

National Oceanography Centre, Southampton

Cruise Report No. XXX

RRS *James Cook* Cruise 30

26 December 2008 – 30 January 2009

Antarctic Deep Rates of Export (ANDREX)

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We are grateful to Phil Hosegood for frequent nightly sampling. We thank the CTD watch groups for various kinds of support. The captain and crew of RRS James Cook enthusiastically supported the ANDREX project. Ute Schuster, Gareth Lee, Simon Ellis, Andy MacDonald, Dave Blomfield and Alex Etchells (UEA) contributed in many ways to the cruise preparations.

1 INTRODUCTION

2 COMPUTING AND INSTRUMENTATION

Leighton Rolley (*NMF, UK*)

2.1 Ifremer TECHSAS System

The Ifremer TECHSAS system is the primary data logger for all navigation, surfmet and winch data. The TECHSAS software is installed on an industrial based system with a high level of redundancy. The operating system is Red Hat Enterprise Linux Edition Release 3.3 . The system itself logs data on to a RAID 0 disk mirror and also logs to the backup logger. The TECHSAS interface displays the status of all incoming data streams and provides alerts if the incoming data is lost. The ability exists to broadcast live data across the network via NMEA.

The storage method used for data storage is NetCDF (binary which is a self describing file and is OS independent) and also pseudo-NMEA (ASCII). The NetCDF data files are currently manually parsed through an application in order to convert them to RVS Format for data processing.

The TECHSAS data logging system was used to log the following instruments:

- Applanix POSMV System (Converted to RVS Format as posmvpos, posmvatt, posmvsat)
- Applanix POSMV System Heading
- Kongsberg Seatex DPS-116 (Converted to RVS Format as dps116p and dps116s)
- Chernikeef EM speed log (converted to RVS format as log_chf)
- Skipper EM Speed Log (converted to RVS Format as log_skip)
- Ships Gyrocompass (converted to RVS format as gyronmea)
- Simrad EA600 Precision Echo Sounder (Converted to RVS Format as ea600)
- NMFD Surface-water and Meteorology instrument suite (Converted to RVS as sm_surf, sm_met and sm_light)
- ASHTECH ADU-5 Altitude Detection Unit Converted to RVS Format as adu5pat and adu5pos)
- NMFSS Cable Logging and Monitoring (Converted to RVS as winch)
- MicroTsg SBE45

2.2 Applanix POSMV System

The Ship's primary GPS System for scientific data and also part of the Dynamic Positioning system is the Applanix POSMV. The POSMV includes an inertial measurement unit capable of providing heading pitch and roll data to the bridge, logged by the techsas system and displayed in the main lab. The POSMV data is also used by the ADCP systems in order to account for ships motion.

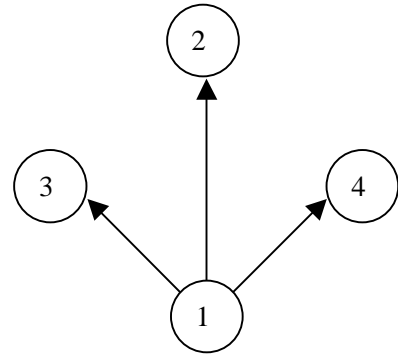
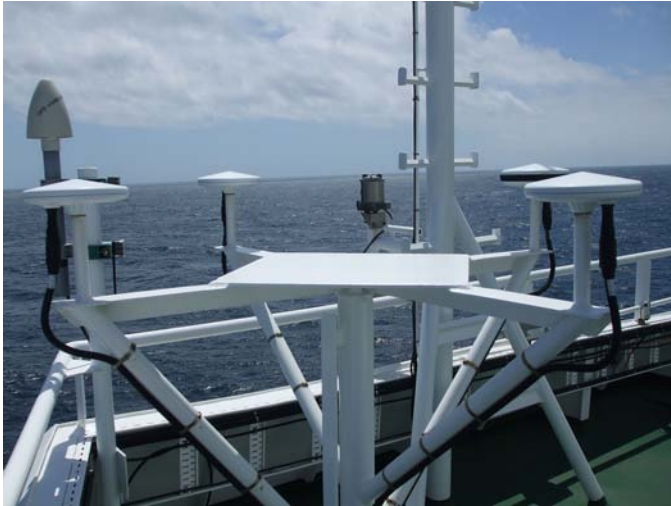
The Applanix IMU is located at the ships centre point and is used as reference for all offsets for instruments on board RRS *James Cook*. The GPS antenna positions are held within the POSMV and the GPS position is corrected for the position of the MRU and so the GPS position that is recorded is the position of the MRU itself.

System Specifications

	Specification (With Differential Correction)	During GPS Outages
Roll, Pitch Accuracy	0.02 ° (1 sigma with GPS or DGPS)	0.02 °
Heave Accuracy	5 cm or 5% whichever is greater for periods of 20 seconds or less	5cm or 5% whichever is greater for wave periods of 20 seconds or less
Heading Accuracy	0.02 ° with 2m antenna baseline	Drift less than 1 ° per hour (negligible for outages < 60 seconds)
Position Accuracy	0.5 – 2m (1 sigma) dependant on differential correction quality	Degradation 2.5m (1 sigma for outages < 30s) <6m (1 sigma for outages < 60s)
Velocity Accuracy	0.03 m/s horizontal	

2.3 Magellan Ashtech ADU-5

This is a four antenna GPS system that can produce attitude data from the relative positions of each antenna and is used to correct the VMADCP for ship motion. The antenna array is located on the port side of the ship's monkey island. The ADU-5 system worked reliably throughout the cruise with some gaps that are quite usual with this system due to the amount of calculations necessary and the roll of the ship causing bad satellite communication. No Large data gaps are present. The ADU-5 forms part of the bestnav system which is an assembly of multiple GPS signals including the gyronmea and emlog stream in order to calculate the best possible position, speed heading pitch and roll of the ship.



The illustrations above show the ADU5 Platform on the starboard side. Black surrounded Antenna indicates AFT. This is the primary antenna which sits behind all 3 other antennas.

ADU5 Offsets with reference to Antenna 1 (used internally by ADU5 for HPR Calculations):

Vector	X(Right Positive)	Y(Forward Positive)	Z(Up Positive)
1-2	0.000	1.203	0.010
1-3	-0.599	0.600	0.010
1-4	0.597	0.598	0.012

Antenna Position on James Cook From MRU (0,0,0)

Antenna	X (Positive Starboard)	Y (Positive Forward)	Z (Positive Up)
1	9.265	1.541	19.416
2	10.463	1.537	19.419
3	9.863	0.932	19.426
4	9.870	2.138	19.419

2.4 SeaTex DPS 116

This DPS116 is a GPS system that was installed primarily as a backup for the POSMV to provide information for the ships DP system for ships use which we now receive an output from. The Seatex is only configured to output a single GPGGA message which we record on the TECHSAS System. The DPS 116 is located at the top of the ships Main mast.

2.5 Ship's Gyrocompass

The Gyronmea is a file that receives its data from the Ships gyro compass located in the Bridge Electronics Space. There are two such Gyros on the bridge and we are able to use either one of them as a source of heading. The selected Gyro is logged by the TECHSAS system and is used as part of the bestnav calculation.

2.6 Chernikeef EM log

The Chernikeef EM log is a 2-axis electromagnetic water speed log. It measures both longitudinal (forward-aft) and transverse (port – starboard) ships water speed. The EM log system was not showing the correct data following the last calibration attempt. The system has been highly unreliable since its installation within the ship and continues to be an ongoing issue that we are attempting to get support from the manufacturer for.

2.7 Skipper Doppler Log

The Skipper Doppler log is the ship fitted speed indicator mainly used by the bridge. It was repeated to the science systems due to the failure of the Chernikeef log to produce reasonable data for the first year and a half of the ships operation. The Skipper is continually logged as it provides good data quality and is a good comparison with the Chernikeef system.

2.8 Simrad EA600 Precision Echo Sounder (PES)

The EA600 Precision Echo Sounder is the ships primary depth readout. The EA600 output is passed to TECHSAS and also to the green display screens in the main lab. The EA600 is mounted on the port drop keel.

2.9 Surfmet System

This is the NMFD surface water and meteorology instrument suite. The surface water component consists of a flow through system with a pumped pickup at approx 5 m depth. TSG flow is approx 18 litres per minute whilst fluorimeter and transmissometer flow is approx 1.5 l/min. Flow to instruments is degassed using a debubbler with 24 l/min inflow and 10/1 min waste flow.

The meteorology component consists of a suite of sensors mounted on the foremast at a height of approx 16.4 m above the waterline. Parameters measured are wind speed and direction, air temperature, humidity and atmospheric pressure. There is also a pair of optical sensors mounted on gimbals on each side of the ship. These measure total irradiance (TIR) and photo-synthetically active

radiation (PAR). The gimbals were removed and had new bearings installed at the beginning of the cruise prior to sailing.

The Non Toxic system was enabled as soon as we were far enough away from land and switched off during the port call in South Georgia and Stanley in order to protect the sea surface sensors from pollution which generally occurs close to land.

The Sea surface temperature probe was found to be faulty and out of calibration. It was displaying values higher than the TSG sensor. This unit will now be sent back to base for calibration and details will be sent on when available. Investigations are currently underway to replace these sensors with more reliable units.

2.10 CASIX PCO2 System

This system is an autonomous pCO₂ system developed by PML and Dartcomm. I advise that you contact Nick Hardman-Mountford at PML for information. The system was run at the same time as the Surfmet system. The System was cleaned on a weekly basis in order to remove fouling from the system as per the manual.

2.11 Network Services

The network itself worked well without any issues. Ports required patching through to enable scientists to use the ports. The wireless system preformed well throughout the cruise.

2.12 Data Storage

Throughout the cruise data was stored in Data32, a Raided data store attached to Cook3. This performed well although transition to the Drobo which was installed on the previous cruise will be better as the USB disks attached to Cook3 get very slow with high traffic. The Level C data was backed up to LTO daily and included the TECHSAS mount from the TECHSAS data logger.

2.13 VSAT

The VSAT suffered from a motor/gearbox malfunction. Downtime was kept to a minimum and confined to the end of the cruise when we had a period of 30 hours without communications. This was addressed by the Technicians and the system was able to provide internet on the transit to Punta Arenas.

3 VESSEL-MOUNTED ACOUSTIC DOPPLER CURRENT PROFILER (VM-ADCP)

Phil Hosegood (*University of Plymouth, UK*)

3.1 Introduction

The aim of cruise JC030/ANDREX aboard the *RRS James Cook* was to quantify the rates of export of Deep Antarctic Bottom Water along the outer rim of the Weddell gyre. On transit from Cape Town a CTD test station (Station 1) was conducted on Julian Day 363 and the drop keel on which the two vessel-mounted acoustic Doppler current profilers (VM-ADCP) are located was lowered. The keel remained lowered until scientific operations were prematurely suspended at approximately 04.00 on Day 14. The position of the final station (Station number 27) is 61° 20.2167' N, 16° 04.854' W.

The report that follows is essentially a reproduction of that written for the preceding cruise, JC029, by Angelika Renner and Mirjam Glessmer. During JC029 several tests were performed using different configurations for the ADCPs, including bottom and water tracking modes, and with the keel lowered and raised. During JC030, however, the ADCPs were operated in Narrowband mode with the keel lowered only.

3.2 The Instruments: OS75 and OS150

Two vessel-mounted RD Instruments ADCPs (VM-ADCP) are installed on the port drop keel. The 75kHz Ocean Surveyor (OS75) sits in front of the 150kHz Ocean Surveyor ADCP (OS150). The latter is situated behind a plate and thus roughly 10 cm higher than the OS75 which is aligned with the bottom of the hull.

The draft of the ship is 6.9 m. When lowered, the keel extends 2.8 m below the hull. The resulting transceiver depths are 6.9 m and 6.8 m for the OS75 and the OS150 respectively when the keel is retracted, and 9.7 m (OS75) and 9.6 m (OS150) when the keel is lowered.

3.2.1 The PCs

The ADCPs are controlled via VmDas through separate PCs. They are located in the main lab in the EK500 rack. The monitors and keyboards are next to the rack. The PC clocks are adjusted to the ship's clock in very long intervals. However, we did not experience major drift or other problems with the clocks during the cruise. The ADCP data are written to the respective PCs. From there they have to be transferred onto the UNIX server. No backup system is installed for either of the ADCP PCs.

3.2.2 Alignment

According to the installation report from the contractors, both ADCPs should be perfectly aligned with the ship's axis. However, after the first couple of days of data collection during JC29, it was noticed that the OS75 is roughly 9 degrees off.

3.3 Data Acquisition: VmDas

The ADCPs were controlled using the proprietary RDI VmDas software, version 1.42. The software is installed on the ADCP PCs in the main lab. VmDas can be used for data acquisition, archiving, processing, display, and reporting. During JC30, the ADCP setup, data logging, preliminary screening, and mapping of beam data onto Earth coordinates was done with VmDas. The final processing was performed at the end of the cruise using a set of Matlab routines.

3.3.1 General settings

During JC30 we ran both the OS75 and OS150 in Narrowband mode with water tracking. We were intending to switch to bottom tracking mode on reaching shallower water later in the cruise but due to the termination of the scientific program, we never reached sufficiently shallow water. Upper and lower reference limits for the 75 and 150 kHz were 150-300 m and 75-150 m, respectively. For JC30, we retained the same settings in VmDas from the previous cruise, JC29. In narrowband mode, the bin size for the OS150 was 8 m, number of bins was set to 60, and the blanking distance was again 6 m. The time between pings was 2 seconds (to be set in VmDas). For the OS75, profiling was set to 60 bins with a bin depth of 16 m and a blanking distance at the surface of 8 m. The time between pings was 2 seconds.

3.3.2 What to set and to check

In VmDas, several things have to be set or checked before start acquiring data. During JC30, the VmDas setting used for the OS75 and the OS150 instruments were identical and as follows:

Open VmDas, click on 'file' _ 'collect data'.

Then in 'options' _ 'edit data options':

- Communications tab:

set up such that under Current Setting the COM Port Setup is set to:

ADCP Input: COM1, 9600, N, 8, 1

NMEA1 Input: COM3, 4800, N, 8, 1

NMEA2 Input: COM4, 19200, N, 8, 1

- ADCP setup tab:

ADCP setup from file (enter the required command file)

time between ping ensembles: 2 seconds

- Recording tab:

name: OS150 JC29 (or OS75 JC29)

number: 1 (has to increase every time the ADCP recording is stopped and restarted, otherwise data loss can occur as VmDas overwrites previously created files!)

max size: 10 (MB; when that size is reached, VmDas starts a new file with automatic numbering)

no dual output directories

- Nav tab:

NMEA Ship Position (GGA) Source: Enable, choose NMEA2 from drop down menu

disable NMEA Ship Speed (VTG) Source

- Transform tab:

Heading Source: PRDID, NMEA Port: NMEA2, Fixed Heading set to 0

Tilt Source: Fixed Tilts 0 Fixed Pitch, 0 Fixed Roll (don't enable tilt correction)

Heading Sensor Magnetic/Electrical Corrections: 0 EV: Primary Heading Error, 0 EV Backup

Heading Error

disable all other corrections

- Averaging tab:

check Temporal

The STA interval was set to 120 seconds, LTA to 600 seconds

Profile Ping Normalisation Reference Layer was enabled and set to start bin = 3, end bin = 10

No changes in Data Screening, User Exit, and Sim Input tabs.

The physical misalignment of the ADCP is set in the command files, not in VmDas.

When the ADCPs are recording, several things should be checked regularly:

- 1) Check the size of the .LOG-files: If there are any problems (e.g. buffer overload, timeouts and resetting of the ADCP, problems with the navigation data stream), they get recorded here. If the file size suddenly increases or the file becomes bigger than 10 KB, an error might have occurred that needs to be resolved.
- 2) Check regularly that the size of the data files is increasing.

- 3) Create and maintain a list with all files created and the setup used. For extraction of on/off station data etc it helps to note station times together with the file sequences.
- 4) Check that GPS data is properly logged and written to the N2R-files.
- 5) Keep an eye on the PC clock deviation from the ship's clock: the last entry in the \$PADCP line in the N2R-files gives the difference in seconds. It should be small (during JC29, it was usually around 0.10). Jumps in the PC clock time can be detected by checking this.

3.3.3 *Output data format*

The filenames of the VmDas data are of the general structure CRUISE_XXX_YYYYYY.END where CRUISE is the name set in the data options recording tab of VmDas (see above), XXX is the number set in the same tab and changed before every restart of recording, and YYYYYY is a number automatically set by VmDas starting at 0 and increasing when the file size becomes larger than max size and a new file is created. END is the filename extension, denoting the different files that are created for each recording. The following list shows all the different file types that were created during JC30 and their content.

- ENR: binary; raw ADCP data file.
- STA: binary; average ADCP data, using the short time period specified in VmDas Data Options.
- LTA: binary; average ADCP data, using the long time period specified in VmDas Data Options.
- ENS: binary; ADCP data after screening for RSSI and correlation, either by VmDas or adjusted by user, and navigation data from .NMS file.
- ENX: binary; ADCP single-ping data and navigation data, after having been bin-mapped, transformed to Earth coordinates and screened for error velocity, vertical velocity and false targets.
- N1R: ASCII text; raw NMEA data, see section 4.
- N2R: ASCII text; raw NMEA data, see section 4.
- NMS: binary; navigation data after screening and pre-averaging.
- VMO: ASCII text; option setting used for collection the data.
- LOG: ASCII text; all logging output and error messages.

More options are available and information about the data files and their format is available in the various OS user guides. Here, a short overview about the structure of the binary data files is given. The structure varies slightly depending on whether only narrowband OR broadband mode are turned on or both are on.

- **Header:** header ID, data source ID, number of data types (i.e. fixed leader, variable leader, etc.) and their offsets.
- **Fixed leader data:** fixed leader ID, ADCP hardware configuration, number of beams, cells, and pings per ensemble, depth cell length, blank after transmit, signal processing mode (narrow- or broadband), output controls, amount of time between ping groups, coordinate transform parameters, heading alignment, heading bias, sensor source, sensors available, distance to middle of first depth bin, length of transmit pulse, distance between pulse repetitions;
- **Variable leader data:** variable leader ID, ping ensemble number, date and time, speed of sound, transducer depth, heading, pitch and roll, salinity and temperature;
- **Variable data:** velocity, correlation magnitude, echo intensity, and status data
- **Bottom track (BT):** BT ID, BT number of pings, correlation magnitude, evaluation amplitude, BT mode, error velocity maximum, BT range, BT velocity, BT correlation magnitude, BT evaluation amplitude, BT maximum depth, receiver signal strength indicator, gain level for shallow water, most significant byte of the vertical range from the ADCP to the sea bottom;
- **Attitude:** fixed and variable attitude data. Fixed attitude data includes the command settings and is the same for all pings. Variable attitude data changes with every ping and consists of heading, pitch and roll;
- **Navigation (ENS, ENX, STA, and LTA-files only):** navigation ID, UTC date and time, PC clock offset, latitude and longitude received after the previous ADCP ping, UTC time of last fix, last latitude and longitude received prior to the current ADCP ping, average navigation speed, true navigational ship track direction and magnetic navigation ship track direction, speed made good, direction made good, flags, ADCP ensemble number, date and time, pitch, roll and heading, number of samples average since the previous ADCP ping for speed, true track, magnetic track, heading, pitch and roll;
- **Checksum:** module 65536 checksum (sum of all bytes in the output buffer excluding the checksum).

If data storing by VmDas is interrupted by e.g. a software crash and/or the data files are not closed properly by VmDas, the checksum can be incorrect and the check in the post processing can fail.

Note: The date recorded by VmDas is given as Julian day. VmDas takes 1st Jan to be day no. 0, different from the ship clock and the other data logging systems!

3.4 Navigation data input

The navigation data is fed directly to the ADCP PCs from the Applanix POSMV System. When starting data recording in VmDas, the navigation data link is opened and started automatically. Errors during the data streaming can be displayed in VmDas in the NMEA Communication-window and are written to the LOG-file. There are two NMEA feeds into the VmDas software. The NMEA1 stream is written to the N1R-files, the NMEA2 stream to the N2R-files. They are also included in the binary data files. The NMEA1 feed provides the following strings: HCHDM, TIROT, HEHDT, PPLAN. NMEA2 gives the GPZDA, PASHR, PRDID, GPGGA, GPHTD, GPRMC messages.

In both files, a message from VmDas is stored in the PADCP line at every ADCP ping. For the postprocessing, the PADCP and the PRDID messages are used. They contain: \$PRDID, pitch, roll, heading, PADCP, ensemble number, date (yyyymmdd), time from PC clock, PC clock offset.

A frequent error message appeared during JC29 and again during JC30 regarding the source of heading, e.g.:

```
[2008/11/07, 10:28:29.997]: GGA data is now unavailable from its primary source
[2008/11/07, 10:28:29.997]: NO GGA data will be stored in the NAV field starting with ens 76
[2008/11/07, 10:28:30.747]: GGA data can now be read from its primary source
[2008/11/07, 10:28:31.997]: PRIMARY GGA data will be stored in the NAV field starting with ens 77
[2008/11/07, 10:38:40.728]: NMEA Heading data is now unavailable from its primary source
[2008/11/07, 10:38:41.696]: NMEA Heading data can now be read from its primary source
```

As during JC29, this message did not appear to affect the data during JC30.

During JR141, Jeremy Robst wrote the program `nav_gaps.pl` that checks the ensemble numbers in the PADCP line in the N1R- or N2R-files for missing numbers, duplicates or backward jumps (for details and the program see the JR165 report).

3.5 Post-processing in Matlab

3.5.1 *The Matlab routines*

For the post-processing of the VmDas data, we used a set of Matlab routines. They were first obtained from IfM Kiel by Mark Inall and adapted for use on the RRS James Clark Ross by Deb Shoosmith. During JR165, Mark Brandon and Angelika Renner cleaned up large parts of the routines and added comments throughout. Since JR165, some further debugging and refinement have been done by Deb Shoosmith, Hugh Venables and Angelika Renner. The structure, general processing, and in- and

output formats remain the same. The following description of the routines and the output data files are taken from the JC29 report that was itself taken from the JR165 ADCP report.

3.5.2 *Remarks and Glossary*

Whenever it says 'run a routine/program/function', it means type in the function name in the Matlab command window and hit enter...

A few terms should be clear:

- file sequence: all files for which in the filename CRUISE_XXX_yyyyyy.END the number at position xxx is the same. These files have been recorded without stopping the ADCP in between and the same setting was used.
- ping and ping ensemble: In case of JR165, they are the same, as a ping ensemble was set to include one ping only.
- amplitude, scaling factor, A: Throughout the routines the factor by which the ADCP data has to be scaled for calibration is called either amplitude, scaling factor or A.
- misalignment (angle), phi: synonyms for the angle by which the ADCP is misaligned in addition to the physical misalignment set in the command files.

In the following section, the processing is described for the OS75. It is controlled through the main routine OS75_JC_jc30.m. The processing of the OS150 data works in exactly the same way, only the main routine needs to be adjusted.

3.5.3 *Quick'n'dirty: How to get processed ADCP data*

There are a few things that have to be set for each cruise in file OS75_JC_jc30.m. These are:

- Add the path where the routines are stored to the Matlab search path.
- The cruise name: variable 'cruise'. The name is used when reading in raw data and saving processed data, and appears in the plots.
- The file sequences: variable 'files'. This determines which of the file sequences are processed. 'files' can be a single number or a vector containing the numbers of several file sequences.
- Paths to data files: variables 'RAWPATH' and 'PATH'. They contain the directory paths to the directory where the raw data is stored ('RAWPATH'), and where the processed data will be written to ('PATH').
- The averaging interval: variable 'superaverage'. 'superaverage' sets the interval over which ping ensembles will be averaged. Unit is seconds.
- The year: variable 'YYYY'. A switch for which lat/lon fix to be used (see below, 5.4): variable 'which_prdid_fix'. Options are a) 1 to use the fix directly after the previous ADCP

ping, or b) any other number to use the fix directly before the current ADCP ping. Set it to 1 if you don't want to bother, it works.

