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| 14. ABSTRACT<br>This report describes a test to evaluate performance of a towed CTD chain manufactured by ADM Elektronik (Germany) and owned jointly by ARL/Penn State and APL/University of Washington. The test was conducted in the vicinity of 71.2 E, 40.2 N on the continental shelf of the US, in preparation for the SW06 experiment, which calls for the chain to be towed repeatedly through nonlinear internal wave (NLIW) packets. As configured for this test, the towed CTD chain employed 48 conductivity, temperature and depth (CTD) fins spaced 3 m apart on a 150 m long cable terminated at the bottom by a V-fin depressor. The test successfully determined 2 kts to 10 kts towing speeds and ship turning rates that are viable operationally and scientifically. A problem was encountered with towing a shortened scope at speeds greater than 4 kts. In general, the checkout test produced results that demonstrate the wealth of information available from the towed CTD chain. |                             |                              |                                           |                                                         |                                                           |
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## **Cruise Report - R/V Endeavor (Oct 4-8, 2005)**

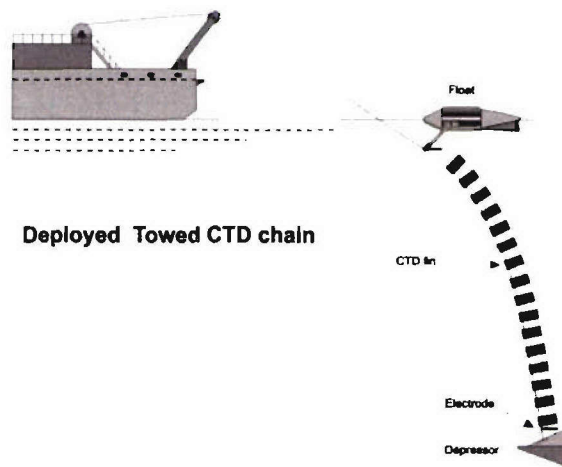
### ***Test of ARL-Penn State/APL-UW Towed CTD chain***

Kevin Williams, Kyle Becker, Frank Henyey, Ren-Chieh Lien, Dajun Tang,

#### **OVERVIEW**

The main purpose of the cruise was to test the CTD chain developed by ADM Elektronik and purchased via ONR funds by ARL and APL. The CTD chain is to be used by Frank Henyey and Kyle Becker during SW06. Frank plans to follow non-linear internal waves (NLIW) as they are generated and propagate toward shore and to monitor NLIW locally during a mid-frequency acoustic experiment by Dajun Tang. Kyle plans on using the CTD chain to measure IW conditions during acoustic propagation experiments being carried out in collaboration with Mosen Badiey. Funding for the cruise was provided to ARL/PSU by ONR Ocean Acoustics (Lee Culver, PI). APL funding was provided by Ocean Acoustics (SW06) and Physical Oceanography (NLIWI).

A simplified diagram of the CTD chain is shown in Fig. 1.



**Figure 1.** CTD chain under tow. During the test cruise the float was not needed.

As configured during the cruise, the chain employed 48 separate CTD fins. Each of these fins measures Conductivity, Temperature, and pressure (to determine Depth). The chain was deployed multiple times over the course of the test cruise.

The test cruise successfully determined towing speeds and ship turning rates that are viable both operationally and scientifically. The scientific goals of SW06 require that the ship be able to make repeated passes through a nonlinear internal wave packet (NLIW) while towing the CTD chain. The cruise included a test of this procedure in which the

chain passed through a NLIW 6 times over the course of 3 hours. The CTD chain results from this 3 hour period demonstrate the wealth of information that can be obtained.

