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MODE SOFAR FLOAT
IN SITU DATA SUMMARY

By

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TECHNICAL REPORT

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ABSTRACT

Ten SOFAR floats were instrumented during the MODE field experiment to record pressure, temperature, and vertical water displacement during a four month drift. This report describes the acquisition and reduction of this data and then summarizes in graphical form some of the principal results.

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I. Introduction

The principal aim of the MODE experiment, conducted in the spring of 1973, was to study large scale currents over a period of four months in an area, 300 km square, of the western north Atlantic centered at $28^{\circ}00'N$, $69^{\circ}40'W$. The SOFAR float program, as an essential part of MODE, successfully constructed twenty large neutrally buoyant floats and tracked them acoustically from distant shore stations as they drifted at a nominal depth of 1500 m near the SOFAR sound channel axis. Of these floats half were instrumented to sense and record water pressure, temperature, and vertical water velocity along the drift path. A photograph of one of these floats just prior to launch is shown in Figure 1. At the end of MODE we had recovered about 320 days of data, representing a return of one half to one third of that originally hoped for. This report describes briefly the acquisition and reduction of the recovered data, and then represents a summary of the results for each float.

A general review of the shipboard SOFAR float program has been reported previously by VOORHIS and WEBB (1973). Each float was assigned a number and during MODE was usually launched, recovered, and relaunched several times. The instrumented floats which furnished the useable data presented here are listed in Table 1 along with other pertinent information and, finally, their drift tracks are shown in Figures 2 to 11.

Table 1. Recovered Instrumented Floats, 1973

Float No.	Drift No.	Launch		Recovery		Duration of useable data
		Date	Time GMT	Date	Time GMT	
1	1	7 April	1746	8 July	1930	27°46.1'N 69°28.3'W
2	1	8 April	0441	4 May	0017	27°38.3'N 69°42.4'W
2	2	30 May	1801	1 July	1215	27°36.4'N 69°01.9'W
5	1	8 April	1747	22 April	2130	27°36.4'N 69°30.6'W
5	2	24 April	1513	11 June	2210	27°59.7'N 71°58.5'W
9	1	10 April	1439	22 April	1330	28°19.0'N 68°34.7'W
9	3	3 June	1454	4 July	1325	28°06.3'N 70°00.9'W
10	1	11 April	1455	23 April	1230	28°40.2'N 70°00.5'W
10	2	4 May	1418	10 June	1327	27°04.0'N 68°56.9'W
10	3	11 June	2056	28 June	0023	27°56.1'N 72°28.5'W

II. Raw data acquisition

The data acquisition system on the floats consisted of a Sea Data digital magnetic tape recorder with specially developed low power sensor circuits. Three environmental variables were recorded every 256 seconds, which was the basic sampling interval.

Water pressure was sensed by a strain gauge potentiometer open to the environment through a port in the bottom end cap of the float (Figure 1). The potentiometer output was converted to frequency and recorded as C_p , the number of cycles counted in a fixed period of six seconds.

Water temperature was sensed by a thermistor mounted within the aluminum wall of the bottom and cap. The thermistor resistance was converted to frequency and recorded as C_T , the number of cycles counted in a fixed period of two seconds.

Vertical water motion was sensed by a technique developed by WEBB and WORTHINGTON (1968) and exploited by VOORHIS (1968). Because the compressibility of the float is less than that of the sea water, vertical currents generate relative vertical flow past the drifting float. This flow acts on an array of tilted vanes mounted axially around the main cylinder at its mid-length, forcing the entire float to rotate about its vertical axis. The resulting rotation is sensed relative to an internal magnetic compass. The vanes consist of four plates of polypropylene 38 x 50 cm. mounted at 45° to the float axis and are shown in Figure 1. The angular orientation of the compass was recorded as C_θ , the number of cycles of a fixed frequency signal passed through a variable time gate controlled by the compass orientation.

The accuracy of the frequency converters and of the time base was determined by a temperature controlled master quartz oscillator with an offset no greater than 1 part in 10^6 .

III. Data reduction

After float recovery the tape cassettes were read and edited for continuity. The variables listed and described in Table 2 were then computed from the edited raw data and were written in the MALTAIS (1969) format on a working tape which was used for all subsequent analysis. The basis quality of this working data such as r.m.s. accuracy, resolution, etc. is also given in Table 2 when known. Described below is the method used to compute each variable.

3.1 Time

This was computed from the float clock by stepping forward 256 seconds per sample from the time the recorder was turned on. The latter was determined relative to 0000 hrs. Greenwich mean time.

