TWP93.0100104
DOC#: TWP-DOC-1.4

SCIENCE AND SITING STRATEGY FOR THE TROPICAL WESTERN PACIFIC ARM CART LOCALE

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Releases:

TWP93.0100101	MARCH 1993
TWP93.0100102	MAY 1993
TWP93.0100103	JUNE 1993
TWP93.0100104	OCTOBER 1993

SCIENCE ISSUES

The overall goal of ARM is the improvement of cloud and radiation modeling and parameterization in global climate models (GCMs). Components of the ARM plan include 1) detailed observations of radiation and cloud properties and associated data analysis, 2) studies of relevant atmospheric processes using high-resolution models with explicit physics, and 3) simulations with mesoscale models and single column versions of GCMs. The design and implementation of the Southern Great Plains (SGP) Cloud And Radiation Testbed (CART) has been predicated on these components. The site location, layout of instruments, acquisition of auxiliary data, and data processing have all been influenced strongly by this conceptual framework. However, as ARM moves on to the implementation of subsequent sites, it is important to realize that the conceptual plan and CART design may need to be modified in order to address the same goal in a different locale. These modifications must be based on an examination of the principal science issues and relevant logistical considerations. This document addresses these issues for the proposed Tropical Western Pacific (TWP) site.

The locale selected for the TWP (Figure 1) lies roughly between 10 °N and 10 °S latitude and 120 °E longitude to the dateline (or a bit further to the east). Climatologically, it is characterized by warm sea surface temperatures, deep and frequent atmospheric convection, high rain rates, strong coupling between the atmosphere and ocean, and substantial variability associated with the El Niño - Southern Oscillation (ENSO) phenomenon. Any number of diagnostic studies can be cited that show the relationship between climatic variability in this region, particularly ENSO, and variability in other portions of the globe. Geographically, this locale is characterized by the maritime continent area in the southwest portion and essentially open ocean in the northeast portion. Because of the large area, relative inaccessibility, and predominance of ocean, this locale also suffers from a critical lack of climatological data from the ocean, the atmosphere, and the interface.

Radiation Budget and Cloud Forcing in the Tropics

The radiation budget of the TWP has been a subject of interest for many years dating back at least to the work of Newell and Dopplick (1970), who computed radiative fluxes for the clear atmosphere based on average soundings. Studies by Webster and Stephens (1980) and Ackerman *et al.* (1988), using a combination of aircraft observations and radiative models, emphasized the importance of deep tropical clouds and cirrus outflow on the radiation budget of the atmosphere and surface. Observational studies based on the Earth Radiation Budget Experiment (ERBE) by Ramanathan et al. (1987) and GCM studies (Slingo and Slingo, 1977) illustrated the strong cloud forcing in this region, and the potential for the shortwave forcing to compensate for longwave forcing. More recently, Ramanathan and Collins (1990) used satellite observations to argue that tropical cirrus clouds may act as a regulatory mechanism in limiting the warmth of the sea surface temperature in the TWP.

Our current understanding of the radiation budget in the tropics can be summarized briefly. Satellite observations provide reliable measurements of absorbed solar and emitted infrared fluxes. These fluxes exhibit a large variability that can be directly tied to the occurrence of deep convection and the presence of extensive, and often optically thick, cirrus decks. The ERBE analysis of the top-of-atmosphere cloud forcing suggests that the longwave and shortwave cloud forcing nearly cancel, *i.e.*, the reduction of outgoing longwave radiation (OLR) caused by the presence of high clouds is approximately compensated by an increased reflection of solar radiation. This compensation is evident in ERBE monthly-mean statistics but, presumably, applies to particular cloud systems as well, albeit with an enhanced variability.

The situation at the surface is dramatically different. Measurements of surface radiation fluxes (Young *et al.*, 1992; Long *et al.*, 1994; G. Stephens, personal communication) show clearly that the dominant variability in net surface radiative forcing is due to the effects of clouds on incoming solar radiation. During convective episodes, incoming solar fluxes can be reduced to as little as 10% of clear-sky values. Due to the high water vapor column amounts in the convective tropics (typically 4.5 to 6.5 precipitable cm), downward IR flux values at the surface are always high; typical ranges are between 400 and 450 W/m^2. The variation can be attrubuted to variations in both column water vapor and cloud cover. Although this range of 50 W/m^2 is small as a percentage of the total, it represents a significant uncertainty in our knowledge of the radiant energy input to the surface.

Similarly, clouds cause a large perturbation to the atmospheric heating rate profile. For clear skies, there is a modest net cooling throughout the tropospheric column due primarily to water vapor emission. At the same time, there is strong surface heating due to large incoming solar fluxes and very small net IR emission. The presence of high, thick clouds alters the situation in important ways. Surface heating is reduced substantially but atmospheric heating is increased markedly, primarily by IR absorption, and also by solar absorption. The magnitudes and vertical distribution of the heating are not well understood since the profiles depend directly on cloud distribution and optical thickness.

Satellite observations offer clear proof that the top-of-atmosphere forcing varies substantially in time and space. Intra-annual temporal variations are largely associated with the migration of the ITCZ and the Madden-Julian oscillation. Interannual variability is linked strongly to the ENSO cycle. Spatial variability is thus linked to both inter and intra annual variability in cloudiness. One particularly important feature of the spatial variability is that it tends to be strongly anchored in the east-west direction. In non-El Niño years, convection sets up in the western end of the basin producing a strong, seasonal west-to-east gradient of cloudiness. In El Niño years, the convection maximum shifts to the central Pacific, which produces a much weaker gradient in the cloud forcing.

This overall picture of tropical radiative heating leads to several obvious implications for the TWP CART operations.

1. Simultaneous observations of cloud properties, water vapor column, and the surface radiation balance are imperative in order to quantify current estimates of surface cloud forcing and relate it to top-of-atmosphere cloud forcing.

2. Long term (multi-year) radiation measurements are a necessity, particularly a set of measurements that spans at least one ENSO event.

3. Measurements at multiple locations are a necessity. In the absence of an El Niño event, the warm SST and maritime continent fix the convective regime in the TWP. The result is a large spatial gradient in cloud amount, extent, and forcing from west to east that covers thousands of kilometers. Understanding the forcing and associated feedbacks requires sampling along this gradient.

It is possible to specify a wide-ranging set of measurements that would have broad applicability in the tropics. However, deploying and operating an extensive collection of instruments could be prohibitively expensive. Thus, we have opted to attempt to define a minimum set of measurements needed to address the scientific objectives. Any instrument set capable of making these measurements is thereby suitable.

To meet the needs of the radiation budget and cloud forcing component, measurements of the surface radiative fluxes are needed, *i.e.*, the upward and downward broad-band solar and infrared fluxes. Since the surface is deemed to be an isotropic emitter, the upwelling IR flux measurement could be satisfied by an IR thermometer.

In order to understand the surface measurements, the radiatively important constituents of the atmospheric column and the temperature profile need to be measured. These constituents include the water vapor profile, aerosol amount, and cloud properties. Note that it is not necessary to obtain complete definition of all the characteristics of these constituents, but rather to measure the radiatively important characteristics.

Water vapor profiles are, of course, difficult to measure particularly in the upper troposphere and on a continuous basis. For climatological purposes in the tropics, a once-daily radiosonde with continuous monitoring of the integrated water vapor column concentration should be sufficient. Augmenting this with continuous measurements of the surface relative humidity and half-hourly measurements of the boundary layer height should allow for a sufficiently detailed reconstruction of the temporal evolution of the water vapor profile.

Temperature profiles would also be measured with the once-daily radiosonde. Augmenting this with continuous observations of surface temperature and boundary layer height, along with more frequent profiling of the low-level temperature profile, should also allow for sufficient representation of the temperature profile.

The limited data available for tropical aerosol suggest that the optical thicknesses are rather low and the size moderately large. Required measurements are the optical thickness at several wavelengths that span the portion of the solar spectrum between 0.4 to 1 μm, and a vertical profile of some quantity related to optical thickness such as volume backscatter.

Defining the cloud properties is obviously the most critical component. First, the cloud geometry must be measured, which includes the location of cloud base and top for single and multiple layers, and the fractional coverage of the sky. For surface flux observations, the most crucial observations are the location of cloud base and fractional coverage. Second, the radiative properties of the clouds need to be determined when possible. Measurements of cloud liquid water and ice water paths and/or cloud optical depth at solar or thermal infrared wavelengths are needed to interpret correctly the surface flux measurements.

Surface and boundary layer meteorological observations (other than those noted above) are not strictly necessary to understand the flux measurements. However, we have found that a great deal of insight into the flux measurements, as well as very useful diagnostics in the case of data outliers, are provided by relatively simple observations. These would include surface measurements of temperature, dew point, wind speed and direction, pressure, and rain rate. Boundary layer measurements of profiles and wind speed and direction, temperature, and dew point are also highly desirable.

Water and Energy Budgets

Quantifying the radiative impact of tropical clouds on the surface energy budget represents only a first step in the ARM goal of improving cloud-radiation models and GCM parameterizations. To move forward on the parameterization problem requires an understanding of (1) the processes responsible for the initiation of tropical convection, (2) the vertical transport of water and energy accomplished by tropical cells, and (3) the microphysical characteristics of the clouds, particularly the prevalent cirrus outflows that are so radiatively important (Ackerman *et al.*, 1988; Ramaswamy and Ramanathan, 1989).

Convective initiation and transport in the tropics have been the focus of a number of intensive field programs spanning many years, beginning with the GARP Atlantic Tropical Experiment (GATE) in 1974, extending through the monsoon experiments in India, Borneo, and Australia, and including most recently, the TOGA Coupled Ocean-Atmosphere Regional Experiment (COARE). As part of the field campaigns, many diagnostic studies have been carried out using data from the campaigns and associated meteorological data (see, for example, Houze *et al.*, 1981; Johnson and Kriete, 1982; Frank and McBride, 1987). It is beyond the scope of this current document to summarize the results of these various programs and associated analyses, which have greatly enhanced our understanding of the problem. In addition, a large number of theoretical and numerical studies have been carried out focusing on convective processes (by a wide range of authors), also contributing greatly to our understanding. Recently, several of these studies (Chen and Cotton, 1988; Churchill and Houze, 1991; Miller and Frank, 1993) have shown the importance of radiative effects in the development and life cycle of tropical cloud systems.

Despite all this work, however, quantification of the role of radiation in the convection problem and the partitioning of diabatic heating between latent heat and radiation has not been accomplished. The reasons are complex but certainly include instrument and aircraft limitations. If ARM is to make significant progress in this area, the program must include a component aimed at obtaining the requisite measurements in tropical conditions.

The ARM concept, as currently being implemented at the Southern Great Plains Site in Lamont, OK, is predicated on simultaneous measurements of radiative fluxes, cloud properties, and environmental variables driving the cloud formation. These measurements are intended to be made on a near continuous basis. Analogous measurements are needed in the TWP to address these issues of convective transport and interaction with radiation. Due to the obvious operational and logistical constraints, determining how these observations are to be acquired in the TWP is difficult. However, we can outline some general constraints.

First, budget studies require a detailed three-dimensional set of near-simultaneous observations of the atmosphere over some mesoscale domain. The needed spatial scale of these observations is not completely defined but is on the order of 100 km X 100 km. Within this domain, environmental variables such as temperature, water vapor, and wind speeds need to be measured with high spatial and temporal resolution. Cloud properties including liquid and ice water contents, precipitation, and microphysical properties also must be measured. Ideally, such measurements should be made in both maritime continent areas and in open oceans. However, it is obvious that making measurements over the required spatial domain in these environments is costly and difficult.

Second, the quantity of measurements required in a temporal sense is not well constrained. It is possible that data needs could be met by a series of intensive observation periods (IOPs) or campaigns. Although this is somewhat counter to the ARM philosophy, the cost and difficulty of acquiring routine long-term mesoscale data in the TWP may require the IOP approach.

Third, the cost and difficulty of making the measurements dictates that ARM develop collaborations with other organizations interested in similar scientific problems. Sharing resources and operations costs is likely to result in a much larger database on convective processes than would be otherwise obtained.

The measurements needed for this component include all the radiation and cloud measurements outlined above. Radar, both cm and mm wave, are absolutely crucial in order to define the extent of convection and amount of precipitation. Multiple soundings surrounding the area of study will also be required in order to quantify the state of the environment. The time and space resolution of these soundings need to be specified carefully but are certainly much higher than can typically be achieved with conventional meteorological data.

