BOFS and Sterna SeaSoar Data Set

SeaSoar is a towed undulating fish that carries a CTD, fluorometer and optical sensors capable of covering the water column from the surface down to 4-500 metres. It is therefore the ideal tool for hydrographic surveying.

SeaSoar was used on two BOFS cruises (DI190 and DI192) and one of the Sterna cruises (DI198).

Discovery 190 was the initial survey cruise for the 1990 BOFS Lagrangian experiment with the primary objective of locating a suitable site for this experiment. The survey comprised a section along 20°W from 48°N to 52°N, followed by a grid survey covering a box from 48-49°N and 18.5-21.5°W.

Discovery 192 was the post-study survey cruise for the Lagrangian experiment that undertook a grid survey covering a box from 46-49°N and 14-17.5°W.

Discovery 198 deployed SeaSoar for an opportunistic section through Drake Passage whilst on passage from Port Stanley to the Bellinghausen Sea. Two ice-edge surveys were carried out in the Bellinghausen Sea, in the vicinity of 66-69°S, 84-87°W.

SeaSoar Data for Cruise Discovery 190
(14th April to 8th May 1990)

1) Instrumentation

The SeaSoar is a hydrodynamic fish towed behind a ship travelling at 8-9 knots linked by a faired cable. The unit has two stub wings whose angle of attack may be set by hydraulic servomotors. Thus the fish is able to climb or dive under the control of command signals from the ship or, more usually, by automatic command signals driven by the on-board pressure sensor.

On this cruise, the SeaSoar cable was approximately 500 metres in length, enabling the fish to 'fly' between the surface and a depth of 330m. The unit was programmed to ascend and descend at approximately 1 m/s which, assuming a towing speed of 8.5 knots, gave a complete oscillation from surface to 300m and back to the surface for every 2.7km travelled.

The SeaSoar contained a Neil Brown Systems Mk3B CTD incorporating a pressure sensor, conductivity cell, platinum resistance thermometer and dissolved oxygen sensor. The unit was mounted horizontally along the body of the fish. A Chelsea Instruments Aquatracka fluorometer was mounted in the nose of the fish sampling through a downward-facing window at an angle of 45 degrees.

The instrument was also fitted with an array of 16 upwelling and downwelling irradiance sensors covering a range of spectral bands. No data are available from these.

2) Data Acquisition

Data were logged using the RVS ‘ABC’ system. The data were sampled at a frequency of 32 Hz. Data reduction was in real time, converting the 32 Hz data to a 1-second time-series (done by the RVS Level A system), which was logged as digital counts on the Level C.

Due to the channel capacity limitations of the Level A hardware, two parallel systems were used, one to log the hydrographic data whilst the other logged the optical data. Synchronisation of the time channels from the two data streams proved an unexpected and, as yet, unsolved problem that is responsible for the non-availability of the optical data.

3) On-Board Data Processing

Much of the SeaSoar data processing was undertaken in close to real time. Data were

logged for four hours and processed during the following four hours whilst the next four-hour segment of data was being logged.

The raw data were passed from the Level C onto a second Sun workstation running the P-EXEC suite of data processing software. Standard procedures were then used to convert the raw counts into engineering units (pressure (db), salinity (PSU), temperature (C), oxygen (ml/l), nominal chlorophyll (mg/m^3)). Salinity was computed from conductivity using the algorithms given in Fofonoff and Millard (1982).

The objectives of the real time data processing were the elimination of spikes and the correction of salinity offsets due to biological fouling. The latter is a problem to which SeaSoar is particularly susceptible, because the fish travels through the water at well over 10 knots and inevitably collides with animals whose remains become lodged in the exposed conductivity cell.

The quality control procedure was to plot out temperature/salinity diagrams for each upcast and downcast, and a time series plot for the segment. These were used to identify spikes and quantify any salinity offsets. Spikes were eliminated (set to null values) and offsets corrected using the editing programs included in the P-EXEC package.

