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ANALYSIS OF SWALLOW FLOAT DATA AT SACLANTCEN
SOFTWARE NOTES FOR FUTURE USE AND DEVELOPMENTS

F. Desharnais

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SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

tel: +39-187-540.111
fax: +39-187-524.600

e-mail: library@saclantc.nato.int

NORTH ATLANTIC TREATY ORGANIZATION

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David L. Bradley
Director

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Executive Summary: The Swallow float was originally designed as a neutrally buoyant, freely drifting unit for the study of deep ocean currents. MPL (Marine Physical Laboratory, Scripps Institution of Oceanography, USA) extended the concept by adding to the float an acoustic pressure sensor (hydrophone) and three orthogonal particle velocity sensors (geophones) for the measurement of acoustic intensity in the deep ocean.

The intensity is a vectorial quantity representing the net acoustic energy flux density at any given frequency. In other words, it represents the amplitude and direction of the acoustic signal emitted by a target at any discrete frequency. The direction to the target is obtained with one single float, as opposed to an array of hydrophones. The system can detect one or several sources simultaneously and estimate their bearings if the sources transmit at different frequencies. The absence of mooring devices on the float ensures very low current flow noise contamination in the frequency range of 0.5 to 25 Hz.

This report summarizes the basic equations governing the analysis of acoustic data from a Swallow float, and indicates how to calculate the acoustic energy flux density with the four sensors of a Swallow float. A description of the SACLANTCEN analysis software is included. The software could be adapted for similar hardware systems.

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Analysis of Swallow float data at SACLANTCEN
Software notes for future use and developments

F. Desharnais

Abstract: A Swallow float is as a neutrally buoyant, freely drifting unit which is deployed in deep water, equipped with one pressure sensor (hydrophone) and three orthogonal particle velocity sensors (geophones) to measure acoustic intensity (magnitude and direction of the net acoustic energy flux density). This report summarizes the basic equation governing the analysis of Swallow float data. A description of the SACLANTCEN analysis software is included. The software was originally developed at the Marine Physical Laboratory, Scripps Institution of Oceanography.

Keywords: Swallow floats, very low frequencies, geophones, acoustic intensity, noise directionality

Contents

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Introduction

During the SACLANTCEN cruise IONEX 92, 11 Swallow floats from MPL (Marine Physical Laboratory, Scripps Institution of Oceanography) were deployed in the deep Ionian Sea to collect acoustic intensity data in the very low frequency range of 0.5 to 25 Hz [1]. Swallow floats are free floating units, each equipped with a pressure sensor (hydrophone) and three orthogonal particle velocity sensors (geophones). The original analysis software for the float data was developed at MPL on a UNIX operating system computer. SACLANTCEN adapted the software to the VAX environment, in order to analyze the data collected during the IONEX 92 experimental cruise.

A description of the floats is given, followed by the basic equations governing the acoustic data analysis. A description of the developed analysis software (with references to the original UNIX code) is also included. As the code is very specific to the Swallow floats, the description is not exhaustive, but aimed at the analysis of acoustic intensity. The analysis of the non-acoustic data collected by the Swallow floats is described and the accuracy of the code is discussed.

Emphasis is placed on items that could be important for future development of Swallow floats or similar systems at SACLANTCEN.

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Swallow floats

Swallow floats are free-floating units with four acoustic sensors (three geophones and one hydrophone (Fig. 1). Each float also contains the data recording hardware, ballast to control the float depth, a compass to derive the true heading of the float, and a high-frequency ITC (International Transducer Corporation) transducer functioning in the 8 kHz range to localize the floats by differential acoustic travel times. The ITC transducer also enables communication between the float and a nearby receiver (located on a research ship) with a set of basic commands (ballast release being one of the commands). More information on the floats is given in [2].

Data recording is automatic at a sampling frequency of 50 Hz for each sensor. Readings for the four acoustic sensors are sequential, producing a 4 ms offset between the samples of two consecutive channels (the total cycle is 20 ms). The sampled values are stored in a temporary buffer, and recorded onto tape is every 45 s. Each 45 s period constitutes a data record, with 2250 samples per record.

The floats also feature an automatic gain control (AGC) system which allows a variable gain of 0 to 36 dB to be added to the signal. An internal calculation is made of the number of clipped points during the last 39 seconds of each 45 s record. If more than 0.5 % of the data points are clipped, the gain is automatically reduced by incremental steps of 0.5 dB. If no clipping occurs, the gain will be raised in the same manner. The gain setting is also recorded on tape, as well as the magnetic heading from the compass, which is aligned to the y- geophone.

The analysis of data from a Swallow float is carried out in two steps. First, the non-acoustic data are extracted and plotted (float heading, data clipping and AGC gain as a function of record number or relative time). The ITC transducer data are also analyzed to extract the high-frequency pinging information, which allows accurate positioning of the floats relative to each other. In a second step, the acoustic time series are analyzed. During this step the data from the four acoustic sensors are combined to produce averages of acoustic intensity, or acoustic energy flux density.

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Basic equations of data analysis

An overview of the equations describing the deep ocean's infrasonic sound field can be found in [2] and [3]. This section only reviews the basic equations that are used for an analysis of the acoustic intensity from Swallow float data.

The equations of conservation of mass and momentum for underwater acoustic propagation in an adiabatic ideal field with time independent properties are:

$$\frac{\partial p(\mathbf{x},t)}{\partial t} + \kappa_s(\mathbf{x})\nabla\mathbf{v}(\mathbf{x},t) = 0 \qquad (1)$$

$$\rho_0(\mathbf{x})\frac{\partial \mathbf{v}(\mathbf{x},t)}{\partial t} + \nabla p(\mathbf{x},t) = 0 \qquad (2)$$

where ρ_0 is the ambient density; κ_s the adiabatic incompressibility; p the acoustic pressure as measured by an hydrophone; $\mathbf{v}$ the acoustic particle velocity as measured by three orthogonal geophones. The acoustic field variables are functions of the position in space $\mathbf{x}$ and time t. These equations are valid only if no acoustic sources are present.

With suitable manipulation of Eq. (1) and Eq. (2), we obtain the following equation for the conservation of energy:

$$\frac{\partial e(\mathbf{x},t)}{\partial t} + \nabla \cdot \mathbf{j}(\mathbf{x},t) = 0, \qquad (3)$$

where $$e(\mathbf{x},t) \equiv \frac{1}{2}\rho_0(\mathbf{x})[\mathbf{v}(\mathbf{x},t)\cdot\mathbf{v}(\mathbf{x},t)] + \frac{1}{2}\frac{1}{\kappa_s(\mathbf{x})}p^2(\mathbf{x},t) \qquad (4)$$

and $$\mathbf{j}(\mathbf{x},t) \equiv p(\mathbf{x},t)\mathbf{v}(\mathbf{x},t) \qquad (5)$$

The expression $e(\mathbf{x},t)$ in Eq. (4) represents the acoustic energy density. The term $\mathbf{j}(\mathbf{x},t)$ in Eq. (5) is the instantaneous acoustic intensity, or the energy flux density at time t, in the direction of particle velocity at the location of the sensor. By taking the expectation (mean of its distribution) of $\mathbf{j}(\mathbf{x},t)$, and estimating it by the time average over a limited time interval, we obtain $\langle\mathbf{j}(\mathbf{x},t)\rangle$, the time-averaged intensity, in direction of the net acoustic energy flow.

With the assumption that the acoustic processes are random functions of time and space (i.e. the hydrophone and geophone time series are stationary and ergodic), taking the expectation of both sides of Eq. (4), and estimating it by the time average over a large time interval T, we obtain:

$$\langle e\rangle=\frac{1}{2}\frac{1}{\kappa_s}\left[(\rho_0 c)^2\sum_{j=1}^{3}\left\langle v_j^2\right\rangle+\left\langle p^2\right\rangle\right] \tag{6}$$

The application of Parseval's theorem [4], which expresses the equivalence of time or frequency domains for describing phenomena, in this case signal energy content, allows Eq. (6) to be brought to the frequency domain to become:

$$E_{\text{tot}}(\mathbf{x},f)=\frac{1}{2}\frac{1}{\kappa_s(\mathbf{x})}\left(\left[\rho_0(\mathbf{x})c(\mathbf{x})\right]^2\sum_{j=1}^{3}S_{v_j}(\mathbf{x},f)+S_p(\mathbf{x},f)\right) \tag{7}$$

The two terms inside the brackets on the right side of Eq. (6) are respectively the geophone-data-derived pressure autospectral density function (introduced by Culver [5]) and the hydrophone pressure autospectral density function. Eq. (7) implies that the mean total acoustic energy density per frequency $E_{\text{tot}}(\mathbf{x},f)$ is proportional to the kinetic (first term right) and the potential (second term right) energy density spectra respectively.

If the expectation of both sides of Eq. (5) is taken, and the generalized Parseval's theorem applied to the result (the reader is referred to [3] for a full development of the equation), we can derive:

$$\mathbf{S}_{p\mathbf{v}}(\mathbf{x},f)=\mathbf{C}_{p\mathbf{v}}(\mathbf{x},f)-i\mathbf{Q}_{p\mathbf{v}}(\mathbf{x},f) \tag{8}$$

$\mathbf{S}_{p\mathbf{v}}(\mathbf{x},f)$ is the one-sided cross-spectral density function between $\mathbf{v}$ and p. $\mathbf{C}_{p\mathbf{v}}(\mathbf{x},f)$, the first term on the right (coincident density function), is called the active acoustic intensity, and it indicates the direction and the magnitude of the mean energy flow at point $\mathbf{x}$. $\mathbf{Q}_{p\mathbf{v}}(\mathbf{x},f)$, the second term on the right (quadrature density function), is the reactive acoustic intensity, which is proportional to the spatial gradient of the pressure autospectrum. It is related to the small scale heterogeneity of the sound field.

The active acoustic intensity represents the mean energy flow. In a spatially homogeneous field, its amplitude will be equal to the amplitude of the pressure spectrum. The reactive acoustic intensity represents the secondary energy flux that is not involved in the net flux of energy. It is usually close to zero for a midwater float in a deep water environment, which indicates that the acoustic field is nearly homogeneous.

The equation of the conservation of momentum (2) can be manipulated to allow its expression in the frequency domain, in terms of the cross spectral density function given above. The result is:

$$2\pi f\rho_0(\mathbf{x})\mathbf{Q}_{p\mathbf{v}}(\mathbf{x},f)+\frac{1}{2}\nabla S_p(\mathbf{x},f)=0 \tag{9}$$

where $\mathbf{Q}_{pv}(\mathbf{x},f)$ and S_p are defined in Eqs. (7) and (8). Once normalized by the pressure autospectrum, and using $\nabla \equiv \partial/\partial\mathbf{x}$, Eq. (9) can be rewritten as:

$$\frac{[\rho_0(\mathbf{x})c(\mathbf{x})]\mathbf{Q}_{pv}(\mathbf{x},f)}{S_p(\mathbf{x},f)} = -\frac{1}{4\pi}\frac{\partial S_p(\mathbf{x},f)}{S_p(\mathbf{x},f)}\left(\frac{\partial\mathbf{x}}{\lambda(\mathbf{x})}\right)^{-1} \tag{10}$$

where $\lambda(\mathbf{x}) = c(\mathbf{x})/f$ is the acoustic wavelength. In other words, the quadrature spectrum $\mathbf{Q}_{pv}(\mathbf{x},f)$ (or reactive intensity), scaled by the characteristic impedance and normalized by the pressure autospectrum, is equal to the change in the pressure autospectrum caused by a change in position which is small in relation to the acoustic wavelength. Eq. (10) is a convenient way to study the statistical significance of the reactive intensity spectrum as it is then normalized to the pressure autospectrum. In a purely homogeneous sound field, the right side of (10) should be null.

4

Analysis of acoustic data

The original data analysis software was written for a UNIX operating system. The equivalent software was rewritten for a VAX computer (see Annex A - Computing environment). The format of the data files is different.

The program SWALLOW is the main software for the calculation of acoustic spectra, intensity vectors, and other parameters as introduced in Section 3. Satellite programs are available to produce other plots (gray plots of the spectra, plots of the original time series, etc.), or to locate the bearing of the main signal in specific frequency bands, etc.

4.1. SWALLOW

The program listing is included in Annex B. The formats of the input files are described in Annex C. The two input files with the time series are organized in groups of 80 records - one hour of data at a sampling frequency of 50 Hz. Except for the calibration files and the window file, the filenames cannot be changed since the program self-defines some of the input filenames and all of the output filenames according to the information given interactively to the program. The input filenames are as in Table 1.

Table 1 *Input file names and descriptions*

Filename	File description
TS-*-####.DAT	Geophone time series
P-*-####.DAT	Hydrophone time series
HEAD*.DAT	Header information
CALGEO.ASC	Calibration curves of the geophones
CALHYDRO.ASC	Calibration curves of the hydrophone
KAISER.DAT	Kaiser-Bessel window (alpha = 2.5)

The star represents the float number (from 0 to 10). The #### is the 4-digit number which is the number of the first record included in the input file (there is a maximum of 80 records per file). Since the floats do not record data in the first 8 hours of any experiment (approximate time for the floats to settle to depth), the first record of the first file is always 0640. The next file will start 80 records later, at record 0720, etc. The header file contains all the header information for the whole experiment - it will contain the float heading, battery voltage, etc. for records 0640 to 2240 (maximum), and there is one such file for each float deployed during an experiment. The calibration files are the same independently of the float number.

During interactive execution, the user is prompted with the questions listed in Table 2. The filename of the geophone time series must be specified, all the other files are opened automatically. We will now describe the tasks performed by the program on a step-by-step basis.

Table 2 *Interactive prompts presented by the program SWALLOW*

Prompt	Example of reply
Input filename - TS...?	TS-2-0640.DAT
First record number?	678
Number of records for average?	4
Comment line?	First deployment, June 1992

The output files created by SWALLOW are listed in Table 3, with the information they contain. The mathematical symbols were explained in Section 3.

Table 3 *Output file names and descriptions*

Filename	File description
SP-*-$$$$.SAP	Hydrophone pressure spectrum, geophone equivalent pressure spectrum, active intensity magnitude spectrum (S_p , $\rho_0^2 c^2 \sum_{j=1}^{3} S_{v_j}$, $C_{pv_xv_yv_z}$)
XY-*-$$$$.SAP	Magnitude and directionality of the active intensity spectrum - XY plane ($\mathbf{C}_{pv_xv_y}$)
XZ-*-$$$$.SAP	Magnitude and directionality of the active intensity spectrum - XZ plane ($\mathbf{C}_{pv_xv_z}$)
YZ-*-$$$$.SAP	Magnitude and directionality of the active intensity spectrum - YZ plane ($\mathbf{C}_{pv_yv_z}$)
Z-*-$$$$.SAP	Magnitude and directionality of the active intensity spectrum - vertical direction ($\mathbf{C}_{pv_z}$)
QX-*-$$$$.SAP	Reactive intensity magnitude spectrum (scaled by pressure) - X geophone ($\rho_0 c\, Q_{pv_x} / S_p$)
QY-*-$$$$.SAP	Reactive intensity magnitude spectrum (scaled by pressure) - Y geophone ($\rho_0 c\, Q_{pv_y} / S_p$)
QZ-*-$$$$.SAP	Reactive intensity magnitude spectrum (scaled by pressure) - Z geophone ($\rho_0 c\, Q_{pv_z} / S_p$)
ZZ-*-$$$$.SAP	Magnitude and directionality of the reactive intensity spectrum - vertical direction ($\mathbf{Q}_{pv_z}$)
G3-*-$$$$.SAP	Magnitude spectrum of particle velocity - X, Y and Z geophones ($\rho_0^2 c^2 S_{v_x}$, $\rho_0^2 c^2 S_{v_y}$, $\rho_0^2 c^2 S_{v_z}$)

In the output filenames, the * symbol represents the float number, and $$$$ is the number of the first record used for the calculations. All spectra are averaged over the period (defined as a number of records) specified to the program during its execution. The files have a ".SAP" extension, meaning they all contain ASCII data which can be readily plotted with the SAPLOT software (described in Annex A). Except for the vector plots (for example XY-*-$$$$.SAP), the basic format is two columns of numbers: the first column has the x axis data for the plot, the second has the y axis data. Examples of plots for each of the output files listed in Table 3 are shown in Fig. 2 a to j.