Aircraft measurements of radiative fluxes, microphysics, and atmospheric state parameters are also required. Current ground-based remote sensing techniques cannot resolve particle size and shape to the required accuracy, and above-cloud radiative fluxes can only be obtained by aircraft.

Unpiloted aerospace vehicle (UAV) technology may offer a cost effective means of obtaining some of the needed measurements. However, this technology is still in its infancy and cannot be relied on at this point to provide inexpensive, reliable observations.

Ocean-Atmosphere Interactions

The choice of the TWP locale was dictated, in large part, by the ocean warm pool and the deep convection associated with it. Satellite observations show that the ocean surface temperatures in the vicinity of the maritime continent (Figure 2) are consistently the warmest and cloud top temperatures are the coldest found anywhere. ERBE maps of monthly-average outgoing longwave radiation show a deep minimum over the area, while solar reflectivities show a corresponding maximum, indicating the prevalence of optically-thick clouds. There is clearly a causal relationship between the warm ocean and deep convection that has to do with the transfer of heat and moisture from the warm ocean to the atmosphere producing surface parcels with high values of moist static energy. When lifted, these parcels develop into deep convective towers. In return, the radiative properties of and precipitation from these cloud systems clearly has an impact on the ocean mixed layer. However, the linkages between the ocean and atmosphere are not well understood quantitatively. Some issues that immediately come to mind are (i) what are the fluxes of radiation, water vapor, sensible heat, and precipitation at the ocean surface, (ii) how do they vary in time and space, (iii) what maintains the ocean warm pool, and (iv) what is the organization of tropical convection and how is it forced? Experiments such as the just completed TOGA COARE have been designed to address these issues, but are limited temporally to periods of a month or a few months. ARM has an opportunity to contribute to answering these questions by carrying out high-quality observations over an extended period of time. Making this contribution, however, will require:

1. long-term measurements of surface fluxes over the ocean.
2. simultaneous measurements of boundary layer structure and cloud properties.
3. spatially extended measurements of atmospheric properties.

IMPLEMENTATION STRATEGY

Over the course of the past year, a workshop and several meetings have been held expressly to consider science issues and measurement needs in the TWP. These meetings have provided stimulating discussions and interesting ideas. From these, we have begun to distill an implementation strategy that flows from an amalgam of science issues and logistical and financial constraints. At a minimum, the TWP science issues require

- continuous, basic observations of radiation and cloud properties over a broad spatial domain;
- detailed, but not necessarily continuous, observations of atmospheric structure and properties at some location(s);
- observations of surface fluxes, boundary layer properties, and cloud structure in a purely oceanic environment.

The first requirement comes from the need to establish the magnitudes and variabilities of the surface radiation budget and cloud forcing across the Pacific basin, the second from the need to understand how tropical convection impacts water and energy budgets in the tropics, and the third from the need to understand the coupling of the ocean and atmosphere and how it impacts convective organization over the water.

The logistical and financial constraints include factors such as

- infrastructure support throughout much of the area of interest is extremely limited or non-existent;
- potential political problems and instabilities mandate against fixed, long-term plans in some areas;
- funding for capital equipment will be phased over several years;
- installing and maintaining instrumentation is so costly that cooperation with other agencies with mutual interests is crucial;
- the envisaged ocean site has not been tried before and will require considerable development work to draft an acceptable plan.

The logistical issues sharpened in our perception as a result of our experiences in the Pilot Radiation Observation Experiment (PROBE), which was carried out in Kavieng, New Ireland, Papua New Guinea, in conjunction with the TOGA Coupled Ocean Atmosphere Response Experiment (Figure 3). Kavieng is the capital of New Ireland, has a commercial airport serviced by Air Nuigini, and a moderately well-developed infrastructure that includes reliable (by tropical standards) power and telephone, good hotel accommodations and food, and a variety of commercial establishments. However, we found that operating a research site at Kavieng was anything but simple. Although we attempted to make arrangements in advance, site preparation required our presence. Shipping was costly and slow, no matter whether by ship or air. Local availability of some materials was highly variable, especially for electronic supplies. The skill and ability of locally-hired people varied and electronic and mechanical talent was very limited.

The experience gained with PROBE highlights the need to design and build systems that are largely self-contained and can operate with only a minimal amount of attention. The high cost and slowness of shipping replacement parts requires that systems be rugged, reliable, and redundant. Standardization of instrument and computer parts, whenever possible, is highly desirable, and some inventory of spare parts will have to be kept on site. Hiring of local people for routine operations and maintenance is possible. Weather Service personnel have experience with standard weather observing instruments, but usually have not had much training in the electronic and mechanical skills required to fully support CART type instruments. An ARM sponsored training program could help this situation and would be welcomed.

Some of these problems could be alleviated by sending permanent staff with the facilities. This, however, would be very expensive as well as very difficult. Even apart from the transportation costs associated with regular rotations off-site, the cost of maintaining an on-site presence using United States citizens may be prohibitively high. Coping with a different life style, mental fatigue, security, and personal safety all need to be addressed. In some of the larger cities in the locale random violence is often targeted at outsiders. This condition may or may not exist in the smaller towns. While sensible precautions can be taken to minimize the possibility of personal injury, these precautions become onerous when stays of months are considered. In addition, in several of the areas under consideration, tropical diseases such as malaria and dengue fever are endemic. Effective preventative medicines can be taken for short periods of weeks to months, but cannot be taken for longer periods. Some strains are resistent to current prophylactic medication. Permanent occupation of such sites would almost certainly increase the chance that the staff would contract these diseases.

While it is not appropriate to go into an extended political analysis of the region, it is important to note that political instability needs to be considered. An investment of millions of dollars in a fixed site could be severely jeopardized by the breakdown of central authority such as is presently occurring in several places in the TWP. This breakdown can result in low-level civil wars, an increase in random violence and vandalism, and an increasing threat to personal safety. Such issues are real enough when travel and short-term occupation of research sites are considered, but become critical when occupation times of 5 to 10 years are considered.

The financial issues are driven by the amount of money available to the ARM program and the need to continue instrumenting the SGP site. It is unlikely that the ARM budget can support the combined development of two major sites simultaneously. Thus, a siting strategy for the TWP that can begin with modest expenditures and expand to fit the yearly funding profile is highly desirable.

Also, the ARM program extends beyond the first two sites to include the North Slope of Alaska, Eastern Ocean Margins, and Gulf Stream sites. The siting strategy for the TWP should provide for common design and development of instruments and a common deployment scheme which could be used at these future sites. Thus, a strategy that is flexible and, to some extent, portable from one remote locale to another is highly desirable. This is particularly important for the ocean-based component of the program, which is likely to be quite expensive. Fashioning a common and economical design for ocean based instrumentation will take considerable time and effort.

Given the high cost of operating a remote environment and current funding limitations, it is critical that the ARM management seizes every opportunity for collaboration with appropriate existing scientific programs and multi-nation organizations in the region. A few installations are being operated in the islands, but these are rather modest in scope and instrumentation. The most active site in the area is maintained by the Australian research community in Darwin. This site has state-of-the-art instrumentation such as Doppler radar and wind profilers, and is being upgraded currently to support TRMM validation research. The Maritime Continent Thunderstorm Experiment (MCTEX) is being planned for the area around Darwin in late 1995 and early 1996. Co-location and cooperation with these activities should be a high priority for ARM.

The combination of science issues with logistical and financial considerations has led to the proposal of a phased, flexible deployment scheme. The scheme is designed to begin the acquisition of data in the TWP soon, augment that acquisition consistently over the next few years, and culminate with the deployment of an oceanic facility. The proposed scheme has five distinct components:

1. Deployment of 3 to 5 Atmospheric Radiation and Cloud Stations (ARCS) across the western Pacific.
2. Adding an augmented ARC station to the Australian Bureau of Meteorology research facilities in Darwin.
3. Development and deployment of an enhanced oceanic facility incorporating some combination of moorings, ocean platforms, and island-based remote sensors.
4. Deployment of upward-looking solar radiometers on some fraction of the 65 to 70 moorings in the TOGA TAO array, which extends across the Pacific basin from 10 °N to 10 °S.

5. Deployment of an ARCS on a dedicated NOAA ship that will be servicing the TOGA TAO array.

1. Atmospheric Radiation and Cloud Stations

The development and deployment of ARCS are central to the TWP siting strategy. The essential plan is to develop an integrated instrument set to measure the surface radiation balance, surface meteorology, cloud properties, and some limited atmospheric quantities. The principal scientific goal is to measure the effect of tropical clouds and water vapor on the radiation budget. The set of measurements needed to meet this goal is a matter for continued discussion and refinement, but a minimum set can be defined. The fundamental measurements are the downwelling broad-band solar and infrared fluxes at the surface. (Upwelling measurements are also of interest, but considerations of surface representativeness make their utility more questionable.) These flux measurements should be augmented by frequency-dependent direct beam measurements. The simplest way for making these measurements is the use of a rotating shadow band radiometer where the direct fluxes are obtained by subtraction of the measured diffuse fluxes from the total fluxes. The measurements can be used to infer optical depth as a function of wavelength. In order to interpret the flux measurments, measurements of cloud properties are needed. These include measurements of cloud base height, cloud frequency (or fractional coverage), cloud top height, and cloud liquid or ice water path. Measurements of atmospheric water vapor, both integrated and total column are also needed. (A detailed description of an ARC station is given in a subsequent section.)

ARCS will be designed to be autonomously operable and portable, following the conceptual design pioneered by the Integrated Sounding Systems of NCAR and NOAA, and subsequently by PROBE. Each ARCS will be constructed in the United States, tested and calibrated, and then shipped to its deployment site, where it will be set up for long-term operation. The system will be designed to require minimal routine maintenance, limited to such tasks as cleaning instrument ports and domes and changing data storage media. No ARM personnel will be permanently detailed to the location of an ARCS, although routine maintenance visits will be necessary.

An immediate concern is the relevance of island-based measurements to the surrounding ocean environment. This is a problem and constraint, but perhaps not as great as anticipated. First of all, care will need to be taken in siting the ARCS to minimize the terrain effects. Thus, a site like Kavieng, which is on the relatively flat end of an elongated island, is to be preferred over a site like Rabaul, which sits in the crater of a volcano. Second, the ARCS measurements are aimed at sampling the effects of clouds on the radiation budget. While there may be some differences in cloud microphysics over the island compared to over the ocean, there are likely to be strong similarities, particularly in the case of cirrus clouds which are not strongly influenced by island effects. Third, the extension of the measurements to the open ocean will come via satellite studies, not via interpolation from various island measurements. The island measurements will serve as reference points for the development and validation of satellite algorithms, which will then be applied over larger areas. Comparable measurements over the nearby ocean to those being made at an ARCS will be highly desirable. Such measurements can be made from oceanic research vessels and it is recommended that as development of the ARCS goes ahead, coordination with ocean research cruises should be explored.

The siting strategy calls for the deployment of three to five ARCSs near the equator spaced from Indonesia to east of the dateline (Figure 6). Obviously, this is a huge area to be covered by so few stations, so deployment of as many ARCS as possible is desirable from a scientific point of view. Logistics and finances suggest that five is perhaps the maximum number that can be accommodated. Actual sites have not been selected, although a variety of island locations have been considered. Because an ARCS can be moved, one possible option is to deploy several near the equator along an east-west line for a few years and then rearrange them to straddle the equator at a particular longitude.

The observational and instrumentation requirements for meeting the scientific objectives of the TWP include knowledge of the vertical distribution of water vapor in the atmosphere. Although this information can be derived to some extent from satellite and ground-based remote sensors, traditional radiosonde launches are still the most reliable and realistic way of obtaining comprehensive vertical water vapor profiles. Because the ARCS are intended to be operated autonomously, the capability to provide automatic balloon launchings from these stations is not likely to be available. Since manned launch facilities supported by ARM would be prohibitively expensive, the siting strategy must give high priority to co-locating each ARCS near a radiosonde launching site that has already been established by the host country.

