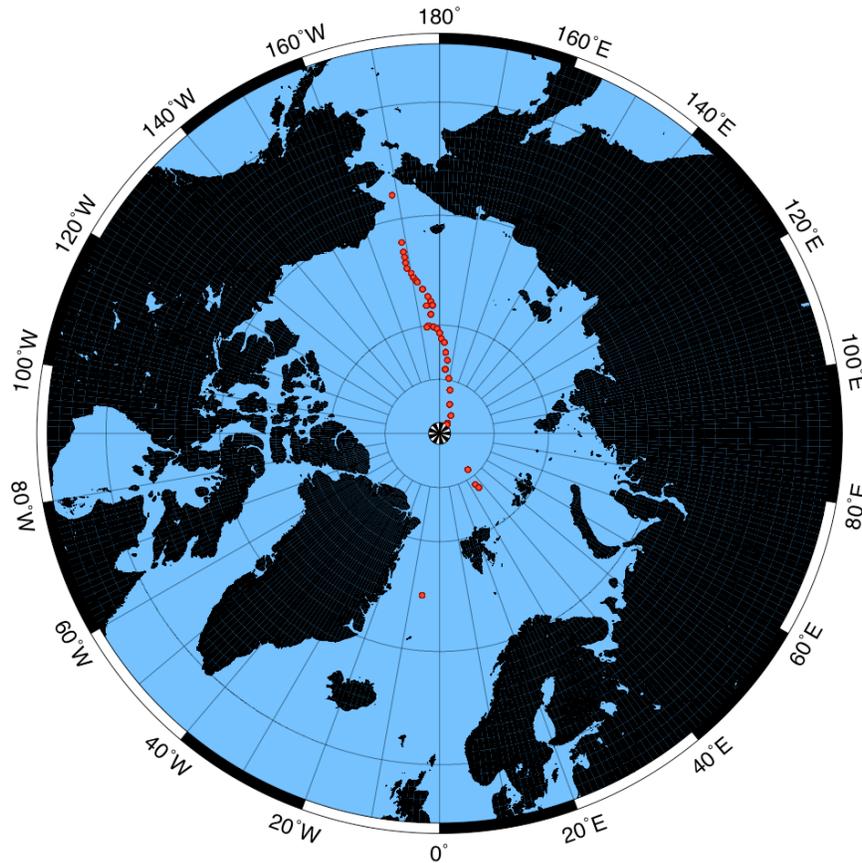


# CRUISE REPORT: AO94

(Updated OCT 2008)



## HIGHLIGHTS

### CRUISE SUMMARY INFORMATION

Section designation	<b>AO94</b>
Expedition designation (ExpoCode)	<b>18SN19940724</b>
Chief Scientists	<b>Dr. Knut Aagaard / APL</b> <b>Dr. Eddy Carmack / IOS</b> <b>Dr. James Swift / SIO</b>
Dates	24 JUL 1994 to 9 SEP 1994
Ship	<i>R/V Louis St. Laurent</i>
Ports of call	Nome, Alaska - Halifax, Nova Scotia
Station geographic boundaries	89°59.9' N 178°37.50' W 137°9.10' E 67°46.6' N
Stations	39
Floats and drifters deployed	0
Moorings deployed or recovered	0

**Chief Scientists:**

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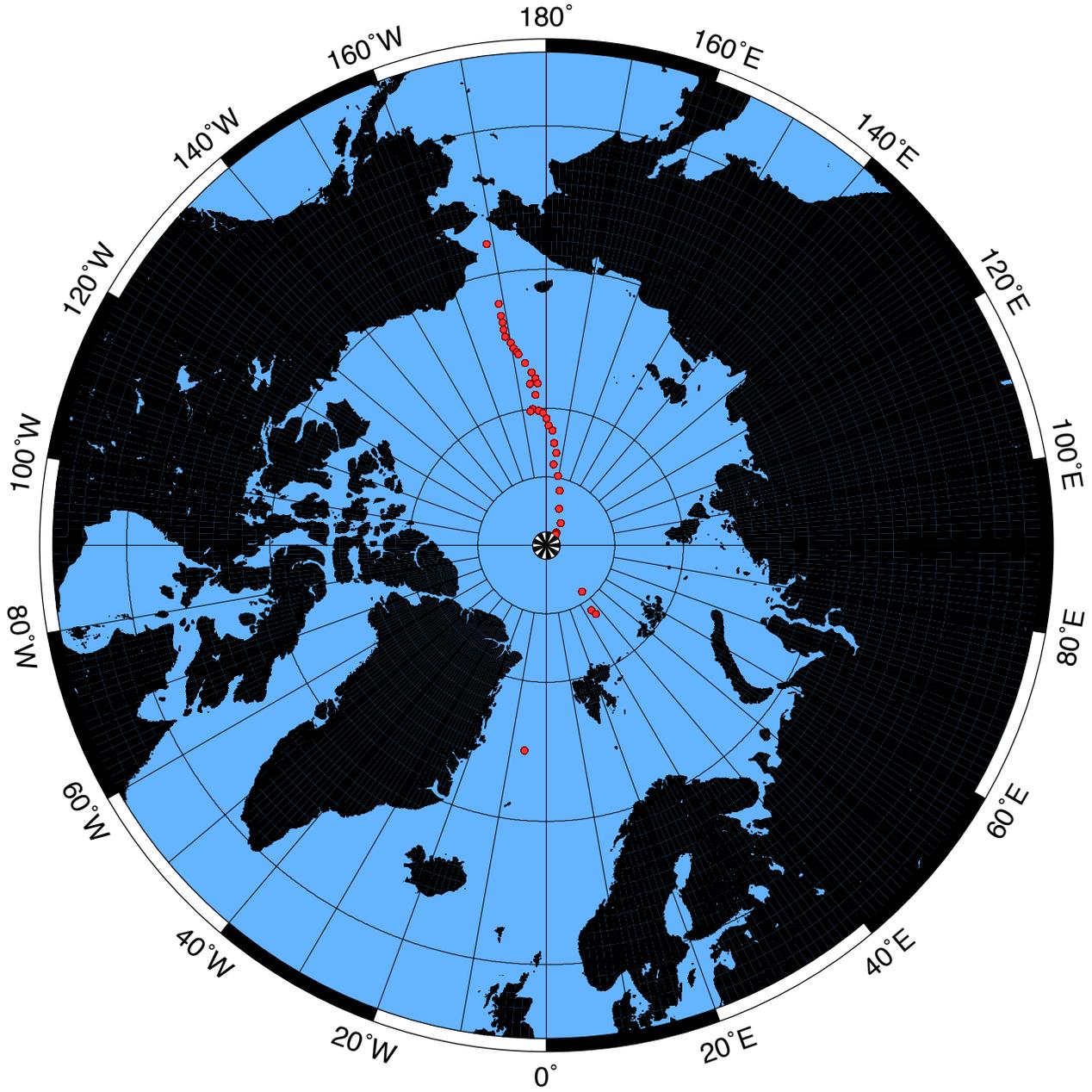
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**Links to text locations.** Shaded sections are not relevant to this cruise or were not available when this report was compiled.

