November 24, 2020

AC-37 (WHOTS-14) Thermosalinograph Processing Report

File location: /export/aukai1/ac/37/thermosal/ac37_thermosal_report.doc

K. Trifonova

Summary

Near-surface temperature and salinity data during the WHOTS-14 cruise (AC-37) were acquired from the thermosalinograph (TSG) system installed on the NOAA Ship Hi'ialakai throughout the cruise (July 26th – August 1st, 2017). The sensors were sampling water from the continuous seawater system running through the ship, and were comprised of one thermosalinograph model SBE-21 (SN 3155) and a micro-thermosalinograph model SBE-45 (SN 0150), both with internal temperature and conductivity sensors located in the ship’s wet lab, about 67 m from separate intakes; and an SBE-38 (SN 0215) external temperature sensor located at the entrance of one of the water intakes. This report reports the processed data from the SBE-21 model, as the SBE-45 micro-thermosalinograph experienced glitches in the data recording. The SBE-21 recorded data every 6 seconds, and the other two instruments recorded data every second. The water intake for the SBE-21 and SBE-38 is located at the bow of the ship, next to the starboard side bow thruster at a depth of 2 m. The intake for the SBE-45 is located near the middle of the ship, also 2 m deep. The system has a pressure gauge showing a flow pressure of about 10 psi during the cruise. Both thermosalinograph systems had a debubbler.

Water samples were taken approximately every eight hours while underway for calibration of the THSL conductivity cell. Navigation data (latitude, longitude, and ship’s speed) were recorded throughout the cruise every second and concatenated with the thermosalinograph data. After visually inspecting the remaining data 14,229 of the 754,531 data points were flagged (Figure 1a-1b) for spikes in conductivity.

The mean difference between CTD and the external temperature sensor was -0.3109 °C. The mean difference between the CTD and the internal temperature sensor was -0.2590 °C. Noise levels in salinity and temperature for WHOTS-14 were 0.000517 psu and 0.00161 °C, respectively. A drift of 0.3×10⁻³ S/m in thermosalinograph conductivity was observed throughout the cruise.

Winds during the cruise were mostly from the ENE with speeds averaging 5 to 10 kts and sea swell ranging 2 to 4 ft swells, respectively.

1. Factory sensor calibration

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

TEMPERATURE SBE-38 (SN 0215) external temperature probe was used to measure temperature at the seawater intake, and was last calibrated on 06 February 2016. Both models, the SBE-45 micro-thermosalinograph sensor (SN 0150) and the SBE-21 analog thermosalinograph sensor (SN 3155) measured
internal temperature.

CONDUCTIVITY SBE-21 (SN 3155) analog thermosalinograph measured conductivity. The conductivity sensor was most recently calibrated on 09 Feb. 2016. This calibration was used to convert the data.

Pressure of 3.44 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 Hiʻialakai was set to record data once every five seconds, but occasionally a record could be written after a longer interval. There were 466 timing errors during WHOTS-14 (Table 1) with most gaps (464) between 1 and 2 seconds and two gaps over 20 seconds long with the largest gap being 473 seconds long.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Timing Errors</th>
<th>Conductivity points detected with median</th>
<th>Temp (Int) points detected with median</th>
<th>Internal Temp Sensor</th>
<th>Temp (Ext) points detected with median</th>
<th>External Sensor</th>
<th>Temp Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>HI</td>
<td>466</td>
<td>0</td>
<td>0</td>
<td>3155</td>
<td>0</td>
<td>0150</td>
<td>0215</td>
</tr>
<tr>
<td>36</td>
<td>HI</td>
<td>369</td>
<td>0</td>
<td>0</td>
<td>3155</td>
<td>0</td>
<td>0121</td>
<td>0215</td>
</tr>
</tbody>
</table>

HI: R/V Hiʻialakai
November 24, 2020

Note: Previous cruises recorded data at different time intervals and have been omitted in order to evade comparing dissimilar data sets.
2.3 Running median filter

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

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of median filter:</td>
<td>5.000</td>
</tr>
<tr>
<td>Running median T threshold:</td>
<td>0.300</td>
</tr>
<tr>
<td>Running median C threshold:</td>
<td>0.100</td>
</tr>
</tbody>
</table>

Results of running median filter:

- Conductivity points detected with median: 0
- 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 3.44 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 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 remaining data 14,229 of the 754,531 data points were flagged (Figure 1a-1b) 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-37/WHOTS-14 Thermosalinograph data after initial processing.
Figure 1b: AC-37/WHOTS-14 Thermosalinograph data after initial processing and quality control.
November 24, 2020

Table 2 lists THSL temperature and salinity noise estimates during previous WHOTS cruises. Temperature and salinity noise for WHOTS-14 is estimated to be 0.0016 °C and 0.00052 psu, respectively, which is typical for previous cruises aboard the NOAA Ship Hi’ialakai.

