Programs of the National Data Buoy Center

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Abstract

Platforms of the National Data Buoy Center provide vital meteorological and oceanographic observations from data-sparse marine areas worldwide. The data are essential for real-time weather forecasting and research programs. This paper provides information on the data-acquisition systems, networks, monitoring capabilities, data processing and dissemination, data quality and availability, and related technology development for these platforms.

1. Introduction

The National Data Buoy Center (NDBC), a part of the National Weather Service (NWS), which is a component of the National Oceanic and Atmospheric Administration (NOAA), operates over 110 moored buoy and Coastal-Marine Automated Network (C-MAN) observation stations for the primary purpose of acquiring environmental data for operational weather analyses and forecasts and other uses. Often, the first indication that forecasters have of rapid intensification or change in movement of storms come from these stations. In U.S. offshore and coastal waters, about 60% of all marine warning actions are instigated by these reports. Data from these stations are a vital part of the hurricane warning system (Sheets 1990).

The high quality of moored buoy measurements compared to other sources is discussed in Wilkerson and Earle (1990) and Pierson (1990). As a result, buoys are used to provide ground truth for surface measurements from satellites. Space-based sensors are vulnerable to systematic biases that can only be compensated by reference to such ground truth. Buoys are being used to develop algorithms for satellite retrieval of winds and other parameters.

Data requirements of NDBC systems are established through two general means. First, the NWS Office of Meteorology, Branch of Marine and Applied Services, identifies the location and measurement requirements for the basic NDBC station network. The NWS provides funding for ongoing operation and maintenance to support the NWS mission to provide routine forecasts and warnings. Additional requirements may be established by groups and agencies other than the NWS, who require special environmental monitoring. Data from all stations are released in real time and submitted to the archive centers regardless of the source of funding.

In addition, a network of approximately 35 drifting buoys is maintained in the oceans of the Southern Hemisphere for the Tropical Ocean and Global Atmosphere (TOGA) research program. National meteorological centers use NDBC data for hemispheric and global numerical analyses. NDBC data are also an important source of observations for research studies. Research programs on the marine boundary layer, wave generation and propagation, coastal ocean circulation analysis and modeling, ocean mixed-layer dynamics and thermodynamics, climate, pollution, etc., frequently use NDBC data.

Descriptions of previously existing programs were provided by Hamilton (1980, 1986). Since the 1986 article, new programs have evolved, and the number of observations from NDBC stations has more than doubled, to well over 1.2 million messages per year. These earlier papers have been referenced in the scientific literature for descriptions of NDBC data, but are now out of date. This article provides updated information about NDBC programs.

2. Moored-buoy network

Figure 1 shows the location of NDBC moored buoys. NDBC has standardized on the 6-m, boat-shaped NOMAD (Navy Oceanographic and Meteorological Automatic Device) buoy (Fig. 2) for deep-ocean deployments. It survives in the most severe environment, can be carried on the deck of U.S. Coast Guard (USCG) vessels for deployment, can be shipped on flatbed trucks to NDBC for refurbishing purposes, and is less costly to maintain and operate than large discus buoys. The 12-m-diameter discus buoys are used in areas of harsh environmental conditions, such as the Bering Sea and, in recent years, on two Great Lakes stations that were evaluated in a test program for year-round performance (most Great Lakes buoys

