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RESEARCH

WORLD OCEAN CIRCULATION EXPERIMENT

SURFACE VELOCITY PROGRAMME PLANNING COMMITTEE

Report of the First Meeting

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and

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The World Climate Applications Programme
The World Climate Impact Studies Programme
The World Climate Research Programme

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TOGA
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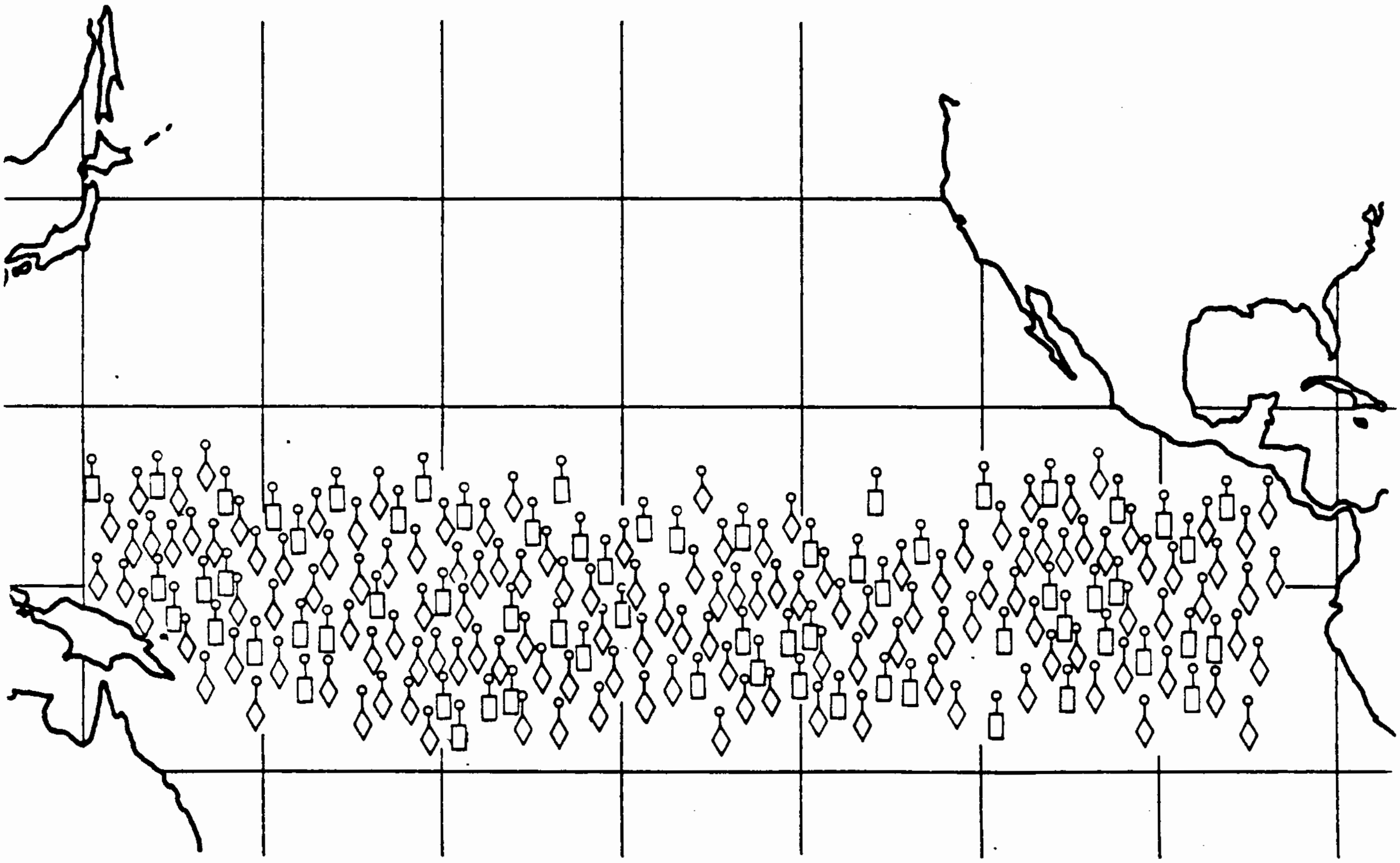

SURFACE CURRENT STUDY

Table of Contents

ABSTRACT

In the tropical Pacific the large-scale interactions between the ocean and the atmosphere are well documented. The sea surface temperature (SST) provides the most direct link in modeling the oceans' influence on the atmosphere. Thus, a principal scientific objective of the Tropical Ocean and Global Atmosphere Programme (TOGA) of the World Climate Research Programme (WCRP), is to accurately measure SST and to correctly model its seasonal and longer time-scale evolution. The two competing hypotheses on the causes of the seasonal and interannual variations in the tropical Pacific are that either surface heat advection or near-surface vertical mixing change the SST. Presently there is a lack of direct measurements to assess the relative role of each process, as well as measurements of SST to the accuracy (± 0.3° C) required for air-sea interaction model improvement in TOGA. Hydrodynamic models of the ocean also require circulation data for verification and model initialization. This document outlines an international programme to measure surface circulation, to assess the strength of vertical mixing and provide accurate in situ data for improved SST analyses in the tropical Pacific.

To accomplish these scientific objectives, it is proposed to deploy a pan-Pacific array of low cost, ARGOS tracked mixed layer drifters with temperature sensors for a three-year period. Drifters would be deployed from research vessels and the TOGA Volunteer Observing Ships Program (VOSP) in the area $15°N - 15°S$, 80° W to 126° E. The desired spatial sampling density is 2° latitude x 10° longitude which can be accomplished by 230 resident drifters. A total of 450 drifters will be released over a 2-year period. Required renewal rates of the array will be determined empirically. The drifter water-following capability will be $\pm 2 cm/sec$ in 7 m/sec winds, and accuracy of temperature measurements will be ± 0.1° C. The SST data will be reported in real time to the Global Telecommunications Systems (GTS), and the circulation data will be used in real time to enhance and verify models of El Niño prediction. Heat advection and mixing at the base of the daily thermocline will be computed. A variety of regional ocean circulation phenomena will be measured and described. By 1990, recommendations will be made to WCRP on the implementation of a joint tropical surface circulation study for TOGA/WOCE (World Ocean Circulation Experiment).

In TOGA, the ocean subsurface thermal structure and sea level projects have been implemented in a pan-Pacific basis. This proposed study will implement the measurement of near-surface currents in an equivalent pan-Pacific basis.

Table of Contents

1. *Introduction*

The most direct influence of the ocean on tropical atmospheric circulation is due to the variability of the sea surface temperature (SST). Hydrodynamic models of this variability demonstrate that in the equatorial Pacific the west-to-east SST gradient maintains the rising air over the Indonesian archipelago, and subsiding air over the eastern basin (Stone and Chervin, 1984). Typically, in August-January the SST gradients are the largest and in February-May, the gradients are the weakest. Substantial spatial and temporal variability of this Walker circulation in the atmosphere occurs during times when the regular seasonal east-to-west SST gradient vacillation is disrupted. During the years when cold water does not appear in the eastern equatorial Pacific and the entire basin is warm, significant world-wide deviations in normal climate patterns are observed. The warming event in the 1982-1983 period was accompanied by the largest and most devastating shifts of tropical rainfall and mid-latitude storminess in modern times (ITPO, 1985). The Tropical Ocean and Global Atmosphere programme (TOGA) has been organized to develop a deeper understanding of the physical basis of this coupled ocean-atmosphere variability, and to construct models which may lead to its prediction. The principal scientific objectives in the ocean portion of the TOGA programme are to accurately measure the SST, and to correctly model its seasonal and longer time-scale evolution (WCP-89).

Sea surface temperature variations are caused by the horizontal movement of water, vertical mixing, and by heat exchange with the atmosphere. To assess the relative importance of these processes and to ascertain whether these are resolved in models in a realistic fashion, requires a comprehensive data set on surface water movements, mixing and heat exchange. TOGA Science Steering Group (WCP-130) has recommended an experiment in the Pacific to acquire a surface circulation data set, and this proposal outlines a programme to meet this objective. The proposed measurements programme is also designed to assess the intensity of vertical mixing at the base of the daily thermocline. Concurrently the TOGA Heat Exchange Project (THEP) will monitor surface heat exchange (Liu and Niiler, 1985).

2. *Causes of SST warming*

Two hypotheses have been advanced as to why cold water occasionally does not surface in the eastern tropical Pacific in the September-January period and a warm SST episode results. The first is that a major disruption of the normal surface circulation occurs. Gill (1983) and Reed (1983) showed that the surface warming could not be caused directly by an increase of observed surface heat flux in the central equatorial Pacific during the 1972 warming event. The hot water, therefore, could have accumulated there by horizontal movement. Gill shows how the eastward heat advection due to Kelvin waves generated by the collapse of the easterlies in the western equatorial Pacific could accomplish an increase of the observed thermal energy in the central Pacific. While no direct observations exist of the surface current affecting advective warming during the 1972 El Niño as postulated in Gill's computation, evidence of such motion exists in the equatorial current measurements during the 1982-83 event (Halpern *et al.*, 1983): zonal equatorial surface currents were reversed and the undercurrent briefly disappeared. Indirect evidence for large-scale horizontal water movements during warm episodes also comes from sea level observations. Rebert *et al.* (1985) show that monthly mean island sea-level variations in the tropics are an excellent measure of the steric level and heat storage. The steric level changes also mirror the depth of the main thermocline. Sea level decreases over broad areas of the western Pacific during warm episodes; in many areas this is due to the rising thermocline. Thus, large volumes of warm water must flow to the east (or poleward) accompanied with rising sea level and deepening thermocline (Pazan and White, 1987). That large-scale changes of circulation must accompany these sea level or thermocline changes is obvious, but only a few measurements have been made which can quantify these (see Section 3), and thus test the warm anomaly advection hypothesis in a quantitative fashion. The evidence of such change during the 1982-83 El Niño event in data from both moored current meters and drifting buoys is available only in the equatorial and South equatorial current in the eastern Pacific (Halpern *et al.*, 1983). The SST anomalies have much larger north-south and east-west scales than existing current measurements.

The second hypothesis of eastern tropical Pacific warming has been succinctly stated by Newell (1986). Newell notes that the maximum surface temperature of the eastern Pacific during warm events is nearly identical to the western Pacific - or 30° C. Thus, he argues that local air-sea interaction, or the balance between evaporation and solar radiation must determine the approach to the warm conditions. This occurs in the east when the local, vertical supply of cold water and/or vertical mixing has been severely reduced. Unfortunately, this hypothesis is difficult to test because vertical motion or vertical mixing rate are difficult to measure over large areas, and estimation of oceanic heating rates requires measurement of a number of noisy meteorological parameters. However, it is a plausible hypothesis and one, as we will show (Section 4), which may be tested with recently developed techniques of analysis of the structure of the daily thermocline.

In summary, a large-scale advection of warm water to the east or a local decrease of vertical mixing have been proposed as mechanisms which contribute significantly to the development of warm episodes in the central and eastern Pacific. Herein we propose a pan-Pacific Lagrangian drift experiment as a contribution toward testing these warming hypotheses and, further, to provide a verification data set for numerical models of the Pacific basin surface circulation, and new data for an improved SST analysis.

3. *The first hypothesis - Heat advection by the tropical Pacific surface circulation*

Ship drift and satellite-tracked buoy drift provide the only comprehensive data set of the large-scale surface circulation of the tropical Pacific. Figures 1a and 1b display the historical ship drift mean velocity and the EPOCS/NORPAX satellite-tracked buoy velocity, respectively. Both diagrams reveal the large zonal current systems - South Equatorial Current (SEC) between 10° S and 3° N, the North Equatorial Countercurrent (NECC) between 3° N and 8° N, and the North Equatorial Current (NEC) north of 8° N. They also show a northward drift north of the equator, and a more subtle southward drift south of the equator. The component of surface flow parallel to the temperature gradient advects heat, and it is this component which we seek to determine during central and eastern Pacific warming episodes. The historical mean temperature gradient is depicted together with the historical mean ship drift on Figure 2. It is apparent from this figure that surface heat advection is due to both zonal and meridional components. It is known that a measure of the zonal component of subsurface flow in the tropical Pacific can be obtained by the geostrophic method applied to subsurface temperature profiles, or from sea level gradients. The surface geostrophic flow relative to 1000 db is equatorward everywhere in this area (Wyrtki, 1975, and Figure 12). The actual flow, which is poleward and driven by the wind, is opposite the direction of the geostrophic flow. Thus, for surface heat advection determination, accurate direct flow measurements are required because indirect methods (e.g., geostrophic methods) would yield a flow (and heat advection) of the wrong meridional sense over large areas of the equatorial Pacific. Figure 3 is a map of the mean horizontal heat advection of $\vec{V} \cdot \nabla$ (SST). It is comparable in magnitude and of same sign as the surface heat flux divergence in a 50 m deep mixed layer (Weare *et al.*, 1980) There are not enough data to construct this field during the warming episodes, neither do we know how accurate such a ship-drift derived map is. A program of direct measurements would allow us to construct the fields of ∇ SST and $\vec{V}$ and hence compute the horizontal advection.

