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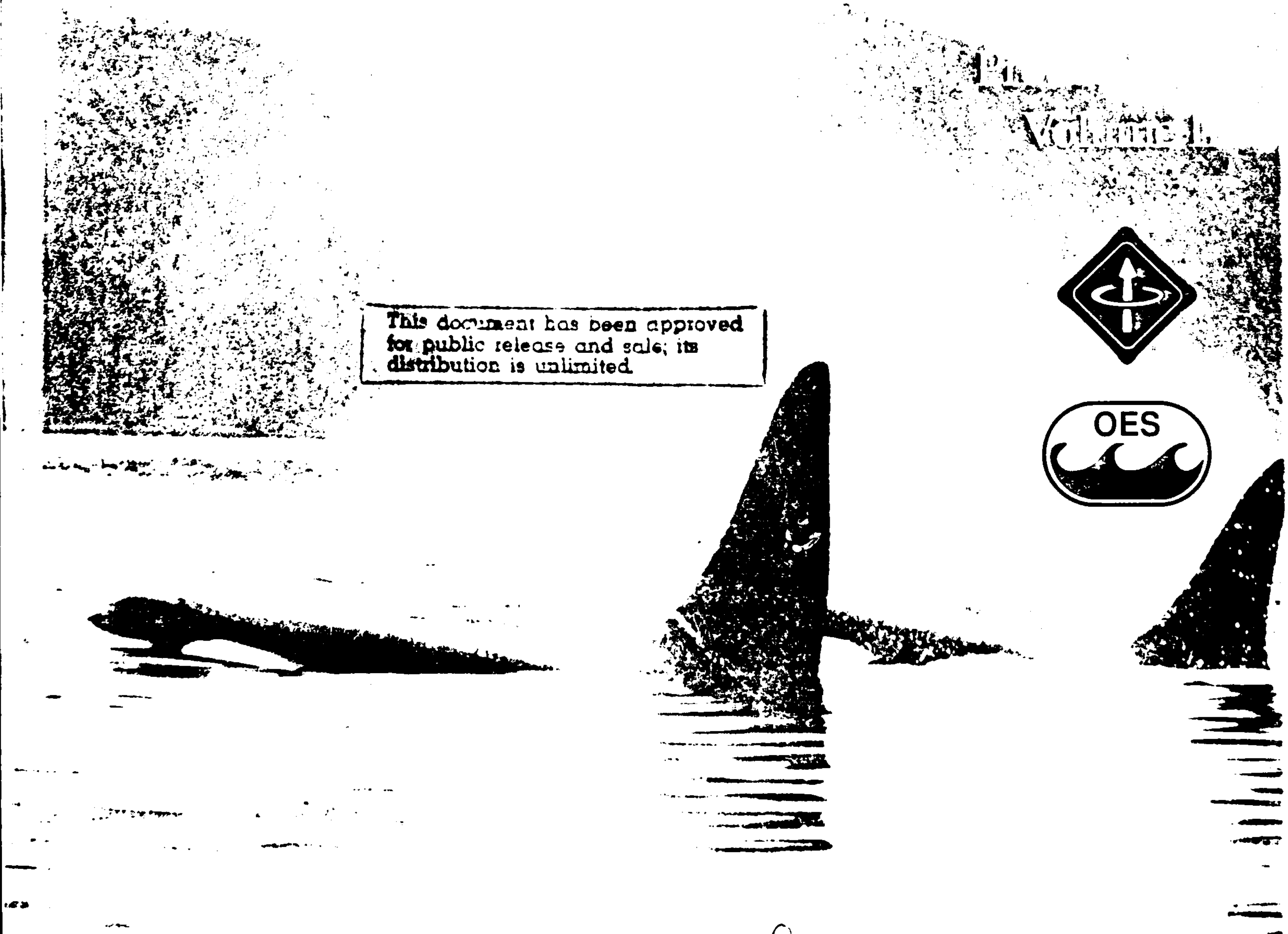

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A prime objective of Naval Oceanography is to get data, "From the sea . . .," and quickly into the hands of the Fleet operators whose safety, sensors, and systems are influenced by it. Changing world politics and economics will undoubtedly reduce the number of maritime observations in the future with increasing reliance being made on automated reporting systems. The Oceanographer of the Navy has been investigating methods to reduce reliance on single profile expendables and ship observations by development of a series of satellite reporting expendable drifting buoys. These buoys will be capable of measuring air temperature, sea surface temperature with depth, ambient noise, wind speed, wind direction, and directional wave spectra. These developmental buoys have been designated by the Navy as AN/WSQ-6 (series) drifting buoys. This paper updates some of the Navy's recent testing of these buoys and provides insight into the engineering challenges ahead for additional sensor development.



