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Instrumentation and Data Acquisition System for an Air-Sea Interaction Buoy

S. SethuRaman, W. A. Tuthill, and J. McNeil

Department of Energy and Environment
Brookhaven National Laboratory
Upton, N.Y. 11973

Abstract

Instrumentation and data acquisition system for a typical air-sea interaction experiment are described. The experiments were conducted with the help of a stable air-sea interaction buoy anchored 5 km offshore in the Atlantic Ocean near Long Island. Errors due to the tilting motions of the buoy are discussed. The instruments were designed to survive the hostile marine environment and maintain their calibration and relatively high frequency response. A line-of-sight RF telemetry system was used to obtain data at a fast rate. Unique power supply features such as a wind charger and a solar panel were used to extend the life of the batteries. Future plans regarding data transmission through geostationary satellites are presented.

1. Introduction

The atmosphere and oceans are in continuous interaction over nearly 70% of the surface of the earth. Through complicated feedback processes, the interaction involves exchanges of energy, momentum, gases, particles, and electrical charges. In order to understand the momentum exchange between the atmosphere and the ocean and the process of current generation, a series of air-sea interaction experiments were conducted during 1977 on the continental shelf of the Atlantic Ocean near Long Island by the Atmospheric Sciences Division of Brookhaven National Laboratory (BNL). These experiments were carried out in conjunction with the coastal boundary layer and diffusion experiments of the Oceanographic Sciences Division at BNL. The purpose of this paper is to describe the instruments and the data acquisition systems used in the 1977 air-sea interaction experiments.

Buoys offer excellent platforms for air-sea interaction experiments owing to the cheaper construction costs and ease in relocation as compared to fixed structures. The main requirements for an air-sea interaction buoy (as compared to the more common oceanographic buoys) are that it be stable, with minimum tilting motions, and that it have features that will facilitate measurements of atmospheric and oceanic variables above, below, and at the surface of the water. The air-sea interaction buoy at BNL was originally designed and built by the Massa-

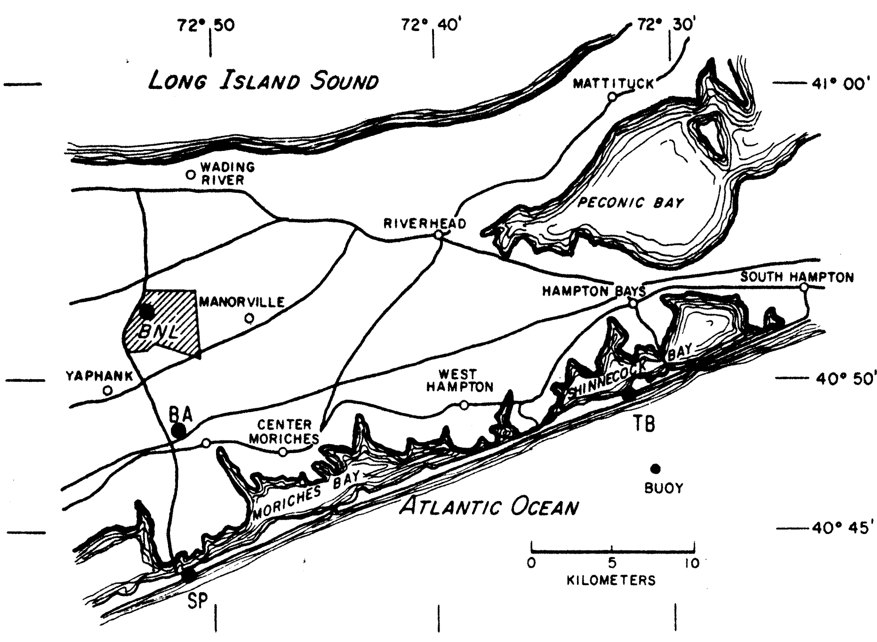

FIG. 1. Map of eastern Long Island showing relative locations of measurement sites: Brookhaven National Laboratory (BNL), Brookhaven Airport (BA), Smith Point (SP), Tiana Beach (TB), and the air-sea interaction buoy (BUOY).

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chusetts Institute of Technology (MIT) for the U.S. Navy and was in use by MIT (Seesholtz, 1968). Later, it was transferred to Woods Hole Oceanographic Institution (WHOI) and was used at the present site (off Long Island) for a brief period in 1975 by WHOI and BNL. In 1976 the buoy was modified at BNL to provide a watertight instrumentation well and devices to adjust the submergence level more accurately (Huszagh and Fink, 1976). The objectives of the 1977 air-sea interaction experiments at BNL were to study the variation of wind stress over water, measure the characteristics of atmospheric turbulence, and understand the process of current generation. This required various meteorological instruments to measure fluxes of momentum, heat, and water vapor. In addition, surface wave characteristics and near-surface currents were measured to understand the basic phenomenon of momentum exchange between the atmosphere and the oceans.

2. Air-sea interaction buoy

The buoy was anchored in the Atlantic Ocean 5 km off the southern shore of Long Island. Its location relative to other coastal meteorological stations and BNL is shown in Fig. 1. A view of the instrumented air-sea interaction buoy with a wind charger is shown in Fig. 2.