3.2 Water pressure

This was computed from the raw count rate C_p using the expression

$$P = a - b C_p - d C_p^2$$

Here a , b , d are constants for each pressure subsystem. They were obtained by calibrating each system with a dead weight pressure tester over the range of 0 to 1724 db. and fitting (in a least square sense) the calibration points with a second order polynomial.

Table 2. Description and quality of basic working data

Variable	Symbol	Units	Sense	Absolute Accuracy	Unaveraged R.M.S. Digital Noise	Drift
time	t	Julian day and day millise.		± 2 min		less than 2.6 sec/mo
pressure	P	decibars		± 5 db	.028 db	- 4 db/mo approx.
temperature	T	°C		± .044°C	.00072°C	less than .001°C/mo
rotation rate	R	revolutions/hour	positive if turning clockwise from above	compass ± 1/100 rev	.090 rev/hr	
float vertical velocity	W _F	cm/sec	positive upwards	± 10 ⁻⁴ cm/sec	.022 cm/sec	
relative vertical water velocity	W _R	cm/sec	positive upwards	± 5%	.015 cm/sec	
true vertical water velocity	W	cm/sec	positive upwards	± 5%	.026 cm/sec	

3.3 Water temperature

The thermistor resistance, R , in ohms was computed from the raw count rate C_T using the expression

$$R = -h + \frac{k}{C_T}, \quad (2)$$

and the water temperature from the resistance using

$$T = [e + f \ln R + g(\ln R)^3]^{-1} - 273.15 \quad (3)$$

In the above h , k are constants for each resistance to frequency conversion circuit and e , f , g are constants for each thermistor. The former were obtained by calibrating each circuit with precision resistance and fitting (in a least square sense) the calibration points with the expression (2). The latter was obtained by calibrating each thermistor in a temperature bath over the range from 0 - 30°C and fitting the calibration points to the expression (3) suggested by BENNETT (1972).

3.4 Rotation rate

This was computed directly from the rate of change of the raw compass count C_θ . The latter decreased by 64 for each clockwise rotation of the float. Hence, the rotation rate in revolutions per hour was given by

$$R = -56.25 \frac{d C_\theta}{dt}, \quad (4)$$

where $\frac{d C_\theta}{dt}$ is the rate of change of the compass count per second.

3.5 Vertical float velocity

This was computed from the rate of change of the water pressure using

$$W_F = - 100 \frac{dP}{dt} \quad (5)$$

where $\frac{dP}{dt}$ is given in decibars per second.

3.6 Relative vertical water velocity

The relative velocity is determined from the rotation rate (4) and is a function of vane geometry, rotational float drag, and float moment of inertia, discussed by VOORHIS (1971). Their relationship for the SOFAR float was established in two ways. The rotation of a 1/20 scale model was observed as it was lowered and raised in a water tank at differing rates scaled such that the flow Reynolds number was similar to that expected at sea. The second way was to determine the rotation rate of the actual float as it sank to its equilibrium depth after launch and as it surfaced on recovery; where both sinking and surfacing rates could be determined from pressure measurement. As a result, the following relation was used to compute relative vertical water velocity from rotation rate,

$$\begin{aligned} \ell |W_R| W_R = & - [m|R| + n|R|^{\frac{1}{2}} + p]R \\ & - q \frac{dR}{dt} \end{aligned} \quad (6)$$

Here m , n , p , q are constants. The quantity ℓ is dimensionless and of order unity. It has two values depending on whether W_R is positive (water up) or negative (water down). This arises because the vertical asymmetry of the float (Figure 1) generates a different flow pattern past the vanes in each mode.

The first term in the bracket on the right of (6) was the most important, by far, in determining the relative velocity during MODE. The constant m had the value of 5.8 meters of water per float revolution.

3.7 True vertical water velocity

This was computed simply by adding the vertical velocity of the float (5) to the relative velocity (6), that is,

$$W = W_R + W_F \quad (7)$$

IV. Analysis and description of reported data

The analysis of all the variables described in the previous section will not be discussed in this report. Instead, selected results are given for the most important quantities; true vertical water velocity, water temperature, and water pressure (or float depth).

Spectral analysis of all data soon showed that its variability could be divided roughly into three regimes according to the time scale of the fluctuations. Of principal interest to MODE, perhaps were the slow variations having periods longer than the local inertial period, which varied from 25 to 27 hrs depending on the latitude of the float drift. A great deal of the variability, however, was concentrated at shorter periods extending from the inertial period to the mean local Väisällä period, which was about 1.6 hours at the average float depth. This was caused by the field of internal waves which continuously advected water with its thermal microstructure up and down past the float as it drifted. Finally, for the shortest periods extending from the Väisällä period down to the

minimum resolvable period of about 8.5 minutes the variability of vertical motion and of temperature both decreased but less rapidly for the latter because of the thermal microstructure.