Inevitably, most of the available time was spent cleaning up the salinity channel. Any rare problems in the temperature channel were apparent from the T/S plots. However, it is quite conceivable for spikes in the chlorophyll or oxygen channels to have passed unnoticed.

The individual four-hour data files were merged into survey leg files and the near surface salinities were calibrated using bottle samples taken from the non-toxic supply shortly before the SeaSoar reached the surface. The sampling was timed to ensure that the SeaSoar passed through the water sampled.

The back-calibration gave rise to the equation below, which has been applied to the data:

$$S_{corr} = 1.031033 * S_{obs} - 1.051615 \qquad (r^2 = 98.4\%: n=24)$$

Dissolved oxygen was computed as a nominal value that was calibrated against water samples collected as described above and analysed following the method of Williams and Jenkinson (1982).

This gave the equation below, which has been applied to the data:

$$O_{corr} = 0.654 * O_{obs} + 2.626 \qquad (r^2 = 79.2\% \ n=9)$$

Nominal chlorophyll was calibrated against extracted chlorophyll data obtained from water samples taken as described above. Samples were filtered and extracted into 90% acetone, then assayed on-board using a Turner Designs bench fluorometer calibrated against absolute chlorophyll standards.

The method of Strass (1990) was applied, using PAR data patched in from the optics

files. The calibration was, however, fraught with problems. First, the extracted data chlorophyll data set used was compromised by instrumental problems with the bench fluorometer. Secondly, the PAR data were subject to errors due to the Level A synchronisation problem discussed above. Thirdly, the extracted chlorophyll data set (63 samples) was small.

It is therefore not surprising that very poor regression statistics (r^2=10.9%) were reported.

The calibrated data were interpolated onto a regular grid with cells 4km long by 8m deep using the P-EXEC program PGRID, based upon UNIRAS interpolation algorithms. These gridded files form the basis for the data set on the CD-ROM. The full 1Hz data (in GF3 format) have been archived by BODC.

4) Post-Cruise Processing

The gridded data files were loaded directly into Oracle tables by a one-off program written for the purpose. This extracted header information for each column in the grid from the underway data file and then loaded the datacycles into a table used for calibrated CTD data. Thus, each column of the gridded data files has been treated as if it were a CTD cast with each profile containing data from 1.5 to 2 (depending on the depth attained) oscillations of the SeaSoar.

Further attention was given to the chlorophyll calibration. A set of samples was frozen on board and subsequently extracted and fluorometrically assayed. This data set was regressed against the chlorophyll values from the appropriate surface bins giving rise to the equation:

$$Chl_{corr} = Chl_{obs}*0.526 + 0.194 \qquad (r^2=42.6\%: n=24)$$

This equation has been applied to the data. The validity of this recalibration is open to question but, due to numerous technical obstacles, a more rigorous recalibration was not possible. There is therefore cause for concern with the chlorophyll calibration for this cruise and users are advised to treat the absolute chlorophyll values with caution.

Dissolved oxygen was converted from ml/l to µM by multiplying the values by 44.66. Oxygen saturations were computed using the equations of Benson and Krause (1984).

5) Data Warnings

Salinity accuracy is not known but the data are believed to be of good quality. In general, good quality SeaSoar data have salinity accuracy of the order of 0.02 PSU. Users concerned about the third decimal place in salinity are warned that these data may not be sufficiently accurate.

The chlorophyll calibration was beset with problems and absolute chlorophyll values should be used with caution.

6) Bibliography

Benson, B.B., Krause, D. Jr. 1984. The concentration and isotopic fractionation of oxygen dissolved in fresh water and sea water in equilibrium with the atmosphere. ***Limnol. Oceanogr***. 29, 620-632.

Fofonoff N.P., Millard R.C. 1982. Algorithms for computation of fundamental properties of seawater. ***UNESCO Technical papers in Marine Science*** 44.

Strass, V. 1990. On the calibration of large-scale fluorometric chlorophyll measurements from towed undulating vehicles. ***Deep Sea Res*** 37(3A): 525-540.

