

3.2 CTD minipack processing and calibration

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Data



The 'C21' SeaSoar system (Allen et al., 2002), used for the first time on D253 (May/June 2001), carries a Chelsea Instruments Minipack CTDF (Conductivity, Temperature, Depth and Fluorescence) instrument which is considerably more compact than the Neil Brown CTD instrument that had traditionally been carried in SeaSoar. The two MiniPack CTDs taken on D285/6 suffered major problems that are discussed later in this section.

During SeaSoar deployments data were recovered, in real time, from the PENGUIN data handling system on SeaSoar by ftp to create identical data files on the EMPEROR Linux PC in the main lab: this is discussed in detail in the preceding technical support section. Thus data were logged in three files, one containing the CTDF measurements, and two other files for the FRRF and OPC data. The FRRF and OPC data are dealt with elsewhere in this report.

All of the variables output by the MiniPack CTDF were calibrated using pre-set calibrations stored in the instrument firmware. The sensors sampled at 16 Hz, but the output variables were one second averages. The variables output were:

Conductivity (mScm^{-1})

Temperature ($^{\circ}\text{C}$)

Pressure (dbar)

ΔT ($^{\circ}\text{Cs}^{-1}$), temperature change over the one second averaging period.

Chlorophyll (mgm^{-3})

Each of these were output at one second intervals and a time/date stamp was added by the DAPS handling software on PENGUIN. The time rate of change of temperature, ΔT ($^{\circ}\text{Cs}^{-1}$) was the difference between the first and the last sample in the one second average of temperature. Firmware calibration coefficients for the two CTDs were as follows:

Minipack serial no. 210012, calibration date 30/01/04,

$$press. = \left(-1.85335 \times 10^{-9} \times bits^2\right) + \left(9.46170 \times 10^{-3} \times bits\right) - 10.2313$$

$$temp. = (5.15065 \times 10^{-11} \times bits^2) + (5.99447 \times 10^{-4} \times bits) - 3.5094$$

$$cond. = (-7.16162 \times 10^{-11} \times bits^2) + (1.11034 \times 10^{-3} \times bits) - 0.9619$$

$$chl. conc. = (0.00208 \times bits) - 3.694.$$

Minipack serial no. 210035, calibration date 10/12/04,

$$press. = (-1.43239 \times 10^{-9} \times bits^2) + (9.41950 \times 10^{-3} \times bits) - 9.4446$$

$$temp. = (5.48513 \times 10^{-11} \times bits^2) + (6.02014 \times 10^{-4} \times bits) - 2.9999$$

$$cond. = (-1.02301 \times 10^{-10} \times bits^2) + (1.12546 \times 10^{-3} \times bits) - 0.9859$$

$$chl. conc. = (0.00211 \times bits) - 3.902.$$

Minipack 210012 was used throughout both D285 and D286 but suffered severe temperature calibration drifting from the middle of the second major tow SS15514. This is clearly apparent below (Fig. 3.3), plotted against the thermosalinograph remote housing temperature. However, at the time, without a CTD deployment at the end of this tow, and with the close proximity of the Crozet Islands, the resulting low salinities seemed plausible. After the third major tow, stn. 15530, the severity of this temperature drift became clearly apparent, now ~0.3 degrees high and getting rapidly worse. From profile to profile the T/S relationship was tight, and the drift was not easily discernable from a single plotpr page (less than 1 mm over the entire page, 10 groups of four profiles at 20 mm offset spacing). After swapping for Minipack 210035, it was found that its conductivity cell did not work and so we were forced to swap 210012 back into the vehicle despite the temperature drift. Following 210012's replacement in the SeaSoar vehicle, during the last major tow, stn. 15041, the drift appeared to have ceased and perhaps even begun to reverse, however the offset was now in the region of 0.4-0.5 °C. Significant effort would be required to recover these data to anything like a reasonable standard. A 'final' calibration was obtained for the D285 data before the end of D286 and is discussed later.