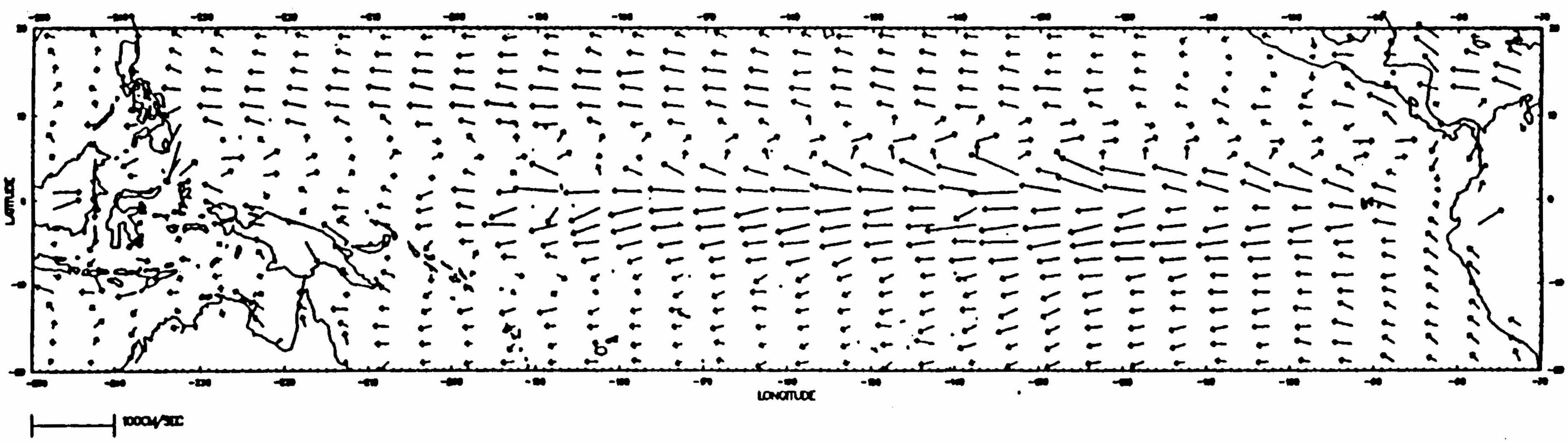

Figure 1a. Annual mean historical ship drift velocity in the tropical Pacific averaged on 2° latitude x 5° longitude scale.

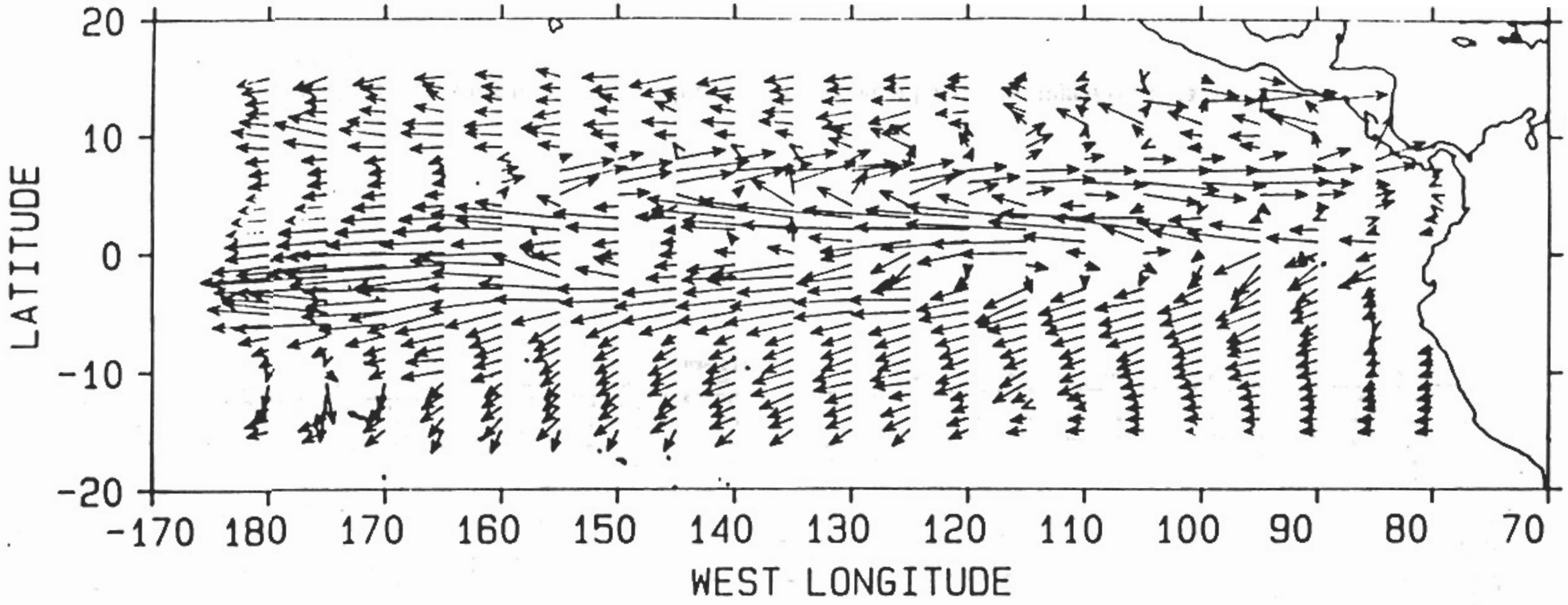

Figure 1b. Average surface current vectors in Central and Eastern Tropical Pacific from EPOCS drifter data (Hansen and Paul, 1984).

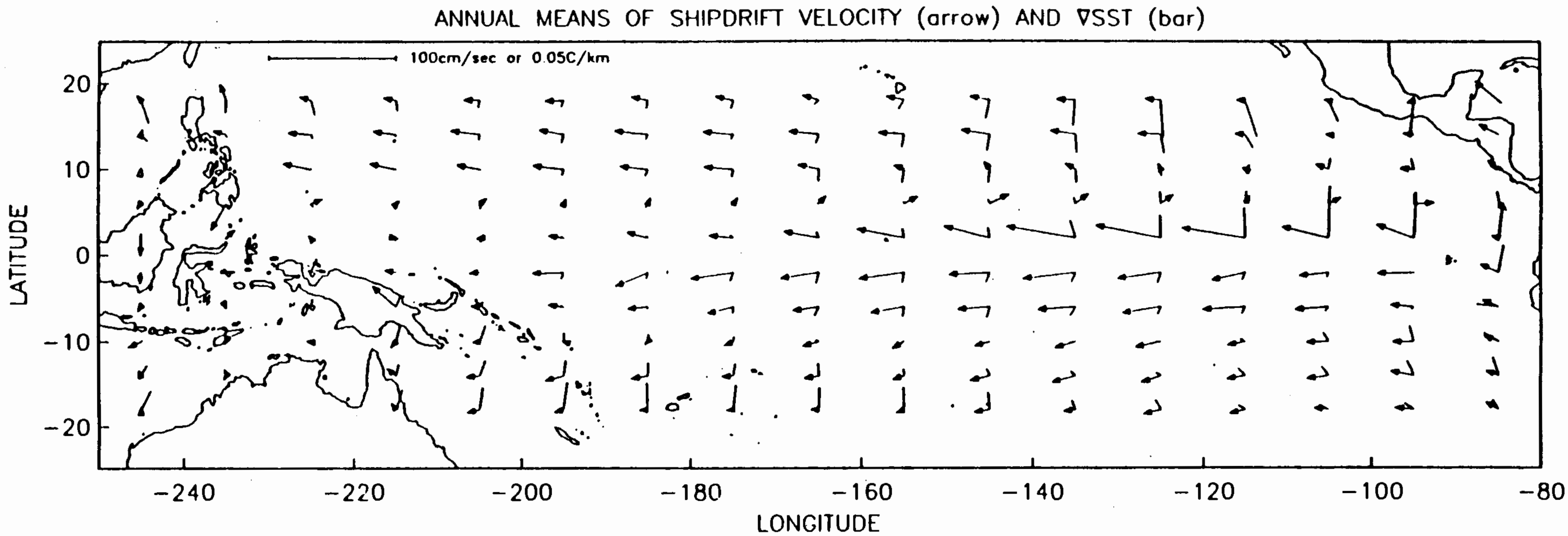

Figure 2. The annual mean ship drift (arrow) and SST gradient (bar) in the tropical Pacific on 4° latitude by 10° longitude resolution.

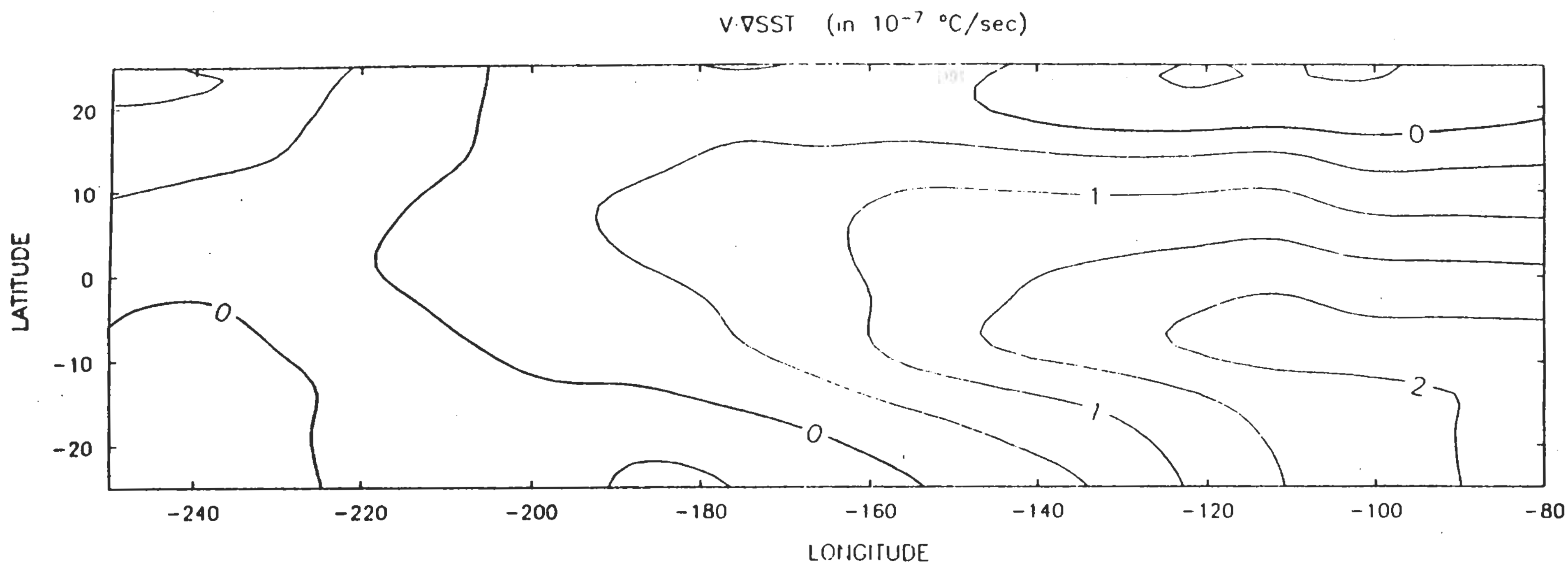

Figure 3. The annual mean horizontal heat advection in the tropical Pacific computed from data in Figure 2.

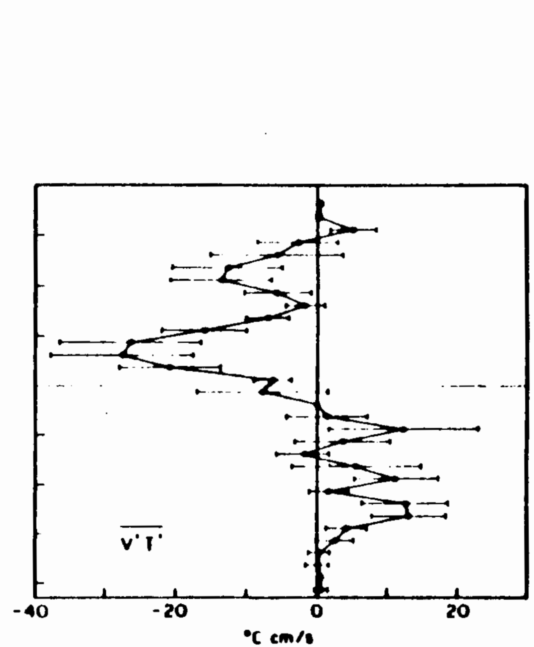

Figure 4. Meridional profiles of eddy flux of momentum and heat by surface currents (Hansen and Paul, 1984).

Horizontal flow patterns are not steady and the time variable components can also transport heat. Hansen and Paul (1984) have dramatically demonstrated how eastern tropical Pacific "eddies" of 25-30 day periods (or "21-day" waves) transport heat toward the equator. Thus, depending upon over what time scale (or space scale) a mean field of horizontal advection is defined, there also can be a corresponding horizontal eddy heat convergence. The eddy transport is due to motions of spatial and temporal scales that are smaller than those of the mean motion and mean temperature. Figure 4 is the horizontal eddy momentum and heat fluxes measured by drifters in eastern Pacific in the 1978-1982 period. Convergence of the eddy heat flux, in the absence of mean advection and vertical diffusion, would cause a rise of SST of 2.5° C per month near the equator. Figure 4 demonstrates that an understanding of both low frequency (seasonal) and "eddy" (high frequency) heat convergence processes are required. The large-scale temperature gradients and surface flows are seasonally dependent, as are the mesoscale or "21-day" waves which carry the eddy heat fluxes. During the 1982-83 warming these waves were much reduced and so would be the eddy heat flux. Within the existing TOGA thermal measurement program (USTOGA 3, 1984), the eddy processes are not resolved by the large-scale geostrophic flow, thus direct measurements of flow which resolve the spatially-varying statistics of the 10-30 day period fluctuations are also essential to testing the horizontal advection hypothesis.

