WORLD CLIMATE PROGRAMME

RESEARCH

INTERNATIONAL COUNCIL
OF SCIENTIFIC UNIONS

WORLD METEOROLOGICAL
ORGANIZATION

WORLD OCEAN CIRCULATION EXPERIMENT IMPLEMENTATION PLAN

Vol. I

Detailed Requirements

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**INTERGOVERNMENTAL
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**SCIENTIFIC COMMITTEE
ON OCEANIC RESEARCH**

The World Climate Programme launched by the World Meteorological Organization (WMO) includes four components:

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

The World Climate Research Programme is jointly sponsored by the WMO and the International Council of Scientific Unions.

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WOCE IMPLEMENTATION PLAN

VOLUME I

'DETAILED REQUIREMENTS'

CONTENTS

FOREWORD

Global climate change and its effects are emerging as the most pressing environmental problem for mankind. Although advances in computer power have put within our vision the possibility of reliable climate forecasts, it is now realised that successful simulation of the broad evolution of global climate beyond a few years will require the inclusion of the dynamics of the world oceans through their full depth.

An indispensable prerequisite is therefore high quality global oceanographic data of unprecedented detail, and specifically data which defines the circulation of the oceans and the exchanges that occur within and between them.

The World Ocean Circulation Experiment (WOCE) is a new international initiative to address this requirement. It has been designed by leading world specialists in oceanography and climate modelling, as members of the WOCE Scientific Steering Group and subsidiary working groups. The WOCE Scientific Steering Group is jointly sponsored by the Joint Scientific Committee for the World Climate Research Programme and the Committee on Climate Changes and the Oceans, which, in turn, are sponsored by the International Council for Scientific Unions, the World Meteorological Organization and the Intergovernmental Oceanographic Commission. WOCE is the major oceanographic component of the WCRP Third Stream, dealing with decadal and longer period variability.

WOCE will require cooperative participation, oceanographic research resources and governmental assistance from many countries. It will exploit a window of opportunity provided by the coming generation of experimental earth observing satellites. From a strong base in conventional oceanography, WOCE will build upon and extend the latest technological advances in ship-borne and automatic observation techniques, and systems of data transmission, management and assimilation.

WOCE will be a proving ground for systems which will form the basis of a permanent ocean observing network to serve all nations by monitoring the state of ocean climate. The success of WOCE will also provide an essential foundation for further multidisciplinary studies of the causes and effects of our changing global environment (such as the International Geosphere Biosphere Programme IGBP).

The Implementation Plan builds upon the WOCE Scientific Plan, published in July, 1986. It can be regarded as a guidebook to define the means proposed and the resources required to achieve the WOCE objectives, in a form that enables prospective scientific participants and their national sponsors to assess their ability to contribute, the standard of commitment required and the methodology proposed.

Apart from being the largest coherent oceanographic experiment ever contemplated, WOCE is an essential step toward the rational description of climate and its evolution. Ultimately, benefits will accrue to nations, both individually and collectively. However, the success of WOCE is dependent upon international oceanographic participation and cooperation to an unprecedented degree. Users of this document are therefore encouraged to take these factors into account when considering the means and the extent of their involvement in this vital enterprise.

G.A. McBean
Chairman, Joint Scientific Committee for the WCRP

Gordon McBean

A.D. McEwan
Chairman, Committee on Climate Changes and the Oceans

Allan McEwan

PREFACE

About 10 years ago, oceanographers realized that growing concern about the Earth's climate could only be addressed seriously if there was much better understanding of the ocean circulation as a whole. In preliminary discussions, they concluded that it was possible to contemplate observing and modelling the ocean sufficiently well to understand quantitatively how the ocean effects present climate, and how the ocean might change under a changing atmosphere.

The scientists involved in this early examination of the possibilities recognized that what needed to be done could not have even been contemplated seriously as recently as five years before. The progress of oceanography and related sciences in the preceding decades had however, brought technical capabilities to a level where the possibility of understanding the global circulation was no longer complete fantasy. Among many developments crucial to taking further, much more deliberate steps, the following were especially important:

(1) Quantitative calculations showing that the ocean carried a significant fraction of the equator-to-pole heat flux, a flux which makes the middle latitudes of the earth habitable.

(2) Demonstration that the interaction of greenhouse and other gases with the ocean circulation was extraordinarily complex, involving exchanges in both directions between ocean and atmosphere, and potential changes in the ocean circulation itself as a result of the increasing presence of these gases.

(3) A sequence of field programmes which had almost delineated the full range of oceanic variability from thousands of kilometres to centimetres, making it plain that the ocean was a turbulent system with interacting components over an enormous range of space and time scales.

(4) The demonstration that satellite-borne instrumentation could provide global and synoptic measurements of surface topography, wind stress, and other important variables for determination of the global circulation.

(5) Developments of in situ instruments of many types, ranging from long-lived direct measurement observational systems to advances in field and laboratory techniques for studying the analytical chemistry of the ocean.

(6) The rapid development of computers and computer models at a pace which if extrapolated reasonably for another decade would become capable of modelling the physics and chemistry of the ocean over all the relevant time and space scales.

These and many other developments meant that the global oceanographic community had within reach the technical capability of examining the ocean as a whole. The need to do so as governments increasingly seek scientific guidance not only about questions of climate, but also about potential sea-level rises, changing oceanic biota, the possibility of dumping long-lived dangerous waste onto the ocean floor, and a host of other long-term consequences of the oceanic circulation.

The conclusion that a World Ocean Circulation Experiment was both necessary and feasible is the result of extensive discussions of many people within and outside governments over a long period of time. This Implementation Plan represents the efforts of hundreds of people from all over the world who have spent thousands of hours grappling with the problem of defining the best possible, yet feasible, scientific plan for understanding the ocean circulation well enough to predict its climate consequences. The reader of this document will appreciate the complexity of the scientific, technical, logistic, and socio-political aspects of reaching the ambitious goals of WOCE.

This Implementation Plan, while it remains imperfect, is intended to stimulate further discussion among scientists, governments and international agencies so as to reach the WOCE goals. The Plan will change as we near the major field phases of the programme; it will continue to change as the programme progresses and we collectively learn more about how the ocean works. The Plan is being published at this time to invite constructive criticism, to allow scientists and governments to formulate their own contributions toward meeting its needs, and in general to invite participation in the most ambitious oceanographic experiment of ali time - one which holds the promise of both exciting scientific advances and of providing immensely important practical knowledge of the human environment.

Carl Wunsch
Chairman, Scientific Steering Group,
World Ocean Circulation Experiment

1. OVERVIEW

1.1 Background

The World Climate Research Programme (WCRP) was established by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) with the objective of determining the degree to which climate can be predicted and the extent of man's influence on climate. To address the various important aspects of global climate, the WCRP has been partitioned into three "Streams" of research, the third of which is concerned with the prediction of climate changes over periods of decades. Because the major scientific problem limiting such predictions is the inability to describe and model the circulation of the World Ocean, the organizers of the WCRP have established the World Ocean Circulation Experiment (WOCE) as the principal activity within Stream Three.

WOCE is, therefore, being organised in conjunction with ICSU's Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The goals and objectives have been formulated by the Scientific Steering Group (SSG) for WOCE, a group established by the SCOR/IOC Committee on Climatic Changes and the Ocean (CCCO) and the WMO/ICSU Joint Scientific Committee to plan and organize the experiment and set scientific priorities for implementation. The goals, objectives, scientific basis and general field programme of WOCE are outlined in the Scientific Plan for WOCE prepared by the SSG and issued as WCRP Publication Series No. 6, 1986.

This WOCE Implementation Plan takes into account developments that have taken place since the publication of the Scientific Plan and provides the basis for moving forward from the scientific planning of WOCE to its implementation. It also provides the basic information for review by the International WOCE Scientific Conference to be held 28 November - 2 December 1988 in Paris. It is anticipated that the results of the Conference will make it possible to assess whether or not the proposed programmes as outlined in this plan can and will be implemented by the nations involved in WOCE.

Although the Implementation Plan provides a detailed scientific framework for WOCE and specific requirements for resources needed for its implementation, it should be remembered that a programme such as WOCE will continue to evolve throughout the lifetime of the experiment. Some elements of this Implementation Plan are likely to remain essentially fixed. These include, for example, the basic goals and objectives of the experiment and the strategy of meeting them through Core Projects. However, as more is learned about the ocean and changes occur in the availability and capability of various technologies, details regarding the implementation of WOCE may change. Even without limitations on the resources needed to carry out the experiment, it may easily turn out that, in the light of new information, changes may be necessary in such aspects of the field programme as the location of a section or the mixture of measurements used to meet a particular scientific objective. The possibility of such change is stated. If the resources available for WOCE are insufficient for the programme, other changes may be necessary. The present timeable for the major WOCE activities is given in Figure (1.1).

1.2 Organisation of this Plan

This plan has been prepared in two volumes. This, the first, gives an overview of the Goals and Objectives of WOCE and the strategy for meeting them, and a summary of the resources required. In the following chapters, details of the implementation of the experimental elements of WOCE, data management, the modelling programme, and detailed tables of resource needs are presented.

The second volume contains the detailed description of the three Core Projects which form the heart of WOCE. It provides the scientific rationale that has led to the field programme for WOCE and provides the details of experimental elements that make up the field programme as well as how, taken together, they constitute a coherent programme that meets the overall objectives of the Core Projects and of WOCE itself. Throughout this first volume references are made to the second volume. This is especially the case regarding the tables describing the detailed field programme.

A full understanding of the scope of WOCE can only be obtained from the material contained in the two volumes. They are however relatively self-contained for readers interested in different aspects of WOCE. Some material, especially figures, is contained in both volumes.

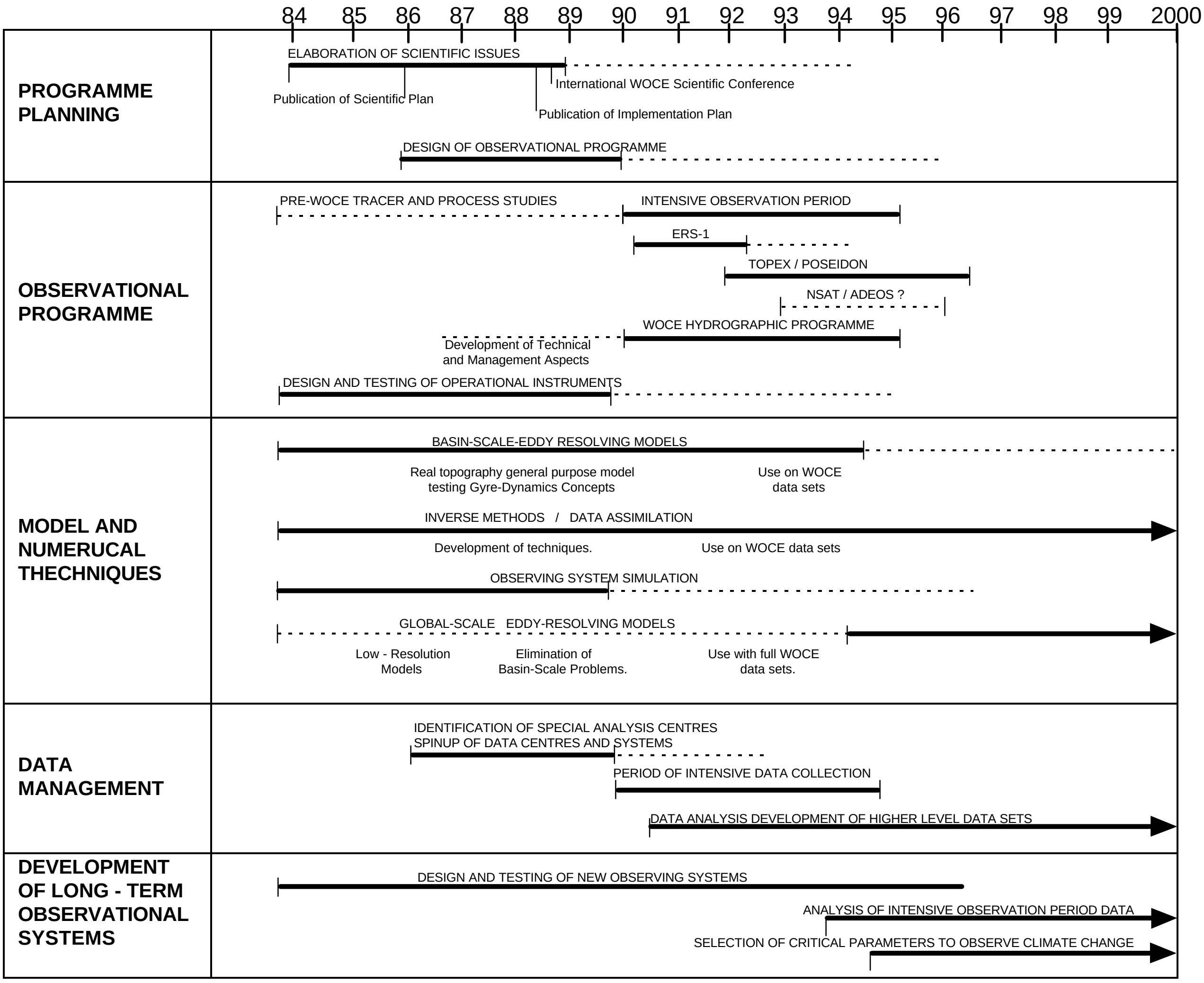


Figure 1.1 Timetable of major WOCE activities

1.3 The Goals and Objectives of WOCE

The goals and objectives of WOCE are as follows:

Goal 1: To develop models useful for predicting climate change and to collect the data necessary to test them.

Goal 2: To determine the representativeness of the specific WOCE data sets for the long-term behaviour of the ocean, and to find methods for determining long-term changes in the ocean circulation.

Within Goal 1 the specific objectives are:

To determine and understand on a global basis the following aspects of the World Ocean circulation and their relation to climate:

(1) The large-scale fluxes of heat and fresh water, their divergences over 5 years, and their annual and interannual variability.

(2) The dynamical balance of the World Ocean circulation and its response to changing surface fluxes.

(3) Components of ocean variability on months to years, mega-metres to global scale, and the statistics on smaller scales.

(4) The rates and nature of formation, ventilation and circulation of water masses that influence the climate system on time scales from ten to one hundred years.

Within Goal 2 the specific objectives are:

(1) To determine the representativeness of the specific WOCE data sets.

(2) To identify those oceanographic parameters, indices and fields that are essential for continuing measurements in a climate observing system on decadal time scales.

(3) To develop cost-effective techniques suitable for deployment in an on-going climate observing system.

This Implementation Plan primarily concerns the experimental programme necessary to meet Goal 1 and its Objectives, although some of the long-term records will be directly applicable to Goal 2. Direct consideration of Goal 2 is being started by a Working Group recently established by the SSG. The SSG concluded that a strategy for attaining Goal 2 could only follow understanding of how to reach Goal 1, and indeed would require knowledge of the ocean obtained through the three Core Projects of Goal 1. Nonetheless, preliminary planning has begun.

The four Objectives of Goal 1, as stated above, are central to the experimental design of the WOCE field programme. They address the principle scientific issues that must be clarified if Goal 1 is to be achieved. Objective (1), concerning the large-scale fluxes of heat and fresh water and their annual and interannual variability, is basic to understanding the role of the ocean in global climate change. At the present time there remain uncertainties not only in the magnitude of the meridional heat flux but also, in some locations, in its sign and there is a need for data sets that will reduce this uncertainty. This will require measurement of both the interior ocean fluxes as well as those across the surface.

Objective (2), concerning the dynamical balance of the circulation and its response to changing surface fluxes, addresses the basic question of the physical mechanisms that control the ocean circulation and its variability. Much remains to be understood before models of the ocean circulation can be developed with an accurate enough representation of oceanic physics that one can have some confidence in their ability to predict climate change.

The need to measure oceanic variability on time scales of months to years and on large space scales as well as the statistics of this variability on smaller scales, Objective (3), is almost self-evident. The extent of the larger-scale changes is one of the great unknowns of the ocean circulation and clearly basic to understanding and modelling climate changes. However, the role of smaller scales in transporting various physical properties of the ocean is also unclear and the extent and strength of this mechanism in the global ocean therefore needs to be determined.

Objective (4) concerns water mass formation and circulation which play a fundamental role in the ocean’s interaction with the atmosphere on climate time scales. Although much as been learned in recent years regarding the mechanisms which control water masses on a global scale, quantitative estimates of rates of formation and transport are required. Water masses and the geochemical tracers that they carry also constitute a method of inferring the ocean circulation and provide a constraint on global models.

1.4 The WOCE Core Projects

The specific needs of Stream 3 of the WCRP come at an opportune time for physical oceanographers. In the early 199Os, oceanographers will have available for the first time satellite measurements of the global surface wind field and sea-surface topography. Other technological developments now allow oceanographers to make global measurements of the ocean circulation using neutrally buoyant floats; the measurement of chemical tracers such as nutrients, fluorocarbons and tritium on small samples; and the ship-borne measurement of near-surface current profiles. In addition, recent meso-scale research programmes have clarified certain aspects of ocean dynamics and allowed the specification of the sampling rates necessary to avoid aliasing space and time fluctuation into lower frequencies, including the mean. Lastly, computing power has been increasing at such a rapid rate that one can now handle global data sets and even contemplate the development of eddy-resolving numerical models of the global circulation during the next decade.

The design of a field programme to meet the goals and objectives of WOCE requires decisions regarding the scope of the programme, the utilization of new technological developments and the availability of resources from the supporting nations. It is necessary to establish a basis on which to make such decisions. The mechanism adopted by the SSG and set forward in the Scientific Plan is to concentrate on three priority Core Projects. The Core Projects are:

Core Project 1, The Global Description

Core Project 2, The Southern Ocean and

Core Project 3, The Gyre Dynamics Experiment.

All three Core Projects are required to meet the Objectives of Goal 1. They differ in the varying aspects of those objectives they address. However, their aims are complementary, they overlap geographically and they share most of the main observing systems.

Core Project 1 will obtain the global data set with which one will be able to obtain a quantitative global description of the circulation of heat, fresh water and chemicals, the formation and modification of water masses and the statistics of ocean variability. These constitute the zeroth order description of the role of the ocean in the planetary climate system. The design of the field programme, as described in Volume II, focuses on a number of components of the oceanic system that are of particular importance. These include the surface layer, which is the part of the.ocean most subject to seasonal and interannual variations due to its interactions with the atmosphere; the abyssal circulation that on decadal time scales is an important part of the overall circulation on climatic time scales; the tropical ocean where special questions need to be addressed concerning the transport of water, heat and salt across the equator; eddies and their importance in transporting heat and chemicals, and the general transport of heat and fresh water which is of first-order importance regarding the ocean's role in decadal climate change.

The Core Project 1 data set is designed to be sufficiently detailed that the major features of oceanic properties such as temperature, salinity, and geochemical tracers, including the dynamic topography, are contourable at all depths where spatial changes are detectable. Direct measurements of the velocity at one depth to the same resolution and the transport in all major boundary currents is also included. Measurements of the surface wind stress and topography will be obtained to the finer resolution available from satellite measurements. Global measurements of the fluxes of heat and fresh water and their storage and transport within and through the surface layers will also be obtained to the extent possible through a combination of satellite and in situ measurements in conjunction with atmospheric general circulation models. This global data set will provide a powerful test for models of the global circulation and will no doubt reveal significant errors in them. Clues as to the cause of these errors should be available through examination of the regional agreement and differences between the models and the data set.

Core Project 2, the Southern Ocean, is concerned with the Antarctic Circumpolar Current and the regions of water mass formation to the north and the south of it. The Antarctic Circumpolar Current (ACC) links the circulation of the Pacific, Atlantic and Indian Oceans and provides the connections that transform the oceanic heat flux from a regional to a global phenomena. South of the ACC, large quantities of heat supplied at low latitudes are lost to the atmosphere and deep water is formed; to the north "mode" water is formed. The experimental programme for the Southern Ocean must include the same large-scale coverage as is to be obtained for Core Project 1. In addition, it addresses the dynamics and significance of the ACC and quantifies the amount of deep water formed as well as examines the mechanisms leading to its formation.

Models of the oceanic circulation are sensitive to the method of representing processes such as mixing by quasi-geostrophic eddies, interactions of the flow with topography, transfer of heat, momentum and fresh water across the atmosphere-ocean boundary and the formation of water masses at the ocean surface and their injection into the interior. Core Project 3, the Gyre Dynamics Experiment, is designed to clarify such processes. The basic strategy is to study in one ocean basin the processes to which ocean models are sensitive so that developments can be made in models for that ocean basin which can be extended with some confidence to models for the global circulation. Core Project 3 includes components which involve intensification of the large-scale measurements planned for Core Project 1. From these measurements within the chosen basin, the North Atlantic, it will be possible to obtain information about the dynamical balances within that basin and to infer the nature and intensity of important small-scale processes. In addition, Core Project 3 includes traditional, localized, process-oriented research programmes directed at resolving mechanisms of particular importance to WOCE. While considerable advantages can be obtained from concentrating the Core Project 3 experiment within one basin, certain processes may be better studied elsewhere.

Although the WOCE strategy is to give priority to the Core Projects, it is recognized that other oceanographic experiments can make a significant contribution to the goals and objectives of WOCE. In addition to large-scale experiments such as TOGA, these could include regional studies allowing, for example, a comparison of similar features in different ocean basins that are only marginally defined by the Core Project 1 data set. Such experiments are encouraged provided they do not draw resources from the three Core Projects presented in this Implementation Plan. The Core Projects must be given priority since they provide the minimum coherent programme that can meet the objectives of WOCE.

1.5 The WOCE Field Programme

The major elements of the WOCE field programme and the shore-based facilities required to meet the objectives of the Core Projects are presented in detail in Chapters 2-5. These are based on the scientific rationale given in Volume II.

In summary, the major observational components are:

(a) full depth, hydrographic/tracer survey, the WOCE Hydrography Programme (WHP), covering the entire ocean once,

(b) repeat hydrography, to at least 1500 m, to provide temporal information,

(c) global deep float releases employing a mixture of pop-up and acoustically-tracked floats,

(d) satellite altimetry calibrated with a sparse global sea-level network,

(e) moored arrays and special float releases to map transequatorial exchange and western and eastern boundary currents, deep boundary currents and exchanges between basins, and the vertical structure of the eddy field,

(f) enhancement of surface meteorological measurements to validate satellite-derived wind and sea-surface temperature measurements,

(g) a surface layer programme using surface velocity drifters, standard hydrographic measurements, XBTs, XCTDs, moored and drifting temperature and temperature/salinity chains,

(h) eddy-resolving XBT/XCTD sections to determine the variation of the strength of the major oceanic gyres on seasonal and interannual time scales.

The above elements represent an extremely diverse, multi-year experiment relying upon the fullest exploitation of the capabilities and resources of oceanographic organizations all around the globe.

A summary of the major resource requirements is given in Table 1.1 and the global observational programmes are depicted in Figures 2.1, 2.2 and 2.4 to 2.6.

Observational Element	Requirement
WHP - One Time Survey	10.4 ship years, based on 270 days at sea per year
Repeat Hydrography and Time Series	15.0 ship years, based on 270 days at sea per year
Subsurface Floats	ca 3 500
Surface Drifters	ca 4 000
Moorings (current meters, Thermistor chain, pressure gauges, Upward-ADCP)	ca 350
Sea level stations	40
XBT standard (750m)	5000/y besides the on-going TOGA programme
XBT deep (1000m)	11500/y besides the on-going TOGA programme
XCTD	depending on technical availability
ADCP	depending on no. of research vessels/VOS available also ca. 40 moored ADCP
Altimetry/Scatterometry	several satellite missions over the next ten years

Table 1.1 Major WOCE Resource Requirements

1.6 WOCE Planning Structure

The WOCE SSG has established a dual planning structure which addresses scientific and operational objectives. The basic scientific planning is undertaken by Core Project Working Groups and a Numerical Experimentation Group supported by special purpose panels. The operational Planning Committees address the observational systems as well as the handling and processing of the resulting data. The structure is presented in Figure (1.7).

The international WOCE programme will be composed of individual national contributions, which, in many cases will constitute a major portion of those Nation's oceanographic potential. For this reason, several nations have established National WOCE Planning Committees which interact regularly with the SSG and the WOCE International Planning Office. This mechanism may not be necessary for all nations participating in WOCE but participants are urged to consider this idea in view of its proven usefulness.

As WOCE moves from the scientific planning to implementation phase, additional organisational arrangements may be necessary. Proposals for a Resource Coordinating Committee and for an Intergovernmental Board are being studied by the SSG and its parent bodies. These proposals, and possibly others, will be discussed at the International WOCE Scientific Conference.

The WOCE International Planning Office (IPO) provides support for the planning of WOCE as it develops under the direction of the SSG and within associated groups. The IPO collaborates with CCCO and JSC in forging links with other WCRP components and in the development of appropriate intergovernmental initiatives through WMO and IOC. The IPO is located at the Institute of Oceanographic Sciences Deacon Laboratory, Wormley, U.K.

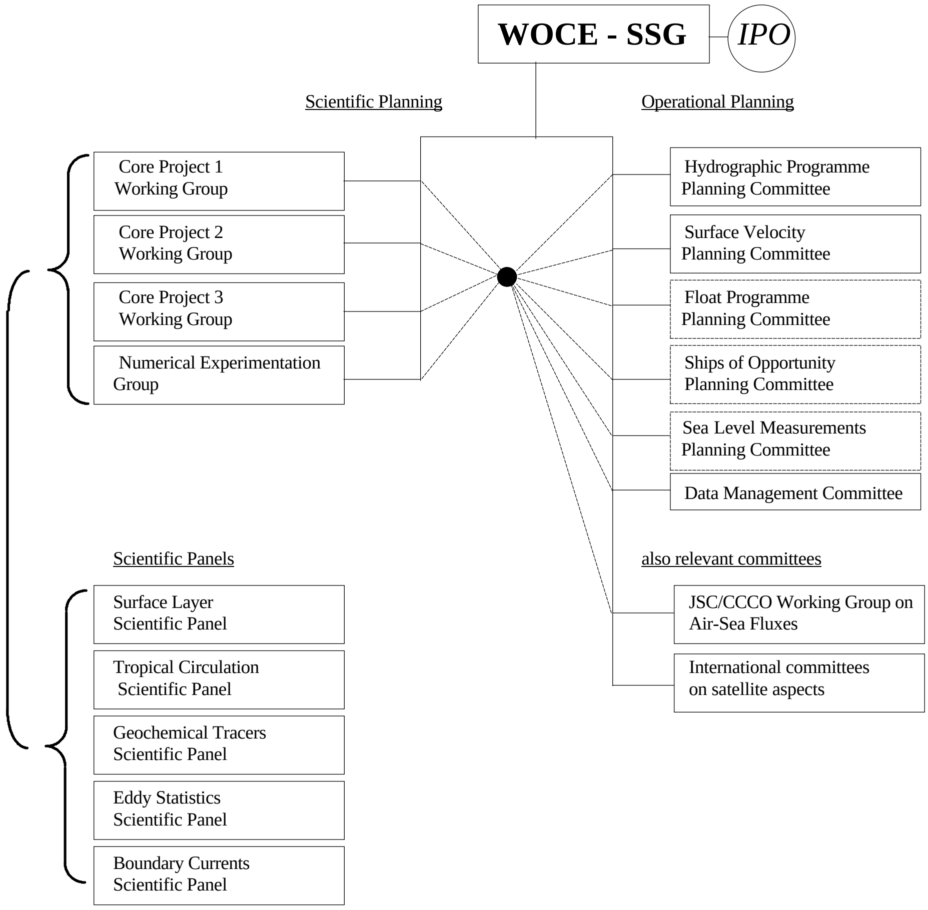


Figure 1.2 WOCE Scientific and Operational Planning Structure

A number of scientific and service groups are cooperating with the SSG in addressing planning and operational issues. These groups include:

Scientific

- TOPEX/POSEIDON - Science Working Team, NASA (USA) and CNES (France)
- ERS-1 - Science Team, European Space Agency
- TOGA - Tropical Ocean Global Atmosphere Programme, WCRP
- JGOFS - Joint Global Ocean Flux Study, SCOR

Service

- IGOSS - Integrated Global Ocean Services System, IOC/WMO
- IODE - International Oceanographic Data Exchange, IOC
- Drifting Buoy Cooperation Panel, IOC/WIVIO
- GLOSS - Global Sea Level Observing System, IOC

2. OBSERVATIONAL PROGRAMMES

This Chapter covers most of the technical aspects of the measurement techniques needed in WOCE. It focuses on those aspects that are important for carrying out these measurements. Beside the technical details, the infrastructure is explained that is needed to guarantee the level of quality, uniformity and consistency of the data and the mechanism proposed and planned to arrive at data sets that are to be used by other groups engaged in WOCE.

2.1 The WOCE Hydrographic Programme

2.1.1 Introduction

The field programme to meet WOCE objectives will be both intensive, with repeated sampling in certain critical regions, and extensive, with a global coverage. The in-situ programmes will take advantage of the opportunity to obtain multi-year, global observations from the next generation of ocean observing satellites. There are a number of 'tools' that will be used in WOCE to study ocean circulation including satellites, drifters, floats, moored buoys and tide gauges. But, perhaps the most venerable involves measurement of distributions of density, temperature, salinity, and chemical tracers. From this, one infers the distribution and sources of water-masses and their flow velocities and patterns. Thus an important component will be a major effort to improve our knowledge of these distributions through the WOCE Hydrographic Programme (WHP). The primary goal of the WHP is to obtain high-accuracy global hydrographic and geochemical tracer measurements.

The WHP includes all the high accuracy hydrographic and geochemical sampling for Core Projects 1, 2 and 3. It covers the setting of standards, quality control, and final centralization of repeated hydrographic sections and stations in the Core Projects. Some of the hydrographic sampling, especially for some repeated stations and sections, and much of the process-oriented programme for Core Project 3, do not require the full suite of measurements or sampling schemes envisioned for the basic global survey. Where possible, however, the same standards and procedures will be used in order to obtain as uniform and accurate a total data set as possible.

It is estimated that some 10 years of ship-time will be needed for the one-time global survey and some 15 years for repeat hydrography. A significant portion of the latter is now being conducted as part of national programmes. No single oceanographic institution or nation has the resources to provide either the ships or measurement capabilities to undertake this programme; thus, the WHP will involve different countries, laboratories and research vessels. This will need extensive international planning. It will be important to ensure uniformity of measurement technique and intercalibration. For this reason alone there is a need for some overall organization with responsibility for quality control of data and to suggest procedural changes when problems are detected. Other compelling reasons for centralized planning for the WHP include the commonality of techniques among the different national groups, the logistical problems inherent in an international seagoing programme, and the need for a uniform final data set for use by WOCE investigators. It will also facilitate cooperation with such programmes as JGOFS with which a commitment exists to assist where possible in the measurement of the oceanic uptake of CO_2.

2.1.2. Standards, Calibration, and Sampling

2.1.2.1 Sampling Accuracies

Sampling accuracies are presented separately for CTD/O_2 sensors and measurements from individual water samples.

CTD-Sensors: the use of dual, or even multiple, sensors on CTDs is advocated. When implemented, any abrupt change in sensor behaviour can easily be detected, while continuing the measurements and thus saving ship-time. This important improvement in reliability will have a very positive effect on the ship-time needed for deep casts, since DSRT thermometers are used only for checking sensor performance and add up to 2 hours of station time for accumulating 'soaking time'. Work has been reported on the development of new conductivity cells (Seabird, NBIS, Salzgitter Elektronik), additional attention will be given to temperature (stability) and pressure sensors (hysteresis). To satisfy the need for uniform data quality during WOCE, there is a need to begin immediately with instrument selection and performance monitoring, overseen by an in-situ measurement working group. Special care will be given to the development of an efficient 0_2-sensor, with similar time response characteristics as the other sensors.

Individual CTD-sensor requirements

T: accuracy of 0.002 ^oC. precision 0.0005 ^oC

S: accuracy of 0.002 PSU, depending on frequency and technique of calibration, precision 0.001 PSU, depending on processing techniques. Although conductivity is measured, data analyses require knowledge of accuracy expressed as salinity.

P: accuracy of 3 dbar with careful laboratory calibration, precision 1 dbar, dependent on processing. Difficulties in CTD-salinity data processing occasionally attributed to conductivity sensor problems or shortcomings in processing, actually may be due to difficulties in accounting for pressure sensor limitations.

O_2: accuracy of 1-1.5%, same for precision. As yet, there is a lack of adequate sensors. In general, a safe way to detect drift or jumps in sensor performance is the use of dual and exchangeable sensors.

Water sample requirements

T: DSRT are available with 0.004-0.005^oC accuracy and 0.002^oC precision for expanded scale instruments. Reliable multiple CTD-sensors have the potential to eliminate the routine use of DSRTs. Digital DSRTs do not require long soaking times and have the potential to serve as a means for calibration and performance checks. Their development and, in particular, their long-term stability will be closely monitored.

S: accuracy 0.002 PSU is possible with Autosal salinometers and great care taken to monitor IAPSO Standard Sea Water. Accuracy with respect to one particular batch of Standard Sea Water can be achieved at 0.001 PSU. Precision of Autosal is better than 0.001 PSU, but great care and experience is needed to achieve these limits on a routine basis as required for WOCE. Laboratories with temperature stability of 1°C are necessary for proper Autosal performance.

Keeping constant temperatures in the room where salinities are determined greatly increases their quality. Also, room temperatures should be noted for later interpretation, if questions about salinities occur. With respect to IAPSO Standard Sea Water, its frequent use is endorsed. It is also noted that changes in Standard Sea Water occur. To avoid these, use of the most recent batches of water is recommended, besides using the ampoules in an interleaving fashion to have a consistency check within a batch or batches.

O_2: accuracy $<$ 1%. Some laboratories achieve 0.5%, which is required for WOCE, and 0.1% precision, with improvements due to developments in ‘new’ end-point detection techniques. Development of these techniques and subsequent adoption is strongly recommended.

SiO_3: accuracy approximately 3% and full-scale precision of 1%. Strong opinion exists that laboratory temperature fluctuations cause significant errors, as 1^oC laboratory fluctuation yields approximately 1% change in SiO_3.

NO_3: approximately 1% accuracy and precision full scale. This standard is probably appropriate to WHP.

PO_4: approximately 1-2% accuracy and precision full scale. It has been recommended that it may be worthwhile to examine standards for nutrients.

^{3}H: 1% accuracy and 0.5% precision with a detection limit of 0.05 tritium unit (TU) in the Northern hemisphere, upper ocean and 0.005 TU elsewhere. This requires the use of the mass spectrometric technique.

δ^3He: 1.5 per mille in accuracy/precision in isotopic ratio; absolute total He of 0.5% with less stringent requirements for use as a tracer (for example, He plume near EPR).

CFMs: accuracy/precision at approximately 1%, blanks at 0.005pM with best technique. Investigation of chlorofluoromethane collection and analysis technology appropriate to these quality levels on “mass production” basis.

Δ^{14}C: 3 per mille via beta-counting on 200-litre samples; 5-10 per mille with Accelerator Mass Spectrometer (AMS) on 0.2 to 0.5 litre samples. Total carbon measurements are required.

^{85}Kr: detection limit of 1% of surface concentration; precision of 4% decreasing to 25% for samples near the detection limit. Requires 200-litre samples.

^{39}Ar: precision of 5% of surface value: minimum detectable amount about 5% of surface value. Requires 1500 litre samples and counting times of the order of 1 month.

^{228}Ra: 5% accuracy/precision on 200 litre samples using a combination of spectrometry and scintillation counting. An increase in efficiency by a factor of 5 may be accessible by liquid scintillation counting. This would reduce the sample size by a factor of 5 or increase the precision about twofold.

δ^{18}O: may be used in high latitudes; these should be measured with accuracies of 0.02 per mille on 40 ml samples.

2.1.2.2 Sampling Schemes

Basic stations will be of the full water column for all measurements. The CTD/O_2 will provide a continuous profile from the surface to within 10 m of the ocean bottom (in good weather over mild topography). Small volume (10 litre) water sampling will be carried out on each cast. The minimum number of samples for a deep cast will be 24; the optimum number of 36 samples will provide better resolution near the surface layer as well as in the deep water. The basic horizontal resolution on each section will be 30 nm with higher resolution near ocean boundaries and large-scale topographic features. Large volume sampling with Gerard barrels will be carried out with a horizontal resolution of 300 nm with 9-18 samples per cast. Geochemical sampling from both large and small volume samples will vary from region to region. For example, stable isotopes of hydrogen and oxygen have been recommended for sampling in high latitudes such as in the Southern Ocean. The specific transects to be occupied and geochemical sampling are discussed in the sections on the Core Project programmes in Volume II of this plan. The scope of the WHP effort can be gauged by the global sampling plan given in Figure 2.1. Descriptions of each of the sections shown in Fig. 2.1 and the repeat sections (Fig. 2.2) are given in Chapter 5. These are summarized in Table 2.1.

2.1.3 Personnel and Ship Requirements

Personnel requirements will vary depending on the operating mode of each technical group. However, assuming a model of three watch groups, requirements are up to nine persons to stand watch, two specialists each for nutrients and CFMs, one specialist each for electronics, data processing, oxygen, salinity, underway acoustic Doppler velocity profiling with ADCPs, and large volume sampling. In addition two people will carry out CO_2 analyses for the Joint Global Ocean Flux Study (JGOFS). For the WHP a scientific party of 16-22 is necessary, on some sections with heavy ancillary measurements up to 30 berths are required. Additional personnel are expected for ancillary measurements, mooring, float and drifter deployments, foreign observers, and students.

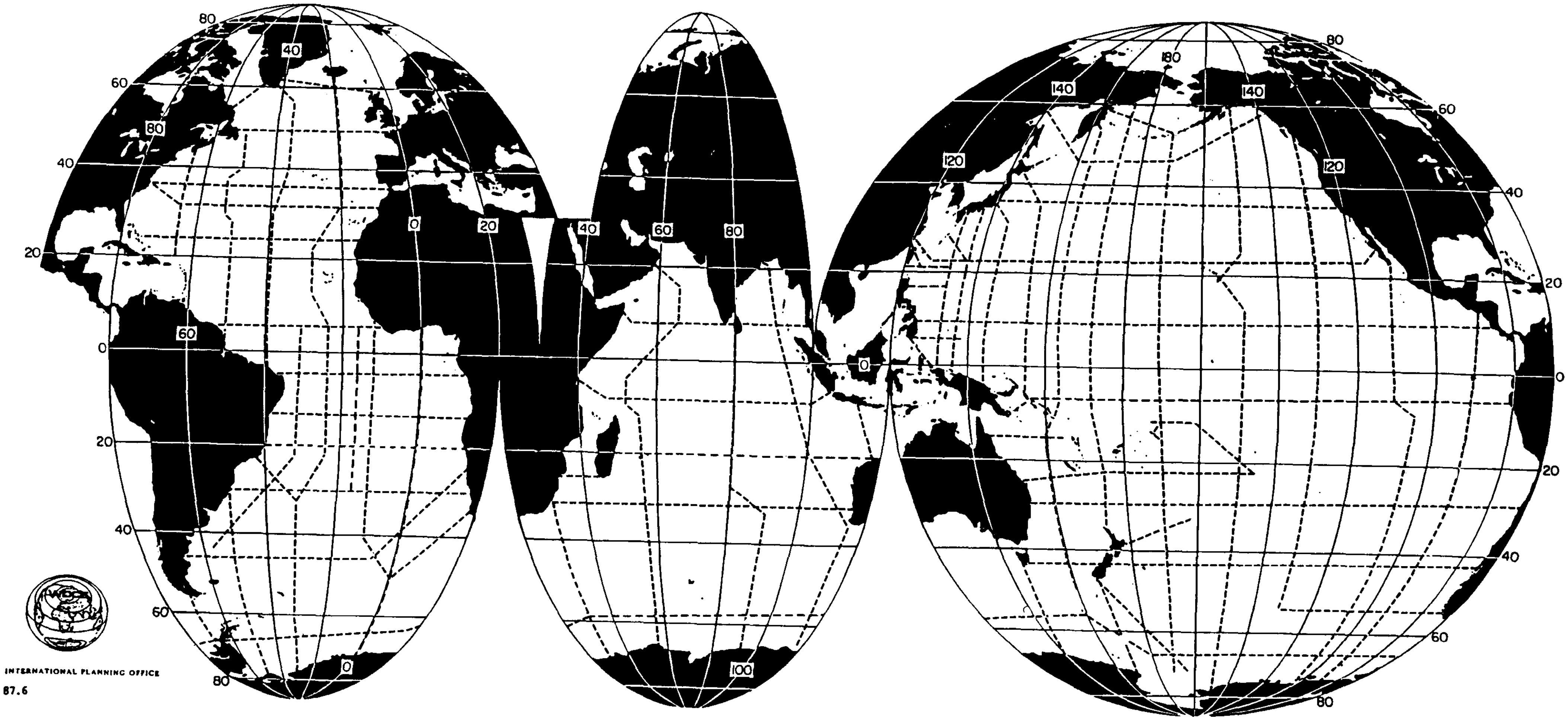


Fig. (2.1) The One-time Global WHP Survey

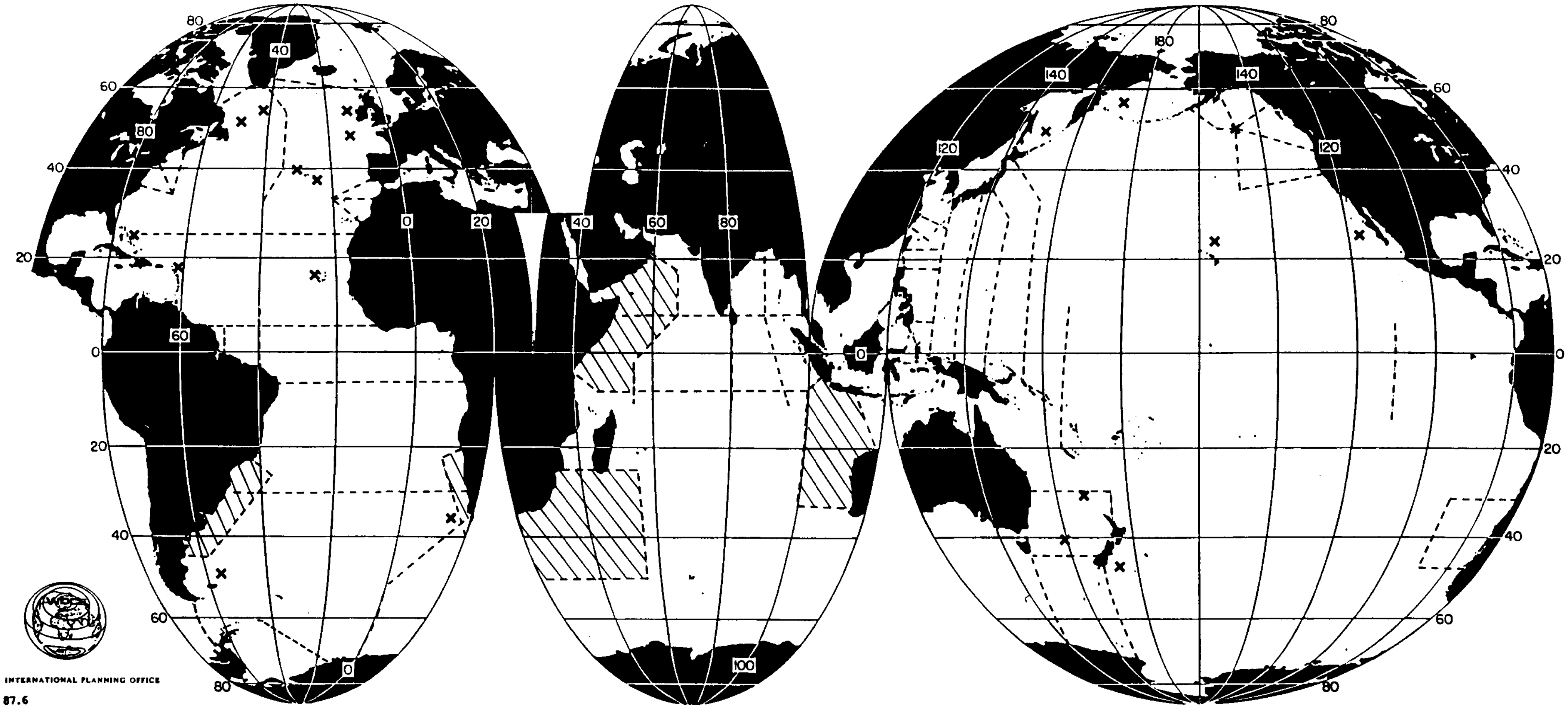


Fig. (2.2) Repeat WHP survey and time-series stations (x). Shaded are intensive study areas.

The research vessels must be equipped with Acoustic Doppler Current Profilers (150 kHz) and GPS navigation. For high latitude work, especially in the Southern Ocean, ice strengthening will be required. Specialized, temperature-controlled labs for water sample analyses will require space equivalent to four 20 ft vans. A semi-enclosed wet lab/rosette room will be required as well as some means of transport for the water sampler to and from the deck. Methods discussed included an overhead rail or a deck-mounted track. Because of the heavy demands on water sampling with the CTD package, there is a need for a dedicated winch and conducting cable as well as an A-frame or similar device for getting the package in and out of the

WOCE HYDROGRAPHIC PROGRAMME

Summary

WHP (One-time Global Survey)

OCEAN	Length (nm)	SV Stations	LV Stations	Ship Days
Atlantic	66 353	2218	245	807
Indian	33 253	1112	123	402
Pacific	115 140	3872	410	1415
Southern	14 979	500	55	184
Global	229 725 nm	7702 stations	833 stations	2808 days at sea

= 10.4 ship years based on 270 days at sea/year

WHP (Repeat Hydrography)

OCEAN	Total Length (nm)	Total Stations	Total Ship Days
Atlantic	112787	3152	839
Atlantic (Core 3)	80 045	800/1076*	703
Indian	12 079	406	91
Pacific	294 105	9649	2189
Southern	20 654	694	210
Global	519 670 nm	800/14977* Stations	4032 Days at sea

= 15.0 ship years based on 270 days at sea/year

* (Full WHP Stations/CTD)

Table 2.1 Summary Requirements of the WOCE Hydrographic Programme

water and a means for moving the package around safely on deck between casts. Roll and heave compensation on the vessel in order to extend the weather window is also desirable. Large volume Gerard bottles will be deployed at selected stations using a trawl winch. Present methods for this sampling (mechanical messenger or acoustic trigger) do not require the trawl wire to have a conducting core. It has, however, to be able to reach the ocean bottom. The ship should be “clean” with regard to 1% and tritium and CFMs and there should be separate air system controls for labs and living spaces. No computers will be required as ship-supplied equipment but environmentally adequate space is required for a centralized computer with some distributed work stations/terminals. It is planned that some forms of data be exchanged between the ship and shore-based labs. This will likely occur in bursts, rather than continuously at low data rates. Commercial communication networks, such as INMARSAT, should be adequate.

The ship-time required has been based on several assumptions as to station time and spacing, speed of the vessel etc. These did not, in a survey done for this assessment, vary much amongst different laboratories. The greatest differences occurred when estimating the number of days at sea per year. These varied between 180 and 320 days/year. Thus, the following estimates of ship-years are based on the assumption that vessels invited to work in the WHP will spend 270 days at sea per year. Individual assessments should always be based on the given number of days at sea for a given section. Only the individual ship operator is able to do this.

2.1.4 Shore-based Facilities

The WHP is an international programme and facilities will need to be shared and coordinated on an international basis. In many instances, facilities now exist to carry out the types of measurements required. Seagoing operational groups and shore-based laboratories and calibration facilities are already capable of meeting the standards listed above. These groups and laboratories need to be expanded so as to meet the volume of sea time and analyses envisioned in the WHP, rather than establishing a new, international WHP organization or new national groups. On the other hand, it has been recognized that a new AMS facility in the USA for analysis of small volume ^{14}C samples will be required.

2.1.5 WHP Management

International coordination of the WHP programme will require continued scientific planning and a management structure that will allow day-to-day planning of operations and the appropriate allocations of resources to the WHP. The appropriate international mechanisms for the coordination of resources for WOCE in general and the WHP in particular is still under consideration. It is clear however that the coordination of the WHP will require the strongest interaction between the agencies suppling resources and the bodies coordinating ships and laboratories for the programme.

2.1.5.1 WHP Planning Committee

The WHP Planning Committee has been established by the SSG to provide the scientific advice necessary for designing and carrying out the WHP as specified by the Core Projects. This includes advice on the accuracy of measurements, facilities required and protocols that must be established. The Planning Committee will also advise and consult with the operational side of the WHP Programme on ship schedules, cruise tracks and the technical aspects of data collection and sample analysis that are required if the WHP is to be effectively carried out.

Four working groups have been established under the WHP Planning Committee to provide advice in the following areas: calibration (procedures and standards), in-situ measurements, standard methods and algorithms, and underway measurements.

2.1.5.2 WHP Project Office

The WHP effort will be carried out in a number of different laboratories throughout the world. To better coordinate the effort and carry out the recommendations of the WHP Planning Committee, a WHP Project Office will be established. This office will receive the bulk of its support from one nation but will have individuals seconded from other countries assisting in its work. It is envisioned this office will consist of a director and approximately six full-time equivalent positions. The primary functions will be to coordinate the WHP effort, provide quality control, track data, provide status reports as needed and provide logistical support to the WHP Planning Committee and WOCE. The Director will be a scientist with established credentials in the measurement and analysis of hydrographic (water column) data. The Director will work closely with the WHP Planning Committee and with the operational groups and data Quality Control Experts (QCEs). The Project Off ice will not field complete teams for cruises but rather work with existing groups and provide some logistical support for pre-cruise planning and post-cruise tracking and quality control of data. The WHP Planning Committee will provide periodic assessment of the Project Off ice performance to the SSG and to the nations providing funding support for the activities of the Office.

