

April 24, 2024

AC-42 (WHOTS-19) Thermosalinograph Processing Report

File location: /export/kela1/aukai1/ac/42/thermosal/ac42_thermosal_report.docx

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Summary

Near-surface temperature and salinity data during the WHOTS-19 cruise (AC-42) were acquired from the thermosalinograph (TSG) system installed on the NOAA Ship *Oscar Sette* throughout the cruise (June 16 - 19, 2023). The sensors were sampling water from the continuous seawater system running through the ship and were comprised of one thermosalinograph model SBE-21 (SN 3168) and a micro-thermosalinograph model SBE-45 (SN 0290), both with internal temperature and conductivity sensors located in the ship's chemistry lab, about 70 m from the hull intake; and an SBE-38 (SN 212) external temperature sensor located at the entrance of one of the water intakes.

All instruments recorded data every second. The water intake is located at the ship's bow, forward from the starboard side bow thruster at a depth of 3 m. The system has a flow meter in the chemistry lab, showing a flow rate of about 1.1 liter/minute during the cruise. Only the SBE-45 has a debubbler. Salinity water samples were taken every 8 hours from the exhaust in the Chemistry lab using 0.25 liter glass bottles to be measured in the UH lab to correct for any drift in the thermosalinograph conductivities.

Navigation data (latitude, longitude, and ship's speed) were recorded throughout the cruise every second and concatenated with the thermosalinograph data. The THSL data were interpolated at the navigation data times.

The mean difference between CTD and the external temperature sensor was -0.01103°C , while the mean difference between the CTD and the internal temperature sensor was -0.21145°C . Noise levels in salinity and temperature for WHOTS-19 were 0.00058926 psu and $0.0013297^{\circ}\text{C}$, respectively.

The SBE-45 micro-thermosalinograph sensor (SN 0290) was calibrated against salinity samples. There were five casts conducted during WHOTS-19, while the thermosalinograph was running. No casts were identified as temperature outliers after comparing them against the thermosalinograph data. No salinity bottles were excluded from the thermosalinograph processing due to larger than expected conductivity differences. The mean bottle – thermosalinograph conductivity difference was -0.0003393 S/m , and the mean CTD–thermosalinograph conductivity difference was 0.0006613 S/m before corrections. After the spline fit correction, the mean bottle-thermosalinograph salinity difference was $0.000006 \pm 0.000976\text{ psu}$.

Conditions during the WHOTS-19 deployment on June 16-17 were favorable. There were 15-16 kt winds from the east during the deployment and a westward current of nearly 0.5 kt near the surface. There were clear skies and no precipitation in the region and there were small short-period wind waves.

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1. Factory sensor calibration

The following Sea-Bird facility calibrations were used to convert the data to engineering units.

TEMPERATURE SBE-38 (SN 0212) external temperature probe was used to measure temperature at the seawater intake and was last calibrated on December 08, 2022. Both models, the SBE-45 micro-thermosalinograph sensor (SN 0290) and the SBE-21 analog thermosalinograph sensor (SN 3168), measured internal temperature and conductivity. The SBE-45 was last calibrated on November 11, 2022, and the SBE-21 sensor on December 29, 2022.

Pressure of 10 dbar, to account for the average of 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:	0.000
Points outside of valid C range:	0.000

2.2 Timing Errors

The thermosalinograph aboard the R/V *Oscar Sette* was set to record data once every second, but occasionally a record could be written after a longer interval. There were 7145 timing errors during WHOTS-19 (Table 1).

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Table 1: Timing Errors and Results of Running Median Filter for Past WHOTS Cruises								
Cruise	Ship	Timing Errors	Conductivity points detected with median	Temp (Int) points detected with median	Internal Temp Sensor		Temp (Ext) points detected with median	External Temp Sensor
					SBE-45	SBE-21		SBE-38
42	OS	7145	5	0	0290	3168	0	0212
41	OS	38	40	332	0290	-	391	0266
40	OS	87042	341	283			1998	
39	OS	26	913	13			100	
38	HI	364	1	0	0150	3155	0	0215
37	HI	466	0	0	0150		0	
36	HI	369	0	0	0121		0	

HI: R/V *Hi'ialakai*; OS: R/V *Oscar Sette*

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2.3 Running median filter

A 5-point running median filter is used to detect temperature and conductivity glitches for cruises on R/V *Oscar Sette*. If a glitch is detected, both the temperatures and conductivities of this record are immediately replaced by the medians.

Length of median filter:	21.000
Running median T threshold:	0.300
Running median C threshold:	0.100

Results of running median filter:

Conductivity points detected with median:	5
Temperature (internal) points detected with median:	0
Temperature (external) points detected with median:	0

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 10 dbar to account for the average 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 into 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 remaining data, 11014 of the 534647 data points were flagged (Figure 1a) for spikes in conductivity.

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.

