIC TEMPERATURE ANOMALIES

The El Nino time series of SST anomalies used was that derived by Weare et al. (1976) and updated by Weare (1986). It is the amplitude of the dominant interannual mode found in an EOF analysis of SSTs over a wide region of the Pacific north of 20°S, and the time series of monthly values is shown in Figure 1. The only pre-treatment of the time series was the removal of a weak linear trend, shown in the figure.

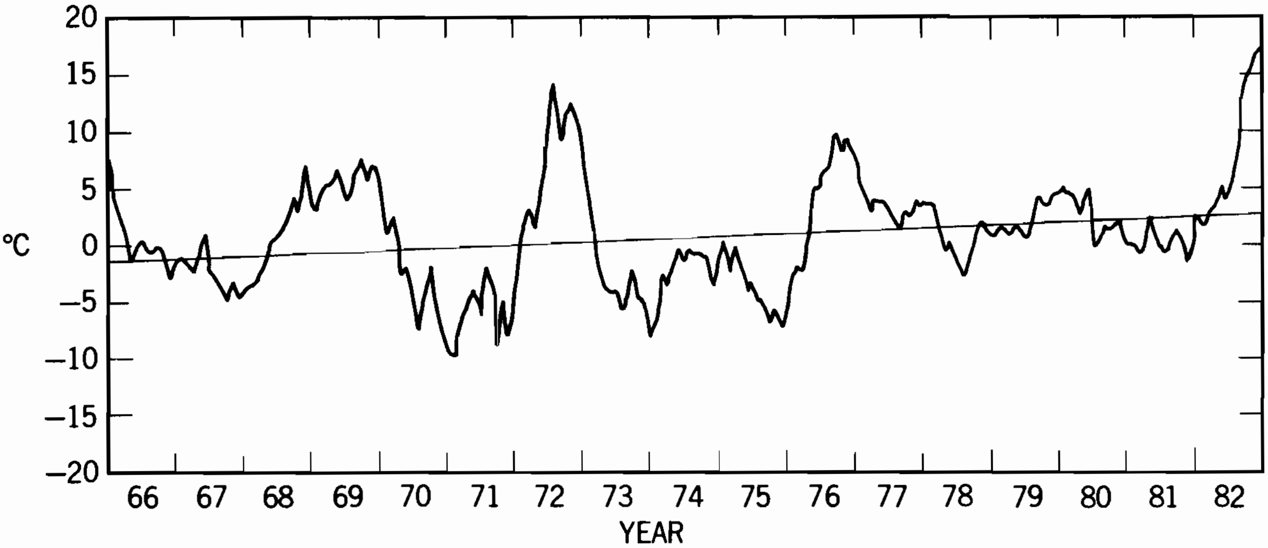

Figure 1. Pacific SST anomaly time series (after Weare [1986]).