- The upper and lower limit of the reference layer: variables 'ref uplim' and 'ref lowlim'. Those are needed for calculation of a reference velocity which is used when doing calibration by water tracking. Unit is meters.
- The misalignment angle and the scaling factor: variables 'misalignment xb' and 'amplitude xb' with $x=b$ for broadband and $x=n$ for narrowband. When running OS75_JC_jc30.m the first time (see below), set the misalignment to 0 and amplitude to 1. After the first run, to correct for the angle and the scaling, set the variables to the mean, median, mode or whichever value is preferred, and run OS75_JC_jc30.m again. Mean, median, and standard deviation are displayed in the plot adcp_calib_calc.ps. To keep track of which values were used, it is a good idea to note down and which file sequences require which correction factors. Deb Shoosmith modified this bit so that only 'misalignment nb' and 'amplitude nb' are used. On JC030 all data are in narrowband mode so that we just use the changed version. It is possible though, to return to the previous version and then process data in both broadband and narrowband mode at the same time. The description below therefore still includes this option.

That is all that should be set. All that needs to be done then is:

- Run OS75_JC_jc30.m.
- Check which values for misalignment angle and scaling factor are derived.
- Set 'misalignment xb' and 'amplitude xb' (with $x=b$ or n) in OS75-JC_jc30.m to these values.
- Run OS75_JC_jc30.m again.

If you reprocess the raw data, make sure to remove the old .ps-files containing the various plots, otherwise the new plots will simply be added instead of written to a new file.

3.5.4 *Description of the processing functions*

(1) The master function: OS75_JC_jc30.m

The main function for the processing is OS75_JC_jc30.m. In there, the environment and variables are set, and the subfunctions are called. See Fig.1 in the JC29 report for an overview of the processing routines, their order and the output.

In the first part the work environment is defined: Matlab paths to the processing routines are added to the Matlab search path, the directory with the raw data and the directory for the processed data are declared, and the file- and cruise names are defined. Then the vector containing the numbers of the file sequences that are to be processed is created. Several choices can be made for the processing: the

variable `superaverage` is used to define the interval over which pings will be averaged in time, unit is seconds. `Which_prdid_string` sets, if the first PRDID fix after the previous PADCP string or the last one before the current PADCP string; this will make sense later, see 5.4.8. The values for `ref_uplim` and `ref_lowlim` give the upper and lower limits of the reference layer of which a velocity is calculated and used as reference velocity. This is of importance mostly for water track calibration in cases where no bottom track data is available (see 5.4.12 and 5.4.13).

Then, during the first run through `OS75_JC_jc30.m`, where no data are processed yet and no calibration data are available, the correction values for the misalignment angle (misalignment `xb`) and the scaling factor (amplitude `xb`) are set to 0 and 1 respectively ($x=n$ for narrowband mode, $x=b$ for broadband mode). For the second run, when values for misalignment `xb` and amplitude `xb` have been calculated, they should be set to the median, mean, mode or whichever value works best. For JR165, it was found that separate misalignment and amplitude correction values for broadband and narrowband mode calculated from files in the respective mode worked better than only one for both modes. To know later how the values used were derived, it is best to write down where they came from.

To keep a record of the settings used to process a set of ADCP data, the settings and the text displayed on screen during the processing are written to a diary called `adcp_proc_log_runX.txt`. `X` will be 1 for the first run (when misalignment `xb` and amplitude `xb` are equal to 0 and 1, resp.) and 2 for the second run (misalignment `xb` and amplitude `xb` do not equal 0 and 1, resp.). After this introductory part, the processing starts. Arrays are declared for later use when calling some of the subroutines, and the file containing calibration point data is deleted if it exists in the processed data directory.

Then, the loop through all file sequences specified above starts. First, the filename is set. Its general structure is `CRUISE_xxx_yyyyyy`. At this point, `xxx` is set to the file sequence number that is the current in the loop and `yyyyyy` is 000000. The files created by `remove_bad_navigation.m` and `subst_bad_seatex.m` are deleted if they exist in the processed data directory.

To go through all files in a file sequence, the switch `ex` and the counter `I` are used. In the while-loop depending on the value of `ex`, the first thing adjusted is the filename so that `yyyyyy` corresponds to the current file of the current file sequence. If the file 'filename'.`ENX` exists in the raw data directory, `ex` will keep the value 1, otherwise it will become zero.

After this, the run through the subroutines begins. This includes all routines described in 5.4.2 to 5.4.11. Once all files have been passed through these routines and the loop is finished, the functions described in 5.4.12 to 5.4.16 are called. After that, all data is processed and saved in the specified directory. The last thing in the main function is a plot of velocities: cross sections of the zonal and meridional velocities are produced and the plots are saved in `adcp_vel_contours.ps`.

(2) read_os.m

In this routine, the raw binary data from VmDas are read. In case of JC30, we used the .ENX files, which contain ADCP single-ping and navigation data. The ADCP single-ping data has already been bin-mapped, transformed to Earth coordinates, and screened for error velocity, vertical velocity and false targets (see VmDas User's Guide).

Read_os.m is called with the file name variable and optional arguments. The latter define which part of the raw data is read:

- 'ends': ???
- 'ens list': list of ensemble numbers
- 'yearbase': start year
- 'second set': read narrow band mode data when both broad and narrow band are collected.
- 'vel': read velocity
- 'cor': read correlation magnitude.
- 'amp': read echo intensity.
- 'pg': read percent good.
- 'ts': read pitch, roll, and heading.
- 'bt': read bottom track data.
- 'nav': read navigation data
- 'all': includes vel, cor, amp, ts, bt, and pg.

More than one argument can be passed on to read_os.m. Arguments can also be numbers.

After the switches are set, the subroutine os_id, which is within read_os.m, is called with the argument id_arg. The value of id_arg depends on the offset of the positions of the data. If both narrowband and broadband data are collected in broadband mode, this also decides which data are read. If id_arg=1, the narrowband data is extracted. Os_id returns the structure id with the positions/identifiers of the data fields in the binary data files. The next step is the first call to the subroutine read_buf, also within read_os.m.

read_buf : This is the part where the binary data is read.

During the first call with only one argument, the configuration of the OS75 ADCP is extracted from the fixed leader data (see 3.3) and stored in the structure config. If one of the checks on number of bytes, header or data source ID or checksum fails, an error message will be returned to read_os.m. Otherwise, information about ADCP hardware and setup that remains the same for all pings is read.

After that and during the second call (with two arguments), the variable, bottom track, attitude, and navigation data is extracted.

After the first call to `read_buf`, the configuration data is used to set up space and size of variables and the reading loop. `read_buf` is called the second time, and the data requested by using the various switches is stored. Before returning to the main routine, variables are adjusted for negative numbers or NaNs. All raw data read in is stored in the structure `OS75_raw` and returned to the main function. There, the structure is written to the file `CRUISE_xxx_yyyyyy_raw.mat`.

(3) `remove_zero_ensembles.m`

The structure `OS75_raw` is handed over to `remove_zero_ensembles.m`. A search for all ensembles whose ensemble number (`OS75_raw.ens_num`) is not zero is done and only those are kept and handed back to the main routine as `OS75_sgl_ping`.

(4) `remove_bad_navigation.m`

Depending on `which_prdid_fix`, `OS75_sgl_ping.nav.txy1` or `2` is checked for time (first row), longitude (second row) and latitude (third row) duplicates. The number of rejected data cycles is printed on screen and saved as `bad` and `good` (=number of data cycles - number of rejected cycles) in the file `CRUISE_bad_nav.mat`. The rejected data cycles are then removed from `OS75_sgl_ping` and the structure handed back to the main routine.

(5) `include_att_jc.m`

Arguments passed on to this routine are `OS75_sgl_ping`, `add_to_ensnum` (for the correction of ensemble numbers; see below) and `which_prdid_fix`. If no file `CRUISE_xxx_000000_att.mat` exists yet in the processed data directory (i.e. the navigation data in the `.N2R`-files has not been read yet), `OS75_sgl_ping` is passed on to `read_nmea_att_jc.m` which is called to read the `.N2R`- (or `.N1R`-) files.

`read_nmea_att_jc.m` The routine goes through all `.N2R`-files in a file sequence. To change to `.N2R`, modify the variable extension. The number of lines to be read in one go is limited to a maximum of 160000, the loop will go on until all lines are read. The text in the `.N2R`-file is read into a matrix. Then lines containing the `$PADCP` or the `$PRDID` string are extracted (for more information on the `$PADCP` and `$PRDID` format see 4). If two `PADCP`-lines are consecutive, the first of them is discharged (no attitude data available for this ping ensemble!). From the `$PRDID`-lines the one following the `$PADCP`-line are extracted, the others discharged. Pitch, roll and heading are read from the remaining `PRDID`-lines and stored. If heading is missing (=999), pitch and roll are set to 999 as well. From `PADCP`-lines, the ping ensemble number, the PC clock offset, and the PC time of the ping ensembles (converted to decimal Julian days) are extracted. After all files are read, the ping ensemble

number is checked and corrected for duplicates, which can appear due to the splitting of the files after the maximum number of lines is read. The data is stored in the structure att which is written to CRUISE_XXX_000000_att.mat. Pitch, roll, heading, and the PC clock offset are plotted and the figures saved to adcp_prh.eps. (Figures need to be improved!) After that, return to include att_jc.m.

The file CRUISE_XXX_000000_att.mat with the att-structure is loaded in. If the structure contains data, the following is done: For further processing the ping ensemble number has to be increasing. When the ADCP times out while waiting for a response and resets, the ensemble number goes back to 1. Here, the ensemble numbers are modified so that they increase throughout the file (for att) and throughout the files of a file ensemble in OS75_sgl_ping.ens_num.

There is already attitude data in the structure OS75_sgl_ping which comes from the .ENX-file. To extract pitch, roll, heading, and PC clock offset which are relevant for the current .ENX-file, a vector is created for each variable of the length max(highest ensemble number in att, highest ensemble number from the .ENX attitude data) and filled with NaNs. Then, the attitude information from att is written into the vector and only the data points corresponding to the ensemble numbers from the .ENX-file are stored. If att is empty, heading, pitch, roll, and PC clock offset are set to NaN.

The extracted attitude data is written to OS75_sgl_ping.att. The attitude data relevant to the current .ENX-file is also saved in the new structure att in CRUISE_XXX_yyyyyyd_att.mat. The modified OS75_sgl_ping is returned to the main routine.

(6) subst_bad_seatex.m

The arguments OS75_sgl_ping.att, and sea file are handed over. In sea_file the number of accepted and rejected (due to bad Seatex data) data points will be stored. A search on OS75_sgl_ping.att data is done for ensembles where

- heading = 0;
- heading = 999;
- pitch and roll = 0;
- the second differential of heading = 0.

The total number of those ensembles is printed on screen and saved as bad in 'CRUISE'_bad_heading.mat. OS75_sgl_ping contains two headings: OS75_sgl_ping.heading which comes from the .ENX-file and OS75_sgl_ping.att.heading from the .N2R-file. Both are from the same instrument (Seapath Seatex), but may be slightly different due to a (very) small time difference in when they are recorded. Therefore, the velocities in OS75_sgl_ping are rotated by the difference. To

get bottom track velocities in the correct orientation, OS75_sgl_ping.bt.vel is multiplied by -1. OS75_sgl_ping with the modified values is returned to the main routine.

(7) correct_offset.m

Using the helper routine uvrot.m, this routine scales the water and bottom track velocities and corrects them for misalignment. From the main routine, the arguments OS75_sgl_ping, misalignment xb and amplitude xb are passed on, x=n or b depending on whether the current file ensemble is in narrow- or broadband mode. The horizontal velocities are multiplied by the scaling factor amplitude xb and rotated by the specified misalignment angle misalignment xb. The heading is adjusted by subtracting the misalignment angle. The modified structure OS75_sgl_ping is returned to the main routine.

(8) ship_vel.m

The routine is called with the arguments OS75_sgl_ping and which_prdid_fix. The latter decides which navigation fix is used for the calculation of the ship velocity: either txy1 or txy2 (see also 5.4.1, 5.5.1). With the help of the routine sw_dist.m from the CSIRO Seawater toolbox, the distance and the direction between the fixes is calculated and then converted to distance in east- and northward direction in meters and time difference in seconds. Dividing distance by time difference results in ship velocity in m/s, which is written to OS75_sgl_ping.ship velocity. If bottom tracking was on, the horizontal bottom track velocities OS75_sgl_ping.bt.vel(1:2,:) should contain values other than NaN. If that is the case, the ship velocity is set to OS75_sgl_ping.bt.vel(1:2,:). The structure OS75_sgl_ping is then handed back to the main routine.

(9) qual_control.m

Several criteria are used in this routine for further quality control. Therefore, the arguments OS75_sgl_ping, beam, heading change and ship velocity change are included in the call. beam is the number of beams of the ADCP instrument, heading change is the maximum change in heading allowed at any one timestep, and ship velocity change is the maximum change in ship velocity allowed at any one timestep. Large changes lead to less reliable ADCP data. The values used during JC29 are 10 per ping for the heading change and 0.5514 m per ping for the ship velocity change. The same values are assumed for JC30 on the basis that no changes were made to the instrument set-up. The first step of quality control uses the error velocity provided through the fourth beam (vel(:,4,:)).

A variable err_vel is set to 2 times standard deviation of the error velocity, and the velocities of all ping ensembles where the absolute value of this velocity exceeds err_vel are set to NaN. Then, if beam = 0, a check using percent good is performed: velocities of ping ensembles with percentage of good four beam solutions equal to zero are set to NaN.

The two following steps look at the heading changes. First, a smoothed version of the heading change ($\text{diff}(\text{heading})$), created using a Hamming-window based, second order filter (see 5.4.17), is checked for values exceeding heading change, and the velocities of affected ping ensembles (i.e. the two ensembles in between which the change is large) are set to NaN. The same is done for the unfiltered heading change.

NOTE: for `mfilter.m` and the therein used Matlab function `filtfilt.m`, the data needs to have a minimum length of 3 times the filter order. This means that files with less than 5 minutes of data cannot be used. Velocities are set to NaN if the change in ship speed exceeds ship velocity change.

A last control is done on absolute horizontal velocities in a reference layer: The eastward and northward velocities in the ninth depth bin are chosen and the ship velocity is added to obtain absolute velocities. Then, velocities of ping ensembles between which the change of either of these reference velocities is larger than 2 m/s are set to NaN.

The structure with the modified velocity array is returned to the main routine. Hugh Venables modified the call to the quality control routine such that in the first run, a quicker, less thorough quality check is done using the routine `qual_control_quick.m` to allow faster processing for quick data checks. During the second run, the above quality control is done.

(10) `calib_points_bt.m`

In this routine, calibration points are extracted using 2-minute averages of ADCP data and various criteria these points have to fulfill. It is called with the arguments `OS75_sgl_ping`, `cal_file`, `which_prdid_fix`, `ref_uplim` and `ref_lowlim`. `cal_file` specifies where the data for calibration extracted here will be written to, `which_prdid_fix` does the same as in `ship_vel.m` (5.4.8).

To average the ADCP data over 2 minutes, the routine `ave_for_calib.m` is called with the arguments `OS75_sgl_ping`, `av time` (set to 120 seconds), `ref_uplim`, `ref_lowlim`, and `which_prdid_fix_ave` for `calib.m`. This routine is a reduced version of `average_pings.m` (see 5.4.11), including only variables required by `calib_points_bt.m`. The possibility of missing out ping ensembles in the averaging process when several `.ENX`-files exist in a file sequence is ignored here (for more about that issue see 4.11).

After the averaging, a check is done whether bottom track velocities are available or not. If all bottom velocities are NaNs, the routine stops and returns to the main program.

The principle used is based on a comparison of ADCP bottom track data and GPS tracks. The bottom velocity recorded by the ADCP should be the same as the GPS derived ship velocity. Therefore, the value $\text{GPS ship speed}/\text{ADCP bottom track speed}$ gives the scaling factor to adjust ADCP velocities, and $-(\text{GPS ship heading} - \text{ADCP bottom track heading})$ is the misalignment angle.

As velocities from bottom tracking are crucial for the calibration, ping ensembles with NaNs in either zonal or meridional bottom velocity are discharged. The ship velocity is derived from navigation data in OS75_sgl_ping.nav and which_prdid_fix sets which fix is used. Ship velocity is then calculated as in ship_vel.m (5.4.8) as distance in east- and northward direction divided by time difference.

The criteria potential calibration points have to fulfill are:

1. the change in ship heading is small;
2. the change in ship speed is small;
3. the ship speed is within the interval average ship speed \pm standard deviation;
4. the ship heading is within the interval average ship heading \pm standard deviation;
5. the bottom speed is larger than a specified minimum speed;
6. there are a minimum number of possible calibration points in a row that fulfill the criteria.

Relevant data at the calibration points are extracted and saved in the structure cal. This includes bottom velocity, speed, heading and range, ADCP velocities and heading, ship speed and heading, and the navigation data. The scaling factor at the calibration points is calculated as is the misalignment angle.

To enable quality control of the intervals of calibration points (interval=row of successive calibration points) and possible filtering by hand after the processing, some statistics are done and included in the structure: average and standard deviations of ship velocity and heading, bottom velocity and heading, scaling factor and misalignment angle, and the number of 2-minute averages in the interval. If the cal file does not exist yet, it is created, otherwise, the data is added to the existing file.

(11) average_pings.m

The routine is called with the arguments OS75_sgl_ping, d_missed, OS75_ave_ping, superaverage, ref_uplim, ref_lowlim, and which_prdid_fix. The time in seconds over which the ping ensembles are averaged is given by superaverage. As the ping ensembles in a file of a file sequence are not necessarily divisible into the specified time intervals without remainder, the structure d missed is used to carry on the surplus ensembles and add them to the ping ensembles of the next file in the same file sequence. If there are ping ensembles left at the end of a file sequence, they will not be included in the averaging. At first, a check is done whether any ping ensembles from the previous file were carried forward. If that is the case, they are added to the current file in the loop. A depth range for the reference layer velocity is set as is the maximum number of depth bins. Pings are averaged in intervals determined by superaverage and using the time stamps in OS75_sgl_ping.nav.txyX where X is either 1 or 2 depending on which_prdid_fix.

Throughout the routine, there are various occasions where (usually) three dimensional arrays are split up into several 2d-arrays. This is done using the reshape-command and the size of the velocity fields. To avoid problems when the original velocity field is 2d instead of 3d, a check is introduced and the variable containing the size of the field is adjusted. Several variables are extracted and derived: the reference layer velocity (zonal and meridional) as mean of the horizontal velocities in the depth range specified by `ref_uplim` and `ref_lowlim`; absolute velocities by adding the ship velocity to the horizontal velocities; percent good from the fourth beam; a value for bottom range for each ping ensemble with the condition that it is between 50 and 1200 m depth and using the median of the four beams; the difference between the headings from the .ENX- and from the .N2R-file (set to NaN if the .ENX-heading does not change for two successive ping ensembles); pitch and roll (set to NaN if data is missing, i.e. > 998); the PC clock offset; the echo intensity as mean over all beams.

The navigation data is set to NaN for ping ensembles where there is no velocity data in any of the beams and any of the depth bins. For the averaging, the heading is broken up into components (-cos and sin) and reconverted to angles in degrees afterwards. Of the extracted variables, the ones included in the averaging are: absolute velocity (all three directions), reference velocity, heading, difference in .ENX- and .N2R-heading, PC clock offset, echo intensity, percent good, and bottom range. Additionally, ship velocity and navigation data (time, longitude, latitude) are averaged. For pitch and roll, the standard deviation is calculated. The data from ping ensembles that were remainders after the averaging is written to `d missed` and returned to the main routine.

The averaged absolute velocity is converted back to velocity relative to the ship by subtracting the averaged ship velocity. The reference layer velocity is then recalculated from the resulting averaged (relative) velocity. The averaged variables are added to the structure `OS75_ave_ping` as are the variables `depth` and `ref.bins` (= numbers of the bins in the reference layer). The structure is then returned to the main routine. `average_pings.m` is the last routine called within the loops through all files in a file sequence and through all file sequences specified. At the end of the loops, the structure `OS75_ave_ping` contains averaged data for all files included in the processing. Before the loops are left, the array `bindepth` containing bin depths for each of the averaged velocity profiles is created. Next steps are the final part of the calibration, blanking the bottom, and removing the ship velocity from the ADCP velocity data.

(12) `calib_points_wt.m`

If there is no bottom track data available, the calibration is done using water track. Again, the search for possible calibration points is done using 2 minute averages produced by `ave_for_calib.m`. First differences are calculated from the average data for the reference velocities (i.e. the water velocities in the reference layer specified by `ref_uplim` and `ref_lowlim`) `du` and `dv`, and the ship velocities `dsu` and

dsv. Of those, only differences were considered for when ship speed exceeded 3 m/s between ensembles not more than 5000 m or 3600 s apart. Using the Matlab function `fminsearch.m`, the following function was minimized for phi and A:

$$f(A, \text{phi}) = (A \cdot du \cdot \cos(\text{phi}) - A \cdot dv \cdot \sin(\text{phi}) + dsu)^2 + (A \cdot du \cdot \sin(\text{phi}) + A \cdot dv \cdot \cos(\text{phi}) + dsv)^2$$

Values for A and phi are written to the array alpha together with relevant heading, navigation, and velocity data, and alpha is handed back to the main routine.

(13) `calib_calc_wt.m`

After alpha has been created in `calib_points_wt.m`, it is passed on to this subroutine. Here, average, median, and standard deviation for phi and A are calculated and written to `cal_file_wt`. The average or the median should then be used during the second run of `OS75_JC_jc30.m` for misalignment and amplitude correction. Several plots of the misalignment and the scaling are also produced and stored in `adcp_correction_stats.ps`.

(14) `calib_calc_bt.m`

During the first run of `OS75_JC_jc30.m`, the misalignment angle and the scaling factor which are to be used for the second run are calculated here. In the second run, the results for phi and A should be closer to zero and one, respectively, than before. The arguments handed over are cal file, which specifies the file with the calibration point data, cruise, misalignment xb and amplitude xb, which are used for the plots created in this routine.

After `cal_file` is read in, scaling factors and misalignment angles outside the interval $\text{average} \pm \text{standard deviation}$ are sorted out. From the remaining points, the average, the median and the standard deviation for A and phi are calculated and added to the structure `cal`. The median is less affected by outliers which might have survived the screening in `calib_points_bt.m` and `calib_calc_bt.m` and should therefore be used as correction value in the second run. Before returning to the main routine, a plot showing the distribution of the misalignment angles and the scaling factors and their temporal evolution is produced. (After returning to the main program, the plot is written to the file `adcp_calib_calc.ps`.)

(15) `bt_mask.m`

`OS75_ave_ping` and `bindepth` are passed on to this routine. Here, a mask is created using the bottom range `bt.range`. With this mask, velocity data below 86% of the bottom range (= water depth) is set to NaNs. The structure containing the modified velocity fields is returned to the main routine.

(16) abs_vel.m

OS75_ave_ping and bindepth are handed over from the main routine. In order to derive absolute water velocities independent of the ship movement, the east- and northward ship velocity is added to the horizontal water velocity (OS75_ave_ping.vel). The same is done for the velocity in the reference layer (OS75_ave_ping.ref.vel). The resulting absolute velocities, the navigation data and the depth array (set to bindepth) are handed back to the main routine within the structure OS75_abs.

(17) Helper routines: julian.m, sw_dist.m, uvrot.m, rot_fun_1.m, mfilter.m

These routines are called on various occasions during the processing. sw_dist.m is part of the CSIRO Seawater toolbox.

3.5.5 Overview of output files

(1) CRUISE xxx_yyyyyy_raw.mat

The structure OS75_raw in this file contains the raw, unedited data from the .ENX-file as read in in include_att_jc.m and read_nmea_att_jc.m. For JC30 the structure consists of:

- vel, cor, amp, pg (arrays of size [number of bins x number of beams x number of ensembles]): velocity, correlation magnitude, echo intensity and percent good for the four beams.
- heading, pitch, roll as [1 x number of ensembles]-array.
- temperature, soundspeed: [1 x number of ensembles]-array. The temperature here is the temperature of the water at the transducer head. It is either set manually or measured. The soundspeed is calculated or set manually.
- dday, ens num,num pings: [1 x number of ensembles]-array. dday is decimal day, ens num the ensemble number of the pings, and num ping the number of pings in each ensemble.
- bt: structure containing the bottom track data:
- vel, range, cor, amp, rssi (arrays of size [4 x number of ensembles]): bottom track velocity, range, correlation magnitude, echo intensity and receiver signal strength indicator for the four beams
- nav: structure containing navigation data:
 - sec_pc_minus_utc: [number of ensembles x 1]-array containing the PC clock offset in seconds;
- txy1, txy2: [3 x number of ensembles]-arrays; first row: time in decimal Julian days, second row: longitude, third row: latitude. txy1 is data from the first PRDID-fix after the previous ADCP ping, txy2 is from the last PRDID-fix before the actual ADCP ping.
- config: structure containing the setup information about the OS75 and VmDas

- depth: [1 x number of bins] array. The array contains the depth of the bins (centre or bottom???) in the configuration used for the actual file sequence.
- error: if reading of data fails, an error message will be stored here, otherwise it should be empty.