2.1.6 Data Management

Immediately following each WHP cruise, a complete copy of the water sample data shall be submitted to the WHP Project Office. The Project Office will be responsible for seeing that these data are sent to one or more data QCEs cooperating with the office. The QCEs will be selected by the WHP Planning Committee and will be responsible for checking for internal (cruise) consistency and for comparing data with either historical data or other WHP measurements in the same geographical region. Any problems with data will be reported to the Project Office, the chief scientists for the cruise, and to the operational groups who carried out the work so that corrective measures can be taken in a timely manner. The same process will occur with continuous CTD data and with measurements made at a later time in shore-based facilities as soon as these data are made available to the chief scientist/principal investigator. This data quality control filter will help provide the chief scientist with a high quality data set, help identify problems at an early phase and ensure uniformity in WHP data, when it is assembled in the WHP DAC.

WHP data will be handled in accordance with the general data sharing policy of WOCE (Section 3.2). During the period of data quality control, preliminary data will be made available to WHP and other WOCE investigators either directly by the operational groups or chief scientists. Data can be used for pre-cruise planning or for other purposes, but it cannot be published or cited without the permission of the principal investigators for a period of up to two years. Following each cruise, short cruise reports will be prepared giving station locations, water sampling summaries and other pertinent information. The Project Office will assist the chief scientists in preparation and distribution of these cruise reports. Final data reports will be the responsibility of the operational groups but data summaries will be made available by the Project Office at the appropriate time.

WHP data sets will be assembled by a Data Assembly Centre (DAC, see Section 3.13) and submitted to a Special Analysis Centre (SAC, see Section 3.11). Data for WOCE purposes will be made available by the relevant centre. The extent of the WHP Project Office's involvement with these Centres remains to be defined.

2.2 Satellite Missions

Previous satellite missions have shown that it is possible to make global synoptic measurements of ocean surface topography (Fig. 2.3), sea surface temperature, and surface winds. This capability makes a global study of ocean circulation possible, and WOCE is being organized to take advantage of new missions planned for the 1990s that are specifically designed for such measurements.

New research missions have been designed to give global coverage of ocean surface topography by precision altimeter, surface winds by scatterometer, and other properties by various passive radiometers. Built primarily on the instrument heritage of Seasat, these missions offer measurement precision and orbit coverage that make accurate determinations of ocean currents and surface winds possible. The missions include the altimeter and scatterometer to be carried on the European Space Agency's ERS-1 satellite, the precision altimeters to be carried by the joint US/French mission TOPEX/POSEIDON, and NASA's scatterometer proposed for Japan's Advanced Earth Observing Satellite (ADEOS). Also involved in the research effort are the radiometers already aloft in the satllites of the NOAA TIROS series, the Defense Meteorological Satellite Program (DMSP) and the Japanese Marine Observation Satellite (MOS) Programme. ERS-1, ADEOS and TIROS also will carry radiometers for the measurement of surface temperature. The DMSP satellites will carry microwave radiometers for atmospheric water vapour and ice measurements.

Two other activities important for WOCE are the planned efforts to measure the global marine geoid and to estimate the global rainfall. Determining the marine geoid at shorter wavelengths (less than 1000 km) requires a dedicated gravity mission. If successful, it will greatly enhance estimates of mean circulation from the ocean surface topographic measurements. Estimates of global rainfall are essential to determining the large-scale patterns of freshwater flux over the ocean, a poorly measured quantity that is a key factor in driving the ocean thermohaline circulation. Plans are being developed to employ satellites to measure both the marine geoid and global rainfall, but not before the mid-1990s. A gravity mission is planned by ESA with U.S. participation as a possibility. Likewise, planning is under way for a Tropical Rainfall Measurement

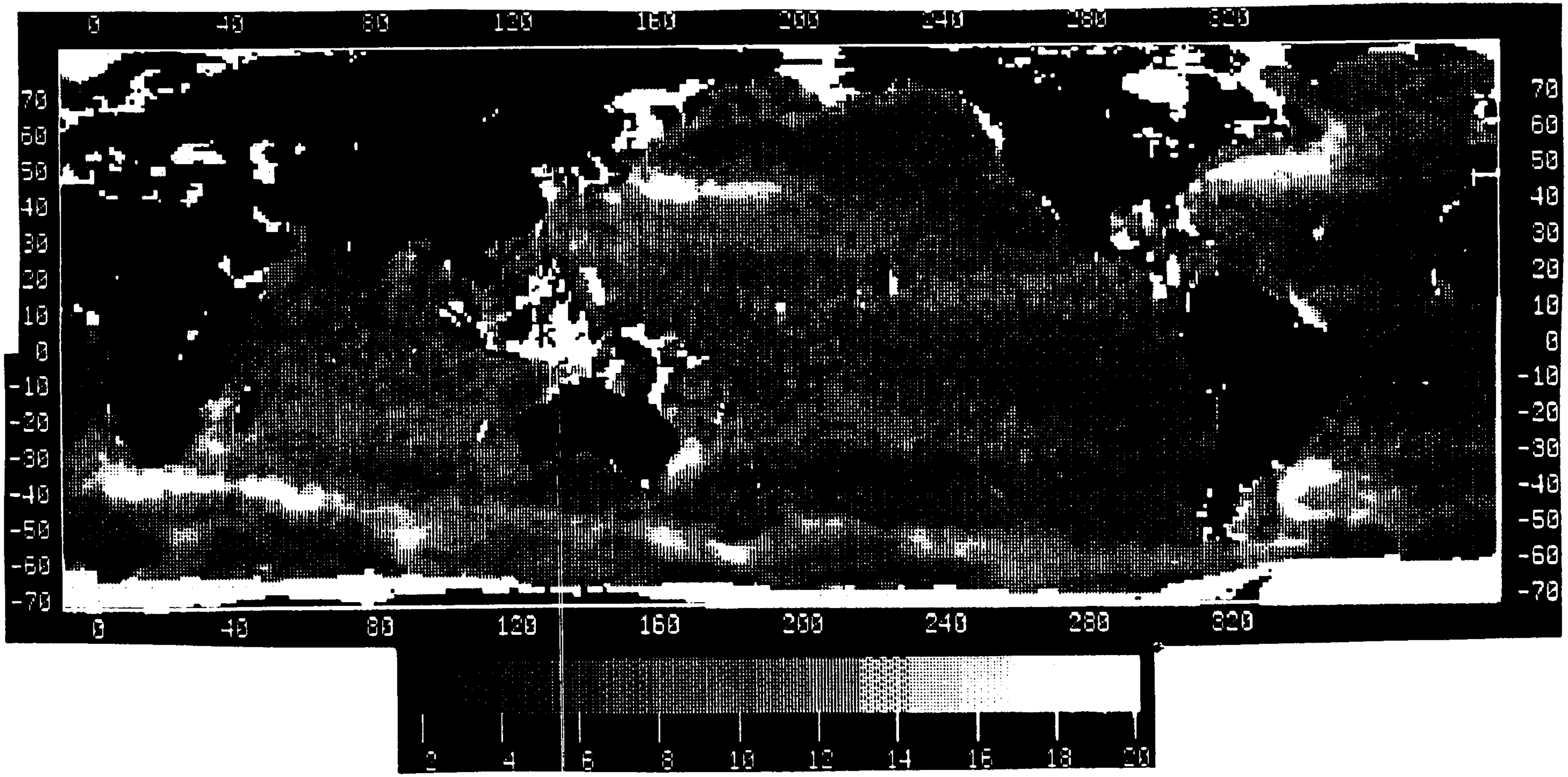


Fig. (2.3) *Sea Surface Height Variability at wavelengths shorter than 2500 km, during 11/86 to 2/87, rms cm, measured by the Geosat altimeter.*
V. Zlotnicki and L. Fu (JPL/Caltech) based on data supplied by R. Cheney and B. Douglas (NOAA/NGS).

Mission (TRMM) to be carried out jointly by the U.S. and Japan. This mission, not yet approved, is aimed primarily at the tropical regions where the rainfall signal is highest.

There are two types of satellite programmes which will contribute to WOCE - research and operational. Within the first category are the oceanographic satellites summarized in Table (2.2); four of these, ERS-1, TOPEX/POSEIDON, ADEOS and MOS-1, are discussed further in Sections (2.2.1-2.2.4). Other missions, which include the operational meteorological satellites, are covered in Section (2.2.5). Data from both types of satellite will be needed for deriving surface fluxes of momentum, heat and water on the scales required for WOCE. Even so, not all the relevant variables can be measured from space and for some of them, particularly those derived from the relatively narrow swath microwave sensors, the sampling frequency is inadequate.

These problems have been recognized by the JSC/CCCO Working Group on Air/Sea Fluxes which has proposed a programme for generating surface flux fields by assimilating remotely-sensed and in situ data into an atmospheric general circulation model. Since it is envisaged that such models will only be run in an operational forecasting environment during the WOCE period, this strategy depends on the availability of satellite data in near real-time, and this will not be true of all the relevant programmes.

2.2.1 ERS-1

2.2.1.1 Mission Details

The European Space Agency's ERS-1, scheduled for launch into a 98.5° inclination orbit in early 1990, carries an altimeter with bore-sight microwave radiometer, a wind scatterometer, a scanning visible and infrared radiometer and a synthetic aperture radar which can be operated either in a regional imaging-mode or a global wave-mode. The altimeter measurement, although not as accurate as that of TOPEX/POSEIDON, will provide data at higher latitudes and at an earlier date. The measurement is less accurate than the TOPEX/POSEIDON measurement primarily because of the satellite orbit (lower, and hence more drag) and less accurate tracking. The ERS-1 scatterometer will not provide as useful a data set as is planned from NSCAT. The ERS-1 scatterometer operates at C-band, for which knowledge of the behaviour of backscatter from the ocean is less, and it is single-sided (NSCAT measures in two swaths), yielding less than 50% of the coverage of NSCAT. However, the three-beam antenna configuration should greatly improve the ability to remove directional ambiguities from the data. The higher inclination orbit will allow observation of sea-ice with the SAR altimeter and ATSR. Its scatterometer must be turned off when its Synthetic Aperture Radar is operating in imaging mode, but such activity is limited to a maximum of 10 minutes per orbit and only when ERS-1 is within range of a SAR receiving station. An along-track scanning radiometer (ATSR) will provide sea surface temperature measurements.

For precise orbit determination a network of sites is required to install PRARE stations. This is of particular importance for the altimeter calibration in conjunction with the in situ sea-level sites (Section 5.3).

2.2.1.2 Data Sets

The data from ERS-1 will include global altimeter, scatterometer, synthetic aperture radar, and radiometer measurements. As noted above, the altimeter measurements will extend to higher latitudes than TOPEX/POSEIDON. If both missions overlap in time, a joint calibration can be made at lower latitudes where both operate, and it may be possible to have an accurate altimeter data set even at the higher latitudes.

Relevant planned products include dealiased wind vectors on a 25 km grid, SST images, precision SST on a 50 km grid, atmospheric water parameters at nadir, sea surface topography, and wave and sea-ice parameters. An advantage of ERS-1 is that all of these are obtained from a single platform.

2.2.1.3 Algorithms

The issues with altimeter and scatterometer algorithms are discussed in Sections 2.2.2.3 (TOPEX/POSEIDON) and 2.2.3.3 (NSCAT/ADEOS). There is an active effort within the European Space

TABLE 2.2 OCEANOGRAPHIC SATELLITES AND THEIR SENSORS

PLATFORM	COUNTRY	LAUNCH/ STATUS	INCLIN. (DEG.)	REPEAT PERIOD (DAYS)	SENSORS	SWATH (KM)	PARAMETERS	COMMENTS
GEOSAT	USA	Operational since Mar. 85	108	17	Altimeter	10	Topography, waves, wind	Expected to function till 1991. No POD
DMSP	USA	June 1987	98	?	SSM/I	1400	Atmospheric water, sea-ice, wind speed	Start of operational SSM/I series
MOS-1b	Japan	1990/Approved	99	17	MESSR VTIR MSR	100 1500 317	Ocean colour SST Atmospheric water,ice	MOS-1a has operated successfully since Feb. 87
MOS-2	Japan	Not announced/ Approved	99	17	3 from SCAT, ALT, VIS/IR OCTS	?	Wind, waves, Topography, SST, Ocean colour	
ERS-1	Europe	1990/Approved	98.5	see comments	Altimeter AMI (wind, wave, image modes) } ATSR MW radiometer	10 (500, 5 l00) 500 20	Topography,waves,wind Wind vector, 'wave' spectrum SST, clouds Atmospheric water	Some products to be produced in real-time. 3-day repeat for first 3 months, then various repeats possible. ERS-2 planned for 1993.
TOPEX/ POSEIDON	USA/ France	1991/1992 (Approved)	65	10	Altimeter (x2) MW radiometer	10 20	Topography, waves,wind Atmospheric water	Repeat periods being discussed
RADARSAT	Canada/ US	1994/Approved	98	?	SAR	40-500	Sea-ice, waves	Various imaging modes
ADEOS	Japan	1993?/Proposed	98	41	OCTS, AVNIR NSCAT?	1500,80 2 x 600	Ocean colour,SST Wind vector	NSCAT participation under negotiation

Agency to address these issues. Of particular interest is the possibility of including scatterometer algorithms allowing wave dependent formulations in a real-time assimilation scheme (see Section 2.2.1.7).

2.2.1.4 Mission Status

ERS-1 is an approved mission, and is on schedule for an Ariane launch in early 1990. Its design life is two years with an expected life of three years or more, and planning is now taking place for a follow-up, ERS-2, with identical instrumentation to be launched in 1993.

2.2.1.5 In situ Data Needs

These are discussed in Sections (2.2.2.5) and (2.2.3.5). ESA is planning support of in situ data studies as part of the overall ERS-1 programme. Calibration and validation during the commissioning phase (initial 6 months) is the responsibility of ESA but validation of off-line products is primarily conducted by the Processing and Archival Facilities (PAFs) (see Section 2.2.1.7) under ESA coordination.

2.2.1.6 Relation between WOCE and Science Working Teams

A formal arrangement for data access and mission advice between the international WOCE Scientific Steering Group and the ERS-1 Science and Applications Investigators' Team (ESAIT) has been proposed and is under consideration. The ESAIT was selected on the basis of proposals submitted in response to an Announcement of Opportunity.

2.2.1.7 Data Flow

The data from ERS-1 will be made available to approved investigators through Earthnet. Near real-time data products will be processed by ESA; off-line products will be generated by the PAFs. The real-time data will be assimilated, in a suitable form, in the initialization cycle of an atmospheric GCM to produce gridded surface fluxes. Since this ERS-1 data stream will include wind and wave parameters, the JSC/CCCO WG on Air/Sea Fluxes has proposed that a third generation wave model be coupled to the AGCM. France has responsibility for over-ocean data from the altimeter and scatterometer, the Federal Republic of Germany will be responsible for the precision orbits and the U.K. will produce SAR and ATSR products together with altimeter ice products. The Earthnet Central Facility in Frascati, Italy will handle data requests and provide catalogue facilities.

2.2.2 TOPEX/POSEIDON

2.2.2.1 Mission Details

TOPEX/POSEIDON will make accurate, global measurements of sea level using the techniques of radar altimetry. The mission will be jointly carried out by NASA and Centre National d'Etudes Spatiales (CNES). The U.S. will provide the satellite, a precision altimeter, a radiometer, and a tracking system; CNES will provide an altimeter, a tracking system, and the launch from the Ariane IV rocket. The mission is scheduled for flight in late 1991 or early 1992 and is planned for three years, with expendables aboard for two additional years. A high altitude orbit has been chosen to minimize the effect of atmospheric drag. The inclination of the orbital plane will be chosen to minimize the aliasing effect of the tides and maximize the ability to measure orthogonal components of the slopes of the ocean surface topography. As a consequence, current planning calls for an orbit inclination of 65^{o}, and higher latitudes will not be covered. High-latitude altimeter coverage will be provided by ERS-1.

2.2.2.2 Data Sets

The mission will provide global measurements of sea surface topography with an rms single-pass accuracy of 14 cm (on a l00-km scale) every 10 days. With all corrections applied, the accuracy is expected to be a few centimetres when multiple passes are combined. Gravity field data will be available from accurate tracking of this and other satellites (which may be used for calculating a geoid useful for studying the permanent (time-averaged) circulation of the ocean over scales of a few thousand km and longer). The altimeter data will be used to make maps of global tides on time scales to the length of the mission, of ocean surface topography and ocean surface geostrophic currents, and of significant wave height and scalar wind speed. The gravity field data will be used together with other similar data to calculate a geoid for use in estimation of mean currents over the period of the satellite mission.

2.2.2.3 Algorithms

Although the altimeter algorithms are reasonably well understood, applications of GEOS-3 and Seasat altimeter data over the past decade have revealed inconsistencies and raised questions about the validity and physical basis for some of the corrections. Moreover, new problems, too subtle to be detected earlier may become apparent in the more accurate new-generation altimeters of Geosat, ERS-1, and TOPEX/POSEIDON. There is a need for a continuing dialogue to be established between scientists involved in the various altimetric projects so that problems in sensor design and algorithm development can be identified and compatibility of data products ensured. Recently, a US/European workshop on this theme was held.

2.2.2.4 Mission Status

Both the U.S. and France have approved this mission, and it is proceeding on schedule. It is expected that the first data will be available about six months after launch.

2.2.2.5 In Situ Data Needs

The primary in situ data needs are for atmospheric pressure, water vapour content, and ionospheric electron content for altimeter corrections and for a sea level data for geophysical validation. The WOCE sea level programme is aimed at providing a global sea level data set, described in Section (2.3) of this plan. Atmospheric measurements of water vapour content are required for correction of the altimetric signal and will be measured by a microwave radiometer on the TOPEWPOSEIDON satellite. A dual frequency altimeter will be used for ionospheric corrections.

2.2.2.6 Scientific Studies

The U.S. NASA and the French CNES have tentatively selected a Science Working Team for the TOPEWPOSEIDON mission. The team, consisting of 38 principal investigators from nine countries, will conduct oceanographic and geophysical investigations using data from the mission, especially the very accurate measurements of sea level that will be made by the satellite. Most of the investigations will make substantial contributions to WOCE. These include studies of (a) the permanent (time-averaged) large-scale circulation of the oceans, (b) the low frequency variability of the large-scale circulation, (c) the variability of gyre and basin scale currents, (d) the statistics of meso-scale variability, (e) the dynamics of the equatorial and tropical regions with emphasis on the tropical Atlantic and Pacific Oceans, and (f) the variability of almost all major regional current systems. In addition, members of the team propose to assimilate satellite data into models for the general circulation of the ocean, thus extrapolating the satellite data into the deeper layers of the ocean. They also will measure and map the global ocean tides.

2.2.2.7 Relation between WOCE and Science Working Teams

Both TOPEX/POSEIDON and NSCAT (see below) will have international Science Working Teams made up of funded principal investigators who will provide scientific advice on the mission and who will have first access to the data. Because the ocean surface topography to be derived from TOPEX/POSEIDON data is crucial to the success of WOCE, and because some use of the observations in the on-going design of the experiment is expected, it is essential that planning for the mission and for WOCE be coordinated and that any mission changes be fully considered with WOCE objectives in mind. Close cooperation is needed between the Science Working Teams and the WOCE Scientific Steering Group.

2.2.2.8 Data Flow

Data from the TOPEX/POSEIDON mission will be formally available through NODS/JPL in the USA and the French data centre AVIS0 to members of the Science Working Team (SWT). Data will be available to all investigators, including those from WOCE, through NODS/JPL, NASA/NSSDC, or NOAA/NESDIS. The baseline for Geophysical Data Record (GDR) production is within 6 months after data collection. There is a proposal that a merged GDR containing data from both the TOPEX and POSEIDON altimeters be produced with a one year delay after acquisition but it is not clear who will assume responsibility for execution and funding of this activity.

2.2.3 NASA Scatterometer (NSCAT)/Advanced Earth Observing Satellite (ADEOS)

2.2.3.1 Mission Details

The ADEOS mission is a Japanese-sponsored polar-orbiting satellite mission designed to provide advance, high resolution measurements of both the global oceans and land masses. The satellite will be placed in a sun-synchronous orbit (41-day repeat, 3-day sub-cycle) at an altitude of approximately 800 km. Mission duration for ADEOS is planned to be at least 3 years, with launch presently scheduled for late 1993.

Japan will provide two optical/infrared radiometers for ADEOS: an Ocean Colour and Temperature Scanner (OCTS) with six visible and six infrared bands, and an Advanced Visible and Near-Infrared Radiometer (AVNIR) with three visible and one infrared band. The OCTS visible measurements will be in the wavelength range 0.44-0.66 μm, while the infrared measurements will be at 0.77, 0.88, 3.70, 8.5, 11, and 12 μm. The instrument will have a 1500 km wide swath and will acquire measurements with spatial resolution of less than 1 km. AVNIR data will be acquired at wavelengths 0.45, 0.55, 0.67, and 0.87 μm, with 16 m resolution and a swath width of 80 km.

The ADEOS programme is requesting proposals from the international community for provision of additional instruments to be carried on the ADEOS mission. NASA will propose the NASA Ku band scatterometer (NSCAT) for flight on the ADEOS mission to acquire all-weather, near-surface wind velocity measurements. In the ADEOS orbit, 'the NSCAT instrument would cover more than 95% of the ice-free, global oceans at least once in every two-day period.

2.2.3.2 THE NSCAT Data Sets

NSCAT will measure surface wind velocities (both speed and direction) with a horizontal resolution of 50 km. Vector wind measurements are made in two 600-km wide swaths (one on each side of the sub-satellite track) separated by a gap of approximately 380 km. Based on pre-launch simulations, it is expected that NSCAT measurement accuracy will be better than 2 m/s (rms) in speed for winds between 3 and 20 m/s and better than 10% for speeds between 20 and 50 m/s. Wind direction accuracies will be better than 20º (rms) for the ambiguity closest to the true wind direction for wind speeds between 3 and 30 m/s. The NSCAT design is based on the scatterometer flown on Seasat, but design enhancements will lead to improved measurement accuracy and coverage relative to the Seasat scatterometer. Most importantly, the addition of a third antenna beam for NSCAT will greatly improve the ambiguity removal skill of the instrument and will allow accurate selection of unique wind directions (based on NSCAT data alone) to be accomplished by ground-based data processing. In addition to the NSCAT flight instrument, the NSCAT System includes a dedicated ground-based data system to reduce raw NSCAT measurements to engineering and geophysical data and to provide the data to NSCAT investigators and selected archive and distribution systems within 14 days of acquisition of the data by NASA. Specific levels of data that will be provided include spatially-collocated radar cross-section measurements, ambiguous and unique vector winds, and spatial/temporal average wind field maps.

2.2.3.3 Algorithms

Development of a satisfactory algorithm for scatterometry is not an easy task. In spite of simultaneous <u>in situ</u> measurements and scatterometer overflights and much work on scattering processes, the physical connections between the wave properties, the wind forcing, and the scatterometer signal are not well understood. Work is underway in the USA and elsewhere to evaluate and improve the algorithms in preparation for the flight of the NSCAT and ERS-1 scatterometer.

2.2.3.4 Mission Status

The ADEOS mission approval for full-scale implementation is expected in December 1988. There is strong support both within NASA and the Japanese Space Agency (NASDA) for flight of NSCAT on ADEOS.

2.2.3.5 In situ data needs

Wind data spanning a global range of conditions will be valuable for validating and improving the accuracy of NSCAT wind velocity measurements. The NSCAT Project will conduct calibration activities, including acquisition of data from two regional field experiments, in the first year following launch of the scatterometer. The design and analysis of ALL comparison data (including ship of opportunity measurements and data from non-NSCAT supported sources) will be coordinated with interested parties in the scientific community. The WOCE Global Surface Layer Programme will coordinate and support in situ measurements, which will also be used for improved estimates atmosphere-ocean exchanges.

2.2.3.6 Relation between WOCE and the NSCAT Science Working Team

As noted above, a Science Working Team for NSCAT has been established. Because of the crucial nature of NSCAT data for WOCE, it is essential that planning for the mission be undertaken with WOCE objectives in mind and that close cooperation be maintained with the WOCE Scientific Steering Group.

2.2.3.7 Data Flow

The data flow is expected to be similar to that described above under TOPEX/POSEIDON. It should be noted that there are no plans at present to provide global wind data in near real-time so that the generation of flux fields by assimilation into AGCMs (as for ERS-1) may not be possible.

2.2.4 Marine Observation Satellite (MOS) Programme

2.2.4.1 Mission Details

MOS-1 is the first of five missions in a 13-year series of satellites designed by the Japan Space Agency NASDA to acquire multi-sensor observations of the ocean. It was launched in February 1987 into a 99^{o} inclination orbit at 909 km altitude and carries two Multispectral Electronic Self-Scanning Radiometers (MESSR), a Visible and Thermal Infrared Radiometer (VTIR) and a passive Microwave Scanning Radiometer (MSR). Its repeat period is 17 days.

The MESSR operates in both visible and near infrared bands, its main oceanographic application is measuring ocean colour. Visible channels are also carried on the VTIR as well as two split windows in the thermal infrared (for SST retrieval) and a water vapour channel. The MSR provides data at two frequencies from which estimates of total water vapour and liquid water may be made.

A similar satellite, MOS-1b, will be launched next, followed by MOS-2 which will carry a different suite of sensors. Although its payload has not been decided it is likely to include active microwave instruments. The MOS series is expected to contribute to WOCE by providing data similar to that from ERS-1, TOPEX/POSEIDON and ADEOS.

2.2.4.2 Data Sets

There is no tape recorder on board MOS-1 so ground stations are needed to achieve coverage in particular areas. Therefore global data sets will not be available from MOS-1. An agreement has been reached allowing ESA to acquire and distribute data over Europe. ESA/Earthnet will supply digital CCT products and quick-look information but not photographic products. The data will be in sensor units rather than geophysical parameters. Products generated by the Japanese will be made available to the worldwide user community but the level to which these will be processed is not known.

2.2.4.3 Algorithms

Both NASDA and ESA are enlisting the help of the scientific community to develop algorithms and demonstrate the utility of the data. In November 1985 NASDA issued the MOS-1 Verification Programme AO aimed at evaluating the geometric and radiometric performances of the sensors, the influence of atmospheric effects and developing algorithms for retrieving geophysical quantities from the raw data. ESA issued a complementary AO in March 1987 to stimulate proposals aimed at demonstrating the practical utility of MOS-1 data acquired in Europe for various research fields, including oceanography.

2.2.4.4 Mission Status

MOS-1 has operated for over a year and has a 2-year design life; the launch of MOS-1b is planned for 1990. MOS-2 has been approved but the proposed launch date has not yet been announced.

2.2.4.5 In situ data needs

The general requirements for data over the oceans are similar to those discussed for other missions though additional biological measurements will be needed in support of the MESSR.

2.2.4.6 Relation between WOCE and Science Working Teams

There is no formal arrangement between WOCE and the investigators participating in the MOS-1 mission.

2.2.4.7 Data Flow

The acquisition and processing of the data acquired in Europe will be managed by the Earthnet Programme Office. All acquisition stations are equipped with processing and archival facilities. Data for the area around Japan will also be acquired and processed at the Earth Observation Centre at Hatoyama-machi. Other stations are located in Thailand and Antarctica.

2.2.5 Other Satellite Missions

On-going operational satellites also will provide data essential to WOCE. Sea surface temperature, near-surface winds (both scalar wind speeds from passive microwave radiometry and vector winds from cloud motion aloft), humidity, and ice cover are all measured routinely by various satellites. In some cases the accuracy is not sufficient for full definition of processes, but the global data sets from operational satellites will be an important part of the implementation of WOCE.

2.2.5.1 Sea Surface Temperature

This is a variable of great importance to understanding the role of the ocean in climate, yet it has proven extraordinarily difficult to measure. A combination of in situ techniques and satellite measurements are being used to produce maps with accuracies of about 1K. Data are routinely available from the AVHRR in a global area coverage mode and a local area coverage mode. WOCE investigators who need specific data from regions not normally covered will have to make special arrangements. SST data also will be available from the ERS-1 and its follow-ups. As discussed in Section (2.2.3), Japan's ADEOS is planned to carry an instrument for measurement of SST and ocean colour, which will provide a useful complement to the other SST missions in place. Given the vigourous activity going on for measurement of this parameter, it does not appear necessary for WOCE to develop specific implementation plans for satellite SST data, except to lend its voice to the need for more accuracy.

2.2.5.2 Near-surface Winds

Although only in situ measurements and the scatterometer can give accurate surface wind vectors, it is possible to estimate them using cloud motions. Clouds are observed by the geostationary satellites; the cloud motion vectors are measured, and the speed and direction extrapolated to the surface with knowledge of the density structure of the atmosphere and boundary layer. WOCE investigators will need access to those data and to the products of the global analyses carried out operationally for numerical weather forecasting purposes in the framework of the World Weather Watch.

2.2.5.3 Near-surface Humidity

Knowledge of surface humidity is critical to understanding latent heat flux. Recent work has shown that a relationship exists between total water content in the atmospheric column above a particular location and the surface humidity. The total water vapour content can be measured with a microwave radiometer such as SSM/I. At present, the TOGA Heat Exchange Project (THEP) is evaluating the production of satellite-derived, air-sea heat fluxes. The extension of these efforts to the entire globe should be evaluated, and archival plans for SSM/I data developed. Given the WOCE interest in heat flux, it will be essential that these data be available, and there may be special requirements for in situ measurements which should be examined within WOCE as well as by the JSC/CCCO Working Group on Air/Sea Fluxes.

2.2.5.4 Ice Coverage

The location of the edge of the ice is an important factor in high-latitude circulation, both north and south. The only technique for all-weather synoptic location and mapping is the microwave radiometer. The SSM/I flown by the USA routinely provides this information. An arrangement has been made to archive and make available the ice edge data. WOCE investigators will be able to obtain the necessary data from the US National Snow and Ice Data Centre.

2.2.5.5 Surface Fluxes

The estimation of surface fluxes will come from a synthesis of several approaches using the research and operational satellite data discussed above and including, where possible, the outputs of atmospheric GCMs in which real-time satellite data have been assimilated. However, it is likely that the assimilation philosophy will not be the only method to be used in the estimation of surface fluxes. Operational satellites (both polar-orbiting and geostationary) will continue to provide measurements of the surface radiation temperature and the incident solar flux. These radiation estimates will be close to meeting WOCE requirements assuming that a mixture of satellite and surface observations with calibration and verification are available. In general, the WOCE plan is to rely on conventional meteorological analyses for heat and moisture fluxes based on improved atmospheric modelling efforts and an upgraded surface observational system using volunteer ships and flux drifters in otherwise uncovered regions (See Sections 2.4.3.2 and 5.4 on surface flux drifters). Once the Tropical Rainfall Measurement Mission is flying, there will be tropical precipitation measurements.

2.3 In Situ Sea-Level Measurements

2.3.1 Introduction

The first goal of WOCE requires in situ sea-level measurements for two major purposes: (a) calibration of altimetric satellite missions and (b) estimates of surface geostrophic currents. In situ sea-level data will also serve as a check on the validity of numerical model results.

The second goal of WOCE, determining the representativeness of the specific WOCE data set for the long-term behaviour of the ocean, will be addressed in part by comparing sea-level measurements made during WOCE with the historical archive held by the Permanent Service for Mean Sea-level (PSMSL). As model predictions improve, consequent in part to WOCE field observations, short term changes in sea-level can be extracted from the record before calculating the long-term trends which are otherwise difficult to isolate.

In general, for altimetric calibration, hourly or preferably six-minute observations are required. Tide gauge measurements must be supplemented with sea-level atmospheric pressure data. It is highly desirable that multiple sensors be used as a check on the quality of outputs and as back-up in case of instrument failures.

The Global Sea-level Observing System (GLOSS) being developed by the IOC provides a framework within which tide-gauge measurements required to meet the WOCE scientific objectives will be made. GLOSS has been developed to serve many purposes including the research needs of WOCE and TOGA and the establishment of a long-term network of tide-gauge stations to monitor sea-level changes. The WOCE period will allow the identification of those gauges which are most representative of ocean conditions and which should therefore be candidates for inclusion in the long-term sea-level network.

2.3.2 Detailed Requirements

2.3.2.1 Altimetric Calibration and Validation

Sea-level measurements are needed to reduce both time-variable, random errors and absolute errors in altimetric satellite orbits and to provide comparison data sets of sea-level anomaly distributions. Sea-level measurements are also needed to provide accurate calibration,in conjunction with precise orbit determination, of the altimeter's time-delay measurement.

Reduction of random orbital errors

WOCE needs tide-gauge data with a two-month delay for early analysis, although all hourly data simultaneous with the satellite missions have potential use. Any data received within 12 to 18 months after the time of measurement will also be of high value.

Observations with a 2-month delay form the Set A of locations from which, for altimeter calibrations, WOCE requires hourly or more frequent values. For an adequate coverage a total of perhaps 10 gauges is envisioned for this rapid delivery mode. Locations which are already in this mode or are likely to be installed are listed in Section (5.3). The appropriate tide-gauges will be selected from this list.

Reduction of Absolute Errors

Sea-level data will be used to reduce the errors in altimetric measurements of sea-level in geocentric coordinates. Gauges sited close to the sub-satellite track traced out by TOPEX/POSEIDON during a ten day period will be used to reduce the ephemeris error to a few centimetres, provided the station positions are known in geocentric coordinates with comparable accuracy and provided that sea-level at the exact sub-satellite track is highly correlated with that at the gauge. The coordinates can be obtained by differential GPS measurements relative to the nearest VLBI satellite tracking station. To collect the appropriate sea-level data, tide-gauges, bottom pressure recorders etc, will be used, depending on the quality of the data, the site specifics and the availability of ancillary data, such as air pressure.

Observations with 12-18 months delay form the Set B, which is needed for use with TOPEX/POSEIDON and ERS-1 altimetric data. WOCE requires an hourly data set from a global set of tide gauge locations. This larger set of sea-level observations for use in altimetric calibration includes the Set A. These, together with the additional gauges discussed below, create the larger high precision global sea-level Set B. It is understood that the full network must include gauges in addition to those already in operation. For an adequate coverage and to meet the requirements of the high-quality calibration, 8-10 tide-gauges per ocean are required, totalling 32 to 40 sites. Tide-gauges adequate to meet the requirements of WOCE are listed in Section (5.3) with indications as to their availability, geocentric reference and potential data link.

Comparison data sets

Tide-gauge data are being used to provide maps of sea-level anomaly in areas such as the Tropical Pacific, where the density of tide gauges is sufficient. A direct comparison with products from altimeter data will verify and subsequently extent the scope and quality of either product. The data set B together with other existing sea-level data will be used.

2.3.2.2 Monitoring geostrophic gradients

Long-term records of sea-level differences across major currents, either between islands or across straits, or in the open ocean in the case of the Antarctic Circumpolar current, will allow monitoring of flow variations. Daily mean sea-level data is adequate for this purpose, but hourly values obtained during WOCE allow:

- non-linear local oceanographic distortions to be seen as higher tidal harmonics, and
- continual checks on gauge performance and identification of potential errors such as datum shifts.

Special attention should be given to the high-latitude Southern Ocean stations which pose special problems because of ice conditions and the infrequency of visits to many of the proposed sites. Support needs to be given to technical developments necessary to make these measurements possible.

2.3.3 Implementation

Above requirements identify two related types of tide-gauge data collection and analysis:

(a) Data collected and generally available for orbit correction within two months, with an accuracy of 3-5 cm (the A set). All gauges in this network will probably transmit data by satellite in near-real time to their national authorities. Hourly values are acceptable, but 6-minute samples are preferred.

(b) A wider based global network of high precision data (the B set). Hourly data to be available within 18 months of collection, accurate to l-2 cm with full datum control and careful checking for inconsistencies and potential errors.

Two in situ sea-level data centres will undertake these separate requirements for WOCE. Data exchange between the two centres and close working arrangements are essential. The detailed data management, validation and processing responsibilities of the two centres are discussed in Chapter 3.

2.3.4 Network Development

Many of the countries being asked to contribute to the tide-gauge network during WOCE have indicated that although eager to participate, they will need assistance from other sources. There are several examples of gauges operating in developing countries through bilateral agreement between local authorities and scientists, and scientists from developed countries. Similar arrangements should be established for each gauge in the network where the local authorities cannot make measurements of sufficiently high quality themselves. One advantage of such cooperative relationships is that gauges can be operated beyond the period of WOCE. Continuing operation is more probable if the local authorities are sufficiently involved in installing and maintaining the gauges and also in the analysis and interpretation of the data so that they can convince national funding agencies of its importance. The GLOSS programme is based on this approach.

The tide-gauge network for GLOSS, as it is presently planned, has been used to identify tide-gauge sites of relevance to WOCE. These are given in Fig. (5.9).

2.3.5 Management

International management of the in situ sea-level programme for WOCE requires continued scientific planning. The day-to-day routine will focus on two aspects: the identification and selection of appropriate tide-gauges and the control of the incoming data stream and its evaluation for WOCE purposes. As the GLOSS network will provide the establishment of the tide-gauges and access to the data, the proposed data centres will provide the data in a form and quality needed for WOCE. Large parts of this scheme are already in place for purposes not very different from WOCE. The existing TOGA sea-level network in the Pacific and its Centre in Hawaii have shown the feasibility of the approach taken for WOCE.

The Sea-level Measurement Planning Committee is being established to oversee the scientific and operational aspects of the programme and to provide continuous liaison with existing international and intergovernmental programmes where needed.

2.3.6 Data Management

All aspects of data quality control, verification of ancillary measurements, data formatting and exchange and final depository are being pursued using the existing international agreements and infrastructure. These are described in the GLOSS Implementation Plan (IOC, 1988). For WOCE specifications see Sections (3.14) and (3.15).

2.4 Floats and Drifters

2.4.1 Introduction

Core Project 1 will involve the first attempt to map directly the large-scale general circulation on a global basis, a task most efficiently accomplished with current-following drifters and floats. The global velocity mapping programme involving drifters and floats is, in scale and objective, a close relative of the WHP and the satellite-based programmes to map surface winds and sea-surface height. Altimetric coverage will provide global observations of the variability of sea surface topography and of the long wavelength components of absolute sea surface topography both of which are essential for measuring currents and their variability during WOCE.

In its most basic form, the global velocity programme has the following objectives:

- To measure the velocity at one subsurface level to be used in conjunction with hydrography in establishing the full-column absolute geostrophic velocity field and its associated transports of heat and tracers.

- To characterize large-scale transport in the upper layer to determine the magnitude and effect of both geostrophic and ageostrophic wind-driven flow.

- To characterize eddy activity and the effect of eddies on transport by mapping eddy energy, single particle diffusivity and Lagrangian time scales with global coverage at the surface and the subsurface reference level.

- To provide observational resolution above the basic global standard in regions where it is needed. For example, vertical resolution should be increased near the equator so that cross-equatorial flow at several levels can be determined where geostrophy cannot be used for vertical extrapolation of velocity.

In the Southern Ocean, Core Project 2, floats and drifters play the same role as in Core Project 1 and are the only instruments capable of directly measuring the large-scale, low-frequency ocean currents over large areas and for long times. Drifting buoys will also serve as platforms for sensors providing other essential data.

Core Project 3 will study certain processes in the Atlantic basin from about 30^{o} S to 60^{o} N in detail in order to make major advances in eddy-resolving models. Two types of experiments will be undertaken: 1) traditional process-oriented experiments that can be carried out in a limited area; and 2) basin scale experiments using many of the same observational techniques as will be used for Core Projects 1 and 2, but in a way as to provide much more detail in the field being observed. The components of Core Project 3 that will require float and/or drifter measurements are: Basin-scale measurements (30$_{o}$ S-60$_{o}$ N); Deep Basin Experiment (Brazil Basin); Structure and Dynamics of the Ekman Layer (Eastern North Atlantic between 25^{o} and 40^{o} N); Subduction (East of the Azores 40^{o} - 50^{o} N and linked with the Ekman Dynamic Experiment); and the Tracer Release Experiments (Brazil Basin and Beta Spiral Site, 27^{o} N, 30^{o} 30’ W). These experiments are explained in detail in Volume II.

2.4.2 Sampling Strategy for Floats

A wide variety of float sampling strategies is planned for WOCE. These are presented in detail in Chapter 5.

2.4.2.1 Float types

It is logistically inefficient to mix float types and tracking. In certain basins acoustically tracked floats will be desired. For example, acoustic tracking is dictated in the North and South Atlantic by the higher resolution required by the Core Project 3 programme, especially near the equator. Interests in the Kuroshio and its recirculation and in the formation of intermediate water in the northeast Pacific also dictate acoustic tracking in the North Pacific. Size and logistic difficulties make much of the Southern Ocean, southern Indian Ocean and South Pacific inappropriate for moored tracking stations and thus dictate use of autonomous floats.

Subsurface floats differ primarily in how their positions are determined. Acoustic tracking permits the continuous tracking needed to infer velocity over intervals of a day. Buoys which rise to the surface for tracking (pop-up) are feasible only to observe the velocity averaged over several weeks but have logistic advantages. The current-following performance of all floats is quite good in the sense that their average horizontal velocity differs from the water’s by small fractions of one mm/s; but none can be considered a Lagrangian particle in the sense that it follows both horizontal and vertical water motions although efforts in this direction are underway.

Acoustically tracked floats also require moored stations to provide positioning. Because these stations involve additional cost, acoustically tracked floats are most efficient when used in high spatial density. This and the capability for continuous tracking make these floats the instrument of choice for intensive studies or when small spatial scales are to be examined. Autonomous pop-up floats, on the other hand, are relatively more convenient logistically for widely dispersed observations of low frequency components of the flow.

The most mature float design uses Sound Fixing and Ranging (SOFAR) tracking; the buoy transmits acoustic signals which are received at moored listening stations and recorded. Work is underway to have these stations relay the data through satellite, thereby potentially extending the listening station servicing interval. Low frequency acoustics are employed so that ranges of the order of 2500 km can be achieved. This makes the floats large so that a typical research vessel can carry only 20 or 30 at a time and the logistic costs are relatively high. These floats have a demonstrated lifetime of at least five years which results in possible total operational costs of the order US$4000 per float per year.

The next most proven approach is the RAFOS float (RAFOS is SOFAR reversed). Moored sound sources are used with floats which receive the acoustic transmission and record the timing information, which after a prescribed period, is relayed via Argos when these buoys pop to the surface. The buoys are small and easily managed in large numbers. They have only been proven for durations of the order of one year but five year lives are feasible. Work is underway to have them rise periodically to the surface for data relay and then return to depth for further acoustic tracking. Modest support of this technology is required to insure a full and proven five-year lifetime capability in time for WOCE. Operational costs for RAFOS floats may be up to 50% lower than SOFAR floats.

The Autonomous LAgrangian Circulation Explorer (ALACE) is a small subsurface current-following float which rises to the surface on approximately monthly intervals to be located by the satellite System Argos. They are less expensive to build than SOFAR floats and, because moorings for tracking are not used, are very much less expensive to use in low density arrays when deployment is done from ships-of-opportunity. Information on short (< month) time scales and short space scales is lost. Prototype floats have been tested for a few months and the first operational deployment is scheduled for early 1989. The present design is capable of 50 cycles to 2000 m over a five year lifetime but longevity is unproven. The velocity error from Argos positioning is small (0.3 mm/s) for submergence-cycle periods of the order of one month. Operational costs under all circumstances should be less than half that of SOFAR floats used in reasonably dense arrays.

2.4.2.2 Float Depths

The primary consideration for float releases is to select a level which will provide the best velocity reference surface for use with hydrography. The level need not be the same for each basin but floats will be placed at some mid-level below the major point of the geostrophic shear of the main pycnocline and where:

- eddy noise is less than near the surface so as to minimize the record length required to reach an accurate mean velocity,

- topographic influence is less than at greater depth, and

- acoustic tracking ranges are relatively long.

The global mapping strategy calls for float releases from 1500 to 2500 m. The overall range of release depths is 500 to 5000 m.

2.4.2.3 Float Density and Deployment

A target resolution for global mapping of velocity for use in conjunction with hydrography is 500 km. There are roughly 1100 such useful resolution cells needed to map the world ocean.

The accuracy of an average velocity estimate is roughly the standard deviation of eddy fluctuations divided by the number of independent observations averaged, which for record length L and integral time scale T is approximately the square root of LT^{-1}. Observations of surface currents and currents at mid-depth indicate an integral time scale between 15 and 25 days (the T here is twice that often reported as the integral scale). Thus, a five-year record will provide the equivalent of more than 100 independent observations and reduces uncertainty of the associated mean velocity to less than 10% of the eddy variability. In most parts of the ocean this provides a substantiat improvement over what can be deduced indirectly from hydrography. For example, 3 cm/s eddy motion at mid-depth would lead to 3 mm/s uncertainty, while 50 cm/s variability in a near-surface western boundary current would give 5 cm/s uncertainty. Neither of these can be approached on the 500 km scale with inverse calculations. On the larger scale, inverse analyses of cross-basin sections give basin-wide average velocity estimates with mm/s uncertainties, much greater than what could be achieved by averaging the 500 km velocity field to a comparably low resolution.

Five years of observation in each of 1100 resolution cells will be required to adequately map velocity at one selected subsurface level globally. Assuming a 5 year lifetime for floats gives an estimated 1100 floats for the global mapping. An additional 540 floats will be required for the Core Project 3 enhanced reference level coverage in the Atlantic Basin and 370 for increased vertical resolution near the equator in all oceans.

Floats are also required for the Deep Basin Experiment (270) and for a number of special studies within all the Core Projects. These are listed in Section 5.4.

A total number of 2707 floats are required for all aspects of WOCE that are presently well-defined.

Most floats can be deployed from WHP and volunteer vessels (VOS) with minimal interference to their normal work. To provide the basic circulation reference data as described above when using WHP vessels, a deployment interval of about 200 nm could be used.

2.4.3 Sampling Strategy - Drifters

2.4.3.1 Surface Velocity Drifters

The near-surface region is the most difficult part of the ocean in which to make accurate velocity measurements. Although it is perhaps the oldest ocean velocity instrument, the surface drifter is also the hardest to make perform well and to calibrate. Recently the performance has improved substantially. The primary error source is wind forcing, either directly or through surface waves. It is now feasible to (a) reduce the error to the order 2 cm/s in 10 m/s winds and (b) to correct for these errors with 30% residual error. It is likely that the requirements for accurate current following will require special purpose drifters not carrying thermistor chains or meteorological sensors other than barometers.

To obtain the measurements needed for WOCE it is important to establish (a) the minimum acceptable current-following accuracy and longevity for drifters, (b) a mechanism to provide rigourous testing of all designs before they are accepted for use, and (c) a mechanism for ensuring that all surface drifter designs meet these criteria. Ensuring that these needs are met is part of the existing programme development.

Almost all surface drifters employ the satellite-based System Argos for positioning and data relay. In this system all buoys use the same radio transmitting frequency and when too many are transmitting in a particular geographic region interference can degrade positioning and data relay. The failure mode is gradual and depends on the amount of data sent by each buoy as well as their number. Experience suggests about 200 buoys within a 5000 km diameter region can coexist. Thus, the level of drifter activity anticipated during WOCE should not overload the Argos system unless there is an unforeseen demand for data transmission capability by other users.

The cost of surface drifters is closely linked to (a) the cost of Argos transmitters and (b) the charges for Argos tracking and data relay services. A drifter large volume production cost of about US$2500 is expected. By sacrificing temporal resolution and having buoys transmit only every second or third day, the Argos charges and load can be reduced. For most designs the lifetime over which drifters have good current-following performance is not known, but is probably two to three years with engineering diligence.

Assuming a lifetime of 2.5 years, an estimated 2 200 drifters are needed for the Core Project 1 global velocity mapping programme based on the same assumptions used for the global float programme presented in Section (2.4.2.3): that is, that velocity will be mapped at a nominal 500 km resolution. A total of 3728 drifters are required for all aspects of WOCE that are presently well defined.

Drifters currently in production or in prototype design can be deployed by ships-of-opportunity, WHP vessels or other regular ship operators such as Antarctic resupply agencies.

A premium is placed by Core Project 2 on the survival of individual systems, including drogues, for the design periods of two and one half years that has been assumed for the global ocean. The Southern Ocean drifters need to be drogued and equipped with thermistors for SST. There is a meteorological requirement to measure the pressure field in the area, using these drifters as platforms. There is also a requirement for thermistor chains in the subantarctic zone where deep winter mixed layers or mode waters form. About 30 of the open ocean drifters are needed to measure the seasonal evolution of these mixed layers.

Buoy design for the sea ice environment shows promise (for example, the FRG Winter Weddell Sea experience). A number of buoys, complete with thermistor and conductivity chains, typically to 200 m depth, could be launched, with a reasonable chance of survival, freezing in if necessary, and then overwintering before coming free the next summer. The first objective is to record the near-surface thermal structure rather than currents. The WMO Executive Committee has recommended that WMO Member States deploy a limited number of drifters in the sea ice zone up to and during WOCE. The small number of such floats likely to be available points to their deployment in a limited area of the Weddell Sea.

The Core Project 3 basin-scale surface velocity requirement is the same as for Core Project 3 basin-scale deep floats, that is, 250 km resolution (see Section 2.4.2.3). The synoptic analyses require that these drifters be not too irregularly distributed within the basin and during the five years of measurement; this can be achieved with multiple deployments, partly from some of the VOS. This requirement calls for an augmentation of 840 drifters to the Core Project 1 drifter programme in the Atlantic Ocean.

Surface currents and sea surface temperature are to be mapped by surface drifters for the Ekman Layer and Subduction Experiments (see Vol.II, Section 5.4). Although 120 of these drifters are required, only 60 will be required in addition to the Core Project 1 network. The deployment of these drifters within the subduction experiment array of surface moorings will provide an opportunity to calibrate these instruments by comparison with more detailed measurements.

2.4.3.2 Surface Flux Drifters

Bulk air-sea interaction parameters include SST, sea level pressure, air temperature, humidity, wind speed and direction (normally measured at about 3 m above the water-line). Below the surface the thermistor chain extends to about 150 m. The thermistor chain data are used to measure the storage of heat in the seasonal thermocline and to ascertain whether the seasonal changes of heat storage in the upper ocean correspond to heat flux changes derived from the meteorological parameters measured by buoys and other sensors producing areal means.