Data transmission from these facilities has not been completely resolved as yet. It would be desirable to have all data transmitted to the ARM data center via satellite link. However, this option is too costly under current conditions. Alternatively, some portion of the data set could be transmitted to the data center via satellite, while the total set is archived at the ARCS and returned to the data center at regular intervals on a storage medium. There are proposed satellite systems that, if realized, could result in a substantial decrease in the cost of transmission rates, which in turn might make it viable to transmit all the data via satellite. Developments in data compression algorithms offer the possibility of transmitting more information using fewer bytes. Given the rapid changes in data storage and transmission technology, the best option is to maintain a high degree of flexibility in the design of the station and adapt to new developments.

2. Augmenting the Darwin Site

The ARM scientific goals are aimed at solving the cloud parameterization issue. Doing so requires an understanding of how the ambient atmosphere forms and maintains clouds, as well as how clouds modify the ambient environment. An ARCS by itself will not be able to address this coupling problem because its sampling is limited to a single vertical column, rather than across a broad area. From the original conception of the TWP site, the task of defining the ambient environment has loomed as the single most difficult aspect of the program. Two issues need to be considered: first, does the geography of the TWP region permit the deployment of an extended CART site such as that being deployed in the SGP, and second, are the financial resources available to ARM to make that site a reality? Some tentative answers to these questions can be given at this point.

The complexity and expense of deploying large, remote-sensing instruments in an open ocean environment make it extremely unlikely that a SGP-like CART site can be deployed in any purely oceanic environment. The required ships or anchored platforms are beyond the financial capability of ARM. The use of a single island is not particularly helpful because the requirement of sampling the ambient atmosphere on a broad scale is not met for a small island and the ambient atmosphere is highly perturbed in the case of a large island. Utilization of a lagoon or island chain is a possibility. However, such locales cannot be considered a purely oceanic environment due to warmer ocean temperatures in the lagoon, changes in wave patterns, and land influences on the boundary layer. Consequently, they offer little advantage over any coastal environment in the maritime continent. Thus, it seems reasonable to suggest that the deployment of an SGP-type CART site in the TWP can only be accomplished in a maritime continental, as opposed to open ocean, environment. This may be somewhat disheartening but represents the current reality.

The cost of maintaining a SGP site in the United States is high. In the remote tropics it becomes overwhelming. The cost of power, communications, transportation, housing, food and water can be incredible. Further, finding staff willing to stay for long periods of time will be difficult. These issues can be minimized at least to some extent by finding a locale that has a reasonable existing infrastructure. Substantial savings can be realized if there are existing meteorological research facilities in such an area, since both the instrumentation and staffing costs will go down.

Thus, if ARM is to have an SGP-like facility in the TWP, it will have to be based largely on land in an area that has an existing stable infrastructure, preferably with existing meteorological instrumentation. A careful look at the region selected for the TWP suggests that only two areas meet the infrastructure and stability requirements: the north of Australia and the Federated States of Micronesia. Both are somewhat at the margin of the TWP domain. The north of Australia is not an ocean domain, but is geographically flat, has a well developed infrastructure, and an active meteorological research site at Darwin. The Micronesian islands vary from lagoon to volcanic in nature, are widely scattered spatially, and have a reasonable infrastructure. However, their meteorological infrastructure is considerably more limited than that at Darwin.

The potential collaboration with the Australian Bureau of Meteorology site argues in favor of Darwin over the Micronesian area. The Bureau currently maintains a Doppler radar, a rain gauge network, a wind profiler, and a fully staffed forecasting facility at Darwin. There are plans to instrument the two islands (Bathurst and Melville) to the north of Darwin with automatic weather stations, surface energy flux budget stations, and rawinsonde sites. These sites would not be occupied continuously but on a campaign basis duriing the Maritime Continent Thunderstorm Experiment (MCTEX) in late 1995 and early 1996. Also, Darwin is a research station for ozone and radiation measurements operated by the Bureau of Meteorology. Adding radiation and cloud sensors at the site and additional sounding capability around the area would allow ARM to meet most of its objectives with regard to defining the ambient atmosphere during the intensive operation periods. The sensors needed at the site are principally those envisaged for the ARCS, although some augmentation would be desirable. For example, the inclusion of an interferometer and an enhanced lidar system would be most beneficial.

Utilizing Darwin as part of the siting strategy has some obvious deficiencies when compared to the original plan. The site is not in a pure tropical ocean environment and the complete instrumentation suite probably will not be operated continuously. However, the site is in a maritime continental environment with a strong annual cycle that ranges from dry offshore flow in the Australian winter to isolated convection during the transition season, to a fully developed monsoon flow in the Australian summer. This provides a wide range of conditions and an opportunity to sample an important tropical monsoon regime. Further, it is a financially and logistically possible option. A great deal more thought and discussion needs to be put into this option and how it might best be put into operation. Preliminary discussions have been held with representatives of the Bureau of Meteorology and there is considerable interest in this combined project. It is anticipated that these discussion will continue in order to flesh out this plan more fully.

3. The Ocean Site

The proposed ocean site is envisaged to provide the capability of making measurements of surface energy fluxes, boundary layer structure, and cloud properties in an oceanic environment. As an adjunct, measurements of similar quantities could be made on a nearby island (small or large) for the purpose of comparing ocean-land differences. The basic objectives would be to establish an array of surface meteorological stations on offshore platforms, primarily buoys, on a scale of about 50 km, a central land facility close to the array, and a larger, movable platform that could be deployed in the array. The buoy array measurements would be made sufficiently far offshore so that land effects would be negligible under most circumstances. The instrumentation on the platforms would be directed at understanding the interface structure and fluxes across the interface. Thus, measurements of atmospheric properties such as temperature, wind, moisture, and precipitation, oceanic properties such as salinity and temperature profile, and interfacial fluxes are required. The central land facility would be equipped with a Doppler radar and perhaps a lidar capable of scanning out over the array. Atmospheric profiling, particularly of the middle and upper troposphere, would also be carried out. The movable platform, either a work boat or towable barge, for example, would be equipped with boundary layer profiling and cloud sensing instrumentation, such as is envisaged for the ARCS. The extent of the instrumentation will of course be dependent on the size of the movable platform.

The proposed combination of instrumentation would address many of the ARM objectives. Surface properties and fluxes could be monitored on a continuous basis, as could cloud structure over the array. The addition of a scanning lidar would permit monitoring of boundary layer structure and thin cloud presence in the absence of convection. The measurements from the movable platform would serve multiple purposes. They would be used to do enhanced monitoring of boundary layer, remotely sample cloud properties, and provide calibration of the buoy measurements. The limitations of the proposed combination is that continuous monitoring of the atmosphere over the ocean will not be possible and tropospheric sampling is likely to be only possible a the land based site.

This is by far the most complicated and expensive aspect of the TWP siting strategy. What is being proposed has not been tried before to this extent, although all the elements have. Developing a thorough plan complete with platform information, sensor description, deployment options, and budget estimates will itself take time, let only the time needed to construct the site. It is anticipated that it will be 3 to 5 years before this site could be brought completely on-line, even if it were given top priority immediately.

One additional factor ought to be included in this discussion. ARM has been exploring the possible use of UAVs in support of the CARTs. The development of simple sounding packages that could be flown on small UAVs would be immensely valuable to this oceanic site. It would provide the means to do atmospheric sampling over a broad spatial area, which is currently missing from this picture. The additional development of simple radiation and cloud sampling packages would also be of great utility to this site. It is unrealistic at this juncture to base siting options on this as yet unavailable technology. However, close coordination between the TWP site planning and the UAV activity should be maintained.

4. TOGA TAO Array

The Pacific Marine Environmental Laboratory (PMEL) has undertaken a program to operate an array of moorings (Figure 4) in the tropical Pacific (Figure 5). Currently, 60 of these moorings are deployed, and a total of 70 should be deployed by December, 1994. Although the future of this array beyond 1994 is not completely assured, the program has considerable support from various global climate programs and is likely to continue for the next decade. The ATLAS moorings are designed to monitor surface winds and temperature and the thermal structure of the upper ocean. There are also plans to include an infrared rain gauge on each of the moorings. PMEL has already mounted a solar broad-band radiometer on a few moorings and integrated the measurement into the mooring data stream, but lacks the funds and support to put radiometers on all the moorings. We are negotiating with PMEL on a cooperative program in which ARM would purchase and support the calibration of a yet to be determined number of radiometers that would be deployed in the array. At this writing the ARM Science Team Executive Committee is evaluating the scientific need for the data that would be obtained. The moorings are serviced approximately once a year and a radiometer would be added to each mooring during this routine maintenance.

This proposal represents a relatively modest investment of funds that will provide measurements of solar insolation across the entire Pacific basin for the next decade. The data can be used to quantify solar heating of the ocean and cloud forcing at each of the moorings. Through calibration and utilization of current satellite algorithms, the data can likely be used to compute these quantities across the entire Pacific basin.

5. ARCS on NOAA Ship

NOAA is currently refitting a ship that will be dedicated to servicing the TOGA TAO buoy array. The ship should begin operations in 1995-1996. It would traverse the area between 10 °N and 10 °S latitude from 140 °E to 90 °W longitude on some regular schedule servicing the buoys. It may be possible to deploy an ARCS on this ship and obtain data throughout and beyond the TWP locale. Combining the ship data with satellite data would allow cloud and radiation observations to be conducted over a large area of the tropical ocean, and provide ground truth in areas that would otherwise be inaccessible.

AN ATMOSPHERIC RADIATION AND CLOUD STATION

A good deal of thought has gone into the proposed ARCS. The current conceptual design has been heavily influenced by the design of the Integrated Sounding Systems developed and deployed by NCAR and NOAA, and by our experiences with PROBE. The fundamental consideration is that all equipment is designed to be packed into and operated from specially modified sea containers that are 8' by 8' by 20' in size (Figure 7A). These standard containers are shipped and handled routinely at ports all over the world. Once the containers are put in place at a research site, the instruments are unpacked and set up for operation. The sea containers are outfitted with air conditioners and become shelters for computers and instruments, as well as work places for staff (Figure 7B). Prefitted ports and antennae are added to the container as needed for instruments that are located inside but need outside access.

The measurements required to meet scientific objectives and suggested associated measurements are listed in Table 1. The choice of observations was dictated first by scientific objectives and secondly by operational constraints. The first priority was measurement of surface radiative fluxes and the basic cloud properties that influence those properties. Measurements of solar and infrared broad-band fluxes, spectrally-resolved and broad-band direct and diffuse solar fluxes, and downward infrared window radiance received the highest priority. Given the relatively low cost of obtaining these observations, some redundancy in measurement capability is deemed useful. Measurements of cloud location were given the next highest priority. These include cloud base height and cloud top height, and the detection of multiple layers, as well as measurements of the spatial extent of cloud coverage. A similar priority was given to measurements of atmospheric water vapor. Unfortunately, there is no available instrument that will make unattended, effective measurements of the water vapor profile, so only water vapor column measurements will be made. The next priority was given to measurements of atmospheric structure, both at the surface and throughout the boundary layer.

Operationally, at a minimum, all the instruments on this list are available as research grade instruments and have been deployed in a field program. The only caveat to this statement is that the current versions of a 10 µm radiometer are calibrated with liquid nitrogen. This is not acceptable for remote, unattended operation and cold calibration will have to be done with a cooling engine. Some of the research instruments will require some engineering work to make them more rugged, weather-proof, and self-contained. There are, however, no perceived insurmountable difficulties with that engineering. We are proceeding with the selection of specific instruments to make the required observations.

Our experience with PROBE indicates that some minimal level of on-site presence will be required. For example, thermopile-type radiometers and pyrgeometers and UVB radiometers require periodic cleaning of the domes. Solar trackers may eventually become out of alignment, and must be reset by hand. In PROBE, power quality problems appear to have caused the Rotating Shadowband Radiometer to shut down periodically, requiring a computerized (and occasionally mechanical) start-up procedure. In a humid environment such as the TWP, the desiccant in the pyranometers requires frequent changing. On-site computerized data storage requires disks (such as Erasable Optical Disks) to be replaced periodically. Although these types of maintenance operations can be minimized by careful design and thorough check-out on the entire system prior to deployment, a totally autonomous operation is probably not possible, particularly in the early stages of deployment. Various options will be explored to assure that the instruments are given appropriate attention. For example, in some instances, an ARCS may offer an opportunity for local university students to learn about handling and maintaining this equipment.

Data acquisition will be done by networked computers. Several options are currently being explored. They will in turn be locally networked to a master work station that will archive all data, process it as necessary for transmission, and send it on schedule. This plan is consistent with that already in place for the ISS's and with the ARM data management scheme.