With no prospect of a replacement CTDF for D286, work began to fit a SeaBird MicroCat CT sensor on SeaSoar. This then used TTY2 serial port on PENGUIN and was expected to provide reliable temperature. In addition, the temperature sensor from

210035 was swapped into 210012 during passage at the end of D285, with the hope that this would at least provide stability, accepting of course that we would not have a

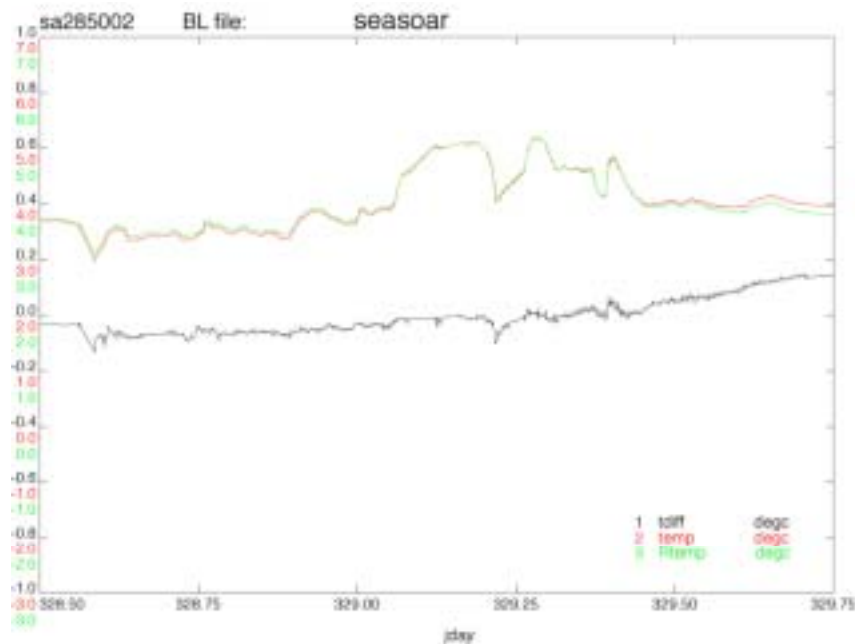


Fig. 3.3 Comparison of minipack (temp) and thermosalinograph (Rtemp) temperatures

relevant calibration. For the first SeaSoar deployment on D286, SS15551, The MicroCat was fitted inside the SeaSoar body with a neoprene tube fitted to take water from the nose of SeaSoar to the instrument. The MicroCat has a free flow conductivity sensor arrangement into which the right diameter hose could easily be fitted, however I had not realised at this stage that the temperature sensor was external to this! It was not possible therefore, to calculate sensible salinity values from this setup. Therefore for the subsequent tows, SS15575 and SS15593, the Microcat was fitted external to the SeaSoar body, on the upper tail plane close to the fin, where there was no requirement for any ducted water supply. The MicroCat was not designed for use on this sort of platform; it had a maximum rate of sampling of just under 1 Hz and it was not possible to synchronise temperature and conductivity measurements sufficiently to produce sensible T/S profiles. The MicroCat instrument was eventually fitted to a mooring as originally planned, and thus the remaining SeaSoar tows, SS15601, SS15608, SS15624, SS15630 and SS15631, were carried out with only the MiniPack CTD sensors. Two new cshell scripts were created, *mcexec0* and *mcexec1*, from those used for processing MiniPack data and discussed later in this section. The principal difference was an additional call to *pcalib* to obtain conductivity in mmho/cm from *mcexec0*, and additional calls to *pmerge* and *pcalc* to obtain pressure data from the MiniPack files and to calculate/apply a lag temperature,

respectively, from *mcexec1*. The temperature data from the MicroCat were useful in guiding our initial calibration of the MiniPack data during D286, however, it is unlikely that a similar instrument will be used on the SeaSoar vehicle again and thus further detailed discussions are not required here.

Processing Steps

The following processing route was followed every 12 hours during SeaSoar tows:

The DAPS data file on EMPEROR was stopped and a new one started every 12 hours, at which time the PENGUIN clock was checked for large drifts and later clock correction if required. The PENGUIN clock was found to gain, but even after nearly six days continuous logging, the PENGUIN clock only gained ~ 40 seconds and thus no offsets were applied to the datasets. The PENGUIN clock was reset at the beginning of each SeaSoar deployment. The latest 12 hour DAPS data files were copied from the EMPEROR PC to the shipboard SUN UNIX system over the ship's ethernet.

