How to process mooring data? A cookbook for MicroCat, ADCP and RCM data

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ANIMATE

Atlantic Network of Interdisciplinary Moorings and Time series for Europe

Calibration of Physical Data

MicroCAT, TD-Logger, ADCP, RCM

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Contents

1 Introduction

This data report summarizes the processing steps that have been undertaken to calibrate/process the physical data (temperature, salinity, currents) collected at three mooring sites in the Northeast Atlantic within the EU FP5 Project - ANIMATE. The goal of the data processing is to provide a consistent quality controlled data set. The data set should contain so called 'metadata' that allow to verify the processing steps that has been performed to convert the raw data to the processed data.
The calibration of other than physical data collected at the sites will be reported elsewhere.

The physical sensors, the data measured and *derived parameters* addressed in this report are:

MicroCAT Temperature, conductivity, (some instruments: pressure), *salinity*

TD-Logger Temperature, pressure

ADCP (Acoustic Doppler Current Profiler) Currents, *depth of the instrument*

RCM (Rotor Current Meters) Currents, (some instruments: temperature, pressure)

1.1 Depth of instruments during deployment

Depth at which measurements have been collected is a critical parameter when interpreting measurements. Pressure and depth are converted through the data processing step using algorithms of (5) and (3). Two effects influence the depth of instruments during deployment:

1) Mooring subduction
A mooring is not a static device. The currents force the mooring and consequently the instruments to move in the water water column during deployment. As the mooring is fixed at the ocean bottom the amplitude of the movement should decrease with depth. Utilizing the **pressure recordings** available from some instruments allow to derive the actual pressure of the other instruments utilizing the mooring outline as planned (nominal depths). In the ideal case at least the first and the last (lowest) instruments have a pressure sensor and one can use linear interpolation to derive the pressure for the instruments in between. If instruments have been mounted above or below this depth range the data have to be extrapolated. If instruments are mounted in a part of the mooring (e.g. slack of telemetry) that may be effected through different dynamics than the main wire other methods have to be used.

Beside the pressure sensor readings the **ADCP's 'beam intensity'** can be used to estimate the location of the instrument relative to the oceans surface. The surface may appear as a maximum in intensity. However, this is only possible if the instruments was configured to allow for the detection (e.g. maximum number of depth cells). As a note, although the typical depth cell size of the instruments is equal or larger 8 m a parable fit may allow to derive the depth with an accuracy of order 1 to 2m.

2) Bottom topography
The oceans bottom topography is not flat and sometimes the mooring is launched at in water with a slightly different depth as it was planned. Therefore a depth (pressure) bias have to be considered for the instruments nominal depth. The bias can be derived comparing nominal depth of the mooring as planned with the available lowest pressure recording of instruments.

1.2 Sampling strategies at the sites

The three sites could not use the same sampling strategy.
Vertical sampling
Through the nature of physical processes (e.g. mixed layer depth) the vertical distribution of the instruments along the mooring wire differs between the sites to allow a rather 'optimal' monitoring. This is also true at one particular site but from one deployment period to the other. The limited number of available instruments set an additional constrain. ADCP data was sampled with different vertical resolution depending on the programmed depth cell sizes: 8 m at PAP (except for PAP 1st deployment with 16 m), 10 m (upward looking) and 16 m (downward looking) at CIS, and 16 m at ESTOC.
The data processing described here does not include a vertical gridding of the original data which should be left to the 'user' as the result depends critically on the technique applied. It should be mentioned that the interpolation technique based on (1) splines is widely used in the community to interpolate a few discrete points vertically as it produces rather smooth (but not necessary true) gradients.

Temporal sampling
The temporal sampling intervals for individual instruments differs depending on the instrument and mooring site and is first of all set by the internal memory available. In general the aim was to allow for a data record of order 1.5 years. Typical sampling for MicroCAT ranges from 15 minutes (ESTOC) to 30 minutes (CIS), while MicroCAT telemetry data comes is available in 2 hours intervals. ADCP data was collected every 30 minutes (CIS) and 2 hours (PAP and ESTOC).
As part of the data processing all instruments have been linear interpolated to a common time axis of every full hour (UTC).

2 MicroCAT data processing

The mooring are equipped with SBE-37 IM (inductive, telemetry possible) and a few SBE-37 SM (serial) MicroCAT devices. All devices have temperature and conductivity sensors while some had also pressure sensors.
The MicroCAT data used to produce the final calibrated data set comes from two sources: delayed mode data and telemetry data. These two sources have different characteristics and priorities in terms of their influence on the final data set:

Delayed mode data
This is data that has been recorded in the instrument and is read out after the deployment. Internally the data recording is programmed to average the 4 last readings from the sensors before a certain time interval has been reached. This data is only available in 'delayed mode' (after recovery of the instruments). If it is available, it will always be used for the final data set.

Telemetry data
Some MicroCAT data was successfully transferred every 2 hours via a telemetry satellite link a shore. Internally the data reads the last averaged record from the MicroCAT 's memory (Hence delayed mode and telemetry data should be identical for some records). This data is used in the processing only when no delayed mode data is available, mainly when instruments have been lost during the deployment period. As the time of a measurements is not transmitted via satellite a time axis is added from the data processor (Maureen Edwards, SOC).

In brief the processing of these two data sources is conducted in a number of steps:
First all data is linear interpolated to a common time axis. One may argue that the data from the individual instruments should be calibrated before interpolation but for practical reasons this is not convenient as a combination of data from a number of instruments in parallel is needed (e.g. pressure sensor correction).
Next the data is corrected for linear drift of the sensors. Depending on the sensor the information for such a drift comes from calibration cast (Temperature, conductivity) or decks readings (pressure). Note, only a linear correction is done.
Next, available pressure recordings (corrected) are linear interpolated to those instruments without pressure sensor. The 'new' pressure values are used to correct the conductivity measurements following the guidelines from the manufacturer (SBE Application Note #10).
Finally salinity and potential temperature and density are calculated. Temperature data is internally recorded in ITS-90 scale. However, to calculate salinity (PSS-78) and density from polynomial fits (3) the IPTS-68 temperature is needed. Conversion is done as $T_{68} = 1.00024 \cdot T_{90}$.

2.1 Interpolation to common time axis

The MicroCAT have recorded data in different temporal resolution between 10 to 30 minutes (table 1). The original records are interpolated to a common time axis of every full hour (start and end time see last to columns in table 1).

Table 1: Sampling interval (Δ t) of MicroCAT at the three different mooring sites and start and end time of interpolation intervals used for the individual moorings.

Site/deploy.	Δ t (sec)	Interpol. Start	Interpol. End
CIS/1	1800	21-Aug-2002 21:00:00	25-Jun-2003 23:00:00
CIS/2	1800	28-Aug-2003 12:00:00	15-May-2004 12:00:00
CIS/3	1200	18-May-2004 19:00:00	09-Aug-2004 19:00:00
PAP/1	600	09-Oct-2002 00:00:00	08-Jul-2003 12:00:00
PAP/2	900	12-Jul-2003 14:00:00	16-Nov-2003 06:00:00
PAP/3	900	17-Nov-2003 18:00:00	20-Jun-2004 15:00:00
ESTOC/1	900	16-Apr-2002 21:00:00	21-May-2002 15:00:00
ESTOC/2	900	13-Apr-2003 00:00:00	29-Oct-2003 07:00:00
ESTOC/3	900	01-Nov-2003 14:00:00	22-Apr-2004 09:00:00
ESTOC/4	900	23-Apr-2004 21:00:00	10-Dec-2004 12:00:00

2.2 Correcting pressure sensors and estimating instrument depth

Allocating a pressure value to all instruments recordings requires a quality control of the recorded pressures (sensor drift) and an offset determination of the instruments relative to the planned mooring outline (topographic bias).

The raw pressure sensor data was first inspected for spurious deck readings of the senors. The decks readings gave a set of bias corrections for some sensors as summarized in table 2.

Table 2: Pressure bias of MicroCAT sorted by mooring site. The bias for each serial number is given as the start bias (t_1) and the stop bias (t_2) while values in between start and stop are linear interpolated. Note: Correct pressure = (recorded pressure) – (value given in table).

Serial #	Site/deploy.	P_{bias,t_1}	time t_1	P_{bias,t_2}	time t_1
2264	CIS/1	0	21-Aug-2002	6	25-Jun-2003
2265	CIS/1	1.3	21-Aug-2002	5	25-Jun-2003
2271	CIS/1	0.3	21-Aug-2002	4.5	25-Jun-2003
2717	CIS/2	-1	28-Aug-2003	1	15-May-2004
2265	CIS/3	27	16-May-2004	52	18-Sep-2004
2717	CIS/3	0	16-May-2004	3.5	18-Sep-2004
2264	CIS/3	10	16-May-2004	9	18-Sep-2004
2271	CIS/3	6	16-May-2004	5	18-Sep-2004
2488	CIS/3	1	16-May-2004	1	18-Sep-2004
2262	CIS/3	0.8	16-May-2004	0.8	18-Sep-2004
2487	PAP/1	0	09-Oct-2002	10	09-Dec-2002
2718	PAP/2	-0.5	12-Jul-2003	4.5	16-Nov-2003
2800	PAP/3	-0.6	18-Nov-2003	3.6	20-Jun-2004
2486	PAP/3	-0.5	17-Nov-2003	-0.5	18-Jun-2004
2718	PAP/3	-0.5	17-Nov-2003	6.4	18-Jun-2004
2974	PAP/3	0	17-Nov-2003	0.6	18-Jun-2004
2712	ESTOC/2	0.6	13-Apr-2003	6	29-Oct-2003
2713	ESTOC/2	0	13-Apr-2003	1	29-Oct-2003
2269	ESTOC/2	2	13-Apr-2003	7	29-Oct-2003
2270	ESTOC/2	1.4	13-Apr-2003	4	29-Oct-2003
2712	ESTOC/3	7	01-Nov-2003	15.2	22-Apr-2004
2713	ESTOC/3	1.1	01-Nov-2003	1.6	22-Apr-2004
2269	ESTOC/3	8	01-Nov-2003	6	22-Apr-2004

The correction was done through a linear interpolation from the offset at the beginning and at the end of the measurement. The change in pressure through this procedure is shown in Fig. 1. The original pressure record from the sensor is shown in black. Deck readings gave offsets of +0.6 dbar at the beginning and +6dbar at the end of the record. Linear interpolation of these biases result in the corrected pressure(magenta line).

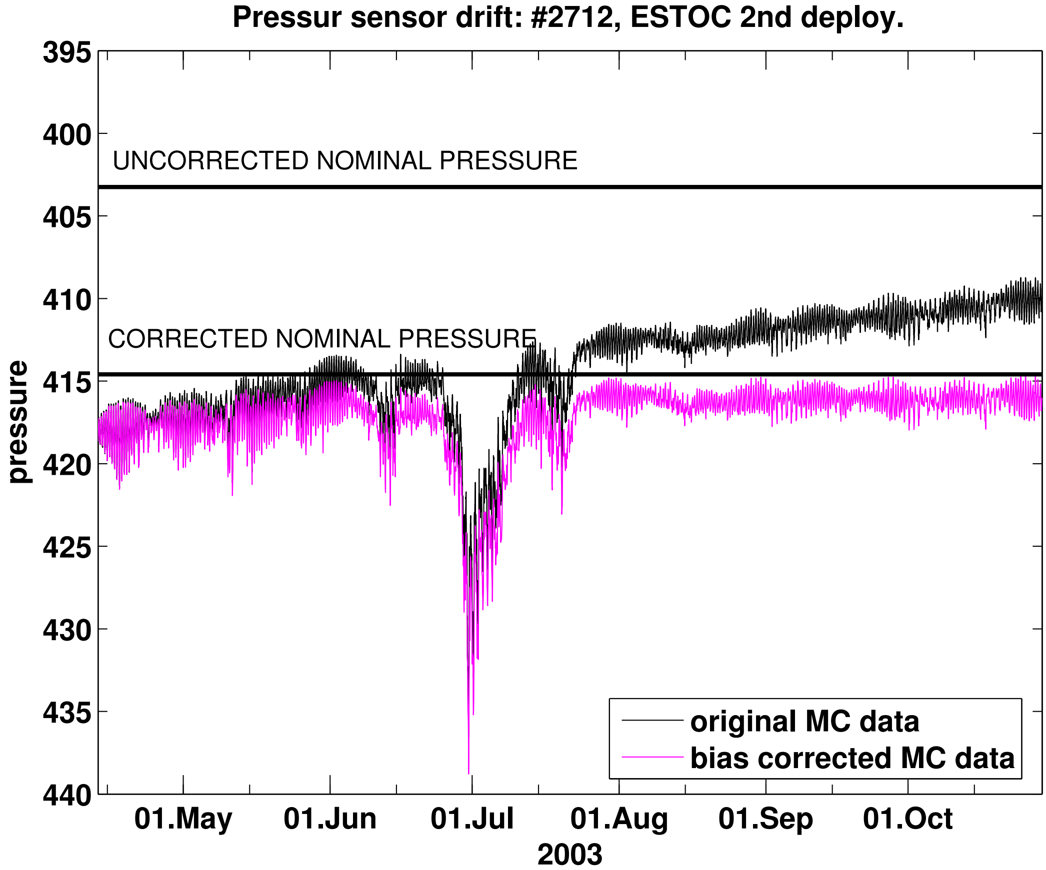

Figure 1: Example for a pressure correction: First the pressure sensor decks readings are used to correct a linear drift defined through the beginning and end decks readings. Next a 'topography bias' is estimated utilizing all available pressure readings at a site in comparison to the nominal depth/pressure which comes from the mooring design (uncorrected nominal pressure). The bias is subtracted from the data and a corrected nominal pressure is obtained.

