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INSTRUMENTATION

DRAFT FINAL REPORT

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4.1 INTRODUCTION

This chapter gives the technical descriptions of data-gathering instrumentation and systems utilized in the Marine Review Committee Experiment at San Onofre.

4.2 IRRADIANCE AND TEMPERATURE INSTRUMENTS

4.2.1 Combination Instruments

For the continuous monitoring of light irradiance and temperature, ECO-M has designed and fabricated three types of instruments:

1) Dual Light Irradiance (I/I)
2) Dual Temperature (T/T)
3) Irradiance and Temperature (I/T)

All of these instruments provide continous monitoring by recording data every hour in digital loggers. The light intensity values during the sampling period (1 hour) are digitized and stored in a shift register. Every hour during the recording cycle, the number from the shift register is stored under the proper address in EPROM and the shift register is reset to zero. The resulting recording represents integrated values of light intensity for each hour of operation, expressed in microEinsteins/m^2/Hr, (μE/m^2/Hr). The temperature sensing system stores absolute values in degrees centigrade in EPROM, which represents the actual temperature at the time of recording. The instruments operate for several weeks (42 days maximum) and provide a maximum of 1024 data points for each channel.

After recovery of the instruments from the ocean, the EPROMS are removed from their underwater housings and the stored data transferred via a microprocessor-controlled EPROM reader to an MRC computer.

The computer-stored data are then reviewed, calibrated and identified. Results are then transferred into the MRC data base. The accuracy and specifications of the system are as follows:

Basic Instrument:

Sampling Rate: Selectable 1/2 - 24 Hrs
Number of Channels: 2 each
Storage Capacity: 1,024 for each channel
Clock Accuracy: 0.003%
Power Comsumption: 0.01 watts max.

Light Integrator:

Count Rate: 140 counts/μa Hr
Accuracy: ±1% @ 25μa
±5% @ 0.1μa

Temperature:

Accuracy: 0.1 °C

where $1\ \mu E = 6.02 \times 10^{17}$ photons and $1\ \mu a = 280\ \mu E/m^{-2}/sec$.

4.2.2 Irradiance Instrument Characteristics

For the MRC experiment, LI-COR LI-192S Underwater Quantum Sensors are used. The LI-192S is a cosine collector (flat sensor) with a relative energy response proportional to the wavelength of the incident light being measured. The actual sensor spectral response profile is compared with an ideal quantum sensor response profile in Figure 4-2-1 (Roemer & Hoagland, 1976).