The following listing is a step-by-step description of the calculations done internally by SWALLOW.

1. Open all input and output files, and set internal variables. The hard-wired variables (which may need to be changed for other experiments) are the following:

> FS = sampling frequency;
> DECLINATION = declination of magnetic North at experimental site;
> ROC = water density * average sound speed (set at 1500 m/s);
> XAXIS, YAXIS, XLEN, YLEN = axis parameters for plotting.

2. Write headers of output files (SAPLOT format).

3. Read HEAD*.DAT, and calculates conversion factor from system units or counts (in a range of -127 to +128) to volts:

$$con1 = \frac{4.98\,[volt]}{255\,[count]}\,\frac{1}{10^{AGC/20}} \bullet \rho_0 c \qquad \text{for the geophone time series;}$$

$$con2 = \frac{4.98\,[volt]}{255\,[count]}\,\frac{1}{10^{AGC/20}} \bullet 1.0\times 10^{6} \qquad \text{for the hydrophone time series.}$$

The AGC setting is used to correct for the specific gain at any given record. The $\rho_0 c$ factor is included to obtain a geophone-equivalent pressure spectrum, and the 1.0×10^6 factor for the hydrophone is needed to convert to units of μPa instead of Pa. Finally, the float heading information is checked and corrected for smooth crossing above 360°.

4. Read the calibration curves as a function of frequency. The 0 Hz frequency bin is filled with a dummy value.

5. Read time series of hydrophone and geophone channels. Values are stored only for the requested records. For each record, the first 150 points are skipped since the data can be contaminated with tape recorder noise [1]. The last 50 points are also skipped since they are all zeros (period during which the data are recorded onto the tape).

6. Read the Kaiser-Bessel window (the use of a different file for the window allows easy changes if required).

7. For each of the requested records:

   A. Interpolate the time series by a factor of 5, using a 65-coefficient sinc function;

   B. Shift the time series by the appropriate number of bins (since the data from the 4 different acoustic sensors are sampled at four different times, it is necessary to shift the individual time series by a different amount to synchronize them);

   C. Desample by a factor of 5;

   D. The four time series are converted from system units (counts) to volts;

   E. The time series of the two horizontal geophones are rotated so the y-geophone is pointing towards true north rather than towards magnetic north (the declination angle for the location of the experiment is hard-wired into the program);

   F. The record is separated into 7 sub-arrays of 512 points with a 50% overlap and for each sub-array:

      a. Multiply the four time series by the Kaiser-Bessel window (x, y, z and p for the x-, y-, z- geophone time series and p for the pressure time series respectively);

      b. Calculate the 3 cross-spectra (XY, XZ, YZ) and the 4 auto-spectra (XX, YY, ZZ, PP), and correct the spectra for windowing and sampling frequency;

      c. Average the 7 sub-arrays for all spectra;

      d. Correct the amplitude and phase of the spectra with the calibration curves. Only the positive frequencies are used (the spectral magnitude is multiplied by 2 to compensate). For the cross-spectrum between the hydrophone time series and one of the geophone time series, the cross-spectral amplitude is divided by each of the calibration curves. Also, the phase of the hydrophone calibration curve is subtracted from the cross-spectral phase, and the phase of the geophone calibration curve is added to the cross-spectral phase. The units are now in $\mu Pa^2/Hz$.

8. Average the cross- and auto-spectra over the requested number of records.

9. The XP and YP cross-spectra are combined to obtain horizontal directionality. Note that the sign of the real part of the spectra may have to be changed depending on the wiring of the geophones. The magnitude of the intensity is converted to dB// 1 $\mu Watt/m^2/Hz$ by subtracting 122 dB.

10. Write output files.

4.2. OTHER SOFTWARE

Numerous programs have been written to perform different tasks on the output files created by SWALLOW. The programs listed in Table 4 can be particularly useful.

Table 4 *Other available software*

Program	Input files	Output files	Description
GRAYH	SP-*-$$$$.SAP	GRAYH.SAP	Produce gray plots of hydrophone spectral data (from SP files)
GRAYG	SP-*-$$$$.SAP	GRAYG.SAP	Produce gray plots of geophone spectral data (from SP files)
GRAYI	SP-*-$$$$.SAP	GRAYI.SAP	Produce gray plots of intensity spectral data (from SP files)
SERIES	TS-*-####.DAT P-*-####.DAT HEAD*.DAT	GX-*-$$$$.SAP GY-*-$$$$.SAP GZ-*-$$$$.SAP HY-*-$$$$.SAP	Plot time series (x, y, z, p) for 12 consecutive records (from TS and P files)
RMS	TS-*-####.DAT P-*-####.DAT HEAD*.DAT	RMS-*-####.SAP	Calculates RMS time series
WRITBAND	XY-*-$$$$.SAP	BRG.SAP	Calculate the bearing of the main signal for selected frequency bands and time periods (from SP files)
SPECAVER	SP-*-$$$$.SAP	AVER.SAP RATIO.SAP	Average spectra of SP files over x records
STICKAVER	XY-*-$$$$.SAP	XYAVER.SAP	Average intensity vectors of XY files over x records
G3AVER	G3-*-$$$$.SAP	GAVER.SAP	Average spectra of G3 files over x records
QAVER	QX-*-$$$$.SAP QY-*-$$$$.SAP QZ-*-$$$$.SAP	QXAVER.SAP QYAVER.SAP QZAVER.SAP	Average spectral ratios of QX, QY and QZ files over x records

5

Validation

This section will show the results of tests that were made on the SWALLOW software to validate both the amplitude of the spectra and the directionality of the intensity vectors. Tests were made with simulated and real ambient noise data.

5.1. TEST OF SPECTRAL LEVEL ESTIMATES

To test the accuracy of the spectrum levels obtained with the hydrophones, simulated ambient noise data were created. The levels were calculated using a separate program written with MATLAB [6] which was simplified to exclude data interpolation and decimation.

As a first step, SWALLOW was run without interpolation and decimation. The resulting spectra (superimposed) are shown in Fig. 3. The two results are very close, with a mean difference of 2.27×10^{-4} dB throughout the frequency band, and a standard deviation of 0.01. The interpolation process induces the greatest error in spectrum levels, therefore we compared the levels of the full SWALLOW program with the previous MATLAB solution (no interpolation). The difference between the two solutions is shown in Fig. 4. An important error appears at the high frequency end of the spectrum, which is due to the interpolation window. The mean difference is up to -0.035 with a standard deviation of 0.21. If the points above 24 Hz are ignored, the mean difference decreases to -0.001 with a standard deviation of 0.029.

The technique used to calculate the spectrum levels from the geophone data is precisely the same as for the hydrophone, although a correction factor of (ρc) is used to obtain equivalent pressure signal from the geophone time series. The differences in levels between the geophones and the hydrophones are mostly due to minor calibration errors, or to the inhomogeneity of the acoustic field.

5.2. TEST OF HORIZONTAL DIRECTIONALITY

The accuracy of the directionality of the acoustic field was tested with real data. Figure 5a shows the spectrum levels of a 3-minute data sample from the IONEX 92 experiment. The 20 Hz tone was transmitted by a very low frequency source towed by NRV *Alliance* due south of the floats' deployment site. The source level was 182 dB re 1μPa @ 1 m during the tow and a distance of 20 km separated the source from the Swallow floats. A very good signal-to-noise ratio was obtained. Figure 5b shows the directionality vectors over the same 3-minute period. The sample is representative of the ambient noise levels throughout the experiment. At 20 Hz the resulting intensity vector, which indicates the direction of the mean acoustic flow, points north (i.e. 180° from the source), with an error of less than a degree. The error differed between floats, with a maximum of 23°.

It is difficult to quantify the accuracy of the bearing obtained with real data. The Swallow float gives the bearing of the resulting acoustic field at any given frequency. Any other source transmitting at the same frequency as the test source will influence the resulting bearing. Another problem is due to the calibration files used for the geophones (Fig. 6). The same calibration curves (for both amplitude and phase) are applied to all geophones, independently of the float. Therefore calibration differences, in either amplitude or phase, may induce bearing differences. Also, for any given float, if the x- geophone has a slightly different response than the y-geophone, the angle accuracy will decrease.

6

Analysis of non-acoustic data

This section presents the software used for the analysis of non-acoustic Swallow float data.

6.1. VARIATION IN TIME OF AGC GAIN, FLOAT HEADING, BATTERY VOLTAGE AND NUMBER OF CLIPPED POINTS

Non-acoustic time-related data as a function of time is of use in locating acoustic and non-acoustic phenomena, and hardware failures. Table 5 describes the software available for the non-acoustic data analysis.

Table 5 *Non-acoustic data analysis software*

Program	Input files	Output files	Description
CLIP	TS-*-####.DAT P-*-####.DAT HEAD*.DAT	CLIP-*-$$$$.SAP	Calculate percentage of clipped points
PLOTCLIP	CLIP-*-$$$$.SAP	CLIP.SAP	Plot percentage of clipped points for entire period of experiment
RECORD	–	–	Give record number associated to time
TIME	–	–	Give time associated to record number

Of primary interest in the analysis of the non-acoustic data is the time variation of the AGC gain, float heading, battery voltage and percentage of clipped points in the acoustic time series (which controls the AGC setting). The percentage of clipped points in the raw time series are calculated (and displayed) with the help of the program CLIP. The AGC gain and float heading data are extracted from the header, and the record number is translated to real time. The synchronization time of the floats' clocks is used to obtain the real time of a record. This synchronization is normally carried out just before the float deployment. It should be remembered that in the case of the MPL Swallow floats, a delay of 8 hours, or 640 records, occurs before the first recording of data to tape. This delay allows the floats to stabilize at the selected depth before recording starts. As all records are 45 s long, any record number may be converted to real time. The program RECORD translates a record number to real time and TIME translates real time to a record number (the float synchronization time is hard-wired into the programs).

Figure 7 shows the variation in time of the battery voltage, compass heading and AGC gain for float 0 during IONEX 92. In this example, the fast variation in heading at record 2050 was associated with physical perturbation of the float (it was probably hit by fish or caught in a current shear). The non-acoustic disturbance was accompanied by a change in gain setting as the geophone channels were overloaded.

For the number of clipped points, the acoustic data is read and compared to the upper and lower amplitudes allowed by the electronics of the system, -127 to 128 (which translates to a range of ± 2.5 volts). The number of clipped points, that is the number of times that the amplitude values are equal to the limit is accumulated over each record, and averaged over the length of the record. This procedure helps in locating periods of time during which one or several of the sensors may have been overloaded. An example is shown in Fig. 8 for the same deployment and the same float as in Fig. 7.

6.2. LOCALIZATION

When operating floats and their operating time frame have been identified, the floats may be localized. The process is complicated by the fact that the floats are free-floating units. Traditionally, the problem has been simplified by anchoring three of the floats to the sea bottom, in a triangular pattern, for each of the deployments. The bottom tethered floats will often have their horizontal geophones shorted out to avoid AGC changes due to a signal overload on these channels from tether noise.

The floats are located by post-processing the signals transmitted and received by the ITC transducers below the floats. Each transducer periodically transmits a 10 ms acoustic pulse (carrier frequency 8 kHz). One such pulse is transmitted every record (i.e. every 45 s), and the floats transmit sequentially, following a "x"-record cycle. The variable x can be changed to satisfy the number of floats used during any one deployment. It is typically set to 12 since 10 to 12 floats are usually deployed at once. Therefore, every float will ping once every 12 records, 10 s after the beginning of the record. The floats ping in turn, i.e. a different float will ping every record, during the 12-record cycle.

The detection of the 8-kHz ping by the individual floats is done by filtering the ITC hydrophone output signal through two bandpass filters: one with a 2-kHz bandwidth centred at 10.5 kHz, and the other with a 0.2-kHz bandwidth centred at 8 kHz. The envelope-detected output is compared with a threshold level. The result is stored on a 8-b register, as a stream of 1's and 0's indicating detection or non-detection. The content of the register is checked every 8 ms, and detections (or non zero byte values) are permanently recorded. Up to 170 detections can be recorded for each 45-s record.

Figure 9 shows the type of information obtained from the detection times. The delay between transmission and reception times has been converted to depth by multiplying it by half a sound speed of 1500 m/s (y axis). The time on the x axis is given by record number. In this example (taken from the first deployment of the IONEX 92 experiment [1]), several detections are made every 12 records (record 640, 652, etc.) In this case, the float transmitting during these records is float 4, therefore at record 640, float 4 is listening to its own ping. Knowing this, the different detections can be interpreted as follows: first, a detection is made at close to 0 m, which is the direct return of the ping reflecting on the glass sphere of the float. There may be some reverberation after the initial signal due to temperature-dependent resonance of the float glass shell. A loud arrival (increasing to 1800 m and then stabilizing) was received after the signal bounced at the sea surface, this arrival is directly related to float depth. Reverberation after the main arrival is due to sea surface scattering. The increasing depth in the first records indicates that the range to the sea surface is increasing, therefore the float was still going down to its settling depth. Similarly the next return - reflected from the bottom - progressively decreases to 1200 m, also indicating that the float was going down to depth. By using the harmonic sound speed for the water column, the detection times can give us two important distances: the distance between the float and the sea surface, and the distance between the float and the sea bottom. These distances can be translated into float depth and total water depth.

By knowing which float pinged during any specific record, we can also differentiate the travel time of the ping between any pair of floats. An example is shown in Fig. 10 (float 2 listening to float 0). Also, in the case of one float listening to another float, we see several detections, corresponding to the different acoustic paths between floats. The shortest time normally indicates the direct acoustic path, and the time can be translated into a slant range between two floats by using a realistic sound speed profile. Some analysis may be required since the direct path is not always detected. This happens in some instances for one deep bottom float listening to another bottom float, when no direct acoustic path is possible because of the shape of the sound speed profile. In this case, the surface reflected path needs to be used to deduct the range of the direct path between the floats.

Accuracy in propagation time (and therefore in range) is very good as it is possible to correct propagation times for potential clock drift. At the beginning of the experiment, all clocks are synchronized, but the time error can grow differently on each clock. As the floats ping at different times, the propagation times of the ping emitted by float A and heard by float B can be compared with the propagation time of the ping going from B to A, and the average of the two times compensates for clock drift.

Once the float depths and inter-float ranges are available every 12 records, the values can be interpolated in time to once a record. A generalized least-square filter algorithm or a Kalman filter algorithm can then be used to locate the floats relative to each other [7] with similar accuracy. The three fixed bottom floats are used to obtain geographical locations for the floats.

7

Conclusions

This memorandum describes some of the software written at SACLANTCEN to allow the analysis of acoustic and non-acoustic data aquired by MPL Swallow floats. The software may be adapted to any type of hardware with similar sensors, such as the SACLANTCEN Swallow float prototypes.

References

[1] Desharnais, F., Urban, H.G. and D'Spain, G.L. SACLANTCEN Swallow float experiment - IONEX 92. In preparation.

[2] D'Spain, G.L., Hodgkiss, W.S., and Edmonds, G.L. The simultaneous measurement of infrasonic acoustic particle velocity and acoustic pressure in the ocean by freely drifting Swallow floats. *IEEE Journal of Oceanic Engineering*, **16**, 1991:195–207.

[3] D'Spain, W.S. Energetics of the ocean's infrasonic sound field. Ph. D. thesis, University of California, San Diego, CA, 1990.

[4] Bendat, J.S. and Piersol, A.G. Random Data: Analysis and Measurement Procedures, 2nd edition. New York, NY, Wiley, 1986. [ISBN 0-471-04000-2].

[5] Culver, R.L. Infrasonic ambient ocean noise spectra from freely drifting sensors, SIO Ref. 85-22. San Diego, CA, Marine Physical Laboratory, Scripps Institution of Oceanography, 1985.

[6] MATLAB - High-performance numeric computation and visualization software. The MathWorks Inc., MA, USA, 1992.

[7] Culver, R.L. Localizing and beamforming freely-drifting VLF acoustic sensors. Ph. D. thesis, University of California, San Diego, CA, 1988.