To allocate a pressure value to the instruments without a sensor the instrument location from the mooring plan are used. However, a 'topographic bias' was estimated first, as the mooring may be deployed in water with a slightly different depth than planned. To estimate the topographic bias the minimum pressure sensor readings are compared to the nominal pressure (depth) of the respective instruments. The median of the bias was added to all instruments without a pressure sensor. As summary of the topographic bias is given in table 3. As an example, the 2nd deployment ESTOC (ACI mooring; mooring 1) was found to be 11m deeper in the water column than anticipated (mooring drawing). As a note, it will be shown later how to derive a topographic bias from the ADCP backscatter intensity, values are listed in table 3 (see ADCP section for further details).

For the instruments without a pressure sensor pressure values are assigned through linear interpolation from neighboring instruments. A linear decrease in amplitude of pressure variability with depth (Figures 2 to 4 was assumed for extrapolation. The assigned and quality controlled pressure recordings are shown in figure 5.

Table 3: Topographic depth bias for the ANIMATE moorings. Estimated from the difference between nominal depth (converted to pressure) and minimum from pressure readings of MicroCAT's. See figure 1 for an example. Positive values in the table (+) stands for: instruments are higher up in the water column than planned (mooring drawing); 'n.a.' is 'not available'.

Site/deploy.	Mooring 1	Mooring 2
	V 433	**V434**
CIS/1	ADCP only, MicroCAT lost z_{ADCP} = +7±1.5 $z_{MicroCAT}$ = 'n.a.'	MicroCAT only z_{ADCP} ='n.a.' $z_{MicroCAT}$ = 0 ± 1
CIS/2	ADCP, MicroCAT #2717 z_{ADCP} = +8± 2 $z_{MicroCAT}$ = +6± 'n.a.'	MicroCAT only z_{ADCP} ='n.a.' $z_{MicroCAT}$ = -1 ±2
CIS/3	n.a.	ADCP, MicroCAT z_{ADCP} = +18 ± 6 $z_{MicroCAT}$ = +9 ± 4
	PAP 1	**PAP 2**
PAP/1	ADCP, MicroCAT #2486 z_{ADCP} = 'n.a.' $z_{MicroCAT}$ =+23.4±'n.a.'	MicroCAT only z_{ADCP} ='n.a.' $z_{MicroCAT}$ = -4 ± 2
PAP/2	n.a.	ADCP, MicroCAT z_{ADCP} = 'n.a.' $z_{MicroCAT}$ = 0 ± 2
PAP/3	ADCP, MicroCAT #2800 z_{ADCP} = 'n.a.' $z_{MicroCAT}$ = +30± 'n.a.'	MicroCAT only z_{ADCP} ='n.a.' $z_{MicroCAT}$ = +14 ± 4
	ACI	**DOLAN**
ESTOC/1	ADCP, MicroCAT z_{ADCP} =+24 ±'n.a.' $z_{MicroCAT}$ =+26±1	'n.a.'
ESTOC/2	ADCP, MicroCAT z_{ADCP} = -4 ±'n.a.' $z_{MicroCAT}$ =-11±0	MicroCAT #1287 z_{ADCP} ='n.a.' $z_{MicroCAT}$ = 'n.a.'
ESTOC/3	ADCP, MicroCAT z_{ADCP} = -1± 3 $z_{MicroCAT}$ = -10 ±0	MicroCAT #1287 z_{ADCP} ='n.a.' $z_{MicroCAT}$ = 'n.a.'
ESTOC/4	ADCP, MicroCAT z_{ADCP} = -14± 3 $z_{MicroCAT}$ = -8±0	MicroCAT #1287 z_{ADCP} ='n.a.' $z_{MicroCAT}$ = 'n.a.'

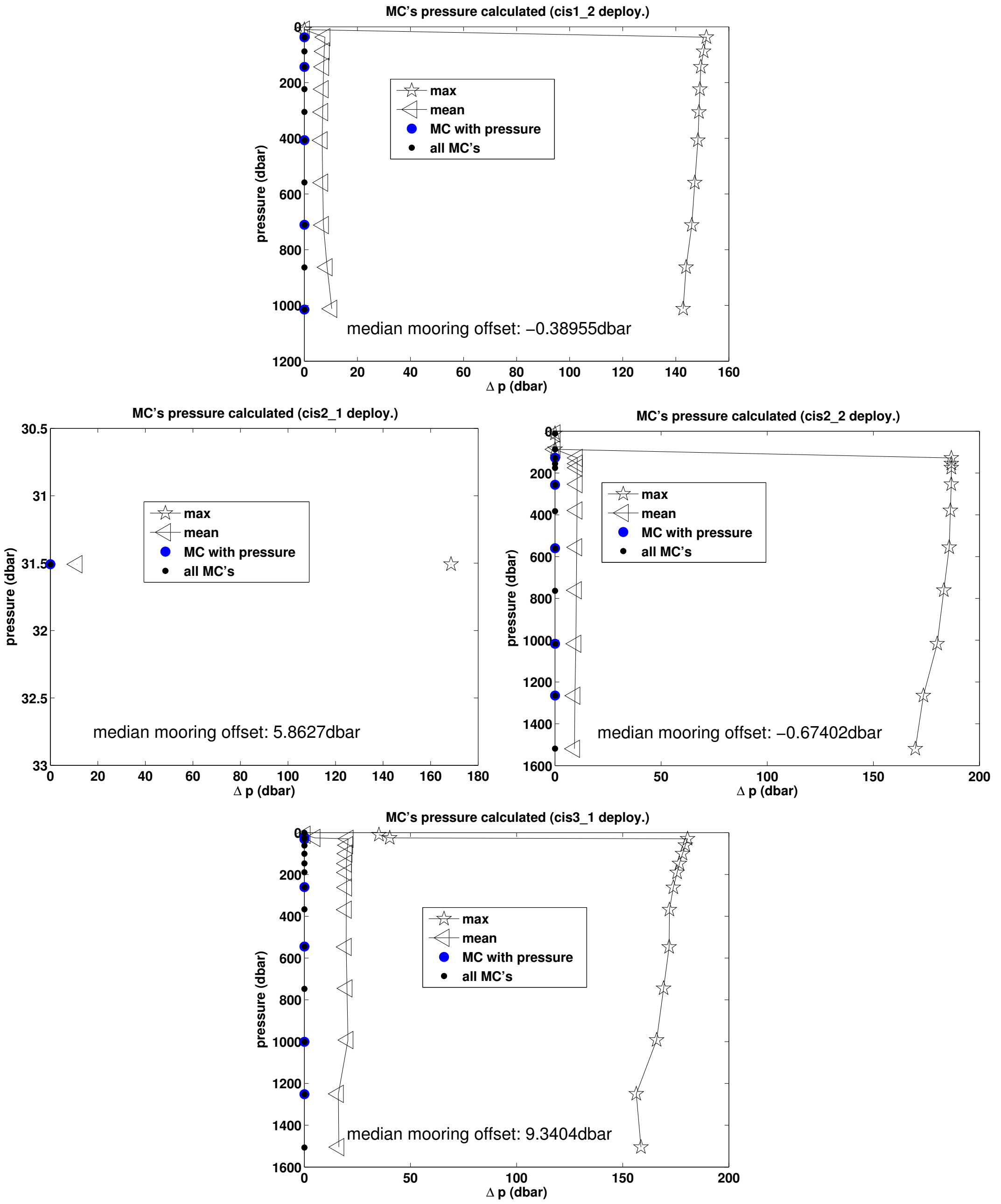

Figure 2: CIS deployment: Estimated pressure for all instruments from those with pressure sensor (blue dots). Maximum and average subduction of instruments is shown.

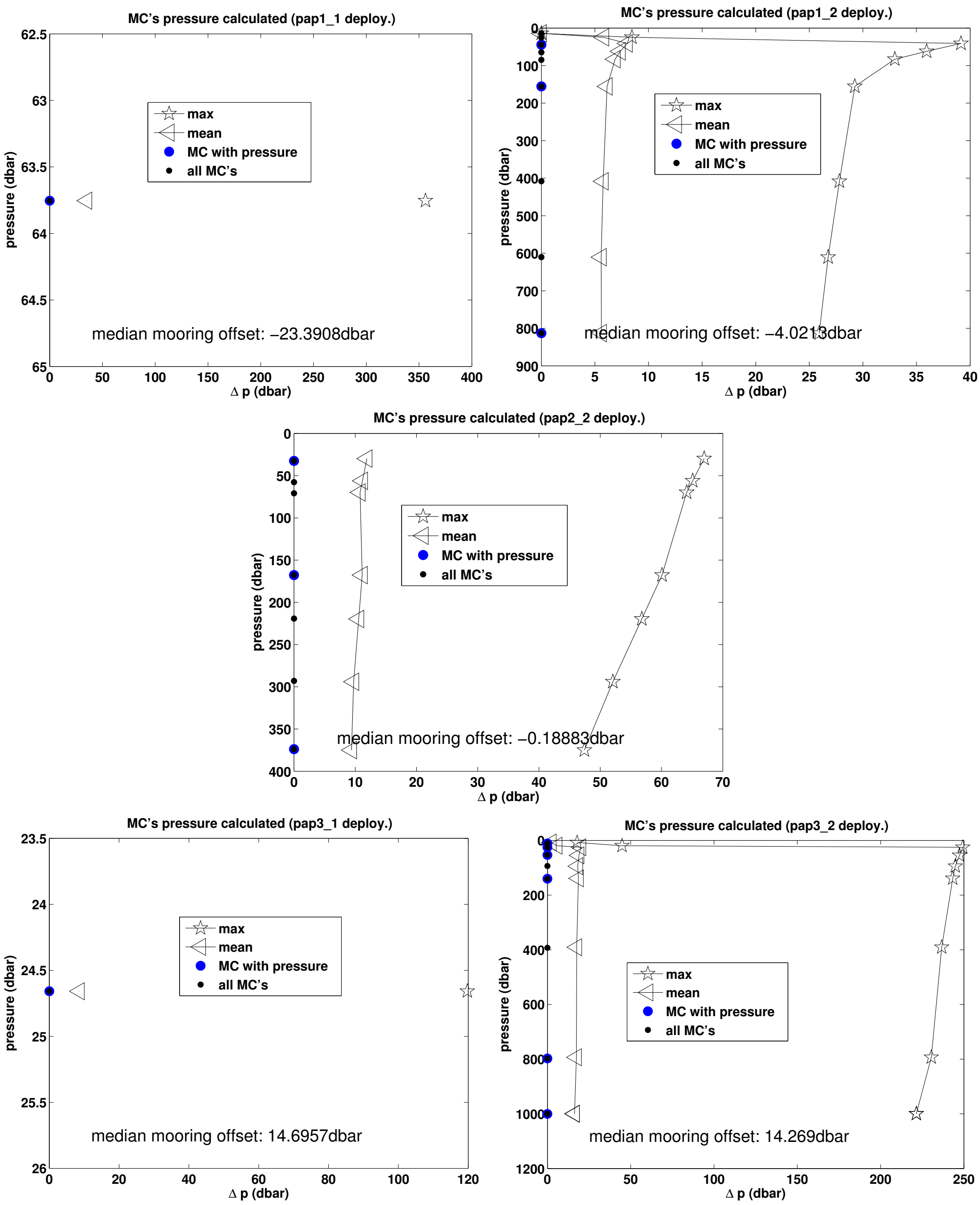

Figure 3: PAP deployment: Estimated pressure for all instruments from those with pressure sensor (blue dots). Maximum and average subduction of instruments is shown.