pgexec0

Read the raw DAPS data into PSTAR format and added information to the PSTAR header. In addition time in seconds was calculated from the Jday variable used by DAPS. Note that it was necessary to use the *-square* command line option for the pexec program *pxtime*. Unless this option was specified *pxtime* rounded the time to the nearest second occasionally giving rise to two records having the same time.

pgexec1

With the Minipack set to output variables in physical units it is not necessary to use the pexec program *ctdcal*, and so this script was written to replace *ssexec1* by D. Smeed during D253. We may review this for temperature during D286, following the drifting temperature problem with MiniPack 210012 during D285. The main steps are

- a) *pcalc* to apply temperature lag correction
- b) *pintrp* to interpolate pressure across gaps in the data. Typically less than 0.3% of the data had to be interpolated
- c) *peos83* to calculate salinity and density.

Pedita was then used to remove the worst surface salinity spiking and rare fluorometer spikes. Further editing for spikes, and salinity offsets due to high vehicle dive rates was carried out by inspection with *plpred*.

Subsequently, 12 hour files were merged to produce a single file for each survey, which was then merged with the navigation data. The data were interpolated to a 4 km by 8 dbar regular grid using *pgridp*.

Temperature Correction

It is necessary to make a correction for the small delay in the response of the CTD temperature sensor for two reasons: First, to obtain a more accurate determination of temperature for points in space and time; second, and more importantly, to obtain the correct temperature corresponding to conductivity measurements, so that an accurate calculation of salinity can be made.

Surprisingly, according to the Minipack users manual, the time response of the temperature and conductivity cells should have been the same. However, a lag in temperature was apparent in the data in two ways. There was a difference between up and down profiles of temperature (and hence salinity) because the time rate of change of temperature has opposite signs on the up and down casts. The second manifestation was the “spiking” of salinity as the sensors traversed maxima in the gradients of temperature and salinity. The rate of ascent and descent of SeaSoar was greater (typically up to 3-4 ms⁻¹ at the beginning of descent and ascent) than that of a lowered CTD package, thus the effects of the temperature lag were more pronounced. Thus, the following correction was applied to the temperature during *pgexec1* before evaluating the salinity

$$T_{corr} = T_{raw} + \tau \cdot \Delta T$$

where ΔT is defined above and τ is constant.

The best value of τ was chosen so as to minimise the difference between up and down casts and noise in the salinity profile. Initially the best value was found to be $\tau = 1.3$ second (stns. 15497-15536), but this noticeably changed after replacement of the Minipack 210012 in the SeaSoar vehicle for SS15541 to $\tau = 1.15$ second. This agreed with the large lag needed on D253, but it was still somewhat concerning and needs to be discussed further with Chelsea instruments.

Following the exchange of temperature sensors between D285 and D286, it was clear that the lag correction required was greatly reduced. At the beginning of D286 (SS15551), the best value was found to be $\tau = 0.3$, and therefore similar to the expected time response of the temperature sensor, 0.3 seconds. However this did not remain stable for the rest of the cruise: $\tau = 0.35$ was found to be a better value for SS15575, returning to $\tau = 0.3$ for stns. 15593-15630. During the final SeaSoar tow, SS15631, the required temperature lag correction changed from $\tau = 0.24$ at the beginning of the tow to $\tau = 0.27$ at the end.

Calibration

Our primary tool for the calibration of the Minipack CTD data was and is the underway thermosalinograph (TSG) connected to the ship's non-toxic supply. With such a poor absolute reference to temperature from the Minipack CTD we were very lucky to find that the TSG was generally stable, well behaved and easy to calibrate during D285 and D286. In the following sections I will therefore deal with the TSG calibration first, moving on to the final calibration of D285 SeaSoar temperature and salinity and finishing with the initial temperature calibrations applied to the D286 SeaSoar data. In this final section I hope also to have provided some pointers for further calibration of the D286 data which should be significantly easier than the procedure that was necessary for the D285 data.

TSG calibration

TSG remote temperature, 'Rtemp' measured at the ship's non-toxic intake, was calibrated to CTD temperature data (discussed elsewhere) from ~ 4 metres water depth during both up and down casts. For both D285 and D286 only a constant offset was required to calibrate the TSG remote temperature to an accuracy of ~ 0.02 , excluding occasional apparently random outliers.