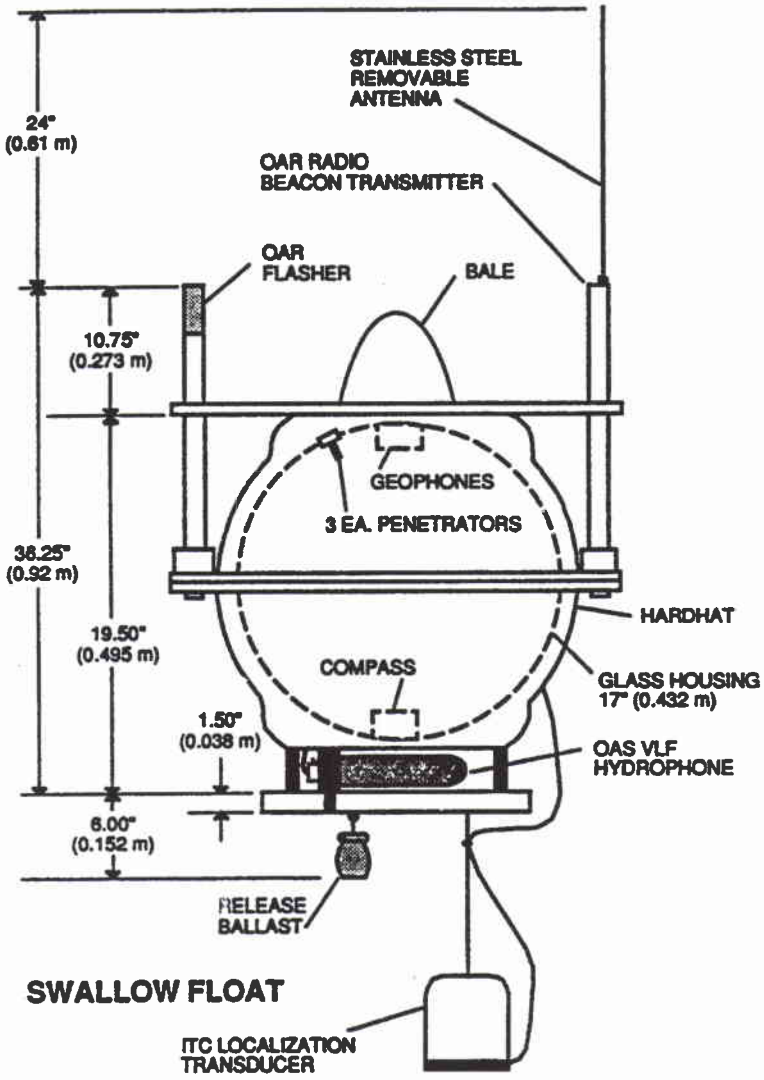

Figure 1 *Swallow float design.*

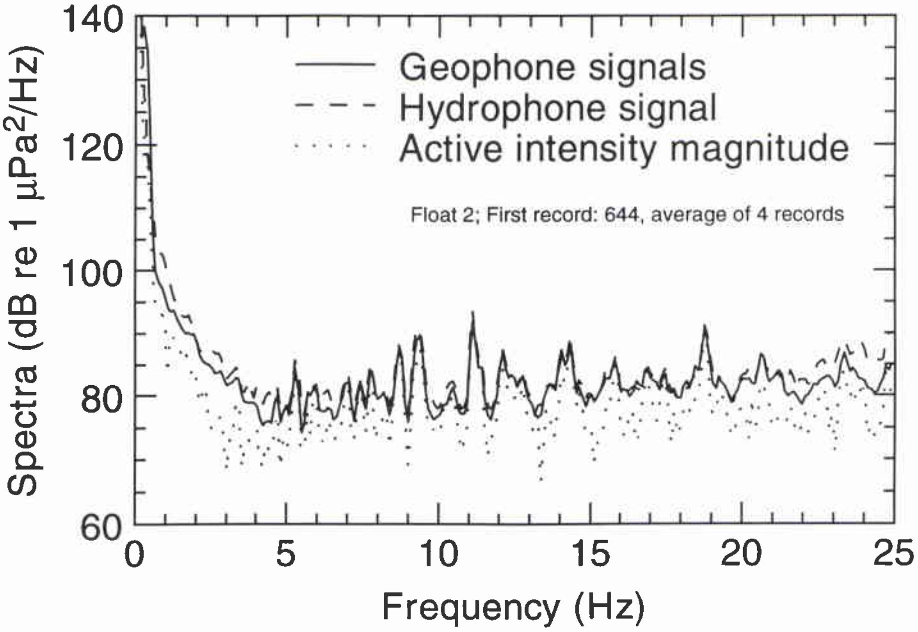

Figure 2a *File SP-2-0644.SAP. Geophone equivalent pressure spectrum (solid line), hydrophone pressure spectrum (dashed line), active intensity magnitude (dotted line).*

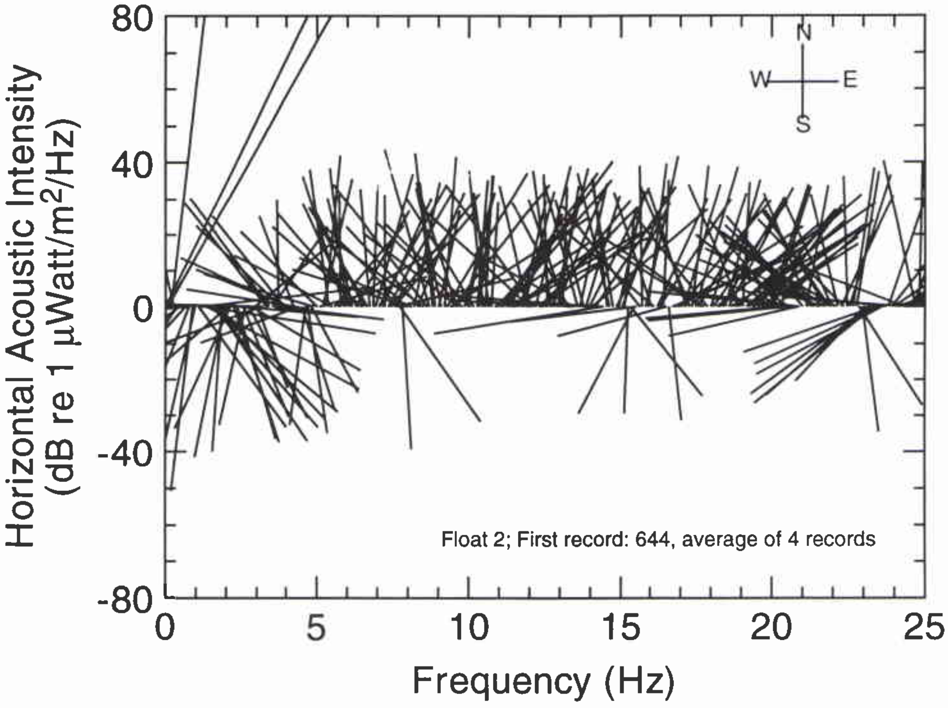

Figure 2b *File XY-2-0644.SAP. Magnitude and directionality of the active acoustic intensity spectrum - XY plane. The magnitude, in dB// 1 μWatt/m²/Hz, is obtained by measuring each vector along the vertical scale, starting at -80 dB.*

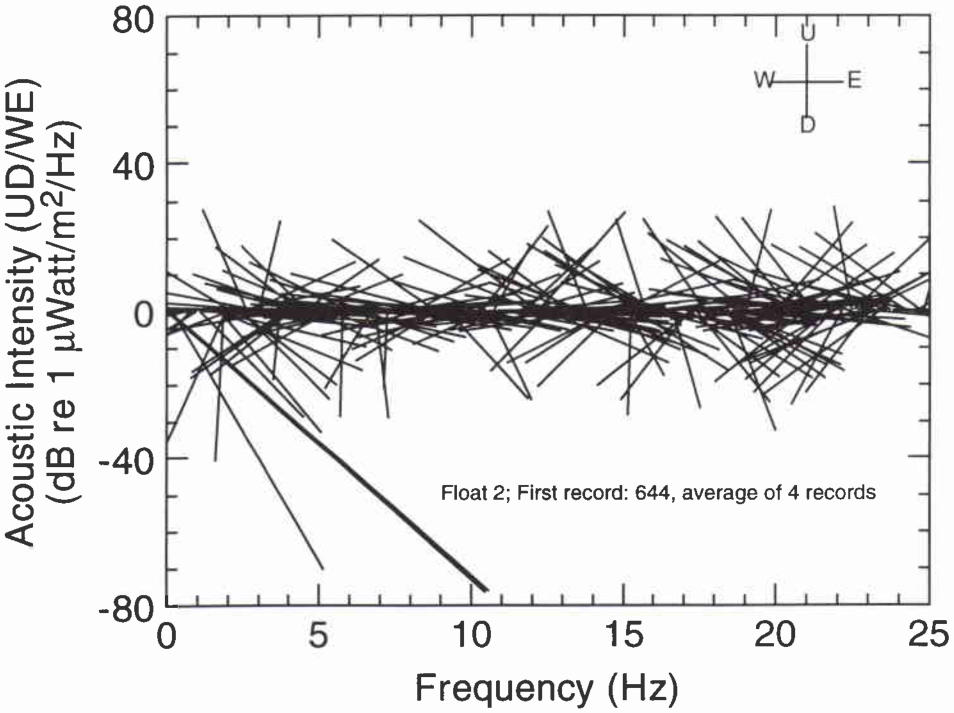

Figure 2c *File XZ-2-0644.SAP. Magnitude and directionality of the active acoustic intensity spectrum - XZ plane. The vertical direction represents the up-down component and the horizontal direction represents the west-east component. The magnitude, in dB// 1 µWatt/m²/Hz, is obtained by measuring each vector along the vertical scale, starting at -80 dB.*

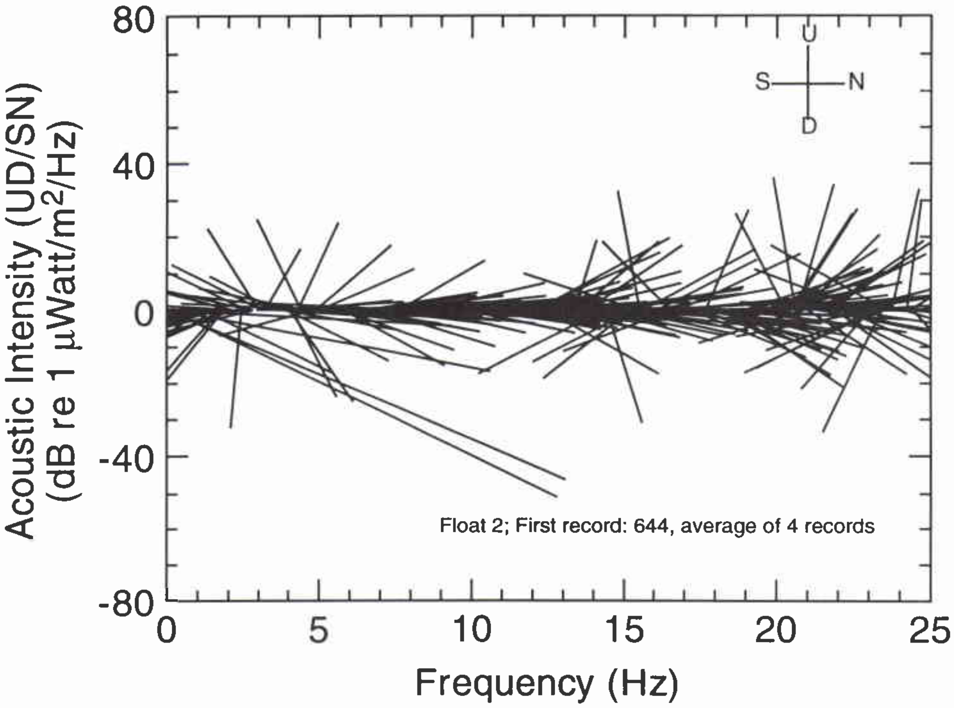

Figure 2d *File YZ-2-0644.SAP. Magnitude and directionality of the active acoustic intensity spectrum - YZ plane. The vertical direction represents the up-down component and the horizontal direction represents the south-north component. The magnitude, in dB// 1 µWatt/m²/Hz, is obtained by measuring each vector along the vertical scale, starting at -80dB.*

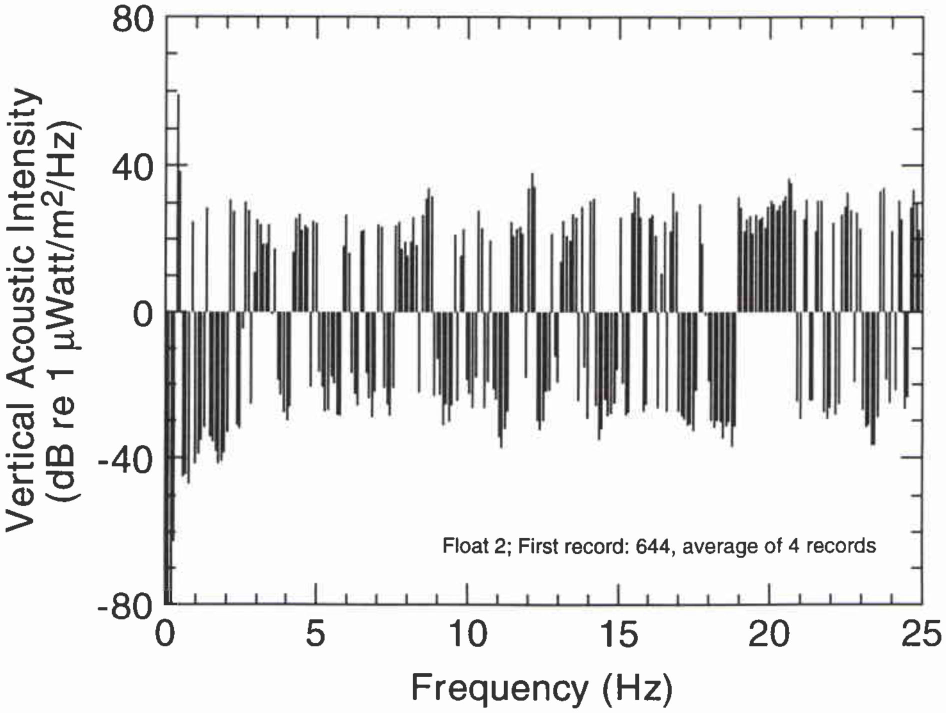

Figure 2e *File Z-2-0644.SAP. Magnitude and directionality of the active intensity spectrum - Z direction. Magnitude and directionality of the active intensity spectrum - XY plane. The magnitude, in dB// 1 μWatt/m²/Hz, is obtained by measuring each vector along the vertical scale, starting at -80 dB.*

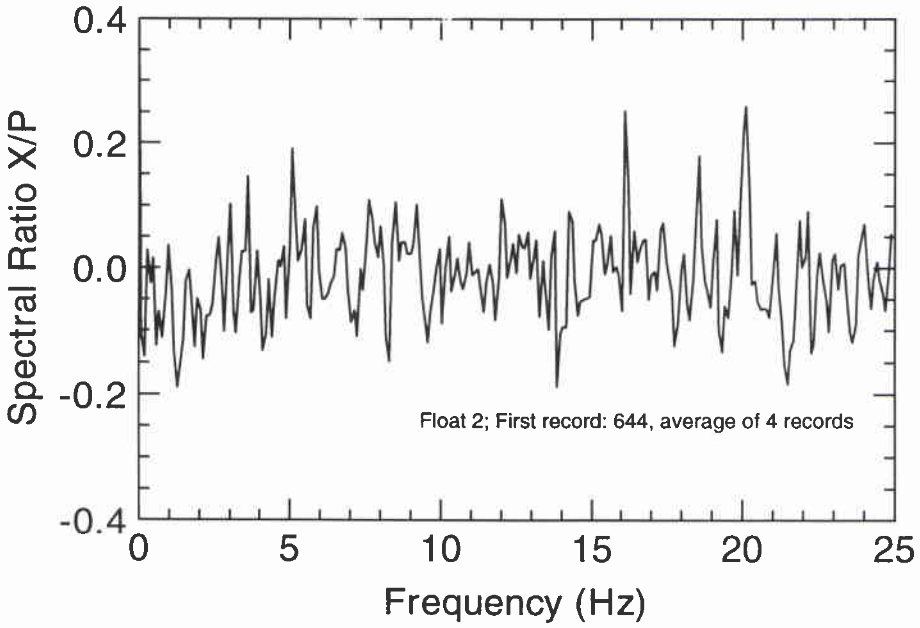

Figure 2f *File QX-2-0644.SAP. Reactive intensity magnitude spectrum (scaled by pressure) - X geophone.*

