IDRONAUT S.r.l.

OCEAN SEVEN 304 CTD LOGGER

LOW POWER MICRO CTD SELF-RECORDING CAPABILITY

The Ocean Seven 304 CTD offers combinations of 16-bit high-resolution data accuracy with long term sensor stability, making this CTD an ideal choice for self-recording profiling and moored applications. The CTD uses state-of-the-art electronics and it is equipped with up to 64Mbytes logging memory. The present report demonstrates the OCEAN SEVEN 304 measurement performances comparing them against a SBE-91 CTD.

Report on performance at sea — June-2004

Foreword

An IDRONAUT OCEAN SEVEN 304 was tested in the Western North Atlantic in April 2004. It was mounted on a CTD and Rosette frame with the OCEAN SEVEN 304 sensors at the height of the SBE 911 C/T sensors. The OCEAN SEVEN 304 was set up to log P, T, and C versus time internally at approximately 8 samples per second with no averaging applied to the data.

A single profile was collected to a depth of approximately 3500 meters with 22 water samples collected on the up cast. This report compares the OCEAN SEVEN 304 with a Seabird 911 CTD and water sample salinities.

Pictured in figure 1 is the mounting arrangement of the OCEAN SEVEN 304 with the SBE 911 C/T sensors at the same height as the OCEAN SEVEN 304 temperature and conductivity sensors. Data from both the down and up profiles of the Seabird 911 have appropriate sensor lags applied and are processed to a uniform pressure series at 2 decibar intervals. The Seabird 911 CTD data files have a file name of OC401010 (station 10) while the OCEAN SEVEN 304 file name is I304_st10.txt. The OCEAN SEVEN 304 data is processed as indicated on the plots.

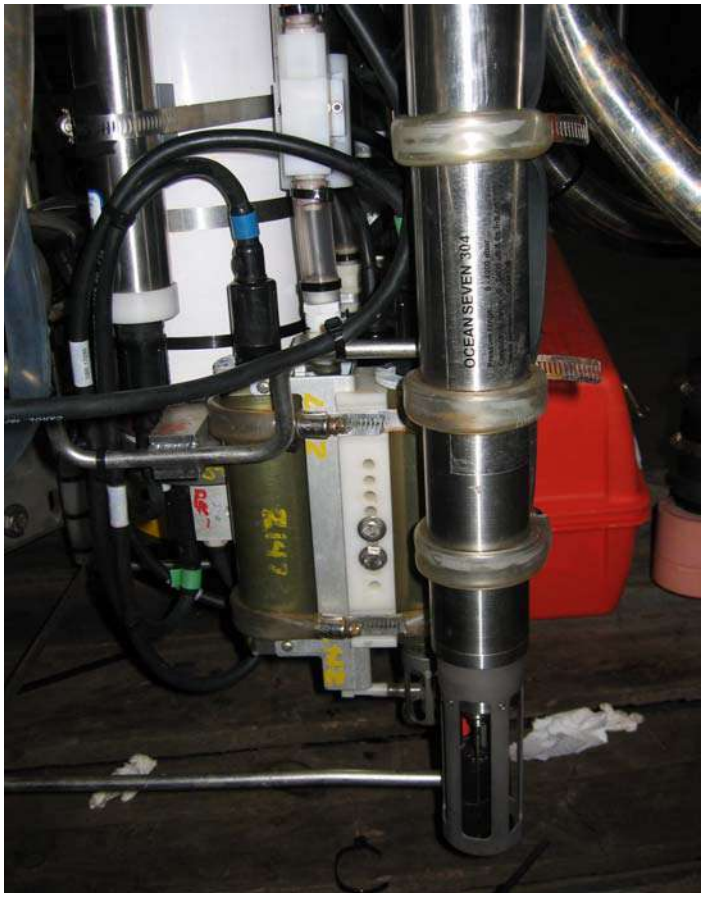

Figure 1 - OCEAN SEVEN 304 in CTD frame with SBE 911 C/T sensors

Data comparison

The up cast OCEAN SEVEN 304 bottle locations were found using a lowering rate (dp/dt) criteria applied to the OCEAN SEVEN 304 pressure sensor data. The pressure data was filtered with a cut-off of approximately 20 second before differencing to create lowering rate. The rosette bottle closing occurs at the end of a bottle stop. The OCEAN SEVEN 304 bottle stop observations shown in Tables II & I are an average of the 45

observations immediately before the completion of a bottle stop ends. The bottle stops locations are indicated by black "*" in the upper panel of figure 2.