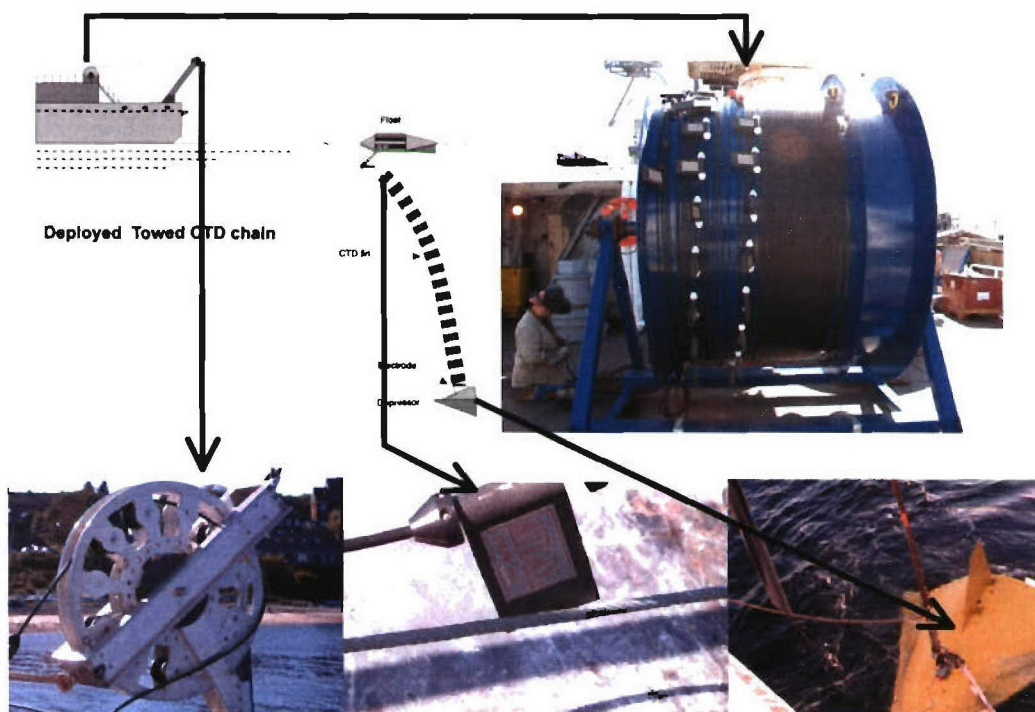
The test cruise also pointed out several areas where improvements can be made and better understanding is needed of the equipment limitations. Several of these items are presented in the "Lessons Learned" section below. None of these items are viewed as show-stoppers for the SW06 experiment.

## **EQUIPMENT**

The towed CTD chain system is comprised of a set of individual CTD fins arranged on a single cable that is towed behind a ship. The individual components required for towing are shown in Fig. 2. The chain is deployed from a 2 m diameter divided drum. To facilitate recovery, the drum is optimally situated so that the fins come off the bottom of the drum. This configuration allows the fins to orient themselves properly with the drum during recovery. In addition, it also seems to provide an optimum wire angle going over the guide block mounted on the ship's stern. As the chain is deployed, line is run through a capstan and block arrangement and taken up on the empty side of the drum. The capstan and line is then used to recover the chain. As mentioned, for deployment, the cable threads through a block suspended from the A-frame designed to rotate about 2-axes to minimize stress on the tow cable while towing, especially during turns. The block is also equipped with an alignment guide designed to rotate the fins up and out of the way as they come out of the water and back through the block. To maximize the chain depth while towing, a large V-wing depressor is attached to the end of the chain cable.

The CTD fins are molded rubber approximately 190 mm long by 100 mm tall with a rounded body that tapers from 50 mm to 30 mm. The insulated cable acts as both strength member for towing and as power/communication line for data collection. Individual sensors are threaded onto the tow cable through a hole at the wide end of the body. The sensors are free to rotate around the cable so that they self align to decrease drag while being towed. The sensors are distributed along the wire according to the number of sensors available and the desired sampling interval in depth. They are held in place using split collars clamped to the cable 5 mm above and below each sensor. Each CTD fin contains sensors to measure pressure (P), temperature (T), and conductivity (C). Power and data transmission are achieved through inductive coupling of each sensor with the tow cable. A deck unit is used to provide power regulation and communication. The wet end of the cable is terminated by an electrode and single line data transmission accomplished by completing the current loop through sea water back to the deck unit through the ship's hull. Digital conversion of the analog sensor data occurs locally within each fin. Once powered on, data sampling and conversion occur almost continuously for each sensor. The sensors run on an internal cycle time of 50 milliseconds, 15 milliseconds of which is needed to acquire any one of the individual parameters T, P, or C. The sensors can be programmed to integrate over several internal cycles in order to minimize spikiness in the data. In a typical configuration, P and C are averaged over 10 internal cycles (150 milliseconds). For data acquisition, the deck unit sends a trigger

signal to all the fins. Data from each of the sensors are then reported at the end of the current internal cycle and held in internal RAM. Before the next trigger occurs, each sensor in the chain is interrogated by the deck unit to send the data stored in RAM for display and archiving. Each data sample is 2 bytes, with a total data message of 6 bytes for all three parameters. Data is archived by specified filename directly to disk.



