August 29, 2013

WHOTS-6 Thermosalinograph Processing Report

File location: /home/aukai1/ac/28/thermosal/whots6_thsl_report.doc

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Summary

Near-surface temperature and salinity data for WHOTS-6 (July 9th – July 17th, 2009) were acquired through the use of a thermosalinograph system aboard *R/V Kilo Moana* (KM). The system was comprised of a remote SBE 45 temperature sensor (S/N 0169) located at the seawater intake situated eight meters below the sea surface in conjunction with a SBE-21 thermosalinograph sensor (S/N 3292) situated in the IMET lab close to the port bow of the ship.

Data were acquired every one second and bottle samples were taken approximately every eight hours for the entire cruise to calibrate the thermosalinograph data. After calibration the mean salinity difference and standard error (standard error = standard deviation / sqrt (sample size)) between the bottle samples and thermosalinograph data was 0.000000 psu ± 0.00014 psu.

Navigation data (latitude, longitude, and ship's speed) were recorded throughout the cruise, once every second, and were merged with the thermosalinograph data stream.

Due to warming from the pump situated ahead of the remote temperature sensor, which has been regularly observed during cruises on the *Kilo Moana,* an offset of -0.2568 °C was applied to the data after comparisons with the CTD data. The data were then flagged and reported as uncalibrated data (flag code "1"). Noise levels in salinity and temperature for WHOTS-6 were 0.0003 psu and 0.0030 °C respectively.

1. Factory sensor calibration

The following factory calibrations were used to convert the data to engineering units.

TEMPERATURE SBE-45: SN 0169 was used to measure temperature at the seawater intake and was last calibrated on December 12th, 2008. Internal temperature was measured with SBE-21 thermosalinograph sensor SN 3292, which was last calibrated on October 30th, 2008.

CONDUCTIVITY SBE-21: Thermosalinograph sensor SN 03292 was used to measure conductivity. The conductivity sensor was most recently calibrated on October 30th, 2008 and this calibration was used to convert the data.

Pressure of 6.0 dbar, to account for the pump pressure, was used to calculate salinity.

2. Processing

2.1 Gross error check

Limits were used to detect gross temperature and conductivity errors. If out of range points were found, linear interpolation was used to replace them.

Temperature lower bound:	18.000
Temperature upper bound:	35.000
Conductivity lower bound:	3.000
Conductivity upper bound:	6.000

Results of the error check:

Points outside of valid T range:	0
Points outside of valid C range:	0

2.2 Timing Errors

The thermosalinograph aboard the R/V *Kilo Moana* was set to record data once every second, but occasionally a record could be written after a longer interval. There were 297 timing errors during WHOTS-6; all errors were associated to a missed sample resulting in a 1 - 2 second gap in the data-set (Table 1).

Table 1: Timing Errors and Results of Running Median Filter for Recent HOT Cruises

Cruise	Ship	Timing Errors	Conductivity points detected with median	Temp (Int) points detected with median	Internal Temperature Sensor	Temp (Ext) points detected with median	External Temperature Sensor
WHOTS-6	KM	297	0	0	3292	3	0169
212	KM	0	0	0	3292	0	0169
211	KOK	814	2	9	2045	34	4073
210	KN	1004	0	4	0122	0	0122
209	KM	99	0	0	3292	0	0396
208	KM	74	0	0	3167	0	0396
206	KM	56	0	0	3167	0	0396
205	KM	78	0	0	3167	0	0396
204	KM	0	0	0	3292	0	0396
203	KM	0	0	2	3292	0	0396

KM: *R/V Kilo Moana* KOK: *R/V Ka'imikai-O-Kanaloa* KN: *R/V Knorr*

2.3 Running median filter

A 5-point running median filter is used to detect temperature and conductivity glitches. If a glitch is detected, both the temperatures and conductivities of this record are immediately replaced by the medians.

Length of median filter:	5.000
Running median T threshold:	0.300
Running median C threshold:	0.100

Results of running median filter (See Table 1 below for results of previous HOT cruises):

Conductivity points detected with median:	0
Temperature (internal) points detected with median:	0
Temperature (external) points detected with median:	3

2.4 Running mean filter

A 3-point triangular running mean filter was used to smooth the temperature and conductivity data after they went through the running median filter.

2.5 Salinity

Salinity was calculated assuming a pressure of 6.0 dbar to account for pressure of the pump.

2.6 Visual Quality Control

After the temperature and conductivity data are processed through the gross error check, median filter, and mean filter, all the temperature (internal and external), conductivity, salinity, speed, and navigation data streams are merged onto one plot for visual assessment. The merged data are visually inspected for spikes in the data that may have passed through the previous filters.

After visually inspecting the data, none of the 651,483 data points had to be flagged for suspicious points (Figure 1).

2.7 Temperature and Salinity Noise

Thermosalinograph noise can be estimated by comparing actual external temperature and salinity data with a calculated running mean. The noise is the standard deviation of these differences. Previous experience suggests that a seventeen-minute running mean provides an ample window of data that does not get influenced by small-scale variability or large-scale frontal type features.