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# Data from the Sea . . ., the U.S. Navy's AN/WSQ-6 (Series) Drifting Buoy Program

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*Abstract* – **A prime objective of Naval Oceanography is to get data, "From the sea . . .," and quickly into the hands of the Fleet operators whose safety, sensors, and systems are influenced by it. Changing world politics and economics will undoubtedly reduce the number of maritime observations in the future with increasing reliance being made on automated reporting systems. The Oceanographer of the Navy has been investigating methods to reduce reliance on single profile expendables and ship observations by development of a series of satellite reporting expendable drifting buoys. These buoys will be capable of measuring air temperature, sea surface temperature, barometric pressure, subsurface ocean temperature with depth, ambient noise, wind speed, wind direction, and directional wave spectra. These developmental buoys have been designated by the Navy as the AN/WSQ-6 (series) drifting buoys. This paper updates some of the Navy's recent testing of these buoys and provides insight into the engineering challenges ahead for additional sensor development.**

## INTRODUCTION

In January 1991, the U.S. Navy endorsed an Operational Requirement (OR) for development of a series of A-sized sonobuoy style, satellite reporting, long life (90 day), mini drifting data buoys (MDDBs). The specifications call for development of three variations of the buoy that will have the capability to measure and report various near surface meteorological and oceanographic environmental parameters. These include measurements such as air temperature (AT), sea surface temperature (SST), barometric pressure (BP), directional wind speed (WS/WD), omnidirectional ambient noise (AN), and subsurface temperature with depth (TZ) at various intervals down to 600 m. These three buoy configurations and specifications are summarized in Table I.

## BACKGROUND

The Oceanographer of the Navy tasked the Naval Research Laboratory's (NRL's) Tactical Oceanographic Warfare Support (TOWS) Program Office to manage development of these buoys to meet specifications. The TOWS program previously evaluated a Canadian manufactured buoy called a Compact Meteorological and Oceanographic Drifter (CMOD). The CMOD comes in a sonobuoy style package and measures AT, SST, and BP. Data are sampled hourly and transmitted via the NOAA polar orbiting satellites via Service ARGOS formats. The CMOD was tested and modified to allow it to be deployed by Navy P-3 Orion aircraft. Sensor evaluation and testing resulted in further refinements to the buoy's sampling technique and the addition of a 100-m prototype thermistor string on 60 buoys. This design effort projected that it would be feasible to use a very thin wire, free flooding cable with potted thermistors for long term (90 day) ocean thermal structure measurements using expendable technology. However, the thermistor string reliability proved to be poor due to salt water leakage into the thermistors, a problem still prevalent in thermistor strings with much larger diameters and better water permeability protection. Improved manufacturing techniques for this cable design have been identified, and subsequent testing of a 100-m TZ buoy showed no thermistor failures over a 102-day life span in an open-ocean test. This design experience has led to other improvements that will be discussed further.

An analysis of daily environmental observation source statistics at the Fleet Numerical Oceanography Center show that the number of drifting buoy observations over the ocean (1200/day) is approaching the number of rawinsonde observations (RAOBS) (1600/day) available over land. However, there is still three times more ocean area than land that needs observation coverage. Satellite SSTs (120,000) and soundings (22,300) account for more than half of the 237,000 observations received daily. Most of the satellite-derived measurements are area estimates. Data from drifting buoys, ships and bathythermograph (BT) observations provide the "sea truth" data for most remotely sensed oceanic parameters. If ship and BT reports decrease as projected, a growing reliance will be made on automated reporting such as buoys.