SENSOR TYPE LI-COR Quantum Sensor LI-190S or LI-192S

SERIAL NUMBER Typical LI-COR Sensor

LI-COR Quantum Sensor Response

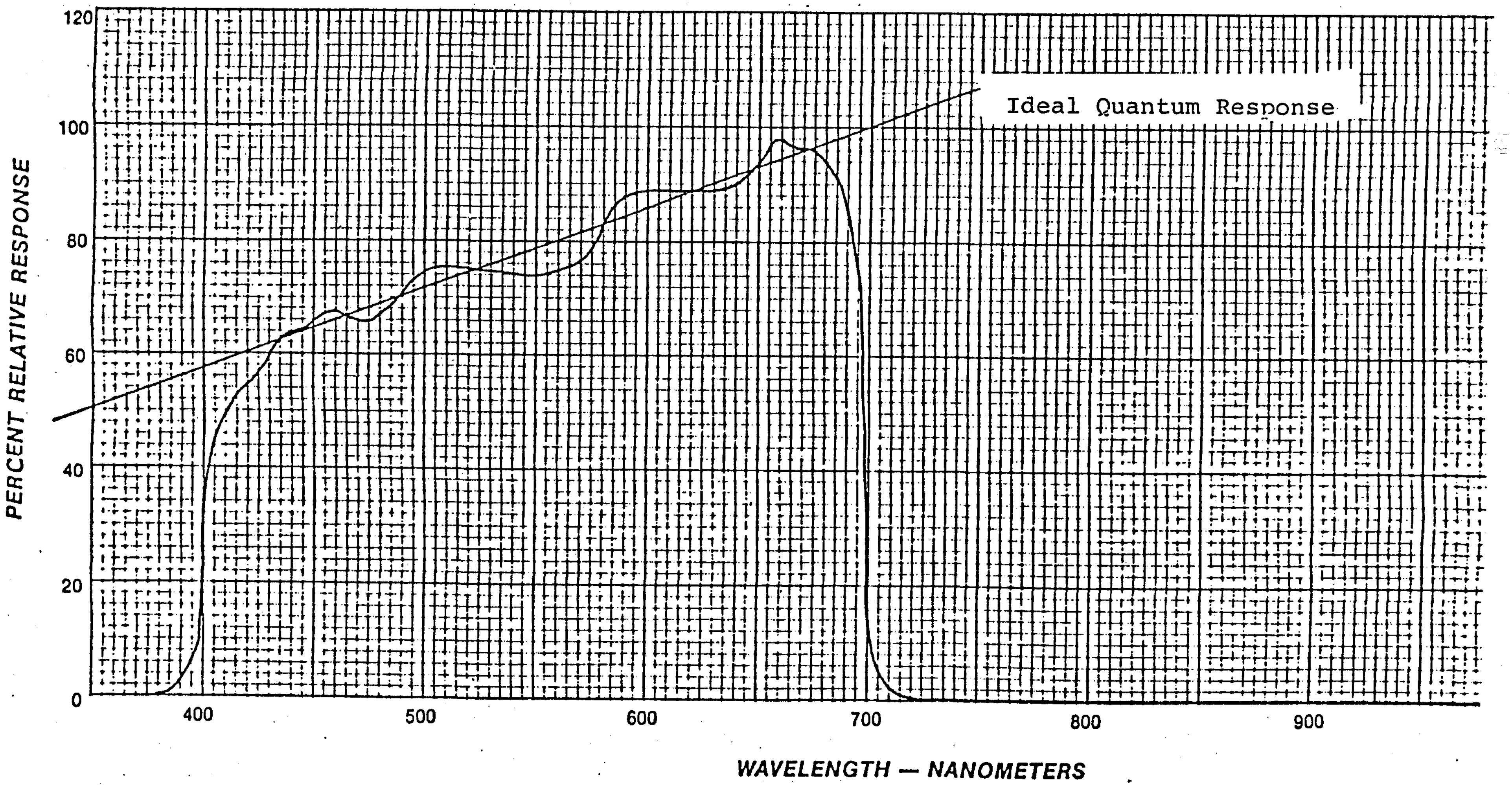


Figure 4-2-1 LI-COR LI-192S Underwater Quantum Sensor Measured Spectral Response, from Roemer and Hoagland, 1976.

The sensor measures the quantum irradiance, Q , which is the number of photons absorbed per square meter per second for any wavelength in its response region from 400 to 700 nm. Ideally, the response of the sensor is defined by

$$Q = A/hc \int_{400}^{700} H(\lambda)\ \lambda\ d\lambda \qquad (1)$$

where h is Planck's constant (6.624×10^{-27} erg sec), c is the speed of light ($(3.0) \times 10^{8}$ m $\sec^{-1}$), A is a conversion factor for counts to Einsteins, H (λ) is the incident irradiance, and λ is the wavelength of the irradiance.

The absolute calibration of the spectral response of the LI-COR sensor is ±5 percent. A source of error in the instrument response is the change in measured irradiance with the angle of observation shown in Figure 4-2-2. A calibration factor for the instrument sensitivity, which depends on the optical properties unique to the geometry of each sensor, is determined by LI-COR and recalibrated yearly. An immersion-effect correction, determined for each sensor, adjusts the underwater response of the instrument for energy loss at the air-water interface, and depends on the refractive properties of the interface. A small source of error in irradiance measurements which is difficult to correct, is the wavelength dependence of the immersion-effect. It was noted by Smith (1969) that for an accurate measurement of total irradiance between 400 and 700 nm, the spectral properties of the water being measured must be considered when calculating the immersion-effect correction. Total estimated error due to the sensor is ±15 percent.