Williams P.J. Leb., Jenkinson N.W. 1982. A transportable microprocessor-controlled precise Winkler titration suitable for field station and shipboard use. ***Limnol. Oceanogr.*** 27, 567-585.

SeaSoar Data for Cruise Discovery 192
(9th June to 27th June 1990)

1) Instrumentation

The SeaSoar is a hydrodynamic fish towed behind a ship travelling at 8-9 knots linked by a faired cable. The unit has two stub wings whose angle of attack may be set by hydraulic servomotors. Thus the fish is able to climb or dive under the control of command signals from the ship or, more usually, by automatic command signals driven by the on-board pressure sensor.

On this cruise, the SeaSoar cable was approximately 600 metres in length, enabling the fish to 'fly' between the surface and a depth of 400m. The unit was programmed to ascend and descend at approximately 1 m/s which, assuming a towing speed of 8.5 knots, gave a complete oscillation from surface to 400m and back to the surface for every 3.6 km travelled.

The SeaSoar contained a Neil Brown Systems Mk3B CTD incorporating a pressure sensor, conductivity cell, platinum resistance thermometer and a Beckmann dissolved oxygen sensor. The unit was mounted horizontally along the body of the fish. A Chelsea Instruments Aquatracka fluorometer was mounted in the nose of the fish sampling through a downward-facing window at an angle of 45 degrees.

The instrument was also fitted with an array of 16 upwelling and downwelling irradiance sensors covering a range of spectral bands. No data are available from these.

2) Data Acquisition

Data were logged using the RVS ‘ABC’ system. The data were sampled at a frequency of 32 Hz. Data reduction was in real time, converting the 32 Hz data to a 1-second time-series (done by the RVS Level A system), which was logged as digital counts on the Level C.

Due to the channel capacity limitations of the Level A hardware, two parallel systems were used, one to log the hydrographic data whilst the other logged the optical data. Synchronisation of the time channels from the two data streams proved an unexpected and, as yet, unsolved problem (coincidence between minimum pressure and maximum irradiance could not be achieved), which is responsible for the non-availability of the optical data.

3) On-Board Data Processing

Much of the SeaSoar data processing was undertaken in close to real time. Data were logged for four hours and processed during the following four hours whilst the next four-hour segment of data was being logged.

The raw data were passed from the Level C onto a second Sun workstation running the P-EXEC suite of data processing software. Standard procedures were then used to convert the raw counts into engineering units (pressure (db), salinity (PSU), temperature (C), oxygen (ml/l), nominal chlorophyll (mg/m^3)). Salinity was computed from conductivity using the algorithms given in Fofonoff and Millard (1982).

The objectives of the real time data processing were the elimination of spikes and the correction of salinity offsets due to biological fouling. The latter is a problem to which SeaSoar is particularly susceptible, because the fish travels through the water at well over 10 knots and inevitably collides with animals whose remains become lodged in the conductivity cell.

The quality control procedure was to plot out temperature/salinity diagrams for each upcast and downcast, and a time series plot for the segment. These were used to identify spikes and quantify any salinity offsets. Spikes were eliminated (set to null values) and offsets corrected using the editing programs included in the P-EXEC package.

Inevitably, most of the available time was spent cleaning up the salinity channel. Any rare problems in the temperature channel were apparent from the T/S plots. However, it is quite conceivable for spikes in the chlorophyll or oxygen channels to have passed unnoticed.

The individual four-hour data files were merged into survey leg files and the near surface salinities calibrated from bottle samples taken from the non-toxic supply shortly before the SeaSoar reached the surface. The sampling was timed such that the SeaSoar passed through the water sampled.

This gave the equation below, which has been applied to the data:

$$S_{corr} = S_{obs} + 0.0545$$

Dissolved oxygen was computed using a nominal calibration.

No meaningful chlorophyll calibration was possible during the cruise due to the severe malfunctioning of the Turner Designs bench fluorometer.

The calibrated data were interpolated onto a regular grid with cells 4km long by 8m deep using the P-EXEC program PGRID, based upon UNIRAS interpolation algorithms. These gridded files form the basis for the data set on the CD-ROM. The full 1Hz data (in GF3 format) have been archived by BODC.