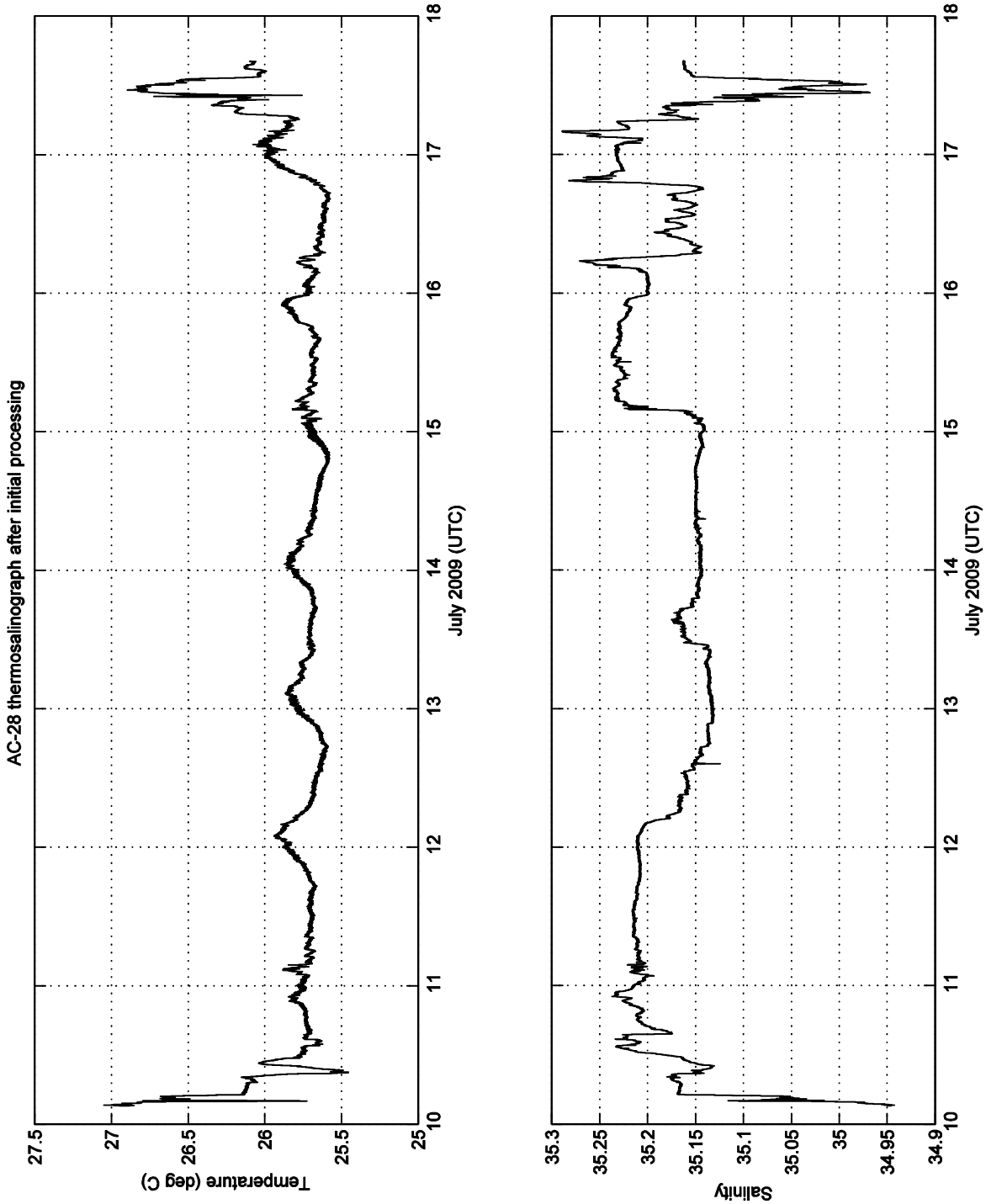


Figure 1: WHOTS-6 Thermosalinograph data after processing and quality control.

Table 2 lists estimates for the noise in the thermosalinograph data (temperature and salinity) during HOT-203 through WHOTS-6. Thermosalinograph noise is estimated by comparing actual external temperature and salinity data with a calculated seventeen minute running mean. The noise is the standard deviation of these differences. Noise levels in salinity data during WHOTS-6 were at 0.0003 psu. Noise levels for the temperature were 0.0030 °C;

Table 2: Thermosalinograph Temperature and Salinity Noise Estimates

Cruise	Ship	Temperature Noise (°C)	Salinity Noise (psu)
WHOTS-6	KM	0.0003	0.0030
212	KM	0.0005	0.0046
211	KOK	0.0151	0.0439
210	KN	0.0022	0.0083
209	KM	0.0012	0.0043
208	KM	0.0008	0.0027
206	KM	0.0008	0.0046
205	KM	0.0008	0.0040
204	KM	0.0011	0.0044
203	KM	0.0007	0.0040

3. CTD Temperature Comparison

3.1 CTD temperature

There were 10 CTD casts conducted during WHOTS-6. The 8 dbar downcast CTD temperature data were used to compare with the thermosalinograph data. One casts (#5) was removed as a conductivity outlier.

3.2 Thermosalinograph

The 8 dbar CTD data are compared directly with the thermosalinograph data recorded three minutes after the CTD "in water" time. The three-minute delay is used because the CTD must equilibrate at ten meters for at least one minute after entering the water. This method of extracting TSG data at the CTD “in water” time will be updated in future processing to make it automated and more accurate.

3.3 Comparison

The mean difference between the CTD and the external temperature sensor was -0.2568°C (Figure 2a). Temperatures recorded by the external temperature sensor were consistently higher than the 8 dbar CTD data. This effect has been seen on previous cruises aboard R/V *Kilo Moana* as seawater entering the port bow intake passes through a pump prior to passing by the external temperature sensor, which apparently warms the water as it passes by.

