

VMP-5500 operation and data during JC068

This document summarizes use of the Rockland Scientific Instruments (RSI) Vertical Microstructure Profiler 5500 (VMP) from the UKORS instrument pool during GEOTRACES 40S, cruise 68 of the RRS James Cook.

The VMP 5500 is a free-fall vertical profiler with the objective of resolving velocity and temperature gradient variances at molecular scales and consequently providing estimates of the rate of dissipation of turbulent kinetic energy (ϵ) and temperature variance (χ). The free-fall configuration is aimed at eliminating vibrations and extraneous tugging associated with even a loose tether. This then requires onboard decision making for dive termination by release of ballast weights. The task of estimating the gradient variances is accomplished with two sets of sensors. A microstructure suite consisting of 2 airfoil shear probes, 2 fast response thermistors and a dual needle conductivity cell resolves scales of 1 meter to several millimeters. A finestructure suite consisting of SeaBird 3 – 4 temperature and conductivity sensors and a pressure transducer resolves scales smaller than 1 meter to those as large as the entire water column.

Fine- and microstructure data are gridded at half-decibar intervals. The microstructure data were sampled at 512 Hz and Fourier transformed using bin lengths of one second centered on the mid-point of the pressure bin. Estimates of finestructure variables (temperature and salinity) were sampled at 32 Hz and averaged on this same grid. Rockland's noise subtraction scheme was used to correct for vibrational contamination of the shear probes. This was accomplished by constructing running estimates of the shear-acceleration coherence over 3 consecutive bins: the half-decibar shear variance estimate represents an average over three consecutive one second intervals centered on the half-decibar pressure bin.

The data files consist of vertical profiles of pressure P , *in situ* temperature T , salinity S , the rate of dissipation of kinetic energy ϵ and temperature variance χ on this $\frac{1}{2}$ Ddar grid for each cast. VMP station data is presented immediately below before details of sensor calibrations.

Station Particulars

VMP operations during GEOTRACES 40S consisted of the profiler being deployed during the CTD/LADCP hydrocast operations. There was both a stainless steel Rosette (SS) for normal water sampling and a titanium (Ti) Rosette for ferrous sensitive applications. Each Rosette had complementary CTD and LADCP units. The conducting cable on the stainless Rosette had transmission issues that impacted data quality early on, especially at Stations 8 and 9. Data quality of one of the LADCP units degraded during the cruise to the point it was declared nonfunctional. The functional unit was mounted to the stainless rosette. See the CTD and LADCP reports for further information. Cast details are tabulated below. VMP operations were uneventful apart from cast 7 profiling to mud and remaining there for several hours. This mishap was due to operator error in specifying dive termination criteria.

Table 1: VMP station positions and particulars. Deployment position is from the cast log. Water depth represents the best estimate from the ship's acoustic resources at deployment and Pmax is the maximum pressure logged by the profile.

VMP cast	Station	latitude	longitude	Pmax	Depth			
	1			400		CTD 001	SS	
				400		CTD 002	Ti	
	2			400		CTD 003	SS	LADCP
				400		CTD 004	Ti	
	3			full		CTD 005	SS	LADCP
				full		CTD 006	Ti	
				400		CTD 007	SS	LADCP
	4			400		CTD 008	SS	LADCP
	5			400		CTD 009	SS	LADCP
	6			3000		CTD 010	SS	LADCP
	7			full		CTD 011	Ti	LADCP?
1		40.0009 S	03.0343 W	1019.7	4463			
	8			400		CTD 012	SS - ng	LADCP
				full		CTD 013	Ti	
				full		CTD 014	SS - ng	LADCP
	9			1000		CTD 015	SS - ng	LADCP
				1000		CTD 016	Ti	
				multi-core				