There is one such file for each .ENX-file in a file sequence.

(2) CRUISE_xxx_000000_att.mat

In this file, the structure att contains the attitude information from all .N2R-files of a file sequence, read during read_nmea_att_jc.m. This includes the following [1 x number of ensembles]-arrays from the \$PRDID and \$PADCP lines:

- heading, pitch, roll;
- pc time: time from the ADCP PC clock;
- pc time offset: offset of the ADCP PC clock from UTC in seconds;
- ens num: the ping ensemble number.

Per file sequence, one file CRUISE_xxx_000000_att.mat is produced.

(3) CRUISE_xxx_yyyyyyd_att.mat

For each file in a file sequence, attitude data is extracted and saved in CRUISE_xxx_yyyyyyd_att.mat. It contains a structure att which consists of the following arrays of size [1 x number of ensembles] per .ENX-file:

- att_heading, att_pitch, att_roll: heading, pitch and roll from the .N2R-files for the ping ensembles in the corresponding .ENX-file;
- heading_orig: heading from the .ENX-file;
- ens_num: the ping ensemble number;
- lat: latitude of the ping ensemble.

The difference between att_heading and heading_orig should be small and therefore negligible. In the case of JC30, they both come from the Applanix POSMV, but there is a small time lapse between the writing of data to the .ENX- and the .N2R-files (see also 4).

(4) CRUISE_xxx_yyyyyy_sgl_ping.mat

Again, one file with single ping data is produced for each .ENX-file. In the structure OS75_sgl_ping, after several steps of quality control, filtering and correcting for misalignment and scaling (after final

processing), data from the four beams, bottom track data, navigation data, configuration data and information about the processing environment are stored:

- all variables that exist in OS75 raw in the file CRUISE_XXX_YYYYY_raw.mat are included; additional variables:
- filename: CRUISE_XXX_000000;
- path, rawpath: paths to the directories where the processed data is written to (path) and where the raw data files are stored (rawpath);
- att: structure containing heading, pitch, roll, and PC clock offset;
- heading_orig: [number of ping ensembles x 1]-array, heading from the .ENX-file;
- ship_velocity: [2 x number of ping ensembles]-array, containing the eastward (first row) and the northward (second row) ship velocity.

(5) CRUISE_cal_points.mat

In this file, all information at bottom track calibration points needed for the calculation of misalignment angle and scaling factor are stored. This includes:

- bt: structure with bottom track data: arrays vel ([2 x number of calibration points]), speed, heading, and range ([1 x number of calibration points]);
- vel: [number of bins x 2 x number of calibration points]-array of east- and northward velocity
- heading: [1 x number of cal. points]-array; heading from .N2R-data;
- nav: structure containing txy1 data at the calibration points;
- ship_speed, ship_heading: [1 x number of cal points]-arrays;
- scaling, phi: scaling factor and misalignment angle at each calibration point; [1 x number of cal. points] array;
- intervals: stats for each interval of successive calibration points; see description of routine calib points bt.m in 5.4.10;
- mode: [1 x number of cal points]-array. 1 or 10 for each calibration point depending on broadband or narrowband mode.
- which file: [number of cal points x 16]-character array with file name of the file the calibration point is from.
- stat: structure with values for the scaling factor (a) and the misalignment angle (phi) as calculated in the routine calib_calc_bt.m, see 5.4.14; the values stored here after the first run of the main routine OS75_JC_jc29.m are the ones that should be used for the second run!

Only one file for all file sequences processed in a run is created.

(6) CRUISE_cal_points_wt.mat

If no bottom track data is available, calibration is done using water track. For this, the array alpha is created. From data in alpha, the misalignment angle phi and the scaling factor scaling are derived and alpha, phi, and scaling are stored in this file.

(7) CRUISE_000_000000_zz_ave_ping.mat

(zz=highest file ensemble number included in the processing)

The structure OS75_ave_ping contains data after averaging over a chosen time interval (xyz = number of velocity profiles after averaging):

- vel: [number of bins x 3 x xyz]-array of average velocity (zonal, meridional and vertical);
- amp, pg: [number of bins x xyz]-arrays; echo intensity and percent good;
- ship_velocity: [2 x xyz]-array of zonal and meridional ship velocity; if bottom track velocity is available, then the ship velocity equals the bottom track velocity;
- heading: [1 x xyz]-array;
- nav: structure containing txy1: [3 x xyz]-array of time (decimal Julian days), longitude and latitude;
- att: structure containing:
 - heading difference: [1 x xyz]-array of the difference between heading from .ENX and .N2R (hopefully equal to zero);
 - pitch, roll, pc time: [1 x xyz]-arrays;
- ref: structure with velocity ([2 x xyz]-array): average over the reference layer, and bins: vector containing the depth bins that lie within the reference layer;
- bt: structure containing range: [1 x xyz]-array of bottom track range;
- depth: [1 x number of bins]-array (bin depths of the setting of the last file sequence processed).

(8) CRUISE_000_000000_zz_abs.mat

(zz=highest file ensemble number included in the processing)

In this file, both OS75_abs and OS75_ave_ping are saved. The latter contains the same fields as in CRUISE_000_000000_zz_ave_ping.mat, where only the values in the velocity field are changed. Additionally, the variable bindepth is included as well. OS75_abs includes (xyz = number of velocity profiles after averaging):

- `vel`: [number of bins x 3 x xyz]-array of absolute velocity (zonal, meridional and vertical), i.e. horizontal velocities are corrected for ship velocity;
- `nav`: structure containing `txy1`: [3 x xyz]-array of time (decimal Julian days), longitude and latitude;
- `ref`: structure with velocity ([2 x xyz]-array): average over the reference layer, and `bins`: vector containing the depth bins that lie within the reference layer;
- `depth`: [number of bins x xyz]-array (bin depths corresponding to the settings used for the velocity profiles).

(9) Plots

adcp_prh.ps For each .N2R-file a plot of pitch, roll, heading, and PC clock offset is produced in `read_nmea_att_jc.m` and saved to `adcp_prh.ps`. They need editing to make them really useful!

adcp_calib_calc.ps After the final filtering of calibration points, misalignment angle and scaling factor are plotted in form of histograms and timeseries (in `calib_calc_bt.m`). There should be two plots after completed processing: the first plot from the first run of `OS75_JC_jc30.m` with amplitude = 1 and misalignment angle = 0, and second plot from the second run using the calculated values for amplitude and misalignment.

adcp_correction_stats.ps These plots show the results of the water track calibration if no bottom track is available, similar to the ones in `adcp_calib_calc.ps`.

adcp_vel_contours.ps The final step in `OS75_JC_jc30.m` is to plot meridional and zonal velocity as it is saved in the structure `OS75_abs` in file `CRUISE_000_000000_zz_abs.mat`. Added in the figure are the cruise track, the values used for correction for misalignment and scaling, the cruise name, and numbers of the file sequences processed. As in `adcp_calib_calc.ps` the first plot is from the first run, the second plot from the second run.

3.6 Calibration

The cruise track during ANDREX was in deep water so that bottom tracking was not possible. We therefore used water tracking to calibrate the entire period with lowered drop keel in the study region. Reference depths used during calibration for JC030 were:

- OS75: lower reference depth = 300 m, upper reference depth = 150 m.
- OS150: lower reference depth = 150 m, upper reference depth = 75 m.

The values then used for the processing during JC30 are:

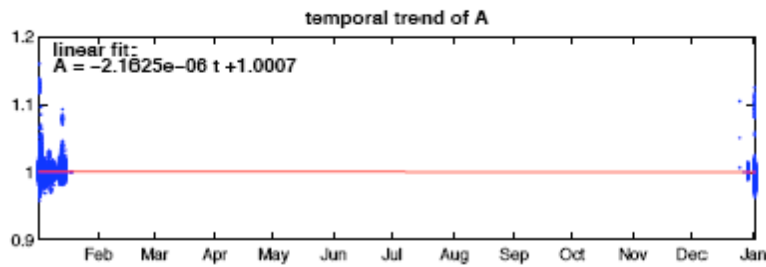
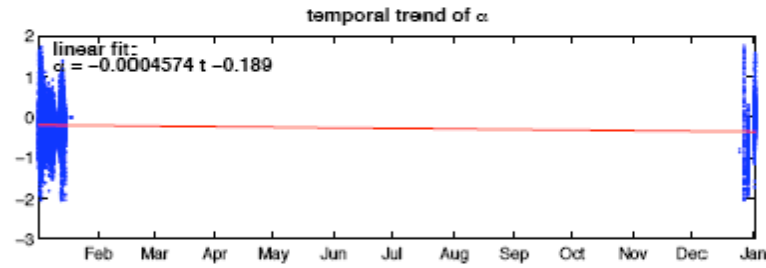
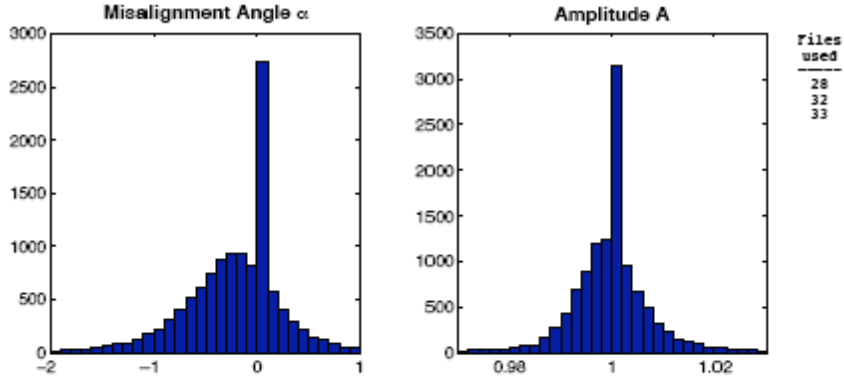
- OS150: misalignment = -0.6605; amplitude = 1.03162
- OS75: misalignment = -0.113; amplitude = 1.004121.

The calibration includes the times the keel was retracted and was performed for the entire cruise data. Figures 1-5 indicate the correction statistics for both instruments generated from the final processing after determining the misalignment angles and amplitude correction factor, and the pitch and roll, heading and PC clock offset statistics from the 75 kHz ADCP. All figures can be found in the respective processed data folders. Figure 6 is the contoured velocity data generated by the master processing function, OS75_JC_jc30.m.

MISALIGNMENT ANGLE DETERMINATION (JC030)
(Water Tracking)

from: 2008/12/23 - 02:24
to: 2008/01/17 - 08:03

Total Duration : -340.765 days
Calibration Points: 11852 of 12179



Statistics:

	amplitude	angle
mean :	1.000590	-0.2088
std :	0.011819	0.4740
median:	1.000000	-0.1330

Figure 3.1: Correction statistics for 75 kHz VM-ADCP.

MISALIGNMENT ANGLE DETERMINATION (JC030)

(Water Tracking)

from: 2008/12/23 - 02:27
to: 2008/01/17 - 08:04

Total Duration : -340.766 days
Calibration Points: 10668 of 11472

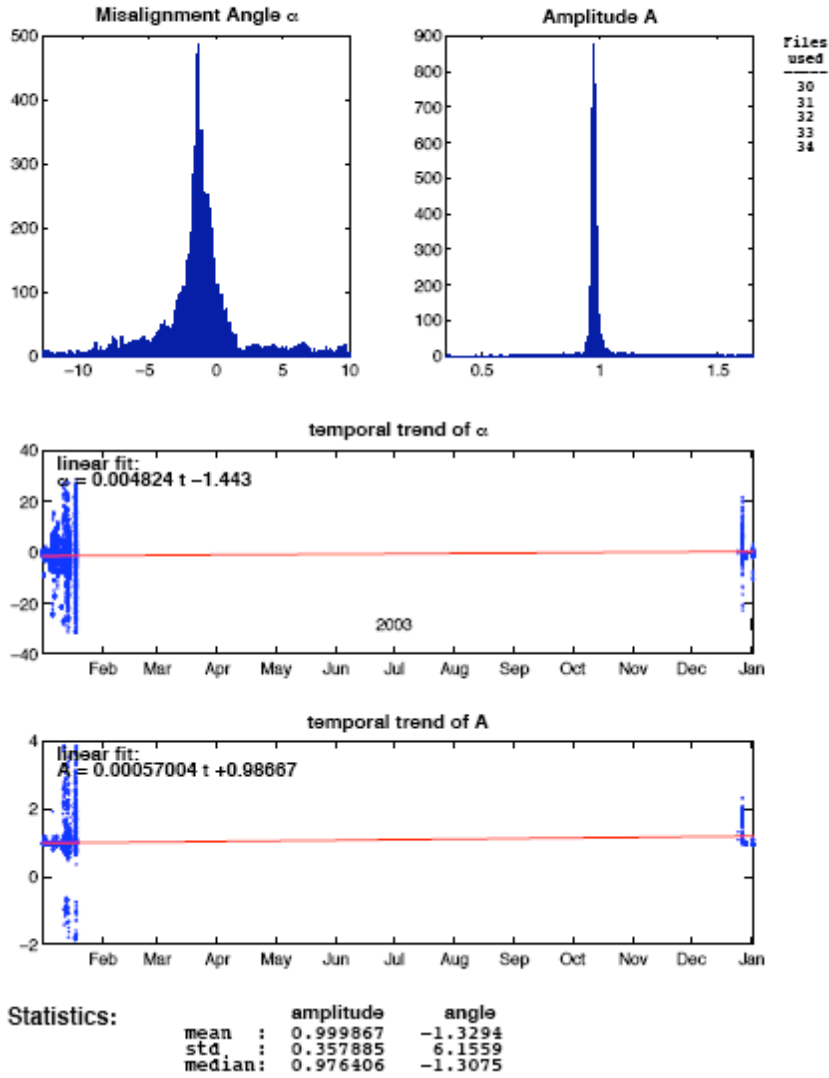


Figure 02: Correction statistics for 150 kHz VM-ADCP

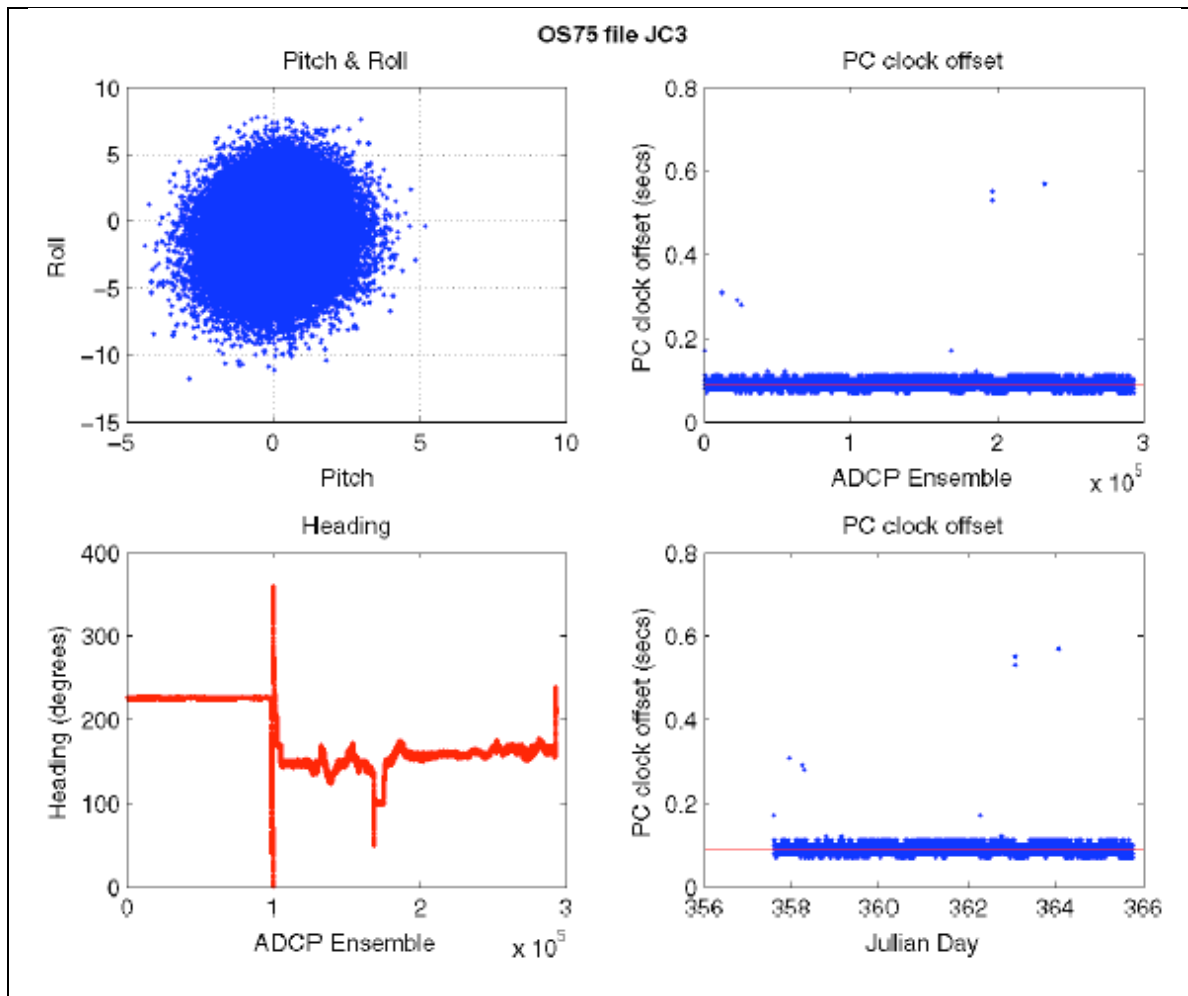


Figure 0: 75 kHz VM-ADCP, file 28, Pitch and roll, PC clock offset (vs. ensemble number), heading and PC clock offset (vs. time), (From file: adcp_prh.ps)

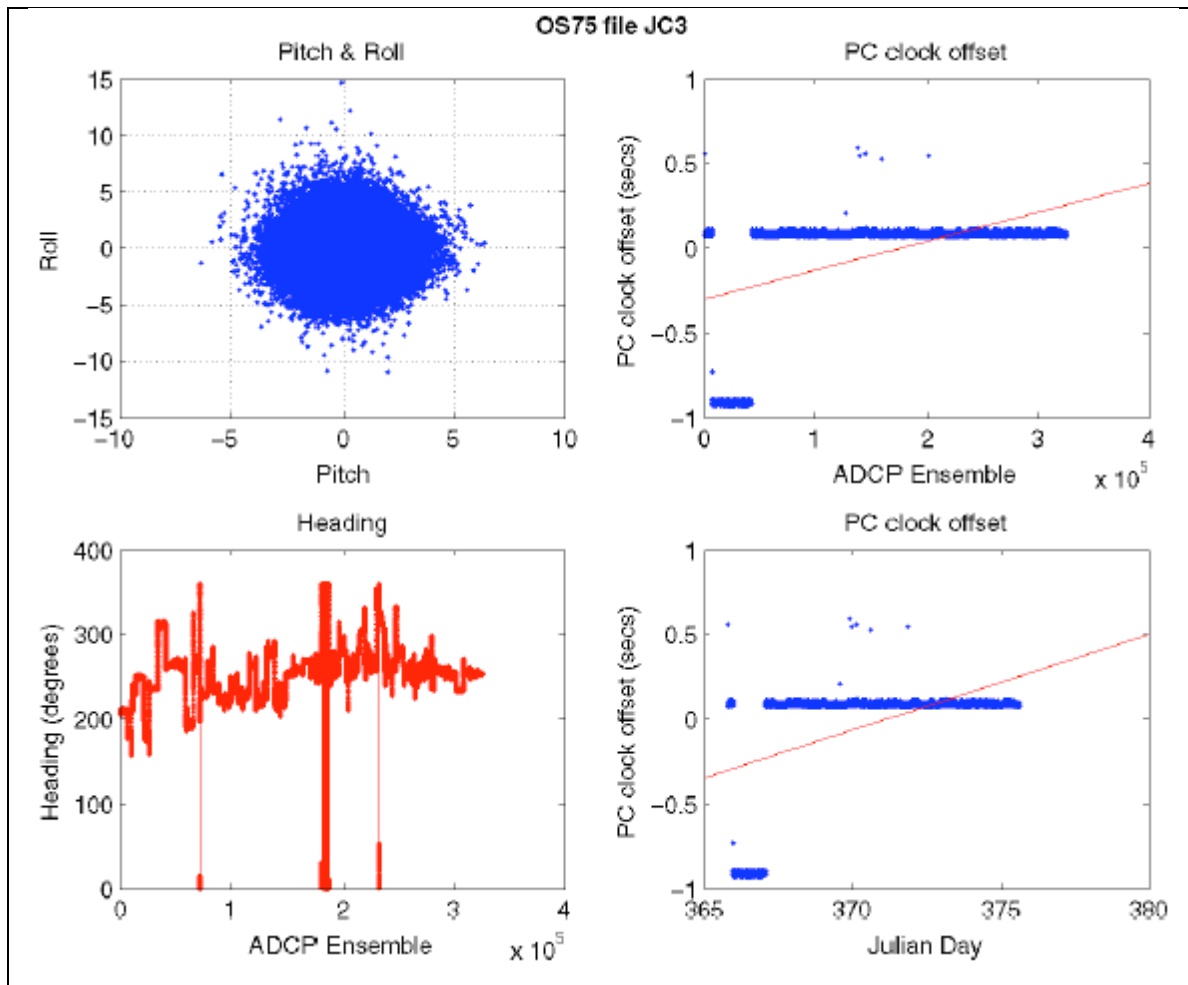


Figure 0: As Figure 3, file 32.

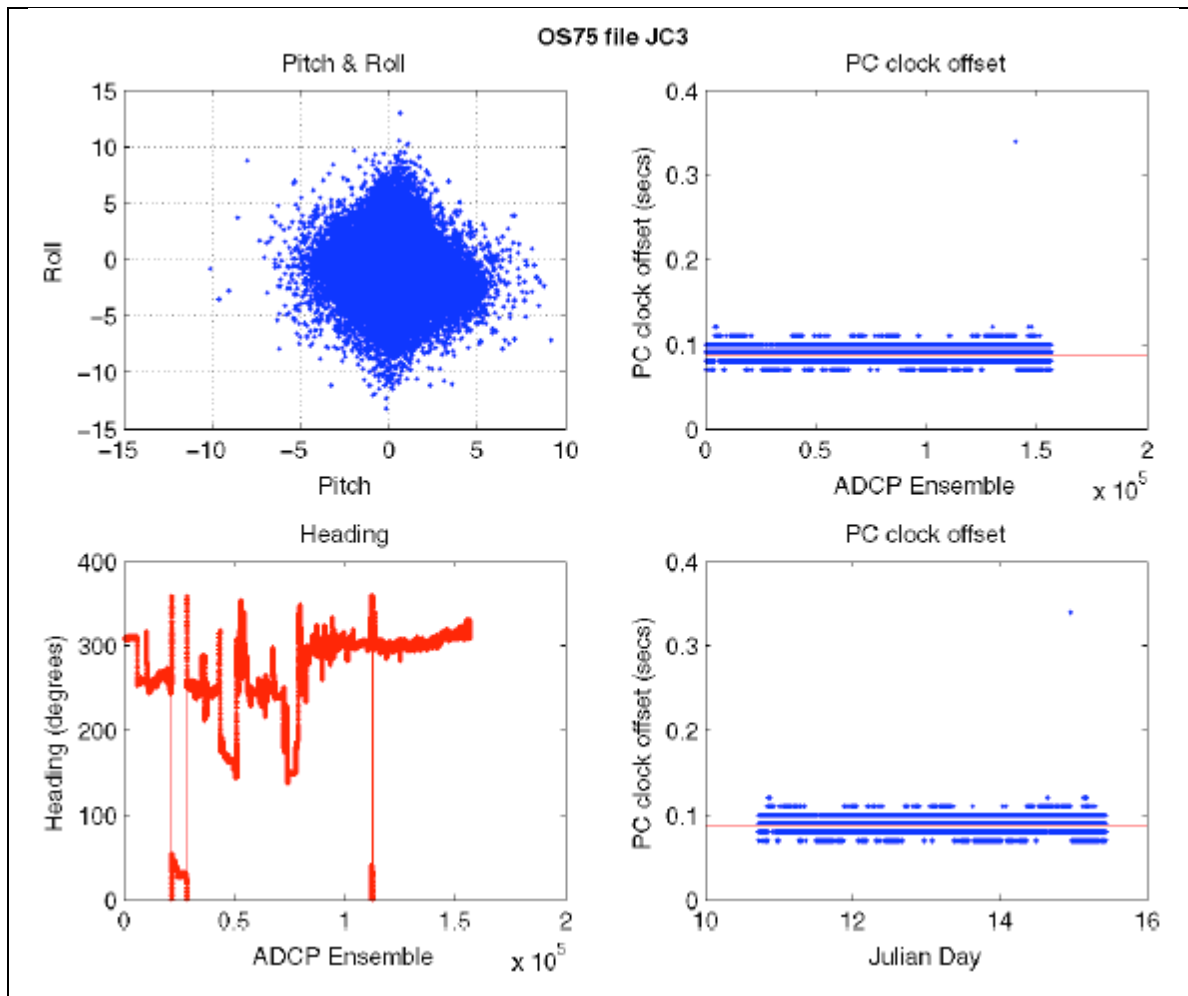


Figure 0: As Figure 3, file 33.