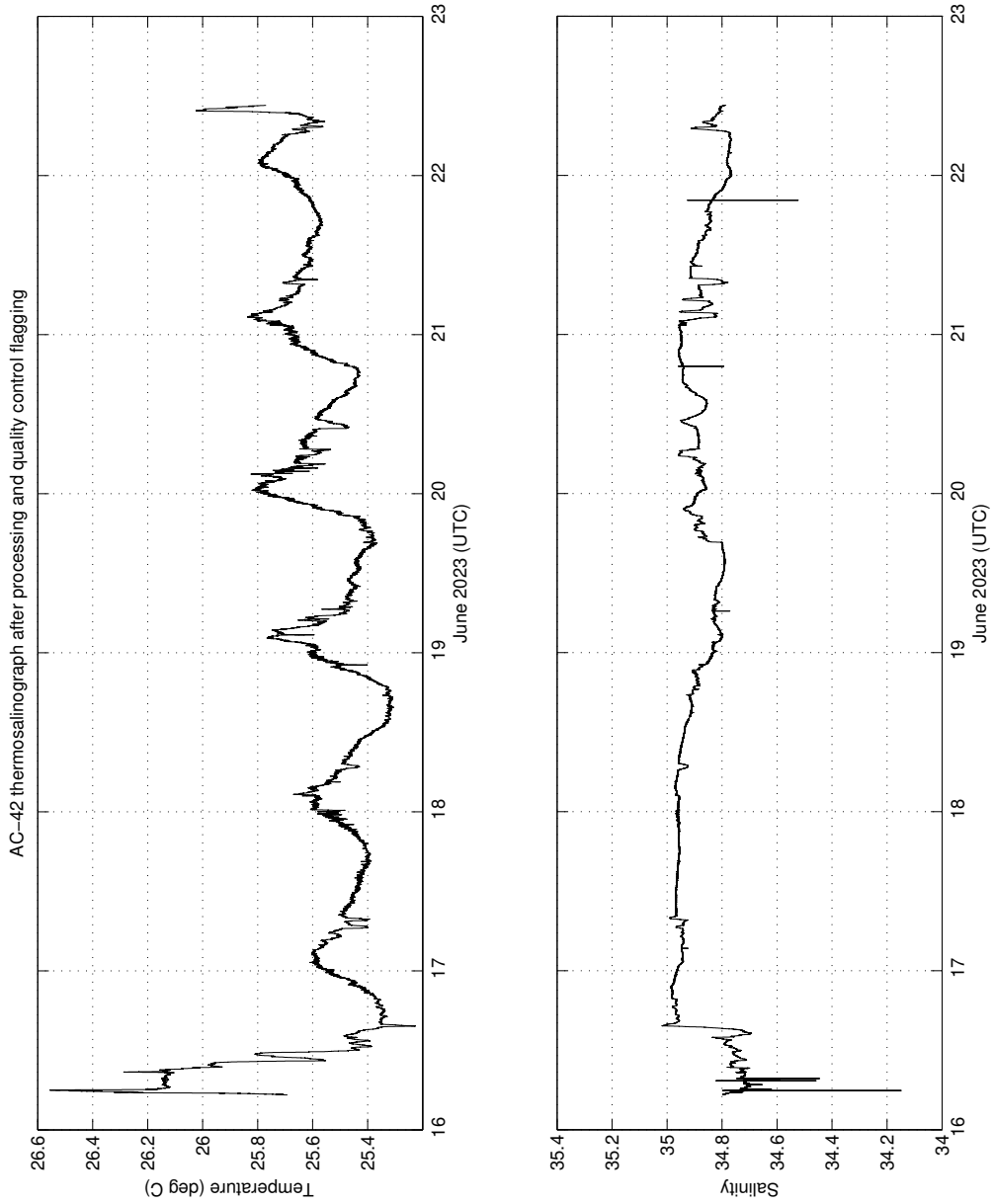


Figure 1a: AC-42/WHOTS-19 Thermosalinograph SN 0290 (SBE-45) data after initial processing and quality control.

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Table 2 lists THSL temperature and salinity noise estimates during previous WHOTS cruises. Temperature and salinity noise for WHOTS-19 is estimated to be 0.0013297 °C and 0.00058926 psu, respectively.

Table 2: Thermosalinograph Temperature and Salinity Noise Estimates				
AC-Cruise	WHOTS	Ship	Temperature Noise (°C)	Salinity Noise (psu)
42	19	OS	0.0013	0.00059
41	18	OS	0.0019	0.00039
40	17	OS	0.0037	0.00044
39	16	OS	0.0043	0.00043
38	15	HI	0.0016	0.00102
37	14	HI	0.0016	0.00052
36	13	HI	0.0142	0.00077
35	12	HI	0.0215	N/A*
34	11	HI	0.0042	0.00515
33	10	HI	0.0087	0.00933

HI: R/V *Hi'ialakai*
OS: R/V *Oscar Sette*

* N/A = noise was too large to be estimated

3. CTD Temperature Comparison

3.1 CTD temperature

There were 5 CTD casts conducted during WHOTS-19, one of which was a test cast offshore Honolulu (Station 20), and four at Station 52 (WHOTS-19). The 3 dbar downcast CTD temperature data from those casts were used to compare with the thermosalinograph data at the time of the casts. This comparison gives an estimate of the quality of the thermosalinograph measurements. No casts were identified as temperature outliers after comparing them against the thermosalinograph data.

3.2 Comparison

The mean difference between CTD and the external temperature sensor was -0.01103 °C (Figure 2), with a standard deviation of ± 0.01203 °C. The mean difference between the CTD and the internal temperature sensor was -0.21145 °C, with a standard deviation of ± 0.01832 °C. The values observed for the mean differences between CTD and external/internal temperature sensors for other WHOTS cruises are visible in Table 3.