An effective strategy for verification is to deploy drifting buoys in arrays which are on the scale at which flux analysis is produced by atmospheric numerical models (about 5^o x 5^o scale at 30^o N). Regions would be selected where ship traffic is sparse and where significant seasonal signals or irregular events occur. Examples of areas which exhibit very different ratios of sensible to latent heat flux and such time variabilities are the Trade Wind regions, the Arabian Sea and the Western Equatorial Pacific. An array would need to be kept operational in each of these regions through two years, with an initial grid of 12-16 buoys, encompassing 15^o of latitude and 30^o of longitude. A number of atmospheric meso-scale features would be contained in each region. The expected lifetime of sensors is about one year; deployment of each array would require 24-32 buoys, for a total of 72-96 units during the WOCE Intensive Observation Period. Details of the required arrays for Core Projects 1 and 3 are given in Section (5.4). The principal advantage of drifting buoys over moored buoys is that the former are less expensive and are easier to deploy from ships-of-opportunity. The disadvantage is that a predetermined array cannot be maintained.

Drifting air-sea interaction buoy arrays are effectively deployed from research vessels or ships-of-opportunity and require about 30 minutes of ship-time per deployment. Prototype buoys are currently in use in TOGA (thermistor chains) and Ocean Storms (thermistor chains, wind sensors, SST, air temperature). However, a humidity sensor has to be adopted for drifting buoy use.

The precise mechanical configuration of the drifting air-sea interaction buoy to be used in WOCE is under development. Engineering and testing is underway in the following areas:

- Propeller wind sensors currently used are subject to rapid deterioration. Wind speed can be measured accurately (within 0.5 m/s) with subsurface high-frequency acoustics and wind direction by conditionally sampled buoy direction. This scheme needs to be tested and implemented.

- The humidity sensor needs to be added to the drifting buoy platform and data stream.

- The current buoy hull and sensors and superstructure are based on pre-FGGE engineering. Additional light-weight hulls with light-weight sensor towers that extend to 3 m above the surface can and should be made.

2.4.4 Data Flow - Floats and Drifters

The data from drifters and ALACE and RAFOS floats will be collected via the Argos system while SOFAR data will come through the traditional principal investigator route. Data will be submitted via both routes to a Drifter Data Assembly Centre (see 3.18) or a Float Data Assembly Centre (see Section 3.19). Service Argos will provide data tapes to Pls and also place the data on the GTS of WWW for early access by the DACs. The data sharing policy given in Section (3.2) will be respected throughout the exchange and processing of float and drifter data.

2.4.5 Management - Floats and Drifters

2.4.5.1 Surface Velocity Planning Committee

The SSG has established a Surface Velocity Planning Committee responsible for providing the scientific advice necessary for designing and carrying out the global surface velocity (and SST) measurement programme using Argos-tracked drifters in Core Projects 1, 2 and 3. The Planning Committee advises on the capability of drifters to measure surface velocity (and SST), the facilities required at sea and on shore for buoy deployment and on the management of the data flow in real time.

2.4.5.2 Float Programme Planning Committee

A Float Programme Planning Committee is being established to plan and coordinate the technical developments required to implement the float measurement programme. The Committee will advise the SSG on the design of the float programme and consider the technical aspects of data collection through Argos and calibration procedures to ensure data quality.

2.5 **Moorings**

2.5.1 Moored Current-meters

Moored current measurements will be used both for direct estimates of current structure and transport, using coherent arrays in relatively confined areas, and for exploration of the vertical structure of the eddy field, using single moorings or incoherent, large-scale arrays. The global proposed measurement locations are shown in Figure 2.4. Details of each mooring/array are given in Section (5.5).

A. Boundary Current/Choke Point Arrays

Direct current and transport measurements at crucial choke points of the ocean circulation and in conjunction with hydrographic sections for heat flux measurements require the deployment of moored current-meters. Most are designated for boundary regions or in confined passages of abyssal circulation. Although it is also possible to obtain such currents and transports through a combination of various other techniques (for example, hydrography combined with floats or ADCP measurements; PEGASUS current profiling) the required resolution of the variability cannot be practically achieved by such alternate methods.

B. Eddy statistic arrays

For exploration of the vertical structure of the eddy field in mid-ocean, it is necessary to deploy a small number of moorings since the combination of single-level float deployment, surface drifters, and altimetry will not permit determination of the vertical structure of variability. Such measurements are lacking in most of the world’s oceans with the exception of the northern part of the subtropical gyres of the North Pacific and North Atlantic. Arrays in the North Equatorial Current of these two oceans would provide the information necessary to complete the description of the mean and fluctuating flow in a subtropical gyre. Other oceans require exploratory single moorings or small arrays in order to determine whether the structure is sufficiently different from that of the explored oceans to warrant additional, more intensive work. Any moorings set to explore eddy variability will require a minimum of five current-meters with reasonable vertical distribution so that each part of the water column (surface layer, intermediate depth and abyss) is sampled.

C. Special Purpose Arrays

A number of mooring arrays are needed for special experiments, especially in Core Project 3. The design of these arrays is particular to the oceanic process which is being investigated.

2.5.1.1 Experimental Design - Boundary Current/Choke Point Arrays

Design of a generic moored array experiment in a boundary current or across a passage during each of the three phases encompasses the following elements:

Phase I: Exploratory

- Ship CTD/XBT/ADCP sections, deep floats, PEGASUS etc. will be used to roughly define vertical structure, current magnitude, horizontal extent/meandering, and in some cases, the existence of the current itself.

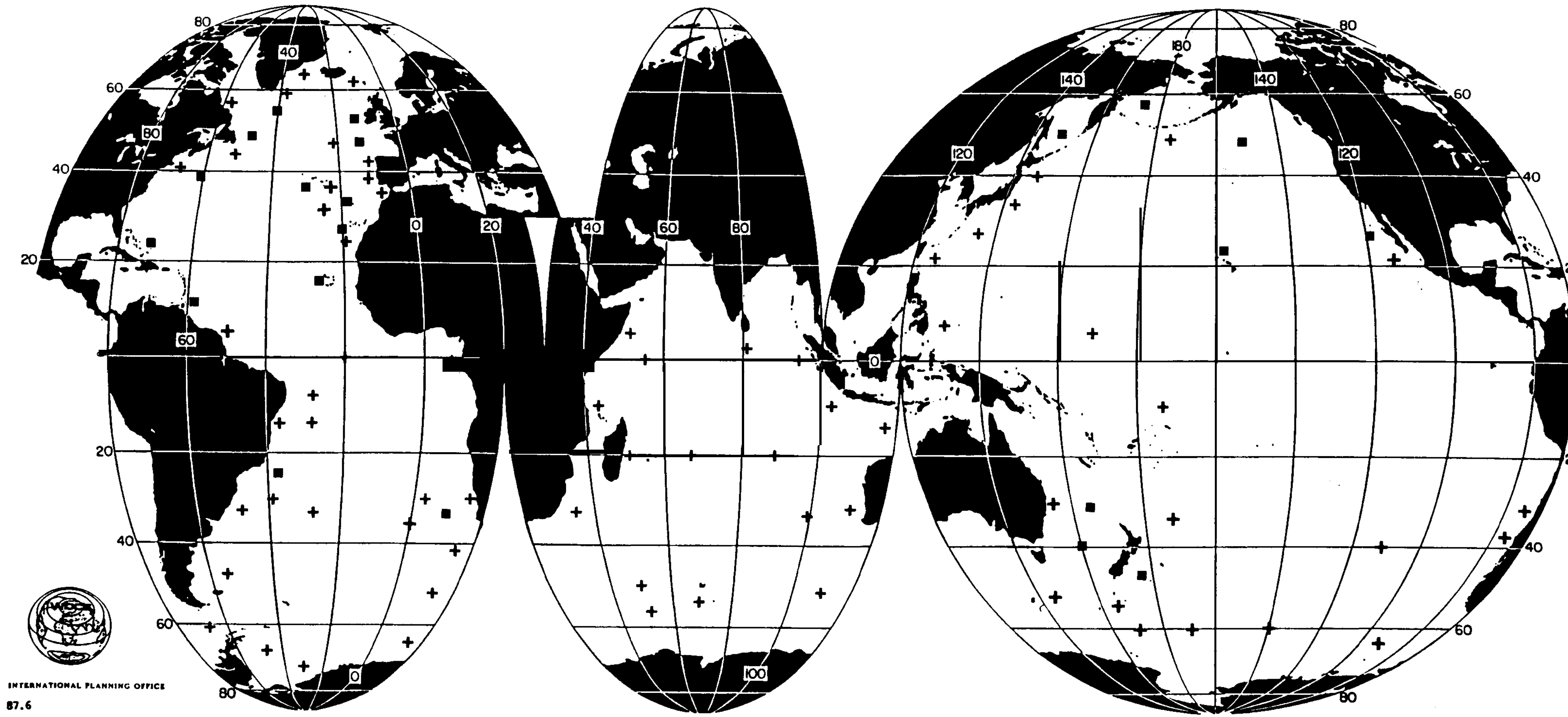


Figure 2.4 Global Moored Instrumentation and Time-Series Stations

■ stations x moorings

- Many of the boundary currents which are to be measured during WOCE do not need a particular exploratory field effort; in some cases, historical data and satellite SST will yield the necessary additional information.

Phase II: Intensive

- Coverage of the boundary current by a moored array of adequate resolution to determine time series of total transport and transport in isopycnal/temperature layers.

- Minimum duration of 18 months, to cover one annual cycle well.

- The use of moored ADCPs, possibly combined with conventional current-meters on the same mooring in strongly-sheared currents such as overflows and equatorial currents and for intense, near-surface currents.

- The combination of moored array measurements with hydrographic sections and direct current profiling (ADCP, PEGASUS) to obtain the T/S relationship for dynamic height calculations and velocity sections for array interpolation/extrapolation (in particular extrapolation towards the surface for conventional subsurface moorings).

- The combination of the moored array with other existing or specially deployed devices to calibrate sea-level stations, bottom pressure gauges, inverted echo sounders, submarine cables, TOPEX/POSEIDON altimetry, and SST for marking current boundaries and meandering/eddies, for use in Phase III.

Phase III: Monitoring

- The continuation of a limited set of measurements throughout WOCE with a design based on the information gathered during the intensive phase.

- Where currents are vertically monotonous, a combination of sea level measurements and inverted echo sounders may be a useful transport indicator (barotropic and baroclinic mode); if there are undercurrents, some moored current profile measurements may have to continue. Geostrophic current profiles could possibly be based on moored temperature alone, if a reliable T/S relation is available.

- Combination of fixed-point monitoring measurements with hydrographic sections to check on the continuity of the correlation of transports and monitoring parameters as determined in Phase II.

2.5.1.2 Experimental Design - Eddy statistics

Sampling in different oceans will be either for a thorough description of eddy variability, for instance in the North Equatorial Current of the North Pacific and North Atlantic, or exploratory in nature. Thus the duration of the experiment and number of moorings involved depends on the particular location and purpose of the measurement. However, the time series length would be timed to coincide with and would be of sufficient duration to compare results with the simultaneous Lagrangian experiments (deep float and surface drifter release). As mentioned above, a minimum of five measurements in the vertical is recommended for sampling all portions of the water column, since the purpose of the moored measurements is to provide the vertical resolution that the Lagrangian experiments will miss. Measurement at the depth of the deep float release is a natural and obvious requirement. Most experiments will utilize current-meters; however, any type of moored instrumentation which provides information on vertical structure throughout the entire water column may be used.

2.5.2 Air-Sea Interaction Moorings

Moored surface buoys carrying meteorological packages (see also Section 2.4.3.2) are required for deployment in areas: (1) where the most accurate measurements of the basic observables and most accurate determination of the long-term air-sea fluxes is desired, (2) which have sparse coverage by ships and drifters, (3) in locations where it is necessary to obtain both in situ forcing and upper ocean response, and (4) where a relatively accurate value at a fixed location is needed to supply ground-truth data for drifters. Data at the original sampling rate will be stored in the buoy; averaged data will be telemetered via ARGOS. The parameters to be measured include SST, air temperature and humidity, sea-level pressure, wind speed and direction, radiation and subsurface temperature to 150 m.

A primary difficulty lies in making a good measurement of the sea surface temperature of the ocean. With diurnal heating, SST may be up to 3 ^{o}C warmer than the temperature at a depth of 1 m; and, during a shower, relatively fresh water can be found at the surface that is cooler than water below. Further, sensors placed on a buoy hull may be affected by the thermal mass of the hull and, if not shielded, may be directly heated by the penetrating radiation. Such radiative heating is also the primary problem with air temperature measurements although aspirated air temperature sensor shields can be used to attempt to bring the error in air temperature down to approximately 0.2 ^{o}C. A surface-piercing thermistor string with sensors shielded from radiative heating can be used together with intelligent sampling to keep error in SST down to a similar magnitude.

Both gimballed mounts and motion detection combined with software correction for tilt will be tested to attempt to bring the error in short-wave and long-wave radiation measurements close to 10 Wm^{-2}. Studies are beginning to improve the estimation of long-wave radiation from the observables. Humidity measurements of the desired accuracy will require the development of new sensors.

A special array of eight surface moorings, each carrying a full set of meteorological instruments to measure short-wave (solar) radiation, long-wave radiation and humidity, is required for the Core Project 3 Ekman Layer and Subduction Experiments. The heat flux estimates should have a long-term average error of not more than about 30 Wm-2. This array would be set across the (mean) Azores high pressure system so that its northern end will be within westerly winds, and the southern end will be within the easterly trade winds, extending roughly from 40^{o} N to 35^{o} N. The surface moorings should carry a string of about ten VMCM instruments to measure current near the sea surface, requiring that the surface buoys have considerable buoyancy. Present deployments of such buoys are limited to about six months duration, so extension of buoy lifetimes is required, preferably to one year.

In addition to moored buoys deployed specifically for WOCE use, the meteorological community currently maintains a number of moored buoys which monitor meteorological parameters. Measurements from these buoys should be utilized in WOCE. The data should be reported at a frequency high enough to be of use with satellite measurements, which may entail discussions with the agencies maintaining the moorings. Attachment of temperature/salinity chains to moorings in selected regions may also be useful.

2.5.3 Data flow

The traditional methods will be used to collect data from moorings whereby the Pls are responsible for recovery, quality control and delivery to the Moored Current-Meter Data Assembly Centre (DAC) (see Section 3.20). It will be the responsibility of the DAC to distribute the data to WOCE and other users in accordance with the WOCE Data Sharing Policy. The DAC will also ensure that the data are subsequently submitted to the WDCs for long-term archival and storage.

Moorings with meteorological packages and, possibly, thermistor chains, will telemeter averaged data to the Pls via ARGOS, with the original sampling rate data stored on the buoy until recovered by the PI.

2.5.8 Mooring Programme Coordination

Initially the IPO will coordinate the activities of the various mooring groups participating in WOCE. The specialized nature of mooring measurements and the different schemes utilized by the laboratories to be involved do not lend themselves to overall management by a planning committee. It is anticipated that laboratories throughout the world will be interested in maintaining specific arrays near their home bases and will provide the necessary resources for these arrays. When that is not the case, the IPO will assist in obtaining the necessary resources and facilitating logistics. The IPO will rely on the Core Project Working Groups and the Boundary Current Scientific Panel for the determination of issues such as prioritization.

2.6 Voluntary Observing Ship Programme

2.6.1 XBT/XCTD

The Voluntary Observing Ship (VOS) Programme will initially use XBTs (450-750 m) but will expand as developments allow to include XBTs down to 1000 m, XCTDs and Acoustic Doppler Current Profiler measurements (see Section 2.7). Industrial production of XCTDs still has to be extended with the accuracy and precision needed for large-scale use in WOCE.

The scientific objectives for the VOS programme are:

- to measure changes in the heat and salt content of the upper ocean on basin scales.

- to estimate the statistics of the thermal field in the upper kilometre. In order to carry out unbiased sampling of the large-scale field and to assess the possible contribution of eddy processes in the general circulation, it is necessary to know the variance of the eddy field and the spatial and temporal covariances:

- to observe the variations of large-scale geostrophic velocity in the upper kilometre and of the zonal and meridional fluxes of heat and salt on time-scales of seasons to years. This objective includes the observations of changes in the subtropical and subpolar gyre interior circulations, the boundary currents, the location of the gyre centres, and the tropical current systems;

There will be two modes'of sampling from commercial ships. The first is an extension of the present TOGA and TRANSPAC-type XBT networks. The low density sampling of such networks will be extended to the middle and high latitude oceans. XCTDs should be included where T/S variability is large and the sampling depth should extend as nearly as possible to the base of the thermocline. This expansion will primarily be aimed at the measurement of heat and salt storage in conjunction with the TOGA heat storage measurement programme in the tropics.

In the second mode, sampling will be by high density (eddy-resolving) XBT/XCTD measurements along a subset of ship tracks. The high density sections will be used to determine spatial statistics of the temperature, salinity, and geostrophic velocity fields and to measure temporal changes in large-scale geostrophic velocity without aliasing effects from meso-scale features. The tracks will include:

- zonal tracks from coastline to coastline near the centre of the subtropical gyres and if possible near the centre of the subpolar gyres;

- two or three meridional tracks crossing the equator and terminating at high latitudes;

- a few additional tracks in the western oceans across the western boundary currents.

The value of the high density sections would be considerably enhanced by the addition of ADCPs on the participating ships.

The two sampling modes should complement one another in several respects. The high density mode samples coherently from coastline to coastline but it does not sample the large areas between the tracks and the repetition rate might be no greater than seasonal. The low density mode provides the missing areal coverage and a greater repetition rate while lacking the spatial resolution for unaliased sampling and the ability to sample small-scale features such as boundary currents. Design of the combined network should be aimed at reinforcing these complementary aspects.

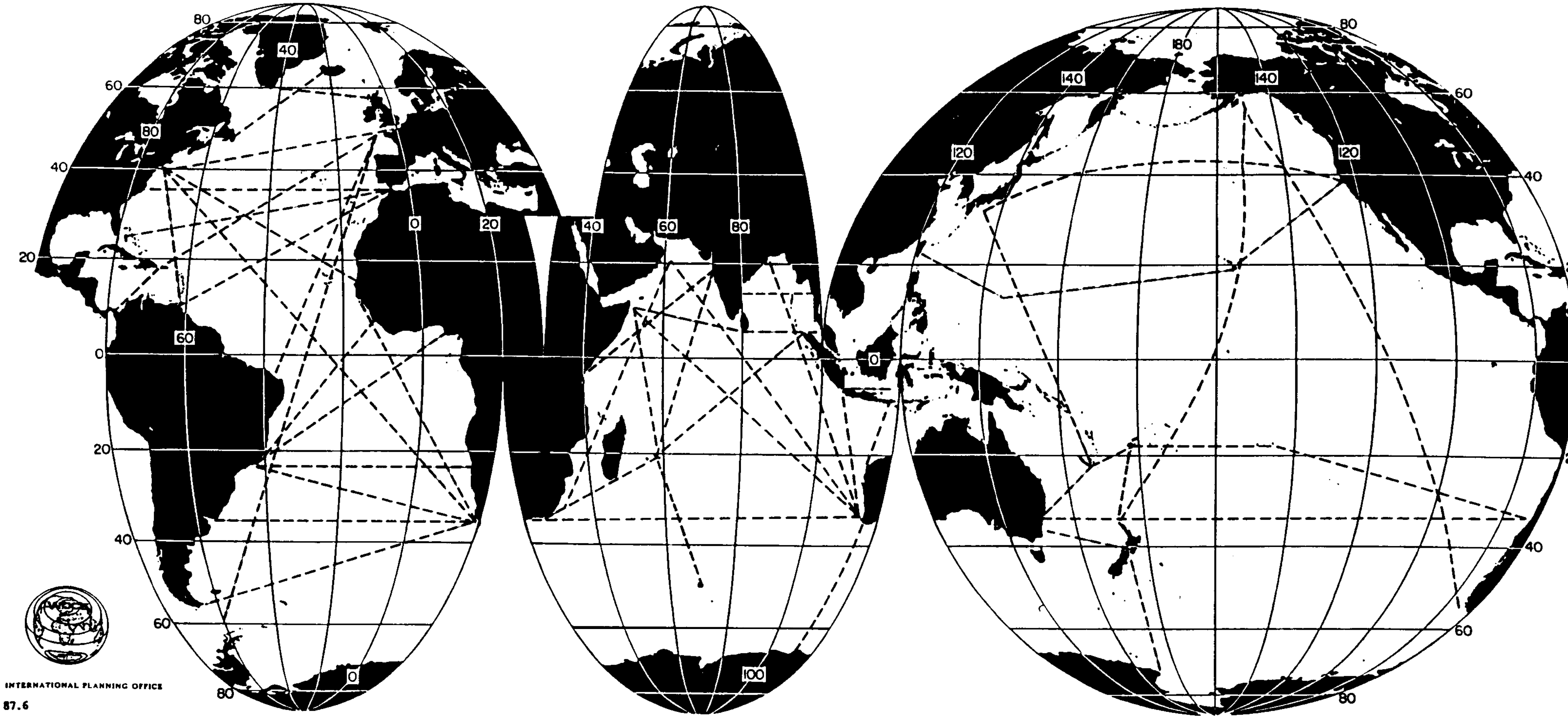


Fig. (2.5) WOCE XBT/XCTD Special Requirements

2.6.1.1 Sampling Strategy

The low density mode has been effective in several regions but is deficient in many others. Although it does not represent the total data base, the IGOSS BATHY/TESAC summary for 1987 (see Figs. 2.6 and 2.7) clearly demonstrates the regions of adequate and inadequate coverage. This mode has benefited from the TOGA efforts to expand the XBT network in the tropics and from the long-standing TRANSPAC programme. The USSR programme SECTION has also helped increase the data availability on IGOSS. These must be extended to those regions still lacking adequate coverage through an expansion of the number of ships cooperating through IGOSS and Special WOCE projects. The latter may be more suited to the high density mode initiatives. The typical sampling frequency of the low density mode is 2 samples/day, normally to 450 m. The depths have varied, however, from 200 m to 1700 m, the latter when CTDs or Nansen casts are used. The low density type data input through IGOSS has increased steadily for the past several years (12% in 1986, 20% in 1987) mainly due to TOGA. A total of 56,893 observations was received in 1987.

The high density mode is to provide XBT/XCTD data at a 50 km interval along selected sections. These data are required seasonally and down to 1000 m. The high density tracks in the Pacific are depicted in Figure (2.5) and are listed in Section 5.6. These tracks require approximately 8 000 observations per year.

The present Core Project 1 XBT/XCTD strategy in the Indian Ocean is to rely on the TOGA network while in the Atlantic, 20 lines have been identified for monthly XBT coverage. These lines are shown in Fig. (2.5) and listed in Section (5.6). The new Atlantic XBT/XCTD lines along with existing XBT projects should satisfy Core Project 3 requirements as well.

Assuming full implementation of the TOGA network, the additional WOCE XBT/XCTD annual requirement is: Atlantic 3 500 probes; Pacific 8 000 probes; and an additional 3 to 5 000 probes in order to take advantage of opportunities to expand the network to other data spare regions: i.e. a total of 16 500 probes per year.

2.6.1.2 Programme Management

One of the main reasons why the quality and quantity of XBT data reaching national and international centres has improved in recent years is the direct involvement of scientific teams in logistics and data processing aspects. This is one of the key elements of the TOGA VOS programme and it will be employed for WOCE as well. Experts will be designated, perhaps on the basis of ocean basins, who will have overall accountability including quality control and responsibility for the production of regional data and analysis products. This will require the enlistment of regional VOS (XBT/XCTD) scientists similar to those in TOGA. Where applicable WOCE and TOGA activities will be combined and coordinated.

The Upper Ocean Thermal Data Assembly Centre operation (see Section 3.17) will be a collaboration between WOCE scientists and a National Data Centre. The scientists will coordinate the data collection, maintain standards of data collection and engineering quality control among individual collection efforts within the basin, and provide the National Data Centre with fully quality-controlled data sets. The National Data Centres will provide the responsible scientists with any data received independently, disseminate data sets to the oceanographic community, maintain the WOCE VOS data base and submit it to the WDCs for long-term storage.

The WOCE Voluntary Observing Ship Programme will be overseen by a VOS Planning Committee to be established by the SSG in consultation with TOGA. The responsibilities of the VOS committee will be to monitor the flow of XBT/XCTD and ADCP data; assist in arranging for additional ships to participate in the scheme; ensuring data quality; and coordination with other international components of the VOS programme, particularly the IOC/WMO Working Committee for IGOSS. The responsible scientists will be members of the Planning Committee.

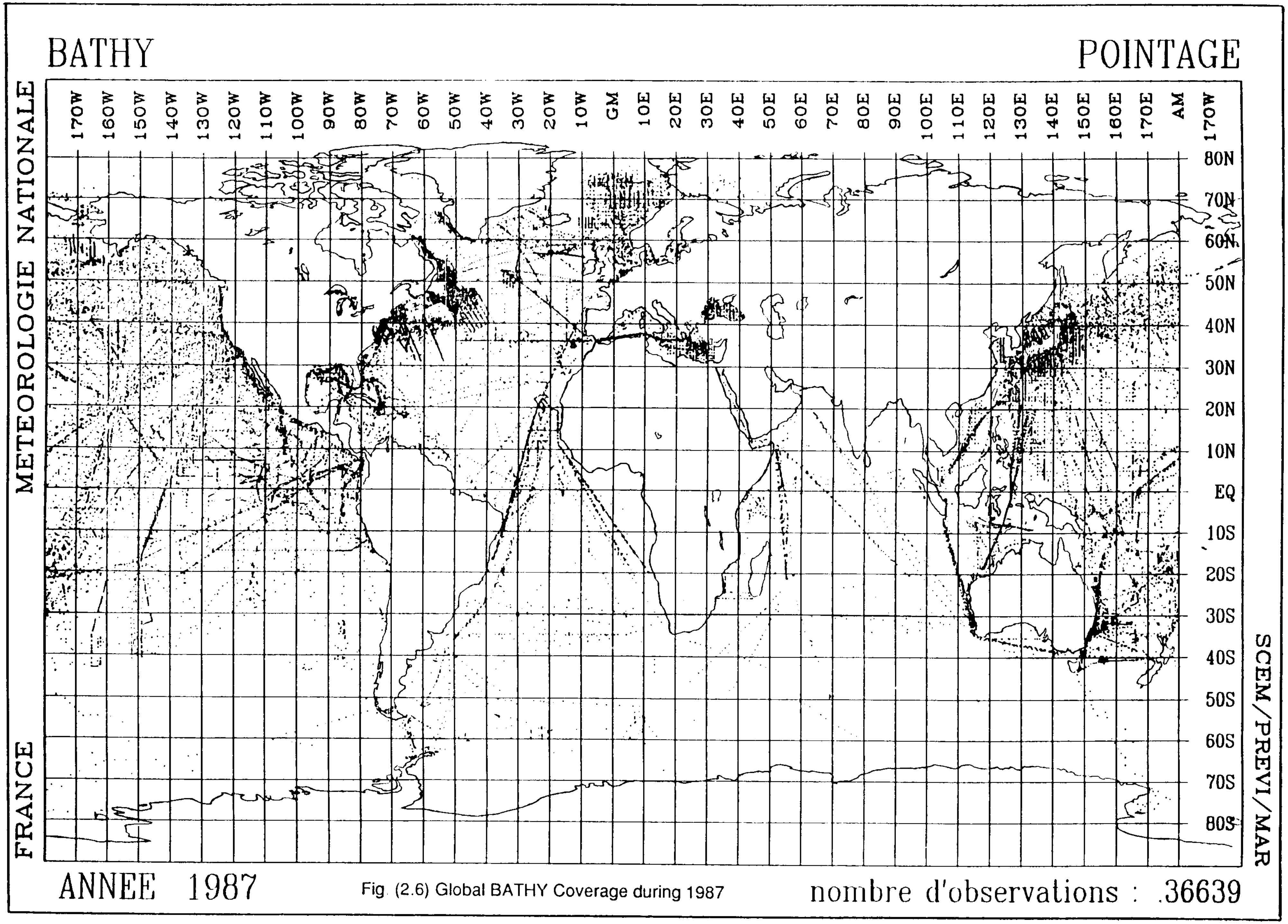


Fig. (2.6) Global BATHY Coverage during 1987

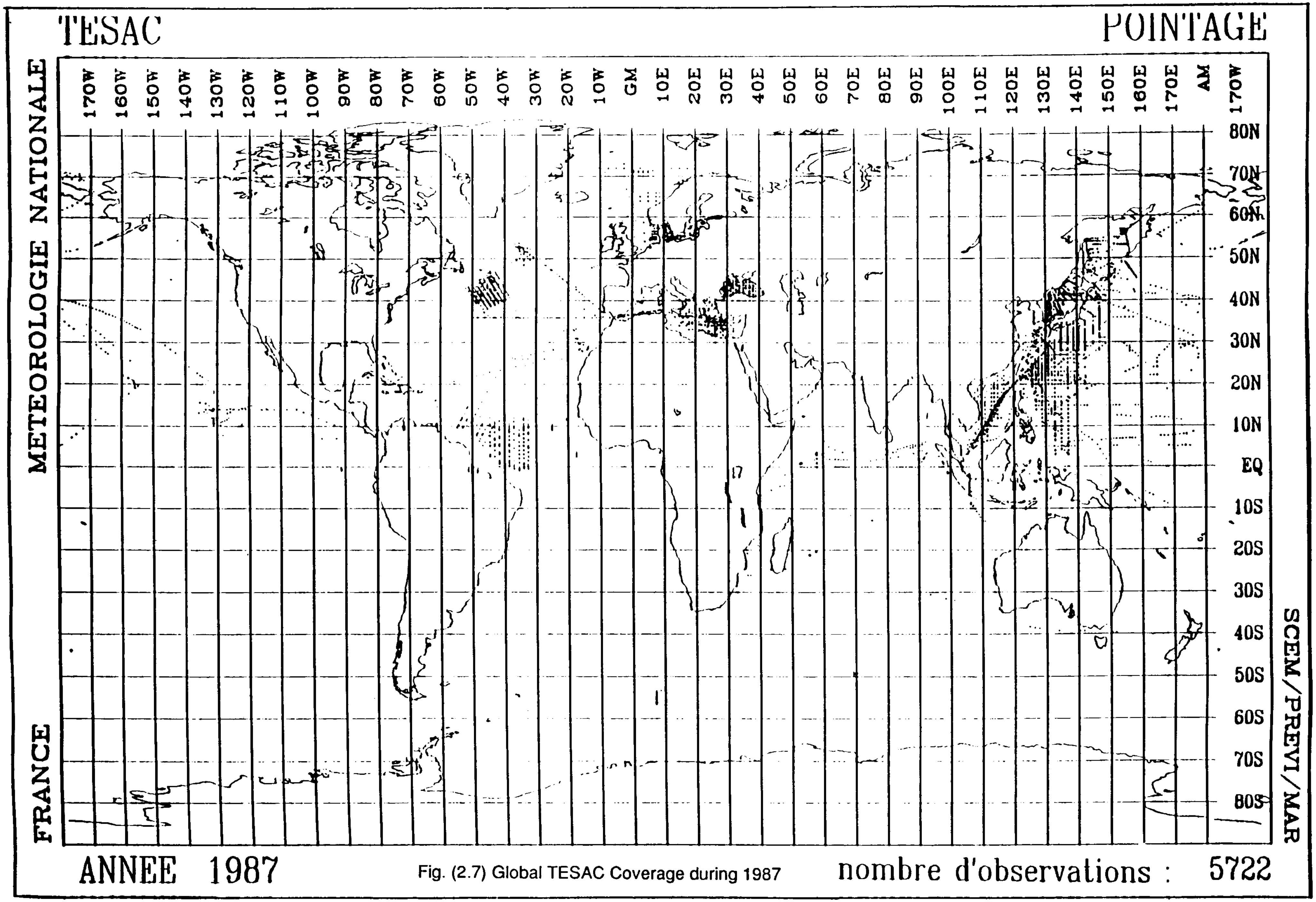


Fig. (2.7) Global TESAC Coverage during 1987

2.6.2 Acoustic Doppler Current Profiling

ADCPs will be used in WOCE both on research vessels and on Voluntary Observing Ships (VOS). Whereas research vessels provide the opportunity for frequent documentation on ship's speed, heading and sea state, thus permitting calibration of transducer and gyro offsets, the deployment on VOSs, which run at constant speeds and headings for long times, limits the calibration of the system components. On the other hand, a well-designed VOS programme will provide a better space-time coverage.

Data from ship-borne ADCPs aboard VOSs are needed to provide large-scale mapping of near-surface current fields, mapping of the meso-scale wave-number structure and measurements of the near-surface shear for the ageostrophic component of the upper ocean velocities.

Although numerous problems have been identified in the use of ADCPs in the ship-borne mode, the advantage of using the commercial ships is the ability to make repeated sections. Since VOSs steam at greater speeds than research vessels, the spatial sampling will be coarser. However, it will also be more uniform and synoptic since no station measurements are made. With regard to data quality, the usefulness of the ADCP measurements made from VOSs needs to be assessed. For example, are commercial ships willing to make routine calibrations? Also, high quality navigation, as with GPS, is required. Since VOS-XBT will be part of WOCE, it is planned to employ a few of these ships as prototypes for an ADCP programme, possibly including a seagoing ADCP operator. The emphasis must be on obtaining useful, high quality data rather than a large quantity of data of uneven quality. ADCP data assembly activities are described in Section (3.16).

2.6.3 Surface Meteorology

The basic meteorological quantities that need to be measured include SST, air temperature, wind speed and direction, barometric pressure, humidity (which may be obtained from the wet bulb depression), short-wave radiation, long-wave radiation, and precipitation. Wind stress, sensible heat flux, latent heat flux and evaporation are determined from these basic data using bulk formulae. Accuracies of 10 Wm^{-2} are sought in estimates of the mean values (averaged over monthly and longer time scales) of each of the four components of heat flux; accuracies of approximately 1 mmd^{-1} are sought in evaporation and precipitation; and accuracy of 10% or 0.01 Pa is sought in stress.

The majority of conventional surface meteorological data are provided by observations from the VOSs. These data contain random errors due to inadequate sampling, poor instrument calibrations, ship air flow disturbance, etc. Effects such as heat contamination from the ship and salt contamination of wet bulbs result in systematic biases. The random errors can be reduced by averaging VOS data in those regions where dense shipping lanes give a relatively large number of VOS reports. In other regions, long time and/or large spatial averages are necessary. There is a need to increase the number of VOS reports from all areas. Methods of assessing the systematic biases are by comparison of the VOS data with meteorological buoys, research ships, or a higher quality subset of the VOS. The latter approach requires the choice of a set of particular vessels and calibrating the exposure of their suite of meteorological instruments carefully.

The quality of VOS observations of cloud cover may not determine the incoming solar radiation to the desired accuracy. Comparisons of incoming solar radiation as a function of elevation and cloud cover using weather ship data show very large scatter of the results. Net short-wave radiation is estimated by measuring downwelling short-wave radiation with a pyranometer and multiplying by $(1 - \alpha)$, where a is the albedo. In view of these uncertainties some improvement in the level of ship-based measurements of incoming short-wave radiation will be needed during WOCE. It is not clear that such a programme could be conducted from surface drifters. Therefore instruments must be carefully calibrated and gimbal-mounted to compensate for ship or buoy motion. Even so, residual motion, and the difficulty of obtaining a clear sky view from a ship, will cause errors additional to those due to the radiometer.

2.6.4 Data Flow

The IGOSS Telecommunication Arrangements will be used as the first line of XBT/XCTD data collection. This entails the transmission of XBT data in BATHY form and XCTD data in TESAC form in accordance with WMO standard code formats (Manual on Codes, Vol.1, WMO-No. 306, rev.1987). The IGOSS Telecommunication Arrangements are contained in the Manuals and Guides No.3, revised edition (UNESC0,1984).

Additionally, surface meteorological data will be collected within the WMO World Weather Watch to the specifications required.

The preferred mode of data transmission from ship to shore is via satellite as data received via that means are of a higher quality and a greater percentage of the data reach users. The latter is also the case when automated processing of transmission systems are used aboard ship. When the data have been received on shore, either via satellites or normal shipboard radio, they are entered on the Global Telecommunication System (GTS) for distribution. The WOCE VOS experts (see Section 2.6.1.2) will have access to data placed on the GTS. Data not submitted through IGOSS - which will accept data up to one month from the time of observation -will be delivered directly to the WOCE VOS experts by Pls or ship's staff. The data will then follow the procedures outlined in Sections (2.6.1.2) and (3.17, Upper Ocean Thermal Data Assembly Centre).

2.7 Acoustic Doppler Current Profiler (ADCP)

ADCPs will be used in WOCE extensively in two different modes: as a ship-borne instrument to measure the vertical profile of currents while the ship is underway and in a moored mode to measure the current profile as a time series. These instruments have demonstrated their usefulness in regions of high current shear. For wider applications several areas in need of development have been identified. In order to further reduce errors that are in the order of 2%, special emphasis is at present given to alignment problems in the ship-borne version and accuracy in low-shear regions. Further developments are focussing on the depth range, which at present is of the order of 400 m for the 150 kHz, and 600 m for 75 kHz transducers. In order to make use of the instrument on a wide basis, more experience and expertise is needed to fully understand its physics.

2.7.1 Ship-borne ADCPs

Any ADCP uses the Doppler shift of scattered sound due to the motion of the scatterers relative to the transducer to infer the velocity of the medium. Errors and biases enter at many points between the reception of the scattered sound and the final estimate of the water velocity. To achieve the accuracy, long-term performance and data quality needed for WOCE, great diligence will be needed to use this instrument to map the near-surface velocity field. In the ship-borne mode beside the errors of the instrument, other constraints on data quality apply. These come from errors in precise positioning - which will preferably be GPS navigation - transducer alignment, influences of the sea-state on the hull, the manoeuvring of the ship and the absence of scatterers. To arrive at high-quality data utmost care has to be taken to qualitatively assess the influence of every component of the system on the data as errors amount to ca. 2% or some cm/s.

The potential uses of ADCP data from the Voluntary Observing Ship programme are listed in Section (2.6.2). On research vessels, in addition to collecting accurate information on ship speed, heading, sea state, etc. for calibration purposes, ADCP data will be used for determining reference velocities for geostrophic currents calculated from hydrographic sections.

2.7.2 Moored ADCPs

Self contained, battery-powered ADCPs are at the present time offered only by one manufacturer. Available systems have a 4-transducer Janus configuration at beam angles of 20" or 30'. An internal processor does ping-to-ping decomposition of beam Doppler velocities into earth coordinates using a fluxgate compass and a two-axis tilt sensor. Ranges observed, looking upwards from submerged buoys are about 400 m for 150 kHz operating frequency and 600 m for 75 kHz. Bin size can be set from 1 m to 32 m, with a maximum of 128 bins for the profile. Ensemble noise amplitude for a 150 kHz system is on the order of 1 cm/s at an ensemble averaging of 400 pings and an 8 m bin width. A particular advantage for long term applications is that the instrument can look upward and measure near-surface currents without itself being exposed to fouling and the hazards of near-surface fishing activities, ice and shipping.

2.7.2.1 Applications for WOCE

Moored ADCPs will be used in WOCE:

- In highly-sheared currents, especially in equatorial areas, where interpolation of sparsely distributed conventional current-meters or extrapolation to the surface would lead to erroneous profiles.

- In shallow currents where one instrument can profile the entire extent of the flow, (for example Greenland-Scotland overflow, Mediterranean outflow).

- In polar regions where there are particular applications of the instrument for convective studies. As the instrument measures the 3D Doppler currents, one can also measure the elusive vertical component of the current.

2.7.2.2 Potential Problems

Potential problems to be contended with are:

- There is a loss of near-surface Doppler data in the upward-looking mode. Near-surface Doppler data from along the 4 beams are biased by side lobe reception of signals which travel straight up to the surface and back. Narrower beam angle reduces the loss (but increases the horizontal current noise amplitude). If the instrument axis is inclined, for example by mooring motion, the range of biased data deepens. Therefore, efforts must be made to keep the instrument as vertical in the water as possible. Good results have been achieved deploying the instrument in a torpedo-shaped float in the Gulf Stream.

- There are data storage limitations. So far, the internal tape cassette recorder successfully tested can only store 1.5 Mbyte (about 2000 standard profiles). A 60 Mbyte recorder tested had a number of failures. A new high-density recorder is under development.

- Although fairly reliable, the instrument is still undergoing iterative improvements and software updates which can, at times, be irritating for the unsuspecting user.

- The assumption is that the scatterers causing the Doppler signal sit passively in the water. However, strong diurnal signals have been observed in echo amplitudes associated with vertical velocities of several cm/s due to active scatterer (zooplankton) immigration. This indicates that caution must be used in the interpretation of vertical current measurements.

- The ADCP employs non-contact measurement. Therefore the temperature and conductivity measurements which are a by-product of conventional current-meters will not be available for the water column above the instrument. A downward looking ADCP mounted in surface buoys with a thermistor/conductivity chain along the mooring wire may be a solution.

2.7.2.3 ADCP Cost

A 150 kHz system presently costs US$56K, i.e. about the equivalent of 3 VACM/VMCM current-meters. If a pressure sensor, is added, the cost is increased by US$8K. However, one may wish to choose an Aanderaa current-meter instead mounted just underneath the ADCP. Manpower and spare pan requirements for a standard turn-around based on prior experience was less than that for rotor instruments.

2.7.3 ADCP Developments

As the ADCP-technology is still developing and a better understanding of the whole system is coming forward, a small group of experts is monitoring these developments. It is responsible for liaising with the programme components of WOCE that require profiles of upper-ocean currents. This also effects new applications of the instrument which at present are not envisaged.

3 DATA MANAGEMENT

3.1 Introduction

WOCE differs from all previous oceanographic experiments in the scope of its goals and of the field-work required to achieve them. It also differs in that several large, diverse data sets have to be combined and evaluated at an early stage of the programme in order to allow their use and interpretation by other participants in WOCE. WOCE will carry on for five years or more during which time the experimental strategy will undergo continuous evaluation in the light of experience from measurements taken early in the experiment. To be credible, nationally and internationally, as a coherent collaborative scientific programme, WOCE needs data management which explicitly addresses the unified nature of the programme and its products. In formulating the data plan, the competing needs of the programme as a whole and the rights of individual scientists who will have made large personal investments of their ideas and their time in obtaining the data have been taken into account. These needs have led to adoption of the following guide-lines for data sharing.

3.2 Data Sharing Policy

To assist the WOCE IPQ in keeping WOCE participants informed of progress, scientists should submit inventories of data collected to the IPO. This should be done within one month after a cruise or at regular intervals (less than 6 months) in the case of continuing observations such as of sea-level and from satellites.

WOCE requires the analysis and synthesis of a wide variety of data. For this to proceed in a timely way it will frequently be important for scientists to make their data sets available at an early stage in support of syntheses by other investigators. When such special needs have been identified by the SSG or national committees, the interim data sets should be submitted to the appropriate WOCE data centre within one month of initial quality control and accompanied by notes specifying the limitations of the set at this interim stage.

Data centres may use this data in creating data products or to perform intercalibrations as specified in WOCE implementation and operational documents.

These centres must not exploit or permit exploitation of the individual data sets prior to their general release, without the agreement of the originating project.

As scientists in WOCE themselves expect individually to benefit from the data collected by a variety of agencies and other scientists, they likewise should make their data available to WOCE data centres for distribution to colleagues, typically within months after collection.

Specific guide-lines are presented in subsequent sections which are directed towards all the components of data management.

3.3 Goals of WOCE Data Management System

1. The creation of data sets for the critical assessment of theories and models.

2. The creation of data sets to be used as boundary conditions on ocean models.

3. The assembly of data sets to provide a comprehensive description of the global ocean circulation.

4. The assembly of useful subsets of existing data for WOCE purposes.

5. Creation of a comprehensive catalogue of these data sets.

6. The dissemination of the data sets to the research community.

The achievement of these goals will as far as possible be based on the direct involvement by research groups in the data management process, aided by national data centres.

3.4 Elements of the Data Management System

A generic description of data flow during WOCE from data collection to data base and publication is given in Fig. 3.1 which is a simplification of the schematic presented in the Scientific Plan for WOCE. That part of the system shown inside the box in Fig. 3.1 is specific to WOCE and must therefore be designed and supported by WOCE.

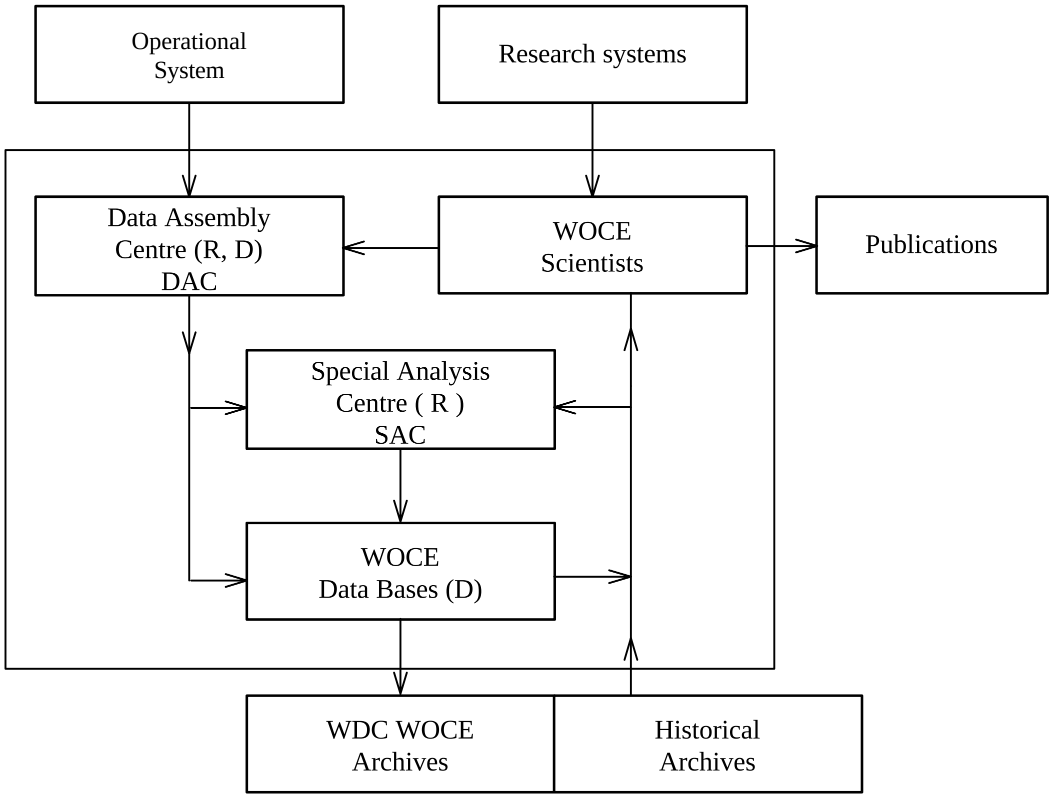


Figure 3.1 Functional Diagram of WOCE Data Management

The components are:

(1) **Research systems** which include all those means by which a WOCE project deploys instruments specifically to acquire data for the project. The scientist has strong control of or influence on the design.

(2) **Operational systems** of importance to WOCE but whose objectives are not primarily those of WOCE. These include:

International Oceanographic Data Exchange (IODE) of IOC - IODE provides a mechanism for delayed mode exchange of oceanographic data between World Data Centres (WDC), National

Oceanographic Data Centres (NODC) and Responsible NODCs (RNODCs) and for the preparation and distribution of data products by RNODCs (see IOC Manuals and Guides, No.9, 1982).

Tropical Ocean Global Atmosphere (TOGA) Programme of WCRP - A number of the TOGA centres are of high relevance to WOCE. They are described fully in the TOGA International Implementation Plan (1987), and include Sub-surface Thermal, Sea Level, and Global Sea Surface Temperature (SST) Centres.

Voluntary Observing Ships (VOS) of WMO - These provide synoptic reports on surface meteorology.

Integrated Global Ocean Services System (IGOSS) of IOC/WMO - IGOSS provides a mechanism for the quasi-synoptic acquisition and distribution of oceanographic data via the Global Telecommunications System (GTS) from ships of opportunity. At present the data arise largely from XBTs.

Drifting Buoy Cooperation Panel of WMO/IOC - The panel provides a framework for the coordination of drifting buoy activities by nations, including data exchange by GTS and data collection by the RNODC for drifting buoys (Marine Environmental Data Service (MEDS), Canada). Data are mainly collected through the Argos system.

Operational Weather Satellites - In addition to transmitting imaging data in the visible and infra-red bands, these provide a vehicle for data relay via the Argos system.

(3) **World Data Centres** were established by ICSU during the IGY and have served since then as the permanent archive of mainly hydrographic and chemical data for programmes large and small. They are valuable as sources for long-term retrieval. They have been requested by the WCRP to provide a permanent archive for data from the WCRP.

(4) WOCE Data Assembly and Quality Control functions are being defined for those measured parameters which generate large data sets of use to the WOCE programme as a whole. These functions will usually be exercised by **WOCE Data Assembly Centres (DAC)** as specified in Section (3.10).

(5) WOCE Data Analysis and Synthesis functions, to be exercised by **WOCE Special Analysis Centres (SAC)**, are envisaged as generating Level III (see Section 3.11) data sets which are variously:

a combination of several basic data sets,

derived parameters, and

interpolations of other data sets onto a grid.

(6) The **WOCE Data Base** function is to provide timely access for all WOCE participants to the data identified according to the data sharing policy for WOCE. This function will usually be exercised by a national data centre cooperating within the WOCE DAC/SAC scheme.

3.5 Definition of Levels of Data

The concept of data levels similar to those used to describe the stages of analysis during FGGE and, more recently TOGA, will be used during WOCE. The definitions of the various data levels given below encompass and extend those adopted for TOGA.