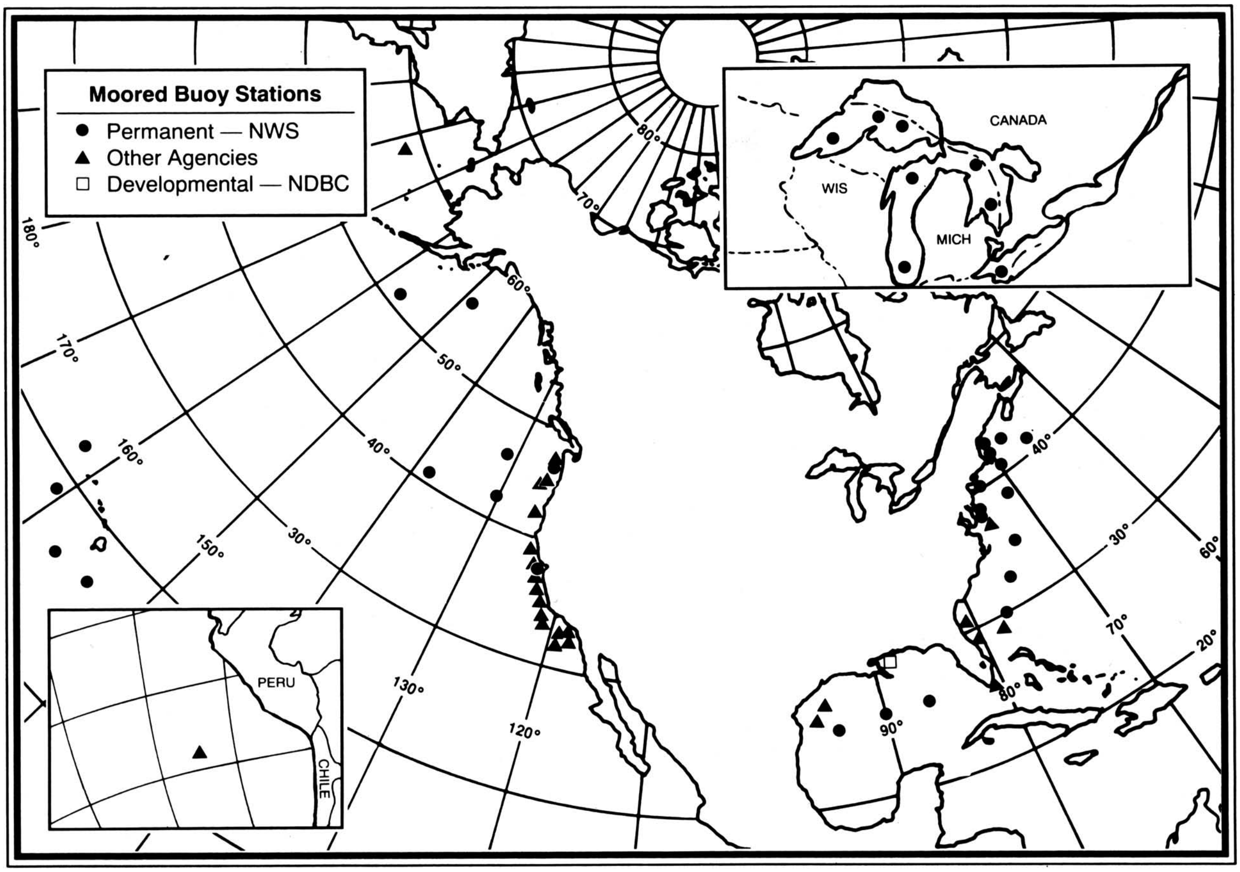

FIG. 1. Map showing the configuration of the NDBC moored-buoy network in December 1991.

are removed in the fall before the onset of the ice season). Seven USCG 12-m-discus, large navigational buoys (LNBs) have been instrumented by NDBC as part of C-MAN to provide observations to NWS. Ten-meter discus buoys (Fig. 3) have been found to capsize in the northeast Pacific Ocean and are now used in less-severe environments, such as coastal areas and the Gulf of Mexico. The 3-m discus buoy (Fig. 4), described in Hamilton (1988), is the hull that is normally used for coastal locations, Great Lakes stations, and directional wave measurements.

In the buoy network, there are normally 33 buoys (including the USCG LNBs) providing data to directly support NWS. There are presently 21 buoys funded by reimbursable users for their own purposes; however, the data are also available to NWS. Reimbursable users include the Minerals Management Service (MMS), the National Ocean Service (NOS), the U.S. Army Corps of Engineers, the National Aeronautics and Space Administration, and the Office of Naval Research. The location of all reimbursable buoy stations are subject to change with time. There is also one NDBC developmental buoy transmitting data.

3. Coastal-Marine Automated Network

In 1981, in response to the need for more coastal and offshore observations, C-MAN was established as a result of an NWS budget initiative. The core network of 40 stations was completed in 1985. Since then, additional C-MAN sites have been installed to meet a variety of requirements. In addition to NWS, other organizations sponsor 11 C-MAN installations to meet their requirements for NDBC high-quality marine/coastal observations. Among these are five major oil companies (through a joint government-industry program) and the Florida Institute of Oceanography. The total existing C-MAN network of 59 stations consists of 7 USCG LNBs and 52 fixed stations located on USCG lighthouses, beach areas, exposed fishing piers, and offshore oil platforms. A C-MAN location map is shown in Fig. 5, and a typical installation is shown in Fig. 6.

Baseline C-MAN measurements include wind speed and direction, peak wind, sea level pressure, and air temperature. At various sites in the network, this capability has been augmented to satisfy other specific requirements. Enhanced meteorological sensor capabilities include measurement of relative humidity, precipitation amount, visibility, solar radiation, and continuous winds. Oceanographic enhancements include water temperature, water level, waves, and subsurface salinity and light intensity. To meet the needs for more frequent observations, selected individual C-MAN stations may be accessed by telephone for more frequent data updates (normally at 15-min intervals).