4. *The second hypothesis - The vertical turbulent flux*

The detailed discussion of the vertical mixing hypothesis is best done in the context of the surface heat balance equation. In the usual hydrodynamic notation, the heat content evolution of the very near surface layer of depth h

$$c\rho\,[\partial_t <T> + \vec{U} \cdot \nabla <T>] = Q_o - Q_{-h}\,. \tag{1}$$

The net surface heat flux is Q_o, the sum of the turbulent flux and radiative fluxes; at depth $z=-h$, these are Q_{-h}. The vertically-integrated temperature is $<T> = \int_{-h}^{0} T dz$ and $\vec{U}$ is the horizontal velocity averaged over depth h. We choose h to be shallower or equal to the depth of the daily thermocline, so that $c\,\rho\,\partial_t <T>$ is the change of heat content of the daily thermocline. The amplitude of the daily cycle of SST is between 0.2° C and 1.0° C, and the daily heat wave seldom penetrates deeper than 20 m (although daily variations have been measured at some locations at 30 and 40 m depths). In the above expression, we have neglected the effect of vertical advection near the surface, where w=0 and the heat flux convergence due to $<\nabla \cdot (c\rho\vec{U}'\,T')>$, where $\vec{U}'$ and T' are the deviations of the velocity and temperature from their respective vertical means (this latter can be shown to be a valid neglect of terms compared to the retained terms from moored array observations in the tropical Pacific [Imawaki *et al.*, 1987]). Following the vertically averaged motion, $(\partial_t + \vec{U} \cdot \nabla) <T> \equiv d<T>/dt$ is the Lagrangian rate of heating.

The hypothesis expressed by Newell (1986) states that the warm episodes are approached during the condition where, on a monthly time scale, the net flux $Q_o \simeq 0$, $d<T>dt \simeq 0$ and the net turbulent flux and radiative flux at the base of the daily thermocline Q_{-h} is much reduced from its usual value. That such conditions cannot occur on a daily basis is obvious, and a detailed analysis of the daily cycle can be shown to offer a technique evaluating the monthly average of Q_{-h}, the turbulent flux at the base of the daily thermocline.

Consider now a measurement which can resolve the daily cycle of heating and cooling of the upper 15-20 m of the water column following its mean motion. Following Imawaki *et al.* (1987), integrate equation (1) from local time 6:00 to 18:00, and again from 18:00 to 6:00, the morning of the next day. The heat budget equations are, with D designating the day time and N the night time averages, respectively,

$$c\rho\left(\frac{d\langle T\rangle^D}{dt}\right) = Q_o^D - Q_{-h}^D \text{ and } \left(\frac{d\langle T\rangle^N}{dt}\right) = Q_o^N - Q_{-h}^N . \quad (2)$$

Now subtract the nightly average from the daily average, thus

$$c\rho\left(\frac{d}{dt}\langle T\rangle^D - \frac{d}{dt}\langle T\rangle^N = Q_o^D - Q_{-h}^D - Q_{-o}^N + Q_{-h}^N \quad (3)$$

Imawaki *et al.* (1987) show that since the latent, sensible and long-wave radiation components of surface heat flux do not change appreciably through any one 24-hour period, and since most of the turbulent flux occurs at night (Moum and Caldwell, 1985), equation (3) can be rearranged to give,

$$\overline{Q_{-h}} = \overline{Q_{-h}^N} - \overline{Q_{-h}^D} = c\rho\,[\frac{d}{dt}\overline{\langle T\rangle^D} - \frac{d}{dt}\overline{\langle T\rangle^N}\,] - \overline{Q_{short}} . \quad (4)$$

where the overbar denotes a monthly ensemble and Q_{short} is the monthly mean, short-wave solar flux. Equation (4) was used by Imawaki *et al.* (1987) to estimate the turbulent flux at the base of the daily thermocline in a number of locations where accurate high vertical resolution temperature time series have been collected in the equatorial Pacific in the 1983-85 period. Figure 5 displays a 15 month time series of $\overline{Q}_{-h}$ from 120° W, 0° N. This estimate agrees favorably with the turbulent flux estimated by microstructure measurements: it is between $70 w/m^2$ and $160 w/m^2$. Thus, if an accurate measurement can be made of the daily cycle of $d\langle T\rangle/dt$ the temperature change following the water, an estimate of the space and time variability of the turbulent flux can be made, and the second hypothesis of warm anomaly can be tested ($\overline{Q_{short}}$ is obtained to an estimated accuracy of ± 10 w/m^2 within other TOGA-supported programs). This estimate is essential to testing the hypothesis of the manner in which SST patterns are produced and as shown in Figure 5, significant long period changes do occur.

5. *Tropical circulation model and data intercomparisons*

One of the principal TOGA objectives is to model the ocean circulation with sufficient realism that the SST fields can be predicted accurately over the tropical oceans. Presently, the best success is achieved in modeling the time variability of the depth of the main thermocline or sea level (Katz and Witte, *ed.*, 1987). This success can be reported because there have been extensive observations of the thermal structure and sea-level in the tropical Atlantic and Pacific, by which intercomparisons can be made. The best agreement is in the area of ± 5° from the equator. It appears that only low vertical resolution adiabatic changes of ocean structure, forced with a realistic wind field, are required to achieve this agreement.

The prediction of SST, in contrast, requires realistic modeling of both surface circulation and vertical mixing. Horizontal mixing processes can be explicitly resolved to a much better degree of realism than vertical mixing by eddy-resolving models (Katz and Witte, *ed*, 1987). Firstly, vertical mixing directly affects SST prediction because heat is directly transferred from warm surface waters to cold water at deeper levels. Secondly, for a fixed wind field the strength of surface currents, and hence the strength of SST advection, depends crucially on how vertical mixing is parameterized in a model. If vertical mixing is strong, momentum imparted by wind is distributed over a deep column and weak surface currents result. Weak vertical mixing results in strong surface advection. In present thermodynamically active models, vertical mixing and mean surface circulation shear are also inexorably related through a local gradient Richardson number parameterization. Local winds are expected to produce a large portion of the local shear and local heating is expected to produce a large fraction of the upper ocean vertical

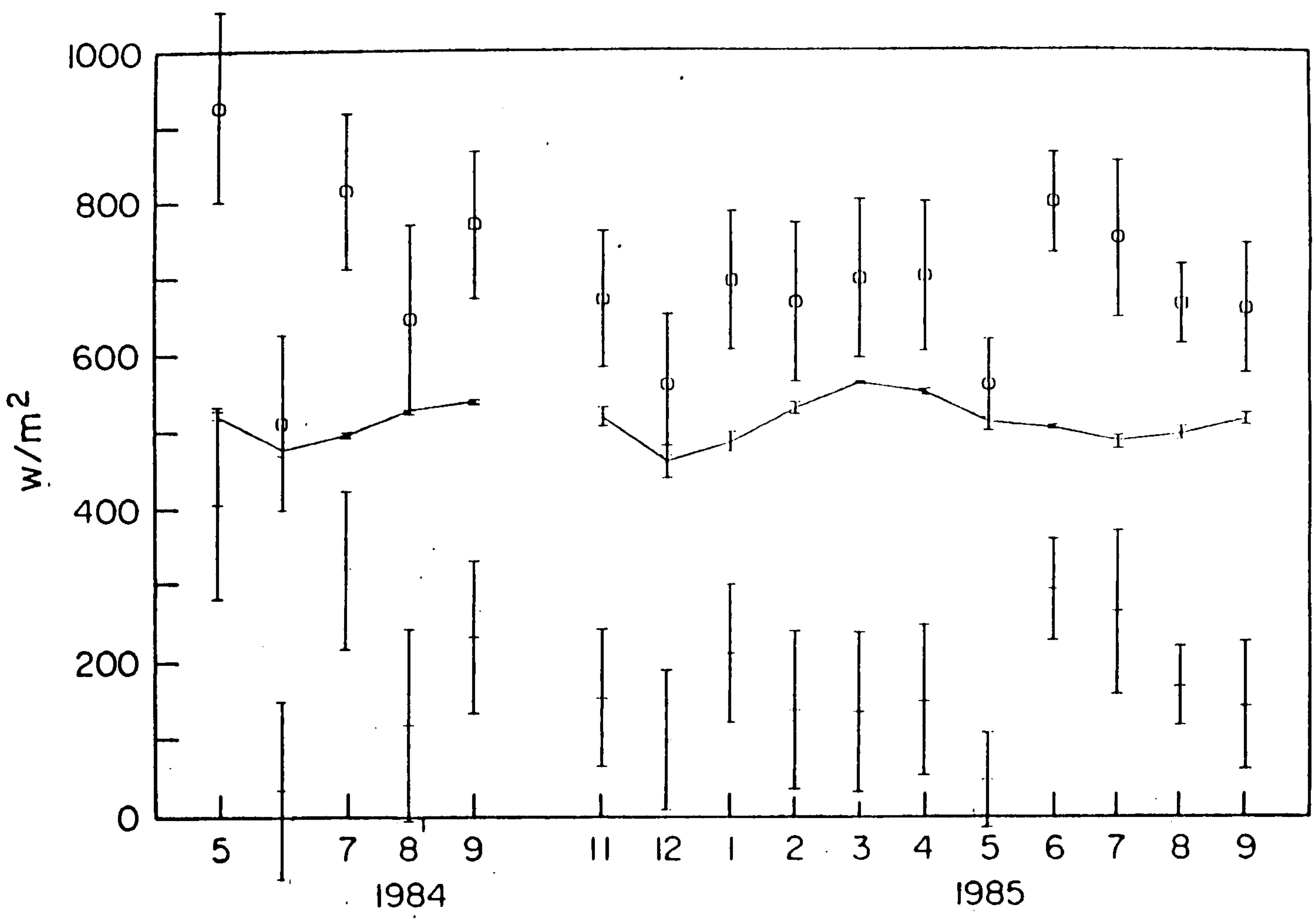

Figure 5. Time series of monthly mean estimates of heat budget in upper 20 m at 0° W, 125° W. The day-to-night differences of $c\rho[\, d\langle\bar{T}\rangle^D - d\langle\bar{T}\rangle^N \,] / dt$ (open circles), the net solar irradiance $\bar{Q}^D_{short}$ (solid line) and the night-to-day differences of turbulent flux $\bar{Q}^N_{-h} - \bar{Q}^D_{-h}$ (crosses) are shown. Abscissa is time in months from 1984 to 1985 (Imawaki *et al.*, 1987) [see equation 4 in text].

stratification. Thus, verifying the surface circulation in a model against data would be both an indirect test of the adequacy of mixing parameterization as well as the realism of the local air-sea fluxes supplied at the surface. Verification of these conditions at one or two points, as can be done from current meter data on the equator (which continues to be available in TOGA) is not sufficient because not enough degrees of freedom exist in the few profiles of currents or stratification to form crucial tests: discrepancies could be due to either mixing or air-sea interaction inadequacy. A pan-Pacific field of surface currents under a large variety of air-sea interaction conditions is required to span a sufficiently wide parameter range of heating, wind-stress and Coriolis force to form critical tests.

With the Equatorial Pacific Ocean Climate Study Program (EPOCS/NOAA), investigators are regularly producing operational model-generated ocean surface current fields from the Pacific. One of the important uses of a well-calibrated and well-resolved surface current data set is the evaluation of the quality of model-generated fields. It is expected that Climate Analyses Center (CAC/NOAA) will continue running the Geophysical Fluid Dynamics Laboratory (GFDL/NOAA) model of the tropical Pacific on an experimental operational basis for the next three years. Tests of the use of the thermal and density data acquired in TOGA in initialization and verification of the model are underway. Scientists at the University of Miami are presently carrying out a comparison of modeled surface current maps with EPOCS surface drifter motion, and will propose to extend this work with the more extensive pan-Pacific data. Scientists at Atlantic Oceanographic and Meteorological Laboratory (AOML/NOAA) are developing methods for assimilation of drifter data in models.

Besides use of surface circulation in operational models, TOGA research mode models require evaluation. Research models run with more complete forcing fields than operational models, because post-GTS surface marine observations have gone into producing the fluxes of heat and momentum. For example, research mode models are integrated forward in time with a number of different vertical and horizontal resolutions and different parameterizations of vertical and horizontal mixing. The research objectives are to use the best surface forcing fields and understand what internal model parameters are most crucial in producing realistic surface currents and realistic surface heat advection - or what ocean process most crucially affects SST prediction.

In summary, the principal scientific objective of the model-data intercomparisons is to test existing operational and research model surface currents against observations, and learn how to use surface current and SST observations to enhance the model's ability to both advect heat in a realistic fashion, as well as to produce more realistic SST maps.

6. *Regional studies of circulation*

The pan-Pacific scientific objectives are to test the competing hypotheses of heat advection and mixing in the surface layers of the tropics. Model intercomparisons with observations will be made. These data sets on ocean velocity and surface temperature, however, are also important for describing and studying a number of more local oceanographic circulation phenomena. To address these in detail, the tropical Pacific basin is divided into eastern, central and western parts. Specific scientific proposals for data analysis and interpretation in these areas will be submitted to regional national agencies and comprise part of the scientific work statements from the principal investigators. A summary of the regional scientific questions and objectives are given below.

6.1 *Eastern Pacific*

6.1.1. *Heat advection in the "Cold Tongue"*

A most salient feature of the sea surface temperature of the tropical Pacific is the development of a region of relatively cool surface water extending from the coast of South America to and along the equator to 150° W or farther during most Austral winters. In El Niño events, this cold tongue fails to develop in the usual way. A study of variations of the heat budget on annual and interannual time scales has been done using drifter data from EPOCS (Figure 6). This study indicates that zonal advection is more important than meridional advection in the region, but this result is limited by sparse data to an area integral result. Finer resolution made possible by more data might yield a different picture. Other results with EPOCS drifter data indicate that meridional advection is of major importance close to the equator (Fig 7).

6.1.2. *Equatorial divergence*

Closely related to meridional advection near the equator is the divergence of Ekman transport. Wind-driven surface current theory indicates, and drifter data from the EPOCS and NORPAX programs confirm, the existence of the divergence of surface currents near the equator under normal wind regimes. Using EPOCS drifter data, it has been possible to estimate climatological divergence and upwelling in the eastern Pacific (Figure 8). Given adequate data, such estimates could be made on an event and time series basis. Present evidence suggests that during El Niño and related warm events, the surface equatorial divergence is much reduced.