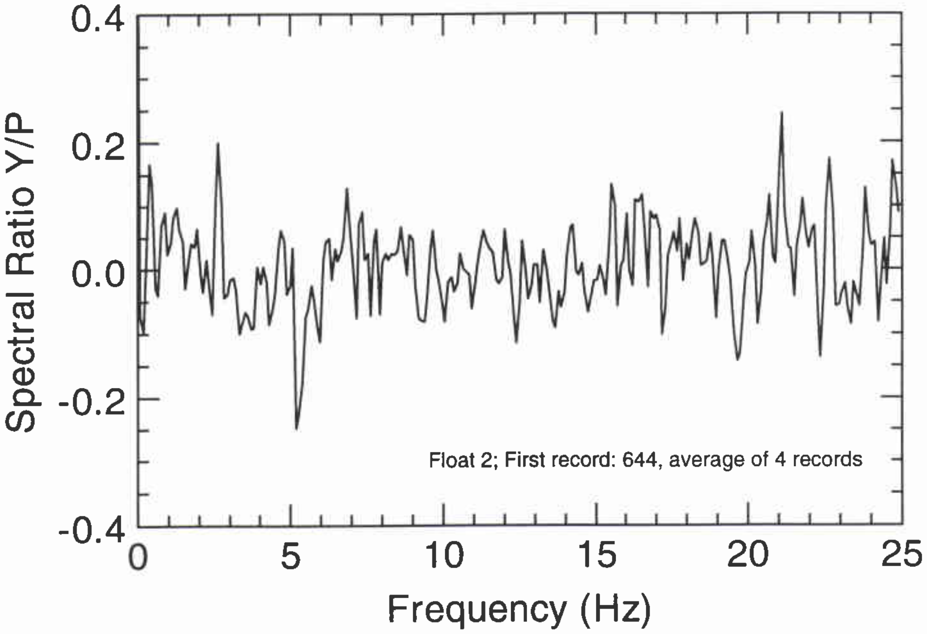

Figure 2g *File QY-2-0644.SAP. Reactive intensity magnitude spectrum (scaled by pressure) - Y geophone.*

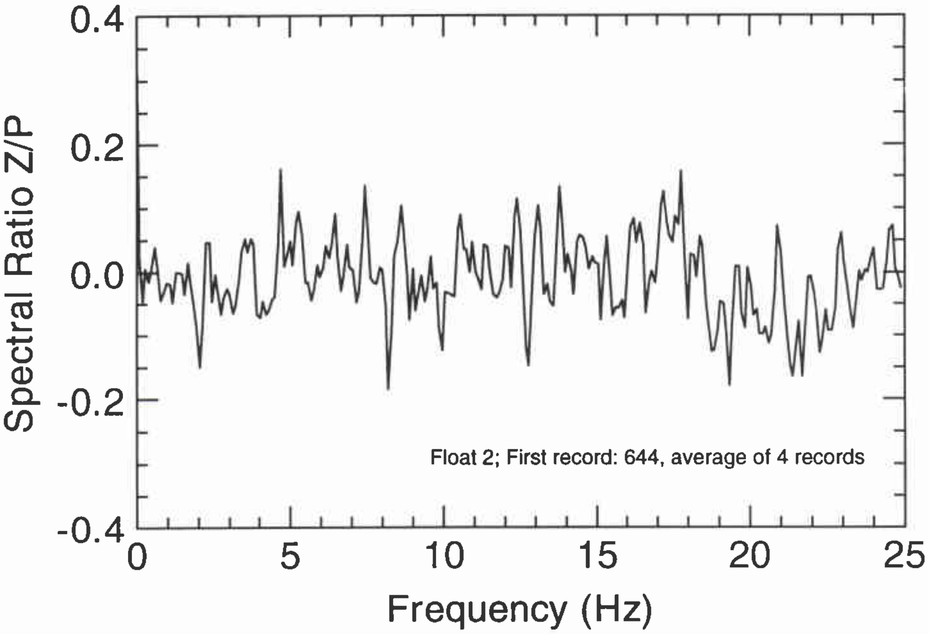

Figure 2h *File QZ-2-0644.SAP. Reactive intensity magnitude spectrum (scaled by pressure) - Z geophone.*

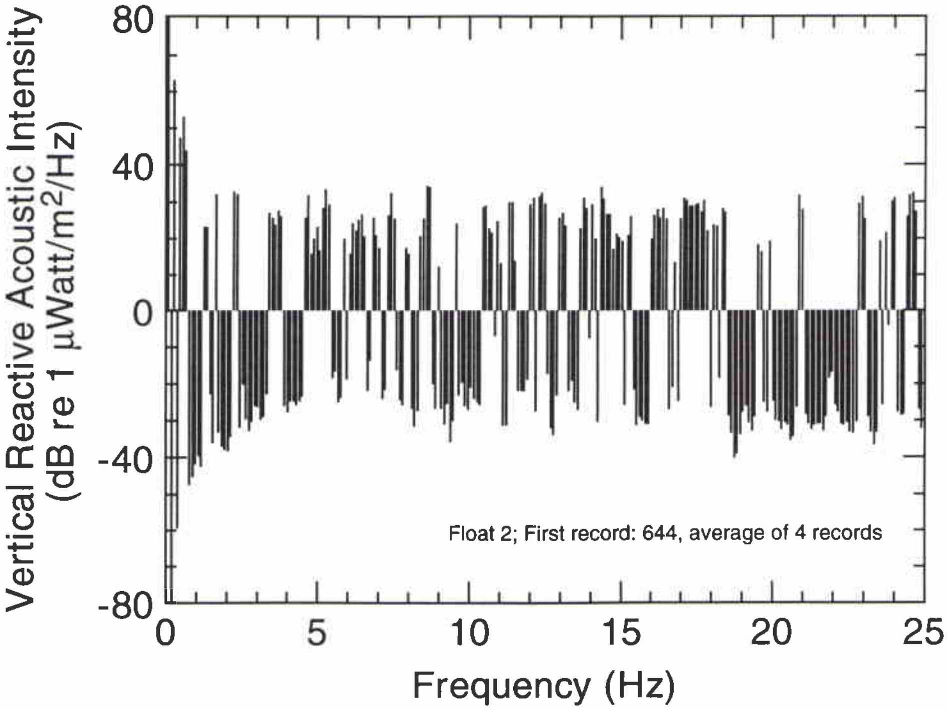

Figure 2i *File ZZ-2-0644.SAP. Magnitude and directionality of the reactive intensity spectrum - Z direction. Magnitude and directionality of the active intensity spectrum - XY plane. The magnitude, in dB// 1 µWatt/m^2/Hz, is obtained by measuring each vector along the vertical scale, starting at -80 dB.*

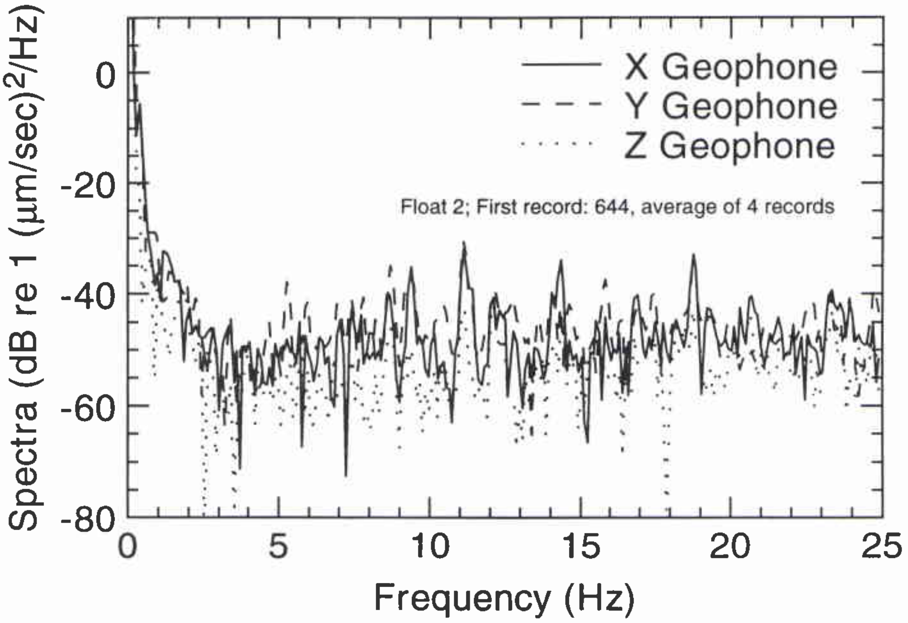

Figure 2j *File G3-2-0644.SAP. Magnitude spectrum of particle velocity - X, Y and Z geophones.*

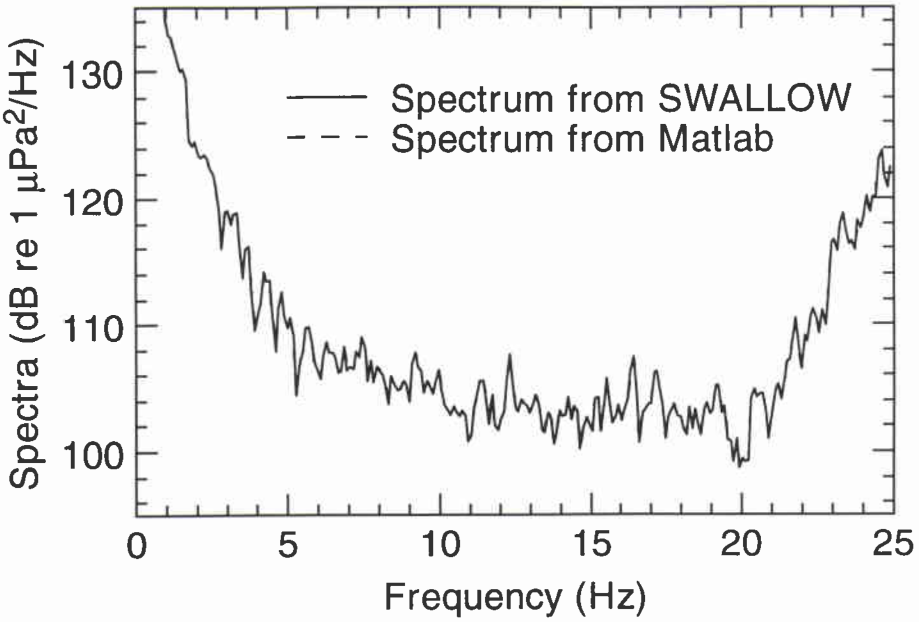

Figure 3 *Hydrophone pressure spectrum for random noise signal. Solid line: obtained with SWALLOW; dashed line: obtained with simple algorithm written with MATLAB. The two curves are almost identical.*

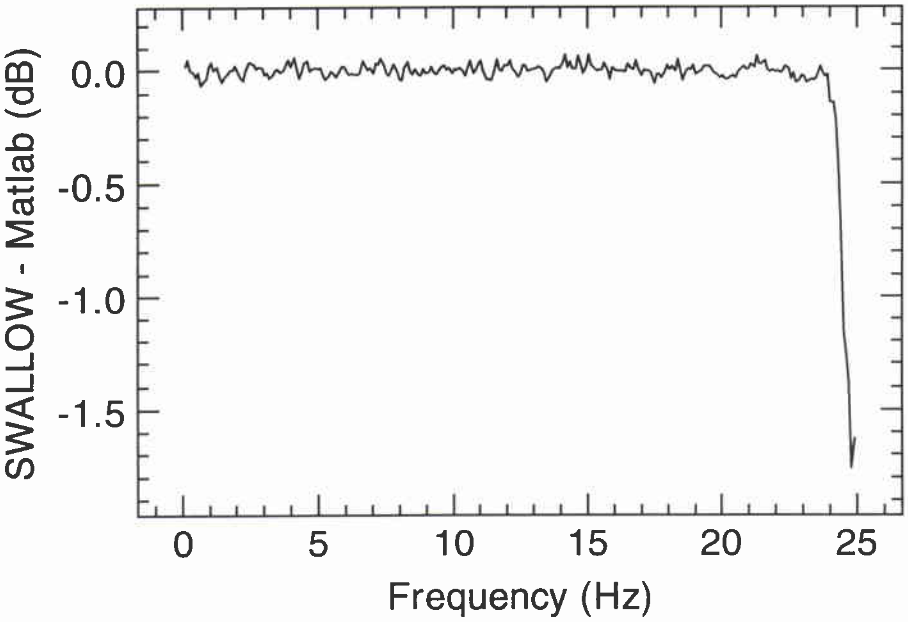

Figure 4 *Difference between SWALLOW and the MATLAB algorithm for the calculation of the hydrophone pressure spectrum of random noise.*

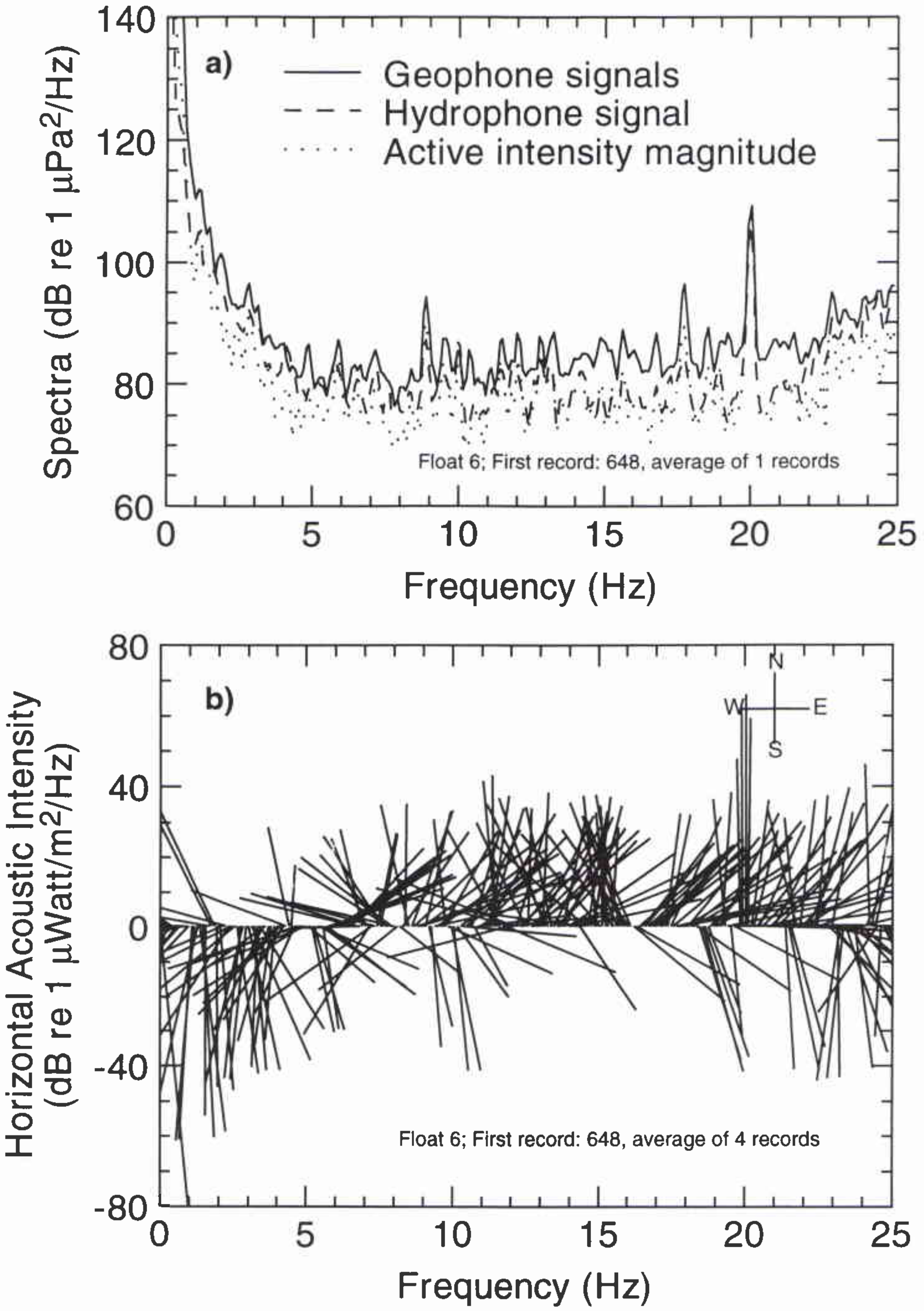

Figure 5 *a) Geophone equivalent pressure spectrum (solid line), hydrophone pressure spectrum (dashed line), active intensity magnitude (dotted line). b) Magnitude and directionality of the active acoustic intensity spectrum - XY plane. A 20 Hz CW tone was transmitted in the water*