## DEVELOPMENTAL PROGRAM

In response to the OR for the buoys, the TOWS program initiated a cost-shared development program with the government of Canada under the auspices of a 1963 U.S./Canadian Defense Development Sharing Agreement



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TABLE I
OPERATIONAL REQUIREMENT SPECIFICATIONS FOR MINI DRIFTING DATA BUOY

| TYPE | SENSOR | RANGE | ACCURACY |
|---|---|---|---|
| Meteorological | Barometric Pressure | 850 to 1054 mb | +/- 1.0 mb |
| | Air Temperature | -30 to +46°C | +/- 0.2°C |
| | Sea Surface Temperature | -5 to +35°C | +/- 0.2°C |
| | Wind Speed | 0 to 63 m/s | +/- 1.0 m/s |
| | Wind Direction | 0 to 360°T | +/- 15°T |
| SHALLOW TZ-MET | Met package as above | | |
| | TZ Tail to 300 m | Logarithmic spacing | |
| | Ten Thermistors | -5 to +35°C | +/- 0.2°C |
| | Pressure Sensor | 0 to 330 db | +/- 3 db |
| | Omni-Hydrophone (100 m) | 5 Hz to 5 kHz | +/- 1 dB |
| DEEP TZ (600 m) | Sea Surface Temperature | -5 to +35°C | +/- 0.2°C |
| | TZ Tail to 600 m | Logarithmic spacing | |
| | Fifteen Thermistors | -5 to +35°C | +/-0.2°C |
| | Pressure Sensor | 0 to 660 db | +/- 3 db |
| | Omni-Hydrophone | 5 Hz to 5 kHz | +/- 1 dB |

TABLE II
BUOY CONFIGURATIONS AND CORRESPONDING NAVY DESIGNATION

| BUOY CONFIGURATION | U.S. NAVY DESIGNATION |
|---|---|
| CMOD | AN/WSQ-6 (XAN-1) |
| CMOD/ANS | AN/WSQ-6 (XAN-2) |
| CMOD/TZ 300 m | AN/WSQ-6 (XAN-3) |
| CMOD/TZ/ANS | AN/WSQ-6 (XAN-4) |
| CMOD/WS/WD | AN/WSQ-6 (XAN-5) |

Title: Buoy, Satellite Transmitting
W - Water Surface Underwater & Combination
S - Special Types
Q - Special or Combination of Purposes
XAN-# - Naval Air Warfare Center Indianapolis Prototype

This multiyear contract called for a phased development of four additional sensors using the basic CMOD package concept. Four buoy configurations were proposed with an option for a fifth. These buoy configurations have been given the designation as AN/WSQ-6 (series) buoys (see Table II). In each phase of the development, the contractor is to build at least six prototype buoys for proof of concept and in-house testing and then, upon demonstration of successful sensor performance capability, deliver 25 of each prototype to the Navy for additional testing. Prior to Navy testing, "dummy buoys" of the same size, weight and center of gravity characteristics were air deployed to ensure the buoys met Navy air safety certification requirements.

DRIFT CHARACTERISTICS

The Navy is committed to using expendable drifting buoys and routinely deploys them worldwide as part of the Naval Oceanography Command's Integrated Drifting Buoy program. These buoys have been used to "tag" certain frontal and oceanographic features and at times provided the only available data for location and movement of these features. Initial evaluations indicated the basic CMOD buoy design is sometimes wind-driven and does not act as a Lagrangian current follower. Subsequently, specially configured drogued mini drifting data buoys have been utilized to evaluate shallow water/oil spill circulation models and current drift trajectory predictions [1]. The National Oceanic and Atmospheric Administration (NOAA) has done a comparison of a drogued mini drifting data buoy with current following shapes and found no substantial difference in its current following ability. A CMOD/ANS (drogued) buoy and a World Ocean Circulation Experiment (WOCE) "standard" buoy were air deployed side by side in June 93 for further evaluation.

