The Variable-Buoyancy Drifting DIMES Shearmeter Instrument

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***Abstract* – A new drifting float has been designed and built for long-endurance continuous measurements of internal gravity waves in the upper 1700 m of the ocean during the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES). The floats measure vertical shear multiple times per hour. They also record temperature and conductivity at the same data rate to record vertical strain and thus Richardson number. They have active buoyancy adjustment so that they can remain on the density surface under analysis in the project. They are tracked acoustically while operating, drop ballast after recording for up to one year, and return data via Iridium satellite.**

I. Introduction

A new subsurface drifting float has been developed and built for use in the joint US/UK Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES) [1]. This device has been designed to measure the weak and difficult to measure shear present in the deep ocean. The weak shear (vertical partial derivative of horizontal velocity, $S = |\partial \boldsymbol{U}/\partial z|$) is the result of weak stratification (vertical density gradient in units of buoyancy frequency, N). The weak stratification itself is also measured. Together these form the gradient Richardson number $Ri=N^2/S^2$, a nondimensional parameter which is linked to shear instability and across-isopycnal mixing throughout the ocean [2]. For example, flow with Ri less than 0.25 is regarded to be subject to shear instability.

The Shearmeter class of instruments is designed to measure shear by the action of cup-anemometer type vanes rigidly mounted to each end of the tall and thin upright-spar float (Fig. 1). Six vanes at equal-arc intervals are at each end, extending to radius 45 cm. Asymmetric drag on the vanes causes the entire instrument to rotate, with rotation sensed with a compass [3]. This is the second generation of Shearmeters. Earlier Shearmeters were 10 meters tall, were of quasi-isobaric aluminum-alloy design, and utilized modified commercial RAFOS float control and data-acquisition electronics [4-6]. The new DIMES Shearmeters are 7.4 m tall, incorporate a variable-volume buoyancy changer to allow vertical migration or profiling, measure more parameters than the previous models, and have a new extended-capability controller.

The main mission of the Shearmeters is to record velocity difference (shear) and density difference (stratification) 10 times per hour for one year at the depth of an injected chemical tracer. Shear and strain (wave-induced changes in stratification, given by the vertical partial derivative of vertical displacement) are dominated by internal gravity waves. The gradient Richardson number, defined earlier, is a ratio involving kinetic energy and potential energy that is related to dissipation and mixing processes in stratified fluids. After the experiment, vertical and horizontal dispersion behavior of the tracer patch will be analyzed in conjunction with time series of the internal-wave forcing parameters from these floats and with measurements from other devices.

In this paper, the requirements governing float design are described next, in Section II. Section III describes mechanical aspects of the float. Section IV covers control and communication electronics. Section V describes sensors; Section VI describes software and control. Observations from a sea test are shown in Section VII, followed by a summary

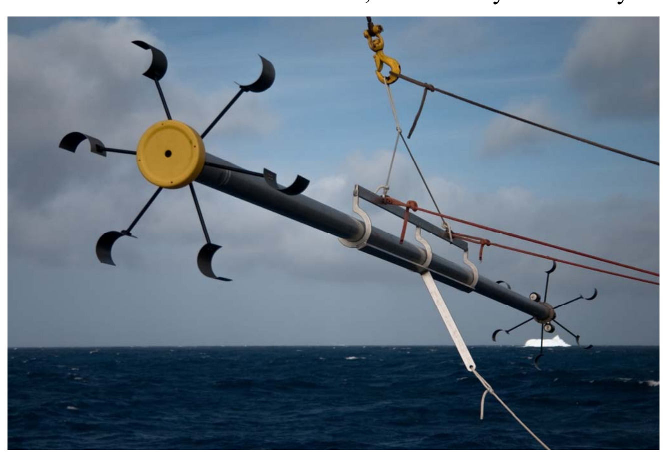

Figure 1. A DIMES Shearmeter is shown. The plastic cover on the lower (near) end of the float protects the oil bladder for the buoyancy pump. The shear-sensing vanes are shown. Photo by Uriel Zajaczkovski.