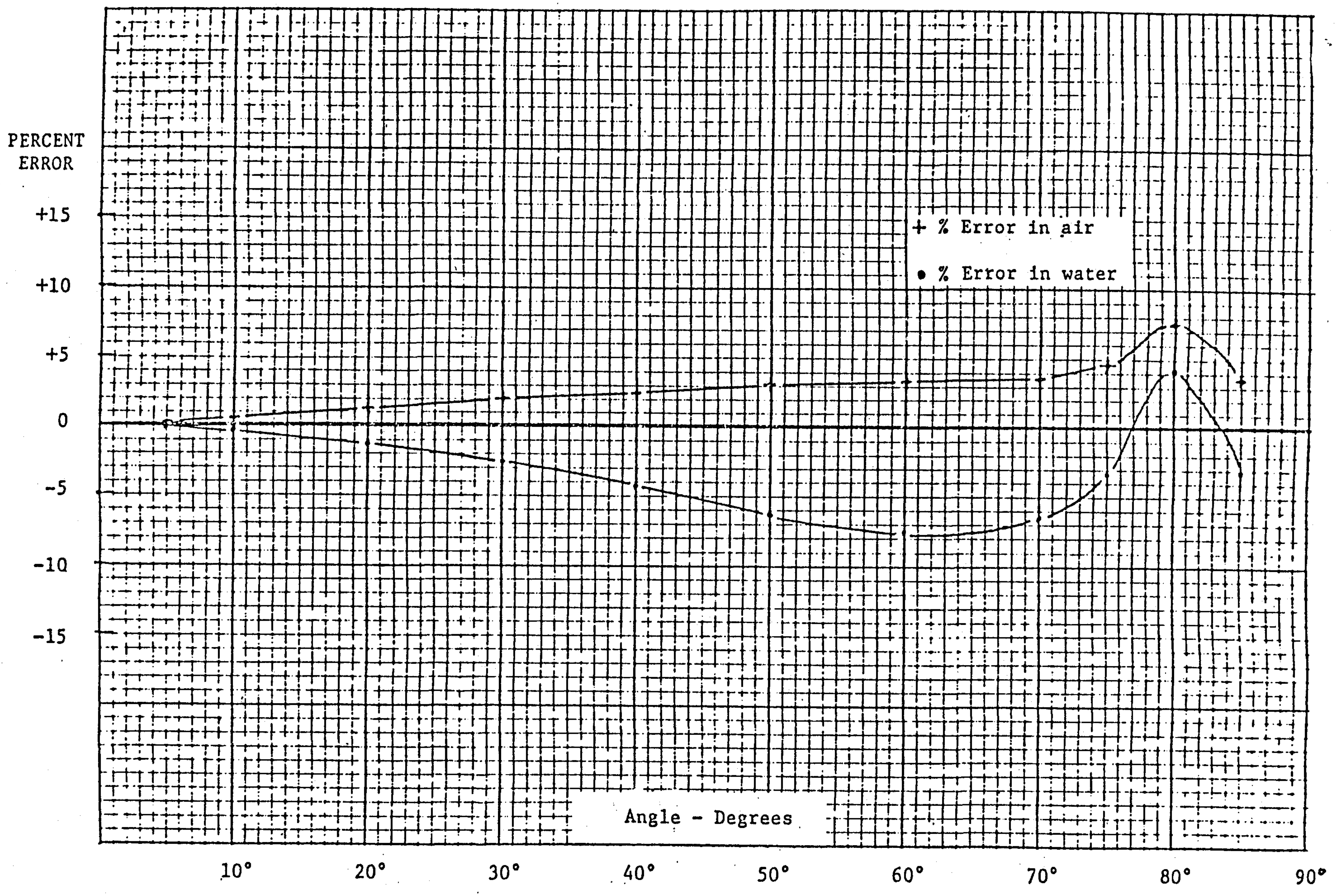


Figure 4-2-2 Cosine Error of LI-COR Underwater Sensors, from Roemer and Hoagland, 1976.

4.2.3 Measurements of Irradiance and Temperature Profiles

Temperature profiles are conducted with the use of ECO-M designed and fabricated digital field instruments. The dual thermistor-type probes, internally compensated, provide reliable temperature readings with an accuracy of $\pm 0.1^{\circ}C$ readable in real numbers on a liquid crystal display.

The new irradiance profile instruments are also designed and manufactured by ECO-M and provide two independent readings: one under water at a given depth, the other an ambient light level on board the vessel.