ACOUSTIC SENSOR

Fig. 1 shows the configurations of the AN/WSQ-6 series buoys. The first (XAN-1) is similar to the standard CMOD which has been used operationally for three years. The XAN-2 configuration calls for the addition of an ambient noise sensor (ANS) hydrophone, located at 100 m, onto a basic CMOD buoy The hydrophone sensor will collect broadband, omnidirectional ambient noise at 16 frequencies between 5 Hz and 25 kHz in one-third-octave band filters using a time bandwidth product of 100. Data are sampled

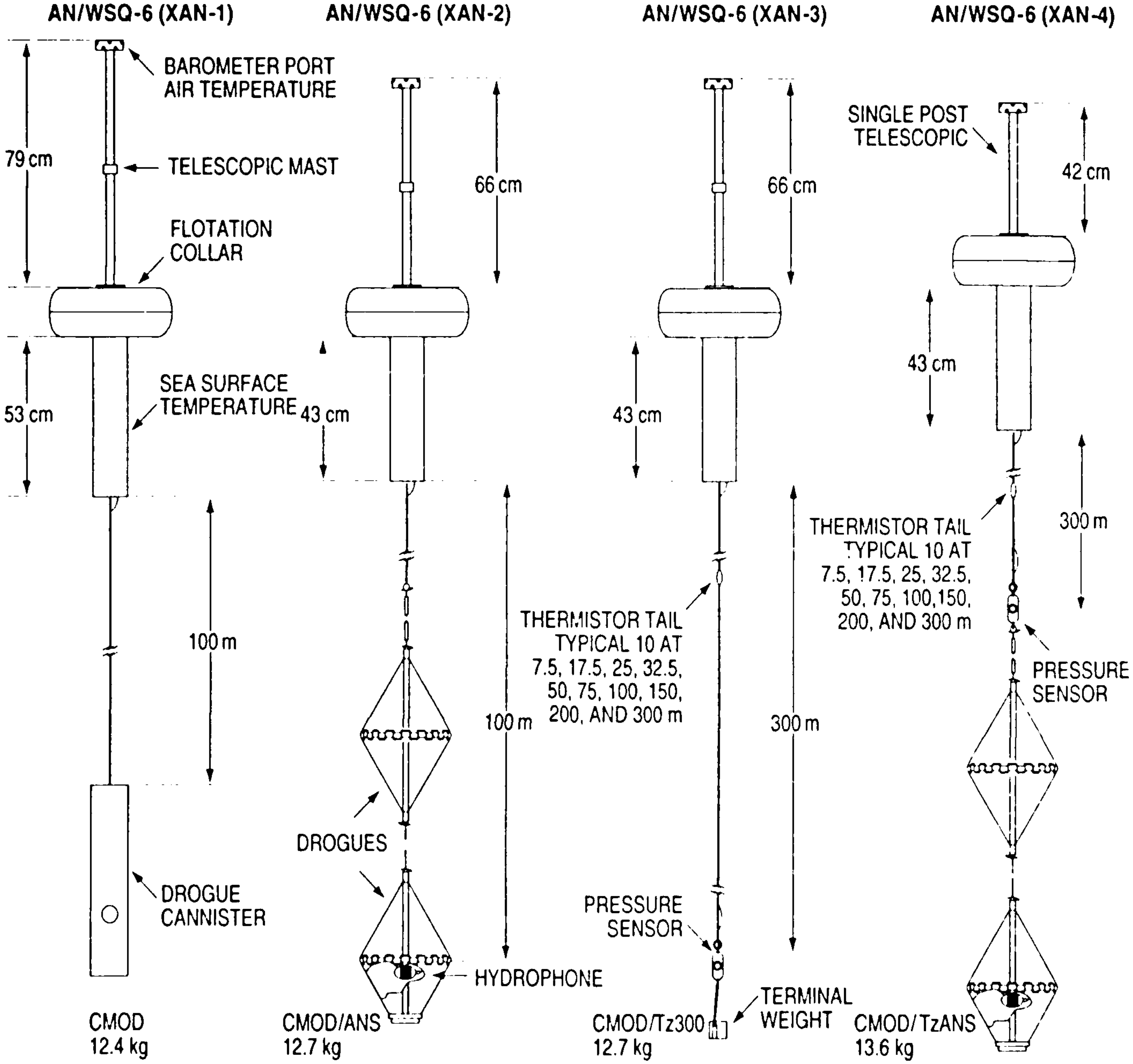


Fig. 1. Mini drifting data buoy configurations and nomenclature.

and updated hourly. The hydrophone assembly is suspended in the center of the lower drogue. The hydrophone contains an integral preamplifier which is powered by and transmits signals over a two-wire link with the surface unit over the frequency band of 5 Hz to 25 kHz. Fig. 2 is a 30-day time series of 6 of the 16 frequencies from one of these buoys which was deployed near Iceland in January 1992. Acoustic variability of 20 or more decibels can be seen on time scales of less than 12 hours. Wind- and weather-related noise events from passing storms have been correlated.