II. Mission Requirements

The mission goal is to obtain continuous measurements of shear (dominated by internal waves) at or near the depth of a chemical tracer injection and dispersion experiment. The DIMES initial work site is near 60°S, 105°W in the Antarctic Circumpolar Current. The remoteness of the site, and the large area that the dispersed patch would fill in the years to follow, favored drifting long-term measurements, as these would not require return trips and would sample a wide area. Quasi-isobaric Shearmeters capable of remaining at the depth of the chemical (trifluoromethyl sulfur pentafluoride) and making continuous measurements of the motions responsible for diapycnal mixing were deemed suitable.

Buoyancy control: One complication is that the density surface on which the vertically very thin tracer patch would lie is sloped. It deepens northward and shoals southward, so that quasi-isobaric prior Shearmeters could drift away from the targeted zone. Thus, a new active-ballast design was chosen.

Sensors: Because a new instrument would be needed it was decided to enhance the measurement capability. In addition to shear (S) measurements, rapid variations of stratification (N) would also be measured. This would give a Richardson-number capability not unlike those made with the RiNo float [7,8]. Sensor requirements would be

- Conductivity/ temperature/ pressure (CTD) at the top end of the float.
- Temperature at the bottom end of the float.
- Compass (rotation and shear).
- RAFOS-system tracking sound pulse arrivals [9].
- GPS position after surfacing at mission termination (aids track reconstruction, backup positioning).

The first three of these three would be need sampling rates of at least four per hour. The RAFOS acoustic receiver samples data in windows once or twice per day. As a quasi-isobaric float, the Shearmeter will move through local water moved vertically by internal waves [10]. This provides a local temperature/salinity relation, used to compute salinity and density at the lower end, and density gradient (N^2).

Communication: Shear is recorded with an integrating method (rotations are resolved and counted) so there is no aliasing. However, vertical strain density-gradient signals at physically allowable internal-wave frequencies (up to one-half or one per hour) could not be integrated and would be subject to aliasing. Thus the CTD and temperature measurements would need to be made many times per hour. The resulting large amount of data would not be passable through the System ARGOS satellite link which was used for prior Shearmeters that sampled once per hour. Thus, a higher bandwidth satellite modem would be needed.

III. Mechanical Components

The Shearmeters are comprised of cylindrical hulls with differing upper and lower end caps. Fitted at the lower end is a Teledyne Webb Research (TWR) APEX buoyancy changer, vanes, and a thermometer. At the upper end are the CTD, GPS/Iridium antenna, vanes, hydrophone, two releasing weights, and a communication port. Prior 10-m Shearmeters had sectional hulls [4]. Those were fragile and awkward, with 3.25-inch OD, 2.75-inch ID tubes. Shorter but wider tube was chosen for the new application; the buoyancy changer product and the chosen CTD circuit board would not fit in the old tube. The larger required diameter meant that the weight and handling difficulty would be much greater at the 10-m length. Previous experiments [4-6] showed that the signal gain obtained by the length was sufficient to allow shorter tubes (signal is shear times length). The hulls are a standard size of the maximum easily-attainable length. The hull properties are

- 4.5-inch outside diameter
- ¼-inch wall
- 6061-T6 alloy
- Not anodized
- 1800 m operating depth
- 24-ft length (7.3m)

The compressibility is close to 2.36×10^{-6} per decibar [11]. Other specifications are

- Hard-coated 6061 end assemblies
- Mass 82 kg (tube displacement 77)
- Payload 40 kg
- Dual drop weights for surfacing
- 230 ml volume (buoyancy) adjustment

With this buoyancy adjustment range, the large floats cannot operate at the target depth (approx 1550 m) and return to the surface by pumping. Therefore a pair of galvanic weight-drop systems was incorporated into the upper end.