6.1.3. *Shear-instability of waves*

From June to October of most years, instability of the shear between the EUC and that part of the SEC lying north of the equator or the shear between NECC and SEC leads to generation of cusp-shaped waves on the equatorial SST front lying north of the equator. The principal feature of the surface currents associated with these waves ia s train of anticyclonic eddies, primarily in the Northern Hemisphere, with eddy velocities of up to 100 cm/s. Hansen and Paul (1984) found that these eddies are instrumental in effecting an equatorially convergent heat transport in the surface layer, counteracting a substantial part of the mean heat transport divergence by the equatorial upwelling and meridional advection (Figure 7). TROPIC HEAT program is proposing an intensive study of the instability waves with current meter moorings and other instrumentation in 1989-1990. If that study is funded, the pan-Pacific drifter project will provide information about the large-scale environment in which it is done, and the statistics of this eddy field over a number of years. Beyond that, drifters have been found to be a particularly sensitive detector of the occurence of these waves and, more emphatically, of their non-occurence. The occurence of the waves west of about 150° W is undocumented.

6.1.4. *Eastern Pacific Warm Pool*

Although most references in the TOGA context are to the western Pacific "Warm Pool," the eastern Pacific contains a secondary warm pool. This warm pool, extending seaward a few thousand kilometers from the coast of Ecuador or Colombia to Mexico, contains surface waters as warm (28–30° C) as those of the western Pacific, but more limited in extent, and especially in depth. It is therefore more prone to variations. One view of El Niño development is that it is a major expansion of the eastern Pacific warm pool, expecially to the south and west. The region of this warm pool is also the generation region for eastern Pacific hurricanes, and it is a major pelagic fishing area. The processes that affect the maintenance and variations of this warm pool are an important part of TOGA in the Pacific sector.

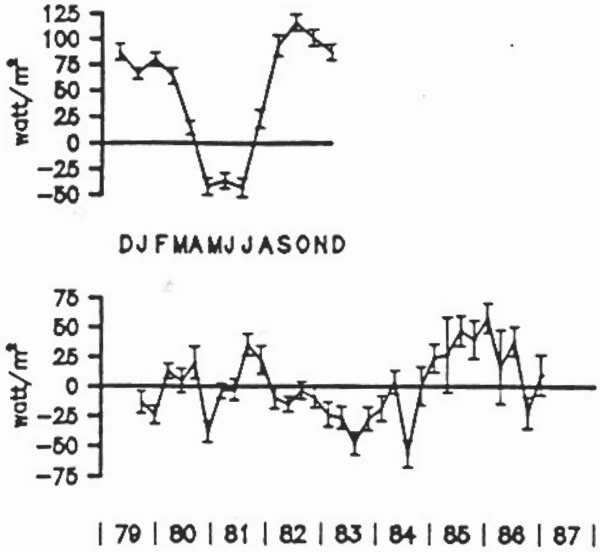

Figure 6. Lagrangian net heating rate estimated from EPOCS drifting buoy and XBT data in the region 0–10° S, 90–130° W.

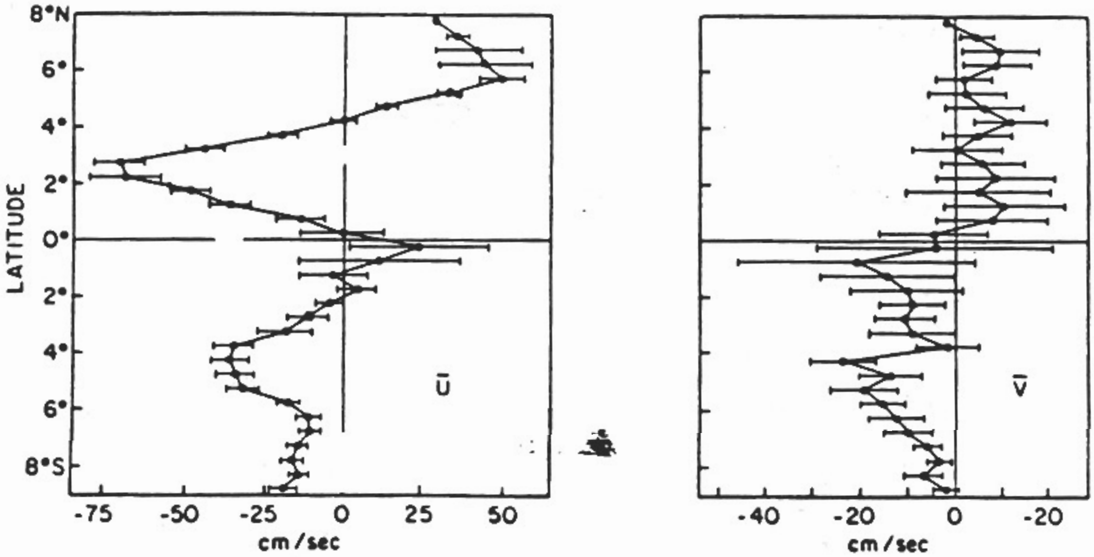

Figure 7. Meridional profiles of average zonal and meridional surface currents in eastern tropical Pacific (Hansen and Paul, 1984).

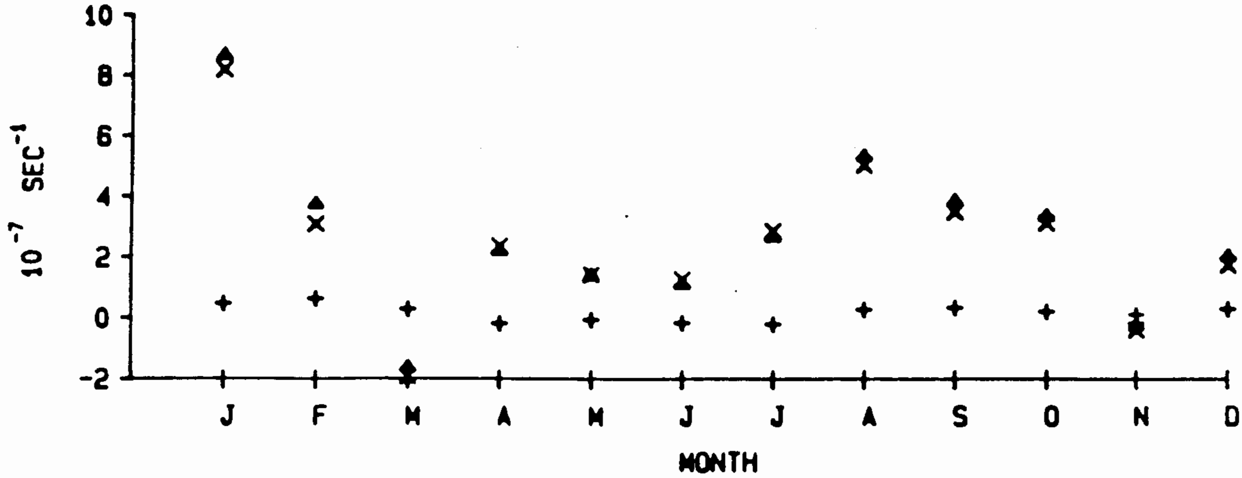

Figure 8. Annual cycle of zonal (+), meridional (x), and total (·) divergence in the region ± 1.5°, 80° W to 110° W. (Hansen and Paul, 1987).

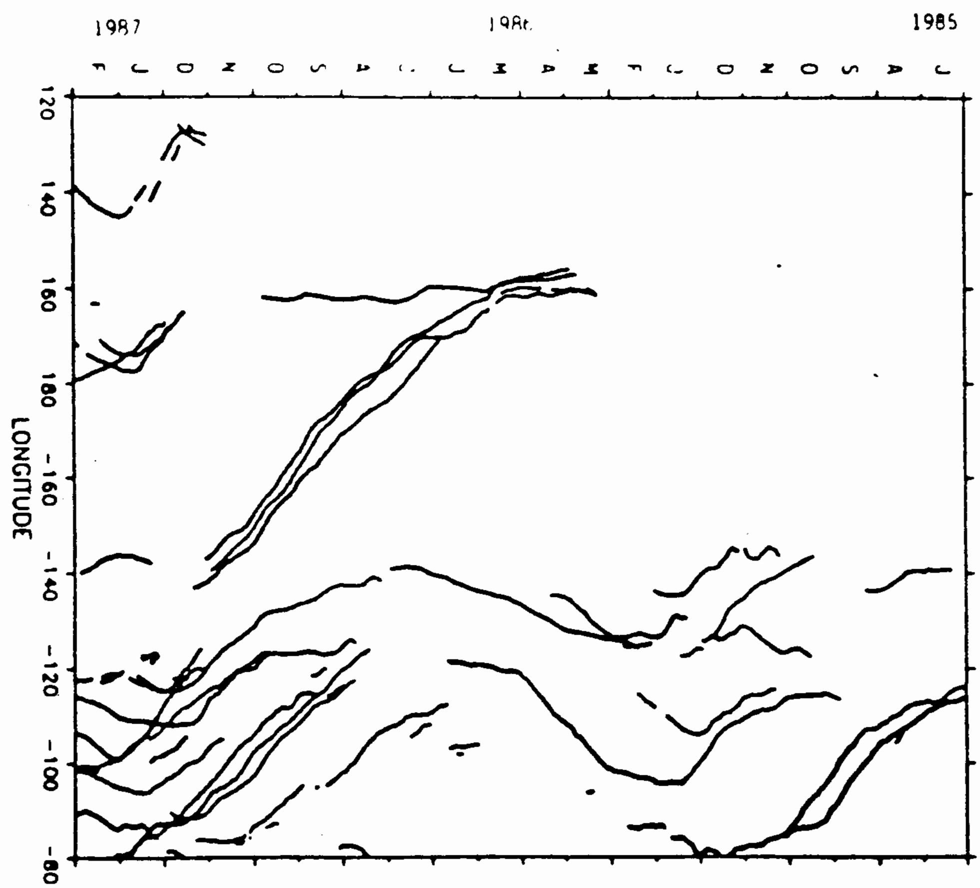

Figure 9. Zonal displacements of drifting buoys in latitude band of the NECC (4° 10° N). Note the annual cycle of NECC east of 140° W. (Hansen *et al.*, 1987).

6.1.5. *The North Equatorial Countercurrent*

A major source of warm water for the eastern Pacific warm pool and for the eastern Pacific generally, is the NECC. This is a major ocean current that extends one-third of the distance around the earth, and in the east undergoes a complete seasonal modulation (Figure 7). Increased focus on the NECC is being planned within EPOCS. Drifter deployments included within the pan-Pacific projects will become an integral part of that program. The special ability of drifters to provide information about spatial patterns in surface currents will be exploited to determine the extent, speed and scales of variability in the NECC. Model results of Philander and Siegel (1985) indicate greatly enhanced flow of the NECC in the eastern Pacific during 1982, but measurements to confirm this finding are few. In the western and central Pacific, variations of the NECC can be inferred from island sea level records. In the eastern Pacific, islands are few; satellite altimetry offers some hope, but drifters are an established method of making the observations needed for understanding and testing the ability of models to simulate this current.

6.1.6. *Eddies generated by coastal winds*

Recent observations indicate that strong winter winds flowing through topographic lows in the central American Cordillera and across the coastline produce an unusual kind of coastal upwelling, especially in the vicinity of the Gulf of Tehuantepec and Gulf of Papagallo, and even in the Gulf of Panama. The upwelling disturbances evolve into eddy structures that can endure for many months and appear to propagate to the west. Freshly-upwelled water is readily detectable in satellite IR imagery, but within relatively short time the surface temperature signature of the eddies is lost beneath the eastern Pacific Warm Pool. Such eddies have been tracked with surface drifters over several months and 3000 km from the region of generation (Figure 10). These eddies are possibly a major source of variability in the North Equatorial Current to the west. Drifters appear to be a most appropriate tool for determining their occurrence and distribution.

6.1.7. *Currents off the coast of Peru and Ecuador*

Most surface current charts of the ocean indicate a Humboldt Current or Peru Current flowing northwestward generally parallel to the coast of Peru. This current is indicated to become the South Equatorial Current westward of about 100° W. Curiously no support of the existence of this current can be found in the tracks of EPOCS drifters. Results to date from EPOCS suggest that the currents off Peru and Ecuador are weak and variable, but have a slow westward or even southwestward drift. A distinct South Equatorial Current is encountered well offshore. The pattern of surface currents in this regions is of considerable importance in evaluating the possible influence of the Peruvian coastal upwelling on the eastern Pacific cold tongue.

