OCEAN OBSERVATIONS IN SUPPORT OF INTERACTIVE MODELS

Paul M. Wolff
Assistant Administrator NOAA, National Ocean Service
Washington, D.C.

Abstract

Technological advances in computers, satellites, communications, modelling and observation collection have led to significant advances in numerical prediction. Further progress is being hampered by our failure to treat the environment as a single, coupled air/ocean system and by the lack of adequate observational coverage over the oceans to accurately specify initial conditions. This paper attempts to point out certain shortcomings in satellite and conventional data coverage needed for numerical prediction and recommends some broad solutions. In the United States, the NOAA National Ocean Service has initiated a modest effort to automate conventional (non-satellite) ocean observation systems; details of this initiative, current results and future plans are outlined.

1. INTRODUCTION

Computers of various sizes and architectures: environmental satellites (meteorological and oceanographic), communications satellites, high-speed digital communications networks and automated observation systems are revolutionizing weather services around the world. During the last decade, significant progress has been made in the fields of global Numerical Weather Prediction (NWP) and the analysis and assimilation of synoptic and asynoptic weather observations. In spite of this progress, the accuracy of numerical forecasts has suffered from the relative sparsity of certain types of observations from oceanic areas and the inability of operational models to operate in a truly interactive mode where the oceans and the atmosphere are represented as coupled environmental system which they are. In the past decade, weather service organizations have given priority to warnings (short-term advisories mainly intended to reduce loss of life from severe weather events) and to climate studies (especially unusual events such as El Nino). Improvement in global forecasting has been limited to a few large centres with the European Centre for Medium-Range Forecasts (ECMWF) being the most notable. Even at the ECMWF there has been a relative lack of progress in the marine area where a good 48-hour forecast has major impact because of delivery constraints and the character of the user problems.

The ECMWF has been hosting a series of informal meetings to address observational data requirements for global models. One of the main objectives of a planning meeting held earlier this year (4-6 March 1987) was to:

- o discuss the requirements, future production prospects, data monitoring and quality control, and communications in relation to observational data, with particular reference to space-based data and new (conventional) observing techniques...

One of the topical areas of interests to this workshop is entitled "Observational Data Acquisition and Monitoring". It is generally agreed that sufficient observational data of acceptable quality is necessary if global NWP is to produce acceptable results.

Observational coverage over ocean areas is of major concern to the Intergovernmental Oceanographic Commission (IOC), the World Meteorological Organization (WMO) and the ECMWF. The purpose of this paper is to contribute to this workshop in the general areas of operational weather problems and ocean observations but more particularly in the specifics of conventional (non-satellite) ocean observations.

2. BACKGROUND

The present Workshop is one of a series, and present attendees may not have participated in all of the earlier meetings. It is therefore appropriate to summarize some of the more important ideas discussed previously, even though the conclusions may be accepted by some as axiomatic.

2.1 The Operational Environmental Problem

To set the stage for a discussion of ocean observations, it is worthwhile to review the processes involved in providing weather and oceanographic services. Figure 2-1 shows a schematic representation of a modern environmental services cycle as we see it. This picture is abbreviated in that only two functional descriptions are used to describe each major component; a more comprehensive view could be presented by using more subtitles. Observations are the starting point in the operational cycle; without them, the other functions become virtually meaningless.

The overall problem involves elements which cover widely different time scales as summarized in Table 2-1. However, each of the elements impacts on one or more of the others in spite of these differences.

Table 2-1: INFORMATION TIME SCALES INVOLVED IN MAJOR COMPONENTS OF THE OPERATIONAL WEATHER PROBLEM

- <u>OBSERVATIONS</u> - Information giving a snapshot of point conditions existing at zero time.
- <u>WARNINGS</u> - Information with time scales of minutes or hours which starts with observations, an analysis or short-range prediction and is designed to prevent loss of life or property.
- <u>NUMERICAL FORECASTS</u> - Information beginning with an analysis of present conditions and extending several days into the future using initial-value, problem-solving methods.
- <u>MONITORING OF GLOBAL CHANGE</u> - Climatological information summarized to detect long-term, global changes in conditions in the air and oceans and to distinguish between natural variability and man-induced changes.

2.2 The Role of the Oceans

The Integrated Global Ocean Services System (IGOSS) was planned, developed and coordinated by the IOC and WMO in recognition of the principle that the oceans and the atmosphere should be observed and studied together because they continuously affect each other. In the past, there has been too much of a tendency to treat meteorology and oceanography as completely separate model domains.

The oceans are the main heat and moisture reservoir for the atmosphere, and ocean currents play a major role in the redistribution of heat. Anomalies in ocean temperature and currents, no matter what the cause, appear to be important factors in shorter-term fluctuations in synoptic weather patterns and in longer-term climatic changes. In reverse, the forces which drive the oceans come through the atmosphere. Atmospheric winds are the driving force in the generation of ocean waves and, together with bathymetry, earth's rotation and tidal forces, are a major factor in determining ocean current structure. Sea ice plays an important role in NWP through its effect on albedo and surface heat exchange.

Most of the advanced, operational NWP models take into account the transfer of heat and moisture into the atmosphere at the air/ocean interface, but most do not accommodate continuous, two-way exchange of heat or momentum account for changes in atmospheric friction due to changes in wave roughness.

It is essential that the environmental structure in the atmosphere over the oceans, at the air/ocean interface and in the near-surface layers of the oceans be accurately specified if both weather and oceanographic prediction are to reach their full potential.

Table 2-2: REQUIREMENTS FOR IMPROVED 1-10 DAY FORECASTS

- Operational use of interactive (coupled) air/ocean models
- Better observational coverage of the total air-ocean system
- More emphasis on conventional ocean observation systems as exemplified by the NOS NOAA Program
- Faster data collection from ocean areas and faster processing of data from ocean observing satellites
- More quality control of ocean observations
- Continuous data ingest from all areas
- Use of the largest, most efficient computers
- Adaptation of more standard, modular software
- More test forecasts to tune/verify operational forecasts (ratio of 5 to 10 test runs with each operational cycle.
- More facilities for testing
- Decision tree testing of results
- Better international communication of positive and negative test results
- Development of better ways to examine NWP outputs

2.3 Numerical Weather Prediction

In recent years global NWP models have extended predictive skill to about a week in the Northern Hemisphere, to more than five days in the Southern Hemisphere and to about three days in the Tropics according to the Final Report on the ECMWF Planning Meeting of 4-6 March 1987. This has been made possible by:

- Improved numerics
- Improved parameterization schemes
- Increases in horizontal/vertical resolution
- Efficient time-stepping algorithms
- Large increases in computer power
- Major improvements in data assimilation
- Improvements in the quality and usage of satellite data

It is interesting to note that improvements in the coverage, quality and usage of conventional ocean data are not yet felt to be a major factor in improved NWP, although there is agreement that air-ocean interaction is important.