IV. Control and Communication System

The Shearmeter control system consists of three circuit boards (Fig. 2). This system forms what is called the Variable

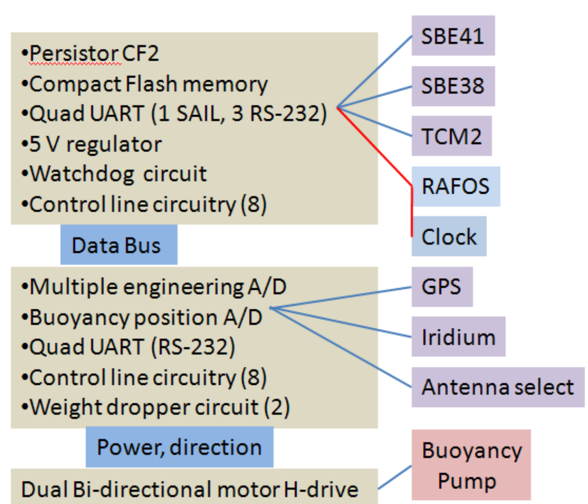

Figure 2. An overview diagram of system components is shown. On the left are three circuit boards. The upper pair of main boards is 3.5×6×1.75 inches. The other board is smaller. To the right are main system components having serial digital interfaces, except for the Teledyne Webb APEX buoyancy pump. The RAFOS and clock use SAIL communications.

Buoyancy Float Controller (VBCF), which can control other devices besides the DIMES Shearmeter. The 3.5×6 inch main board contains a CF2 Microcontroller (Persistor Instruments, Inc., Marstons Mills, MA). This controls all float operations. Other main components on this board are listed in the figure. The CF2 uses an operating system called PicoDOS which allows code to be develop in ANSI standard C language, cross-compiled, and downloaded. Other components on the main board not shown in the figure are a SAIL serial communication interface converter (see below), and RS232 serial converters. The control lines (for sensor power control, watchdog circuit, buoyancy pump direction control, etc.) are taken from the data bus using CF2 chip-select lines.

A second large board is stacked with the first, connected with a data/address bus and other lines. The additional digital and analog circuitry of this board is listed in Fig. 2. Data handled by the A/D circuitry are buoyancy pump piston position, internal temperature, internal pressure, main battery voltage, Iridium battery voltage, and galvanic weight-dropper currents. This board also contains internal pressure and temperature sensors for leak detection.

Other systems are an Iridium modem model A3LA (NAL Research, Manassas, VA) and a small circuit board that switches the antenna between GPS and Iridium.

Internal digital communication with sensors and Iridium is via either RS 232 interface or Serial ASCII Interface Loop (SAIL). SAIL is required for the RAFOS receiver and clock boards, both from Seascan Inc., (Falmouth, MA). The clock board delivers precise time which is needed to maintain RAFOS acoustic reception timing accuracy.

Power is from 15-volt parallel stacks of alkaline cells, 18 kg total weight. This quantity of batteries is adequate for one year of operation at the sampling rates indicated in this paper.

V. Sensors

The sensors on the Shearmeters are off-the-shelf systems with the exception of the shear-measurement vanes.

Vanes: The vane end elements (Fig. 1) are 13×13 cm half cylinders of aluminum alloy sheet, approx. 1 mm thickness.

CTD: At the upper end is a SBE41-CP Coriolis CTD (Sea-Bird Electronics, Inc., Bellevue, WA USA). This is a pumped CTD system with anti-fouling protection for the enclosed conductivity cell. Absent debris altering the dimensions of the cell, the system should retain salinity calibration throughout the mission. The temperature calibration is expected to be of order one millideg. C for the mission (up to one year). Sampling protocal: Five seconds of data at 1 Hz are averaged once per 6 minutes. (Some initial data discarded. programmable to other rates, if desired.)

Temperature: The lower end has a Sea-Bird SBE38 temperature sensor. This has a stainless-steel probe extending through a port in the end cap. This is also expected to remain calibrated to order one millidegree. The difference between the upper and lower end temperatures is expected to be about 10 millideg. C at the DIMES site/depth. Eight measurements are averaged, once per 6 min. (Programmable to other sampling rates, if desired.)

GPS: Garmin Intenational (Olathe, KS) model ISH-W**.** This is used when at surface after weight-dropping.

Compass: Rotation rate is directly related to shear. The sensor is a TCM2.6 attitude sensor (PNI Corporation, Santa Rosa, CA). The calibration is such that 10-m shearmeters typically rotate at a rate of one to two per revolutions hour when *N*=0.0017 rad/s (one cycle per hour) and internal wave are typical, consistent with mean or median *Ri* near one. Aveage rotation is proportionally slower for lower *N*. Shearmeters data collected to date have been from areas with average or higher than average internal-wave shear. The compass is currently sampled once per minute.