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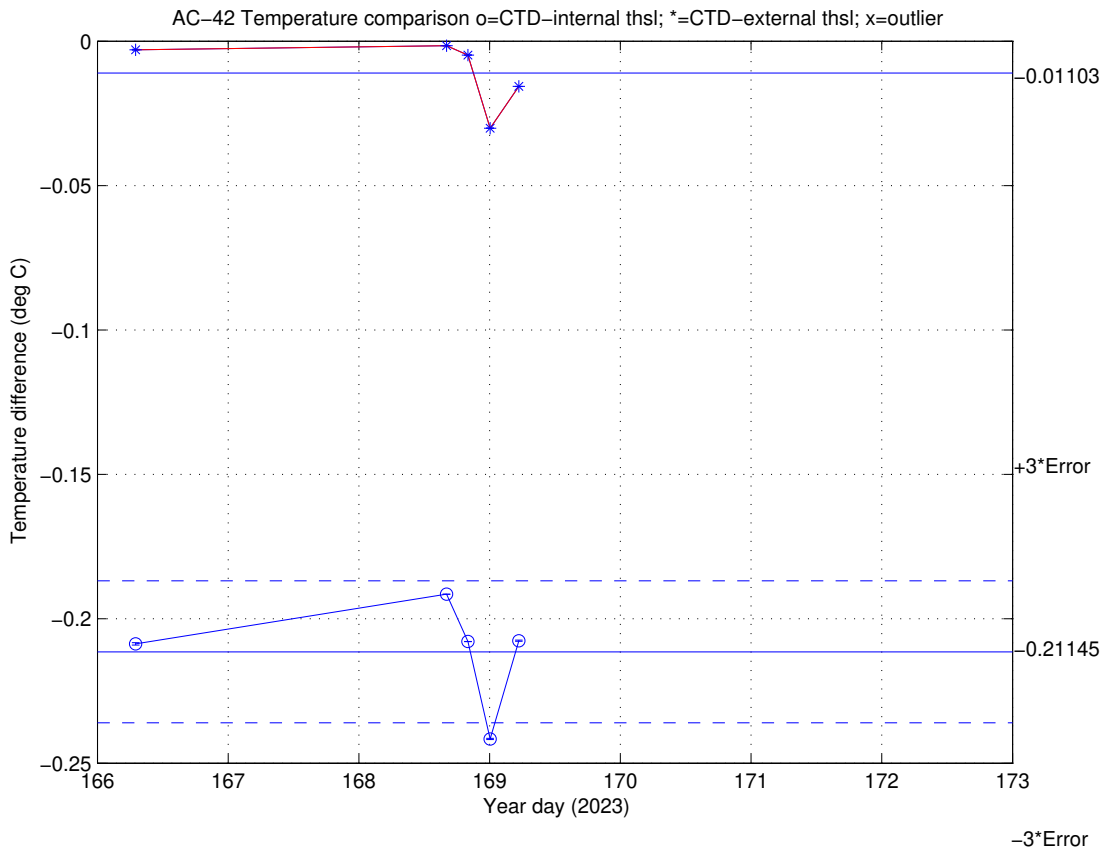


Figure 2: AC-42/WHOTS-19 Thermosalinograph temperature comparison; outliers removed.

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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 WHOTS-10 through WHOTS-19 are shown in Table 3.

Table 3: CTD-Thermosalinograph Temperature Comparisons						
AC-Cruise	WHOTS-Cruise	Ship	ΔT (°C) CTD-Int	Internal Temp. Sensor #	ΔT (°C) CTD-ext	External Temp. Sensor #
42	19	OS	-0.21145	0290	-0.01103	0212
41	18	OS	-0.12737	0290	-0.00360	0266
40	17	OS	-0.24693	0290	-0.00796	0266
39	16	OS	0.05813	0290	0.00374	0266
38	15	HI	-0.00992	3155	-0.03263	0215
37	14	HI	-0.25903	3155	-0.31092	0215
36	13	HI	-0.30691	3155	-0.02820	0215
35	12	HI	-0.39990	3155	-0.00660	0215
34	11	HI	-0.02212	3155	-0.00519	0215
33	10	HI	-0.02481	3155	-0.00436	0215

HI: R/V *Hi'ialakai*

OS: R/V *Oscar Sette*

4. Salinity Bottle and CTD salinity comparison

4.1 Bottle data

The thermosalinograph salinity was calibrated by comparing it to bottle salinity samples drawn from a water intake next to the thermosalinograph every 8 hours throughout the cruise. Twenty salinity samples were collected from the thermosalinograph and measured on August 29, 2023, by Fernando C. Pacheco. Samples were analyzed as described in the WHOTS-19 cruise report

(http://www.soest.hawaii.edu/whots/proc_reports/WHOTS19_Cruise_Report.pdf). 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 10 dbar to include the pressure of the pump.

4.2 Thermosalinograph

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The thermosalinograph and sampling spigot aboard R/V *Oscar Sette* is situated less than one meter apart. Thus, there should be a minimal 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 (to try and incorporate the reading recorded just before 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 3 dbar downcast CTD salinity, the internal thermosalinograph temperature, and a pump pressure of 10 dbar. There were 5 CTD casts conducted during WHOTS-19, while the thermosalinograph was running.

4.4 Comparison

No salinity bottle was excluded from the thermosalinograph processing due to larger than expected conductivity differences

After removing outliers, the mean bottle – thermosalinograph *SN 0290 (SBE-45)* conductivity difference was -0.0003393 S/m, and the mean CTD–thermosalinograph conductivity difference was 0.0006613 S/m.

For reference, the mean (bottle-thermosalinograph and CTD-thermosalinograph) conductivity differences for previous WHOTS cruises are shown in Table 4.