	11			aborted		CTD017	SS	LADCP
2		40.0000 S	13.0001 W	3074.8	3183			
				full		CTD 018	Ti	
				full		CTD 019	SS	LADCP
				2225		CTD 020	SS	
3	12	40.0007 S	16.4661 W	2992.6	3080			
				full		CTD 021	SS	LADCP
				full		CTD 022	Ti	LADCP
				400		CTD 023	SS	
4				3019				
				400		CTD 024	Ti	
5	13	39.9993 S	19.9324 W	3737.2	3783			
				full		CTD 025	SS	LADCP
				full		CTD 026	Ti	LADCP
				1500		CTD 027	SS	LADCP
6	14	40.0001 S	23.8001 W	4122	4162			
				full		CTD 028	SS	LADCP
				full		CTD 029	Ti	LADCP
				400		CTD 030	SS	LADCP
	15			400		CTD 031	SS	LADCP
7		40.0000 S	28.0000 W	4308.2				
				full		CTD 032	Ti	LADCP
				full		CTD 033	SS	LADCP
	16			400		CTD 034	SS	LADCP
8		39.9941 S	32.4927 W	4848.8				
				full		CTD 035	Ti	LADCP
				full		CTD 036	SS	LADCP
	17			1000		CTD 037	SS	LADCP
9		40.0000 S	37.4166 W	5121.1				
				full		CTD 038	Ti	
				full		CTD 039	SS	LADCP
				1500		CTD 040	Ti	
				full		CTD 041	Ti	LADCP
	18			test		CTD 042		
				400		CTD 043	SS	LADCP
10		40.0000 S	42.4167 W	5172.8	5169			
				full		CTD 044	Ti	
11				5169.0	5157			
				full		CTD 045	SS	LADCP
12				5969.3	5146			
				1500		CTD 046	Ti	
13	19	39.9939 S	47.4167 W	5262.4	5257			

				full		CTD 047	SS	LADCP
				full		CTD 048	Ti	
				400		CTD 049	SS	LADCP
	20			400		CTD 050	SS	LADCP
14		38.0123 S	50.9952 W	4789.5	4798			
				full		CTD 051	SS	LADCP
				full		CTD 052	Ti	
15				4821.7	4825			
				full		CTD 053	SS	LADCP
				full		CTD 054	SS	LADCP
				full		CTD 055	SS	LADCP
16	21	37.0256 S	52.5025 W	3276.5	3313			
17				3276.2	3325			
				400		CTD 056	SS	LADCP
				-		CTD 057	misfire	
				full		CTD 058	Ti	
18				3276.5	3325			
				600		CTD 059	SS	LADCP
				500		CTD 060	Ti	
19	22	36.5385 S	53.1018 W	1468.2	1520			
				full		CTD 061	SS	LADCP
20				1418.2	1515			
				full		CTD 062	Ti	
21	23			661.9				SADCP
	24							

Calibrations

Calibration of the instrument is largely accomplished with the RSI setup file, which also contains dive control information for each cast. An example of the RSI setup file for Station 10 is included below. This setup file contains information on the instrument calibration for the accelerometer, magnetometer and pressure transducer dating to June-July 2011. SeaBird C/T sensors SN#4969 with calibration date 2009-04-17 and SN#3240 with calibration date 2009-05-08 were used for the duration of the cruise.

```
# ODAS setup file for internally recording instruments
# Modified 2010-09-17 by DC
```

```
#####
```

```
prefix: jc068_010_
disk: /root/data
rate: 512
resize: 1
no-fast: 8
no-slow: 1
profile: vertical
man_com_rate: 3
max_time: 11000
max_pressure: 4768
```

```
#####
```

channel: 0,GND1
channel: 1,Pitch,1955,17154,0,0,0,0,0,0
channel: 2,Roll,-338,13000,0,0,0,0,0,0
channel: 3,az,343,12855,0,0,0,0,0,0
channel: 10,Pres,-11.1,0.29503,-2.19e-7,0,0,0,0,0
channel: 11,P_dP,-11.7,0.29535,-2.687e-7,0,0,0,0,0

