THE INVERTED ECHO SOUNDER

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Abstract

The Inverted Echo Sounder (IES) is an ocean bottom moored instrument which very accurately measures the time required for an acoustic pulse to travel from the bottom to the ocean surface and back. The round-trip acoustic travel time varies in response to changes in the mean temperature structure in the water column above the instrument, which in turn may be used as a sensitive indicator of the shifting paths of ocean currents in many locations.

The instrument is housed in a 17" diameter glass sphere and carries all the necessary control, transmit and receive electronics, a digital cassette recorder and an acoustic release receiver. It can operate in water depths to 6700 m for periods of up to one year and requires no additional mooring equipment other than an anchor.

Records from four IES's deployed under the Gulf Stream northeast of Cape Hatteras are shown along with steps in the processing of the data.

Introduction

In the ocean the temperature, salinity and sound velocity vertical profiles vary temporally, and consequently the acoustic travel time through the water column varies. The Inverted Echo Sounder (IES) transmits pulses of 10 kHz sound from the ocean floor and records the time τ for the echo to return from the ocean surface; τ varies by a few milliseconds in response to changes in sea surface height and to variations in the inverse sound speed integrated through the water column above the instrument. Rossby (1969) showed conceptually that such a measurement effectively monitors changes in the depth of the main thermocline. Watts and Rossby (1977) discuss data from seven IES deployed in the Sargasso Sea during MODE. Because the acoustic travel time is inherently an integral measurement, it is insensitive to fine structure in the vertical, but is dominantly influenced by vertical displacements which are coherent throughout the water column.

The instrument configuration has been evolving since its initial design and development to more recent deployments to monitor the path of the Gulf Stream (Watts and Olson, 1978). The present design operates unattended for long periods at the ocean bottom, and thus can be deployed to study high current regions or otherwise hostile environments.

Instrument Description

A summary of the operational characteristics of the instrument are listed in Table 1 and a block diagram of the electronics is shown in Figure 1.

Operational depth	6700 meters max.
Acoustic frequency	10.24 kHz
Acoustic power	103 dB re 1μB @ 1 meter
Acoustic pulse length	6.4 milliseconds
Sampling rate	1 every 10 seconds
Timing stability	< .001%
Measurement resolution	49 seconds
Data storage	magnetic tape
Battery	Lithium-80AH @ 15V
Deployment time	12 months max.

Table 1: IES Operation Characteristics

All timing functions are derived from a crystal controlled 20.480 kHz oscillator which drives a series of counters. The travel time counter is started when a 6.4 millisecond 10.240 kHz acoustic pulse is transmitted. When the echo returning from the surface is detected, the count is loaded into parallel-to-serial shift registers. The resulting travel time is an eighteen bit binary number with the least significant bit equivalent to 49 microseconds. From the shift registers, the travel time is shifted serially into a 1024 bit buffer to free the registers for the next echo sounding. This process is repeated once every 10 seconds for a preselected burst length, whereupon the travel times are stored on a Sea Data Model 610 tape recorder along with the deployment elapsed time. The instrument then stops echo sounding until the next burst begins.

Control of the burst length and the time between bursts, the burst rate, are handled by the burst length and burst rate counters respectively. The burst rate counter also serves as the deployment elapsed time clock. Switches

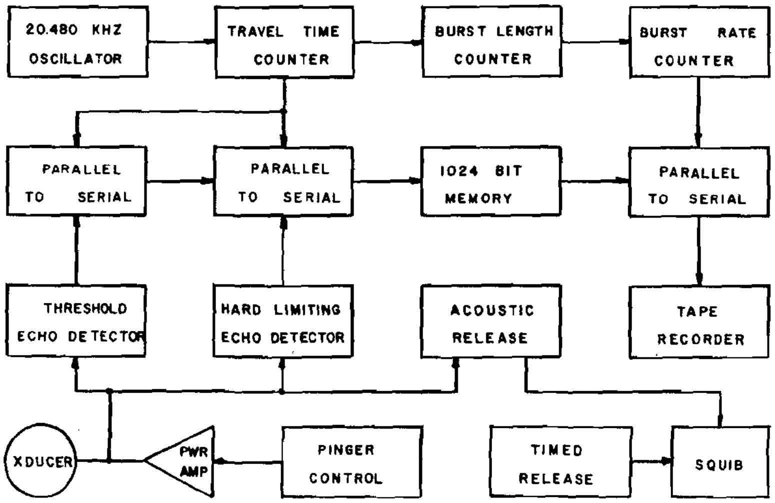

FIGURE 1:INVERTED ECHO SOUNDER BLOCK DIAGRAM

have been included in both counters that can be set prior to launch for burst lengths of up to 56 echo soundings and burst rates of 15, 30, 60 or 120 minutes. In this way the sampling rate can be tailored to the specific experiment.