ARCS OPERATIONAL DESIGN CONSIDERATIONS

The set of instruments selected for the required ARCS measurements must be designed to obtain observations at specifications required by the scientific objectives of the ARM/TWP program. The reliable and cost effective operation of the ARCS instruments requires careful planning for their facilities and operational support. The ARCS design and related cost will depend strongly on a careful analysis of the ARM program's scientific requirements for the TWP and associated cost-benefit analyses. This section discusses some of the operational and maintenance issues associated with the ARCS concept. From a practical standpoint we consider anything unrealistic for the early stages of ARCS operations that isn't working today. We will stay abreast of the latest technological developments and factor them into future planning.

Characteristics of Possible ARCS Sites

Regions where ARCS sites might possibly be located are shown in Figure 6. If we were to establish ARCS in these regions they would be on the average at least 2000 kilometers apart. The most likely ARCS site would be on a small to medium size island which would be generally characterized by some or all of the following:

- a unique set of strengths and problems
- a well defined and serious local government
- limited local infrastructure designed to support basic needs
- at best, once per day airline service with limited cargo capacity
- one or two average hotels
- average to poor water, electricity, and phone services
- an elementary and high school
- a medical facility of some sort
- a harbor, dock, and ability to handle 20 foot seacontainers
- a Weather Service office with one or two observers

Operational Design Concept

The ARCS must be designed to operate with an absolute minimum of local "technical" support and maintenance. Local requirements must be routine, simple, and straight forward. To plan on exceptions to this policy is unrealistic and would be outside the current perceived operational budget for the TWP. A realistic high level of redundancy will most probably be required. Cost benefit analyses should be done to determine the extent of required instrument redundancy on an observation by observation basis. To the extent possible system diagnostics should be done remotely and remote and/or local power down/up capability should be provided. Below we discuss some of the issues to ARCS operations.

1. Acceptable Data Loss

The design, operational feasibility, and cost of operating the ARCSs depends to a large extent on the determination of acceptable data loss criteria. The ARM program must determine realistic criteria for ARCS observations which meet scientific objectives and logistical and budget constraints. This would include an analysis of critical sets of observations that are valuable only if all the observations in the set are available. For instance, wet-bulb temperature, dry-bulb temperature, and pressure are a critical set for humidity determinations. Scientific requirements must be analyzed carefully and cost benefit analyses performed for each observation or critical set. These analyses will drive required levels of remote evaluation, power up/down capability, and redundancy in the ARCS design.

2. Remote Evaluation Capability

There must be some means of remotely determining the quality of instrument performance. We are not talking here about suspect data being tagged by the data system. We are talking about knowing on an acceptable time scale when an instrument may need attention.

It is unrealistic to expect instantaneous wide bandwidth data transmissions back to the Data Center in the early stages of ARCS operations. Some limited data will possibly be sent back via satellite as is done with NOAA's ISSs. This situation may require that high density data on some storage media be shipped back to the Data Center. Without a quasi-independent instrument evaluation scheme large blocks of tagged data could be accumulated and without knowing it until much later.

Again the time intervals that the ARM program can accept data loss drive what we do here. If good observations are required at minute intervals, then to insure them requires evaluating instrument performance every minute. If instrument performance is evaluated at longer intervals then there is a risk involved which depends on the length of the interval and reliability factors for the instrument making the observation. The acceptance of reasonable risks requires a cost benefit analysis based on realistic program goals, available budgets, and experience with the reliability of the instruments. Our guess is that in the early stages of ARCS operations a daily evaluation will be a reasonable goal.

Some possibilities are:

- Local operators go through daily check list and phone in findings.
- Interrogate systems periodically via phone modem. NOAA has this capability for the ISSs.

- Transmit an instrument performance data block during one or more satellite transmissions. For example, one transmission per day might be devoted to instrument performance.

3 Power Down/Up Capability

In many instances downed systems can be brought back on line by simply powering them down and then restoring the power or rebooting computer systems. It is recommended that all instrument systems that could possibly be restarted by this method have the capability. Ideally this would best be done remotely via computer control, but instructing the local operator to flip switches on a carefully thought out and designed electrical distribution box could also provided this capability. To highlight the importance of this compare the cost of a few phone calls to the TWP with two round trip airline tickets, per diem, and other associated travel expenses.

4. Redundancy

For some ARCS observations it may be wise to have a completely redundant system. In other cases we may be able to accept the risk of having no redundancy. These requirements cannot be determined apriori, but will require cost-benefit analyses which includes consideration of data requirements, acceptable loss intervals, and associated costs. Redundant computer systems and data communications equipment should received considerable attention for the TWP.

5. Special Considerations

The ARCS facilities must be able to provide a proper and reliable operating environment for the selected instruments. Some examples of some of the things that we will have to worry about in the TWP are:

- well insulated housing with reliable and redundant air-conditioning and dehumidification equipment
- backup electrical power depending on cost benefit analyses factoring in each site's electrical power situation

- special viewing ports or precipitation sensing hatches for remote sensing instruments (NOAA/WPL sucessfully used a rain sensing hatch with the FIRS during PROBE).

6. *Day-To-Day Operations And Maintenance*

High-level technical personnel are not generally available on the islands. Weather Service personnel appear to be the best source of local operational support. They are trained in standard weather observing techniques and instrumentation and usually have some PIBAL experience. PNG weather observers were used successfully in PROBE and at other TOGA COARE sites to operate rawinsondes. Reports are not in from the all the TOGA COARE sites, but these operations went pretty smoothly at the PROBE site with the exception of when non-routine problems occurred.

7. *Security*

Physical security will probably best be addressed by good fencing and arrangements with the local governments.

8. *Periodic Maintenance And Calibration*

Periodic routine instrument maintenance and calibration will be required by qualified technical personnel to insure reliable long-term operation of an ARCS. It is conceived that routine maintenance and calibration would be accomplished by one or two technicians visiting the ARCS sites on some periodic basis (3 months, 6 months, ????) combined with some sort of swap out scheme. Visits will likely be more frequent for the early stages of the first ARCS than for the subsequent ones. The optimal frequency will fall out naturally with experience or be dictated by budget.

9. *Emergency Repairs*

The same team that performs the periodic routine maintenance and calibration should be available to go to an ARCS site and make emergency repairs with a response time defined by acceptable down time considerations. Because this will be an expensive operation realistic considerations of acceptable data recovery must be made. It is unrealistic to expect major emergency repairs on time scales less than about a week.

10. Central Inventory, Repair, and Calibration Facility

A minimum of spare parts will be kept at each ARC site. If there is no one to install them, then there is no reason for them to be there; they can be brought in by the repairer. A local supply of expendables and simple replacement items such as anemometer cups and vanes will be kept at each site.

The majority of spare systems and replacement parts will be kept at a central facility (*e.g.*, in US, Australia, one of the ARCS sites). This most likely would be the home base for the maintenance and repair team. At this facility parts can be dispatched to the ARCS sites when needed and damaged parts can be repaired or sent in for repair. This should reduce considerably the inventory of spare equipment that has to be on hand at anyone time. Calibration will most likely be handled on a swap-out basis from the same or another central facility. Issues with on-site vs. off-site calibration will have to be dealt with for each instrument.

ARCS DEPLOYMENT

First and Second ARCS Sites

We recommended that the first ARCS be located at the Weather Service Station at Momote Airfield, Los Negros Island, Manus Province, Admiralty Islands, Papua New Guinea (2.05 °S, 147.43 °E). Figure 8A shows the location of Manus province in the western Pacific and Figure 8B shows the province in more detail.

This site would serve the west-central region of the TWP locale identified in Figure 6. It lies in the transition zone between the maritime continent and oceanic regimes of the locale. It is recommended as the site of the first ARCS because:

- it meets scientific and logistical criteria
- we have a good start at addressing the logistical, social, and political issues in Manus Province
- there are adequate existing facilities, infrastructure, and support personnel
- NOAA/NCAR operates a long-term Integrated Sounding System at the Momote Airfield

- its small size and remoteness tend to isolate it from the political unrest in other parts of Papua New Guinea

We recommend that the second ARCS be temporarily deployed in Darwin, Australia for the Marine Continent Thunderstorm Experiment (late FY95 to early FY96).

After MCTEX ARCS-II would be relocated in a the more oceanic regime of the central region of the TWP somewhere roughly between 165 °E and 170 °W. Although we are not recommending a specific central region site at this time, some candidates are Nauru, Tarawa, and Kanton because of known existing facilities.

Tentative Deployment Schedule

Our current best guess at a deployment schedule for five ARCS is given in the chart of Figure 9. Calendar years are used in this presentation. This plan calls for the first ARCS to be deployed in the TWP in early 1995 at Manus in Papua New Guinea. The second ARCS would be deployed to Darwin, Australia for MCTEX in late 1995 and early 1996 and then moved to a permanent site in the central region of the TWP locale. The third ARCS would be deployed in late 1996 either on the NOAA ship which will be servicing the TOGA TOA mooring array by that time or at a site in the eastern region of the locale. The fourth ARCS would either be placed in the eastern or western region in mid 1997. The fifth ARCS is planned for either the eastern region or the ocean site.

Deployment schedules depend on resolution of budget, logistical, and host government issues. The deployment plan will be updated as information becomes available.

ARCS DESIGN TEAM

The ARCS concept is the heart of the TWP CART observational program. However, it is being managed as a long-term asset to the overall ARM program. Properly designed ARCSs could serve the NSA, EOM, and GS, as well as provide a more integrated system for some of the observations at the SGP. This demands we do a careful job of up-front thinking, planning, and designing the ARCS while meeting programmatic requirements for the TWP. This is a challenge, but one worth meeting.

In order to facilitate the design, development, siting, and operation of ARCSs an ARCS Design Team has been established under the auspices of the TWPPO as shown in Figure 10. The six major ADT functions and their responsibilities are:

- Science: ensure that ARCS are designed, implemented, tested, sited, and operated to meet ARM scientific objectives.
- Facilities Implementation Team (FIT): design, develop, implement, and test ARCSs to meet scientific objectives.
- Siting: ensure that ARCSs have a suitable site and support facilities for long-term quality operations.
- Operations: ensure that ARCS are calibrated, maintained, and operated for optimal reliable data flow.
- ES&H: ensure that the ARCS are designed, constructed, sited and operated in an environmentally responsible and safe manner.
- Education: provide for local, regional and national education programs related to ARCS operations.

The FIT is further structured as shown in Fig. 10. A full-time dedicated manager will coordinate, integrate, and supervise all phases ARCS activities from the design to the time it is shipped to its site. The FIT manager will report directly to the ADT leader in the TWPPO. The FIT manager is a key person to the success of the ARCS concept.

The major functional areas of the FIT and their responsibilities are:

- Instruments: specify, design (if needed), select, procure, and provide operational guidance for appropriate instruments for making ARCS observations
- Data Systems: specify, design (if required), select, procure, and provide operational guidance for appropriate ARCS's data acquisition and communications
- Facilities: specify, design (if required), select, procure, and provide operational guidance for the physical facilities to house and support ARCS instruments and data systems.

The ADT leader will ensure that all activities are focused, integrated, and coordinated to meet ARCS objectives and operational constraints and meet the ARM program's goals.

APPENDIX A

REGIONAL RESOURCES

We have developed numerous contacts with scientists and agencies throughout the pacific Basin, with the aim of increasing our resource base for logistic, technical, scientific, environmental, social and safety issues that may arise. It is essential that we not only follow the required regulations in each country where we site an ARCS, but also that we become aware of regional, national and local sensitivities to any impact that we may have as a result of installing an ARCS and conducting research in the Pacific. Maintaining cordial relations at all levels of contact that we may have will ensure that the TWP program continues on schedule. Some of these resources are summarized in the following sections, with the chief contact for the organization listed below along with other resources.

South Pacific Regional Environment Programme (SPREP)

SPREP, a multinational organization based in Apia, Western Samoa, has 27 member nations including the island nations of the South Pacific as well as Australia, New Zealand, United States of America, United Kingdom, and France. Their mandate is to provide international coordination for environmental issues and concerns in the region. They have grown from 3 to 20 staff in the last year and are definitely one of the key players for environmental oversight in the region.