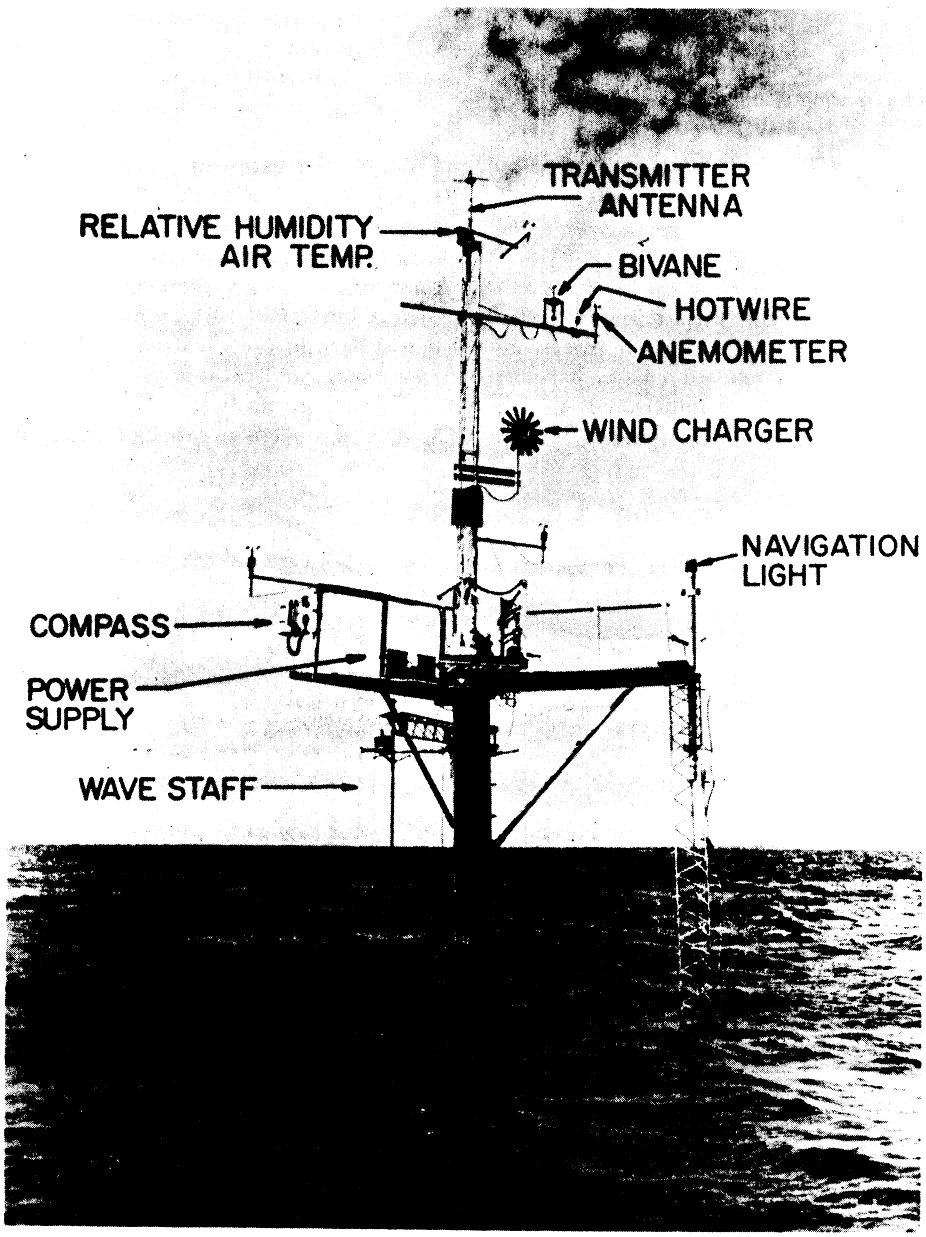


FIG. 2. Air-sea interaction buoy with meteorological and oceanographic instruments and a wind charger.

The platform of the buoy is ~5 m above the water surface. An aerial view of the buoy (Fig. 3 and cover) indicates the horizontal extent of the platform. A view of a model of the buoy (Fig. 4) shows the underwater features. The buoy is 24 m long from the working platform to the drag plate at the bottom. The diameter varies from 60 cm at the lower sections to 45 cm near the platform. The decreased area near the surface reduces wind drag and wave action. The long cylindrical shape, horizontal drag plate at the bottom, and the enormous weight of the buoy (9000 kg) minimizes accelerating and tilting motions caused by the waves. The buoy is provided with a 6 m high meteorological tower above the platform and a 16 m long oceanographic tower below the platform. A watertight instrumentation well 175 cm deep provides an ideal place for the electronics that control the instruments and data processing and transmitting systems. The well is covered with a submarine-type top door to prevent any leakage of water. Oscillating tilt of the buoy is of the order of ±5°. Vertical displacements (5–15 cm) occur only with long waves, or swells. Two-dimensional gimbal mounts with friction-free point bearings are used to isolate sensitive instruments from even these small tilts.

3. Errors caused by the tilting motions of the buoy

Waves tend to induce movement of the buoy. There are two effects due to the tilting motion of the buoy: 1) a

