OC 3570
OPERATIONAL OCEANOGRAPHY & METEOROLOGY
(SUMMER QUARTER AY 2005)

PROJECT

VARIABILITY IN SOUND SPEED PROFILES DERIVED FROM XBT DATA USING SALINITY FROM T/S RELATIONSHIP AND CLIMATOLOGICAL NORMALS VIS-À-VIS IN-SITU CTD OBSERVATIONS

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Background

1. The warfighters need an affordable, reliable operational capability in all environments and the ability to foresee environmental changes that may affect their capabilities. The variable ocean environment greatly affects the efficiency of all naval operations, such as movement of equipment and supplies over the beach, missile targeting or aircraft carrier operations; it also affects the performance of the sensors and systems used by Navy. Knowledge of this environment and its impact on the various sensors available to the users in the field are critical to the choice of sensor(s), ability to gain knowledge of the tactical battlespace, and effective delivery of weapons. Thus, the knowledge of the ocean battlespace environment is important for the entire spectrum of naval warfare. These needs translate to the requirements for understanding processes and phenomenon; measurements and mapping; nowcasts and forecasts of ocean variability; and translation of environmental effects to their impacts on sensors, platforms, structures, and operations.

2. The success of every undersea naval operations i.e., anti-submarine warfare (ASW), mine and counter mine warfare (MIW) and naval special operations revolves around sound propagation in ocean environment.

Statement of Problem

3. It is an established fact that the sound velocity (SV) is a function of temperature, salinity and pressure. In real scenario during operational deployments, naval ships are not able to deploy CTDs for in-situ data collection for operational reasons and have access to only XBT observations. This leads to calculation of sound velocity based on in-situ temperature profile and historical salinity data, which in turn is used as input for sonar performance prediction models.

4. It is proposed to study the differences in SV profiles computed from the following:-

(a) In-situ temperature profiles recorded by XBTs and

(i) Mean sea surface salinity.

(ii) Nearest mean salinity profiles.

(iii) Temperature-Salinity relationship derived polynomial fit.

(b) Ship's CTD measurements.

5. If the differences are significant, what are their implications on sonar performance?

Data and Methods

6. **Duration**. For this study CTD and XBT collected during the following two legs of "OC3570 - Operational Oceanography Cruise" on board R/V Point Sur (details of vessel placed at Appendix A) have been used:-

(a) Leg I - 18 – 20 Jul 05

(b) Leg II - 21 – 23 Jul 05

7. **Area**. The area of study is Monterey Bay bounded by the following co-ordinates:-

(a) 36.25 N 122.50 W (b) 36.25 N 121.80 W

(c) 36.85 N 122.50 W (d) 36.85 N 121.80 W

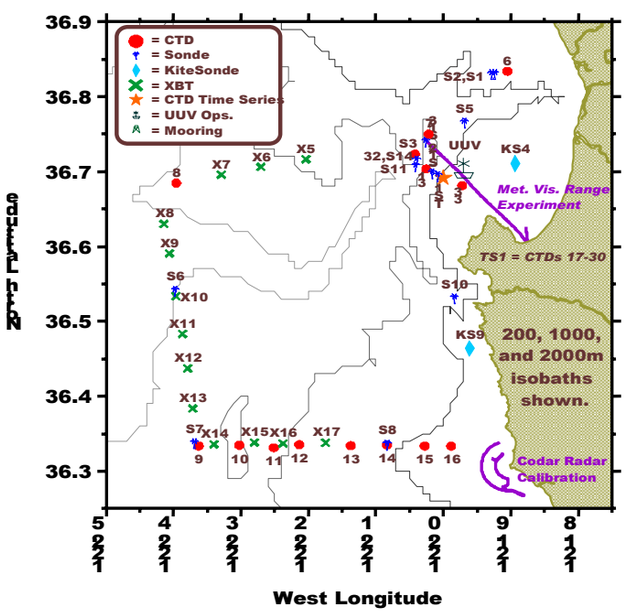


Fig 1. Cruise Area

8. **Data Collection**.

(a) **Data Sources**. In this study following data have been used:-

(i) CTD & XBT data collected during the two legs of the cruise.

(ii) **RClimo**. High resolution Regional Climatology for the Central California Coastal Region[1] (RClimo) for the month of August. The Regional climatology covers the area between 32.50 – 39.70 ^{0}N and 127.50-119.20 ^{0}W [Fig 2] and has been prepared using 3537 profiles for

[1] 'High resolution Regional Climatology for the Central California Coastal Region'. Hyoon-Sook Kim, Avijit Gangopadhyay, Leslie K Rosenfeld and Frank L Bub. 2005

the month of August. The data has been averaged on a high resolution grid and objectively interpolated for average profiles to provide regular grids. The preparation of RClimo involves the computation of averages over density layers in the vertical and allowing for data gaps in the horizontal if data is not available at high resolution. The objective analysis in the second step uses the correlation length scales derived from the data itself and an averaging radius to preserve the scales and variability of the synoptic fields. RClimo provides temperature and salinity profiles on a 20 km resolution grid upto 5000m of depth.

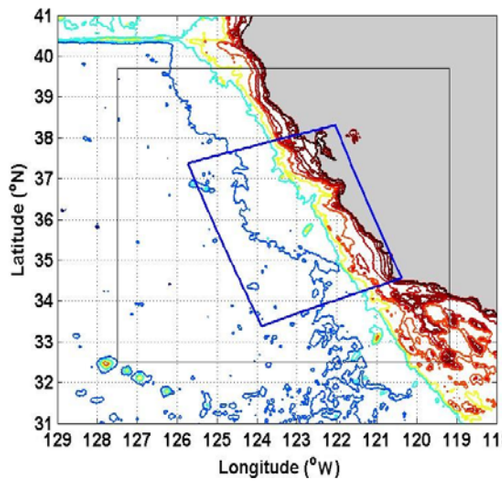


Fig 2. Regional Climatology Area

(iii) **Generalized Digital Environmental Model (GDEMV)**. In addition, the average sound velocity and salinity data for the month of July at following positions available from unclassified Naval Oceanographic Data Warehouse website (https://128.160.23.42) have been used: -

(aa) 36.75 N & 122.50 W

(ab) 36.25 N & 122.25 W

(ac) 36.75 N & 122.25 W

(b) **Measuring Equipment**. The brief descriptions of the measuring systems (CTD and XBT) used for data collection are placed at Appendix B.

(c) **Deployment of Equipment**. The details of CTD and XBT deployments together with graphical depiction are placed at Appendix C.

(d) **Observations**. During the two phases of the cruise, a total of 32 XBT and 60 CTD profiles were taken. Details of the data utilized vis-à-vis total observations for the study are tabulated below:-

Leg	Equipment	Total	Time Series (TS)	Non-TS	TS Used	Non-Ts Used
1	CTD	25	14	11	14	06
	XBT	13	-	13	-	06
2	CTD	35	13	22	13	15
	XBT	19	-	19	-	14

9. **Methodology**. The study has been carried out in two parts utilizing non-time series and time series data respectively in the following manners: -

(a) **Non-Time Series Observations**. The XBT and CTD observations were taken in close proximity only during the non-time series part of the cruise. For every XBT observation, a sound velocity profile has been worked out using Medwin Equation[2], as this equation holds well for depths upto 1000 m. The sound velocity profiles have been created for with XBT temperature profiles using salinity derived in the following manner:-

(i) **TS Relationship derived Sound Velocity**. TS relationship has been worked out using all the 60 CTD profiles recorded during the cruise. Based on this TS relationship, a polynomial fit has been generated by dividing the TS plot in four segments as no single polynomial fit upto 5th order was able to define the relationship. The polynomial function used for generation of salinity and in turn sound velocity profile for each XBT profile used is shown in Fig 3.

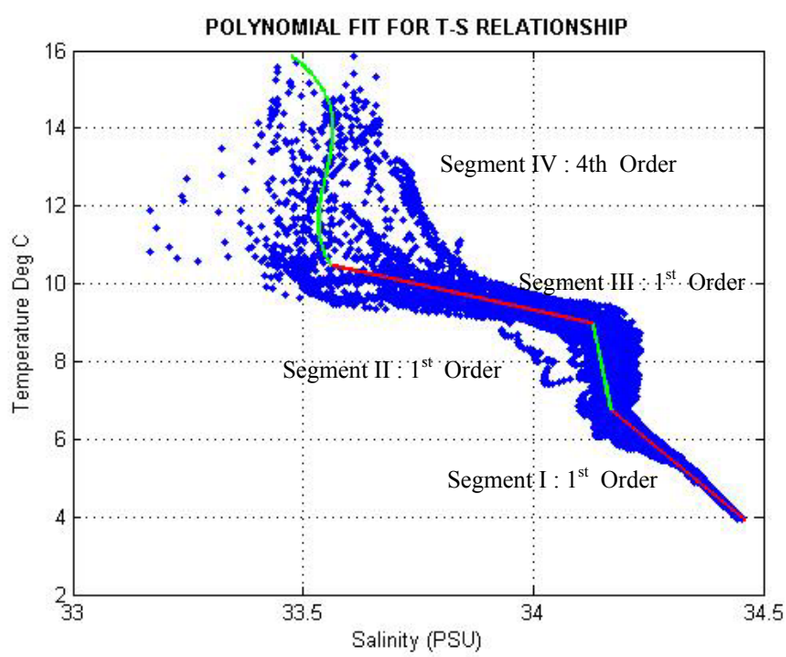


Fig 3. Polynomial for TS relationship

[2] Principles of Underwater Sound. Urick, Robert J.

(ii) **Regional Climatology (RClimo) derived Sound Velocity**. For every XBT observation used, a nearest salinity profile has been extracted from RClimo and ingested with the respective XBT temperature profile to generate sound velocity profile.

(iii) **Surface Salinity derived Sound Velocity**. For every XBT profile, using surface salinity extracted from RClimo, a sound velocity profile has been constructed to study the effect of single salinity value vis-à-vis a profile.

(b) **Time Series Observations**. The time series observations TS1 and TS2 recorded during the two legs of the cruise have been analyzed to study hourly variations in temperature, salinity, sound speed profiles, Sonic Layer Depths (SLD) and Deep Sound Channel (DSC) axis (if present).

Results and Discussion

10. **Non-Time series results**. The 20 in number observations used for non-time series analysis reveal the followings:-

(a) The TS relationship generated sound speed profiles are the closest to the CTD in-situ observations in the neighborhood followed by RClimo based generated sound speed profiles. The sound velocity profiles generated with sea surface salinity (derived from RClimo) shows the maximum departure from the in-situ CTD observed sound speed profiles. The salinity profile generated by TS relationship are almost identical to CTD observed salinity values whereas, RClimo salinity profiles show lower values than the CTD salinity values. The difference is varies between 0.4 to 0.7 PSU at surface and at about 400 m of depth it merges with the CTD profiles. The results are placed at Appendix D. This is so because the TS relationship has been generated from the in-situ CTD data. Thus, if the area is sampled with CTD prior to the operational need, a fairly accurate acoustic assessment can be made based on the TS relationship generated from the CTD data and in-situ XBT observations.

(b) The axis of maximum sound speed (SLD) has been found very close to surface. The range of variations in minimum sound speed profile is comparable in all the three cases but DSC depths derived from the sea surface salinity shows negative co-relation w.r.t CTD observations (Table 1).

Method	Min Sound Vel	DSC axis
RClimo	0.702	0.128
TS-Polyfit	0.690	0.129
Surface Salinity	0.725	-0.202

Table 1 – Co-relation w.r.t. CTD Observations

(c) The large departure seen in minimum velocity calculated using mean surface salinity, as compared to other two methods, establishes the need for a salinity profile for accurate assessment of acoustic conditions. The departures are shown in Fig 4.

(d) The large variations in the sound velocity in the surface layers is the indicative of upper layers being more dynamic and influenced by surface forcing (insolation, cooling and wind stress).