South Pacific Applied Geoscience Commission (SOPAC)

SOPAC's headquarters is in Suva, Fiji. Its fundamental objective is to assist its Island member countries in identifying, assessing and developing the non-living marine resource potential of the extensive marine resource jurisdictions they have declared under the United Nations Law of the Sean Convention of 1992. SOPAC is comprised of 14 member countries (Australia, Cook Islands, Federated States of Micronesia, Fiji, Guam, Kiribati, Marshall Islands, New Zealand, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu, and Western Samoa). This includes most the countries in the TWP with which ARM may need to work. SOPAC has good political and technical contacts, and has offered their assistance.

The University of the South Pacific (USP)

The University of the South Pacific (USP) main campus is in Suva, Fiji. It has satellite centers in 12 member countries (Fiji, Tonga, Western Samoa, Solomon Islands, Kiribati, Tuvalu, Cook Islands, Vanuatu, Niue, Tokelau, Nauru, Marshall Islands). Considerable instruction is conducted via two-way satellite connections from the main campus. Faculty in the Physics Department have interests related to the ARM program which include climate change, meteorology, ENSO, soil physics, solar radiation, satellite data acquisition, applied computing and electronics, and field data acquisition. They could be an important resource for contact with students, scientists, and collaborative research, as well as giving us guidance in political and social areas.

United Nations Educational, Scientific, and Cultural Organization's (UNESCO) Office of the Pacific States

The UNESCO Regional Ofiice, in Apia, Western Samoa, represents scientific and educational interests in the Pacific region. They are able to serve as a link for us to broad social and scientific organizations throughout the region, and have expressed an interest in being keep current with our plans.

Papua New Guinea National Weather Service

The Weather Service in Papua New Guinea operates Weather Service stations at airports throughout the country. The PROBE experiment was collocated with such a station in Kavieng, New Ireland Province, and a candidate ARCS site is the Weather Service station at Momote Airport, Manus Province. The Weather Service personnel at each station are qualified to operate standard instrumentation. Officials of the Weather Service are interested in cooperating with ARM, and could be able to help us with local and national logistics during installation, maintenance, and operation of an ARCS.

Manus Provincial Government, Papua New Guinea

The island Province of Manus is a candidate site for an initial ARCS installation. The Provincial Government has expressed an interest in hosting such an installation, and is very willing to work with us to ensure full compliance with any regulations that apply. They are particularly interested in any research results that ARM may produce, and in developing educational interactions with students and universities in Papua New Guinea.

Australian Bureau of Meteorology Research Centre (BMRC)

BMRC has extensive experience in tropical meteorological research with ongoing field work in the Darwin area. We are proposing to augment the Darwin research site with an expanded ARCS and will be working closely with BMRC and the Northern Territory Regional Director of the Australian Bureau of Meteorology (see Appendix B) in this installation. BMRC is also planning a major campaign, the Maritime Continent Thunderstorm Experiment (MCTEX) for 1995-1996 in Northern Australia. We are considering participating in this experiment.

Commonwealth Scientific and Industrial Research Organization (CSIRO)

CSIRO has an active Atmospheric Research Division with ongoing projects in the tropics. They participated in the PROBE effort in TOGA/COARE and have made a significant contribution. They have had experience in public relations and environmental compliance in Australia and will be a resource for both logistics and research issues.

Tropical Ocean Global Atmosphere/Coupled Ocean Atmosphere Response Experiment (TOGA/COARE)

TOGA/COARE is a multinational effort headed by NCAR and NOAA. Personnel have current extensive experience in conducting field research in the Pacific. We will be relying on their expertise in areas of logistics, international cooperation, measurement strategies, design and conduct of IOPs, and instrument maintenance.

University of Hawaii

We have established relations with the Meteorology Department, the Physics Department, the Hawaii Institute of Geophysics (HIG), and the Joint Institute of Marine and Atmospheric Research (JIMAR) at the University of Hawaii at Manoa. They have a wide range of capabilities and interests in tropical meteorology and instrumentation. Roger Lukas at JIMAR was one of the chief scientist for TOGA COARE. The Meteorology Department has experience in the tropics, particularly at Christmas Island.

NEPA AND SAFETY PLANS

Preliminary ES&H Questionnaires and the DOE Environmental Checklist documents were filled out and submitted to the DOE Albuquerque Operations Office in 1992. The followup work for satisfying NEPA requirements for the TWP has focused on our intent to comply with all extra-territorial regulations. A memo of intent to comply was forwarded to by Albuquerque Operations Office in January 1993, and a followup memo of progress completed in April 1993. The memo of progress focused on additonal information obtained by Barnes and Clements from their visti to the TWP locale in February 1993. An exemption from further requirements to prepare DOE/NEPA documentation was received from DOE in May, 1993.

Plans for development of Environmental Assessment documents (drafted 11/20/92) and Health and Safety documents (drafted 4/5/93) are both based on a modular structure in which a site-specific document for an ARCS is tiered to overall volumes for the entire TWP project. Both plans have received a verbal preliminary approval by the NEPA and Safety officers in the LANL management structure. These plans will be under continuous revision as we proceed, and the current version is always available for review.

RESOURCES AND CONTACTS

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APPENDIX C: Acronymns

ARCS	Atmospheric Radiation and Cloud Stations
ARM	Atmospheric Radiation Measurement
CART	Cloud and Radiation Testbed.
COARE	Coupled Ocean Atmosphere Response Experiment
CSIRO	Commonwealth Scientific and Industrial Research Organization
ENSO	El Niño Southern Oscillation
ERBE	Earth Radiation Budget Experiment
ES&H	Environment, Safety, and Health
FAX	Facsimile
FIRS	Fourier-transform Infrared Sounder (Spectrometer?)
FIT	Facilities Implementation Team
GCM	Global Climate Model
HIG	Hawaii Institute of Geophysics
ITCZ	Intertropical Convergence Zone
JIMAR	Joint Institute for Marine and Atmospheric Research
LANL	Los Alamos National Laboratory
LIDAR	Light Detection and Ranging
MCTEX	Maritime Continent Thunderstorm Experiment
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Protection Act
NOAA	National Oceanic and Atmospheric Administration
OLR	Outgoing Longwave Radiation
PMEL	Pacific Marine Environmental Laboratory
PNG	Papua New Guinea
PROBE	Pilot Radiation Observation Experiment
SGP	Southern Great Plains
SOPAC	South Pacific Applied Geoscience Commission
SPaRCE	Schools of the Pacific Rainfall Climate Experiment
SPREP	South Pacific Regional Environmental Program
SST	Sea Surface Temperature
TAO	Tropical Ocean Atmosphere

TCIPO	TOGA COARE International Program Office
TOGA	Tropical Ocean Global Atmosphere
TRMM	Tropical Rainfall Measurement Mission
TWP	Tropical Western Pacific
TWPPO	TWP Program Office
UAV	Unmanned Aerospace Vehicle
UNESCO	United Nations Educational, Scientific, and Cultural Organization.
USP	University of the South Pacific
UVB	Ultraviolet B
WPL	Wave Propagation Laboratory

Table 1

ARCS Observations And Possible Instruments

OBSERVATIONS	POSSIBLE INSTRUMENTS
SURFACE FLUXES	
Broad-band	Solar and IR radiometers
Spectral	IR thermometer
Direct	Rotating shadow band radiometer Total, diffuse, direct radiometer Sun photometer
CLOUD PROPERTIES	
Location, structure, phase	LIDAR Millimeter radar
Sky coverage	Whole sky imager
Optical depth, emissivity	Rotating shadow band radiometer Total direct, diffuse radiometer Sun photometer Zenith view 10 micron radiometer
WATER VAPOR	
Amount	Microwave radiometer
Vertical profiles	Rawinsonde
AEROSOLS	
Optical depth	Sun photometer Rotating shadow band radiometer Total, diffuse, direct radiometer
Vertical profiles	LIDAR
BOUNDARY LAYER STRUCTURE	
Temperature, wind, and humidity profiles	915 MHz profiler with RASS Rawinsonde
SURFACE METEOROLOGY	
Wind speed and direction, temperature, pressure, humidity, rain rate	Surface weather station

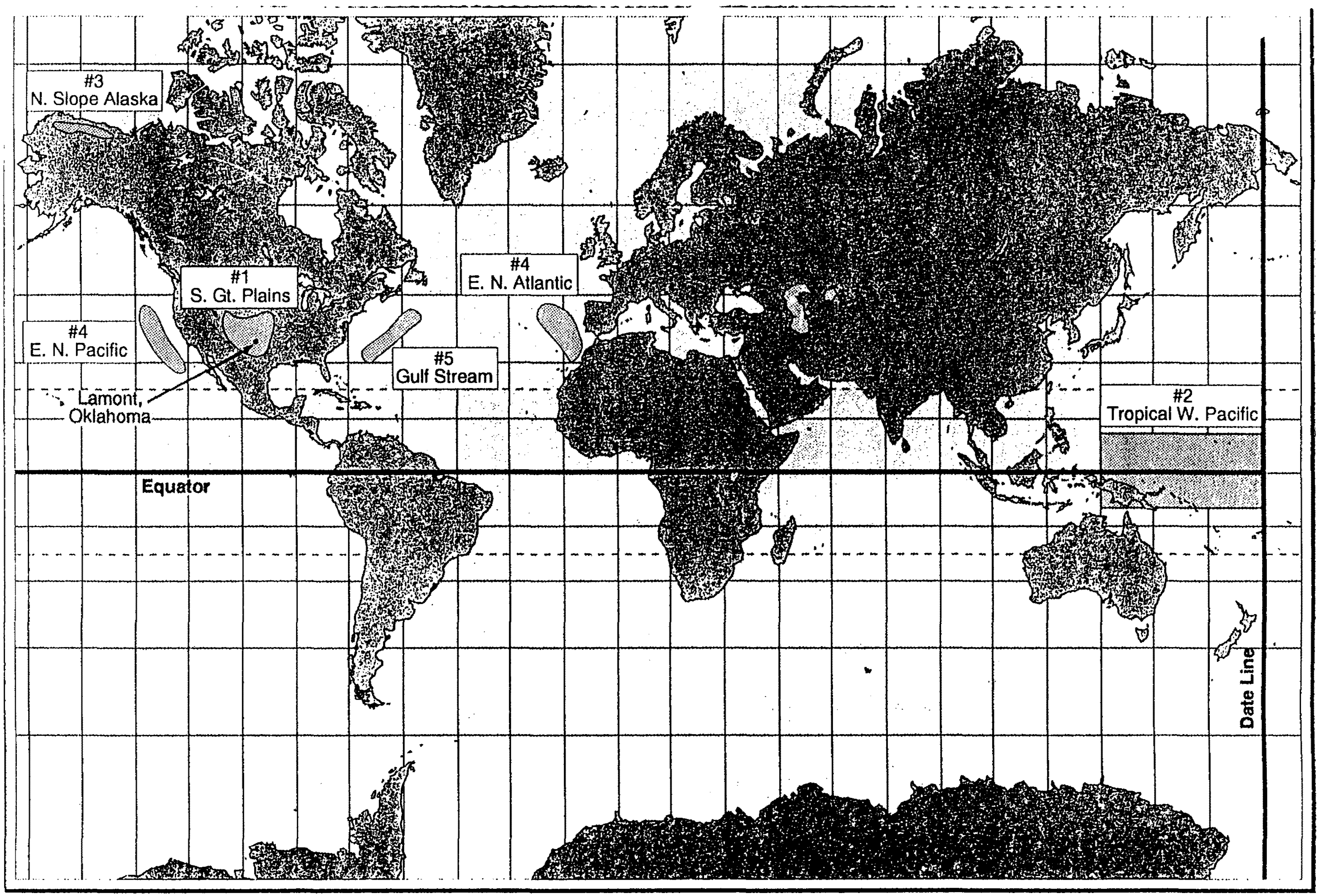


Fig. 1. Locales for the ARM Cloud and Radiation Testbed(CART) sites.