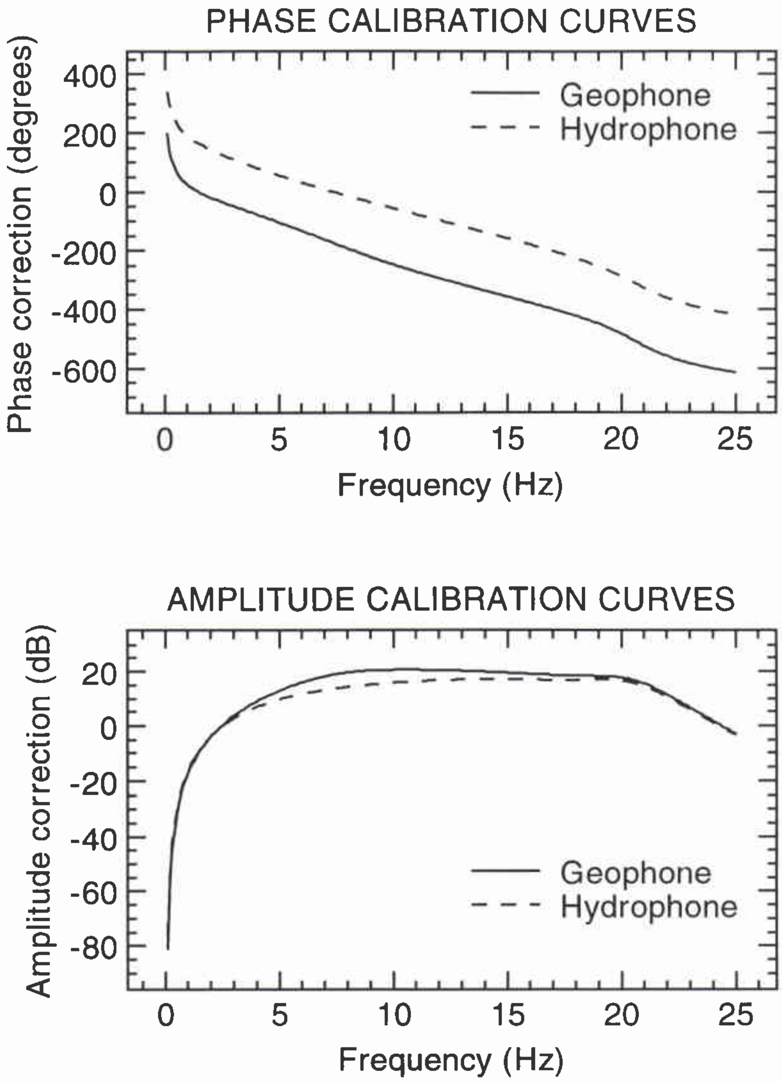

Figure 6 *Phase and amplitude calibration curves for the hydrophones and the geophones.*

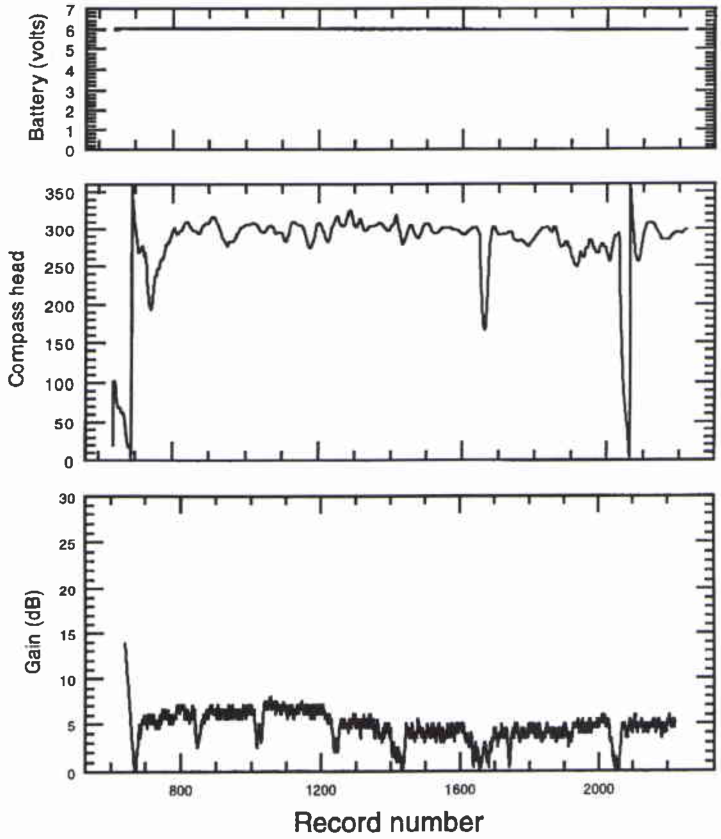

Figure 7 *Battery voltage, compass heading and AGC gain as a function of record number for Float 0 (IONEX 92 experiment).*

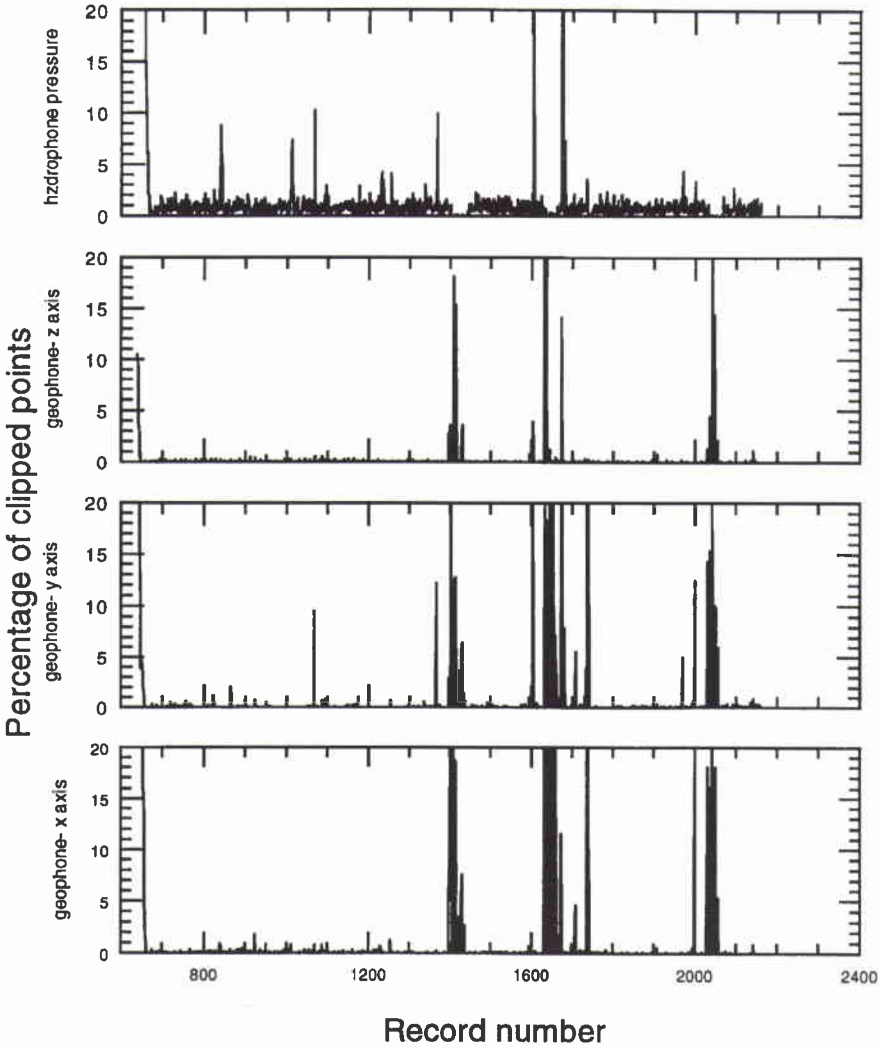

Figure 8 *Percentage of clipped points as a function of record number for all four acoustic channels of Float 0 (IONEX 92 experiment).*

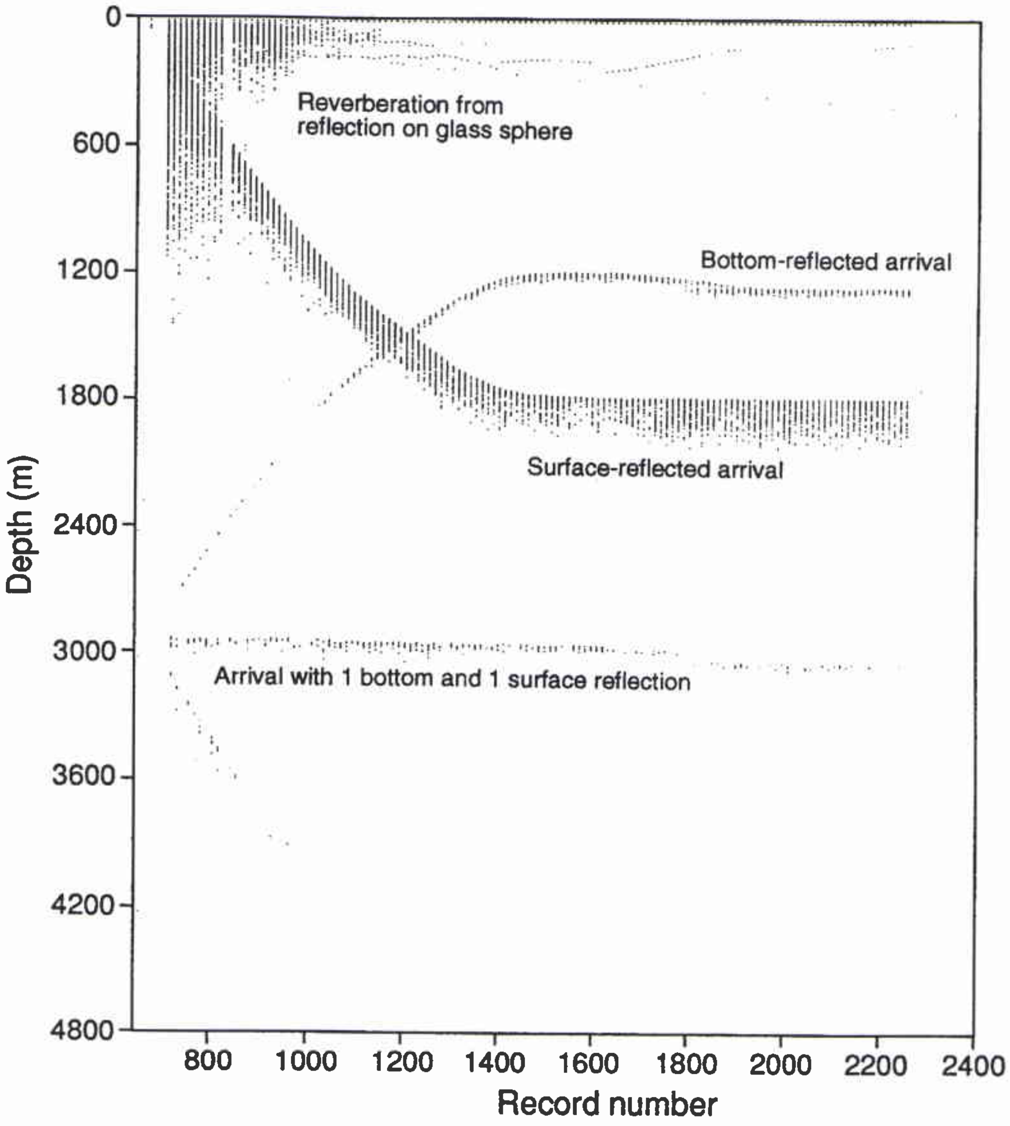

Figure 9 *ITC data: Float 4 listening to self (IONEX 92 experiment).*

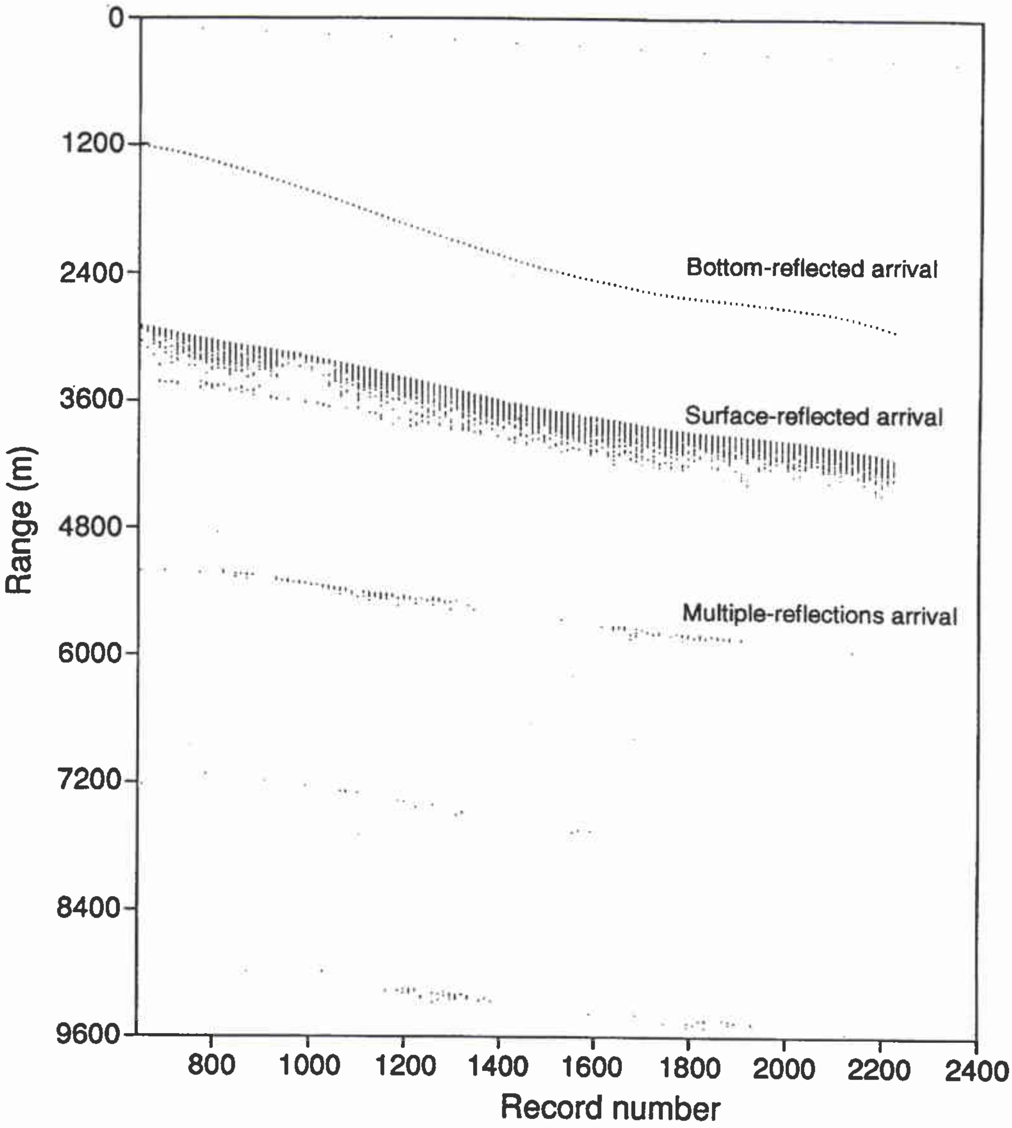

Figure 10 *ITC data: Float 2 listening to Float 0 (IONEX 92 experiment).*

Annex A
Computing environment

In order to use the software mentioned in this report, one needs a VAX running VMS operating system version 5.1 or newer, a VAX VMS Fortran compiler, and a plotting package such as the SAPLOT package, which supports ASCII input files. All the programs can be run on any terminal able to emulate a Tektronix 4014 graphics terminal.