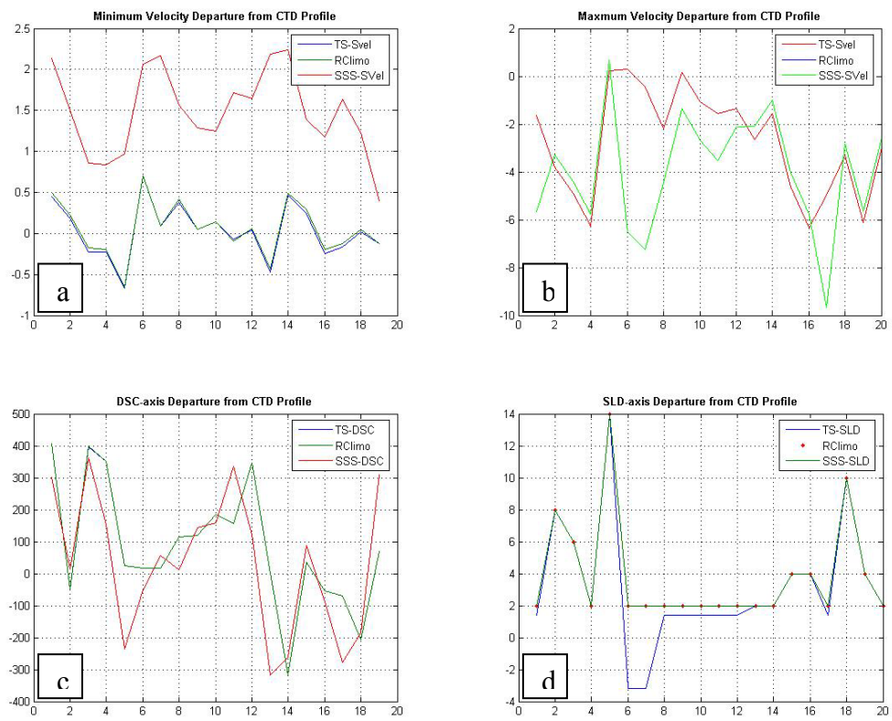


Fig 4 – Departure from CTD observations (a) Min Sound Velocity, (b) Max Sound Velocity, (c) DSC-axis, (d) SLD-axis

(e) The sound velocity profiles based on XBT observation when compared with average sound velocity profiles of GDEMV performed better emphasizing the importance of in-situ observations. Salinity profiles of RClimo, TS relationship and CTD when compared with GDEMV profiles, the RClimo shows the maximum departure (~0.7 psu) at surface and GDEMV lies in between CTD and RClimo Appendix E.

11. **Time series results**. The time series data recorded during both the legs show the followings: -

(a) The hourly variations in sound velocity maximums observed near the surface are higher than the hourly variations in sound velocity minimums. The graphical displays are placed at Appendix F.

(b) The thermocline breaks out with the time during night hours and the strength of negative gradient weakens due to radiative cooling (reference Appendix F).

(c) The maximum and minimum sound velocity observed during Leg 2 is lesser than the Leg 1 [Fig 5 (a)].

(d) The axis of Deep Sound Channel (DSC) is deeper (between 650 – 750 m) during Leg 2 as compared to Leg 1 (50-250 m). Also, DSC shows higher variation during Leg 1 as compared to Leg 2 [Fig 5 (b)].

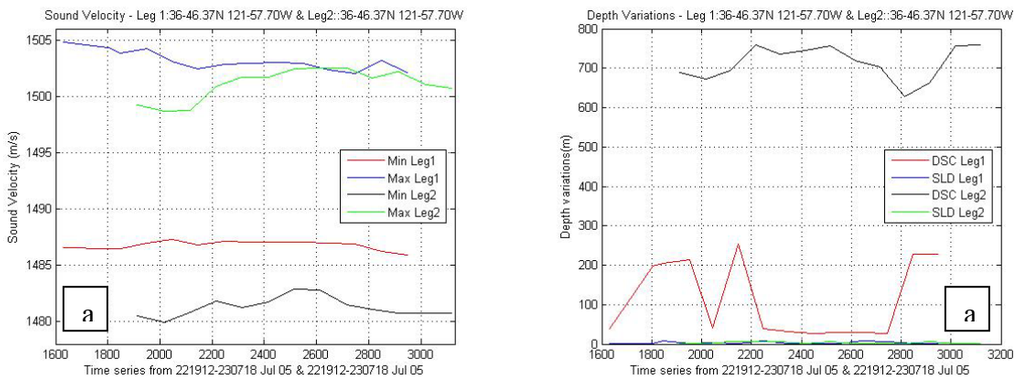
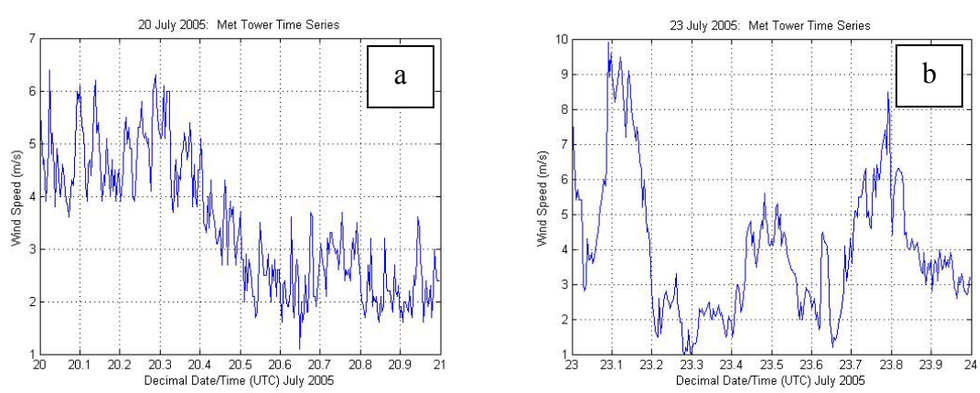


Fig 5 – Time Series CTD observations during the Leg 1 and Leg 2 (a) Min and Max Sound Velocity variations, (b) DSC and SLD axis variations

(e) This could be attributed to higher wind stress [Fig 6(a) & (b)] leading to strong mixing and lower SSTs [Fig 6(c) & (d)] during Leg 2 pushing the layer deeper as compared to Leg 1. The higher variation in DSC axis during Leg 1 could be co-related to the presence of strong internal tide as evident in density plot of time series for Leg 1 and Leg 2 [Fig 7].



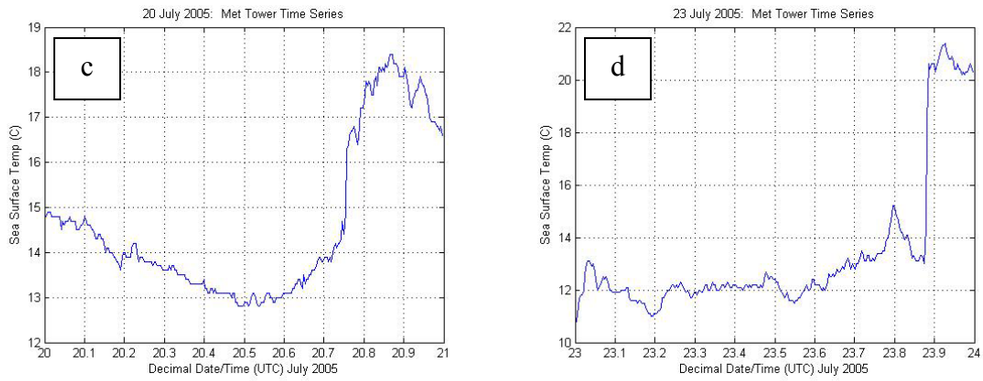


Fig 6 – Surface observations during the Leg 1 and Leg 2 (a) Wind speed – 20 Jul (Leg1), (b) Wind speed – 20 Jul (Leg2), (c) Sea surface temperature (Leg1), (d) Sea surface temperature (Leg2).

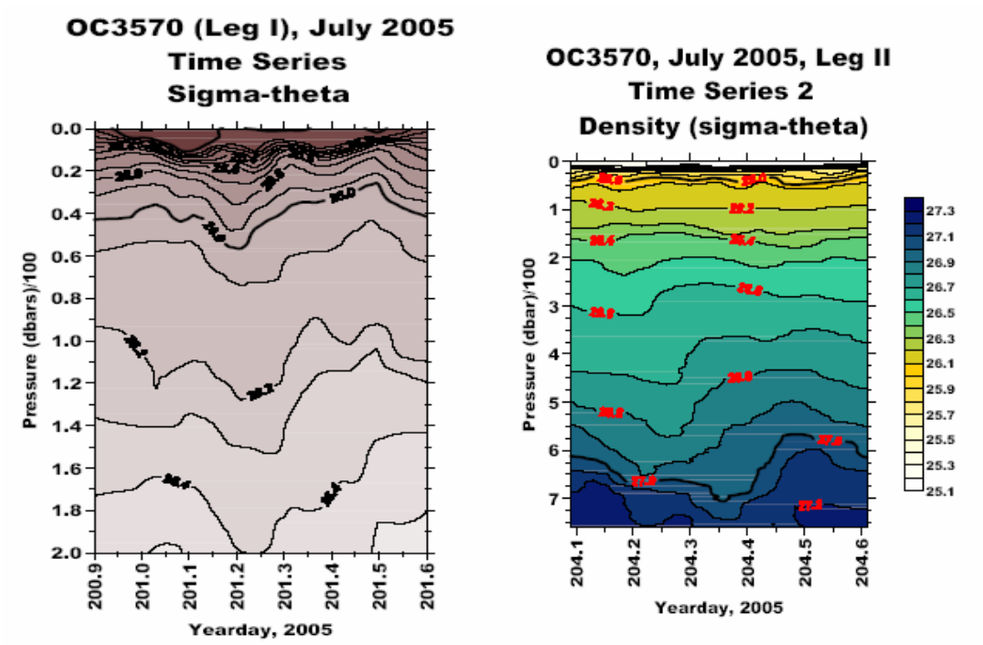


Fig 7 – Density plot of Leg 1 & 2 showing presence of Internal Tide during Leg 1

Conclusion

13. The following aspect of the ocean variability in the Monterey Bay and its impact on ocean acoustic has been ascertained: -

(a) The depth of minimum sound velocity (DSC axis) depends on salinity and hence to ensure the optimal performance of the underwater sensors, the relative importance of the following be taken into account: -

(i) In-situ data.

(ii) Prior survey of area as close as possible in time.

(iii) Climatology as close as possible in terms of time and space.

(b) Temporal variations are significant and hence must be accounted for while using historical/ climatological data.

(c) Upper oceanic layer is more dynamic than deeper layer.

(d) Surface conditions can alter acoustic conditions.

(e) Internal tide can greatly influence DSC axis.

References

- http://www.seabird.com/products/spec_sheets/911data.htm
- http://www.sippican.com
- Hyoon-Sook Kim, Avijit Gangopadhyay, Leslie K Rosenfeld and Frank L Bub. ‘High resolution Regional Climatology for the Central California Coastal Region’. 2005
- Urick, Robert J. Principles of Underwater Sound. 3rd edition
- https://128.160.23.42/gdemv/gdemv.html

Appendix A
(Refers to Para 6)

R/V POINT SUR

1. The R/V POINT SUR, owned by the National Science Foundation (NSF), is operated for the Central California Oceanographic Cooperative (CENCAL) by Moss Landing Marine Laboratories, which is located on Monterey Bay. Designed by Rudolph F. Matzer, as was the CAPE HATTERAS, the vessel was built in 1980 by Atlantic Marine inc., and is especially suited for short to medium-length cruises. The R/V POINT SUR normally operates in waters off California, Oregon and Washington, with extended cruises to Mexico, Hawaii and Alaska.

2. R/V POINT SUR is well equipped with all the necessary navigational, laboratory and mechanical facilities that support biological, geological, chemical and physical oceanographic research. Setting and recovering current meters, chemical sampling, diving, biological trawling, gear testing and seismic reflection profiling are among a number of operations within the ship's capabilities.