<b>Cruise Summary Information</b>	<b>Hydrographic Measurements</b>
Description of Scientific Program	<b>CTD Data:</b>
Geographic Boundaries	Acquisition
Cruise Track (Figure): PI CCHDO	Processing
Description of Stations	Calibration
Description of Parameters Sampled	Temp/Press
Bottle Depth Distributions (Figure)	Salinities
	Oxygens
Floats and Drifters Deployed	<b>Bottle Data</b>
Moorings Deployed or Recovered	Salinity
	Oxygen
Principal Investigators	Nutrients
Cruise Participants	Carbon System Parameters
	CFCs
Problems and Goals Not Achieved	Radiocarbon
Other Incidents of Note	
<b>Underway Data Information</b>	
Navigation Bathymetry	<b>References</b>
Acoustic Doppler Current Profiler (ADCP)	<b>Acknowledgments</b>
Thermosalinograph	<b>Data Processing Notes</b>
XBT and/or XCTD	
Meteorological Observations	
Atmospheric Chemistry Data	

**AO94 • Aagaard/Carmack/Swift • 1994 • R/V Louis St. Laurent**



*Produced from .sum file by CCHDO*

## Introduction

Traditionally both Canada and the United States have relied on aircraft and drifting ice camps in supporting scientific work in the Arctic Ocean. Early examples include the so-called Ski Jump project in 1951–1952 and the ice stations Alpha and Bravo in 1957. These efforts have been particularly successful in advancing process studies, obtaining certain time series measurements and exploring limited areas; they have been less successful in carrying out synoptic survey work and sophisticated geographically distributed measurements requiring heavy equipment and elaborate laboratory facilities. In the open ocean the latter are typically done from shipboard, but not until 1987, when the German research icebreaker *Polarstern* crossed the Nansen Basin of the Arctic Ocean, did a modern Western research vessel successfully operate in the Polar Basin.

Russian scientists had also primarily used aircraft and drifting stations, having pioneered these techniques beginning with Papanin's North Pole I station in 1937. While the large and powerful Russian polar icebreaker fleet, one of which first reached the North Pole in 1977, routinely operates within the Polar Basin, the vessels are generally not used as scientific platforms. Meanwhile, the voyage of the *Polarstern* in 1987 was followed in 1991 by a remarkable joint Swedish–German undertaking using the icebreakers *Oden* and *Polarstern* to cross both the Nansen and Amundsen Basins, reaching the North Pole and returning to the Atlantic via northeast Greenland. A U.S. icebreaker, the *Polar Star*, started out with the two European vessels but had to turn back near 85°N because of mechanical difficulties.

Inspired by the planned Swedish–German undertaking, but also deeply concerned that North American scientists would be unable to participate in ship-supported work in the Arctic Ocean, Ed Carmack and I met with Canadian and U.S. Coast Guard representatives in Ottawa in the fall of 1989 to inquire about interest in making a scientific crossing of the Arctic Ocean and about whether the two Coast Guards thought such an undertaking was realistic. The immediate response was positive on both counts, and the initial target for the crossing was set as the summer of 1993. The next 58 months or so were filled with a stream of planning activities involving interested scientific parties, the ship operators and funding agencies. Two major changes were made:

- Because of the long planning time required, the expedition was moved back one year to 1994; and
- Because the yard schedule for the *Polar Sea* required her to be in Seattle on 1 October, the route was altered to return directly to the Pacific from the North Pole, rather than via the Atlantic, that is, crossing the Canada Basin twice, but with an expected net saving of time.

Thanks to the efforts of a great many caring people, the myriad pieces in this planning activity all came together, and late in the evening of the 24th of July 1994 the *Louis S. St-Laurent* and the *Polar Sea* steamed northward from Nome to start the Canada–U.S. 1994 Arctic Ocean Section.

From the beginning the scientific goal of the undertaking had been to substantially increase the observational base necessary for understanding the role of the Arctic in global change. The objective was thus to make those measurements that would best promote the analysis and modeling of the biological, chemical and physical systems related to the Arctic and global change, and the controlling processes in these systems:

- Ocean properties pertinent to understanding circulation and ice cover;
- Biological parameters essential for defining the Arctic carbon cycle;
- Geological observations necessary for understanding past climates;
- Concentration and distribution of contaminants that impact the food chain and the environment;
- Physical properties and variability of the ice cover; and
- Atmospheric and upper ocean chemistry and physics relevant to climate.

In the following chapters, we shall see how all this came out.

## Chronology

The CCGS Louis S. St-Laurent and the USCGC Polar Sea departed Victoria, British Columbia, together on the evening of the 17th of July 1994. The majority of the scientific party of 70 persons boarded by helicopter in Nome, Alaska, on July 24th; several scientists had sailed with the ships from Victoria to set up equipment and make preliminary measurements. We sailed through the Bering Strait on July 25th and entered the ice in the northern Chukchi Sea early in the afternoon of the following day.

During the first few days, the ships worked some distance apart, as the ice was not severe. However, from the 30th of July onward, ice coverage was typically complete, and the ships moved close together, operating in tandem for the most efficient icebreaking, taking turns leading. This greatly reduced the fuel consumption for the trailing icebreaker. The ships icebreaking in tandem averaged 3–5 knots during the northbound transit. Visibility was generally poor throughout the time spent in the ice, with fog and overcast the rule. July 31st was the only full clear day. Passive microwave satellite imagery (SSM/I) received in real time aboard the Polar Sea provided excellent strategic information on ice conditions for planning the northbound route and stations.

Beginning in the central Chukchi Sea, the station line ran northward east of the Russia–U.S. Convention line, but once past 200 nautical miles from Wrangell Island, our track turned northwestward across the Chukchi Abyssal Plain and onto the Arlis Plateau, which we reached on the 3rd of August at 78°N. Heavy multi-year ice limited our eastward penetration down the flank of the plateau to longitude 174°18'W. We therefore resumed the station line northward, with the intent of covering the region to the east along 78°N on the return voyage. Near 80°N we again attempted a section to the northeast, but difficult ice conditions limited our penetration in that direction to 80°13'N, 172°46'W. We therefore continued working northwestward across the Mendelejev Ridge and into the Makarov Basin.

On Monday the 8th of August we had an overflight and data transfer by a Canadian ice reconnaissance flight carrying side-looking radar, which mapped the ice in a swath 200 km wide and extending 1100 km along our intended track northward. From this imagery it was clear that difficult ice conditions lay to the east. Detailed helicopter ice reconnaissance the next few days confirmed this, and on Sunday the 14th, near 85°N, 170°E, we decided to continue onto the Lomonosov Ridge near 150°E before turning east and running the final northward leg of the outbound voyage along 150–155°W

On the 15th of August the helicopter-borne CTD party found a new undersea mountain when the wire stopped paying out and they brought up mud from 850 m where the chart showed 3700 m. Three miles away on either side they found no bottom at 1450 m.

The next three days brought a northeast gale, snow and poor visibility, and progress was slow through the heavy ice. On the 19th we reached our station on the crest of the Lomonosov Ridge at 88°47'N, 143°E, where we planned to turn eastward. There we found the water at intermediate depth to be about 1°C warmer than we had seen at the base of the ridge, suggesting that the large gap in the ridge shown in the charts does not exist. We had also observed sediment-laden ice (“dirty ice”) throughout the long northward track, from the ice edge in the Chukchi Sea to the North Pole, indicating that sediment incorporated in the ice on the shallow continental shelves is transported hundreds of kilometers across the Arctic.