Numerical Weather Prediction is a truly global problem because it is essential to treat cross-equatorial flow. In our opinion, there are certain specific requirements which must be met if 1-10 day forecasts from NWP models are to continue to improve; these are summarized in Table 2-2.
Computer hardware is evolving very rapidly and with lowered costs; there are no foreseeable problems ahead with either hardware speed (Peled, 1987 and Meindl,1987) or storage capacity (Kryder, 1987). It is essential that the biggest and fastest computers be used in the large, operational NWP centres. The programming problem still remains (Gelernter,1987) and must be addressed with standard, portable, building block approaches (Kahn, 1987 and Foley, 1987) using common language and formats.

2.4 Ocean Observations in Support of NWP

The oceans comprise 70 percent of the earth's surface. The coupling between the atmosphere and the oceans and the fact that NWP is an initial value problem demand that initial conditions in both media be accurately specified. NWP models, to perform at levels of which they are capable, require initial and verification data which match the resolution of the model and the parameterization processes it contains. Lower boundary conditions in operational NWP models become more important as model resolution and forecast length are increased; at the present time, the specification of lower boundary conditions over the oceans is considered to be weaker than over land.

To improve NWP and oceanographic prediction, we need all the ocean observations we can afford -- especially, conventional observations. In some areas and for some seasons, the oceans have great stability, changes are slow, and there is a tendency to believe that occasional sampling is sufficient. There are many areas and times, however, where the ocean has been observed to undergo a surface temperature change in 24 hours which is nearly as great as the change from one season to the next. The danger is that an infrequently observed quantity is often described as slow changing.

Sea Surface Temperature SST) is now being used in operational NWP models as part of the boundary specification, but is typically assumed to remain constant throughout the forecast period. The use of interactive or coupled air-ocean models would alleviate this deficiency, but specification of the Mixed Layer Dept (MLD) and/or the temperature and density profiles in the upper 100 meters of the ocean (and treatment of two-way heat exchange) would be required to predict changes in SST.

Long-term sea ice coverage is typically used to define the albedo in operational NWP models, but it would be better to use synoptic observations of ice coverage, ice depth and ice edge to specify the lower boundary in Arctic/Antarctic regions.

If numerical weather and oceanographic prediction are to reach their full potential, it is essential to define the initial conditions adequatelly:

- o In the upper atmosphere over the oceans
- o In the atmospheric boundary layer over the oceans
- o At the air/ocean interface
- o In the near-surface layers of the oceans

3. REQUIREMENTS FOR OCEAN OBSERVATIONS

When the environmental prediction problem is recognized as global and interactive, it is obvious that researchers, major forecast centers and climate centres must be prepared to utilize ocean data from diverse platforms equipped with different sets of instruments. This applies to satellites as well as to conventional, surface-based, observing systems.

Lange et al (1986), in a summary of a special Workshop/Seminar held in Seattle, Washington on severe ocean storms, came to several important conclusions concerning maritime explosive deepeners or "bombs":

- o NUMERICAL MODELS DO NOT HANDLE "BOMBS" VERY WELL.
  Probably because they most often occur in sparse data areas where initial analyses are poor at both the surface and in the upper air AND because the scale around the Low center is small with respect to mesh length.

- o MANUAL ANALYSIS OR QUALITY CONTROL OF NUMERICAL ANALYSES IS ESSENTIAL TO DEFINE THE INITIAL STATE OF "BOMBS".
  Because synoptic reports near the center of explosive deepeners are frequently rejected as being unbelievable. This quality control can be done by computer

There are specific ocean observations which are needed to support NWP; fortunately, most of these are also valuable to support other applications. There are some ocean observations which have little direct use in NWP but are required by other operational activities. A major non-operational user of ocean observations of various types is the World Climate Research Programme (WCRP) and the various associated climate research centers.

3.1 Key Observation Parameters

Table 3-1 lists some of the most critical ocean observation requirements as we see them. Most of these support NWP but a few are more applicable to specialized (customized) oceanographic prediction in support of maritime user activities such as commercial fishing, shipping, pollution monitoring, offshore oil/gas operations etc. Table 3-1 includes an attempt to prioritize the importance of various oceanic parameters to operational Numerical Weather Prediction.

Table 3-1: GENERAL OCEAN OBSERVATION REQUIREMENTS IN SUPPORT OF ENVIRONMENTAL PREDICTION (Those most applicable to NWP are indicated with an asterisk *).

UPPER ATMOSPHERE

- o Temperature/moisture profiles with height ***
- o Wind profiles with height ***
- o Cloud cover **

ATMOSPHERIC BOUNDARY LAYER

- o Temperature/moisture structure ***
- o Wind structure ***

(Stability structure) ***

AIR/OCEAN INTERFACE

- o Sea surface temperature ***
- o Air temperature and dewpoint ***

(Air-sea temperature difference) ***

- o Surface wind ***
- o Surface pressure **
- o Surface currents *
- o Water (sea) level
- o Wind waves and swell (spectra?) *
- o Solar radiation *
- o Precipitation *
- o Sea surface salinity *
- o Sea ice coverage **
- o Pollutant concentrations
- o Chemical/biological data
- o Ocean color (chlorophyll concentration)

SUBSURFACE

- o Temperature/salinity/density profiles with depth **
- o Current structure with depth *

*** Critical importance to NWP
** Important to NWP
* Some importance to NWP

3.2 Satellite Observation Systems

In planning meetings held at the ECMWF it has been assumed that much of the additional data from oceanic regions, and any major increases in total data coverage, will have to come from remote sensing systems. The 4-6 March 1987 meeting went so far as to conclude that...."apart from improvements in the techniques to retrieve temperature and humidity from satellite sensed radiances, the Global Observing System (GOS) appears to have degraded since the FGGE year".

Satellites are doing a reasonably good job of measuring some of the parameters listed in Table 3-1. These include:

- Cloud cover (and cloud temperatures)
- Atmospheric temperature and moisture profiles
- Sea surface temperature
- Ice cover

It has also been demonstrated that satellite systems are capable of measuring other parameters listed in Table 3-1 but are either not now doing so, or are doing so only to a limited extent. These key parameters include:

- Surface winds
- Wave heights
- Ocean color (chlorophyll content)
- Water (sea) level
- Surface currents (derived from water level)

Finally, there are a few important oceanic parameters which are either not amenable at all to remote sensing or are difficult to measure from satellites. These include:

- Surface pressure
- Subsurface temperature/salinity/density structure
- Subsurface current structure

Fortunately, most of the parameters listed in the two categories where satellites are not now doing an adequate job can also be measured by automated surface-based systems which can forward the results using satellite Data Collection Platform (DCP) technology.