3. **Description of Vessel**.

LENGTH (LOA): 135 feet BEAM (extreme): 32 feet DRAFT (max): 9 feet GROSS TONNAGE: 298 tons DISPLACEMENT (L tons): 539, full load	LABORATORY (sq. ft.): 704 total WET: 96 DRY: 488 ELECTRONICS: 120
COMPLIMENT: CREW: 9 TECHNICIANS: 1 SCIENTIFIC PERSONNEL: 11	SEWAGE SYSTEM: MSD: Omnipure 8MC - 1800 gallons/day HOLDING TANK: 1800 gallons
MAIN PROPULSION: Two Caterpillar 379TA marine diesel, 565 shp each BOW THRUSTER: None SHIP'S SERVICE GENERATORS: Two at 175 KW each PROPELLERS: 2 controllable pitches	INCINERATOR: None Garbage returned to port.
SPEED: CRUISING: 10 knots FULL: 11.5knots MINIMUM: 0.1 knots	STATE ID #: CF-1872-XF
ENDURANCE: 21 days, limited by stores RANGE: 6,800 NM at 10 Knots FUEL CAPACITY: 28,695 gallons	CLASSIFICATION: American Bureau of Shipping (ABS) Load-line Certification

OWNERSHIP: Title held by National Science Foundation	

Scientific Capabilities

4. **Brief Description**. The R/V Point Sur is a general-purpose oceanographic vessel built by Atlantic Marine 1981, sponsored by the National Science Foundation. Installed scientific equipment on the Point Sur includes:-

Navigation:
GPS: Three on bridge: Magnavox 200 6 channel DGPS, Furuno GP80n and an Ashtech ADU2 three-dimensional positioning GPS. DGPS USCG differential signal received for all.

RADAR: Two Furuno digital color radars with target/nav plotters and gyro stabilization.

Gyrocompass: Two Sperry MK 37, one located in the main lab and one located on bridge.

Speed Log: Acoustic Doppler on bridge.

Communication:
Cellular phone: One on the bridge and one in the lab.
Satellite KVH Track Phone on bridge.
Nera Saturn Bm INMARSAT B.

VHF Marine Band: Two fixed units on bridge and two hand-held units.

Single Side Band: One unit on bridge.

Winches:
Hydrographic: CTD Markey CUBE-6s holding 5000 meters of .322 inch EM cable.
Hydrographic: Markey DUSH-5 holding 5000 meters of .322 inch EM cable.
Trawl: Northern Line holding 10,000 meters of .5 inch of wire rope.

Deck Equipment:
Aft Crane: Appleton Crane, SWL 3000 lb @ 34 feet, 6000 lb @ 27 feet.
Forward Crane: Alaska Marine, SWL 2000 lb.
Capstan: Removable hydraulic.

Frames:
A-frame, stern, 10,000 lbs, ramp width 12', 17' clearance
Gallows-frame, stbd side, 5,000 lbs, 11' clearance

Installed Scientific Equipment:
ADCP: R. D. Instruments 150 kHz Vessel Mounted.
R. D. Instruments 300 kHz Vessel Mounted
Echosounder: Knudsen dual frequency echosounder, 12 and 3.5 kHz., Raytheon PTR, EPC 4800 LSR.
CTD/Rosettes: Two Sea Bird 9/11 plus systems with complete sensor suites.
Data Acquisition System: Data acquisition system samples and logs data from meteorological sensors, thermosalinograph, fluorometer transmissomentr and GPS.
UPS: 7 kVA UPS, supplies clean and backup power to lab.
Scintillation Counter: Beckman 5801
Pure Water System: Milli-Q 1 mega ohm pure water system.

Vans:
Refrigeration Van:
Portable van commonly used for processing sediment cores. This van is owned by a researcher at MLML but has occasionally been leased to various ship users.

Appendix B
(Refers to Para 8(b))

SEABIRD ELECTRONICS - CTD SBE 911plus

1. **Features**.

(a) Accurate and stable modular Conductivity and Temperature sensors

(b) Paroscientific Digiquartz® pressure sensor

(c) *TC-Ducted Flow* and pump-controlled time responses to minimize salinity spiking

(d) 24 Hz all-channel scan rate

(e) Depth capability 6800 meters (22,300 ft) (aluminum) or 10500 meters (34,400 ft) (titanium)

(f) Built-in interface for dual C & T sensors (sensors optional)

(g) 8 A/D channels and high power capability for auxiliary sensors

(h) Modem channel for real-time water sampler control (without data interruption)

(i) Built-in NMEA 0183 interface to merge real-time GPS data with the CTD data

(j) Optional Serial Data Uplink allows 9600 baud data pass-thru on shared CTD telemetry channel

(k) Optional SBE 17*plus* V2 SEARAM module for *in-situ* recording and programmable Carousel bottle firing

(l) Powerful Windows software included

2. **System Components**. The 911*plus* CTD system includes:-

(a) SBE 9*plus* **Underwater Unit** with sensors for C, T, and P and a submersible pump

(b) optional auxiliary sensors

(c) SBE 11*plus* V2 **Deck Unit**

3. For real-time data collection, an electro-mechanical seacable (single- or multi-conductor), a slip-ring equipped winch, and computer for data display and logging are typically supplied by the user. An optional SBE 17*plus* V2 SEARAM **Recorder and Auto Fire Module** provides *in-situ* recording and self-contained CTD operation, and can be user-programmed to trigger bottle closure on a Carousel Water Sampler, eliminating the need for the Deck Unit, conductive seacable, and slip-ring equipped winch.

4. **SBE 9*plus* Underwater Unit**. The standard SBE 9*plus* underwater unit has an aluminum housing rated to 6800 meters (22,300 ft), and is supplied with one conductivity and one temperature sensor (fitted with a *TC Duct* and constant-flow pump), and an internally mounted, temperature-compensated Paroscientific Digiquartz pressure sensor for 6000 meter.

5. **SBE 11*plus* V2 Deck Unit**. SBE 11*plus* V2 Deck Unit includes RS-232 and IEEE-488 computer interfaces, a modem channel for real-time water sampler control (including water sampler control push buttons and status lights), NMEA 0183 interface for adding GPS position to CTD data, 12-bit A/D input channel for surface PAR sensor, switch-selectable 115/230 VAC operation, audio tape interface (data backup), LED readout for raw data, and audible bottom contact (or altimeter) alarm. The 11*plus* V2 also provides a remote pressure output (useful as an input signal for towed vehicle control) and a programmable serial ASCII data output containing up to seven variables in computed engineering units. Calibration coefficients are stored in EEPROM, and a separate microcontroller converts raw CTD data to temperature, depth, salinity, etc. The 11*plus* V2 is shipped in a free-standing cabinet with a hardware kit for mounting in a standard 19-inch electronics rack.

6. **SEASOFT**. Supplied with each SBE 911*plus*, SEASOFT calculates a suite of seawater parameters, including salinity, density, buoyancy, sound velocity, etc., and fully supports auxiliary sensors for oxygen, light transmission, PAR, fluorescence, and many other variables. SEASOFT provides real-time plots or number readouts while saving raw data to a disk file from which an ASCII or binary intermediate file in engineering units may subsequently be made. Post-processing utilities provide bin averaging, wild point editing, filtering, time-aligning, and color video graphing / hard copy plotting of profiles, waterfall overlays, and density-contoured TS plots. When operating the 911*plus* with a water sampler, complete bottle housekeeping files based on firing confirmations are recorded. SEASOFT is upgraded frequently; new versions are supplied free to 911*plus* users and posted on our website for easy access by the user community.

Specifications.

7. **Master Clock Error Contribution[2]:**

   (a) Conductivity: 0.00005 S/m

   (b) Temperature: 0.00016 °C

   (c) Pressure: 0.3 dbar with 6800 m (10,000 psia) pressure sensor

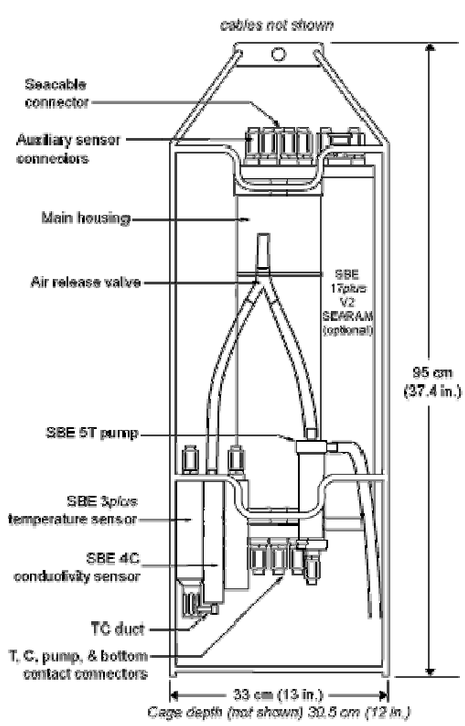
8. **General**.

	Measurement	Initial	Typical	Resolution	Time

	Range	Accuracy	Stability/ Month	at 24 Hz	Response[1]
Conductivity	0 - 7 S/m (0 - 70 mmho/cm)	0.0003 S/m (0.003 mmho/cm)	0.0003 S/m (0.003 mmho/cm)	0.00004 S/m (0.0004 mmho/cm)	0.065 second
Temperature	-5 to +35 °C	0.001 °C	0.0002 °C	0.0002 °C	0.065 second
Pressure	0 to full scale -- 1400/2000/4200/6800/10,500 m (2000/3000/6000/10,000/15,000 psia)	0.015% of full scale	0.0015% of full scale	0.001% of full scale	0.015 second
A/D Inputs	0 to +5 volts	0.005 volts	0.001 volts	0.0012 volts	5.5 Hz 2-pole Butterworth Low Pass Filter

[1]*Single pole approximation including sensor and acquisition system contributions.*

[2] *Based on five-year worst-case error budget including ambient temperature influence of 1 ppm total over -20 to +70 °C plus 1 ppm first year drift plus four additional year's drift at 0.3 ppm per year.*



SBE

SIPPICAN MARK 12 XBT SYSTEM

1. Expandable bathy Thermograph (XBT) is a temperature profiling device with respect to depth. The instrument is extensively used by naval ships for collection of temperature profiles which serves as basic input in acoustic models. The XBT contains a precision thermistor located in the nose of the probe. Changes in water temperature are recorded by changes in the resistance of the thermistor as the XBT falls through the water.

2. **Probe Packaging and Storage.** XBT probes packaged in cardboard (degradable) cartons must be protected from direct exposure to rain, snow, salt spray etc. Cartons must be handled carefully and protected from heavy shock loads and dropping. They must be stored upright as damage may occur to the fine wire in the probes if they are stored on their sides or upside down for any length of time. Probes should also be protected from extremes in temperature and whenever possible should be stored in air conditioned spaces. Acceptable storage temperatures range between -60°C to +70°C, however, probes should be protected from extremes. During the cruise T7 XBT probes were used.

3. **Launchers**. The three versions of launchers, LM-2A Deck Launcher, LM-3A Hand Launcher and LM-4A Thru-Hull Launcher, interface with the MK12 system through the Connector Box. The LM-3A is the most commonly used launcher aboard VOS ships and is usually equipped with 100 ft. of cable. Proper connector box installation/wiring is critical for reliable operation (see below). Care should be taken to prevent damage to the cable when passing through hatches and doorways. Whenever possible the LM-3A should be stored inside and protected from extremes in temperature. It is not necessary or recommended that a spent XBT canister be stored in the LM-3A between probe drops.

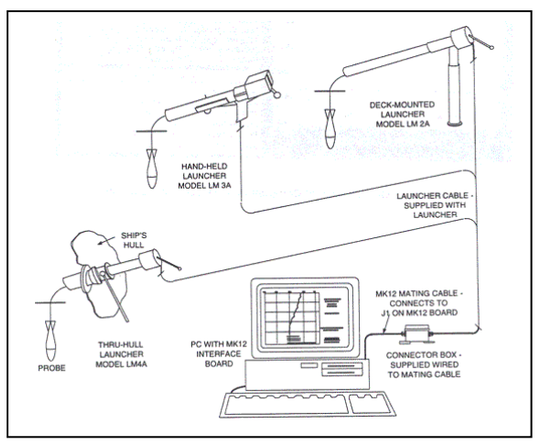
4. **Specifications**.