<table>
<thead>
<tr>
<th>AC-Cruise</th>
<th>WHOTS</th>
<th>Ship</th>
<th>Temperature Noise (°C)</th>
<th>Salinity Noise (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>14</td>
<td>HI</td>
<td>0.0016</td>
<td>0.00052</td>
</tr>
<tr>
<td>36</td>
<td>13</td>
<td>HI</td>
<td>0.0142</td>
<td>0.00077</td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>HI</td>
<td>0.0215</td>
<td>N/A*</td>
</tr>
<tr>
<td>34</td>
<td>11</td>
<td>HI</td>
<td>0.0042</td>
<td>0.00515</td>
</tr>
<tr>
<td>33</td>
<td>10</td>
<td>HI</td>
<td>0.0087</td>
<td>0.00933</td>
</tr>
</tbody>
</table>

HI: R/V Hi’ialakai
*N/A = noise was too large to be estimated

3. CTD Temperature Comparison

3.1 CTD temperature

There were 13 CTD casts conducted during WHOTS -14, one of which was a test cast off shore Honolulu (Station 20) and six casts each at Station 52 (WHOTS-14) and Station 50 (WHOTS-13), respectively. The 4 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. Of the 13 casts, cast 1, 2, 12, and 13 were identified as temperature outliers after comparing it against the thermosalinograph data, and removed from the analysis.

3.2 Comparison

The mean difference between CTD and the external temperature sensor was -0.31092 °C (Figure 2), with a standard deviation of ±0.06479 °C, which was more than a magnitude of ten higher then observed on previous cruises. This value of -0.31092 °C was applied as an offset to the thermosalinograph external temperature record to correct for an apparent warming, as compared to the CTD. These final corrected temperature values are flagged as suspicious, as the source of discrepancy with the CTD is unknown. The mean difference between the CTD and the internal temperature sensor was -0.25903 °C, with a standard deviation of ±0.02950 °C, which was similar to values observed on previous cruises. The values observed for the mean differences between CTD and external/internal temperature sensors for the most recent cruises aboard the NOAA Ship Hi’ialakai are shown in Table 3.
Figure 2: AC-37/WHOTS-14 Thermosalinograph temperature comparison; outliers removed.
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-14 are shown in Table 3.

Table 3: CTD-Thermosalinograph Temperature Comparisons

<table>
<thead>
<tr>
<th>AC-Cruise</th>
<th>WHOTS-Cruise</th>
<th>Ship</th>
<th>ΔT (°C) CTD-Int</th>
<th>Internal Temp. Sensor #</th>
<th>ΔT (°C) CTD-ext</th>
<th>External Temp. Sensor #</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>14</td>
<td>HI</td>
<td>-0.25903</td>
<td>3155</td>
<td>-0.31092</td>
<td>0215</td>
</tr>
<tr>
<td>36</td>
<td>13</td>
<td>SH</td>
<td>-0.30691</td>
<td>3155</td>
<td>-0.02820</td>
<td>0215</td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>HI</td>
<td>-0.39990</td>
<td>3155</td>
<td>-0.00660</td>
<td>0215</td>
</tr>
<tr>
<td>34</td>
<td>11</td>
<td>HI</td>
<td>-0.02212</td>
<td>3155</td>
<td>-0.00519</td>
<td>0215</td>
</tr>
<tr>
<td>33</td>
<td>10</td>
<td>HI</td>
<td>-0.02481</td>
<td>3155</td>
<td>-0.00436</td>
<td>0215</td>
</tr>
</tbody>
</table>

HI: R/V Hi’ialakai

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-four salinity samples were collected between July 25th and August 3rd, 2017 from the thermosalinograph aboard the NOAA Ship Hi’ialakai and measured on August 14th, 2017 by Svetlana Natarov. Samples were analyzed as described in the WHOTS-14 cruise report (http://www.soest.hawaii.edu/whots/cruise_reports.html). 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 3.44 dbar so as to include the pressure of the pump.