3.2.1 Geostationary Satellites

The geostationary satellites such as GOES-NEXT METEOSAT, INSAT-B and GMS all provide outstanding cloud images for the areas they cover. Depending upon sensors carried and data processing algorithims, they may also provide SST observations, cloud drift winds, temperature and moisture profiles. Some also have DCP capabilities for collection and forwarding of observations from surface measurement systems.

In our opinion, geostationary satellites are not being used to their full potential for: (a) remote sensing of oceanic parameters, (b) collection/-forwarding of data from surface observation systems or (c) international relay of ocean observation collectives and numerical products.
There should be 5 or 6 geostationary environmental satellites on station at all times. All such geostationary satellites should be equipped with:

- Radiometers for clouds and sea surface temperature.
- Atmospheric profiler.
- Data Collection Platform (DCP) capability for collection/forwarding of surface observations.
- Communications relay capability to distribute observation collectives and numerical products around the world if practical.

Timeliness goals for collection, quality control and forwarding of conventional observations using the last two capabilities listed above for geostationary satellites should be one hour or less.

Because of the great importance of geostationary satellites to global observation and their relatively long operational life, consideration should be given to having duplicate sensor systems on board whenever feasible. Table 3-2 summarizes our most important conclusions concerning geostationary environmental satellites.

3.2.3 Polar Orbiting Satellites

Polar orbiting satellites such as the NOAA-N, DMSP, GEOSAT etc. now in operation and planned systems such as NOAA-NEXT, ERS-1, Landsat-6, etc. will continue to be major sources of cloud images, atmospheric soundings, surface temperatures, ice and snow cover, significant wave height and surface wind observations. These satellites are important because they cover polar areas outside line-of-sight range of geostationary systems.

There should be at least three polar-orbiting environmental satellites in operation at all times. In our opinion, they should be configured as combination meteorological/oceanographic satellites and all should include DCP capabilities. The minimum recommended sensor suite includes:

- o Radiometers for clouds and SST
- o Atmospheric profiler
- o Scatterometer for surface wind vectors
- o Altimeter for sea-level wave heights, scalar winds and ice
- o Synthetic Aperture Radar
- o Ocean Color Scanner (or multi-purpose, SeaWIFS-type system)

o DCP capability for collection, storing and forwarding of data from automated surface observation systems.

The goal for collection, quality control and forwarding of surface observations handled by polar-orbiting satellites equipped with a DCP capability should be two hours or less.

Again, consideration should be given to duplicate sensor systems -- especially the profiler, scatterometer and altimeter. Table 3-3 summarizes our most important conclusions concerning polar orbiting environmental satellites.

Table 3-2: CONCLUSIONS CONCERNING GEOSTATIONARY ENVIRONMENTAL SATELLITES

- o THEY ARE A MAJOR SOURCE OF OBSERVATIONAL COVERAGE
- o THEY ARE NOT NOW BEING USED TO THEIR FULL POTENTIAL
- o FIVE OR SIX GEOSTATIONARY SATELLITES SHOULD BE OPERATIONAL AT ALL TIMES
- o ALL GOES-TYPE SATELLITES SHOULD BE EQUIPPED WITH:
  - Radiometer for clouds and SST
  - Atmospheric sounder system
  - Data Collection Platform (DCP) capability
  - International weather communications relay capability (Satellite-to-Ground and Satellite-to-Satellite)
- o BECAUSE OF THE IMPORTANCE AND LONG LIFE OF GEOSTATIONARY SATELLITES, CONSIDERATION SHOULD BE GIVEN TO DUPLICATION OF SENSOR SYSTEMS
- o TIMELINESS GOAL FOR COLLECTION, QUALITY CONTROL AND FORWARDING OF CONVENTIONAL DATA RECEIVED BY THE DCP SYSTEM SHOULD BE LESS THAN ONE HOUR

Table 3-3: CONCLUSIONS CONCERNING POLAR-ORBITING ENVIRONMENTAL SATELLITES

- o THEY ARE A MAJOR SOURCE OF OBSERVATIONAL COVERAGE AND ARE ESPECIALLY VALUABLE FOR COVERAGE OF HIGHER LATITUDES.

- o AT LEAST THREE POLAR ORBITING SATELLITES SHOULD BE OPERATIONAL AT ALL TIMES.

- o ALL POLAR ORBITERS SHOULD BE EQUIPPED WITH BOTH METEOROLOGICAL AND OCEANOGRAPHIC SENSORS SUCH AS:

  - Radiometer for clouds and SST
  - Atmospheric sounder system
  - Scatterometer for vector winds
  - Altimeter for sea level, wave heights, wind speeds, and ice
  - Synthetic Aperture Radar for ice and ocean features
  - Ocean color scanner

- o CONSIDERATION SHOULD BE GIVEN TO DUPLICATION OF KEY SENSOR SYSTEMS.

- o ALL POLAR ORBITERS SHOULD BE EQUIPPED WITH A DCP CAPABILITY.

- o TIMELINESS GOALS FOR COLLECTION, QUALITY CONTROL AND FORWARDING OF CONVENTIONAL OBSERVATIONS HANDLED BY THE DCP SYSTEM SHOULD BE TWO HOURS OR LESS.

3.2.4 Satellites and Surface Data Collection Platforms

As discussed in the previous paragraphs covering geostationary and polar orbiting satellites, it is essential that both types include a capability to receive and forward data from automated surface observation systems using DCP technology. Within NOAA there has been a major effort to automate the collection of data from all types of remote surface observation platforms, but especially from oceanic platforms. Virtually all moored buoys, drifting buoys and C-MAN (Coastal and Marine Automated Network) systems are now interrogated using DCP technology.

NOAA's National Ocean Service (NOS) is making a major effort to automate collection of ship synoptic weather reports and Expendable Bathythermograph (XBT) soundings through the Shipboard Environmental (Data) Acquisition System (SEAS). Additional automated systems include the Next Generation Water Level Measurement System (NGWLMS), the Automated Shipboard Aerological Program (ASAP),the Acoustic Doppler Current Profiler (ADCP) and others. All of these can and should use satellite DCP.