VI. Software and control

The CF2 controller provides flexibility in the VBFC system. There are many possibilities for conditional sampling, substituting other sensors, sleep intervals, delayed start, etc.

In the Shearmeter mission configuration, the Seascan clock provides a continuous one-minute interrupt that triggers all operations. The data-sampling operations are all triggered by these signals. All mission parameters are input prior to deployment. This can be done via a through-hull connection.

The Shearmeters have been programmed to stay at a target potential density surface. After sensing settlement to equilibrium, they begin a buoyancy-control sequence to first get to the proper potential density surface using feedback from the CTD, and then remain there. It is possible that this adjustment must be made right way, or it may be needed months later after drifting in the DIMES area of sloped isopycnals. In the event that the CTD salinity is judged to be in error based on programmed-in knowledge of the local

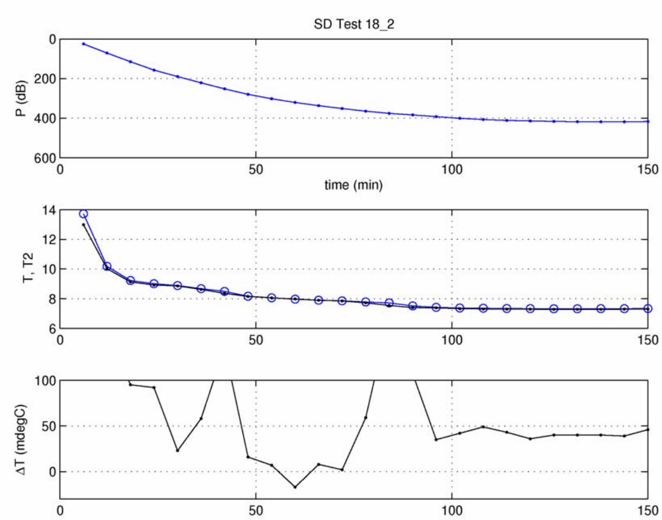

Figure 3. Pressure and temperature data from a test deployment on 18 May 2008. The float falls to the equilibrium depth in 100 minutes. At this time the temperature difference between the two ends begins to sense strain.

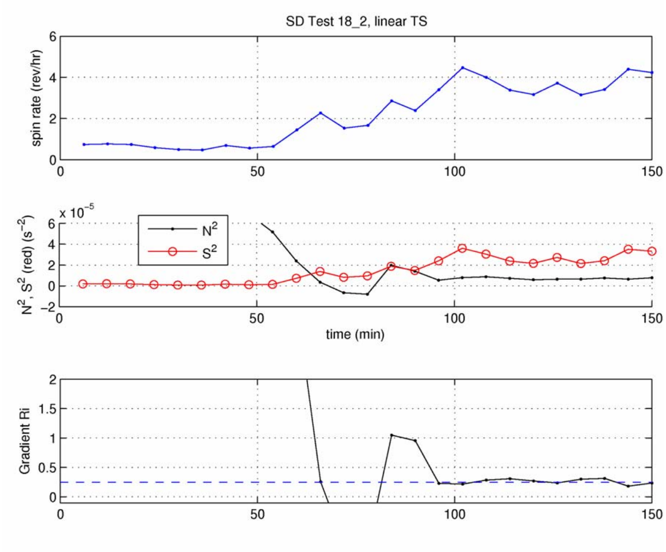

Figure 4. Additional data from the 18 May 2008 deployment are shown. (Upper) After 100 minutes the spin rate reflects horizontal shear. (Center) N^2 (density gradient) derived from the upper CTD density data and lower temperature data combined with temperature/salinity conditions derived from CTD data is shown, with shear (S) squared. (Lower) Richardson number N^2/S^2 is shown.

temperature/salinity conditions, the float is instead operated in backup mode to remain at a target temperature. (Salinity measurements are less stable than temperature measurements.) During the first day after settling the adjustment is made every CTD sampling interval. For the next two days it is done once per hour. On the fourth day it is done every 12 hours. Thereafter it is done once per day. If adjustments are large and the instrument has not settled before the next query, no adjustment is made. During this interval all data are collected and stored at the rates given in Section V.