4.1 Spectral analysis

The autospectra of the vertical water velocity W and of the rate of water temperature change $\frac{dT}{dt}$ are shown in Figures 12 to 21 for each float drift. They are remarkably similar from float to float and illustrate the features discussed above. All spectra were computed from nine overlapping pieces of unfiltered data sampled every 256 seconds using the TIMSAN program written for the Moored Array project at W.H.O.I. Means were removed before the computation and for all spectra there are 20 degrees of freedom per spectral estimate.

4.2 Internal wave energy variations

As a measure of the internal wave sea state we have computed the daily potential energy P and vertical kinetic energy K_v of the high frequency vertical motion as follows

$$\begin{aligned} P &= \frac{1}{2} \rho \overline{N^2 (Z - \bar{Z})^2} \\ K_v &= \frac{1}{2} \rho \overline{(W - \bar{W})^2} \end{aligned} \tag{8}$$

where

$$W = \frac{dZ}{dt}$$

and the averaging is done over one day. In the above N is the mean Vaisalla frequency taken as 3.9 radians/hr. and ρ is the water density. The daily variations of P , K_v are plotted for each float in Figures 22 to 31. From these plots one can determine that the r.m.s. internal wave vertical velocity and amplitude was about 0.45 cm/sec and 10.0 m respec-

tively.

4.3 Low frequency variations

In order to remove the effects of internal waves the records of water pressure, temperature, and vertical velocity were low pass filtered with a Gaussian hat filter having a half width of one day and an amplitude response shown in Figure 32. The resulting filtered pressure and temperature are shown as a function of time for each float in the upper panel of Figures 33 to 42. Time is expressed in these figures as year-days where 0000 GMT on 1 January 1973 begins year day 1.

A conspicuous feature of the pressure is the steady increase indicating slow float sinking. At present we believe this was caused by contraction of the main cylinder due to compressional creep. During MODE float depth could be determined only for the instrumented floats reported here. Their pressure sensors indicate a mean depth of 1525 ± 24 meters after launch (1525 meters equals 1540 db in the MODE area). Thereafter, they sank an additional 15 meters within the first 24 hours and then slowed their descent thereafter to about 0.85 m/day. Assuming all floats in MODE behaved similarly we can estimate that the average float drifted at the mean depth of 1555 meters during the experiment.

It soon became clear that our measurements of vertical water velocity (6) from float rotation were not really good enough to determine accurately the small low frequency vertical motions having periods longer than a couple of days. There were two reasons for this. First, the actual motions were small enough to be contaminated (aliased) by high frequency motions unresolved by our sampling interval. Second, the basis vertical asymmetry of the float (Fig. 1) required very precise calibration of rotation as a function of up versus down motion (the con-

stant ℓ in (6)) for each float in order to resolve very slow motions in the presence of internal waves. This we were not able to provide. We have, instead, estimated the low frequency vertical water displacement from the variation in water temperature, assuming a constant vertical temperature gradient during the drift, and correcting for the slow sinking of the float. Calling this displacement Z^* it was calculated from

$$Z^* = -(T_z)^{-1} (T - T_0) - (D_F - D_{F0}) , \quad (9)$$

where T_z is the constant temperature gradient, taken as $1.5 \times 10^{-3} \text{ }^\circ\text{C/m}$, and T , D_F are the filtered low pass temperature and float depth respectively. The zero subscripts refer to values at the beginning of each record so that the displacement is initially set to zero. The resulting values of Z^* computed for each float appear in the lower panel in Figures 33 to 42.

4.5 Float vertical response

This response can be computed from two independent measurements; the relative vertical water velocity (6) past the float, and the vertical velocity of the float itself (5). The relationship between these two, as discussed by VOORHIS (1971), depends on a number of factors; the density and thermal stratification of the water, the compressibility and thermal expansion coefficient of the float, and the drag geometry and inertia of the float.

The response has been computed for the second drift of SOFAR float #10 and is summarized in Figure 43. Shown as a function of frequency are the coherence between W_F and W_R , their amplitude ratio, and the phase

angle by which W_R lags W_F in time.

The coherence is high throughout the internal wave band and the ratio of float motion to relative motion is less than 0.5. At higher frequencies the coherence drops due to density microstructure and the float to relative motion increases due to float inertia. The float response is purely resistive (drag controlled) at about 1 cycle/hour when the phase lag is 90° .

V. References

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VI. Acknowledgements

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Figure 32. Amplitude response of low pass filter used to smooth data.

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Figure 43.

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-24-

28° 30' N-

69° W

68° W

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15
13
11

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