Two echo detectors have been included. A hard limiting receiver from a Sea Link Systems acoustic transponder is more sensitive for deep water operation, while a second, simple, fast recovery threshold detector is used for shallow water applications.

The power amplifier for the transducer is also driven from the master oscillator. It is a conventional transformer coupled design that drives the transducer to ±103 dB re 1μB at 1 meter on the vertical axis above the instrument. This sound pressure level is sufficient to insure adequate signal-to-noise ratios in the return echo so that the instrument can operate in all sea states to depths of 6700 meters.

Additional circuitry has been included to enable recovery of the instrument. The primary recovery system is an acoustic command receiver, also manufactured by Sea Link Systems. A timed release which runs off the master oscillator is provided as a back-up. If either of these releases is activated, an explosive squib is fired to mechanically separate the instrument from its anchor.

Since the whole instrument is physically quite small, several relocation aids have been provided. A second timer, again running off the main oscillator, can be set to turn on the pinger at a predetermined time so that it pings at a fixed rate, typically once every 16 seconds. This serves as an acoustic homing beacon and is usually set to turn on just prior to when the ship returns to the area for recovery of the instrument. We have tracked it at distances of up to 10 km. When the anchor release is activated the ping rate changes to 2 seconds. At the surface an Ocean Applied Research radio transmitter and flasher aid in its recovery.

Power for the electronics is provided by Lithium-organic cells which were selected for their high energy density and low weight. With a full complement of batteries they provide 80 Ampere hours at 15 VDC, which is sufficient for deployments of 12 months.

One of the primary goals in designing the IES was to make it completely self-contained so that no mooring components other than an anchor would be required. Since this meant the instrument had to provide its own buoyancy for recovery, yet be capable of withstanding the pressures of very deep deployments, a 17" diameter glass sphere was selected as the pressure housing. These are readily available from the Benthos Co., and have the additional advantage of being relatively inexpensive. While care must be used in assembling the glass sphere to avoid scratching or breaking it, it has performed extremely well with no leakage in any of the deployments.

A picture of the configuration of the electronics is shown in Figure 2 and a fully assembled instrument is shown in Figure 3. In air, the instrument weighs approximately 90 pounds and has about 20 pounds of buoyancy in water. The radio and flasher are mounted upside down for deployment since the weight of the transducer causes the instrument to turn over when it is released from the bottom.

Field Tests

Four inverted echo sounders were deployed northeast of Cape Hatteras on a line across the Gulf Stream, during a period when a cyclonic Gulf Stream ring approached from the southeast and coalesced with the stream (Watts and Olson, 1978).

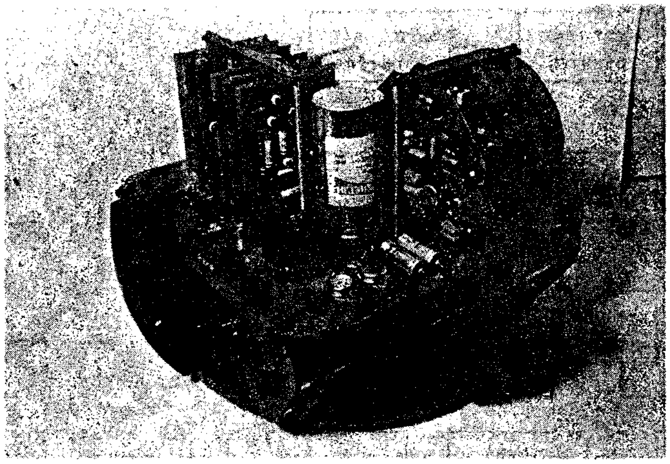

Figure 2: IES Electronics

These records have been chosen to illustrate the steps of the data processing. A subsampled set of the raw data is shown in Figure 4a (top trace). Every eighth data point is shown; i.e., from each 15 minute burst of 32 measurements, four points are plotted. The echoes from this simple threshold detector are approximately normally distributed and show an rms scatter of ± 0.6 msec.