The Navy has taken delivery of the 25 AN/WSQ-6 XAN-2 prototype units and "MIL SPEC" testing of this configuration has been completed. Much of the testing is being done through the Naval Air Warfare Center (NAWC), Indianapolis, Indiana. These include air safety certification, examination of Hazards of Electromagnetic Radiation to Ordinance (HERO), survivability to shock and vibration extremes, temperature and humidity extremes, accelerated aging, hydrophone acoustic response, antenna beam pattern verification, verification of the ARGOS communications

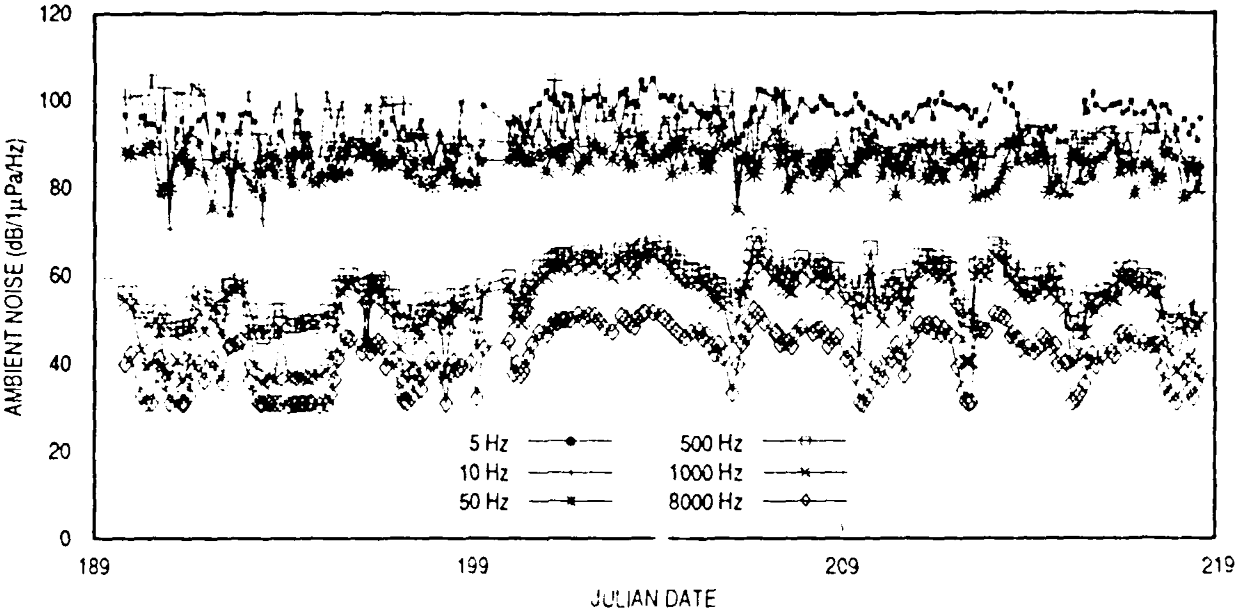


Fig. 2. Thirty day ambient noise summary from buoy 12689

format, and open-ocean deployment, air deployment evaluation including underwater video of water entry and deployment of buoys in operational scenarios. Test units have shown sensor ability to meet nearly all the specifications with the exception of 90-day life on subsurface sensors. Preliminary analysis of available data indicates premature failure of the copper conductors and possible fatigue failure in the suspension system rubber compliance members after about two weeks of constant wave action. The result is a total loss of subsurface data or contamination of the acoustic data due to flow induced and mechanical noise. A cable design improvement is being implemented for testing in future configurations.