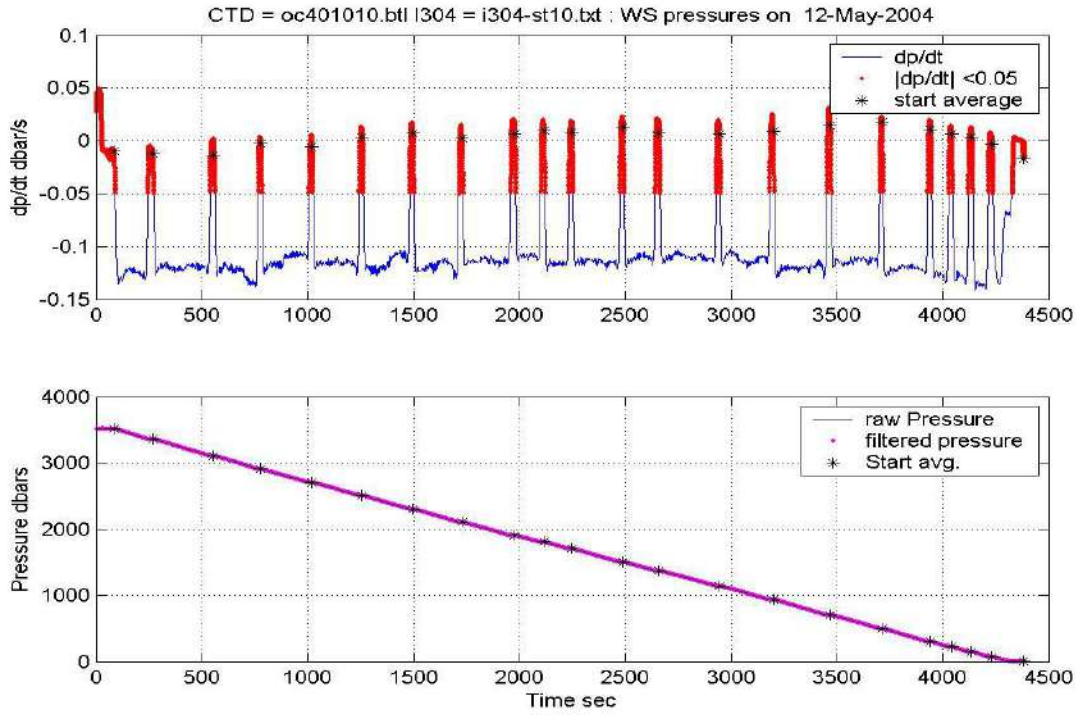

Figure 2 lowering rate (dp/dt) for upcast with (*) indicating assumed bottle stop positions in OCEAN SEVEN 304

Table I

OCEAN SEVEN 304 data are an average of 45 observations of the bottle stop pressure, temperature, conductivity and salinity as located on figure 2 merged together with corresponding Seabird 911 bottle stop average pressure, primary temperature (T1) and salinity data plus water sample salinities collected from 10 liter rosette sampler water sample bottles. The difference of the secondary (T2) and primary temperature and the water sample salinity complete Table I. The OCEAN SEVEN 304 salinity in Table I is calculated from uncorrected OCEAN SEVEN 304 pressure (P), temperature (T), and conductivity (C) as shown in Table I using the 1978 Practical Salinity Scale (PSS-78). CTD salinities (S) from both instruments are calculated using PSS-1978 :

S = sw_salt(C/42.914,t90tot68(T),P)

Where function t90tot68 converts temperatures on ITS-90 back to IPTS-68 (see Matlab function in Appendix).

TABLE I Uncorrected OCEAN SEVEN 304 measurements

%	OCEAN SEVEN 304 uncorrected					SBE 911 Shipboard CTD				
% Scan #	Pres.	Temp.	Cond.	Salt	Theta	Pres.	Tmp.	Saltsbe	T1-T2	SaltWS*
% Numb.	DBAR	ITS-90	mS/cm	PSS	Deg C	Dbar	Deg.C	psu		psu*
% *******	*******	*******	*******			******	*******	*******		***** *
697	3518.1	2.1877	32.3221	34.9166	1.9010	3508.6	2.1872	34.8930	-0.0005	34.8908
2159	3362.0	2.2254	32.3013	34.9199	1.9543	3351.9	2.2247	34.8960	0.0011	34.8943
4471	3109.0	2.3010	32.2799	34.9263	2.0543	3098.3	2.3023	34.9008	-0.0002	34.8997
6253	2907.1	2.5110	32.3965	34.9355	2.2802	2897.8	2.5108	34.9115	-0.0003	34.9091
8182	2708.9	2.6637	32.4622	34.9433	2.4495	2700.0	2.6633	34.9186	-0.0007	34.9166
10079	2508.8	2.8874	32.5905	34.9528	2.6886	2500.3	2.8857	34.9277	0.0001	34.9268
11985	2308.3	3.1218	32.7262	34.9608	2.9383	2301.1	3.1207	34.9355	-0.0001	34.9347
13848	2109.0	3.2869	32.7962	34.9640	3.1197	2102.4	3.2853	34.9380	-0.0003	34.9366
15841	1907.7	3.4021	32.8156	34.9617	3.2521	1900.3	3.4032	34.9348	-0.0003	34.9317
16950	1807.5	3.4512	32.8168	34.9596	3.3098	1800.9	3.4514	34.9320	-0.0002	34.9299
18001	1706.3	3.5185	32.8381	34.9632	3.3854	1700.4	3.5179	34.9336	-0.0002	34.9309
19930	1505.3	3.7449	32.9728	34.9822	3.6270	1499.7	3.7468	34.9522	0.0000	34.9502
21298	1377.1	3.8677	33.0349	34.9894	3.7599	1371.0	3.8702	34.9598	0.0000	34.9577
23573	1145.9	4.0503	33.1053	34.9953	3.9610	1141.2	4.0504	34.9633	-0.0002	34.9614
25611	940.0	4.4786	33.4316	35.0305	4.4036	937.9	4.4780	34.9985	-0.0002	34.9967
27772	707.8	4.8903	33.7036	35.0326	4.8328	705.1	4.8877	34.9998	-0.0002	34.9974
29727	503.7	6.3098	34.9436	35.0739	6.2641	501.4	6.3160	35.0411	-0.0009	35.0411
31561	301.6	9.8096	38.2894	35.2505	9.7747	300.4	9.8223	35.2175	0.0019	35.2182
32351	224.0	11.5347	40.1429	35.4838	11.5061	223.4	11.5443	35.4523	0.0016	35.4466
33115	150.3	11.1913	39.5928	35.3004	11.1725	149.6	11.1871	35.2655	-0.0041	35.2698
33880	73.9	16.8604	46.2679	36.2960	16.8482	73.4	16.8355	36.2520	0.0106	36.2596
35080	2.3	21.0714	50.4429	36.1511	21.0710	2.8	21.0717	36.1180	0.0031	36.1207