Level 0 data are raw data telemetered from a spacecraft and which require data processing for conversion to Level I.

Level I data are instrument readings, normally in engineering units (e.g. volts), that require conversion into meteorological and oceanographic variables specified in the data requirements. The raw data records are to be retained by the participants but not, in general, exchanged as part of the standard data flow.

Level II data are values of the universal meteorological and oceanographic variables either obtained directly from instruments or derived from Level I data, e.g. wind velocity, sea level, SST. These data are subdivided into two classes with different timeliness characteristics.

Level II-a data are WWW, IGOSS, and other information required for research and monitoring activities in which rapid data availability is important.

Level II-b data are distinguished from Level II-a data by a delayed cut-off allowing the acquisition of a more complete data set and/or the application of quality control. Typically these data will be produced by a DAC.

Level III data are processed products derived from Level II data by analysis techniques. Typically these data would be produced by an SAC.

3.6 Implementation of WOCE Specific Elements

The Core Projects describe a complex and distributed research activity continuing over many years. Implementation is influenced by the knowledge that:

- Expertise related to the various data types and the problems in creating high-quality data sets lies in many different research institutions.

- The problems of acquiring, organizing, formatting, distributing and archiving data are familiar to established data centres.

Fig. (3.1) indicates, through the letters R and D, the typical but not exclusive role of the research groups (R) and existing data centres (D) in WOCE data management.

The existing competence will be used to create a number of WOCE centres to carry out, as joint operations of research laboratories and data centres, the functions discussed in Section (3.4). Their objective will be to maximize the quality, accessibility and timeliness of the data for WOCE scientists. The system is decentralized but not so fragmented that accessibility of the data would be degraded.

A **Data Information Unit** (DIU) has been specified (see 3.7) to provide a source of information on the progress of WOCE. This unit will hold and update catalogue information on the progress of the centres, the data content of the data bases and more general information about the national and international projects in WOCE.

The ready availability of national and world-wide data communications networks during WOCE will have a major impact on how oceanographic data for the experiment are managed. Many of the institutions where oceanic research will take place during WOCE already make some use of national networks for data transfer whilst electronic mail is already firmly established and widely used in WOCE planning. The distributed nature of the data bases and of the centres, points to the need for good communication with each other and with WOCE scientists. It is important, therefore, that research groups and data centres attempt to adopt compatible strategies for data communication. Because of the long lead-time to implement arrangements for networks, WOCE must keep under review the technical requirements for networks. These include questions of geographical coverage, data capacity, need for international data links and ways to establish such links.

3.7 Data Information Unit

Objectives

(1) To disseminate, as available, summaries of the progress of WOCE and of the data products from data assembly and analysis centres and from other relevant centres.

(2) To maintain a record of the disposition and availability of data sets collected as part of WOCE or which are directly relevant to WOCE goals.

This implementation plan calls for the establishment of a number of WOCE data centres. Data will become available from them at widely varying times. These times will be, in part, dependent on the internal priorities of individual national and multi-national projects in WOCE and partly on the nature of the specific data. The Data Information Unit, by maintaining effective contact with these centres and with national projects, will summarize and post in catalogues the progress of the data acquisition and analysis. It will also maintain a bibliography of WOCE related documents. The catalogues will be on-line and will indicate the simplest way of accessing the data.

(3) To maintain summaries of WOCE projects, and related projects including their aims, participating scientists, expected data types and volumes, and a bibliography of the experiment.

(4) To document the standards and procedures as agreed by the SSG and its working groups.

As in previous large field experiments (e.g. MODE, GATE, JASIN), during the course of the planning there will be recommendations on the preferred ways to carry out operations to achieve common and high standards in sampling and data processing. The prolonged duration of WOCE relative to past programmes implies that there will be a considerable evolution of agreements on the way to carry out the work. There will be a need for easily accessible statements of the up-to-date position.

(5) To disseminate intended cruise tracks and programmes well in advance the object being to permit maximum use of available ship time and to set up useful intercalibration studies between different groups.

(6) To set up and maintain a directory of WOCE participants, working groups, etc. including, for example, addresses, mailboxes, telephone numbers, in order to facilitate communications in WOCE.

3.8 Formats

The diversity of the data contributing to the WOCE data base demands that data sets be identifiable as to content and format in some systematic way on transmission to another scientist or data centre.

Some data sets may be so large as to exclude any option except the most efficient in terms of packing density. However, these should be explicitly identified as special cases and in general the Level II and III data for general use by WOCE should be exchanged in character form.

Important elements of the GF3 format system are

- It allows for the precise and easily readable description of the data, the number and type of which can be expanded or contracted to meet the specific requirements. This is particularly important, for example, when sending hydro/chemical data in which the number of parameters varies significantly from cruise to cruise.

- The data can be compressed very effectively, within the limitations of a character format, using scaling factors.

- Calibration data is conveniently transmitted as part of the record.

- Additional information pertinent to the circumstances of the data collection is encouraged in plain language records.

- The Format is well supported and is documented in IOC Manuals and Guides No.17 Vol.2 “Technical Description of the GF3 Format and Code Tables”, UNESCO 1987.

All WOCE data centres, therefore, exchange data as ASCII files (with the proviso below on large data sets) conforming in their general structure to the GF3 format developed by the Technical Committee on International Oceanographic Data Exchange of IOC.

Those who locate and acquire their data through downloading from an on-line data base will need to be aware of the record structure of that data base. General recommendations as to format may not be appropriate in this case, but guide-lines on necessary supporting inventory information to assist the recipient of the data should be part of the specifications for WOCE data centres.

For those acquiring or sending significant quantities of data, there is an extensive Fortran software package (GF3-Proc) that provides a convenient and automated conversion between a scientist’s own working formats and GF3. It is available on a number of operating systems. The package is fully described in “Users Guide to the GF3-Proc Software” which is Vol.4 of the above guide.

3.9 Data Management Committee

The SSG has established a Data Management Committee to be responsible for the overall planning and oversight of operations of the WOCE data management and exchange activities. This responsibility will be carried out in cooperation with all WOCE Working Groups and Planning Committees and other international organizations and scientific programmes such as IOC, WMO, JGOFS and TOGA. The Committee will promote the timely availability and distribution of WOCE data sets and products in accordance with the WOCE data sharing policy and advise the SSG on national offers to assume responsibility for individual components of the system.

3.10 Guide-lines for WOCE Data Assembly Centres (DAC)

A WOCE Data Assembly Centre will usually be established jointly between a **Research Institution** participating in WOCE and a **National Data Centre.** The sponsoring organizations of these institutions are expected to make a long-term commitment to the centre. Depending on the nature of the data and the needs of the programme, there may be more than one centre for a specific type of data.

The following guide-lines will be considered in evaluating proposals to create WOCE DACs.

(1) The data (in situ, remotely-sensed, or model) must be identified by the WOCE SSG as essential to WOCE objectives.

(2) The host country must be prepared to operate a centre for a minimum of 5 years.

(3) A Chief Scientist, active in using the data set for his research in WOCE, must be identified to supervise the activities of the WOCE DAC and maintain the quality of the data set over the life of WOCE.

(4) The role of the Chief Scientist within the DAC is to:

   (a) Be responsible for overall performance of the DAC;

   (b) Document and carry out objective and subjective quality control, to agreed WOCE procedures, of the collated data sets received;

   (c) Carry out scientific quality control of the data set;

(d) Provide Level II products on a regular basis for dissemination by the collaborating national data centre.

(5) The data set will usually arise from systematic sampling according to an accepted plan and standards, with calibrations clearly documented, of a parameter (e.g., sea level) or suite of parameters (e.g., vertical profiles of T, S, O_2) to a required accuracy established in this Plan.

(6) The role of the national data centre within the DAC is to:

(a) Carry out data tracking, collation, and limited objective quality control of the collated data set from the multiplicity of data sources constituting the data collection network;

(b) Transfer updated collated data sets to the Chief Scientist responsible for maintaining the quality control of the data sets and for producing Level II products;

(c) Receive the quality-controlled data set from the Chief Scientist on a regular and timely basis;

(d) Disseminate Level II and III products in a timely manner to WOCE scientists in accordance with the WOCE Data Sharing Policy;

(e) Establish catalogues and inventories;

(f) Deliver quality-controlled data sets and inventories to the World Data Centres for long-term storage and public dissemination;

(g) Develop as required, standards for formats, documentation, and disseminate these to WOCE investigators through the WOCE IPO/Data Information Unit.

3.11 Special Analysis Centres (SAC)

In accordance with the outline of their functions given in Section (3.4), SAC activities will be largely based in research groups taking part in WOCE, their data being drawn from the data assembly centres and historical archives and their products being passed to the WOCE data base for distribution.

The expectation is that several research groups will generate level III data sets which arise from the analysis and synthesis of multiple level II data sets and of models, and which will be of general interest and utility to other WOCE groups. The SACs are proposed as a formal mechanism by which WOCE identifies such data sets and encourages their distribution. Proposals for the establishment of SACs are expected to be made as outgrowths of specific research proposals and from SSG review of the experiment as it proceeds. Examples of such activities are level III sets of wind fields from satellite and in-situ data and from models; reference sea level derived from synthesis of multi-satellite altimeter and in-situ data and surface geostrophic and ageostrophic fields from analysis of scatterometer, altimeter and drifter data. As seen by the flow diagram Fig.(3.1) the creation of an SAC implies a commitment to place in the WOCE data base, in a timely way, well documented copies of their level III data products for distribution to other WOCE groups.

3.12 Requirements for DACs and SACs

Major data sets for which there will be WOCE DACs include:

- Hydrography and Tracers,
- Current Meters,
- Surface Drifters (current and flux measurement),
- Sub-surface Floats,
- In-situ sea level,
- Acoustic Doppler Current Profiler,
- Altimetry,

- Scatterometry,
- XBTs and XCTDs,
- Surface Meteorological Observations

When the need for a specific DAC is determined by a Planning Committee, (see Fig 1.2),it will be established using the guide-lines given in Section (3.10). Similar guide-lines will be used to evaluate offers to establish SACs.

Draft specifications for most of the DACs listed above are contained in the following sections. These will provide a baseline for individual groups which are considering the operation of a DAC for WOCE. Some elements of these specifications have not been fully defined and are therefore left blank.

3.13 Hydrographic Data Assembly Centre

1. General Statement of Functions:
The WHP DAC will monitor the functioning of the WHP Programme as regards its data quality, assemble and quality control the data of the WHP to the specifications established by the WHP and will maintain a data base of these parameters.

2. Participating Organizations:

The designated WHP Project Office will ensure timely delivery of high quality data from WHP ships and from shore-based analytical facilities. It will be supported by a dispersed group of Data Quality Experts knowledgeable on specific data types or regions.

A national data centre will be responsible for the assembly, maintenance, formatting to a common format, and distribution of the data base.

3. Period for which support committed:
Minimum 5 years.

4. Chief Scientist designated by the WHP Project Office and level of staffing:

5. Data Sources:
Primary and secondary data (calibrations, station and instrument descriptions) from WHP ships and research ships of national programmes using CTDs, Rosettes, and large volume samplers.

6. WOCE requirements on the data (precision, accuracy, space/time filtering...):
See Section (2.1) for detailed specifications.

7. Quality Control and Data Processing:
The DAC will have the principal task of ensuring that the data are achieving the quality standards set for the WHP. This task will be carried out by a dispersed group of data quality experts (volunteer or specifically funded) cooperating with the WHP Project Office who are scientists knowledgeable and interested in a specific data type or region. They will receive the on-board analyzed sample data. Their primary duty is to inform the Project Office quickly (2 weeks-l month) of serious problems of consistency or quality with a data set about which the originator should be informed. It may take longer to respond on some chemical data sets, in view of the nature of the analyses.

The DAC will attempt to ensure the intercalibration of WOCE data sets using a variety of means and sources.

The DAC will be responsible for assembling and merging into the data base, if appropriate, other hydrographic and tracer data sets collected in the WOCE time frame. The DAC will maintain the WOCE data base of hydrographic and chemical data and distribute it to Pls on request.

8. Data Base:
The data base will include profiled data at standard pressure intervals, all the sample analyses and calibration data, the “environmental” data of the station (date, time, corrected depth, etc), together with annotations on the station added at sea or by the DAC (for example data on methods, precision and accuracy).

The data analyzed on board from the rosettes should generally be available within 6 months of delivery to the DAC. The calibrated profiler data will usually be available one year after the cruise with prior rights to submission for publication remaining with the responsible Pls for the first 2 years after the cruise.

Requests for the data should be answerable by downloading or by tape or floppy disk. GF3-format structure is proposed for exchange as it conveniently includes calibration and annotation as well as expanding or contracting according to the number of parameters.

9. Data Products:
A WHP Special Analysis Centre will create specific data products arising from the WHP and will assimilate data from other components of the experiment. The SAC will work in close cooperation with the archiving facilities of the WHP-DAC.

10. Directory:
A directory will be maintained to allow easy tracking of data availability from WOCE cruises (without reference to the main data base). The directory will be available on-line and accessible over a network, through the DIU.

3.14 In-situ Sea-Level Data Assembly Centre for Altimetry (Rapid Delivery Mode)

1. General Statement of Functions:
To assemble hourly (or more frequent) sea-level and associated atmospheric pressure data from specified gauges for use in initial altimetry calibration (see Chapter 2.3, Set A).

2. Participating Organizations:

3. Period for which Support Committed:
January 1990 - A minimum of 5 years commencing in 1990.

4. Chief Scientist and Level of Staffing:

5. Data Sources:
The principal data sources will be island tide gauges fitted with transmitters for satellite relay to the centre. Others, critical to the immediate needs of satellite altimetry, will be included if the data can be delivered in the overall time frame. Present estimates are that 10 well distributed gauges world-wide will be sufficient.

6. WOCE Requirements on the Data:
The accuracy, relative to a local reference datum, should be 1 cm. The initial data should be free of significant aliasing from frequencies above the sampling frequency of not less than 1 c.p.h. Timing should be known to within 2 minutes.

7. Quality Control and Data Processing:

<u>Verification</u>:
Readability of the data will be checked within 15 days of transmission to the centre and, if there appear to be problems in the operation of the gauge, the appropriate authority and the WOCE IPO will both be notified.

<u>Calibration</u>:
Standard quality control checks will then be applied and any failure reported to the operator of the gauge who will if possible send corrected data to the centre within one month.

8. Data Base:

<u>Description</u>:
Sea level and air pressure at a minimum of hourly intervals with quality control flags.

<u>Accessibility:</u>
On-line via telephone link and as two-monthly-update tape.

<u>Timeliness</u>:
The need is to deliver the data within two months in a convenient form to those requiring the data for satellite altimeter calibration. The potential customers are a subset of the Pls for TOPEX/POSEIDON and ERS1. The data will also be delivered to the centre holding the comprehensive sea level set.

<u>Format</u>:
Tape format in GF3, on-line format to be developed.

9. Data Products:

10. Directory:

<u>Content</u>:
Station details - position and accuracy, levelling history, data received, data processed and available.

<u>Accessibility:</u>
Preferably on-line at data base, but otherwise at DIU.

11. Other Dependent WOCE Data Sets:
Altimetry.

3.15 In-situ Sea-Level Data Assembly Centre (Comprehensive Set)

1. General Statement of functions:
To assemble hourly (or more frequent) sea level and associated atmospheric pressure data from gauges specified in Section 2.3 (set B)

2. Participating Organizations:

3. Period for which support committed:
A minimum of 5 years commencing in 1990.

4. Chief Scientist and Level of Staffing:

5. Data Sources:
The principal data sources will be tide-gauges well exposed to the ocean that are a subset of the IOC's Global Sea-Level Observing System (GLOSS). A subset will come from the rapid delivery sea-level data centre (see 3.14). Additional data can come from deep-sea pressure gauges and inverted echo-sounders.

6. WOCE Requirements on the Data:
The accuracy of sea level, relative to a local reference datum, should be 1 cm and of air pressure 1 mb. The initial data should be free of significant aliasing from frequencies above the sampling frequency which should preferably be hourly. Timing should be known to within 2 minutes.

The local datum should be recoverable through a set of auxiliary and permanent bench-marks. Details of the datum, the method of its determination, and the installation should be documented at the centre.

7. Quality Control and Data Processing:

<u>Verification</u>:
Readability of the data will be checked within 15 days of transmission to the centre and the appropriate authority and the WOCE IPO notified if there appear to be problems in the operation of the gauge.

<u>Calibration</u>:
Standard quality control checks will be applied including:

- checking for spikes and physically unreasonable values;
- screening of residuals after removal of regular tidal variations as diagnostic for datum shifts and other errors;
- checking against adjacent stations for unusual signals.

Any failure will be reported to the operator of the gauge who will if possible send corrected data to the centre within one month.

8. Data Base:

<u>Description</u>:
Sea level and air pressure with quality control flags for each station. Both daily residuals and hourly data will be available.

<u>Accessibility:</u>
On-line and as six-monthly update tape.

Timeliness:
The need is to make the data available within 12-18 months to WOCE scientists.

Format:
Tape format in GF3, on-line format to be developed.

9. Data Products:
Summaries giving maps, details of gauge locations, filtering, summary statistics, and plots of low frequency variations.

10. Directory:

Content:
Station details including position and accuracy, levelling history, data received, data processed and available.

Accessibility:
On-line at data base otherwise at DIU.

11. Other immediately dependent WOCE data sets:
None

12. Archive:
Annually with PSMSL and at the end of the experiment with WDC after full checking and editing.

3.16 Acoustic Doppler Current Profiler Data Assembly Centre

Acoustic Doppler Current Profiler data has the potential to provide unique information in the study of the ocean surface layer and to provide a reference for the geostrophic field. However, as instrumental and processing techniques are far from standardized, it is not recommended that a central WOCE data base of ADCP data be established at this time. There is a strong need now for a referral centre.

1. General Statement of Functions:

   - maintain records of the characteristics of ADCPs in use during WOCE,
   - track the processing of data from these instruments,
   - develop and advise on operational and analytical techniques,
   - assemble as appropriate a WOCE data base of ADCP data.

2. Participating organizations:
   Should include, in addition to the operating centre, experienced Pls to advise the centre.

3. Period for which support committed:
   Minimum 5 years

4. Chief Scientist and Level of Staffing:
   Should include a panel of experienced Pls to advance the Centre.

5. Data Sources:
   Manufacturers and operators of ADCPs.

6. WOCE Requirements on the Data - (Precision, Accuracy, Filtering...)
   At this time precision and accuracy for WOCE are limited largely by the instrument performance and installation.

7. Quality Control and Data Processing:

8. Data Base:
   No central data base is proposed at this time but discussion at present suggests that a 10 km horizontal and 10 m vertical resolution would be appropriate for a Level III archive. This will be tempered by navigational accuracy and instrument performance. For the present, processed data sets should be retained in the originating laboratories.

9. Data product:
   Reports on methods for calibration, processing algorithms, instrument characteristics. Proposals for standardization. Bulletin board for “current awareness”.

10. Directory:
    Data base of each ADCP containing data series taken with instrument, location of tracks, quality control, format of data, location of data, state of quality control and processing, availability to others. As the data will be more dispersed than for some other data sets the directory activity of the centre assumes the greatest importance.

11. Other Immediately-dependent WOCE Data Sets:

12. Archive:
    A long term aim is the creation of a Level III archive.

3.17 Upper Ocean Thermal Data Assembly Centre

1. General Statement of Functions:
Assemble and quality control temperature data from XBTs and CTDs during the WOCE programme. Maintain a data base of these parameters in accordance with the principles given in this chapter and make the data base available to WOCE.

2. Participating Organizations:
Research groups active in WOCE will provide scientific quality control. To achieve maximum quality, it is proposed that there be one science group associated with the centre responsible for each of the Pacific, Atlantic, and Indian Oceans.

An established national oceanographic data centre to assist the research groups in the acquisition of the data, to maintain the data base and make it available to WOCE scientists.

Where possible, cooperation with TOGA in the assembly of upper ocean thermal data is desirable. Support of the TOGA programme in the tropical Pacific has been given by the Joint Environmental Data Centre (JEDA), a collaboration between the Scripps Institution of Oceanography and the US/NODC. Similar arrangements are required for WOCE globally.

3. Period for which support committed:
For a period of 10 years commencing in 1990.

4. Chief Scientist and Level of Staffing:
The Pls of the 3 participating research groups will operate as a ‘Chief Scientists Panel’ of that Data Assembly Centre.

5. Data Sources:
The initial data sets are those BATHY and TESAC messages transmitted by the IGOSS system over the WMO/GTS network. In addition, there are data from other operational systems. These are assembled by the national data centre and transmitted to the data research groups for quality control and the generation of products. At a later stage, hard copies of the data sets, which are more error-free, are assembled and replace the original IGOSS data sets. Some additional sources such as CTD data are also incorporated.

6. WOCE Requirements on the Data - (Precision, Accuracy, Space/time Filtering...):
See Section (2.6) for details.

7. Data processing:
The national data centre assembles and reformats the data to a common format and carries out initial quality control, identifies duplicate data and merges in the delayed mode data sets and transmits the data to the research group. The research groups carry out comparative studies with historical data sets, including the production of monthly anomaly plots, both for the use of the programme and as a help in identifying data quality problems. It is also able to report problems arising from data sparsity and recommend corrective action to WOCE.

8. Data Base:
Some delayed mode data sets in standard format could be made available, for urgent WOCE use, within a month of acquisition. It is not proposed that the real-time data sets be available prior to full scientific quality control. The full quality controlled level II data base will be updated at, typically, six month intervals.

9. Data Products:
Monthly data distribution and anomaly charts are generated as part of the quality control process. These should generally be available either as hard copy or as graphs on an on-line information base maintained by the Data Information Unit.

10. Directory:
At a minimum, a directory should be maintained and updated every 3 months with a list of track lines completed and a statement concerning quality control of each track.

3.18 Surface Drifter Data Assembly Centre

1. General Statement of Functions:
Assemble and quality control the time series of drifter tracks and associated data from the surface drifters launched during WOCE. Maintain a data base of these parameters in accordance with the principles given in this chapter and make the data base available to WOCE.

2. Participating Organizations:
A research group(s), active in the surface current drifter programme will provide the necessary specialist scientific oversight of the data assembly. The Marine Environmental Data Service (MEDS) of Canada, acting as the RNODC for drifting buoy data, will maintain the data base and make it available to WOCE scientists. The specific duties will be developed by the Surface Velocity Planning Committee of active participants in the drifter programme.

3. Period for which Support Committed:
For a period of 10 years commencing in 1990.

4. Chief Scientist and Level of Staffing:

5. Data Sources:
Drifter data, including location data, is initially transmitted to Service Argos which normally transmits the data on tape to Principal Investigators and places it on GTS. (Monthly back-up tapes from Argos will be provided by Argos to MEDS).

Additionally MEDS, in collaboration with the research groups, will maintain a record of all calibrations and buoy characteristics.

6. WOCE Requirements on the Data - (Precision, Accuracy, Space/time Filtering...):
See Section (2.4) for details.

7. Data processing:
It is anticipated that the basic quality control will be carried out by the research groups deploying the instruments. In particular the buoys specifically designed for current measurement require pre-determined hull and drogue shape corrections for drift to be applied prior to insertion in the WOCE data base. The MEDS, receiving data from GTS, can rapidly assess the performance of the drifters and routinely report to Principal Investigators potential problems. It will also maintain and update a WOCE data base as the data is received from collaborating research groups, incorporating the description of the buoy type and calibrations with the other data.

8. Data Base:

<u>Content</u>:
Drifter ID, time series of position and additional parameters if measured. Also, calibrations, Pls, and description of processing and of buoy characteristics.

<u>Timeliness</u>:
The data sets can be available in the DAC within a month after acquisition for access by other WOCE projects requiring them to support their own analyses. Early general release of the calibrated data by Pls is encouraged but as their analysis for the data cannot be complete until the end of the deployment programme their agreement MUST be obtained for publication, prior to the end of their programme, of conclusions primarily dependent on these data sets.

9. Data Products:
MEDS will produce monthly summary charts of the progress of the global drifter programme based on data transmitted over the GTS.

The Surface Velocity Planning Committee will recommend products to be produced that will provide the WOCE community with information on the progress of the experiment.

10. Other programmes needing early access to drifter data:
    Those drifters with thermistor chains will produce valuable input to the Upper Ocean Thermal Data Assembly Centre. The surface and air temperature and pressure may be required by meteorological centres.

11. Directory:
    A directory summarizing progress of each deployment will be available at the data centre and the WOCE Data Information Unit.

3.19 Sub-Surface Float Data Assembly Centre

1. General Statement of Functions:
   Assemble the time series of float tracks and associated data from the RAFOS, ALACE and SOFAR buoys launched in WOCE. Maintain a data base of these parameters in accordance with the principles given in this chapter and make the data base available to WOCE.

2. Participating Organizations:
   A research group, active in the subsurface float programme will provide the necessary specialist scientific oversight of the data assembly. A national oceanographic data centre will maintain the data base and make it available to WOCE scientists. The specific duties will be developed by the Float Programme Planning Committee.

3. Period for which support committed:
   For a period of 10 years commencing in 1990.

4. Chief Scientist and Level of Staffing:

5. Data Sources:
   ALACE and RAFOS data sets will come through Argos system to Principal Investigators. It is recommended that back-up tapes also be sent to the collaborating national data centre for retention until the analyzed quality controlled sets are sent to the Chief Scientist of the WOCE centre. These tapes would not be used outside the centre without the agreement of the Float Programme Planning Committee.

   SOFAR data sets will only come through the traditional Principal Investigator route after recovery of the receivers.

6. WOCE Requirements on the Data - (Precision, Accuracy, Space/time Filtering...):
   See Section (2.4) for details.

7. Data Processing:
   It is anticipated that the basic quality control will be done by the PI groups deploying the instruments and that the functions of the centre will be to ensure that there are no inconsistencies between data sets, that the data are uniformly formatted, and that the scientifically significant details of the individual deployments are included with the data set.

8. Data Base:

   <u>Content</u>:
   Float ID, nominal depth, time series of position and additional parameters if measured. Also, calibrations, Pls, and description of processing.

   <u>Timeliness</u>:
   The data sets should be available in the DAC one month after acquisition for access by other WOCE projects. Early general release of the data by Pls is encouraged but as their analysis of the data cannot be complete until the end of the deployment programme their agreement MUST be obtained for publication, prior to the end of their programme, of conclusions primarily dependent on these data sets.

9. Data Products:
   The Float Programme Planning Committee will recommend products to be produced that will provide the WOCE community with information of the progress of the experiment.

10. Directory:
    A directory summarizing progress of each deployment will be available at the data centre and WOCE Data Information Unit. It may contain for each float: the responsible PI, float type, nominal depth, launch data and approximate position and time of most recent sightings, updated monthly.

3.20 Moored Current Meter Data Assembly Centre

1. General Statement of Functions:
To assemble moored current records (and associated time series of pressure, temperature and salinity) collected as part of the WOCE programme together with important time series from non-WOCE sources.

2. Participating Organizations:
A data centre and research group with expertise in handling vector time series information.

3. Period of Commitment:
For a period of 7 years commencing 1990.

4. Chief Scientist and Level of Staffing:
Project leader plus 1.5 my/y (assuming infrastructure already exists).

5. Data Sources:
Data will come from participating WOCE laboratories and from other sources.

6. WOCE Requirements on the Data - (Precision, Accuracy, Filtering...):
See Section (2.5) for Details.

7. Quality Control and Data Processing:
Data will be calibrated, screened and checked by the originating laboratory and be accompanied by documentary evidence of the conditions under which the data were collected and the processing procedures to which the data have been subjected. All data will be further screened by the data centre to identify and eliminate remaining spurious observations, to reconcile timing information and to produce a data base of information in a standard format.

8. Data Base:
The data base will hold the time series of physical parameters measured together with time information, position (in three dimensions) and all relevant background information. The time series will be held in the basic form in which they are submitted but will also be held in a version standardised to a common sampling interval. In addition, a low passed (detided) version will also be held. The filter characteristics to be determined by the WOCE community. Data will be available to contributing laboratories and non-WOCE investigators in accordance with the WOCE data sharing policy (see Section 3.2). Data exchange via GF3 format - primarily on magnetic tape.

9. Data Products:
Initially only inventory type products will be produced but summary statistical information may be produced later.

10. Directory:
A data inventory will be produced which will be continuously updated and accessible via computer link. A hardcopy version will be distributed annually.

4. NUMERICAL MODELLING

The developing and testing of ocean models capable of predicting climate change is the central objective of WOCE (Goal 1). To predict climate change on decadal time scales, ocean models ultimately need to be coupled to atmospheric GCMs. To be a credible tool for this purpose, the models must be compatible with the observed elements of the global circulation, specifically with the observed temperature/salinity and tracer distributions and the surface fluxes of heat, fresh water and momentum.

It is customary and useful to distinguish between prognostic models on the one hand, and inverse or data assimilative models on the other. Prognostic models give in principle a complete dynamical description of the ocean circulation. They predict the evolution of the fields of temperature and salinity, as well as the circulation, from an initial state provided that the corresponding surface boundary fluxes are prescribed. The evolution of passive tracers can also be included as long as their initial state and surface fluxes are known. The main objective of inverse modelling is to determine the actual circulation state, including those variables which are not directly observed, and to determine model parameters by requiring compatibility of model results with observations. The improved parameters can later be used for predictive calculations.

Some of the scientific problems associated with these model classes are discussed in Volume II, Chapters 3, 4, 5 of this Implementation Plan. It should be realized, however, that ultimately the distinction between those concepts may become blurred, and that the same computer code may be used for either purpose.

4.1 Models Available for WOCE

4.1.1 Prognostic models

Prognostic modelling of the general circulation has proceeded along two distinct but complementary paths over the last decade. On the one hand there are models with active thermodynamics and moderate-to-high vertical resolution, but low horizontal resolution. These have been developed in an attempt to represent the large-scale hydrographic structure and climatic properties (the rates of water mass formation, heat and fresh water transports, sea surface temperature anomalies, etc) of individual ocean basins or the world ocean. In order to incorporate the full compliment of thermodynamic processes, these models have utilized the primitive equation system. This contains high frequency gravity wave modes and, thus, requires relatively short time steps during integration, even for low horizontal resolution. The strong dissipation required to maintain numerical stability in these low resolution models inhibit physical instabilities as well so that the only source of time variability in the solutions is time dependence in the atmospheric forcing. This class of models has been moderately successful in simulating the mean circulation and hydrographic structure of the world ocean, and very successful in predicting the variability of the circulation and upper ocean thermal structure in more limited areas, for example, the tropics, where the variability is predominantly wind forced.

On the other hand there are prognostic models with high horizontal resolution, but low vertical resolution. These have been developed in order to investigate the dynamics of time-dependent meso-scale eddies, and their interactions with the mean flow. This class of models has shown some success in representing the distribution of eddy kinetic energy and horizontal scales of the intense currents of the subtropical gyres. The majority of these calculations have been carried out using the quasi-geostrophic equation system that does not contain the high frequency gravity modes, and is hence much more economical to integrate than the primitive equation system. However, diabatic processes and realistic topography are difficult to incorporate in these models, and they are limited to non-global domains. For this reason quasi-geostrophic models will not play a dominant role during WOCE, although they can still be very useful tools for specific purposes.

The advent of the current generation of supercomputers has made feasible the convergence of these two modelling approaches. Simulations which include both a detailed representation of the thermodynamic processes responsible for water mass formation, and sufficient horizontal resolution to allow the physical instabilities responsible for active eddying, have recently become practical for basin-scale studies in idealized basins. However, the immense computational requirements (see below) have limited integration times to 10-20 years so that thermal equilibrium could not be achieved (and so far salinity has never been included as a state variable in EGCMs). Although it can be expected that this situation will significantly improve as the development of computer technology continues, it is unlikely that before the end of WOCE it will become practical to run eddy-resolving models on a global domain to thermohaline equilibrium.

While the role of eddies has been of most concern to many modelers, two other aspects of presently available models are also somewhat unsatisfactory:

(a) Parametrisation of subgrid-scale processes

While the conservation laws for heat, salt, momentum etc. follow from first principles, the theoretical basis for the parametrisation of unresolved processes is rather unsatisfactory. Empirical relationships for subgrid-scale fluxes inevitably are of limited validity. Crucial model variables can thus depend heavily on poorly known parameters (for example, the meridional heat flux on diapycnal mixing). Parametrisations for turbulent mixing and entrainment in the seasonal boundary layer will need improvement. In models which do not resolve eddies the eddy-induced fluxes of heat, salt and momentum obviously need to be correctly parameterised, specifically with regard to the dominant isopycnal direction of eddy heat and salt transport.

(b) Numerical formulation

Ideally, model results should depend only on the specified physical situation, and be insensitive to the numerical formulation (for example, isopycnal layers versus level coordinates, spectral versus finite difference techniques, numerical advection algorithms and explicit versus implicit schemes). Numerical accuracy is mainly limited by spatial resolution. An intercomparison of various coarse-resolution models (0(200 km) horizontally, 12 levels vertically) which was organized by the WOCE Numerical Experimentation Group has shown that the details of the numerical formulation can indeed be very important for certain aspects of the results. One can expect that this sensitivity will be significantly reduced as the spatial resolution of models increases.

4.1.2 Inverse Models and Data Assimilation

The main objective of inverse modelling is to determine the actual circulation state, including those variables which are not directly observed, to detect possible inconsistencies between model and observations, and to improve the determination of model parameters (for example, mixing coefficients). In principle, inverse models can also be used to aid experiment design, although in practice this aspect is usually achieved less formally. The following ingredients are essential for any inverse model:

(a) a set of dynamical principles (for example, thermal wind, conservation of heat, salt, potential vorticity), including an assessment of their accuracy. In contrast to prognostic models, the dynamical specification need not necessarily be complete;

(b) a set of data from observations (for example, hydrographic or tracer sections, surface topography from satellite altimetry), including an estimate of observational errors;

(c) a priori information (or prejudice), which comprises knowledge gained from previous experience, and which is essential to cope with the often underdetermined nature of inverse problems.

While some inverse models are formulated with respect to a particular data set (for example, in the model by Wunsch) velocities are defined only between station pairs, and beta-spiral methods only give local estimates), ultimately a representation on a regular grid or some equivalent is desirable. Inverse methods can produce such regularly gridded solutions; the major issues concern the computational load, and techniques are being explored for performing such inversions in computationally economical fashion. Formally, a solution to this problem can be obtained using the concept of adjoint equations or related optimisation procedures.

Comparatively new methods directed at systematic study of the sensitivity of time evolving models both to interior model parameters and initial conditions using adjoint systems have begun to be used in both meteorology and oceanography. Experiments with simplified circulation models have been encouraging. However, a rigourous application of these techniques to 3-D models involves many runs of a GCM, and it is not yet clear whether this will become feasible during WOCE. Although in a technical sense less optimal, data assimilation procedures as used in meteorology seem more appropriate for the incorporation of large data sets into models, especially for the analysis of satellite wind and altimeter data. Methods of data insertion into ocean models have been developed in the TOGA programme, and although the space-time scales in mid-latitudes are different, similar methods can be applied.

Diagnostic or robust diagnostic models constitute a more traditional approach for the incorporation of hydrographic data into circulation models, essentially by relaxing towards the observed temperature and salinity fields. Diagnostic models are easy to implement and inexpensive to run. Their main disadvantage as currently configured is that they violate heat and salt conservation, i.e those principles in which oceanographers have most confidence, while not allowing deviations from less well known momentum respective vorticity budgets.

4.2 Modelling and the Core Projects

4.2.1 Core Project 1

The most urgent requirement for Core Project 1 are the development of a global inverse model and of a data assimilation scheme focusse don the analysis of the data from the WOCE Hydrographic Programme. Specific models with limited dynamics which are based on a representation of variables along the observed sections are currently being developed (Schlitzer, pers comm.) . Ultimately, however, global GCMs have to be operated in an inverse mode: These methods are conceptually straightforward, but a number of practical questions must be solved to decrease the necessary amount of computing to acceptable levels. An effort coordinated by the WOCE Numerical Experimentation Group will focus on this problem and attempt to mobilize the expertise that exists in the international modelling community in this area. Another related effort is a global robust-diagnostic calculation with a free thermocline currently performed by A. Semtner, NPS Montere y (l/2 degree resolution, l/3 degree in progress for 20 levels. It is being written in a multi-tasked code for parallel computing).

The continuing development of prognostic circulation models for the global water mass distribution is also of high priority. Ideally, such models should be eddy-resolving. However, for many purposes integration to thermohaline equilibrium will be necessary, requiring integration times of a few thousand years. This is not feasible with present computing capabilities, and unlikely to become feasible before the end of the WOCE period. Hence the use of models which parameterised the effects of eddies must continue for the foreseeable time. Models that can describe water mass characteristics in sufficient detail require a very high resolution in the vertical. The currently most ambitious effort, that of M. Cox, GFDL Princeton, has a resolution of 1 degree globally and 44 vertical levels.

In conjunction with global prognostic circulation models, modelling of passive tracer distributions is required for two purposes:

(i) to diagnose those characteristic properties of GCMs (effective mixing, vertical transports) which are difficult to extract by a direct analysis due to the large spatial variability in vertical velocity fields, and

(ii) to detect model deficiencies through comparison of model results with observed tracer distributions (which, strictly speaking, is an objective of inverse modelling).

The most useful tracers are the time-dependent tracers CFCs and tritium/helium $^{3}H/^{3}He$ which contain information on ventilation in the main thermocline and in high latitudes, and ^{14}C which contains information about the deep-ocean circulation.

A reliable global circulation model is also needed as a basis for models of the oceanic carbon cycle. Modelling of the global carbon cycle is essential for the prediction of climate change on decadal time scales addressing the CO2 programme and supported in cooperation with the JGOFS programme.

4.2.2 Core Project 2

Modelling efforts related to Core Project 2 will focus on the dynamics of the Antarctic Circumpolar Current, the formation of water masses in the Southern Ocean, and the meridional fluxes of heat and fresh water into the different ocean basins. Except for specific models of sea ice, the same spectrum of models as in other areas of WOCE is available for these purposes, although addressing somewhat different dynamical regimes.

The Fine Resolution Antarctic ocean Model (FRAM) is a specific effort by a group of UK scientists which addresses several of these objectives. An eddy-resolving model of the Southern Ocean south of 25^o S which is based on the Cox/Bryan/Semtner-code is operated. A coarse-resolution version is first run to full thermohaline equilibrium, and from that equilibrium state the eddy-resolving version will be integrated for 0(20-40) years so that a dynamical (though not thermohaline) equilibrium is achieved. The project addresses a number of questions that are relevant for the role of the Southern Ocean for the global circulation, including

(a) what are the dominant dynamical balances in the circumpolar current (including its variability), and what controls the total volume transport?

(b) what is the role of eddies for the meridional fluxes of heat and fresh water? How much of these fluxes result from interaction with the atmosphere as compared to inter-basin fluxes?

(c) what controls the formation and maintenance of the frontal zones where characteristic water masses are being formed?

(d) how is the transport of Antarctic Bottom Water into the different deep ocean basins achieved?

Under the direction of a steering group of scientists, a core team is responsible for carrying out the main model runs and for providing the output in a suitable form. The computations are performed on the Rutherford Cray XMP. The output will be analyzed by a group of principal investigators, each of them responsible for a specific topic (for example, analysis of a physical process, geographical region etc.).

Although FRAM is a national UK project, international collaboration is encouraged through funds for senior visitors. While it is currently the major modelling activity related to Core Project 2, several other efforts which address specific aspects of the Southern Ocean circulation are planned or in progress. At the AWI, Bremerhaven, a coupled ocean-sea ice model is developed which focuses on water mass formation and its seasonal and interannual variability in the presence of sea ice. A quasi-geostrophic model of the Southern Ocean (horizontal resolution 20 km) is aimed at the dynamical balances of the ACC, specifically the role of eddies and the interaction with topography (form drag). A primitive equation EGCM with a l/6 degree resolution for 90^o of the circumpolar region (Drake Passage, Weddell Sea) is being developed to study eddy dynamics in a subdomain of the ACC.

4.2.3 Core Project 3

The focus of Core Project 3 modelling is on gyre-scale circulation models. Eddy-resolving models on this scale with full thermodynamics have just become feasible. The tremendous effort to operate and, especially, to analyse the results of such models requires close cooperation between different modelling groups. Various groups in the USA have recently started the ocean Community Modelling Effort (CME) in scientific collaboration with the Numerical Experimentation Group (NEG) with the aim of performing a series of numerical experiments. The objectives of the initial experiments are to critically evaluate the ability of existing ocean general circulation models to meet WOCE goals, to determine which aspects of the models are most in need of improvement, and to establish a framework for community cooperation in model development and analysis.

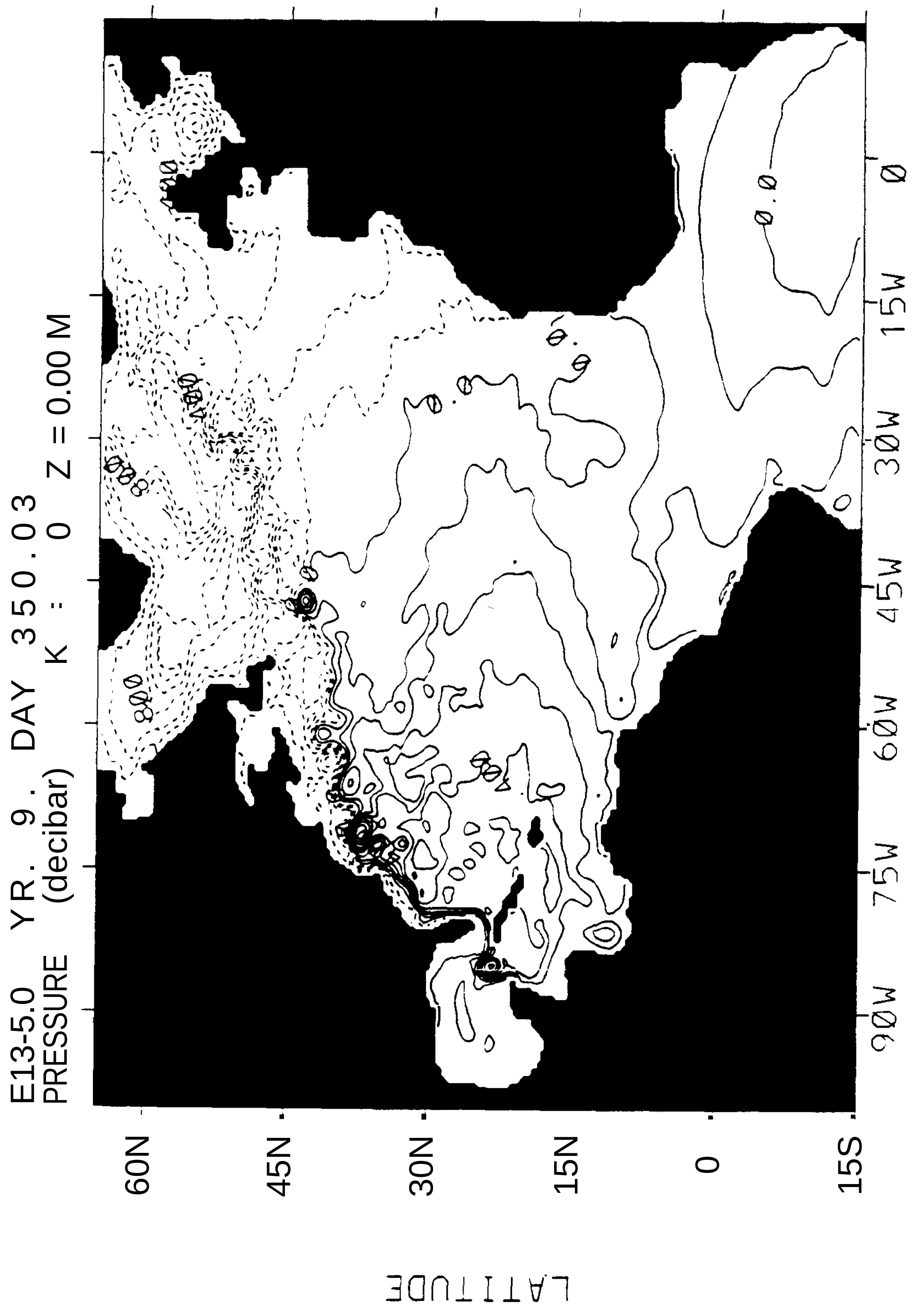


Fig.(4) Equivalent Surface Height (from rigid lid sea-surface pressure) near year 10 of the 25 year integration. Contour intervals 10 cm. Solid positive, dashed negative. Labels 0.0, 0.400, 0.800 in metres. (From Holland, Community Modelling Effort)

The first experiment of the Community Modelling Effort is a simulation of the North Atlantic basin with a focus on the subtropical and subpolar gyres. The experiment is being carried out at NCAR for both eddy-resolving and non-eddy-resolving horizontal resolutions and has the following specific scientific objectives:

1. to make a first estimate of the resolution dependence of the large scale features of the solution and its integrated quantities and to determine the minimum resolution requirements for meeting WOCE modelling objectives.

2. to estimate the sensitivity of the large-scale features of the solution to details of the surface forcing (drag coefficients, the form of the T-S boundary conditions, time scale of forcing variability).

3. to develop methods for, and to estimate the sensitivity of the solution to, the specification of mid-ocean open boundary conditions.

4. to attempt to determine the source of difficulty in the simulation of the overflows across the Greenland-Scotland ridge system and to develop methods to overcome these difficulties.

These experiments are carried out with the Bryan-Cox-Semtner primitive equation model. The basin includes the North Atlantic and Gulf of Mexico-Caribbean Sea complex from 15^o S to 65^o N. The effects of the Mediterranean Sea and the northern adjacent seas will be parameterised. The horizontal resolution is approximately 30 km at a latitude of 33.6 degrees. The vertical resolution varies from 35 m at the surface to 250 m at the bottom, with a total of 30 levels. An initial result of this calculation is given in Figure 4.

After completion of this first experiment, a second calculation with a similar configuration will be carried out at the Cray XMP of the University of Kiel. The focus will be on the influence of fluctuating forcing, specifically the wind forcing, on the influence of small-scale topographic features and on the sensitivity to certain parameters representing subgrid-scale processes. The exact configuration will depend on the results of the first experiment so that maximum information can be gained.

During WOCE there will be several other major modelling efforts such as FRAM or the CME for different regions of the World Ocean; for example, at the time of the preparation of this document plans in France for an eddy-resolving models of the South Atlantic (to be run on the Cray-2 in Paris) are well underway, and a very-high-resolution QG-model focussed on simulating float tracks and artificial tracer releases is presently running.

It is important to establish close cooperation among the various groups. In some cases, difficult problems yet to be overcome are common to all the regions that will be studied. Choices quite similar to those suggested above for the North Atlantic will have to be made in all these efforts. Thus, modellers must be able to learn from each other as the work progresses in order to achieve the most rapid model development. Coordination of all these efforts will make the whole more than the sum of the parts, and for processes on decadal time scales a World Ocean eddy-resolving model seems feasible within the WOCE period.

Inverse modelling related to Core Project 3 objectives will initially focus on the time variability of the circulation. Simplified quasi-geostrophic models for the incorporation of satellite altimeter data are currently being developed by various groups. Most approaches so far use assimilation procedures as developed for meteorological problems. The ultimate goal of these efforts is a model which permits a combination of different data types (altimeter, hydrographic/tracers, floats) in order to determine the circulation state and to constrain model parameters.

4.3 Resources for Modelling

4.3.1 Computer Requirements

The speed of computing has been the main limitation to progress in ocean circulation modelling. For a class-6 computer with 200 million operations per second, an eddy-resolving model like FRAM requires approximately 100 CPU-hours integration time per model year. To proceed with the integration for only 10 model years per calendar year therefore requires that approximately 20% of the total CPU time of the machine is spent on this project.

The total computing capacity available for ocean circulation modelling purposes in various countries is estimated very approximately to be (in % of one-processor Cray XMP, as of January 1988): US 150-200%, UK 40%, France 60% (from 1989 on), FR Germany 80-100%. In the past 3 decades, the maximum computing speed has increased by one order of magnitude roughly every 6 years. If this trend continues, global eddy-resolving integrations over 0(20-50) model years will become feasible during the field phase of WOCE. It is important that the ocean modelling community will have sufficient access to that increase in capacity. To fully utilize the capabilities of the upcoming generation of parallel computers, the development of multi-tasking code even for existing models is required.

Besides the excessive computing time, a huge amount of data handling and storage is required for eddy-resolving models. Typically, one magnetic tape is necessary to save the model status for a single time step for later analysis. For projects such as FRAM or the CME, this transforms into many hundreds of tapes per run as a minimum requirement. Optical discs or solid state storage devices can significantly facilitate data handling and exchange.

(b) Organization and manpower

Ocean modelling traditionally has been undertaken by small groups or individual scientists. However, the excessive requirements that arise during operation and analysis of large-scale models require coordinated group efforts. The operation of an eddy-resolving model needs a core team which is responsible for the day-to-day operation, archiving of results and preparing the software to access the results. The analysis normally will be performed at the same computer but not necessarily by the same group. The results must be accessible to other groups at different institutions for analysis. An efficient electronic communication system is therefore a necessary prerequisite.

The total number of scientists world-wide working actively with ocean circulation models is rather small. If the challenging problems of modelling in WOCE are to be solved successfully, the manpower of ocean modellers must be increased. A strong effort to entrain students and young scientists into the field is therefore necessary.

5. DETAILS OF THE OBSERVATIONAL PROGRAMME

This chapter gives details of the observational programme for WOCE. It is arranged in tables that uniquely identify in the first column the individual component, followed by a code - CP1, CP2 or CP3 - to indicate the appropriate Core Project for which the component has been requested. Keywords for its scientific justification, reference to a more extensive background in Volume II of the Implementation Plan, location, and constraints defined by time, space or programme requirements are also provided. This is followed by logistical details and, if applicable, information on the time frame. The right-most column in the tables is kept empty. It is there that contributions, or commitments will be entered once they have been identified.

