STAR 2006 David Starr Jordan CTD PROCESSING

STAR 2006 CTD data files were collected using a Sea-Bird 911*plus* profiling instrument aboard the NOAA Ship David Starr Jordan (DSJ). The 911*plus* consists of the 9*plus* underwater CTD and 11*plus* V2 Deck Unit, which has high resolution sampling (24Hz) and pump-controlled conductivity and temperature flow-through sensors. Data were collected using Sea-Bird's SeaSave Win32 v. 5.34 and have been processed using Sea-Bird's SBE Data Processing v. 7.26.7. More information regarding the SBE software and recommended data processing procedures can be found online at www.seabird.com.

Each CTD directory on the data server contains two folders named Raw and Data. CTD set-up information, pressure test results, and data collected at sea are stored in the Raw folder. All information and files used in processing are saved in the Data folder, including documentation, configuration files, calibration sheets, intermediate processing steps and final data.

No changes in sensor use on the DSJ CTD during the STAR 2006 were necessary. The table below lists the sensors used. The owners of the sensors were responsible for their maintenance.

	Casts	Temp 1, 2	Cond 1, 2	Pressure
Legs 1-6	001-173	T1448, *T1352*	C1165, *C1145*	P0311

MMTD-owned, *PMC-owned*

STAR 2006 DSJ CTD SENSOR CALIBRATION

SWFSC MMTD uses Sea-Bird Electronics conductivity, temperature and pressure sensors. Sea-Bird Electronics conductivity sensors drift with usage and time, while temperature and pressure sensors drift primarily over time. Annual calibrations of the conductivity and temperature sensors are necessary to estimate and correct for this drift during data processing. Pre and post-cruise calibration certificates for the DSJ sensors used during STAR 2006 are in the \CON_Files\Calibrations folder.

Conductivity, temperature, and pressure are computed as polynomial functions of the sensor frequencies stored in the raw data file. We follow Sea-Bird recommended procedures for adjusting calibration coefficients for drift between calibrations (Sea-Bird App. Note # 31). Details can be found in the internal document "CTD Calibration Adjustments MMTD.pdf".

The Excel spreadsheet, CTDcalibrations STAR 2006_DSJ.xls, in the \Documentation folder, contains the pre and post-cruise calibration information for the conductivity, temperature and pressure sensors. It then derives slope or offset values used to correct the calibration coefficients used in both the Data Conversion and Derive modules of Sea-Bird's SBE Data Processing software. The adjusted configuration files used to process the STAR 2006 DSJ data (Appendix 1) are in the \CON_Files folder.

Conductivity Sensor Correction:

The SBE 4C series conductivity sensor has a measurement range of 0.0 to 7.0 Siemens/meter (S/m), which spans the conductivity range of SWFSC MMTD's study areas. The SBE 4C sensor is rated to have an initial accuracy of 0.0003 S/m; with a resolution (at 24Hz) of 0.00004 S/m.

The primary conductivity sensor C1165 was calibrated on 31 December 2005 and 9 March 2007. As discussed below, post-cruise calibration coefficients were used to process the data with no slope adjustment.

The secondary conductivity sensor C1145 was calibrated on 27 February 2004 and 8 March 2007. Post-cruise calibration coefficients were used to process the data with no slope adjustment, because the pre-cruise calibration was more than 2 years before the cruise.

An initial processing was done using pre-cruise calibration coefficients with slope adjustments for the conductivity sensors according to our normal procedures. The primary conductivity sensor, C1165, had an unusually large postslope (1.0009575), which required a slope adjustment by leg. Sea-Bird then cleaned and replatinized C1165 because of the positive drift equivalent to +0.002 psu/month. This processing gave large and varying differences between conductivity and salinity values from the primary and secondary sensors (Fig. 1). Consequently, the data were reprocessed using the post-cruise calibrations for both sensors. This processing resulted in a much closer agreement between the sensors (Fig. 1). The fact that the difference between the conductivity readings from the two sensors was relatively constant throughout the cruise, when the data were processed with post-cruise calibrations, suggests that the change in the response of C1165 occurred prior to the cruise and supports the use of post-cruise calibration coefficients.