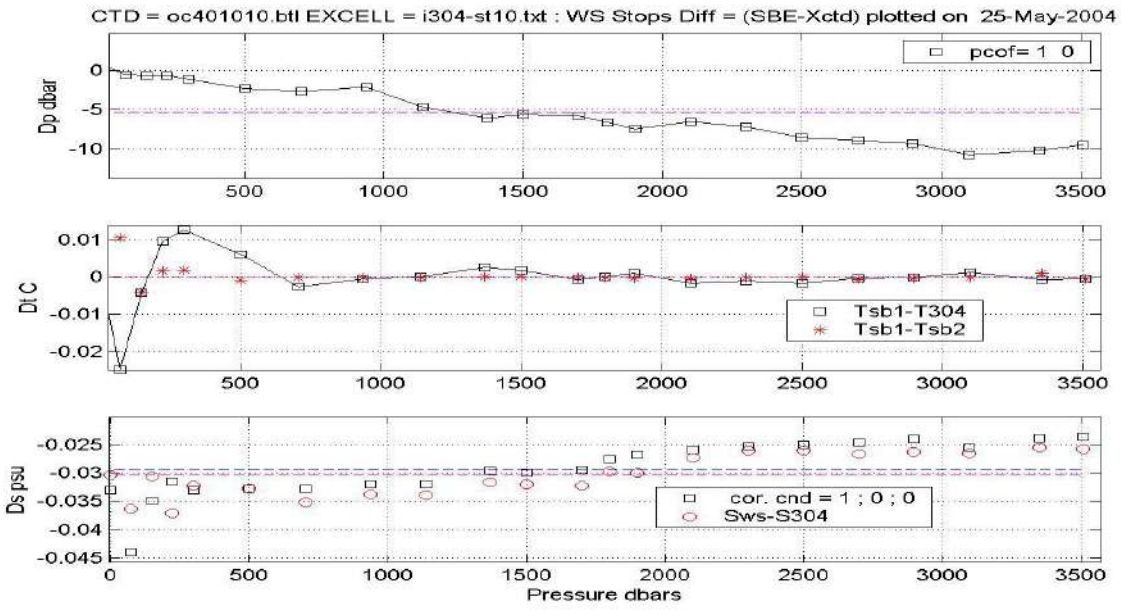

Figure 3 Difference (SBE - OCEAN SEVEN 304 uncorrected) pressure, temperature, and salinity plotted versus pressure.

The field temperature data of the OCEAN SEVEN 304 compares very well with both SBE 911 CTD temperatures. Only those temperature differences in higher temperature gradient regions (i.e. Shallower than 500 decibars) do not match within a millidegree. The Idronaut pressure sensor calibration reads increasingly deeper than the SBE 911 pressure. A least squares linear fit between the OCEAN SEVEN 304 and SBE 911 pressure values gives the following slope and bias coefficients; pcof =[0.99693925453714 -0.45584242461625] which are applied to the OCEAN SEVEN 304 pressure data in Table II. The OCEAN SEVEN 304 conductivity is found to read higher than the SBE 911 and is corrected to the SBE conductivity using a conductivity slope adjust factor cslop=0.99915. There is also a vertical dependence seen in bottom panel (Ds) of figure 3 that requires the following quartz glass conductivity cell geometry corrections of;

	beta	=	3.0e-8;
	alpha	=	-5.5e-7
to remove:	C	=	C*(1+alpha.*(t-T0)+beta.*(p-P0))

A room temperature laboratory OCEAN SEVEN 304 conductivity check prior to the cruise indicated that the OCEAN SEVEN 304 conductivity read higher than the bath salinity and required a conductivity slope=0.99947 adjustment to match as compared to the field adjustment of 0.99915.