Unless specific information is provided in the "Time Frame" column, it is assumed the item will occur within the five year WOCE Intensive Observation Period (IOP) but at a precise time yet to be determined.

The individual items in these tables have been coded to identify them in a unique way. The coding O.I.i describes in the

- first digit 'O' the Ocean Basins A for Atlantic, I for Indian, P for Pacific and S for Southern Ocean,
- the second group 'I' of up to three digits identifies the programme component, i.e.
  - 'blank' for the WOCE Hydrographic Programme,
  - R for Repeat Hydrography,
  - RS for Repeat Hydrography time series stations
  - X for XBT/XCTD lines of the Voluntary Observing Ship Programme,
  - D for drifters in regional studies, DG in the Global Programme,
  - F for floats in regional studies, FG in the Global Programme,
  - SF for surface flux moored buoys, SFG in the Global Programme,
  - SFD for surface flux drifters, SFDG in the Global Programme,
  - TS for thermistor/conductivity chains,
  - CM for current meter rigs.

These are followed by a third digit 'i' for continuous numbering.

Thus ACM1 would read Atlantic, Current-Meter rig No.1 and PR12 is Pacific, repeat Hydrography section No. 12.

The tables are divided, in analogy to Chapter 2, by technique. They are then further sub-divided into the four major ocean basins, the Atlantic, Indian, Pacific and Southern Ocean. Each technique is summarized in table form at the beginning of the relevant section giving the total WOCE requirements.

The following sections cover the requirements for:

5.1 Hydrographic Programme

5.2 Satellites

5.3 Sea-Level Measurements

5.4 Floats and Drifters

5.5 Moorings

5.6 Voluntary Observing Ship

5.1 Hydrographic Programme

WOCE HYDROGRAPHIC PROGRAMME

Summary

WHP (One-time Global Survey)

OCEAN	Length (nm)	SV Stations	LV Stations	Ship Days
Atlantic	66 353	2218	245	807
Indian	33 253	1112	123	402
Pacific	115 140	3872	410	1415
Southern	14 979	500	55	184
Global	229 725 nm	7702 stations	833 stations	2808 days at sea

= 10.4 ship years based on 270 days at sea/year

WHP (Repeat Hydrography)

OCEAN	Total Length (nm)	Total Stations	Total Ship Days
Atlantic	112 787	3152	839
Atlantic (Core 3)	80 045	800/1076*	703
Indian	12 079	406	91
Pacific	294105	9649	2189
Southern	20 654	694	210
Global	519 670 nm	800/14977* Stations	4032 Days at sea

= 15.0 ship years based on 270 days at sea/year

*(Full WHP Stations/CTD)

(GLO001) 6/7/88

ATLANTIC OCEAN-WHP

(Global One-Time Full-Depth Hydrographic/Tracer Survey)

Line	Length (nm)	SV Stations	LV Stations	Days
A1	1787	60	7	23
A2	2012	67	8	25
A3	3347	112	13	43
A4	3433	115	13	44
A5	3347	112	12	43
A6	2529	84	9	31
A7	2916	98	11	35
A8	2959	99	11	35
A9	3002	100	11	36
A10	3519	118	13	42
A11	3734	125	14	45
A12	(Southern Ocean section S2)			
A13	3476	116	13	41
A14	3949	132	14	42
A15	2099	70	8	26
A16	6230	208	22	75
A17	3390	113	12	43
A18	3906	130	14	47
A19	2916	98	11	35
A20	2572	86	10	32
A21	(Southern Ocean section S1)			
A22	1582	53	6	20
A23	3648	122	13	44
21 lines	66353 nm	2218 stations	245 stations	807 days

(GLO001)10/5/88

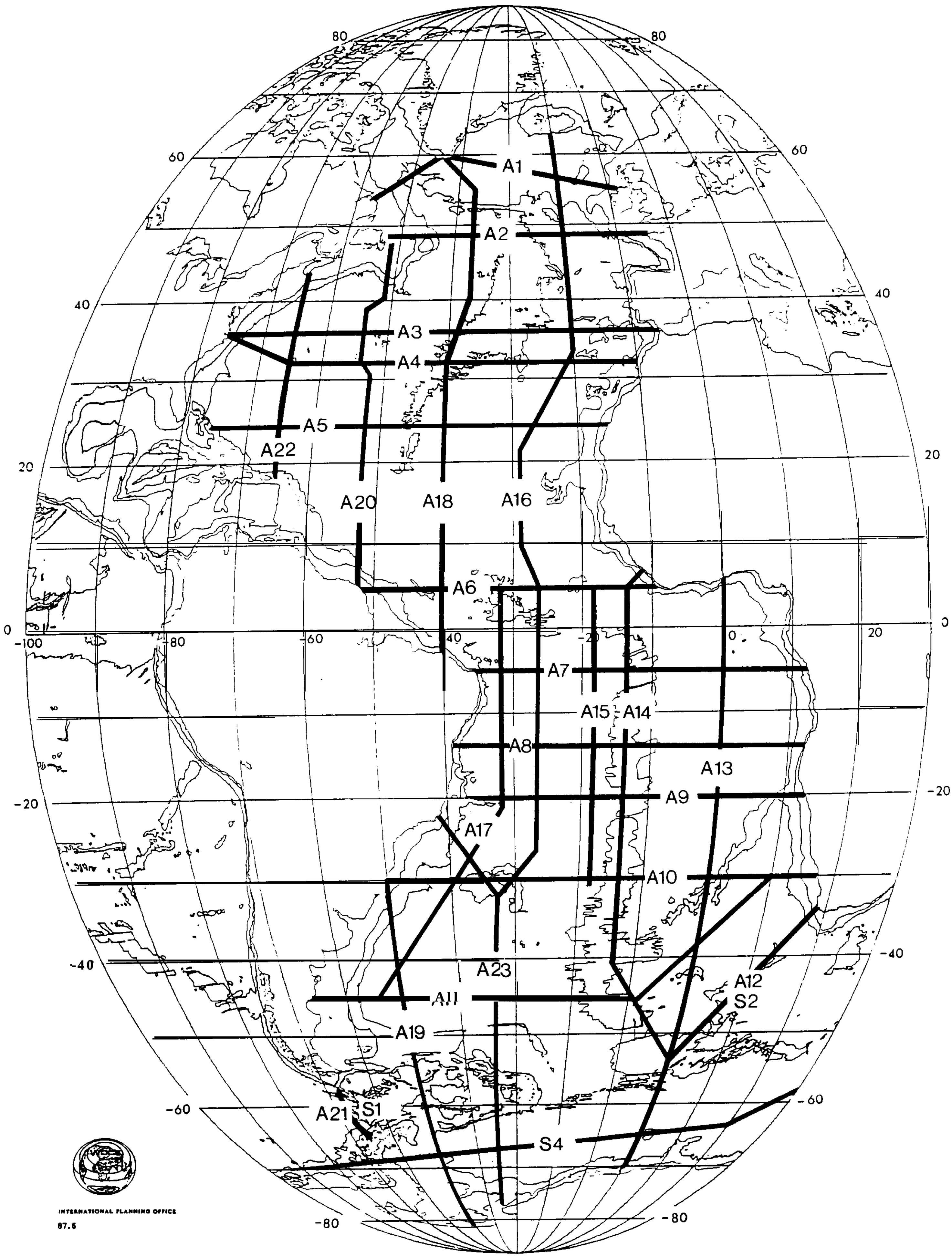


Figure 5.1 One-time WHP Survey of the Atlantic Ocean

PROJECT - WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Zonal) Atlantic

(ATL/001) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (VOL.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
A1/CP1	Measurement of waters entering and leaving Nordic Seas and Arctic Ocean. Cuts across northern parts of subpolar gyre.	3.4.1.2/3/4/5	57°N - Ireland/ Greenland/ Labrador	Care must be taken on slopes to map the deep boundary undercurrents found there. Repeat upper 1500m as,often as possible, partrcularly in winter or early spring to determine depth of winter mixing (AR7). Repeat for deep boundary currents for interannual changes (AR7). Mooring ACM 8.	Length = 1787nm No. SV STA = 60 No. LV STA = 7 Total Days = 23		
A2/CP1	Repeat of 1981 Long Lines, 1957 IGY Section. Measure Northward flow of North Atlantic Current and recirculation southwards in eastern basin. Measure equatonvard flows near western boundary.	3.4.1.2/3/4	48°N - English Channel to Newfound-land		Length = 2012nm No.SV STA = 67 No.LV STA = 8 Total Days = 25		
A3/CP1	Repeat of Long tines and IGY Sections. Cross Northern part of subtropical gyre. Comparison with earlier sections will show decadal changes in N. Atlantic water mass abundance.	3.4.1.2/3/4	36°N		Length = 3347nm No.SV STA = 112 No.LV STA = 13 Total Days = 43		
A4/CP1,3	Passes through centre of subtropical gyre.	3.4.1.2/3/4/5 5.3.2	32°N - Morocco/ Bermuda/ Hatteras	Morocco to Bermuda to be occupied once. Bermuda to Hatteras to be occupied seasonally as part of AR6.	Length = 3433nm No.SV STA = 115 No. LVSTA = 13 Total Days = 44		
A5/CP1	Repeats Long Lines and decadal IGY sections for variability. With current meters on either end to provide estimates of oceanic meridional HEAT FLUX.	3.4.1.2/3/4/5/9	24°N - Africa to Bahamas	Current meters at eastern and western boundaries. ACM 1 and 2. Repeat section AR1	Length = 3347nm No.SV STA = 112 No.LV STA = 12 Total Days = 43		
A6/CP1,3	Provide estimate of meridional flows into and out of equatorial region. Estimate of exchange into and out of Gulf of Guinea.	3.4.1.2/3/4 5.3.3 5.3.4	5°N - Africa to South America	Review status following further analysis of research may result in section being moved to 6° or 7°N to avoid Gulf of Guinea and Amazon Plumes. Common start point off coast of Africa with Section A14.	Length = 2529nm No.SV STA = 84 No.LV STA = 9 Total Days = 31		

PROJECT - **WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Zonal)** **Atlantic**

(ATL/001) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (VOL.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
A7/CP1,3	Similar to A6 Provide estimate of flows into and out of equatorial region.	3.4.1.2/3/4 5.3.3 5.3.4	4°S - Africa to South America	Coordinate with CP3 Deep Basin Experiment and Tropical Programme	Length = 2916nm No. SV STA = 98 No.LV STA = 11 Total Days = 35		
A8/CP1,3	Lower priority because of 1988 SAVE section in vicinity.	3.4.1.2/3/4 5.3.3	13°S - Africa to South America	Make assessment following review of results from 1988 SAVE section.	Length = 2959nm No.SC STA = 99 No.LV STA = 11 Total Days = 35		
A9/CP1,3	Crosses northern part of subtropical gyre. Provide estimate of mass, heat and salt transport in western boundary current.	3.4.1.2/3/4 5.3.3	20°S - Africa to South America		Length = 3002nm No. SV STA = 100 No.LV STA = 11 Total Days = 36		
A10/CP1,2,3	Crosses centre of subtropical gyre. Provide estimate of oceanic meridional HEAT FLUX in association with current meters on either end.	3.4.1.2/3/4/5/9 4.3.1.1 4.3.2.1 4.4.5 5.2.5.3 5.3.3	30°S - Africa to South America	Heat flux and current measurements by current meters at eastern and western boundaries ACM3 and 4. Repeat Sections AR2. Short sections from coast out to 4000m required every 14 days on both ends of line (CP2).	Len th = 3519nm No. S V STA = 118 No.LV STA = 13 Total Days = 42		
A11/CP1,2	With A10 provide estimates of meridional flows into and out of Atlantic basin.	3.4.1.2/3/4 4.3.1 1	45°S - South Am. to 45°S, 9°W to 30°S, 10°E	Coordinate with A10. Keep section west of Agulhas Retroflection to avoid contamination of mean mass, heat and salt transports.	Length = 3734nm No.SV STA=125 No.LV STA = 14 Total Days = 45		

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
A12/CP1,2	Just to west of Agulhas Retroflection. Provide estimate of net exchange from Indian to S. Atlantic Ocean associated with Agulhas Current. Crosses ACC and central segment of Weddell Gyre.	3.4.1.2/3/4 4.3.1.1.	33^oS 18^oE to 53^oS, 0^o and south along 0^o to 65^oS	Choke Point section S2. Section A13 (south of 53^oS) Compare to 1984 AJAX for study of time variability. Coordinate with CP2 ADCP measurements important.	Length = 2443nm* No. SV STA = 820* No. LV STA = 9* Total Days = 31*		
A13/CP1,2	Runs through centre of S. Atlantic eastern basin. Provide estimates of exchange of mass across Measure volume, heat and salinity flux from Indian to Atlanttc. Calculation of geostrophic shear and absolute velocity field.	3.4.1.2/3/4 4.3.1.1	0^o - Africa south to 65^oS	Overlaps section A12/S2 south of 53^oS, If A12/S2 and A13 are run closely in time, it will not be necessary to occupy stations twice. Stations close to Walvis Ridge must be carefully sited to estimate mass exchange.	Length = 3476nm No. SV STA= 116 No.LV STA = 13 Total Days = 41		
A14/CP1,2	Estimation of exchange in and out of Gulf of Guinea. Detect exchange of water masses across Mid-Atlantic Ridge.	3,4,1.2/3/4 4.3.1 .1	14^oW - Africa south to 40^oS to 53^oS, 0^o	Cross African shelf and slope orthogonally. Stations to be densely spaced across important rift zones of Mid-Atlantic Ridge. South of 30^oS is also section S2.	Length = 3949nm No. SV STA = 132 No.LV STA = 14 Total Days = 42		
A15/CP1,3	Map eastern end of Brazil Basin for CP3 abyssal circulation experiment.	3.4.1.2/3/4 5.3.3	19^oW - 5^oN to 30^oS		Length = 2099nm No. SV STA = 70 No.LV STA = 8 Total Days = 26		
A16/CP1,3	Repeat of 1981 Long Lines Section. Estimate exchange of deep water between eastern and western basins at equator and mid-Atlantic Ridge.	3.4.1.2/3/4 5.3.3	ca. 20^oW - Iceland to 32^oS, 32^oW	Stations to be densely spaced near equator and Mid-Atlantic Ridge.	Length = 6230nm No.SV STA = 208 No. LV STA = 22 Total Days = 75		
A17/CP1,3	Offshore of western boundary currents of subtropical and subpolar gyres. Close mass budgets of interior circulation of subtropical and subpolar gyres. Quantify western boundary currents.	3.4.1.2/3/4 5.3.3	5^oN, 32^oW south to 21^oS, 32^oW then to 45^oS, 54^oW	Adjust to pass through centre of deep channels or gaps between basins.	Length = 3390nm No. SV STA= 113 No.LV STA = 12 Total Days = 43 Five sections orthogonal to A17 south of 21_oS should be occupied into coast.		

*Not included in Atlantic Ocean totals

PROJECT - WHIR (Global One-Time Full-Depth Hydrographic/Tracer Survey - Meridional) **Atlantic**

(ATL/002) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
A18/CP1,3	Crosses Irminger Basin, Gibbs Fracture Zone, N. Atlantic Current, M-A Ridge. Measure flows in Irminger Basin, N. Atlantic Current, and across equator within western boundary current.	3.4.1.2/3/4/5 5.3.2	40°W - Greenland to Brazil	Decreased station spacing across the Oceanographer and Hayes Fracture Zones. Line south of 10°N is AR4. Line north of 33°N is AR5	Length = 3906nm No.SV STA = 130 No.LV STA = 14 Total Days = 47		
A19/CP1,2	Crosses Argentine Basin, ACC and into w. edge of Weddell Sea.	3.4.1.2/3/4 4.3.1.1	50°W - South Am. to Antarctica	Closer station spacing at region of complex topography and at ACC.	Length = 2916nm No.SV STA = 98 No.LV STA = 11 Total Days = 35		
A20/CP1	Follows 1981 Long Lines section. Crosses subtropical gyre away from fight recirculation region. Provides estimate of flow along S. Am. coast as it enters and exits equatorial region.	3.4.1.2/3/4	52°W - Grand Banks to South America	Avoid Corner Seamounts between 40° and 30°N.	Length = 2572 No.SV STA = 86 No.LV STA = 10 Total Days = 32		
A21/CP1,2	Crosses Drake Passage Extend time series measure-ments from ISOS programme (1975-81). Estimate flow through Passage.	3.4.1.2/3/4 4.3.1.1	64°W S. America to Antarctica	Also Choke Point Section S1. Should extend into Bransfield Strait.	Length = 679nm* No.SV STA = 23* No. LV STA = 4* Total Days = 9*		
A22/CP1	Crosses Gulf Stream and w. end of fight recirculation region.	3.4.1.2/3/4	65°W - Nova Scotia to Bermuda to Puerto Rico	Cross Nova Scotia slope orthogonally to avoid difficulty with strong tidal flows. Closer spacing required across Gul f Stream	Length = 1582nm No.SV STA = 53 No.LV STA = 6 Total Days = 20		
A23/CP1,2	Crosses ACC. Estimate of transport. Sample outflow of AABW in eastward flowing portion of Weddell G re. Measure c aracteristics of Pacific water into eastern Scotia Sea.	3.4.1.2/3/4 4.3.1.1	35°W - S. Am. to 32°S, 32°W southward to Antarctica	Dense stations near 30°S between Brazil and Argentine Basins and in regions of high topography between 50° and 60°S.	Length = 3648nm No.SV STA = 122 No.LV STA = 13 Total Days = 44		

*Not included in Atlantic Ocean Totals

ATLANTIC OCEAN-WHP
(Repeat Hydrographic Sections)

Line	Length	Stations	Days	Repeats/yr	Years	Total Repeats	Total Length	Total Stations	Total Days
AR1	3347	112	23	4	1	4	13388	448	92
AR2	3519	118	25	4	1	4	14079	472	100
AR3	1300	44	10	4	2	8	10400	352	80
AR4	750	25	10	4	1	4	3000	100	40
AR5	1750	59	15	4	1	4	7000	236	60
AR6	900	30	7	4	1	4	3600	120	28
AR7 (partial - East)	1238	42	10	3	5	15	18570	630	150
AR7 (partial - West)	550	18	5	1	5	5	2750	90	25
AR8	2700	48	18	4	2	8	21600	384	144
AR9	2300	40	15	4	2	8	18400	320	120
9 lines	18354 nm	536 stations	138 days				112787 nm	3152 Stations	839 Days

(Repeat Hydrography - Special Projects under Core Project 3)

Line	Length	Stations		Days	Repeats/yr	Years	Total Repeats	Total Length	Total Stations		Total Days
AR10 (full)	2400	40	(full)	21	4		4	9600	160	(full)	84
AR10	2340	78		18	4		4	9360	312		72
AR11 (full)	2400	40	(full)	21	4		4	9600	160	(full)	84
AR11	900	30		7	4		4	3600	120		28
AR12 (full)	2400	40	(full)	21	4		4	9600	160	(full)	84
AR13 (full)	2400	40	(full)	21	4		4	9600	160	(full)	84
AR13	1100	37		9	4		4	4400	148		36
AR14 (full)	2400	40	(full)	21	4		4	9600	160	(full)	84
AR15	7350	254		90	1			7350	254		90
AR16	1790	60		14	1			1790	60		14
AR17	5545	182		43	1			5545	182		43
	31025 nm	200	(full)	286 Days				80045 nm	800	(full)	703 Days
		641	(CTD)						1076	(CTD)	

N.B.
- partial: one-time section repeated in part
- complete: one-time section repeated complete
- full: full-depth requirement as compared to same section with depth-limited repeat

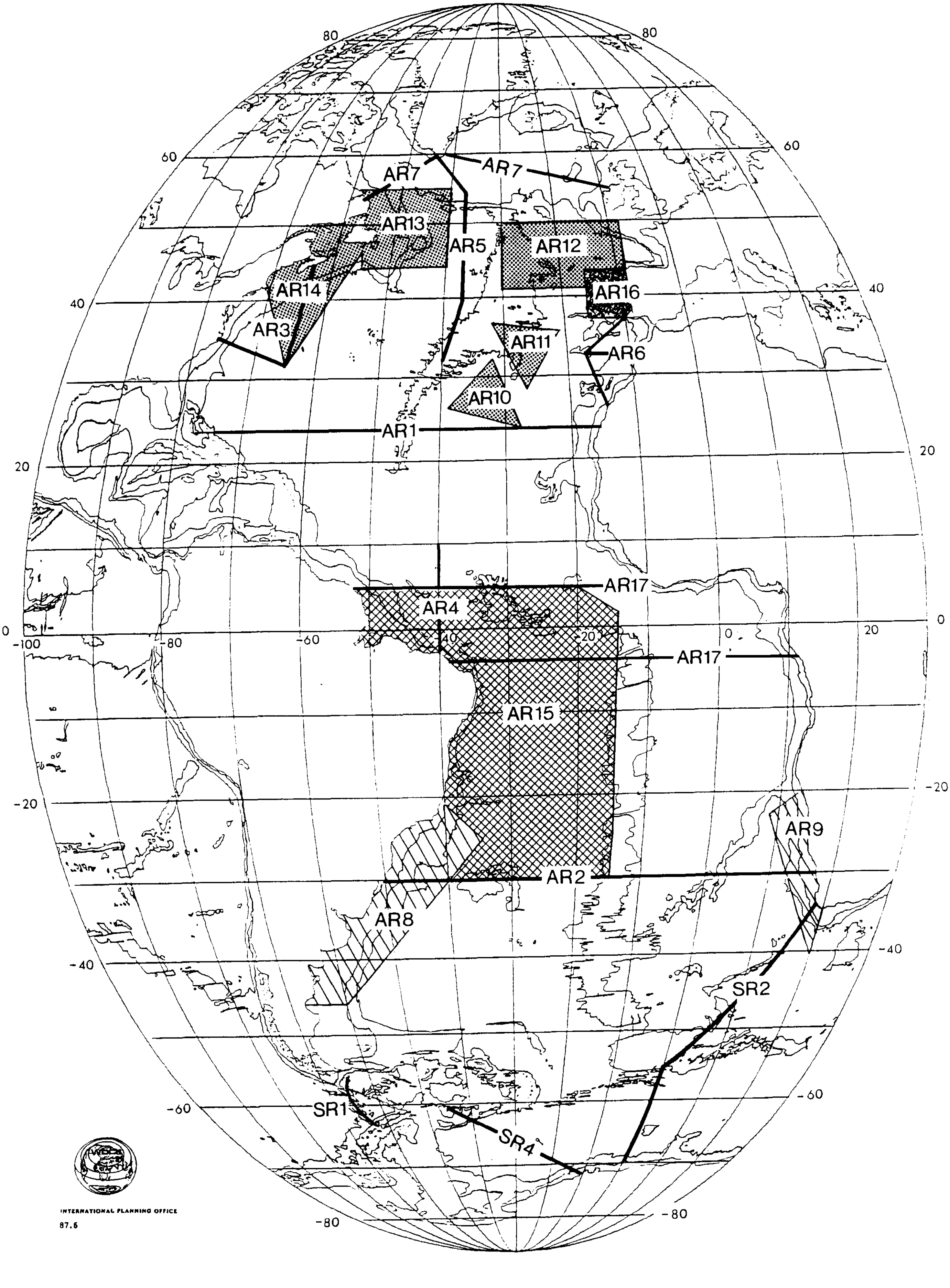


Figure 5.2 Repeat WHP Hydrography in the Atlantic Ocean

PROJECT - WHP (Repeat Hydrographic Sections)

Atlantic

(ATL/003) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AR1/CP1	Estimate of how heat flux associated with heating and cooling of upper layers varies over an annual cycle.	3.4.1.2/5/9	24°N Africa to Bahamas	On Heat Flux Section A5. Current meters ACM1 & 2 located at eastern and western boundaries. Sample at least to 1500m.	Length = 3347nm No. Stations = 112 Days/Section = 23 Repeats/year = 4 No. years = 1 Total Days = 92		
AR2/CP1,2,3	Estimate of how heat flux associated with heating and cooling of upper layers varies over an annual cycle.	3.4.1.2/5/9 4.3.1.1. 4.3.2.1 5.2.5.3	30°S Africa to South Am.	On Heat Flux Section A10. Current meters ACM3 & 4 located at eastern and western boundaries. Sample at least to 1500m. CP3 may give more stringent requirements.	Length = 3519nm No. Stations = 118 Days/Section = 25 Repeats/year = 4 No. years = 1 Total Days = 100		
AR3/CP1,3	Information on response of subtropical gyre to vari-ations in wind stress.	3.4.1.5 5.3.2	Cape Cod to Bermuda to Nova Scotia or Hatteras	CTDs to full depth if possible, occupy at least to 1500m and preferably to 2000m . Vessel to have ADCP. Full depth SV samples once/year, especially in regions of W. boundary under currents. See also AR14.	Length = 1300nm No. Stations = 44 Days/Section = 10 Repeats/year = 4 No. years = 2 Total Days = 80		
AR4/CP1,3	Estimate seasonal variability of N. boundary current. Variability of flow into and out of equatorial regions.	3.4.1.5 5.3.4	40°W 1 0°N to Brazil	Southern end of Section A18.	Length = 750nm No. Stations = 25 Days/Section = 10 Repeatslyear = 4 No. year = 1 Total Days = 40		
AR5/CP1.3	Estimate systematic changes in branches of N. Atlantic Current as function of season and wind stress.	3.4.1.5 5.3.2	40°W Greenland to 33°N	Northern end of Section A18. Sample at least upper 1500-2000m. Repeat late fall, late winter, mid-summer and repeat one season.	Length = 1750nm No. Stations = 59 Days/Section = 15 Repeats/year = 4 No. years = 1 Total Days = 60		
AR6/CP1,3	Seasonality of boundary currents and possible comparison to upwelling off NE Africa coast.	3.4.1.5 5.3.2	Morocco to Madeira to Lisbon or Canaries	Vessel to bee equipped with GPS and ADCP. Alternate return sections Madeira to Lisbon and Madeira to Canaries.	Length = 900nm No. Stations = 30 Days/Section = 7 Repeats/year = 4 No. years = 1 Total Days = 28		

PROJECT - WHP (Repeat Hydrographic Sections)

Atlantic

(ATL/003) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AR7/CP1,3 (Partial - East)	Estimate amounts and charac- teristics of various mode waters transformed during each successive cooling cycle. Estimate various overflows into Atlantic from the Nordic seas.	3.4.1.5 5.3.2	57°N Ireland to Greenland	Salinity measurements are vital. Observe to at least 2000m. Occupation to bottom, with small station spacing over ridges and slopes to estimate overflows.	Length = 1238nm No. Stations = 42 Days /Section = 10 Repeats/year = 3 No. years = 5 Total Days = 150		
AR7/CP1 (Partial - West))	Estimate amounts and charac- teristics of various mode waters transformed during each successive cooling cycle. Estimate various overflows into Atlantic from the Nordic seas.		57°N Greenland to Labrador	Repeat in late winter each winter or early spring.	Length = 550nm No. Stations = 18 Days/Section = 5 Repeats/year = 1 No. years = 5 Total Days = 25		
AR8/CP1,3	Study western boundary region. Enhanced measurements to define transport, especially at 30°S.	3.4.1.5 5.2.5.3	20°S to 45°S along S. American coast	Also need hydrographic sections and moorings. See ACM 3.	Series of sections from shelf into ocean at 5° lat. intervals 20°-45°S. Section = 200nm Total = 2700nm No. Stations = 48 Days/Repeat = 18 Repeats/year = 4 No. years = 2 Total Days = 144		
AR9/CP1,3	Study Benguela upwelling region along south western coast of Africa. Determine exchange of Indian Ocean water with S. Atlantic subtropical gyre, especially at 30°S.	3.4.1.5 5.2.5.3	20°-40°S	Need hydrographic sections and moorings. See ACM 4.	Series of sections From shelf into ocean at 5° lat. intervals 20°-40°S. Section = 200nm Total = 2300nm No. Stations = 40 Days/repeat = 15 Repeats/year = 4 No. years = 2 Total Days = 120		

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AR10/CP3	CONTROL VOLUME I continuation of "beta-triangle". Resolve changes in density field on seasonal/interannual time scales. Allow special averaging over the eddy field.	5.3.2 5.4.3.3	27°N, 32.5°W (C.V.I, Beta-Triangle)	Observe 40 stations to full WHP standards spaced every I00km (60nm) over an area of 800 x 1000km. Sample in late fall, late winter and mid-summer, repeat one season. Each repeat to include a section along 32° 30°W (A4) from 27°N to 5°N and along 27°N from 32° 30°W to Africa.	Length = 24 00nm No. Stations = 40 Days/Section = 21 No. Repeats = 4 Total Days = 84 Length = 2340 No. Stations = 78 Days/Section = 18 No. Repeats = 4 Total Days = 72 Total C.V.I = 156		
AR11/CP3	CONTROL VOLUME II In subduction region of N.A. subtropical gyre south of line of zero wind stress curl and is a more energetic area of meso-scale activity than C.V.I. Resolve changes in density field on seasonal/interannual time scales. Allow special averaging over the eddy field.	5.3.2 5.4.3.3	34°N 27.5°W (C.V.II, region Sub-duction)	Observe 40 stations to full WHP standards spaced every 100km (60nm) over an area of 800 x 1000km. Sample in late fall, late winter and mid-summer, repeat one season. The C.V. should be connected to the gyre boundaries by repeating section A4 from 27°N eastward to the shelf. Coordinated with section A18.	Length = 2400nm No. Stations = 40 Days/Section = 21 No. Repeats = 4 Total Days = 84 Length = 900 nm No. Stations = 30 Days/Section = 7 No. Repeats = 4 Total Days 28 Total C.V.II = 112		
AR12/CP3	CONTROL VOLUME III Study processes of moderately deep convection. Understand relationship of inter-gyre partition and exchange of changes in air-sea flux fields over the volume with time. Study structure of wintertime convection and springtime restratification and their relationship with atmospheric forcing and structure of upper ocean circulation. Resolve changes in density field on seasonal/interannual time scales. Allow special averaging over the eddy field.	5.3.2	42° to 50°N, 09° to 30°W (C.V.III, Northeast Atlantic)	Observe 40 stations to full WHP standards spaced every 100km (60nm) over an area of 800 x 1000km. Sample in late fall, late winter and mid-summer, repeat one season. Coordinate with detailed planning of sections A2 and A16. Repeat of A2 at time of AR12 needed.	Length = 2400nm No. Stations = 40 Days/Section = 21 No. Repeats = 4 Total Days = 84		

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AR13/CP3	CONTROL VOLUME IV Response of subpolar gyre to seasonal forcing; mixing of Arctic low-salinity water into open ocean and Labrador Sea Water Spreading.	5.3.2	46°N - 56°N 40°W - 55°W (C.V.IV, Southern Labrador Sea)	Observe 40 stations to full WHP standards along sections crossing major current systems and water boundaries. Sample in late fall, late winter and mid-summer, repeat one season. Repeat section AR7 and western half of A2. Coordinate with AF1 and ACM 6.	Length = 2400nm No. Stations = 40 Days/Section = 21 No. Repeats = 4 Total Days = 84 Length = 1100nm No. Stations = 33 Days/Section = 9 No. Repeats = 4 Total Days = 36 Total C.V.IV = 120		
AR14/CP3	CONTROL VOLUME V Study seasonality of strength tight recirculation gyres of subtropical circulation. Resolve changes in density field on seasonal/interannual time scales. Allow special averaging over the eddy field.	5.3.2	Cape Cod-Bermuda-Nova Scotia (C.V.V, Recirculation Regime)	C.V. is based on repeats of section AR3. Coordinate with on-going programmes monitoring and modelling the Gulf Stream downstream of Hatteras. Observe 40 stations to full WHP standards spaced every 100km (60nm) over an area of 800 x 1000km. Sample in late fall, late winter and mid-summer, repeat one season. See AR3.	Length = 2400nm No. Stations = 40 Days/Section = 21 No. Repeats = 4 Total Days = 84		
AR15/CP3	DEEP BASIN EXPERIMENT Discriminate between interior and boundary mixing processes. Define water masses in passages, western boundary currents and where there are cross-equatorial exchanges.	5.3.3	Brazil Basin (5°N to 30°S 15°W to S.A.)	A detailed hydrographic/tracer programmes in the region equalling 150% of the original CP1 WHP sampling is being designed.	Deep Basin Totals: Length = 7350nm No. Stations = 254 Total Days = 90		
AR16/CP3	EASTERN BOUNDARY CURRENTS	5.4.5	West of Iberian Peninsula	Together with Control Volume Experiment if feasible	Length = 1790nm No. Stations = 60 Total Days = 14		
AR17/CP3	TROPICAL PROGRAMME	5.3.4.3	5°N and 4°S sections. Note: These lines may be shifted towards 10° N, 8°S.	One repeat of sections A6 and A7. These sections may be observed using mixture of repeat hydrography, moored IESs, XBTs, etc. to meet WOCE objectives. The precise programme remains to be designed.	Length = 5545nm No. Stations = 182 Total Days = 43		

PROJECT - WHP (Hydrographic Time Series Stations)

Atlantic
(ATL/006) 3/6/88

Designation/ Core Project	Keywords/Justification	Reference (Vol. II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ARS1/CP1	Continue present series. Quantify variations in water mass properties.	3.4.1.5	Bermuda (Panulirus)	Continue tracer sampling		Continuous monthly until 2000	
ARS2/CP1	Continue present series. Quantify variations in water mass properties		Newfound-land (station 27)	Continue present series		Continuous monthly until 2000	
ARS3/CP1	Continue present series. Quantify variations in water mass properties		Ocean Station "Charlie"	Continue present series		Continuous monthly until 2000	
ARS4/CP1	Quantify variations in water mass properties.		Bahamas	New Station required		Ten year commitment from 1990	
ARS5/CP1	Quantify variations in water mass properties.		Barbados	New Station required		Ten year commitment from 1990	
ARS6/CP1	Quantify variations in water mass properties.		Madeira	New Station required		Ten year commitment from 1990	
ARS7/CP1	Quantify variations in water mass properties.		Cape Verde	New Station required		Ten year commitment from 1990	
ARS8/CP1	Quantify variations in water mass properties.		Canaries	New Station required		Ten year commitment from 1990	
ARS9/CP1	Quantify variations in water mass properties.		Azores	New Station required		Ten year commitment from 1990	
ARS10/CP1	Quantify variations in water mass properties.		W. of Ireland	New Station required		Ten year commitment from 1990	
ARS11/CP1	Quantify variations in water mass properties.		S. of Ireland	New Station required		Ten year commitment from 1990	
ARS12/CP1	Quantify variations in water mass properties.		Similar stations in S. Atlantic	Several new Stations required		Ten year commitment from 1990	

INDIAN OCEAN-WHP
(Global One-Time Full-Depth Hydrographic/Tracer Survey)

Lines	Length (nm)	SV Stations	LV Stations	Days
I1	2830	95	11	35
I2	3949	132	14	48
I3	3734	125	14	44
I4	593	20	3	8
I5	4423	148	16	54
I6	2228	75	9	25
I7	5972	199	21	72
I8	4767	159	17	58
I9	3820	127	14	46
I10	937	32	4	12
10 Lines	33253 nm	1112 Stations	123 Stations	402 Days

INDIAN OCEAN-WHP
(Repeat Hydrographic Sections)

Lines	Length (nm)	Stations	Days	Repeats	Total Days
IR1	2830	95	22	1	22
IR2	3949	132	31	1	31
IR3	2300	77	17	1	17
IR4	1000	34	7	1	7
IR5	2000	68	14	1	14
5 Lines	12079 nm	406 Stations	91 Days		91 Days

(Glo001) 4/7/88

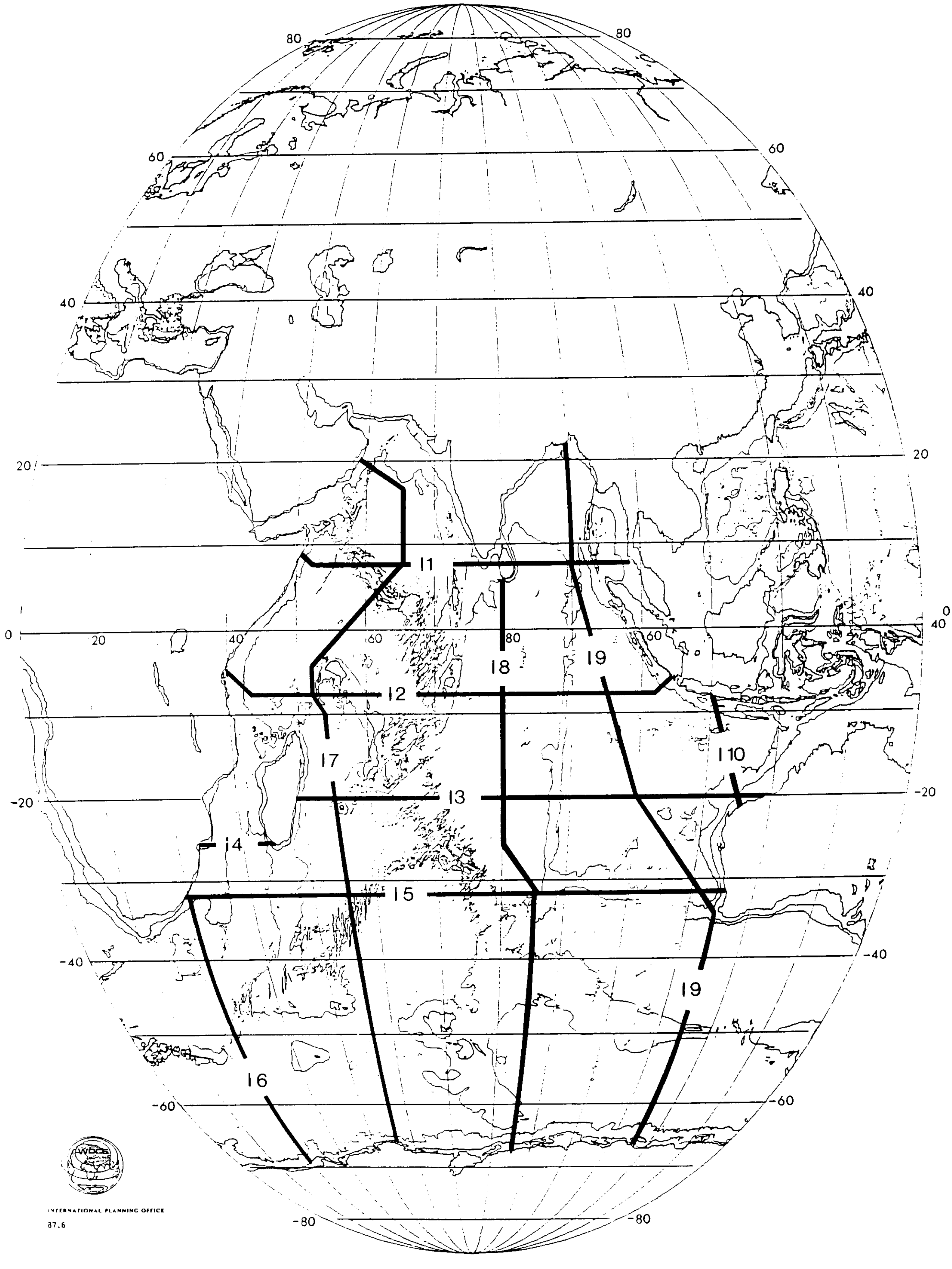


Figure 5.3 One-time WHP of the Indian Ocean

PROJECT- WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Zonal) Indian

(IND/001) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	**Responsible** Operator
I1/CP1	Closes Arabian Sea and Bay of Bengal, samples Somali Current where it is deep.	3.2.1/2 3.4.3.2	8°N	Occupy during extreme of monsoon. Repeat as IR1	Length = 2830nm No. SV STA = 95 No. LV STA = 11 Total Days = 35		
I2/CP1	Provide near equatorial meridional HEAT FLUX.	3.2.1/2 3.4.3.2	8°S Rising to 5°S at each end of line	Region of line is afflicted with variable meandering zonal currents. Occupy during extreme of monsoon. Repeat as IR2.	Length = 3949nm No. SV STA = 132 No. LV STA = 14 Total Days = 48		
I3/CP1	Samples subtropical gyre	3.2.1/2 3.4.3.2	20°S		Length = 3734nm No. SV STA = 125 No. LV STA = 14 Total Days = 44		
I4/CP1	Samples Mozambique Channel.	3.2.1/2 3.4.3.2	25°S between Africa and Madagascar		Length = 593nm No. SV STA = 20 No. LV STA = 3 Total Days = 8		
I5/CP1,2	Principal meridional HEAT FLUX section for the Indian Ocean.	3.2.1/2 3.4.3.2/9 4.3.1.1 4.3.2.1 4.4.5	32°S	Boundary current and heat flux measurements by ICM1 and 2. Short sections from coast out to 4000m required every 14 days on both ends of line (CP2).	Length = 4423nm No. SV STA = 148 No. LV STA = 16 Total Days = 54		

PROJECT- **WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Meridional)** **Indian**

(IND/002) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
I6/CP1,2	Measures structure of Agulhas, Agulhas Return and ACC currents. Comparison with ACC structure measured on line 17 will reveal alteration in filamentation induced by ACC/Topography interaction.	3.2.1/2 3.4.3.2/3/4/5 4.3.1.1	30°E Africa to Antarctica	Coordinate with section 17 Also Choke Point section for CP1.	Length = 2228nm No. SV STA = 75 No. LV STA = 9 Total Days = 25		
I7/CP1,2	Measures central Arabian Sea, west of Seychelles-Mauritius Plateau, Mascarona and Madagascar basins, then along 57°E to Antarctica.	3.2.1/2 3.4.3.2/3/4/5 4.3.1.1	55°E Arabia to Antarctica	Coordinate with CP2. Becomes CP2 section along 57°E south of 30°S. Northern segment to be repeated as IR3. Occupy during extreme of Monsoon.	Length = 5972nm No. SV STA = 199 No. LV STA = 21 Total Days = 72		
I8/CP1,2	Mid-ocean section across which HEAT AND FRESH WATER FLUXES will be measured.	3.2.1/2 3.4.3.2/3/4/5 4.3.1.1	80°E Sri Lanka-Antarctica At 25°S veer to 90°E south of 32°S	Coordinate with CP2. Becomes CP2 section along 90°E south of 30°S. Northern segment to be repeated as IR4. Occupy during extreme of Monsoon.	Length = 4767nm No. SV STA = 159 No. LV STA = 17 Total Days = 58		
I9/CP1,2	Samples eastern Bay of Bengal and eastern Indian Ocean boundary current system.	3.2.1/2 3.4.3.2/3/4/5 4.3.1.1	100°E Bay of Bengal to Australia to 115°E south of 35°S	Coordinate with CP2. Becomes CP2 section along 115°E south of 35°S. Northern segment to be repeated as IR5. Occupy during extreme of Monsoon.	Length = 3820 No. SV STA = 127 No. LV STA = 14 Total Days = 46		
I10/CP1	Closes off Pacific-Indian ocean throughflow regions.	3.2.1/2 3.4.3.2/3/4	110°E Java to Australia		Length = 937nm No. SV STA = 32 No. LV STA = 4 Total Days = 12		

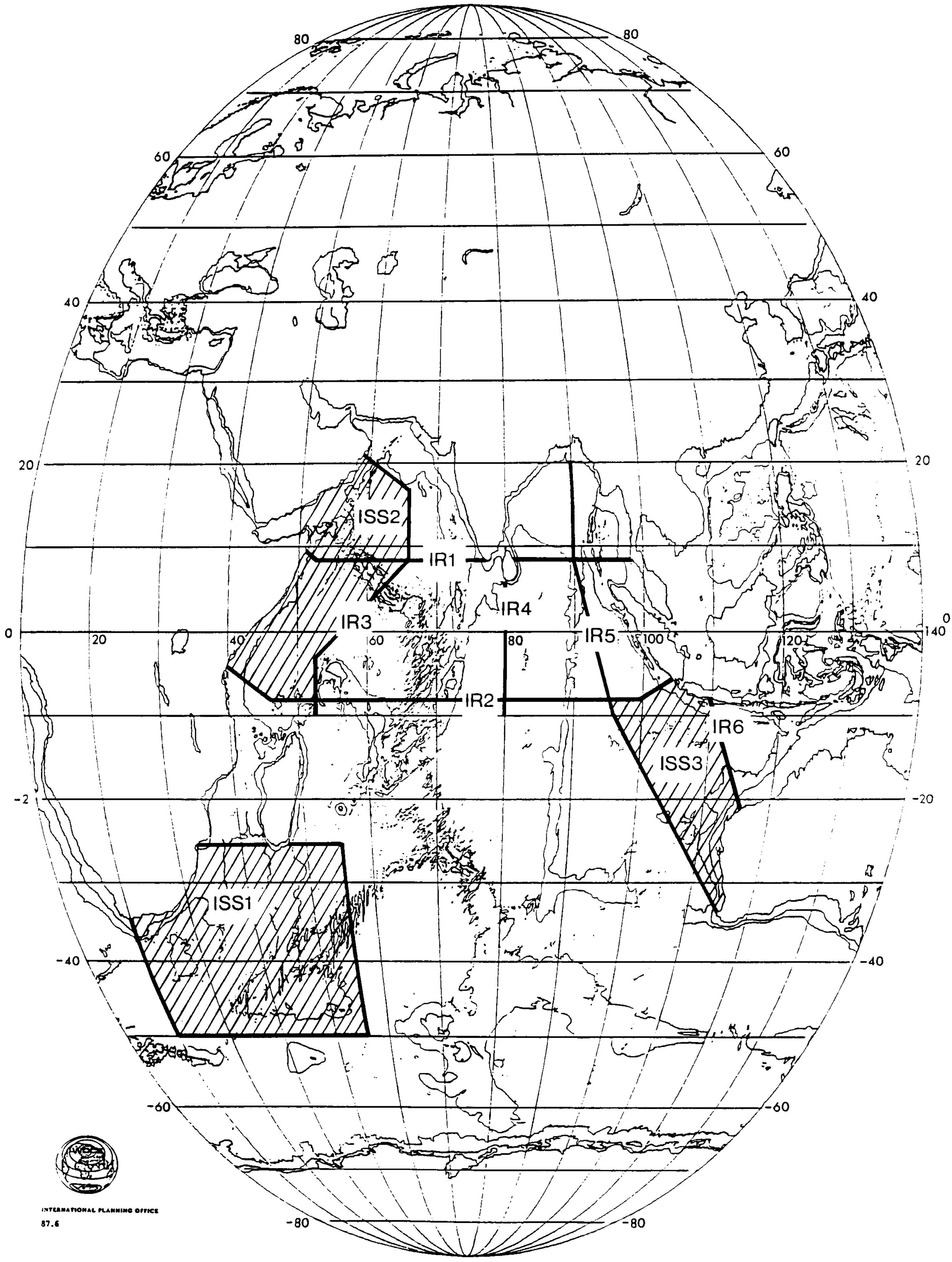


Fig. (5.4) Repeat Hydrography in the Indian Ocean

PROJECT - WHP (Repeat Hydrographic Sections)

Indian
(IND/003) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol. II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IR1/CP1	Seasonal variability of meridional fluxes within Arabian Sea and Bay of Bengal.	3.2.3 3.4.3.2/5	8°N	Occupy during extreme of winter or summer Monsoon. Repeat of Section I1.	Length = 2830nm No. Stations = 95 Days/section = 22 Repeats = 1 Total Days = 22		
IR2/CP1	Seasonal variability of near equatorial meridional heat flux.	3.2.3 3,4.3.2/5	8°S Shifting to 5°S at each end of line	Occupy during extreme of winter or summer Monsoon. Repeat of Section I2.	Length = 3949nm No. Stations = 132 Days/section = 31 Repeats = 1 Total Days = 31		
IR3/CP1	Seasonal variability of meridional fluxes within Arabian Sea.	3.4.3.2/5 3.2.3	55°E Arabia to 10°S	Occupy during extreme of winter or summer Monsoon. Northern portion of I7.	Length = 2300nm No. Stations = 77 Days/section =17 Repeats = 1 Total Days = 17		
IR4/CP1	Seasonal variability of meridional fluxes of heat and fresh water.	3.2.3 3.4.3.2/5	80°E Sri Lanka to 10°S	Occupy during extreme of winter or summer Monsoon. Northern portion of I8.	Length = 1000nm No. Stations = 34 Days/section = 7 Repeats = 1 Total Days = 7		
IR5/CP1	Seasonal variability of meridional fluxes of Bay of Bengal and eastern Indian Ocean.	3.2.3 3.4.3.2/5	100°E Bangladesh to 10°S	Occupy during extreme of winter or summer Monsoon Northern portion of I9.	Length = 2000nm No. Stations = 68 Days/section = 14 Repeats = 1 Total Days = 14		
IR6/CP1	Closes off Pacific-Indian ocean throughflow regions	3.2.1/2 3.4.3.2/3/4	110°E Java to Australia	Occupy during extreme of winter or summer Monsoon. Repeat of I10.	Length = 937nm No. SV STA = 32 No. LV STA = 4 Total Days = 12		

PROJECT - WHP (Special Survey Areas)

Indian

(IND/004) 817/88

Designation/ Core Project	Keywords/Justificaton	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ISS1/CP1	Thermocline ventilation and eddy/mean flow interaction in Agulhas recirculation gyre.	3.2.1/2 3.4.3.2	S.W. Indian Ocean, Agulhas Recirculation Regime		CTD, CM moorings floats.	Over 2 years	
ISS2/CP1	Arabian Sea gyre response to the monsoon onset including joint effects of: entrainment, advection of upwelled water and Ekman pumping in determining mixed layer depth and surface cooling.	3.2.1/2 3.4.3.2	N.W. Indian Ocean/ Arabian Sea, Somali current, Arabian Sea Regime		Air-sea flux measurements. CTD, ADCP, moorings	Over 2 years with inten sification during Monsoon onset.	
ISS3/CP1	Seasonal/interannual Pacific-Indian Ocean throughflow pathways and variability Water mass formation.	3.2.1/2 3.4.3.2	Eastern Indian Ocean, Indonesia to Australia		CTD sections, moorings.	Over 2 years	