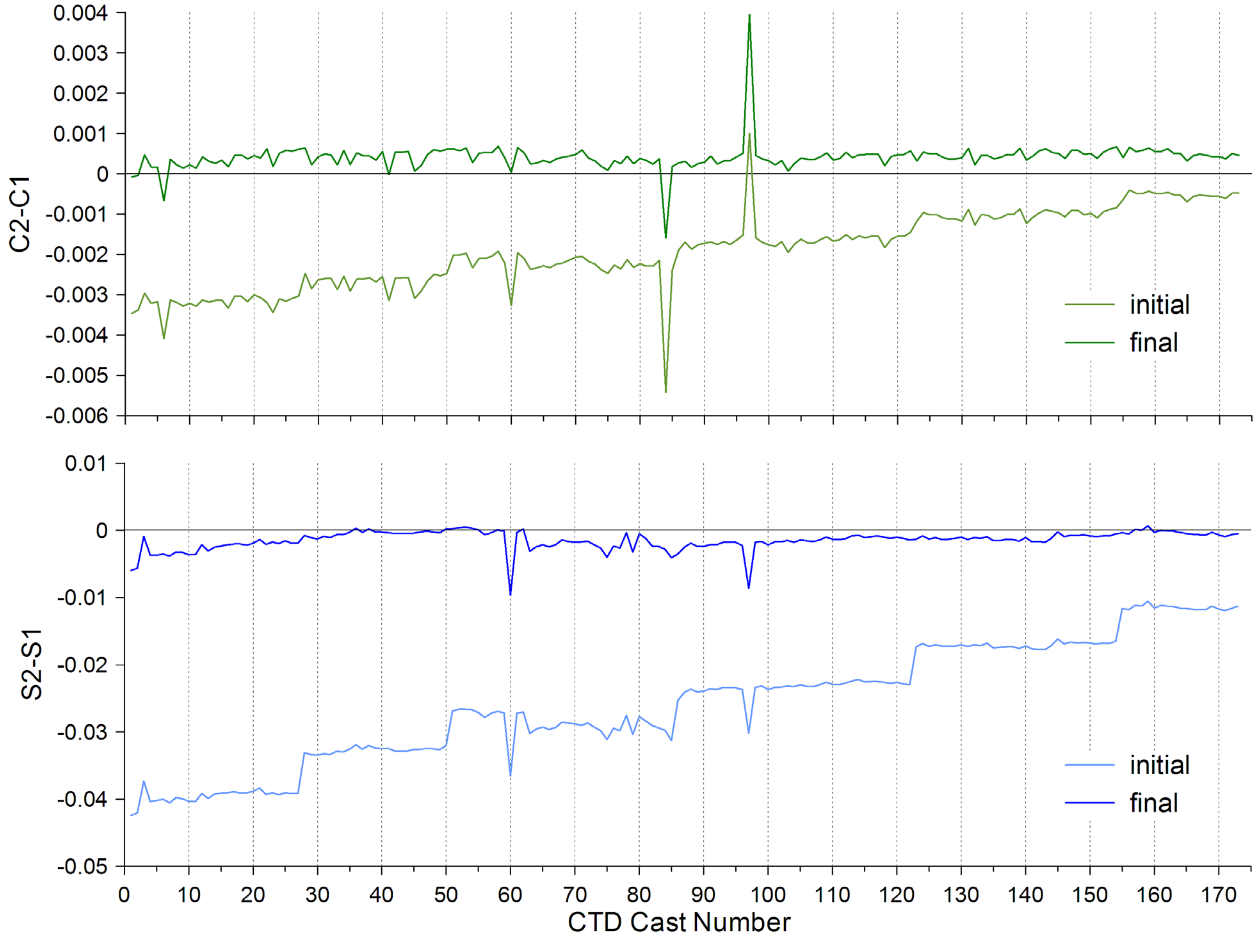


Fig. 1. Time series of differences between values from primary (C1 = C1165) and secondary (C2 = C1145) conductivity sensors for 2006 Jordan CTD casts processed twice (initial and final) as described in the text. Each conductivity (top) and salinity (bottom) difference value is a mean of 1m bin-averaged downcast values.