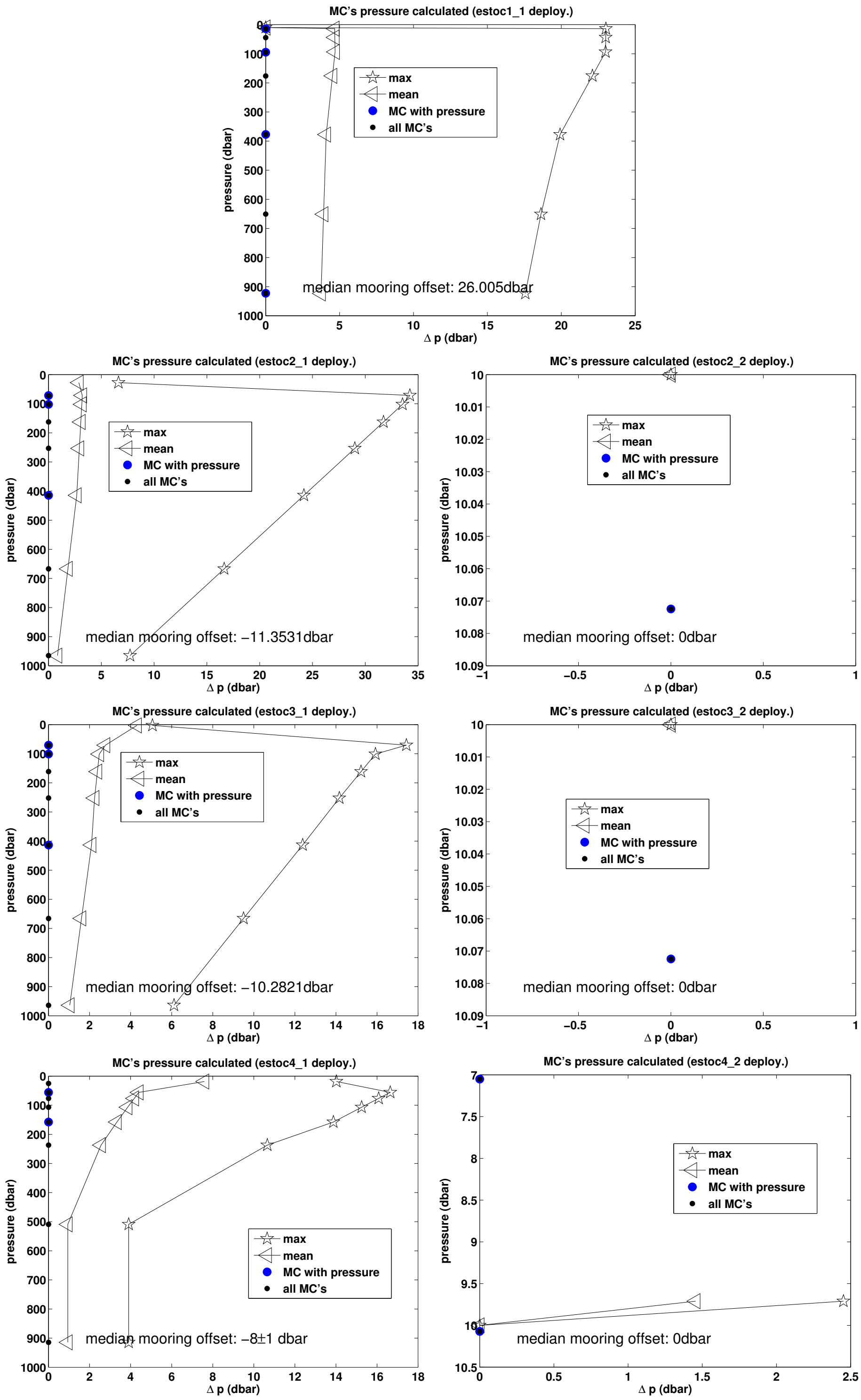

Figure 4: ESTOC deployment: Estimated pressure for all instruments from those with pressure sensor (blue dots). Maximum and average subduction of instruments is shown.

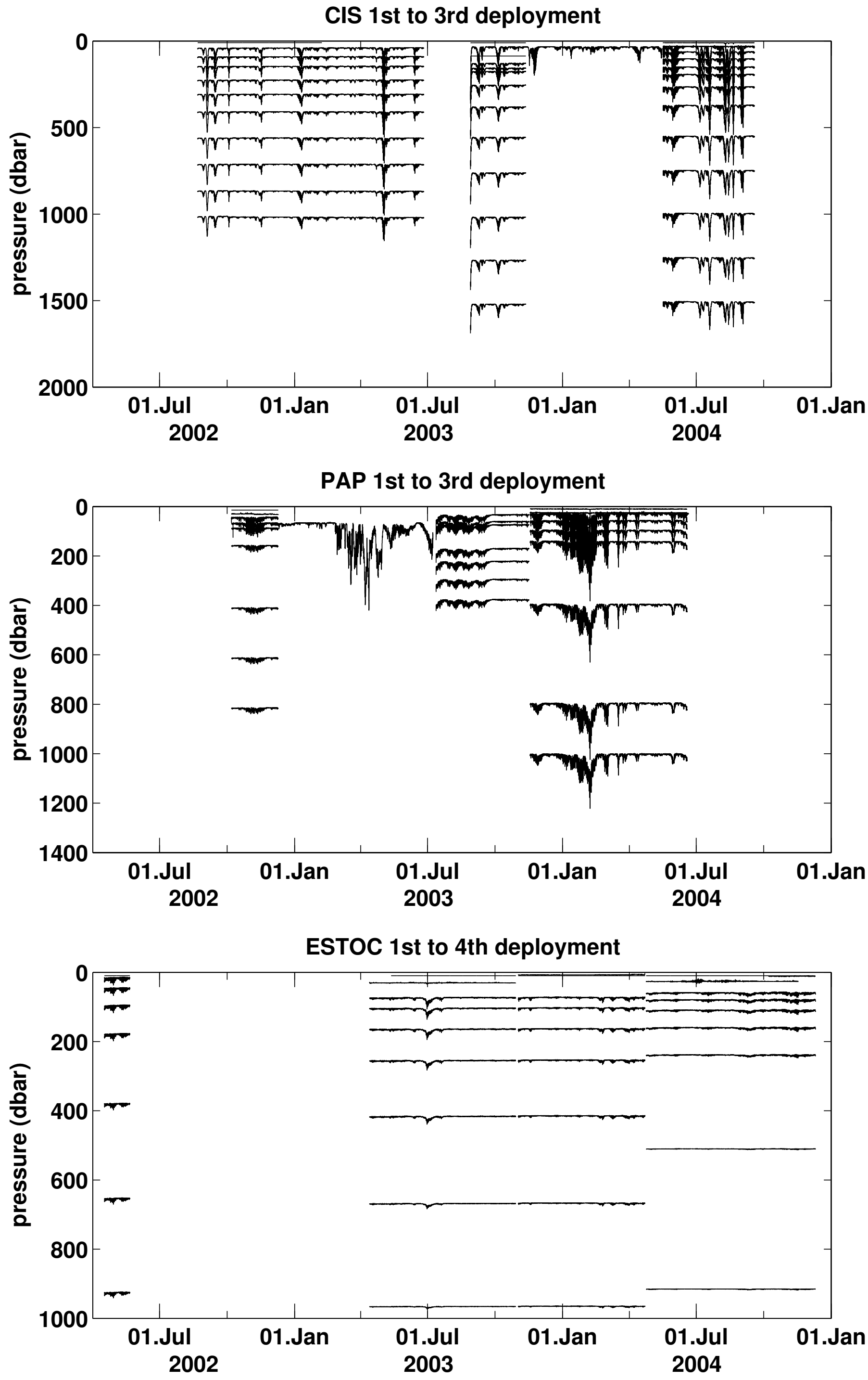

Figure 5: Corrected pressure values for all three mooring site for the 1st, 2nd and 3rd deployment period: CIS (upper), PAP (middle), ESTOC (lower).

2.3 Physical data correction

The MicroCAT data correction has two parts: First a correction for the deformation of the conductivity cell for instruments without a pressure senor, second a bias correction can be done utilizing a simultaneous CTD/MicroCAT recording from a reference cast.

With the allocated pressure values for each instrument a correction for the compressibility effect of the conductivity cell was applied following the guidelines from the manufacturer (SBE Application Note #10). For pressure differences of order 20 dbar this values is smaller 10^{-4} in salinity, however, for pressure difference larger 250 dbar this values becomes 10^{-3} in salinity.

If time permitted during the cruises, a CTD/MicroCAT calibration cast was performed. Comparing the data from the two instruments a bias correction (if only one calibration cast was available for a certain instrument) or a linear drift correction, based on at least two bias estimates, was applied. A minimum requirement for a valid calibration cast is a stop time of at least 8 minutes in a region with weak vertical gradients. Only the CTD and MicroCAT data from the stop time can be used for calibration as the sensors have different response times. Not all CTD calibration casts fullfill the requirements for a bias estimate (see section 6.2 for details). The current status of the CTD/MicroCAT calibration casts is summarized in table 4.

Table 4: Physical data calibration casts summary.

Site/deploy.	Cruise; Station/cast	Comment
CIS/1	P293; st. 660/cast 206	Calibrated CTD
CIS/2	P302; st. 620/cast 1, 2	Calibrated CTD
CIS/3	BS 2004-3	No calibration cast
CIS/4	CD 161	No calibration cast
PAP/1	D266; st. 15049	CTD failure
PAP/2	P300; st. 409, st. 415	Calibrated CTD
PAP/3	P306; st. 864/cast 1	Calibrated CTD
PAP/4	CD158; st 56514/cast 4	Calibrated CTD
ESTOC/1	M53/1b; st. 181/cast 5	Calibration unknown
ESTOC/2	P296; st. 55	Calibration unknown
ESTOC/3	P305	No calibration cast
ESTOC/4	P310	Stop time too short
ESTOC/5	P319; st.8	SBE Lab. calibrated

As one example the CTD/MicroCAT calibration cast for CIS first deployment is shown in Fig. 6. As mentioned earlier calibration is done versus time. The pressure recordings of the CTD show that two calibration stops have been made (upper left), one in 1500 dbar and one in 1000 dbar. However, only the stop in 100 dbar is used for calibration as the vertical gradients in temperature and salinity where low. The other three subfigures show the CTD and MicroCAT data at the 1000 dbar stop. As the MicroCAT were new purchased a small and relative constant bias between for all MicroCAT sensors are found (compare also table 5)

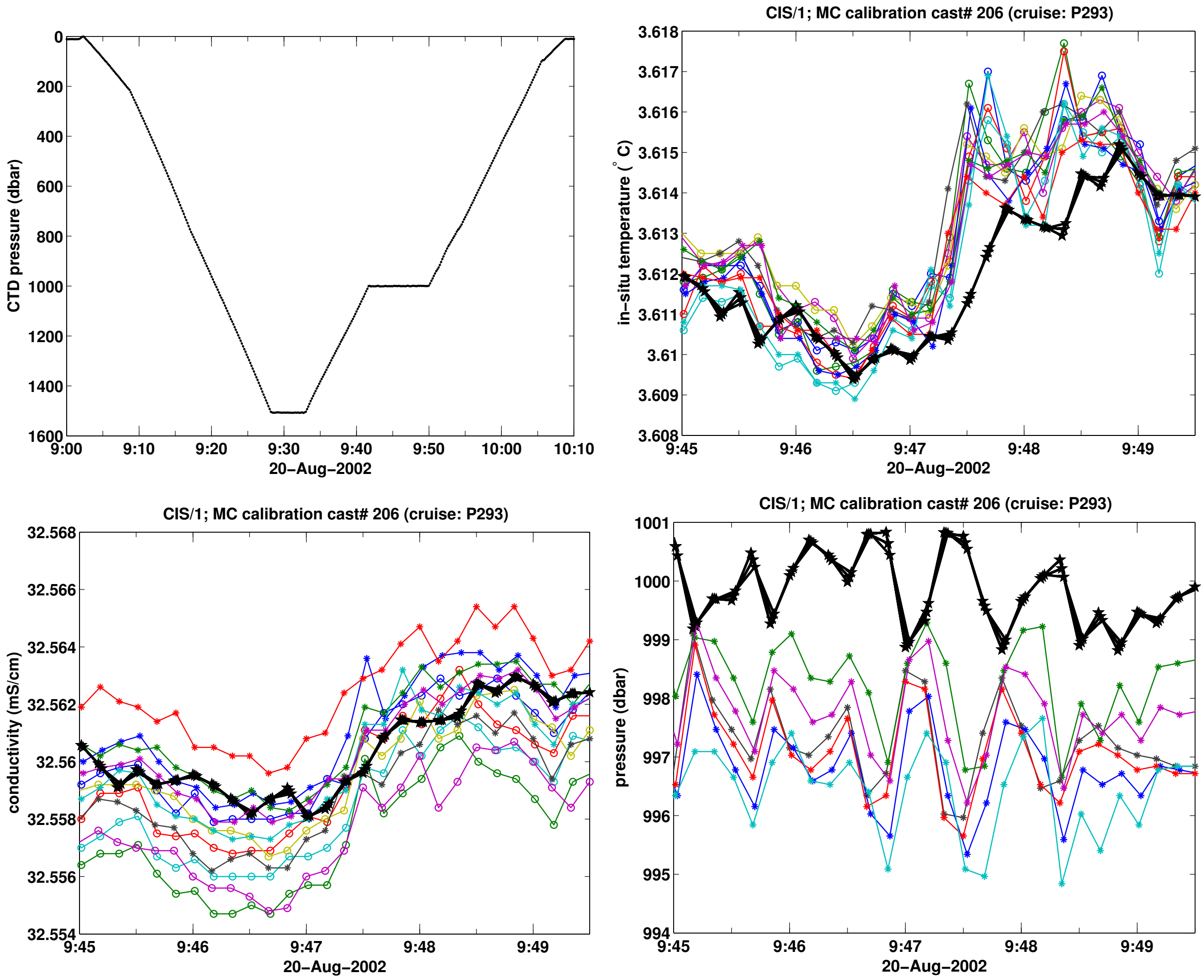

Figure 6: CTD/MicroCAT calibration cast CIS 1st deployment (P293 cruise). (upper left) CTD pressure versus time, (upper right) CTD (thick black line) and MicroCAT (colored lines) temperature, (lower left) CTD (thick black line) and MicroCAT (colored lines) conductivity (lower right) CTD (thick black line) and MicroCAT (colored lines) pressure. Calibration was done only for 1000 dbar stop as it was a low gradient environment.