6.2 *Central Pacific*

6.2.1. *SST anomalies*

During ENSO events, the normal seasonal development of the SST patterns across the entire Pacific are disrupted. In the central Pacific, these anomalies are the most effective in coupling to the atmosphere, because these SST changes can effectively "trigger" the onset of atmospheric low-level convergence of moisture and upper-level heating by enhanced precipitation. The east-west movement of the SST anomaly pattern is described in Figure 11, which shows the 28.5° C isotherm location in the equatorial band. If this movement is produced by currents, a net flow to the east - or at least significant weakening of the normal westward flow - has to occur. Such anomalous patterns have not yet been observed over the broad central Pacific. The pan-Pacific network offers the opportunity of obtaining a comprehensive description

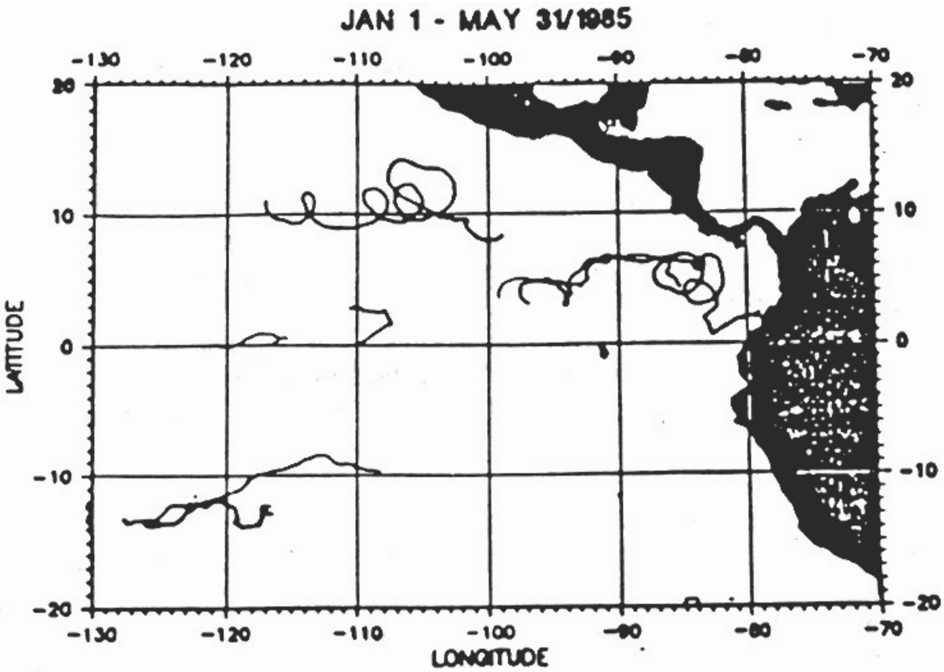

Figure 10. Mesoscale eddy near 10° N and possibly also near 5° N generated by coastal wind events (Hansen, private communication, 1987).

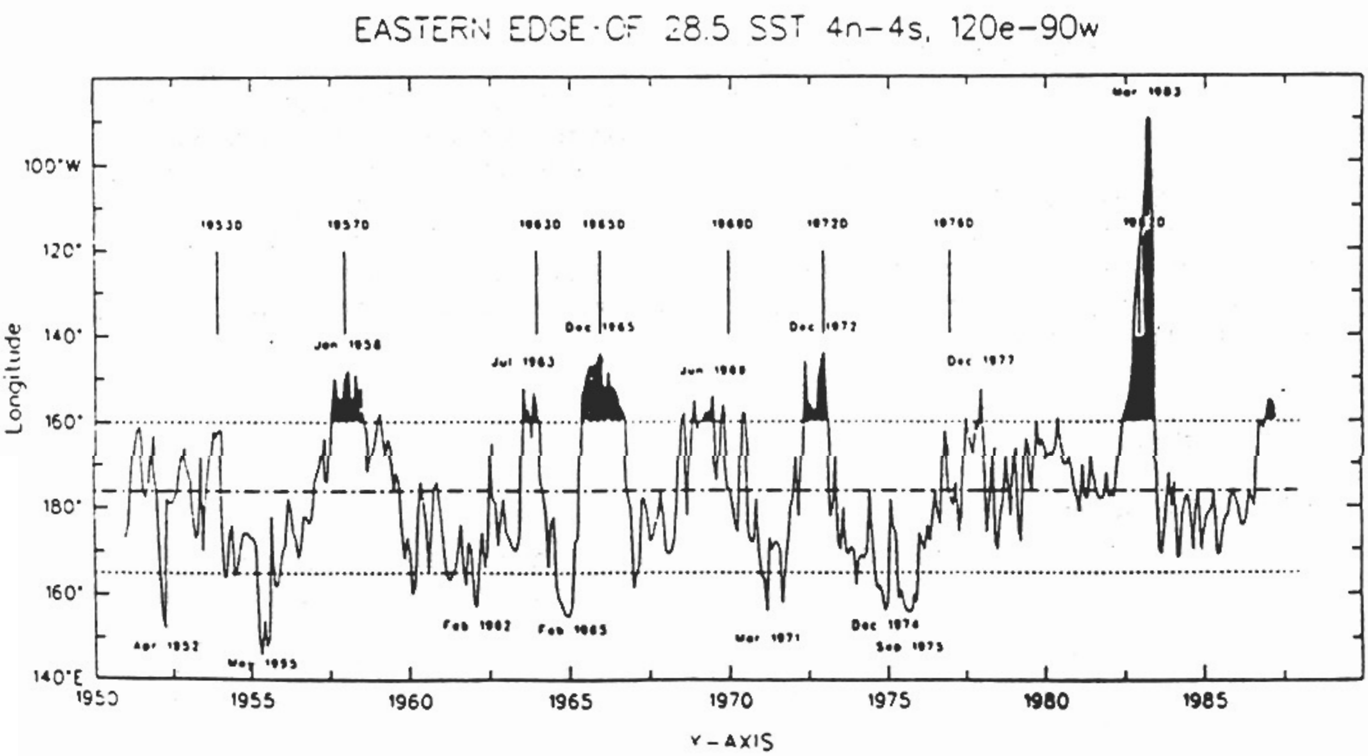

Figure 11. Longitudinal movement of the 28.5° C SST surface between 4° N and 4° S. El Niño events occur when the 28.5° C surface crosses 160° W (Diaz, 1987, private communication).

of these and other patterns important in ocean-atmosphere interactions.

6.2.2. *Equatorial mixing*

East of 140° W, a principal source of surface heat transport and variability is produced by "21-day" waves. In the central Pacific, a lower frequency energy band of 40 to 60 day oscillations is evident from current meter measurements (Knox and Halpern, 1982). The horizontal eddy energy in the central tropical Pacific is unknown. The importance in mixing momentum and heat by the tropical mesoscale has already been underscorerd in the development of the eastern cold tongue, and such an evaluation must also be made in the central Pacific. Circulation measurements across the Pacific can provide a direct assessment of the importance of eddy mixing in the entire equatorial zone and an effective test can be formulated as to whether numerical models parameterize or resolve this mixing correctly.

6.2.3. *Equatorial divergence*

Easterly winds are equally strong across the eastern and central Pacific. The eastern Pacific exhibits what is believed to be wind-driven equatorial divergence, which results in the upwelled cold tongue. The manifestations of the cold tongue in the central Pacific are not as obvious, yet the surface divergence is presumed to exist due to the strong easterly winds. There are virtually no surface circulation measurements from which to compute or describe a surface divergence pattern.

6.2.4. *The wind-driven currents*

The ship meteorological observations in the central Pacific are the most dense because the merchant ship traffic between North America and Australia transits this region. In this area of the ocean, the most realistic test of the tropical wind-driven ocean currents can be made because the winds are the best resolved, as are the geostrophic currents by VSOP-XBT measurements. The geostrophic currents north of the equator imply a southward surface flow toward the equator, while historical ship drifts and EPOCS buoy motion imply a northward component (Figure 12). Thus, the wind-driven meridional component of the surface flow in the central Pacific must be larger and of the opposite sign than the geostrophic flow. Drifter movements can describe the strength of the surface circulation, and subtraction of the geostrophic flow estimates produced by TOGA thermal analysis will produce a picture of the wind-driven currents.

6.3 *Western Pacific*

6.3.1. *The large-scale circulation*

The circulation of the western Pacific is comprised of the confluence of a number of extensive current systems. The SEC runs northwestward along the north coast of New Guina, may cross the equator and near 5° N, 130° E, veers offshore or retroflects into the NECC. The SEC disappears during the period November to April and is replaced by the southeastward flowing New Guinea Coastal Current. This eastward flow appears to be connected in ship drift maps to the SEC which extends from the Solomon Islands east to near 155° E. The westward flowing NEC divides at the western boundary near 12° N; part flows northward into the Kuroshio and part flows southward as the Mindanao Current. Part of the Mindanao Current flows into the Celebes Sea, turns counterclockwise, and flows out through the Molucca Sea merging with the other part which veers offshore into the NEC near 5° N, 130° E. The confluence zone of the Mindanao Current and SEC at 3° N forms the origin of water flowing eastward in the NECC which crosses the whole Pacific Ocean. These currents of the western equatorial Pacific are very swift, have enormous transports (e.g., $40 \times 10^6\ m^3/sec$ for NECC) and large seasonal and interannual variations.

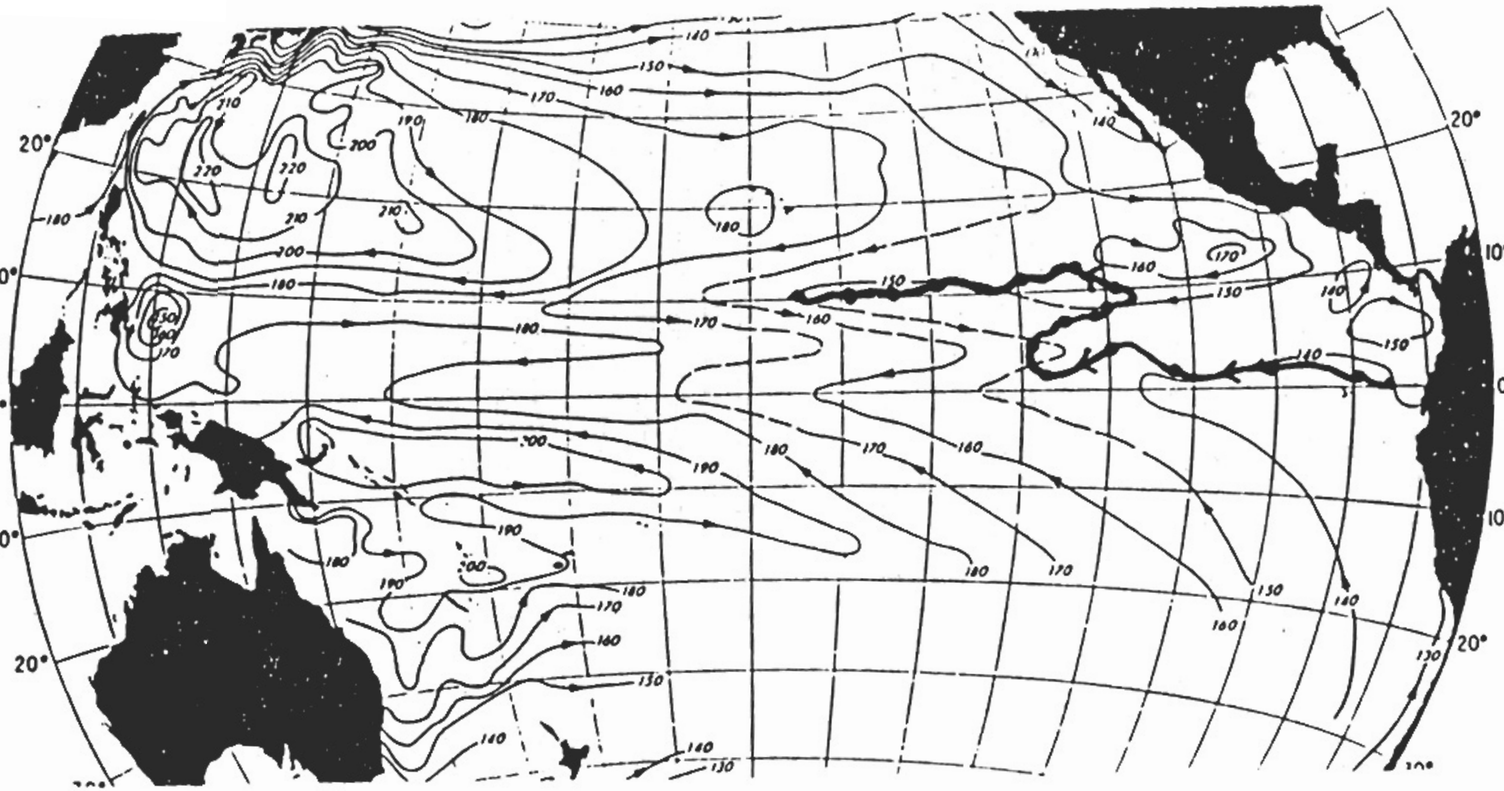

Figure 12. The geopotential anomaly contours (with arrows) relative to 1000 db for November-December (Wyrtki, 1975), and typical track of an EPOCS drifting buoy. [Hansen, private communication, 1987]. The buoy is deployed on the equator at 85°W and travels northward and westward to 11°N, 154°W in 320 days (last 160 days without a drogue). (Dots mark 20 day displacements.) The implied 1000 db reference velocity is to the south and buoy drift is to the north.