Temperature Sensor Correction:

The SBE 3*plus* series temperature sensor has a measurement range of -5.0 to 35 °C, which spans the range of temperatures in SWFSC MMTD's study areas. The SBE 3*plus* sensor is rated to have an initial accuracy of ± 0.001 °C and a resolution (at 24 samples per second) of 0.0003 °C.

The primary temperature sensor T1448 was calibrated on 30 December 2005 and 29 March 2007. The average iOffset was -0.000370°C; consequently, no offset adjustment was needed.

This secondary temperature sensor T1352 was calibrated on 19 January 1999 and 8 March 2007. Secondary temperature sensor values were computed from post-cruise calibration factors, with no adjustment, because of the excessive length of time since the previous calibration.

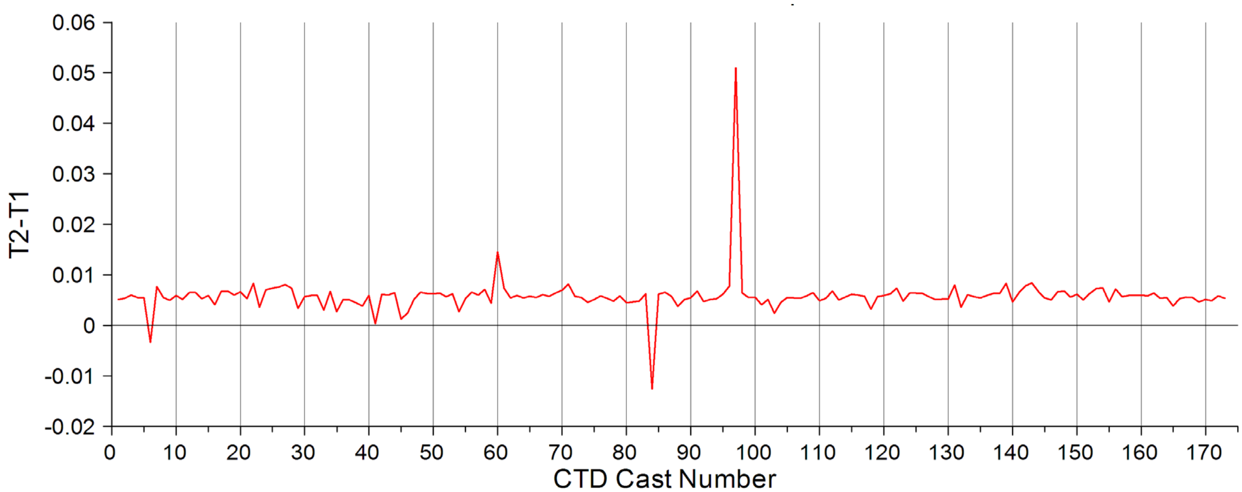


Figure 2. Time series of differences between values from primary (T1 = T1448) and secondary (T2 = T1352) temperature sensors for 2006 Jordan CTD casts. Each difference value is a mean of 1m bin-averaged downcast values.

Temperature differences from the dual sensors were consistently +0.0059 °C (secondary – primary), except for casts 6, 60, 84 and 97 (Fig. 2). Primary temperature will be used for derived variables, because this sensor has been sent to Sea-Bird for calibration more frequently.

Pressure Sensor Correction:

The SBE Paroscientific Digiquartz pressure sensor is rated to have an initial accuracy of 1.02m (i.e., 0.015% of the full scale range, which is 0 – 6800m). We do not exceed a maximum vertical depth of 1100m. Initial resolution (at 24Hz) is 0.068m (i.e., 0.001% of the full scale range).