4.2 Thermosalinograph

The sampling spigot aboard the NOAA Ship Hi’ialakai is located within less than one meter of the SBE-21 and SBE-45 thermosalinographs, and both systems are equipped with de-bubblers. Salinity samples were drawn from the flow through system, located less than 0.5 m from the SBE-21 and consequently there should be virtually no delay between when the water passes through the thermosalinograph and it being sampled. A 90 second average centered on the sample draw 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 4 dbar downcast CTD salinity, the internal thermosalinograph temperature, and a pump pressure of 3.44 dbar. There were 13 CTD casts conducted during WHOTS-14, while the thermosalinograph was running. Casts 1, 2, 12, and 13 were removed from the analysis as temperature outliers and casts 1, 3, and 9 as conductivity outliers. Of the 24 thermosalinograph bottles sampled, bottles 1, 2, 12, 13, 16, and 23 were identified as conductivity outliers and removed as well.

4.4 Comparison

After removing outliers, the mean bottle – thermosalinograph conductivity difference was -0.00360 S/m and the mean CTD–thermosalinograph conductivity difference was -0.00380 S/m.

Both the bottle – thermosalinograph and CTD – thermosalinograph mean differences during WHOTS-14 were typical of cruises aboard the NOAA Ship Hi’ialakai. For reference, the mean (bottle-thermosalinograph and CTD-thermosalinograph) conductivity differences for other recent HOT cruises are shown in Table 4.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Date</th>
<th>ΔC (S/m) Bot-Thsl</th>
<th>ΔC (S/m) CTD-Thsl</th>
<th>Conductivity Sensor #</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>HI</td>
<td>25 July – 3 August, 2017</td>
<td>-0.0036040</td>
<td>-0.0037954</td>
<td>3155</td>
</tr>
<tr>
<td>36</td>
<td>HI</td>
<td>25 June – 3 July, 2016</td>
<td>-0.0008525</td>
<td>-0.0009547</td>
<td>3155</td>
</tr>
<tr>
<td>35</td>
<td>HI</td>
<td>9 – 16 July, 2015</td>
<td>0.0026696</td>
<td>0.0028029</td>
<td>3155</td>
</tr>
<tr>
<td>34</td>
<td>HI</td>
<td>15 – 23 July, 2014</td>
<td>0.0042708</td>
<td>-0.0035719</td>
<td>3155</td>
</tr>
<tr>
<td>33</td>
<td>HI</td>
<td>9 – 16 July, 2013</td>
<td>0.0067595</td>
<td>0.0070611</td>
<td>3155</td>
</tr>
</tbody>
</table>

HI: R/V Hi’ialakai
Figure 3: AC-37/WHOTS-14 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 3.44 dbar (Figure 4).

With these corrections, the mean bottle-thermosalinograph salinity difference is 0.000000 ± 0.000233 psu. The CTD-thermosalinograph salinity differs by -0.002269 ± 0.000369 psu. The mean bottle-THSL and CTD-THSL salinity differences were similar to typical cruises aboard R/V Hi’ialakai. For comparison purposes, the mean bottle-THSL differences and the mean CTD-THSL differences for other WHOTS cruises are shown in Table 5.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>ΔS (psu) Bot-Thsl</th>
<th>ΔS (psu) CTD-Thsl</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>HI</td>
<td>0.000000</td>
<td>-0.002269</td>
</tr>
<tr>
<td>36</td>
<td>HI</td>
<td>-0.000001</td>
<td>-0.001217</td>
</tr>
<tr>
<td>35</td>
<td>HI</td>
<td>0.000001</td>
<td>0.000724</td>
</tr>
<tr>
<td>34</td>
<td>HI</td>
<td>0.000001</td>
<td>-0.022094</td>
</tr>
<tr>
<td>33</td>
<td>HI</td>
<td>-0.000038</td>
<td>0.004725</td>
</tr>
</tbody>
</table>

HI: R/V Hi’ialakai

Table 5: Thermosalinograph Salinity Differences after spline fit correction
Figure 4: AC-37/WHOTS-14 Thermosalinograph conductivity cubic spline corrections.
Figure 5: AC-37/WHOTS-14 Thermosalinograph salinity corrections.
November 24, 2020

6. Final Products

Located in directory: /export/aukai1/ac/37/thermosal

Final data is in file: ac37thsl.dat

File ac37thsl.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.