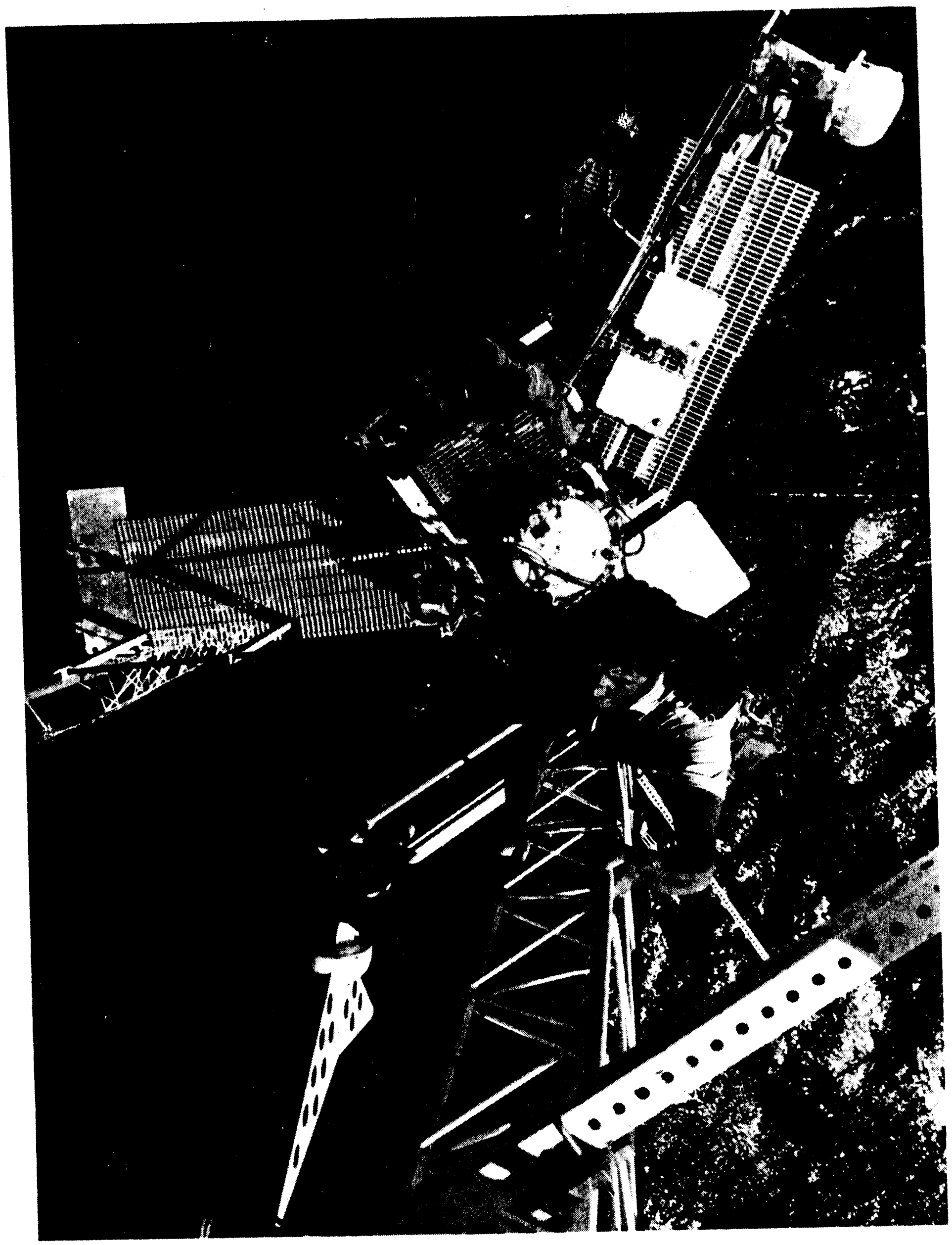


FIG. 3. Aerial view of the buoy showing the horizontal extent of the platform.

"false" observation induced by the motion of the sensor at wave frequencies, and 2) variation in the axes of the sensor due to the time-varying tilt of the mast.

Pond (1968) has estimated errors in measuring turbulent stress for a time dependent tilt, $\theta(t) = \theta_0 \sin\omega t$, where θ_0 is the maximum amplitude at the dominant frequency and ω is the frequency. For an oscillating tilt of ±6° the error is estimated to be ~1% of the true value, and the error increases to ~15% for a tilt of ±23°. Thus, for a buoy designed to keep the mean tilts close to zero, errors in measuring turbulent fluxes by the eddy correlation technique are very small. This is due to the following reasons:

1) The tilt is essentially caused by the dominant wave. The wave spectrum is very narrow (less than a decade wide), whereas spectra of turbulent velocities are several times wider and the contribution of momentum flux is mostly from low-frequency eddies.
2) Correlations at wave frequencies are not perfect owing to contrasting phase relations. For example, turbulent velocities, u (longitudinal) and w (vertical), are approximately out of phase. But the corresponding oscillating velocities, u' and w', of the buoy caused by the orbital velocities of the waves are approximately in quadrature. Our measurements indicate the correlation between u and w to be about −0.5, whereas the overall correlations between u and w' and between w and w' were close to zero.

But there may be some contribution to variances of longitudinal and vertical velocity fluctuations if the oscillating tilt of the buoy is large. However, this can be easily corrected because the contribution to the variance due to the motion of the buoy will be in a narrow band of frequency of the dominant waves. Since fixed platform data show no peaks in the variance spectra for u or w at wave frequencies, any peaks in the wave frequencies above the smooth background give an estimate of the effect of the motion of the buoy. Another possibility is measuring the horizontal and vertical accelerations of the buoy simultaneously with the wind fluctuations and applying corrections to the instantaneous values.

The air-sea interaction buoy described in this paper has been specifically designed to keep the mean tilts close to zero and the oscillating tilts very small, typically of the order of ±5°. As was mentioned previously, the following design features help in achieving this objective:

1) The long, cylindrical shape of the buoy (Fig. 4) reduces the cross-section area of the buoy, and thus the drag on the buoy in the wave zone has been minimized. With a large submerged length, much of the buoy is in a depth range not affected by the orbital velocities induced by wave motion and hence this provides a stabilizing effect.
2) The weight of the buoy of ~9000 kg acts as a stabilizing force.
3) The large drag plate at the bottom minimizes accelerations and acts as another stabilizing factor.

Preliminary analysis of the data was carried out to derive surface drag coefficients (SethuRaman, 1976, 1978) from momentum fluxes obtained by the eddy correlation method. The results indicated that the surface drag coefficient depends on the aerodynamic roughness of the sea surface, as was found by early measurements from a fixed tower on the beach (SethuRaman and Raynor, 1975). The results were also comparable with studies