CTD pressure deck tests are stored in the \Raw\DSJ\Pressure_tests folder.

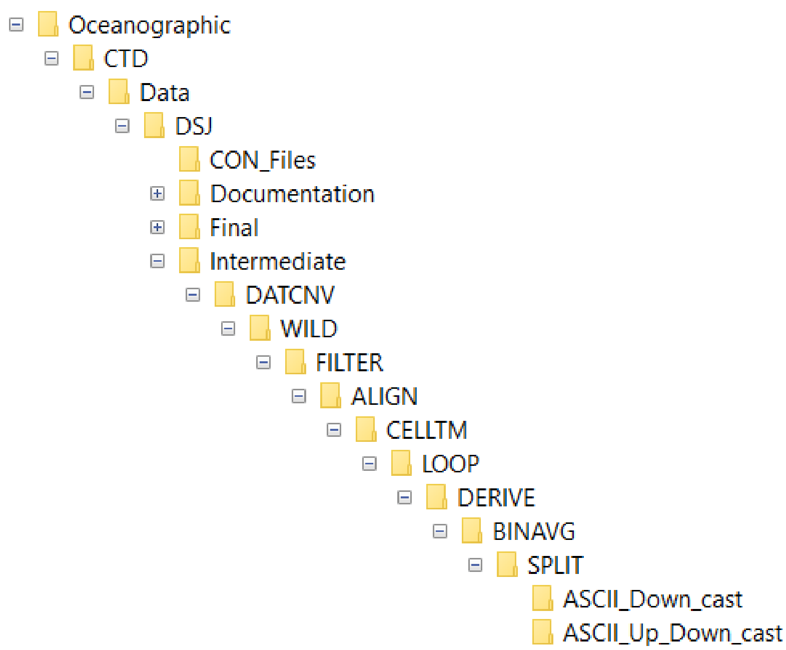
The CTD pressure sensor P0311 was calibrated on 21 October 2005 and 20 March 2007. Seven deck tests were conducted on the DSJ during STAR2006 resulting in offsets of -4.4235, -4.2745, -4.2105, -4.3885, -4.1475, -4.1513, and -4.3065 db; the results of these tests were consistent. Therefore, the average deck test offset of -4.27 db was used in the *.con file.

We use pre-cruise calibration coefficients for each sensor when available. Before running the processing modules, it is essential to ensure that the correct sensor configuration coefficients and corrections are loaded into the *.con files used by the SBE Data Processing program. Offset and slope adjustments are obtained from CTDcalibrations ORCAWALE 2008 MACII.xlsx in the \Documentation folder. Configuration files for the sensors used on the McArthur II during ORCAWALE 2008 are listed in Appendix 1.

STAR 2006 CTD SBE MODULE PROCESSING

The SBE Data processing modules that were applied to the raw STAR 2006 DSJ data are listed below. Each SBE module creates a program setup file, named *.psa. The *.psa files are located in the folder preceding their output, i.e. the ‘Derive.psa’ file is found in the ‘LOOP’ folder. Output .cnv files are kept in binary format to speed processing and reduce file sizes. The final module – ASCII Out – converts the binary data to ASCII format; if examination of the data is needed during earlier processing steps, the Translate module can be used to convert to the binary data to ASCII.

Modules are run in the following order: Data Conversion, Wild Edit, Filter, Align CTD (as needed), Cell Thermal Mass, Loop Edit, Derive, Bin Average, Split, ASCII Out. The processed data in various stages are in the \Intermediate folder:



1. **Data Conversion Module:**

Data Conversion converts raw SBE 911plus data, which are typically stored as frequencies and voltages in the *.dat file, to engineering units and stores the converted data in a *.cnv file.