The biases for all CTD/MicroCAT calibration casts that allowed for an estimate are summarized in tables 5 to 7. From the tables it can be seen that, after bias correction, the general accuracy of the temperature data is better 0.002 K in comparison to the CTD measurements. The accuracy of the conductivity sensor can be expected better 0.008 mS/cm (in salinity: 0.007 @ 5°C, 0.014 @ 25°C). Pressure sensor data is better 1 dbar, although drifts can be high, as mentioned earlier, and may not be linear during deployment.

Table 5: MicroCAT offset from calibration casts at CIS. Δ*parameter* is based on MicroCAT data minus CTD data, 'n.a.' is not available.

Site/deploy.	cast	MC#	depth	date	Δ Press.	Δ Temp.	Δ Cond.
CIS/1	206	2252	1000	20-Aug-2002	n.a.	0.001±0.001	0.0030±0.0008
CIS/1	206	2253	1000	20-Aug-2002	n.a.	0.001±0.002	0.0002±0.0011
CIS/1	206	2254	1000	20-Aug-2002	n.a.	0.001±0.001	0.0022±0.0011
CIS/1	206	2255	1000	20-Aug-2002	n.a.	0.000±0.001	0.0012±0.0010
CIS/1	206	2256	1000	20-Aug-2002	n.a.	0.001±0.001	0.0005±0.0008
CIS/1	206	2257	1000	20-Aug-2002	n.a.	0.001±0.001	0.0024±0.0008
CIS/1	206	2262	1000	20-Aug-2002	-2.6±1.3	0.001±0.001	-0.0014±0.0009
CIS/1	206	2263	1000	20-Aug-2002	-3.0±1.2	0.001±0.001	0.0008±0.0010
CIS/1	206	2264	1000	20-Aug-2002	-1.6±1.1	0.001±0.001	0.0006±0.0007
CIS/1	206	2265	1000	20-Aug-2002	-2.8±1.3	0.001±0.001	0.0021±0.0008
CIS/1	206	2266	1000	20-Aug-2002	-3.4±1.1	0.000±0.001	-0.0004±0.0010
CIS/1	206	2271	1000	20-Aug-2002	-2.1±1.2	0.001±0.001	0.0001±0.0007
CIS/2	1	2252	2237	25-Aug-2003	n.a.	-0.001±0.000	0.0079±0.0005
CIS/2	1	2254	2237	25-Aug-2003	n.a.	-0.001±0.000	0.0042±0.0005
CIS/2	1	2255	2237	25-Aug-2003	n.a.	-0.002±0.000	0.0043±0.0006
CIS/2	1	2256	2237	25-Aug-2003	n.a.	-0.001±0.000	0.0031±0.0005
CIS/2	1	2264	2237	25-Aug-2003	-2.6±0.7	-0.001±0.001	0.0030±0.0005
CIS/2	1	2265	2237	25-Aug-2003	2.4±0.4	-0.002±0.000	0.0056±0.0006
CIS/2	1	2271	2237	25-Aug-2003	-1.6±0.5	-0.001±0.000	0.0049±0.0005
CIS/2	2	2257	2262	25-Aug-2003	n.a.	-0.001±0.000	0.0070±0.0006
CIS/2	2	2262	2261	25-Aug-2003	-1.4±0.2	-0.001±0.000	0.0007±0.0006
CIS/2	2	2263	2262	25-Aug-2003	-2.9±0.5	-0.002±0.000	0.0081±0.0008
CIS/2	2	2488	2261	25-Aug-2003	1.8±0.8	-0.002±0.000	-0.0074±0.0005
CIS/2	2	2492	2262	25-Aug-2003	n.a.	-0.003±0.000	-0.0027±0.0005
CIS/2	2	2717	2262	25-Aug-2003	-3.8±0.3	-0.003±0.000	0.0017±0.0003
CIS/2	2	2799	2262	25-Aug-2003	n.a.	-0.005±0.000	-0.0013±0.0003

Table 6: MicroCAT offset from calibration casts at PAP. Δ*parameter* is based on MicroCAT data minus CTD data, 'n.a.' is not available.

Site/deploy.	cast	MC#	depth	date	Δ Press.	Δ Temp.	Δ Cond.
PAP/2	409	2809	4830	08-Jul-2003	n.a.	-0.001±0.000	-0.0022±0.0002
PAP/2	409	2934	4830	08-Jul-2003	n.a.	-0.001±0.000	0.0002±0.0002
PAP/2	415	2486	3078	10-Jul-2003	5.1±0.4	-0.001±0.001	0.0071±0.0008
PAP/2	415	2718	3079	10-Jul-2003	-8.1±0.6	-0.002±0.000	0.0011±0.0009
PAP/2	415	2812	3079	10-Jul-2003	n.a.	-0.000±0.001	0.0007±0.0008
PAP/2	415	2933	3079	10-Jul-2003	n.a.	-0.001±0.001	0.0007±0.0009
PAP/2	415	2974	3079	10-Jul-2003	-4.3±0.5	0.000±0.001	-0.0075±0.0007
PAP/3	864	1520	606	17-Nov-2003	n.a.	0.002±0.005	0.0198±0.0045
PAP/3	864	2800	606	17-Nov-2003	-2.0±1.3	0.001±0.004	0.0005±0.0039
PAP/4	4	0961	501	21-Jun-2004	n.a.	-0.001±0.001	-0.0244±0.0061
PAP/4	4	1520	501	21-Jun-2004	n.a.	0.001±0.001	0.0260±0.0011
PAP/4	4	2809	501	21-Jun-2004	n.a.	0.002±0.002	0.0013±0.0019
PAP/4	4	2812	501	21-Jun-2004	n.a.	0.000±0.001	0.0041±0.0013
PAP/4	4	2486	501	21-Jun-2004	-0.5±0.5	0.003±0.002	0.0173±0.0016
PAP/4	4	2718	501	21-Jun-2004	-8.5±0.6	0.001±0.002	0.0039±0.0019
PAP/4	4	2800	501	21-Jun-2004	-2.8±0.5	-0.002±0.002	-0.0077±0.0011
PAP/4	4	2974	501	21-Jun-2004	-1.8±0.6	0.001±0.002	-0.0046±0.0013
PAP/4	4	3415	501	21-Jun-2004	-1.3±0.4	0.002±0.002	-0.0009±0.0020
PAP/4	4	3416	501	21-Jun-2004	-1.3±0.6	-0.001±0.002	-0.0003±0.0018

Table 7: MicroCAT offset from calibration casts at ESTOC. Δ*parameter* is based on MicroCAT data minus CTD data, 'n.a.' is not available.

Site/deploy.	cast	MC#	depth	date	Δ Press.	Δ Temp.	Δ Cond.
ESTOC/1	5	2258	1002	13-Apr-2002	n.a.	-0.001±0.002	0.0010±0.0014
ESTOC/1	5	2259	1002	13-Apr-2002	n.a.	0.000±0.001	0.0003±0.0012
ESTOC/1	5	2260	1002	13-Apr-2002	n.a.	0.000±0.001	0.0000±0.0011
ESTOC/1	5	2261	1002	13-Apr-2002	n.a.	0.001±0.001	0.0006±0.0008
ESTOC/1	5	2267	1002	13-Apr-2002	0.2±0.4	-0.001±0.002	0.0009±0.0016
ESTOC/1	5	2268	1002	13-Apr-2002	0.3±0.3	-0.000±0.001	0.0044±0.0013
ESTOC/1	5	2269	1002	13-Apr-2002	0.6±0.7	0.000±0.001	-0.0004±0.0007
ESTOC/1	5	2270	1002	13-Apr-2002	0.1±0.7	0.001±0.002	0.0002±0.0012
ESTOC/2	5	2260	3004	11-Apr-2003	n.a.	-0.000±0.001	-0.0050±0.0008
ESTOC/2	5	2261	3004	11-Apr-2003	n.a.	0.000±0.001	-0.0003±0.0008
ESTOC/2	5	2269	3004	11-Apr-2003	-11.6±0.6	0.000±0.001	0.0000±0.0009
ESTOC/2	5	2270	3004	11-Apr-2003	-6.4±0.6	0.000±0.001	-0.0009±0.0009
ESTOC/2	5	2712	3004	11-Apr-2003	-8.5±0.6	-0.002±0.001	0.1510±0.0120
ESTOC/2	5	2713	3004	11-Apr-2003	-9.6±0.6	-0.001±0.001	0.0016±0.0008
ESTOC/2	5	2801	3004	11-Apr-2003	n.a.	-0.003±0.001	-0.0038±0.0008
ESTOC/2	5	2802	3004	11-Apr-2003	n.a.	-0.002±0.001	-0.0021±0.0009
ESTOC/5	8	2260	502	14-Dec-2004	n.a.	0.004±0.005	-0.0147±0.0054
ESTOC/5	8	2261	502	14-Dec-2004	n.a.	0.005±0.004	-0.0098±0.0036
ESTOC/5	8	2269	502	14-Dec-2004	-4.8±1.2	-0.002±0.004	0.0057±0.0062
ESTOC/5	8	2270	502	14-Dec-2004	-7.7±0.3	0.004±0.003	0.0688±0.0083
ESTOC/5	8	2712	502	14-Dec-2004	-463.7±0.3	0.000±0.005	-0.0002±0.0089
ESTOC/5	8	2713	502	14-Dec-2004	-1.4±0.7	0.002±0.005	0.0150±0.0041
ESTOC/5	8	2801	502	14-Dec-2004	n.a.	-0.008±0.004	-0.0076±0.0072
ESTOC/5	8	2802	502	14-Dec-2004	n.a.	0.001±0.005	-0.0016±0.0044