4) Post-Cruise Processing

The gridded data files were loaded directly into Oracle tables by a one-off program written for the purpose. This extracted header information for each column in the grid from the underway data file and then loaded the datacycles into a table used for calibrated CTD data. Thus, each column of the gridded data files has been treated as if it were a CTD cast with each profile containing data from 1.5 to 2 (depending on the depth attained) oscillations of the SeaSoar.

A set of surface water samples corresponding to SeaSoar arrivals at the surface was taken, filtered through GF/F filter papers and frozen. These were extracted into 90% acetone back in the laboratory and assayed fluorometrically.

This data set was used to calibrate the fluorometer as follows. First, surface bin values corresponding to the sampling times were obtained and compared against the extracted chlorophyll values. The result showed a weak but significant correlation (r=0.69). Bringing irradiance (from a sensor on the ship's mast) into the calibration significantly increased the correlation (r=0.81). This may partially result from the log transforms used in the regression, but a subsequent analysis of the magnitude of the residuals at midday showed a marked improvement when PAR was considered.

The calibration equation derived was:

$$\text{chl}(\text{mg/m}^3) = \exp(0.000735*\text{PAR} + 0.670*\log(\text{nominal chlorophyll}) - 0.536) \quad (r^2=65.8\%)$$

No PAR channel was available for the SeaSoar data. This problem was overcome by using CTD data to determine the following empirical relationship between the surface underway PAR and the PAR at depth:

$$\text{PAR} = \exp(\log(\text{surface PAR}) - 0.085*(\text{pressure}-6))$$

These two equations were combined to generate recalibrated chlorophyll data from the binned nominal chlorophyll data set. Comparisons of the calibrated chlorophyll values with the extracted chlorophyll data set and the data from the underway Turner Designs instrument were most encouraging.

Dissolved oxygen was converted from ml/l to µM by multiplying the values by 44.66. Surface bin values were then regressed against contemporaneous samples determined following the methods of Williams and Jenkinson (1982).

Empirical analysis of the data showed that for the first three legs of the SeaSoar survey (until 07:45 on June 14th) the following relationship could be derived:

$$O_{corr} = O_{obs}*0.962 + 29.3 \qquad (r^2=86.8\%)$$

The resulting calibrated data showed good agreement with the underway Endeco dissolved oxygen data. For the rest of the SeaSoar survey, the equation below was derived:

$$O_{corr} = O_{obs}*0.387 + 167 \qquad (r^2=29.0\%)$$

The statistics of this calibration are very poor and the good agreement with the Endeco data observed for the first three legs of the survey breaks down. Consequently, users are advised to use the oxygen data from the latter part of the survey with extreme caution. These data have been flagged as suspect in the database.

Oxygen saturations were computed using the equations of Benson and Krause (1984).

All the calibrations described above have been applied to the data.

5) Data Warnings

Salinity accuracy is not known but the data are believed to be of good quality. In general, good quality SeaSoar data have salinity accuracy of the order of 0.02 PSU. Users concerned about the third decimal place in salinity are warned that these data may not be sufficiently accurate.

The dissolved oxygen data after 07:45 on 14th June 1990 are of poor quality and are best ignored. They have been flagged as suspect in the database.

6) Bibliography

Benson, B.B., Krause, D. Jr. 1984. The concentration and isotopic fractionation of oxygen dissolved in fresh water and sea water in equilibrium with the atmosphere. ***Limnol. Oceanogr***. 29, 620-632.

Fofonoff N.P., Millard R.C. 1982. Algorithms for computation of fundamental properties of seawater. ***UNESCO Technical papers in Marine Science*** 44.

Williams P.J. Leb., Jenkinson N.W. 1982. A transportable microprocessor-controlled precise Winkler titration suitable for field station and shipboard use. ***Limnol. Oceanogr.*** 27, 567-585.