The options selected for processing in Data Conversion were as follows:

name 0 = prDM: Pressure, Digiquartz [db]
name 1 = c0S/m: Conductivity [S/m]
name 2 = t090C: Temperature [ITS-90, deg C]
name 3 = c1S/m: Conductivity, 2 [S/m]
name 4 = t190C: Temperature, 2 [ITS-90, deg C]
name 5 = sbeox0Mm/Kg: Oxygen, SBE 43 [umol/Kg]

name 6 = flag: 0.000e+00
file_type = binary

Fortran program ScrData (programmer: Paul Fiedler) was used to flag values outside of these broad ranges: pressure -5 to 1200 db, temperature -1 to 33 deg C, and conductivity 2.5 to 7.0. The program first checks the range of values (primary and secondary, if present) in the header file. If any span exceeds the above limits, the program writes a new file in which each bad value, and the values in the two scans preceding and the two scans succeeding the bad value, are flagged. The original file is renamed with an "x" prefix. For each edited file, the total number of scans, the number of values that were outside limits, and the number of values flagged is summarized in the file *ScrData.dat* in the \Intermediate\DATCNV\ folder. Of 179 CTD files, 178 had no outliers, and 1 had secondary conductivity outliers. Flagged values are ignored in subsequent processing.

2. Wild Edit Module:

Wild Edit flags outliers in temperature, conductivity, and oxygen data so that they are not used in further processing. Wild Edit's algorithm requires two passes through the data in blocks of *npoint* scans. The first pass computes the mean and standard deviation and temporarily flags values that differ from the mean by more than *pass1_nstd* standard deviations. The second pass recalculates the mean and standard deviation, excluding values flagged in the first pass. Scans that differ from the mean by more than *pass2_nstd* standard deviations are replaced with a bad data flag. The criteria established by *pass2_nstd* can be overridden using *pass2_mindelta*; specifically, if data are within *pass2_mindelta* of the mean, they are not flagged.

The options selected for processing in Wild Edit were as follows for all casts:
wildedit_pass1_nstd = 2.0
wildedit_pass2_nstd = 15.0
wildedit_pass2_mindelta = 0.000e+000
wildedit_npoint = 100

These options are Sea-Bird defaults, except that *pass2_nstd* was changed from 20.0 to 15.0 to identify more outliers.

3. Filter Module:

The Filter module is run to reduce high-frequency noise in the pressure data, which is caused by counting jitter or other unknown sources. It is important to remove this noise before running the Loop Edit module. Loop Edit flags data that exhibit a change in the CTD velocity. Velocity is calculated using only three successive scans; consequently, noisy pressure data can result in erroneously flagged scans. Filter runs a low-pass filter on the data, which smoothes high frequency (rapidly changing) data. To produce zero phase (i.e., no time shift), the filter is first run forward through the data and then run backward through the data. Pressure data is typically filtered with a time constant equal to four times the CTD scan rate. We run a low-pass filter on the pressure data with time constant = 0.15 seconds, as recommended by Sea-Bird Electronics Inc.

The options selected for processing in Filter were as follows for all CTD casts:

filter_low_pass_tc_A = 0.030
filter_low_pass_tc_B = 0.150
filter_low_pass_A_vars =
filter_low_pass_B_vars = prDM

4. Align CTD Module:

It is essential that all variables derived from the data, such as salinity, density, and sound speed, use measurements of temperature and conductivity from same parcel of water. It is practically impossible to instantaneously measure the same parcel of water with all sensors due to the physical location of the sensors on the unit and the different time delays of the sensors. The typical time delay of conductivity relative to temperature, 0.073 seconds, is automatically corrected by the SBE 11plus Deck Unit during data collection. If spikes are observed in the processed salinity profiles, further alignment of conductivity may be necessary. The Align CTD module can be used to align the conductivity data relative to pressure.

Fortran program TRIALIGN.EXE (programmer: Paul Fiedler) was run to find the optimum alignment value for conductivity (i.e., the number of scans by which to advance conductivity). TRIALIGN finds the maximum temperature gradient within a 240-scan window using linear regression; TRIALIGN tests for the gradient using only the first 10,000 scans to ensure data are from the downcast and imposes the criteria that depth must change by at least 5m in the 240-scan window. Conductivity alignments are tested within the region of maximum temperature gradient because misalignment of temperature and conductivity often results in excessive salinity spikes when temperature is changing rapidly. Within the window, scans are shifted by -24 to +24. For each shift, salinity is derived for each scan and a linear regression is fit to the salinity values. The shift that results in the minimum standard deviation of the regression residuals is selected as the optimal value for that cast. Optimal values for all casts are averaged to obtain a single alignment value for the cruise (one scan is 0.042 seconds).