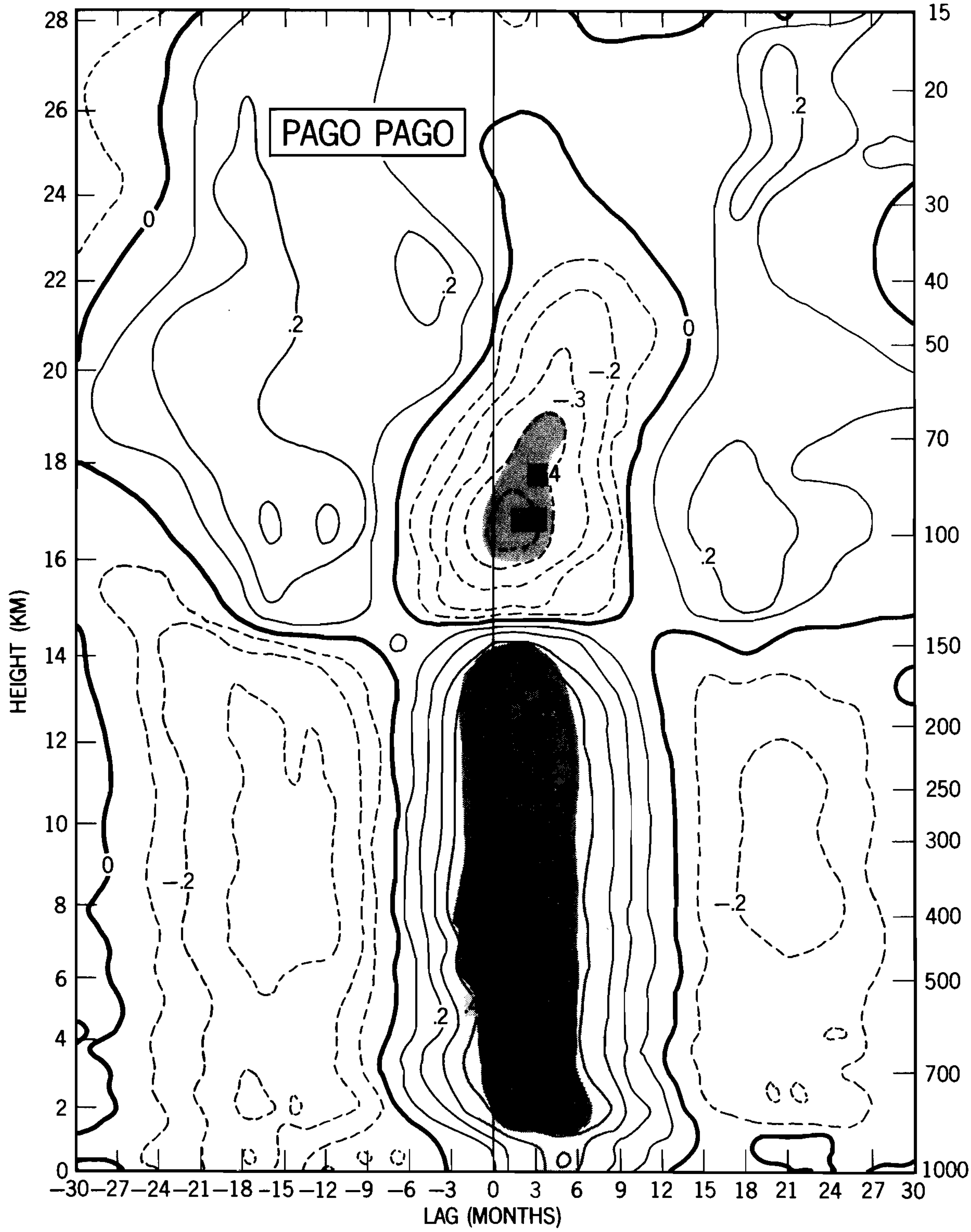

Figure 2. Contour plot of cross-correlation coefficients between time series of Figure 1 and monthly mean atmospheric temperature anomalies at Pago Pago. The ocean leads the atmosphere for positive lags.

The atmospheric temperature time series for each of the 5 stations and for each of the 30 pressure levels (nearly 2 million individual measurements in all) were reduced to monthly means, and anomaly series were formed by subtracting the 17-year mean for each calendar month from the individual values. Fairly pronounced trends were evident at all levels, and were removed before carrying out the analysis. The trends and their significance are discussed below.

For each station, the temperature anomalies at each pressure level were cross-correlated with the SST anomaly time series for lags of ± 30 months (positive lag means SST leads the atmosphere). Figure 2 shows the result for Pago Pago in the form of contours of equal cross-correlation coefficient. Dark and light shading indicate correlation significant at the 99% and 95% levels respectively, taking autocorrelation in the individual time series into account.

The main features are:

(1) Strong positive correlation in the main troposphere, from 850 hPa to 150 hPa, with the atmosphere lagging the ocean by about 2 months.
(2) Strong negative correlation between 100 hPa and 60 hPa, with a similar lag.
(3) A transition region between 150 hPa and the tropopause at about 100 hPa.
(4) A surface layer below 850 hPa, with little significant correlation.
(5) Disappearance of the signal above about 40 hPa (22 km).

A generally similar picture is seen at the other four stations, but with interesting differences from station to station, and with a systematic variation in lag.