The sensor for underwater measurements is attached to a balanced, weighted fixture to assure that the sensor element is parallel with the surface of the sea and the deck sensor is placed on a gimbal to provide a relatively stable position for surface ambient light measurement. The display units (liquid crystal) provide numerical values for irradiance measurements in (μE).

During cruises, when the vessel assumes the proper position at a station, the light/temperature sensing unit and a precision depth transducer are lowered to a discrete depth to record temperature, depth, and light level underwater together with light level at the sea surface. As the sensor unit is lowered or raised the profile is accomplished.

Data from each profile are recorded, transferred via keypunch to the MRC computer and entered into the proper data base file.

Units are also available to take either temperature or irradiance profiles separately.

Profile Instrument Specifications:

Sampling Rate:	Continuously
Number of Channels:	4
Power Consumption:	1 watt
Accuracy:	
Temperature:	0.1°
Irradiance:	15%
Depth:	10%

4.3 CURRENT AND WAVE INSTRUMENTS

4.3.1 Current Measurements

During this study we used two different types of current meters. From 1977 to 1984, we used Davis-Weller vector-averaging instruments. These instruments sample two orthogonal velocity components of the horizontal vector field through the use of two sets of rotors mounted at right angles to each other (**Figure 4-3-1**). The velocity components measured by each rotor are continuously vector-averaged and these averaged values are recorded at pre-programmed intervals on a 4-channel cassette tape. Orientation data from the Fluxgate magnetic compass is acquired simultaneously. In addition, temperature is monitored with a pressure-case-embedded thermistor.

The data base is checked for errors such as transients, spikes, or other faults. These are corrected and the data then analyzed.

The specifications of the Davis-Weller current meter areas are as follows.

Sampling Rate:	8 minutes
Number of Channels:	4

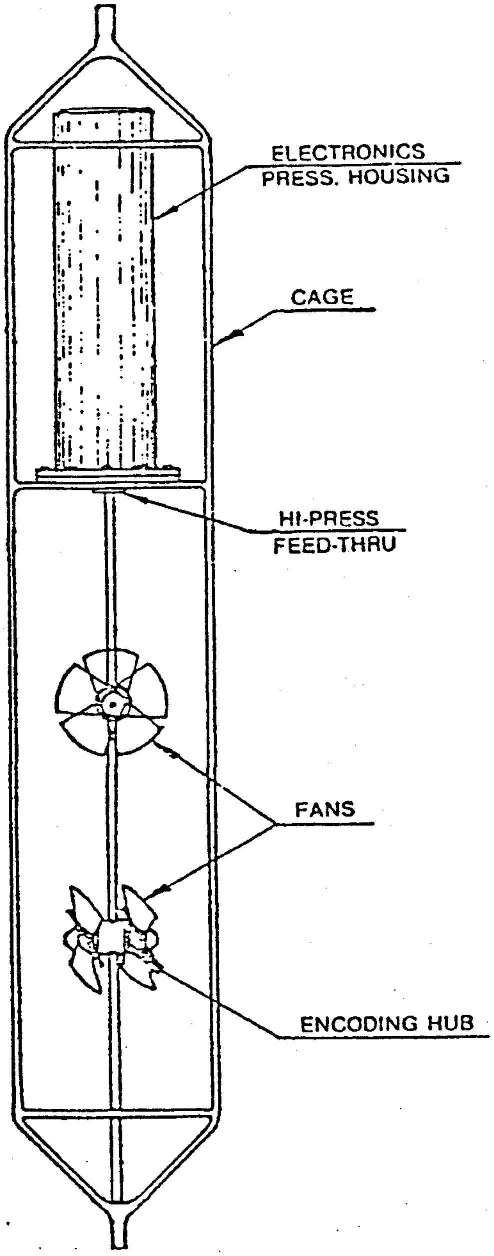
Deployment Period:	4-6 weeks
Timing Accuracy:	100 ppm
Power Consumption:	≃ 48W/deployment
Threshold:	≃ .5 cm/sec

Since January 1985, we have used the Inter-Ocean model S-4. The S-4 is an electro-magnetic spherical current meter that is about the size of a basketball. It is self-contained, has no proturding sensors or external moving parts, resulting in a low-drag instrument that is easy to deploy, maintain, and recover. It is well-suited for taut line moorings to depths of 1000 meters. The S-4 housing is fabricated from glass-filled cycloaliphalic epoxy which has high strength, is dimensionally stable and corrosion proof. The exposed metal is titanium, making up the load bearing shaft and sensor electrodes. This combination of materials provides excellent protection against corrosion.