Cruise	Ship	Date	ΔC (S/m) Bot-Thsl	ΔC (S/m) CTD-Thsl	Conductivity Sensor #
42	OS	16-19 June, 2023	-0.0003393	0.0006613	0290
41	OS	22-27 July, 2022	0.0010348	0.0008750	0290
40	OS	24 August – 1 September, 2021	-0.0027680	-0.0027917	0290
39	OS	4 – 12 October, 2019	0.0011404	0.0009010	0290
38	HI	21– 29 September, 2018	-0.0020785	-0.0022545	3155
37	HI	25 July – 3 August, 2017	-0.0036040	-0.0037954	3155
36	HI	25 June – 3 July, 2016	-0.0008525	-0.0009547	3155
35	HI	9 – 16 July, 2015	0.0026696	0.0028029	3155

HI: R/V Hi'ialakai

OS: R/V *Oscar Sette*

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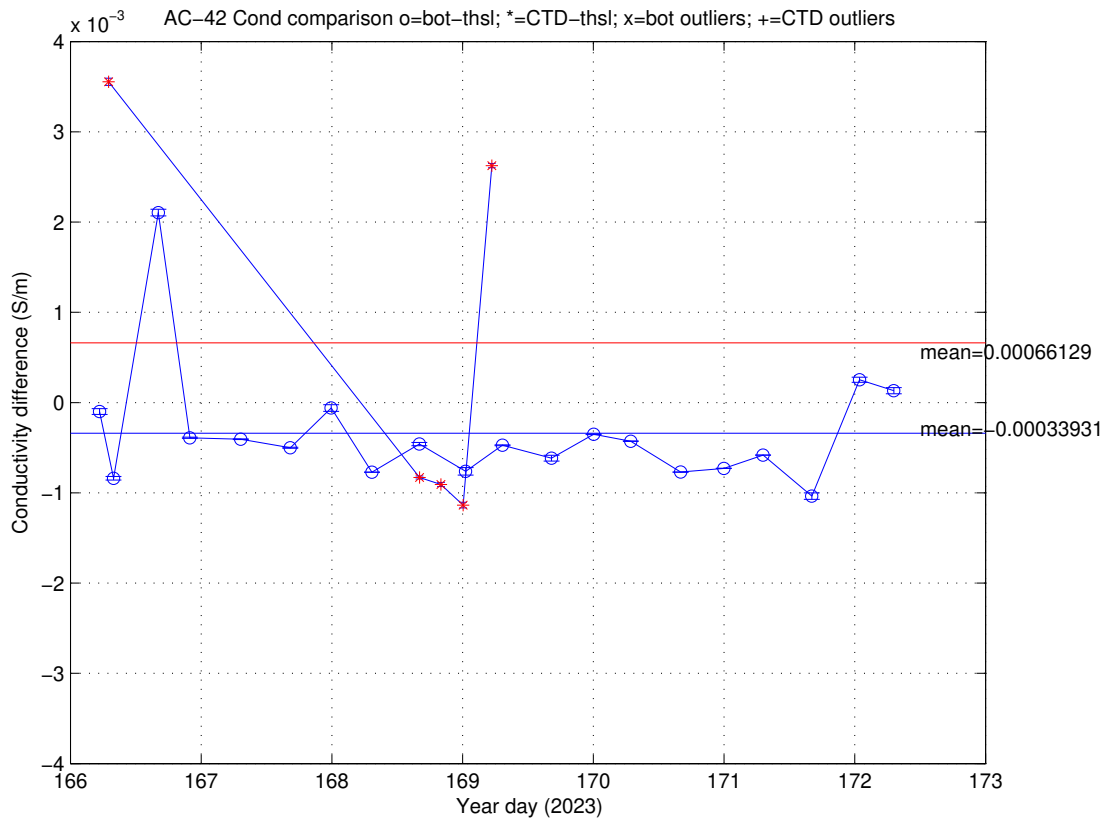


Figure 3: AC-42/WHOTS-19 Thermosalinograph conductivity comparison; outliers removed.

5. Corrected comparison (Bottle and CTD)

A cubic spline fit was superimposed on the salinity bottle – thermosalinograph *SN 0290 (SBE-45)* 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 10 dbar (Figure 4).

With these corrections, the mean bottle-thermosalinograph salinity difference is 0.000006 ± 0.000976 psu. The CTD-thermosalinograph salinity differs by 0.007705 ± 0.006708 psu. The mean bottle-THSL and CTD-THSL salinity differences were within the range of other WHOTS cruises. For comparison purposes, the mean bottle-THSL differences and the mean CTD-THSL differences for other WHOTS cruises are shown in Table 5.

Cruise	Ship	ΔS (psu) Bot-Thsl	ΔS (psu) CTD-Thsl
42	OS	0.000006	0. .000976
41	OS	-0.000006	-0.001098
40	OS	0.000000	-0.000178
39	OS	-0.000004	-0.002875
38	HI	0.000005	-0.001385
37	HI	0.000000	-0.002269
36	HI	-0.000001	-0.001217
35	HI	0.000001	0.000724
34	HI	0.000001	-0.022094
33	HI	-0.000038	0.004725