The analysis software package is located on Optical Disk 267A, in the saveset called "SWALLOW.BCK". The package includes Fortran code files, and examples of input and output files. The SAPLOT graphic package is currently located on SACLANTCEN VAX computer, in the directory:

SYS$USRROOT1:[PR21_SUPER.SHARE.SAPLOT].

Instructions on how to use SAPLOT are found in the file 00README.TXT, on the same directory.

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Annex B
Listing of SWALLOW

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PROGRAM SWALLOW
C
C     Interpretation of MPL Swallow floats data
C     F. Desharnais,  March 93
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      IMPLICIT NONE

      REAL AMP1(257),AMP2(257),PHA1(257),PHA2(257),W(512)
      REAL AGC(41),HEAD(41),CON1(41),CON2(41)
      REAL ODIRX1(41),DIRX1(41),DIRX(2048)
      REAL DX,DY,DZ,DP,B,C,VOLT,FREQ
      REAL P(90000),X(90000),Y(90000),Z(90000)
      REAL VXII(2050),VYII(2050),VZII(2050),PRI(2050)
      REAL VXINT(10246),VYINT(10246),VZINT(10246),PRINT(10246)
      REAL THETAF(2048),VX(2048),VY(2048),VZ(2048),VI(2048)
      REAL THETAI,THETAII,SLOPE
      REAL AMPLX(256,40),AMPLY(256,40),AMPLZ(256,40)
      REAL PHASEX(256,40),PHASEY(256,40),PHASEZ(256,40)
      REAL VXX(256,40),VYY(256,40),VZZ(256,40),PPR(256,40),VH(256,40)
      REAL VXX1(256,7),VYY1(256,7),VZZ1(256,7),PPR1(256,7)
      REAL PVXF(256),PVYF(256),PVZF(256),PPRF(256)
      REAL VHF(256),CPVT(256),QVXF(256),QVYF(256),QVZF(256)
      REAL CPVXY,CPVXZ,CPVYZ,CPVZZ
      REAL RECNUM,FS,PI,DECLINATION,X2,W2,ROC
      REAL XAXIS,YAXIS,XLEN,YLEN

      COMPLEX ZX(512),ZY(512),ZZ(512),ZP(512)
      COMPLEX PVX(256,40),PVY(256,40),PVZ(256,40)
      COMPLEX PVX1(256,7),PVY1(256,7),PVZ1(256,7)
      COMPLEX CPVX(256,40),CPVY(256,40),CPVZ(256,40)

      INTEGER*4 ICOUNT,IREF1,IREF2,WARN(41)
      INTEGER NFFT,NHFFT,NFFTS,NRECNUM,NEXPECT
      INTEGER IFLOAT,IFIRST,NDEPART,ILEN,NRECORDS
      INTEGER I,J,K,ID,IE,IEE,IG,IP,IPP,IPP1,IR,IW,INTI
      INTEGER LIM1,LIM2,NSKIP

      CHARACTER COMMENT1*80,COMMENT2*80

      COMMON/PLOT/XAXIS,YAXIS,XLEN,YLEN,FS

!     Initialization of parameters
!     fs = sampling frequency
!     declination angle for area
!     nfft = fft size
!     roc = water density * average sound speed
!     xaxis and yaxis are related to the stick plot scale
!     xlen and ylen are the axis lengths (inches) for the stick plot
      PI=3.1415926536
```

```
        FS=50.
        DECLINATION=PI/180.*2.
        NFFT = 512
        NHFFT = NFFT/2
        NFFTS = 7
        ROC=1000.*1500.
        XAXIS=REAL(NHFFT)   !x axis length in units of frequency bins
        YAXIS=160.       !y axis length in dB//1 uWatt/m**2/Hz
        XLEN=17.05/2.54     !x axis length in inches
        YLEN=13.15/2.54     !y axis length in inches

!       Open input and output files
        CALL OPENFILES(COMMENT1,COMMENT2,NDEP ART,IFIRST,NRECORDS)

!       Write header of output Saplot files
        CALL WRITHEAD(COMMENT1,COMMENT2)

!       Read head.dat file (AGC gain, heading, volt for each record)
!       and calculate unit conversion factors
!       NDEPART = first record # for average, RECNUM = record #
        I=1
        NEXPECT = NDEPART - 1 + I
        DO WHILE (.TRUE.)
            READ(10,*,END=20)RECNUM,B,C,VOLT
            NRECNUM=INT(RECNUM)
            IF (NRECNUM.GT.(NDEPART-1) .AND. I.LE.(NRECORDS+1)) THEN
                AGC(I)=B
                HEAD(I)=C
                CON1(I)=4.98/255/10**(AGC(I)/20)*ROC
                CON2(I)=4.98/255/10**(AGC(I)/20)*1000000.
                ODIRX1(I)=C*PI/180.
                IF (NEXPECT .EQ. NRECNUM) THEN
                    WARN(I)=1.
                    NEXPECT= NEXPECT + 1
                ELSE
                    WARN(I)=1.
                    WARN(I-1)=FLOAT(NRECNUM-(NDEPART-1+I)+1)
                    DO J=1,INT(WARN(I-1)-1)
                        type *,J,'  WARNING: record',NEXPECT+J-1,'  missing'
                    END DO
                    NEXPECT=NEXPECT+INT(WARN(I-1))
                END IF
                I=I+1
            END IF
        END DO
20      CONTINUE

!       Unwrap heading angle
        CALL UNWRAP(ODIRX1,NRECORDS,DIRX1)

!       Read geophone and hydrophone calibration files (amplitude and
!       phase vs frequency), and initialize first point
27      FORMAT(F9.6,1X,F9.6,1X,F11.6)
        I=2
        DO WHILE (.TRUE.)
            READ(11,*,END=21)FREQ,AMP1(I),PHA1(I)
            READ(12,*,END=22)FREQ,AMP2(I),PHA2(I)
            PHA1(I)=PHA1(I)*PI/180.
            PHA2(I)=PHA2(I)*PI/180.
```

```
          I=I+1
        END DO
 21     CONTINUE
 22     CONTINUE
        AMP1(1)=AMP1(2)
        AMP2(1)=AMP2(2)
        PHA1(1)=PHA1(2)
        PHA2(1)=PHA2(2)

!       Verify if any record is missing in the header file and
!       sets record numbers to analyze, then read 3 geophones (X,Y ,Z) and
!       1 hydrophone (P) time series. IFIRST = first record # in file.
        IREF1=(NDEPART-IFIRST)*2250 +1
        IREF2=(NDEPART+NRECORDS-IFIRST)*2250 +1
        ICOUNT=1
        DO WHILE (.TRUE.)
          READ(13,*,END=23)DP
          READ(14,*,END=23)DX,DY,DZ
          IF (ICOUNT.GE.IREF1 .AND. ICOUNT.LT.IREF2) THEN
            P(ICOUNT-IREF1+1)=DP
            X(ICOUNT-IREF1+1)=DX
            Y(ICOUNT-IREF1+1)=DY
            Z(ICOUNT-IREF1+1)=DZ
          END IF
          ICOUNT=ICOUNT+1
        END DO
 23     CONTINUE

!       Read window file
        W2=0
        DO IW=1,NFFT
          READ(9,*)W(IW)
          W2=W(IW)**2+W2
        END DO

!       Initialize arrays
        DO IPP=1,NHFFT
          PVXF(IPP)=CMPLX(0.,0.)
          PVYF(IPP)=CMPLX(0.,0.)
          PVZF(IPP)=CMPLX(0.,0.)
          QVXF(IPP)=0.
          QVYF(IPP)=0.
          QVZF(IPP)=0.
          PPRF(IPP)=0.
          VHF(IPP)=0.
        END DO

!***** For each record to analyze:   ***************
        DO IR=1,NRECORDS
!         Initialize arrays
          DO IPP=1,NHFFT
            PVX(IPP,IR)=CMPLX(0.,0.)
            PVY(IPP,IR)=CMPLX(0.,0.)
            PVZ(IPP,IR)=CMPLX(0.,0.)
            VXX(IPP,IR)=0.
            VYY(IPP,IR)=0.
            VZZ(IPP,IR)=0.
            PPR(IPP,IR)=0.
            VH(IPP,IR)=0.
```

```
        END DO
!       Skip the first 150 points of time series (tape-recorder noise)
!       and select following 2050 points.
        NSKIP=151
        LIM1=((IR-1)*2250)+NSKIP
        LIM2=LIM1+2049
        INTI=(LIM2-LIM1)*5 +1
        J=1
        DO K=LIM1,LIM2
           VXII(J)=X(K)
           VYII(J)=Y(K)
           VZII(J)=Z(K)
           PRI(J)=P(K)
           J=J+1
        END DO

!       Interpolate time series (factor of 5)
        CALL SINCINTERP(VXII,VXINT,2050,10246,5,32)
        CALL SINCINTERP(VYII,VYINT,2050,10246,5,32)
        CALL SINCINTERP(VZII,VZINT,2050,10246,5,32)
        CALL SINCINTERP(PRI,PRINT,2050,10246,5,32)

!       Align time series
        DO ID=1,INTI-7
           VXINT(ID)=VXINT(ID+7)
           VYINT(ID)=VYINT(ID+6)
           VZINT(ID)=VZINT(ID+5)
           PRINT(ID)=PRINT(ID+4)
        END DO

!       Decimate time series by a factor of 5
        DO IE=1,INTI-10,5
           IEE=(IE-1)/5+1
           VXII(IEE)=VXINT(IE)
           VYII(IEE)=VYINT(IE)
           VZII(IEE)=VZINT(IE)
           PRI(IEE)=PRINT(IE)
        END DO

!       Convert volts to uPa**2 (gain corrected levels)
!       Rotate x and y levels to take magnetique declination into account
        DO IG=1,2048
           VXII(IG)=VXII(IG)*CON1(IR)
           VYII(IG)=VYII(IG)*CON1(IR)
           VZII(IG)=VZII(IG)*CON1(IR)
           PRI(IG)=PRI(IG)*CON2(IR)
           VI(IG)=SQRT(VXII(IG)**2+VYII(IG)**2)
           IF (VI(IG).EQ.0) VXII(IG)=0.000001
           THETAI=ATAN2(VYII(IG),VXII(IG))
           SLOPE=(DIRX1(IR+1)-DIRX1(IR))/(2250.*WARN(IR))
           DIRX(IG)=DIRX1(IR)+FLOAT(NSKIP-1+IG)*SLOPE
           THETAF(IG)=THETAI-DIRX(IG)-DECLINATION
           VX(IG)=VI(IG)*COS(THETAF(IG))
           VY(IG)=VI(IG)*SIN(THETAF(IG))
           VZ(IG)=VZII(IG)
        END DO

!       The time series of each record is split into nffts (7) overlapping
!       arrays of nfft (512) points.  Each subarray is windowed, converted
```

```
!           to complex values. 3 cross-spectra (XY, XZ, YZ) and 4 auto-spectra
!           (XX, YY, ZZ, PP) are calculated, and then corrected for the
!           windowing and the sampling frequency. The subarrays are added
!           together.
            DO IP=1,NFFTS
                IPP1=(IP-1)*NHFFT
                DO IPP=1,NFFT
                    ZX(IPP) = CMPLX(W(IPP)*VX(IPP1+IPP),0.)
                    ZY(IPP) = CMPLX(W(IPP)*VY(IPP1+IPP),0.)
                    ZZ(IPP) = CMPLX(W(IPP)*VZ(IPP1+IPP),0.)
                    ZP(IPP) = CMPLX(W(IPP)*PRI(IPP1+IPP),0.)
                END DO

                CALL FFT(ZX,9,NFFT,-1)
                CALL FFT(ZY,9,NFFT,-1)
                CALL FFT(ZZ,9,NFFT,-1)
                CALL FFT(ZP,9,NFFT,-1)

                DO IPP=1,NHFFT
                    PVX1(IPP,IP)=2.*ZX(IPP)*CONJG(ZP(IPP))/W2/FS
                    PVY1(IPP,IP)=2.*ZY(IPP)*CONJG(ZP(IPP))/W2/FS
                    PVZ1(IPP,IP)=2.*ZZ(IPP)*CONJG(ZP(IPP))/W2/FS
                    VXX1(IPP,IP)=2.*ZX(IPP)*CONJG(ZX(IPP))/W2/FS
                    VYY1(IPP,IP)=2.*ZY(IPP)*CONJG(ZY(IPP))/W2/FS
                    VZZ1(IPP,IP)=2.*ZZ(IPP)*CONJG(ZZ(IPP))/W2/FS
                    PPR1(IPP,IP)=2.*ZP(IPP)*CONJG(ZP(IPP))/W2/FS
                    PVX(IPP,IR)=PVX(IPP,IR)+PVX1(IPP,IP)
                    PVY(IPP,IR)=PVY(IPP,IR)+PVY1(IPP,IP)
                    PVZ(IPP,IR)=PVZ(IPP,IR)+PVZ1(IPP,IP)
                    VXX(IPP,IR)=VXX(IPP,IR)+VXX1(IPP,IP)
                    VYY(IPP,IR)=VYY(IPP,IR)+VYY1(IPP,IP)
                    VZZ(IPP,IR)=VZZ(IPP,IR)+VZZ1(IPP,IP)
                    PPR(IPP,IR)=PPR(IPP,IR)+PPR1(IPP,IP)
                END DO
            END DO
!           Division by nffts for average of the 7 subarrays.
            DO IPP=1,NHFFT
            PVX(IPP,IR)=PVX(IPP,IR)/REAL(NFFTS)
            PVY(IPP,IR)=PVY(IPP,IR)/REAL(NFFTS)
            PVZ(IPP,IR)=PVZ(IPP,IR)/REAL(NFFTS)
            VXX(IPP,IR)=VXX(IPP,IR)/REAL(NFFTS)
            VYY(IPP,IR)=VYY(IPP,IR)/REAL(NFFTS)
            VZZ(IPP,IR)=VZZ(IPP,IR)/REAL(NFFTS)
            PPR(IPP,IR)=PPR(IPP,IR)/REAL(NFFTS)
        END DO

!       The amplitude and phase of the f ft are corrected with the
!       calibration curves. The 3 cross-spectra and 4 auto-spectra
!       of each analyzed record are accumulated.
!       The amplitude of the cross-spectra are converted to watt/m**2.
        DO IPP=1,NHFFT
            AMPLX(IPP,IR)=CABS(PVX(IPP,IR))
            AMPLY(IPP,IR)=CABS(PVY(IPP,IR))
            AMPLZ(IPP,IR)=CABS(PVZ(IPP,IR))
            IF (PVX(IPP,IR).EQ.0) THEN
                PHASEX(IPP,IR)=0.
            ELSE
                PHASEX(IPP,IR)=ATAN2(AIMAG(PVX(IPP,IR)),REAL(PVX(IPP,IR)))
            END IF
```