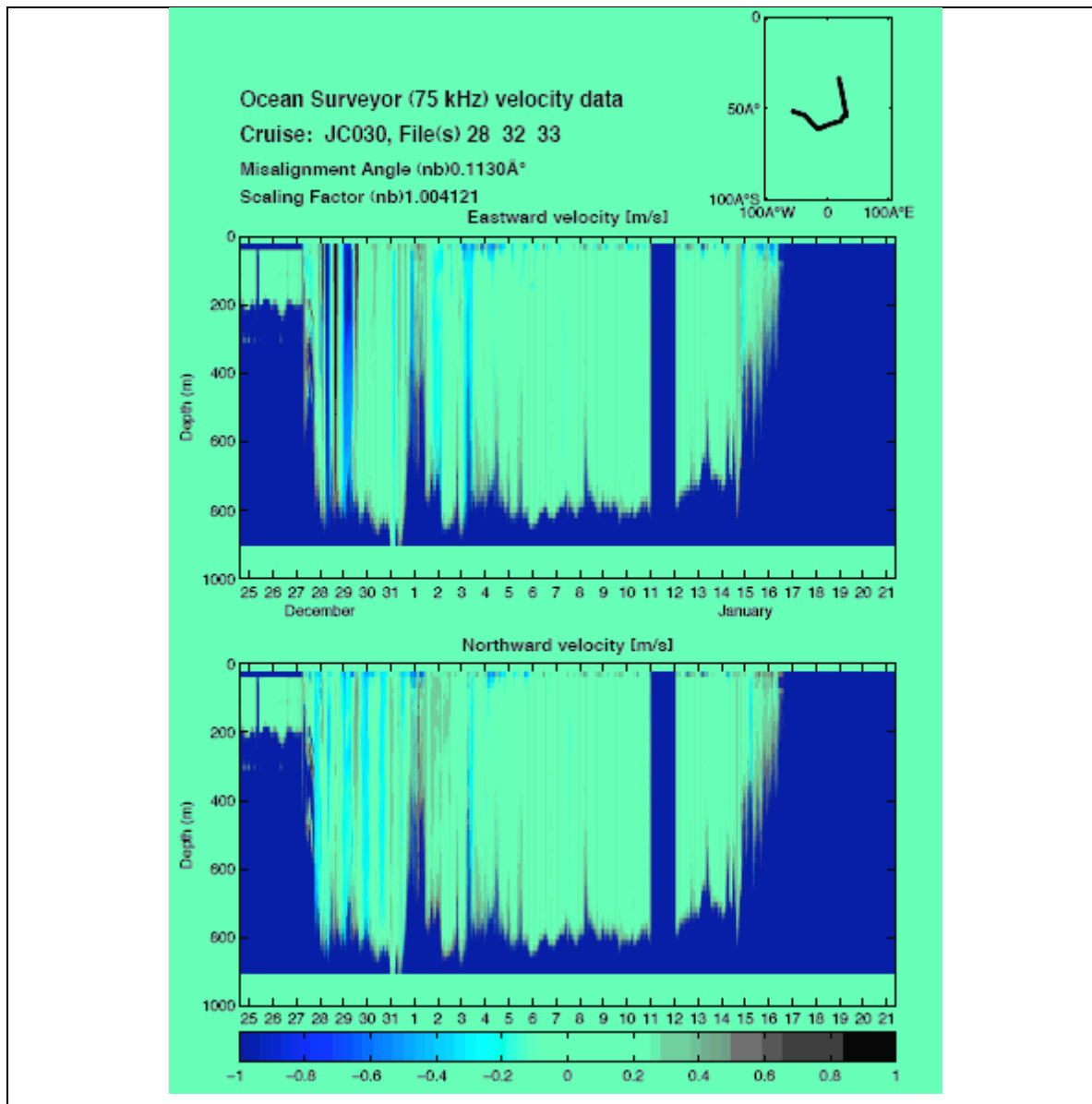


Figure 0: Contoured velocity, 75 kHz ADCP, all files following final processing and misalignment and amplitude corrections.

4 LOWERED ACOUSTIC DOPPLER CURRENT PROFILER (L-ADCP)

Loïc Jullion (*NOCS, UK*)

The L-ADCP measures the instantaneous velocity profile of scatterers drifting with the currents. The instrument sends an acoustic ping and listen for the echo return by scatterers present in the water column. The velocity of the scatters relative to the CTD package is calculated from the Doppler shift of the backscattered sound received by the four beams looking in four different directions. One pair of beams obtains one horizontal and one vertical velocity and the other pair of beams obtain a horizontal velocity orthogonal to the first one and a second estimate of the vertical velocity. The second vertical velocity gives an estimate of the data quality.

4.1 Deployment

The LADCP was configured to have a standard 10 x 16 m bins, with one water track and one bottom track ping in a two second ensemble. There was also a 5m blank at the surface. Data were collected in earth coordinates. The instruments were mounted in a downward looking orientation and positioned near the centre of the CTD frame.

Prior to each station the ADCP was connected to a laptop in the wet lab (via a serial port – USB adapter) for pre-deployment tests and the instrument was programmed (see script below). After each station the instrument was reconnected to the laptop for the retrieval of the data. The battery package was charged between stations. The raw data (.000 files) for each station were downloaded from the instrument and copied into a central data directory.

During the test station (station 1), the LADCP failed and came back after the cast filled with water (despite the instrument being brand new and according to the manufacturer, much more reliable than the old LADCPs). The LADCP was replaced for the start of the ANDREX line. During station 9, the LADCP rebooted during the cast, leading to the creation of two incomplete files. After station 18, when the failure of beam 4 was discovered, the LADCP was removed and it was decided not to use anymore LADCPs until we had reached the start of the ALBATROSS repeat line in order to save our remaining LADCPs for the most important part of the cruise (which never happened due to the medical evacuation) and for the following cruises. A total of 17 stations were occupied with the LADCP mounted onto the CTD frame (stations 2-18). Out of these 17 stations, the LADCP was fully functional only during the first one (Station 2). From station 3 to 18, one 3 beams were working (Figure 1).

Due to the failure of beam 4, most of the stations are processed using the 3 Beam solution of the LDEO software (the software detects alone the problem with the beam and switch to 3-beam processing) whereas the UH software cannot cope with 3-beam solutions.

4.2 Data processing

The data obtained by the instrument needs to be processed to:

- Remove the velocity of the scatterers relative to the CTD package and to the ship.
- Correct the sound velocity using the in situ CTD measurements.
- Average the individual ensembles into one vertical velocity shear profile.
- Calculate the depth of the instrument.
- Calculate the barotropic velocity profile from the ship navigation data.
- Combine both the baroclinic and barotropic profiles.

Two independent methods are available to process LADCP data. Both methods are used here in order to compare their performances and because both gives several useful diagnostics:

The University of Hawaii (UH) software, developed by Eric Firing, averaged the individual velocity shear into one full depth geostrophic shear.

The Lamont-Doherty Earth Observatory (LDEO) software (version 7b), developed by Martin Visbeck, uses inverse techniques to calculate the geostrophic shear adding extra data such as shipboard-ADCP data or bottom-tracking data to constraint the results. It is also used for obtaining bottom track profiles, to monitor the beams of the instrument and to calculate three-beam solutions for stations 3 to 18 as the UH software is unable to cope with 3-beams only.

The raw data (.000 files) for each stations are downloaded from the instrument and are stored into a directory:

/data32/JC030/LADCP/JC030_ADCP_data/

The raw files are then copied into the desired directory to be processed.

To avoid redundancy, the directories containing the raw data used for the processing (LADCP, CTD, navigation) were set for the UH software and symbolic links were used for the LDEO software. This avoids having two sets of raw data.

IMPORTANT FOR JC30: First station was done in 2008 and the others in 2009. The time information (sm.mat) extracted from the gps data (in the /gps/ directory). Here, we use symbolic

links to link sm.mat to the correct file (jc30sm2008.mat or jc30sm2008.mat). This link needs to be changed once station 2 has been processed.

4.2.1 UH software

The UH software is a combination of PERL and MATLAB scripts. The first step is to copy the raw files into the correct directory and to link the .000 data files to files using the UH nomenclature. We used a down-looking Workhorse LADCP, therefore the files were named: *jNNN_02*. The *_02* is used for consistency with previous cruises.

Processing steps:

Load the ADCP data into a database (*load.prl*) and get information about the cast, including nominal cast position, depth, and start time ...

Calculate the baroclinic shear profiles (*domerge.prl*) and apply corrections and editing options which were kept constant throughout the cruise.

do_abs.m calculates the absolute velocities and produced a standard set of profiles that are displayed. Up to this point, only the uncorrected data (down, up and mean profiles) are available with the depth-averaged set to zero.

Once, the CTD data are calibrated, the data were interactively matched to the ADCP vertical velocities (*fd.m*), and the true depth information for the cast merged into the database together with sound speed data corrected for temperature and salinity.

Then, the *domerge.prl* and *do_abs.m* steps are done once again to obtain the corrected shear profiles.

4.2.2 LDEO software

The LDEO software is a set of MATLAB scripts. On board of the James Cook, the directories were:

/data32/pstar/jc30/ldeo/jc0812/: the processing directory,

and

/data32/pstar/ldeo/ldeo_ladcp_software/v7/: the software directory.

The results are stored in directories named: */JC30NNN/*

Processing steps:

This software is much quicker to run as it is only a set of MATLAB scripts and just two MATLAB files (*sp.m* and *lp.m*) need to be run.

sp.m sets the correct raw directories.

lp.m sets the software directory and some of the processing options and launch the processing (*laproc.m*)

Like for the UH software, the LDEO software correct the sound speed using the CTD calibrated data. The barotropic velocity is calculated from the ship position at the beginning and end of the cast. The software excludes bad quality data (large tilt of the CTD package, low back scattering).

4.3 Data quality and preliminary results

Two main problems arise during JC30: the failure of beam 4 and a lack of scatterers in the deep ocean. Because the software developed by the university of Hawaii cannot cope with 3 beam solutions, the post-cruise processing was done using the version 7b of the software developed by Martin Visbeck at LDEO. This software presents the advantages of detecting the presence of suspicious beams and to switch to a 3-beam solution as shown in the text below extracted from the processing log of station 15.

```
LOADRDI: Loading data
loading down-data ./raw_ladcp/JC030_015m.000
ISBB: BB-data
raw data has 559+2 bytes per ensemble
read 13724 ensemble and 16 bins
Name      Size      Bytes Class  Attributes
btd      54896x16      7026688 double
using increased bottom echo amplitudes to create bottom track
use bin below maximum for bottom track
created 504 bottom track data from normal velocities
removed 0 values because of low percent good
found 36 bad bottom error velocities and discarded them
!!!!!!!!!!!! WARNING WARNING WARNING !!!!!!!!!!!!!
detected 55 % 3 BEAM solutions
!!!!!!!!!!!! WARNING WARNING WARNING !!!!!!!!!!!!!
removed 285 values because of high error velocity
removed 8 bottom values because of high error velocity
```


*using whole profile since no start time was given
removed 0 profiles due to larger tilt than 22
removed 8 profiles due to larger tilt difference than 4
multiply weight of bin 1 by 0.5
!!!! WARNING one beam might be broken !!!!!!!!*

The LDEO inverse processing technique allows to constraint the LADCP data with extra sources of information (the shipboard ADCP data that provides information on the upper ocean velocities and the bottom track velocities calculated by the built-in bottom tracking mode of the instrument). Because of the low number of scatterers in the water column and of the 3-beam solution that had to be used for most of the stations, one must be careful when evaluating the quality of the LADCP data. The different processing options offered by the LDEO software were applied to the JC30 data in order to assess the changes made to the solution by the different options.

The individual profiles were checked for inconsistencies between the different processing methods (See for Fig. 3 for station 15). Constraining the solution with bottom track or shipboard ADCP data resulted in strong offset between the resulting velocity profiles. The different processing methods diagnosed a strong vertical shear, especially below 2000 meters, that led us to think that the quality of the data was poor as most of the stations were situated within the Weddell Gyre, a region with a very weak baroclinic shear due to the homogeneous water masses present in the Weddell Sea. This was confirmed by comparing the LADCP velocity profiles to geostrophic profiles calculated from CTD data: The geostrophic shear during JC30 is weak and shows further evidence that the quality of the LADCP data is questionable. The poor data quality can be attributed to the lack of scatterers in the deep ocean below 2000 m as shown in Figure 2 and to the failure of beam 4. The resulting zonal and meridional velocities and the associated errors shown in figure 4, 5 and 6 respectively results are the results from the inversion using both the bottom track and shipboard-ADCP data to constraint the inversion. The large errors below 2000m suggest that the results should be considered with care below 1500-2000m.

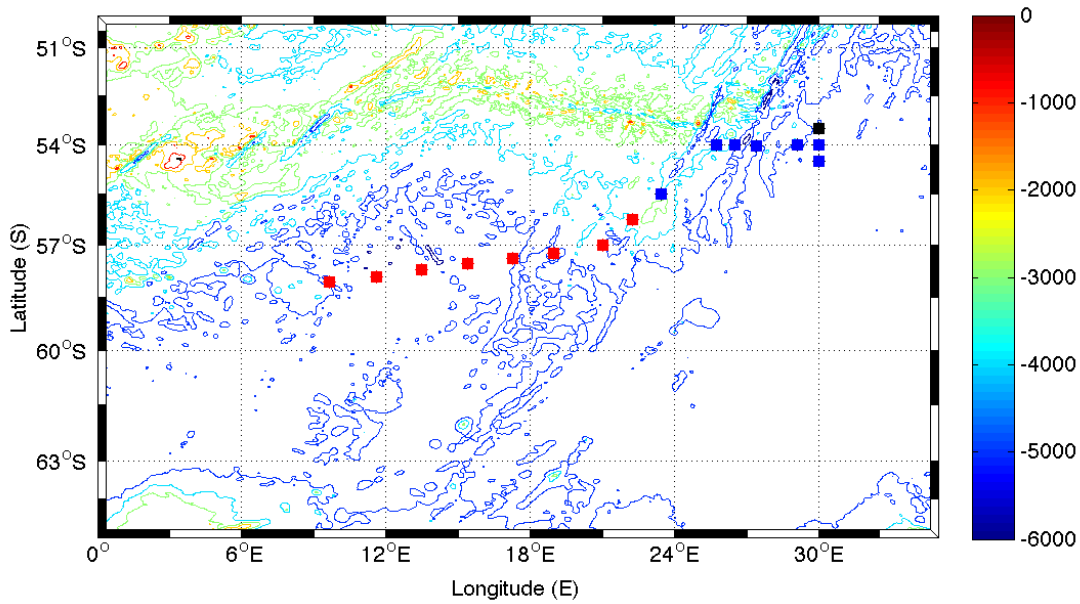


Figure 01: JC30 stations with LADCP profiles. The black square shows the position of the only station with a fully-working LADCP. The blues squares show stations with a weak beam and the red squares show the stations with a broken beam.

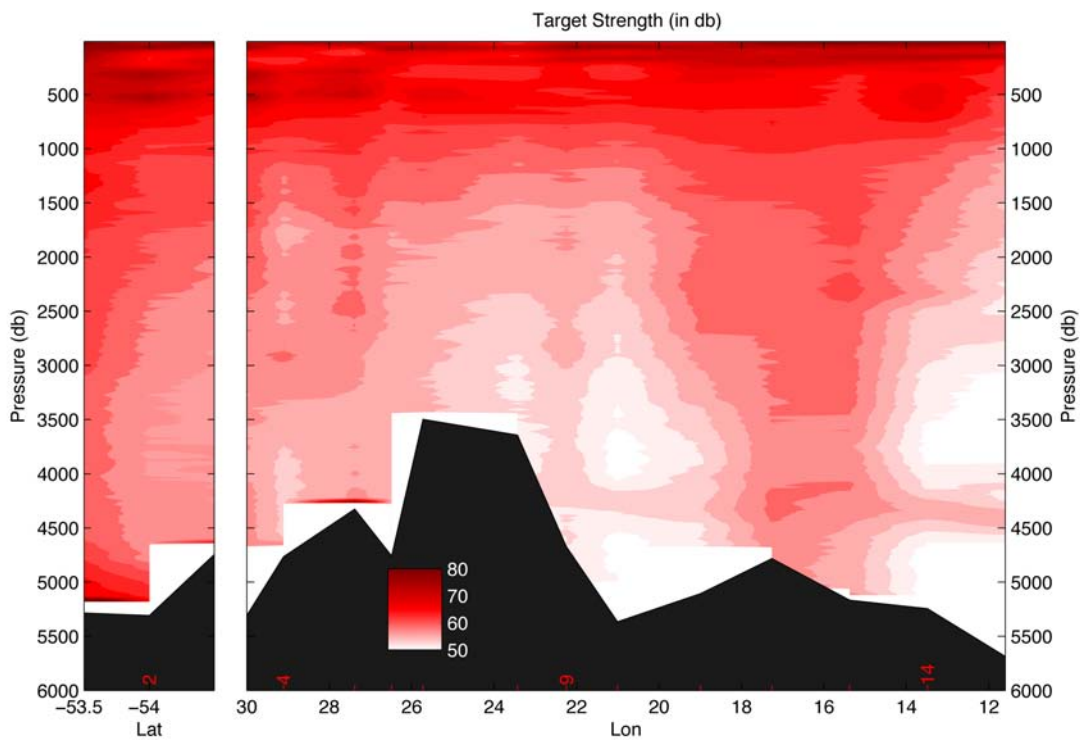


Figure 0: Acoustic backscatter (in db) during JC30. The left panel shows the I6S repeats and the right panel shows the quasi-zonal section. Station numbers are shown in red.

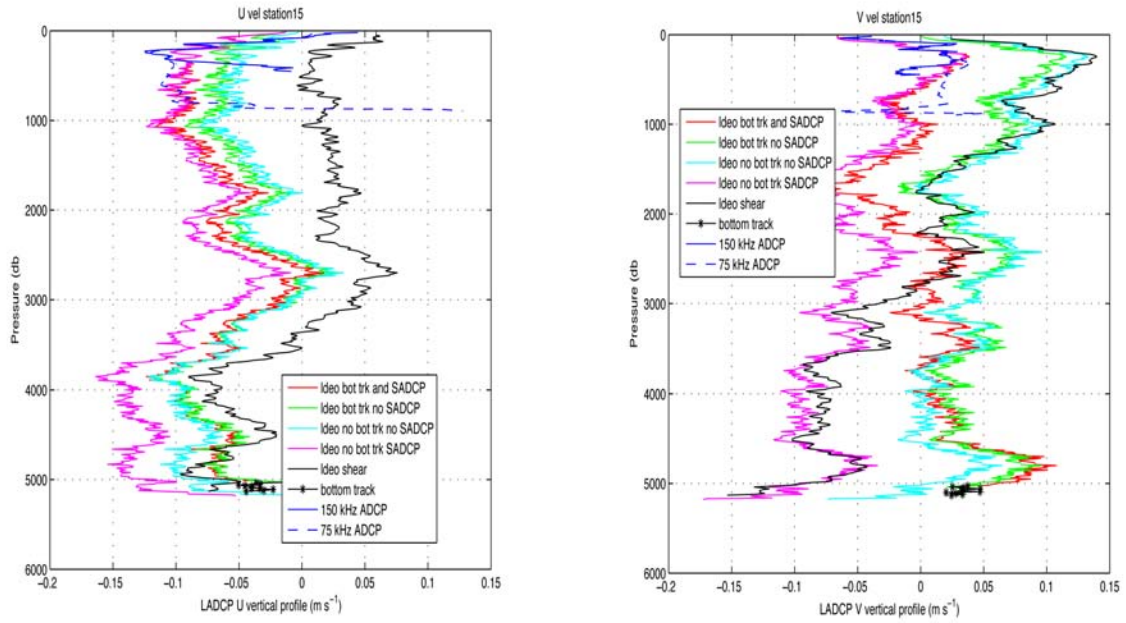


Figure 0: Comparison between the different processing of options for the U (left) and V (right) velocity profiles for station 15. The VM-ADCP and bottom-track velocities used by the software are also shown.

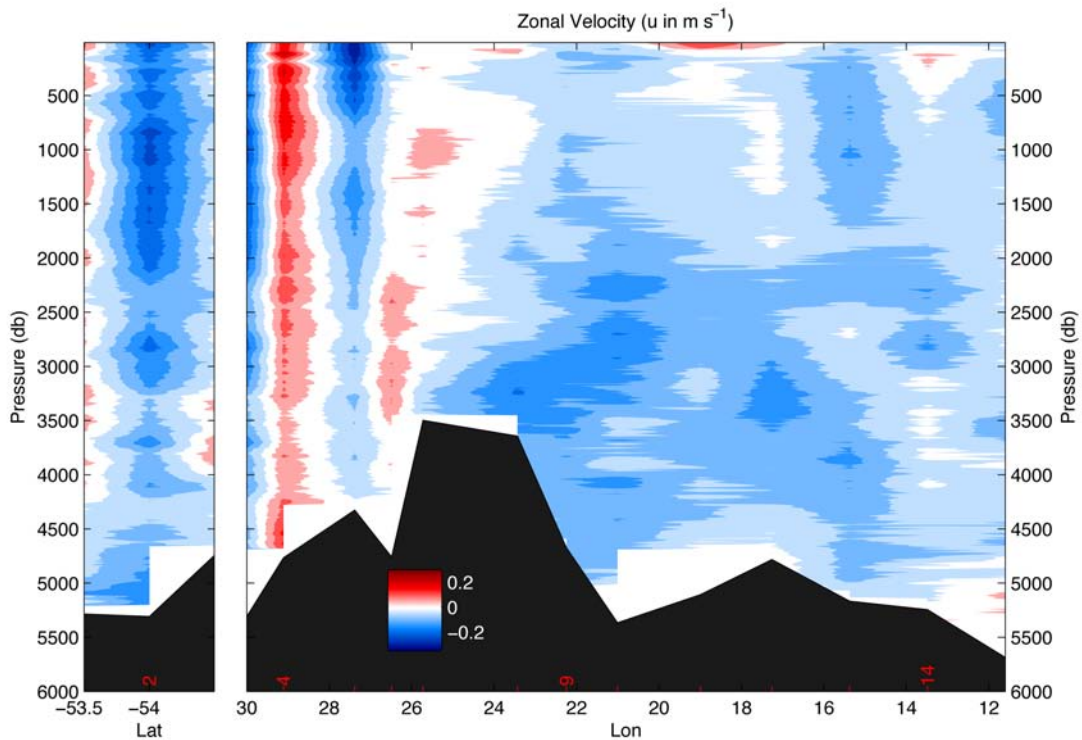


Figure 0: Zonal velocity (in m s^{-1}) section for the I6s repeats (left) and the main ANDREX line (right). Positive velocities are eastward.