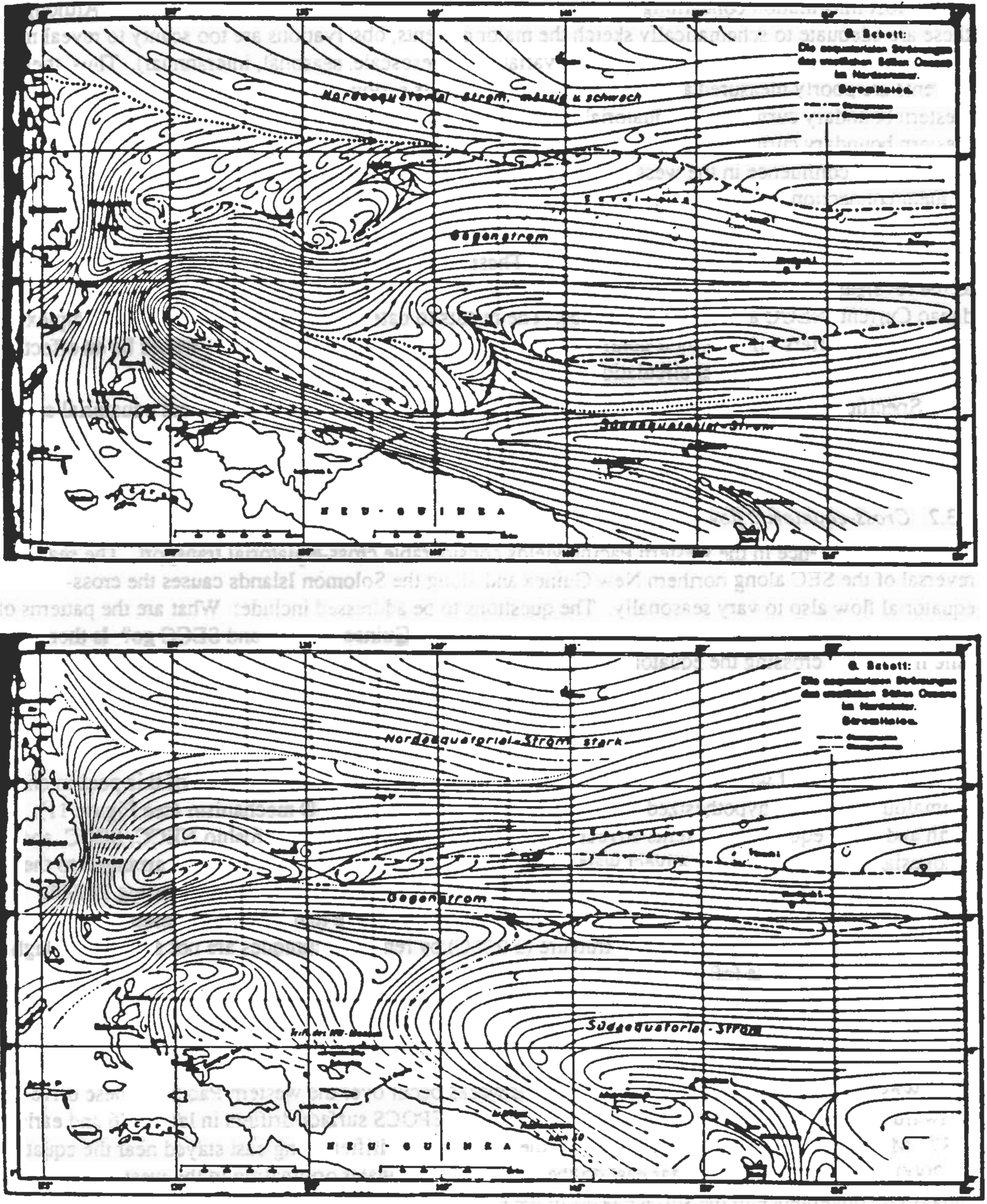

Figure 13. Schematic diagram of surface currents in Western Tropical Pacific based on ship drift measurements (Schott, 1939). Top panel shows June-Aug and bottom panel shows Jan-March periods.

Figures 13 displays this circulation schematically in the opposing seasons of the monsoon.

Most information concerning the surface circulation comes from historical ship drifts. Although these are adequate to schematically sketch the major currents, observations are too scanty to reveal much about the continuity of the currents, or their variations (mesoscale, seasonal, interannual). Thus, these currents are poorly measured and our knowledge of them is seriously deficient. The interaction of western boundary currents and equatorial circulation is unknown. What is the continuity between western boundary currents and the NECC and the Indonesian throughflow? The Mindanao Current and SEC cause a confluence in the west. What is the pattern of their retroflection into the NECC and its subsequent connection to the NEC?

Recently a few drifting buoys have been tracked in the equatorial western Pacific (Cresswell, Lindstrom, Hansen, personal communication). These have revealed interesting features of the flow such as the reversal of the SEC north of New Guinea (Figure 14), and a cyclonic gyre consisting of the Mindanao Current, NECC and NEC (Figure 15). The results to date suggest that because of the complex spatial patterns, drifters - due to their combined space-time sampling characteristics - would be an effective tool in learning about general circulation features and swift western Pacific systems.

Specific goals are to measure, describe and understand the western boundary and equatorial circulation in the western Pacific.

6.3.2. *Cross-equatorial flow*

The confluence in the western Pacific yields considerable cross-equatorial transport. The seasonal reversal of the SEC along northern New Guinea and along the Solomon Islands causes the cross-equatorial flow also to vary seasonally. The questions to be addressed include: What are the patterns of this flow at different seasons? Where does flow in the New Guinea Current and SECC go? Is there a time mean flow crossing the equator in the West?

6.3.3. *Western Pacific warm pool*

A large pool of warm water exists in the western Pacific. Eastward advection of this pool in an anomalous fashion is hypothesized to be an important part of the ENSO mechanism (see Figure 11). The north and south equatorial currents advect warm water into the pool; the Kuroshio NECC, SECC, and Indonesian Sea's throughflow advect water out of it. How is this complex circulation arranged so the warm pool is maintained in normal years, and how does it spread advected eastward during El Niño years? What is the short and long-term variability of its near-surface temperature? Present remote techniques of determining the warm pool structure (± 0.7° C) by remote techniques are not accurate enough for the TOGA requirements (±0.3°).

6.3.5. *West wind bursts and eastward jets*

Westerly wind bursts with period of several weeks occur over the western Pacific. These drive an eastward jet along the equator as observed by several of EPOCS surface drifters in late 1986 and early 1987. Most drifters going west diverge from the equator; one drifter going east stayed near the equator for 2000 km (Figure 15). How far east do these jets carry the water originating in the west? What is the equatorial convergence in the surface layer in the eastward jet?

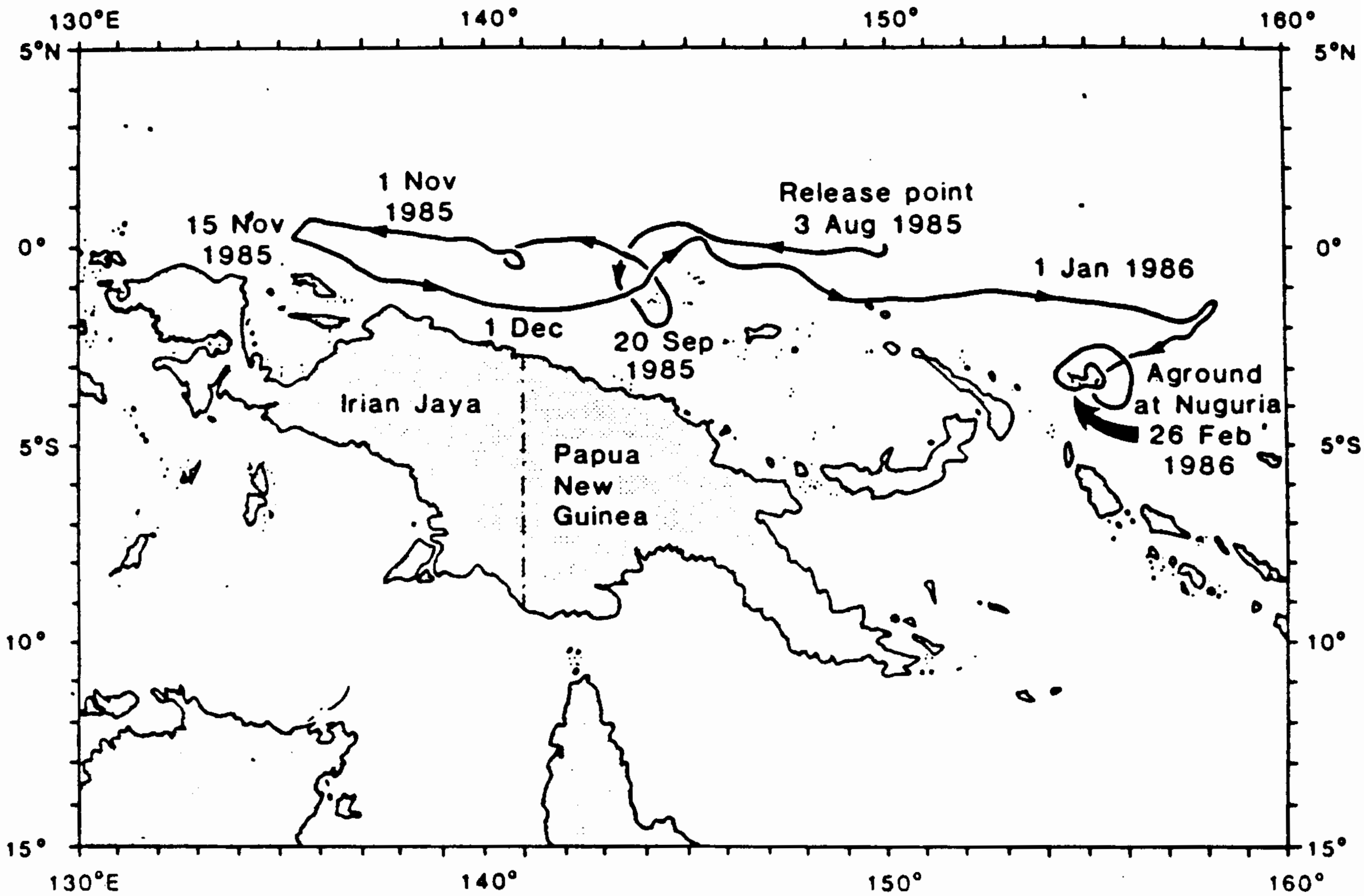

Figure 14. Trajectory of a satellite-tracked buoy in the western Tropical Pacific Ocean showing the seasonal reversal of the SEC north of New Guinea (G. Cresswell and E. Lindstrom, personal communication). This seasonal switch in current direction agrees to a large extent with historical shipdrift data for the same region.

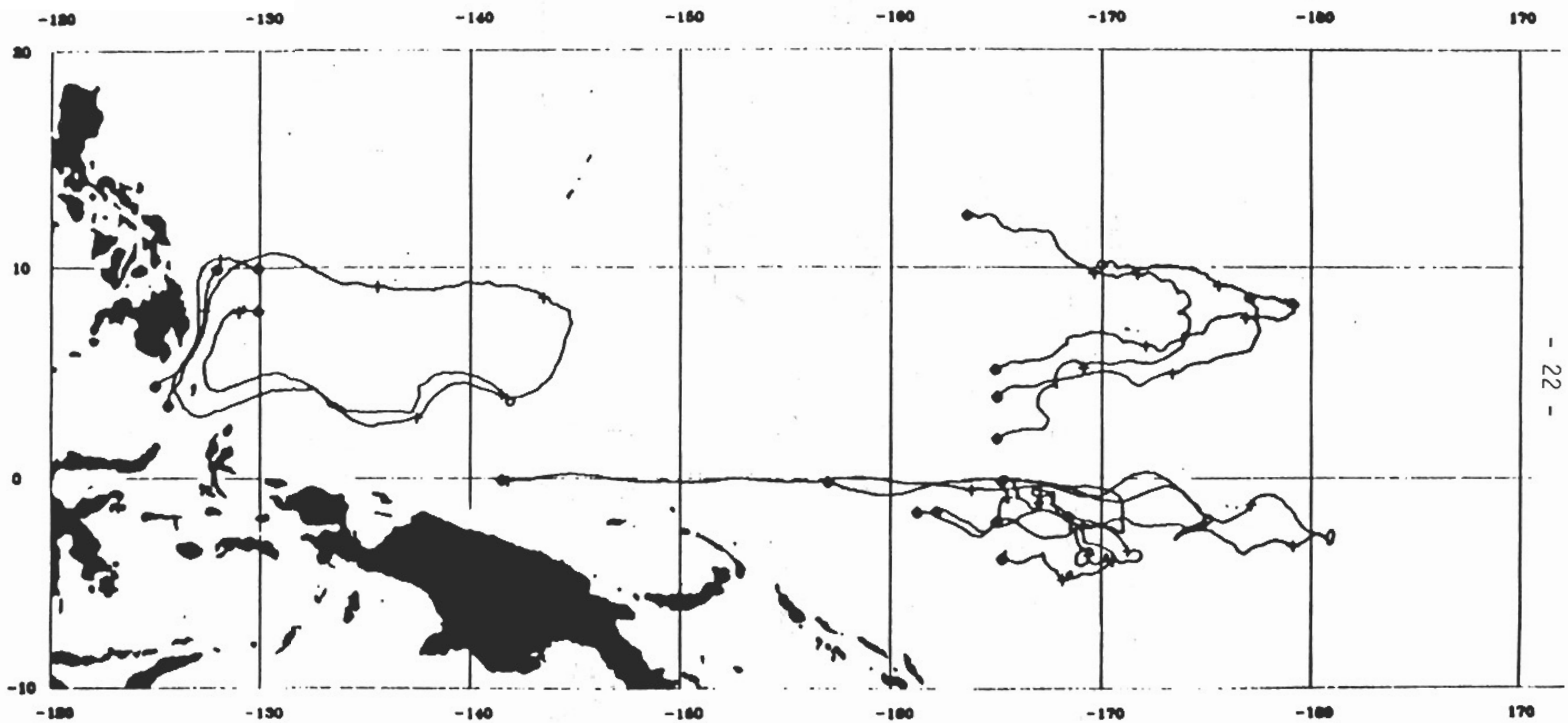

Figure 15. Trajectories of drifting buoys deployed in western equatorial Pacific during Fall, 1986. Closed circles denote initial location, plus signs at first day of each month (Hansen, private communication, 1987).

7. *The Lagrangian Drift Experiment*

7.1 *Overview*

The scientific goal of the pan-Pacific Surface Current Study is to provide a critical test of the competing hypotheses of advection and mixing as key factors in tropical Pacific warming cycles.