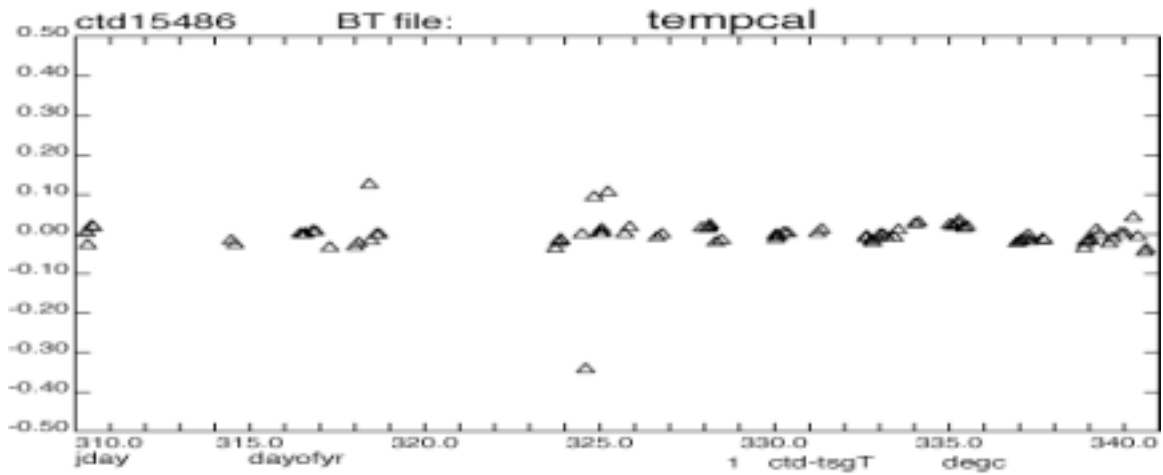


Fig.3.4 Comparison of corrected TSG temperature with CTD temperature for D285, where corrected TSGtemp = Rtemp – 0.065

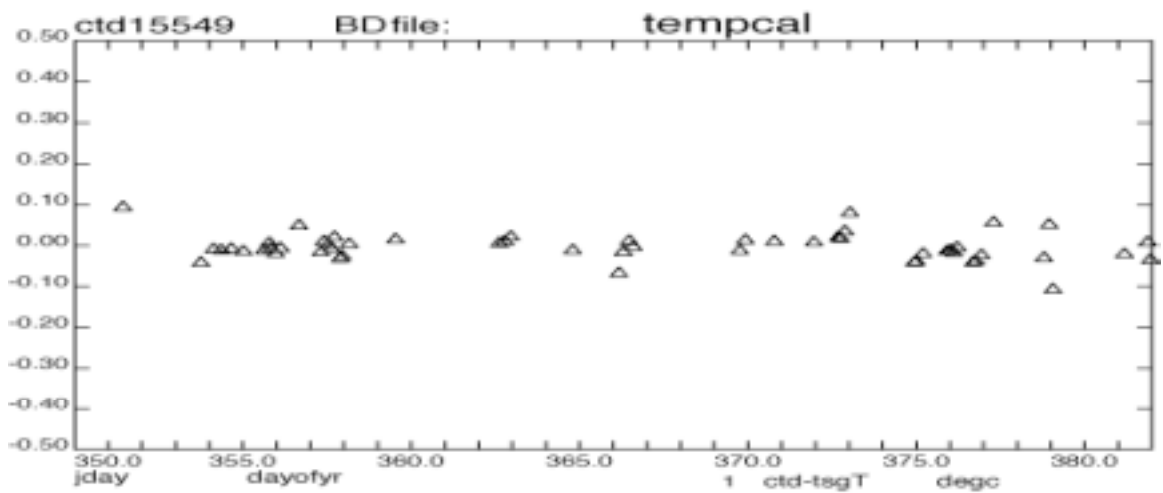


Fig.3.5 Comparison of corrected TSG temperature with CTD temperature for D286, where corrected TSGtemp = Rtemp – 0.050

For D285, calibrated TSG temperature (TSGtemp) was determined as

$$TSGtemp = Rtemp - 0.065$$

For D286, calibrated TSG temperature (TSGtemp) was determined as

$$TSGtemp = Rtemp - 0.050$$

TSG salinity was then calibrated to underway bottle samples determined using the Guildline Autosal and discussed elsewhere in this report. During both D286 and D285 the TSG salinity offset was found to have a significant but linear temperature dependence. This was calibrated out as follows, using *pcalc*.