Currents are measured by creating a magnetic field and sensing the voltage induced by the movement of water through the field. Current vectors can be measured at programmable intervals and vector averaged immediately, i.e. north and east components of the current are computed and stored. Data are recorded in a non-volatile solid state memory at established intervals. Retrieval of data is accomplished through a serial port in the current meter by using a portable computer.

The specifications of the S-4 current meter are given below.

Type:	Electro-Magnetic, 2 axis
Range:	0-350 cm/sec
Resolution:	0.2 cm/sec
Accuracy:	±1 cm/sec
Vertical Response:	True cosine response (internally software corrected with tilt option)



Schematic diagram of the Davis-Weller Vector Averaging Current Meter. Two sets of fans, especially designed to operate with a flat cosine response, are mounted at 90° to each other on a common vertical axis. Four optical sensors, located in the fan hubs, are assimetrically mounted to read each of the two rotating encoding discs, thereby providing rate and direction of rotation information.

Figure 4-3-1 Davis-Weller Vector Averaging Current Meter

4.3.2 Wave Measurements

From 1981 through December 1986 we measured wave climate at a station maintained offshore of SONGS Unit 1. The station is located approximately 800 m upcoast from Unit 1 near the offshore end of the songs Unit 3 diffuser. The measuring instrument is at a water depth of 12 m and at 1 meter above bottom.

During this period, we used three different types of wave climate instruments, all with sensors that measure the wave induced pressure at the level of the sensor. **Table 4-3-1** lists the names of the sensors and the periods of deployment.

TABLE 4-3-1

Name of Wave Climate Instrument	Deployment Period
S101	JUN81 - DEC83
EC01	JAN84 - APR85
MOS4	APR85 - DEC86

In the following pages, we will discuss the 3 systems:

1. The S101 is a system which incorporates a pressure sensor and an electromagnetic current meter to measure pressure and orthogonal components of current velocities. The system activates every 12 hours for approximately 34 minutes and samples every 2 seconds giving 1024 data points per recording interval. The velocity components are measured with respect to the current meter coordinate axis which is defined by the position of the measuring electrodes. Subsequently, the components are rotated to the u, v axis of the MRC Coordinate System in which positive u is in the direction 108° magnetic and positive v is in the direction 18° magnetic. The data are stored on 2 cassettes fitted inside the underwater package.

The data on the cassettes are transcribed to a 9-track tape readable by a digital computer system for storage and retrieval for further analysis. Every 34 minutes the pressure time series was Fourier transformed. The Fourier coefficients of the surface elevation η are obtained by applying the frequency dependent depth correction given by the linear wave theory frequency which can be studied to about 0.3 Hz. At frequencies higher than this, small amounts of noise may be amplified into large sea surface variations.

The total variance $<\eta^2>$ of the surface displacement is obtained for each recording period by summing the variance in the frequency range 0.02 - 0.3 Hz. A significant wave height is then obtained from the following formula:

$$H_S = 4(<\eta^2>)^{1/2} \quad .$$

The root-means-square wave height is calculated from

$$H_{rms} = (8<\eta^2>)^{1/2} \quad .$$

To estimate the mean direction of the observed wave field, the cospectral values between pressure and the two velocity components must be calculated. The mean direction α can be determined from these values by the formula:

$$\tan \alpha = C_{pv}(f) \;/\; C_{pu}(f)$$

where $C_{pv}(f)$ is the cospectral value between pressure and longshore velocity and $C_{pu}(f)$ is the cospectral value between pressure and on-offshore velocity at a frequency f. The cospectral values at the peak frequencies were used to calculate α so that the direction given represents the direction of the wave having a period at which maximum energy occurred. This period where maximum wave energy occurred is defined as the wave period estimate (T). Since the velocity components have been expressed in the MRC Cartesian Coordinate System, the directions given are measured in degrees counterclockwise to the positive v axis which is in the direction 108° magnetic. The coastline is oriented such that 030° magnetic is directed onshore. Therefore, for $\alpha = 78^{\circ}$, surface waves would be heading directly onshore. For $\alpha > 78^{\circ}$, the waves would be coming onshore from a downcoast direction, and for $\alpha < 78^{\circ}$, surface waves would be coming onshore from an upcoast direction.