SeaSoar Data for Cruise Discovery 198
(11th November to 14th December 1992)

1) Instrumentation

The SeaSoar is a hydrodynamic fish, manufactured by Chelsea Instruments, which was towed behind a ship travelling at 8-9 knots (5-6 knots in bad weather) linked by a faired cable. The unit has two stub wings whose angle of attack may be set by hydraulic servomotors. Thus the fish is able to climb or dive under the control of command signals from the ship or, more usually, by automatic command signals driven by the on-board pressure sensor.

On this cruise, the SeaSoar cable was approximately 600 metres in length, enabling the fish to 'fly' between the surface and a depth of 430m. The unit was programmed to ascend and descend at approximately 1 m/s which, assuming a towing speed of 8.5 knots, gave a complete oscillation from surface to 430m and back to the surface for every 4km travelled.

The SeaSoar contained a Neil Brown Systems Mk3B CTD incorporating a pressure sensor, conductivity cell, platinum resistance thermometer and a brand new dissolved oxygen sensor. The unit was mounted horizontally along the body of the fish. A Chelsea Instruments Aquatracka fluorometer was mounted in the nose of the fish sampling through a downward-facing window at an angle of 45 degrees. A single 2-pi PAR scalar irradiance sensor (manufactured by Chelsea Instruments from a PML design) was fitted to the top of the fish (fixed mount) to measure downwelling scalar irradiance.

2) Data Acquisition

Data were logged using the RVS ‘ABC’ system. The data were sampled at a frequency of 32 Hz. Data reduction was in real time, converting the 32 Hz data to a 1-second time-series (done by the RVS Level A system), which was logged as digital counts on the Level C.

3) On-Board Data Processing

3.1) Processing and Editing

Much of the SeaSoar data processing was undertaken in close to real time. Data were logged for four hours and processed during the following four hours whilst the next four-hour segment of data was being logged.

The raw data were passed from the Level C onto a second Sun workstation running

the P-EXEC suite of data processing software. Standard procedures were then used to convert the raw counts into engineering units (pressure (db), salinity (PSU), temperature (C), oxygen (ml/l), nominal chlorophyll (mg/m^3)). Salinity was computed from conductivity using the algorithms given in Fofonoff and Millard (1982).

The objectives of the real time data processing were the elimination of spikes and the correction of salinity offsets due to biological fouling. The latter is a problem to which SeaSoar is particularly susceptible, because the fish travels through the water at well over 10 knots and inevitably collides with animals whose remains become lodged in the exposed conductivity cell.

The quality control procedure was to plot out temperature/salinity diagrams for each upcast and downcast, and a time series plot for the segment. These were used to identify spikes and quantify any salinity offsets. Spikes were eliminated (set to null values) and offsets corrected using the editing programs included in the P-EXEC package.

Inevitably, most of the available time was spent cleaning up the salinity channel. Any rare problems in the temperature channel were apparent from the T/S plots. However, it is quite conceivable for spikes in the chlorophyll or oxygen channels to have passed unnoticed.

3.2) Sample Calibrations

The individual four-hour data files were merged into survey leg files and the near surface salinities were calibrated using bottle samples taken from the non-toxic supply when the SeaSoar reached the surface. Subsequent analysis showed that this timing was far from perfect. However, the surface mixed layer was sufficiently homogenous for this not to be a significant problem.

<u>Salinity</u>

The salinity back-calibration gave rise to the corrections below, which have been applied to the data:

Drake Passage transect	$S_{corr} = S_{obs} + 0.015$
First ice-edge survey	$S_{corr} = S_{obs} + 0.024$
Second ice-edge survey (part 1)	$S_{corr} = S_{obs} + 0.044$
Second ice-edge survey (part 2)	$S_{corr} = S_{obs} + 0.010$

There are two values given for the second ice-edge survey. During the first half of the survey the behaviour of the conductivity cell was described in the cruise report as ‘aberrant’ with large ($\pm$0.015) variation in the required salinity correction, which was attributed to the presence of krill shoals. The sensor settled down for the second half of the survey. The salinity accuracy was reported as within 0.01 PSU for 99% of the time the SeaSoar was deployed.