### THERMISTOR STRING

The XAN-3 is equipped with a 300-m thermistor (TZ) string with 10 thermistors at depths of 7.5, 17.5, 25, 32.5, [illegible], 75, 100, 150, 200, and 300 m. These thermistor depths correspond to Navy standard Optimum Thermal Interpolation Scheme (OTIS) model depths and will be used to seed [illegible] model output. A pressure sensor will allow correction [illegible] depth differences. Experience with the 100-m TZ buoy prototype indicated that the most notable failure [illegible] was a slow short to seawater and potential copper [illegible] stress fatigue. A new torque-balanced cable was [illegible] that incorporated the thermistors "in line" with an [illegible] water blocked organic polymer (polyurethane) [illegible]. The thermistor attachment and water-blocking technique uses a unique polymer to metal bonding technology [2]. The design specifications allow for [illegible] of other configurations by the addition of two internal wire leads to add a hydrophone or other sensors to the cable. The cable specifications have been given to two independent manufacturers and electromechanical verification and testing of the prototype cable design specifications have been completed. Manufacturer testing of the thermistor string prototypes will be completed by late 1993 followed by Navy tests similar to the XAN-2.

### COMBINED TZ/ANS BUOY

The XAN-4 prototype will combine the thermistor string and hydrophone on one buoy. This configuration will have a redesigned antenna and mast assembly, increased sensor payload capacity and incorporation of a UHF command active receiver for buoy scuttling. Due to present reporting format limitations, only 11 frequencies (vice 16) from 5 Hz to 8 kHz will be reported in addition to the meteorological and thermistor sensor data. Packaging constraints due to available cable diameter and space available may limit the actual length of the TZ cable to only 200 m. If subsurface sensor longevity can reliably exceed 60 days, this buoy will prove to be a tremendous multiparameter data gathering instrument. It can be used to gather time series correlated data for a variety of remote sensing applications. The first prototype buoy of this configuration was deployed in Halifax harbor in July 93 and all buoy sensors were functioning properly at the time this paper was submitted.

### WIND SPEED/DIRECTION SENSOR

A crucial sensor needed for the buoy is a wind speed and direction sensor. The XAN-5 will incorporate a prototype sensor for this application. This sensor development is viewed as the most technically challenging. Small mechanical anemometer cup and vane type devices have been added to larger buoys where power and space were adequate. None of these devices lend themselves to the miniaturization and reliability required for small expendable buoys. The wind sensor for this buoy should have no moving parts, lend itself to expendable low-power technology and yet be accurate enough to act as a "bell ringer" for gale and storm force winds and portray wind shifts associated with passage of synoptic scale weather features. Many nonmechanical techniques have been investigated. One of these is the Wind Observation Through Ambient Noise (WOTAN) technique where correlation has been shown to exist between wind speed and estimates obtained by evaluation of ambient noise at selected frequencies [3]. Researchers at the Naval Postgraduate School have investigated these techniques and assisted in the evaluation of the mini drifting data buoys. A modified WOTAN technique was applied to acoustic data from one of the ambient noise drifting buoys deployed near Bermuda in 1992 and compared to Defense Meteorological Satellite Program (DMSP) derived Special Scanning Microwave Imaging (SSM/I) wind speed estimates over the area, the results are shown in Fig. 3. Although the correlation in this case was excellent, other data in different water masses from the Pacific indicate that the algorithm may not be universal [4]. Further research in this area is needed. NOAA is currently investigating acoustic techniques for classification and quantification of precipitation. Although promising, this technique is not proven enough for expendable buoy applications. A German company is presently designing a wind speed sensor using a differential strain gauge technique that they have successfully demonstrated. This technique appears to lend itself to the miniaturization and power requirements of an expendable sensor. A phase I design effort and bread board sensor development effort was initiated in January 1993. If successful it will be integrated onto an AN/WSQ-6 prototype buoy and tested in 1994 with funding obtained through the Office of Naval Research.

## WAVE BUOY

A development to add directional wave spectra capabilities to a CMOD-style buoy was also initiated this year. A three axis accelerometer and magnetometer technique will be used to extract directional wave spectra from buoy motions. Buoy/wave response function corrections and encoding of wave processing results for transmission by ARGOS will be required. Techniques similar to those used on larger buoys maintained by the National Data Buoy Center can be utilized to look at the high-frequency component of the wave spectrum for estimation of wind speed and