Figure 3 shows the lag in the mid-troposphere as a function of longitude of the station, and indicates that the signal appears to propagate slowly outward from a center near 135°W, where the lag would probably be close to zero (if there were a station to observe it). The zonal propagation speed is about 0.8 meters per second, considerably less than typical wind speeds.

INTERPRETATION

The slow propagation speed, and the close similarity of the speeds in the troposphere and stratosphere, suggest that the mechanism is not simply the advection of air from a region of enhanced convective activity. Two other possibilities are:

(1) Enhancement of the large-scale tropospheric subsidence and stratospheric upwelling resulting from increased convective activity centered near 135°W. In this case, the tropospheric subsidence can be considered as a sign of an enhanced and displaced Walker circulation accompanying El Nino events, while the stratospheric upwelling can be considered as a sign of an enhanced Hadley circulation.

(2) An increase in the extent of optically thick mesoscale cirrus sheets in the upper troposphere resulting from enhanced convective activity, leading to radiative warming of the troposphere below and radiative cooling of the stratosphere above.

Both of these mechanisms may be contributing to the effect, and some effort is needed to try to devise ways of estimating their relative effectiveness.

ATMOSPHERIC TEMPERATURE TRENDS

Significant trends were found in the 1966-1982 atmospheric temperature anomaly time series at all pressure levels. Figure 4 shows the slope of a least-squares straight-line fit to the trend at each of the five stations for several pressure levels. The station trends all show similar characteristics - a warming below the 150 hPa level, which continues into the lower stratosphere only at the near-equatorial stations of Yap and Majuro. The other stations show a transition to a cooling trend near the tropopause and at the base of the stratosphere, weakening with increasing height and becoming irregular above about 40 hPa.