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 on Figure 6 and Figure 7 indicate the period of time when Station ALOHA was occupied during AC-37/WHOTS-14.
Figure 6: AC-37/WHOTS-14 final thermosalinograph data.
Figure 7: AC-37/WHOTS-14 final navigation data.
November 24, 2020

AC-37/WHOTS-14: 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: 5.000
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: 5 seconds
Number of timing errors: 466.000
Largest gap (seconds): 473.000
Number of timing errors 1-2 sec: 464
Number of timing errors 3-5 sec: 0
Number of timing errors 6-9 sec: 0
Number of timing errors >10 sec: 2
Gap: 17851872.0 - 17852081.0
Gap: 17937598.0 - 17938071.0
Number of gaps > 20 secs: 2.000

Running median filter with replacement:
November 24, 2020

# 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: 0.000

A 3-point triangular running mean smoothing filter was applied
Manually flagged Temperature and/or Conductivity data:

- Flagging 11549-11571 with 23 on Day 206: 23 points flagged
- Flagging 15454-15486 with 23 on Day 206: 33 points flagged
- Flagging 19731-19742 with 23 on Day 206: 12 points flagged
- Flagging 22921-22930 with 23 on Day 206: 10 points flagged
- Flagging 246496-246504 with 23 on Day 208: 9 points flagged
- Flagging 257647-257654 with 23 on Day 209: 8 points flagged
- Flagging 257694-257703 with 23 on Day 209: 10 points flagged
- Flagging 258393-258400 with 23 on Day 209: 8 points flagged
- Flagging 258409-258418 with 23 on Day 209: 10 points flagged
- Flagging 286114-286125 with 23 on Day 209: 12 points flagged
- Flagging 286218-286227 with 23 on Day 209: 10 points flagged
- Flagging 342684-342693 with 23 on Day 209: 10 points flagged
- Flagging 343452-343470 with 23 on Day 209: 19 points flagged
- Flagging 363421-363434 with 23 on Day 210: 14 points flagged
- Flagging 385277-385287 with 23 on Day 210: 11 points flagged
- Flagging 478362-478371 with 23 on Day 211: 10 points flagged
- Flagging 605625-605636 with 23 on Day 213: 12 points flagged
- Flagging 650706-650723 with 23 on Day 213: 18 points flagged
- Flagging 746578-746589 with 23 on Day 214: 12 points flagged
- Flagging 747580-754530 with 44 on Day 214: 6951 points flagged
- Flagging 748118-754530 with 44 on Day 214: 6413 points flagged
- Flagging 754224-754530 with 44 on Day 214: 307 points flagged
- Flagging 754224-754530 with 44 on Day 214: 307 points flagged

----------------------------------------
Total points flagged: 14,229 of 754,531
# of gaps in speed file: 0.000
**November 24, 2020**

**AC-37/WHOTS-14:**

*datacmpcond.out*

**Julian Days:** 206 215

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Total</th>
<th>Outliers</th>
</tr>
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<tbody>
<tr>
<td>CTDs</td>
<td>Bottles</td>
<td>ctd</td>
<td>bottle</td>
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<tr>
<td>13</td>
<td>24</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**STATISTICAL DATA OF MEAN TEMPERATURE DIFFERENCE**

<table>
<thead>
<tr>
<th></th>
<th>CTD-int</th>
<th>CTD-ext</th>
<th>Ext-Int Temp (°C)</th>
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</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.25903</td>
<td>-0.31092</td>
<td>0.05189</td>
</tr>
<tr>
<td>Std Error</td>
<td>0.01115</td>
<td>0.02449</td>
<td>0.02691</td>
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<tr>
<td>Std Dev.</td>
<td>0.02950</td>
<td>0.06479</td>
<td>0.07119</td>
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</table>

**STATISTICAL DATA OF MEAN CONDUCTIVITY DIFFERENCE**

<table>
<thead>
<tr>
<th></th>
<th>Bot-thsl</th>
<th>CTD-thsl</th>
<th>Conductivity, S/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.0036040</td>
<td>-0.0037954</td>
<td></td>
</tr>
<tr>
<td>Std Error</td>
<td>0.0000511</td>
<td>0.0000578</td>
<td></td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.0002168</td>
<td>0.0001528</td>
<td></td>
</tr>
</tbody>
</table>

**STATISTICAL DATA OF MEAN SALINITY DIFFERENCE**

<table>
<thead>
<tr>
<th></th>
<th>Bot-thsl</th>
<th>CTD-thsl</th>
<th>Salinities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0000000</td>
<td>-0.002269</td>
<td></td>
</tr>
<tr>
<td>Std Error</td>
<td>0.000233</td>
<td>0.000369</td>
<td></td>
</tr>
<tr>
<td>Std Dev.</td>
<td>0.000987</td>
<td>0.000975</td>
<td></td>
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