The median travel time for each burst of 32 is then determined and the resulting time series is plotted in Figure 4b (lower trace). In this record semidiurnal oscillations of approximately 1 msec peak-to-peak amplitude are clearly present; these are primarily due to variations of the free surface height by tides of approximately 75 cm amplitude (p-p). Internal tide oscillations contribute to a small extent here also and can be studied if the deterministic effect of the surface tide is removed.

The low frequency large amplitude changes in this record are due to a rapid change in the main thermocline depth, as the cold front associated with the ring core passes across the instrument site.

We have compared all four IES records with a sequence of coinciding XBT and STD measurements of the temperature profile above each site as our ship surveyed the region. A traditional parameter describing the Gulf Stream position is the 15°C isotherm depth, Z_{15}, within the sharpest gradient of the main thermocline. The relationship between Z_{15} and the acoustic travel time is found to be linear in agreement with the predictions of Rossby (1969). Figure 5 shows that 15°C isotherm depths derived from the IES records agree with values simultaneously measured. The rms deviation from a perfect fit is 18m compared to a total observed range of variability from 100 to 700m.

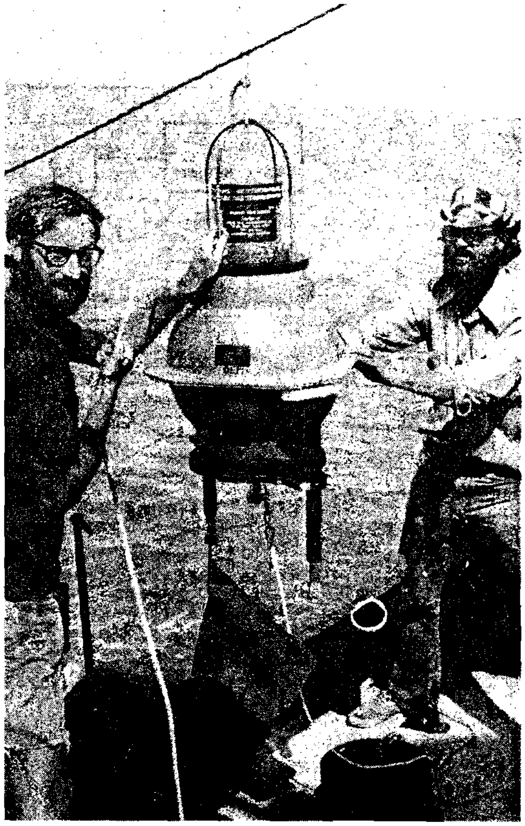

Figure 3: Fully Assembled Instrument

The four IES records, rescaled to Z_{15} time series, are shown in Figure 6, arranged from top to bottom respectively with the northwestern to southeastern records of the linear array. At the outset the northern instrument (IES 77F, top trace) was at the northern edge of the Gulf Stream where Z_{15} $\sim$250 m, while the southern instruments (IES 77H and I) were in Sargasso water with the thermocline 600 to 700 m deep. From 11 to 15 September the Gulf Stream shifted northwestward, as shown by the deepening thermocline in the top trace. The cold front associated with the oncoming ring core first passed the southern site 13-14 September and proceeded up through the array reaching IES 77F on 17-18 September. (Instrument IES 77G malfunctioned prior to 16 September, but the record shows the passage of this front).

Such rapid evolution of the temperature field and currents may be common in this region of the ocean and elsewhere. Simultaneous data is required from an array of sites (preferably two-dimensional) to adequately describe the process. To monitor it would traditionally require a