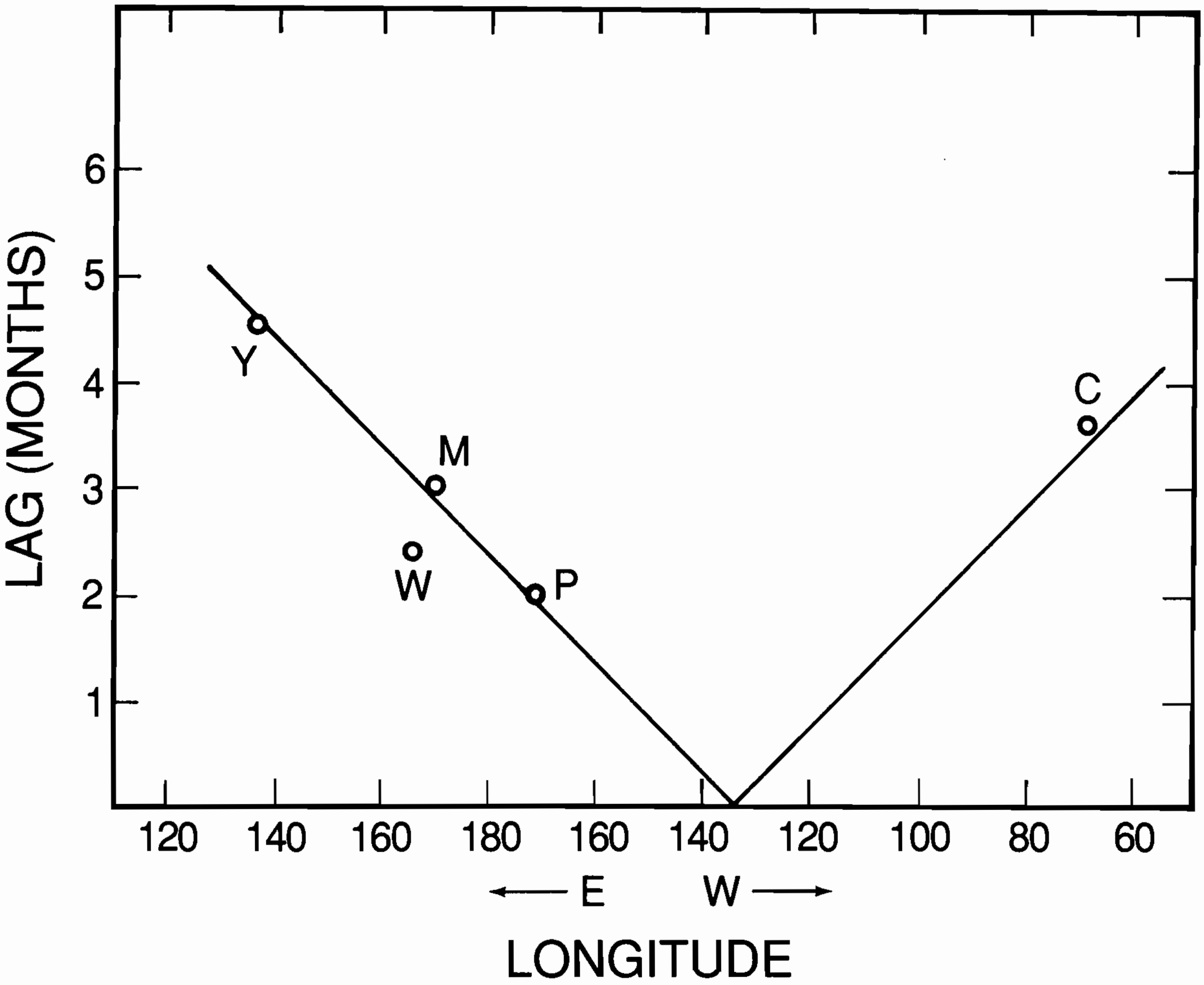

Figure 3. Lag of maximum correlation in the mid-troposphere as a function of station longitude for Yap, Majuro, Wake Island, Pago Pago, and Curacao. The straight lines have slopes of 0.8 meters per second at the equator.

The variation with height is somewhat similar to the height variation of the correlation patterns illustrated in Figure 2, and suggests that the trends seen in the atmosphere may reflect a warming trend in the tropical Pacific during the 1966-82 time period. The cause of such a warming is a matter for speculation.

CONCLUSIONS

(1) The signals of tropospheric warming and stratospheric cooling that accompany El Nino events are clearly evident in tropical radiosonde data, and appear to propagate both westward and eastward from a center near 135°W at a speed of about 0.8 m s^{-1}.

(2) The relative importance of dynamical (Walker and Hadley circulations) and radiative (extensive cirrus sheets) effects in producing the signal needs to be determined.

(3) Long-term trends in atmospheric temperature over the period 1966 to 1982 are consistent with an overall warming of the tropical Pacific.

(4) Extension of the analysis to study (a) the characteristics of the signal at other tropical

and extratropical locations, (b) the behavior of the signal at earlier times, before 1966, and (c) the existence of a corresponding signal at intraseasonal frequencies, is being planned.