This was confirmed when TRIALIGN gave a mean optimum advance of +0.006 sec (SE=0.0035, see Trialign0.dat in \FILTER, which has the following columns: CTD file name, pressure (db) at the maximum temperature gradient, maximum temperature gradient (deg C/db), optimal advance (scans), and relative standard deviation of residuals). This value is equivalent to 0.14 scans and is not statistically different from zero. Slight alignment of C1145 was needed; TRIALIGN cave a mean optimum advance of +0.061 sec (SE=0.0025).

The options selected for processing in Align CTD were as follows for all casts:

alignctd_adv = c1S/m 0.061

5. Cell Thermal Mass Module:

Cell Thermal Mass uses a recursive filter to remove conductivity cell thermal mass effects from the measured conductivity. In areas with large temperature gradients, the thermal mass correction is on the order of 0.005 psu. In areas with small temperature gradients, the correction is negligible.

The following Sea-Bird Electronics Inc. recommendations for Cell Thermal Mass when processing SBE 9plus data, with TC duct, were used:

 # celltm_alpha = 0.0300, 0.0300
 # celltm_tau = 7.0000, 7.0000
 # celltm_temp_sensor_use_for_cond = primary, secondary

6. Loop Edit Module:

Loop Edit flags data that exhibit a change in the mean CTD ascent or descent rate (e.g., pressure reversals or slowdowns). Such changes in ascent or descent rates are usually created by ship heave as the CTD unit is lowered or raised, and indicate unreliable data. Data that have been flagged are documented in the *.cnv header. In this module, we remove any scans that were flagged as bad during data collection.

The options selected for processing in Loop Edit follow the recommendations of Sea-Bird Electronics Inc. for all casts:

 # loopedit_minVelocity = 0.250
 # loopedit_surfaceSoak: minDepth = 1.0, maxDepth = 5, useDeckPress = 0
 # loopedit_excl_bad_scans = yes

7. Derive Module:

Derive uses pressure, temperature, and conductivity from the input *.cnv file to compute the following oceanographic variables, which are routinely used in the assessment of protected species (other variables are available upon request):

- Salinity
- Density (density, sigma-theta, sigma-t, sigma-1, sigma-2, sigma-4)
- Depth (salt water, fresh water)
- Sound velocity (which can be calculated using the Chen-Millero, DelGrosso or Wilson equation)
- Average sound velocity (the harmonic mean from the surface to the current CTD depth, which is calculated on the downcast only)

The following processing options were selected in this module for all CTD and SEACAT casts:

 # name 5 = depSM: Depth [salt water, m], lat = 31
 # name 6 = potemp090C: Potential Temperature [ITS-90, deg C]
 # name 7 = potemp190C: Potential Temperature, 2 [ITS-90, deg C]

name 8 = T2-T190C: Temperature Difference, 2 - 1 [ITS-90, deg C]
name 9 = C2-C1S/m: Conductivity Difference, 2 - 1 [S/m]
name 10 = sal00: Salinity, Practical [PSU]
name 11 = sal11: Salinity, Practical, 2 [PSU]
name 12 = secS-priS: Salinity, Practical, Difference, 2 - 1 [PSU]
name 13 = sigma-é00: Density [sigma-theta, kg/m^3]
name 14 = sigma-é11: Density, 2 [sigma-theta, kg/m^3]
name 15 = svCM: Sound Velocity [Chen-Millero, m/s]
name 16 = avgsvCM: Average Sound Velocity [Chen-Millero, m/s]
name 17 = svCM1: Sound Velocity, 2 [Chen-Millero, m/s]

Note that there is no option in Sea-Bird's SBE Data Processing SEASOFT-Win32 to calculate Average Sound Velocity from secondary sensor data.