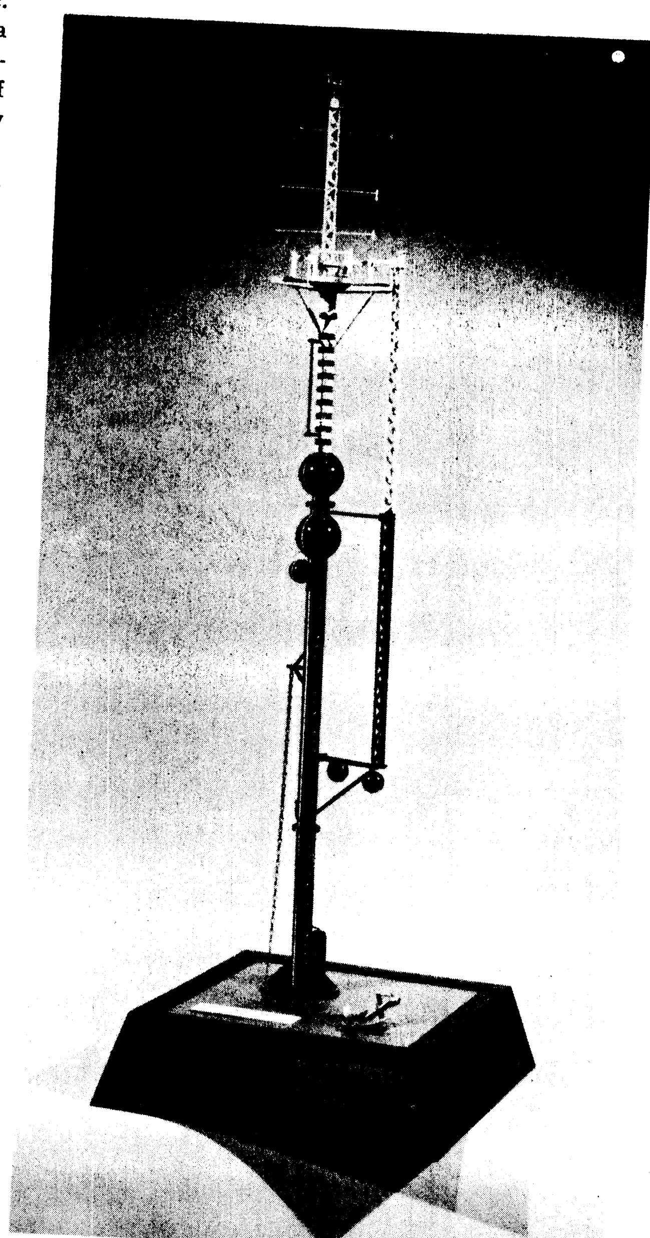


FIG. 4. A view of the scale model of the air-sea interaction buoy indicating the underwater features. Mean water level was generally ~4 m below the platform.

conducted elsewhere from fixed platforms (Kitaigorodskii, 1973).

4. Instruments

Air-sea interaction studies need instrumentation that will measure parameters (that induce exchange) over, under, and on the sea surface. In this section, details of the meteorological and oceanographic instruments that were used on the buoy will be given. Instruments on the buoy were designed to provide the following information: 1) wind stress by two independent methods, *viz.*, eddy correlation and wind profile; 2) atmospheric stability; 3) water vapor flux; 4) surface wave characteristics; and 5) buoy motion.

a. Atmospheric surface layer

Direct measurements of momentum flux were made with the BNL bivane (SethuRaman and Tuthill, 1977, 1978) and a cantilever hot-wire anemometer. When the momentum flux is downward, the atmosphere exerts a tangential stress on the ocean, often called wind stress.