For D285, calibrated TSG salinity (TSGsalin) was determined as

$$TSGsalin = Salinity - 0.1314 - (0.0012 * TSGtemp)$$

For D286, calibrated TSG salinity (TSGsalin) was determined as

$$TSGsalin = Salinity - 0.1180 - (0.0024 * TSGtemp)$$

however, in this case there was also a noticeable linear temporal drift of 0.01 in magnitude towards the end of the survey (beginning at jday 375) which was calibrated out using *tabcal*.

D285 SeaSoar Minipack 'final' calibrations

Comparison with the calibrated thermosalinograph data was made throughout by selecting SeaSoar Minipack data on a depth range of 3-6 metres using *datpik*.

SS15497

Against TSGsalinity, the SeaSoar salinity was 0.02 high and for this tow there appeared to be no significant problem with temperature. Following calibration of salinity as

$$salin = salin - 0.02,$$

a reasonable match with ctd15496 was possible but a similar match with ctd15498 was not achieved, possibly because of poor co-location with the end of the SeaSoar tow.

I am happy with this calibration to an accuracy of ~0.02 in both salinity and temperature, with the following caveats. Firstly, during daylight hours of jday 219 there was no correlation between minipack and TSG data. It is possible that this results from a transient surface skin heating phenomenon known as the 'afternoon effect' but it looks more serious and I can find no clear explanation. Secondly, the Minipack temperature appeared high by 0.02 over the TSG until it jumped to being ~0.015 low at midnight on jday 320. No temperature calibration has been made for this as the point of transition did not correlate with salinity; which, and finally, was high by 0.02 until a period of bad weather over midnight jday 321 where SeaSoar failed to reach the surface due to reduced ship speed. After this point the salinity appears to have drifted to a zero offset before returning to a 0.02 offset by the end of the deployment.

SS15514

Against the calibrated TSGtemp, the SeaSoar temperature began to drift noticeably from the beginning of this deployment. Furthermore, the rate of drift appeared to increase with

time. Initially it looked as though three linear drift gradients might best characterise the offset. However in echo of the problems encountered with Stn. 15497, it seemed impossible to reconcile intercept points that explained both salinity and temperature offsets. In the end a second order polynomial fit was derived using MS Excel, fitting to jday (normalised to the start of the deployment - 329) at 6 decimal place resolution. Thus temperature was calibrated as

$$temp = temp - 0.0163 - (0.1177 \times jday^*) - (0.1946 \times (jday^*)^2)$$

where

$$jday^* = jday - 329.$$

Referenced to the thermosalinograph, this left a residual offset in salinity of ~ 0.007 low within an accuracy of 0.025 (estimated). Comparison with previous ctd casts indicated a residual offset of 0.004 low but with respect to the noise level there was little point in calibrating any further. I am happy with the calibration to ~ 0.03 in temperature and salinity.

SS15519

This was a very short deployment and for much of the time SeaSoar failed to reach the surface - experimenting with flight parameters as this was the first time the deep OPC (much heavier, although smaller, 6000 m rated pressure case) had been carried on SeaSoar. Comparison with the calibrated TSGtemp allowed us to apply a constant offset of

$$temp = temp - 0.235.$$

The recalculated salinity showed a possible residual offset against TSGsalin but considerable less than 0.01 high. I was not able to make any sensible T/S match with ctds; but this is probably accounted for by deployment/recovery distances and rapid spatial changes in water mass characteristics. I am happy with the calibration to ~ 0.03 in both temperature and salinity.

SS15530

Continued temperature drift by comparison with the calibrated TSGtemp allowed us to apply a drifting temperature calibration as follows

$$temp = temp - 0.16 - (0.22 \times jday^*)$$

where

$$jday^* = jday - 334.$$

The recalculated salinity showed an additional moderate temporal drift. And a good match to to ctd 15528 (some distance before) and ctds 15531/2/4 gave significant robustness to the identification of this drift. Thus I further calibrated salinity as follows

$$salin = salin + 0.012 - (0.077 \times jday^*)$$

where again

$$jday^* = jday - 334.$$

I am satisfied with temperature to an accuracy of ~ 0.02 . Given temperature, however, I would consider salinity to be within 0.01; what a shame about the caveat!