   (a) Temperature accuracy ± 0.1ºC

   (b) Maximum rated depth - 760 m

   (c) Ship speed – 15 knots

   (d) Vertical resolution – 65 m



Schematic of XBT System

5. **Launching Precautions**. Probes should be launched from the leeward side of the vessel and as far aft as possible. Launching from these locations helps obtain high reliability and will minimize the chances that the fine copper probe wire will come in contact with the ships hull which may cause spikes in the data or a catastrophic wire break. It is permissible to gently handle the wire as it dereels in order to lead it away from the ships hull or superstructure. In extreme

cases where the weather conditions or ships heading continuously blow the wire into the hull, it is possible to launch the probe into your hand and then gently toss it over the side away from the ship. Avoid using radio transmitters (VHF, HF, and SSB) during the XBT deployment as the fine copper wire will act as an antenna. The RF transmission may interrupt the XBT data which will cause large spikes and noise on the profile. Deploying XBT's during thunderstorms should also be avoided as there is always the potential danger of a lightning strike to the operator and / or damage to the XBT system.

Appendix C
(Refers to Para 8(c))

DETAILS OF CTD AND XBT DEPLOYMENTS DURING CRUISE—OC3570, 18-23 July, 2005

1. Depart MLML @ 1539Z on 18 July 2005. Begin Leg I.

Station	Position		Depth (dbar)	Time (UTC)	Comments
July 18, 2005					
CTD 6	36-50.03	121-54.29	66.0	1651-1658	M0
CTD 7	36-44.99	122-01.30	1092.7	1912-1956	M1
July 19, 2005					
XBT 7	36-41.76	122-19.76	760.0	0755	
CTD 8	36-41.07	122-23.76	1010.0	0822-0912	M2
XBT 8	36-37.80	122-24.85	760.0	0938	
CTD 9	36-20.02	122-21.78	1010.6	1139-1220	CUC9
XBT 14	36-20.15	122-20.42	760.0	1235	
CTD 10	36-20.08	122-18.16	960.0	1255-1335	CUC8
XBT 15	36-20.30	122-16.82	760.0	1350	
CTD 11	36-19.88	122-15.09	960.0	1407-1443	CUC7
XBT 16	36-20.22	122-14.27	760.0	1458	
CTD 12	36-20.12	122-12.82	920.0	1511-1545	CUC6
XBT 17	36-20.28	122-10.46	760.0	1605	
CTD 13	36-20.04	122-08.23	642.0	1622-1646	CUC5
Begin Time Series 1					
CTD 17	36-41.47	122-00.01	202.0	2330-2342	
July 20, 2005					
CTD 18	36-41.47	122-00.02	232.6	0103-0114	
CTD 19	36-41.46	121-59.94	212.7	0147-0201	
CTD 20	36-41.55	121-59.99	214.0	0251-0302	
CTD 21	36-41.47	122-00.01	202.0	0346-0358	
CTD 22	36-41.54	122-00.01	254.0	0446-0459	
CTD 23	36-41.53	122-00.13	232.4	0548-0559	
CTD 24	36-41.48	121-59.91	192.3	0645-0658	
CTD 25	36-41.42	122-00.08	217.0	0747-0800	
CTD 26	36-41.49	121-59.96	198.0	0847-0856	
CTD 27	36-41.49	121-59.96	198.0	0946-0958	
CTD 28	36-41.50	121-59.98	218.0	1046-1101	
CTD 29	36-41.50	122-00.02	238.0	1149-1159	
CTD 30	36-41.51	122-00.03	262.9	1247-1303	
End Time Series 1					

2. Arrive MLML @ 1808Z on 20 July 2005. End Leg I.

3. Depart MLML @ 1602Z on 21 July 2005. Begin Leg II.

Station	Position		Depth (dbar)	Time (UTC)	Comments
July 21, 2005					
CTD 34	36-45.46	122-01.93	1010.3	1802-1837	M1
Station	**Position**		**Depth (dbar)**	**Time (UTC)**	**Comments**
July 22, 2005					
CTD 37	36-41.53	122-01.03	708.0	0140-0210	

XBT	18	36-41.48	122-03.76	760.0	0225	
CTD	38	36-41.52	122-04.79	1012.0	0234-0315	
XBT	20	36-41.52	122-06.70	760.0	0330	No XBT
19.						
CTD	39	36-41.49	122-08.55	1024.0	0345-0421	
XBT	21	36-41.41	122-10.51	760.0	0435	
CTD	40	36-41.45	122-12.55	1010.2	0500-0536	
XBT	22	36-41.50	122-14.10	760.0	0549	
CTD	41	36-41.55	122-15.93	1010.0	0604-0642	
XBT	23	36-41.62	122-17.90	760.0	0656	
CTD	42	36-41.49	122-19.62	1010.0	0713-0753	
XBT	24	36-41.52	122-22.18	760.0	0804	
CTD	43	36-41.49	122-23.39	1010.7	0814-0853	
XBT	25	36-41.49	122-25.64	760.0	0905	
CTD	44	36-41.51	122-27.12	1010.2	0917-0957	
XBT	26	36-38.52	122-27.19	760.0	1028	
XBT	31	36-23.51	122-27.16	760.0	1205	
CTD	45	36-19.96	122-27.17	1010.0	1230-1312	CUC11
XBT	32	36-20.11	122-26.62	760.0	1323	
CTD	46	36-19.98	122-25.28	1010.0	1338-1417	CUC10
XBT	33	36-19.99	122-23.79	760.0	1439	
CTD	47	36-20.03	122-21.83	1010.0	1450-1529	CUC9
XBT	34	36-20.12	122-19.98	760.0	1549	
CTD	48	36-20.07	122-18.20	834.0	1604-1641	CUC8
XBT	35	36-20.15	122-15.80	760.0	1702	
CTD	49	36-20.07	122-15.15	960.0	1713-1750	CUC7
XBT	36	36-20.29	122-13.91	760.0	1804	
CTD	50	36-20.03	122-12.77	920.0	1815-1858	CUC6
XBT	37	36-20.03	122-10.88	760.0	1922	
CTD	51	36-20.07	122-08.44	682.0	1941-2013	CUC5

July 23, 2005

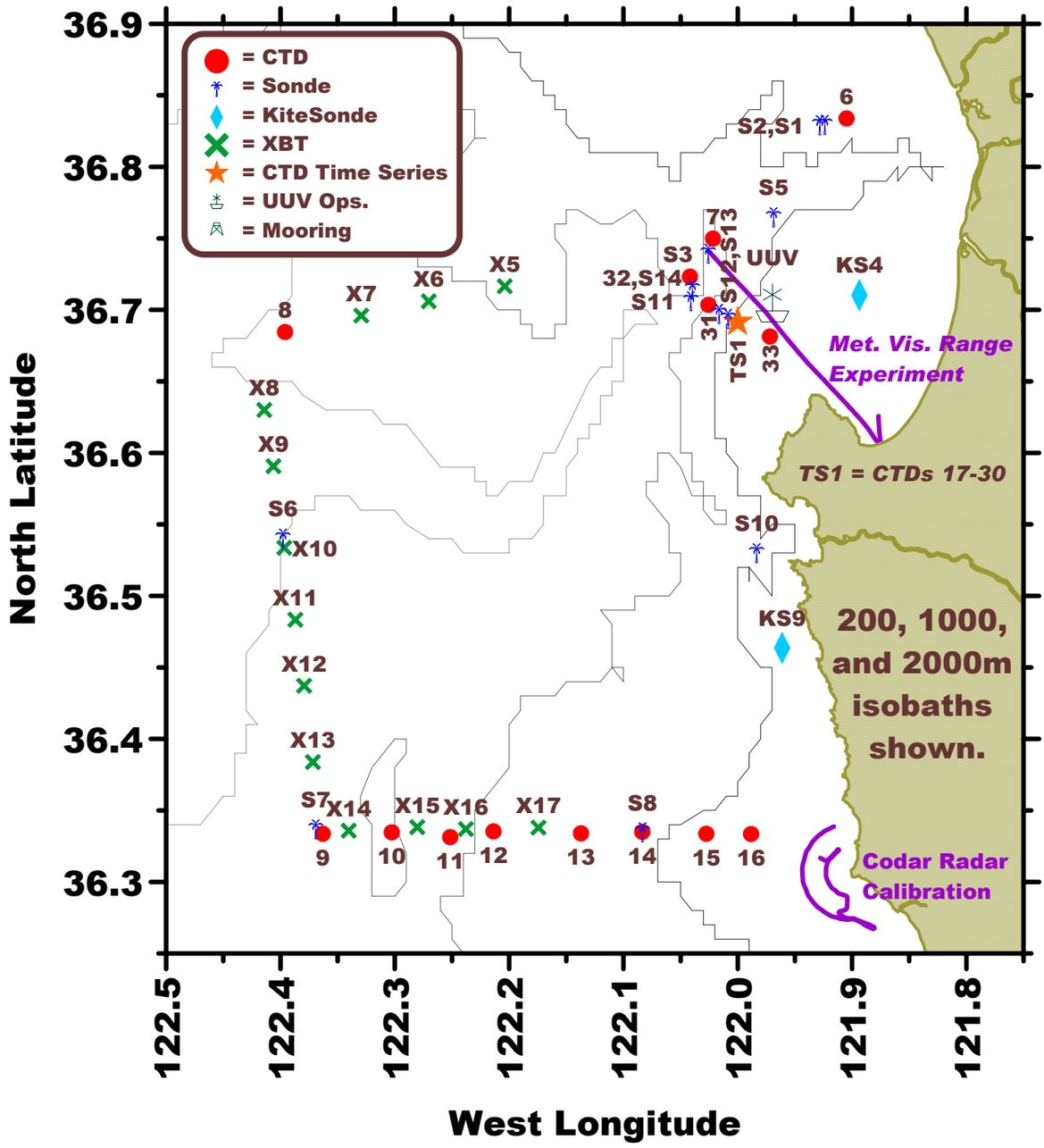
Begin Time Series 2

CTD	56	36-46.31	121-57.70	758.0	0212-0243
CTD	57	36-46.32	121-57.70	758.0	0317-0346
CTD	58	36-46.34	121-57.71	758.0	0415-0446
CTD	59	36-46.33	121-57.74	758.0	0516-0550
CTD	60	36-46.34	121-57.70	758.0	0615-0652
Sonde	24	36-46.27	121-58.11	----	0644
CTD	61	36-46.33	121-57.72	758.6	0715-0748
CTD	62	36-46.32	121-57.71	758.0	0815-0845
CTD	63	36-46.36	121-57.75	758.0	0915-0944
CTD	64	36-46.34	121-57.74	756.0	1015-1045
CTD	65	36-46.32	121-57.70	758.0	1115-1144
CTD	66	36-46.30	121-57.70	758.0	1214-1246
CTD	67	36-46.35	121-57.74	758.0	1318-1349
CTD	68	36-46.40	121-57.72	758.0	1418-1446