4. Western Pacific Automated Meteorological Observing Stations (WESTPAC-AMOS)

When the U.S. Air Force discontinued tropical cyclone aircraft reconnaissance in the western Pacific in 1987, a number of actions were taken to augment the data normally available from that area. These actions were designed to provide an improved in situ database to support tropical cyclone forecasting activities. Among the actions taken were an increase in the hours of operation of the Micronesian weather offices, an increase in upper-air soundings at these offices from one to two per day, and the establishment of an extensive network of automatic meteorological stations (WESTPAC-AMOS) throughout Micronesia.

While the NWS Pacific Region (NWSPR) has the overall program management responsibility for the network, NDBC designed the systems, handles the procurement, assists in the installations, and quality controls the observational data. The Department of the Interior provides the NWSPR with the recurring funds to maintain the network.

Two systems were installed in the Republic of the Marshall Islands (Enewetak and Ujae) in 1989, and as of January 1992, there were a total of seven stations operational (Fig. 7) (the moored buoy on the map is funded by the Corps of Engineers for another project). The exact locations of future stations have not yet been firmly established; however, plans are for a network of 20 automatic stations by the mid-1990s. Figure 8 shows a typical WESTPAC installation. The stations measure the standard C-MAN parameters of wind speed and direction, peak wind, sea level pressure, and air temperature.

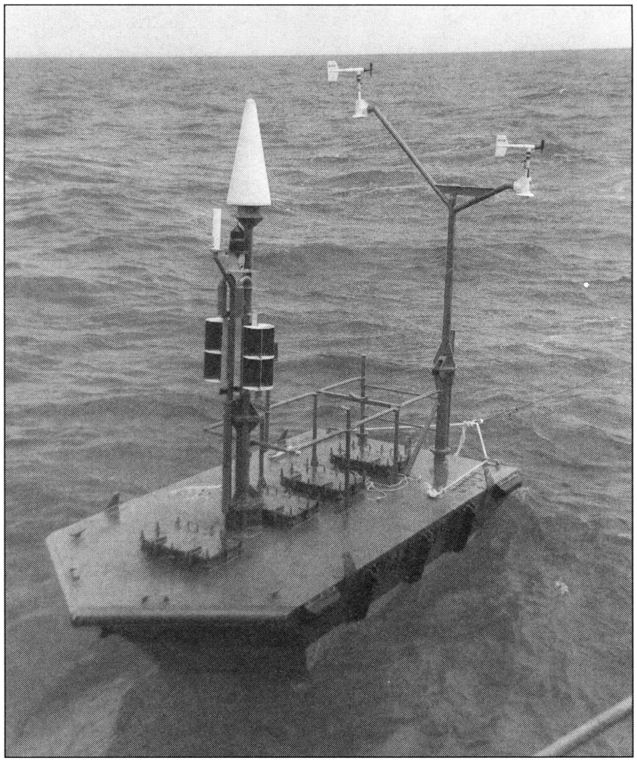

Fig. 2. NDBC 6-m NOMAD buoy.

5. Drifting buoys

Drifting buoys were deployed in the South Pacific Ocean in 1978–79 for the First GARP Global Experiment (FGGE). Besides their scientific value to FGGE, the buoy data were found to be extremely valuable for real-time weather forecasting because there had been a lack of surface observations in that area.

Fig. 3. 10-m-diameter discus buoy with Coast Guard cutter in the background. NDBC relies heavily on Coast Guard support for station service visits.

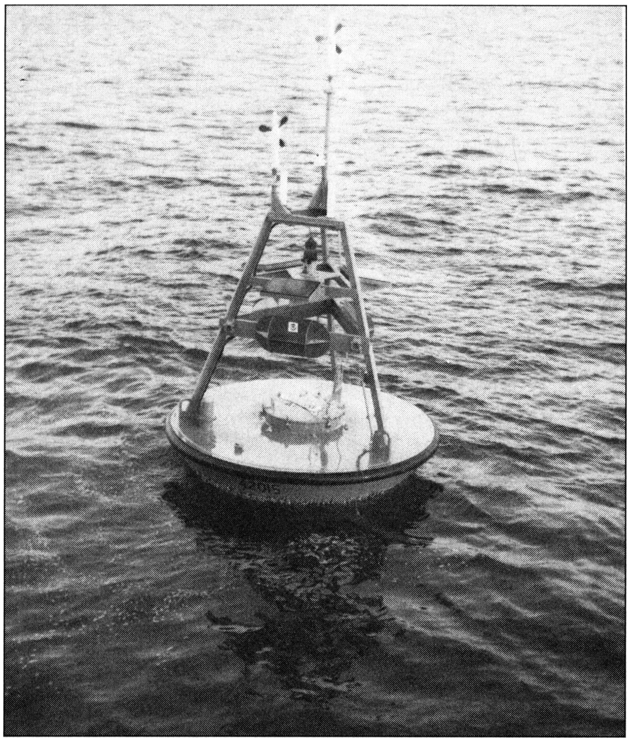

Fig. 4. 3-m-diameter discus buoy.