TABLE II with Corrected OCEAN SEVEN 304 P & C

%	OCEAN SEVEN 304 Corrected					Shipboard CTD				
% Scan #	Pres.	Temp.	Cond.	Salt	Theta	Pres.	Tmp.	Saltsbe	T1-T2	Salt WS*
% Numb.	DBAR	Deg. C	mS/cm	PSS	Deg C	Dbar	Deg.C	psu		psu *
%		ITS-90					ITS-90			
% *******	*******	*******	*******			******	*******	*******		*******
697	3506.8	2.1877	32.3259	34.8880	1.9012	3508.6	2.1872	34.8930	-0.0005	34.8908
2159	3351.3	2.2254	32.3049	34.8911	1.9545	3351.9	2.2247	34.8960	0.0011	34.8943
4471	3099.0	2.3010	32.2832	34.8972	2.0545	3098.3	2.3023	34.9008	-0.0002	34.8997
6253	2897.7	2.5110	32.3997	34.9061	2.2803	2897.8	2.5108	34.9115	-0.0003	34.9091
8182	2700.2	2.6637	32.4652	34.9137	2.4496	2700.0	2.6633	34.9186	-0.0007	34.9166
10079	2500.7	2.8874	32.5933	34.9230	2.6887	2500.3	2.8857	34.9277	0.0001	34.9268
11985	2300.7	3.1218	32.7288	34.9307	2.9384	2301.1	3.1207	34.9355	-0.0001	34.9347
13848	2102.0	3.2869	32.7986	34.9337	3.1198	2102.4	3.2853	34.9380	-0.0003	34.9366
15841	1901.4	3.4021	32.8178	34.9312	3.2522	1900.3	3.4032	34.9348	-0.0003	34.9317
16950	1801.5	3.4512	32.8189	34.9290	3.3099	1800.9	3.4514	34.9320	-0.0002	34.9299
18001	1700.6	3.5185	32.8401	34.9324	3.3854	1700.4	3.5179	34.9336	-0.0002	34.9309
19930	1500.2	3.7449	32.9746	34.9512	3.6271	1499.7	3.7468	34.9522	0.0000	34.9502
21298	1372.4	3.8677	33.0366	34.9583	3.7600	1371.0	3.8702	34.9598	0.0000	34.9577
23573	1142.0	4.0503	33.1068	34.9639	3.9610	1141.2	4.0504	34.9633	-0.0002	34.9614
25611	936.7	4.4786	33.4328	34.9989	4.4036	937.9	4.4780	34.9985	-0.0002	34.9967
27772	705.2	4.8903	33.7046	35.0007	4.8328	705.1	4.8877	34.9998	-0.0002	34.9974
29727	501.7	6.3098	34.9444	35.0416	6.2642	501.4	6.3160	35.0411	-0.0009	35.0411
31561	300.2	9.8096	38.2900	35.2177	9.7748	300.4	9.8223	35.2175	0.0019	35.2182
32351	222.9	11.5347	40.1434	35.4506	11.5061	223.4	11.5443	35.4523	0.0016	35.4466
33115	149.4	11.1913	39.5932	35.2673	11.1725	149.6	11.1871	35.2655	-0.0041	35.2698
33880	73.2	16.8604	46.2682	36.2616	16.8482	73.4	16.8355	36.2520	0.0106	36.2596
35080	1.8	21.0714	50.4429	36.1166	21.0710	2.8	21.0717	36.1180	0.0031	36.1207

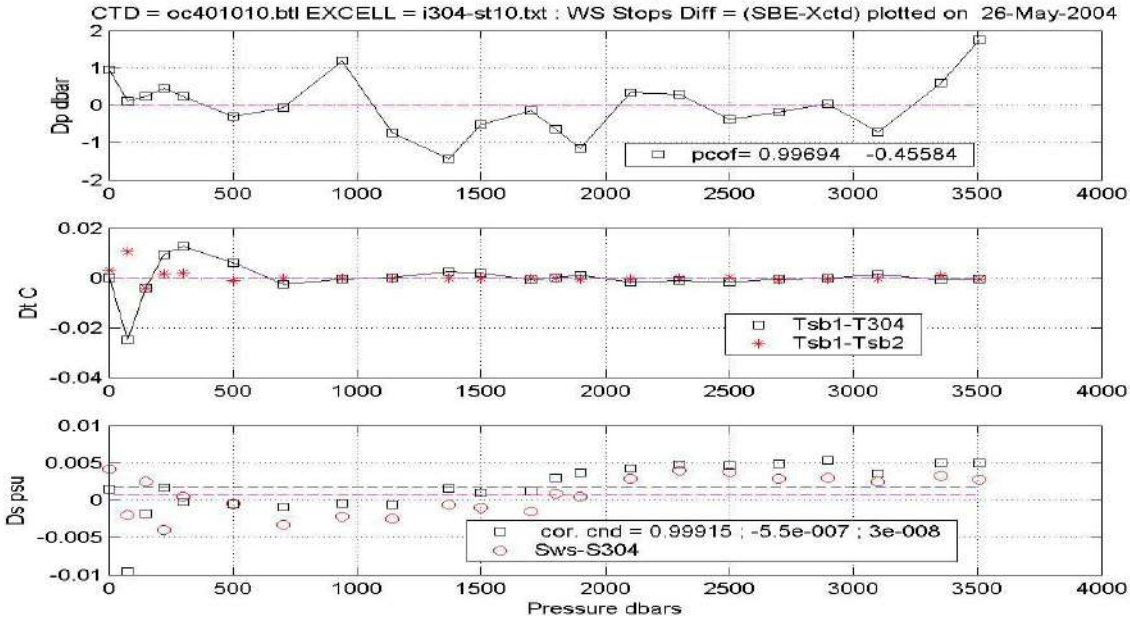

Figure 4: Difference (SBE - OCEAN SEVEN 304 corrected) pressure, temperature, salinity (red o are from bottle salinities) versus pressure and red * temperatures are SBE (T1-T2).

The raw deep-water OCEAN SEVEN 304 measurements at 8 hertz are displayed in figure 5 and show a peak-to-peak salinity variation of 0.02 psu. Figure 6 shows histograms of the raw OCEAN SEVEN 304 measurements. Note the standard deviation of conductivity (0.0026 mS/cm) and salinity (0.0033 psu) and contrast these values with histograms of the lag corrected value of conductivity (0.0011 mS/cm) and salinity (0.0017 psu) shown in figure 7. The raw OCEAN SEVEN 304 conductivity contributes most of the noise to the salinity measurement (temp. Std. = 0.0009 C). Applying a recursive filter to conductivity with a 2 scan lag (see Appendix for Matlab function recur_fn.m) matches the conductivity to the temperature and reduces both the conductivity and salinity noise as indicated in figure 7.

To provide a fair comparison of the OCEAN SEVEN 304 time series data at 8 hertz to the SBE 911 2-decibar pressure averaged profile data, a roll filtered and 2-decibar pressure averaged OCEAN SEVEN 304 down profile is presented in the deep water plots in figures 5 (black) and figure 9 (red). An estimate of the salinity noise 2-decibar salinity noise is made for deepest 100 decibars by calculating the standard deviation (Std.) after removing a salinity trend.