**Figure 2.** The components of the CTD chain, as configured during the test cruise. Note that no float was used.

Communication with the deck unit for data acquisition is achieved using a PC running the DOS program CTDCHAIN.EXE. Commands to and data from the sensors are relayed through the deck unit via RS-232 serial cable. Execution of the program requires a pair of configuration files with the suffixes CFG and CAL. The CFG file is used to specify (by fin address) the order of the individual fins along the tow cable. This is used to determine the order in which individual CTD fins are queried to send data. The CAL file is comprised of a list of fin addresses and a corresponding list of calibration coefficients that apply for each sensor in a fin. Although not used for data archiving, the CAL file is used to display calibrated temperature, depth, and conductivity data on the screen - either as waterfall (timeseries) plots or as ASCII text. The ASCII text display is useful for monitoring the depth of the deepest sensor while towing in shallow water. The duty cycle, or repetition rate for the trigger signal is set by the user in the CTDCHAIN.EXE program. A 2 second duty cycle was used during the check-out test.

**ARL/PSU:** Kyle Becker, Tom Weber, Paul Gabel, Joy Lyons  
**APL/UW:** Kevin Williams, Frank Henyey, Ren-Chieh Lien, D. J. Tang

**Monday Oct 3<sup>rd</sup>:** All components of the CTD chain were loaded on the RV Endeavor by Penn State and R/V Endeavor crew. Penn State personnel carried out sensor checks. Though there was some concern about the conductivity sensors (resolved later) the system was deemed operational and a morning departure set.

The ship came to an all-stop in 200 m deep water. The CTD chain was deployed such that the depressor was approximately 153 meters below the air/water interface. As the CTD chain acquired data, the ship's CTD was yo-yo'ed several times so that the two systems could be compared and the chain sensors calibrated in-situ.

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It was noted that the method used to deploy the block off the A-frame resulted in the chain cable rubbing during turns. Paul and the ship's boatswain discussed a solution to be implemented during SW06.

In the late afternoon it was decided that we understood the chain towing configuration well enough to make an initial run into shallow water and attempt to follow a NLIW toward shore at least to the 100 m contour. The 600 kHz ADCP turned out to be essential in locating and following the NLIW (as there is no high-frequency echosounder on the Endeavor). The research party was broken into two shifts with the first shift (Kyle, Paul, Frank, Ren-Chieh) operating from 18:00 to 24:00. During this first shift a NLIW was located via radar and ADCP and passes were made through it several times over the next 3 hours. Throughout the cruise, the bridge provided very useful help by informing us whenever they saw NLIW's on the radar.

After this successful NLIW test the ship returned to deep water to continue testing using the cable with different deployment lengths so as to determine the cable streaming as a function of length and tow speed. Bringing in 25 meters of cable while underway proved to be a challenge. Again, Paul and Kyle believe they have ideas to improve this iteration.

**Thursday Oct 6<sup>th</sup>:** The second shift (Kevin, DJ, Joy, Tom) came on duty at midnight. The chain had just been changed to a 100 m length configuration (?). Shortly thereafter it was noted that the pressure readings from several of the sensors were very noisy. Further investigation revealed that we had apparently hooked a marker buoy from a bottom deployed lobster line.

Though the pressure readings were an on-going issue, tests continued. At the point where we had the 75 m cable length we decided that we could try another foray into shallow water to follow a NLIW into shallower water than the previous test. As we started to carry out this test the bottom 6 pressure sensors failed completely. At that point the NLIW following test was terminated and the entire chain brought on-board.