NDBC maintains a network of approximately 35 drifting buoys in the Southern Hemisphere for NOS in support of the TOGA research program. These buoys provide approximately 90 000 valuable observations each year of sea level pressure, water temperature, and air temperature in areas where such observations are scarce.

The TOGA drifter has been designed to withstand severe environmental conditions. In 1984, three TOGA-type drifters were air deployed in the path of Hurricane Josephine. These buoys provided reliable data in extremely high winds and seas (Black et al. 1988). In the 6 years that the buoys have been deployed for TOGA, the mean-time-to-failure of the buoys has been over 420 days. Table 1 shows the percent of TOGA drifting-buoy sensors still operating over 18 months, based on 220 buoy deployments since late 1984. A description of the TOGA drifter is given in Kozak et al. (1991).

Additional capabilities have been developed for drifting buoys. Figure 9 shows a wind-speed and direction-measuring drifter. Wind speed was proven operationally valid during the Hurricane Josephine test. A favorable evaluation of wind direction was recently completed (Gilhousen 1992). Figure 10 is a

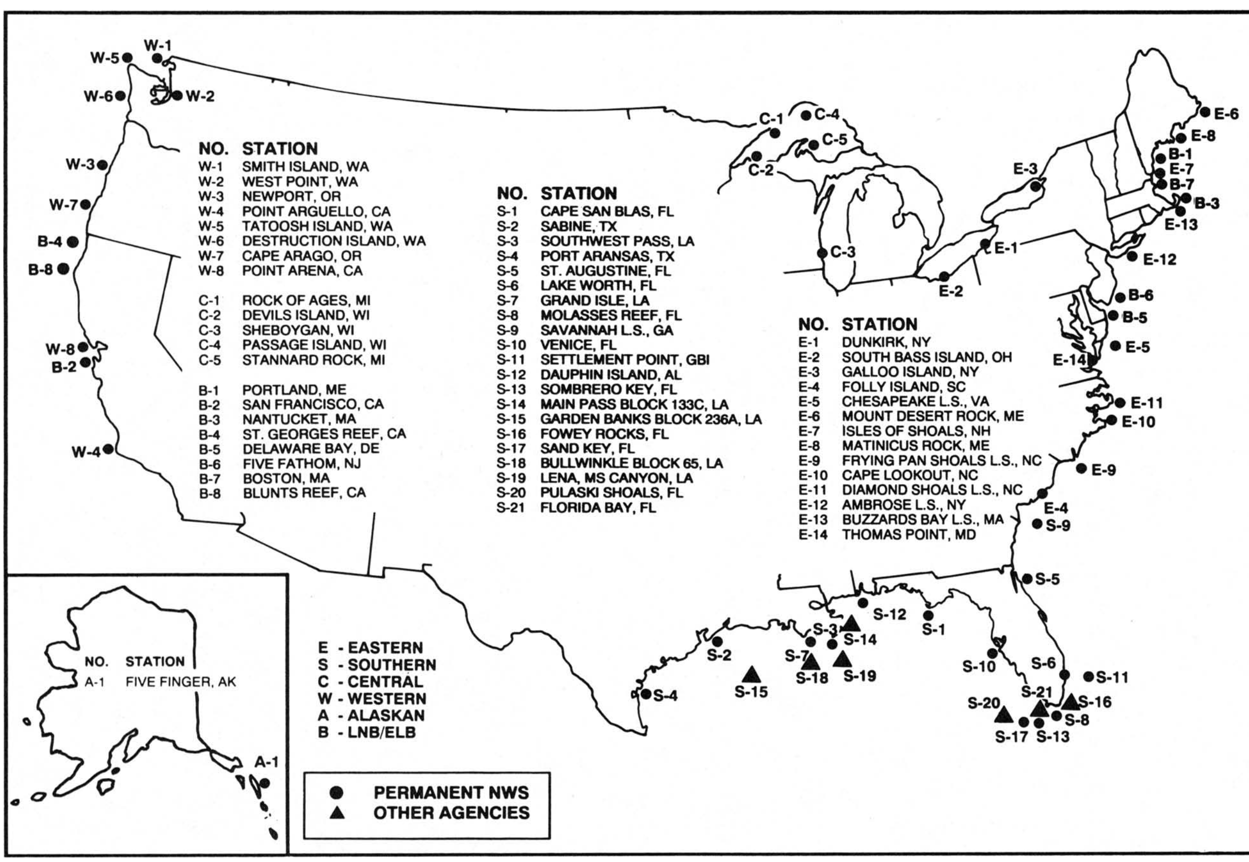

Fig. 5. Configuration of the NDBC C-MAN stations in the U.S.