The scientific objectives are to:

1. Produce accurate (± 0.3° C) maps of the monthly mean SST for atmospheric circulation modeling and climate monitoring.

2. Measure the large-scale surface transport of thermal energy across the tropical Pacific basin.

3. Describe and evaluate the role of the surface mesoscale field in transporting heat and momentum.

4. Determine the changes of heat budget of the daily cycle and its day-to-night differences. From this, using monthly mean short-wave flux data, estimate turbulent fluxes at the base of the daily thermocline.

5. Determine what are the time-dependent, wind-driven surface currents in the tropics.

6. Provide a data set for evaluating and testing numerical models of the tropical Pacific surface circulation both in real time and research mode.

Each regional area has more specific objectives to which the pan-Pacific data set will contribute. These are developed in individual proposals.

The technical objectives are to to:

1. Obtain a 2-3 year data set of Lagrangian drift at 15 m depth of the entire Tropical Pacific between 15° S and 15° N on a 2° latitude and 10° longitude resolution.

2. Obtain a selected number of 20 m daily temperature cycles.

3. Learn how to maintain a population of drifters in the desired resolution from ships of opportunity and research vessels. Develop a TOGA/WOCE plan for tropical surface current measurements for the 1990-1995 period.

4. Establish and maintain a testing and calibration program for accuracy of thermal sensors and current-following of drogues. Evaluate survivability of drogue configurations.

7.2 *Instrumentation*

The Lagrangian drifter is the only practical instrument with which the surface circulation can be measured over areas as vast as the tropical Pacific. Moored current meters can provide some sparse time series; present TOGA plans are to maintain these at 165°E, 140°W and 110°W on the equator. Satellite or island sea level and thermal field can yield only the geostrophic flow which, because of the strong wind-driven component, can be opposite to the meridional surface current component derived from the historical buoy and ship drift (see Figure 12). In the past few years, the cost of Lagrangian drifters has been reduced by a factor of two or three from FGGE type drifters (to less than 3000 U.S. dollars in lots of 100 or more). These have a small surface element to reduce wind and wave loads and a large, self-deployable subsurface drogue. Model and field calibration studies indicate their slippage through the vertically-averaged flow past the drag center of the drogue can be reduced to become as little as 1-2 cm/sec in the tropical wind-wave conditions (Niiler *et al.*, 1987). These are packaged in soluble card-board containers which release the drifter upon coming in contact with sea water, making deployment from ships of opportunity or air deployment practicable.

In the proposed experiment, the drogue center will be at 15 m depth. Two shapes of drogues will be used: a 3.5 m diagonal TRISTAR and a long holey sock. Figure 16 shows one proposed initial specifications of each configuration. These have identical drogue to surface float and tether drag area ratios and, according to the simplest hydrodynamic scaling, should have identical water-following characteristics. The water-following characteristics of each system, however, will be assessed in drifter calibration experiments (see Section 7.4). The reason for choosing the two shapes to be manufactured by at least two different commercial and/or scientific groups is to test various techniques of construction on the survivability of drifters at sea. At the conclusion of this study, recommendations can be made as to which system (or which combination) should be used for the TOGA/WOCE objectives in the 1990 decade. Today there simply is not enough statistical information on post-FGGE, low-cost drifters, to assess their survival efficacy beyond a 9-month period. A selected number of drifters will carry a small thermistor chain, with 4 thermistors as the tether line. The thermistor chain is required for determining the daily cycle of heating and cooling, and estimation of the turbulent flux near the surface. The data sampling in the tropics will be six to seven samples per 24-hour period, every third day.

In summary, the design objectives of the drifter configurations are:

1. Slip with respect to the theoretical drag center of the drogue should be less than 2 cm/sec in tropical wind, wave and shear conditions.

2. SST-system measurement accuracy of ± 0.1°C. The SST data message should be GTS compatible. When subsurface temperature is measured, required accuracy is ± 0.04°C.

3. Drogue theoretical drag center at 15 m with less then ±3 *m* vertical excursion in vertical shears of 2 cm/sec/m.

4. Drogue on/off indicator should measure if tether line has severed.

5. Report of the entire daily data set from each third day, is required.

The choice of a 2° *x* 10° scale for the resolution of surface currents is not entirely rational over the entire tropical Pacific, as we do not know what the coherence scales of Lagrangian surface currents are. The computation of the actual coherence scales of surface currents is one of the objectives of the study so

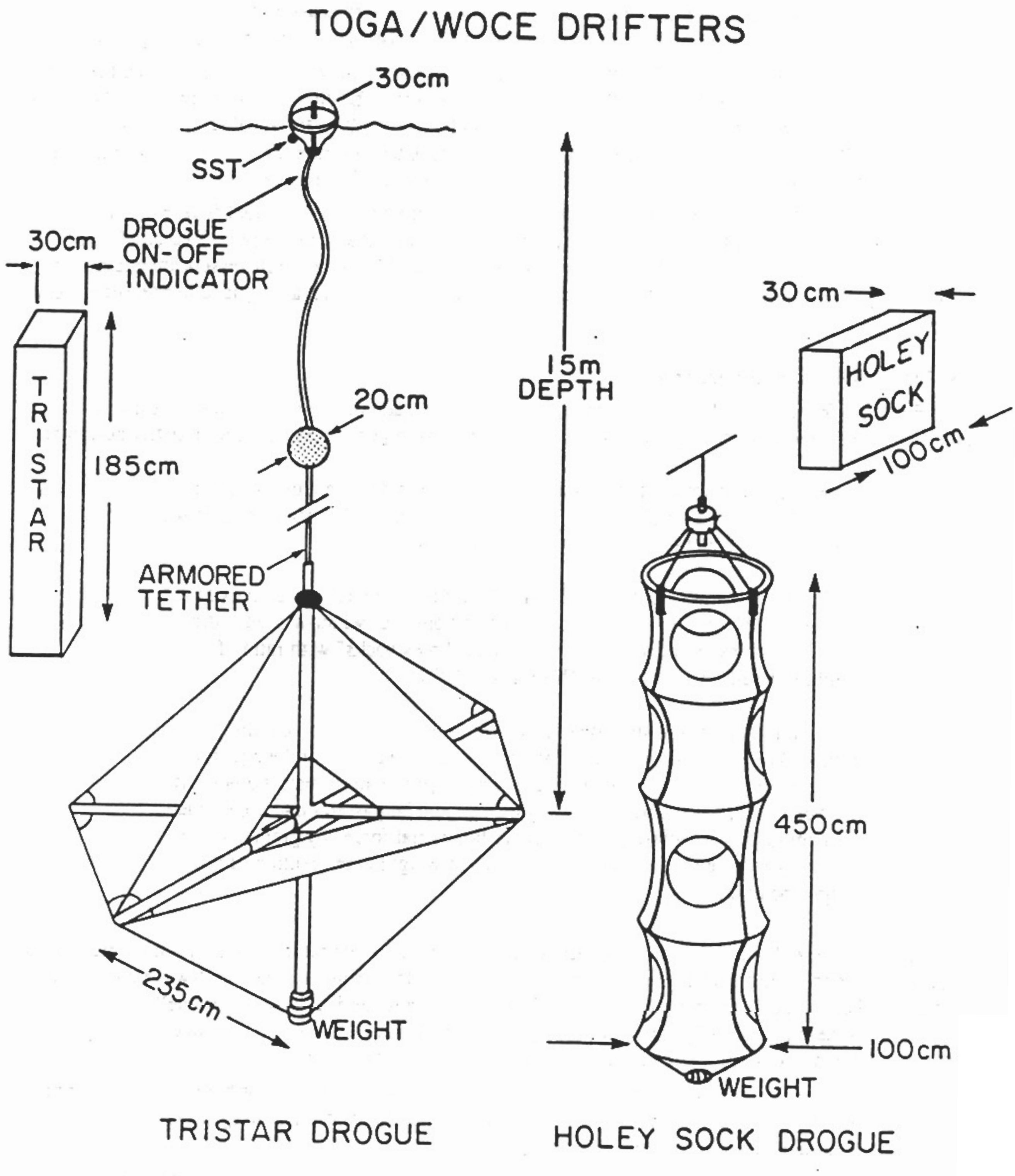

Figure 16. Schematics of ARGOS tracked, mixed layer drifters to be used in this experiment.

a more rational plan can be made for the 1990 decade. The guidelines are, of course, the coherence scale derived from subsurface temperature measurements, which on El Niño time scales are larger than $2^\circ \times 10^\circ$, but on seasonal time scales are smaller (USTOGA-3). In the eastern Pacific "21-day" eddy field, the coherence scale depends both upon direction and time because these eddies propagate westward.

The choice of the accuracy of current following capability (2 cm/sec) is based on the requirement of obtaining 10% accurate advection in a 20 cm/sec current system. The choice of accuracy of 0.1°C in SST is based on the requirement of obtaining temperature gradients on a $2^\circ \times 10^\circ$ resolution to 10% accuracy in the central Pacific. The accuracy of ± 0.04°C for subsurface temperature measurements is so the daily cycle of 0.4°C can be resolved to 10%, and daily heat storage change to 60 w/m^2 (or 10% of the signal).

The success of the design objectives will be assessed with field dat over the lifetime of this study. A number of drifter calibration experiments are planned to ascertain the absolute performance of all proposed systems in the field. A number of recoveries at sea from TOGA research vessels are planned to inspect progressive drogue deterioration patterns which do not register on a drogue tether on/off indicator.

7.3 *The drifter calibration experiment*

From the few field calibration studies which have been made in the mid-latitude conditions, we have found that to reduce the slip through the water, the most important parameters in drifter design are:

1) A large drag area of the drogue compared to the drag area of the tether and surface floatation elements. To keep the slip below 2 cm/sec in 10 m/sec winds, a drag area ratio of 50 is a minimum (Niiler *et al.*, 1987).

2) The drogue must not have excessive "sailing" character. Examples of drogues which can "sail" in laboratory conditions are "window shade" drogues, "circular cylinders (wind socks)," and "holey socks" with ratio of height to width in excess of 10 (Nath *et al.*, 1979).

3) An internal tension should be kept in the subsurface tether and drogue to reduce "kiting" in the presence of strong shears expected near the equator and keep the drogue drag center at the design specification (here ± 3 m). At the same time, a weak negative buoyancy should be passed on to the surface element to prevent aliasing of vertical to horizontal forces by gravity waves. This may require that a subsurface float and a weight at the bottom of the drogue be used.

It is emphasized that these design concepts, though based on laboratory model and numerical model studies, require thorough field evaluation. The behavior of a drogue in sheared, wind-wave conditions of the tropical Pacific cannot be reproduced in the laboratory or a numerical model very well, because of the inherent non-linear nature of hydrodynamic drag and the inability of models to simulate the complex, three-dimensional nature of the interaction of waves with the surface floats.

As part of the proposed experiment, field calibration tests of all drogue configuration used (or proposed) will be done so their performance in following water at the theoretical drag center of the drogue in the tropical conditions are quantitatively established.

A typical calibration study would consist of a deploymemt of drifters with attached neutrally-buoyant current sensors and pressure sensors on the top and bottom of the drogue. The attending vessel would record wind, wave and 2-3 m vertical resolution shear of currents between the current meters with the doppler acoustic log (or other means). The difference of flow measurement at the current sensors would also serve as a calibration for the doppler acoustic log. A number of studies in typical wind-wave and shear conditions within the tropical Pacific would be carried out. Intercomparisons among drogues released from the same site are not planned as drogues will separate quickly in the natural ocean turbulence, and their difference of performance cannot be assessed quantitatively because upon separation, these will be in different water masses of unequal vertical shear. Valid data can in principal be obtained from this kind of intercomparison, but multiple releases of different drifters will have to be made to gather sufficient statistics. Such experiments are difficult to manage in tropical open ocean conditions. Calibration studies are a requirement established by TOGA ad hoc panel on ocean drifters (WCP-103), but the accuracy requirements for this study are more stringent than recommended there. This is due to the requirements of measuring advection and vertical turbulent fluxes. A more detailed description of calibration studies is given in individual proposals.

7.4 *Deployment strategy*

The area of the Pacific which is of direct interest to the proposed surface circulation study spans from 80° W to 126° E, and 15° S to 15° N, and it contains about 230, 2° x 10° boxes. The objective of the experiment is to build up to a sampling array of drifters on that scale through a two-year period. The design life of the Lagrangian drifters discussed in section 7.2 is two years; however, very few drifters have existed that long. Presently, 9 months to 1 year lifetimes are common (Niiler *et al.*, 1987). Loss rates due to biofouling, capture by ship traffic and run-up on beaches are minor in the eastern Pacific, but are expected to be greater in the western Pacific because of the density of islands and local small ship traffic. Thus, the minimum number of drifters required for this study is 230, and conservative maximum is 450. The larger number is a conservative estimate based on experience gained already on typical displacements and survival rates with drifters in the tropical Pacific, and is nearly twice the sampling density we will require. Our strategy, therefore, will have to be an evolving one in which we begin with two 50-60 buoy deployments two months apart from VOSP and research vessels, and within two years work up to the desired density. Our estimate is that 350-360 drifters will be required to achieve this objective.

In understanding the deployment strategy and sequence, constant reference will be made to Figure 17 and the mean ship drift chart Figure 1. The deployment sequence will be as follows:

1) Four (4) drifters will be deployed in April 1988 along 110° W, 15°–3° S. These will drift westward and are expected to begin to fill the ship track gap between 110° W and 150° W. They are marked with squares on Figure 17.

2) Fifty three (53) drifters will be deployed in June-July (1988) period. These are marked with circles on Figure 17. They are expected to show a predominant east-west drift for the next two months, depending upon latitude.

3) Sixty (60) drifters will be deployed two months later, in Aug-Sept 1988. These generally are released at the deployment #2 locations, and are marked with triangles in Figure 17.

4) Continued releases will be made at the eastern boundary, the eastern equator and the western boundary, throughout the next eight months (total of 37 buoys). These releases are expected to be in areas where buoys are known to exit the most rapidly. Table I describes these releases.