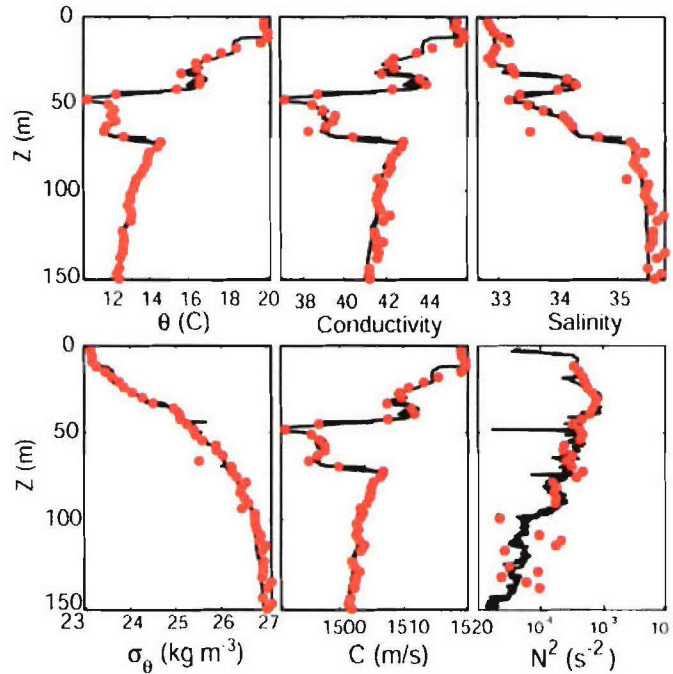
Visual inspection of the chain revealed significant chafing above the 6<sup>th</sup> sensor from the bottom. This chafing caused a short to seawater at that point thus the loss of signal from the bottom 6 sensors. We decided to construct a shorter array (about 30 m) using 12 of the CTD fins redeployed on the other end of the chain cable. This reconfiguration was completed around 22:00 at which point tests continued.

**Friday Oct 7<sup>th</sup>:** Testing ended when we again lost the signals from the bottom sensors. The chain was brought back on-board for the last time. The bottom part of the cable again looked chafed. The reason for the chafing could not be definitively identified; a float was seen leaving the vicinity of the ship after it stopped.

After bringing the chain on-board we continued to search for NLIW in the 70-100 m depth range using the 600 kHz ADCP. We started to port around 18:00.

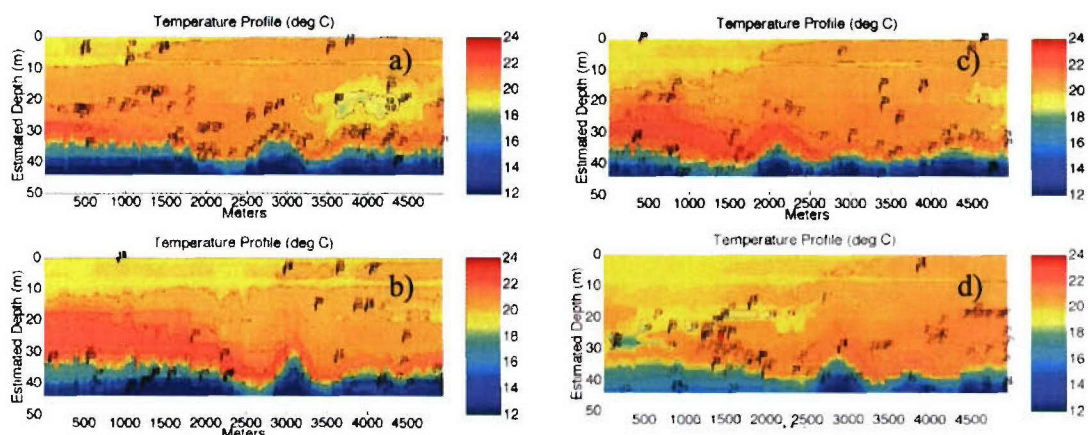
## RESULTS

The two most significant results from the standpoint of the SW06 experiment were the comparison of the chain data against the ship CTD (Figure 3) and the traversal of the same NLIW several times (Figure 4). These results demonstrate the viability of the chain to carry out the type of measurements proposed for SW06. All the data show the importance of having salinity as well as temperature. There are strong temperature inversions that are density compensated by salinity variations. For example the strong temperature feature at 50 to 70 m in figure 3 is almost entirely absent from the density profile.