<u>Oxygen</u>

The usual CTD oxygen calibration technique for the group working up the SeaSoar

was to compute dissolved oxygen concentration from the CTD temperature (T_{CTD}) and pressure (P), plus the oxygen sensor current (C_{oxy}) and temperature (T_{oxy}) readings using the algorithms:

$$T = a * T_{CTD} + b * T_{oxy}$$

$$\text{Oxygen} = \rho * C_{oxy} * \exp(-\alpha * T + \beta * P)$$

The coefficients a and b were chosen (often 0.75 and 0.25) to minimise hysteresis between upcast and downcast profiles due to the slow response of the oxygen temperature sensor. The coefficients ρ, α and β where then determined to obtain the best fit to water bottle oxygen data.

However, this procedure did not work well for the SeaSoar oxygen data for this cruise due to the small temperature gradients south of the Polar Front and the high vertical speed of SeaSoar through the water compared to a CTD. An alternative approach was adopted in which the oxygen current was 'speeded up' using the formula:

$$C_{oxy}(t_0) = \text{raw}C_{oxy}(t_0) + \tau\,[\text{raw}C_{oxy}(t_1) - \text{raw}C_{oxy}(t_{-1})]/(t_1 - t_{-1})$$

Where t_{-1}, t_0 and t_1 were successive 1-second values and the oxygen temperature was ignored (i.e. coefficient b was set zero). The coefficient τ was set to 15 for the Drake Passage section and to 10 for the ice-edge surveys.

The oxygen sample set (analysed following the protocols of Williams and Jenkinson (1982)) used consisted of the usual surface samples (taken every two hours) collected when the fish was about to surface supplemented by CTD bottle data collected along 85°W. This was necessary because of problems with the underway sampling in Antarctic conditions. The coefficient values chosen were ρ=1.472, α=-0.036 and β=0.0003965. Oxygen values were quoted as within 2% except in the region of the thermocline where accurate calibration proved impossible.

Oxygen saturations were computed using the equations of Benson and Krause (1984).

<u>Chlorophyll</u>

The fluorometer was calibrated against fluorometric extracted chlorophyll determinations on non-toxic samples drawn just before SeaSoar was due to surface. Only samples collected when the ambient light was below 2 W/m^2 were included in the calibration. Two calibration equations were derived, one for the Drake Passage section and one for the ice-edge survey area:

Drake Passage

$$\ln(\text{chl}) = -2.5067 + 1.1071\ V \qquad (r^2 = 0.81)$$

Ice-edge

$$\ln(chl) = -4.8823 + 1.8957\ V \qquad (r^2 = 0.92)$$

3.3) Gridding

The calibrated data were interpolated onto a regular grid with cells 4km long by 8m deep using the P-EXEC program PGRID, based upon UNIRAS interpolation algorithms. These gridded files form the basis for the data set on the CD-ROM. The full 1Hz data (in GF3 format) have been archived by BODC.

4) Post-Cruise Processing

The gridded data files were loaded directly into Oracle tables by a one-off program written for the purpose. This extracted header information for each column in the grid from the underway data file and then loaded the datacycles into a table used for calibrated CTD data. Thus, each column of the gridded data files has been treated as if it were a CTD cast with each profile containing data from 1 to 2 (depending on the depth attained) oscillations of the SeaSoar.

5) Data Warnings

None.

6) Bibliography

Benson, B.B., Krause, D. Jr. 1984. The concentration and isotopic fractionation of oxygen dissolved in fresh water and sea water in equilibrium with the atmosphere. ***Limnol. Oceanogr***. 29, 620-632.

Fofonoff N.P., Millard R.C. 1982. Algorithms for computation of fundamental properties of seawater. ***UNESCO Technical papers in Marine Science*** 44.

Williams P.J. Leb., Jenkinson N.W. 1982. A transportable microprocessor-controlled precise Winkler titration suitable for field station and shipboard use. ***Limnol. Oceanogr.*** 27, 567-585.