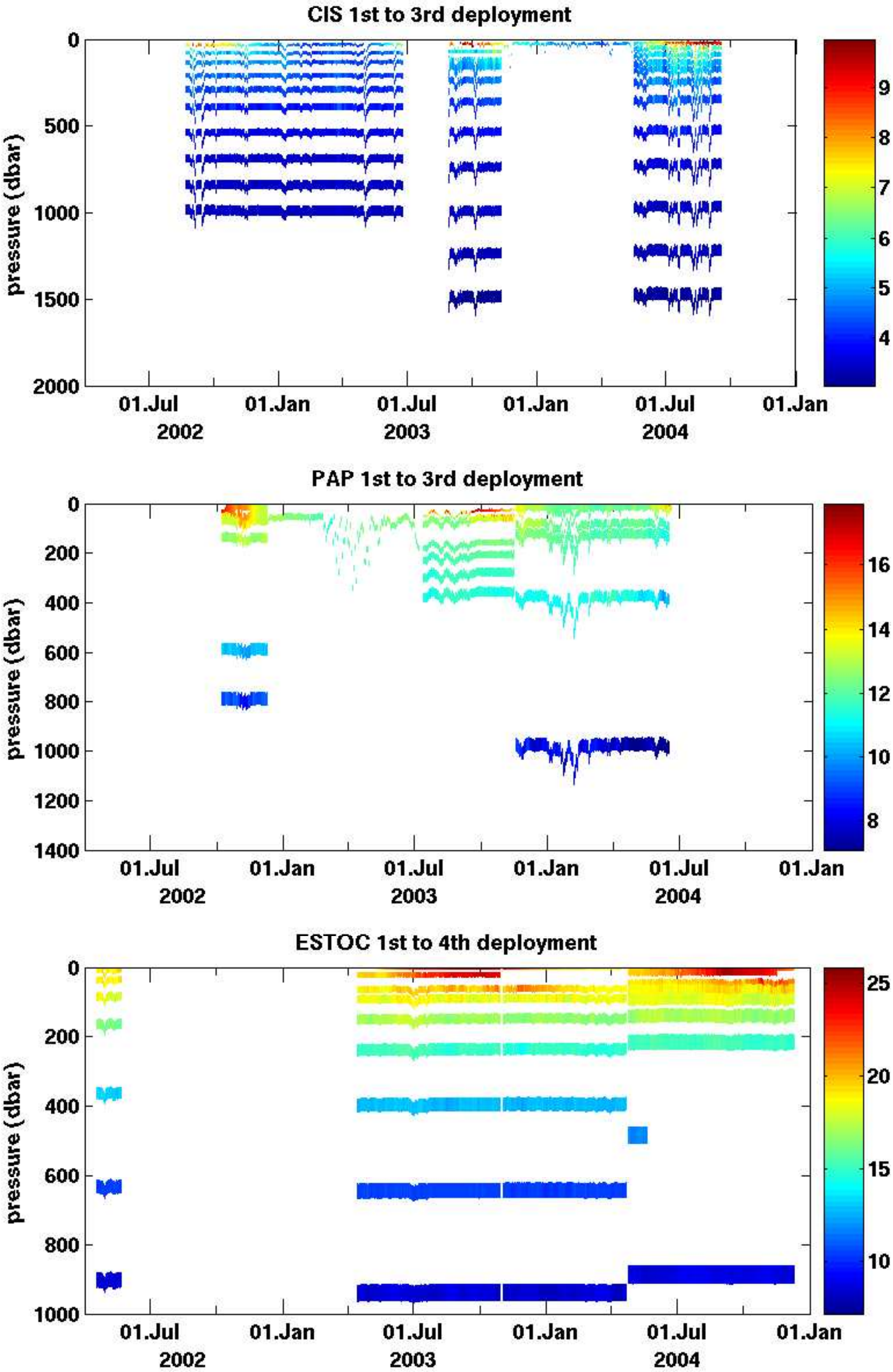

Figure 7: Potential temperature for all three mooring site for the 1st, 2nd and 3rd deployment period: CIS (upper), PAP (middle), ESTOC (lower).

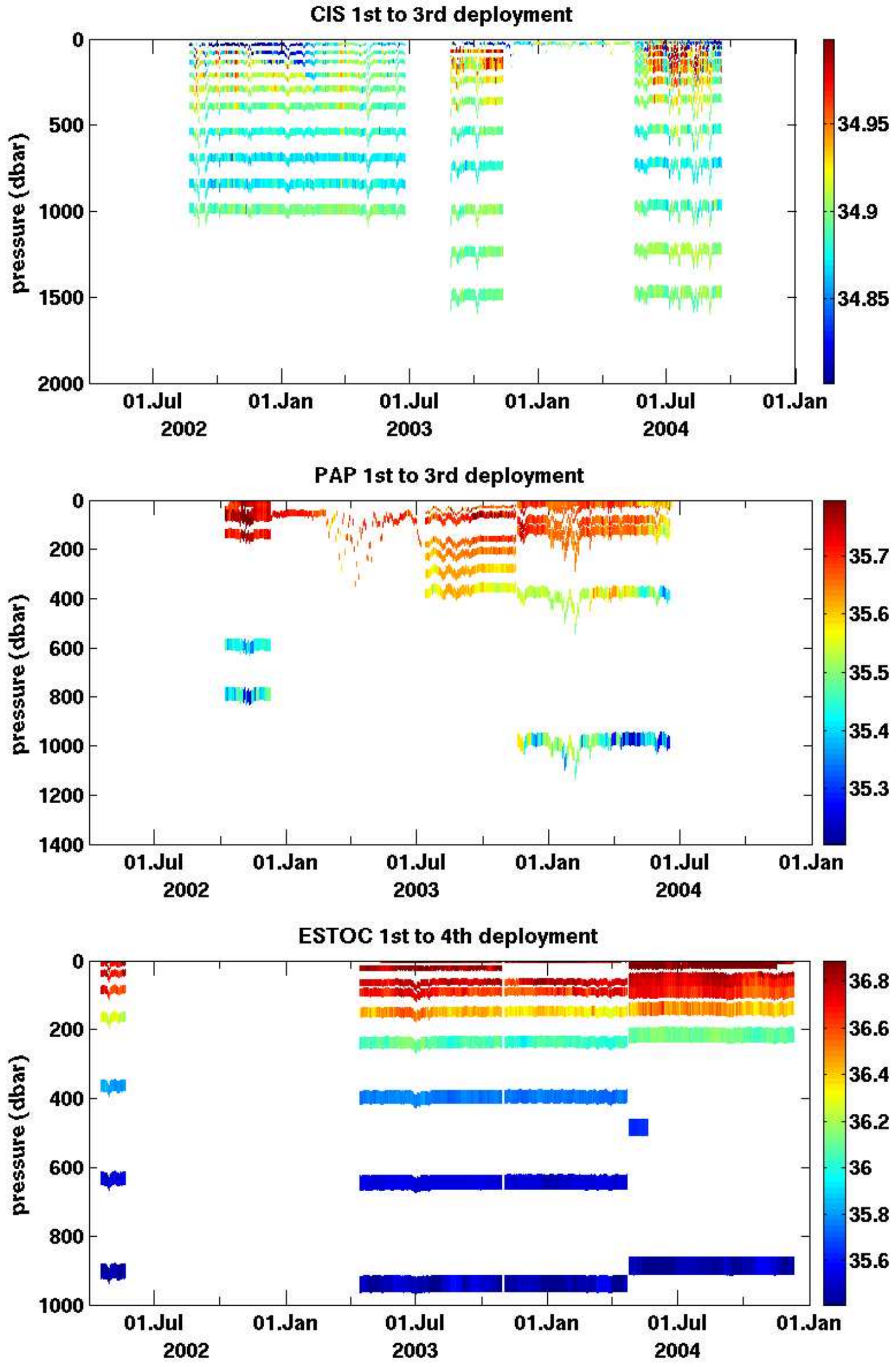

Figure 8: Salinity for all three mooring site for the 1st, 2nd and 3rd deployment period: CIS (upper), PAP (middle), ESTOC (lower).

2.4 Quality check of data

The final quality check of the data was guided by visual inspection of the data and in comparison with climatological data (Hydro Base 2) based on (2). Attention was drawn only to the salinity/conductivity data.
Outliers in conductivity have been remove for some periods utilizing the potential temperature/conductivity relation. The outliers were replaced with values derived from a linear fit of potential temperature and conductivity derived from the respective instrument. A summary of period is given in Table 8. Overall there is a good agreement

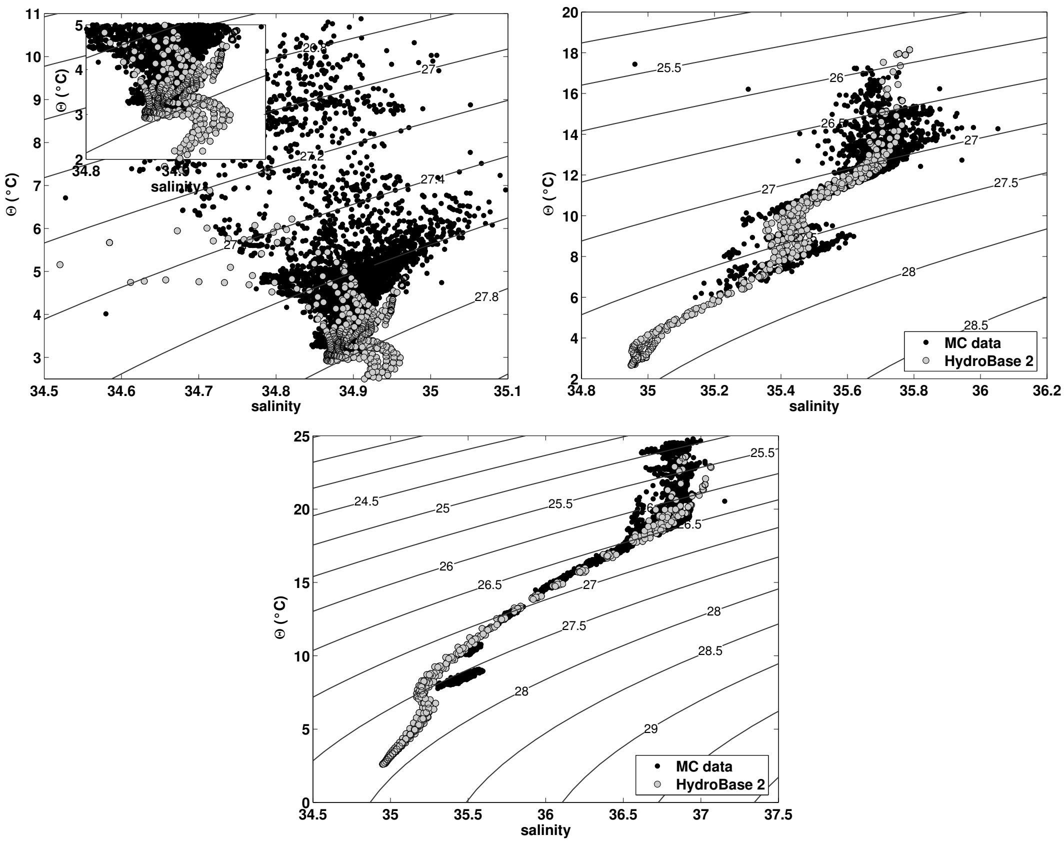

Figure 9: Temperature/salinity diagram of the processed data (black dots) and the climatological (Hydro Base 2) values (gray dots): CIS (upper), PAP (middle), ESTOC (lower).

between the Hydro Base data and the processed data for all three sites (Fig. 9). There are some deviations as the increase in salinity at the level of the Mediterranean Water (density about 27.6kg m^{-3}) at all three sites which could be real. In addition, at the CIS site there is a very different T/S curve for water around 3°C. This is consistent with recent changes in the region which is not captured in the climatological data and needs further investigations.

Table 8: Summary of period were conductivity data was corrected.

Site/deploy.	MicroCAT	Time
PAP/1	2490	No conductivity data available
PAP/1	2487	09-Oct-2002 to 19-Oct-2002
PAP/2	2809	01-Oct-2003 to 10-Oct-2003
PAP/3	2486	02-May-2004 to 03-May-2004
PAP/3	2934	09-May-2004 to 12-May-2004 27-May-2004 to 28-May-2004
ESTOC/2 ESTOC/2	2260 2269	11-Jul-2003 to 12-Jul-2003 01-Aug-2003 to 29-Oct-2003
ESTOC/4	2713	06-Jun-2004 to 13-Jun-2004

3 TD- Logger data processing

To compensate for a number of lost MicroCAT's five Temperature/Pressure logger where deployed for the 3rd deployment period at the PAP site. The logger were programmed to record temperature and pressure every 20 minute. Unfortunately only three of the five instruments recorded useful data (Tab. 9).

Table 9: TD logger at PAP 3rd deployment.

serial #	24	25	26	27	28
nom. depth	67	252	603	803	1003
data	yes	no	no	yes	yes

The TD logger data was processed with the MicroCAT data and like an MicroCAT without conductivity sensor. It can be identified from the 'instrument type' variable.

4 ADCP data processing

Most of the ADCP data processing is done internally in the instrument. This comprises the conversion from beam coordinate velocity data into earth coordinates considering the 3-d position of the instrument. Position information are derived from internal recording of heading, pitch and roll. The conversion procedure is outlined in the manufacturers hand book(4).

The additional processing which was done comprises: interpolating the data to a common time axis, correcting for misalignment through local magnetic declination and estimating the instrument depth. No correcting for the assumptions of incorrect sound speed were applied as changes are normally less than a millimeter per second on the absolute speed and hence much smaller than the typical uncertainty of the measurements.

4.1 Interpolation to common time axis

The sampling interval for the individual mooring site was not uniform throughout the sites (Tab. 10) and ranged between 0.5 and 2 hours. The data was not further interpolated, only the data recorded while the devices were no longer at the site are removed.

Table 10: Summary of ADCP instruments, sampling interval, depth cell size and possible determination of instrument depth from beam intensity data.