PACIFIC OCEAN-WHP

(Global One-Time Full-Depth Hydrographic Survey)

Lines	Length (nm)	SV Stations	LV Stations	Days
P1	3519	117	13	42
P2	4939	164	17	59
P3	6660	222	23	80
P4	8812	294	30	108
P5	7525	251	26	93
P6	7134	238	25	86
P7	6101	203	21	73
P8	1927	64	7	23
P9	2228	74	8	27
P10	2486	83	9	29
P11	3218	107	11	39
P12	(Southern Ocean section S3)			
P13	6058	202	21	74
P14	7339	245	25	89
P15	8597	287	29	103
P16	8382	280	28	101
P17	7736	258	26	93
P18	5843	195	20	70
P19	5326	178	18	64
P20	1080	36	5	14
P21	5350	178	19	65
P22	780	26	4	10
P23	1800	60	7	22
P24	300	10	2	5
P25	600	20	3	9
P26	600	20	3	9
P27	300	10	2	5
P28	600	20	3	9
P29	300	10	2	5
P30	600	20	3	9
29 Lines	116,140 nm	3872 Stations	410 Stations	1415 Days

(Glo001) 10/5/88

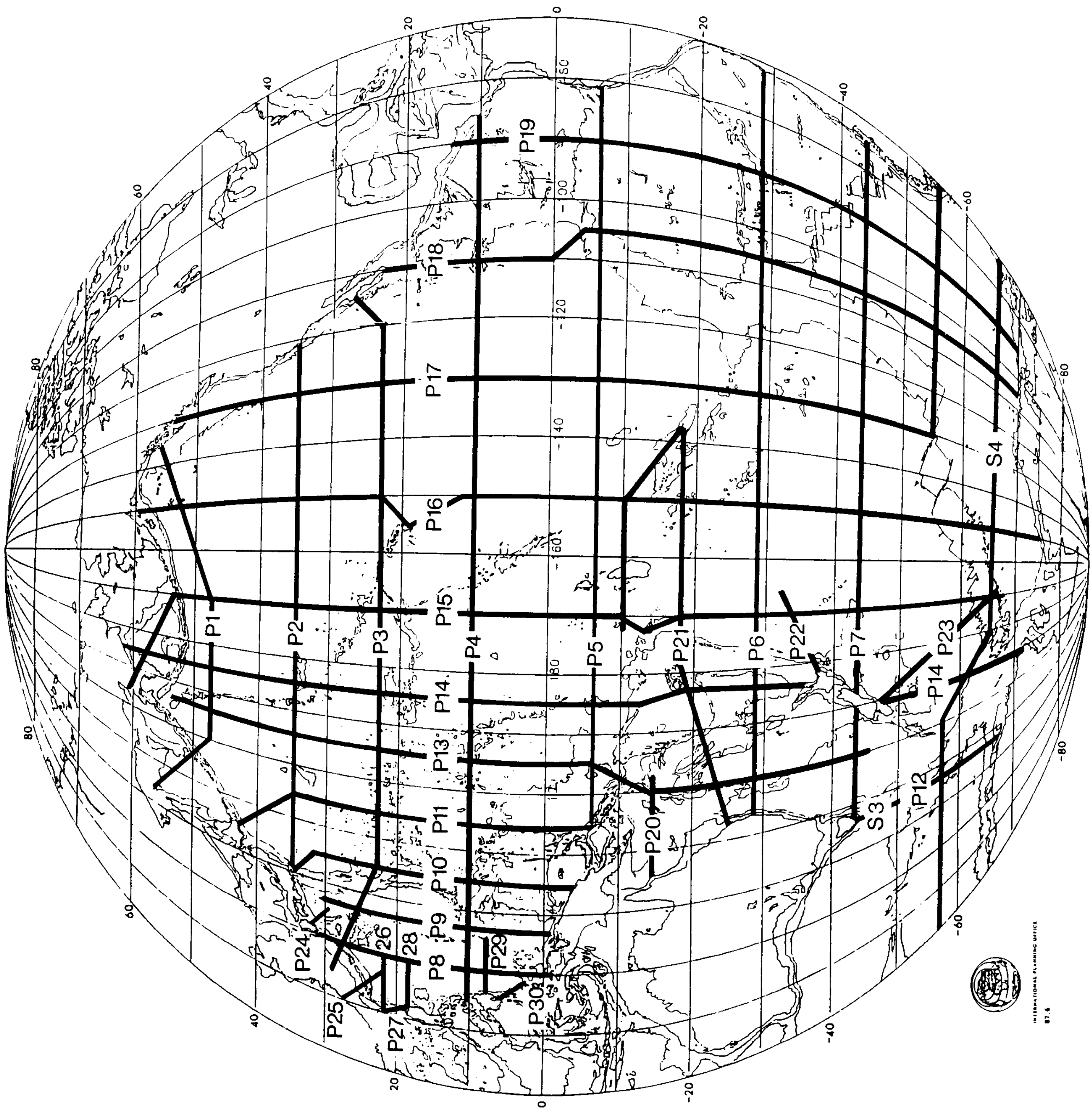


Figure 5.5 One-time WHP Survey of the Pacific Ocean

PROJECT- **WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Zonal)** **Pacific**

(PAC/004) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
P1/CP1	Measures undersampled central part of subpolar gyre	3.4.2.2/3/4	47°N Raising to 58°N on either end		Length = 3519nm No.SV STA = 117 No.LV STA = 13 Total Days = 42		
P2/CP1	Mapping - to avoid gap between central subtrop-ical and subpolar section	3.4.2.2/3/4	35°N		Length = 4939nm No.SV STA = 164 No. LV STA = 17 Total Days = 59		
P3/CP1	North Pacific Meridional HEAT FLUX section. Crosses Central sub-tropical gyre. Repeats 1985 section.	3.2.5 3.4.2.2/3/4/9	24°N	Boundary current and heat flux measurements by PCM1 and 2. Repeated hydrography from VOS. Western end of line repeated as PR 18.	Length = 6660nm No.SV STA = 222 No.LV STA = 23 Total days = 80		
P4/CP1	Between NEC and NECC. N. equator bracket for cross-equatorial transport estimates.	3.4.2.2/3/4	10°N		Length = 8812nm No.SV STA = 294 No.LV STA =30 Total Days = 108		
P5/CP1	S. equator bracket for cross-equatorial transport estimates	3.4.2.2/3/4	7°S	Important that direct measurements of shear in the upper ocean be made in addition to hydro-graphic measurements.	Length = 7525nm No.SV STA = 251 No.LV STA = 26 Total Days = 93		
P6/CP1,2	South Pacific Meridional HEAT FLUX section. Crosses Central sub-tropical gyre. Repeats 1967 SCORPIO section.	3.2.5 3.4.2.2/3/4/9 4.3.1.1 4.3.2.1 4.4.5	28°S	Repeat sampling of western end via PR11. Boundary current and heat flux measurements by PCM3 and 4. Short sections from coast out to 4000m required every 14 days on both ends of line (CP2).	Length = 7134nm No.SV STA = 238 No.LV STA = 25 Total Days = 86		
P7/CP1	Cross subtropical/gyre. Measure transport into Pacific. Southernmost section north of ACC. Repeats 1967 SCORPIO section.	3.4.2.2/3/4	43°S		Length = 6101 nm No.SV STA = 203 No.LV STA = 21 Total Days = 73		

PROJECT- WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Meridional) **Pacific**

(PAC/005) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
P8/CP1	Section has been occupied repeatedly. Samples western region of subtropical gyre and perturbed region north of Kuroshio Extension	3.4.2.2/314	130°E	Occupy once during WOCE following full specifications of WHP.	Length = 1927nm No.SV STA = 64 No.LV STA = 7 Total Days = 23		
P9/CP1	Section has been occupied repeatedly. Samples western region of subtropical gyre and perturbed region north of Kuroshio Extension.	3.4.2/3/4	137°E	Occupy once during WOCE following full specifications of WHP.	Length = 2228nm No.SV STA = 74 No.LV STA = 8 Total Days = 27		
P10/CP1	Section has been occupied repeatedly Samples western region of subtropical gyre and perturbed region north of Kuroshio Extension.	3.4.2.2/3/4	145°E	Occupy once during WOCE following full specifications of WHP.	Length = 2486nm No.SV STA = 83 No.LV STA = 9 Total Days = 29		
P11/CP1	Section has been Occupied repeatedly. Samples western region of subtropical gyre and perturbed region north of Kuroshio Extension.	3.4.2.2/3/4	155°E	Occupy once during WOCE following full specifications of WHP.	Length = 3218nm No.SV STA = 107 No.LV STA = 11 Total Days = 39		
P12/CP1,2	Grosses ACC. Choke Point Section Measure volume, heat, and salinity flux. Calculation of geostrophic shear and absolute velocity field.	3.4.2.2/3/4 3.4.2.5 4.3.1.1	146°E S. of Tasmania	Also section S3 To be repeated as SR3 and PR12. ADCP data are important along line.	Length = 1539nm° No.SV STA = 51° No.LV STA = 6° Total Days = 19° °Not included in Pacific Ocean totals		
P13/CP1	Westernmost section to include both N. & S. Pacific. Measure tropical circulation with equatorial portion of line.	3.4.2.2/3/4 3.1.5	165°E 160°E in S. Pacific	Repeat hydrography and moored measurements required from 10°N to 17°S (PR15).	Length = 6058nm No.SV STA = 202 No.LV STA = 21 Total Days = 74		
P14/CP1,2	Southern end of line PR13) crosses ACC. measure transport Alternate Choke Point section.	3.4.2.2/3/4 4.3.1.1	175°E 170°E S. of New Zealand	Eastward shift at line N. of Fiji might be located along Empress Seamount to measure flow through chain Repeated XBTsurveys south of Fiji to New Zealand.	Length = 7339nm No.SV STA = 245 No.LV STA = 25 Total Days = 89		

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
P15/CP1,2	Divides N. Pacific between regions of high energy to west and low energy to east.	3.4.2.2/3/4 4.3.1.1	170°W	Should extend into central Ross Sea.	Length = 8597nm No.SV STA = 287 No.LV STA = 29 Total Days = 103		
P16/CP1,2	Southern end of line has high priority for Core Project 2. Sample Ross Gyre.	3.4.2.2/3/4 4.7.1.1	150°W	Closely spaced stations required over mid-ocean ridge. Sea ice can be formidable even in austral summer on southern end.	Length = 8382nm No.SV STA = 280 No.LV STA = 28 Total Days = 101		
P17/CP1,2	Located in data poor regions. Zonal extension of line at 57°S samples deep flow in Bellingshausen Basin.	3.4.2.2/3/4 4.3.1.1	130°W South to 57°S, then east to Cape Horn	Southern portion of line also CP2 section.	Length = 7736nm No.SV STA = 258 No.LV STA = 26 Total Days = 93		
P18/CP1,2	Coincides with a heavily sampled TOGA XBT line at equator. Measure tropical circulation with equatorial portion of line.	3.4.2.2/3/4 3.1.5 4.3.1.1	110°W to N. of Eq. 105°W to S. of Eq.	TOGA XBT Programme. Repeat sampling from 5°N to 15°S (PR16) Southern portion of line also CP2 section.	Length = 5843nm No.SV STA = 195 No.LV STA = 20 Total Days = 70		
P19/CP1,2	Only meridional section crossing deepest parts of basins east of East Pacific Rise.	3.4.2.2/3/4 4.3.1.1	90°W	Southern end of line high priority for CP2 section	Length = 5326nm No.SV STA = 178 No.LV STA = 18 Total Days = 64		

PROJECT- WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey - Special) **Pacific**

(PAC/001) 3/6/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
P20/CP1	Samples the Coral Sea. Repeats western boundary segment at 1987 trans-Pacific section.	3.4.2.2/3/4	15°S Australia to 165°E		Length = 1080nm No.SV STA = 36 No.LV STA = 5 Total Days = 14		
P21/CP1	Closes off northern end of Tasman Sea and samples west Fiji Basin, and deep flow through Samoa Passage and Penrhyn Basin. The Fiji-Tahiti segment samples N. end of SW Pacific Basin and abyssal flow from the South.	3.4.2.2/3/4	Australia at 24°S to Fiji, Tahiti, 10°S, 162°W and westward to 175°W		Length = 5350nm No.SV STA = 178 No.LV STA = 19 Total Days = 65		
P22/CP1	Samples deep western boundary flow over Chatham Rise	3.4.2.2/3/4	East Cape NZ to 33°S, 168°W		Length = 780nm No.SV STA = 26 No.LV STA = 4 Total days = 10		
P23/CP1	Samples Campbell Plateau and southern arm of the S.W. Pacific Basin	3.4.2.2/3/4	South Is. NZ to 64°S, 168°W		Length = 1800nm No.SV STA = 60 No.LV STA = 7 Total days = 22		
P24/CP1	Sample Kuroshio	3.4.2.2/3/4	Kyushu SW across Kuroshio	To be repeated as PR17.	Length = 300nm SNo.SV STA = 10 No.LV STA = 2 Total days = 5		
P25/CP1	Sample East China Sea.	3.4.2.2/3/4	China to Ryukyu Islands	To be repeated as PR19.	Length = 600nm No.SV STA = 20 No.LV STA = 3 Total days = 9		
P26/CP1	Sample Mindanao Current.	3.4.2.2/3/4	22°N from Taiwan to 130°E	To be repeated as PR20.	Length = 600nm No.SV STA = 20 No.LV STA = 3 Total days = 9		
P27/CP1	Estimate flow through Bassii Strait.	3.4.2.2/3/4	Taiwan to Luzon	To be, repeated as PR21.	Length = 300nm No.SV STA = 10 No.LV STA = 2 Total Days = 5		
P28/CP1	Sample Kuroshio.	3.4.2.2/3/4	18°N from Luzon to 130°E	To be repeated as PR22.	Length = 600nm No.SV STA = 20 No.LV STA = 3 Total days = 9		
P29/CP1	Sample Mindanao Current.	3.4.2.2/3/4	7.5°N from Mindanao to 130°E	To be repeated as PR23.	Length = 300nm No.SV STA = 10 No.LV STA = 2 Total days = 5		
P30/CP1	Estimate flow into Indonesian Archipelago.	3.4.2.2/3/4	Mindanao SE to Indonesia	To be repeated as PR24.	Length = 600nm No.SV STA = 20 No.LV STA = 3 Total Days = 9		

PACIFIC OCEAN-WHP
(Hydrographic Time Series from Research Vessels-Sections)

Lines	Length (nm)	Stations	Days	Repeats/yr	Years	Total Repeats	Total Length	Total Stations	Total Days
PR1	1927	64	15	1	5	5	9635	320	75
PR2	2228	74	18	2	5	10	22280	740	180
PR3	2846	83	20	1	5	5	14230	415	100
PR4	3218	107	25	1	5	5	16090	535	125
PR5-6	1050	35	8	4	5	20	21000	700	160
PR7-8	1350	45	11	4	5	20	27000	900	220
PR9-10	3000	100	23	2	5	20	60000	2000	230
PR1 1	1400	47	11	4	5	20	28000	940	220
PR12	(Southern Ocean section SR3)								
PR13	2394	80	19	1	5	5	11970	400	95
PR14	1900	64	14	4/1	5	8	15200	512	112
PR15	1800	61	18	2	5	10	18000	610	180
PR16	1200	21	6	2	5	10	12000	210	60
PR17	300	11	3	4	5	5	1500	55	60
PR18	600	21	6	4/2	5	12	7200	252	72
PR19	600	21	6	2	5	10	6000	210	60
PR20	600	21	6	2	5	10	6000	210	60
PR21	300	11	3	2	5	10	3000	110	30
PR22	600	21	6	2	5	10	6000	210	60
PR23	300	11	3	2	5	10	3000	110	30
PR24	600	21	6	2	5	10	6000	210	60

24 lines 28,213 nm 919 Stations 227 Days 294,105 nm 9649 Stations 2189 Days

(glo001) 10/5/88

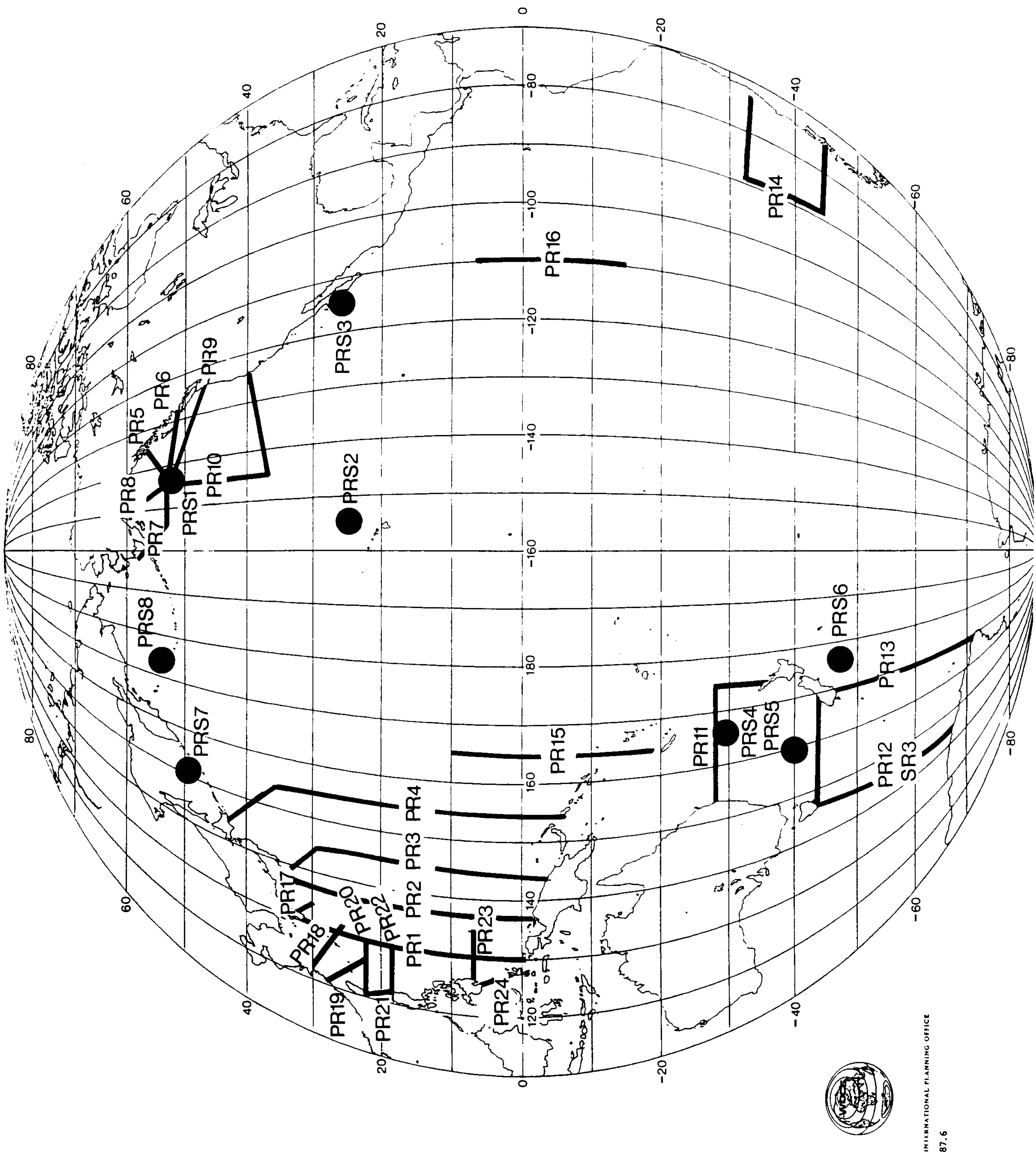


Figure 5.6 Repeat WHP in the Pacific Ocean

PROJECT-WHP (Repeat Hydrographic Sections)

Pacific
(PAC/003) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PR1/CP1	Continuation of long term measurements. Samples energetic western tropical gyre and western tropical Pacific.	3.4.2.5	130°E	Core Project 1 line P8 Repeat throughout WOCE.	Length = 1927nm No. Stations = 64 Days/Section 15 Repeat/Year 1 No. of Years 5 Total Days = 75	WOCE IOP	
PR2/CP1	Continuation of long term measurements. Samples energetic western tropical gyre and western tropical Pacific.	3.4.2.5	137°E	Core Project 1 line P9	Length = 2228nm No. Stations = 74 Days/Section = 18 Repeat/Year = 2 No. of Years = 5 Total Days = 180		
PR3/CP1	Continuation of long term measurements. Samples energetic western tropical gyre and western tropical Pacific.	3.4.2.5	144°E	Core Project 1 line P1O	Length = 2486nm No. Stations = 83 Days/Section = 20 Repeat/Year = 1 No. of Years = 5 Total Days = 100		
PR4/CP1	Continuation of long term measurements. Samples energetic western tropical gyre and western tropical Pacific.	3.4.2.5	155°E	Core Project 1 line P11	Length = 3218nm No. Stations = 107 Days/Section = 25 Repeat/Year = 1 No. of Years = 5 Total Days = 125		
PR5-6/CP1	Have been run for many years. Provide information on variability of subpolar gyre and westward propagation of events from coast.	3.4.2.5	Canada to OWS Papa		Length = 1050nm No. Stations = 35 Days/Section = 8 Repeat/Year = 4 No. Years = 5 Total Days = 160		
PR7-8/CP1	Recently begun. Provide monitoring of Alaska current and sub-polar gyre.	3.4.2.5	Alaska to OWS Papa		Length = 1350nm No. Stations = 45 Days/Section = 11 Repeat/Year = 4 No. Years = 5 Total Days = 220		
PR9-10/CP1	Provide subtropical bounds on region of bifurcation.	3.4.2.5	USA to OWS Papa		Length = 3000nm No. Stations = 100 Days/Sections = 23 Repeat/Year = 2 No. Years = 5 Total Days = 230		
PR11/CP1	EAC eddies are same as mean current. Need to define EAC and access its contribution to subtropical gyre circulation.	3.4.2.5 3.4.2.2/3/4	28°S from Australia to 178°E South to NZ	Necessary part of transport estimates of South Pacific Heat Flux section P6.	Length = 1400nm No. Stations = 47 Days/Section = 11 Repeat/Year = 4 No. of Years = 5 Total Days = 220		

PROJECT- WHP (Repeat Hydrographic Sections) **Pacific**

(PAC/003) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol. II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PR12/CP1,2	Monitor flow south of Australia from Indian to Pacific Oceans. Primary transport section. Flow from section combined with measurements from Indonesian Archipelago will be compared with Drake Passage flow to produce net inter-ocean transport estimates.	3.4.2.5 4.3.1.1 3.4.2.2/3/4	Tasmania to Antarctica	Coordinate with CP2. Choke Point section S3. Also section P12. At least one repeat should occur during austral winter.	Length = 1539nm* No. Stations = 51* Days/Section = 12* Repeat/Year = 1* No. of years = 5* Total Days = 60* *Not included in Pacific Ocean Totals		
PR13/CP1,2	Alternative to line PR13, and provides same information for inter-ocean transport estimates. Provide estimate of flow into Pacific south of NZ and north into Tasman Sea.	3.4.2.5 4.3.1.1 3.4.2.2/3/4	Tasmania to New Zealand South to Antarctica	Coordinate with CP2. Possible replacement for Choke Point section S3. At least one repeat should occur during austral winter.	Length = 2394nm No. Stations = 80 Days/Section = 19 Repeat/Year = 1 No. of Years = 5 Total Days = 95		
PR14/CP1	Monitor bifurcation of the west wind drift.	3.4.2.5	Eastern South Pacific	Maintenance of current meter-T/S mooring PCM14. Possibly use large fishing vessels to assist in hydro-raphy and XBT sampling. our repeats first year, once per year next four years.	Length = 1900nm No. Stations = 64 Days/Section = 14 Repeats/Year = 4/1 No. of Years = 5 Total Days = 112		
PR15/CP1	Measure tropical circulation. Continuation of TOGA and SURTROPAC programmes.	3.1.5 3.4.2.2/3/4/5	165°E 10°N to 17°S	Tropical portion of line P13. Sample to 1000 or 1500m. Coordinate with TOGA, SURTROPAC	Length = 1800 No. Stations = 61 Days/Section = 18 Repeats/Year = 2 No. of Years = 5 Total days = 180		
PR16/CP1	Measure tropical circulation.	3.1.5 3.4.2.2/3/4/5	110°W 5°N to 15°S	Tropical portion of line P18. Sample to 1000m. Coordinate with TOGA.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Years = 2 No. of Years = 5 Total Days = 60		
PR17/CP1	Samples the Kuroshio	3.4.2.2/3/4/5	Kyushu SW across Kuroshio	Repeat of line P24.	Length = 300nm No. Stations = 11 Days/Section = 3 Repeats/Year = 4 No. of Years = 5 Total Days = 60		

PROJECT- WHP (Repeat Hydrographic Sections) **Pacific**

(PAC/003) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol. II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PR18/CP1	Continuation of long term measurements along the North Pacific Heat Flux section.	3.4.2.2/3/4/5	China to 24°N, 135°E	Repeat of western end of heat section line P3. Four repeats first year, twice per year next 4 years.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Year =4/2 No. of Years = 5 Total Days = 72		
PR19/CP1	Sample East China Sea.	3.4.2.2/3/4/5	China to Ryukyu Islands	Repeat of line P25.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Year = 2 No. of Years = 5 Total Days = 60		
PR20/CP1	Sample Mindanao Current. Estimate variability.	3.4.2.2/3/4/5	22°N from Taiwan to 130°E	Repeat of line P26.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Year = 2 No. of Years = 5 Total Days = 60		
PR21/CP1	Estimate variability of flow through Bassii Strait.	3.4.2.2/314/5	Taiwan to Luzon	Repeat of line P27.	Length = 300nm No. Stations = 11 Days/section = 3 Repeats/Year = 2 No. of Years = 5 Total Days = 30		
PR22/CP1	Sample Kuroshio. Estimate variability.	3.4.2.2/3/4/5	18°N from Luzon to 130°E	Repeat of line P28.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Year = 2 No. of Years = 5 Total Days = 60		
PR23/CP1	Sample Mindanao Current. Estimate variability.	3.4.2.2/3/4/5	7.5°N from Mindanao to 130°E	Repeat of line P29.	Length = 300nm No. Stations = 11 Days/Section = 3 Repeats/Year = 2 No. of Years = 5 Total Days = 30		
PR24/CP1	Estimate variability of flow into Indonesian Archipelago.	3.4.2.2/3/4/5	Mindanao SE to Indonesia	Repeat of line P30.	Length = 600nm No. Stations = 21 Days/Section = 6 Repeats/Year = 2 No. of years = 5 Total Days = 60		

PROJECT - WHP (Hydrographic Time Series Stations)

Pacific
(PAC/002) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PRS1/CP1	Monitor water properties more frequently than possible with sections for temporal variability. Continuation of long time series.	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	OWS Papa	Schedule as part of repeat section(s). Locate at Papa to ensure time series.		Continuous monthly for 10 years	
PRS2/CP1	Monitor changes in properties in central subtropical gyre.	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	North of Hawaii	Near Hawaii for logistics but should be as far away as practical. Has been started as USA-GOFS time series station.	Hydro station	Continuous monthly for 10 years	
PRS3/CP1	Monitor boundary region for transport estimates within California Current	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	24°N, 115°W	Should be near section P3. Station is not near oceano- graphic institution and may need to be moved.		Continuous monthly for for 10 years	
PRS4/CP1	Provide index of eastward flowing EAC	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	28°S, 167°E	Also PTS1.	Either hydro station or moored T/S chain	Continuous monthly for 10 years	
PRS5/CP1	Provide index of eastward flowing EAC	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	40°S, 160°E	Also PTS2	Either hydro station or moored T/S chain	Continuous monthly for 10 years	
PRS6/CP1	Observations of subpolar mode water and AAIW. With PR14, mooring will provide index of S. Pacific circulation.	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	47°S, 175°E	Operate in conjunction with current meter and T/S chain (PCM14, PTS6) on line PR14	Either hydro station or moored T/S chain	Continuous monthly for 10 years	
PRS7/CP1	Study dense water formation in North Pacific.	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	50°N, 150°E	Logistically difficult because of ice and seas	Either hydro station or moored T/S chain	Continuous monthly for 10 years	
PRS8/CP1	Study dense water formation in North Pacific.	3.4.2.5 3.2.3 7.1.2.2 3.4.2.7	55°N, 173°E	Logistically difficult.	Either hydro station or moored T/S chain	Continuous monthly for 10 years	

SOUTHERN OCEAN-WHP

(Global One-Time Full-Depth Hydrographic Survey)

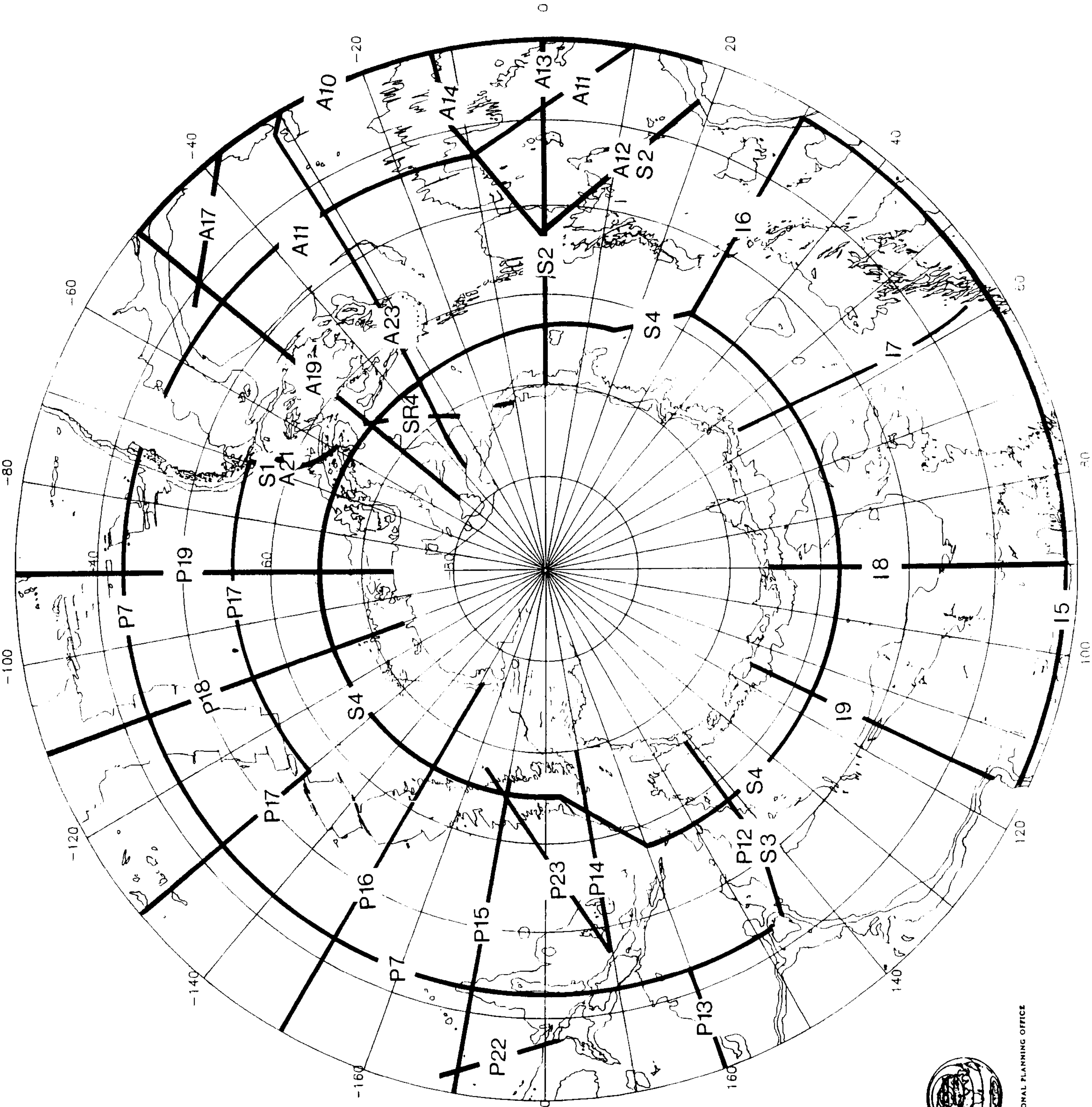
Lines	Length (nm)	SV Stations	LV Stations	Days
S1	679	23	4	9
S2	2443	82	9	31
S3	1539	51	6	19
S4	10318	344	36	125
4 Lines	14979 nm	500 Stations	55 Stations	184 Days

SOUTHERN OCEAN-WHP

(Repeat Hydrographic Sections)

Line	Length (nm)	Stations	Days	Repeats/yr	Years	Total Repeats	Total Length	Total Stations	Total Days
SR1	679	23	6	1	4	4	2716	92	24
SR2	2443	82	27	1	4	4	9772	328	108
SR3	1539	51	12	1	4	4	6156	204	48
SR4	1005	35	15	1	2	2	2010	70	30
	5666	191	60				20654 nm	694 Stations	210 Days

(Glo001) 8/7/88



INTERNATIONAL PLANNING OFFICE
87.6

Figure 5.7 One-time WHP Survey of the Southern Ocean

PROJECT - WHP (Global One-Time Full-Depth Hydrographic/Tracer Survey)

Southern
(SOU/005) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
S1/CP1,2	Define water mass characteristics within circumpolar belt. Crosses Drake Passage. Extends time series measurements from ISOS Programme (1975-81). Calculation of geostrophic shear and absolute velocity field.	4.3.1.1 3.4.1.2/3/4	64°W S. America to Antarctica	Final placement contingent upon siting of Choke Point flux experiment of CP2. Also CP1 section A21. Also repeat section SR1. Extend section into Bransfield Strait.	Length = 679nm No.SV STA = 23 No.LV STA = 4 Total Days = 9		
S2/CP1.2	Measure volume, heat and salinity flux from Indian to Atlantic. Calculation of geostrophic shear and absolute velocity field. Define water mass characteristics within circumpolar belt.	4.3.1.1 3.4.1.2/3/4	18°E Africa to Antarctica 33°S, 18°E to 53°S, 0° and south along 0° to 65°S	Must be located to west of Agulhas Retroflection. Final placement contingent upon siting of CP2 Choke Point flux experiment. Also section A12, southern portion of A13, repeat section SR2.	Length = 2443nm No.SV STA = 82 No.LV STA = 9 Total Days = 31		
S3/CP1,2	Measure Indian/Pacific volume, heat and salinity flux. Calculation of geostrophic shear and absolute velocity field. Define water mass characteristics within circumpolar belt.	4.3.1.1 3.4.2.2/3/4/5	146°E Tasmania to Antarctica	Section P14 at 170°E is an alternate Choke Point section in association with P7 between Tasmania and N.Z. Final placement contingent upon siting of CP2 Choke Point experiment. Also section P12, repeat sections PR12 and SR3.	Length = 1539nm No.SV STA = 51 No.LV STA = 6 Total Days = 19		
S4/CP2	Cross mid-section of cyclonic gyres south of ACC. Sample northward flux of AABW. Study ocean/sea-ice interaction. Parallels Antarctic Divergence separating west from east wind drift.	4.3.1.1	65°S Parallels Antarctic Divergence	Carry out early in WOCE to allow improved experimental design for specific objectives. Ice will be a problem in Weddell Sea even during austral summer so an ice breaker will be required. Need for ocean properties below sea-ice cover as part of special study topics. If a Weddell polynya develops, sampling at close time intervals within polynya is required. As sections approach Antarctica, station spacing should be tightened to 500m isobath intervals.	Length = 10318 No.SV STA = 344 No.LV STA = 36 Total days 125	Austral Summer	

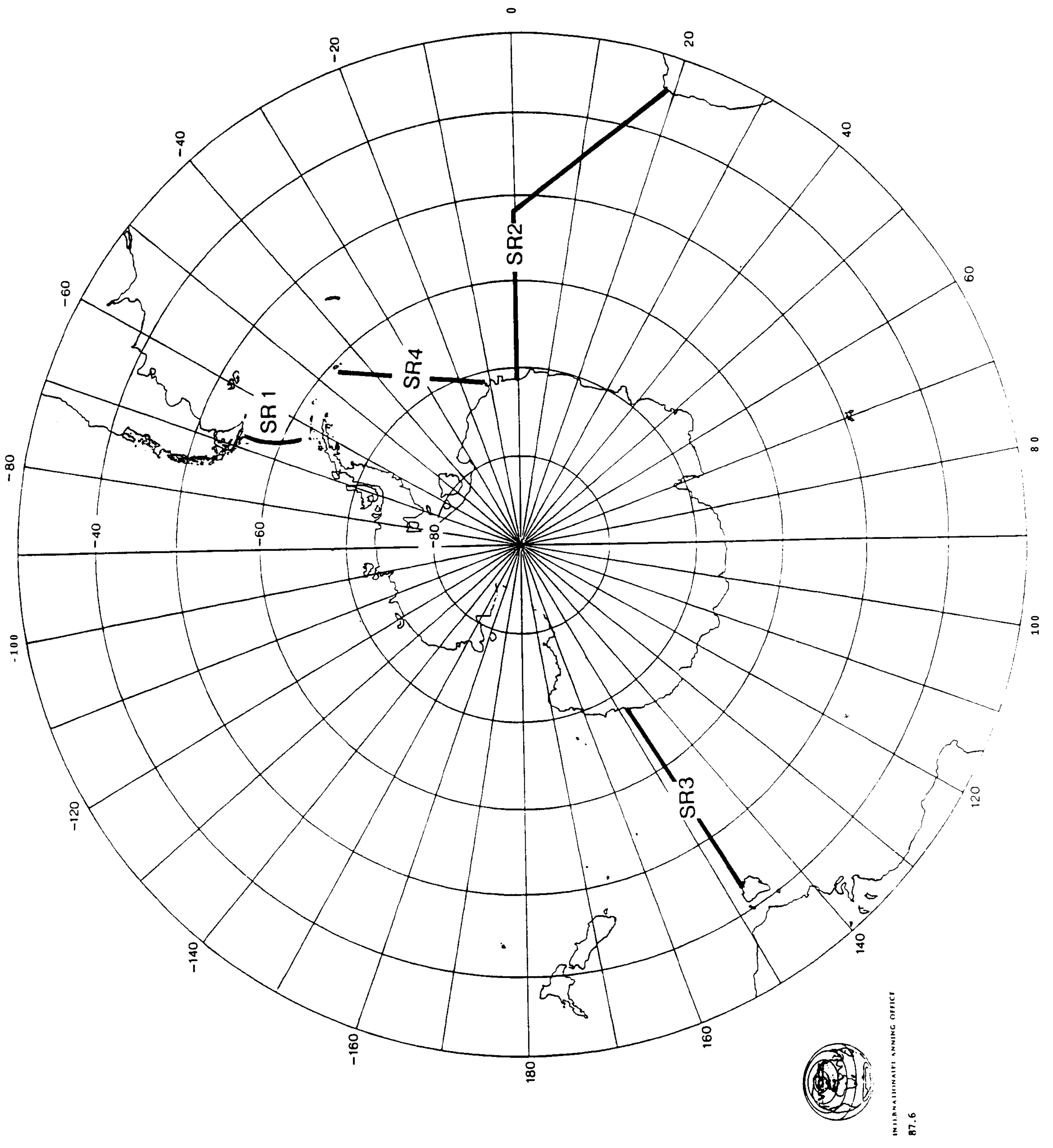


Fig. (5.8) Repeat WHP Hydrography in the Southern Ocean

PROJECT- **WHP (Repeat Hydrographic Sections)** **Southern**

(SOU/006) 8/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
SR1/CP2	Define variability of water mass characteristics within circumpolar belt. Crosses Drake Passage. Extends time series measure-ments from ISOS Programme (1975-81). Investigate variability of deep convection in Bransfield Strait Calculate geostrophic shear and absolute velocity field.	4.3.1.1	64°W S. America to Antarctica	Also sections A21, S1. Occupy at least once as Austral winter section.	Length = 679nm No. Stations = 23 Days/Section = 6 Repeats/Year = I No. of years = 4 Total Days = 24		
SR2/CP2	Measure variability of volume, heat and salinity flux from Indian to Atlantic. Calculate variability of geos-trophic shear and absolute velocity field.	4.3.1.1	18°E Africa to Antarctica 33°S, 18°E to 53°, 0° and south along 0° to 65°S	Also sections A12, S2, southern portion of A13. Must be located to west of Agulhas Retroflection. At least one winter section required.	Length = 2443nm No. Stations = 82 Days/Section = 27 Repeats/Year = 1 No. of Years = 4 Total Days = 108		
SR3/CP2	Measure variability of Indian/Pacific volume, heat and salinity flux. Calculate variability of geos-trophic shear and absolute field.	4.3.1.1	146°E Tasmania to Antarctica	Also sections S3, P12. At least one winter section required.	Length = 1539nm No. Stations = 51 Days/Section = 12 Repeats/Year = 1 No. of years = 4 Total Days = 48		
SR4/CP2	Measure variability of volume, heat and salinity flux across Weddell Gyre and boundary currents.	4.3.2.4	Cape Norwegia to South Orkneys (Weddell Sea)	At time of deployment and recovery SCM7.	Length = 1005nm No. Stations = 35 Days/Section = 15 Repeats/Year = 1 No. of years = 2 Total Days = 30		

5.2 Satellites

5.2.1 ERS-1

The first European Remote-sensing Satellite (ERS-1) is scheduled for launch in 1990 on Ariane-4. For calibration purposes it will initially be placed into a 3-day repeat orbit at a height of 777 km but it has the capability to change its orbit up to 6 times to meet different user requirements. This will be achieved by small adjustments to the height. The subsatellite track will extend to 82°N and S.

ERS-1 will be the first satellite since Seasat to carry a suite of radar sensors for observing the ocean, the core instruments being:

(1) An Active Microwave Instrument operating at 5.3 GHz (i.e. C-band) and which combines the functions of a Synthetic Aperture Radar (having both an imaging mode and a wave mode) and a wind scatterometer. This will be the first time that either a C-band SAR or scatterometer will have been carried on a civilian spacecraft (Previous SARs and scatterometers operated at L-band and Ku-band respectively).

(2) A Radar Altimeter, operating at 13.7 GHz (Ku-band), a frequency similar to that used by the GEOS-3, Seasat and Geosat altimeters. Provision of an ice-mode will allow improved tracking over rough parts of ice sheets.

Geophysical Measurements and ERS-1 Performance Parameters

Main Geophysical Parameter	Range	Accuracy	Main Instrument
Wind Field			
- Velocity	4-24 m/s	±2 m/s or 10% whichever is greater	Wind Scatterometer and Radar Altimeter
- Direction	0-360°	±20°	Wind Scatterometer
Wave Field			
- Significant Wave Height	1-20 rn	±0.5 rn or 10% whichever is greater	Radar Altimeter
- Wave Direction	0-360°	±15°	SAR Wave Mode
- Wavelength	50-1000 rn	20%	SAR Wave Mode
Earth Surface Imaging			
- Oceans	80 km	Geometric/Radio metric	SAR Imaging Mode
- Coastal Zones	(minimum	Resolutions:	
- Sea-Ice	swathwidth)	(a) 30 m/2.5 dB	
- Land		(b) 100 m/1 dB	
Altitude			
- Over Ocean	745-825 km	2 m absolute	Radar Altimeter
- Polar Ice-Sheets		±10 cm relative	
Satellite Range		±10 cm	PRARE
Sea Surface Temperature	500 km swath	±0.5°K	ATSR (IR)
Water Vapour	in 25 km spot	10%	µW Sounder

Other sensors provided on the basis of national funding are the Precise Range And Range-rate Equipment (PRARE) of FRG and the Along-Track Scanning Radiometer and Microwave Sounder (ATSM/M) of UK/France. The ATSR/M's main contributions will be in the accurate determination of SST and in providing the water vapour correction for altimetry. Improved correction for atmospheric effects in SST retrievals is achieved by viewing the same area of sea at nadir and at 55°.

A significant upgrading of the altimetry mission has been made possible by the inclusion of PRARE, which will be used for determining the radial position of ERS-1 at decimetre level. The system relies on two-way microwave ranging to a number of ground stations which can be deployed around the globe. (Precise orbit determination is also facilitated by the presence of a laser retroreflector.)

Performance specifications for some of the geophysical quantities to be measured by ERS-1 sensors are shown above.

To stimulate further scientific interest in the mission ESA issued an Announcement of Opportunity in May 1986. An unexpectedly large number of proposals was received (representing about 300 individual investigations and 500 organizations). After a thorough evaluation process about 200 Pis were selected to form the ERS-1 Science and Applications Investigator's Team. It is expected that 20 to 30 of these will act as Coordinating Investigators.

The contact regarding scientific aspects is the ERS-1 Mission Manager, G. Duchossois located at ESA HQ, 8-10 Rue Mario Noikis, F-75738 Paris Cedex 15, France.

5.2.1 TOPEX/POSEIDON

TOPEX/POSEIDON is a joint NASA/CNES mission which is scheduled for launch in 1991/2 on an Ariane 4 launcher. Its orbit configuration differs from that of ERS-1 in that it will be non sun-synchronous, with an inclination of 65°±0.5° and a height of around 1300 km. A repeat period of 10 (possibly 20) days is most strongly favoured.

TOPEX/POSEIDON is an altimetric mission and the remote sensing instruments in the payload are directed to this theme. They are:

(1) A NASA two-frequency radar altimeter (Ku-band and C-band) which will allow correction for ionospheric effects.

(2) A CNES single frequency (Ku-band), solid-state altimeter.

(3) Boresight passive microwave radiometer to provide estimates of the wet tropospheric correction.

The two altimeters will not be on simultaneously, the POSEIDON altimeter being operated for only 1 day in 20.

In addition TOPEX/POSEIDON carries systems for precise tracking which will be used to determine a very accurate orbit. DORIS (Doppler Orbit and Radio Positioning Integration by Satellite) will be the primary CNES tracking and NASA will rely on laser tracking, with GPS (Global Positioning System) as an experimental addition. Like PRARE, the ERS-1 tracking system, DORIS relies on having a number of ground stations around the globe (about 50 are planned) which communicate at microwave frequencies with a package onboard the satellite.

The accuracy of the global orbit determination is expected to be 13 cm and the objective is to measure sea surface topography with a single-pass accuracy of 14 cm. Estimates of significant waveheight and wind speed will also be possible.

5.3 Sea-Level Sites

For the two sea-level data sets A and B described in Chapter 2.3, the following sites, taken from the GLOSS list, meet the logistical and site-specific requirements. The availability of the data depends on various factors which influence the data delivery delay. This in turn will determine the primary depository of the data for the rapid delivery or the high-precision mode. Indicated in this list are the potentially available tidegauges. Those that will have geocentric leveling provided by the DORIS-system are indicated by an asterisk (*). Approximately 10 stations will be chosen on the set A rapid-delivery stations.

Pacific Ocean	**GLOSS Number**	
Christmas Island	146	
Ponape	115	
Tarawa	113	
Majuro	112	
Nauru	114	
Rabaul	65	
Honiara	66	
Rarotonga	139	
Callao	173	
Kapingamarangi	117	
Johnston	109	
Valparaiso	175	
Kanton	145	
Easter	137	(*)
Nuku Hiva	142	
Penrhyn	143	
Wake	105	
Funafuti	121	
Noumea	123	(*)
Socorro	162	
Papeete	140	(*)

Atlantic 0cean	**GLOSS Number**	
Reykjavik	229	(*)
Bermuda	221	
Ponta Delgada	245	
Porto Grande	254	
Tristan de Cunha	266	(*)
St. Helena	264	(*)
Ascension	265	
St. Peter & Paul Rocks	199	
Trindade	265	
Stanley/Falklands	189	
South Georgia	187	(*)
South Sandwich	188	
Bouvet	269	

Indian Ocean	**GLOSS Number**	
Cocos I	46	
Reunion	17	(*)
Christmas 1	47	
Gan	27	
Diego Garcia	26	(*)
Mombasa	8	
Port Louis	18	
Port Victoria	273	
Male (Maldives)	28	

Southern Ocean	**GLOSS Number**	
St Paul	24	(*)
Crozet	21	
Kerguelen	23	(*)
Marion 1	20	(*)
Hobart	56	
Macquarie	130	
Chatham Is.	128	(*)
South Orkney (Signy)	296	(*)
Bahia Scotia	186	
Peter 1	136	
Russkaya	135	
Mawson	22	
Syowa	-	
Sanae	-	
Dumond d'Urville	131	(*)
Mirny -	93	
McMurdo	134	
Faraday	-	
Palmer	183	
Casey	278	
Arctowski	-	

5.3.1 Tide-Gauges for Monitoring Geostrophic Gradients

The following pairs of tide-gauges have been selected to provide differences of sea-level height in order to estimate flow variations between these stations.