Idronaut 304 :	Std. = 0.00060 psu
SBE 911:	Std. = 0.00016 psu

It should be noted that the recorded OCEAN SEVEN 304 data resolution for cond. & temp. are 0.001 C & mS/cm while the SBE 911 has a data resolution an order of magnitude greater (i.e. 0.0001).

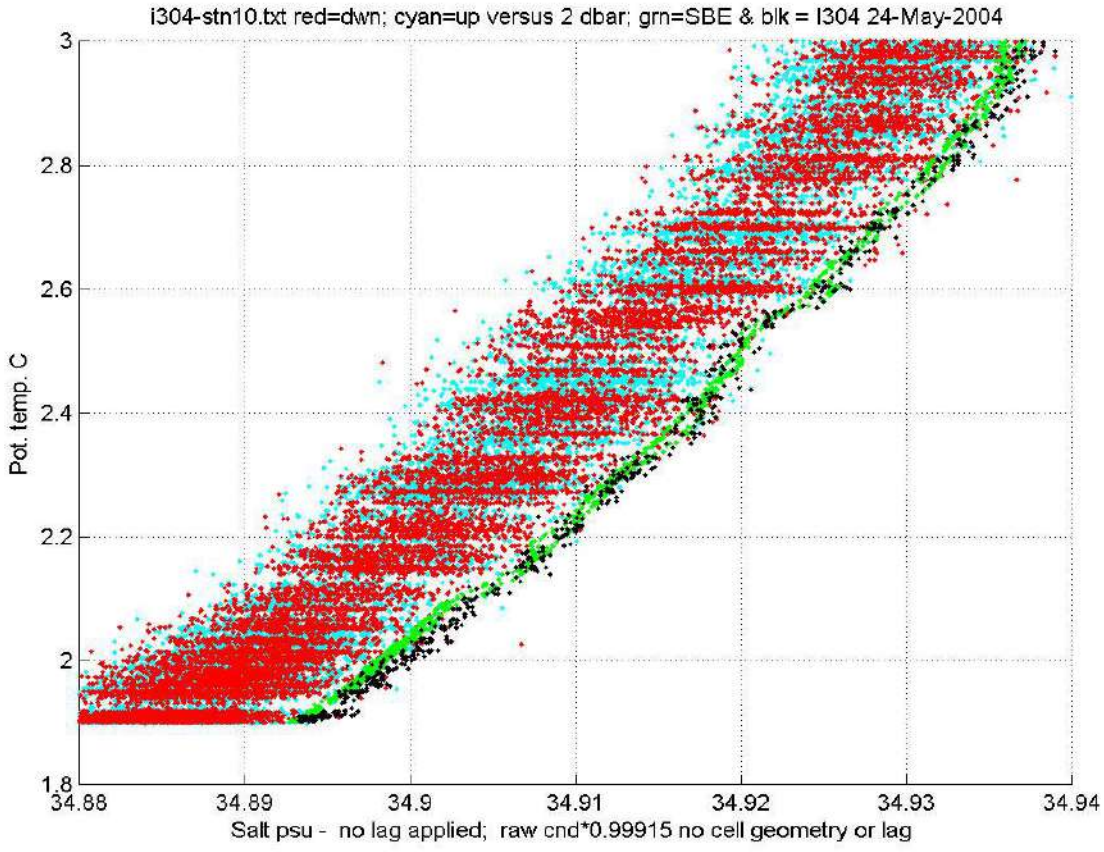

Figure 5; Red & cyan are unlagged OCEAN SEVEN 304 salinity while black (OCEAN SEVEN 304) & green (SBE911) 2-dbar pressure average with sensor lags applied.

TABLE III - Salinity comparison

% Scan Numb.	# OS304 PSS	SBE psu	SaltWS psu	WS-SBE psu	WS-OS304* psu *
697	34.8880	34.8930	34.8908	-0.0022	0.0028
2159	34.8911	34.8960	34.8943	-0.0017	0.0032
4471	34.8972	34.9008	34.8997	-0.0011	0.0025
6253	34.9061	34.9115	34.9091	-0.0020	0.0029
8182	34.9137	34.9186	34.9166	-0.0020	0.0029
10079	34.9230	34.9277	34.9268	-0.0009	0.0038
11985	34.9307	34.9355	34.9347	-0.0008	0.0040
13848	34.9337	34.9380	34.9366	-0.0014	0.0029
15841	34.9312	34.9348	34.9317	-0.0031	0.0005
16950	34.9290	34.9320	34.9299	-0.0021	0.0009
18001	34.9324	34.9336	34.9309	-0.0027	-0.0015
19930	34.9512	34.9522	34.9502	-0.0020	-0.0010
21298	34.9583	34.9598	34.9577	-0.0021	-0.0006
23573	34.9639	34.9633	34.9614	-0.0019	-0.0025
25611	34.9989	34.9985	34.9967	-0.0018	-0.0022
27772	35.0007	34.9998	34.9974	-0.0024	-0.0033
29727	35.0416	35.0411	35.0411	0.0000	-0.0005
31561	35.2177	35.2175	35.2182	0.0007	0.0005
32351	35.4506	35.4523	35.4466	-0.0057	0.0015
33115	35.2673	35.2655	35.2698	0.0043	0.0025
33880	36.2616	36.2520	36.2596	0.0076	-0.0020
35080	36.1166	36.1180	36.1207	0.0027	0.0041