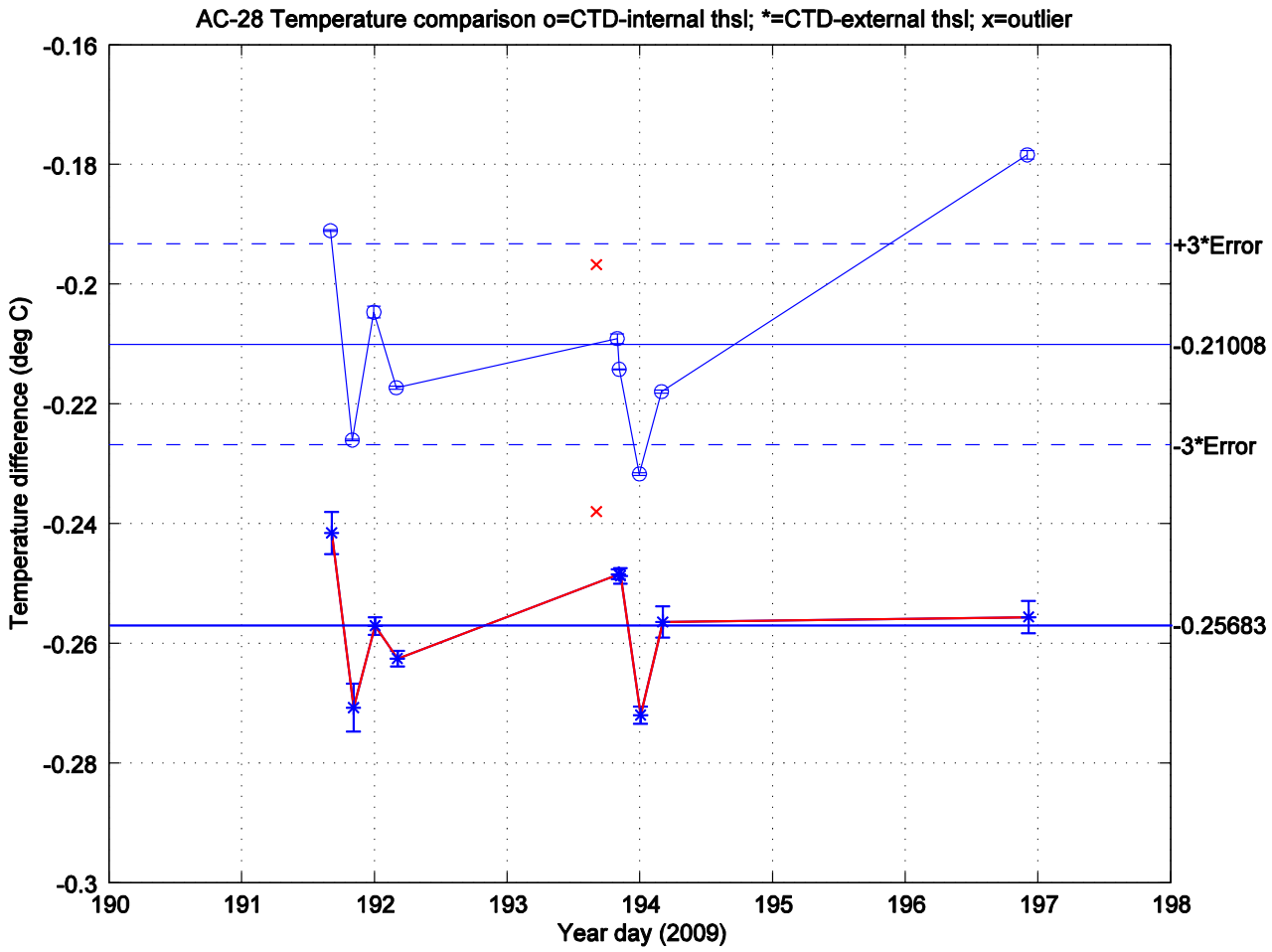


Figure 2a: WHOTS-6 Initial thermosalinograph temperature comparisons.

For comparison purposes, the mean temperature differences between the CTD and the external temperature sensor and the mean temperature differences between the CTD and the internal temperature sensor for HOT-203 through WHOTS-6 are shown in Table 3.

Table 3: CTD-Thermosalinograph Temperature Comparisons

Cruise	Ship	ΔT (°C) CTD-Int	Internal Temp. Sensor #	ΔT (°C) CTD-ext	External Temp. Sensor #
WHOTS-6	KM	-0.2101	3292	0.0000*	0169
212	KM	-0.2179	3292	0.0000*	0169
211	KOK	-0.1194	2045	-0.0627	4073
210	KN	-1.670	0122	0.0000*	0021
209	KM	-0.230	3292	0.0000*	0396
208	KM	-0.261	3167	0.0000*	0396
206	KM	-0.295	3167	0.0000*	0396
205	KM	-0.365	3167	0.0000*	0396
204	KM	-0.369	3292	0.0000*	0396
203	KM	-0.308	3292	0.0000*	0396

4. Salinity Bottle and CTD salinity comparison

4.1 Bottle data

Twenty-four salinity samples were collected from the thermosalinograph bottle spigot while at sea; measured on July 22nd, 2009 by Paul Lethaby. Making the comparison in conductivity units instead of salinity eliminates the effect of temperature therefore the conductivity of each bottle was calculated using the salinity from the bottle, the internal thermosalinograph temperature, and a pressure of 6.0 dbar so as to include the pressure of the pump.

4.2 Thermosalinograph

The thermosalinograph and sampling spigot aboard R/V *Kilo Moana* are situated less than one meter apart from each other. Thus, there should be very little delay between the time when the water passes through the thermosalinograph and when it reaches the sampling spigot. Thermosalinograph data were extracted within a 30 second window around the bottle sample times minus a 10 second delay (in order to try and incorporate the reading recorded just prior to bottle sampling). The 30 second mean, centered 10 seconds before the bottle sample time, was chosen for processing purposes.

4.3 CTD Conductivity

In order to make the comparison in conductivity units, the CTD conductivity was calculated using the 8 dbar downcast CTD salinity, the internal thermosalinograph temperature, and a pressure of 6.0 dbar. There were 10 CTD casts conducted while the thermosalinograph was running.