Table 1. A table showing the percent of TOGA drifting-buoy system components still operating after specified times since deployment. Figures are based on performance of 220 buoys deployed from 1984 to 1991.

			SENSORS		
	Transmitter (%)	**Air pressure (%)**	**Sea surface (%)**	**Air temperature (%)**	**Survival rate of all sensors operating (%)**
After 3 months	88	84	85	87	83
After 6 months	81	78	78	80	76
After 9 months	76	72	73	74	70
After 12 months	68	64	65	66	63
After 15 months	62	58	59	61	57
After 18 months	40	37	38	40	37

time-series plot of wind direction and speed measurements at 1 m from a drifting buoy adjusted to 10 m, compared to a nearby moored buoy with anemometers at 10 m. Subsurface temperature measurements to a 600-m depth have shown some promise. These systems were designed to report to a resolution of 0.1°C and a total system accuracy within ±1.0°C. Further development and formal testing are required before they can be considered fully operational.

6. Payload data

The kinds of measurements that NDBC systems can provide are shown in Table 2. Both moored buoys and C-MAN stations have redundant wind sensors. On large discus buoys, the propeller-type anemometers are located 10 m above the water; on NOMAD and 3-m discus buoys, they are at the 5-m level. In addition to the actual measurements, winds from moored buoy and C-MAN stations are extrapolated to 10 and 20 m in the real-time data messages. The extrapolation is accomplished by means of an algorithm that utilizes air–sea temperature differences to eliminate the effect of atmospheric stability to make the adjustment (Liu et al. 1979; Liu and Schwab 1987). This permits weather forecasters to more easily compare wind observations to standard reference levels and other observation sites.

The total system accuracies listed in Table 2 represent the values to which the data can be reasonably quality controlled. Intercomparison of NDBC moored-buoy winds have shown that they meet the accuracy requirements listed in Table 2 (Gilhousen 1987).

Certain selected stations measure "continuous" winds, which are consecutive 10-min wind averages taken throughout the hour. In addition to computing each 10-min wind velocity, the minute during which the hourly peak 5-s wind occurred and the hourly standard deviation of wind speed are computed. These wind measurements are being used to validate surface winds measured from satellites. Most C-MAN stations in the Gulf of Mexico and on the Atlantic coast south of Cape Hatteras also report "continuous" winds, which are useful for determining the intensity and distribution of winds in and near hurricanes and other severe storms.

7. Data transmission, processing, and dissemination

Observations from moored buoys, C-MAN stations, and WESTPAC stations east of Guam are normally transmitted hourly through the Geostationary Operational Environmental Satellite (GOES) system to the National Environmental Satellite, Data, and Information Service (NESDIS) command and data-acquisition site at Wallops Island, Virginia. The National Weather

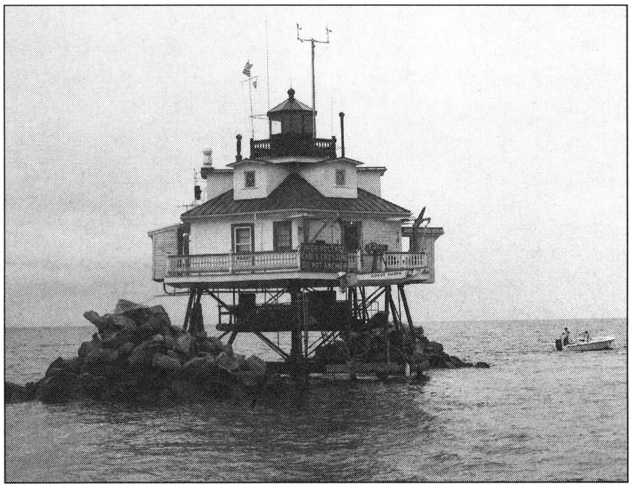

Fig. 6. C-MAN station at Thomas Point, Maryland.

TABLE 2. A listing of measurements provided by NDBC systems. Meteorological data sent in real time are averaged over 8 min on moored buoys, 2 min on fixed C-MAN stations. Wave data on all systems are averaged for 20 min.