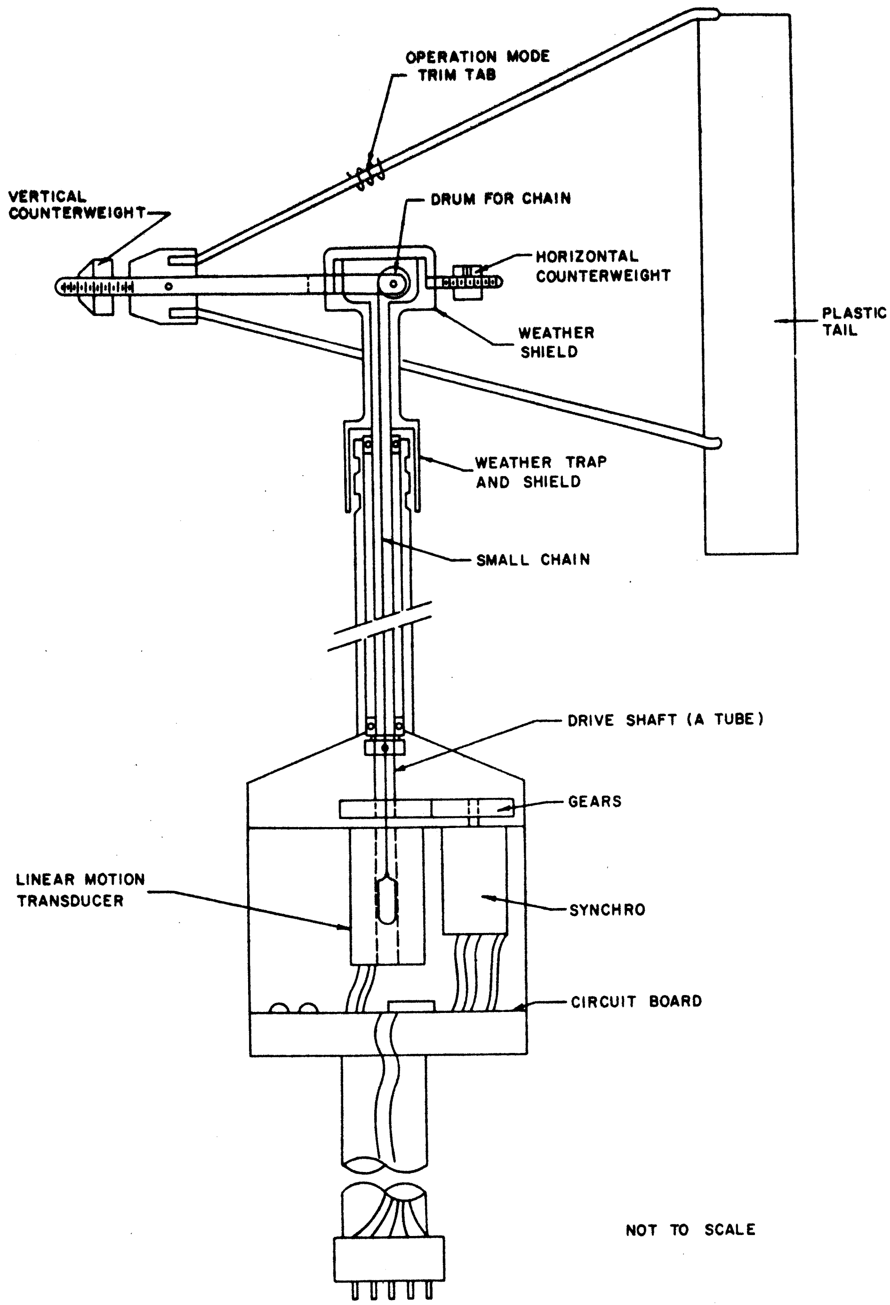


FIG. 5. Line diagram of the BNL bivane indicating its unique construction, which permits prolonged use in the atmosphere.

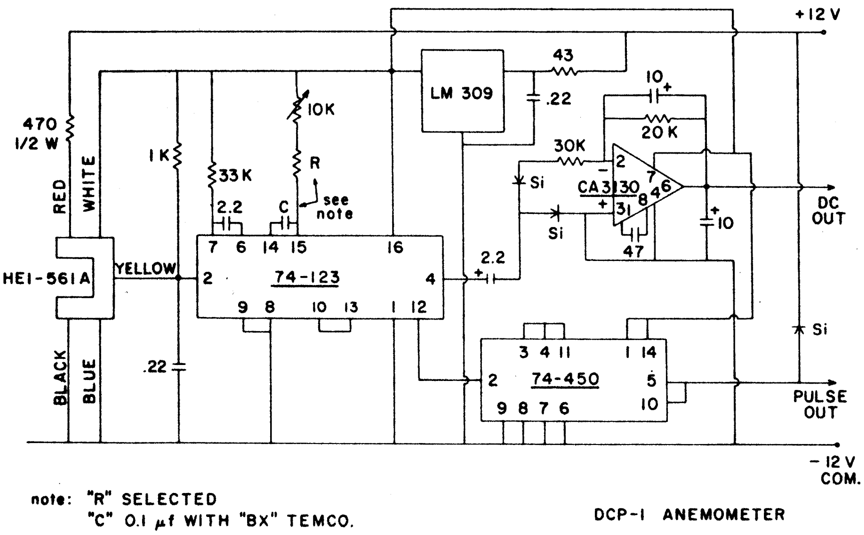


FIG. 6. Circuit diagram of the BNL cup anemometer. It uses a photo transistor light chopper transducer. The resistance (R) is selected depending on the range of output required and is set with the series potentiometer, which serves as a vernier calibration control.

The bivane was developed at BNL and has the unique characteristics of high-frequency response and ruggedness for prolonged use in a marine environment. The distance constant of the bivane was found to be 0.6 m. A line diagram of the construction of the BNL bivane is shown in Fig. 5. The mechanism for measuring the vertical component of the wind consists of a very light gold chain attached to the side of a metal drum turned by the vane. As the vane moves up and down, the length of chain wound on the drum changes. The chain drops down through a hole in the vane's vertical support shaft. On the lower end of the chain is a small iron cylinder riding in a linear transducer transformer. As the cylinder moves up or down (depending on the vane movement), inductance changes cause varying voltage output. Lateral velocity fluctuations were measured by the bivane with a selsyn and a sine/cosine transformer. The bivane was gimbal mounted to isolate the instrument from buoy motions.

Longitudinal velocity fluctuations were measured with a single-sensor temperature-compensated hot-wire anemometer manufactured by Thermo-Systems, Inc. The metal-clad hot-wire sensor had a frequency response of 5 Hz, and calibrations were found repeatable after at least 3 weeks' use in the atmosphere. The effect of a tilt of ~4° on the sensitivity of the hot wire was found to be negligible. These two instruments were also used to obtain information regarding atmospheric turbulence. A cup anemometer at the same level acted as a backup and helped in checking the calibration of the hot wire periodically. The cup anemometer was designed and fabricated at BNL (Fig. 6) and uses photo transistor light chopper transducers to increase its response. A view of the three instruments is shown in Fig. 7.

Wind stress was also measured by the profile method. This consisted of measuring mean wind speeds at four or five different levels above the water surface. One anemometer was usually mounted below the platform and four above. Since the anemometers had a reasonably good frequency response (~1 Hz) for moderate winds (2 m/s), a knowledge of the vertical variation of longitudinal turbulence could also be obtained. Other flux measurements consisted of heat and water vapor on occasion. Air temperature was continuously measured. Relative humidity was measured as continuously as possible with a Vaisala capacitance-type probe. In addition, sea temperature was measured to determine the atmospheric stability defined in terms of the flux Richardson number.

b. Wave characteristics

Due to the mobility of the sea surface, drag characteristics change depending on the sea state conditions. Hence, for air-sea interaction experiments a knowledge of the surface wave characteristics becomes essential. A wave staff configuration was used, and the three wave staffs were arranged in an equilateral triangle fashion 1 m apart (Fig. 2). Capacitance-type wave staffs, 4 mm in diameter, were used. Arms and the central support for this device consisted of stainless steel tubing with insulated ends. Design and fabrication of this device was done at BNL. Electronics consisted of a square wave oscillator whose pulse width varied linearly with a small change in sensor capacitance. The electronics were specially treated to minimize any effects due to submergence during rough sea conditions. This square wave frequency was processed in an operational amplifier to yield a voltage output proportional to the change in sensor capacitance that exists between the water and the central conductor of an insulated wire. By simultaneously measuring the wave height variations at each of the three wave staffs and correlating the data, spectra of wave heights, wave slopes, and wave directions can be computed. A computer program was developed to obtain the wave slope and wave direction spectra. Wave directions were then corrected for the rotation of the buoy measured by a magnetic compass.

c. Oceanic surface layer

Information regarding the variation of density and current is needed to understand the exchange between the atmosphere and the oceans. A current meter manufactured by Marsh-McBirney, Inc., was fixed to the oceanographic tower at a depth of ~2 m below the sea surface to monitor the variations in wind drift currents. Profiles of two-dimensional current, temperature, and salinity were observed with oceanographic spar buoys at four locations near the air-sea interaction buoy during May and August 1977.

d. Buoy motion

Buoy motion consists of rotation, tilt, and vertical acceleration. A gimbal-mounted compass was used to determine the orientation of the buoy. The compass was located on the platform far enough from the steel section of the buoy to avoid any effects on its accuracy. Output

FIG. 7. A close-up view of the gimbal-mounted bivane, hot-wire anemometer, and cup anemometer on the buoy. One of the BNL personnel vessels is also seen in the photograph.