3.3 Conventional Observations

Satellites will continue to be the major source of observations over the oceans, but conventional observation systems are needed for several reasons:

- They provide ground-truth for satellite observations.
- They serve as "anchor points" for numerical analyses based on all-source data.
- They can obtain subsurface data which cannot be measured by satellite borne sensors.
- Extended conventional time series from fixed points are ideal for model and hypothesis testing, climate research etc.

Traditional ocean data gathering systems such as ships, moored and drifting buoys and tide gauges have served the marine user well. The increasing need for global data from the ocean environment in near real time demands that we take full advantage of technological advances in platforms, measurement systems, sensors and data telemetry. The thrust of ocean data collection from non-satellite sources is now shifting toward automated systems. The remainder of this section focuses primarily on the application of new technology and methods.

3.3.1 Atmospheric Sounders

New ground-based microwave doppler devices for remotely profiling upper air winds are now being tested in prototype networks in the United States, and longer-range procurement plans for operational systems have been formulated. It appears that this technology could be applied on offshore platforms and possibly even on larger moored buoys and ships. In the meantime, NOAA is focusing on a semi-automated conventional method for taking upper air soundings from car carriers, container ships, bulk carriers operating on routes which are most important to increased upper atmosphere coverage over the oceans.

Automated Shipboard Aerological Program (ASAP)

The ASAP is a highly-automated, cost-effective technique to take upper air soundings of the type previously made by Ocean Station Vessels. At 00 and 12GMT, a helium-filled balloon and attached expendable instrument package are launched automatically from the participating ship. An onboard computer automatically receives, processes and transmits sounding data (rate of ascent, height, pressure, temperature, wind speed and direction) to the National Meteorological Center (NMC) via GOES. Subject to funding approval, the United States and Canada plan to deploy six operational ASAP systems.

Doppler Wind Profilers

Doppler Wind Profiler networks are now being installed within the continental U.S. to obtain nearly continuous profiles of tropospheric wind structure. In a demonstration effort, profilers developed by NOAA's Environmental Research Laboratories are scheduled to be deployed on strategically located islands. The first such installation will be on Canton Island in the equatorial Pacific; others are planned for Christmas Island and Ponape.

In addition, a new fixed-array doppler radar system is undergoing test and evaluation for installation on fixed sites such as land or marine vehicles to sample the lowest 1-5 km of the atmosphere.

3.3.2 Surface Observation Systems

Voluntary Observing Ships (VOS) Program

Ship weather reports have historically been a major source of surface marine observations. The Voluntary Observing Ships (VOS) Program established by the WMO now involves approximately 7500 ships from 47 countries. The reports from these ships contain up to 19 elements including:

- o Sea level pressure
- o Wind velocity
- o Air temperature
- o Cloud data
- o Wave height/direction/period
- o Sea surface temperature

These data are reported by radio messages and are typically sent only when the radio operator is on watch. A reduction in the number of shipboard radio operators and in the number of operators at shore intercept stations has led to a steady decrease in the number of ship reports received at the forecasting centres. The answer to this problem lies in automation of the shipboard observation and transmission process.

Shipboard Environmental (Data) Acquisition System (SEAS)

NOAA is modernizing ship weather reporting through its SEAS Program (McLain et al, 1986 and Szabados et al, 1987). SEAS is a shipboard automated station that receives, stores and transmits meteorological and oceanographic data utilizing the GOES geostationary satellite. Two basic versions of SEAS are now in operational use:

- o The Manual SEAS which handles Meteorological observations only and where the report is entered manually at the keyboard.
- o The Semi-automatic SEAS which handles Meteorological and XBT observations where surface pressure and the XBT sounding are entered automatically and the remainder of the report parameters, including TESAC messages, are entered manually at the keyboard.

Both versions transmit their data automatically. Third generation SEAS systems will calculate pressure tendency; automatically enter wind, air temperature and relative humidity and will be interfaced with Acoustic Doppler Current Profilers, CTD, XSV and XCTD probes and with the ship's SATNAV and/or Loran C navigation systems for automatic entry of date/time, ship position and ship course and speed. Future versions of SEAS will still be Personal Computer (PC)-compatible systems which are affordable, modular, small in size and easily installed on and removed from ships. More detail concerning the results of the NOAA/NOS SEAS/XBT Automation Project is contained in Section 5.2 of this paper.

Next Generation Water Level Measurement System (NGWLMS)

The NGWLMS uses an acoustic sensor to measure the height of the water surface instead of conventional float and bubbler methods. The acoustic sensor, when coupled with new geodetic techniques based on the Global Positioning System (GPS) and Very Long Baseline Interferometry provides an opportunity to accurately link relative motion between the sea surface and land (Beaumariage and Scherer, 1987).

Water level data from the NGWLMS will be transmitted using DCP technology. The DCP system planned for the NGWLMS will accommodate up to 11 additional sensors; these may include:

- Backup water level sensor
- Air temperature
- Water temperature
- Water Density
- Conductivity
- Current speed and direction
- Wind speed and direction
- Barometric pressure
- Rainfall data

This means that the NGWLMS can also function as an automatic remote weather station. Communication between the NGWLMS DCP and the central data base facility in Rockville, Maryland will be via the GOES satellites, with telephone circuits as a backup. Section 5.3 of this paper provides additional details concerning NOS's deployment schedule for the NGWLMS.

Buoys and Coastal Marine Automated Network (C-MAN) Stations

Through the NOAA Data Buoy Center (NDBC), the United States has been steadily increasing surface oceanic data coverage through the deployment of moored and drifting buoys and the activation of C-MAN stations. In 1986 NDBC buoys contributed a total of 296,566 observations from a network representing 16,356 buoy days on station. During the same period, a total of 48 NOAA C-MAN sites were in operation for a total of 14,055 station days (with a schedule of hourly observations, this represents a coastal observation potential of 337,320 observations during 1986). NDBC has also equipped nine Large Navigational Buoys (LNBs) to take weather and oceanographic observations and is developing several types of drifting buoys capable of making surface as well as subsurface observations. All of the buoys and C-MAN stations deployed by NDBC utilize DCP technology and automatically forward their observations via either GOES or NOAA polar-orbiting satellites.

3.3.3 Subsurface Profilers

SEAS/XBT Systems

The SEAS program and the way it can accept an Expendable Bathythermograph (XBT) signal from a subsurface sounding probe, process the sounding into an XBT message and automatically forward the message via GOES is described in detail by Szabados et al (1987). The next generation of the SEAS system will also be able to handle CTD, XSV and XCTD soundings in a fully automated mode.