Meanwhile, on the 17th we had had ice reconnaissance by a long-range Canadian aircraft, and on the 19th, while the ships remained on station on the ridge, we flew a 215-nautical-mile helicopter reconnaissance flight over the intended track. These showed very heavy ice at the location of our intended crossing point of the Lomonosov Ridge to the east, so we decided to continue northward on the section we were on and then return along an alternative route that would recross the ridge farther south. From there we would attempt to get onto the eastern flank of the Alpha Ridge to do seismic work and addi-



Route of the first surface circumnavigation of North America and Greenland. The *Louis S. St-Laurent* began and ended its voyage in Halifax. The *Polar Sea* began and ended in Seattle.

tional piston coring before continuing both these and our many other planned programs on the long voyage back to Alaska.

However, this was not to be, for shortly after starting northward down the steep ridge flank, early Sunday morning on the 21st of August, and about 50 nautical miles from the Pole, the Polar Sea lost one of its four blades on the starboard propeller. Divers also sighted some damage to the blades on the centerline and port shafts. These casualties required that the expedition take the shortest route out of the ice, which was toward Svalbard. Our intended section northward took us in that direction, and since we had already surveyed that route by helicopter and knew it to be feasible, we decided to continue on our course. That same afternoon a U.S. Coast Guard C-130 aircraft from Kodiak dropped spare parts for our satellite receiver. At 0230 Monday morning, Alaska standard time, we reached our next science station at 90°N, the first North American surface ships to do so, and the first surface ships ever to do it directly over the long unexplored route from the Pacific side of the Arctic Ocean. Our station at the Pole took 28 hours, as we fully deployed every sampling program. Not only could we compare conditions with those found three years earlier by Swedish and German investigators, but we could add a great many new measurements (for example, the concentration and distribution of a great variety of contaminants).

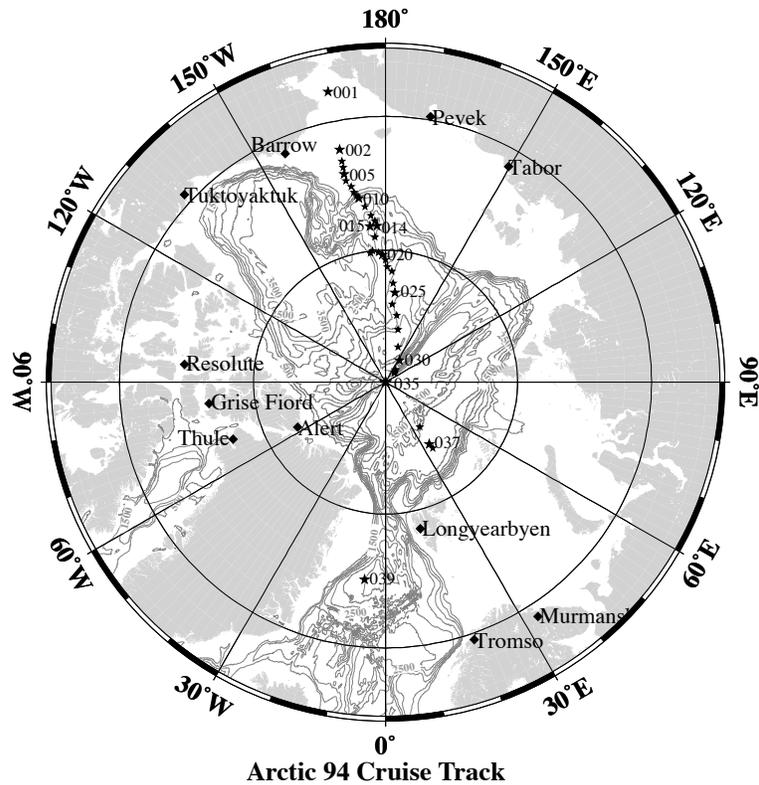
The last few hours before we arrived at the Pole, we had seen a large ship on the horizon. The ship, which proved to be the Russian nuclear icebreaker Yamal, had stopped in the ice about 20 nautical miles from the Pole to produce a children's television program. The Yamal planned to sail south along our intended track the next day, coincident with the shortest route out of the ice and the one that we needed to take because of the loss of one of Polar Sea's propeller blades. At 0800 on the 23rd we got underway toward Yamal's position, 20 nautical miles to the southeast. Before noon an extraordinary rendezvous took place as the icebreakers of the three largest Arctic nations—Russia, Canada and the United States—commenced a historic polar gathering. More than 550 men, women and children met near the North Pole on the ice. The Yamal's officers and crew hosted a barbecue on the ice, and the three ships were open for tours. This unprecedented and impromptu rendezvous near the North Pole in many ways symbolized a new era of international cooperation in the Arctic Ocean.

That evening all three ships sailed southward together toward Svalbard and made good progress, reaching south of 86°N by Thursday morning the 25th. At that point the ice conditions had improved, and we parted company with the Yamal to resume our scientific work, consonant with expeditiously exiting the Polar Basin. The pattern of southerly progress in somewhat lighter ice continued, and we occupied several high-quality science stations in the Eurasia Basin. On the 27th we had an airdrop of helicopter parts. The same day we received word from the U.S. Department of State that we were not permitted to continue the work southward within 200 nautical miles of Svalbard. We therefore terminated our in-ice section with a station at 83°51'N, 35°41'E. On Tuesday the 30th of August we exited the ice northwest of Svalbard, making course for Iceland. On the 31st we stopped the St-Laurent for a contaminant and oceanographic station in the Greenland Sea at 75°N, 6°W. This proved to provide an excellent end point for the Arctic Ocean Section, since it showed the prominent role of the Arctic Ocean outflow in changing the convective region of the Greenland Sea in recent years to a warmer and more saline state.

The Polar Sea disembarked most of its scientific party in Keflavik, Iceland, on the 3rd of September and then proceeded to Nova Scotia in company with the St-Laurent, the ships being slowed enroute by a storm with winds exceeding 60 knots. The St-Laurent disembarked its scientific party in Dartmouth on the 9th of September, bringing to a close a remarkable and productive voyage. We had completed a highly successful scientific voyage literally across the top of the world, from the Pacific through Bering Strait, across Canada Basin, to the North Pole and into the Atlantic via Fram Strait.

**ARCTIC OCEAN 94**  
*CCGS Louis S. St. Laurent*  
24 July 1994 - 9 September 1994  
Nome, Alaska - Halifax, Nova Scotia

**CHIEF SCIENTISTS**  
Dr. Knut Aagaard  
Applied Physics Laboratory  
University of Washington  
and  
Dr. Eddy Carmack  
Institute of Ocean Sciences  
and  
Dr. James Swift  
Scripps Institution of Oceanography



**Oceanographic Data Facility (ODF)**  
**Final Cruise Report**  
**3 July 1998**

*Data Submitted by:*

Oceanographic Data Facility  
Scripps Institution of Oceanography  
La Jolla, CA 92093-0214

## *Ocean Circulation and Geochemistry*

### **A CTD/Hydrographic Section across the Arctic Ocean**

*(James Swift)*

The objectives of our water column work were:

- To study the origin and circulation of the waters of the Arctic Ocean and nearby seas;
- To determine the surface-to-bottom distributions and sources of the physical and chemical characteristics;
- To study the location, origin and structure of subsurface boundary currents; and
- To contribute to studies of the response of the regimes to environmental forcing.