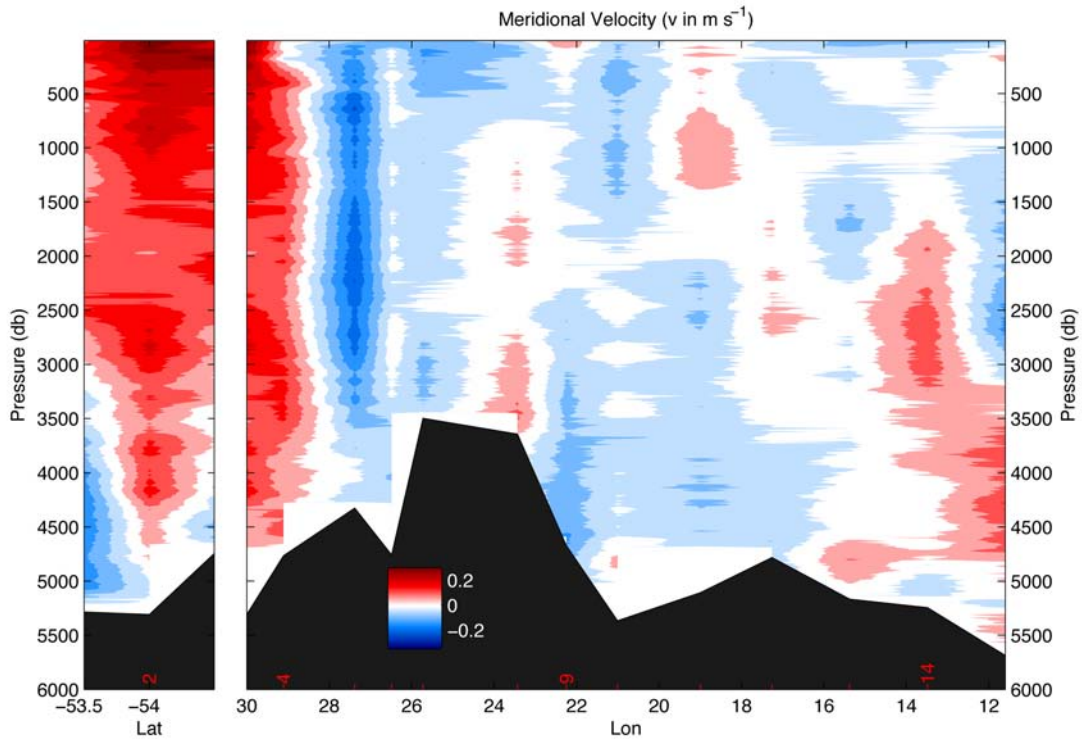


Figure 0: Meridional velocity (in m s^{-1}) section for the I6s repeats (left) and the main ANDREX line (right). Positive velocities are northward.

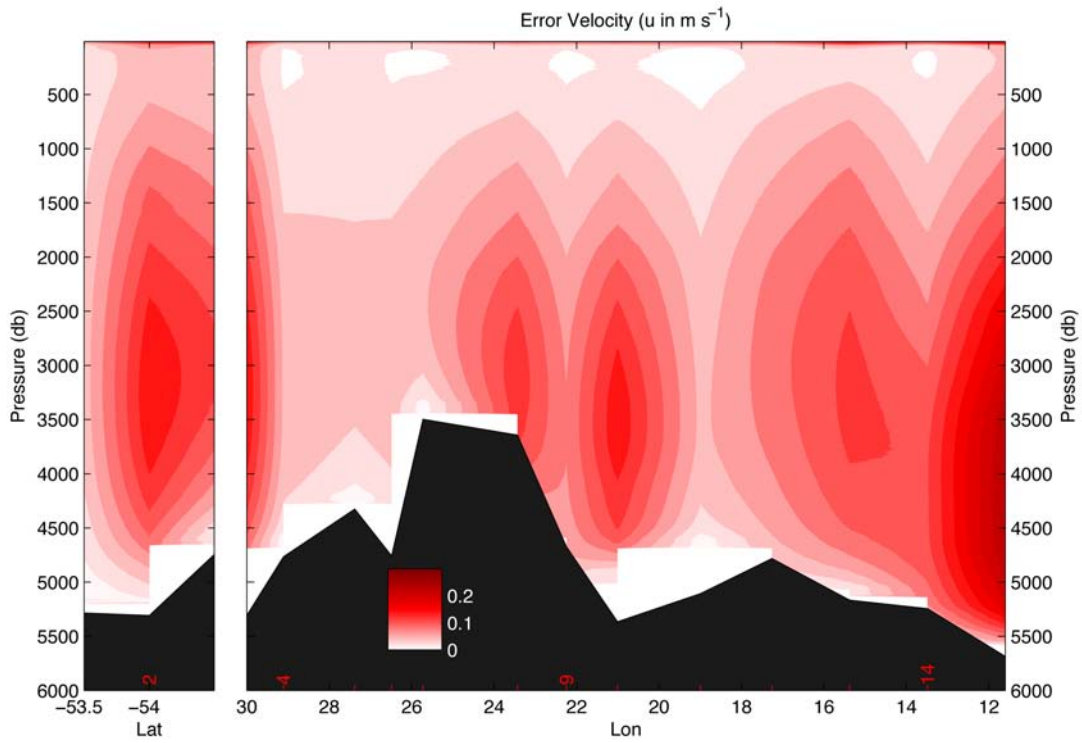


Figure 0: Error associated with the LADCP velocities (in m s^{-1})

5 CHEMICAL ANALYSIS

5.1 Inorganic Nutrient Analysis

Paul Morris (*NOCS, UK*)

5.1.1 *Methods*

Analysis for micro-molar concentrations of nitrate and nitrite (nitrate from hereon), phosphate and silicate was undertaken on a Skalar SansPlus segmented autoanalyser following methods described by Kirkwood (1996), with the exception that the pump rates through the phosphate line were increased by a factor of 1.5, which improves reproducibility and peak shape. A dilution loop for the sample line of the silicate channel was also installed giving a 2.9 times dilution (Figure 1). This was done in anticipation of the very high silicate concentrations expected in the area to be sampled. Samples were drawn from Niskin bottles on the CTD rosette into 35 ml coulter counter vials and kept refrigerated at approximately 4°C until analysis, which usually commenced within 0.5 to 2.0 hours. Stations were run individually because there was a large gap ca. >8 h between stations. Overall, all 27 stations were sampled with all Niskins being sampled. This totaled about 648 samples. An artificial seawater matrix (ASW) of 40 g l⁻¹ sodium chloride was used as the inter-sample wash and standard matrix. The nutrient free status of this solution was checked by running Ocean Scientific International (OSI) nutrient free seawater on every run. A single set of mixed standards were made up by diluting 5 mM solutions made from weighed dried salts in 1 l of ASW into 1 l plastic volumetric flasks. On setting up the lab all labware was washed with 10% HCl and rinsed with MQ water. Data processing was undertaken using Skalar proprietary software and was done at regular intervals throughout the cruise. The wash time and sample time of the autosampler were 90 s; the lines were washed daily with 0.5 mol l⁻¹ sodium hydroxide and 10% Decon 90. Time series of baseline, instrument sensitivity, calibration curve correlation coefficient, nitrate reduction efficiency and duplicate difference was compiled to check the performance of the autoanalyser over the course of the cruise.

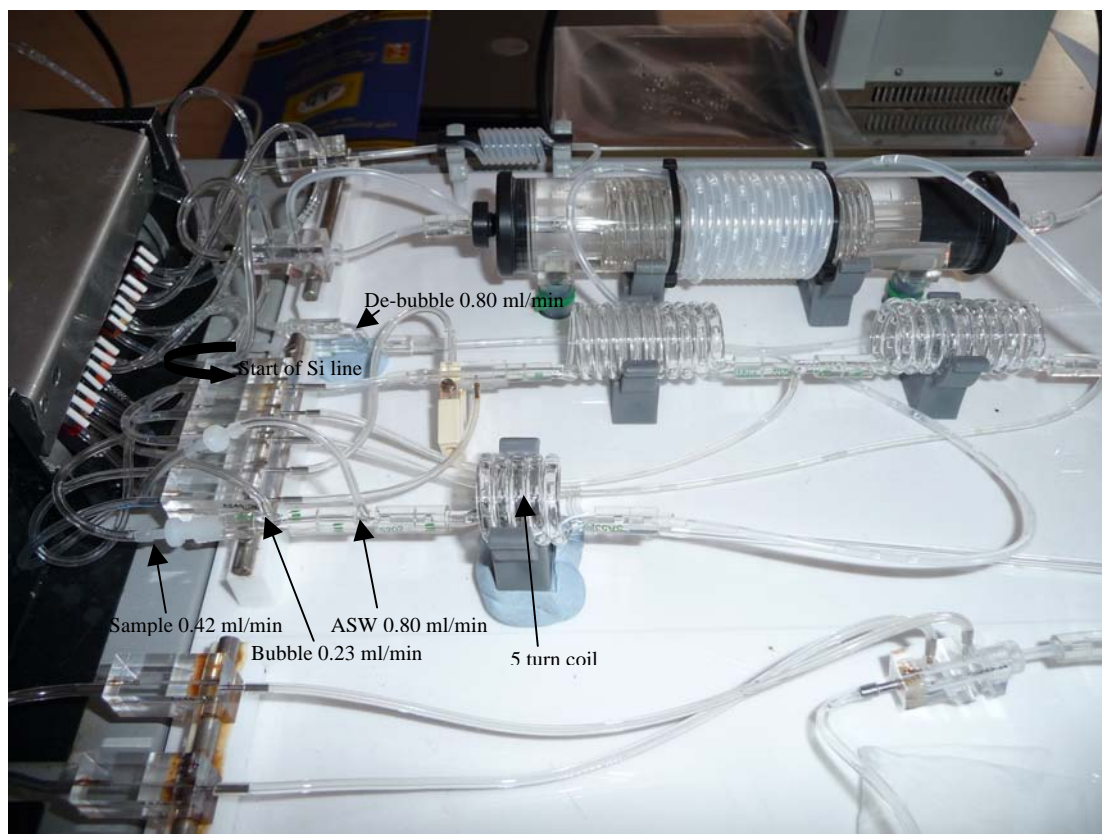


Figure 0-1: Details of the dilution loop for the silicate line.

5.1.2 Performance of the Analyser

Overall the autoanalyser performed very well. New pump tubing was installed at the start of the cruise and turned around to use the other half of the tubing before run 18. Some noise in the phosphate baseline prompted us to try using the second set of integrator cables, however this did not make much difference. The bulbs in the two detectors were replaced before run 23, and this appeared to give a smoother baseline and cleaner peaks. Therefore it is my suggestion that whenever the autoanalyser is to be extensively used the bulbs, as well as the pump tubing, are renewed at the start of the cruise despite their previous usage history.

5.1.3 Specific Details

1. During run 9 the autosampler needle jammed down the side of one of the sample cups. As the instrument was unattended at this time a large amount of air was taken up. When this was discovered the majority of the samples were salvaged by managing to get a drift and a wash sample through the analyser before the run finished. To quality control this run and to recover the 3 lost samples the whole profile was run again on the next shift and cross checked. Little to no difference was found between runs. Several days after this event the autosampler became unreliable, so was swapped out for a spare and fixed by one of the technicians.

2. During run 25 the water bath was not switched on before the start of the run. This was discovered during the calibration phase of the run, so the run was stopped and restarted. As a result of this the Skalar software malfunctioned and ceased to work and is believed to have become corrupted. A re-install of the software could not solve the problem and consequently the run was aborted. As a result a backup computer was used and the samples were run on the next shift.

3. The reproducibility of the 3 chemistries were determined by running at least 2 samples in triplicate for every station. For each set of 57 sets of triplicates the relative standard deviation (RSD) was calculated. The average RSD was 0.40%, 0.38% and 0.38% for nitrate, silicate and phosphate respectively.

4. The performance of the autoanalyser was monitored via the following parameters: baseline value, calibration slope (instrument sensitivity), calibration correlation, low nutrient seawater, bulk nutrient seawater and nitrate reduction efficiency. These parameters will be presented as a time series against run number in Figures 2-6.

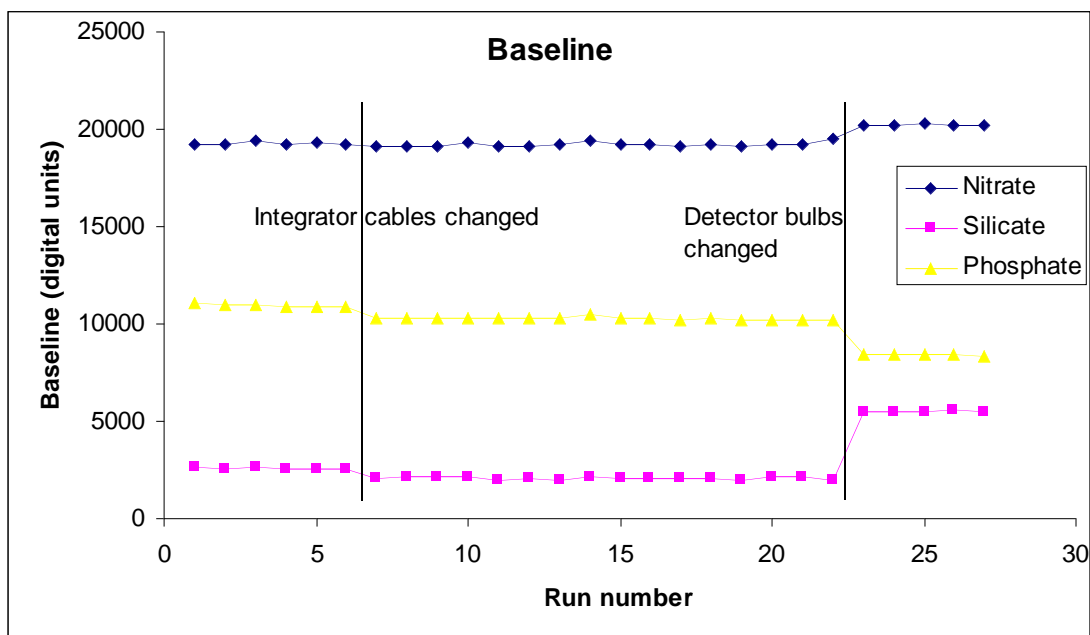


Figure 0-2: Time series of baseline values in digital units. The baseline remained very constant except when the integrator cables and detector bulbs were changed, marked by the vertical lines.

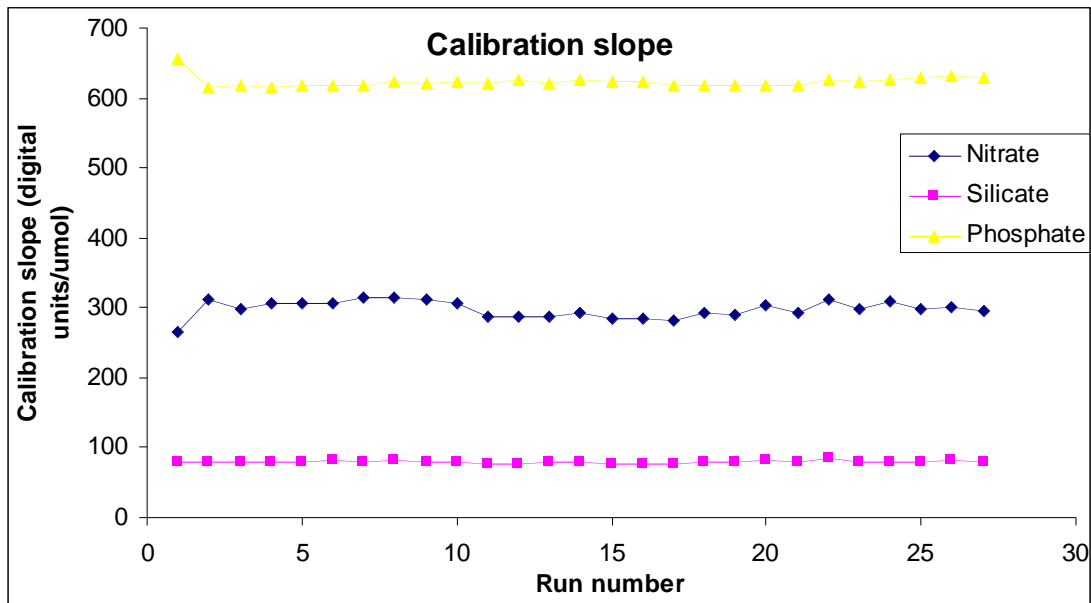


Figure 0-3: Time series of calibration slopes. This shows the sensitivity of the autoanalyser in digital units per $\mu\text{mol l}^{-1}$. The sensitivity of the autoanalyser remained constant over the course of the cruise, apart from run 1 where phosphate and nitrate were sl

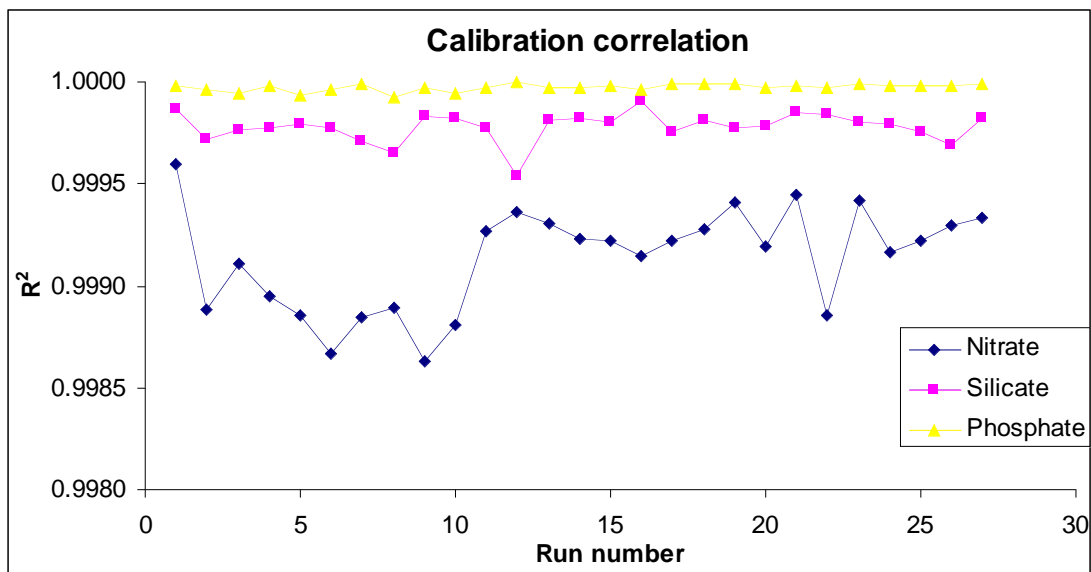


Figure 0-4: The calibration correlations never had an r^2 less than 0.998 and were mostly better than 0.999.

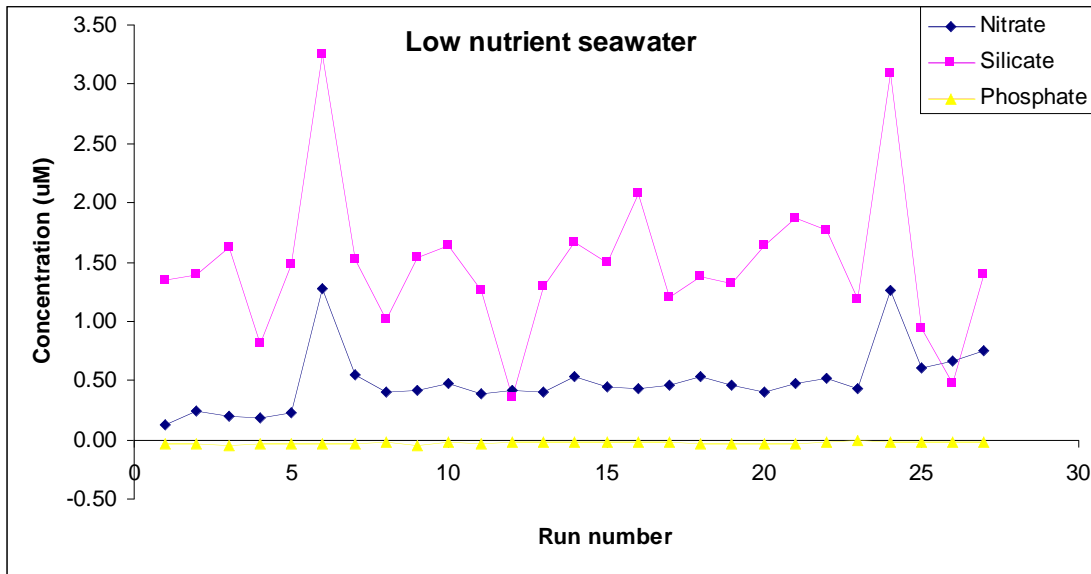


Figure 0-5: Low nutrient seawater (LNS) purchased from OSI was used to check the artificial seawater (ASW) for contamination. The concentrations measured in LNS were $0.49 \pm 0.26 \mu\text{M}$, $1.48 \pm 0.62 \mu\text{M}$ and $-0.03 \pm 0.01 \mu\text{M}$ ($\pm\sigma$, $n=27$) for nitrate, silicate and phosphate resp

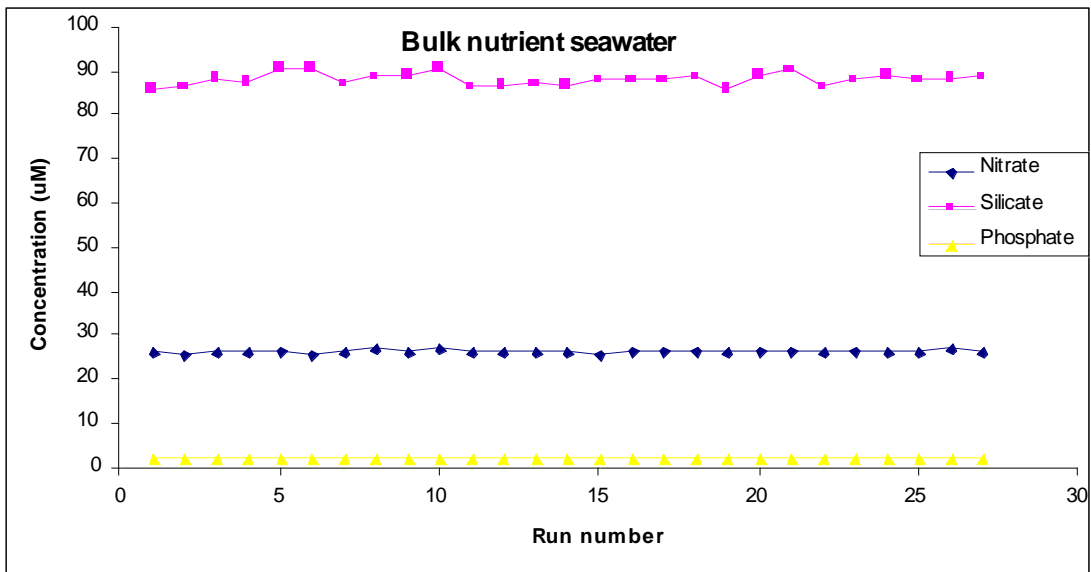


Figure 0-6: Time series of bulk nutrient seawater concentrations. The average concentration was $26.30 \pm 0.29 \mu\text{M}$, $88.11 \pm 1.43 \mu\text{M}$, $1.81 \pm 0.01 \mu\text{M}$ ($\pm\sigma$, $n=27$) for nitrate, silicate and phosphate respectively.