4.4 Comparison

The mean bottle – thermosalinograph conductivity difference was -0.00319 S/m and the mean CTD–thermosalinograph conductivity difference was -0.0030 S/m. Cast #5 was removed as a conductivity outlier (Figure 3). Bottles #1 and #23 were also removed as outliers due to their large conductivity differences when compared to the thermosalinograph (Figure 3).

Both the bottle – thermosalinograph and CTD – thermosalinograph mean comparisons displayed values within range of typical HOT cruises. For reference, the mean (bottle-thermosalinograph and CTD-thermosalinograph) conductivity differences for WHOTS-6 and other recent HOT cruises are shown in Table 4.

Table 4: Thermosalinograph Conductivity Comparisons before correction

Cruise	Ship	Date	ΔC (S/m) Bot-Tsg	ΔC (S/m) CTD-Tsg	Conductivity Sensor #
WHOTS-6	KM	Jul 10th – Jul 16th, 2009	-0.00319	-0.0030	3292
212	KM	Jul 02nd – Jul 06th, 2009	-0.00305	-0.0031	3292
211	KOK	May 26th – May 30th, 2009	0.00050	0.00004	4073
210	KN	Apr 27th – May 01st, 2009	-0.09206	0.0928	0122
209	KM	Feb 16th – Feb 20th, 2009	-0.00076	-0.0006	3292
208	KM	Jan 19th – Jan 23rd, 2009	0.02755	0.0276	3167
206	KM	Nov 29th – Dec 2nd, 2008	-0.00054	-0.0004	3167
205	KM	Oct 9th – Oct 13th, 2008	-0.00052	-0.0003	3167
204	KM	Aug 15th – Aug 19th, 2008	-0.00334	-0.0034	3292
203	KM	Jul 25th – Jul 29th, 2008	-0.00318	-0.0030	3292

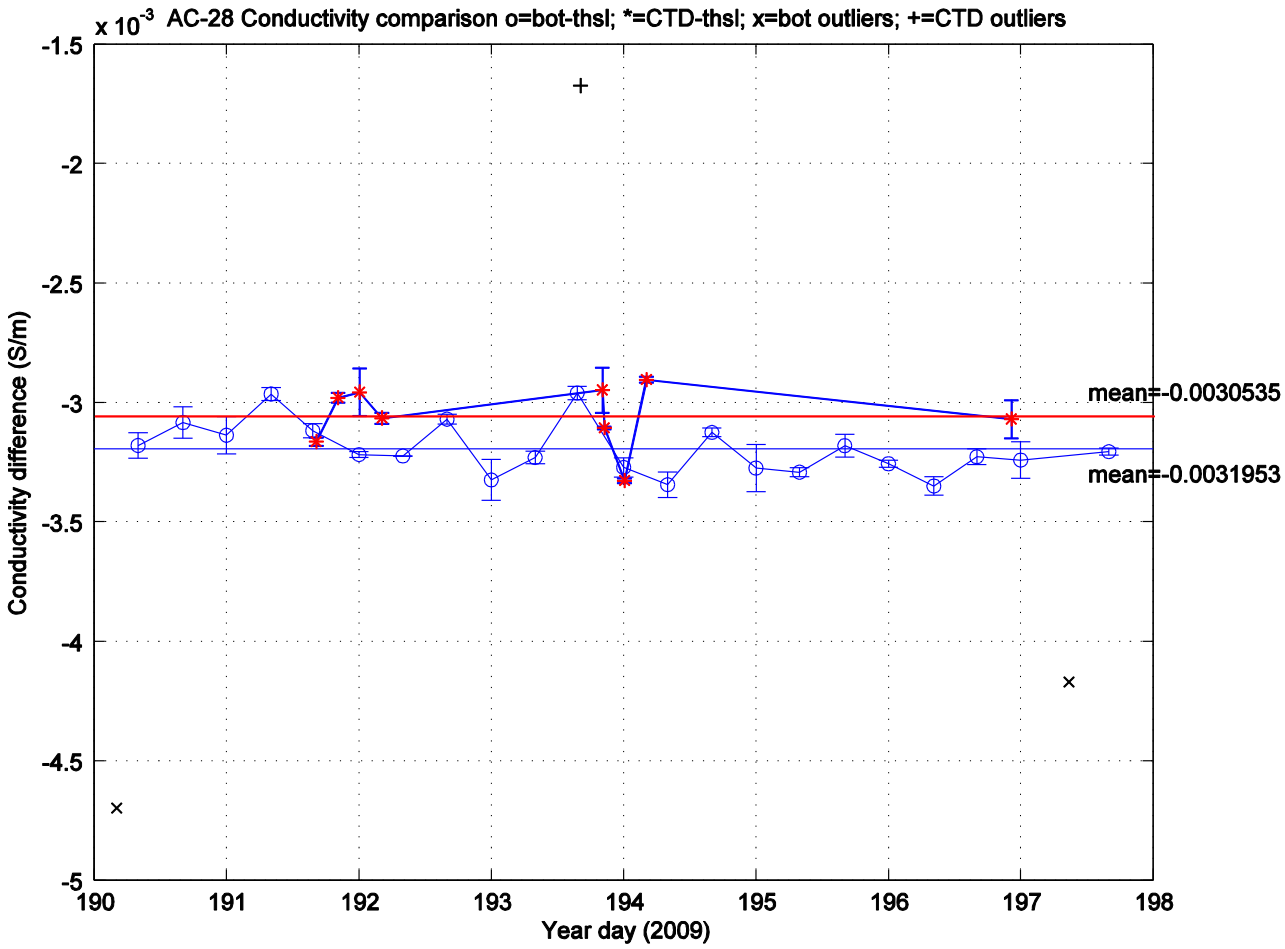


Figure 3: WHOTS-6 Thermosalinograph conductivity comparison; outliers removed.