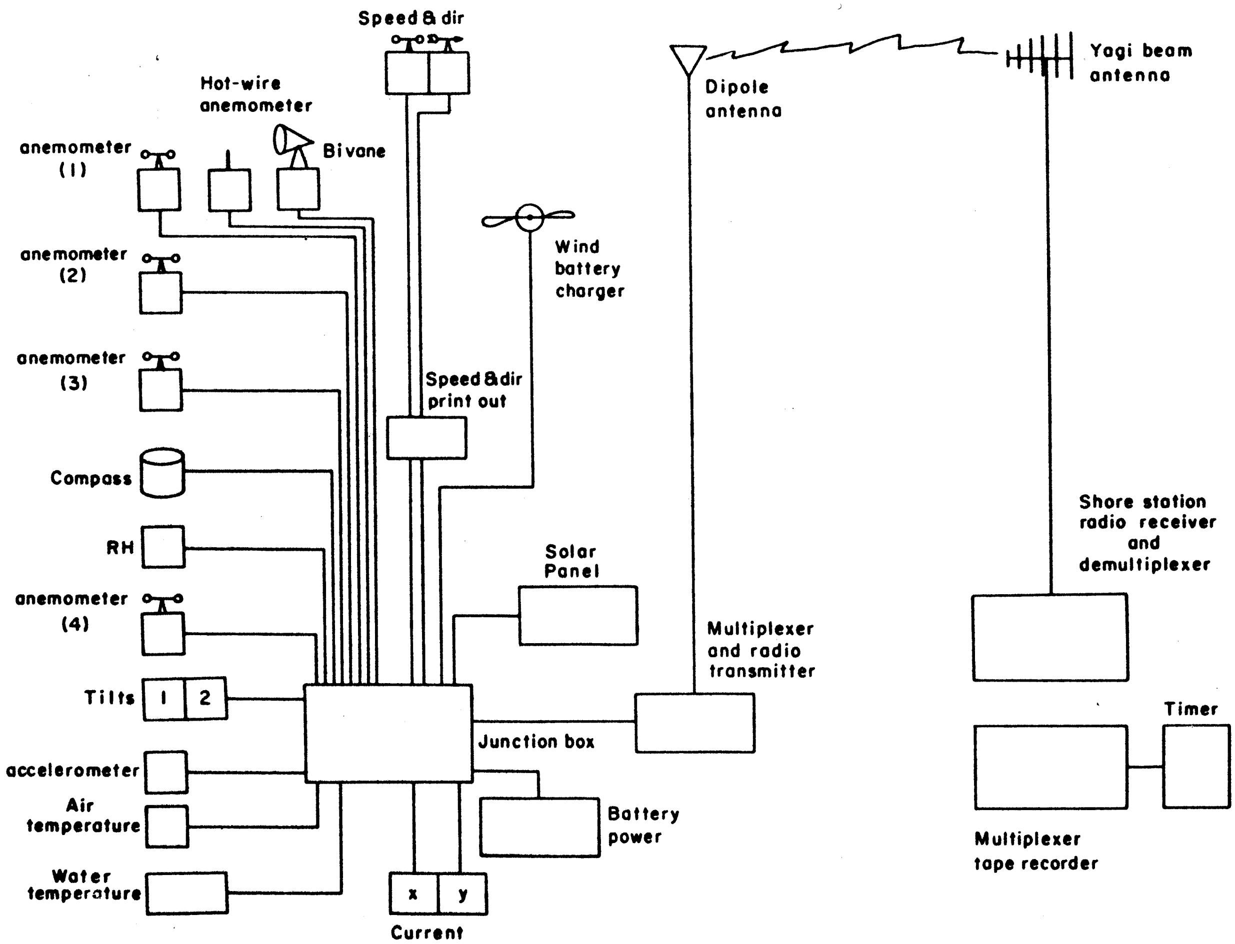


FIG. 8. Line diagram indicating the air-sea interaction experimental setup with line-of-sight RF telemetry system.

from the compass was directly recorded to apply any corrections in the wave direction computations. Analog output from the compass was also used to correct the wind direction measured continuously by a directional vane and to obtain true wind direction. Two-dimensional tilt sensors were used to measure the tilting motions of the buoy caused by the surface waves. Vertical accelerations were monitored continuously with an accelerometer. Acceleration data were later processed to obtain information about the vertical displacements of the buoy to apply corrections to wave height measurements.

5. Data acquisition

During the initial stages of the experiments (for a few weeks), data were recorded with a digital recorder operated at the buoy with automated remote control. Electronics at the well consisted of a junction box that acted as an interface between the dc power supply, the instruments, and the recorders. Seventeen analog outputs from the instruments were recorded in digital form by the magnetic tape recorder. In addition, the voltage level of the dc power supply was also recorded to monitor any loss in accuracy due to a decrease in the voltage level. The tray containing the junction box and the recorders was lowered into the instrumentation well. The junction box was connected to the instruments and the power supply through watertight portholes in the circumference of the well. A block and tackle in the meteorological tower helped in lifting the tray for easy access to electronics. A Metro Data digital recorder was used and was set to RECORD mode for 10 min every 2 h by an external timer. Observations were recorded at a rate of 150 per minute. A chart recorder continuously recorded wind speed, wind direction, air temperature, sea temperature, and relative humidity. This provided basic information when the digital recorder was not operating; it also acted as a backup. Several low-pass active filters were used to process the analog outputs before recording them in a digital recorder to avoid aliasing problems in later analysis.