HI: R/V Hi'ialakai OS: R/V *Oscar Sette*

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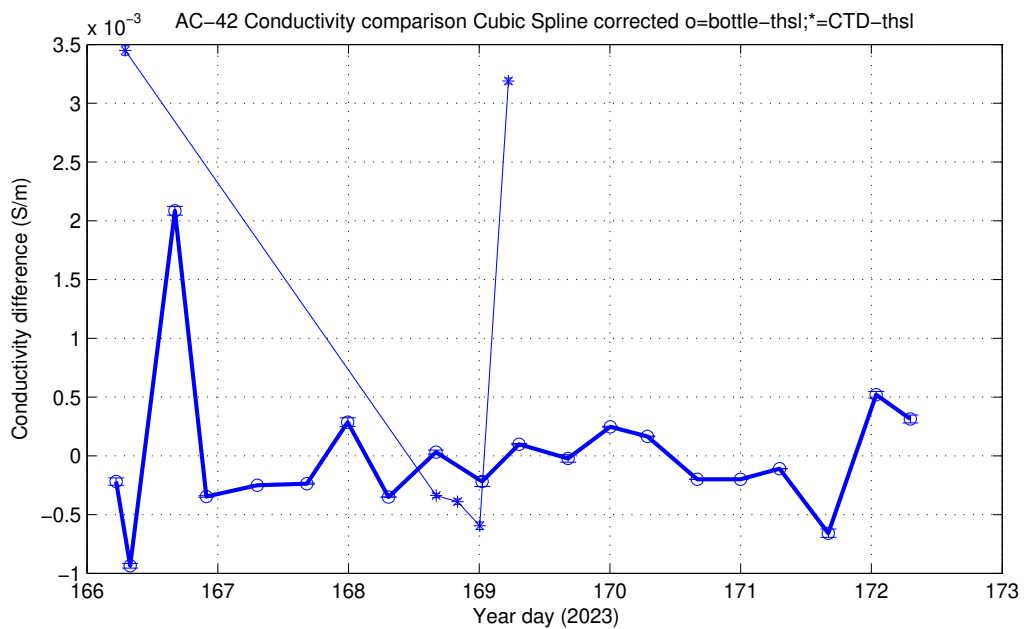
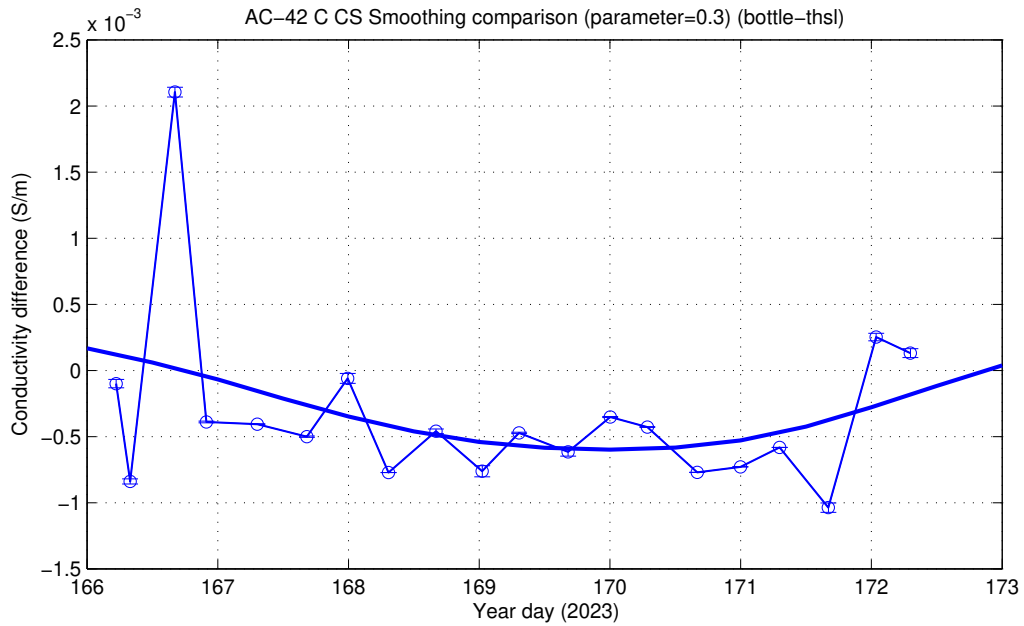


Figure 4: AC-42/WHOTS-19 Thermosalinograph conductivity cubic spline corrections.