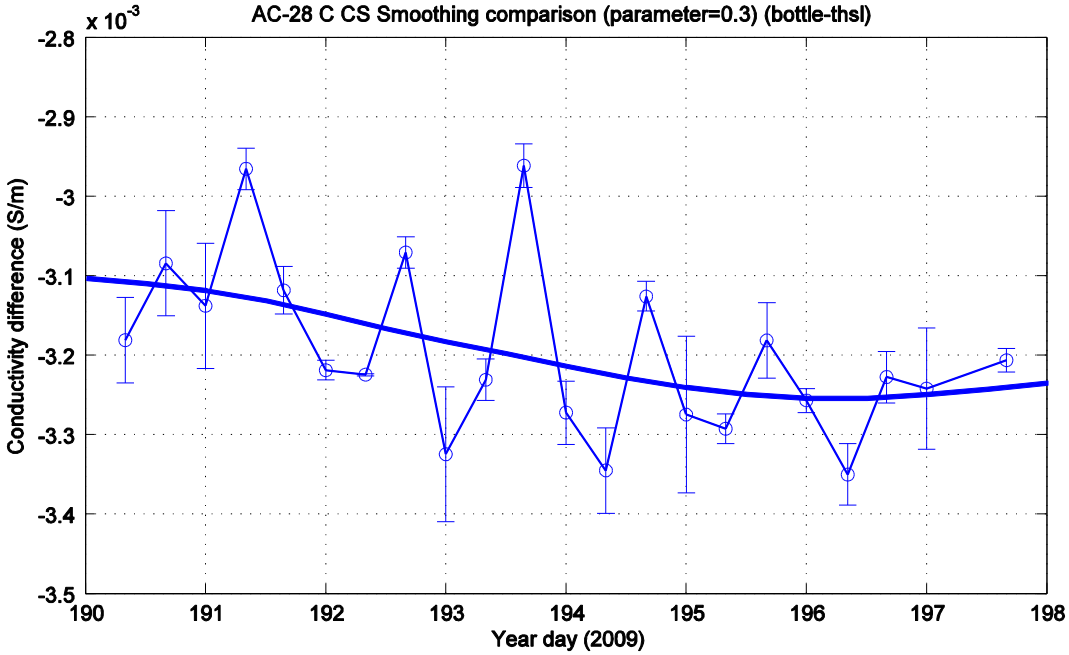
5. Corrected comparison (Bottle and CTD)

A cubic spline fit was superimposed on the salinity bottle – thermosalinograph comparison. The cubic spline fit was calculated using a Matlab cubic spline routine entitled "csaps". A smoothing parameter between 0 and 1 can be entered into the "csaps" routine. A parameter of 0 applies a least squares fit straight line fit to the data. On the other extreme, a smoothing parameter of 1 applies a "natural" cubic spline interpolant. After examining the effect of different smoothing parameters, a parameter of 0.3 was chosen and plotted in Figure 4 (top). The lower panel shows the bottle-thermosalinograph comparison after correcting the thermosalinograph using the cubic spline fit. This fit was then used to correct the thermosalinograph conductivities. Salinity was calculated using the cubic spline corrected conductivities, thermosalinograph internal temperatures, and pressure of 8 dbar (Figure 4).

With these corrections, the mean bottle-thermosalinograph salinity difference is 0.000000 +/- 0.0001 psu. The CTD-thermosalinograph comparison differs by 0.00096 +/- 0.0003 psu. The CTD-thermosalinograph salinity difference was similar to other recent cruises on R/V *Kilo Moana.* For comparison purposes, the mean (bottle-thermosalinograph) differences and the mean (CTD-thermosalinograph) differences for other recent HOT cruises are shown in Table 5.

Table 5: Thermosalinograph Salinity Differences after spline fit correction

Cruise	Ship	ΔS (psu) Bot-Tsg	ΔS (psu) CTD-Tsg
WHOTS-6	KM	0.000000	0.000969
212	KM	0.000002	-0.000368
211	KOK	-0.000007	-0.00348
210	KN	-0.000027	0.006016
209	KM	0.000001	0.001090
208	KM	-0.000001	0.000797
206	KM	-0.000002	0.000982
205	KM	-0.000000	0.001798
204	KM	0.000001	-0.000150
203	KM	-0.000001	0.001294