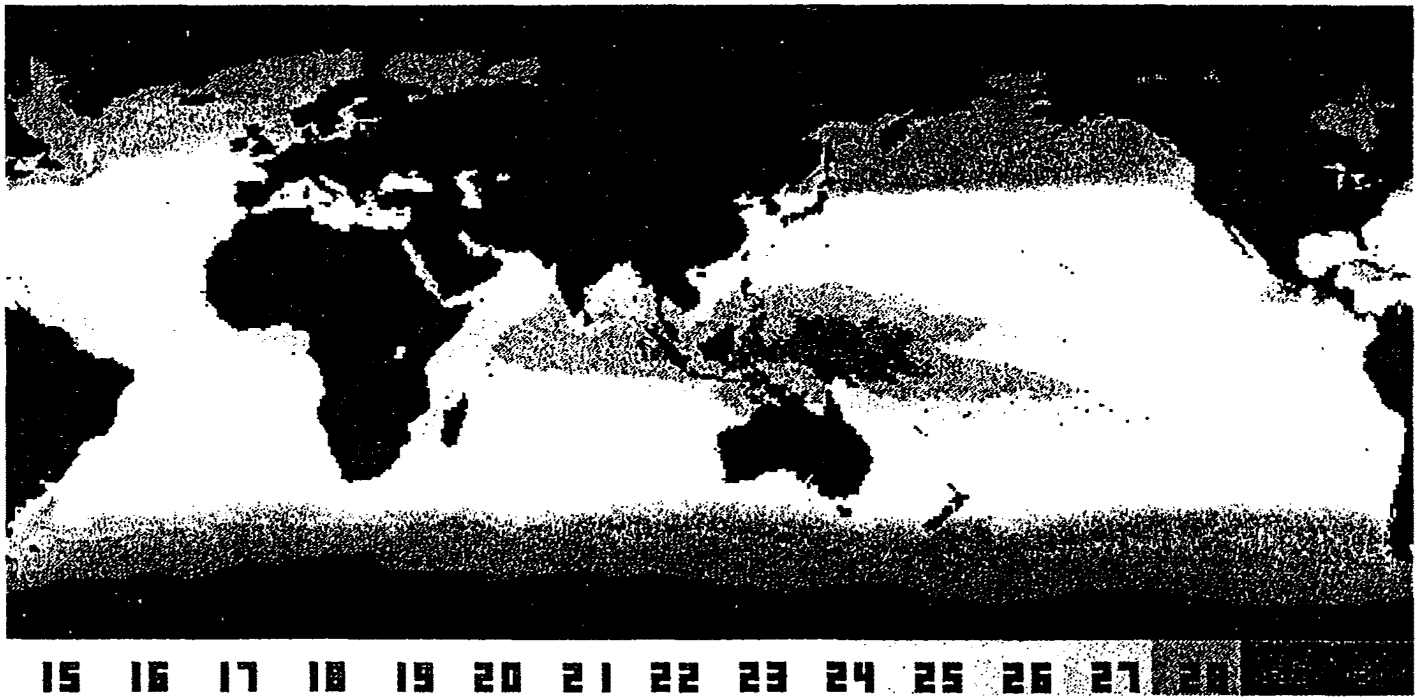


Fig. 2 Annual mean sea-surface temperature (SST) image computed from satellite AVHRR-MCSST data. Color scale is in degrees centigrade. The 28°C surface isotherm approximately bounds the warm water pool of the western Pacific and eastern Indian oceans. Because the turbulent heat exchange between the ocean and the atmosphere is a highly nonlinear function of SST, and because of the very large size of the warm pool region, the global atmosphere is extremely sensitive to the SST anomalies in the warm pool.

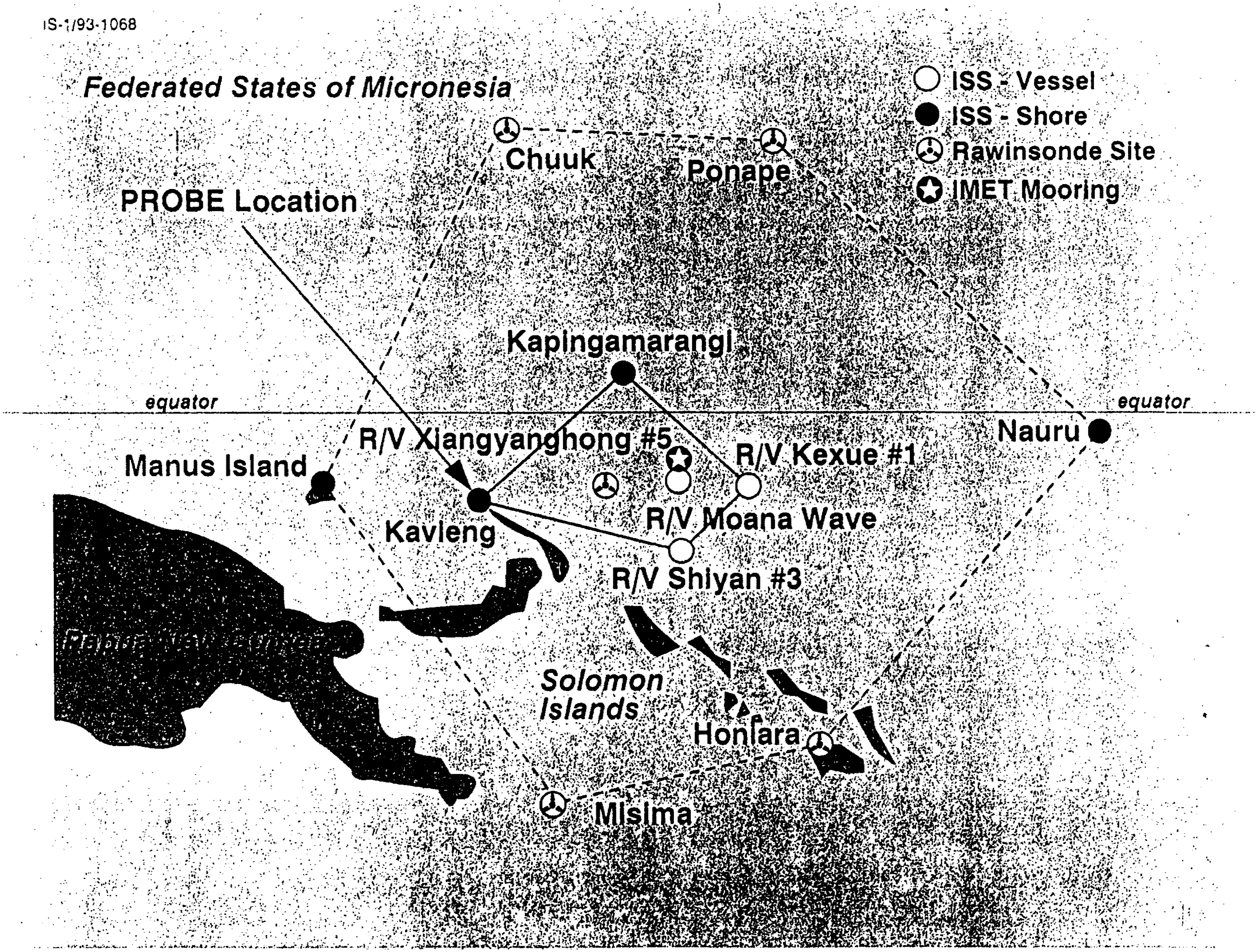


Fig 3. Location of PROBE during TOGA COARE. The solid lines delineate the Intensive Flux Array area within the overall TOGA COARE study area.

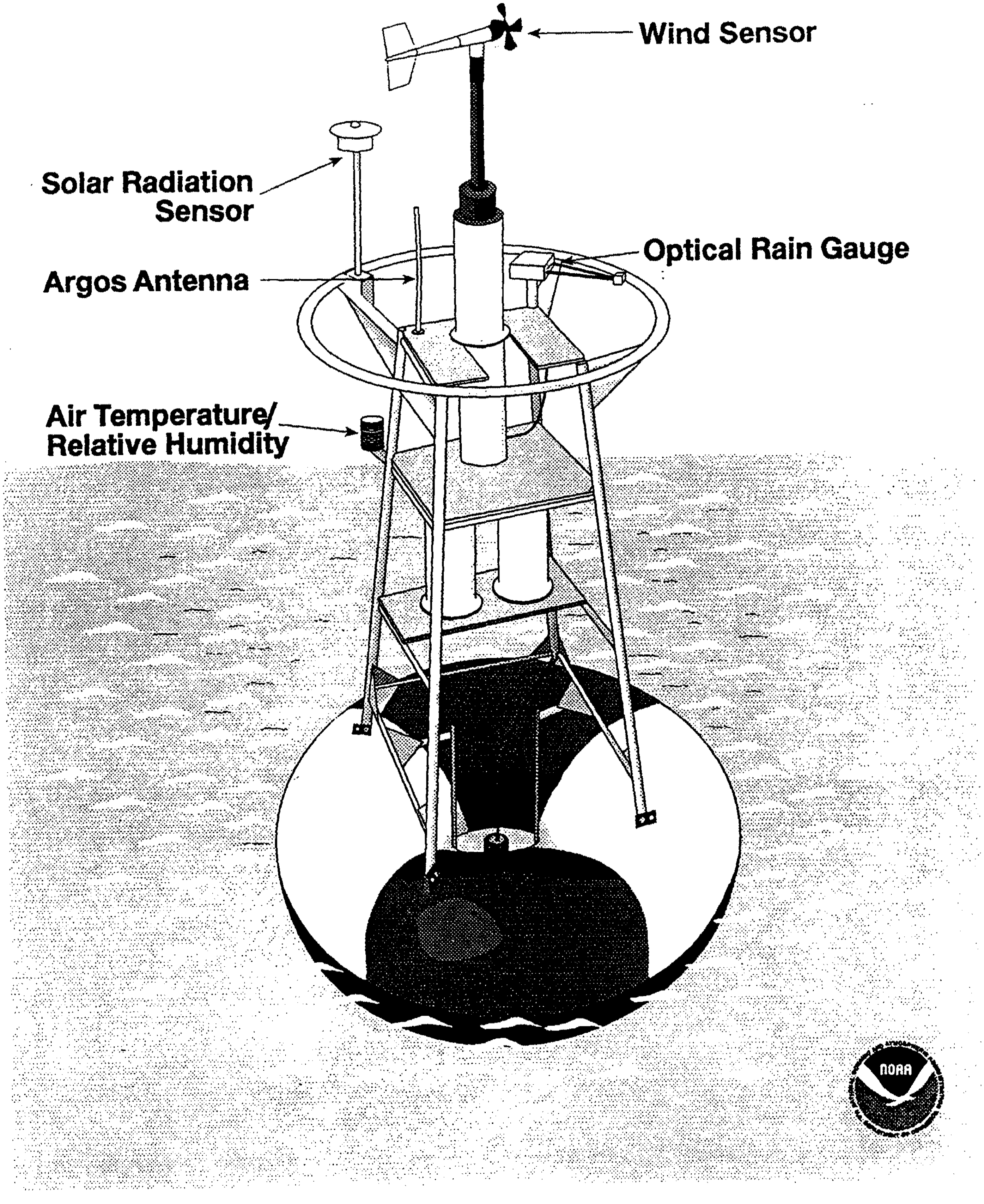


Fig 4. Atlas mooring to be deployed in the TOGA TAO array.