SS15536

Continued temperature drift by comparison with the calibrated TSGtemp allowed us to apply a drifting temperature calibration as follows

$$temp = temp - 0.299 - (0.1353 \times jday^*)$$

where

$$jday^* = jday - 335.5.$$

The recalculated salinity showed a moderately good fit to zero residual offset at an accuracy level of 0.02. Comparison to ctds was interesting. A clear match could be obtained between the beginning of the survey and ctd15537/ctd15538, and a clear match could be obtained between the end of the survey and ctd15534. This is best explained by the triangular nature of the survey N.E from M8 E/W and returning in a S.E. direction to and through M8 E/W. The match at the beginning of the tow indicated that the Minipack salinity was still 0.02 high - which agreed with the moderate fit to the TSGsalin. At the end of the survey the ctd match indicated that the Minipack was 0.005 high, whereas the TSGsalin also indicated 0.02. So why not calibrate further ? Well the fit to TSGsalin indicated the Minipack to be low by as much as 0.02 for much of the middle part of the survey. Additionally a good T/S comparison was made between SeaSoar stn. 15536 and stn. 15497, which overlapped in space twice, with no offset following calibration of the latter. Thus I am happy with leaving the calibration there as within ~ 0.02 in salinity and temperature.

SS15541

Temperature appeared to stop drifting (well that's good, it was getting a little warm - not tropical but warm nonetheless !). Comparison with the calibrated TSGtemp and ctds 15540/2/3/4 allowed us to apply a constant offset temperature calibration as follows

$$temp = temp - 0.46.$$

The recalculated salinity left a moderate drift from 0.00 to 0.02 low by comparison with TSGsalin. However, comparison with the ctds gave no compelling evidence to believe this, if anything such a comparison indicated a zero offset. I am therefore happy with the calibration to ~ 0.02 in both temperature and salinity.

D286 SeaSoar Minipack initial 'calibrations'

With the SeaBird Microcat data for the first three deployments of SeaSoar we were at least able to compare temperature sensors. The temperature sensor on Minipack 210012 was now that from Minipack 210035, however, the calibration coefficients built into firmware remained. Therefore we effectively had an uncalibrated or mis-calibrated sensor. I expect that a quadratic fit to temperature is still required, and a re-calibration from CTG, post D288, will help particularly if we work with CTG towards a good output. However two things were obvious. Firstly, that visual comparison with the SeaBird Microcat temperature profiles (at expanded temperature scale - ~0.01 resolution) indicated very little temperature dependence. Secondly that comparison with the uncalibrated thermosalinograph remote temperature indicated significant drifts and jumps in the Microcat temperature data at the 0.01 - 0.03 level. This, as will now be discussed is at least similar to that shown in the Minipack data after a constant offset is taken into account. Early comparison between the uncalibrated thermosalinograph temperature and the 3-6 metre SeaSoar Minipack data indicated a large but reasonably constant offset around 0.7 degC high.

SS15551

Comparison of Minipack and Microcat temperature pressure profiles indicated a constant temperature offset even at a vastly expanded temperature scale of 1 degC per 2 cm x-axis unit. Therefore a constant calibration was applied such that

$$temp = temp + 0.70.$$

Re-calculation of salinity and comparison with ctd T/S profiles at the beginning and end of the deployment indicated a residual offset of 0.015 in salinity but no attempt was made to calibrate for this.

SS15575

In 3-6 metre data, what initially looked like a temperature dependant Minipack temperature offset to the Microcat temperature data was not applied. This was because such an offset was not clearly apparent in depth profile comparisons. And, furthermore, the Microcat temperature displayed time drifts (at the 0.02 degC level) and jumps (at the 0.01 degC level) when compared with the 'uncalibrated' TSG data which were not apparent in a similar comparison between the Minipack and the TSG. Therefore I chose to apply a best fit constant calibration of

$$temp = temp + 0.67$$

Re-calculation of salinity and comparison with ctd15576 indicated a residual offset of 0.010 in salinity but no attempt was made to calibrate for this.