Site/deploy.	Type/serial	Δt (hours)	Bin size	Depth estimate
CIS/1	WH/#2141	0.5	10 m	yes
CIS/2	WH/#2141	0.5	10 m	yes
	LR /#2330	0.5	16 m	–
CIS/3	WH/#2141	0.5	10 m	yes
	LR/#2330	0.5	16 m	–
PAP/1	WH/#2140	2	8 m	no
	BB/#1614	2	8 m	–
PAP/2	WH/#2140	2	8 m	no
	BB/#1614	2	8 m	–
PAP/3	WH/#2140	2	8 m	no
	BB/#1690	2	8 m	–
ESTOC/1	WH/#2379	2	16 m	yes
ESTOC/2	WH/#2379	2	16 m	no
ESTOC/3	WH/#2379	2	16 m	yes
ESTOC/4	WH/#2379	2	6 m	yes

4.2 Estimating the instrument depth

Two different approaches are used to estimate the depth of the measured velocities: Utilizing the ADCP beam intensity from the upward looking instrument and utilizing neighboring MicroCAT data. Not all instruments allow to derive the depth as the configuration (number of depth cells) was not set adequately (Tab. 10 and Fig. 10).

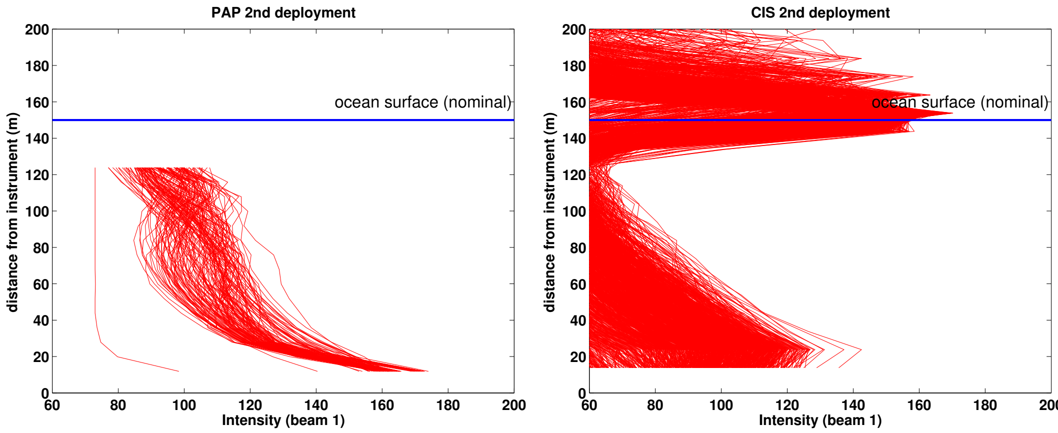

Figure 10: Examples for Beam Intensity profiles (Beam #1) from the upward looking ADCP for PAP (left) and CIS (right). The intensity maximum at the surface at CIS can be used to derive the depth of the instrument. The configuration of the PAP instrument does not allow for an depth estimate. Note however, the weak maximum at about 100m depth from the PAP instrument which indicates the vertical migration of particles.

For the instruments which allow for the depth estimate (see Tab. 10) a parable fit was performed to three neighboring data points including the peak intensity which allow to derive the depth with a higher resolution than the depth cell size (6). The distance from the individual beam intensity maximum (ray length, r) has to be converted to the depth of the instrument (z) considering the pitch and roll recordings of the ADCP (Fig. 11, left). Pitch and roll are expressed relative to the heading which is aligned with the beam 1/2. Utilizing the beam angle (γ, 20°for our instruments) and the roll (ϵR) respective pitch (ϵP) one can calculate the instrument depth:

$$
\begin{aligned}
z(\text{beam}1,2) &= r(\text{beam}1,2) \cdot cos(\gamma + \epsilon R) \cdot cos(\epsilon P) \\
z(\text{beam}3,4) &= r(\text{beam}3,4) \cdot cos(\gamma + \epsilon P) \cdot cos(\epsilon R)
\end{aligned}
$$

where the ray length r is sum of the location of the maximum intensity, the first bin distance and the z_{offset}, which is the focus of the rays (for a workhorse: $cot(\gamma) \cdot 68.5/1000$). For an example of the so derived depth see Fig. 11 (right).

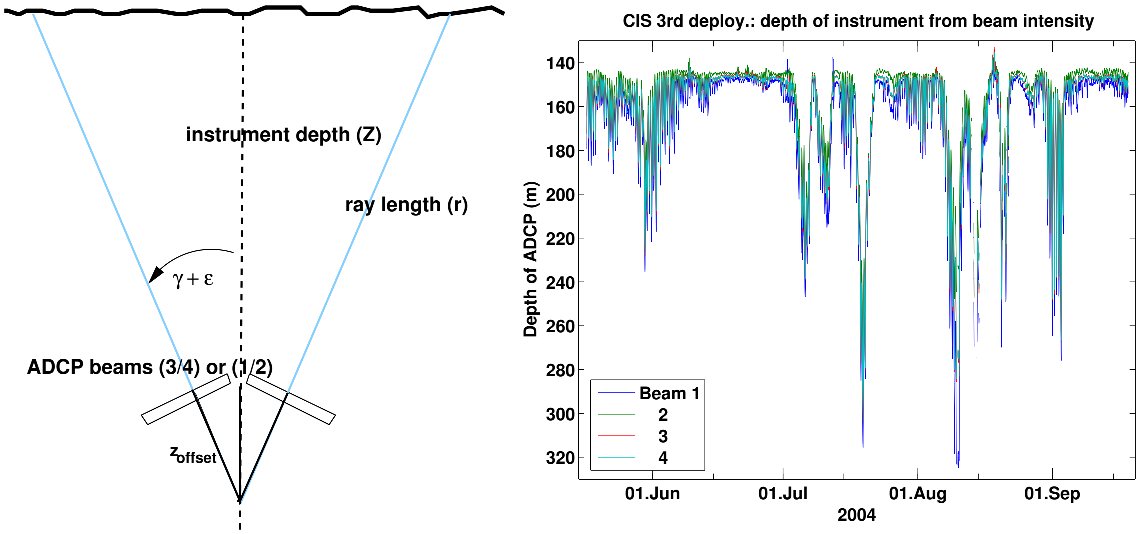

Figure 11: (left) Schematic on geometric setup to derive instrument depth from upward looking ADCP's beam intensity. (right) Depth of instrument derived from the upward looking ADCP's beam intensity. See text for details.

The second approach to derive the depth was by using the MicroCAT pressure readings. In case more than one mooring was deployed only the MicroCAT from the ADCP mooring can be used. Individual mooring movements can be very different from each other, even if they are not far apart, through the way buoyancy is distributed along the wire. Interpolation of the MicroCAT pressure to ADCP instrument depth was done from the nearest MicroCAT without considering a depth decay of the movements amplitude. For the interpolation, first the nominal ADCP instrument depth was corrected for the MicroCAT derived topographic bias (Tab. 3). Next the MicroCAT depth variability was added to the corrected ADCP nominal depth.

4.3 Correction for the local magnetic declination

We used the International Geomagnetic Reference Field (IGRF) model data from 1995 to correct for the local magnetic declination (Tab. 11). Technically the velocity component data is decomposed into speed and direction and the magnetic deviation is added to the direction data. The so corrected direction is back transformed into the east/north components. The effects of such a correction is larger for larger magnetic declinations.

Table 11: Approximate magnetic declinations from true north at the three ANIMATE mooring sites.

site	CIS	PAP	ESTOC
magnetic declination (°)	-24	-9	-7

Figure 12 to 14 show the change in the velocity (corrected velocity - original velocity) for the third depth cell (approximately 130m water depth) for all three sites from the 1st to the 3rd deployment.

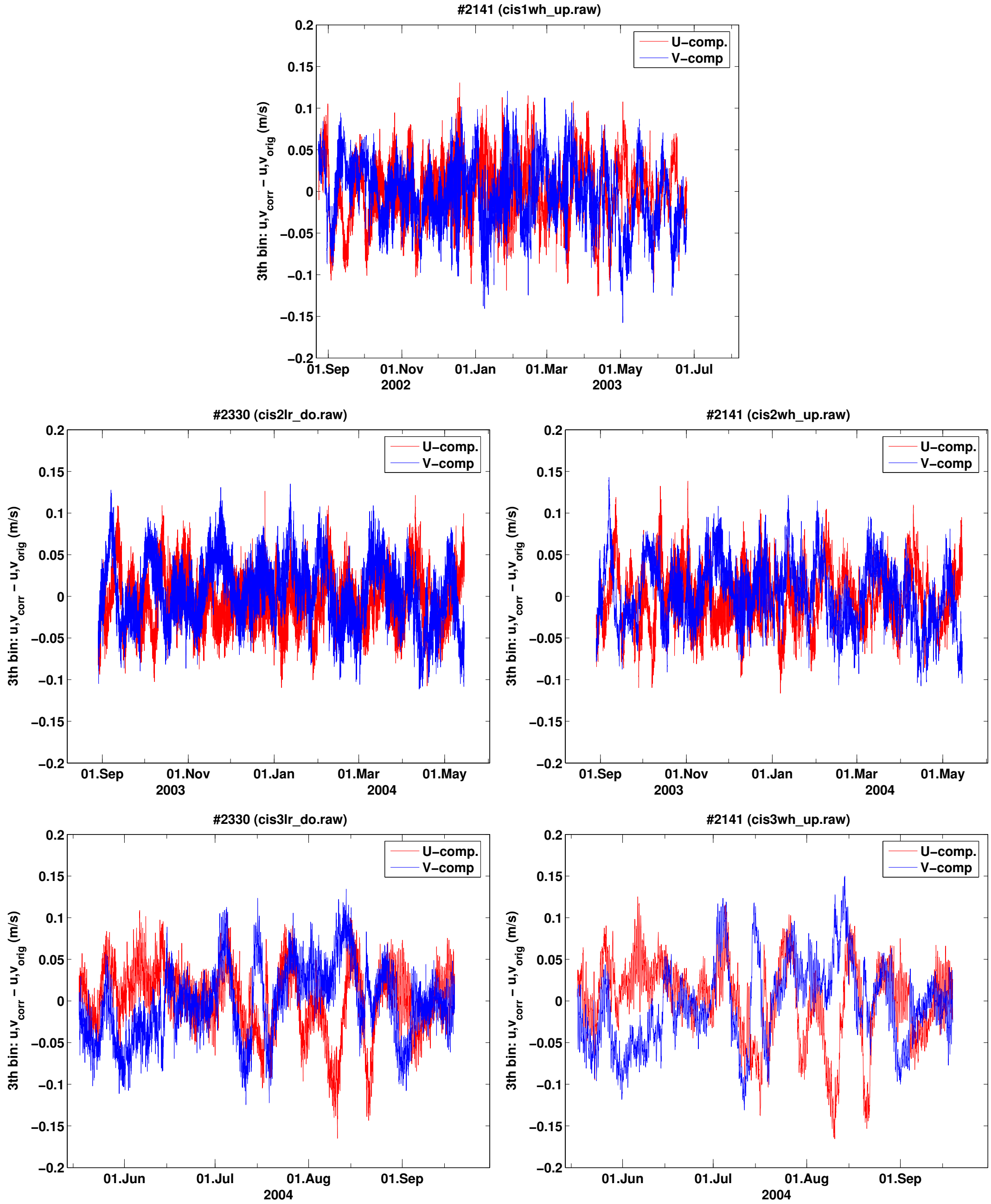

Figure 12: Change in magnitude of velocity components (corrected velocity - original velocity) for the third depth cell (approximately 130m water depth) for CIS