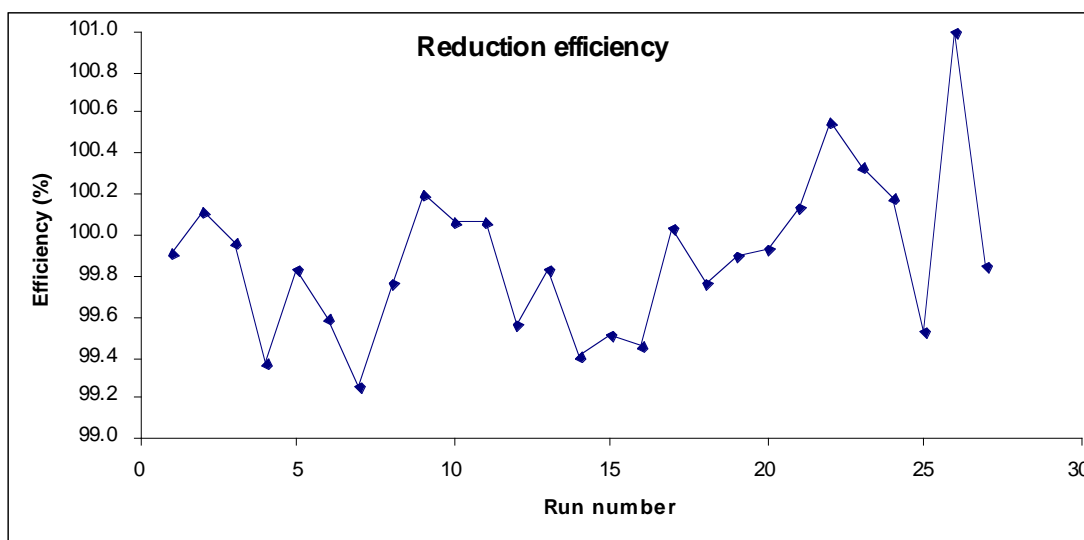


Figure 0-7: The ability of the cadmium column to reduce nitrate to nitrite. The reduction efficiency was between 99-101% for all runs. The cadmium column was in good enough condition from the previous cruise to be used for ANDREX and did not need changing during

5.2 Dissolved Oxygen

Sinhue Torres-Valdes (*NOCS, UK*)

5.2.1 Preamble

All 27 stations occupied during ANDREX were sampled for dissolved oxygen (DO). Sampling for DO was done just after CFCs and/or Tritium were sampled. Seawater was collected directly into pre-calibrated glass wide neck bottles using a Tygon tube. Before the sample was drawn, bottles were flushed with seawater for several seconds (about 3 times the volume of the bottle). Care was taken to avoid bubbles inside the sampling tube and sampling bottle. The fixing reagents (i.e., manganese chloride and sodium hydroxide/sodium iodide solutions) were added just after the temperature of the sample was recorded using a hand held thermometer. In most cases the temperature was recorded while sample was being taken. Samples were thoroughly mixed following the addition of the fixing reagents and were then kept in a dark plastic crate for 30-40 min to allow the precipitate to settle to <50% the volume of the bottle. Once the precipitate had settled all samples were thoroughly mixed for a second time in order to maximize the efficiency of the reaction. Analyses were carried out within 2 h of sample collection.

5.2.2 Methods

DO determinations were made using a Winkler Ω -Metrohm titration unit (794 DMS Titrino) with an amperometric system to determine the end point of the titration (*Culberson and Huang, 1987*).

Chemical reagents were previously prepared at NOCS following the procedures described by *Dickson* (1994). Recommendations given by *Dickson* (1994) and by *Holley and Hydes* (1994) were adopted. Thiosulphate calibrations were carried out every 4-5 days and using a 1.667 mM certified OSIL iodate standard. Calibration values summarised in Table 1 and shown in Figure 1 suggest little variation of the standard volume and thiosulphate concentration over time. Calculation of oxygen concentrations were facilitated by the use of an Excel spreadsheet provided by Dr. Richard Sanders (NOCS). This spread sheet has been modified/corrected to include pipettes' calibrated dispensing volumes (i.e., reagents and iodate standard additions have been calibrated). Replicate measurements of randomly-selected samples were also carried out in order to test for reproducibility. At least 1 Niskin bottle was always sampled in duplicate and any misfires were used to either duplicate other Niskin bottles or to sample in triplicates. In total, replicates (2 or 3) were done in 56 bottles throughout the 27 CTD casts. Results showed that variability of replicate measurements was $\leq 0.8 \mu\text{mol-O}_2 \text{ L}^{-1}$. This value is rather high, since previous measurements with this equipment have produced values $\leq 0.3 \mu\text{mol-O}_2 \text{ L}^{-1}$. During two previous cruises however, we have encountered problems with recently bought (July 2007) oxygen bottles, whose lids started falling apart due to manufacture defects. This situation prompted us to use bottles of different makes and lid designs, what we believed were the main reason for obtaining slightly less precision of replicate samples. During ANDREX we particularly noticed that in many cases the first measurement was producing lower concentrations than expected by comparison with adjacent samples. We thought one reason may be that after the first titration, the thiosulphate within the dispenser may have been slightly diluted by the sample being titrated. Another reason we thought about, was that the calibrated glass bottle designated to sample the first Niskin was responsible for this results. With the data obtained up to the last station we were not able to determine whether either of the two reasons mentioned above were the cause of producing apparently low values. We were about to test both ideas when unfortunately the cruise had to be cancelled.

Table 0-1: ANDREX O₂ determinations; Number of thiosulphate calibrations, dates on which calibrations were carried out, mean blank titre volume, standard titre volume (STD) and molarity of thiosulphate solution.

Calibration number	Date	Blank (mL)	STD (mL)	Thiosulphate Molarity
1	27/12/2008	0.0033	0.5024	0.198
2	01/01/2009	0.0033	0.4974	0.200
3	05/01/2009	0.0014	0.4933	0.201
4	09/01/2009	0.0012	0.4975	0.199
5	13/01/2009	0.0022	0.4993	0.199

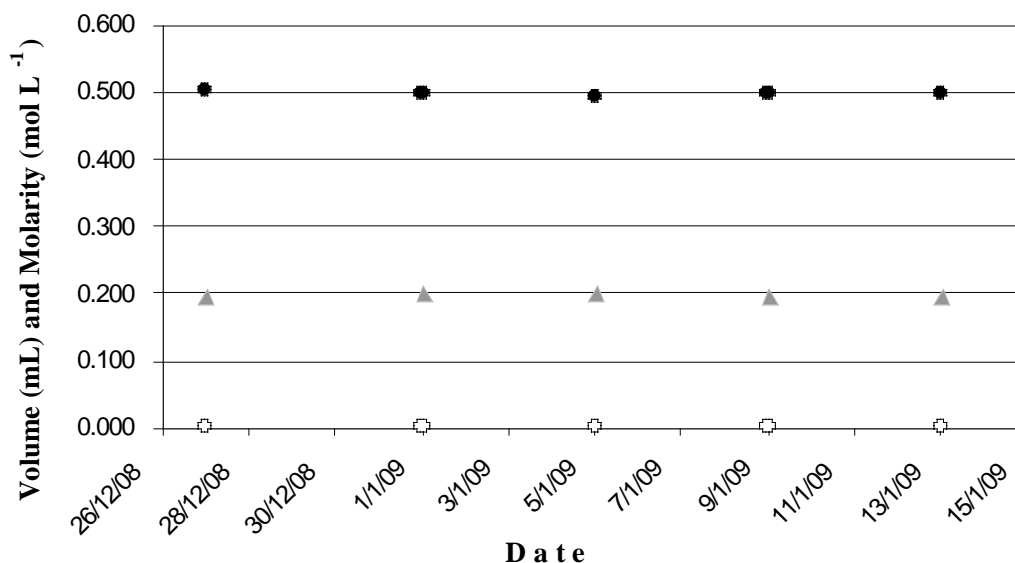


Figure 0-1: Volume of thiosulphate solution added to titrate 10 ml of a 1.667 mM iodate standard (black dots), volume of blank (white dots) and molarity of the thiosulphate solution (gray triangles).

References

- Culberson, C.H. and Huang, S. (1987) Automated amperometric oxygen titration. *Deep Sea Research*, 34, 875-880.
- Dickson, A.G. (1994) Determination of dissolved oxygen in seawater by Winkler titration. Technical report, WOCE operations manual, WOCE report 68/91 Revision 1 November 1994.
- Holley, S.E. and Hydes, D.J. (1994) Procedures for the determination of dissolved oxygen in seawater. Technical report, James Rennell Centre for Ocean Circulation.
- Kirkwood, D. (1996) Nutrients: Practical notes on their determinations in seawater. ICES Techniques in marine environmental sciences. 17, 1-25.

5.3 Tritium, Noble gas and Radiocarbon sampling

Róisín Moriarty for Chris Ballentine (*University of Manchester, UK*).

Brett Longworth for William Jenkins (*helium isotopes lab and national ocean sciences accelerator mass spectrometry lab, Wood Hole, USA*)

Dissolved noble gases, tritium and radiocarbon can each be used as tracers of water mass formation and circulation. These tracers have differing boundary conditions with respect to air-sea-ice

interactions and evolve over different intrinsic and extrinsic time scales. Thus the distributions of these tracers should help deconvolve the complex processes and water masses associated with WSBW production.

To this end, a sampling plan was chosen to maximize coverage in areas of interest to the project. We concentrated samples in the deep and shallow depths, using wider spacing in the middle depths. In general every 4th station was sampled, giving coverage for every other station when combined with samples taken for the Manchester helium/tritium lab. This scheme was shifted at times to sample the deepest point in passages and shallow points on rises. Distance between sampled stations was kept under 100nm.

Helium/noble gas samples were taken immediately after CFC's; ¹⁴C and tritium were taken after DIC. Generally, samples for noble gas and tritium were taken on different stations from radiocarbon, although all three were taken on later stations due to large spacing between stations.

We generally try to sample surface ~0-10, 100, 150, 200, 400, 600, 800, 1000, 1500, 2000, 3000, 3500, 4000, 4500, 5000, bottom -200, bottom -100, bottom -50 and bottom. At station 12 it was decided to up the resolution a little and fill 1000m gaps i.e. between 2000 and 3000 upping the number of samples in deep water (>4500m) to 20 including 1 replicate, keeping in mind that not all depths are sampled because of problems with the Niskin bottles (not firing or leaking). The plan was to decrease the number of samples taken (~8 and 12) as bottom depths decrease towards the end of the cruise. (Plan of proposed stations for sampling attached).

5.3.1 *Helium/Noble gases*

Samples for helium and other noble gases were taken (directly after the CFC samples) in 3/8" copper tubing mounted in clamping and support assemblies which give 90mL samples. The sampler was connected to the niskin with tygon tubing before opening the niskin and slowly lowering the sampler, reducing bubbling during filling. About 1L of water was allowed to flow through the sampler while tapping with a mallet to remove bubbles. When water exiting the sampler was bubble free, clamping bolts were tightened, starting with the top of the sampler. After sampling, the ends of the tubing and clamps were rinsed with fresh water and then with isopropanol. All the leaking Niskin bottles were avoided. Samples were labelled (cruise, station number, bottle number [a or b as a duplicate was taken from each bottle]) and packed to be sent back to the University of Manchester or WHOI.

5.3.2 *Tritium*

Tritium samples were taken in 1L glass bottles directly after the CO₂ samples. The bottles were shipped clean and back-filled with argon to prevent atmospheric contamination. Samples were taken

with a length of tygon tubing attached to the niskin which was held upwards to rinse with sample water before filling bottles. Bottles were filled upright and shielded from wind and spray, leaving a head space and capping immediately. After sampling, bottles were labeled and sealed with electrical tape. All the leaking Niskin bottles were avoided.

5.3.3 Radiocarbon

Water for analysis of ^{14}C in DIC was sampled in 500mL glass-stoppered flasks. The bottles were rinsed twice with ~50mL of sample water before filling. With tygon tubing inserted to the bottom, the bottles were overfilled, using about 750mL of water. About 10mL of water was dumped to create a head space, and 100 μL of saturated mercuric chloride solution was added to prevent biological activity during storage. Bottles were sealed with a greased glass stopper and rubber-banded to keep the stopper from loosening.

5.3.4 Sampling

A total of 164 helium/noble gas samples, 165 tritium and 147 radiocarbon samples were taken in the 27 stations of the cruise for the WHOI laboratory and the samples should be analyzed within the coming year. Helium and tritium were sampled on stations 3, 7, 11, 15, 17, 21, 23, 25 and 27, and radiocarbon samples were taken on stations 3, 8, 12, 16, 20, 23, 25, and 27. Generally, 18-20 depths were sampled, and leaky or misfired niskins were skipped. All samples will be returned to WHOI from Southampton and No major problems were encountered during sampling.

A total of 127 helium/noble gas samples were taken for the Manchester laboratory (Stations 1 (test), 5, 9, 13, 17, 19, 24 & 26).

Notes

- There was some modification to the sampling equipment and the procedure during the first couple of stations. (see modification log)
- Weather on the whole was good and risk of contamination was low.
- Róisín Moriarty from the helium/tritium isotope lab in Manchester and Brett Longworth (WHOI) worked together on all stations. Having two persons sampling resulted in much more efficient sampling, allowing us to keep up with the general flow of work around the rosette. On a number of stations we enlisted help. We were always on hand to supervise what was going on.
- One inter lab comparison station was carried out at station 17.

5.4 Inorganic carbon and oxygen

Dorothee C.E. Bakker and Shaun Scally (*UEA, UK*)

Mario Hoppema (*AWI, Germany*)

5.4.1 Rationale

In the Southern Ocean ventilation of the deep ocean and uptake of anthropogenic CO₂ take place. Deep water upwelling at the surface leads to exchanges of heat, CO₂, and other gases with the atmosphere. Estimates of net oceanic CO₂ uptake south of 50°S for ~1995 range from 0.1-0.5 Pg C yr⁻¹ (Pg = 10¹⁵ g) (Rayner et al., 1999; Takahashi et al., 2002, 2009). The relatively small net sink may reflect a transition from a pre-industrial source for atmospheric CO₂ to a modern day CO₂ sink. Most of the anthropogenic CO₂ taken up by the Southern Ocean is transported north along equal density surfaces (Caldeira and Duffy, 2000), presumably in Antarctic Intermediate Water and Subantarctic Mode Water. A reduction of vertical mixing and upwelling in the Southern Ocean would probably increase the atmospheric CO₂ level (Sarmiento et al., 1998; Matear and Hirst, 1999). Changes in the extent of wintertime sea ice could promote an increase in outgassing of CO₂ in winter (Bakker et al., 2008). Global warming might provoke such changes in the Southern Ocean (Sarmiento et al., 1998).

The outstanding feature of the Southern Ocean is the world's largest current structure, the Antarctic Circumpolar Current (ACC). South of it ventilation processes take place near and on the continental shelves. The Weddell Gyre is a large elongated clockwise rotating gyre, south of the ACC. Major quantities of dense deep and bottom water are produced here, which are likely to be accompanied by uptake of anthropogenic CO₂. In the western Weddell Gyre the largest share of dense waters is produced. Part of this water leaves the gyre circulation through deep passages in the northern boundary of the gyre, while another part is transferred to the eastern gyre. In the eastern Weddell Gyre major interaction takes place with the ACC (Gouretski and Danilov, 1993). The region is also important from a biogeochemical point of view, but little is known about it. The few available data on the partial pressure of CO₂ (pCO₂) suggest that the region is a significant CO₂ sink (Hoppema et al., 2000; Bakker et al., 2008). Our cruise track along the northern boundary of the Weddell Gyre repeated a previous realisation in the north-eastern gyre (ANT13/4 in 1996).

5.4.2 Objectives

- Quantification of the carbon budget for the Weddell Gyre.
- Determination of the distribution of anthropogenic CO₂ along the northern boundary of the Weddell Gyre

- Comparison with earlier carbon data and determination of interannual variability along the eastern part of the section
- Assessment of CO₂ air-sea transfer in the Weddell Gyre, particularly in its north-eastern part.
- Investigation of processes and mechanisms leading to the remarkable summertime CO₂ sink of the north-eastern Weddell Gyre.

5.4.3 *Methods: Underway pCO₂ and oxygen*

Seawater supply

The ship's seawater supply provided a high volume of water for underway sampling. A screw pump transported the water from 5 m depth at the bow to the laboratory container. During part of the cruise, bubbles were observed in the pCO₂ equilibrator (see below). Temperature and salinity of the intake water were determined by the ship's thermosalinograph (TSG). Unfortunately, the TSG data was found to be unreliable, far beyond the 0.1°C accuracy needed for pCO₂ analysis. A full comparison has therefore been made by Sheldon Bacon between CTD temperatures and onboard temperature sensors. In the laboratory container which was placed at the aft deck, the seawater passed an oxygen sensor, a strainer with a bypass, and finally the equilibrator for pCO₂ analysis. The bypass was incidentally used for discrete sampling water for dissolved inorganic carbon (DIC) and alkalinity.

Partial pressure of CO₂ in surface water and marine air

Continuous measurements of the partial pressure of CO₂, pCO₂ (actually xCO₂ in μmol mol⁻¹), in surface water and marine air were made from the beginning of the section at 30°E to the Falkland Islands with the UEA underway pCO₂ system. Marine air was pumped through tubing from the deck above the bridge (monkey island) at about 16 m height. Seawater from the ship's surface water supply was introduced at a rate of 2-3 l min⁻¹ into the equilibrator. A Pt-100 probe accurately determined the water temperature in the equilibrator. A long vent kept the headspace of the equilibrator close to atmospheric pressure. The CO₂ content and the moisture content of the headspace were determined by an infrared LI-COR 7000 analyser. The analysis of the CO₂ content in the headspace was interrupted for that of the CO₂ content in marine air (20 minutes per six hours) and in three CO₂ standards (30 minutes per six hours each). Samples from the equilibrator headspace and marine air were partly dried to 10°C below the ambient temperature in an electric cool box. The standards bought from BOC amounting to 248.44 ± 0.03 (25-B18), 350 (35-B04) and 455.59 ± 0.08 (45-B18) μmol CO₂ mol⁻¹ and nitrogen (zero CO₂) had been calibrated against certified NOAA standards prior to the cruise and will be recalibrated upon the return of the equipment to UEA. The analyses were carried out for a flow speed of 100 ml min⁻¹ through the LI-COR at a slight overpressure. A final analysis for each parameter was made at atmospheric pressure with no flow. The flow and overpressure did not have a discernable effect on the CO₂ and moisture measurements, once the pressure had been corrected for. The

correction by Takahashi et al. (1993) will be used to correct for warming of the seawater between the ship's water intake and the equilibrator. The pCO₂ measurements will be time stamped by our own GPS positions. The precision and accuracy of the pCO₂ data are likely to be approximately 1 µatm, as determined during previous cruises (e.g. Bakker et al., 2001). The pCO₂ data await data quality control.

Oxygen concentration of surface water

In many oceanic processes oxygen (O₂) is complementary to CO₂. Therefore, it is useful to measure oxygen concomitantly with CO₂. The O₂ concentration and water temperature were measured with an optode, model 3930 from Aanderaa. The oxygen measurement is based on dynamic luminescence quenching of luminophore molecules (platinum porphyrine) embedded in a sensing foil, which is exposed to the surrounding water (Aanderaa, 2003). A light emitting diode (LED) and a photo-diode are placed on the instrument side of the foil. Absorption of a photon from the blue-green photo-diode excites the luminophore molecules in the foil. If a luminophore molecule does not collide with another molecule, it will return to its initial state by emitting a photon. However, if a luminophore molecule collides with an O₂ molecule, it transfers its excitation energy to the oxygen molecule. The intensity of fluorescent light thus decreases with the O₂ concentration. The photo-diode detects the quantity of this fluorescent light.

The instrument is contained in cylindrical titanium housing with a length of 160 mm and a diameter of 40 mm. A purpose-built titanium housing positions the optode in the seawater flow. The optical window of the optode is in the wider part of the housing and in the centre of the flow. The external housing is positioned vertically. The optical window of the optode is put in the direction of the flow, in order to minimize any effects from air bubbles. The temperature sensor just enters the wider part of the external housing. The data from the optode were logged on the data logger, model 3660 (Aanderaa), and passed on every minute to the laptop of the online pCO₂ system.

The optode has a measuring range of 0-500 µM, with a resolution better than 1 µM and an accuracy better than 8 µM or 5%, whichever is greater (Aanderaa, 2003). The optode is valid for a salinity range of 33-37. Software in the data logger calculates the oxygen concentration (µM) from the raw data and the calibration coefficients of the oxygen sensor. The oxygen optode has its own internal thermometer for the calculation of the oxygen concentration in addition to the external temperature sensor. The O₂ data will be checked against oxygen concentrations determined by the precise Winkler method in surface samples at CTD stations (Paul Morris and colleagues).

5.4.4 Methods: Vertical profiles of DIC and alkalinity

Rosette sampling

Water samples for the determination of DIC and alkalinity were drawn from the 20 l Niskin bottles on the CTD rosette and collected in 500 ml glass bottles in the usual way to avoid gas exchange with the air. All, but one, CTD stations were sampled (Figure 1). All Niskins were sampled on every CTD. Depths were distributed evenly over the water column with a bias towards the upper 1000 m. Unfortunately one to four Niskin bottles did not close at most stations. A total of 547 rosette samples were analysed for DIC and alkalinity. All samples were analysed within 12 hours of collection, i.e. the analyses were performed immediately after water sampling, starting with the shallowest samples. The samples were not poisoned.

Dissolved Inorganic Carbon measurements

Water samples were first analysed for Dissolved Inorganic Carbon (DIC), also denoted as Total CO₂ (TCO₂). Samples were kept cold before measurement in a water bath (about 4°C) or in cool boxes and were also measured at this low temperature to prevent bubble formation in the extractor tubing. One or two replicate analyses were made on each sample bottle. Also replicate samples from the rosette were drawn. The DIC concentration was determined by the coulometric method after the method of Johnson et al. (1987) using an extractor unit built after the design by Robinson and Williams (1992). The system has a carry-over effect, such that the first replicate of a sample was discarded if a large DIC change occurred between samples. This was the case between surface and deep samples, and especially between all samples and the certified reference material (CRM). The latter have a significantly lower DIC value than the samples. Generally all samples from one station were run using the same coulometer cell. In a few cases two stations were run with one coulometer cell. When starting up the cell sufficient junk samples were run for the blanks to come down. At least one CRM (batch 92 of Prof. Dickson, SIO) was used per coulometric cell and station. The data await final quality control.

Initial results are shown in Figure 2. The DIC concentration is relatively low in the upper water column with some pronounced minima in the summer mixed layer. Low DIC in the surface waters is presumably caused by a combination of dilution by melt water and biological carbon uptake (Bakker et al., 2008). The DIC maximum at 200 to 1000 m depth corresponds to maxima in temperature and salinity and reflects the presence of Circumpolar Deep Water (CDW) or Warm Deep Water (WDW). Relatively low DIC north east of 20°E and 57°S indicates the influence of ACC waters. The DIC concentration gradually decreases below the WDW.

Titration Alkalinity measurements

The alkalinity measurements were made by potentiometric titration with a VINDTA instrument (#7, version 3C, developed by Mintrop, 2004). The acid consumption up to the second endpoint is equivalent to the titration alkalinity. The system uses a highly precise Metrohm Titrino 719S for

adding acid, an ORION-Ross pH electrode and a Metrohm reference electrode. The burette, the pipette (volume approximately 100 ml), and the analysis cell have a water jacket around them. A second VINDTA system (#4, version 3C), after fixing various problems, was used during about half of the cruise for running replicates of the first system.

Water samples came from the same bottles that were previously used for DIC analysis. They were allowed to warm to about 25°C in the water bath before measurement. The titrant (0.1 M hydrochloric acid, HCl) was made in the home laboratory. One sample was run for each sample bottle. Sufficient replicate analyses were run for determining the measurement precision and the precision of sampling. At least one new CRM of batch 92 was run per station; additionally CRMs previously used for DIC analysis were run. The alkalinity data need correction for seawater density and nutrient concentrations. The data await final quality control.

Initial results are shown in Figure 3. Alkalinity has a clear minimum in surface waters and reaches fairly constant values below 400 to 600 m depth. Normalisation to a constant salinity (by multiplication with a constant salinity of 34.5 and division by the in situ salinity) suggests that alkalinity is conservative in this depth range and that most of this vertical TA change results from dilution by freshwater. The alkalinity data hint at higher alkalinity in the central Weddell Gyre (8°E to 17°W) than in the eastern gyre, but this requires further study. Finally there is some suggestion of relatively low alkalinity at 15°E and 25°E, but this could be an artefact of the data analysis.

5.4.5 *Recommendation*

Stable and calibrated shipboard sensors for the measurement of sea surface salinity and temperature with better than 0.1°C accuracy should be routinely available on the NERC research fleet.