SS15593

Once again, considerable relative drifting and jumping between near surface temperature values from the Minipack and the Microcat were not borne out in depth profile comparisons. Indeed such comparisons indicated little or no pressure or temperature related offset and therefore I chose, once again, to apply a best fit constant calibration of

$$temp = temp + 0.67$$

This appeared to be safe to an accuracy of ~ 0.02 but little better. A more complicated time dependent offset was hinted at by comparison with the 'uncalibrated' TSGtemp but this will have to wait until after the cruise.

A comparison of conductivity/depth profiles hinted at the Minipack high by 0.01 over the Microcat, but constant throughout the survey. After temperature calibration and re-calculation of salinity, a good match comparison with ctd15592 indicated a residual high offset of just 0.0025 in salinity. Interestingly the early Microcat temperature profiles showed a significant offset to this ctd, confirming that the large, rapidly drifting, offset in temperature at the beginning of this deployment was probably due to the Microcat and not the Minipack.

SS15601

The SeaBird Microcat was removed for the mooring at M2 prior to this deployment. Matching with the preceding ctd profiles at M6 and subsequent profiles at M2, indicated that the Minipack temperature was low by between 0.60 and 0.68, and clearly hinting at a lower offset that had been applied to the previous SeaSoar deployments. I chose to apply a best fit constant calibration of

$$temp = temp + 0.65.$$

SS15608

The initial calibration is based on a comparison with preceding ctds at M2 and the end of SeaSoar deployment stn. 15601. The ctds indicated that the Minipack temperature was low by between 0.60 and 0.64, and the comparison with SeaSoar stn. 15601 indicated that the Minipack temperature was low by between 0.63 and 0.68. I chose to continue to apply a best fit constant calibration of

$$temp = temp + 0.65.$$

SS15624

This was a mesoscale survey that began and ended at M3. The initial calibration is based on a comparison with preceding and subsequent ctds at M3. No really good match was found despite the transect through M3 during the survey, however the comparisons indicated that the Minipack was low by between 0.64 and 0.71. I therefore chose to revert to the best fit constant calibration of

$$temp = temp + 0.67.$$

Following re-calculation of salinity a better T/S fit to the ctd profiles was possible and this indicated that the Minipack temperature was still low by between 0.03 and 0.08.

SS15630

This deployment began at M3 and was to survey a number of east-west legs whilst progressing generally northwards towards M10. Bad weather less than 12 hours after deployment forced the ship to slow to below 4 knots and significantly restricted the vertical flight profile SeaSoar. Eventually, a termination failure forced vehicle recovery at the earliest opportunity, which was not until the next morning. Comparison with ctds

15627/8/9 at M3 indicated a temperature offset of between 0.71 and 0.74, but with a particularly good match to 0.74. I therefore chose a best fit constant calibration of

$$temp = temp + 0.74.$$

However, following re-calculation of salinity a better T/S fit to the ctd profiles was possible and this indicated that the Minipack temperature was now high by ~ 0.05 and that residual salinity was high by ~ 0.03 .

SS15631

This deployment completed the run to M10. Comparison with ctd 15632 at M10 provided a good match to an offset of 0.81. I therefore chose a best fit constant calibration of

$$temp = temp + 0.81.$$

Summary

As found on D253, a great advantage of the inductive conductivity cell used in the CTG Minipack is that the occurrence of spikes and offsets due to biological fouling is virtually nil. Thus it was entirely feasible for all the SeaSoar processing to be undertaken by just one scientist.

However, the stability of the instrument's temperature sensor is clearly a worrying problem. Such a wild drift in temperature seriously threatens our ability to recover some of the data, and must raise doubts over the long term suitability of the Minipack instrument for the SeaSoar vehicle. In 2001, this instrument was one of the first of the modern miniaturised CTD instruments on the market, however, there now exists considerable choice in the market place including instruments from SeaBird, the company that currently holds the standard in lowered CTD accuracy. However it is noted that the tight replication between T/S profiles that are achieved, once a suitable temperature correction is determined, might be hard to beat.

Allen, J., J. Dunning, V. Cornell, M. Moore and N. Crisp 2002. Operational Oceanography using the 'new' SeaSoar ocean undulator. *Sea Technology*, **43**(4), 35-40.