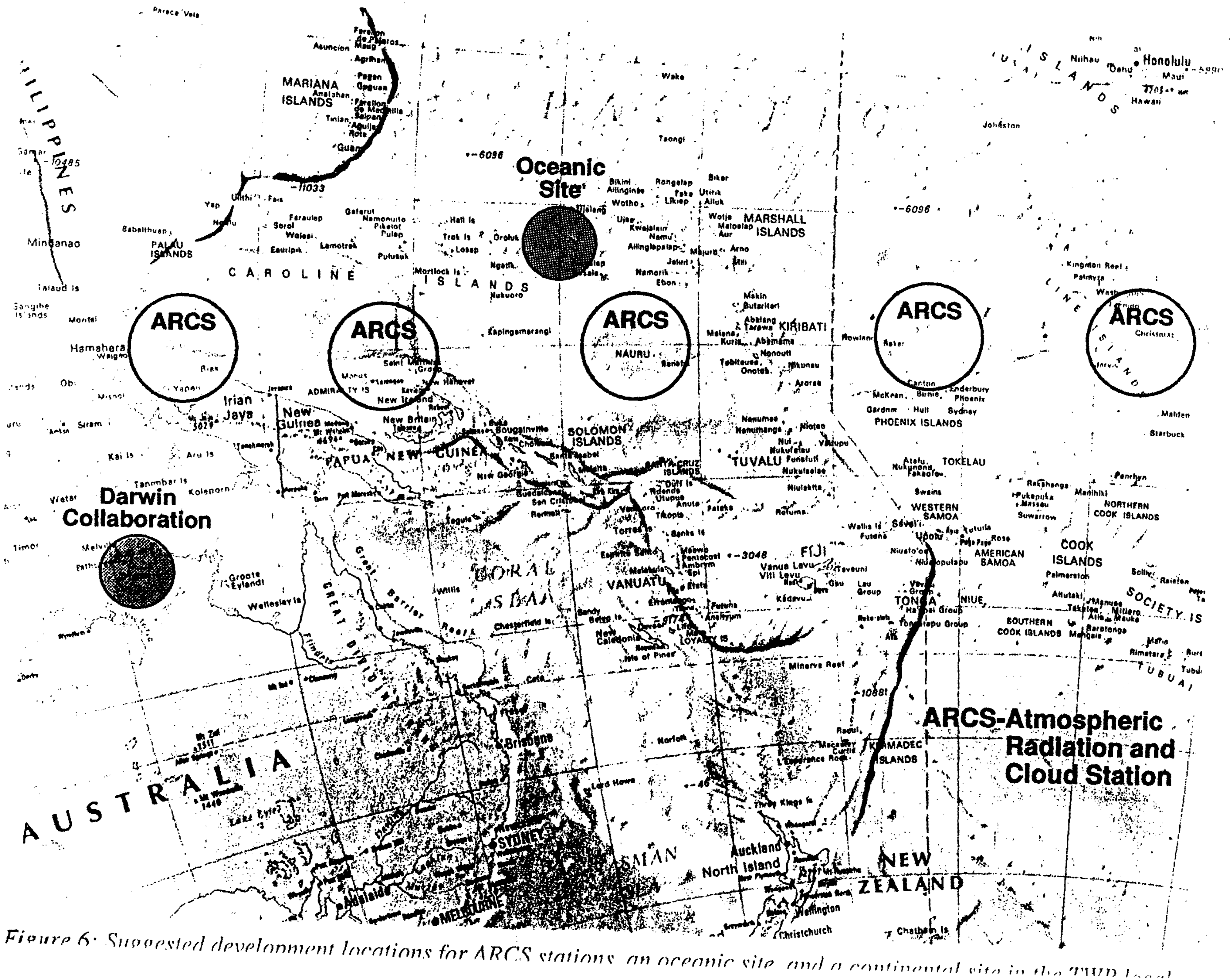
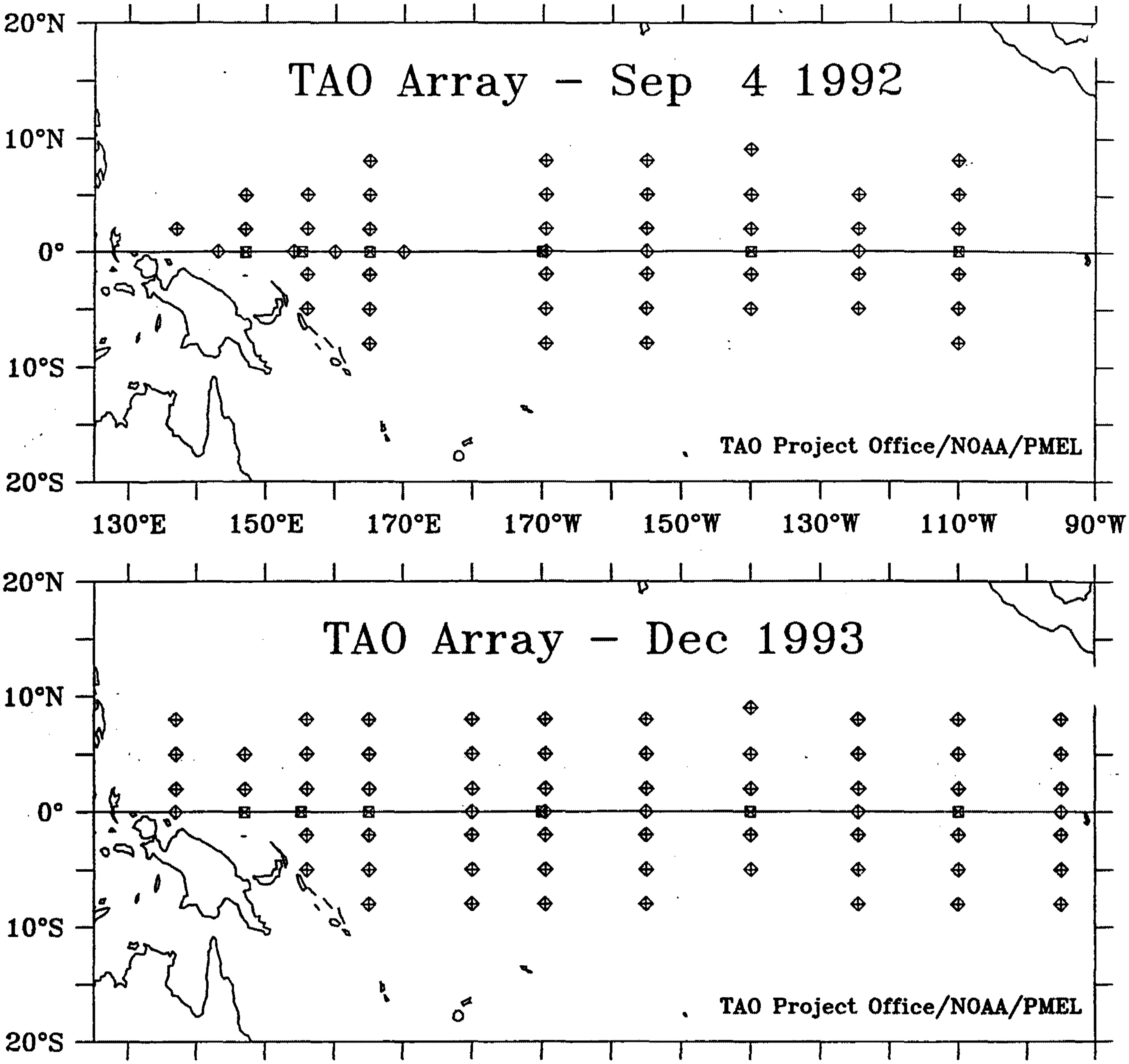


Figure 6: Suggested development locations for ARCS stations, an oceanic site, and a continental site in the TWP


TAO Array - Sep 4 1992

TAO Project Office/NOAA/PMEL

TAO Array - Dec 1993

TAO Project Office/NOAA/PMEL

Fig. 5. TOGA TAO array of buoys being deployed across the Pacific basin.

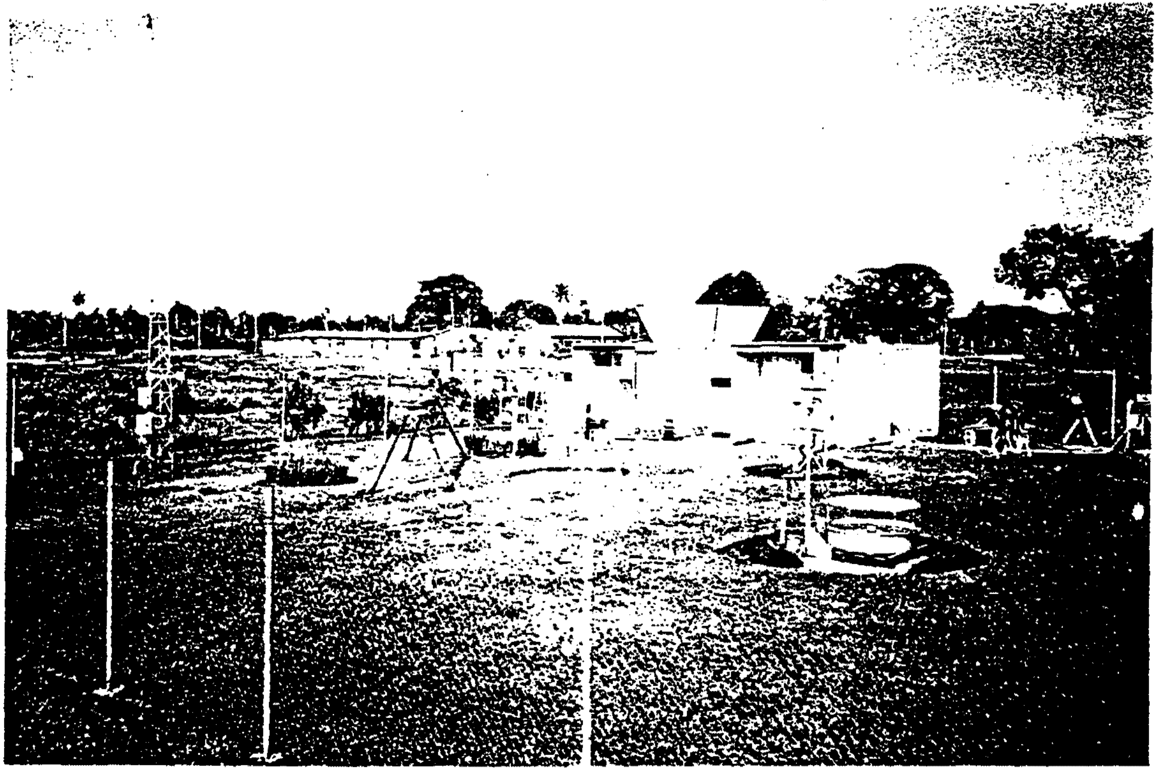


Fig. 7A. Sea containers served as instrument shelters and laboratories at PROBE.

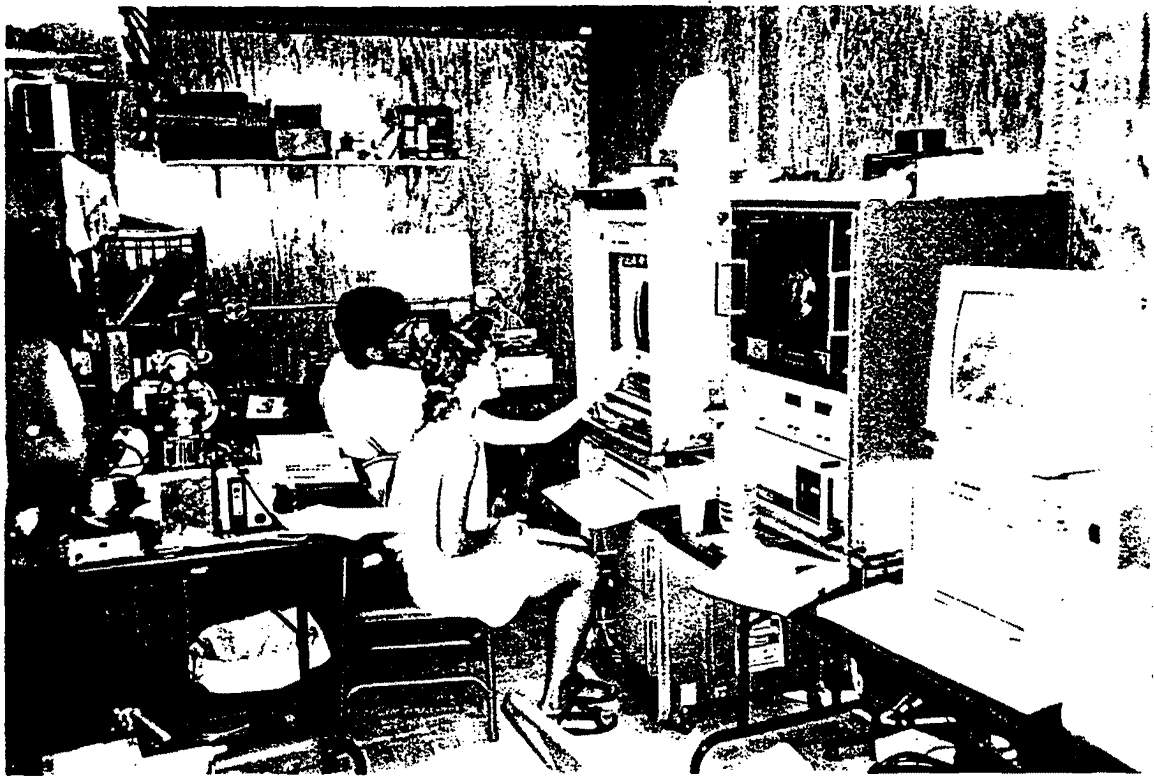


Fig. 7B. Inside the PROBE sea container at PROBE.