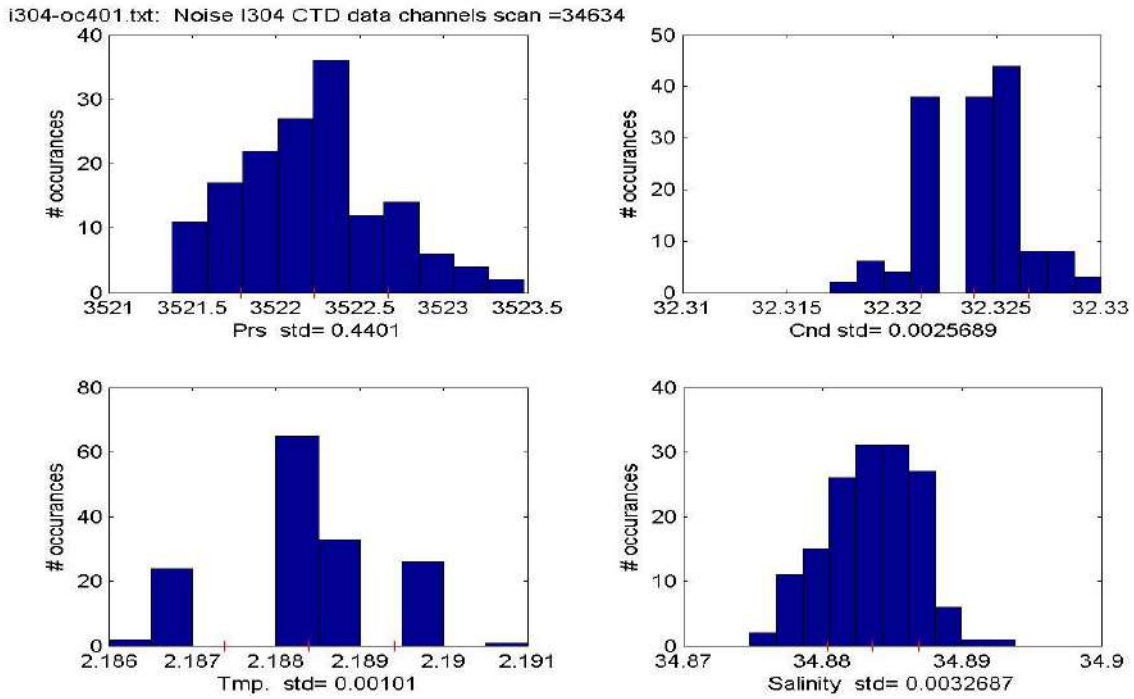

Figure 6: Raw data unlagged: note cond. & salinity noise levels are higher than figure 7 applying recursive filter to conductivity

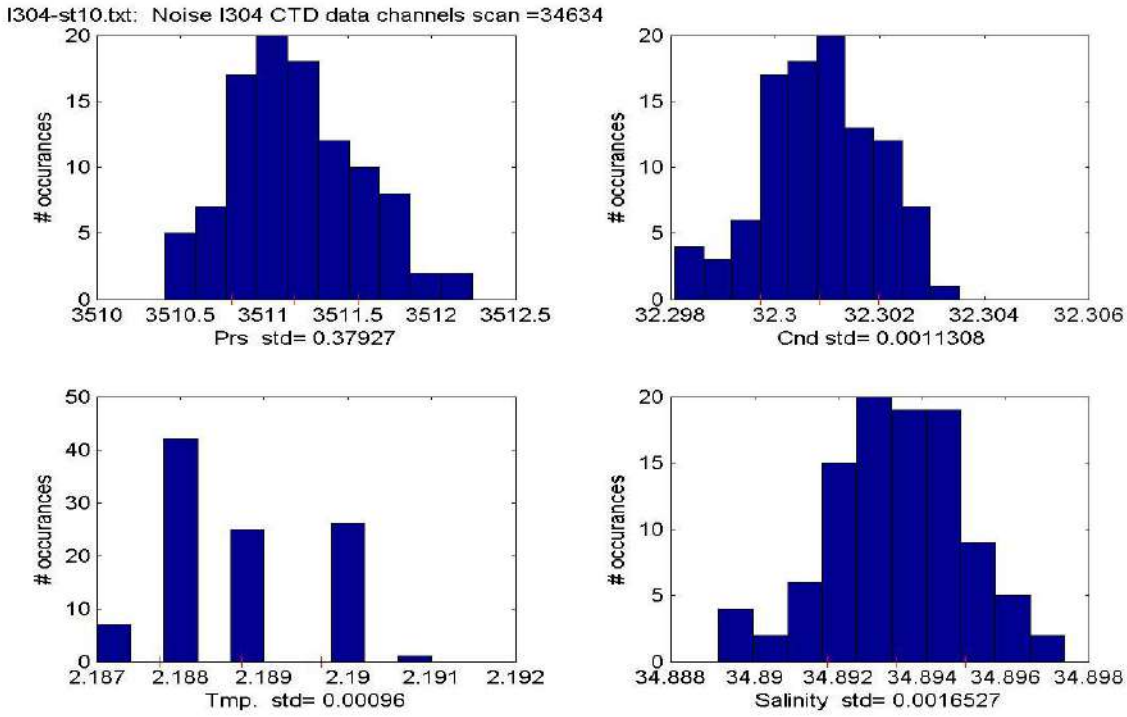

Figure 7: Deep observations with cond. recursively lagged 2 scans: note noise of cond. & salinity reduced to half of unlagged (see figure 6).

The full down and up profiles of the OCEAN SEVEN 304 and SBE 911 salinity and temperature are plotted versus pressure in figure 8. A temperature lag of 0.25 seconds (Tlag=2 scans) was applied to conductivity using a recursive filter (i.e. c=recur_fn(cr,Tlag see appendix). A detailed down profile of time-series and 2-decibar pressure averaged temperature and salinity for the deepest 200 decibars is shown in figure 9.