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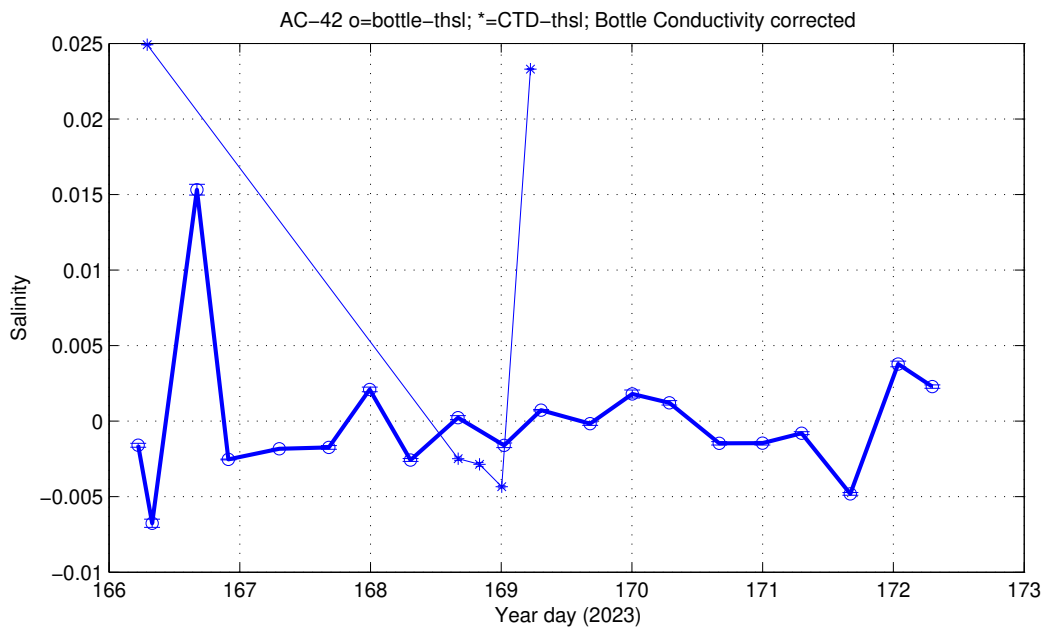
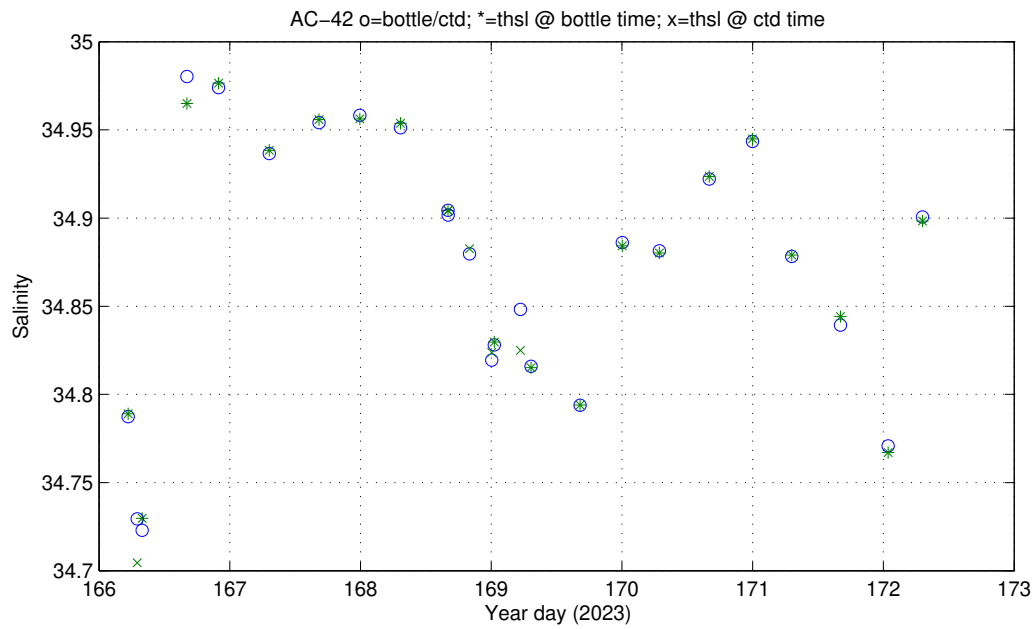


Figure 5: AC-42/WHOTS-19 Thermosalinograph salinity corrections.

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6. Final Products

Located in directory: /export/kela1/aukai1/ac/42/thermosal

Final data is in the file: ac42thsl.dat

File ac42thsl.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 refers to the salinity data.

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 6 and shows that the thermosalinograph data correspond well with the CTD data and salinity bottles. Potential density is also computed and plotted. A time series of latitude, longitude, and ship's speed can be seen in Figure 7 at the same scale. The vertical dashed lines in Figure 6 and Figure 7 indicate the period of time when Station ALOHA was occupied during AC-42/WHOTS-19.