Parameter	Reporting range	Reporting resolution	Sample interval (s)	Sample period (min)	Total system accuracy
Wind speed	0–62 m s^{-1}	0.1 m s^{-1}	1	8–10**	±1 m s^{-1} or 10%
Wind direction	0°–360°	1°	1	8–10**	±10°
Peak wind	0–82 m s^{-1}	1 m s^{-1}	1	8–10**	±1 m s^{-1} or 10%
Air temperature	–40° to 50°C	0.1°C	90	8–10	±1°C
Barometric pressure	900–1100 hPa	0.1 hPa	4	8–10	±1 hPa
Surface water temperature	–7°–41°C	0.1°C	1	8–10	±1°C
Solar radiation*	0–2150 W m^{-2}	0.5 W m^{-2}	1	8–10	±5%
Relative humidity*	0%–100%	0.1%	1	8–10	±6%
Significant wave height	0–35 m	0.1 m	0.39	20	±0.2 m or 5%
Wave period	3–30 s	0.1 s	0.39	20	±1 s
Nondirectional wave spectra	0.03–0.40 Hz	0.01 Hz	0.39	20	—
Directional waves*	0.03–0.35 Hz	0.01 Hz	0.5	20	±5°

*Parameter reported on selected buoys **Continuous winds measured on selected buoys

Service Telecommunications Gateway (NWSTG) in Silver Spring, Maryland, receives the data from NESDIS, processes the data, and performs real-time gross-error checks for range and time-continuity limits. C-MAN reports are encoded into WMO code format FM 12-IX—SYNOP (modified); WESTPAC data are coded into FM 12-IX—SYNOP; and buoy data are coded into WMO format FM 13-IX—SHIP. The messages are transmitted hourly on the Automation of Field Operations and Services (AFOS) network, on the Global Telecommunications System (GTS), and to NDBC. They are also available on the NWS family of services.

Spectral wave data are processed into a special

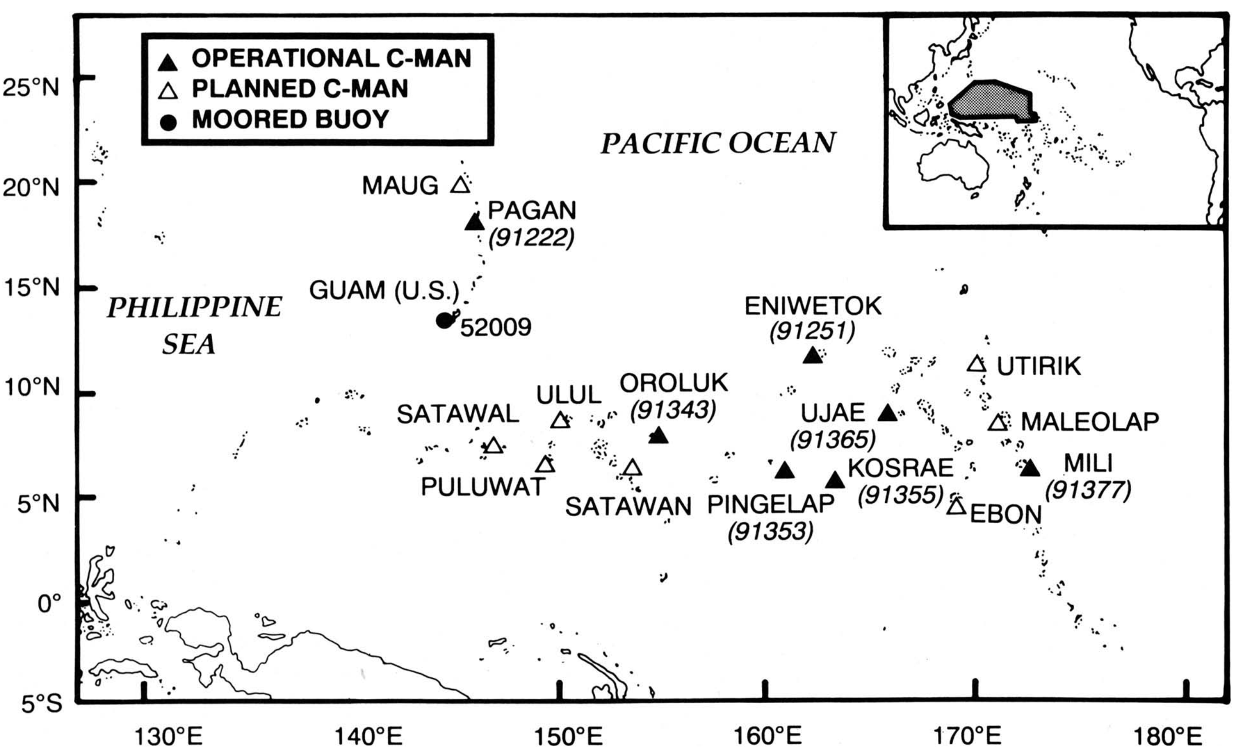

FIG. 7. Map of established stations in WESTPAC. The location of future stations is subject to change.