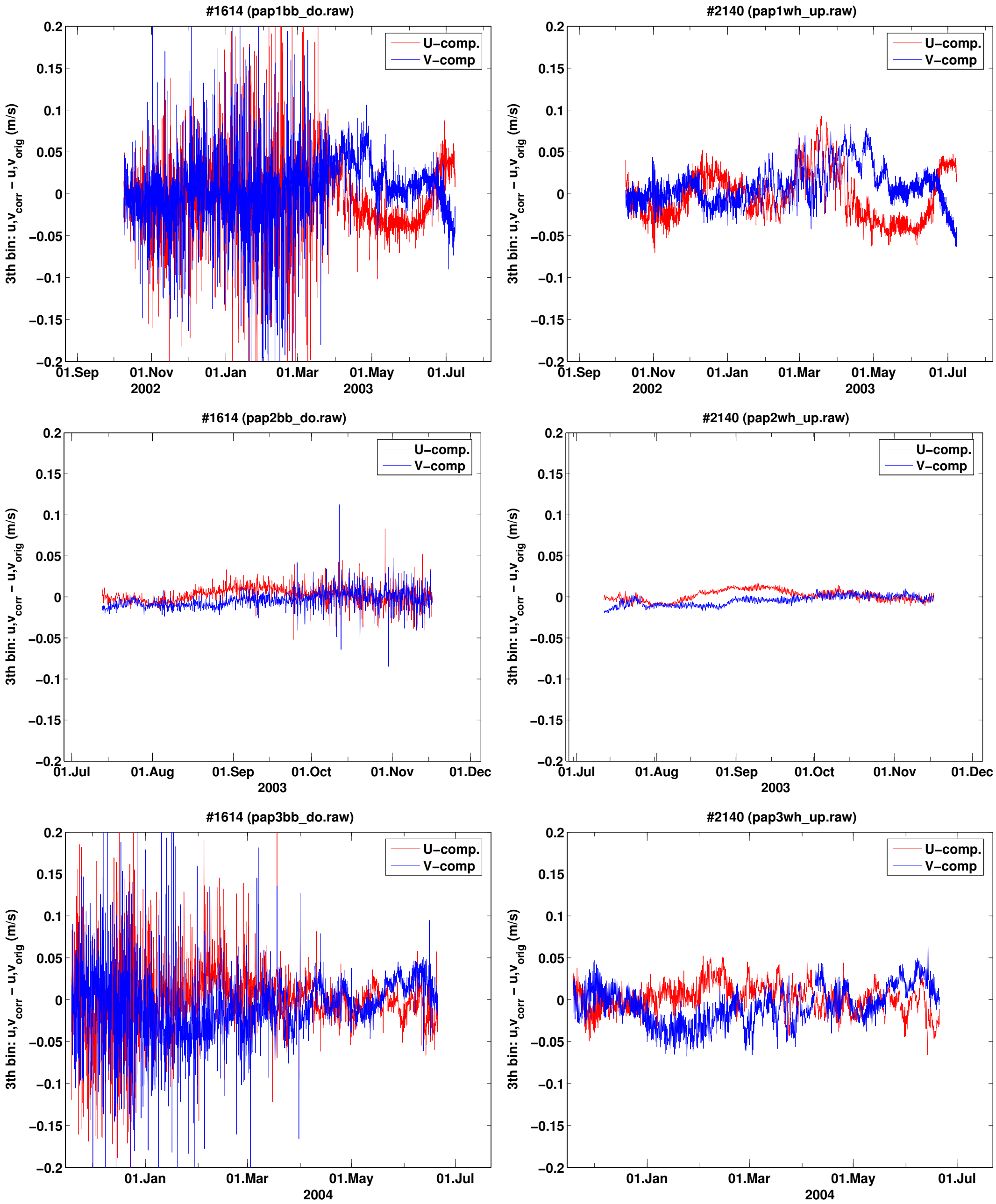

Figure 13: Change in magnitude of velocity components (corrected velocity - original velocity) for the third depth cell (approximately 130m water depth) for PAP

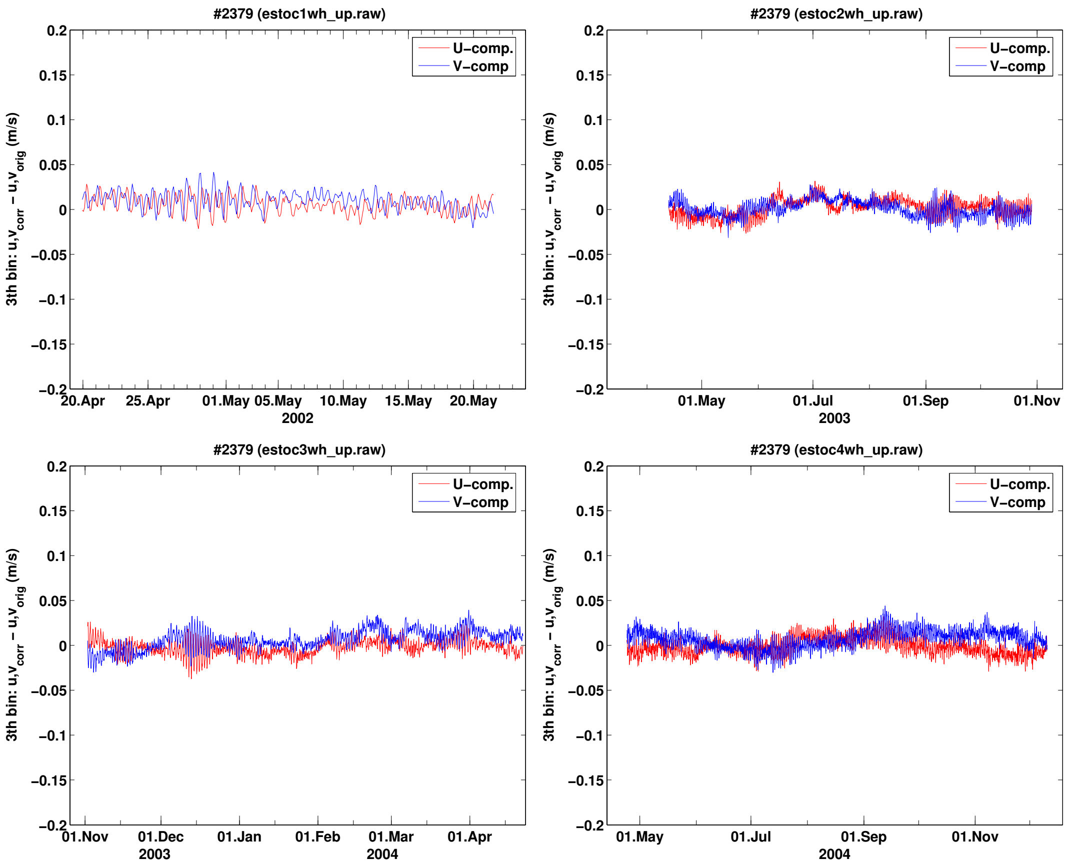

Figure 14: Change in magnitude of velocity components (corrected velocity - original velocity) for the third depth cell (approximately 130m water depth) for ESTOC

4.4 Correction for sound speed

Typically the ADCP is only equipped with a temperature sensor that does allow to derive actual sound speed (C_{real}) at the transducer heads. However, there is a possibility to correct the measured speed ($V_{uncorrected}$) for measurements with a wrong sound speed (C_{ADCP}) setting (4):

$$V_{corrected} = V_{uncorrected}(C_{real}/C_{ADCP})$$

Typically this changes the velocities less than a millimeters per second (Fig. 15) and no correction was done for the instruments.

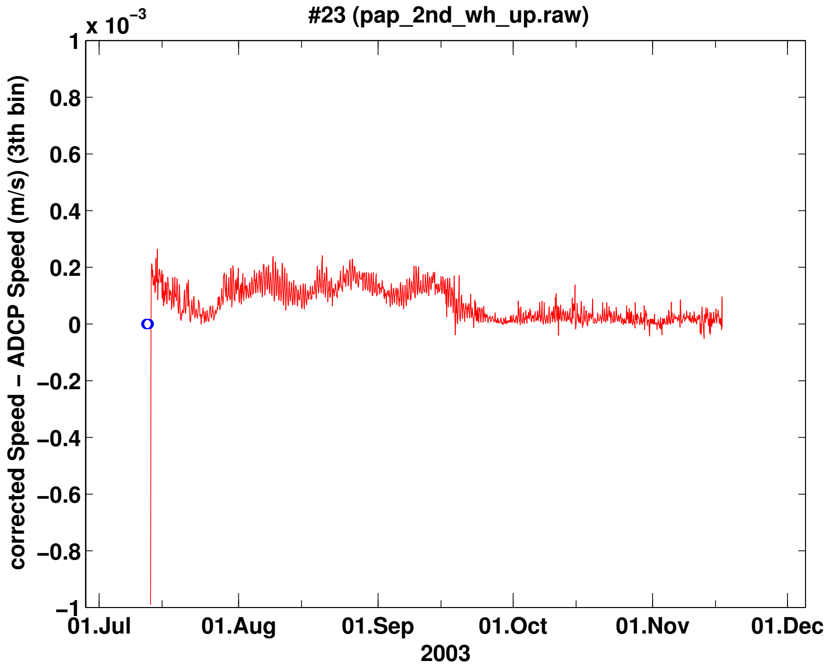

Figure 15: Change in velocities due to sound speed correction - PAP 2nd deployment

4.5 Quality check of data

A consistency check was done between the upward and downward looking instruments 1st bin for the CIS and PAP site (Figs. 16 and 17). These two bin are close to each other (order 20 m apart) and velocities should be quite similar. For both sites the difference scatter around zero, however, the downward looking broad band instrument at the PAP site (Fig. 17) is very noisy and consequently the differences are larger.
ESTOC does not allow for such a check as there was only an upward looking WH instrument deployed.

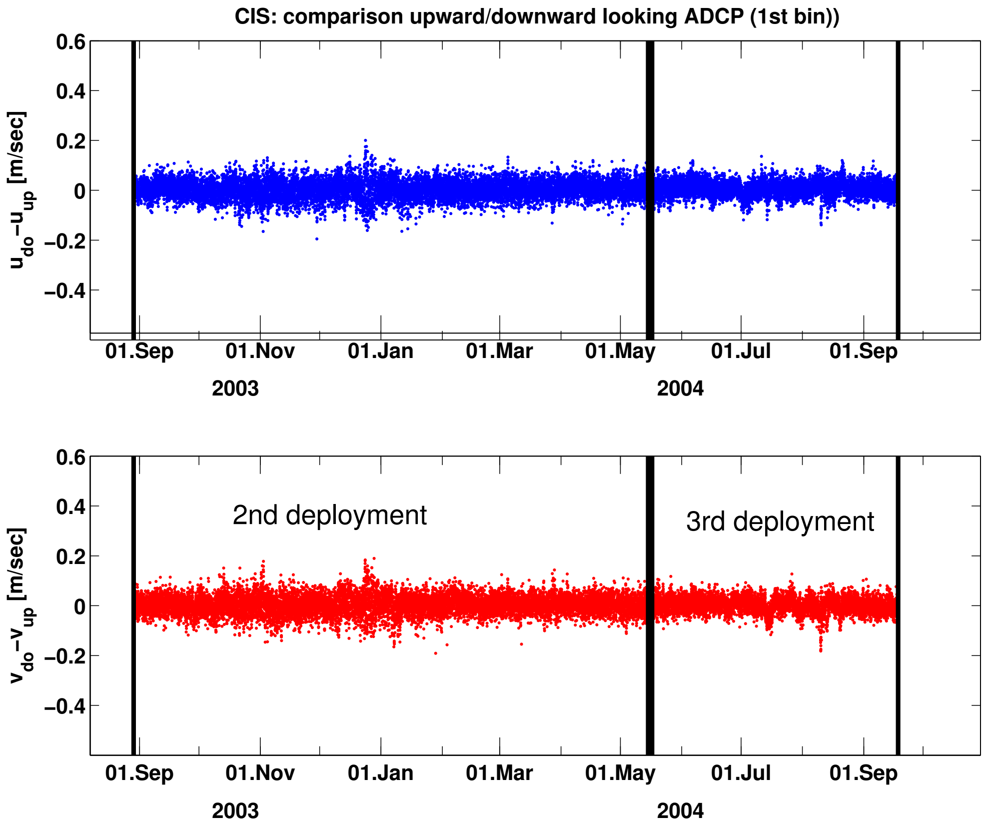

Figure 16: Difference in east (blue) and northward (red) velocities of 1st bin at the CIS site (CIS 1st deployment had only and upward looking ADCP.

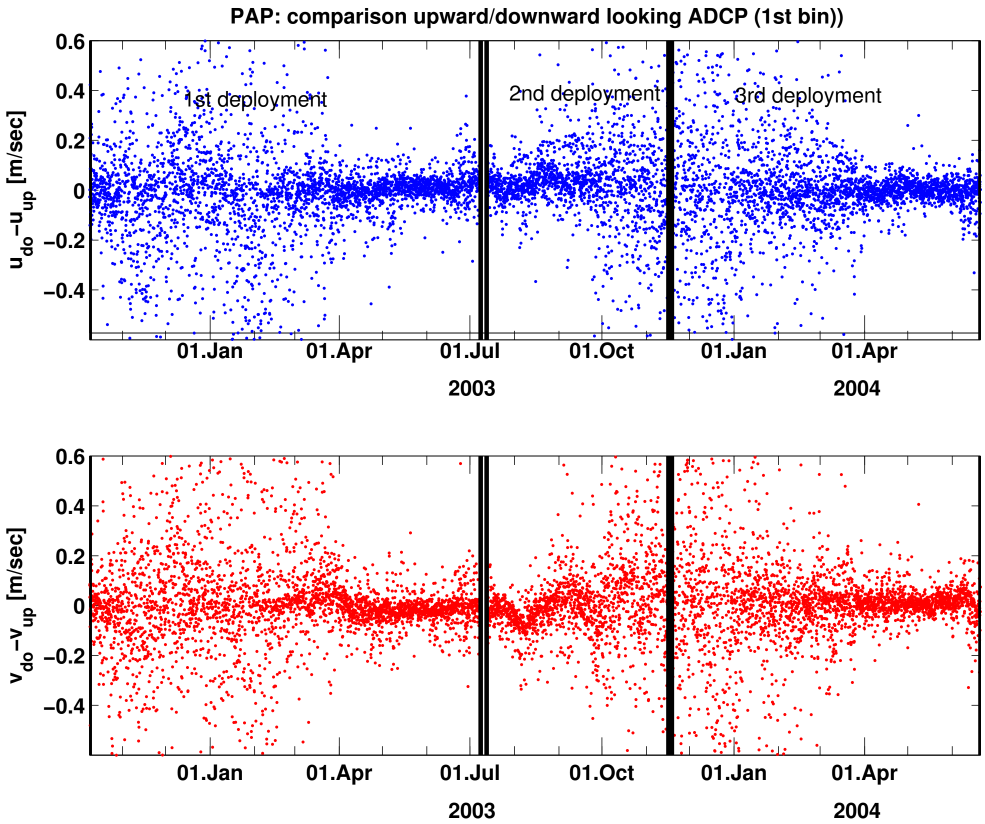

Figure 17: Difference in east (blue) and northward (red) velocities of 1st bin at the PAP site.