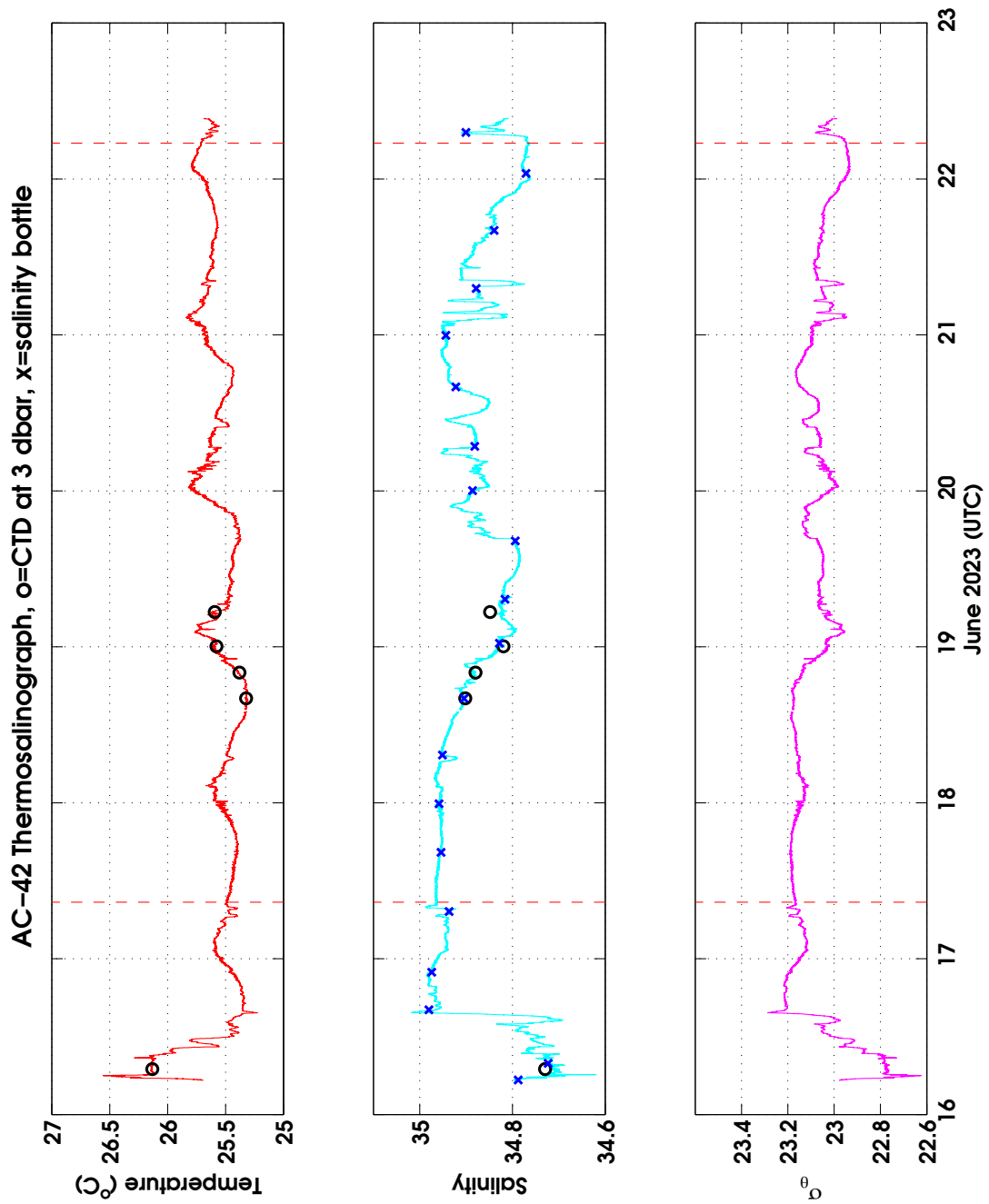


Figure 6: AC-42/WHOTS-19 final thermosalinograph data. o=CTD; x=Salinity bottle.

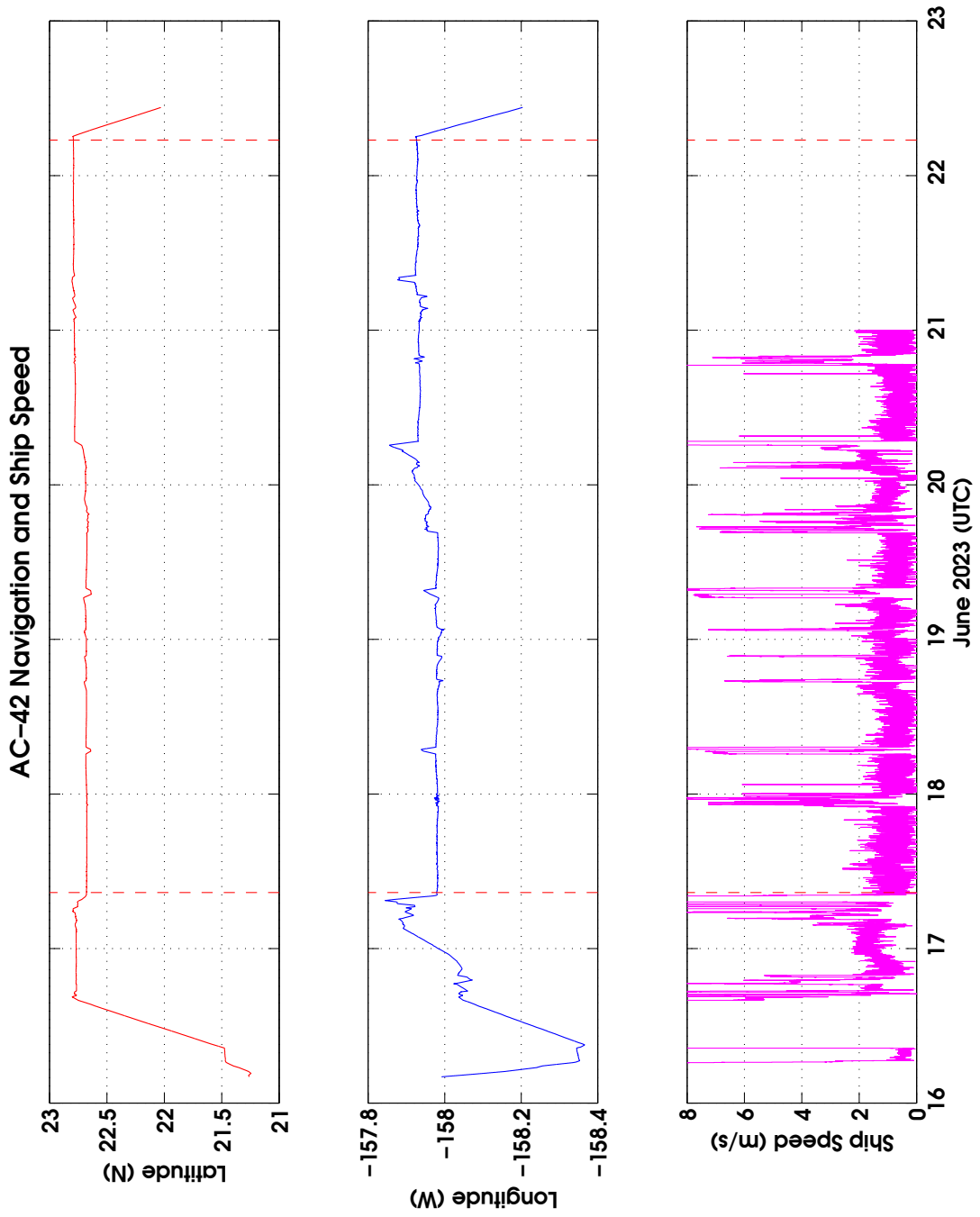


Figure 7: AC-42/WHOTS-12 final navigation data.