The water column program provided the trans-Arctic section a complete program of CTD (conductivity, temperature and depth) and “small-volume” hydrographic measurements meeting World Ocean Circulation Experiment parameter and quality recommendations.

The *Louis S. St-Laurent* is well equipped for high-latitude CTD/rosette work. On the starboard side of the vessel there is a small CTD/computer van and a large double-van rosette room. The rosette was launched through a large A-frame. The *Louis S. St-Laurent* is also outfitted with a full suite of laboratories for the analytical equipment.

We collected water column measurements at 35 hydrographic stations along the AOS-94 route: beginning on the Chukchi shelf, then across the Chukchi Abyssal Plain and Makarov Basin, then down the Eurasian side of the Lomonosov Ridge to the North Pole. Water column work was cut short at that point because the *Polar Sea* developed mechanical problems. Both ships exited the Arctic together through Fram Strait, occupying an additional four stations en route.

The U.S./Canadian water column measurement team on the *Louis S. St-Laurent* carried out full-depth CTD profiling and 36-level rosette sampling. Water samples were collected for chlorofluorocarbons (CFCs), helium, oxygen, CO<sub>2</sub> system components, AMS <sup>14</sup>C, tritium, <sup>18</sup>O, nutrients, salinity, trace metals, radionuclides and organic contaminants. CTD and water sampling was carried out at 39 stations and was remarkably trouble free.

We examined sections of potential temperature, salinity and density anomalies referred to 0 and 2000 db from the CTD data for our section from the Chukchi shelf to the North Pole. We observed multiple warm cores in the Atlantic layer (depths of about 200–400 m) near 1.0°C along the Chukchi boundary and warmer than 1.5°C on the Eurasian side of the Lomonosov Ridge. Earlier data from the Makarov Basin showed no water in this layer warmer than 0.5°C. In 1993 the Institute of Oceanographic Sciences (Patricia Bay) group found water warmer than 1°C on the Makarov slope just north of the Chukchi Sea. The AOS-94 data extend this finding, showing the Atlantic layer near both the Chukchi and Lomonosov ridge boundary areas to be 0.5°C warmer than measured before 1993. In some places the insulating fresh, cold upper layer was somewhat eroded, though far from completely. One of the important issues facing us now is to place this warming in context. Such subdecadal variability is important to climate models.

We found the central Canadian sector of the Arctic Ocean to be an oceanographically active environment, not a “dead end” isolated from any active role in the global circulation by the shallow sill through the Bering Strait, the Lomonosov and other ridges, and its sheer distance from the North Atlantic Ocean. Instead, the Canadian sector is importing water, modifying it and exporting it in ways that have important effects and consequences.

For example, biological activity on the Chukchi shelf is so high in summer that phytoplankton photosynthesis can supersaturate oxygen in the surface waters there by almost 50% in places, yet the debris left behind by those organisms and their predators sinks and decays, regenerating nutrients and

using up oxygen on the bottom of the shelf. These shelf-bottom waters can get rather dense, due partly to brines released from ice formation above, and then flow off the shelf, carrying regenerated nutrients and, potentially, contaminants into the central basin.

Winter shelf waters have been thought to reach rather high densities. Although there are observations of this, establishing a direct connection to the deep waters, which seems essential to models of deep water formation in the Arctic, has been elusive. We found during AOS-94 what is perhaps an important new piece to this puzzle: At station 22, on the periphery of the Makarov Basin, we saw a bolus of water dense enough to be centered at 1000 m, with unique characteristics indicating that it could have come only from the shelf. Relatively high CFC concentrations confirmed its recent origin. This bolus has entered the Makarov Basin and now slowly freshens the deep water. This may be the first direct observation of “new” high-density shelf water actually in the deep basins.

There is a weak, deep horizontal salinity gradient across the Chukchi–Makarov sector, with higher deep salinities near the pole on the Canadian side of the Lomonosov Ridge. At station 22 in the southeastern Makarov Basin we saw deflections in the salinity isopleths due to the bolus of relatively fresh, cold, young deep water.

Isopycnals generally slope slightly down from pole to shelf across the domain covered by this section, with more significant deflections associated with each principal bathymetric feature, and circulation associated with the bolus of young deep water found at station 22. Sharp isopycnal slopes over the Lomonosov Ridge (stations 30–34) showed geostrophic adjustment to relatively strong upper-layer flow along the ridge crest. The most intense deep deflections in sigma-2 were found on the Eurasian flank of the Lomonosov Ridge and, to a lesser extent, on the southeast flank of the Makarov Basin.

On their own the AOS-94 CTD/hydrographic/tracer/contaminant data are a unique, well-placed and important data set, providing the first reference-quality section across the Chukchi Abyssal Plain and Makarov Basin and a careful, synoptic section of closely spaced stations across the Eurasian flank of the Lomonosov Ridge near the North Pole. The AOS-94 section also joins to the *Oden* 1991 section in the Makarov Basin near the Lomonosov Ridge, and these in turn can be joined to the *Polarstern* 1987 Nansen Basin section to form a nearly complete, shelf-to-shelf trans-Arctic section of high-quality surface-to-bottom multi-tracer stations.

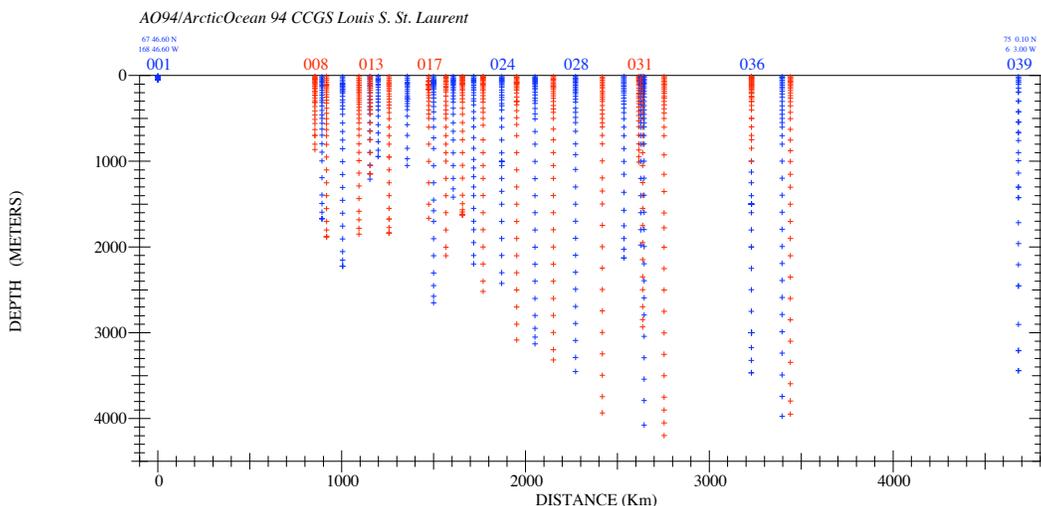
## 1. DESCRIPTION OF MEASUREMENT TECHNIQUES AND CALIBRATIONS

### 1.1. Basic Hydrography Program

The basic hydrography program consisted of salinity, dissolved oxygen and nutrient (nitrite, nitrate, phosphate and silicate) measurements made from bottles taken on CTD/rosette casts, plus pressure, temperature, salinity and dissolved oxygen from CTD profiles. There were 39 stations consisting of 55 casts. 14 of these were radionuclide casts which are not reported. All the casts were done in the ice with the exception of station 39, which was located in the Greenland Basin. Station 35 took place at the North Pole. Much of the cruise was carried out in low visibility with fog or overcast conditions and with air temperatures around -1 to +1 °C. The coldest air temperature was about -6 °C. No insurmountable problems were encountered during any phase of the operation.