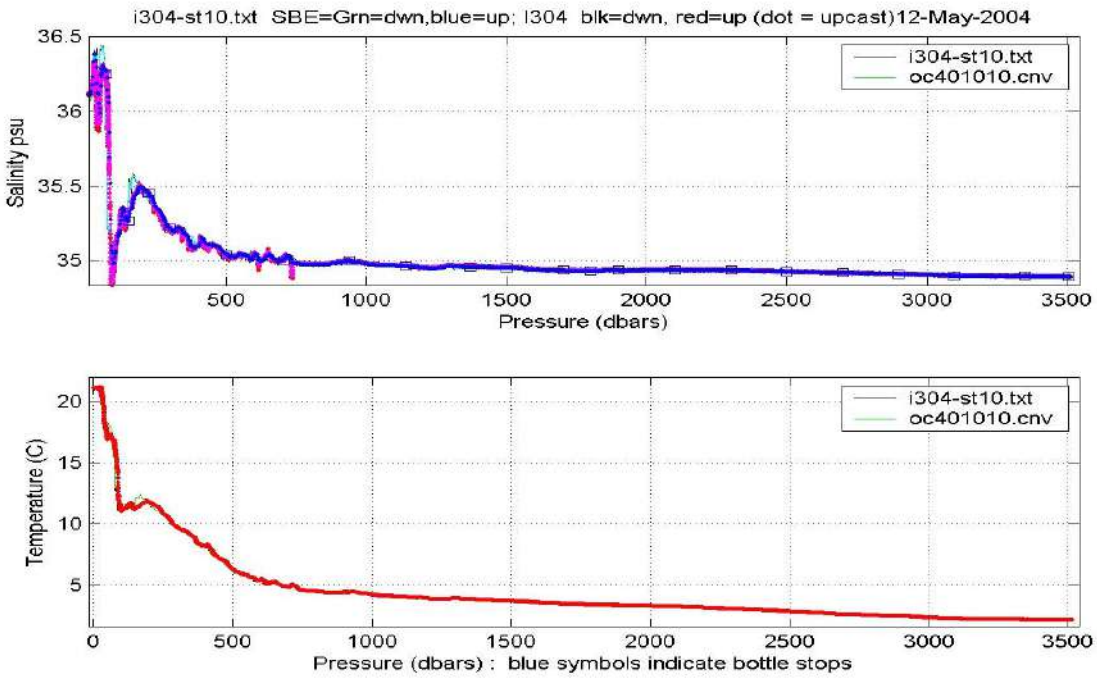

Figure 8 Corrected OCEAN SEVEN 304 & SBE 911salinity and temperature versus pressure.

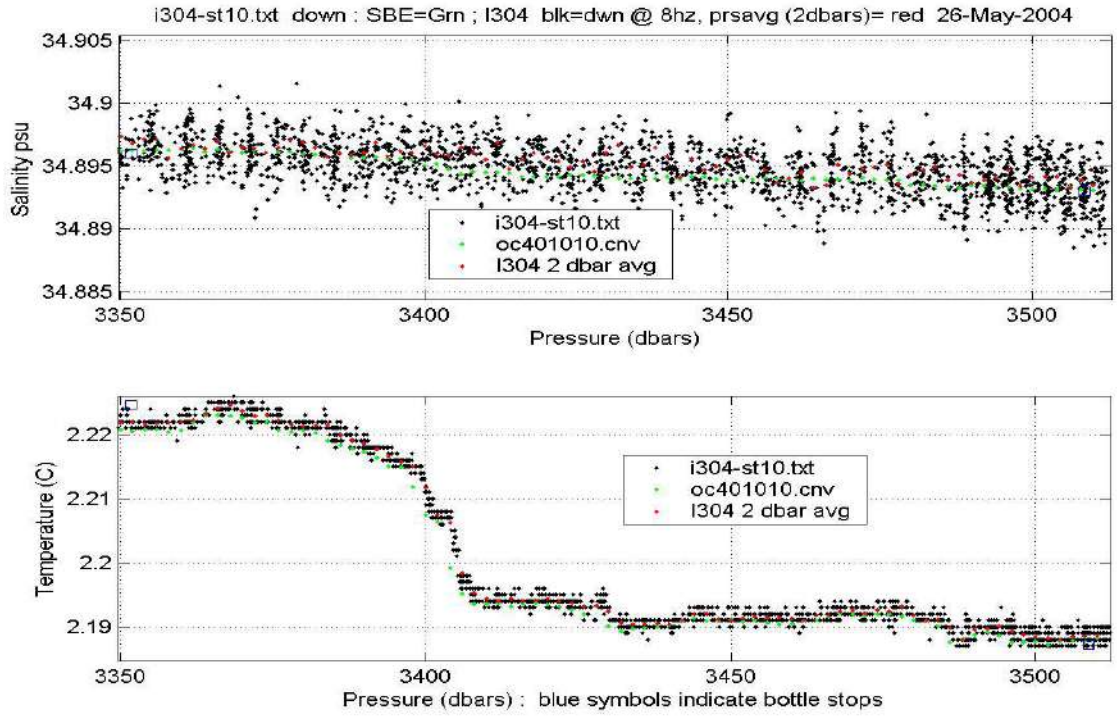

Figure 9: Expanded plot of T & S versus P for OCEAN SEVEN 304 and SBE 911 in deep water.