Acoustic Doppler Current Profiler (ADCP)

NOAA is working on a ship mounted acoustic instrument to measure profiles of ocean current velocity versus depth using doppler shift technology. The current soundings will be processed on board, probably hourly, on a PC-type microprocessor. Profile messages will be transmitted via GOES satellites using a DCP system. Subject to funding constraints, NOAA is planning to equip four of its own vessels with NOS real time ADCP systems.

4. IMPACT OF NUMERICAL PREDICTION ON DESIGN/OPERATION OF OCEAN OBSERVATION SYSTEMS

To a large extent, numerical prediction and the grid spacing used by numerical models influence ocean platform spacing and the time interval between useful observations from any surface-based system. In order to correctly model changes in a fluid such as the atmosphere, one must accurately specify conditions on any open boundaries. Since most large NWP models are now global, this means it is essential to specify boundary conditions at the ocean surface.

4.1 Observation Collection

In section 3.2 it was pointed out that satellite observation systems are going to be the major source of ocean observations, but that present systems are not all they could be. In our opinion, we need a definitive study of ocean observing satellites leading to a cost-effective plan for:

- Selection of sensor suites.
- International support of and specifications for satellite Data Collection Platform (DCP) systems.
- Special processing centers for satellite data.
- Better quality control of satellite data.
- Faster relay of satellite data.

At the present time, some satellite footprints are not even clearly defined.

If a processing capability powerful enough to handle all available satellite data is implemented at the large forecast centres, such a facility would also have sufficient capacity to handle all conventional observations from ocean areas. This should be an operational goal.

It is clear that numerical models are being based upon denser grid systems and are being designed to accomplish continuous data assimilation. These developments require modifications to our conventional observing schemes whereby we evaluate trade-offs between observation location and spacing and optimum frequency of sampling. Some of the impacts of numerical prediction on conventional ocean observation programs as we see them are presented in Table 4-1.

Table 4-1: SOME POSSIBLE MODIFICATIONS TO CONVENTIONAL OCEAN OBSERVATION PROGRAMS DICTATED BY REQUIREMENTS TO SUPPORT NUMERICAL PREDICTION

- ALL OBSERVATIONS SHOULD BE COLLECTED, QUALITY CONTROLLED AND COMMUNICATED IN LESS THAN ONE HOUR USING GOES AND LESS THAN TWO HOURS USING POLAR ORBITER COLLECTORS
- OBSERVATION FREQUENCY SHOULD BE HOURLY FOR SURFACE SYNOPS AND SIX-HOURLY FOR ATMOSPHERIC AND SUBSURFACE SOUNDINGS FROM SURFACE PLATFORMS
- SPECIAL OBSERVATIONS SUCH AS AUTOMATIC (DOPPLER) WIND/TEMPERATURE SOUNDINGS AND CURRENT SOUNDINGS SHOULD BE TAKEN ALMOST CONTINUOUSLY ON DEMAND TO SUPPORT R&D AND MODEL DIAGNOSTIC TESTS

4.2 Observation Quality Control Procedures

Before collectives of satellite and conventional ocean observations are communicated internationally or used internally by major numerical centres, they should be subject to rigorous quality control. They need to be checked for internal (e.g., vertical) consistency, conformance to coding/formatting regulations, etc. and need to be compared to neighboring observations, short-range numerical "first guess" values for each parameter, climatological extremes, etc.

NOAA believes that quality control is so important that a special quality control division has been established within the Ocean Products Center (OPC) at the National Meteorological Center (NMC). This division has its own microcomputers with which to effect quality control of incoming ocean observations and outgoing ocean products.

Microcomputer-based editing systems known as Quality Improvement Profile Systems (QUIPS) located at NMC and in the U.S. Navy's Fleet Numerical Oceanography Center (FNOC) now decode and edit all U.S. BATHY and TESAC messages before they are placed on the Global Telecommunications System (GTS). These two centers also quality control all incoming BATHY/TESAC messages received via the GTS. It is understood that a QUIPS capability will be implemented by the Australian Meteorological Service. An expanded version of the QUIPS is being developed to edit all synoptic marine weather and drifting buoy observations as well as reports from coastal stations (C-MAN) and next-generation profilers such as the ADCP (McLain et al, 1987 manuscript).

4.3 National/International Relay of Ocean Observation Collectives

Ideally, every centre which puts ocean observation collectives onto the GTS should quality control the data using QUIPS-type procedures before the data are entered. If operational numerical forecast centres are going to initiate model runs within 2-3 hours of nominal synoptic time (data cutoff of say 2+30 hours), collection, quality control and relay of ocean observation collectives must be better than it now is. In our opinion, this means that all of the steps involved need to be automated to the greatest possible extent.

Table 4-2 lists possible actions which would speed national and international relay of clean ocean data collectives.

Table 4-2: LIST OF RECOMMENDED ACTIONS TO SPEED UP NATIONAL AND INTERNATIONAL RELAY OF CLEAN OCEAN DATA COLLECTIVES.

- o AUTOMATE THE TAKING OF OCEAN OBSERVATIONS TO THE MAXIMUM USING SYSTEMS SUCH AS SEAS/XBT, C-MAN, ADCP, NGWLMS, ASAP etc.
- o AUTOMATE OBSERVATION COLLECTION TO THE MAXIMUM USING SATELLITE DATA COLLECTION PLATFORM (DCP) TECHNOLOGY
- o AUTOMATE REGIONAL QUALITY CONTROL USING TECHNOLOGY SUCH AS THE QUIPS AND ENHANCED QUIPS
- o SPEED UP INTERNATIONAL RELAY BY USING GOES SATELLITES AS COMMUNICATIONS RELAY STATIONS (SATELLITE-TO-GROUND AND SATELLITE-TO-SATELLITE)

5.0 NOAA OCEAN OBSERVATION PROGRAMS AND STUDIES

5.1 Ship of Opportunity Programs

It is NOAA's policy to continue to support the Voluntary Observing Ships (VOS) program. This applies to ships which rely totally on manual report preparation and relay by the ship radio operator as well as to ships being equipped with more automated systems. The ECMWF reports that it is receiving about 4,300 surface ship reports per day; we believe that this number could be doubled with better international support of ship visitation and Port Meteorological Officer programs. VOS ships which are outfitted with NOAA's new SEAS systems are carefully selected based upon:

- o Exhibited interest in the VOS program.
- o Use of routes which contribute to better overall oceanic data coverage.

5.2 The SEAS/XBT Automation Project

The NOAA/NOS SEAS/XBT system is described in Section 3.3.2 of this paper. During the four years that the SEAS/XBT program has been the responsibility of NOS, the number of operational units has grown to a total of 113 at the time of this meeting. These units are now deployed globally aboard the vessel types shown in Table 5-1. These vessels are currently taking MET as well as XBT observations. Figure 5-1 shows the location of the 14,552 MET reports received from NOS SEAS units in the period from January 1 through June 30, 1987.