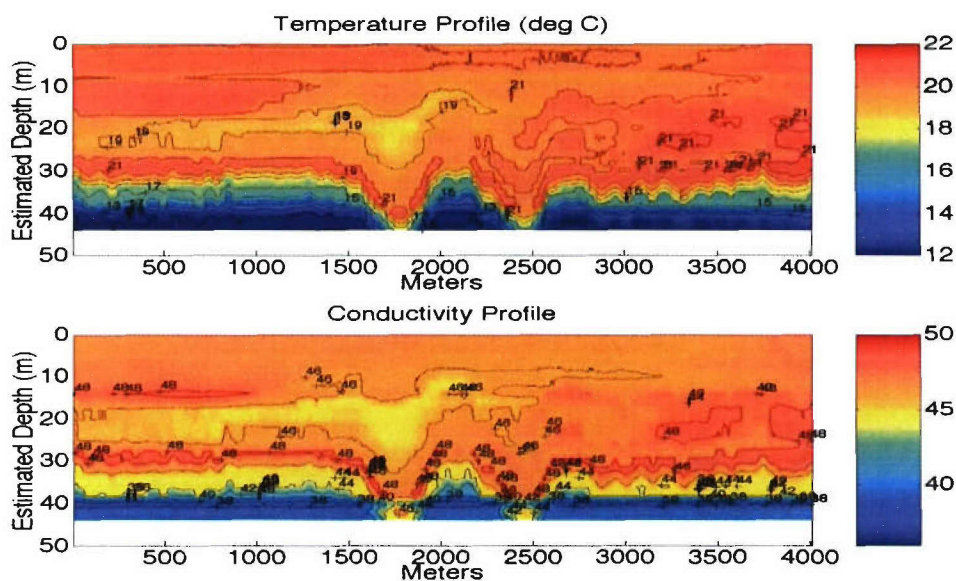


**Figure 3:** Ship CTD data (black lines) compared to CTD chain data (red dots).

Another scientific result is the comparison with other observations (shelfbreak primer, SWARM, etc.) in this region. The most obvious difference of the ambient oceanography is that, in our cruise, the pycnocline was deeper than for the other observations. The NLIW's we found were very different (whether because of the deeper pycnocline, or for other reasons, we cannot tell at present). Previously measured packets had many more waves than we saw. The packet of figure 4 and one shown in figure 5, have only two waves each. The many-wave packets are absent. This feature reminds one of the situation in the South China Sea, where individual solitary waves occur.



**Figure 4:** Temperature field images for 4 passes through the same NLIW. Elapsed times between passes were 30 minutes (a to b), 27 minutes (b to c) and 46 minutes (c to d).



**Figure 5:** Another wave packet consisting of two waves. Strong temperature inversions are present, but density compensated. The horizontal dependence of the temperature and conductivity are evident.

## LESSONS LEARNED/TO DO LIST/QUESTIONS

1. Block deployment scheme caused cable rub in some conditions. Paul has determined fix for this issue.
2. The steel drum made it necessary to hook-in to the cable at different points as the cable length was changed. Would it be better to go back to a wood drum? Possibly items 5 & 7 are caused by not hooking to the end of the cable.
3. Related to question 2, the procedure for raising the cable in 10 m increments is complicated by the need to re-position the tap. Kyle feels he can make the repositioning much more efficient. However, would the wood drum eliminate this issue?
4. The operation of bringing in cable while underway was “challenging”. Paul and Kyle have a method that they believe will make it much easier. One problem was the snap of the alignment guide when a sensor went over one of the small rubber wheels due to the long pendulum length of the support for the guide.
5. Pressure sensors become problematic when chain is towed. It seems like enough are always working to get the cable streaming configuration but this has needs to be examined more critically. Also, the reason for why this is happening needs to be understood with the goal obviously being to eliminate the problem. Further data analysis will be done to determine if problem is caused by strum, flow noise, or both. It may be possible to run tests in the ARL water tunnel to simulate the effects of towing at depth to resolve this issue.
6. Would fairing help make the sensor readings more reliable? Should we put them on given that it might? What are the cons here? (No strumming was visible at the point where the cable entered the water)
7. Other sensors also seem to have some dropouts in data under tow. This problem seems less severe but again a better understanding is needed. Worst case is that it is indicative of a condition that will get worse during long term use, i.e. SW06.
8. Were all the chafing problems due to lobster line buoys? Seems like the likely answer but can't be sure.
9. The ADCP display is not optimal for detecting the waves. A near-real-time display of the density from the CTD sensors would be better. Can the data be recovered & processed in near real time, in addition to the archiving as done now?
10. The 600 kHz ADCP processing package indicated poor results below about 50 m. If this remains true with more careful processing, a slightly lower frequency ADCP is needed -- 300 kHz would be ideal.