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AC-42/WHOTS-19:

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 : 7145.000

Largest gap (seconds): 18.000

Number of timing errors 1-2 sec: 7116

Number of timing errors 3-5 sec: 27

Number of timing errors 6-9 sec: 1

Number of timing errors >10 sec: 1

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: 5.000

of conductivity points replaced with median: 5.000

of External Temperature running median filter replaced

Running median filter with replacement:

Points replaced with median: 0.000

A 3-point triangular running mean smoothing filter was applied

Manually flagged Temperature and/or Conductivity data:

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flagging 1- 4331 with 44 on Day 166 : 4331 points flagged
flagging 6582- 6606 with 23 on Day 166 : 25 points flagged
flagging 9872- 9894 with 23 on Day 166 : 23 points flagged
flagging 9872- 9900 with 23 on Day 166 : 29 points flagged
flagging 11953-11985 with 23 on Day 166 : 33 points flagged
flagging 12290-12310 with 23 on Day 166 : 21 points flagged
flagging 12319-12343 with 23 on Day 166 : 25 points flagged
flagging 12754-12777 with 23 on Day 166 : 24 points flagged
flagging 13114-13138 with 23 on Day 166 : 25 points flagged
flagging 25499-25511 with 23 on Day 166 : 13 points flagged
flagging 31697-31833 with 23 on Day 166 : 137 points flagged
flagging 32019-32185 with 23 on Day 166 : 167 points flagged
flagging 38265-38278 with 23 on Day 166 : 14 points flagged
flagging 82793-82814 with 23 on Day 167 : 22 points flagged
flagging 177354-177368 with 23 on Day 168 : 15 points flagged
flagging 193907-193917 with 23 on Day 168 : 11 points flagged
flagging 204705-205954 with 44 on Day 168 : 1250 points flagged
flagging 208108-208119 with 23 on Day 168 : 12 points flagged
flagging 211358-211372 with 23 on Day 168 : 15 points flagged
flagging 229129-229144 with 23 on Day 168 : 16 points flagged
flagging 229164-229177 with 23 on Day 168 : 14 points flagged
flagging 229213-229224 with 23 on Day 168 : 12 points flagged
flagging 229553-229563 with 23 on Day 168 : 11 points flagged
flagging 229629-229641 with 23 on Day 168 : 13 points flagged
flagging 229649-229662 with 23 on Day 168 : 14 points flagged
flagging 229694-229707 with 23 on Day 168 : 14 points flagged
flagging 229747-229758 with 23 on Day 168 : 12 points flagged
flagging 229761-229774 with 23 on Day 168 : 14 points flagged
flagging 229780-229791 with 23 on Day 168 : 12 points flagged
flagging 229819-229841 with 23 on Day 168 : 23 points flagged
flagging 229909-229921 with 23 on Day 168 : 13 points flagged
flagging 230129-230146 with 23 on Day 168 : 18 points flagged
flagging 241179-241199 with 23 on Day 169 : 21 points flagged
flagging 241182-241199 with 23 on Day 169 : 18 points flagged
flagging 261871-261892 with 23 on Day 169 : 22 points flagged
flagging 392979-393000 with 23 on Day 170 : 22 points flagged
flagging 393001-393009 with 23 on Day 170 : 9 points flagged
flagging 482985-483000 with 23 on Day 171 : 16 points flagged
flagging 483001-483017 with 23 on Day 171 : 17 points flagged
flagging 530136-534646 with 44 on Day 172 : 4511 points flagged

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Total points flagged: 11014 of 534647

of gaps in speed file: 0.000

AC-42/WHOTS-19:

datacmpcond.out

Julian Days: 166 173

<i>Total</i>	<i>Total</i>	<i>Outliers</i>	
<i>CTDs</i>	<i>Bottles</i>	<i>ctd</i>	<i>bottle</i>
5	20	0	0

STATISTICAL DATA OF MEAN TEMPERATURE DIFFERENCE

	<i>CTD-int</i>	<i>CTD-ext</i>	<i>Ext-Int Temp (C)</i>
<i>Mean</i>	-0.21145	-0.01103	-0.20042
<i>Std Error</i>	0.00819	0.00538	0.00980
<i>Std Dev.</i>	0.01832	0.01203	0.02192

STATISTICAL DATA OF MEAN CONDUCTIVITY DIFFERENCE

	<i>Bot-thsl</i>	<i>CTD-thsl</i>	<i>Conductivity, S/m</i>
<i>Mean</i>	-0.0003393	0.0006613	
<i>Std Error</i>	0.0001481	0.0010036	
<i>Std Dev.</i>	0.0006621	0.0022440	

STATISTICAL DATA OF MEAN SALINITY DIFFERENCE

	<i>Bot-thsl</i>	<i>CTD-thsl</i>	<i>Salinities</i>
<i>Mean</i>	0.000006	0.007705	
<i>Std Error</i>	0.000976	0.006708	
<i>Std Dev.</i>	0.004366	0.015000	