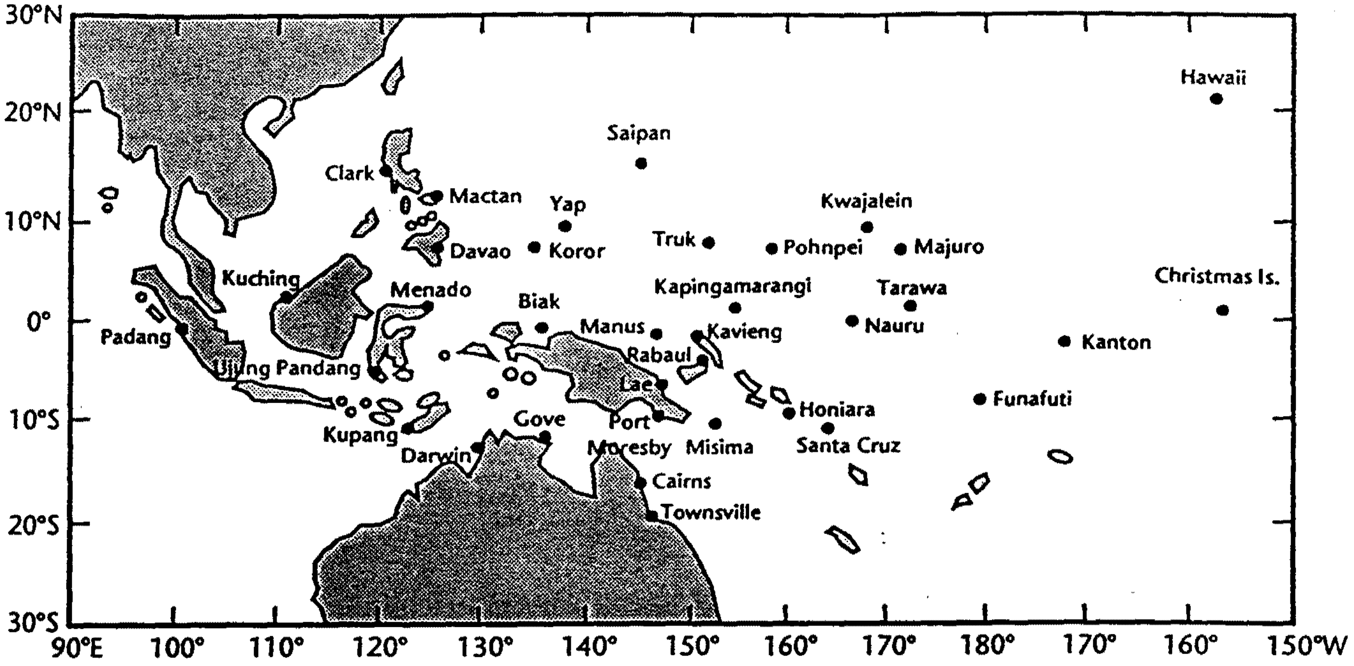


Fig. 8A. Tropical Western Pacific region showing Manus Province at about 2^{o}S and 147^{o}E.

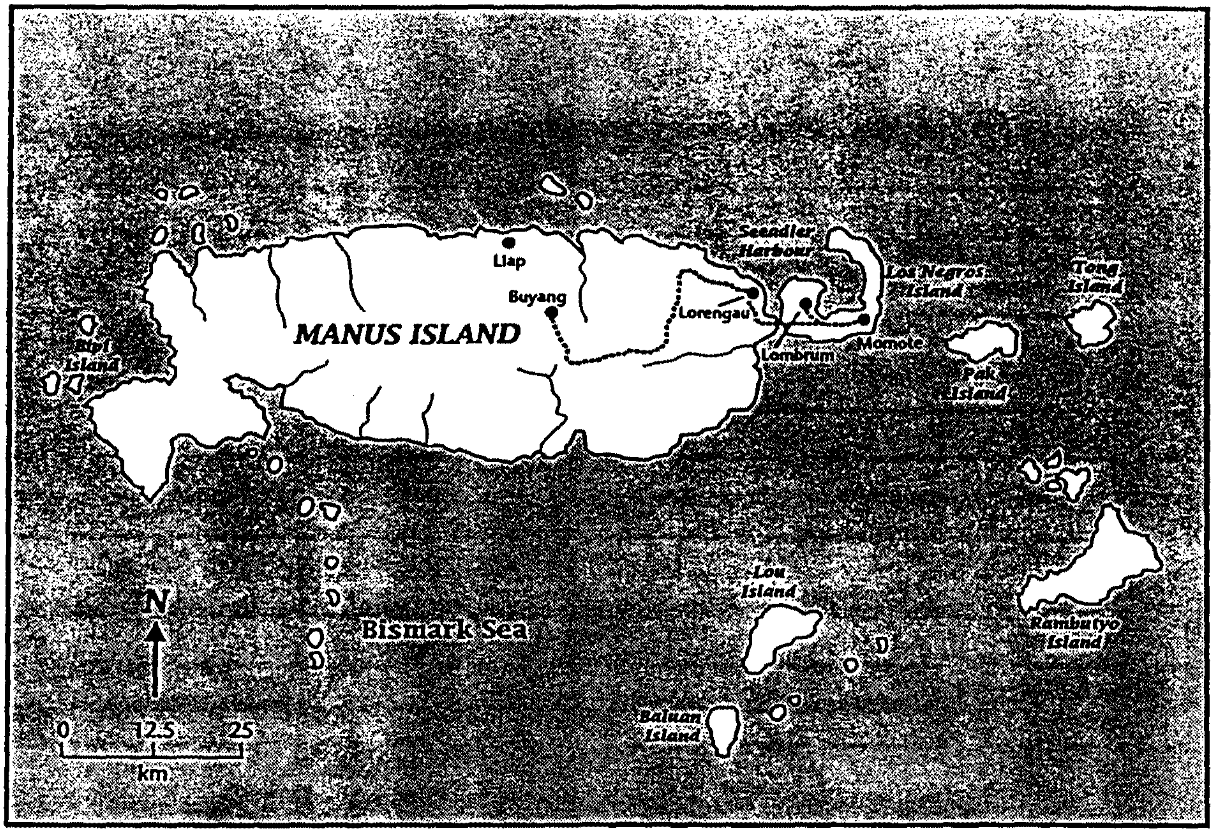


Fig. 8B. Manus Province. The Momote airfield is located on the eastern end of Los Negros Island.

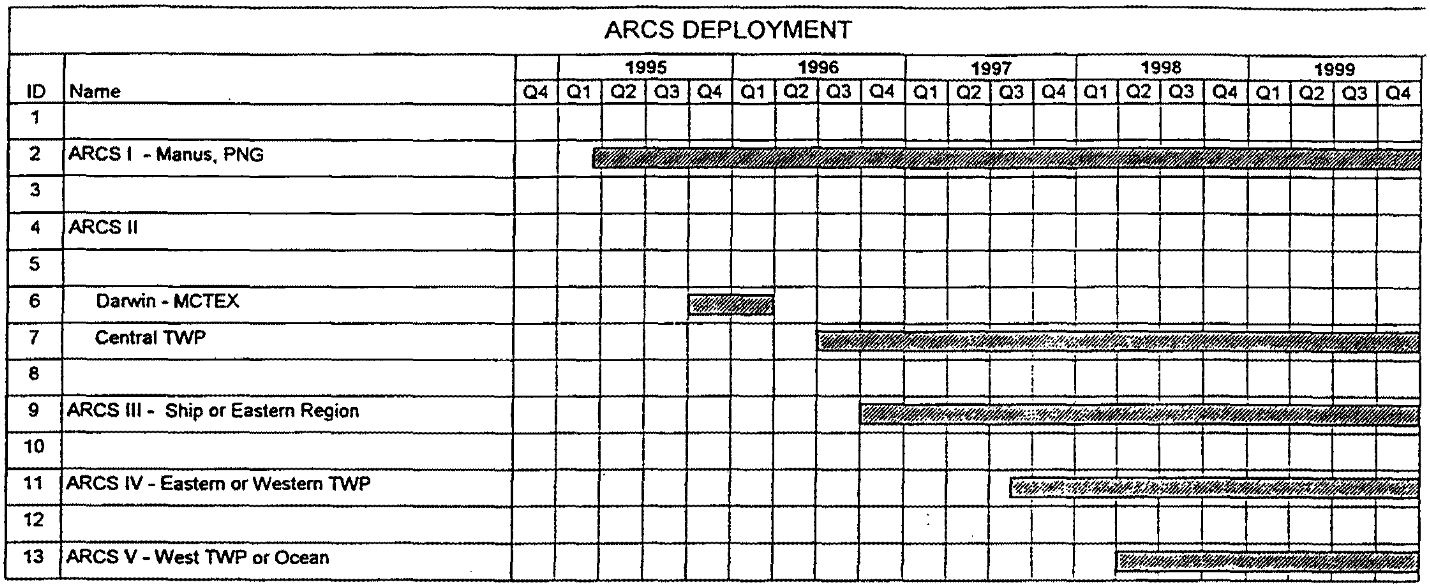


Fig. 9. Current estimate of deployment schedule for ARCSs.

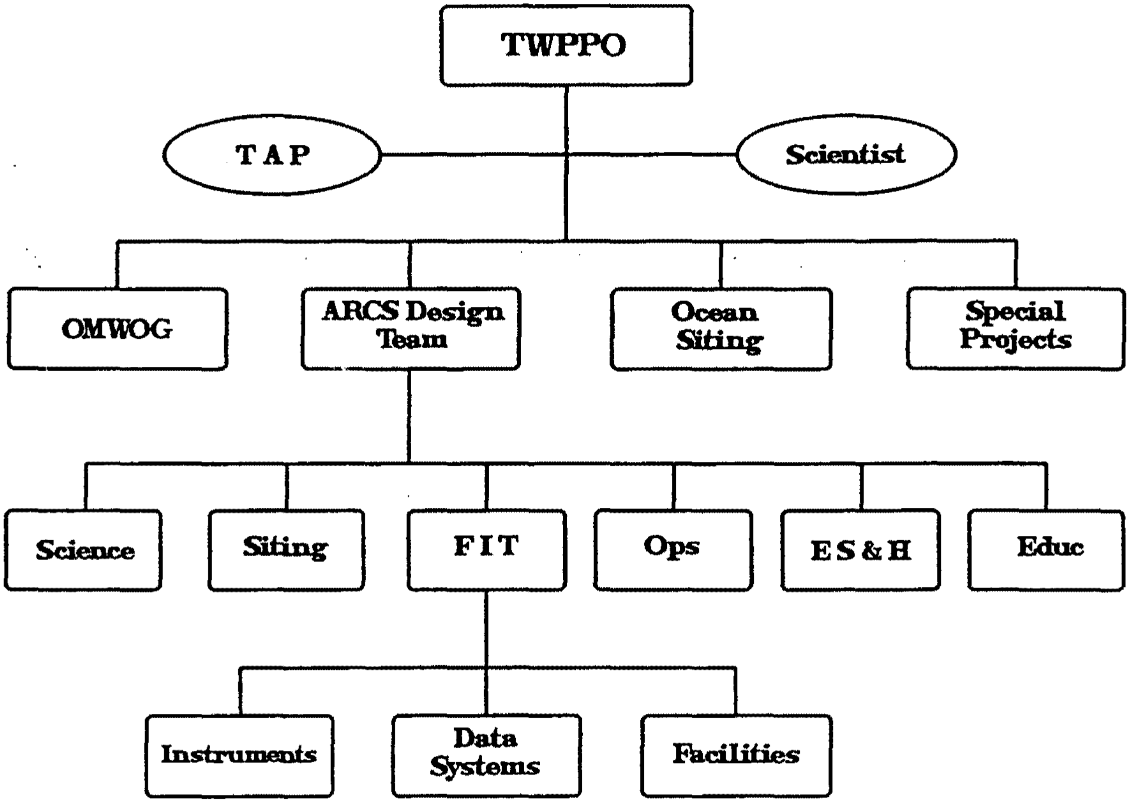


Fig. 10. Tropical Western Pacific Program Office (TWPPO) organization. TAP is Technical Advisory Panel; FIT is Facilities Design Team.