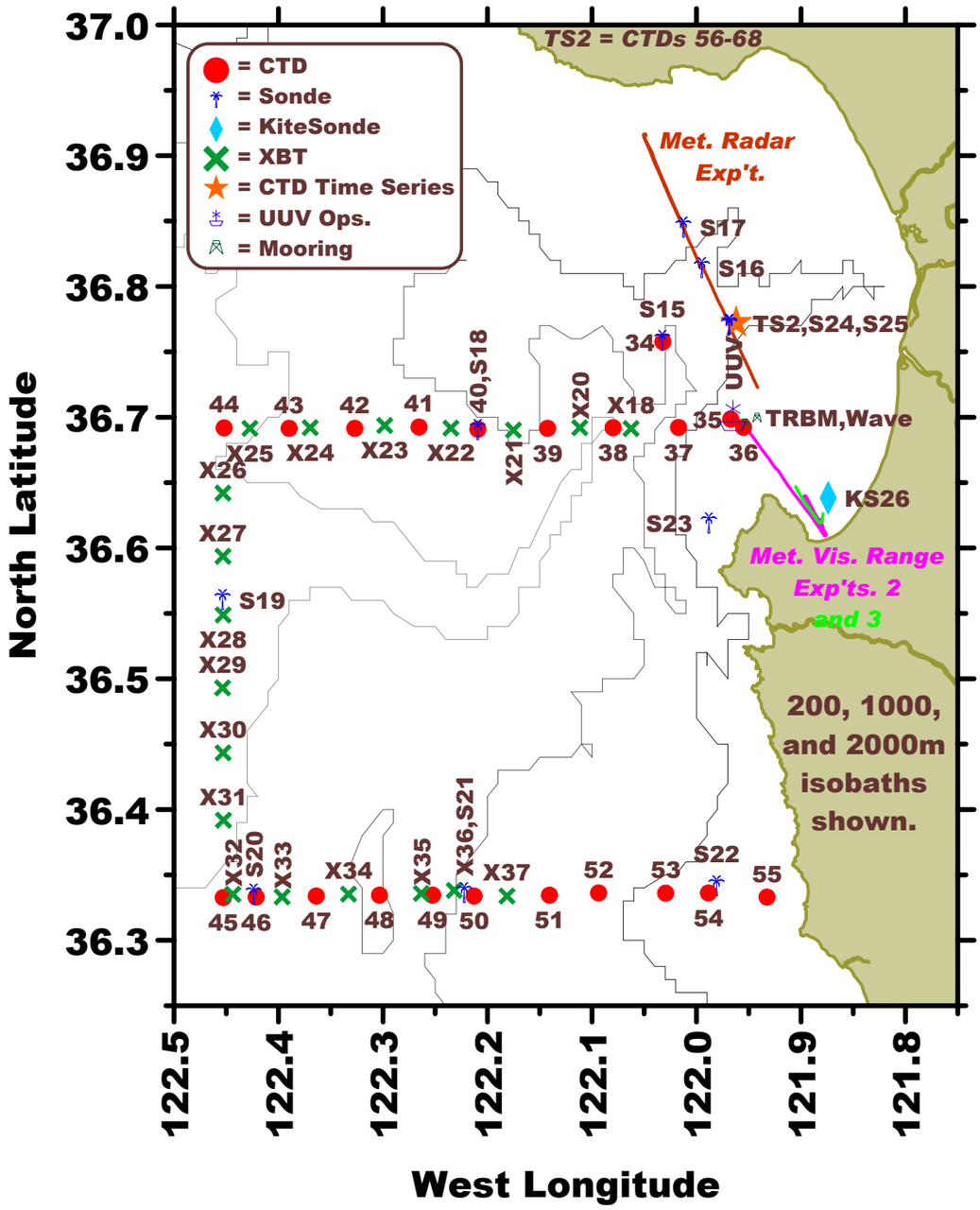
End Time Series 2

4. Arrive MLML @ 2116Z on 23 July 2005.

OC3570, July 2005
Leg I



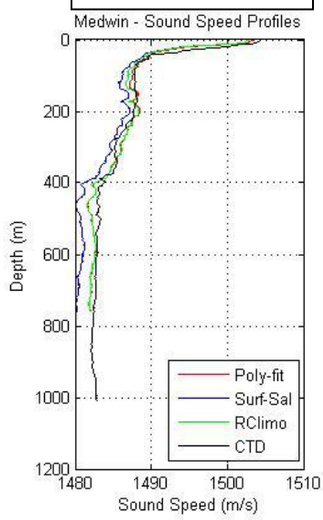
OC3570, July 2005
Leg II



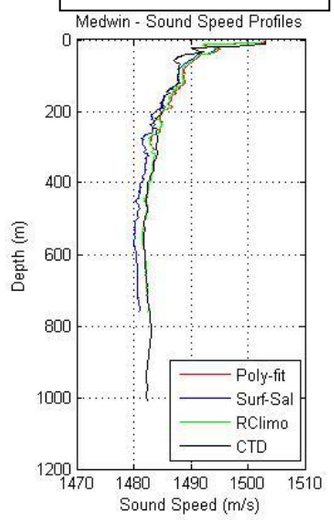
Appendix D
(Refers to Para 10(a))

RESULTS OF NON-TIME SERIES OBSERVATIONS
(SOUND VELOCITY PROFILES)