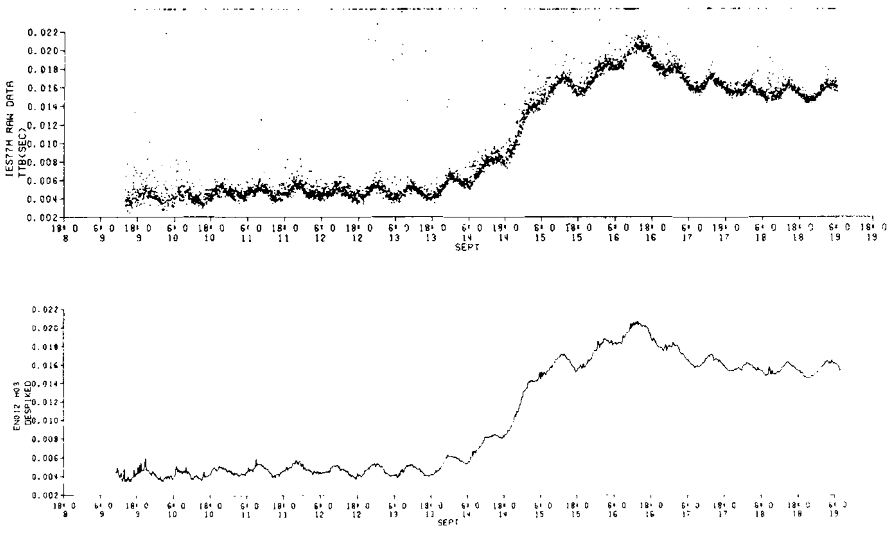

Figure 4: IES Raw Data (Top Trace) and Median Travel Times (Bottom Trace)

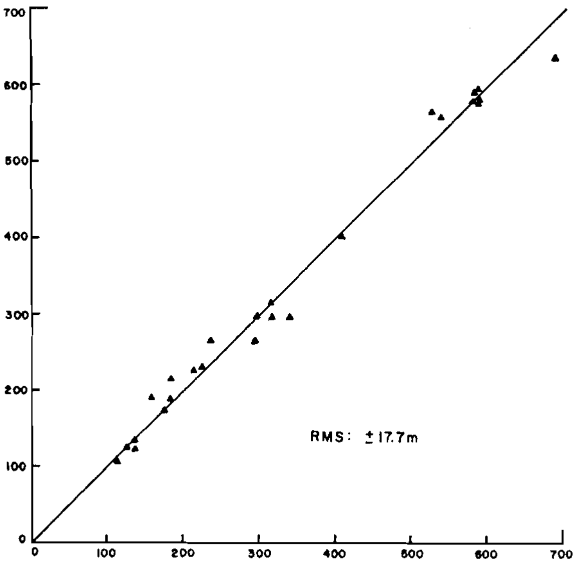

FIGURE 5: OBSERVED 15°C. ISOTHERM DEPTH (meters)

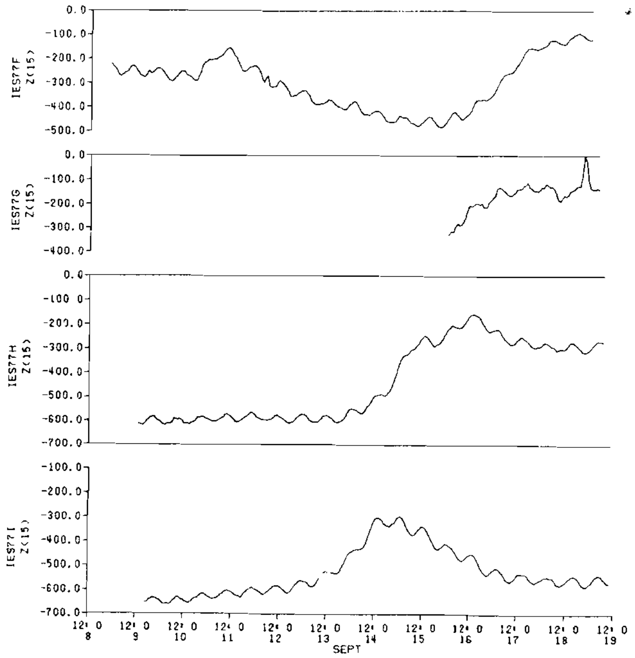

Figure 6: IES Data Under Gulf Stream
Near Cape Hatteras

multiple-ship survey over an extensive time period. We therefore view the IES as a cost-effective means to study the horizontal and temporal variability in the dominant vertical structure of the oceans.

Summary

The features combined within the IES, namely the compact lightweight package and the multiple relocation aids including an acoustic homing beacon, make the instrument suitable for deployment and recovery operations from small boats as well as large research ships; it is relatively independent of accurate shipboard navigational aids, allowing unrestricted choice of operating area.

References

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