CTD #6 was used for all but the last 3 stations, where CTD #1 was used. There were problems with the pylon deck unit which caused tripping problems starting at station 13 and continuing through station 15. There are 2 casts reported for station 13, since there were no bottles for the first cast due to the pylon deck unit malfunction. The CTD deck unit blew a fuse during cast 4 for station 26, which caused a delay of over 1 hour while the problem was diagnosed and repaired. Station 36 has 2 casts reported, as the conductivity sensor was replaced for the second cast. Then it was thought that the main temperature sensor malfunctioned. Therefore, CTD #6 was replaced by CTD #1 for the remaining 3 stations. The CTD oxygen sensor was malfunctioning throughout the cruise, and so these data were not calibrated. The uncalibrated CTD oxygen data are reported in this data set.

The distribution of samples is illustrated in Figure 1.1.0.



**Figure 1.1.0** Arctic 94 sample distribution, stas 1-39

### 1.2. Water Sampling Package

Hydrographic (rosette) casts were performed with a rosette system consisting of a 36-bottle rosette frame (ODF), a 36-place pylon (General Oceanics 1016) and 36 10-liter PVC bottles (ODF). Underwater electronic components consisted of ODF-modified NBIS Mark III CTDs (ODF #1 and #6) and associated sensors and Benthos altimeter. The CTD was mounted horizontally along the bottom of the rosette frame, with a Sersomedics dissolved oxygen sensor. CTD #1 had an FSI secondary PRT sensor deployed next to the CTD. CTD #6 had 2 separate PRT turrets. The altimeter provided distance-above-bottom in the CTD data stream. The rosette system was suspended from a three-conductor 0.322" electro-mechanical cable. Power to the CTD and pylon was provided through the cable from the ship. Separate conductors were used for the CTD and pylon signals. The dissolved oxygen, secondary temperature and altimeter were interfaced with the CTD, and their data were incorporated into the CTD data stream.

The deck watch prepared the rosette approximately 45 minutes prior to a cast. All valves, vents and lanyards were checked for proper orientation. The bottles were cocked and all hardware and connections rechecked. Upon arrival at station, time, position and bottom depth were logged and the deployment was begun. The rosette was deployed from the boat deck on the starboard side.

Each rosette cast was lowered to within 10-15 meters of the bottom, unless the bottom return from the altimeter was extremely poor. Bottles on the rosette were each identified with a unique serial number. These numbers corresponded to the pylon tripping sequence, 1-36, where the first (deepest) bottle tripped was bottle #1.

Averages of CTD data corresponding to the time of bottle closure were associated with the bottle data during a cast. Pressure, depth, temperature, salinity and density were immediately available to facilitate examination and quality control of the bottle data as the sampling and laboratory analyses progressed.

Recovering the package at the end of deployment was essentially the reverse of the launching. The bottles and rosette were examined before samples were taken, and any extraordinary situations or circumstances were noted on the sample log for the cast.

Routine CTD maintenance included soaking the conductivity and CTD  $O_2$  sensors in distilled water between casts to maintain sensor stability. The rosette was stored in a heated rosette room between casts to insure the CTD was not exposed to extreme cold or wind.

Rosette maintenance was performed on a regular basis. O-rings were changed as necessary and bottle maintenance was performed each day to insure proper closure and sealing. Valves were inspected for leaks and repaired or replaced as needed. No bottle replacements were necessary during the cruise.

There were intermittent level-wind and brake problems with the winch on board the *CCGS Louis S. St. Laurent* during the cruise, causing occasional stops during casts. Longer stops are noted in [Appendix B](#).

### **1.3. Underwater Electronics Packages**

CTD data were collected with modified NBIS Mark III CTDs (ODF #1 and #6). These instruments provided pressure, temperature, conductivity and dissolved  $O_2$  channels, and additionally measured a second temperature as a calibration check. Other data channels included elapsed-time, altimeter and several power supply voltages. The instrument supplied a 15-byte NBIS-format data stream at a data rate of 25 Hz. Modifications to the instrument included a revised dissolved  $O_2$  sensor mounting; ODF-designed sensor interfaces for  $O_2$  and FSI PRT (CTD #1 only); implementation of 8-bit and 16-bit multiplexer channels; an elapsed-time channel; instrument ID in the polarity byte and power supply voltages channels.

[Table 1.3.0](#) summarizes the serial numbers of instruments and sensors used during Arctic 94.

### ARCTIC OCEAN 94 CTD CONFIGURATION SUMMARY

ODF CTD ID#	Pressure	Temperature		Conductivity	Casts
		PRT1	PRT2		
6	131911*	15777†	16183†	2932-H154=	Stas 1 - 36-1
				O2=	Sta 36-2
1	131910*	14304†	N/A	5902-F117=	Stas 37 & 38
			1321‡		Sta 39

\* Paine Model 211-35-440-05 strain gage/0-8850psi

† Rosemount Model 171BJ

‡ FSI Model OTM-D212

= NBIS Model 09035-00151

≡ GO Model 09035-00151

**Table 1.3.0** Arctic 94 Instrument/Sensor Serial Numbers

The NBIS temperature compensation circuit on the pressure interface was disabled; all thermal response characteristics were modeled and corrected in software.

The  $O_2$  sensor was deployed in a pressure-compensated holder assembly mounted separately on the rosette frame and connected to the CTD by an underwater cable. The  $O_2$  sensor interface was designed and built by ODF using an off-the-shelf 12-bit A/D converter.

Although the secondary temperature sensors were located within 6 inches of the CTD conductivity sensors, they were not sufficiently close to calculate coherent salinities. They were used as secondary temperature calibration references rather than as redundant sensors, with the intent of eliminating the need for mercury or electronic DSRTs as calibration checks.

The General Oceanics 1016 36-place pylon was used in conjunction with the General Oceanics pylon deck unit. There were some tripping problems caused by the G.O. pylon/deck unit combination. Usually these could be resolved by the console operator via the pylon diagnostics routine. This combination provided generally reliable operation except for stations 13 through 15. On station 13, cast 1, the pylon deck unit failed. The backup pylon deck unit was used until repairs were completed to the original (station 13, cast 2 and stations 14 and 15). The pylon emitted a confirmation message containing its current notion of bottle trip position, which was useful in sorting out mis-trips. The acquisition software averaged CTD data corresponding to the rosette trip once the trip was initiated until the trip confirmed, typically 2-4.5 seconds on Arctic 94.