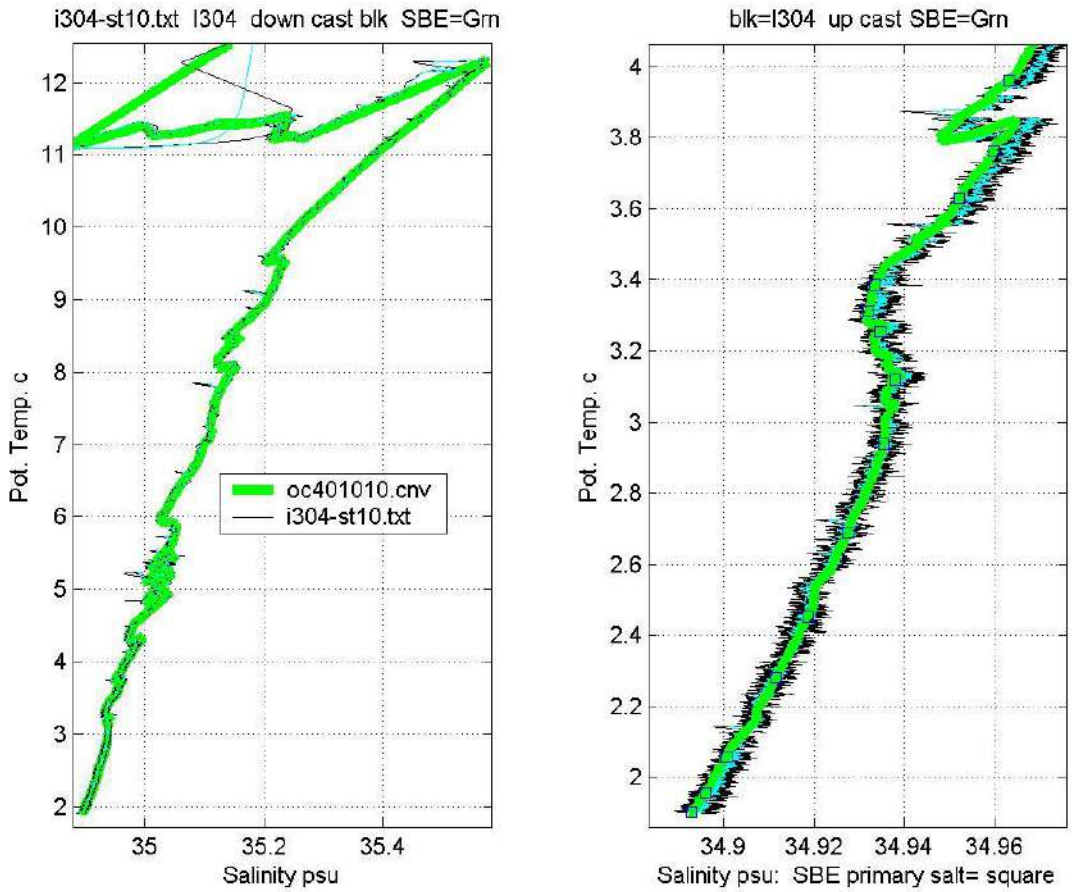

Figure 10: Pot. Temp. versus Salinity Deeper waters; down (left); up (right)

The close match of salinity between the OCEAN SEVEN 304 and SBE 911 is demonstrated for both down and up profiles, for the entire profile and for a detailed section of the deepest portion of the water column shown in figures 10 a & b. Both CTD instruments have sensor lag corrections and pressure averaging applied to the data. The OCEAN SEVEN 304 also has a conductivity slope of 0.99915 and Quartz glass cell geometry corrections applied

Summary

A comparison was made of the IDRONAUT OCEAN SEVEN 304 and a Seabird 911 CTD over depths from the surface to 3500 decibars in the Western North Atlantic. The temperature compares extremely well in all regions of the profile except where strong temperature gradients preclude valid data checks. The average temperature difference is nearly zero (i.e. Average DT= Tsbe1 – Ti304= -0.00015 C). The OCEAN SEVEN 304 pressure sensor appears to have a systematic pressure calibration error making the deep observations read high by roughly 0.3 percent compared to the SBE 911. The OCEAN SEVEN 304 conductivity measure high compared to the bottle salinity measurements and is corrected by adjusting the conductivity slope down to 0.99915. The conductivity sensor has a Quartz cell. Cell geometry corrections for dimensional changes with pressure (bulk modulus = 5.3E+6 psi) and temperature (5.5E-7 cm/cm/C) obtained from the CRC Handbook improved the conductivity measurements. Applying a recursive filter to lag conductivity before computing salinity improves the noise of both by a factor of 2.5. The conversion of the OCEAN SEVEN 304 data to a lagged, roll-filtered and pressure averaged data set at 2 decibar intervals further improves the OCEAN SEVEN 304 noise.

Appendix

Matlab processing algorithms:

```
function [c1]=recur_f_2(c,w)
%function [c1]=recur_f_2(c,w)
% recur_f_2 (x,W)
% x is input data
% exp. filter to lag cond. to match temp.
% W is lag in scans;
% W = 1/(1+1/W)
%  y=y(j-1)*W+x(j)*(1-W)
% jmt Feb 1999
%
w1=1/(1+1/w);
a(1)=1;
a(2)=-w1;
b(1)=(1-w1);
cb=c(1);
c1=filter(b,a,(c-cb));
c1=c1+cb;
return


function t68 = t90tot68(t90)
%function t68 = t90tot68(t90)
%
%-------------------------------------------------------------------------------
% Converts temperature from ITPS-90 to ITS-68
%
%     Input:
%            t90  -  Temperature  [ PTS-90]
%
%     Output:
%            t68  -  Temperature  [IPTS-68]
%
%     References:
%
%     Checkvalue:  T90toT68(100) = 100.024
%
%-------------------------------------------------------------------------

%  S. Chiswell 1991

t68 = t90/0.99976;
```