Station Pairs

Palmer	183	-	Puerto Williams	180
Cape Hatteras	219	-	Bermuda	221
Reykjavik	229	-	Angmagssalik	228
Hobart	56	-	Dumont d'Urville	131
Bluff Harbour	129	-	McMurdo	134
Simons Town	268	-	Sanae	*(-)*
Bimini	211	-	Key West	216

For the following areas appropriate tide-gauges have to be selected:

Indonesian Islands
Caribbean

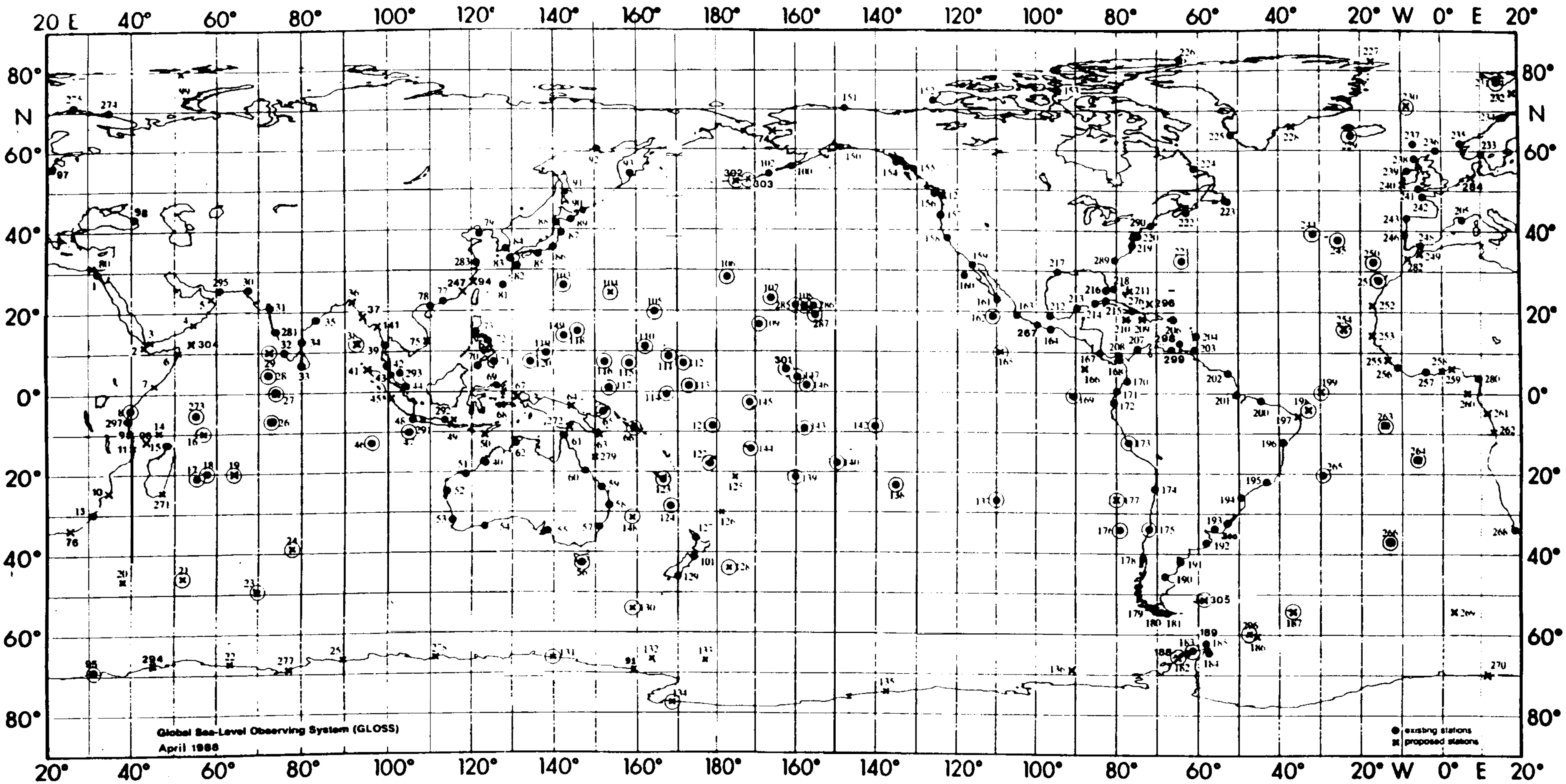


Fig. (5.9) The basic GLOSS global network of sea level gauges. Gauges marked with a circle are to be used for the 2-month 'A' data set. Each gauge in this network, particularly those in the Antarctic, will be reviewed during 1989 for operational viability.

5.4 Floats and Drifters

FLOAT PROGRAMME SUMMARY

GLOBAL	MAPPING CORE PROJECT 1		1100
	AFG-225. IFG-180. PFG-495, SFG-200		
ATLANTIC	AF1	Labrador Sea water spreading	12
	AF2	AABW spreading in the North Atlantic	25
	AF3	Cross Equatorial transport	100
	AF4	CP3 Basin scale enhancement	540
	AF5	CP3 Deep Basin Experiment	270
	AF6/7	Tracer releases	60
	AF8	CP3 Ekman Layer/subduction	160
INDIAN	IF1	Cross Equatorial transport	90
	IF2	WBC and Basin exchanges	TBD
	IF3	Indo/Pacific throughflow	TBD
PACIFIC	PF1	Kuroshio recirculation	TBD
	PF2	South Pacific WBC	TBD
	PF3	Enhance heat flux sections 24°N and 28°S	TBD
	PF4	Cross Equatorial transport	180
	PF5	Deep flow - Samoa to Penrhyn basins	20
	PF6	Deep flow - Southern to Pacific Ocean	TBD
SOUTHERN	SF1	Subantarctic/subtropic transition	100
	SF2	Cyclonic gyres, ice covered regions	50
TOTAL			**2707 + TBDs**

N.B.: TBD - to be determined

(GLO002)
05.07.88

PROJECT- WFP (Deep Float Releases) **Atlantic**

(ATL/007) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AFG/CP1	Map large-scale general circulation of Atlantic Ocean using floats in conjunction with hydrography and altimetry. Characterisation of eddy activity. Determination of paths of Cross-equatorial flow at several levels. Provision of reference level for geostrophic calculations. Exploration of water mass formation sites.	3.3.2 3.4.1.10	Atlantic Basin North of 45°S	CP1 deep circulation. Use a combination of SOFAR, RAFOS and ALACE floats with associated moorings (acoustic in CP3 overlap region). Coordinate with CP2 south of 45°S assuming 5-year float/life time.	Depth = 2500m Deployment from WHP, VOS and other ships. Total = 225	WOCE IOP	
AF1/CP1	Follow spreading of Labrador Sea water.	3.2.4 3.4.1.10	55°N, 50°W Labrador Sea		12 Pop-up Floats Deploy at end of Boreal Winter. Locate floats at periods of 50 to 100 days over 5 years. Repeat deployment and tracking after 5 years.		
AF2/CP1	Determine how AABW spreads northwards in western basin of N. Atlantic.	3.2.4 3.4.1.10	24°N, from 60°W to Mid-Atlantic	If pop-ups are used they should initially be located every 50 days.	25 SOFAR or Pop-up Floats. Depth of 5000m. Initial spacing 50km.		
AF3/CP1,3	Determine pathway and volume flux of various cross equatorial flows.	3.2.4 3.3.2 3.4.1.11	5°S from 15° to 30°W	Combination of SOFAR and RAFOS floats preferable to pop-ups in order to better resolve narrow intense flows that might exist near equator.	2500m depth for deep reference. 1000m depth for AAIW = 50 floats. 4000m depth for AABW = 50 floats. 1000m and 4000m floats seeded around 5°S with a greater concentration to the west. Total = 100.		
AF4/CP3	BASIN-SCALE Enhancement. Improve space and time scale resolution of mid-level circulation in interior of a well measured ocean basin. provide boundary conditions for smaller scale CP3 experiments.	5.2.4	Atlantic Basin North of 30°S.	CP3 deep circulation. (tropical S. Atlantic), upper layer dynamics (subtropical N. Atlantic), control volumes. Use a combination of SOFAR and RAFOS floats and associated moorings. Could require between 15-30 mooring operations for sound source and listening devices.	Depth = 2500m. Deployment from WHP, VOS and other ships. Total = 540.	WOCE IOP	

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AF5/CP3	DEEP BASIN EXPERIMENT spatial variation of interior mean flow and eddy kinetic energy levels. Investigate spatial continuity of deep water boundary currents and comparison with vertical shear from hydrography. provide crucial information for box models.	5.3.3	Brazil Basin	Assume 5-year life span for floats. Sample AAIW and AABW addition to 2500m reference level. Also seed deep passages and western boundary currents.	Depth and Floats: WOCE IOP AAIW (1000m) = 100. AABW (4000m) = 100. Ref. (2500m) = 50. Passages and WBC = 20. Total = 270.		
AF6/CP3	DEEP BASIN TRACER RELEASE Measure diapycnal mixing in the basin interior. Improve understanding of basin circulation.	5.3.3 5.4.4	Brazil Basin	Coordinate with other components of Deep Basin Experiment. Floats are one component of tracer release experiment and must be incorporated as part of a “package". Experience gained from the first release will determine if additional releases and floats are feasible/required.	Depth = 2000 4000m. At least 20 floats for each release.		
AF7/CP3	BETA-TRIANGLE TRACER RELEASE Measure diapycnal mixing in the basin interior. Improve understanding of basin circulation. Compare diffusivities from tracer release and other C,V. measurements.	5.3.2 5.4.4	Beta-spiral Control Volume	Coordinate with other components of B-spiral C,V. Floats are one component of tracer release experiment and must be incorporated as part of a "package". Experience gained from the first release will determine if additional releases and floats are feasible/required.	Depth = 650m At least 20 floats for each release.		
AF8/CP3	EKMAN LAYER/SUBDUCTION Determine wind-driven ageostrophic transport and its depth distribution. Determine variation and depth of transport as a function of stratification. Determine age distribution at main thermocline waters and vertical horizontal pathways of flow from mixed-layer to the thermocline. Study principal mechanisms that cause subduction.	5.3.2 5.4.2/3	40°N-25°N Near Azores	Development of SOFAR floats modified to follow isotherms. Coordinate deployments with 2 yr. lifespan of current-meters array ACM 19. Pop-ups should be used to provide interpolation of thermocline velocity between subduction moorings. Schedule to coincide with other WOCE elements and scatterometer.	Depth = upper 500m Isotherm tollower SOFAR floats = 40. ALACE floats = 120. Total = 160.	1991/2-3/4.	

PROJECT- **WFP (Deep Float Releases)** **Indian**

(IND/005A) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IFG/CP1	Map large-scale general circulation of Indian Ocean in conjunction with hydrography and altimetry. Characterisation of eddy activity. Study the large-scale current response to monsoon forcing in Arabian Sea Map Agulhas regime.	3.3.2 3.4.3.10 4.4.3	Indian Basin North of 45°S	Could require 5-10 mooring operations for sound source or listening I devices. Use a combination of SOFAR, RAFOS and ALACE floats and associated moorings. ALACE are required in more southerly portions of Basin in association with Southern Ocean. Coordinate with CP2 south of 30°S.	Depth = 2000-2500m Deployment from WHP, VOS and other ships. Total = 180	WOCE IOP	
IF1/CP1	Measure pathways of cross-equatorial transport	3.4.2.10	8°S Across Basin		Depth and floats: AAIW (1000m) = 45 AABW (4000m) = 45 Total = 90		
IF2/CP1	Determine spreading of waters in three deep northward (meridional) western boundary currents and preferred pathways for exchange among the basins.	3.4.3.9/10	Central Equatorial region		Depth of release = 3500m		
IF3/CP1	Investigate path of Pacific-Indian Ocean throughflow in Indian Ocean and determine if link exists to the South Atlantic.	3.4.3.10	Timor channel		Shallow level floats of 700m or less		

PROJECT- **WFP (Deep Float Releases)** **Pacific**

(PAC/0 11) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PFG/CP1	Map large-scale general circulation of Pacific Ocean using floats at one level in conjunction with hydrography and altimetry. Characterisation of eddy activity.	3.3.2 3.4.2.10 4.3.1.2	Pacific Basin North of 45°S	Could require 30-60 mooring operations for sound source or listening devices. Use a combination of SOFAR, RAFOS and ALACE floats and associated moorings. ALACE are required in more southerly and interior portions of basin and Southern Ocean. Coordinate with CP2 south of 30°S.	Depths 2500m. Deployment from WHP, VOS and other ships. Total = 495	WOCE IOP	
PF1/CP1	Measure Kuroshio and its recirculation at two levels and enhanced resolution. Characterise intermediate water formation.	3.4.2.10	NW Pacific and Kuroshio recirculation.		Shallow floats in thermocline. Deep floats at 2500m		
PF2/CP1	Measure South Pacific western boundary current and its circulation at two levels.	3.4.2.10	Tasman Sea, S. Fuji Basin and area east of N.Z.	Combined drifter (PD1) and float programme.	Depth = 2500m and in thermo-cline in EAC, 2500m and deep E of N.Z.		
PF3/CP1	Improve quality of sampling for velocity reference level at 24°N and 28°S heat flux sections.	3.4.2.10	24°N 28°S	Enhanced seeding required along the 24°N and 28°S HEAT FLUX sections.			
PF4/CP1	Measure equatorial transport at two/three levels.	3.4.2.10	10°N to 10°S across Pacific	Combined drifter (PD2) and float programme. Need highest sampling in western position of Pacific.	AAIW (1000m) = 90 AABW (4000m) = 90 Total = 180		
PF5/CP1	Studies pathways of deep flow from Samoa Basin through Samoa Passage or into Penrhyn Basin.	3.4.2.10	10°S, 175°W	Coordinate with sections P5, 15 and 21, current meters PCM11.	Deep floats = 20		
PF6/CP1,2	Study pathways of deep flow between the southern and Pacific Oceans.	3.4.2.10 4.3.1.2	43°S and 57°S on both sides of Pacific Rise				

PROJECT- **WFP (Deep Float Releases)** **Southern**

(SOU/007) 4/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
SFG/CP1,2	Map large-scale general circulation of Southern Ocean at one level in conjunction with hydrography and altimetry. Map absolute mean near-surface geostrophic flow with low resolution and variability with high resolution. Characterisation of eddy activity in Southern Ocean where barotropic flow is particularly strong.	4.3.1.2 3.3.2 4.4.3	Southern Ocean (45°S to Antarctica)	Use combination of RAFOS and ALACE floats. ALACE are required in southerly regions. Coordinate with CP1.	Depths - 45°S to ACC = 500m; South of ACC = 250m. Total = 200		
SF1/CP1,2	Observe relative motion of Southern Ocean water masses to northern derived water masses in transition between sub-antarctic and subtropic water masses.	4.3.1.2 4.4.3	North of the ACC	Deploy within water mass core layers and pair with floats deployed under SFG when feasible.	Use RAFOS ALACE floats at different levels. Total = 100		
SF2/CP2	Study southern sectors of cyclonic gyre,	4.3.2.4 4.4.3	Polar ice-covered regions.		10 RAFOS floats per year. Total Floats = 50.		

DRIFTER PROGRAMME SUMMARY

				W/TS
GLOBAL	MAPPING CORE PROJECT 1 ADG-450, IDG-360, PDG-990, SDG-400		2200	40
ATLANTIC	AD1	CP3 Basin scale enhancement	840	
	AD2	CP3 Ekman Layer/subduction	60	
	ASFDG	CP1 Surface flux	96	TBD
	ASF	Basin scale surface flux	TBD	TBD
INDIAN	ID1	Interannual variability of surface flow	200	70
	ISFDG	CP1 Surface flux	96	TBD
PACIFIC	PD1	Southern Pacific WBC	TBD	
	PD2	Cross Equatorial transport	TBD	
	PSFDG	CP1 Surface flux	96	TBD
SOUTHERN	SD1	Sea Ice cover dynamics	100	50
	SD2	Mixed layer of Weddell Gyre	40	40
TOTALS			**3728**	**200**

(GLO002)
06.07.88

PROJECT- **Drifters (Surface Velocity Programme)** **Atlantic**

(ATL/012) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ADG/CP1	Characterize large-scale transport in upper layer so that magnitude and effect of geostrophic and ageostrophic wind-driven flow is determined. Map total near surface flow and describe low-frequency large-scale variability. Test models of wind-driven flow and quantify transport of heat in upper layer, its role in ocean climate and its variability. Examination of near-surface flow and its variations in west wind drifts and bifurcabons along eastern boundaries.	3.2.4 3.2.7 3.3 3.3.2	Atlantic Basin North of 45°S	Satellite altimetry for geostrophic height. Satellite scatterometry for oceanic surface winds. Assume drifter life of 2.5 yrs. Deployment from WHP, VOS or other ships. Coordinate deployments in southern portion *of* basin and Southern Ocean with on-going WWW/TOGA drifting buoy programmes. Drifters should be drogued. Arrangements should be undertaken to assure even deployment and reseeding throughout basin or as required.	Some drifters measuring surface pressure and SST for improvement of flux estimates. Five year coverage. Original deployment = 225 Reseeding 225 Total = 450		
AD1/CP3	BASIN-SCALE measurements. Statistical and synoptic analyses for surface layer velocity and lateral transport. Areas of primary interest are the geostrophic gyres, ageostrophic wing-driven currents and tropical zone currents.	5.2.3	Atlantic Basin North of 30°S	Deploy in coordination with ADG above. Coordinate with XBT/XCTD programme. Drifters should be drogued. Arrangements should be undertaken to assure even deployment and reseeding throughout basin as required. Assume drifter life of 2.5 years.	Five year coverage. Original deployment = 420. Reseeding = 420. Total = 840.		
AD2/CP3	EKMAN LAYER/SUBDUCTION Mapping of surface currents and sea surface temperatures.	5.4.2.4 5.4.3.5	50°N to 25°N Near Azores	CP1 Global Survey drifters as enhanced by AD1 will provide 60 of the required 120 drifters. Deploy within the ACM25/26 array of CV. surface moorings for calibration.	Additional drifters required for AD2 = 60.		

PROJECT- **Drifters (Surface Flux)** **Atlantic**

(ATL/013) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ASFDG/CP1	Verification of surface fluxes of heat and momentum.	3.2.7 3.2.8 3.3.1 3.4.1.8	Sparsely sampled regions of Basin.	Likely regions for deployment include Labrador Sea, NW Atlantic, and South of 40°S. Coordinate with WOCE Meteorological VOS programme. Assume 1 year lifetime.	Surface flux drifters with thermistor chains. Requirement may be partially met by moored instruments (ASFG). At least 1 array of 16 drifters. Original deploy-ment = 16 Reseeding = 80 Total = 96	WOCE IOP	
ASF1/CP3	BASIN-SCALE Measurements Enhancement in resolution for for air-sea fluxes of momentum, heat and water.	5.2.2	Atlantic Basin	To be coordinated with VOS Meteorological Programme and low resolution coverage provided by ASFDG and ASFG and with sea level pressure and SSt on surface velocity drifters ADG and AD 1.	Surface flux drifters with meteorological sensors.	Throughout	

PROJECT- **Drifters (Surface Velocity Programme)** **Indian**

(IND/005) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IDG/CP1	Characterize large-scale transport in upper layer so that magnitude and effect geostrophic and ageostrophic wind-driven flow is determined. Map total near surface flow and describe low-frequency large-scale variability. Test models of wind-driven flow and quantify transport of heat in upper layer, its role in ocean climate and its variability. Examination of near-surface flow and its variations in west wind drifts and biturcations along eastern boundaries.	3.2.4 3.2.7 3.3.2	Indian Basin North of of 45°S	Satellite altimetry for geostrophic height. satellite scatterometry for oceanic surface winds. Assume drifter life of 2.5 yrs. Deployment from WHP, VOS or other ships. Coordinate deployments in southern portion of basin and Southern Ocean with on-going WWW/TOGA drifting buoy programmes. Drifters should be drogued. Arrangements should be undertaken to assure even deployment and reseeding throughout basin or as required.	Some drifters measur-Ing in surface pressure and SST for improvement of flux estimates. Five year coverage. Original deploy-ment = 180 Reseeding = 180 Total = 360 1/3 of drifters with thermistor chains.	WOCE IOP	
ID1/CP1	Interannual variability of surface flows.	3.2.4 3.4.3.10	55°E 12°N to 15°S	Assume drifter life of 2.5 years.	Seasonal release at 1° resolution = 100 drifters 1/3 of drifters with thermistor chains. Releases repeated 2 times to give a 5 year coverage. Total = 200	WOCE IOP	

PROJECT- **Drifters (Surface Flux)** **Indian**

(IND/010) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IDSFG/CP1	Verification of surface fluxes of heat and momentum.	3.2.7 3.2.8 3.3.1 3.4.3.8	Sparsely sampled regions of Basin	Coordinate with WOCE meteorological VOS programme. Assume 1 year lifetime,	Surface flux drifters with thermistor chains Requirement may partially be met by moored instruments (ISFG). At least 1 array of 16 drifters. Original deploy-ment = 16 Reseeding = 80 Total = 96	WOCE IOP	

PROJECT- Drifters (Surface Velocity Programme) — Pacific

(PAC/009A) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PDG/CP1	Characterize large-scale transport in upper layer so that magnitude and effect of geostrophic and ageostrophic wind-driven flow is determined. Map total near surface flow and describe low-frequency large-scale variability. Test models of wind-driven flow and quantify transport of heat in upper layer, its role in ocean climate and its variability. Examination of near-surface flow and its variations in west wind drifts and bifurcations along eastern boundaries.	3.2.4 3.2.7 3.3.2	Pacific Basin North of 45°S	Satellite altimetry for geostrophic height. Satellite scatterometry for oceanic surface winds. Assume drifter life of 2.5 yrs. Deployment from WHP ships, VOS or other ships. Coordinate deployments in southern portion of basin and Southern Ocean with on-going WWW/TOGA drifting buoy programmes. Drifters should be drogued. Arrangements must be undertaken to assure even deployment and reseeding throughout basin or as required.	Some drifters measurin surface pressure and SST to improve flux estimates. Full five year coverage. Original deployment = 495 drifters Reseeding = 495 Total 990 =	WOCE IOP	
PD1/CP1	Measure South Pacific western boundary current regime.	3.2.4 3.4.2.10	Tasman Sea, S. Fuji Basin and area east of N.Z.	Combined float (PF2) and drifter programme			
PD2/CP1	Measure pathways of cross-equatorial transport.	3.2.4 3.4.2.10	10°N to 10°S across Pacific	Combined float (PF4) and drifter programme			

PROJECT- Drifters (Surface Flux) — Pacific

(PAC/009A) 4/7/88

Designation/ Core Project	**Keywords/Justification**	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PDSFG/CP1	Verification of surface fluxes of heat and momentum	3.2.7 3.2.8 3.3.1 3.4.2.8	Sparsely sampled regions of Basin	Likely regions for deployment include eastern tropical Pacific, central and eastern S. Pacific and Southern Ocean. Coordinate with WOCE Meteorological VOS programme.	Use surface flux drifters with thermistor chains Requirement may be partially met by mooring instruments (PSFG). At least one array of 16 drifters. Original deployment = 16 Reseeding = 80 Total = 96		

PROJECT- **Drifters (Surface Velocity Programme)** **Southern**

(SOU/010) 6/7/88

Designation/ Core Project	**Keywords/Justification**	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
SDG/CP1,2	Characterize large-scale transport in upper layer so that magnitude and effect of geostrophic and ageostrophic wind-driven flow is determined. Map total near surface flow and describe low-frequency large-scale variability. Test models of wind-driven flow and quantify transport of heat in upper layer, its role in ocean climate and its varia-bility. Examination of near-surface flow and its variations in west wind drifts and bifurca-bons along eastern boundaries.	3.2.4 3.2.7 3.3.2 4.3.1.2/4 4.4.2	Southern Ocean South of 45°S	Satellite altimetry for geostrophic height. Satellite scatterometry for oceanic surface winds. Deployment from WHP, VOS or other ships. Coordinate deployments in southern portion of basin and Southern Ocean with on-going WWW/TOGA drifting buoy programmes. Drifters should be drogued. Deployments should be intense in region of ACC and southern edges of subtropical gyres. Assume drifter lifetime of 2.5 years.	200 drifters maintained during the 5-year WOCE intensive observing period 10% of drifters should have T/S chains. All drifters to measure surface pressure and SST. original deploy-ment = 200 Reseeding = 200 (if 2.5 yr lifetime maintained). Total = 400.	Begin 6-12 months before WOCE IOP	
SD1/CP2	Dynamics and thermo-dynamics of sea-ice cover Surface pressure field.	4.3.1.2/4	Circumpolar in ice fields	If possible, buoys should also measure ice thickness. Buoys must be ice-strengthened. Track buoys via Argos.	20 drifters per year, 10 T/S chains for 5 years Deploy in clusters of 5 near Antarctic bases during austral summer and autumn. Total drifters = 100 With T/S chains = 50.		
SD2/CP2	Mixed layer characteristics of Weddell Gyre. Monitor seasonal stability of water column.	4.3.1.2	Weddell Gyre	Deploy in incoherent array Coordination with ice studies is recommended.	20 drifters each of two years. Drifters with 300m T/S chains. Total drifters = 40.	Austral summer	

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5.5 Moorings

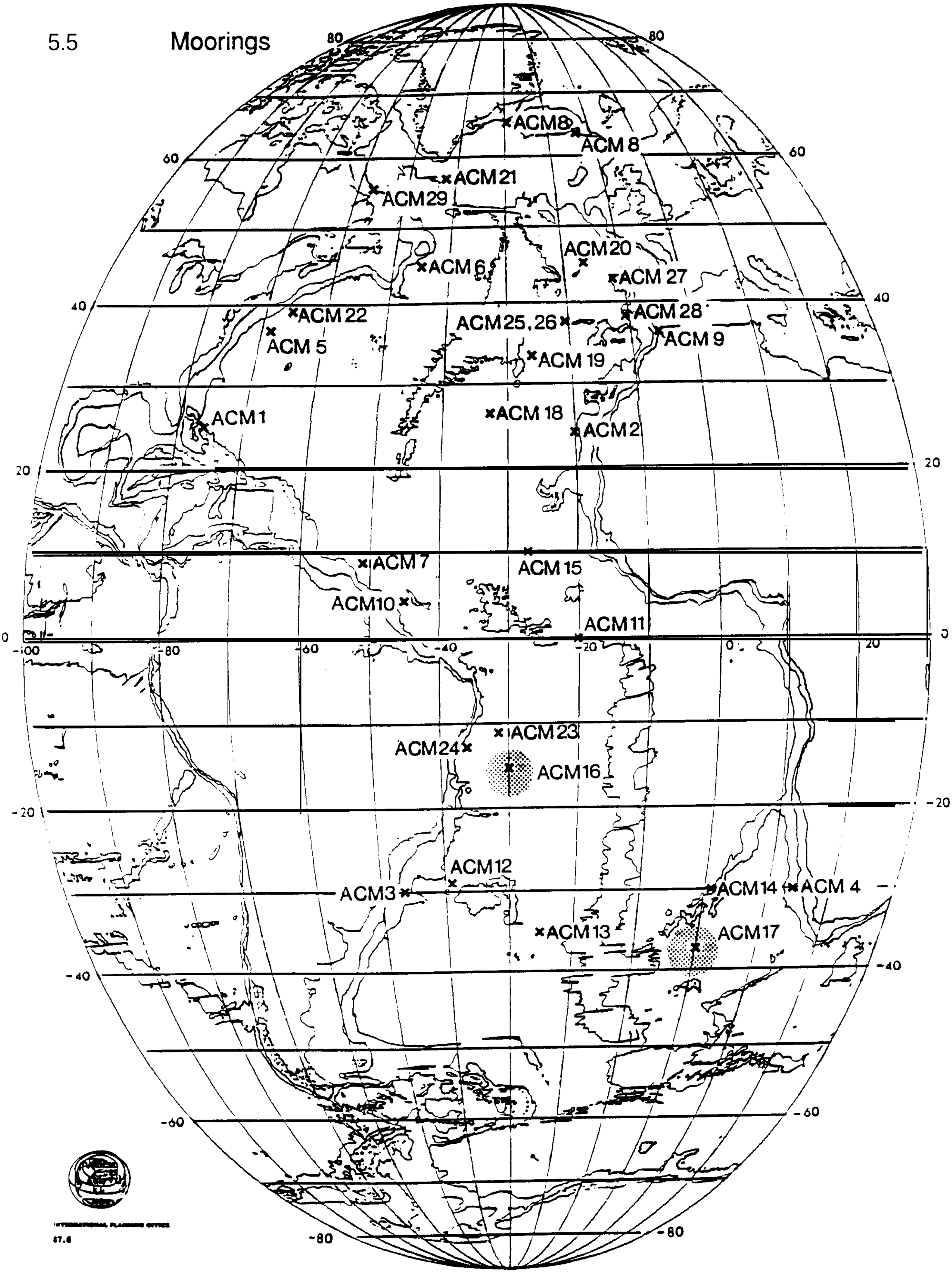

Fig. (5.10) Moored Instrumentation Sites in the Atlantic Ocean

PROJECT- Moorings (Heat Flux and Boundary Currents) **Atlantic**

(ATUO 10) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
ACM1/CP1,3	On HEAT FLUX Section A5. Measure meridional HEAT transport in western N.Atlantic. Estimate mean transport and variability of N.A. western boundary current. Monitor transport through Florida Strait. Explore existence of flows in upper and bottom layers offshore Bahamas.	3.2.5 3.4.1.9 5.2.5.1	24°N, 78°W	On sections A5 and AR1. Good transport measurements can be made using cross-channel sea-level differences and voltage as measured by a cable in Florida Strait. Deployment must coincide with WHP Section.	3-5 moorings with 12-20 C.M.	12-18 months while A5 and AR2 being occupied.	
ACM2/CP1,3	On HEAT FLUX Section A5. Measure meridional HEAT transport in eastern N. Atlantic. Estimate mean transport and variability of N.A. eastern boundary current.	3.2.5 3.4.1.9 5.2.5.1	24°N, 22°W	Exploratory and intensive arrays required. Deployment must coincide with WHP Section.	3-5 moorings with 12-20 C.M.	12-18 months while A5 and AR2 being occupied.	
ACM3/CP1,2,3	ON HEAT FLUX Section A.10. Measure meridional HEAT transport in western S. Atlantic. Estimate mean transport and variability of S.A. western boundary current.	3.2.5 3.4.1.9 4.3.1.1 4.3.2.1 4.4.5 5.2.5.1/3	30°S, 45°W	Both shallow and deep C.M. required. Exploratory and intensive arrays required. Satellite altimetric and scatterometer measurements required during operational period. Deployment must coincide with WHP Section. Coordinate with CP3 Basin-scale measurement requirements.	5 moorings, each with 5 C.M. Total C.M. = 25	12-18 months while A10 being occupied.	
ACM4/CP1,2,3	ON HEAT FLUX section A 10. Estimate mean transport and variability of S.A. eastern boundary current. Measure meridional heat transport in eastern S. Atlantic	3.2.5 3.4.1.9 4.3.1.1 4.3.2.1 4.4.5 5.2.5.1/3	30°S, 15°E	Exploratory and intensive arrays required. Satellite altimetric and scatterometer measurements required during operational period. Deployment must coincide with WHP Section. Coordinate with CP3 Basin-scale measurement requirements.	5 moorings each, with 5 C.M. Total C.M. = 25	12-18 months while A10 being occupied.	
ACM29/CP1	On Section Al across the Labrador Shelf and Slope to measure the fluxes of fresh water and heat being transported equatorward from the Arctic by the Labrador Current		55°N, 56°W	Must get estimate of monthly heat and fresh water flux throughout the WOCE IOP. Requires T and S measurements in the upper 100m in the presence of sea ice and icebergs.	3 moorings, robust T/S chain when available, ice drifters, estimates of ice thickness for ice flux estimates. 4 C.M. each. Total C.M. = 12,	Continuous WOCE IOP	

PROJECT- Moorings (Boundary Currents and Deep Flow Arrays) — Atlantic

(ATL/009) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
ACM5/CP1,3	Measure transport of western boundary current of N. Atlantic subtropical gyre.	3.2.5 3.4.1.9 5.2.5.1	35°N, 65°W SE of Cape Cod		5 moorings with 25 C.M.		
ACM6/CP1,3	Measure transport of western boundary current of N. Atlantic subtropical gyre.	3.2.5 3.4.1.9 5.2.5.1	45°N, 45°W E. of Grand Banks		5 moorings with 25 C.M.		
ACM7/CP1,3	Measure transport of western boundary current of N. Atlantic subtropical gyre. Measure cross-equatorial flow along coast of S. America.	3.2.5 3.4.1.9 5.2.5.1	10°N, 50°W	Experiment can be better designed following results of pre-WOCE and TOGA experiments.	3 moorings with 12 C.M.		
ACM8/CPl,3	Measure inflow of NADW into Atlantic over Greenland-Iceland- Faroe-Scotland ridge system.	3.2.5 3.4.1.9 5.2.5.1/2	G-I-F-S Ridge system	Monitoring for T/S variability alone would require considerably fewer instruments. On Section Al.	Denmark Strait - 8 moorings with 3/4 current-meters each. Other areas - 6 moorings with 3/4 current-meters each.	Throughout WOCE.	
ACM9/CP1,3	Measure inflow of Mediterranean Water into Atlantic. Estimate net salt flux into N. Atlantic from Med. Sea during WOCE.	3.2.5 3.4.1.9 5.2.5.2	Straits of Gibraltar	Results of 1986/87 study will help design effective array.		Throughout WOCE.	
ACM10/CP1,3	Measure transport of Antarctic Bottom Water into N. Atlantic.	3.2.5 3.4.1.9 5.3.3.4	4°N, 40°W Ceara Rise	Deploy single long term mooring as soon as possible.	Five mooriings, each with 3 C.M. Total C.M. = 15	Throughout WOCE.	
ACM11/CP1,3	Estimate exchange of deep waters between western and eastern basins.	3.2.5 3.4.1.10 5.3.3.4	0°, 20°W Romanche Fracture Zone	Must determine spatial and temporal scales of exchange. Exploratory measurements are needed before long term array is designed.	Five moorings, each with 3 C.M. Total C.M. = 15	Exploratory ASAP. WOCE IOP.	
ACM12/CP1,3	Measure exchange of deep waters through Verna Channel (Rio Grand Gap) into eastern basin of S. Atlantic.	3.2.5 3.4.1.9 5.3.3.4	30°S, 39°W Verna Channel	Deploy single long term mooring as soon as possible.	Five moorings, each with at least 3 C.M. Total C.M. = 6	Throughout WOCE.	
ACM13/CPl,3	Estimate exchange of deep water between western and eastern basins.	3.2.5 3.4.1.10 5.3.3.4	37°S, 27°W Hunter Gap	Exploratory measurements are needed before long term array is designed.	Five moorings, each with at least 3 C.M. Total C.M. = 15	Exploratory ASAP. WOCE IOP.	
ACM14/CP1,3	Measure exchanges of deep waters over Walvis Ridge into eastern basin of S. Atlantic.	3.2.5 3.4.1.10 Ridge	30°S, 03"E Walvis	Review recent tracer data and LONG LINES sections to determine if there is significant flow into eastern basin. If yes, a search for pathway and measurements will be necessary.			

PROJECT- **Moorings (Eddy Statistics)** **Atlantic**

(ATL/004) 3/6/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
ACM15/CP1	Indicate vertical and temporal characteristics of eddy velocity and temperature field of N. Atlantic.	3.2.5 3.4.1.12	10°N, 27°W		Full depth One mooring with 6 C.M.		
ACM16/CP1	Test similarity of eddy velocity field of S. Atlantic to N. Atlantic.	3.2.5 3.4.1.12	Brazil Current to interior of S.Atlantic sub-tropical gyre		Full depth 3-5 moorings each with 6 C.M. Total C.M. = 18-30		
ACM17/CP1	Determine vertical structure of eddy field and its variability with season and distance from Drake Passage, the ACC and/or the Agulhas Retroflection Region.	3.2.5 3.4.1.12	Higher Lat. S. Atlantic		Full depth 6-10 moorings each with 6 C.M. Total C.M. = 36-60		

PROJECT- **Moorings (CP3 Special Projects)** **Atlantic**

(ATL/014) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ACM18/CP3	CONTROL VOLUME I	5.3.2	27°N, 32.5°W (C.V.I.)		Three moorings, Each with 3-5 C.M. Total C.M. = 9-15.		
ACM19/CP3	CONTROL VOLUME II	5.3.2	34°N, 27.5°W (C.V. II)		Three moorings, Each with 3-5 C.M. Total C.M. = 9-15		
ACM20/CP3	CONTROL VOLUME III	5.3.2	42° to 50°N 09° to 30°W (C.V.III)		Three moorings, Each with 3-5 C.M. Total C.M. = 9-15		
ACM21/CP3	CONTROL VOLUME IV	5.3.2	46 to 56°N west of 40°W (C.V.IV)		Three moorings, Each with 3-5 C.M. Total C.M. 9-15		
ACM22/CP3	CONTROL VOLUME V	5.3.2	Cape Cod-Bermuda-Nova Scotia (C.V.V)		Three moorings, Each with 3-5 C.M. Total C.M. = 9-15		
ACM23/CP3	DEEP BASIN Experiment - Site Moorings. Measurement of mean flows and transports where signal is expected to be large. Obtain long-term statistics at several sites for estimating errors in means determined from float measurements and for judging the importance of long-term, interannual variations. Provide information to help guide the WOCE Float Programme, as well as further geographic explorations of the eddy field.	5.3.3.4	Brazil Basin	Not all measurements are to be made simultaneously. Five sites are to be sampled.	Five site moorings, each with 4 C.M. Total C.M. 20	Begin ASAP. Continues for two years.	
ACM24/CP3	DEEP BASIN Experiment - Deep western boundary currents. Measure strength and horizontal structure of DWBC.	5.3.3.4	Western Brazil Basin	Relatively broad deep flows. AABW and NADW currents are separated in the vertical Meridional variations are important as these give the amount of water lost in the interior of the Basin. Two, preferably three sections (arrays) are required.	Three arrays of eight moorings, each with 4 C.M. Total C.M. = 96.		

PROJECT- **Moorings (CP3 Special Projects)** **Atlantic**

(ATL/014) 6/7/88

Designation/ Operator Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible
ACM25/CP3	EKMAN LAYER and SUBDUCTION Map surface flux fields which drive the seasonal cycle. Map Ekman convergence which leads to Ekman pumping and vertical motion.	5.4.2 5.4.3.5	50° to 25°N near Azores, (C.V. I & II)	Also ASF1. To reduce ship's manpower requirements the buoys should be capable of deployment for at least one year periods so lifetime extension is required over present buoys. Drifters AD2 deployed in vicinity for calibration.	8-14 surface moorings, each with 10 VMCM meters. Total C.M. = 80-140 VMCM.	Two year duration.	
ACM26/CP3	EKMAN LAYER and SUBDUCTION Define field of mean velocity. Measure dynamic height around the surface moorings in ASF1/ACM25.	5.4.2 5.4.3.5	50° to 25°N near Azores (C.V.I & II)	Deploy in conjunction with ASF1/ACM25. Deploy drifters AD2 in vicinity for calibration.	Twelve subsurface moorings, each with 3 VACM. Depth of 100, 300 and 700m. Total C.M. = 36 VACM.	Two year duration.	
ACM27/CP3	EASTERN BOUNDARY CURRENTS	5.4.5	43°N across slope		Six moorings, each with 3-4 C.M. Total C.M. = 18-24.	WOCE IOP	
ACM28/CP3	EASTERN BOUNDARY CURRENTS	5.4.5	38°N across slope		Six moorings, each with 3-4 C.M. Total C.M. = 18-24.	WOCE IOP	

PROJECT- Moorings (T/S Chain Measurements) — Atlantic

(ATL/005) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
ATS1/CP1	Monitor changes in upper column leading to renewal of Labrador Sea water.	3.2.5 3.4.1.7 3.2.8	Central Labrador Sea	May be possible to use surface flux drifters with T/S chains to lesser depth. Possibly used in the drifting mode in centre of gyre.	Monitor at least upper 2000m. Report data daily or more frequently via satellite	At least over boreal winter months	
ATS2/CP1	Monitor mode water formation in high latitude S. Atlantic.	3.2.5 3.4.1.7 3.2.8	Brazil-Maldives Current	Possibly used in the drifting mode in centre of gyre	Monitor at least upper2000m. Report data daily or more frequently via satellite.		

PROJECT- Moorings (Air-Sea Flux) — Atlantic

(ATL/005) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
ASFG/CP1	Verification of surface fluxes of heat and momentum determined from remote sensing or from atmospheric GCMs. Observations on upper ocean temperature and salinity field to test coupled models and to provide a constraint on regional estimates of evaporation differences.	3.2.8 3.2.8.1 3.3.1 3.4.1.8	Under-sampled portion of Atlantic	Coordinate with VOS meteorological programme.	Moored buoys with surface flux instrumentation and T/S chains. Requirement may be partially met by drifting buoys (ASFDG).		
ASF1/CP3	EKMAN LAYER and SUBDUCTION. Map surface flux fields which drive the seasonal cycle. Map Ekman convergence which leads to Ekman pumping and vertical motion.	5.4.3.5	50° to 25°N, Near Azores (C.V. 1 & 2)	Also ACM25. Measurements of long wave radiation and humidity from buoys is not standard and will require development.	Eight to fourteen surface moorings, each carrying full met. instruments including shortwave and longwave radiation and humidity.	Two year duration	

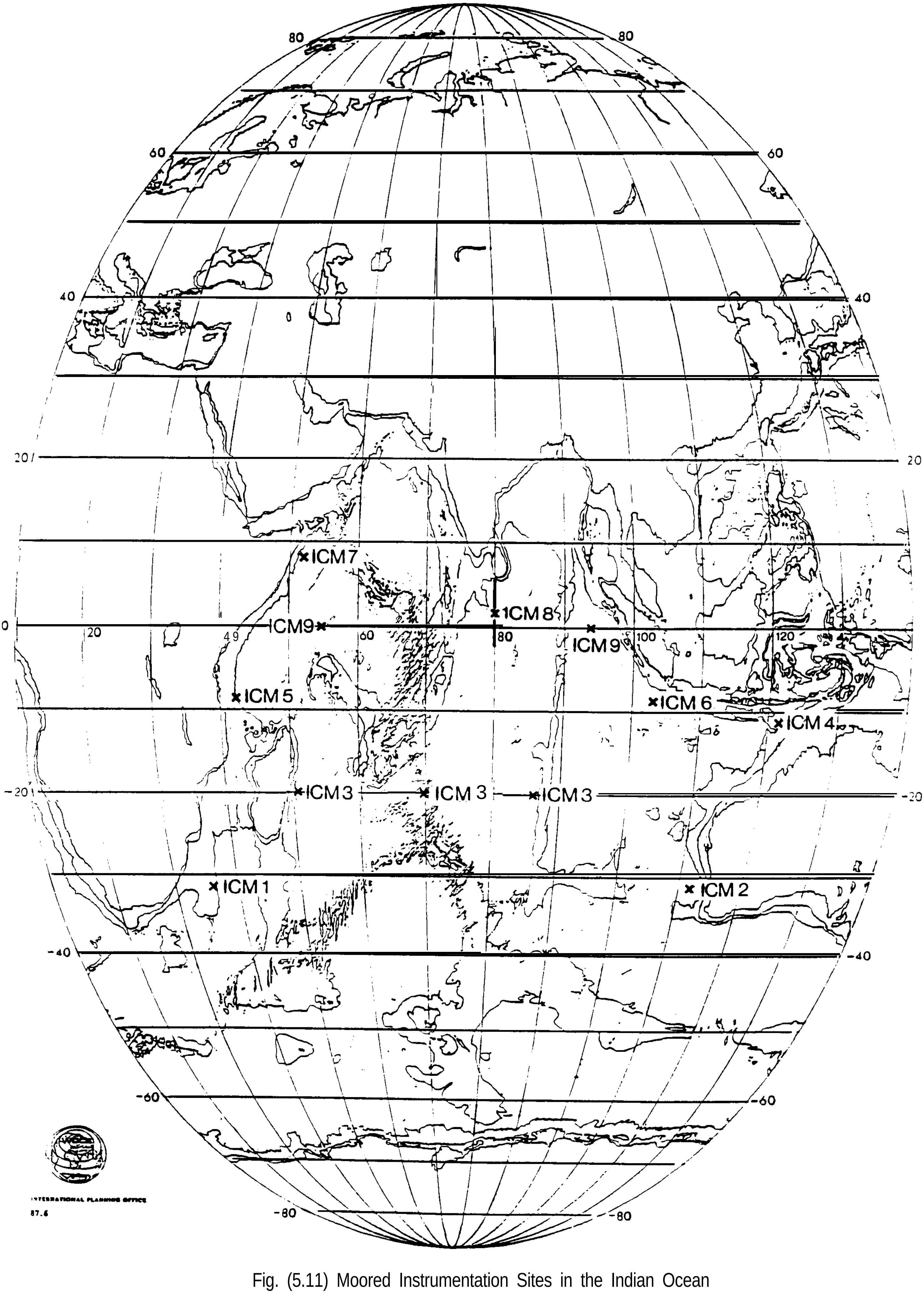

Fig. (5.11) Moored Instrumentation Sites in the Indian Ocean

PROJECT- Moorings (Heat Flux and Boundary Current) **Indian**

(IND/006A) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ICM1/CP1,2	On HEAT FLUX section I5. Measure meridional HEAT transport in western Indian Ocean. Both boundary currents and heat flux. Measure transport and variability of Agulhas Current.	3.2.5 3.4.3.9 4.3.1.1 4.3.2.1 4.4.5	32°S Agulhas Current	On western end of I5. Part of special/survey ISS1 Satellite altimetric and scatterometer measurements required during operational period.	5 moorings, each with 5 C.M. Total C.M. = 25	Austral summer	
ICM2/CP1,2	On HEAT FLUX section I5. Measure meridional HEAT transport in eastern Indian Ocean. Boundary currents and heat flux. Measure transport and seasonal/interannual variability of Leeuwin Current.	3.2.5 3.4.3.9 4.3.1.1 4.3.2.1 4.4.5	32°S Leeuwin Current	On eastern end of I5. Southern terminus of special/survey ISS3. Satellite altimetric and scatterometer measurements required during operational period.	5 moorings, each with 5 C.M. Total C.M. = 25	Austral summer	

PROJECT- Moorings (Boundary Current and Deep Flow Arrays)

Indian

(IND/006) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol. 11)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
ICM3/CP1	Measurements of three northward deep boundary currents at (1) 20°S and Madagascar, (2) central Indian Ridge, and (3) 90°E.	3.2.5 3.4.3.9	20°S and Madagascar. Indian Ridge. 90°E		Deep boundary current measure-ments only		
ICM4/CP1	Measure Pacific/Indian throughflow.	3.2.5 3.4.3.9	12°S, 124°E Timor Sea	Array may have to be reconsidered in view of Indo-Pacific throughtlows.	Monitoring phase array only (reduced array)		
ICM5/CP1	Upper portion of array will measure East African Coast current. Below 2500m array will cover deep western boundary current.	3.2.5 3.4.3.9	8°S, 42°E East Africa	On western end of section I2.			
ICM6/CP1	Exploratory measurements of currents off Sumatra.	3.2.5 3.4.3.9	8°S, 102°E West of Sumatra	On eastern end of section I2. Exploratory shipboard profiling required prior to array design.			
ICM7/CP1	Measure seasonal cycle of northern branch, Somali current transport and deep boundary current.	3.2.5 3.4.3.9	8°N, 52°W Horn of Africa	On western end of section I1. Deep boundary current was found to flow in opposite directions during two previous studies.			
ICM8/CP1	Measure transport variability of SW/NE monsoon current north of 2°N. Study seasonal and inter-annual variations of equatorial jet and undercurrents.	3.2.5 3.4.3.9	80°E from Sri Lanka to 2°S		Large system of arrays covering two current regimes. Possibly 6 moorings, each with an upward looking ADCP.		
ICM9/CP1 (West)	Measure events propagating along equator.	3.2.5 3.4.3.9	0°, 55°E		Single mooring including upward looking ADCP.		
(East)	Measure events propagating along equator.		0°, 93°E		Single mooring including upward looking ADCP.		