#### 1.4. Navigation and Bathymetric Data

GPS position and bottom depth were logged manually three times for each CTD/rosette deployment: at the beginning of the cast, at the bottom of the cast and at the end of the cast. An ELAC 12KHz PDR (provided by IOS) was occasionally used to determine bottom depth. It proved to be unreliable in the ice, and not compatible with the Benthos pinger on the rosette.

#### 1.5. CTD Data Acquisition, Processing and Control System

The CTD data acquisition, processing and control system consisted of a Sun SPARCstation 2 computer workstation, ODF-built CTD deck unit, General Oceanics 1016 pylon deck unit, CTD and pylon power supplies, and a VCR recorder for real-time analog backup recording of the sea-cable signal. One other Sun SPARCstation 2 system was networked to the data acquisition system. Each Sun system consisted of a color display with trackball and keyboard (the CTD console), 18 RS-232 ports, 2.5 GB disk and 8mm cartridge tape. These systems were available for real-time CTD data display and provided for hydrographic data management and backup. Each sun SPARCstation was equipped with a printer and an 8-color drum plotter.

The CTD FSK signal was demodulated and converted to a 9600 baud RS-232C binary data stream by the CTD deck unit. This data stream was fed to the Sun SPARCstation.

The pylon deck unit was connected to the data acquisition system through a serial port, allowing the data acquisition system to initiate and confirm bottle trips. A bitmapped color display provided interactive graphical display and control of the CTD rosette sampling system, including real-time raw and processed CTD data, winch and rosette trip displays.

The CTD data acquisition, processing and control system was prepared by the console watch a few minutes before each deployment. A console operations log was maintained for each deployment, containing a record of every attempt to trip a bottle as well as any pertinent comments. Most CTD console control functions, including starting the data acquisition, were initiated by pointing and clicking a trackball cursor on the display at icons representing functions to perform. The system then presented the operator with short dialog prompts with automatically-generated choices that could either be accepted as defaults or overridden. The operator was instructed to turn on the CTD and pylon power supplies, then to examine a real-time CTD data display on the screen for stable voltages from the underwater unit. Once this was accomplished, the data acquisition and processing was begun and a time and position were logged for the beginning of the cast. A backup analog recording of the CTD signal on a VCR tape was started at the same time as the data acquisition. A rosette trip display and pylon control window popped up, giving visual confirmation that the pylon was initializing properly. Various plots and displays were initiated. When all was ready, the console operator informed the deck watch by radio.

Once the deck watch had deployed the rosette and informed the console operator that the rosette was at the surface (also confirmed by the computer displays), the console operator or watch leader provided the winch operator with a target depth (wire-out) and maximum lowering rate, normally 60 meters/minute for this package. The package then began its descent, building up to the maximum rate during the first few hundred meters, then optimally continuing at a steady rate without any stops during the down-cast.

The console operator examined the processed CTD data during descent via interactive plot windows on the display, which could also be run at other workstations on the network. Additionally, the operator decided where to trip bottles on the up-cast, noting this on the console log.

The PDR was monitored to insure the bottom depth was known at all times.

The console operator monitored the rosette's distance to the bottom using the altimeter display. Around 100 meters above the bottom, depending on bottom conditions, the altimeter typically began signaling a bottom return on the console. The winch speed was usually slowed to ~30 meters/minute during the final approach. The winch and altimeter displays allowed the console operator to refine the target depth relayed to the winch operator and safely approach to within 10-15 meters of the bottom.

Bottles were closed on the up-cast by pointing the console trackball cursor at a graphic firing control and clicking a button. The data acquisition system responded with the CTD rosette trip data and a pylon confirmation message in a window. A bad or suspicious confirmation signal typically resulted in the console operator repositioning the pylon trip arm via software, then re-tripping the bottle, until a good confirmation was received. All tripping attempts were noted on the console log. The console operator then instructed the winch operator to bring the rosette up to the next bottle depth. The console operator was also responsible for generating the sample log for the cast.

After the last bottle was tripped, the console operator directed the deck watch to bring the rosette on deck. Once the rosette was on deck, the console operator terminated the data acquisition and turned off the CTD, pylon and VCR recording. The VCR tape was filed. Usually the console operator also brought the sample log to the rosette room and served as the *sample cop*.

## 1.6. CTD Data Processing

ODF CTD processing software consists of over 30 programs running under the Unix operating system. The initial CTD processing program (ctdba) is used either in real-time or with existing raw data sets to:

- Convert raw CTD scans into scaled engineering units, and assign the data to logical channels;
- Filter various channels according to specified filtering criteria;
- Apply sensor- or instrument-specific response-correction models;
- Provide periodic averages of the channels corresponding to the output time-series interval; and
- Store the output time-series in a CTD-independent format.

Once the CTD data are reduced to a standard-format time-series, they can be manipulated in various ways. Channels can be additionally filtered. The time-series can be split up into shorter time-series or pasted together to form longer time-series. A time-series can be transformed into a pressure-series, or into a larger-interval time-series. The pressure calibration corrections are applied during reduction of the data to time-series. Temperature, conductivity and oxygen corrections to the series are maintained in separate files and are applied whenever the data are accessed.

ODF data acquisition software acquired and processed the CTD data in real-time, providing calibrated, processed data for interactive plotting and reporting during a cast. The 25 Hz data from the CTD were filtered, response-corrected and averaged to a 2 Hz (0.5-second) time-series. Sensor correction and calibration models were applied to pressure, temperature, conductivity and  $O_2$ . Rosette trip data were extracted from this time-series in response to trip initiation and confirmation signals. The calibrated 2 Hz time-series data, as well as the 25 Hz raw data, were stored on disk and were available in real-time for reporting and graphical display. At the end of the cast, various consistency and calibration checks were performed, and a 2.0-db pressure-series of the down-cast was generated and subsequently used for reports and plots.

CTD plots generated automatically at the completion of deployment were checked daily for potential problems. The two PRT temperature sensors were inter-calibrated and checked for sensor drift. The CTD conductivity sensor was monitored by comparing CTD values to check-sample conductivities and by deep Theta-Salinity comparisons with adjacent stations. The CTD  $O_2$  sensor was not calibrated to check-sample data as it was malfunctioning during this cruise.

A few casts exhibited conductivity offsets due to biological or particulate artifacts. Some casts were subject to noise in the data stream caused by sea cable or slip-ring problems, or by moisture in the interconnect cable between the CTD and external sensors (i.e.  $O_2$ ). Intermittent noisy data were filtered out of the 2 Hz data using a spike-removal filter. A least-squares polynomial of specified order was fit to fixed-length segments of data. Points exceeding a specified multiple of the residual standard deviation were replaced by the polynomial value.

Density inversions can be induced in high-gradient regions by ship-generated vertical motion of the rosette. Detailed examination of the raw data shows significant mixing occurring in these areas because of "ship roll". In order to minimize density inversions, a ship-roll filter was applied to all casts during pressure-sequencing to disallow pressure reversals. Since most of this cruise occurred in the ice, ship-roll was not a significant factor.