5.4.6 *Data availability*

The final pCO₂, DIC, alkalinity, and O₂ data will be stored with other cruise data at the British Oceanographic Data Centre (<http://www.bodc.ac.uk/>). The data will become publicly accessible once the results have been published. The carbonate parameters will also be submitted to the international, publicly accessible CO₂ databases at the Carbon Dioxide Information Analysis Center (<http://cdiac.esd.ornl.gov/oceans/>).

References

- Aanderaa (2003) TD 218 Operating manual oxygen optode 3830 and 3930. 9th edition. Aanderaa Instruments AS, Bergen, Norway, 44 pp.
- Bakker, D.C.E., A.J. Watson, C.S. Law (2001) Southern Ocean iron enrichment promotes inorganic carbon drawdown. *Deep-Sea Research II* 48, 2483-2507.

- Bakker, D.C.E., M. Hoppema, M. Schröder, W. Geibert, H.J.W. de Baar (2008) A rapid transition from ice covered CO₂-rich waters to a biologically mediated CO₂ sink in the eastern Weddell Gyre. *Biogeosciences* 5, 1373-1386.
- Caldeira, K., P.B. Duffy (2000) The role of the Southern Ocean in uptake and storage of anthropogenic carbon dioxide. *Science* 287, 620-622.
- Gouretski, V.V., A.I. Danilov (1993) Weddell Gyre: Structure of the eastern boundary. *Deep-Sea Research I* 40, 561-582, 1993.
- Hoppema, M., M.H.C. Stoll, H.J.W. de Baar (2000) CO₂ in the Weddell Gyre and Antarctic Circumpolar Current: Austral autumn and early winter. *Marine Chemistry* 72, 203-220.
- Johnson, K.M., K.D. Wills, D.B. Butler, W.K. Johnson, C.S. Wong (1993) The performance of an automated continuous gas extractor and coulometric detector. *Marine Chemistry* 44, 167-188.
- Matear, R.J., A.C. Hirst (1999) Climate change feedback on the future oceanic CO₂ uptake. *Tellus* 51B, 722-733.
- Mintrop, L. (2004) VINDTA, Versatile Instrument for the Determination of Titration Alkalinity. Manual for versions 3S and 3C. Version 2.0. MARine ANalytics and DATA (MARIANDA), Kiel, Germany, 45 pp.
- Rayner, P.J., I.G. Enting, R.J. Francey, R. Langenfelds (1999) Reconstructing the recent carbon cycle from atmospheric CO₂, δ¹³C and O₂/N₂ observations. *Tellus* 51B, 213-232.
- Robinson, C., P.J. leB Williams (1992) Development and assessment of an analytical system for the accurate and continual measurement of total dissolved inorganic carbon.. *Marine Chemistry* 34, 157-175.
- Sarmiento, J.L., T.M.C. Hughes, R.J. Stouffer, S. Manabe (1998) Simulated response of the ocean carbon cycle to anthropogenic climate warming. *Nature* 393, 245-249.
- Schlitzer, R., 2009. Ocean Data View, <http://odv.awi.de>.
- Takahashi, T., J. Olafsson, J.G. Goddard, D.W. Chipman, S.C. Sutherland (1993) Seasonal variation of CO₂ and nutrients in the high-latitude surface oceans: a comparative study. *Global Biogeochemical Cycles* 7, 843-878.
- Takahashi, T., Sutherland, S.C., Sweeney, C. Poisson, A., Metzl, M. et al. (2002) Global sea-air CO₂ flux based on climatological surface ocean pCO₂, and seasonal biological and temperature effects. *Deep Sea Research II* 49, 1601-1622.
- Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D.W., Hales, B., Friederich, G., Chavez, F., Sabine, C., Watson, A.J., Bakker, D.C.E., Schuster, U., Metzl, N., Inoue, H.Y., Ishii, M., Midorikawa, T., Nojiri, Y., Koertzing, A., Steinhoff, T., Hoppema, J.M.J., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R., Wong, C.S., Delille, B., Bates, N.R., Baar, H.J.W. de (2009) Climatological mean and decadal change in surface ocean pCO₂, and net sea-air CO₂ flux over the global oceans. *Deep-Sea Research II*. 56: 544-577. doi:10.1016/j.dsr2.2008.12.009.

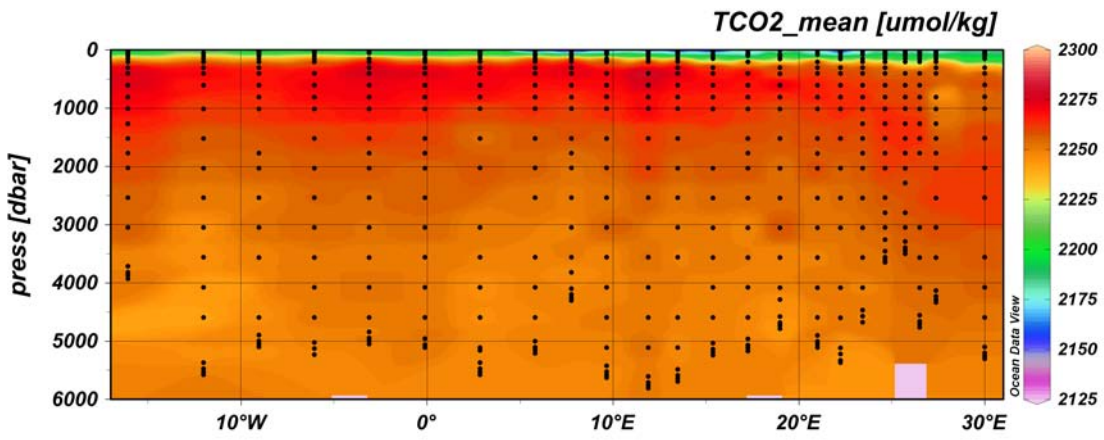
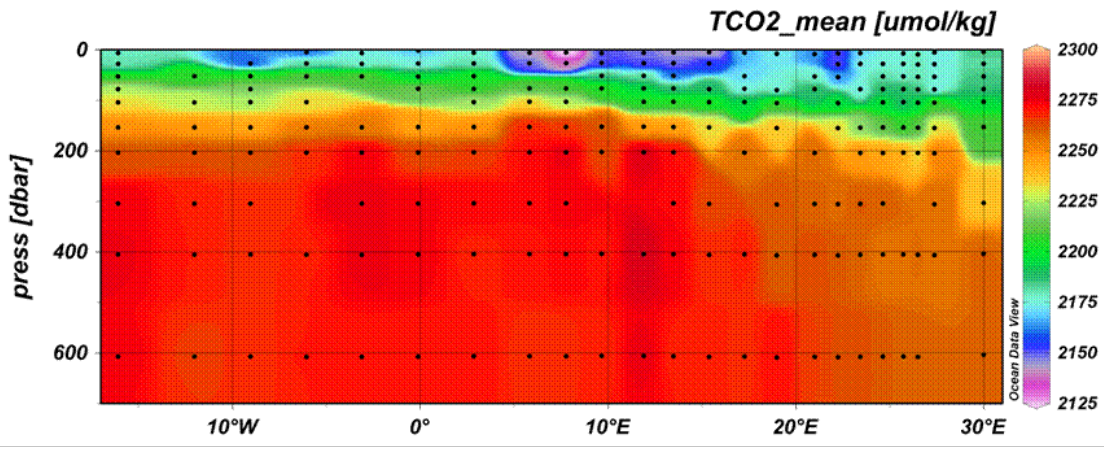


Figure 0-1: The vertical distribution of DIC (or TCO₂) (preliminary data) along the ANDREX section a) in the upper 700 m and b) across the water column. The dots indicate the location of samples taken. Bottom topography has not been indicated and is roughly 10 m.

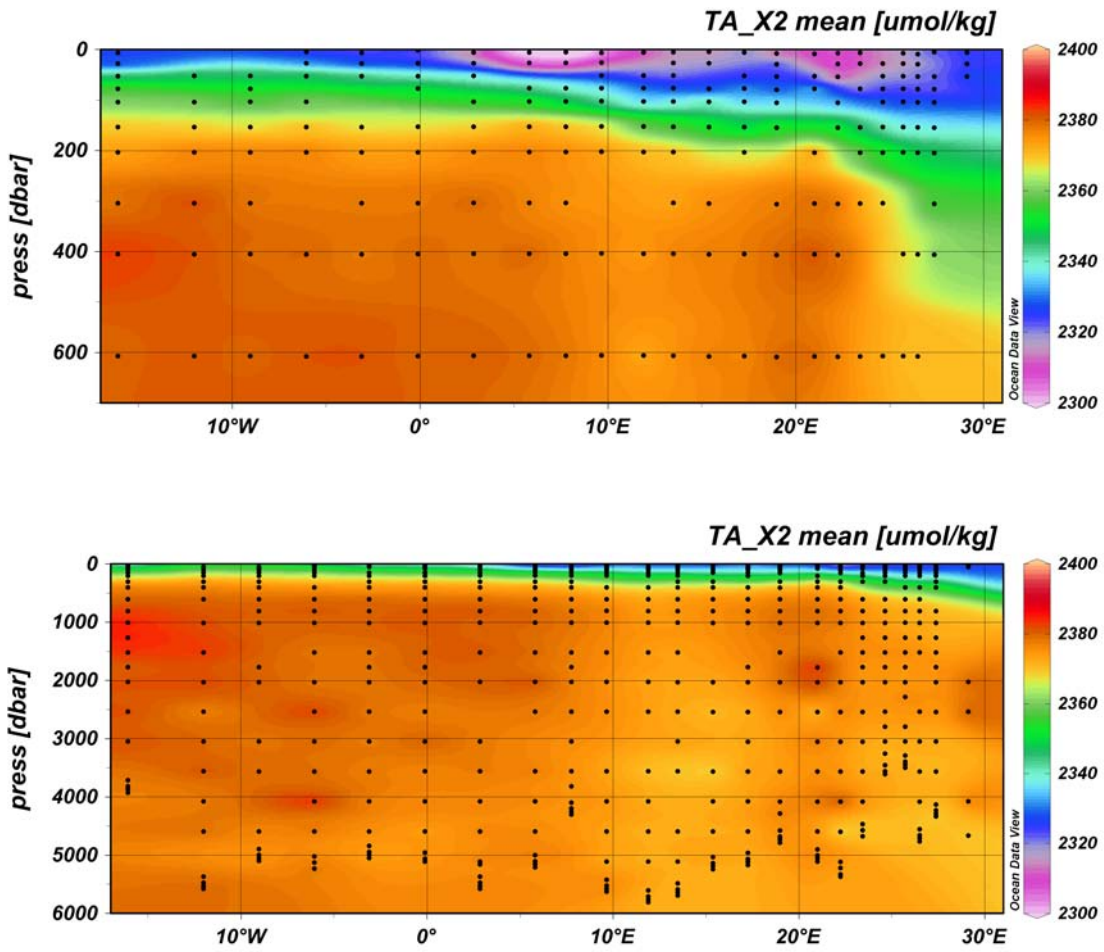


Figure 0-2: The vertical distribution of total alkalinity (preliminary data) along the ANDREX section a) in the upper 700 m and b) across the water column. The dots indicate the depth of samples taken. Bottom topography has not been indicated and is roughly 10 m.

5.5 Stable oxygen isotope

Loïc Jullion (*NOCS, UK*) & Mike Meredith (*BAS, UK*)

As a parallel project to ANDREX, we obtained funding from the NERC Small Grants round to investigate the freshwater composition of water masses exiting the Weddell Gyre, by making measurements of the stable isotopes of oxygen (O_{18}) in seawater on ANDREX and I6S (Figure 1). O_{18} is useful in high latitude freshwater studies, since it enables quantification of freshwater from separate sources. When measured alongside salinity, O_{18} allows the determination of inputs of freshwater from meteoric sources (glacial ice melt, precipitation) separately from those due to oceanic sources (sea ice melt). The Weddell Gyre is a region where the O_{18} of the pure glacial and non-glacial freshwater components are sufficiently well-known to enable quantification of their exports by this method.

The measurements of O_{18} will be combined with salinity and velocity fields derived from the cruises, and will enable us to quantify for the first time the individual exports of different forms of freshwater (sea ice melt, precipitation and glacial melt) from the Gyre into the global oceanic THC. Comparison with (sparse) historical data will reveal any changes in the freshwater composition of individual water masses, and place our measurements in the context of interannual and decadal change. The implications for controls on ocean circulation and climate against a background of a changing hydrological cycle will be assessed.

During JC30, every other station was sampled for O_{18} (14 stations sampled in total). Due to the limited amount of samples available (the price of the analysis limits the number of samples that we can get to the laboratory for analysis), most samples were drawn near the surface Niskin bottles, where the ice-melt signal is expected to be the strongest and near the bottom, where several flavours of Antarctic Bottom Water can possibly be found.

Samples were drawn into 50ml glass bottles, which had been rinsed once with water from the Niskin. These then had a silicon bung inserted and a metal crimp overlaid, which was sealed with a pair of crimping tongs. The bung and crimp are the same as are used for sealing bottles of OSIL standard seawater. Toward the end of the JR239 section, it was realized that we had been over-enthusiastic in our sampling near the start, and that we would run out of 50ml bottles before the eastern end was reached. Accordingly, we re-used standard seawater bottles that had been left over from the salinity analyses; these (although significantly larger, and therefore more troublesome to transport and store) are perfectly adequate for the task. All samples will be transported back to the UK, and will be delivered to the NERC Isotope Geosciences Laboratory, Keyworth, for laboratory analysis.

6 CTD

Sheldon Bacon and Dave Teare (*NOCS, UK*)

The CTD system comprised the following equipment. Seabird 911+ CTD with dual pumped temperature and conductivity sensors. Seabird SBE43 dissolved oxygen sensor, fitted in the primary T\C duct. Seabird SBE32 carousel with twenty-four OTE externally sprung, twenty litre bottles. A downward looking RDI 300 KHz workhorse ADCP. Chelsea Instruments Alphasacka (transmissometer) and Aquatracka (fluorometer). Benthos 915T altimeter. Wetlabs light-backscatter BBRTD. An IOS 10 KHz pinger and a Sonardyne location beacon.

The CTD processing route is described in some detail in Bacon (2010), the RRS *Discovery* cruise 332 report, and is briefly summarised here. For each station, initial processing was carried out using SeaBird software, running (in order) DatCnv, AlignCTD, WildEdit, CellTM and Translate. Unix processing using Pstar then followed. Script ctd0 takes the ascii output from Translate, converts to Pstar and sets headers; the .24hz file is output. Script ctd1 performs basic editing and averaging; .1hz and .10s files are output. Script ctd2 crops the head and tail of the .1hz file to output the .ctu file, and averages the downcast to output the .2db files. Script fir0 converts the .ros file into Pstar format, takes data from the .10s file and pastes it into a new file fir30nnn. Script samfir creates the file sam30nnn containing variables from fir30nnn so that the results from the bottle sampling analysis can be added.

The bottle sampling analysis provides calibration data for the CTD conductivity and oxygen sensors. Script sal0 reads in the sample bottle salinity files (Excel text) and outputs Pstar files sal30nnn.bot. Script sal1 pastes bottle file values into sam30nnn files. Script sal2 calculates bottle conductivity. Script oxy0 reads in the sample bottle oxygen files (Excel text) and outputs Pstar files oxy30nnn.bot. Script oxy1 pastes bottle file values into sam30nnn files. Script oxy2 converts bottle oxygens into $\mu\text{mol/kg}$. Script oxy3 replaces upcast CTD oxygen in sam30nnn with the downcast value using Pstar program pbotle.

CTD conductivity calibrations were determined by calculating the (bottle minus CTD) conductivity differences for both CTD sensors. For CTD variable cond, and for the 145 values in the range (-0.005, 0.005) mmho/cm, the mean difference was -0.0004 (sd 0.0013). For CTD variable cond2, and for the 145 values in the range (-0.005, 0.005) mmho/cm, the mean difference was -0.0009 (sd 0.0013). CTD conductivities were adjusted with these offsets, and salinities recalculated. See figure 6.1 for bottle minus CTD salinity differences.

CTD oxygens were adjusted, as for D332, using an offset and a pressure-dependent term, so:

$$O_{\text{bottle}} - O_{\text{CTD}} = a + bP$$

The values of a and b were found to be 6.3932 and 0.0015837, respectively, and CTD oxygens adjusted accordingly.

Table 6.1: JC30 station positions. Station number (statnum) is 30nnn; beboen signifies station beginning (1), station bottom (2), station end (3); timings are conventional (year-month-day, hour-minute-second); positions are in degrees and decimal minutes; pmax is station maximum pressure (dbar).

statnum	beboen	ymd	hour	lat		lon		pmax db
		YYYYMMDD	HHMMSS	DEGR	MIN	DEGR	MIN	
30001	1	20081228	074905	040	47.824 S	022	44.184 E	
30001	2	20081228	094101	040	47.573 S	022	42.449 E	5255
30001	3	20081228	111236	040	47.436 S	022	41.498 E	
30002	1	20081231	183004	053	29.999 S	030	0.003 E	
30002	2	20081231	201444	053	29.999 S	029	60.000 E	5283
30002	3	20081231	230847	053	29.998 S	029	59.998 E	
30003	1	20090101	055953	054	0.000 S	030	0.004 E	
30003	2	20090101	073657	054	0.001 S	030	0.004 E	5307
30003	3	20090101	103133	054	0.002 S	030	0.002 E	
30004	1	20090101	143110	054	29.995 S	030	0.005 E	
30004	2	20090101	163703	054	29.996 S	030	0.005 E	4743
30004	3	20090101	193041	054	29.996 S	030	0.006 E	
30005	1	20090102	013102	054	0.210 S	029	6.658 E	
30005	2	20090102	030845	054	0.210 S	029	6.657 E	4771
30005	3	20090102	055822	054	0.210 S	029	6.658 E	
30006	1	20090102	141119	054	1.401 S	027	23.033 E	
30006	2	20090102	155355	054	1.693 S	027	22.904 E	4337
30006	3	20090102	183340	054	2.082 S	027	22.721 E	
30007	1	20090102	233623	054	0.173 S	026	29.318 E	
30007	2	20090103	011401	054	0.174 S	026	29.319 E	4765
30007	3	20090103	035901	054	0.172 S	026	29.319 E	
30008	1	20090103	075635	054	0.964 S	025	43.609 E	
30008	2	20090103	091521	054	0.964 S	025	43.604 E	3501
30008	3	20090103	111817	054	0.963 S	025	43.609 E	
30009	1	20090103	192837	054	45.175 S	024	38.287 E	
30009	2	20090103	205639	054	45.172 S	024	38.286 E	3647
30009	3	20090103	231043	054	45.172 S	024	38.287 E	
30010	1	20090104	072903	055	29.963 S	023	26.049 E	
30010	2	20090104	090111	055	29.963 S	023	26.047 E	4677
30010	3	20090104	113201	055	29.966 S	023	26.050 E	
30011	1	20090104	192857	056	14.693 S	022	14.838 E	
30011	2	20090104	211320	056	14.694 S	022	14.836 E	5373
30011	3	20090104	235336	056	14.691 S	022	14.836 E	
30012	1	20090105	072524	057	0.053 S	021	0.359 E	
30012	2	20090105	091241	057	0.054 S	021	0.356 E	5111
30012	3	20090105	115814	057	0.053 S	021	0.359 E	
30013	1	20090105	191659	057	13.802 S	018	59.390 E	
30013	2	20090105	204730	057	13.804 S	018	59.388 E	4787
30013	3	20090105	233148	057	13.802 S	018	59.387 E	
30014	1	20090106	055732	057	22.179 S	017	15.561 E	
30014	2	20090106	073332	057	22.125 S	017	15.519 E	5171

30014	3	20090106	100251	057	22.127	S	017	15.517	E	
30015	1	20090106	170606	057	32.251	S	015	22.501	E	
30015	2	20090106	185308	057	32.251	S	015	22.504	E	5243
30015	3	20090106	212020	057	32.253	S	015	22.501	E	
30016	1	20090107	051936	057	42.791	S	013	29.278	E	
30016	2	20090107	070846	057	42.792	S	013	29.269	E	5693
30016	3	20090107	094223	057	42.890	S	013	29.038	E	
30017	1	20090107	172829	057	53.743	S	011	35.846	E	
30017	2	20090107	192247	057	53.765	S	011	36.000	E	5813
30017	3	20090107	220852	057	53.762	S	011	36.000	E	
30018	1	20090108	062642	058	4.003	S	009	39.660	E	
30018	2	20090108	081419	058	4.010	S	009	39.655	E	5631
30018	3	20090108	105631	058	4.010	S	009	39.656	E	
30019	1	20090108	182904	058	19.885	S	007	45.564	E	
30019	2	20090108	195743	058	19.872	S	007	45.563	E	4305
30019	3	20090108	215724	058	19.873	S	007	45.567	E	
30020	1	20090109	055102	058	25.044	S	005	49.573	E	
30020	2	20090109	074358	058	24.971	S	005	49.555	E	5211
30020	3	20090109	100532	058	24.979	S	005	49.560	E	
30021	1	20090109	211420	058	49.031	S	002	51.451	E	
30021	2	20090109	230115	058	49.031	S	002	51.452	E	5581
30021	3	20090110	015736	058	49.029	S	002	51.450	E	
30022	1	20090110	120631	059	12.783	S	000	6.969	W	
30022	2	20090110	134821	059	12.783	S	000	6.971	W	5163
30022	3	20090110	163239	059	12.780	S	000	6.972	W	
30023	1	20090111	025310	059	37.615	S	003	6.666	W	
30023	2	20090111	043722	059	37.616	S	003	6.666	W	5051
30023	3	20090111	072257	059	37.612	S	003	6.665	W	
30024	1	20090111	172649	060	0.280	S	006	3.832	W	
30024	2	20090111	192042	060	0.280	S	006	3.831	W	5231
30024	3	20090111	214459	060	0.279	S	006	3.830	W	
30025	1	20090112	092303	060	24.031	S	009	2.257	W	
30025	2	20090112	110206	060	24.035	S	009	2.257	W	5103
30025	3	20090112	134507	060	24.033	S	009	2.259	W	
30026	1	20090113	011828	060	47.781	S	012	0.677	W	
30026	2	20090113	031720	060	47.780	S	012	0.680	W	5581
30026	3	20090113	060510	060	47.779	S	012	0.679	W	
30027	1	20090113	222439	061	20.227	S	016	4.856	W	
30027	2	20090113	234404	061	20.219	S	016	4.848	W	3929
30027	3	20090114	020617	061	20.222	S	016	4.849	W	

SeaBird sensor types, serial numbers and calibration dates

Date: 04/14/2011

Instrument configuration file: C:\Documents and Settings\dml\Desktop\SheldonJC030\CTD005.CON

Configuration report for SBE 911plus/917plus CTD

Frequency channels suppressed : 0
Voltage words suppressed : 0
Computer interface : RS-232C
Deck unit : SBellplus Firmware Version >= 5.0
Scans to average : 1
NMEA position data added : Yes
NMEA depth data added : No
NMEA time added : No
NMEA device connected to : deck unit
Surface PAR voltage added : No
Scan time added : Yes

1) Frequency 0, Temperature

Serial number : 03P-4116
Calibrated on : 3 September 2008
G : 4.42598619e-003
H : 6.84453782e-004
I : 2.44752965e-005
J : 2.01756698e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity

Serial number : 04C-2580
Calibrated on : 3 September 2008
G : -1.03504968e+001
H : 1.52151375e+000
I : 4.04775865e-004
J : 5.44771095e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

Serial number : 83008
Calibrated on : 10 Sep 08
C1 : -4.093335e+004
C2 : -1.005887e-001
C3 : 1.104120e-002
D1 : 3.017600e-002
D2 : 0.000000e+000
T1 : 2.992572e+001
T2 : -3.202788e-004
T3 : 3.724670e-006
T4 : 2.870340e-009
T5 : 0.000000e+000
Slope : 0.99995000
Offset : -1.45830

AD590M : 1.285350e-002
AD590B : -8.337660e+000

4) Frequency 3, Temperature, 2

Serial number : 03P-4105
Calibrated on : 17 Sept 2008
G : 4.39437796e-003
H : 6.48191237e-004
I : 2.34394537e-005
J : 2.12096134e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 04C-3052
Calibrated on : 3 September 2008
G : -1.01167738e+001
H : 1.41017872e+000
I : 2.62673478e-004
J : 5.16150703e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Oxygen, SBE 43