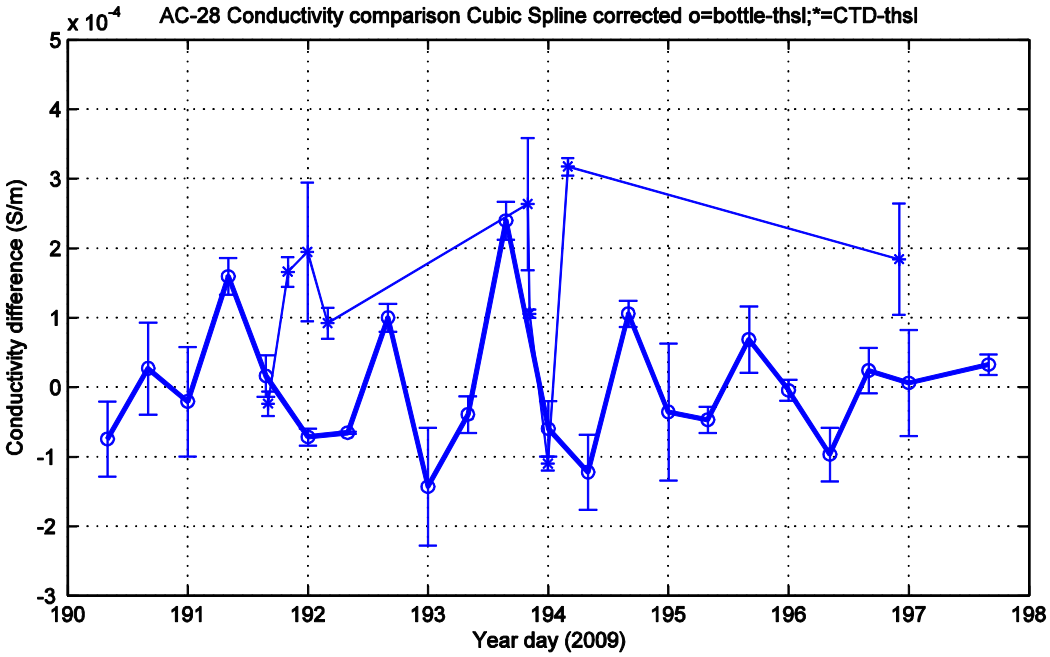
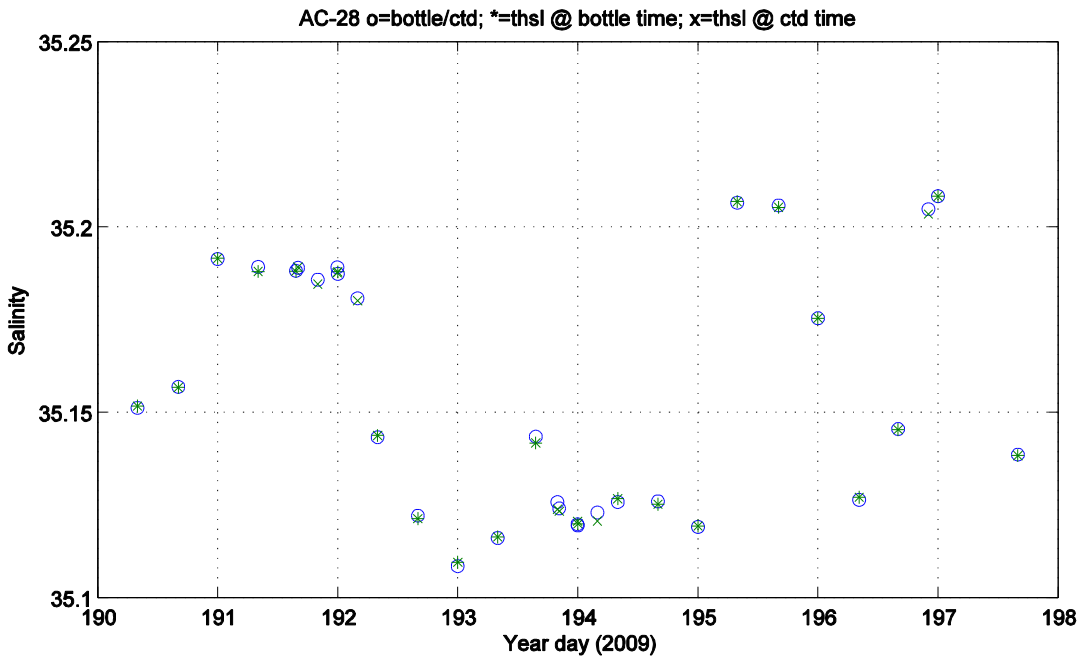


Figure 4: WHOTS-6 Thermosalinograph conductivity cubic spline corrections



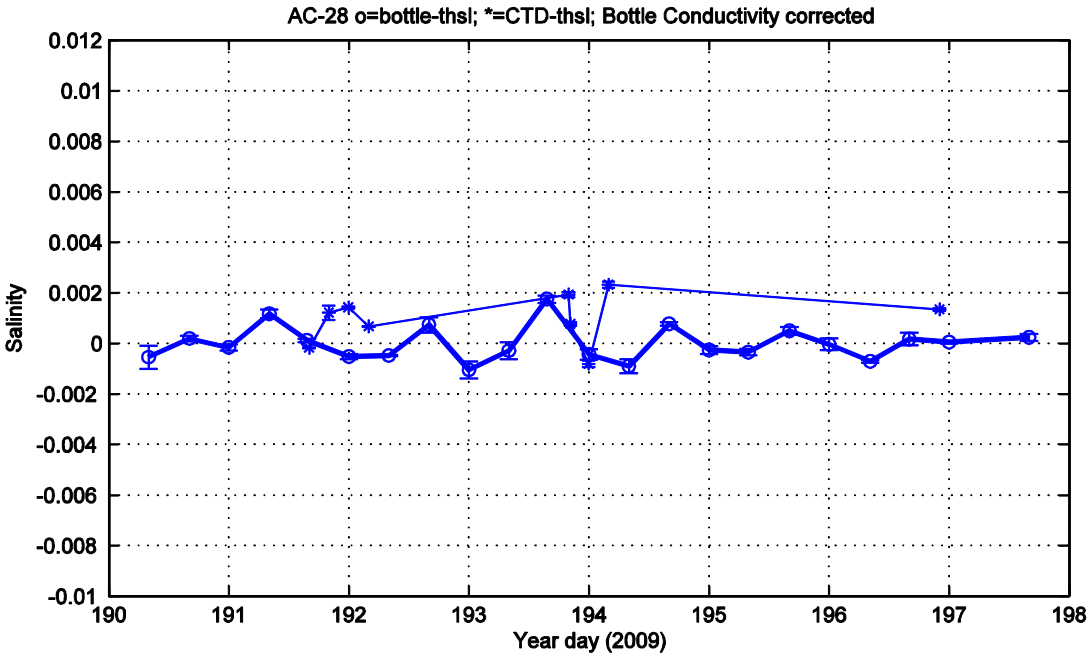


Figure 5: WHOTS-6 Thermosalinograph salinity corrections.