To calculate average sound velocity, the following values were used:
minimum pressure = 2 db [average depth of the acoustic array]
minimum salinity = 20 psu [recommended Sea-Bird Electronics Inc.]
Latitude = 10 °N [this value is used only if NMEA latitude is not available in the header]

The profiles output by the Derive module were inspected by the Senior Oceanographer for bad data caused by sensor failure, temperature inversions, low surface salinity measurements (likely the result of rain), and spikes in salinity. Comments about each cast are in \Documentation\ STAR2006 DSJ CTD Cast info.xls. Comment codes are:

A – acceptable
IV – temperature inversion
R – reject cast

8. Bin Average Module:

The bin average module averages temperature, conductivity, pressure, and oceanographic variables in user-selected intervals; the intervals may be defined using pressure, depth, scan number, or time range. SWFSC MMTD uses 1m bins, with no surface bin. In this module, we exclude scans that were flagged as bad during the loop edit module.

The following processing options were selected in this module for all casts:
binavg_bintype = meters
binavg_binsize = 1
binavg_excl_bad_scans = yes
binavg_skipover = 0
binavg_surface_bin = no, min = 0.000, max = 5.000, value = 0.000

9. Split Module:

Split separates the data from an input *.cnv file into upcast (pressure decreasing) and downcast (pressure increasing) *.cnv files. Downcast only files are output because they do not contain the data collected when the bottles are fired (e.g., repetitive sampling at the same pressure). Consequently, they are used to derive variables such as thermocline depth and strength.

The following options were selected in this module for all casts:

split_excl_bad_scans = no
output the downcast only (into the \Split folder).
This adds a 'd' at the beginning of the filenames.

10. ASCII Out Module:

ASCII Out outputs the header and/or the data from a binary data file (*.cnv). Data are written to an ASCII file (*.asc), while the header information, which lists each processing module and the variables applied, is written to a separate ASCII file (*.hdr).

This module was run twice. First, to convert the complete cast; second, to convert the downcast-only files created with the SPLIT module.

The following options were selected in this module for all casts:
Output Header and Data files
Label Column at top of the file
Column separator = space

FINAL PRODUCT

ASCII Out outputs the header and/or the data from a binary data file (*.cnv). Data are written to an ASCII file (*.asc), while the header information, which lists each processing module and the variables applied, is written to a separate ASCII file (*.hdr).

ASCII down-cast output files, containing only data recorded by the secondary sensors and no error flags, can be found in the \Final\ASCII_Down_cast folder.

The file headers have been saved separately from the final ASCII data files in both directories. The header files contain time in two separate fields: "System UpLoad Time" and "NMEA UTC (Time)". The time in the "System UpLoad Time" field is taken from the PC used to the collect the data and may not be accurate (e.g., this field may be recorded in local time, rather than Coordinated Universal Time, and may not have been adjusted for local time zone changes). The Coordinated Universal Time in the "NMEA UTC (Time)" field is taken from the GPS unit and is accurate as long as the GPS functioned properly.

The downcast profile is used to derive variables commonly used in protected species assessments, such as thermocline depth and strength. Plots of complete casts show hysteresis, or depth offsets, of 5-8 m. The error in the depth, as indicated by the offsets, are expected to occur primarily in the upcasts due to "package wake" (i.e., the "shadowing" of the sensors by the rosette and frame as the CTD is pulled up through the water column). Additionally, the upcasts include repetitive sampling of the same depth when bottles are fired to collect water samples.