5 RCM data processing

Rotor current meters (RCM) where used in combination with sediment traps. Only Aanderaa current meters of the type RCM 8 and RCM 7 have been used. An overview on deployed RCM is given in Tab. 12. Data processing from the RCM data comprises the conversion of the raw data into physical units utilizing polynomial expressions and the the correction for magnetic declination (see Tab. 11). Respective conversion sheets are either available for each instruments from the manufacturer or have been derived from lab calibrations.

For a few instruments a calibration cast was performed as with the MicroCAT . The RCM was mounted on the rosette and lowered. CTD and RCM reading are compared and re-calibration was initiated.

Table 12: Summary of RCM instruments. Senor types: V (velocity), T (temperature), p(pressure)

Site/deploy.	Type	Serial nr.	Δt (min.)	Senors	Comment
CIS/1 (1011m)	RCM 8	# 10076	120	V, T, p	data
(2272m)	RCM 8	# 125	120	V, T	data
CIS/2 (1002m)	RCM 8	# 10076	120	V, T, p	data lost
(2325m)	RCM 8	# 125	120	V, T	data
CIS/3 (1004m)	RCM 8	# 11622	120	V, T, p	data
(2327m)	RCM 8	# 9821	120	V, T	data
PAP/1 (1090m)	RCM 7	# 11674	60	V, T, p	
(3095m)	RCM 8	# 9447	60	V, T	
(4745m)	RCM 8	# 12356	60	V, T	
PAP/2,3 (3085m)	RCM 8	# 11571	60	V, T	
(4753m)	RCM 8	# 9415	60	V, T	
ESTOC/1 (1003m)	RCM 8	# 7724	–	–	lost, no data
(3021m)	RCM 8	# 10315	–	–	lost, no data
ESTOC/2 (3019m)	RCM 8	# 11348	120	V, T, p	
ESTOC/3 (3019m)	RCM 8	# 11348	120	V, T, p	
ESTOC/4				No RCM deployed	

6 Standard configurations future deployments

Defining a 'standard' configuration for the instruments is a difficult task as the technical premises (e.g. memory or battery capacity) may differ even for the same type of instruments. Some basic requirements should always be met: maximize data recovery but ensure enough battery capacity and memory space is available, not only for the planned deployment duration but add another 50% to encounter prolonged deployment through modified cruise plans, bad weather, ... The two suggested configurations below are an attempt to ensure quality of the data. Modifications for the standard configurations for both instruments (MicroCAT and ADCP) is first (and for MicroCAT only) a higher sample frequency. For the MicroCAT a 'How to' for performing a calibration cast is given as well.

6.1 MicroCAT configuration

Recommended time interval is 1200 seconds (20 minutes), average interval is 4. Please ensure that the MicroCAT internal clock is set properly (UTC) and all devices start collecting data at the same time having every third sample at a full hour.

6.2 How to perform a useful calibration cast

To obtain CTD and MicroCAT data that can be used to calibrate the MicroCAT data a number of data aquisistion steps and configurations are needed.

CTD setup

At least the following parameters need to be recorded:

1. Time (best is julian days; time of sample is okay as well)
2. Pressure (dbar)
3. Conductivity (mS/cm)
4. Temperature (°C)
5. Salinity – to identify gradient!

CTD cast

The task is to collect data in a very stable (no gradient) environment for a sufficiently long time (8 minutes). As MicroCAT and CTD sensors are typically 1 m apart from each other they obtain measurements at different depth therefore virtually no gradient in temperature **and** salinity are a prerequisite.

The responce time of the CTD and MicroCAT sensors is different (MicroCAT longer) therefore at least 8 minutes of stop time are needed.

Please note: A calibration cast that does not meet these two basic prerequisites (no gradient, 8 minutes stop time) can not be used for calibartion!

MicroCAT setup for calibration

Before mounting the MicroCAT 's on the rosette the following setup has to be done

1. Set sampling interval as short as possible (typically 10 sec.)
2. Do a time check of the internal MicroCAT clock (UTC) and adjust if necessary.
3. Set reference pressure to 0.0 dbar (for instruments without pressure sensor)

MicroCAT handling after the cast

Download the cast data.

Please note: Before final deployment change the sampling interval back to 1200 sec and set the reference pressure (for those instruments without a pressure sensor) to the respective pressure (depth) as outlined in the mooring plan.

6.3 ADCP configuration

A standard configuration for the upward looking workhorse ADCP at the ANIMATE sites moored at about 150m water depth is given below. The temporal resolution (0.5 hours) allows to analyze the tidal signals, the vertical resolution extends far out of the water column to allow for recording when the device is lowered through mooring subduction as well as using the beam intensity to derive the instrument depth (and maybe surface roughness estimates). Note: always ensure correct setting of internal clock (UTC)!

Standard configuration for upward looking workhorse ADCP (300kHz) at the ANIMATE sites (depth 150m). Note: Instrument starts pinging immediately! use the TG command for setting a definite start time (not TF).

CR1	Reset WH to factory settings
CF11101	Flow control: all, except send data to serial port
ED1500	Deployment depth
ES35	Set water salinity (could be modified)
EX11111	Coordinate transformation (default)
EZ1111111	Source of environmental sensor data
WB1	Bandwidth mode 1: high profiling range
WD111100000	Data collected in memory
WF176	Blank after transmit (1.76m)
WN30	Number of depth cells (30)
WP30	Pings per ensemble (average of 30 pings)
WS800	Depth cell size (8 m)
WV170	Ambiguity velocity (1,75 cm/s)
TE00:30:00.00	Time per ensemble (30 minutes)
TP01:00.00	Time between pings (1 minute)
CK	Keep parameters
CS	Start pinging

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A MicroCAT MatLab data format

The processed MicroCAT data was written into MatLab structure and saved in MatLab *.mat format. Two files are generated: one contains all (processed and raw) data used to create the processed data file named *site* (cis, pap, estoc) *deployment period* (1, 2, 3, ..) *_mc_all*. The other file contains only the processed data *site* (cis, pap, estoc) *deployment period* (1, 2, 3, ..) *_mc_work*.

For example the third deployment period of PAP is stored in the two files: *pap3_mc_all.mat* and *pap3_mc_work.mat*. Loading the first file (*pap3_mc_all.mat*) into the MatLab workspace gives a structured variable pap3. The variable pap3 contains five structures which address the two moorings maintained during the third deployment period at PAP.

moor:	[1x2 struct]	details (position etc.) of the two moorings
mc:	[1x2 struct]	details on MicroCAT (serial #, nominal depth (planned), for each mooring
proc:	[1x1 struct]	processed data all in one
calib:	[1x2 struct]	details on calibration (bias for P, T, C) for each mooring
raw_data:	[1x7 struct]	The raw data converted to physical units

The pap3.moor structure contains the following two structured arrays:

name	Name of the two moorings
deploy_nr	Deployment number of the two moorings (in this case 3)
moor_nr	Number of the mooring at the deployment site (in this case 1 and 2)
lat	latitude positions of the two moorings
long	longitude positions of the two moorings

The pap3.mc structure contains the following two structured arrays:

serial	Serial number of instruments
type	Type of instrument used (e.g. SBE 37-IM, SBE 37-SM, Mini T, ..)
nominal_depth	Nominal depth (m) of instruments as in the mooring plan
interp_sampling_dt	Sampling interval the data is interpolated
moor_estimated_p_offset	Estimated 'topographic bias' of the mooring

The pap3.proc structure contains the calibrated data merged for the two sites and interpolated to every full hour. Data from the individual sites can be extracted using the pap3.proc.moor_nr variable.

press:	[11x5182 double]	processed pressure (dbar)
sal:	[11x5182 double]	processed salinity (PSS-78)
temp:	[11x5182 double]	processed in-situ temperature (IPTS-68) (°C)

cond:	[11x5182 double] corrected conductivity (mS/cm)	
pdens:	[11x5182 double] density anomaly (kg m^{-3})	
ptemp:	[11x5182 double] potential temperature (°C)	
serial:	[2800 2812 .....] instruments serial number	
moor_nr:	[2 2 2 1 2 2 2 ...] Mooring number	
mtime:	[1x5182 double] MatLab day number (1 corresponds to 1-Jan-0000)	
processing_date:	'24-Nov-2004'	Date file was cerated
processing_institute:	'IFM-GEOMAR, ...'	Responsible/contact for data processing

The pap3.calib structure contains the following arrays on calibration of the sensors (sorted by serial numbers):

cond_off_serial	Serial number: bias correction conductivity
cond_off_begin	Conductivity bias at beginning (see pap3.calib.start)
cond_off_end	Conductivity bias at end (see pap3.calib.stop)
temp_off_serial	Serial number: bias correction temperature
temp_off_begin	Temperature bias beginning
temp_off_end	Temperature bias end
press_off_serial	Serial number: bias correction pressure
press_off_begin	Pressure bias beginning
press_off_end	Pressure bias end
start	time at which bias correction starts
stop	time at which bias correction ends

The pap3.raw_data structure contains the following structured arrays:

temp	Raw temperature data for each instrument
press	Raw pressure data for each instrument
cond	Raw conductivity data for each instrument
mtime	Raw day number (day 1 is 1-Jan-0000)
press_ref	Reference pressure of instrument if no pressure sensor (else NaN)

The second file (*pap3_mc_work.mat*) is just a 'lighter' version of the first with the calibration details (pap3.calib) and the raw data (pap3.raw_data) removed.

B ADCP MatLab data format

The processed data was written into MatLab structure and saved in MatLab *.mat format. Loading the file result in a structured variable (adcp) in the workspace (Note, loading multiple files will override the structure, rename). The structured variable contains:

name:	Mooring site and deployment
config:	Structure with configuration of ADCP (see below)
mtime:	day number (day 1 is 1-Jan-0000)
pitch:	ADCP pitch sensor readings
roll:	ADCP roll sensor readings
heading:	ADCP heading readings
temperature:	ADCP temperature sensor readings
salinity:	'not available' - no sensor was on ADCP
east_vel:	Eastward velocity (m/sec) (per depth cell and time)
north_vel:	Northward velocity (m/sec) (per depth cell and time)
vert_vel:	Vertical velocity (m/sec) (per depth cell and time)
error_vel:	Error velocity (m/sec) (per depth cell and time)
intens:	Intensity (per beam, depth cell and time)
processing_name: '	Name of institute and contact for processing
processing_date:	Date of processing file
device_nr:	ADCP device serial number
depth_mc:	Depth cell depth (m) derived from neighboring MicroCAT
depth_mc_source:	Distance ADCP and MicroCAT used for depth estimate
depth_intensity:	Depth cell depth (m) derived from ADCP intensity
depth_intensity_diff_mean:	Mean difference (m) between single beams depth estimate
depth_intensity_diff_std:	Standard dev. between single beams depth estimate
surface_intensity:	ADCP intensity at the surface
lat:	Nominal latitude of ADCP
long:	Nominal longitude of ADCP
adcp_nominal_depth:	Nominal depth (mooring plan) of ADCP
magnetic_declination:	Local magnetic declination used for calculations

The structure *adcp.config* contains a number of technical settings of the instrument during its operation:

name:	Type of instrument (workhorse WH, broadband BB)
beam_angle:	Beam angle (e.g. 20°)
beam_freq:	Frequency of operation
beam_pattern:	configuration of beams ('convex', concave)
orientation:	Orientation ('up', 'down')
pings_per_ensemble:	Number of pings per ensemble (WP command)

cell_size:	Depth cell size (m) (WS command)
blank:	Blank distance (m) from transducer (WF command)
time_between_ping_groups:	Time per ensemble (TE command)
bin1_dist:	Distance (m) of the first depth from transducer