6. Final Products

Located in directory: /home/aukai1/ac/28/thermosal

Final data is in file: ac28thsl.dat

File ac28thsl.dat contains seven variables per line: Year, time (UTC), longitude, latitude, temperature (°C), salinity (psu), and the error flags. The first number of the error flag variable refers to the temperature data while the second number refers to the salinity data. All external (remote) temperature sensor data were offset and were corrected using the mean CTD – external temperature difference of -0.25683°C (see Section 3.3) and flagged as uncalibrated.

For the error flags, a "1" denotes uncalibrated data, a "2" denotes good data, a "3" denotes suspicious data, and a "4" denotes bad data. The data manager will decide if suspicious data are either a "3" suspicious or a "4" bad. A final plot of the temperature and salinity can be seen in Figure 7 and shows that the thermosalinograph data correspond well with the CTD data and salinity bottles. Sigma theta is also computed and plotted. A time-series of latitude, longitude, and ship's speed can be seen in Figure 8 at the same scale. The vertical dashed lines on Figure 6 and Figure 7 indicate the period of time when Station ALOHA was occupied during WHOTS-6.

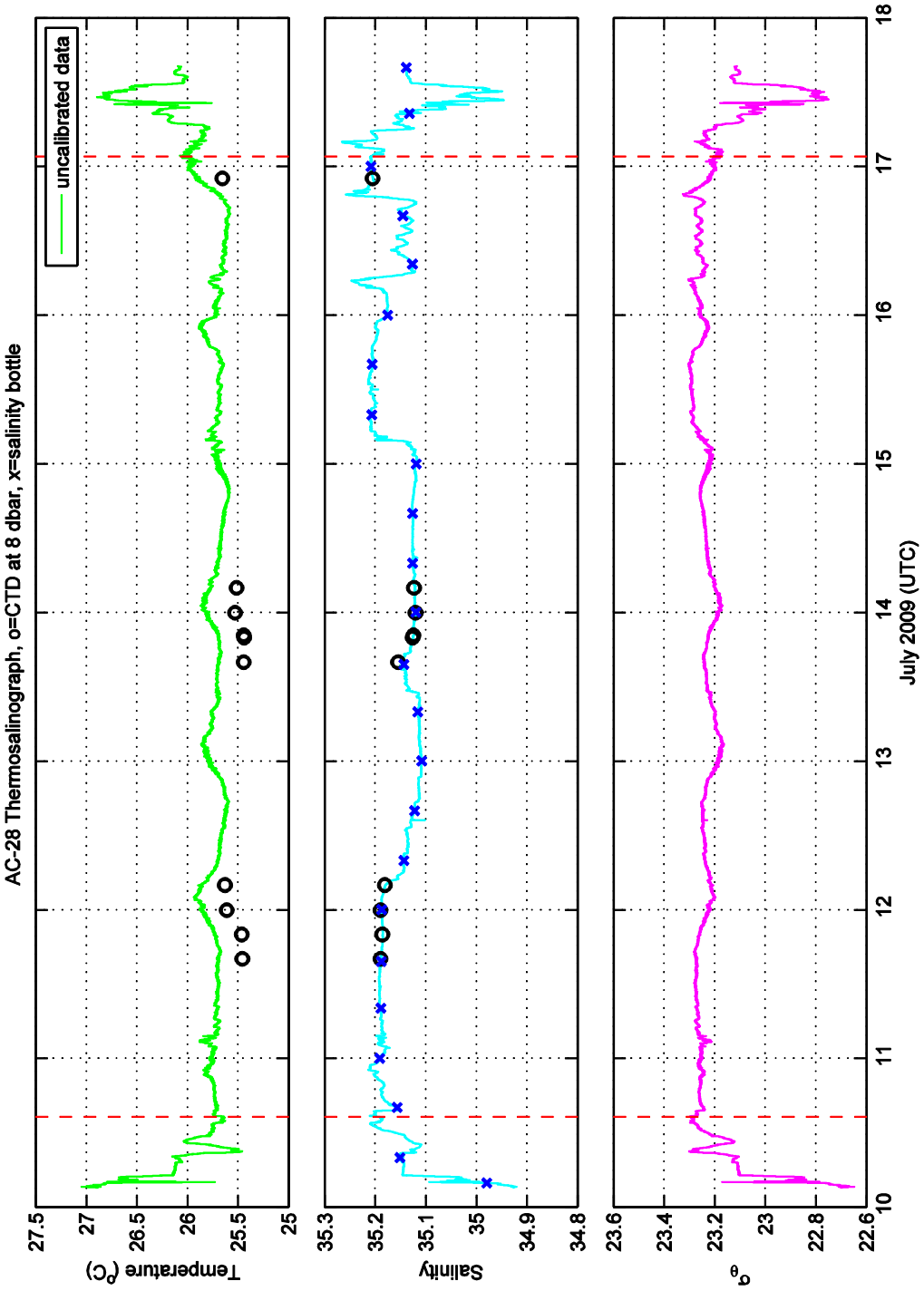


Figure 6: WHOTS-6 Final thermosalinograph data.