Table 5-1: DEPLOYMENT DISTRIBUTION (PERCENTAGES) OF SEAS/XBT UNITS BY VESSEL TYPE. (N=113 as of December 1987).

Type	Percent
COMMERCIAL	53
NOAA	24
FOREIGN GOVERNMENT	8
UNIVERSITY	6
FISHING	5
OTHER GOVERNMENT VESSELS	4

Approximately 275 ships representing 20 countries are now taking Bathythermograph soundings. In the period from July through September 1987, NOS handled 12,875 XBT messages which exhibited an error rate of about 0.51 per report. It is conservatively estimated that over one-third of all unclassified (non-military) Bathythermograph soundings are now taken by NOS automated SEAS/XBT systems. Table 5-2 presents a summary of the NOS SEAS program since its inception, while Figure 5-2 shows an example of the subsurface profile data plots made by the NOAA/NOS Ocean Applications Group (OAG) for SEAS data submitted by the vessel MC ARTHUR (call sign WTEJ). The OAG keeps similar plots for all vessels participating in the SEAS/XBT program.

Figure 5-1 Location of MET reports received from NOS SEAS units in the period from January 1 through June 30, 1987.

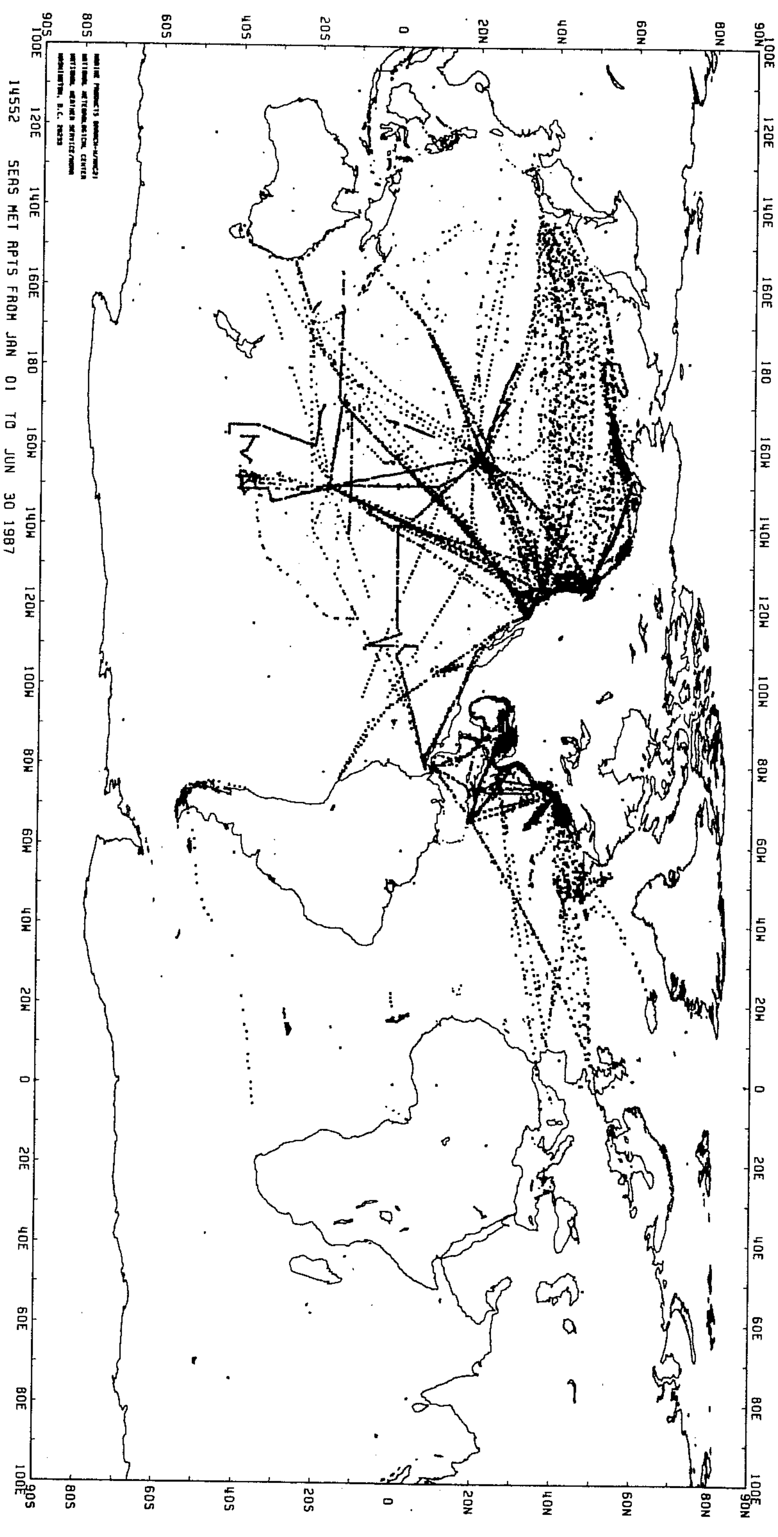

Figure 5-2 Subsurface profile data plots of SEAS data transmitted by NOAA Ship MCARTHUR.