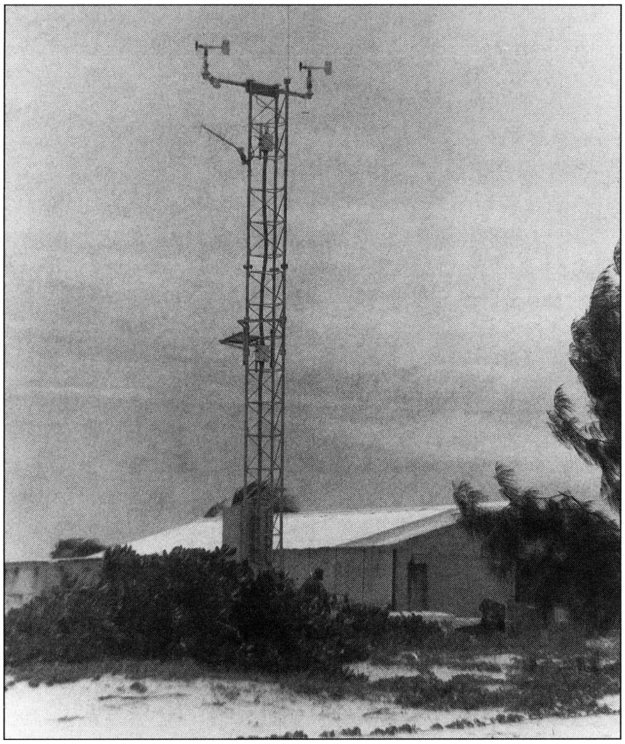

FIG. 8. Photo of the WESTPAC C-MAN installation at Eniwetok Atoll.

U.S. format message and transmitted every 3 h on AFOS. Spectral wave data are also converted to the FM 65-WAVEOB format for dissemination on the GTS and to the NWS family of services.

Drifting-buoy data are transmitted through the Polar Orbiting Environmental Satellite system, and the data are routed from NESDIS to the Service Argos, Inc. (SAI) facility in Landover, Maryland, and to CLS/ Service Argos in Toulouse, France. SAI processes the data from North American–owned drifters, runs gross-error checks, and codes the data into FM 18-DRIFTER. The reports are then sent to the NWSTG for transmission on communications circuits.

WESTPAC stations east of Guam have an Argos-reporting payload that serves as a backup to the primary GOES system. Stations to the west of Guam, out of GOES range, have both primary and secondary backup Argos payloads. WESTPAC reports from SAI are converted at the NWSTG to FM 12-IX—SYNOP.

8. Quality control

The real-time quality control checks at NWSTG are very effective at removing the large errors caused by intermittent data-transmission problems and data from obviously failed sensors. On the other hand, these checks do a poor job of detecting errors caused by sensor degradation. To remove these bad data from distribution, more stringent quality control is performed at NDBC. Automated checks between redundant sensors, stricter range and time-continuity limits, and comparison with gridded fields from the National Meteorological Center and the European Centre for Medium-Range Weather Forecasts are instituted and suspicious data are flagged. Color graphics, such as line plots, scatter plots, and contour maps, are produced on demand by data-quality analysts to closely evaluate the flagged data. Time-series plots and wave-spectra curves help analysts distinguish between true sensor or system failure and legitimate data in near-real time. Data from nearby stations can be plotted to aid in this comparison. Through the NDBC computer center, a database at NWSTG is maintained that provides sensor calibration and indicates which sensors are failed and which is best when two duplicate sensors exist. Sensor drift is corrected by scaling parameters in the NWSTG database to ensure that accurate data are released.

Every month, the validated data are forwarded to the National Climatic Data Center (NCDC) and the National Oceanographic Data Center (NODC). Approximately 90% of all possible data that can be collected from NDBC stations are routinely received in real time and archived. NDBC data can be obtained from NCDC and NODC. Spectral wave data can only

FIG. 9. Photo of the top portion of a wind speed and direction (WSD) drifting buoy.