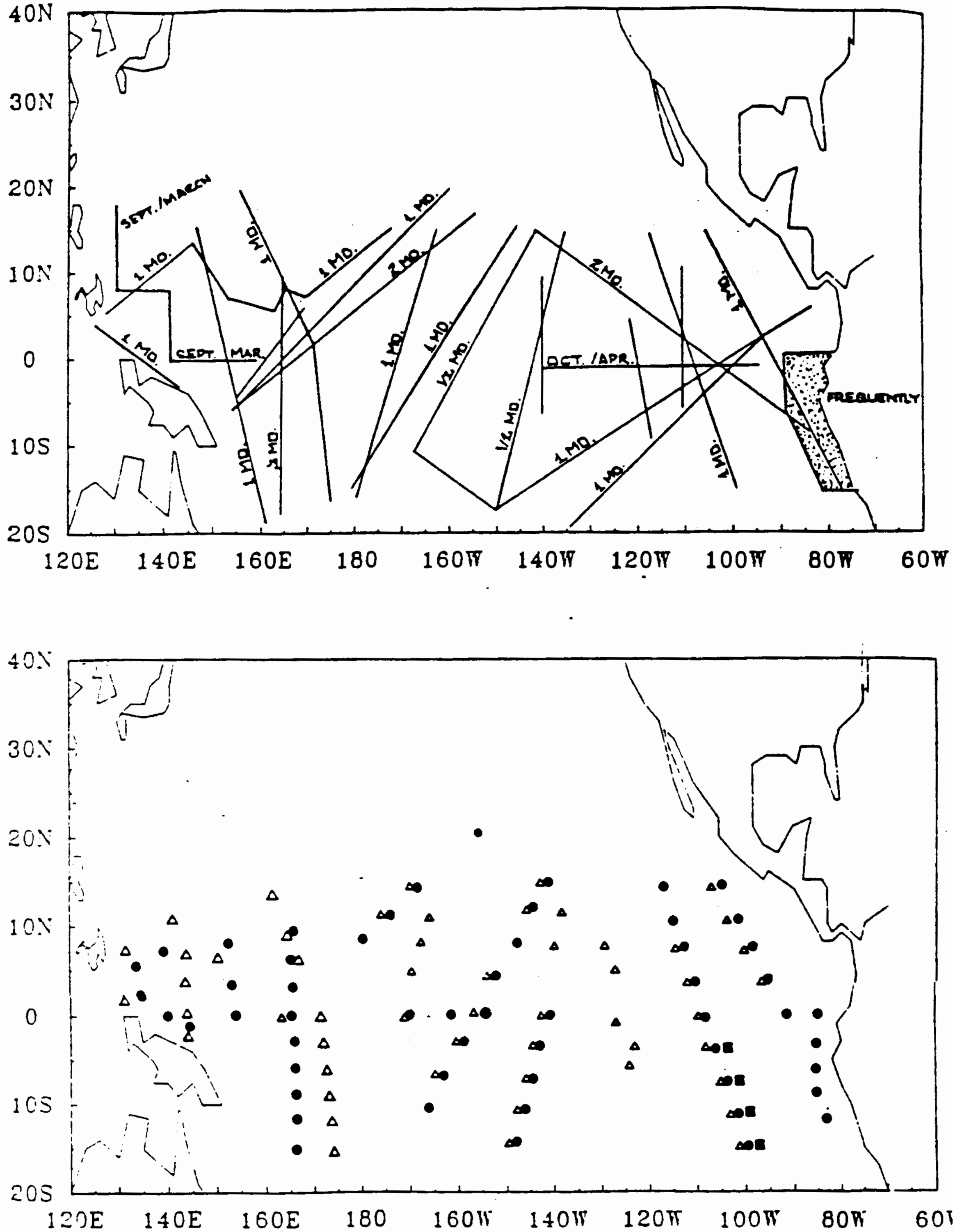

Figure 17. Ship of opportunity tracks available for deployment of drifting buoys with approximate frequency of occupancy (top panel). The deployment of locations for drifters April 1988 (squares), June-July 1988 (circles), and Aug-Sept 1988 (triangles). Additional deployments are planned for the western boundary, equatorial and eastern boundary areas. In the second year, deployments will be made from ship routes on top panel as empty regions occur.

Table I - Deployment vessels for drifting buoys. The symbol T is time measured in months.

CRUISE TYPE, SHIP NAME	NUMBER OF BUOYS, GENERAL AREA				
	June - July 1988	Aug - Sept 1988			
	T = 0	T = +2	T = +6	T = +8	+10
SIO/ORSTOM Volunteer Ships:					
PACIFIC ISLANDER	2 (150° E)	3 (170° E)			
MICRO INDEP.	6 (150° E)	3 (130° - 150° E)			
CAP ANAMUR	3 (170° W)	1 (165° E), 2 (170° W)			
LILLOOET	1 (170° W), 1 (160° W)	4 (165° W)			
POLYNESIA	8 (150° W)	7 (150° W)			
MOANA PACIFIC	5 (140° W)	7 (140° W)			
MT. CABRITE*	9 (110° W)				
JAPAN TUNA		5 (125° W)			
SEAL ISLAND		7 (100° W)			
AOML Volunteer ships:					
(ORE SHIP)	5 (95° W)	4 (95° W			
(COASTAL ECUADOR)	2 (85° W)	2 (85° W)	2 (85° W)	2 (85° W)	
(COASTAL PERU)	3 (85° W)	2 (80° W)	3 (80° W)	2 (80° W)	
Research Vessels:					
MOPS R/V (NOAA)		3 (95° W)			
EPOCS R/V			7 (Equator)		7 (Equator)
R/V CORIOLIS	9 (165° E)				
PRC R/V:					
R/V XIANGYANGHONG #14		6 (175° E) (Nov) 6 (140° E) (Oct)		6 (West. Pac)	
TOTALS:	4 (April)	53	60	12	10

MT. CABRITE will pre-deploy 4 buoys at T = - 2 (April - May, 1988) so they can float into potential data void northeast of Tahiti.

In the first year about 150 buoys will be deployed.

As stated in Section 7.1, one technical objective of this study is to learn how to deploy and maintain an array of drifters on a $2° \times 10°$ resolution in the complicated surface circulation of the tropical Pacific. The proposed plan is based on experience gained with drifters over the past 9 years and presently it is as rational a start for a pan-Pacific array as can be made in 1988. Numerical simulations of drifters motion are not useful as currents can, and will, depart significantly from the climatological ship drift. The release strategy of 7 north-south legs separated by 20° longitude is based on the fact that drifters move about 15-20 km/day, principally in the east-west direction and in two months they will have been displaced 8°–12° in longitude. These fill the gap between the deployment lines, and two months later, another array is released to achieve the 10° east-west resolution. The desired latitude resolution scale of 2° will not be achieved until the middle of the second year.

In the second year, more judicious releases will be made, depending upon where the gaps in buoy density occur. The first year will be done by deployment of drifters from U.S. contribution, but in the second year, significant French (50-60 drifters) and Australian (10-20 drifters) will occur. Thus, by the end of two years 350-360 drifters will have been released, filling the pan-Pacific basin to the required sampling density (with expected losses of 60/% from first year deployment by the end of the second year).

The proposed schedule of deployment cannot be delayed significantly if appropriate recommendations are to be made to the TOGA/WOCE for global deployment strategy by 1990.

7.5 *Data management*

Several agencies in various countries will participate in this project's investigations. Numerous regional as well as basin-wide objectives have been identified. It is certain that drifting buoys nominally provided from one agency or country will, over their operating lifetime, depart the regional area of interest and become of value to others. To assure uniformity in data processing procedure, and facilitate efficient access to data and their reporting, a drifting buoys data center for this study will be established at AOML/NOAA in Miami.

At the center, raw ARGOS data will be sampled on an approximately daily basis. Buoy location maps based on weekly drifts will be distributed to project participants on a regular basis and more detailed data will be made available on a dial-up system.

The magnetic tape data received from SERVICE ARGOS will be quality-controlled and interpolated to uniform intervals at AOML. These processed data will be provided to project P.I.'s and submitted to the National Oceanographic Data Center (NODC) at the end of the study. All P.I.'s will have direct SERVICE ARGOS access to the data through the experiment number and password. The P.I.'s will collaborate in publication of descriptive data reports on a yearly basis.

SST data will be disseminated via the GTS for use in operational analysis and other TOGA purposes. In monthly intervals, the velocity data will be made available to all TOGA real time ocean model projects for initialization and verification purposes. The monthly data will be reported in the *Climate Analysis Bulletin* and released to any country participating in TOGA through the International TOGA Program Office (ITPO). Island nations of the Pacific have expressed special interest in these data sets. Many of these data products are currently being done at AOML/NOAA for EPOCS.

The pan-Pacific Surface Current Study will be managed by a council of P.I.'s, with ex-officio representation from ITPO (to aid in rapid distribution of the data products to the international community). The P.I.'s will elect a chair-person who will report on a regular basis to the TOGA-Science Steering Group on the overall scientific results of the study. Individual P.I.'s will report to their respective funding agencies on the specific results. P.I.'s will meet at least once each year to discuss the project results and write joint papers and data reports.

8. *International Components*

8.1 2*Australia*

Australia's participation in the experiment, through the contribution of drifters and the payment for ARGOS tracking, will begin when Dr. Cresswell and other Australian investigators successfully acquire funds from the Australian government (by fall 1988). In preparation for and in support of this activity, the experiment's principal investigators have agreed to approach the key Australian scientific policy makers informally. The approach will include communication of an outline of the experiment, the perceived benefits to Australia and the global community, and a suggested Australian role. More formal requests will be made from the ITPO for Australian participation in 1990-1995 period for the extended TOGA/WOCE studies.

In view of both the progressive lowering in price of drifters and the proposal to only obtain tracking by ARGOS on every third day, the chances of Australia's participation from late 1988 onwards are quite reasonable. Australia's intellectual contribution to the study would come through the 5+ year commitment that Dr. Lindstrom has made to WEPOCS, and through the great value that the drifter SST measurements will have for the initialization of climate models (Meyers and Nicholls). Dr. Lindstrom has conducted two cruises into the WEPOCS area and obtained 6 months of current meter records from 150°E on the equator. He has a third cruise planned for April/May 1988 in which he and Drs. Godfrey and McDougall will further the description of the circulation and examine mixing processes.

Dr. Lindstrom plans to cooperate with his U.S. colleagues to maintain a current meter mooring at 150°E for 5 years. This would naturally lead to intercomparisons with currents measured by the drifter data set. He has already compared the track of one of Dr. Cresswell's drifters with the 6-month record from the current meter at the drogue depth. The two measurement method suggested a slab-like behavior of the upper water, with currents at the current meter being reflected in the movements of the drifter as far as 15° longitude farther to the west. Drs. Meyers and Nicholls would like to access the SST data in real time via the GTS for input into climate models. The data would be compared with XBT results and derived geostrophic currents.

In summary, Australia has scientists with a strong interest in the drifter study and they will be able to scrutinize, use and interpret the data from it. The chances of participation with Australian drifters are reasonable, with a proposed start date of late 1988.

8.2 *France* (Bouees derivantes TOGA [BODEGA])

In a cooperation between LODYC (Reverdin) and ORSTOM Noumea (Henin, Picaut, Delcroix), it is planned to seed the longitude 165° between 2°N and 12°S with drifting buoys. The buoys would be launched four times a year during the TROPAC or SURTROPAC cruises, starting in mid 1989.

Specific scientific interests are in the seasonal cycle of the South Equatorial Countercurrent and in the occurence of eastward jets. Complementarity between the near surface currents obtained from the buoy drifts and the other estimates of currents from current profiling or geostrophy will be investigated. The daily temperature cycle near the surface and its seasonal cycle also are of interest. Between fifty and seventy buoys could be deployed with funding requested from various French funding agencies grouped into a Climate Programme Committee (the Programme National pour l'Etude du Climat). Modeling activities (Delecluse, LODYC) are also planned, aimed at understanding the vertical penetration of energy in the upper ocean. Specific goals are to parameterize more correctly the vertical and horizontal mixing in the upper ocean of an ocean general circulation model.

8.3 *Japan*

Informal contacts have been made with Japan through the Japanese TOGA-SSG representative, Prof. A. Sumi, and representatives of the *Research Project on the Variations of the Atmosphere-Ocean Coupled System in the Tropical Pacific*, which will become the long-term TOGA project in Japan. One of the principal components of the above proposal is "observations by drifting and moored buoys." This document will serve as a basis for further, specific exchange with Japanese P.I.'s and participation is expected from Japan during the second year of the study.

8.4 *United States*

The principal investigators from the U.S. are Dr. Hansen (Atlantic Oceanographic and Meteorological Laboratory/NOAA), Prof. Niiler (Scripps Institution of Oceanography), Dr. Richardson (Woods Hole Oceanographic Institution), and Dr. Hwang (Rosenstiel School of Marine and Atmospheric Sciences). The principal investigators have interests in the eastern, central and western Pacific, and in data-numerical model comparisons, respectively. EPOCS TOGA has been requested to supply 112 drifters and NSF to supply 204 drifters for this study over a two-year period.

The proposed study was a focus of discussion at the U.S. TOGA Workshop in "Dynamics of Equatorial Oceans," during August 11-15, 1987, in Honolulu, Hawaii (Katz and Witte, *ed.*, 1987). Fifty-five tropical scientists met and concluded that:

"In conjunction with sea-level and upper ocean thermal structure, direct measurements of near-surface currents are a valuable contribution in understanding large-scale circulation throughout the tropics."

In TOGA, the thermal structure and sea level projects have been implemented on a pan-Pacific basis. This proposed study will implement the measurement of near-surface currents on an equivalent pan-Pacific basis.

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