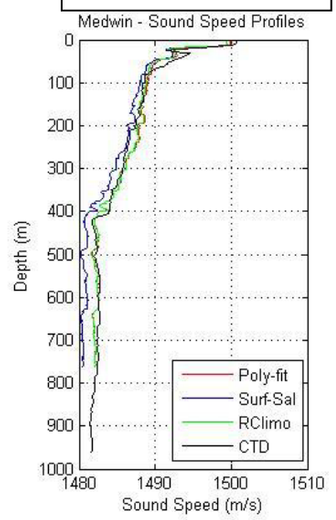
XBT 8 & CTD 8



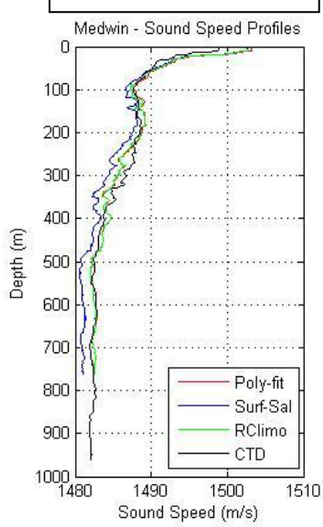
XBT 14 & CTD 9



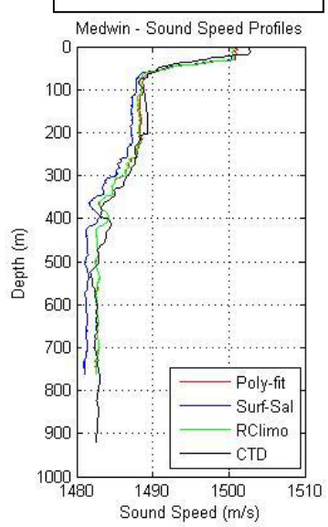
XBT 15 & CTD 10



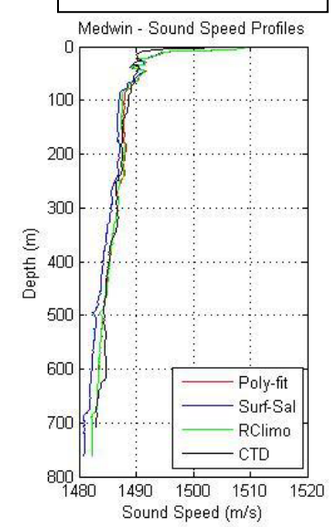
XBT 16& CTD 11



XBT 17& CTD 12



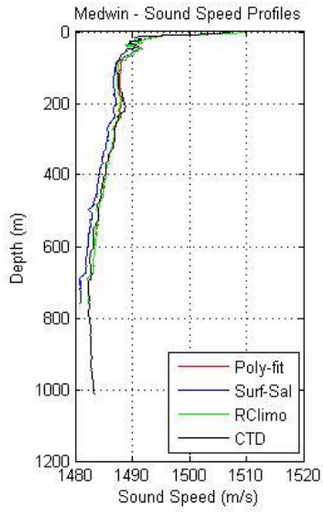
XBT 18& CTD 37

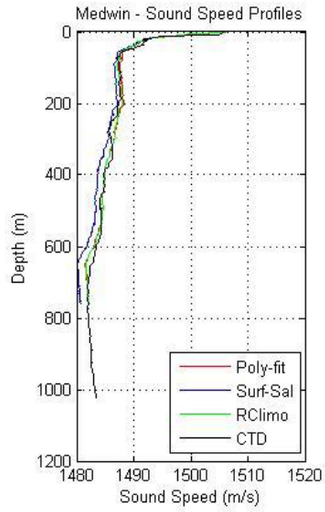


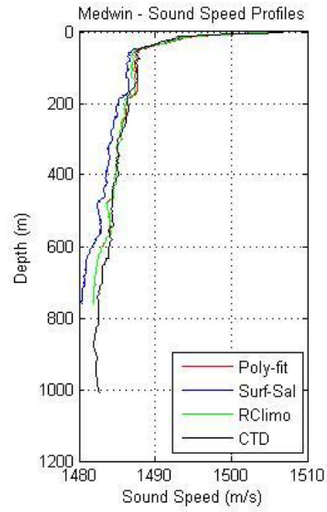
XBT 18& CTD 38

XBT 20& CTD 39

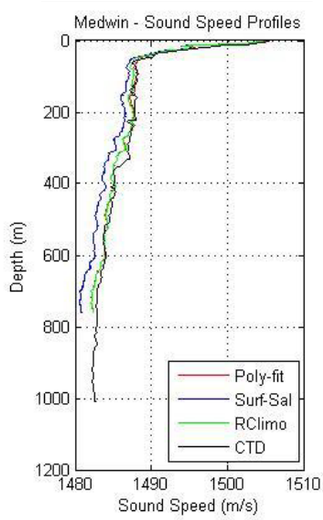
XBT 21& CTD 40



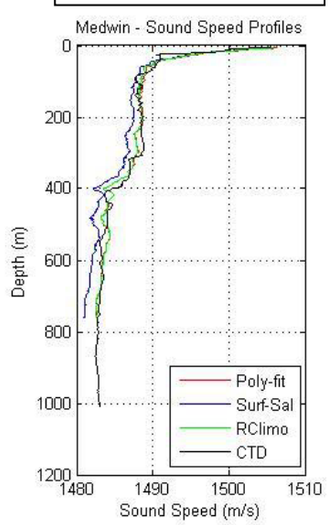




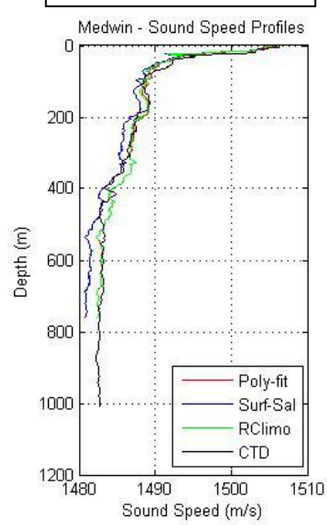
XBT 22& CTD 41



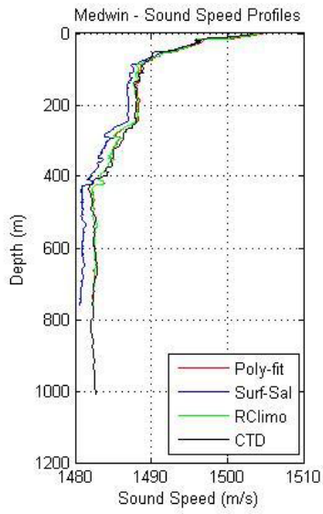
XBT 23& CTD 42



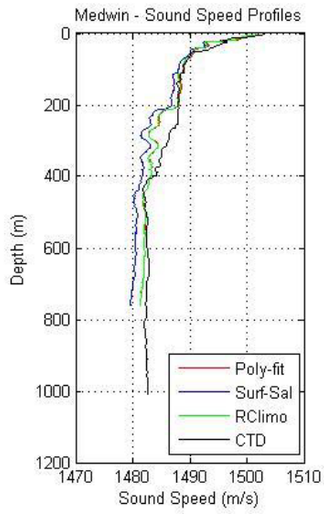
XBT 24& CTD 43



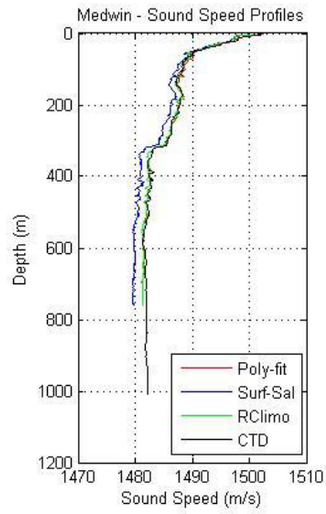
XBT 25& CTD 44



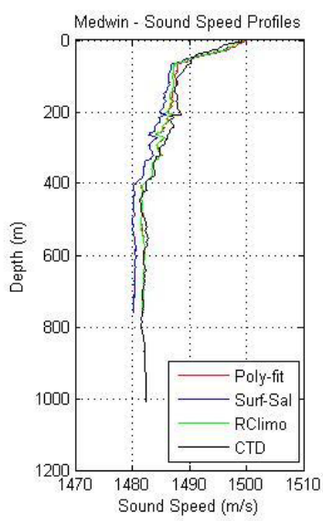
XBT 26& CTD 44



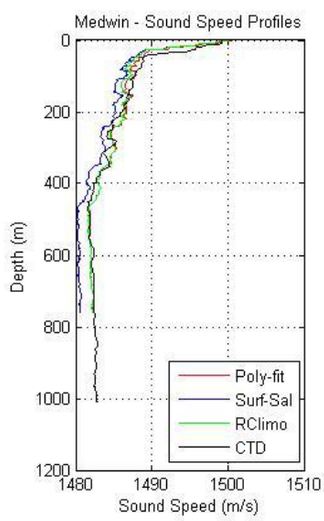
XBT 32& CTD 45



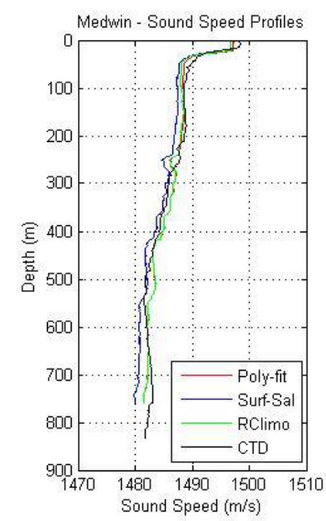
XBT 33& CTD 46



XBT 34& CTD 47



XBT 35& CTD 48



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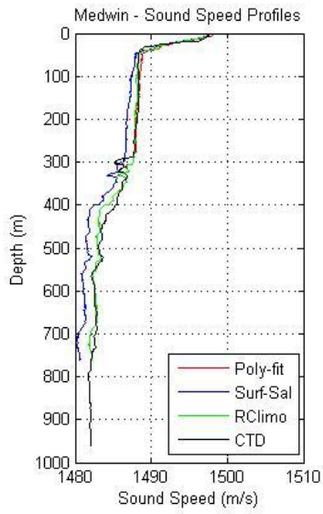
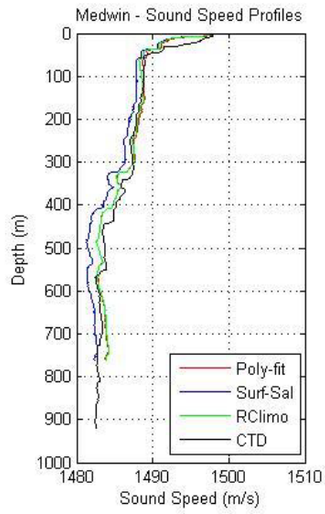
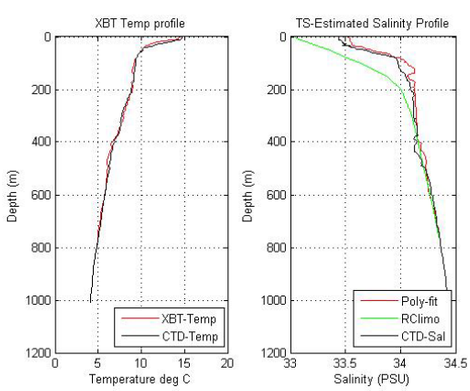


XBT 37& CTD 50

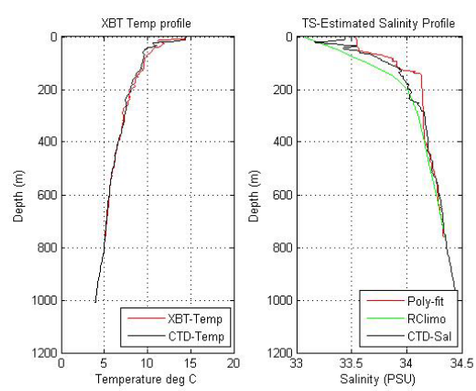


RESULTS OF NON-TIME SERIES OBSERVATIONS (TEMPERATURE-SALINITY PROFILES)

XBT 8 & CTD 8

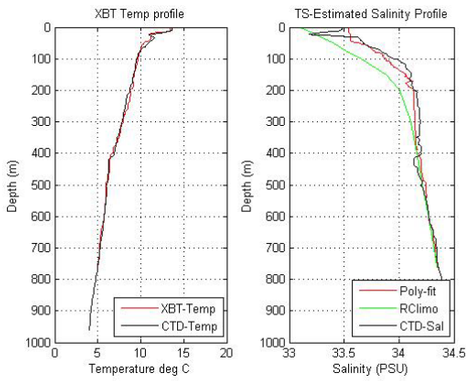


XBT 14 & CTD 9

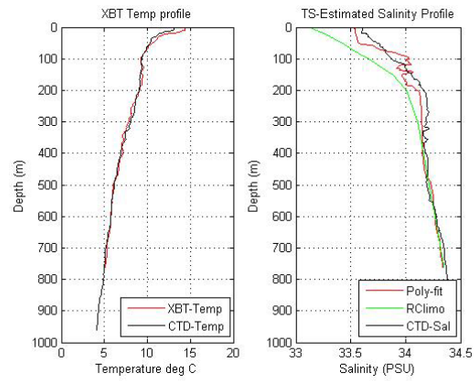


XBT 15 & CTD 10

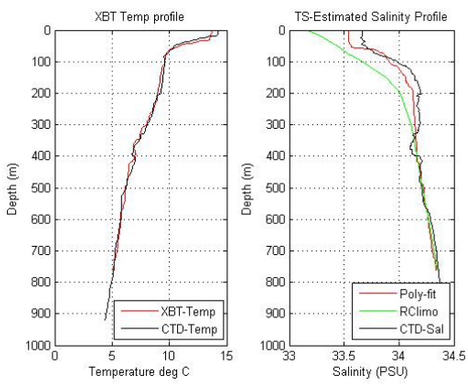
XBT 16 & CTD 11



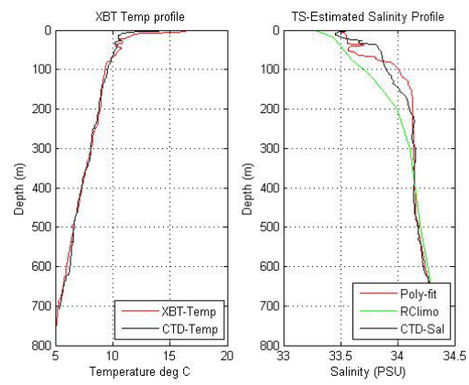
XBT 17 & CTD 12



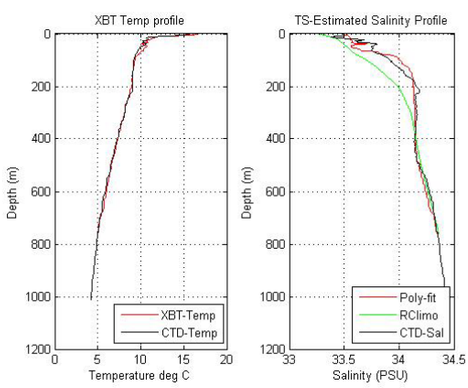
XBT 18 & CTD 37



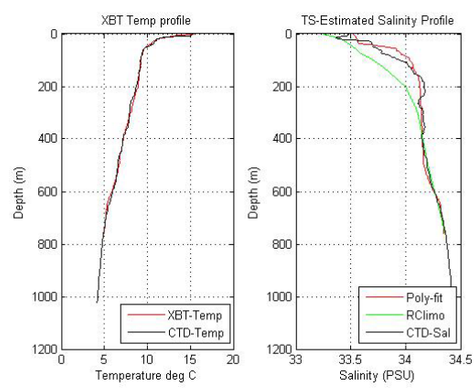
XBT 18 & CTD 38



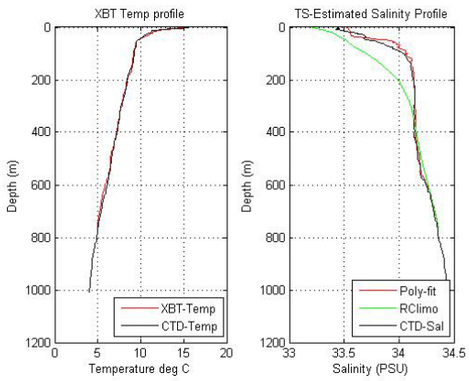
XBT 20 & CTD 39



XBT 21 & CTD 40



XBT 22 & CTD 41



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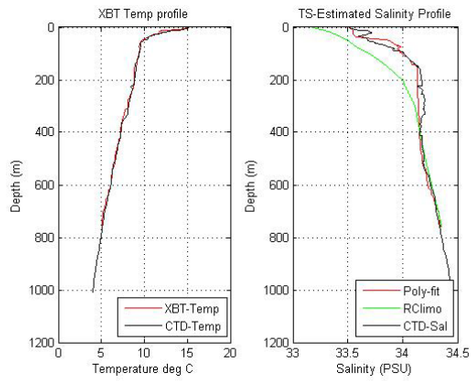
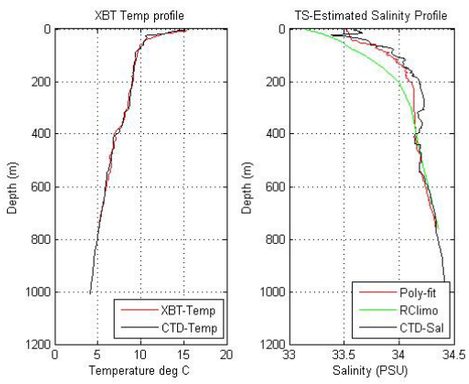
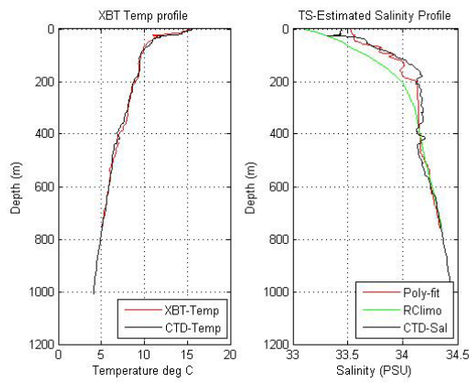