The first few seconds of in-water data were excluded from the pressure-series data, since the sensors were still adjusting to the going-in-water transition.

Pressure intervals with no time-series data can optionally be filled by double-quadratic interpolation. The only pressure intervals missing/filled during this leg were at 0 db, caused by chopping off going-in-water transition data at pressure-sequencing.

When the down-cast CTD data have excessive noise, gaps or offsets, the up-cast data are used instead. CTD data from down- and up-casts are not mixed together in the pressure-series data because they do not represent identical water columns (due to ship movement, wire angles, etc.). The 2 up-casts used for final Arctic 94 data are indicated in [Appendix B](#).

There is an inherent problem in the internal digitizing circuitry of the NBIS Mark III CTD when the sign bit for temperature flips. Raw temperature can shift 1-2 millidegrees as values cross between positive and negative, a

problem avoided by offsetting the raw PRT readings by  $\sim 1.5^{\circ}\text{C}$ . The conductivity channel also can shift by 0.001-0.002 mmho/cm as raw data values change between 32767/32768, where all the bits flip at once. This is typically not a problem in shallow to intermediate depths because such a small shift becomes negligible in higher gradient areas.

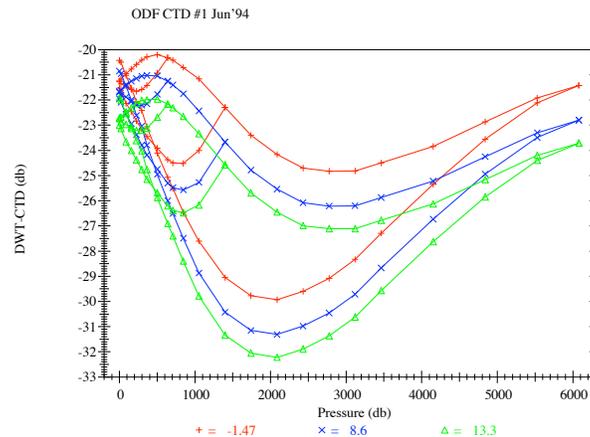
[Appendix B](#) contains a table of CTD casts requiring special attention; Arctic 94 CTD-related comments, problems and solutions are documented there in detail.

### 1.7. CTD Laboratory Calibration Procedures

Pre-cruise laboratory calibrations of CTD pressure and temperature sensors were used to generate tables of corrections applied by the CTD data acquisition and processing software at sea. These laboratory calibrations were also performed post-cruise.

Pressure and temperature calibrations were performed on CTDs #1 and #6 at the ODF Calibration Facility in La Jolla. The pre-cruise calibrations were done in June 1994 prior to the Arctic Ocean 94 expedition and the post-cruise calibrations were done in September 1994 for CTD #6, and October 1994 for CTD #1.

The CTD pressure transducers were calibrated in a temperature-controlled water bath to a Ruska Model 2400 Piston Gage pressure reference. Calibration data were measured pre-cruise at 13.30/8.60/-1.47  $^{\circ}\text{C}$  to 3 maximum loading pressures pre-cruise (640/1400/6080 db). The post-cruise CTD #1 calibration data were measured at  $-0.62^{\circ}\text{C}$  to a maximum loading pressure of 6080 db. For CTD #6, the post-cruise calibration data were measured at  $-1.50/8.55^{\circ}\text{C}$  to maximum loading pressures of 6080/1400 db. Figures 1.7.0 and 1.7.1 summarize the CTD #1 laboratory pressure calibrations performed in June and October 1994, and figures 1.7.2 and 1.7.3 summarize the CTD #6 laboratory pressure calibrations performed in June and September 1994.



**Figure 1.7.0** Pressure calibration for ODF CTD #1, June 1994.

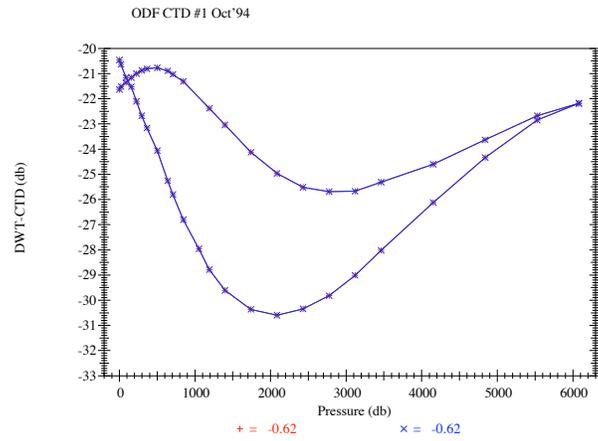


Figure 1.7.1 Pressure calibration for ODF CTD #1, October 1994.

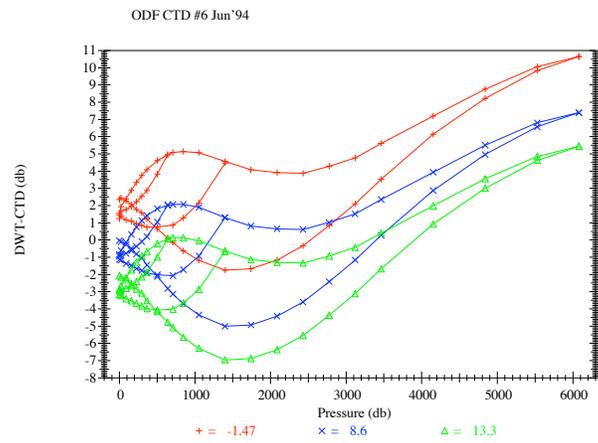


Figure 1.7.2 Pressure calibration for ODF CTD #6, June 1994.

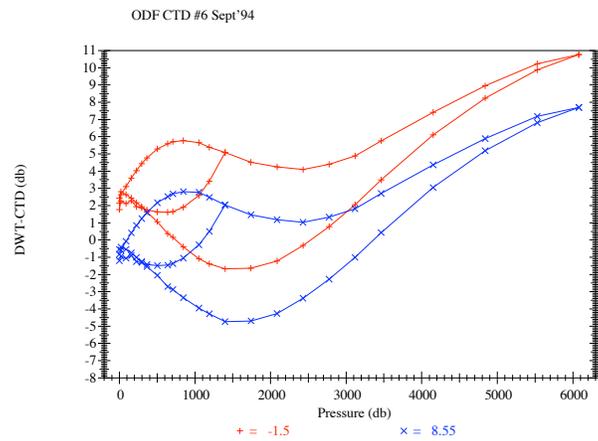
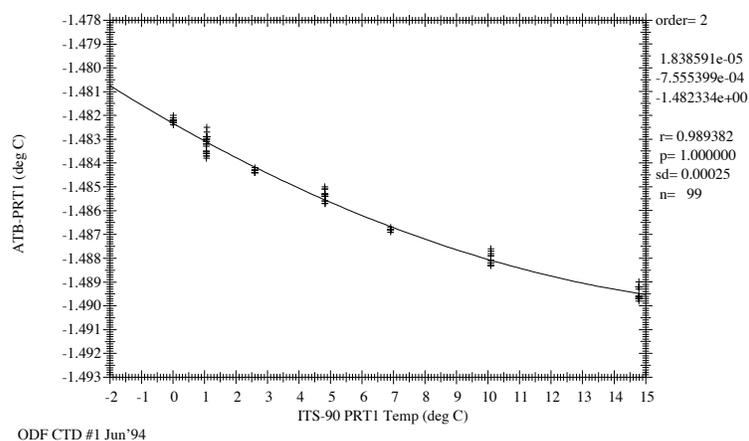