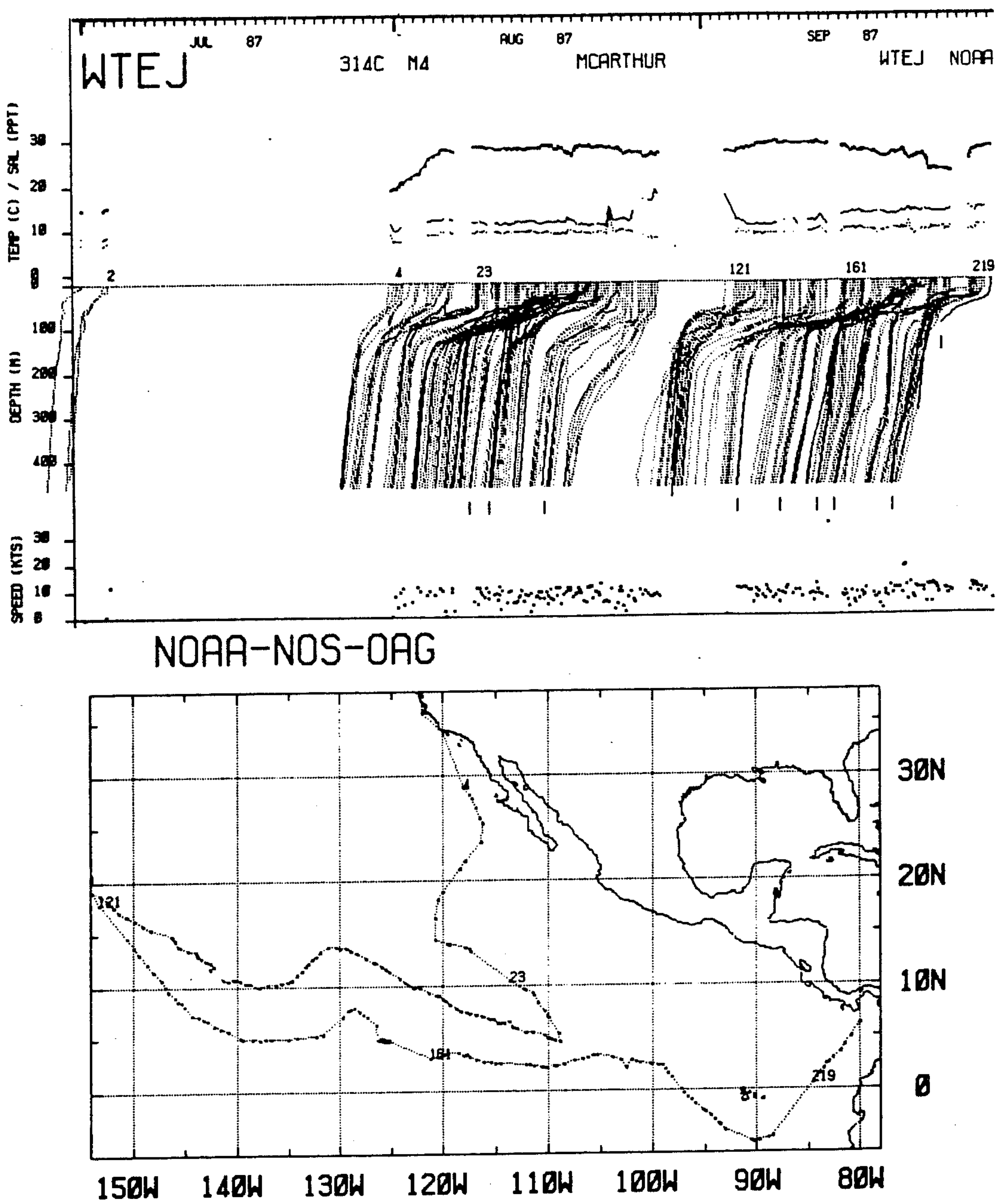

Table 5-2: SUMMARY OF THE NOS SEAS PROGRAM

	FY 84	FY 85	FY 86	FY 87	FY 88
Deployments	5	40	75	110*	(180)
Data Return					
o MET			17,000	30,000	(60,000)
o XBT			6,000	10,000	(15,000)
o TESAC					(1,500)

* 113 units as of December 1, 1987.

5.3 Advanced Observation Systems

Subject to funding, NOS intends to install four Acoustic Doppler Current Profiler (ADCP) systems on its own ships in the coming fiscal year. All of these will be equipped for real time transmission of data. In addition, NOS plans a major expansion in the Next Generation Water Level Measurement System (NGWLMS) in the next four years. Installation schedules for the NGWLMS are shown in Table 5-3.

Table 5-3: NOS INSTALLATION SCHEDULE FOR NEXT GENERATION WATER LEVEL MEASUREMENT SYSTEMS

	Total Units Deployed
FISCAL YEAR 1988	50
FISCAL YEAR 1989	100
FISCAL YEAR 1990	150
FISCAL YEAR 1991	250

150 UNITS IN U.S. NETWORK
100 UNITS IN GLOBAL NETWORK

5.4 Cross Equator Flow Studies

The NOAA/NOS Ocean Applications Group (OAG) has been examining the hemispheric variability of atmospheric mass in a study of cross equator flow. A fine resolution terrain data base (10 x 10 minutes) is used to reduce Sea Level Pressure (SLP) to surface pressure. Surface pressure is then converted to mass and summed for each hemisphere. The FNOC SLP analyses and the ECMWF 1000mb analyses have both been used as input to this project. Total mass time series have been plotted for the Northern Hemisphere 1946-1987 and Southern Hemisphere 1981-1987.

The time series plots show that large exchanges of atmospheric mass occur between hemispheres on a time scale of days to weeks with the largest exchanges occurring in Northern Hemisphere winter. More variability is seen in the Southern Hemisphere time series of atmospheric mass; this is presumably because data coverage is poorer in the Southern Hemisphere. The OAG has calculated for the 15-day period from February 5-20, 1987, a mean cross equator flow of about 1.5 cm/sec would be required to maintain balance. Looked at in another way, balance to be achieved through a cross equator jet confined to 20 degrees of longitude and 250mb in depth would have to have a mean speed of 0.72 m/sec. Figure 5-3 shows an example of a typical atmospheric mass time series maintained by the OAG, while Table 5-4 summarizes key aspects of the project.

Figure 5-3 Typical Atmospheric Mass Time Series Maintained by NOAA/NOS.