```
          IF (PVY(IPP,IR).EQ.0) THEN
              PHASEY(IPP,IR)=0.
          ELSE
              PHASEY(IPP,IR)=ATAN2(AIMAG(PVY(IPP,IR)),REAL(PVY(IPP,IR)))
          END IF
          IF (PVZ(IPP,IR).EQ.0) THEN
              PHASEZ(IPP,IR)=0.
          ELSE
              PHASEZ(IPP,IR)=ATAN2(AIMAG(PVZ(IPP,IR)),REAL(PVZ(IPP,IR)))
          END IF
          AMPLX(IPP,IR)=AMPLX(IPP,IR)/10.**(AMP1(IPP)/20.)/
  $       10.**(AMP2(IPP)/20.)/10.**(122./10)
          AMPLY(IPP,IR)=AMPLY(IPP,IR)/10.**(AMP1(IPP)/20.)/
  $       10.**(AMP2(IPP)/20.)/10.**(122./10)
          AMPLZ(IPP,IR)=AMPLZ(IPP,IR)/10.**(AMP1(IPP)/20.)/
  $       10.**(AMP2(IPP)/20.)/10.**(122./10)
          PHASEX(IPP,IR)=PHASEX(IPP,IR)-PHA1(IPP)+PHA2(IPP)
          PHASEY(IPP,IR)=PHASEY(IPP,IR)-PHA1(IPP)+PHA2(IPP)
          PHASEZ(IPP,IR)=PHASEZ(IPP,IR)-PHA1(IPP)+PHA2(IPP)
          CPVX(IPP,IR)=CMPLX(AMPLX(IPP,IR)*COS(PHASEX(IPP,IR)),
  $       AMPLX(IPP,IR)*SIN(PHASEX(IPP,IR)))
          CPVY(IPP,IR)=CMPLX(AMPLY(IPP,IR)*COS(PHASEY(IPP,IR)),
  $       AMPLY(IPP,IR)*SIN(PHASEY(IPP,IR)))
          CPVZ(IPP,IR)=CMPLX(AMPLZ(IPP,IR)*COS(PHASEZ(IPP,IR)),
  $       AMPLZ(IPP,IR)*SIN(PHASEZ(IPP,IR)))
          PVXF(IPP)=PVXF(IPP)+REAL(CPVX(IPP,IR))
          PVYF(IPP)=PVYF(IPP)+REAL(CPVY(IPP,IR))
          PVZF(IPP)=PVZF(IPP)+REAL(CPVZ(IPP,IR))
          QVXF(IPP)=QVXF(IPP)+AIMAG(CPVX(IPP,IR))
          QVYF(IPP)=QVYF(IPP)+AIMAG(CPVY(IPP,IR))
          QVZF(IPP)=QVZF(IPP)+AIMAG(CPVZ(IPP,IR))
          VXX(IPP,IR)=VXX(IPP,IR)/10.**(AMP1(IPP)/10.)
          VYY(IPP,IR)=VYY(IPP,IR)/10.**(AMP1(IPP)/10.)
          VZZ(IPP,IR)=VZZ(IPP,IR)/10.**(AMP1(IPP)/10.)
          PPR(IPP,IR)=PPR(IPP,IR)/10.**(AMP2(IPP)/10.)
          VH(IPP,IR)=VXX(IPP,IR)+VYY(IPP,IR)+VZZ(IPP,IR)
          PPRF(IPP)=PPRF(IPP)+PPR(IPP,IR)
          VHF(IPP)=VHF(IPP)+VH(IPP,IR)
      END DO
!******* End of loop for each record:  **********
      END DO

      WRITE(27,'(A)')' CURVE'
      WRITE(28,'(A)')' CURVE'
      WRITE(29,'(A)')' CURVE'
!     The cross and auto spectra are divided by the total number of records.
!     The horizontal cross-spectra are combined to obtain horizontal
!     directionality.  The spectra file are written (SP and G3).
      DO IPP=1,NHFFT
          X2=REAL(IPP-1)/XAXIS*FS/2.
          PVXF(IPP)=PVXF(IPP)/REAL(NRECORDS)
          PVYF(IPP)=PVYF(IPP)/REAL(NRECORDS)
          PVZF(IPP)=PVZF(IPP)/REAL(NRECORDS)
          QVXF(IPP)=QVXF(IPP)/REAL(NRECORDS)
          QVYF(IPP)=QVYF(IPP)/REAL(NRECORDS)
          QVZF(IPP)=QVZF(IPP)/REAL(NRECORDS)
          VHF(IPP)=VHF(IPP)/REAL(NRECORDS)
          PPRF(IPP)=PPRF(IPP)/REAL(NRECORDS)
          CPVT(IPP)=SQRT(PVXF(IPP)**2.+PVYF(IPP)**2.+PVZF(IPP)**2.)
```

```
         WRITE(27,*)X2,10.**(12.2)*QVXF(IPP)/PPRF(IPP)
         WRITE(28,*)X2,10.**(12.2)*QVYF(IPP)/PPRF(IPP)
         WRITE(29,*)X2,10.**(12.2)*QVZF(IPP)/PPRF(IPP)
         CALL WRITSTICK(PVXF,PVYF,PVZF,QVZF,IPP)
      END DO
      WRITE(26,’(A)’)’ CURVE’
      WRITE(31,’(A)’)’ CURVE’
      DO IPP=1,NHFFT
         WRITE(26,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(VHf(IPP))
         WRITE(31,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(ABS(PVXF(IPP)))
      END DO
      WRITE(26,’(A)’)’ CURVE’
      WRITE(31,’(A)’)’ CURVE’
      DO IPP=1,NHFFT
         WRITE(26,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(PPRF(IPP))
         WRITE(31,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(ABS(PVYF(IPP)))
      END DO
      WRITE(26,’(A)’)’ CURVE’
      WRITE(31,’(A)’)’ CURVE’
      DO IPP=1,NHFFT
         WRITE(26,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(CPVT(IPP))+122.
         WRITE(31,*)REAL(IPP-1)/XAXIS*FS/2.,10*ALOG10(ABS(PVZF(IPP)))
      END DO

!     Close files
      CLOSE(9)
      CLOSE(10)
      CLOSE(11)
      CLOSE(12)
      CLOSE(13)
      CLOSE(14)
      CLOSE(15)
      END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE OPENFILES(COMMENT1,COMMENT2,NDEPART,IFIRST,NRECORDS)
!     Open input and output files
!     F. Desharnais, 1993

      IMPLICIT NONE
      INTEGER IFLOAT,IFIRST,NDEPART,ILEN,NRECORDS,ILF
      CHARACTER INFILE*36,INLINE*80
      CHARACTER COMMENT1*80,COMMENT2*80,DEPART*4

!     Open file with geophone time series
      INFILE = ‘TS-2-0640.DAT’
      WRITE(*,’(‘’$ Input filename -  TS...? ‘’)’)
      READ (*,’(Q,A)’)ILF,INFILE
      OPEN(UNIT=14,NAME=INFILE,STATUS=’OLD’,CARRIAGECONTROL=’LIST’)
!     Deduct name of file with hydrophone time series + open file
      IF (ILF.EQ.13) THEN
       READ(INFILE(1:ILF),’(3X,I1,1X,I4,4X)’)IFLOAT,IFIRST
      ELSE
       READ(INFILE(1:ILF),’(3X,I2,1X,I4,4X)’)IFLOAT,IFIRST
      END IF
      INFILE(1:2)=’ P’
      OPEN(UNIT=13,NAME=INFILE,STATUS=’OLD’,CARRIAGECONTROL=’LIST’)
!     Get number of first record to analyze
      WRITE(*,’(‘’$ First record number? ‘’)’)
```

```
        READ (*,*)NDEPART
        WRITE(DEPART,’(I4)’) NDEPART
        IF (DEPART(1:1).EQ.’ ‘) DEPART(1:1)=’0'
!       Get number of records to analyze
        WRITE(*,’(‘’$ Number of records to average? ‘’)’)
        READ (*,*)NRECORDS
!       Deduct name of output file for stick plots + open file
        IF (ILF.EQ.13) THEN
            WRITE(INFILE(1:ILF),999)IFLOAT,DEPART
        ELSE
            WRITE(INFILE(1:ILF+1),998)IFLOAT,DEPART
        END IF
999     FORMAT(‘XY-’,I1,’-’,A4,’.SAP’)
998     FORMAT(‘XY-’,I2,’-’,A4,’.SAP’)
        OPEN(UNIT=15,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’XZ’
        OPEN(UNIT=16,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’YZ’
        OPEN(UNIT=17,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’ Z’
        OPEN(UNIT=18,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’ZZ’
        OPEN(UNIT=19,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’QX’
        OPEN(UNIT=27,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’QY’
        OPEN(UNIT=28,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’QZ’
        OPEN(UNIT=29,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
        INFILE(1:2)=’G3'
        OPEN(UNIT=31,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
!       Deduct name of output file for spectra plots + open file
        INFILE(1:2)=’SP’
        OPEN(UNIT=26,NAME=INFILE,STATUS=’NEW’,CARRIAGECONTROL=’LIST’)
!       Open file with kaiser window
        OPEN(UNIT=9,NAME=’KAISER.DAT’,STATUS=’OLD’)
!       Get name of header file and open it
        INFILE = ‘HEAD2.DAT’
        IF (IFLOAT.LT.10) THEN
            WRITE(INFILE(5:5),’(I1)’)IFLOAT
        ELSE
            INFILE(1:10)=’HEAD10.DAT’
        END IF
        OPEN(UNIT=10,NAME=INFILE,STATUS=’OLD’)
!       Open file with geophone calibration
        OPEN(UNIT=11,NAME=’CALGEO.ASC’,STATUS=’OLD’)
!       Open file with hydrophone calibration
        OPEN(UNIT=12,NAME=’CALHYDRO.ASC’,STATUS=’OLD’)

!       Get comment to write in output files
        COMMENT1=’June 92, 1st deployment’
        WRITE(*,’(‘’$ Comment line (June 92, 1st deployment)? ‘’)’)
        READ (*,’(Q,A)’)ILF,COMMENT1
        COMMENT2=’Float  6;  First record:  640, average of 12 records’
        WRITE(COMMENT2(7:8),’(I2)’) IFLOAT
        WRITE(COMMENT2(26:29),’(I4)’) NDEPART
        WRITE(COMMENT2(43:44),’(I2)’) NRECORDS

        RETURN
```

```
      END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WRITHEAD(COMMENT1,COMMENT2)
!     Write header of output files
!     F. Desharnais, 1993

      CHARACTER COMMENT1*80,COMMENT2*80
      COMMON/PLOT/XAXIS,YAXIS,XLEN,YLEN,FS

!     Write header of output Saplot file with XY  stick plot
      WRITE(15,*)’AXSET ‘,XLEN,YLEN
      WRITE(15,’(A)’)’RANGE 1 0 25'
      WRITE(15,’(A)’)’RANGE 2 -80 80'
      WRITE(15,’(A)’)’CSET -1 0'
      WRITE(15,’(A)’)’LSET -1 0'
      WRITE(15,’(A)’)’FORMAT 6'
      WRITE(15,’(A)’)’LABEL 1'
      WRITE(15,’(A)’)’Frequency (Hz)’
      WRITE(15,’(A)’)’LABEL 6'
      WRITE(15,’(A)’)’Horizontal  Acoustic Intensity’
      WRITE(15,’(A)’)’LABEL 2'
      WRITE(15,’(A)’)’(dB re 1 !FNT13;m!FNT3;W att/m!SUP;2!BAK;/Hz)’
      WRITE(15,’(A)’)’ILABEL 0 -1.2'
      WRITE(15,’(A)’)COMMENT1
      WRITE(15,’(A)’)’ILABEL 0 -1.5'
      WRITE(15,’(A)’)COMMENT2
      WRITE(15,’(A)’)’XLABEL 20.78 73'
      WRITE(15,’(A)’)’!SIZ10;N’
      WRITE(15,’(A)’)’XLABEL 20.78 48'
      WRITE(15,’(A)’)’!SIZ10;S’
      WRITE(15,’(A)’)’XLABEL 19.25 60.25'
      WRITE(15,’(A)’)’!SIZ10;W’
      WRITE(15,’(A)’)’XLABEL 22.3 60.25'
      WRITE(15,’(A)’)’!SIZ10;E!BAK;’
      WRITE(15,’(A)’)’CURVE’
      WRITE(15,’(A)’)’21 72'
      WRITE(15,’(A)’)’21 52'
      WRITE(15,’(A)’)’CURVE’
      WRITE(15,’(A)’)’19.8 62'
      WRITE(15,’(A)’)’22.2 62'

!     Write header of output Saplot file with XZ stick plot
      WRITE(16,*)’AXSET ‘,XLEN,YLEN
      WRITE(16,’(A)’)’RANGE 1 0 25'
      WRITE(16,’(A)’)’RANGE 2 -80 80'
      WRITE(16,’(A)’)’CSET -1 0'
      WRITE(16,’(A)’)’LSET -1 0'
      WRITE(16,’(A)’)’FORMAT 6'
      WRITE(16,’(A)’)’LABEL 1'
      WRITE(16,’(A)’)’Frequency (Hz)’
      WRITE(16,’(A)’)’LABEL 6'
      WRITE(16,’(A)’)’Acoustic Intensity (UD/WE)’
      WRITE(16,’(A)’)’LABEL 2'
      WRITE(16,’(A)’)’(dB re 1 !FNT13;m!FNT3;W att/m!SUP;2!BAK;/Hz)’
      WRITE(16,’(A)’)’ILABEL 0 -1.2'
      WRITE(16,’(A)’)COMMENT1
      WRITE(16,’(A)’)’ILABEL 0 -1.5'
      WRITE(16,’(A)’)COMMENT2
```

```
        WRITE(16,’(A)’)’XLABEL 20.78 73'
        WRITE(16,’(A)’)’!SIZ10;U’
        WRITE(16,’(A)’)’XLABEL 20.78 48'
        WRITE(16,’(A)’)’!SIZ10;D’
        WRITE(16,’(A)’)’XLABEL 19.25 60.25'
        WRITE(16,’(A)’)’!SIZ10;W’
        WRITE(16,’(A)’)’XLABEL 22.3 60.25'
        WRITE(16,’(A)’)’!SIZ10;E!BAK;’
        WRITE(16,’(A)’)’CURVE’
        WRITE(16,’(A)’)’21 72'
        WRITE(16,’(A)’)’21 52'
        WRITE(16,’(A)’)’CURVE’
        WRITE(16,’(A)’)’19.8 62'
        WRITE(16,’(A)’)’22.2 62'

!       Write header of output Saplot file with  YZ stick plot
        WRITE(17,*)’AXSET ‘,XLEN,YLEN
        WRITE(17,’(A)’)’RANGE 1 0 25'
        WRITE(17,’(A)’)’RANGE 2 -80 80'
        WRITE(17,’(A)’)’CSET -1 0'
        WRITE(17,’(A)’)’LSET -1 0'
        WRITE(17,’(A)’)’FORMAT 6'
        WRITE(17,’(A)’)’LABEL 1'
        WRITE(17,’(A)’)’Frequency (Hz)’
        WRITE(17,’(A)’)’LABEL 6'
        WRITE(17,’(A)’)’Acoustic Intensity (UD/SN)’
        WRITE(17,’(A)’)’LABEL 2'
        WRITE(17,’(A)’)’(dB re 1 !FNT13;m!FNT3;W att/m!SUP;2!BAK;/Hz)’
        WRITE(17,’(A)’)’ILABEL 0 -1.2'
        WRITE(17,’(A)’)COMMENT1
        WRITE(17,’(A)’)’ILABEL 0 -1.5'
        WRITE(17,’(A)’)COMMENT2
        WRITE(17,’(A)’)’XLABEL 20.78 73'
        WRITE(17,’(A)’)’!SIZ10;U’
        WRITE(17,’(A)’)’XLABEL 20.78 48'
        WRITE(17,’(A)’)’!SIZ10;D’
        WRITE(17,’(A)’)’XLABEL 19.25 60.25'
        WRITE(17,’(A)’)’!SIZ10;S’
        WRITE(17,’(A)’)’XLABEL 22.3 60.25'
        WRITE(17,’(A)’)’!SIZ10;N!BAK;’
        WRITE(17,’(A)’)’CURVE’
        WRITE(17,’(A)’)’21 72'
        WRITE(17,’(A)’)’21 52'
        WRITE(17,’(A)’)’CURVE’
        WRITE(17,’(A)’)’19.8 62'
        WRITE(17,’(A)’)’22.2 62'