An RF telemetry system (Climatronics, Inc.) was installed within a few days to obtain data from the buoy. This facilitated continuous monitoring of the data and improved data collection efficiency. A line diagram showing the complete installation is given in Fig. 8. The data were transmitted at 410.8 MHz, a frequency specifically assigned to BNL for air-sea interaction experiments. Analog data from the instruments at the buoy were digitized, multiplexed, and transmitted at 4 per second. In this new experimental installation the receiving station was located at Tiana Beach, 5 km away from the buoy. This station was chosen rather than BNL to facilitate correlation of measurements made at the beach from a 24 m high meteorological tower (Fig. 9) with those telemetered from the buoy. Also, because of the shorter distance, a low-power transmitter could be used. Wind speed and wind direction were continuously obtained at Tiana Beach from an Aerovane on the tower. This station is part of a climatological network used in coastal meteorological studies (Fig. 1). A Metro Data digital recorder was used to record the data. During coastal meteorological experiments, data from the buoy and from the tower were simultaneously recorded for future analysis. Since the receiving station was readily accessible, the remote timer that controlled the recorder was operated to obtain data 10 min every hour. On occasion, data were also obtained continuously for several hours. The data cartridge was then brought to BNL for further processing on the CDC-6600 and CDC-7600 digital computers.

Because of the remote location of the buoy, a dc power supply was essential. During the initial stages of the experiments, two large 12 V lead-acid batteries were used with a capacity of ~180 A h. They were then replaced with several smaller 12 V Gel/Cell batteries to provide easier handling. The batteries were continuously charged with a 25 W AMPAIR wind charger (Fig. 2). The wind charger was 0.6 m in diameter, and its position on the tower was carefully selected to avoid any effect on the meteorological instruments. A 25 W solar panel has been built for summer use. This unique system of power supply extended the life of the batteries significantly and helped in obtaining uninterrupted data.

6. Future work

An air-sea interaction buoy superior to the one shown in Figs. 2 and 4 has been designed and is being constructed. The principal design objectives for this new buoy were to provide the following:

1) an instrument support system having a high degree of stability while moored at sea with minimum vertical motion and tilt;
2) a mechanical assembly with the necessary strength to withstand violent storms;