channel: 16,SBT1E,4.32537891e-3,6.37309337e-4,2.07607960e-5,1.74222871e-6,1000.0,24e6,128,0,0
channel: 17,SBT1O,4.32537891e-3,6.37309337e-4,2.07607960e-5,1.74222871e-6,1000.0,24e6,128,0,0
SN 4969, 2009-04-17
channel: 18,SBC1E,-1.02924723e1,0,1.62338043e0,-3.31963134e-3,3.57122893e-4,24e6,128,0,0
channel: 19,SBC1O,-1.02924723e1,0,1.62338043e0,-3.31963134e-3,3.57122893e-4,24e6,128,0,0
SN3240, 2009-05-08
channel: 32,Mz, 64,68.88,0,0,0,0,0,0
channel: 33,My, 41.5,72.57,0,0,0,0,0,0
channel: 34,Mx, 236,-70.43,0,0,0,0,0,0

#####

```
matrix: 255      1      2      3      5      7      8      9      12
matrix: 0        1      2      3      5      7      8      9      12
matrix: 4        1      2      3      5      7      8      9      12
matrix: 6        1      2      3      5      7      8      9      12
matrix: 10       1      2      3      5      7      8      9      12
matrix: 11       1      2      3      5      7      8      9      12
matrix: 16       1      2      3      5      7      8      9      12
matrix: 17       1      2      3      5      7      8      9      12
matrix: 18       1      2      3      5      7      8      9      12
matrix: 19       1      2      3      5      7      8      9      12
matrix: 32       1      2      3      5      7      8      9      12
matrix: 33       1      2      3      5      7      8      9      12
matrix: 34       1      2      3      5      7      8      9      12
matrix: 35       1      2      3      5      7      8      9      12
matrix: 36       1      2      3      5      7      8      9      12
matrix: 37       1      2      3      5      7      8      9      12
```

User supplied processing code accomplishes the calibration of the individual microstructure sensors. Gains for preemphasis circuits are also applied in this context. Shear probe usage and calibrations appear in Tables 2 and 3. Microstructure temperature and conductivity probe usage is summarized in Table 4. Table 4 also contains time constants to correct for the slow diffusion of heat through the fluid boundary layer surrounding thermistor tip. This time constant is estimated by regression of microstructure temperature and conductivity spectra selected from regions having high dissipation where thermal stratification dominates the saline contribution.

Table 2: JC068 shear probes and usage

station	S1	S2	
% 01-07	M713	M712	
% 08-13	M722	M712	M713 replaced due to slightly higher noise level
% 14-17	M722	M390	S2 big fuzz on #13
% 18	M722	M394	S2 seemed larger than S1. Cal? Used post-cruise calibration.
% 19-21	M390	M394	S2 seemed larger than S1. Cal? Used post-cruise calibration.

Table 3: shear probe calibrations

probe	calibration	date
M712	0.0664	19/9/12
M713	0.0603	19/9/12
M722	0.0636	19/9/12
M390	0.0738	01/11/11
M394	0.0710	21/10/11

Table 4: temperature/conductivity probes: usage and time constants (Tau)

station	T1	T2	C
% 1-21	#352, Tau = 0.00875	#383, Tau = 0.00825	#C97, Tau = n/a

The gains of the various preemphasis circuits for this instrument are:

P_diff_gain = 20.3; % Gain of pressure pre-emphasis ~20.5

T1_diff_gain = 1.00; % T1 differentiator gain ~1.0

T2_diff_gain = 0.99; % T2 differentiator gain ~1.0

Sh1_diff_gain = 1.01; % Shear Channel 1 differentiator gain ~1.0

Sh2_diff_gain = 1.00; % Shear Channel 2 differentiator gain ~1.0

Finally, the micro-temperature and micro-conductivity were calibrated by regressing against the SeaBird 3-4 sensors. To accomplish this, the known preemphasis of the microstructure temperature and conductivity channels is removed with a digital filter and the resulting signal is averaged on the same ½ Dbar bins as the finestructure sensors. The linear regression assumes the true microstructure signal is a second order polynomial function of the SeaBird signal. Attempts to define a suspected pressure dependence of $O(0.01 \text{ C} / 100 \text{ m})$ for the unprotected thermistors have not been satisfactory to date and thus not included in the regression. The regression of the conductivity sensors discards data shallower than 50 Dbar to avoid transitory wetting phenomena of the microstructure probes.