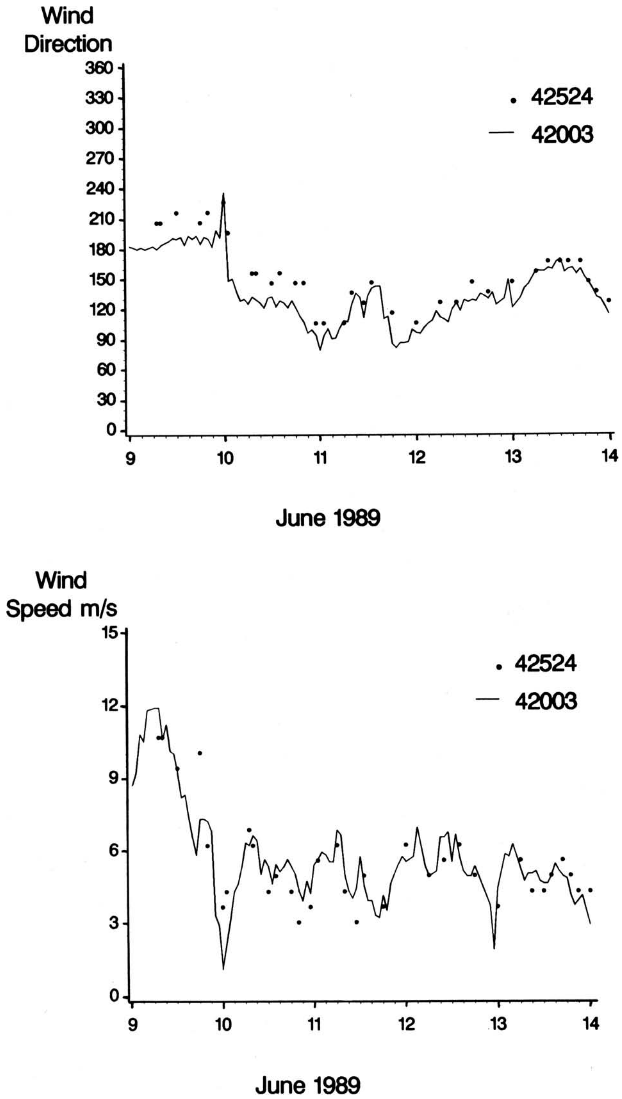

FIG. 10. Time-series plot comparing wind direction and speed measurements at 1 m above the water by a WSD drifter (42524) compared to measurements at 10 m from a moored buoy (42003).

be ordered from NODC. Table 3 gives the extreme values of parameters measured by NDBC systems. Climatic summaries are prepared periodically at NCDC; the latest publication is *Climatic Summaries for NDBC Buoys and Stations Update 1* of February 1990.

9. Technology development

On behalf of MMS, NDBC has deployed two buoys off the southern California coast that are equipped with acoustic doppler current profilers (ADCP). Every hour, the ADCP data-collection system measures and reports the current vector in 16-m-thick layers (or depth cells), from 16 m below the surface to a depth of 336 m. An evaluation of the data has begun using nearby current meters deployed by Scripps Institute of Oceanography.

A coastal buoy has been developed to provide a low-cost, lightweight, reliable buoy for use in the coastal environment. The buoy carries the standard meteorological and waves sensor suite and can measure directional waves. A coastal oceanographic line-of-sight buoy has also been designed to measure waves, water temperature, and other oceanographic parameters in semiprotected waters for transmission to nearby C-MAN stations.

C-MAN stations located on offshore platforms or other suitable structures now have the capability of obtaining nondirectional wave data using the laser wave-height sensor. This sensor is a low-cost, accurate, and reliable system and calculates significant wave height, dominant wave period, and wave spectra.

NDBC has been engaged in a cooperative agreement with NOAA's Environmental Research Laboratory to design, procure, and install a field demonstration network of 30 upper-air wind profilers. This project is well under way, and at present, more than 20 units have been installed and are successfully operating. NDBC is also installing Profiler Surface Observing Systems to obtain observations of wind, precipitation amount, air temperature, and dewpoint every 6 min at

TABLE 3. The location and magnitude of extremes measured at NDBC stations.

Parameter	Value	Location	Platform	Date
Significant wave height	16.9 m	51.9°N, 155.9°W	Buoy	19-01-91
Wind speed	47.3 m s^{-1}	25.9°N, 85.9°W	Buoy	20-11-85
Wind gust	58.5 m s^{-1}	25.9°N, 85.9°W	Buoy	20-11-85
Barometric pressure (max)	1054.9 hPa	56.3°N, 148.3°W	Buoy	04-02-89
Barometric pressure (min)	940.3 hPa	Folly Island, South Carolina	C-MAN	22-09-89
Air temperature (max)	38.7°C	St. Johns Light, Florida	C-MAN	19-07-86
Air temperature (min)	–31.1°C	St. Lawrence Island, Alaska	Land	19-02-87
Water temperature (max)	34.3°C	25.9°N, 93.6°W	Buoy	19-08-85
Water temperature (min)	–1.9°C	Thomas Point Light, Maryland	C-MAN	27-12-89

14 selected profiler sites. These measurements are embedded in the profiler message transmitted to the Profiler Control Center in Boulder, Colorado, and are used for network assessment purposes.

Other activities that are in progress include: development of reliable, lower-cost sensors, electronic payloads, and hull/mooring systems; advanced wave directional measurement systems; precipitation sensors for buoy and C-MAN use; and subsurface water-temperature measurements and applications of water quality measurements.

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