The root-mean-square wave velocity U_{rms} is calculated from the following equation:

$$U_{rms} = \sqrt{\frac{2 <\eta^2>*(2\pi \;/\; T)}{\sinh \;(2\pi h \;/\; L)}}$$

where h is the water depth (h=12m) and L is the wave length.

The wave length is calculated by solving the following equation in

$$L = \frac{gT^2}{2\pi} \tanh \;(2\pi h/L)$$

where g is the acceleration of gravity.

2. The ECO1 is a simplified wave-recorder designed by ECOSystems. This instrument reads pressure every two seconds for about half an hour, several times a day, but it computes wave statistics in situ and stores these instead of the pressure reading. Before each main recording period, the instrument reads for a few minutes and computes and stores a trial mean pressure p^*. It then takes about 1000 instantaneous pressure readings p_i and accumulates the sums of (p_i-p^*) and $(p_i-p^*)^2$, and also the number of times (p_i-p^*) changes sign. After the last reading, it computes and stores the mean pressure $\overline{p} = (p_i-p^*) + p^*$, the variance $\overline{p'^2} = \overline{(p_i-p^*)^2} - (\overline{p}-p^*)^2$ an estimate of the period T given by the recording time divided by half the number of sign changes in the (p_i-p^*).

Knowing the distance ($h-z \sim 50$ cm) of the instrument above the bottom, the mean pressure $\overline{p} = z$, the variance $\overline{p'^2}$, and the period T, the following quantities are computed from the recorded statistics:

- The total water depth h is the fixed depth h_m below MLLW plus the tide height, so the variations of h over time provide a tide record.
- The propagation parameter $kh = 2\pi / L$, given by $kh \tanh kh = 4\pi^2 h/gT^2$, (L is the wavelength);
- The variance of surface displacement $<\eta^2> = \overline{p'^2} \cosh^2 kh$;
- The variance of wave-orbital velocity near the bottom $\overline{u^2} = (4\pi^2 T^2) <\eta^2> \cosh^2 kh$.

We would like to point out that the analysis techniques adapted for this instrument give approximate results for the actual wave climate conditions. Secondly the estimation of wave period from the number of zero crossings of (p_i-p^*) is certainly subject to more uncertainties than the method of choosing the highest peak from the computed wave spectrum.

3. Since April 1985 we have used the S-4 Inter Ocean Current Meter (MOS4) displayed 1 m off the bottom and programmed to measure wave pressure and horizontal wave velocity (2-components). The measurements have been carried out every 12 hours for 17 minutes, with a sample rate of 1 sample/sec.

Every 17 minutes the pressure time series is Fourier transformed and the sea surface elevation spectrum is obtained from the wave pressure spectrum using the Linear Wave theory. The analysis techniques for this sensor are analagous to the one adapted for S101.

The specification of the fitted pressure sensor is as follows:

Range	0-1000 dBar
Resolution	1 dBar
Accuracy	± 0.25% full scale

4.4 SALINITY INSTRUMENTS

4.4.1 Conductivity, Temperature and Depth Meter

The equipment used for measuring conductivity, temperature and depth is a miniature "Salinity, Temperature, Depth" Probe (Model STD-12) manufactured by Applied Microsystems, Inc. The STD-12 is a small, easy to deploy instrument, ruggedly constructed of 6061-T6 aluminum, with other external fittings of 316 stainless steel. The aluminum parts are hard anodized and protected with antifouling epoxy paint. The physical size is 4" (10.2 cm) diameter, and 26.8" (67.5 cm) long. A sacrificial zinc anode is attached to ensure season after season of corrosion free operation. The salinity is not measured directly but is calculated using the conductivity, temperature and pressure measurements.