Serial number : 43-0862
Calibrated on : 30 September 2008
Equation : Sea-Bird
Soc : 4.28700e-001
Offset : -4.98400e-001
A : -1.49650e-003
B : 1.37000e-004
C : -3.10980e-006
E : 3.60000e-002
Tau20 : 1.15000e+000
D1 : 1.92630e-004
D2 : -4.64800e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

7) A/D voltage 1, Free

8) A/D voltage 2, Fluorometer, Chelsea Aqua 3

Serial number : 088108
Calibrated on : 9 January 2008
VB : 0.174500
V1 : 2.092100
Vacetone : 0.198200
Scale factor : 1.000000
Slope : 1.000000
Offset : 0.000000

9) A/D voltage 3, Altimeter

Serial number : 1040
Calibrated on : March 2003

Scale factor : 15.000
Offset : 0.000

10) A/D voltage 4, Free

11) A/D voltage 5, Free

12) A/D voltage 6, User Polynomial

Serial number : BBRTD-115R
Calibrated on : 13 May 2008
Sensor name : Wetlabs backscatter
A0 : -0.00034810
A1 : 0.00295000
A2 : 0.00000000
A3 : 0.00000000

13) A/D voltage 7, Transmissometer, Chelsea/Seatech/WET Lab CStar

Serial number : 161045
Calibrated on : 8 Sept 2005
M : 24.0279
B : -0.4806
Path length : 0.250

Scan length : 41

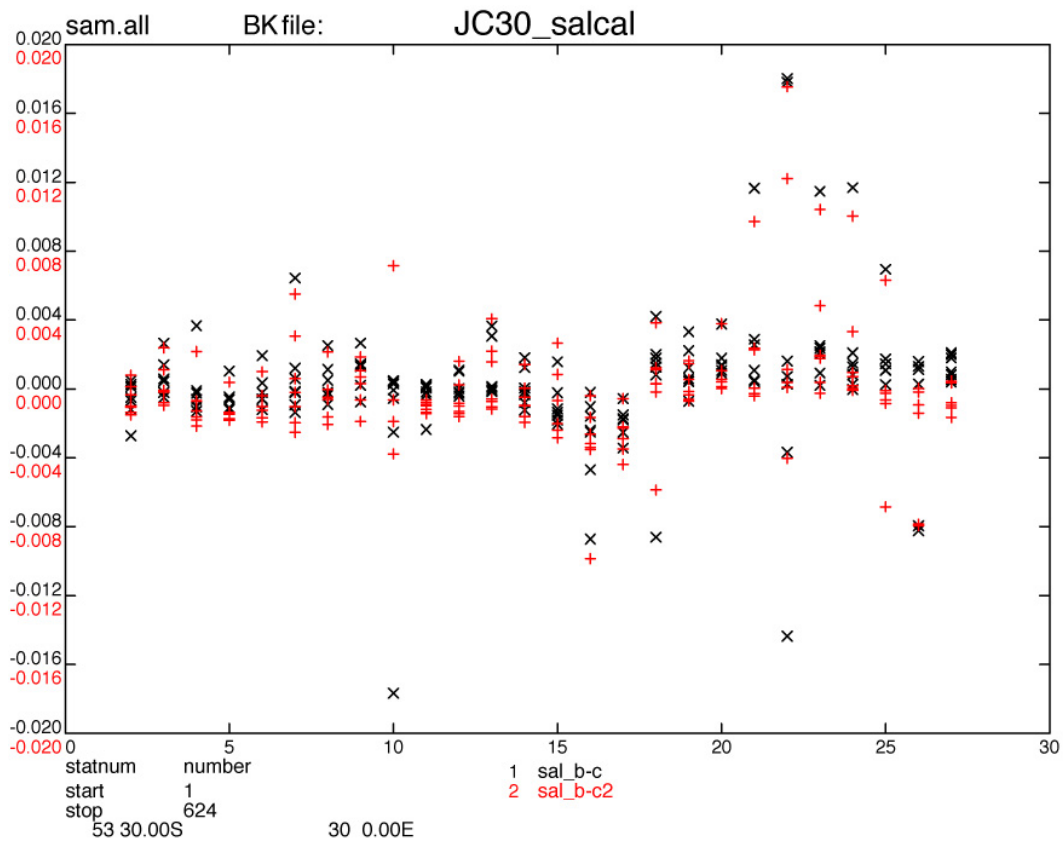


Figure 6.1: Comparison of sample and CTD salinities post-calibration: bottle minus CTD channel 1 salinity (black), bottle minus CTD channel 2 salinity (red).

7 UNDERWAY MEASUREMENTS

7.1 Thermosalinograph

It became apparent that there was a serious problem with the thermosalinograph (TSG) remote (ie external) temperature measurements, which should be the sea surface temperature (SST) measurement. The instrument was found to be faulty but no spare was available. The resources available to attempt to construct a viable record of SST (and salinity) were: the regular TSG housing temperature (temp_h) and conductivity, plus a new TSG instrument (the SeaBird SBE45 microTSG), and CTD data. The following text describes the identification of the problem(s), and the subsequent processing to generate continuous SST and surface salinity records.

Figure 7.1 compares TSG remote and housing temperatures with the SBE45 temperature. The green (SBE45: temp) and black (temp_h) track each other closely; their difference (blue: T_t-th) is small. The red (temp_r) tracks both of the others less well, and as is seen in the difference from the SBE45 (cyan: T_t-tr), there is large variability on long timescales (range of up to 1 °C over days/weeks) and on short timescales (fuzziness over hours/days, range of ~0.2 °C). Therefore TSG temp_r is unusable, and both TSG temp_h and SBE45 temp are potentially usable.

Figure 7.2 compares SBE45 temp and TSG temp_h with CTD temperatures from between 5 and 7 m water depth (the non-toxic intake is at about 6 m depth); temp_r is also included, for confirmation of the above conclusion. The green (CTD minus TSG temp_h: T_ct2-th) and red (CTD minus SBE45 temp: T_ct2-tb) offsets are of magnitude (sd) of -0.277 (0.038) and -0.341 (0.054) °C respectively. The TSG housing temperature (temp_h) is a little less noisy than the SBE (lower sd compared with CTD). Also, the SBE45 record stops on 15-01-2009 (ie does not continue to the end of the cruise). For these two reasons, the TSG temp_h is chosen on which to base the SST record.

Figure 7.3 compares CTD, TSG and SBE45 conductivities. The black (CTD minus SBE45) is fairly stable over the whole record (mean difference -0.259, sd 0.048 mS/cm), whereas the red (CTD minus TSG) is less accurate and less stable (mean difference over -2.5 mS/cm in the early part, -2.3 in the later part). The SBE45 is clearly preferable for conductivity, but the record does not last to the end of the cruise; therefore the whole of the SBE45 cond record is used, and the record extended to the end of the cruise with the TSG cond.

The surfmet data stream for the whole cruise, Cape Town to Stanley, was downloaded into file smt301.raw. Variables time and temp_h were copied out into an intermediate file, smt301.T1. This file was edited to remove bad data – outside the limits (-10, 40) °C, then despiked with a median filter allowing a maximum difference between adjacent data points of 0.2 °C, and finally cleaned up with an interactive editor. A second file was then created, smt301.T2, containing a second copy of the

variable temp_h. In this file, one of the temp_h variables was renamed SST and calibrated by comparison with CTD temperatures (primary sensor, CTD variable temp2): $SST = temp_h \text{ minus } 0.277 \text{ } ^\circ\text{C}$.

To generate a continuous good-quality surface conductivity record, first the SBE45 record, variables time and cond, were copied out between 000000Z on 26-12-2008 and 133419Z on 15-01-2009 (output file SBE45.C1); cond was converted from S/m to mS/cm ($cond = cond \times 10$). The conductivity record was manually despiked, then calibrated by comparison with CTD conductivities (primary sensor, CTD variable cond2): $cond = cond \text{ minus } 0.259$. Next, to fill through to the end of the cruise, the variables time and cond were copied from smt301.raw into file smt301.C1 between 133420Z on 15-01-2009 and 120000Z on 21-01-2009. This record was edited (limits 20-60 mS/cm) then manually despiked, then calibrated by comparison with CTD data (as for the SBE45): $cond = cond \text{ minus } 2.262$. The two conductivity records were then joined to form a single continuous record (output file surfcond); the continuous SST record (file smt301.T2) was merged onto this record (output file surfTC); a pressure variable, set to 0 db, was added (output file surfPTC); then salinity was generated from the combined SST and conductivity records (output file jc30_surfTS). Spikes were edited manually. Finally, navigation was added (output file jc30_surfTS.nav), and a 1-minute-averaged file created (jc30_surfTS.nav.1min). Figure 7.4 plots the whole cruise SST and surface salinity record vs. time. Remaining gaps are the result of the non-toxic supply being turned off, either due to entry into harbour, proximity to sea ice, or unfeasible daftness.

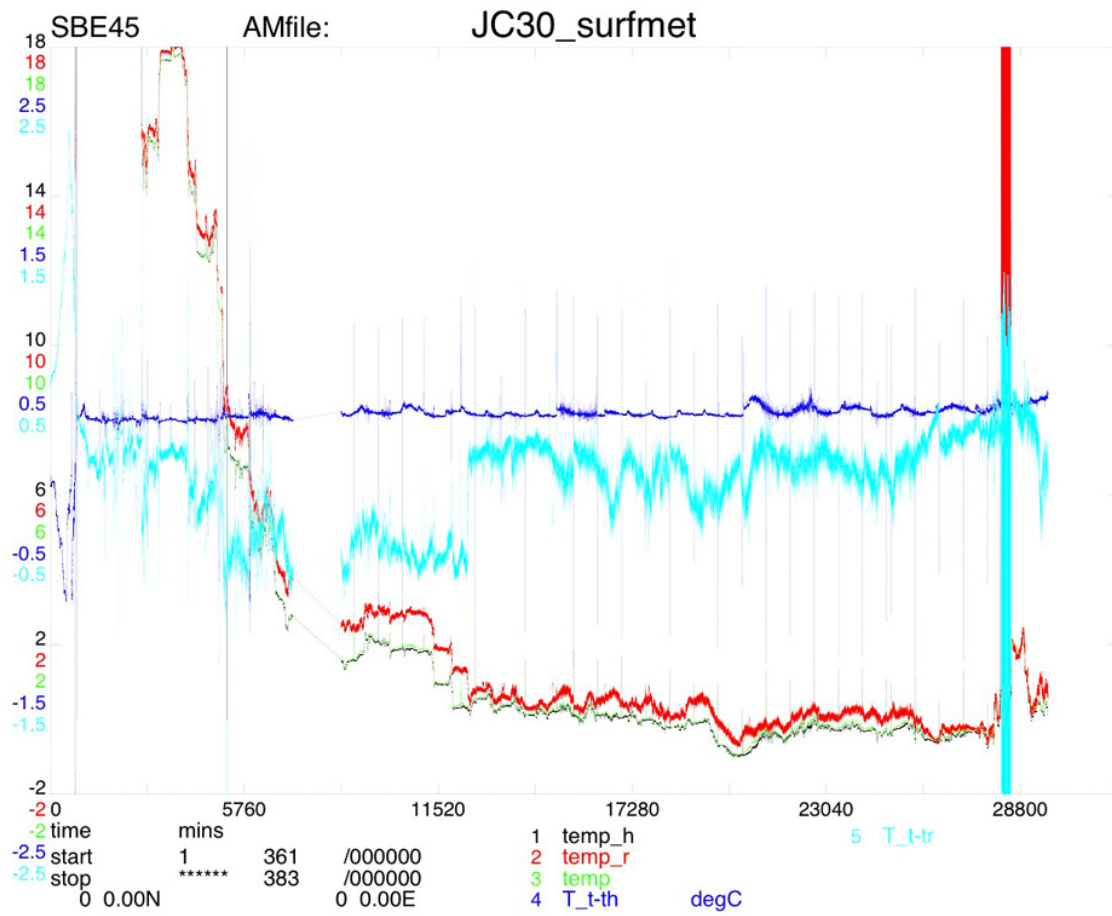


Figure 7.1: Records of (1) TSG housing temperature (temp_h, black), (2) TSG remote temperature (temp_r, red), (3) SBE45 temperature (temp, green), (4) temp minus temp_h (T_t-th, dark blue), (5) temp minus temp_r (T_t-tr, light blue).

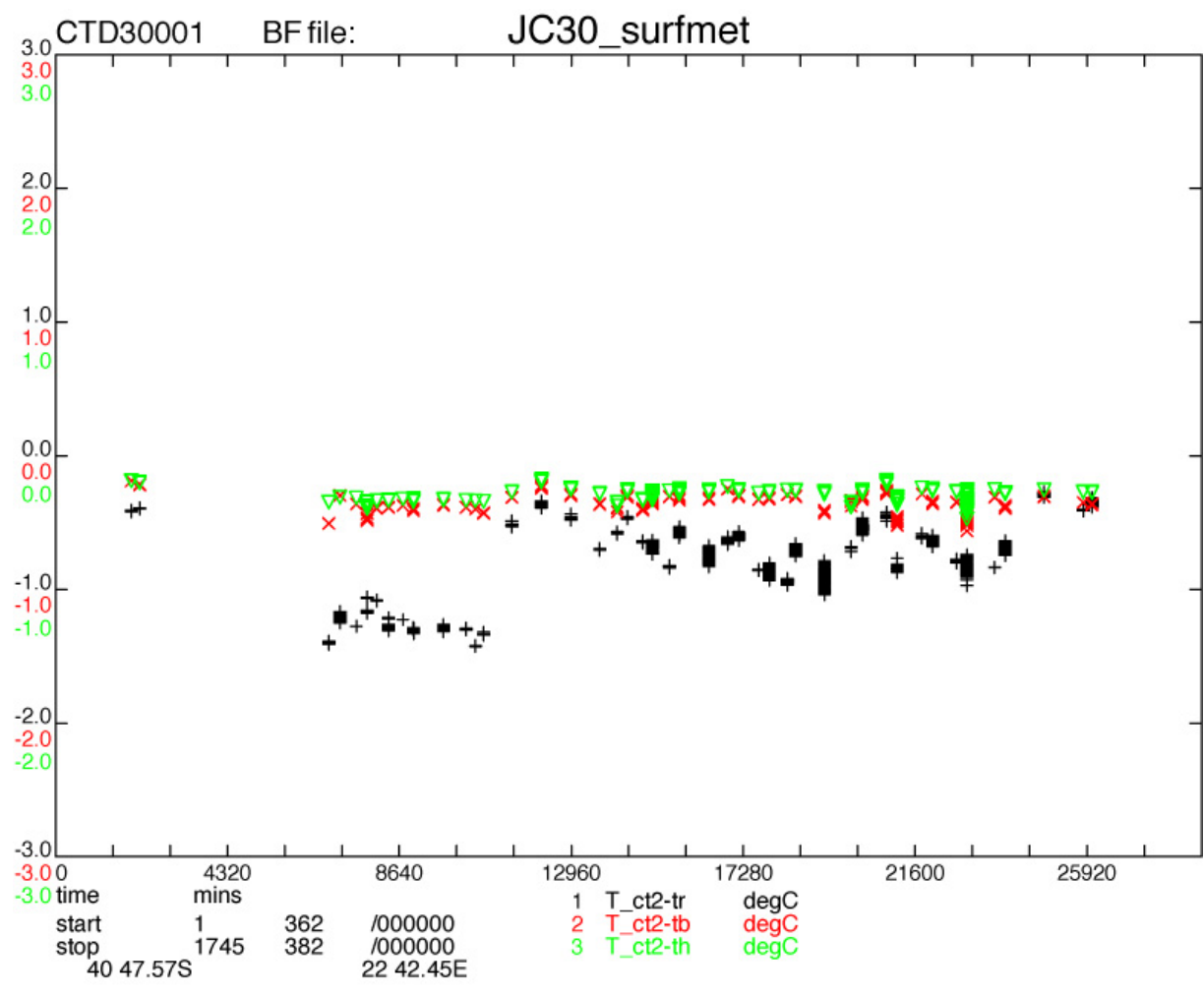


Figure 7.2: Comparison of CTD primary temperature (temp2) with surface temperatures (as CTD minus surface): (1) CTD minus TSG remote temperature (black, T_ct2-tr), (2) CTD minus SBE45 temperature (red, T_ct2-tb), (3) CTD minus TSG housing temperature (green, T_ct2-th).

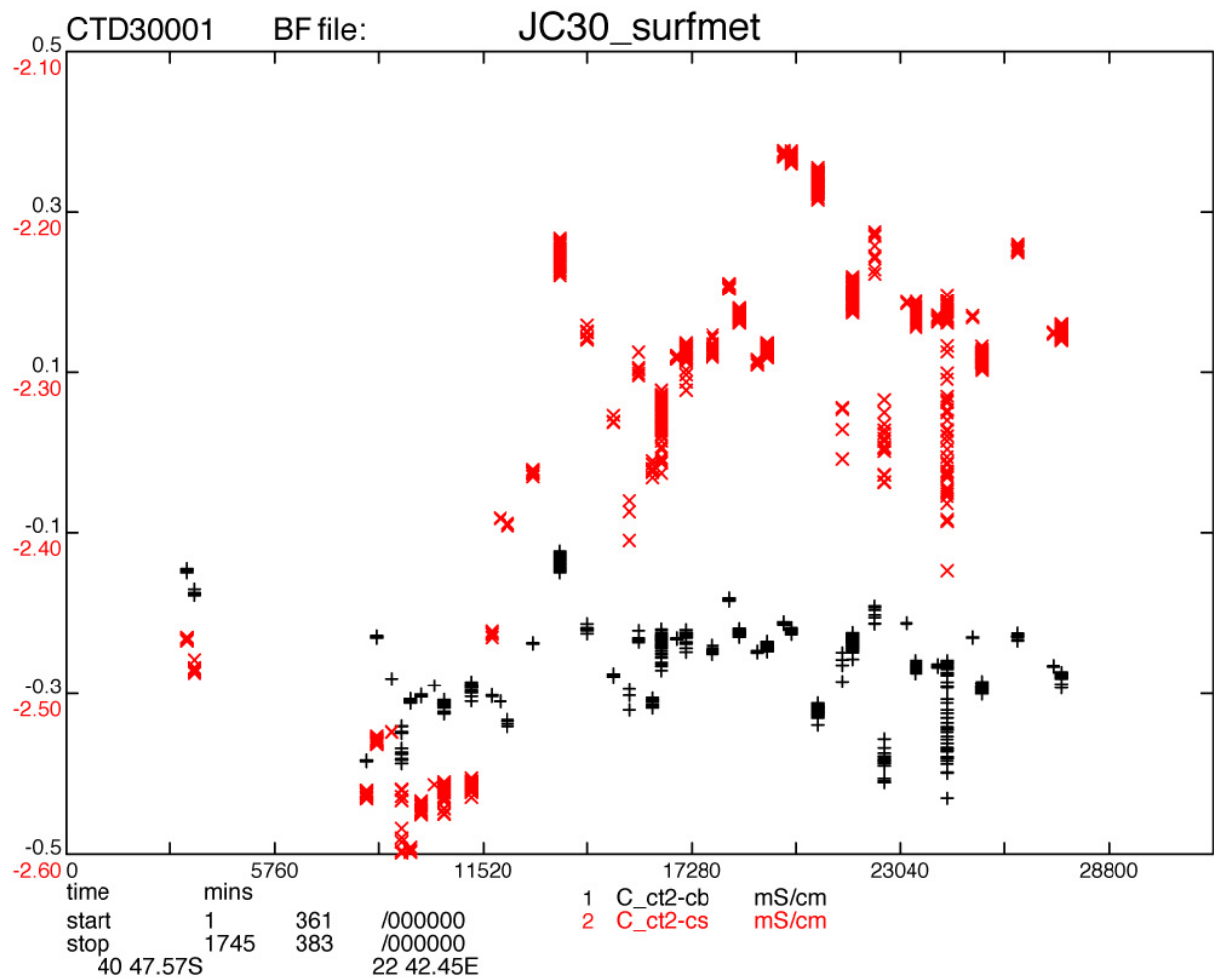


Figure 7.3: comparison of CTD primary conductivity (cond2) with surface conductivities (as CTD minus surface); (1) CTD minus SBE45 cond (black, C_ct2-cb), (2) CTD minus TSG cond (red, C_ct2-cs).

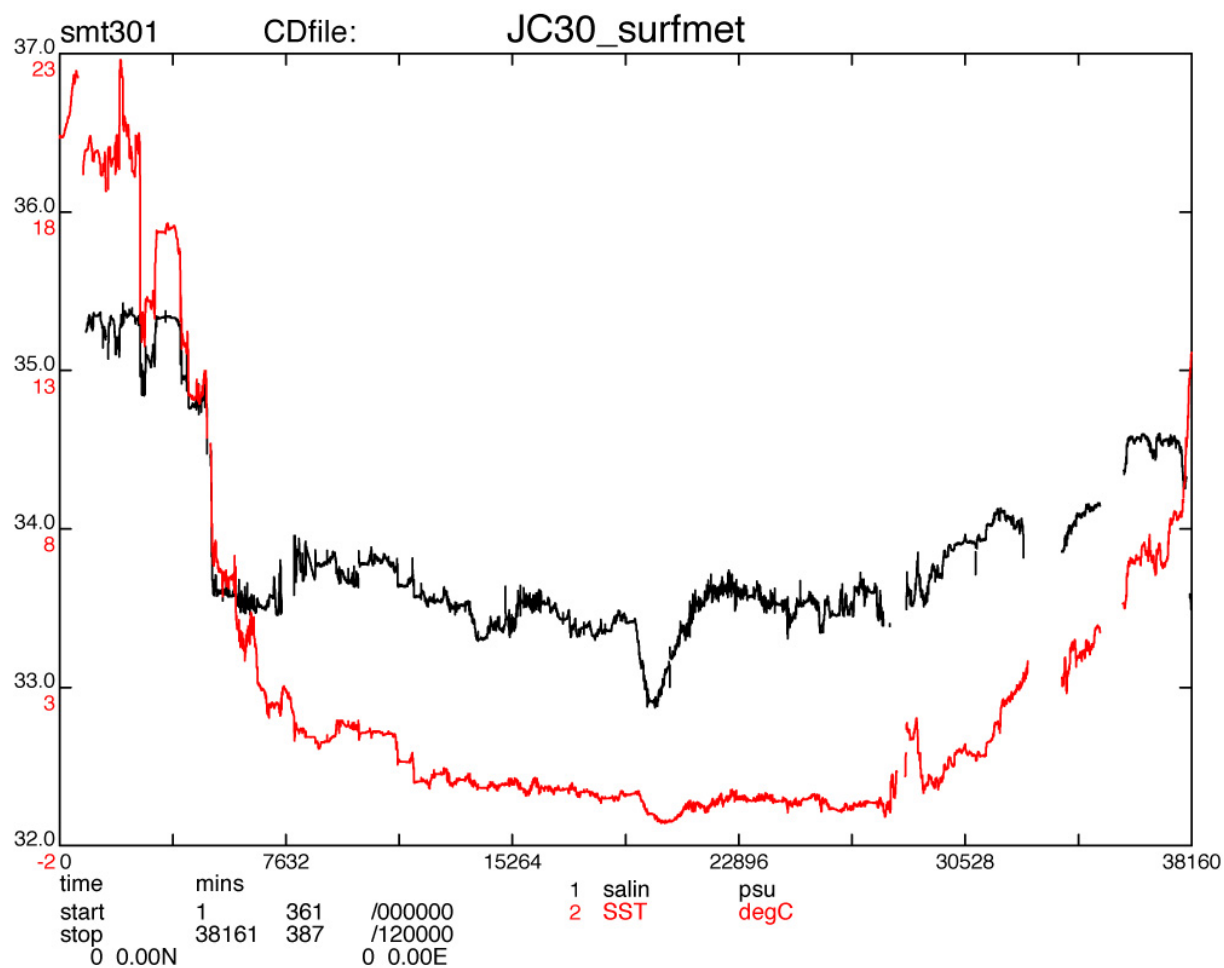


Figure 7.4: Full cruise record of calibrated sea surface temperature (SST, red) and salinity (black).