PROJECT- **Drifters (Surface Velocity Programme)** **Indian**

(IND/005) 6/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IDG/CP1	Characterize large-scale transport in upper layer so that magnitude and effect of geostrophic and ageostrophic wind-driven flow is determined. Map total near surface flow and describe low-frequency large-scale variability. Test models of wind-driven flow and quantify transport of heat in upper layer, its role in ocean climate and its variability. Examination of near-surface flow and its variations in west wind drifts and bifurcations along eastern boundaries.	3.2.4 3.2.7 3.3.2	Indian Basin North of 45°S	Satellite altimetry for geostrophic height. Satellite scatterometry for oceanic surface winds. Assume drifter life of 2.5 yrs. Deployment from WHP, VOS or other ships. Coordinate deployments in southern portion of basin and Southern Ocean with on-going WWW/TOGA drifting buoy programmes. Drifters should be drogued. Arrangements should be undertaken to assure even deployment and reseeding throughout basin or as required.	Some drifters measuring surface pressure and SST for improvement of flux estimates. Five year coverage. Original deployment = 180 Reseeding = 180 Total = 360 1/3 of drifters with thermistor chains.	WOCE IOP	
ID1/CP1	Interannual variability of surface flows.	3.2.4 3.4.3.10	55°E 12°N to 15°S	Assume drifter life of 2.5 years.	Seasonal release at 1° resolution = 100 drifters 1/3 of drifters with thermistor chains. Releases rep~ated 2 times to give a 5 year coverage. Total = 200	WOCE IOP	

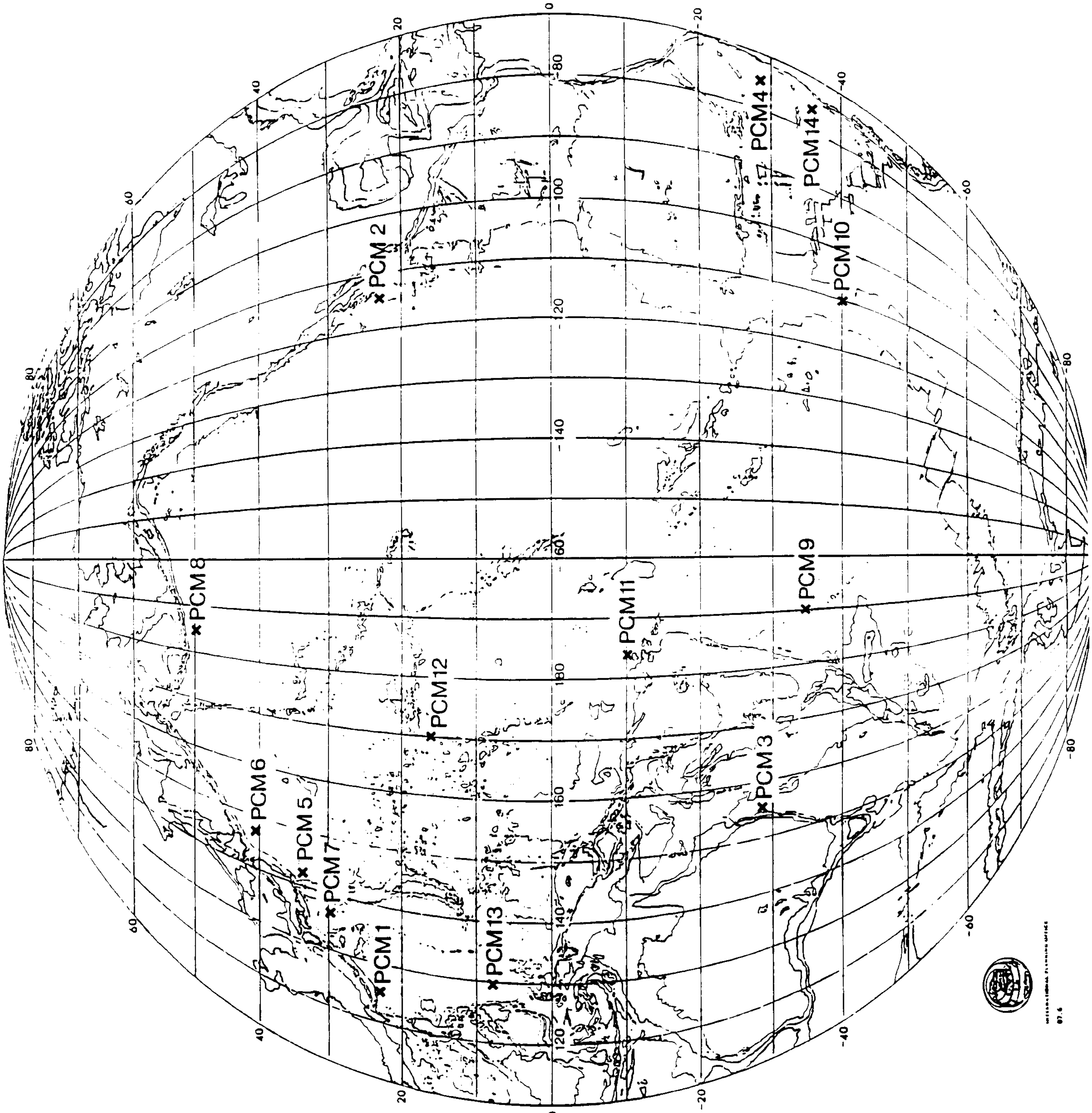

Fig. (5.12) Moored Instrumentation Sites in the Pacific Ocean

PROJECT- Moorings (Heat Flux and Boundary Current) **Pacific**

(PAC/007A) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PCM1/CP1	On HEAT FLUX section P3. Measure meridional heat transport in N. Pacific. Measure transport and variability of Kuroshio.	3.2.5 3.4.2.2 3.4.2.9	24°N, 125°E	Section P3. Deployment must coincide with WHP section.			
PCM2/CP1	On HEAT FLUX section P3. Measure meridional heat transport in N. Pacific. Measure transport and variability of California Current.	3.2.5 3.4.2.2/9	24°N, 115°W	Section P3. Deployment must coincide with WHP section.			
PCM3/CP1,2	On HEAT FLUX section P6. Measure meridional heat transport in S. Pacific. Transport and variability of EAC.	3.2.5 3.4.2.2/9 4.3.2.1 4.4.5	28°S, 155°E E. Australia Current	Section P6 Satellite altimetric and scatterometer measurements required during operational period. Deployment must coincide with WHP section.	5 moorings, each with 5 C.M. Total C.M. = 25	Austral summer	
PCM4/CP1,2	On HEAT FLUX section P6. Measure meridional heat transport in S. Pacific. Transport and variability of Peru Current.	3.2.5 3.4.2.2/9 4.3.2.1 4.4.5	28°S, 75°W Peru-Chile Current	Section P6. Satellite altimetric and scatterometer measurements required during operational period. Deployment must coincide with WHP section.	5 moorings, each with 5 C.M. Total C.M. = 25	Austral summer	

PROJECT- **Moorings (Boundary Current and Deep Flow Arrays)** **Pacific**

(PAC/007) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PCM5/CPI	Structure and variability of Kuroshio.	3.2.5 3.4.2.9	Vicinity of Japan		4-5 moorings.		
PCM6/CP1	Structure and variability of de 10 Link flows along the Izu Ridge and northern boundary.	3.2.5 3.4.2.9	N.E. of Japan		Deep current measurements.		
PCM7/CP1	Western boundary for deep circulation.	3.2.5 3.4.2.9	West of Izu-Ogasawara Ridge		Deep current measurements.		
PCM8/CP1	Provide better transport structures.	3.2.5 3.4.2.9	S. of Aleutians at 175°W		Deep current measurements.		
PCM9/CP1,2	Measure deep flow as it enters S.W. Pacific Basin from south.	3.2.5 3.4.2.9	37°S, 170°W Chatham Rise		Deep current measurements.		
PCM10/CP1	Measure deep flow into eastern South Pacific. Transport expected to be smaller than at PCM9.	3.2.5 3.4.2.9	40°S, 110°W E. Pacific Rise	Coordinate with PCM9.	Deep current measurements.		
PCM11/CP1	Deepest passage between North and South Pacific. Understanding of abyssal connection between N. and S. Pacific. Measure deep flow.	3.2.5 3.4.2.9	10°S, 175°W Samoan Passage		Deep current measurements.		
PCM12/CP1	Between Central Pacific Basin and Northwest Pacific Basin. Measure deep flow into western North Pacific.	3.2.5 3.4.2.9	17°N, 170°E	Lower priority than PCM11.	Deep current measurements.		
PCM13/CP1	Structure and variability of Mindanao Current Measure the southward flow along the western boundary which is fed by the North Equatorial Current	3.2.5 3.4.2.9	7°N, 130°E				
PCM14/CP1	Deep circulation measurements	3.2.5 3.4.2.9	35°S, 75°W	Maintain in association with PR14 and/or Antarctic supply ships. Part of PTS6.	Single moorings current meters and thermistor chain.		

PROJECT- Moorings (T/S Chain Measurements) — Pacific

(PAC/008) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PTS1/CP1	Provide index to eastward flowing EAC.	3.2.3 3.4.2.5/7	28°S, 167°E	Also PRS4.	Either moored T/S chain or Hydro station.		
PTS2/CP1	Provide index to eastward flowing EAC.	3.2.3 3.4.2.5/7	40°S, 160°E	Also PRS5.	Either moored T/S chain or Hydro station.		
PTS3/CP1	Observations of subpolar mode water and AAIW. With PR14 mooring and PCM14, will provide index of S. Pacific circulation.	3.2.3 3.4.2.5/7	47°S, 175°E	Operate in conjunction with current meter and T/C chain (PCM14, PTS6) on line PR14 Also PRS6.	Either moored T/S chain or Hydro Station.		
PTS4/CP1	Study dense water formation in North Pacific.	3.2.3 3.4.2.5/7	50°N, 150°E	Logistically difficult because of ice and seas. Also PRS7.	Either moored T/S chain or Hydro station.		
PTS5/CP1	Study dense water formation in North Pacific.	3.2.3 3.4.2.5/7	55°N, 173°E	Lower priority than PTS4/PR36 but logistically more feasible Also PRS8.	Either moored T/S chain or Hydro station.		
PTS6/CP1	Measure deep circulation.	3.2.5 3.4.2.517/9	35°S, 75°W	Maintain in association with PR14 and/or Antarctic supply ships. Part of PCM14.	Single mooring with T/S chain and currentmeters		

PROJECT- Moorings (Air-Sea Flux) — Pacific

(PAC/008) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PSFG/CP1	Verification of surface fluxes of heat and momentum determined from remote sensing or from atmospheric GCMs. Observations on upper ocean temperature and salinity field to test coupled models and to provide a constraint on regional estimates of evaporation differences.	3.2.8 3.3.1 3.4.2.8	Undersampled regions of Pacific	Coordinate with VOS meteorological programme	Moored buoys with surface flux instrumentation and T/S chains. Requirement may be partially met by drifting buoys.		

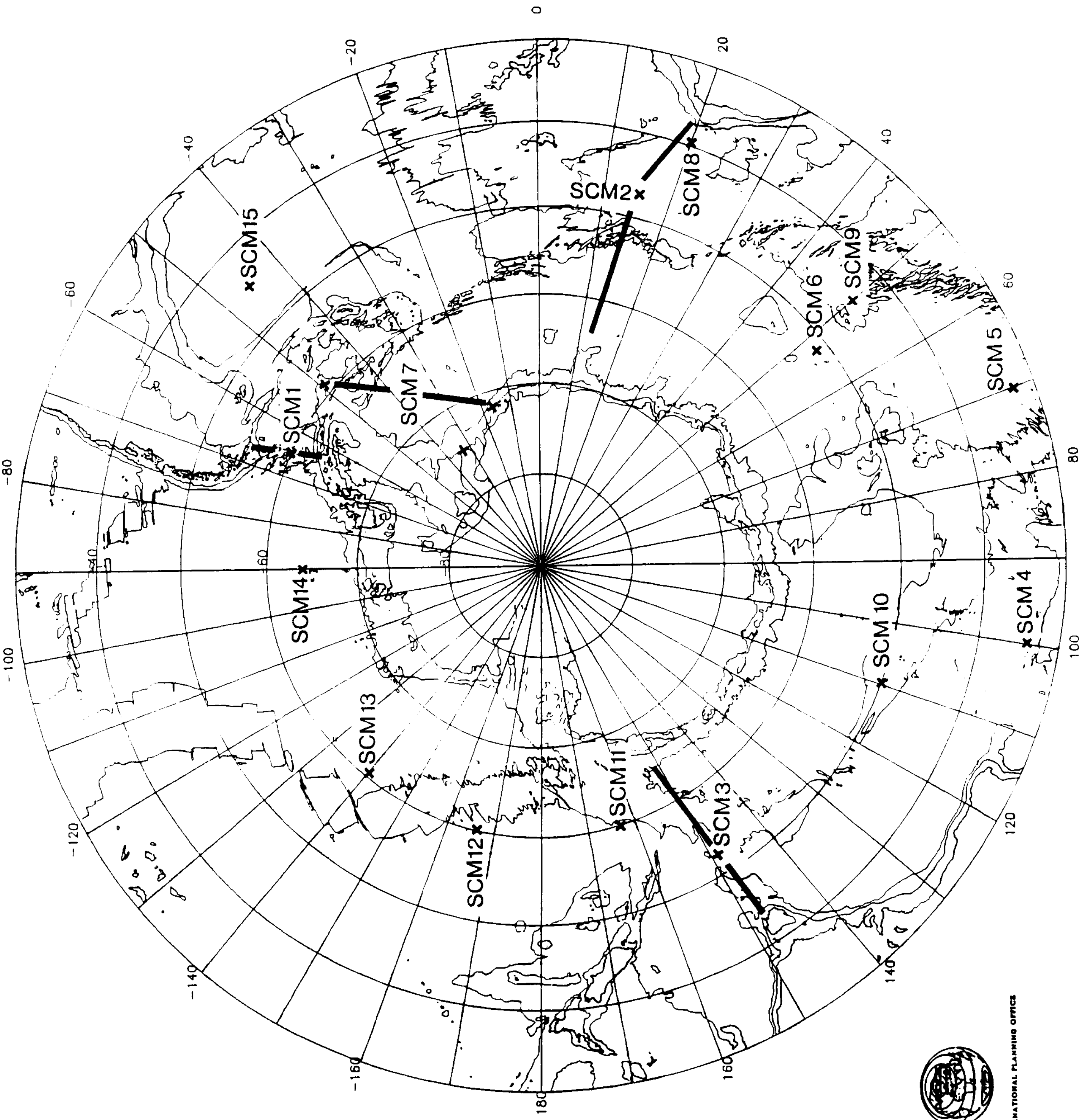

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Fig. (5.13) Moored Instrumentation Sites in the Southern Ocean

PROJECT- Moorings (Transport Measurements - Choke Point Fluxes) **Southern**

(SOU/001) 3/6/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
SCM1/CP2	On CHOKE POINT Section S1 Measure mean flux and variations of ACC and divergencies in ocean sectors. Provide density profile across Passage.	4.3.2.1 4.4.5	Drake Passage	Moored T/C sensors extending to within 200m of surface for density profile. ADCP profiles to be used to level along path connecting pressure gauge sites. If ADCP is not sufficiently precise, a short-term current-meter array sufficient to resolve the eddy field will be required (12 moorings and 34 deep current meters). Sampling with a vertical resolution of 100m is required. Deployment must coincide with WHP section.	Bottom pressure gauge on either side and at intervening topographic features. inverted echo sounders at each side. Total of 6 moorings 3 C.M. per mooring Total C.M. = 18.		
SCM2/CP2	On CHOKE POINT Section S1 Measure mean flux and variations of ACC and divergencies in ocean sectors. Provide density profile across passage.	4.3.2.1 4.4.5	Africa to Antarctica	Moored T/C sensors extending to within 200m of surface for density profile. ADCP profiles to be used to level along path connecting pressure gauge sites. If ADCP is not sufficiently precise, a short-term current-meter array sufficient to resolve the eddy field will be required (18 moorings and 36 deep current meters). Sampling with a vertical resolution of 100m is required. Deployment must coincide with WHP section.	Bottom pressure gauge on either side and at intervening topographic features. inverted echo sounders at each side. Total of 8 moorings. 3 C.M. per mooring Total C.M. = 24.		
SCM3/CP2	Measure mean flux and variations of ACC and divergencies in ocean sectors On CHOKE POINT Section S3.	4.3.2.1 4.4.5	Tasmania to Antarctica	Moored T/C sensors extending to within 200m of surface for density profile. ADCP profiles to be used to level along path connecting pressure gauge sites. If ADCP is not sufficiently precise a short-term current-meter array sufficient to resolve the eddy field will be required (18 moorings and 36 deep current meters). Sampling with a vertical resolution of 100m is required. Deployment must coincide with WHP section.	Bottom pressure gauge on either side and at intervening topographic features. Inverted echo sounders at each side. Total of 8 moorings. 3 C.M. per mooring Total CM = 24.		

PROJECT- **Moorings (Boundary Current and Deep Flow Arrays)** **Southern**

(SOU/008) 5/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
SCM4/CP2	Measure flow of AABW into Indian Ocean Basin.	4.3.2.1 4.4.5	32-S, 100°E		One mooring with 5 C.M.	Austral summer	
SCM5/CP2	Measure flow of AABW into Indian Ocean Basin.	4.3.2.1 4.4.5	30°S, 75°E		One mooring with 5 C.M.	Austral summer	
SCM6/CP2	Measure flow of AABW into Indian Ocean Basin.	4.3.2.1 4.4.5	25°S, 52°E 50°S, 52°E		Two moorings with 5 C.M. Total C.M. = 10	Austral summer	
SCM7/CP2	Monitor western boundary current in the Weddell Sea.	4.3.2.4	58°S, 50°W to 72°S, 12°W and 75°S, 34°W	A series of 5 arrays at 100km spacing from the flank of S. Orkney Plateau into the gyre would resolve eddy field. During observational period also monitor inflow of relatively warm salty deep water into Weddell Sea off Cape Norwegia. Monitor outflow from Filchner Depression.	Ten moorings with 3 C.M. each. Total C.M. = 30. T/S sensors on moorings monitoring Filchner Depression. At time of deployment/ recovery, observe a CTD section with ADCP from S. Orkneys to Cape Norwegia.	Austral Summer	

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
SCM8/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. High eddy energy in region of Agulhas Retroflection.	4.3.2.2 4.4.5	South of Africa, 40°S, 20°E	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM9/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. High eddy energy region where ACC crosses Kerguelen Plateau.	4.3.2.2 4.4.5	Kerguelen Plateau at 45°S	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM10/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. Low eddy energy based on Seasat data.	4.3.2.2 4.4.5	South of Australia, 50°S, 1 10°E	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM11/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. Region of high eddy energy based on Seasat data. Study bifurcation of ACC south east of N.Z.	4.3.2.2 4.4.5	South of N.Z. at 60°S, 165°E	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM12/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. Region of low eddy energy based on Seasat data.	4.3.2.2 4.4.5	South Pacific, 60°S, 165°W	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	

PROJECT- **Moorings (Eddy Statistics)** **Southern**

(SOU/004) 3/6/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme	Logistical Details Constraints	Time Frame	Responsible Operator
SCM13/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. High eddy energy region as ACC crosses mid-ocean ridge.	4.3.2.2 4.4.5	South Pacific, 60°S,140°W	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM14/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. Low eddy energy region where ACC crosses S.E. Pacific Basin.	4.3.2.2 4.4.5	S.W. of Chile, 63°S, 90°W	Deployment must occur during operational period of the satellite altimeters.	Two moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 10.	2 year duration	
SCM15/CP2	Estimate vertical variation of eddy energy and horizontal heat flux. Study cross/down stream wavenumber statistics of ACC in the Atlantic sector (North-South variation in eddy covariances).	4.3.2.2 4.4.5	East of Argentina, 45°S. 45°W	Deployment must occur during operational period of the satellite altimeters.	Four moorings to full depth with 5 C.M. each. One C.M. on each mooring to have pressure sensor. All C.M. to have expanded temper-ature scales. Total C.M. = 20.	2 year duration	

5.6 Voluntary Observing Ships

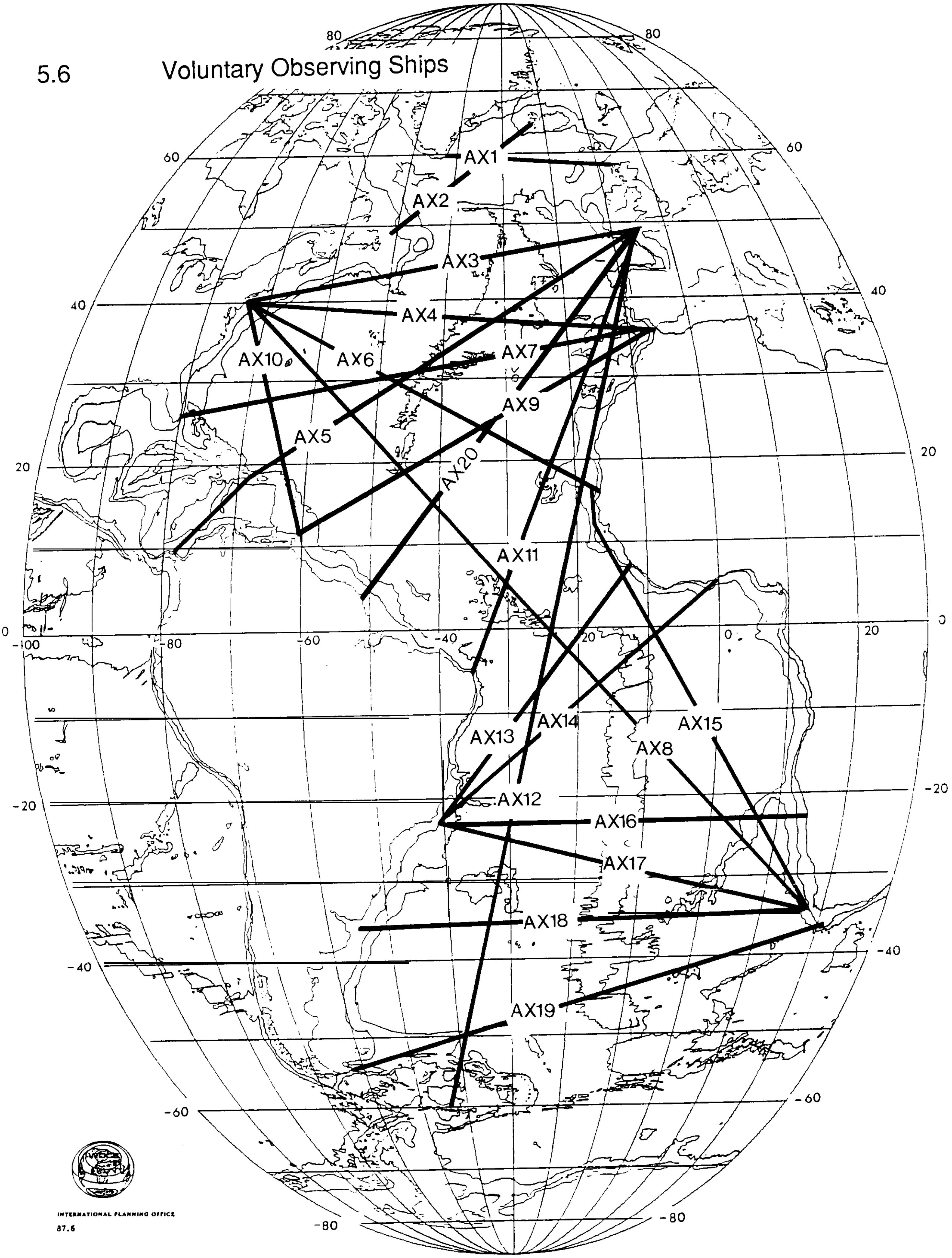

Figure 5.14 VOS Network in the Atlantic Ocean

PROJECT - VOS (XBT/XCTD Sections)

Atlantic
(ATL/008) 11/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AX1/CP1,3	Monitor seasonal and interannual variability in the heat and fresh water contents of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Greenland to Scotland	Salinity and high density sampling required.	Extend to 1000m	Monthly	
AX2/CP1,3	Monitor seasonal and Interannual variability in the heat and fresh water contents of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Iceland to Grand Banks	Salinity required. Extra deep probes required.	Extend to 2000m in Labrador Sea	Monthly	
AX3/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	New York to English C.		Extend to 1000m	Monthly	
AX4/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Baltimore to Gibraltar		Extend to 1000m	Monthly	
AX5/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Panama to English C.	Coordinate with TOGA	Extend to 1000m	Monthly	
AX6/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	New York to Dakar	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX7/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Miami to Gibraltar		Extend to 1000m	Monthly	
AX8/CP1.3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	New York to Cape of Good Hope	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX9/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Trinidad to Gibraltar	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX10/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	New York to Trinidad	Coordinate with TOGA.	Extend to 1000m	Monthly	

PROJECT - VOS (XBT/XCTD Sections)

Atlantic
(ATL/008) 11/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
AX11/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 5.2.3	Brazil to English C.	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX12/CP1,2,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 4.3.1.1 5.2.3	Europe to Mid Atlantic Islands and/ or Antarctica	Use supply ships. Coordinate with TOGA. Coordinate with CP2 for ships going to Antarctica.	Extend to 1000m	Each supply run	
AX13/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Rio de Janeiro to Liberia	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX14/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Rio de Janeiro to Nigeria	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX15/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Dakar to Cape of Good Hope	Coordinate with TOGA.	Extend to 1000m	Monthly	
AX16/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Rio de Janeiro to Angola		Extend to 1000m	Monthly	
AX17/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Rio de Janeiro to Cape of Good Hope		Extend to 1000m	Monthly	
AX18/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 3.4.1.6 5.2.3	Buenos Aires to Cape of Good Hope		Extend to 1000m	Monthly	
AX19/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 5.2.3	Cape Horn to Cape of Good Hope		Extend to 1000m	Monthly	
AX20/CP1,3	Monitor seasonal and interannual variability in the heat content of the upper ocean.	3.2.3 5.2.3	English Channel to Guyana	Coordinate with TOGA.	Extend to 1000m	Monthly	

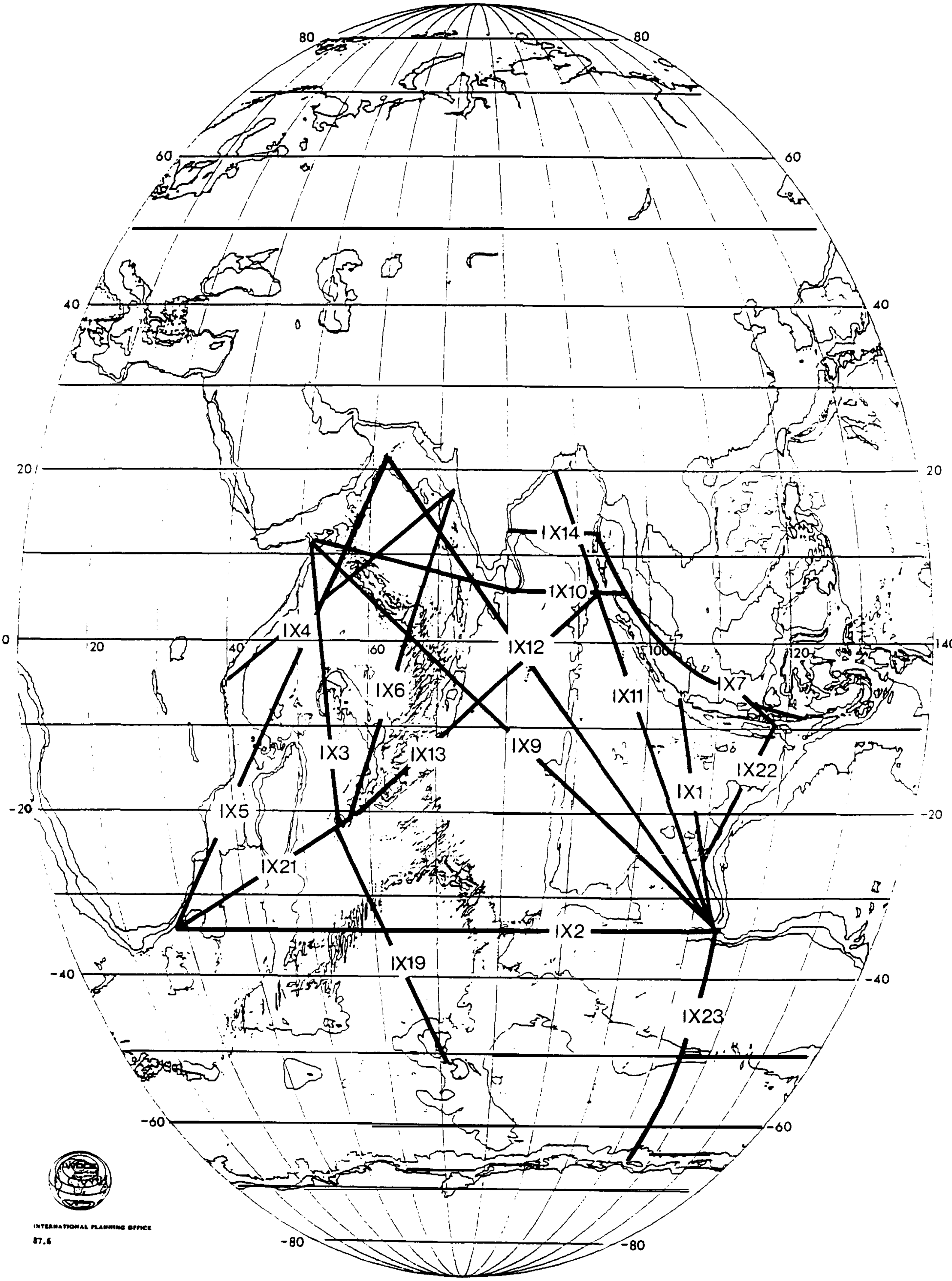

Figure 5.15 VOS Network in the Indian Ocean

PROJECT - VOS (XBT/XCTD Sections)

Indian
(IND/011) 27/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IX1/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Java/Arufa Sea	Coordinate with TOGA.		Monthly	
IX2/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Cape of Good Hope - Fremantle	Coordinate with TOGA.		Monthly	
IX3/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Red Sea - La Reunion	Coordinate with TOGA.		Monthly	
IX4/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Mombasa - Bombay	Coordinate with TOGA.		Monthly	
IX5/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Dubai - Durban	Coordinate with TOGA.		Monthly	
IX6/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	La Reunion - Bombay	Coordinate with TOGA.		Monthly	
IX7/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Java Sea - Malacca Strait	Coordinate with TOGA.		Monthly	
IX9/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Red Sea	Coordinate with TOGA.		Monthly	
IX10/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Singapore - Sri Lanka - Somalia	Coordinate with TOGA.		Monthly	
IX11/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Karachi	Coordinate with TOGA.		Monthly	
IX12/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Dubai	Coordinate with TOGA.		Monthly	
IX13/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Mauritius - Penang	Coordinate with TOGA.		Monthly	
IX14/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Malacca Strait - Andaman Sea	Coordinate with TOGA.		Monthly	
IX19/CP1,2	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	La Reunion - Kerguelen	Coordinate with Core Project 2.	Extend to 1000m	Whenever possible	

PROJECT - VOS (XBT/XCTD Sections)

Indian

(IND/011) 27/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
IX21/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Mauritius - Durban	Coordinate with TOGA.		Monthly	
IX22/CP1	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Sunda Strait	Coordinate with TOGA.		Monthly	
IX23/CP1,2	Monitor seasonal and interannual variability in the heat and fresh water content of the upper ocean.	3.2.3 3.4.3.6 5.2.3	Fremantle - Antarctica	Coordinate with Core Project 2.	Extend to 1000m	Whenever possible	

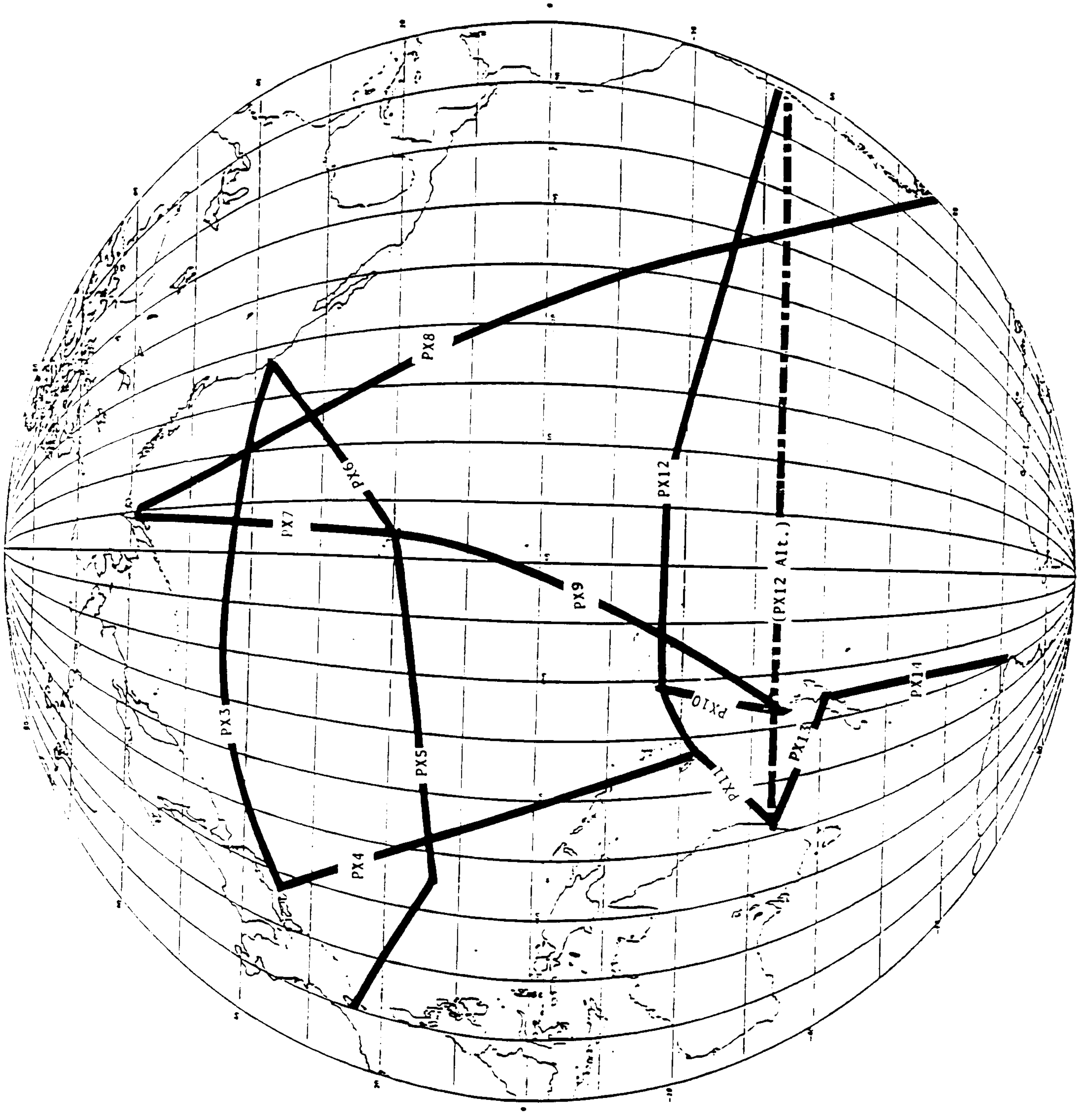

Figure 5.16a VOS high-density Network in the Pacific Ocean
b VOS TRANSPAC Network PX1
c VOS TOGA Network PX2

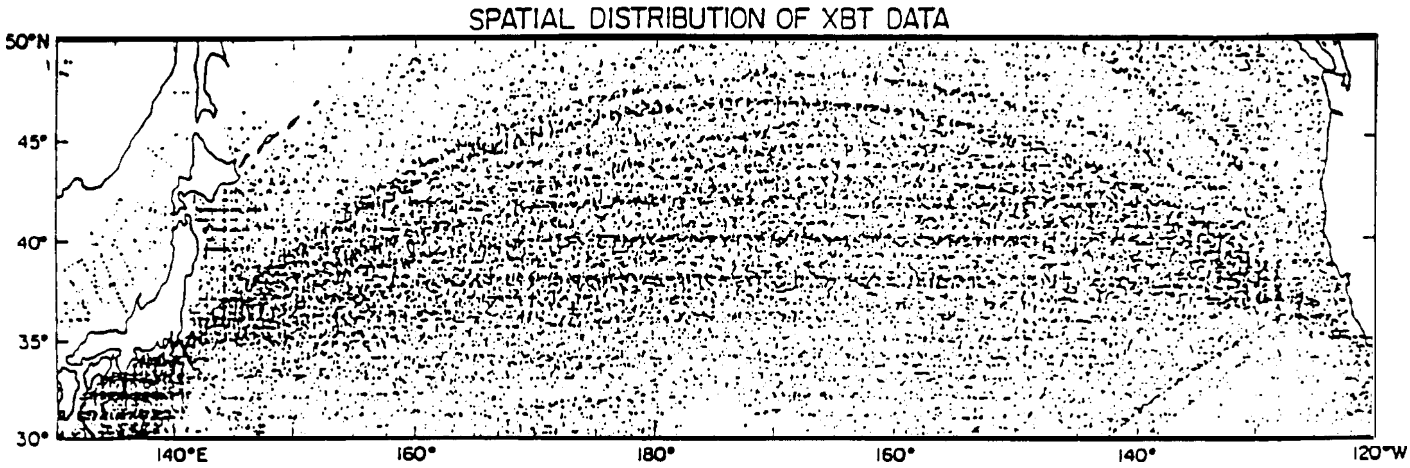

Fig. 5.16 b The TRANSPAC Network in the Northern Pacific Ocean

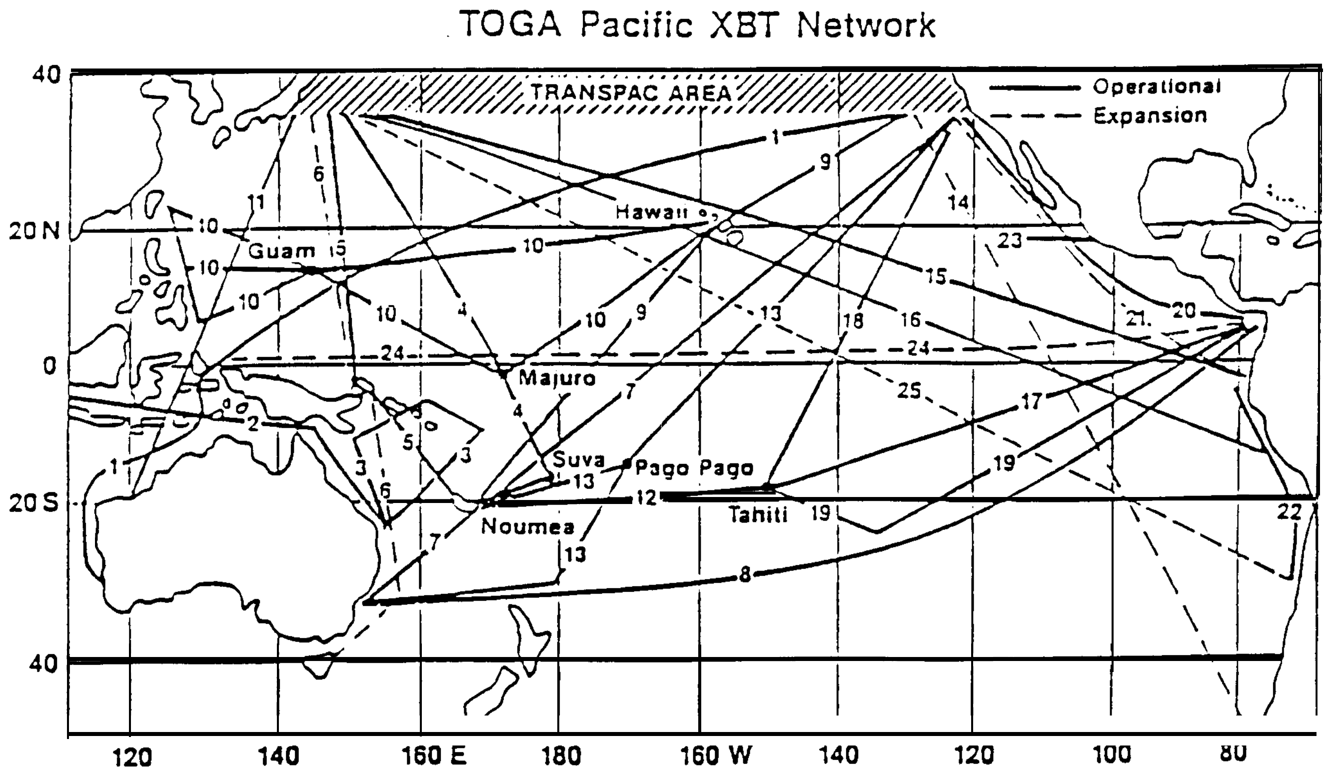

Fig. 5.16 c The TOGA Pacific XBT Network

PROJECT- **VOS (XBT/XCTD Sections)** **Pacific**

(PAC/006) 11/7/88

Designation/ Core Project	Keywords/Justification	Reference (Vol.II)	Location	Time/Space/Programme Constraints	Logistical Details	Time Frame	Responsible Operator
PX1/CP1	Continuation of TRANSPAC Frogramme. Low density sampling for heat and salt storage.	3.2.3 3.4.2.6	30°N-50°N across N. Pacific	Coordinate with TRANSPAC.	Upper 400-750 metres.	Continuous	
PX2/CP1	Continuation of TOGA XBT Network. Low density sampling for heat and salt storage.	3.2.3 3.4.2.6	30°S-30°N across Pacific.	Coordinate with TOGA.	Upper 400-750 metres.	Continuous	
PX3/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Tokyo to San Francisco		Extend to 1000m depth.	Seasonally	
PX4/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Tokyo to Noumea		Extend to 1000m depth.	Seasonally	
PX5/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Taiwan to Guam to Hawaii		Extend to 1000m depth.	Seasonally	
PX6/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6 3.4.2.5	Hawaii to San Francisco		Extend to 1000m depth.	Seasonally	
PX7/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Hawaii to Kodiak		Extend to 1000m depth.	Seasonally	
PX8/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Valdez/Alaska to Drake Passage		Extend to 1000m depth.	Seasonally	
PX9/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Hawaii to Auckland		Extend to 1000m depth.	Seasonally	
PX10/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Suva to Auckland		Extend to 1000m depth.	Seasonally	
PX11/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Sydney to Suva		Extend to 1000m depth.	Seasonally	
PX12/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Suva to Tahiti to Valparaiso (or Sydney to Valparaiso).		Extend to 1000m depth.	Seasonally	
PX13/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Sydney to Wellington		Extend to 1000m depth.	Seasonally	
PX14/CP1	High density sampling (eddy-resolution).	3.2.3 3.4.2.6	Christchurch to McMurdo		Extend to 1000m depth.	Each supply run	

LIST OF ACRONYMS AND SPECIAL TERMS

AABW	Antarctic Bottom Water
AAIW	Antarctic Intermediate Water
ACC	Antarctic Circumpolar Current
ADCP	Acoustic Doppler Current Profiler
ADEOS	Advanced Earth Observing Satellite
AGCM	Atmospheric General Circulation Model
AJAX	1983 Oceanog. cruise along 0° Meridian into Weddell Sea (USA, TAMU SIO)
ALACE	Autonomous Lagrangian Circulation Explorer
AO	Announcement of Opportunity
AMI	Active Microwave Instrument
AMS	Accelerator Mass Spectrometer
Argos	Satellite location and data collection system (CNES and NOAA)
Atlantis	Research Vessel (USA)
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
Bomb-^{14}C	Radioisotope of Carbon - generated by nuclear bomb testing
CCCO	Committee on Climatic Changes and the Ocean (SCOR and IOC)
CDW	Circumpolar Deep Water
CFC	Chlorofluorocarbon
CFM	Chlorofluoromethane
CME	Community Modelling Effort
CNES	Centre National d°Etudes Spatiales (France)
CTD	Conductivity Temperature Depth (instrument)
DAC	Data Assembly Centre (WOCE)
Discovery	Research Vessel (UK)
DMSP	Defense Meteorological Satellite Program
DORIS	Doppler Orbit and Radio Positioning Integration by Satellite
DSRT	Deep Sea Reversing Thermometer
ECMWF	European Centre for Medium-Range Weather Forecasts
EGCM	Eddy-resolving General Circulation Model
ENSO	El Nino-Southern Oscillation
EOSC	Earth Observations Science Committee (of ESA)
ERS-1	European Space Agency Remote Sensing Satellite
ESA	European Space Agency
FASINEX	Frontal Air-Sea Interaction Experiment
FGGE	First GARP Global Experiment (WMO)
FRAM	Fine-Resolution Antarctic Model (UK)
GARP	Global Atmospheric Research Programme (WMO/ICSU)
GATE	GARP Atlantic Tropical Experiment
GCM	General Circulation Model
GEOSECS	Geochemical Ocean Sections Study
GF3	General Format No 3
GFDL	Geophysical Fluid Dynamics Laboratory (USA)
GOFS	Global Ocean Flux Study (USA)
GPS	Global Positioning System (USA)

GLOSS	Global Sea-Level Observing System (IOC)
GRADO	CNES Gravity Satellite (France)
GRM	NASA Gravity Satellite (USA)
GTS	Global Telecommunication System (WMO)
HUMICAP	Humidity sensor on drifters (FASINEX)
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Services System (IOC/WMO)
IGY	International Geophysical Year (1957)
INDIGO	French programme, Indien Gaz Oc6an
IPO	WOCE International Planning Office
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IODE	International Oceanographic Data/Information Exchange (IOC)
IR	Infra-red (Radiometers)
ISOS	International Southern Ocean Studies
ITPO	International TOGA Planning Off ice
JASIN	Joint Air-Sea Interaction Experiment
JEDA	Joint Environmental Data Center
JGOFS	Joint Global Ocean Flux Study
JSC	Joint Scientific Committee for WCRP (WMO/ICSU)
LONG LINES	Long Hydrographic Sections Programme (USA)
LORAN-C	Long Range Area Navigation System "C"
LOTUS	Long-Term Upper Ocean Study, Woods Hole, 1983
LUCIE	Study of circulation north and west of Australia (Leeuwin Current)
LV	Large Volume water samples (>1 00 1)
Meteor	Research Vessel (FRG)
MESSR	Multispectral Electronic Self-Scanning Radiometer
MODE	Mid-Ocean Dynamics Experiment
MOS	Marine Observations Satellite
MSR	Microwave Scanning Radiometer
NADW	North Atlantic Deep Water
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NEG	WOCE Numerical Experimentation Group
NOAA	National Oceanic and Atmospheric Administration
NOBREX	North Brazil Current Experiment
NODC	National Oceanographic Data Centre (IODE)
NSCAT	NASA Scatterometer (Satellite) (USA)
NSF	National Science Foundation (US)
OCTS	Ocean Colour and Temperature Sensor
OGCM	Oceanic General Circulation Model
PEGASUS	Current profiling system
POD	Precise Orbit Determination
Polynya	Wind or current driven opening in winter sea-ice
POSEIDON	Satellite Programme (France)
PRARE	Precise Range and Range Rate Equipment (ERS-1)
QCE	Quality Control Experts (WOCE Hydrographic Programme)

RADARSAT	Radar Satellite (Canada)
RAFOS	SOFAR spelled backwards (float which receives sound signals)
SAC	Special Analysis Centre (WOCE)
SAR	Synthetic Aperture Radar (Satellite)
SAVE	South Atlantic Ventilation Experiment
SCAR	Scientific Committee on Antarctic Research (ICSU)
SCOR	Scientific Committee on Oceanic Research (ICSU)
SCORPIO	Oceanographic Cruise in the South Pacific, 1968, US
SLP	Sea Level Pressure
SIO	Scripps Institution of Oceanography, La Jolla
SSM/I	Special Sensor Microwave/Imager
SOFAR	Sound Fixing and Ranging (float with sound source)
SOP	Ship of Opportunity Programme
SSC	Scientific Steering Committee (US-WOCE)
SSG	Scientific Steering Group (WOCE or TOGA)
SSMI	Special Sensor Microwave Instruments (Satellite)
SST	Sea Surface Temperature
STACS	Subtropical Atlantic Climate Study (US)
SV	Sverdrup ($10^6 M^3 S^{-1}$) Measure of water flow
SV	Small Volume water samples (<10 l)
SURTROPAC	Survey of the Tropical Pacific Experiment (France)
T/C	Temperature/Conductivity sensor chains on drifters
T/S	Temperature/Salinity
TOGA	Tropical Ocean and Global Atmosphere (Programme) (WCRP)
TOPEX	Ocean Surface Topography Experiment (Satellite) (USA)
TOPEX/POSEIDON	Ocean Topography Experiment (NASA/CNES Satellite Programme)
TRANSPAC	Trans-Pacific Experiment
TRANSIT	Satellite Navigation (position location) System (USA)
TTO	Transient Tracers in the Ocean (Survey)
UNESCO	United Nations Educational, Scientific and Cultural Organization
US WOCE	United States of America component of WOCE
VACM	Vector Averaging Current-Meter
VLBI	Very Long Baseline Inferometry
VMVM	Vector Measuring Current-Meter
VOS	Voluntary Observing Ship Scheme (WMO)
VTIR	Visible and Thermal Infrared Radiometer
WBC	Western Boundary Current
WCP	World Climate Programme (of WMO/ICSU)
WCRP	World Climate Research Programme (WMO/ICSU)
WDC	World Data Centre
WHP	WOCE Hydrographic Programme
WHOI	Woods Hole Oceanographic Institution, Woods Hole
WMO	World Meteorology Organization (Geneva)
WOCE	World Ocean Circulation Experiment (WCRP)
WWSP86	Winter Weddell Sea Project 1986
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature Depth (Probe)

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<u>LIST OF REPORTS</u>

WCRP-1 VALIDATION OF SATELLITE PRECIPITATION MEASUREMENTS FOR THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (Report of an International workshop, Washington, D.C., 17-21 November 1986) (WMO/TD-No. 203)

WCRP-2 WOCE CORE PROJECT 1 PLANNING MEETING ON THE GLOBAL DESCRIPTION (Washington, D.C., USA, 10-14 November 1986) (WMO/TD-No. 205)

WCRP-3 INTERNATIONAL SATELLITE CLOUD CLIMATOLOGY PROJECT (ISCCP) WORKING GROUP ON DATA MANAGEMENT - SIXTH SESSION (Ft. Collins, USA, 16-18 June 1987) (WMO/TD-No. 210)

WCRP-4 JSC/CCCO TOGA NUMERICAL EXPERIMENTATION GROUP - FIRST SESSION (Unesco, Paris, France, 25-26 June 1987) (WMO/TD No. 204)

WCRP-5 CONCEPT OF THE GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (Report of the VC Study Group on GEWEX, Montreal, Canada, 8-12 June 1987 and Pasadena, USA, 5-9 January 1988) (WMO/TD-No. 215)

WCRP-6 INTERNATIONAL WORKING GROUP ON DATA MANAGEMENT FOR THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT, (Second Session, Madison, USA, 9-11 September 1988) (WMO/TD-No. 221)

WCRP-7 CAS GROUP OF RAPPORTEURS ON CLIMATE, (Final Report, Leningrad, USSR, 28 October-1 November 1985) (WMO/TD-No. 226)

WCRP-8 JSC WORKING GROUP ON LAND SURFACE PROCESSES AND CLIMATE, (Final Report, Third Session, Manhattan, USA, 29 June-3 July 1987) (WMO/TD-No. 232)

WCRP-9 AEROSOLS, CLOUDS AND OTHER CLIMATICALLY IMPORTANT PARAMETERS: LIDAR APPLICATIONS AND NETWORKS, (Final Report, Meeting of Experts, Geneva, Switzerland, 10-12 December 1985) (WMO/TD-No. 233)

WCRP-10 RADIATION AND CLIMATE: Report of the First Session, JSC Working Group on Radiative Fluxes (Greenbelt, USA, 14-17 December 1987) (WMO/TD-No. 235)

WCRP-11 WORLD OCEAN CIRCULATION EXPERIMENT - IMPLEMENTATION PLAN - DETAILED REQUIREMENTS (Volume I) (WMO/TD-No. 242)

WCRP-12 WORLD OCEAN CIRCULATION EXPERIMENT - IMPLEMENTATION PLAN - SCIENTIFIC BACKGROUND (Volume II) (WMO/TD-No. 243)

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