To avoid oscillation about the target density surface, the pumps must be carefully controlled. The vertical movement in density units (or temperature units as a backup) per pumping time interval is a user-provided parameter. This must be computed from actual ocean data (or climatology) and float properties. A damped approach to the target surface (within user-specified tolerance, again user-specified) is assured by pumping for only one-half the interval calculated to move the float all the way to the target.

Data are stored in daily files. Upon mission completion, two weights are dropped and data are returned using Iridium short-burst data mode. This mode will operate when the antenna is constantly dunked due to expected high sea states.

There are various mission abort features. For example, in the event of a clock failure the mission is terminated and data are transmitted.

VII. Results

One DIMES Shearmeter was deployed six times during 16-18 May 2008. The tests were west of San Diego, California. *RV R. G. Sproul* was used. The final test was a free drift test and included the sensor vanes. Fig. 3 shows pressure and temperature data from this deployment. Fig. 4 shows rotation data, derived density-gradient values, and derived shear data.

The float spun rapidly in comparison with open Atlantic Ocean deployments [4,5,6], at four revolutions per hour. It also moved northward at greater than one km per hour. The gradient Richardson number remained steady at a value near one-quarter, indicating marginally stable flow. The steady low Richardson number indicating flow on the edge of stability differs from highly variable shear typically observed, and may be related to the presence of the escarpment upstream (to the southeast) within the observed northward flow (Fig. 5).

During these tests the seas were smooth and GPS fixes were obtained. Data transmission involved Iridium modem data phone call, and was successful. This differs from the short-burst transmission uplink-only mode to be used in the Southern Ocean.

VIII. Summary

The DIMES Shearmeters have been designed to provide a long-term Lagrangian finestructure measurement capability. The DIMES mission is to measure shear, strain, and Richardson number ten times per hour for year, while having the float trajectory along an isopycnal surface monitored acoustically.

Studies of mixing processes responsible for the evolution of temperature and salinity on isopycnal surfaces are attainable with this float. The ability to remain on an isopycnal surface using active buoyancy control coupled with CTD measurements allows this.

The stand-alone three-board Variable Buoyancy Float Controller digital/analog electronics unit is highly flexible and

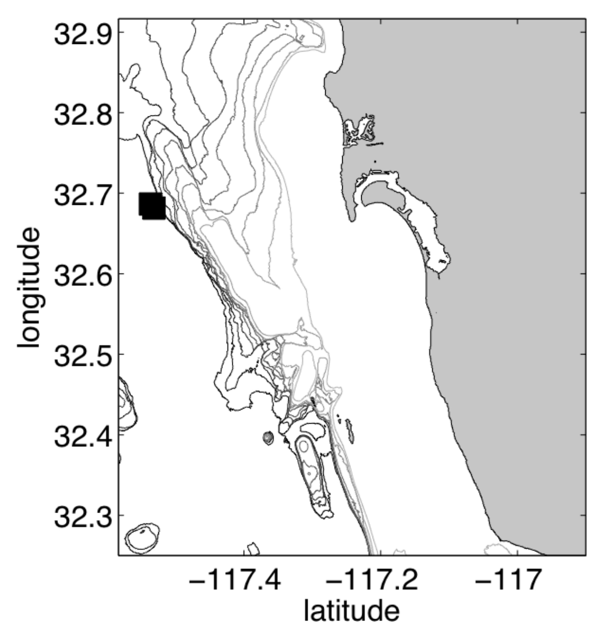

Figure 5. The 18 May 2008 deployment location is shown with two superimposed large squares (deployment and recovery points). San Diego Bay can be seen in the center. Contour intervals are 100 meters, with a maximum of 1000 m.

capable, and is adaptable to other purposes besides Shearmeter control. An example would be use in a shorter (more portable) float with biological, chemical, optical, or physical sensors making measurements in either profiling or hovering mode, possibly adaptively or conditionally sampling, and/or profiling, based on characteristics of the data.

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