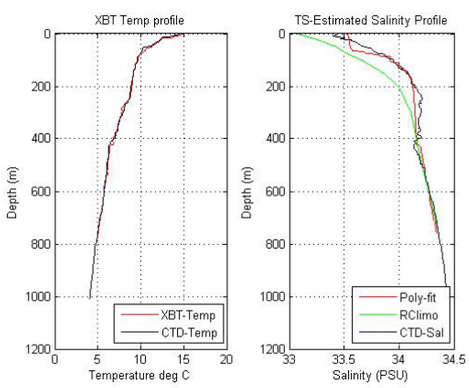
XBT 24 & CTD 43



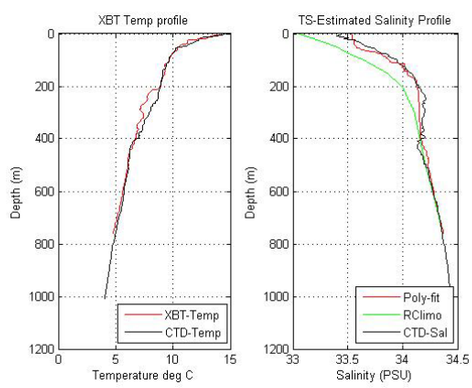
XBT 25 & CTD 44



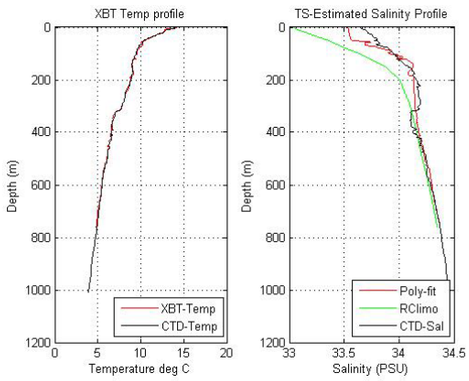
XBT 26 & CTD 44

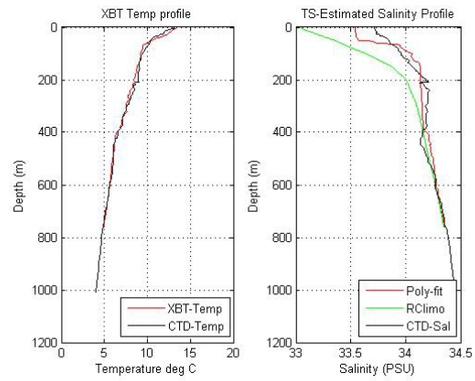


XBT 32 & CTD 45

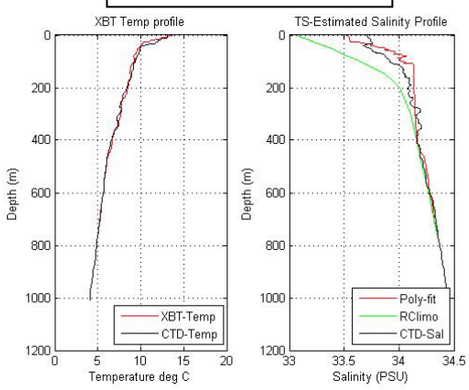


XBT 33 & CTD 46

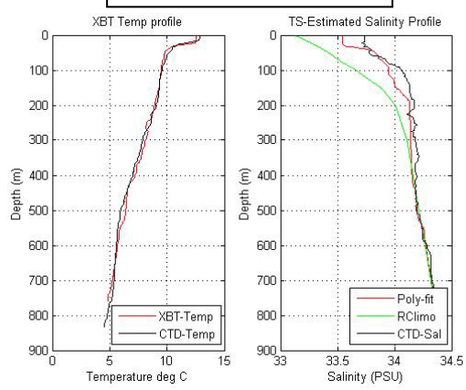




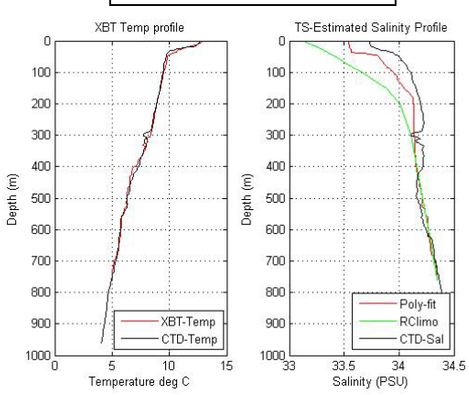
XBT 34 & CTD 47



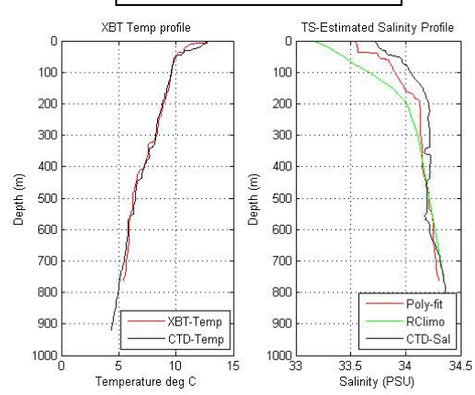
XBT 35 & CTD 48



XBT 36 & CTD 49

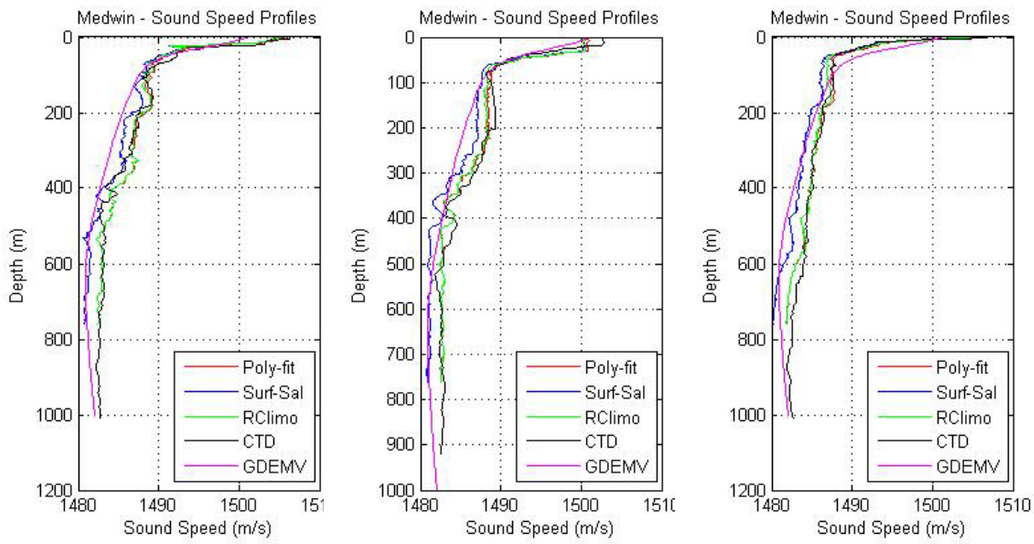


XBT 37 & CTD 50

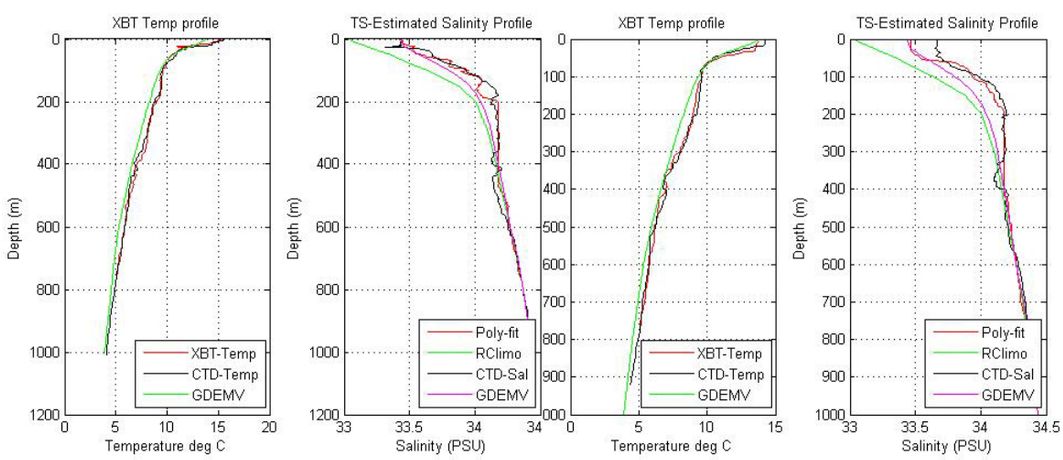


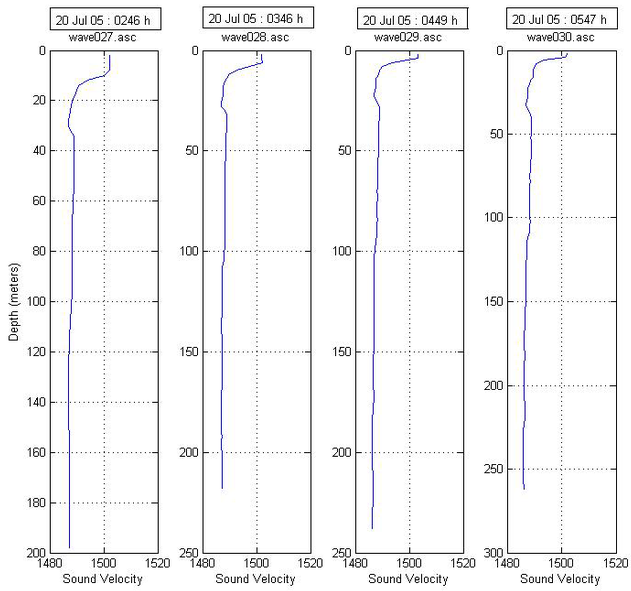
Appendix E
(Refers to Para 10(e))

COMPARISION OF SOUND VELOCITY RESULTS WITH GDEMV DATA

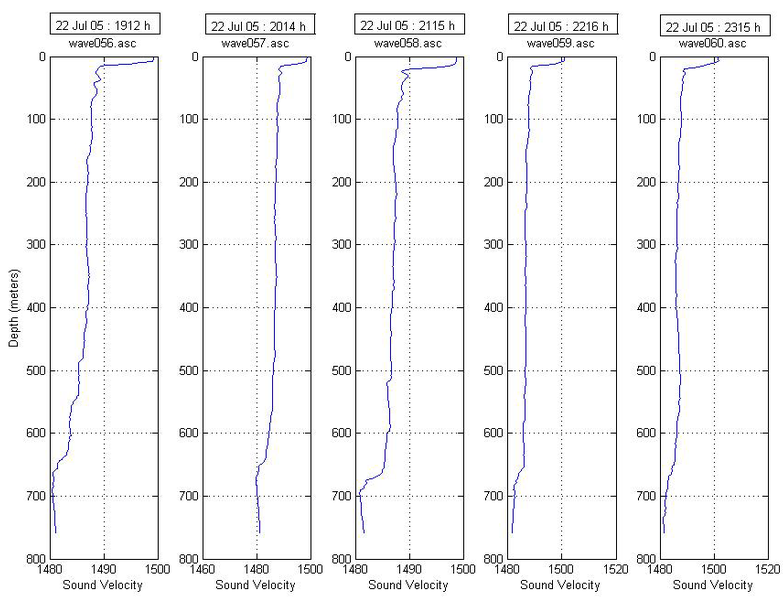


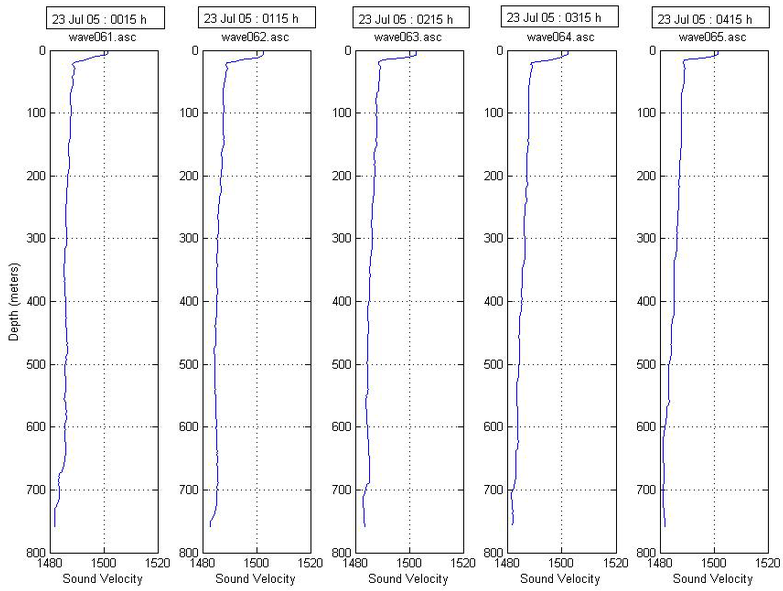
COMPARISION OF SALINITY PROFLES WITH GDEMV DATA

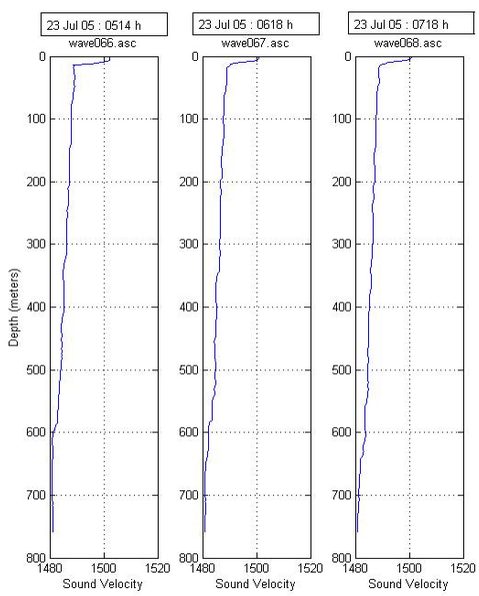



20 Jul 05 : 0246 h
wave027.asc
20 Jul 05 : 0346 h
wave028.asc
20 Jul 05 : 0449 h
wave029.asc
20 Jul 05 : 0547 h
wave030.asc
Depth (meters)
Sound Velocity