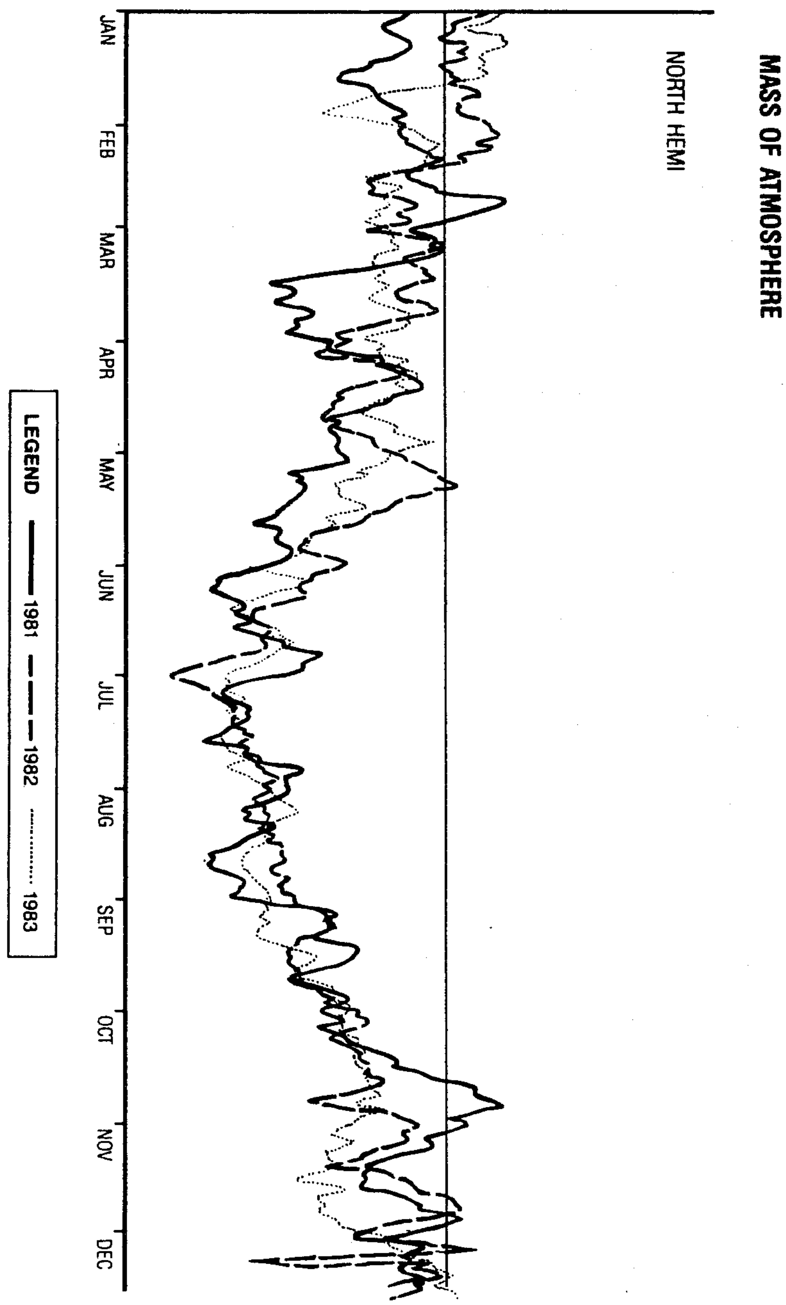

Table 5-4: KEY ASPECTS OF THE NOAA/NOS CROSS EQUATOR FLOW STUDY PROJECT

APPROACH

- o USE A 10'X10' TERRAIN DATA BASE TO REDUCE SLP TO SURFACE PRESSURE.
- o CONVERT SURFACE PRESSURE TO MASS AND SUM BY HEMISPHERES.

INPUT DATA

- o FNOC 6 HOUR SLP ANALYSES, NORTHERN HEMI. 1945-1987
- o FNOC 6 HOUR SLP ANALYSES, SOUTHERN HEMI. 1981-1985
- o ECMWF DAILY 1000MB ANALYSES, NORTHERN AND SOUTHERN HEMI. 1980-1985 *

RESULTS

- o MASS TRANSFERS BETWEEN HEMISPHERES ARE APPARENT. THERE IS RECIPROCITY BETWEEN HEMISPHERES.
- o THE LARGEST EXCHANGES OCCUR IN NORTHERN HEMISPHERE WINTER.
- o EXCHANGES OCCUR ON A TIME SCALE OF DAYS TO WEEKS.
- o TIME SERIES PLOTS OF SOUTHERN HEMISPHERE ATMOSPHERIC MASS ARE MORE "NOISY" THAN FOR THE NORTHERN HEMISPHERE (PROBABLY DUE TO THE POORER DATA COVERAGE IN THE SOUTH).
- o DURING A 15-DAY PERIOD IN FEBRUARY 1987, A MEAN CROSS EQUATOR FLOW OF ABOUT 1.5 CM/SEC WOULD BE REQUIRED TO ACHIEVE BALANCE.

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* 1000MB HEIGHTS CONVERTED TO SLP VIA STANDARD ATMOSPHERE

5.5 IGOSS Participation

NOAA is an active participant in IGOSS programs and is currently making its inputs to the Draft "IGOSS General Plan and Implementation Programme, 1989-1995 Outline". NOAA/NOS programs for automation of upper-air, surface and subsurface ocean observation systems will make a major contribution to IGOSS observation goals in the next few years.

6. HYPOTHESIS TESTING AND MODEL DIAGNOSTICS

In our opinion, operational numerical prediction centres are not making enough developmental model runs to adequately test hypotheses. Several developmental runs should be made for each operational forecast run. Hypothesis testing should be a decision tree operation, and the results should be freely exchanged on an informal basis with other major centres. Series of conventional observations at close intervals in time should be used as one of the most important modes for verification of hypothesis tests.

References

Beaumariage, Donald C. and Wolfgang D. Scherer, 1987: New technology enhances water level measurement; the next generation water level system from the National Ocean Service is designed to provide real-time data for navigation. Sea Technology, May 1987, pp 29-32.

Foley, James D., 1987: Interfaces for advanced computing. Scien. Amer. Oct. 1987, pp 127-135.

Gelernter, David, 1987: Programming for advanced computing. Scien. Amer. Oct. 1987, pp 91-98.

Kahn, Robert E., 1987: Networks for advanced computing. Scien. Amer., Oct. 1987, pp 136-143.

Kryder, Mark H., 1987: Data-storage technologies for advanced computing. Scien. Amer., Oct. 1987, pp 117-125.

Lange, O., R. Fett, R. Landis, G. Wells, G. Rash, E. Aucillo, M. Horito and J. Janunuzzi, 1986: Summary of a workshop/seminar on oceanic storms. Bull. Am. Met. Soc. 67, pp 1271-1277.

McLain, D.R., P.D. Stevens and R.A. Bauer, 1986: Real-time reporting of ocean temperature and salinity profiles. Proc. Intn'l. Symp. Marine Data Systems, April 30-May 2, 1986, New Orleans.

McLain, D.R., R.A. Bauer and R. Davies, Manuscript 1987: Quality control of real-time ocean profile observations in the United States. III Pacific Cong. Mar. Scien and Tech., May 16-20,1988, Hawaii.

Meindl, James D., 1987: Chips for advanced computing. Scien. Amer., Oct. 1987, pp 78-88.

NASA/NOAA/EOSAT, 1987: System concept for wide-field-of-view observations of ocean phenomena from space. Report of the Joint EOSAT/NASA SeaWIFS Working Group, 92pp.

Peled, Abraham, 1987: The next computer revolution. Scien. Amer., Oct. 1987, pp 57-64.

Szabados, Michael, Charles Roman and Bob Taylor, 1987: Transmission of real time oceanographic and meteorologic data from ships. Proc. Oceans-87, Vol. Three, pp 863-869.