!       Write header of output Saplot file with Z stick plot
        WRITE(18,*)’AXSET ‘,XLEN,YLEN
        WRITE(18,’(A)’)’RANGE 1 0 25'
        WRITE(18,’(A)’)’RANGE 2 -80 80'
        WRITE(18,’(A)’)’CSET -1 0'
        WRITE(18,’(A)’)’LSET -1 0'
        WRITE(18,’(A)’)’FORMAT 6'
        WRITE(18,’(A)’)’LABEL 1'
        WRITE(18,’(A)’)’Frequency (Hz)’
        WRITE(18,’(A)’)’LABEL 6'
        WRITE(18,’(A)’)’Vertical Acoustic Intensity’
        WRITE(18,’(A)’)’LABEL 2'
```

```
        WRITE(18,'(A)')'(dB re 1 !FNT13;m!FNT3;W att/m!SUP;2!BAK;/Hz)'
        WRITE(18,'(A)')'ILABEL 0 -1.2'
        WRITE(18,'(A)')COMMENT1
        WRITE(18,'(A)')'ILABEL 0 -1.5'
        WRITE(18,'(A)')COMMENT2

!       Write header of output Saplot file with REACTIVE Z stick plot
        WRITE(19,*)'AXSET ',XLEN,YLEN
        WRITE(19,'(A)')'RANGE 1 0 25'
        WRITE(19,'(A)')'RANGE 2 -80 80'
        WRITE(19,'(A)')'CSET -1 0'
        WRITE(19,'(A)')'LSET -1 0'
        WRITE(19,'(A)')'FORMAT 6'
        WRITE(19,'(A)')'LABEL 1'
        WRITE(19,'(A)')'Frequency (Hz)'
        WRITE(19,'(A)')'LABEL 6'
        WRITE(19,'(A)')'Vertical Reactive Acoustic Intensity'
        WRITE(19,'(A)')'LABEL 2'
        WRITE(19,'(A)')'(dB re 1 !FNT13;m!FNT3;W att/m!SUP;2!BAK;/Hz)'
        WRITE(19,'(A)')'ILABEL 0 -1.2'
        WRITE(19,'(A)')COMMENT1
        WRITE(19,'(A)')'ILABEL 0 -1.5'
        WRITE(19,'(A)')COMMENT2

!       Write header of output Saplot file with spectra plots
        WRITE(26,'(A)')'AXSET 6.7 4.3125'
        WRITE(26,'(A)')'FORMAT 6'
        WRITE(26,'(A)')'RANGE 1 0 25'
        WRITE(26,'(A)')'RANGE 2 60 140'
        WRITE(26,'(A)')'LSET 3 6'
        WRITE(26,'(A)')'LABEL 1'
        WRITE(26,'(A)')'Frequency (Hz)'
        WRITE(26,'(A)')'LABEL 2'
        WRITE(26,'(A)')'Spectra (dB re 1 !FNT13;m!FNT3;Pa!SUP;2!BAK;/Hz)'
        WRITE(26,'(A)')'LEGEND 3'
        WRITE(26,'(A)')'Geophone signals'
        WRITE(26,'(A)')'Hydrophone signal'
        WRITE(26,'(A)')'Active intensity magnitude'
        WRITE(26,'(A)')'ILABEL 0 -1.2'
        WRITE(26,'(A)')COMMENT1
        WRITE(26,'(A)')'ILABEL 0 -1.5'
        WRITE(26,'(A)')COMMENT2

!       Write header of output Saplot file with QX/SP  plots
        WRITE(27,'(A)')'AXSET 6.7 4.3125'
        WRITE(27,'(A)')'FORMAT 6'
        WRITE(27,'(A)')'RANGE 1 0 25'
        WRITE(27,'(A)')'RANGE 2 -0.4 0.4'
        WRITE(27,'(A)')'LABEL 1'
        WRITE(27,'(A)')'Frequency (Hz)'
        WRITE(27,'(A)')'LABEL 2'
        WRITE(27,'(A)')'Spectral Ratio X/P'
        WRITE(27,'(A)')'ILABEL 0 -1.2'
        WRITE(27,'(A)')COMMENT1
        WRITE(27,'(A)')'ILABEL 0 -1.5'
        WRITE(27,'(A)')COMMENT2

!       Write header of output Saplot file with QY/SP  plots
        WRITE(28,'(A)')'AXSET 6.7 4.3125'
```

```
        WRITE(28,'(A)')'FORMAT 6'
        WRITE(28,'(A)')'RANGE 1 0 25'
        WRITE(28,'(A)')'RANGE 2 -0.4 0.4'
        WRITE(28,'(A)')'LABEL 1'
        WRITE(28,'(A)')'Frequency (Hz)'
        WRITE(28,'(A)')'LABEL 2'
        WRITE(28,'(A)')'Spectral Ratio  Y/P'
        WRITE(28,'(A)')'ILABEL 0 -1.2'
        WRITE(28,'(A)')COMMENT1
        WRITE(28,'(A)')'ILABEL 0 -1.5'
        WRITE(28,'(A)')COMMENT2

!       Write header of output Saplot file with QZ/SP  plots
        WRITE(29,'(A)')'AXSET 6.7 4.3125'
        WRITE(29,'(A)')'FORMAT 6'
        WRITE(29,'(A)')'RANGE 1 0 25'
        WRITE(29,'(A)')'RANGE 2 -0.4 0.4'
        WRITE(29,'(A)')'LABEL 1'
        WRITE(29,'(A)')'Frequency (Hz)'
        WRITE(29,'(A)')'LABEL 2'
        WRITE(29,'(A)')'Spectral Ratio Z/P'
        WRITE(29,'(A)')'ILABEL 0 -1.2'
        WRITE(29,'(A)')COMMENT1
        WRITE(29,'(A)')'ILABEL 0 -1.5'
        WRITE(29,'(A)')COMMENT2

!       Write header of output Saplot file with 3 spectra of separate
!       geophone components
        WRITE(31,'(A)')'AXSET 6.7 4.3125'
        WRITE(31,'(A)')'FORMAT 6'
        WRITE(31,'(A)')'RANGE 1 0 25'
        WRITE(31,'(A)')'RANGE 2 -80 10'
        WRITE(31,'(A)')'LSET 3 6'
        WRITE(31,'(A)')'LABEL 1'
        WRITE(31,'(A)')'Frequency (Hz)'
        WRITE(31,'(A)')'LABEL 2'
        WRITE(31,'(A)')'Spectra (dB re 1 (!FNT13;m!FNT3;m/sec)!SUP;
 &      2!BAK;/Hz)'
        WRITE(31,'(A)')'LEGEND 3'
        WRITE(31,'(A)')'X Geophone'
        WRITE(31,'(A)')'Y Geophone'
        WRITE(31,'(A)')'Z Geophone'
        WRITE(31,'(A)')'ILABEL 0 -1.2'
        WRITE(31,'(A)')COMMENT1
        WRITE(31,'(A)')'ILABEL 0 -1.5'
        WRITE(31,'(A)')COMMENT2

        RETURN
        END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        SUBROUTINE UNWRAP(ODIR,NRECORDS,DIR)
!
!       Wraps angles over 360 degrees if necessary
!       F. Desharnais,  August 93
!       Based on Matlab "unwrap"
!
        REAL ODIR(41),DIR(41),B(41),C(41),D(41),E(41),F(41)
        REAL PI,MIN,NREC
```

```
      NREC=NRECORDS+1
      PI=3.1415926536
      MIN=2*PI
      DO I=1,NREC
         IF (ODIR(I).LT.MIN) MIN=ODIR(I)
      END DO

      B(1)=ODIR(1)
      DO I=2,NREC
         B(I)=ODIR(I)-ODIR(I-1)
      END DO

      DO I=1,NREC
         IF (B(I) .GT. PI) THEN
            C(I) = -1.
         ELSE
            C(I)=0.
         END IF
         IF (B(I) .LT. -PI) THEN
            D(I) = 1.
         ELSE
            D(I)=0.
         END IF
         E(I) = (C(I)+D(I))*2.*PI
         DO J=I,1,-1
            F(I)=E(J)+F(I)
         END DO
         DIR(I)=ODIR(I)+F(I)
      END DO

      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     Subroutine : FFT
C
C     Origin : by Richard Hughes
C
C     Purpose : To calculate complex FFT's.
C
C     Inputs : A = Complex array containing data to be FFT'd.
C     M = Power of 2 which equals the length of the FFT .
C     N = Length of the FFT.
C     ISIGN = Flag to indicate either forward(-1) or reverse(1)
C     transform.
C     Outputs : A = Complex array containing FFT'd data.
C
C=========================================================
C     MAIN CODE
C=========================================================
C
      SUBROUTINE FFT(A,M,NN,ISIGN)
C
      COMPLEX*8 A(NN),U,W,T
      PI = 3.1415926536
      N = 2**M
      NV2 = N/2
      NM1 = N-1
```

```
      double precision arg,c
      dimension ww((2*ip+1)*(nf-1))
      pi=atan(1.)*4.
      nfm2=nf-2
      ip1=ip+1
      ip21=ip*2+1
      nf2=nf/2
      c= -.5*(2.0/(ip*nf+nf/2))**2
      fnr=1.0/nf
      do 20 k=0,nfm2
          k2ip=k*ip21+ip1
          if ((k+1) .le. nf2) ioff=-(k+1)
          if ((k+1) .gt. nf2) ioff=nf-(k+1)
          t= -ioff*fnr
c     Window sincs with a Gaussian taper (exp() )
          do 10 j= -ip,ip
c             print *,k,j,t,ioff
              sinc=1
              arg=pi*(t-j)
              if (arg .ne. 0) sinc=sin(arg)/arg
 10       ww(k2ip+j)=sinc*exp(c*(j*nf+ioff)**2)
 20   continue
      return
      end

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE WRITSTICK(PVXF,PVYF,PVZF,QVZF,IPP)
!     Writes output stick plot files (XY, XZ, YZ, Z, ZZ)
!     F. Desharnais, 1993

      REAL CPVXY,CPVXZ,CPVYZ,CPVZZ,CQVZZ,THET AII,X2
      REAL PVXF(256),PVYF(256),PVZF(256),QVZF(256)
      INTEGER IPP

      COMMON/PLOT/XAXIS,Y AXIS,XLEN,YLEN,FS

      WRITE(15,'(A)')' CURVE'
      WRITE(16,'(A)')' CURVE'
      WRITE(17,'(A)')' CURVE'
      WRITE(18,'(A)')' CURVE'
      WRITE(19,'(A)')' CURVE'

      PVXF(IPP)=-PVXF(IPP)
      PVYF(IPP)=-PVYF(IPP)
      CPVXY=10*ALOG10(SQRT(PVXF(IPP)**2.+PVYF(IPP)**2.))+80.
      THETAII=ATAN2(PVYF(IPP),PVXF(IPP))
      WRITE(15,*)REAL(IPP-1)/XAXIS*FS/2,0.
      X2=(CPVXY*COS(THETAII)*(XAXIS/XLEN*YLEN/Y AXIS)+IPP-1)/XAXIS*FS/2.
      WRITE(15,*)X2,CPVXY*SIN(THET AII)

      CPVXZ=10*ALOG10(SQRT(PVZF(IPP)**2.+PVXF(IPP)**2.))+80.
      THETAII=ATAN2(PVZF(IPP),PVXF(IPP))
      WRITE(16,*)REAL(IPP-1)/XAXIS*FS/2,0.
      X2=(CPVXZ*COS(THETAII)*(XAXIS/XLEN*YLEN/Y AXIS)+IPP-1)/XAXIS*FS/2.
      WRITE(16,*)X2,CPVXZ*SIN(THET AII)

      CPVYZ=10*ALOG10(SQRT(PVZF(IPP)**2.+PVYF(IPP)**2.))+80.
      THETAII=ATAN2(PVZF(IPP),PVYF(IPP))
      WRITE(17,*)REAL(IPP-1)/XAXIS*FS/2,0.
```

```
      X2=(CPVYZ*COS(THETAII)*(XAXIS/XLEN*YLEN/YAXIS)+IPP-1)/XAXIS*FS/2.
      WRITE(17,*)X2,CPVYZ*SIN(THETAII)

      CPVZZ=10*ALOG10(ABS(PVZF(IPP)))+80.
      CPVZZ=SIGN(CPVZZ,PVZF(IPP))
      WRITE(18,*)REAL(IPP-1)/XAXIS*FS/2,0.
      WRITE(18,*)REAL(IPP-1)/XAXIS*FS/2,CPVZZ

      CQVZZ=10*ALOG10(ABS(QVZF(IPP)))+80.
      CQVZZ=SIGN(CQVZZ,QVZF(IPP))
      WRITE(19,*)REAL(IPP-1)/XAXIS*FS/2,0.
      WRITE(19,*)REAL(IPP-1)/XAXIS*FS/2,CQVZZ

      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

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Annex C
Input files formats

The original software was written for a UNIX system computer. What is presented here is the equivalent software rewritten for a VAX VMS Operating System (see Annex A - Computing environment). The format of the data files are different for both software. The UNIX system uses the original MPL Swallow float format, which is described in [3]. The data files were originally translated into an ASCII format to simplify the preliminary analysis. The version presented here still uses the ASCII input format, which makes it easier for the user to go through the software and make potential modifications for other types of hardware.

The input time series are contained in two sets of files for each float: one file with the hydrophone time series (eg. P-2-0640.DAT), one file with the three geophone time series (eg. TS-2-0640.DAT). The amplitude is in system units (in a range of -127 to +128), the conversion to volts and then to dB//μPa^2/Hz is done within the software SWALLOW.

There are two calibration files: one for the hydrophone (CALHYDRO.ASC) and one for the geophones (CALGEO.ASC). The files each contain 3 columns: the frequency, the amplitude calibration curve (in dB), and the phase calibration curve (in degrees). The same hydrophone calibration curve is used for all the hydrophones, and the same geophone calibration curve is used for all geophones, independently of the float number, or the orientation of the geophone within the float.

Another ASCII file (eg. HEAD2.DAT) contains all the header information in four columns of data: the record number, the AGC gain (dB), the float magnetic heading (degrees), and the battery voltage (volts). There is one such file for each float used during any experiment.

One last file (KAISER.DAT) contains a Kaiser-Bessel window with an alpha of 2.5 (512 bins).

Examples for each of the files follow.

P-2-0640.DAT

```
 127
-128
 -79
 112
  88
 -72
 -49
  57
 -39
  81
```

```
652.00   8.0784   345.94   6.1328
653.00   7.5771   343.12   6.1328
654.00   7.1032   341.72   6.1328
655.00   6.5812   341.72   6.1328
656.00   6.0887   341.72   6.1328
657.00   6.5812   343.12   6.1328
658.00   6.0887   343.12   6.1328
659.00   5.5581   341.72   6.1328
...
```

KAISER.DAT

```
0.268082E-02
0.301299E-02
0.336391E-02
0.373414E-02
0.412426E-02
0.453483E-02
0.496644E-02
0.541967E-02
0.589510E-02
0.639333E-02
0.691497E-02
0.746060E-02
0.803085E-02
0.862632E-02
0.924762E-02
0.989536E-02
0.105702E-01
0.112727E-01
0.120035E-01
0.127633E-01
...
```

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F. Desharnais

Title

Analysis of Swallow float data at SACLANTCEN. Software notes for future use and developments.

Abstract

A Swallow float is a neutrally buoyant, freely drifting unit which is deployed in deep water, equipped with one pressure sensor (hydrophone) and three orthogonal particle velocity sensors (geophones) to measure acoustic intensity (magnitude and direction of the net acoustic energy flux density). This report summarizes the basic equation governing the analysis of Swallow float data. A description of the SACLANTCEN analysis software is included. The software was originally developed at the Marine Physical Laboratory, Scripps Institution of Oceanography.

Keywords

acoustic intensity – geophones – noise directionality – Swallow floats
very low frequencies

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SACLANT Undersea Research Centre
Viale San Bartolomeo 400, 19138 La Spezia,
Italy

*[From N. America: SACLANTCEN CMR-426
(New York) APO AE 09613]*

Tel: +39 (0)187 540 111
Fax:+39 (0)187 524 600

E-mail: library@saclantc.nato.int

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