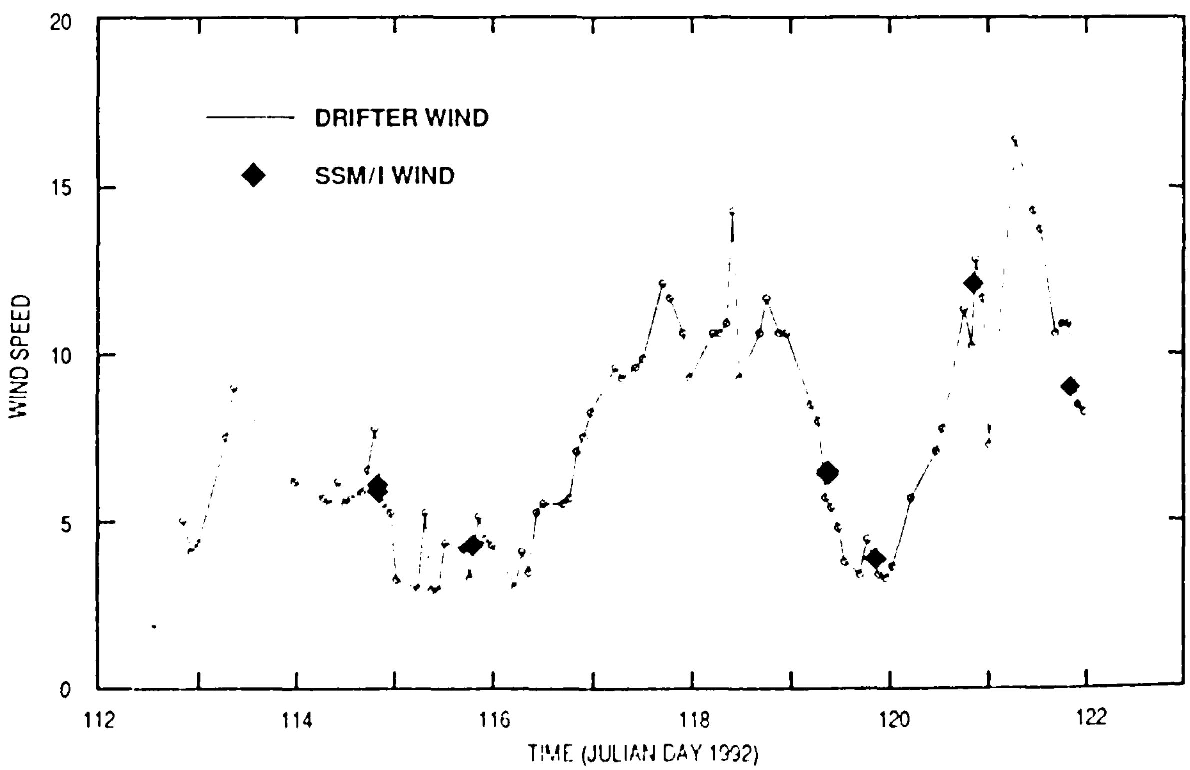


Fig. 3. Comparison of WOTAN wind speed estimates to SSM/I winds

direction [5]. This design prototype will require an integrated processor capability and additional power for processing. As more sensors are added, power budgets and data sampling strategy will have to be revised or the buoys will have much shorter life spans. Moored or drifting versions of this buoy will be used to support the Navy's new initiatives to support shallow-water conflict scenarios.

## OPTICAL BUOY

The TOWS office has also supported a National Aeronautics and Space Administration (NASA) initiative to add a multichannel passive upwelling optical radiance filter to the bottom of a CMOD-style buoy. This buoy prototype has seven passive optical filters that correspond to the channels of sensors on the upcoming SeaWifs ocean color satellite. Successful air deployment and testing of three of these buoys was accomplished in Pacific equatorial and Gulf of Mexico waters this past year. Plans are in place to make an optical chain with several radiance or irradiance sensors at various depths using the thermistor chain technology on a similar optical buoy design.

## SUMMARY

The developmental phase of the AN/WSQ-6 is expected to be completed by late 1994 with transition to an operational buoy program in 1995. Performance specifications will be written and an openly competed procurement contract will be initiated. The Navy's Commander Naval Oceanography Command and the Program Executive Office for Fleet sonobuoy procurement have agreements in place to transition this buoy program to full operational status. Multiparameter, long-life, expendable instrumentation such as the AN/WSQ-6 buoys are a vital key to the success of the U.S. Navy's contribution to a global ocean observing system.

## ACKNOWLEDGMENTS

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