In total, 179 valid CTD casts were conducted during STAR 2006 on the DSJ. The data set is comprised of 173 normal station casts and 6 test casts in which all bottles are tripped at 500m. The format of the downcast output files, containing only primary sensor data, are shown below.

```
  PrDM     C0S/m    T090C  DepSM Potemp090C   Sal00 Sigma-é00    SvCM  AvgsvCM Nbin
 2.011  5.364927  27.6538  2.000   27.6533  33.4438  21.3371  1538.95  1538.95  11
 3.017  5.365673  27.6570  3.000   27.6563  33.4465  21.3381  1538.98  1538.95  24
 4.023  5.365637  27.6561  4.000   27.6551  33.4466  21.3386  1538.99  1538.96  47
 5.028  5.365699  27.6565  5.000   27.6553  33.4465  21.3385  1539.01  1538.97  50
```

The columns are:
PrDM = Digiquartz pressure in decibars (db)
C0S/m = Primary conductivity in Siemens per meter (S/m)
T090C = Primary temperature, in degrees Celsius (ºC), calculated using the ITS-90 standard
Sal00 = Salinity, in practical salinity units (psu), derived from the primary temperature and conductivity sensors
DepSM = Salt water depth in meters (m)
Sigma-é00 = Density [sigma-theta], in kilograms per cubic meter (kg/m^3), calculated from the primary temperature sensor and derived salinity
SvCM = Chen-Millero's sound velocity in meters per second (m/s) calculated from the primary temperature sensor and derived salinity
AvgsvCM = Chen-Millero's average sound velocity in meters per second (m/s) calculated from the primary temperature sensor and derived salinity
Nbin = number of scans used to calculate the bin average

Perl program CTDPositionCheck (programmer: Dan Prosperi) was used to check the CTD cast date/times and positions recorded in the header files against the edited TSG file for the survey. 178 of 179 files had matching TSG records; one file needed a longitude correction.

Paul Fiedler, 16 June 2021

Appendix 1. STAR 2006 DSJ Sea-Bird CTD Data Processing Configuration File

STAR 2006 DSJ.con

```
Frequency channels suppressed : 0
Voltage words suppressed      : 4
Computer interface            : RS-232C
Scans to average              : 1
Surface PAR voltage added     : No
NMEA position data added      : No
Scan time added               : No

1) Frequency 0, Temperature

   Serial number : 1448
   Calibrated on : 22-Mar-07
   G             : 4.82393572e-003
   H             : 6.72237137e-004
   I             : 2.59500268e-005
   J             : 2.07179761e-006
   F0            : 1000.000
   Slope         : 1.00000000
   Offset        : 0.0000

2) Frequency 1, Conductivity

   Serial number : 1165
   Calibrated on : 09-Mar-07
   G             : -3.96752349e+000
   H             : 5.47689293e-001
   I             : 1.90561733e-004
   J             : 1.98409688e-005
   CTcor         : 3.2500e-006
   CPcor         : -9.57000000e-008
   Slope         : 1.00000000
   Offset        : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC

   Serial number : 53561/0311
   Calibrated on : 21-Oct-2005
   C1            : -4.123560e+004
   C2            : 1.043267e+000
   C3            : 1.330030e-002
   D1            : 4.018400e-002
   D2            : 0.000000e+000
   T1            : 3.020637e+001
   T2            : 4.924132e-005
   T3            : 3.833950e-006
   T4            : 6.451910e-009
   T5            : 0.000000e+000
   Slope         : 0.99998000
   Offset        : -4.27000
   AD590M        : 1.167000e-002
   AD590B        : -8.165620e+000

4) Frequency 3, Temperature, 2

   Serial number : 1352
   Calibrated on : 08-Mar-07
   G             : 4.85510300e-003
   H             : 6.78090622e-004
   I             : 2.63647229e-005
   J             : 2.06701743e-006
   F0            : 1000.000
   Slope         : 1.00000000
   Offset        : 0.0000

5) Frequency 4, Conductivity, 2

   Serial number : 1145
   Calibrated on : 08-Mar-07
   G             : -4.20264711e+000
   H             : 4.64198294e-001
   I             : -6.47373037e-005
   J             : 2.67875408e-005
   CTcor         : 3.2500e-006
   CPcor         : -9.57000000e-008
   Slope         : 1.00000000
   Offset        : 0.00000
```