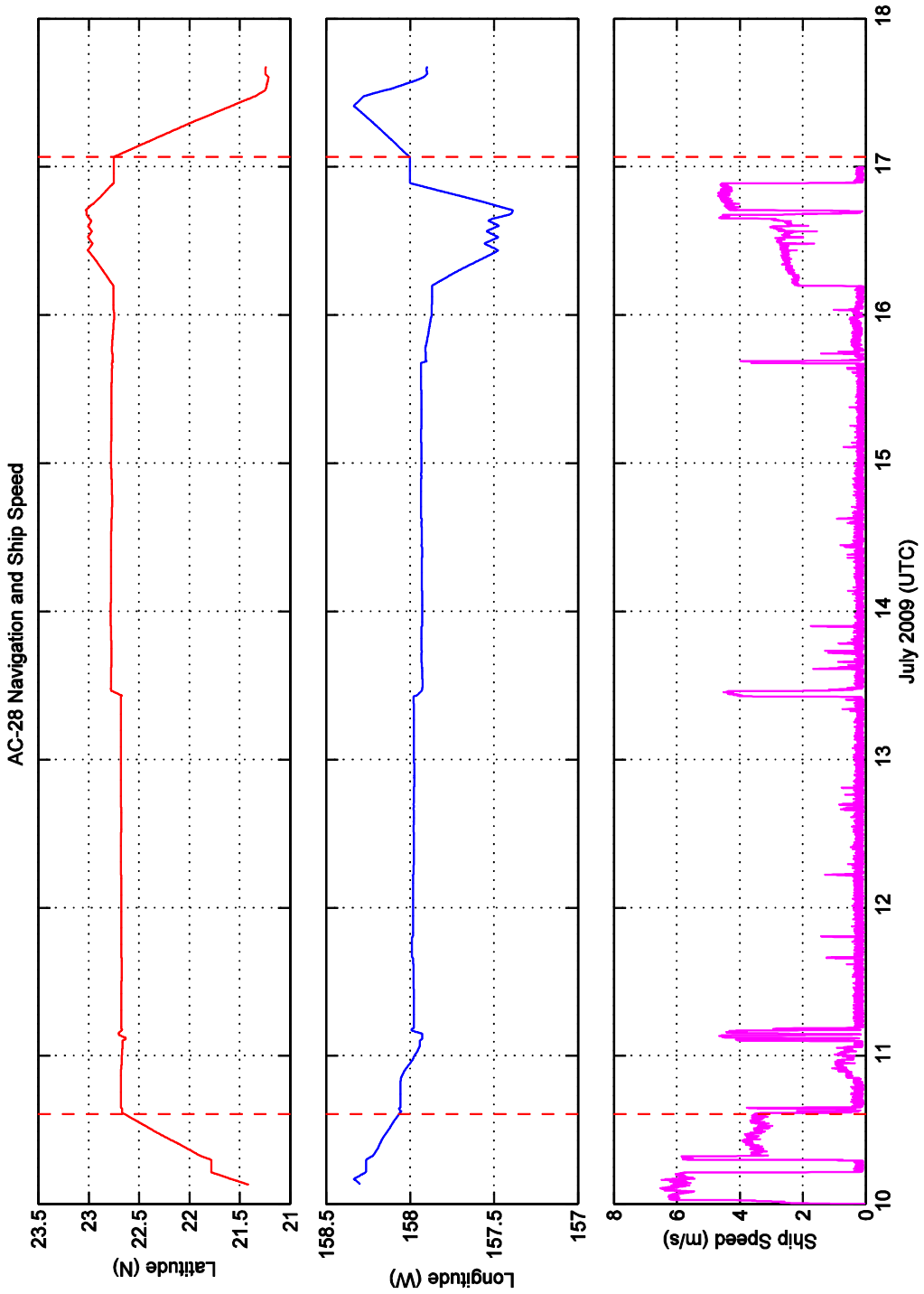


Figure 7: WHOTS-6 Final navigation data.

WHOTS-6: **procsail.rep**

Processing parameters:
Temperature lower bound: 18.000
Temperature upper bound: 35.000
Conductivity lower bound: 3.000
Conductivity upper bound: 6.000
Length of median filter: 21.000
Running median T threshold: 0.300
Running median C threshold: 0.100

RESULTS:
Gross error check:
Points outside valid T range: 0.000
Points outside valid C range: 0.000

Timing errors check:
Data interval: 1 seconds
Number of timing errors : 297.000
Largest gap (seconds): 2.000
Number of timing errors 1-2 sec: 297
Number of timing errors 3-5 sec: 0
Number of timing errors 6-9 sec: 0
Number of timing errors >10 sec: 0
Number of gaps > 20 secs: 0.000

Running median filter with replacement:
# of internal temperature glitches: 0
# of internal temperature and conductivity points replaced with median: 0.000

# of conductivity points replaced with median: 0.000

# of External Temperature running median filter replaced
Running median filter with replacement:
Points replaced with median: 3.000

A 3-point triangular running mean smoothing filter was applied

Manually flagged Temperature and/or Conductivity data:

flagging 1-651483 with 12 on Day 190 : 651483 points flagged

Total points flagged: 651483
# of gaps in speed file: 0.000

WHOTS-6: **datacmpond.out**

Julian Days: 190 198

Total CTDs	Total Bottles	Outliers ctd	Outliers bottle
10	24	1	2

STATISTICAL DATA OF MEAN TEMPERATURE DIFFERENCE

	CTD-int	CTD-ext	Ext-Int Temp (C)
Mean	-0.21008	-0.25683	0.04676
Std Error	0.00559	0.00339	0.00654
Std Dev.	0.01677	0.01017	0.01961

STATISTICAL DATA OF MEAN CONDUCTIVITY DIFFERENCE

	Bot-thsl	CTD-thsl	Conductivity, S/m
Mean	-0.0031953	-0.0030535	
Std Error	0.0000230	0.0000438	
Std Dev.	0.0001079	0.0001313	

STATISTICAL DATA OF MEAN SALINITY DIFFERENCE

	Bot-thsl	CTD-thsl	Salinities
Mean	0.000000	0.000969	
Std Error	0.000145	0.000328	
Std Dev.	0.000679	0.000984	