The "Temperature" sensor is a fast response microbead thermistor mounted in a stainless steel capilliary tube, designed for pressure insensitive measurements. Special laboratory aging techniques ensure repeatable measurements within ±0.01°C over a range of -5 to +35°C for periods exceeding one year.

A patented "Conductivity" sensor, manufactured by Applied Microsystems, is another feature designed into the STD-12. This four electrode device demonstrates excellent long-term stability, and high precision in areas of extreme fouling. Careful design considerations in both the electrode positioning and excitation circuitry results in the cell having wide dynamic range; ie. from distilled water to 50 ppt salinity. The accuracy of the conductivity measurements are ±.01 mS/cm and resolution ±.003 mS/cm.

The pressure sensor used in this instrument is a monolithic semiconductor strain gauge. On command the STD-12 reads the ambient atmospheric pressure from the depth sensor and corrects the surface reading of pressure to zero depth, which is typically accurate to 0.1% of full scale (with a selected range of 0-100 psi).

Data are collected in a solid state memory of 60K RAM. Seven thousand six hundred forty-eight scans maximum can be stored per deployment.

Output/input and power-up is accomplished via two "double contact" underwater connectors. Communication with the on-board computer is provided with an adaptor for conversion to standard RS-232A format data. However, the signal from the instrument to the adaptor requires only two polarity independent wires.

4.5 SESTON FLUX INSTRUMENTS

4.5.1 Seston Traps

The seston traps (sometimes called sediment traps) are rigid plastic tubes 2.5 cm in inside diameter and 30 cm long, closed at the bottom and open at the top, mounted vertically in the water. The rate of accumulation of seston in the traps is measured as the height of accumulated seston in mm divided by the accumulation time in days. This variable is called seston flux F (mm/day), and does actually represent the net mean volume flux (volume per unit area per unit time) of particles through the mouth of the tube.

In still water, the mean downward seston flux for particles in a particular range of size would be given by $F = SC$, S being the settling rate and C the mean ambient volume concentration for particles in that range. In the presence of horizontal velocities due to waves and currents, though, turbulence generated at the mouth of the tube produces some exchange of water between the tube and the outside, and seston accumulates at the bottom by the combined processes of water exchange and settling-out of seston from the water in the tube, as well as by seston simply falling through the water at the mouth.

The exchange of water involves water entering the tube with the ambient seston concentration C, and an equal flow of water leaving the tube with a lower concentration C' because some seston has settled out of this water during its residence in the tube. Calling the mean exchange-rate E, we can write the total flux into the tube as

$$F = SC + E(C-C'), \text{ or } F = SC\{1+(E/S)(C-C')/C\}$$

The factor $(C-C')/C$ goes from zero for $E/S \to \infty$ (non-settling particles) to one for $E/S \to 0$ (particles settling very fast compared to the exchange-rate). We can suppose roughly that $(C-C')/C \sim (aS/E)$

for large E/S, with a on the order of 1, giving F ~ (1+a) SC for the slowest-settling particles. For the fastest-settling particles, we have F ~ SC in any case; in between, with S comparable to E , we have something intermediate, with some dependence on E for any given S . Overall, we can bracket F between one and a few times SC for any size of particle, with variations due to varying E confined to this range.

This simple theory of open-tube traps is generally supported by the flume experiments of Gardner (Journal of Marine Research, 38, 1, 1980), which showed F within ± 50% or less of SC for inorganic particles with a range of diameters up to about .02 mm, corresponding to $S \leq .02$ cm/sec. This upper settling-rate was on the same order as the lengths of the traps divided by the residence-times of dyed water in the traps, which gave a rough measure of the exchange-rates E.

The variable F measured by seston traps, then, is an index of seston volume concentration, weighted by settling-rate so that it selects strongly against finer and less dense particles, with some uncertainty due to variations in E with varying ambient water-velocity.

The reported values of F for a given deployment and station are the means of three (occasionally two) tubes mounted at the same height about 2 m apart.

If the accumulated seston approaches the top of the tube, the turbulence can wash some of it out, and the net collection rate slows and ultimately stops. This should be kept in mind in considering results in which measured seston flux exceeds about 20 mm/day over a deployment longer than 10 days.