Signal - to - Noise Optimization

Finally, the processing code¹ attempts to maximize signal to noise ratios by accounting for the particular vibrational and electronic noise signatures of the instrument. Relative noise levels are a function of fall rate and vary with the instrument configuration. The algorithm described below defines a noise floor for the various sensors and then estimates gradient variances by integrating individual spectra to the point where they intersect that noise floor. This process takes two rounds of processing: one to establish the noise floor and a second to produce the intended result. The noise floor was established here by averaging segments of abyssal data from relatively quiescent environments. The noise floors will be fall rate dependent, and the instrument descent rate decreases with increasing depth, but noise issues are most problematic at depth and the intent is to provide optimal deep mixing estimates.

Shear probes

Residual noise in the shear probes was dealt with by subtracting a noise floor of $P_n = 1 \times 10^{-7} \text{ s}^{-2}/\text{cps}$. These are *not* average noise levels. The quoted noise levels represent those ½ Dbar data segments having the lowest 5-10% of the sample variances, with the complication that the sample data have contributions from both noise and oceanic signal. These shear noise estimates are very much lower bounds on the average noise. The noise floor translates into dissipation rates of approximately $1 \times 10^{-11} \text{ W/kg}$ after integrating the shear spectrum to 10 cps: $\epsilon = 15/2 \nu S \approx 15/2 \times 1.5 \times 10^{-6} \text{ m}^2 \text{ s}^{-1} P_n(f) \times 10 \text{ cps}$, with molecular viscosity ν and shear variance S . A variable integration endpoint was defined as the first spectral estimate smaller than P_n . The dissipation estimate was produced by integrating the difference of the observed spectra and P_n to this end point.

Temperature/Conductivity probes

Noise spectra were fit to the deep segments of the profile and used to define the integration endpoint of the spectral integration. Analytic representations of the noise spectra (P_n) are

temperature: $P_n(f) = 0.35e-10 * f^{3.25} [\text{sinc}(f / 512)]^4 \text{ C}^2\text{m}^{-2} / \text{cps}$

conductivity: $P_n(f) = 0.20e-10 * f^{3.25} [\text{sinc}(f / 512)]^4 \text{ mmho}^2\text{m}^{-2} / \text{cps}$

with f being frequency in cycles per second (cps), $\text{sinc}(x) = \sin(\pi x) / \pi x$ and 512 Hz being the sampling frequency of the microstructure data. The levels of the noise spectra are likely slowly varying with fall rate, but the attempt here is to constrain the noise when signal-to-noise ratios are not large, i.e. in the abyss, so the constants reflect depths of 3000-5000 meters. These curve fits for temperature and conductivity noise represent the average electronic noise spectra of the system. A high frequency cut-off of 64 Hz was implemented in the integration scheme. At this point the thermistor response is down by an order of magnitude and corrections beyond this are ... optimistic.

After the second round of processing, a mask was developed to discard noisy data. For a normal data set, this mask consists of two steps:

- (I) visually inspecting for isolated spikes that are more than an order of magnitude larger than their neighbors, then replacing those with a nominal bad data value, such as NaN,

and then estimating the gradient variance S from two redundant probes S_x and S_y with

- (II)
 - if ($S_x < 5 S_y$ & $S_y < 5 S_x$) then $S = (S_x + S_y) / 2$;
 - else
 - if ($S_x > 5 S_y$) $S = S_y$;
 - if ($S_y > 5 S_x$) $S = S_x$;
 - end .

¹ The processing code used here is the matlab file “micro_diagnostics_v1.3.1.m”.