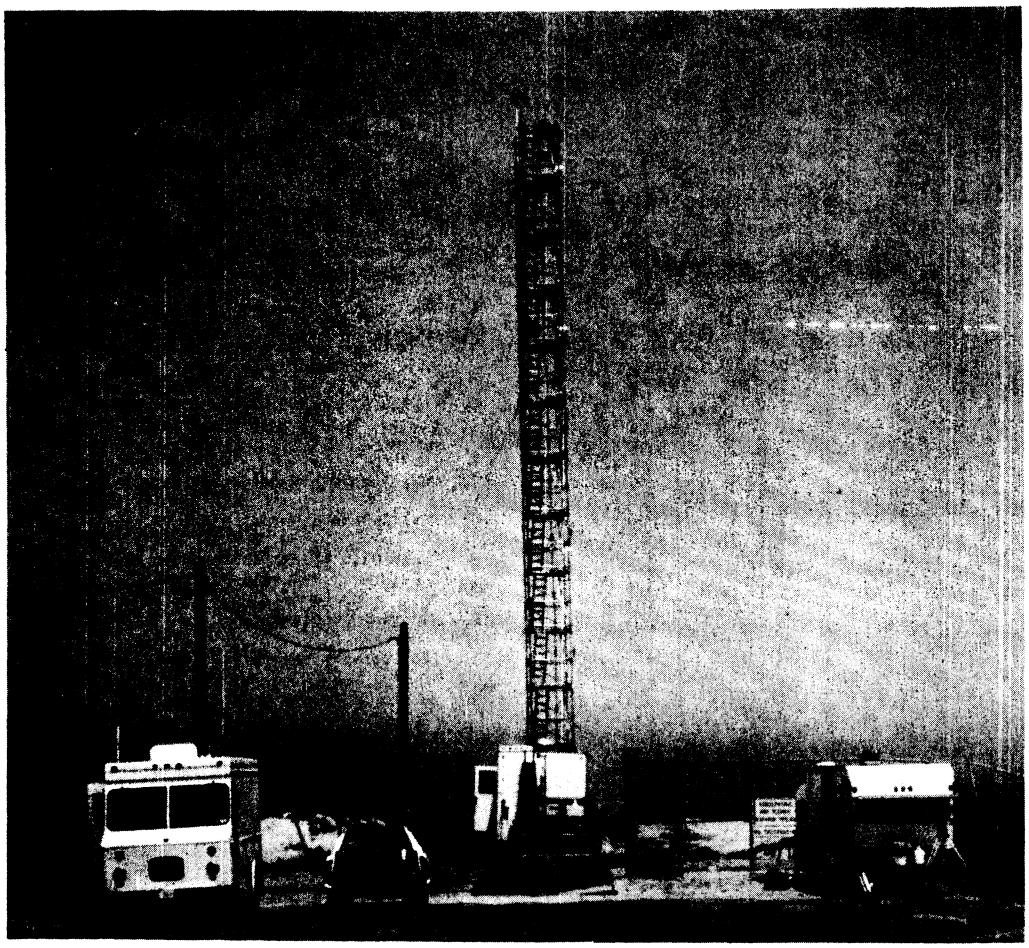
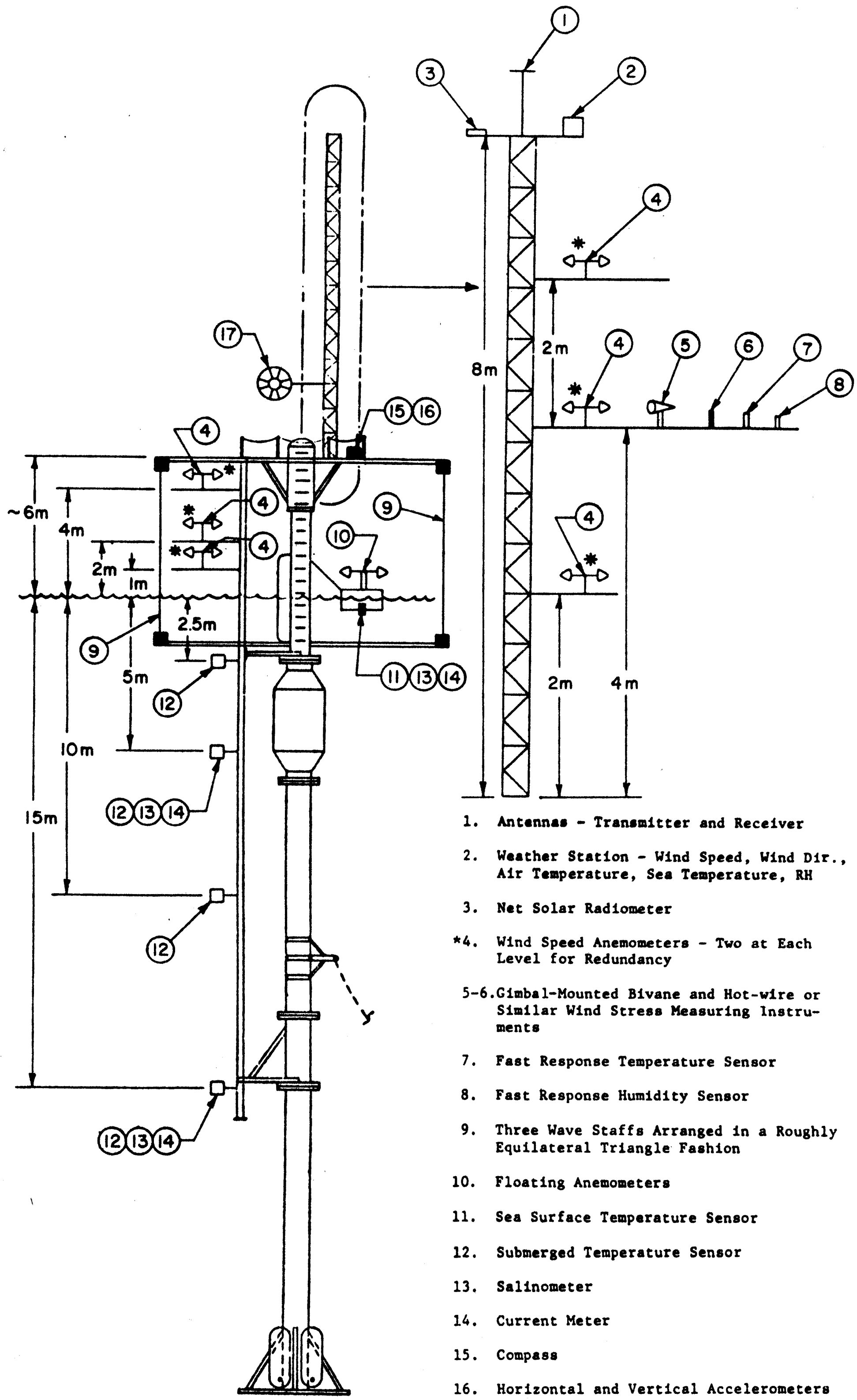


Fig. 9. Meteorological tower at Tiana Beach.



1. Antennas - Transmitter and Receiver
2. Weather Station - Wind Speed, Wind Dir., Air Temperature, Sea Temperature, RH
3. Net Solar Radiometer

*4. Wind Speed Anemometers - Two at Each Level for Redundancy

5-6. Gimbal-Mounted Bivane and Hot-wire or Similar Wind Stress Measuring Instruments

7. Fast Response Temperature Sensor
8. Fast Response Humidity Sensor
9. Three Wave Staffs Arranged in a Roughly Equilateral Triangle Fashion
10. Floating Anemometers
11. Sea Surface Temperature Sensor
12. Submerged Temperature Sensor
13. Salinometer
14. Current Meter
15. Compass
16. Horizontal and Vertical Accelerometers
17. Wind-Powered Battery Charger

FIG. 10. Line diagram of the proposed air-sea interaction buoy with a typical experimental setup.

3) an assembly that could be easily dismantled and reassembled to permit expeditious overland transport via commercial carriers from one site to the next.

Vertical accelerations will be minimized by providing a high ratio of the overall mass to the mass displayed in the wave zone and by providing a transverse damper plate at the bottom. Maximum vertical stability will be obtained by providing a high metacenter. A self-buoying underwater instrument support structure and a meteorological tower on the top will form the base of the measuring system. Other features of the proposed buoy that may be of help in remote ocean sites are the remote-controlled deployment system to change the position of the buoy from horizontal to vertical and an incremental waterline adjustment system. A line diagram of the proposed buoy with instruments for a typical air-sea interaction study is shown in Fig. 10.

In order to gain an understanding of the exchange processes at the edges of the continental shelf and in deep oceans, air-sea interaction buoys may have to be deployed farther offshore. The data in such cases will have to be telemetered via satellite to the shore station. Work has already begun at BNL to achieve this goal in data acquisition. This will consist of a system that includes a microprocessor to compute fluxes of momentum, heat, water vapor, gases, etc., and to preaverage the outputs from all meteorological and oceanographic instruments and a radio transmitter to transmit mean data via the Geostationary Operational Environmental Satellite (GOES) operated by the National Environmental Satellite Service of NOAA.

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