LEG 2

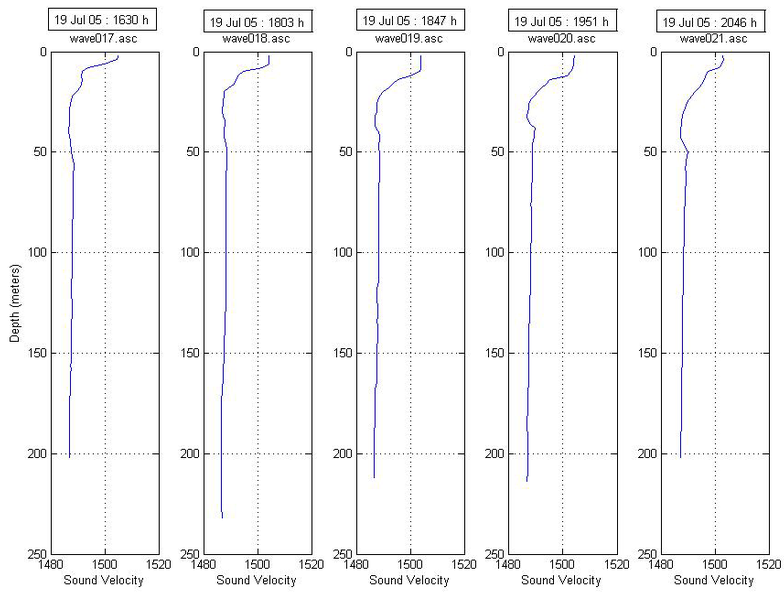

22 Jul 05 : 1912 h
wave056.asc
22 Jul 05 : 2014 h
wave057.asc
22 Jul 05 : 2115 h
wave058.asc
22 Jul 05 : 2216 h
wave059.asc
22 Jul 05 : 2315 h
wave060.asc
Depth (meters)
Sound Velocity

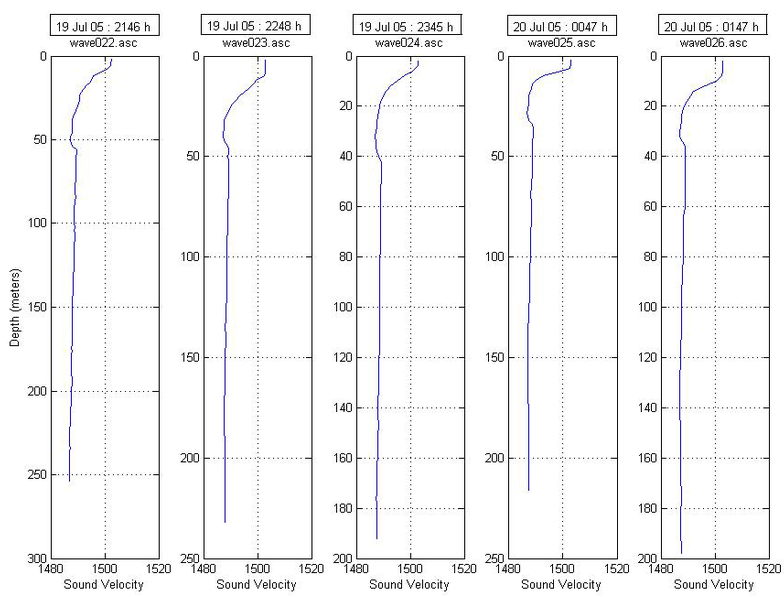

23 Jul 05 : 0015 h
wave061.asc
23 Jul 05 : 0115 h
wave062.asc
23 Jul 05 : 0215 h
wave063.asc
23 Jul 05 : 0315 h
wave064.asc
23 Jul 05 : 0415 h
wave065.asc
Depth (meters)
0
100
200
300
400
500
600
700
800
1480
1500
1520
Sound Velocity

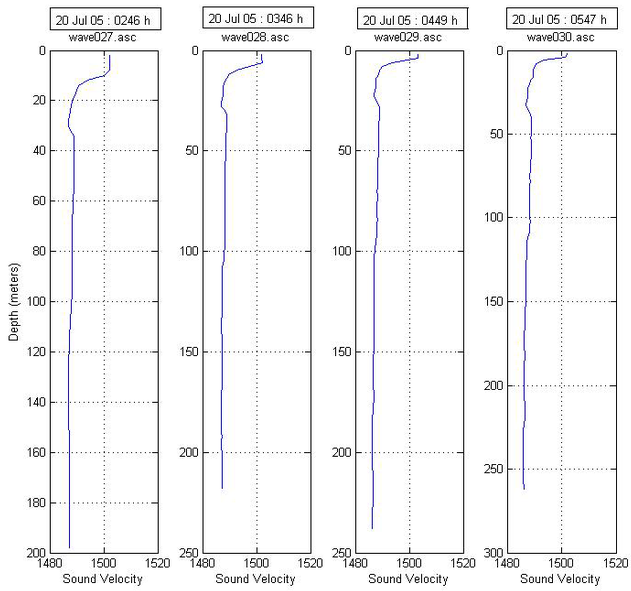

23 Jul 05 : 0514 h
wave066.asc
23 Jul 05 : 0618 h
wave067.asc
23 Jul 05 : 0718 h
wave068.asc
Depth (meters)
0
100
200
300
400
500
600
700
800
1480
1500
1520
Sound Velocity

Appendix F
(Refers to Para 11(a) & (b))

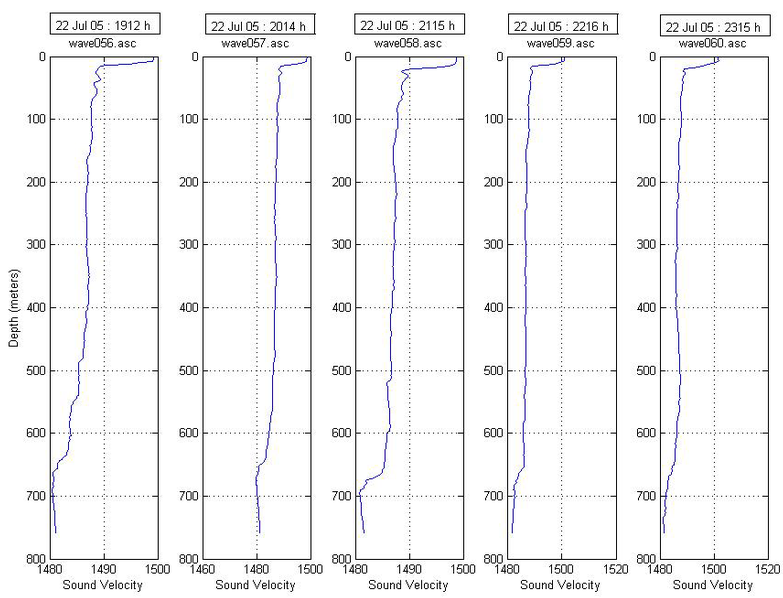
RESULTS OF TIME SERIES OBSERVATIONS

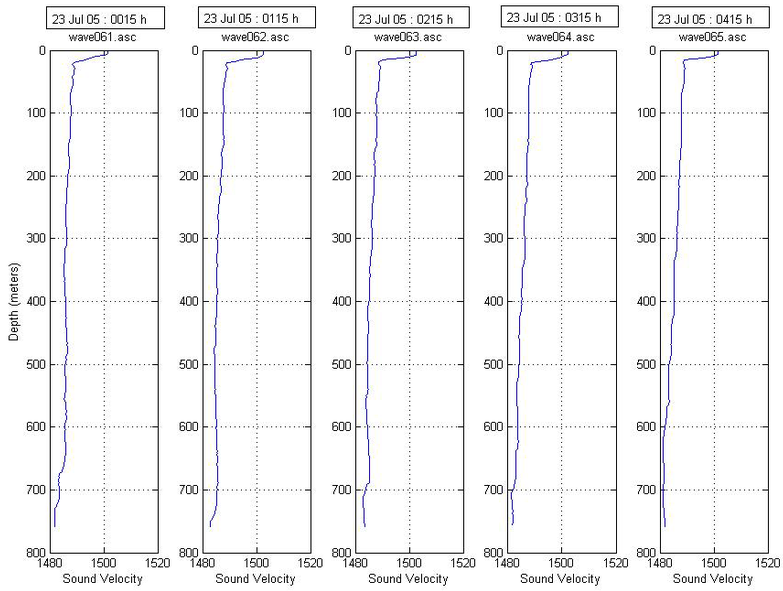


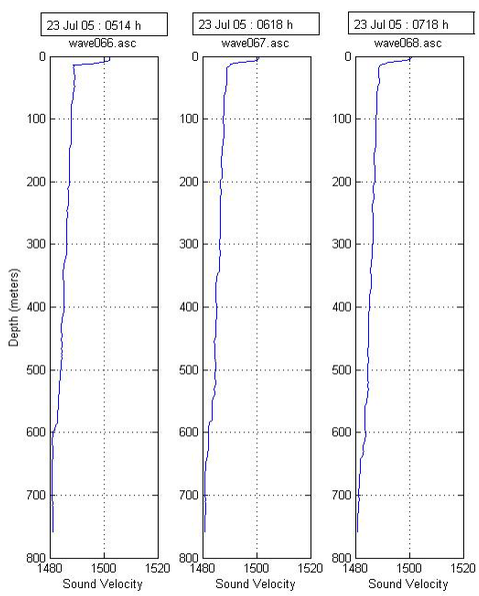



20 Jul 05 : 0246 h
wave027.asc
20 Jul 05 : 0346 h
wave028.asc
20 Jul 05 : 0449 h
wave029.asc
20 Jul 05 : 0547 h
wave030.asc
Depth (meters)
Sound Velocity

LEG 2


22 Jul 05 : 1912 h
wave056.asc
22 Jul 05 : 2014 h
wave057.asc
22 Jul 05 : 2115 h
wave058.asc
22 Jul 05 : 2216 h
wave059.asc
22 Jul 05 : 2315 h
wave060.asc
Depth (meters)
Sound Velocity


23 Jul 05 : 0015 h
wave061.asc
23 Jul 05 : 0115 h
wave062.asc
23 Jul 05 : 0215 h
wave063.asc
23 Jul 05 : 0315 h
wave064.asc
23 Jul 05 : 0415 h
wave065.asc
Depth (meters)
0
100
200
300
400
500
600
700
800
1480
1500
1520
Sound Velocity


23 Jul 05 : 0514 h
wave066.asc
23 Jul 05 : 0618 h
wave067.asc
23 Jul 05 : 0718 h
wave068.asc
Depth (meters)
0
100
200
300
400
500
600
700
800
1480
1500
1520
Sound Velocity