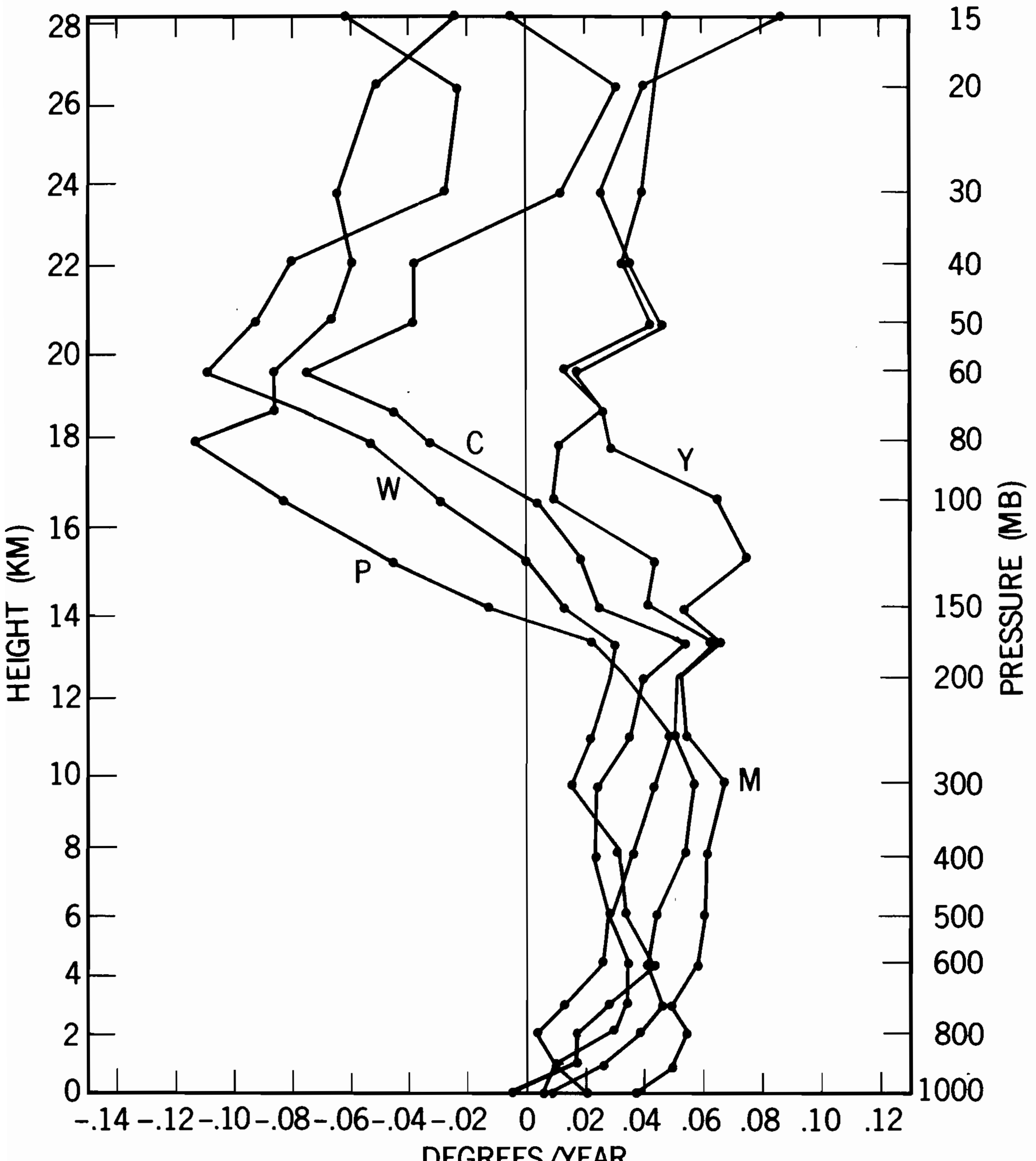

Figure 4. Slopes of the linear trend in temperature anomaly at the 5 stations during 1966-82.

REFERENCES

Reid, G.C., K.S. Gage, and J.R. McAfee, The thermal response of the tropical atmosphere to variations in equatorial Pacific sea-surface temperature, *J. Geophys. Res.*, in press, 1989.

Weare, B.C., An extension of an El Nino index, *Mon. Wea. Rev.* **114**, 644-647, 1986.

Weare, B.C., A.R. Navato, and R.E. Newell, Empirical orthogonal analysis of Pacific sea surface temperatures, *J. Phys. Oceanogr.* **6**, 671-678, 1976.

WESTERN PACIFIC INTERNATIONAL MEETING AND WORKSHOP ON TOGA COARE

Nouméa, New Caledonia
May 24-30, 1989

PROCEEDINGS

edited by

Joël Picaut *
Roger Lukas **
Thierry Delcroix *

* ORSTOM, Nouméa, New Caledonia
** JIMAR, University of Hawaii, U.S.A.

INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE
POUR LE DÉVELOPPEMENT EN COOPÉRATION

Centre de Nouméa

TABLE OF CONTENTS

MEETING COLLECTED PAPERS

WATER MASSES, SEA SURFACE TOPOGRAPHY, AND CIRCULATION

EL NINO/SOUTHERN OSCILLATION 1986-87

MOMENTUM, HEAT, AND MOISTURE FLUXES BETWEEN ATMOSPHERE AND OCEAN

EMPIRICAL STUDIES OF ENSO AND SHORT-TERM CLIMATE VARIABILITY

MISCELLANEOUS