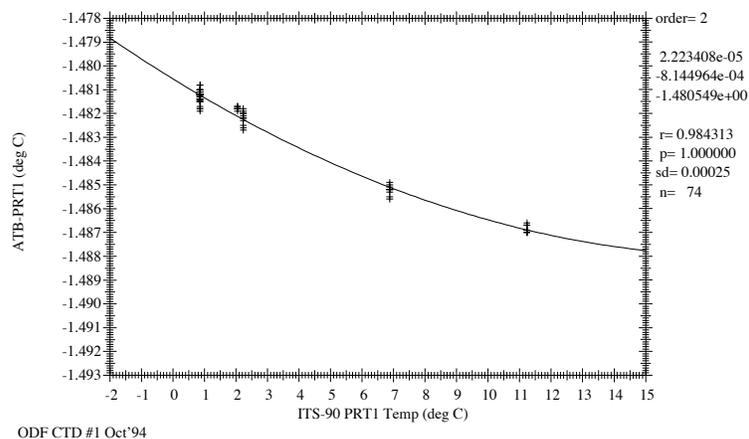
Figure 1.7.3 Pressure calibration for ODF CTD #6, September 1994.

Additionally, dynamic thermal-response step tests were conducted on the pressure transducer to calibrate dynamic thermal effects. These results were combined with the static temperature calibrations to optimally correct the CTD pressure.

CTD PRT temperatures were calibrated to an NBIS ATB-1250 resistance bridge and Rosemount standard PRT in a temperature-controlled bath. The primary and secondary CTD temperatures were offset by  $\sim 1.5^\circ\text{C}$  to avoid the 0-point discontinuity inherent in the internal digitizing circuitry. Standard and PRT temperatures were measured at 7 different bath temperatures between  $-1.5$  and  $14.0^\circ\text{C}$ , both pre- and post-cruise (CTD #1 only measured at 4 temperatures post-cruise). Figures 1.7.4 and 1.7.5 summarize the laboratory calibrations performed on the CTD #1 primary PRT during June 1994 and October 1994. Figure 1.7.6 summarizes the laboratory calibrations performed on the CTD #6 primary PRT during June 1994. There was no post-cruise laboratory calibration for the CTD #6 primary PRT as it was believed to have malfunctioned during station 36, cast 2, after the conductivity sensor was replaced. After that cast, CTD #1 was put into place, and the main PRT for CTD #6 was worked on after its return to the laboratory. Figures 1.7.7 and 1.7.8 summarize the laboratory calibrations performed on the CTD #6 secondary PRT during June 1994 and September 1994.



**Figure 1.7.4** Primary PRT Temperature Calibration for ODF CTD #1, June 1994.



**Figure 1.7.5** Primary PRT Temperature Calibration for ODF CTD #1, October 1994.

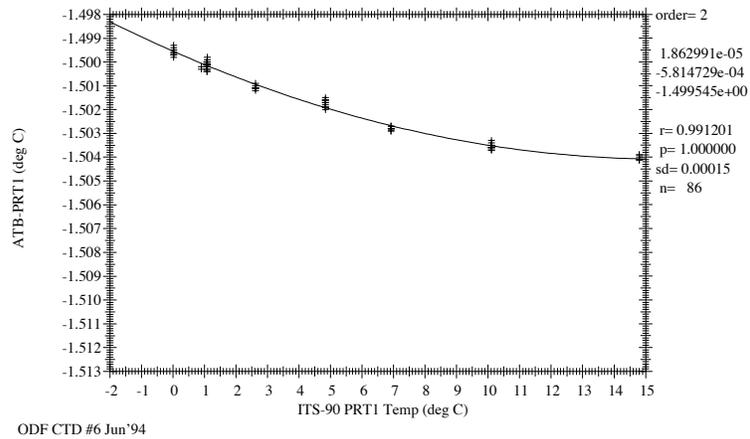


Figure 1.7.6 Primary PRT Temperature Calibration for ODF CTD #6, June 1994.

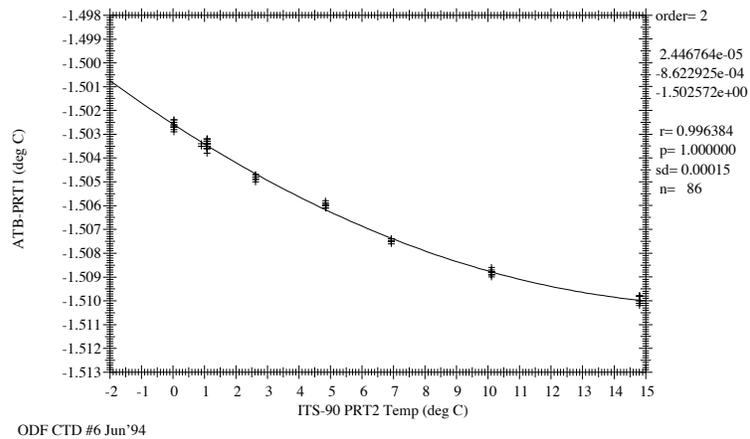


Figure 1.7.7 Secondary PRT Temperature Calibration for ODF CTD #6, June 1994.

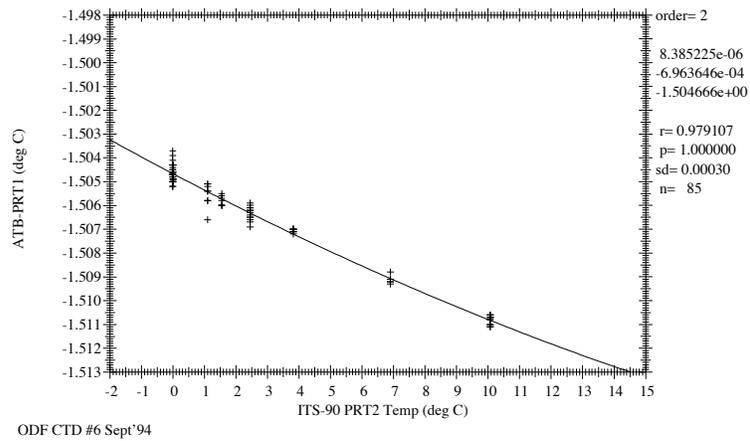


Figure 1.7.8 Secondary PRT Temperature Calibration for ODF CTD #6, September 1994.

These laboratory temperature calibrations were referenced to an ITS-90 standard. Temperatures were converted to the IPTS-68 standard during processing in order to calculate other parameters, including salinity and density, which are currently defined in terms of that standard only. Final calibrated CTD temperatures were reported using the ITS-90 standard.

### **1.8. Final CTD Calibration Procedures**

A redundant sensor was used on each CTD as a temperature calibration check while at sea. CTD conductivity was calibrated to *in-situ* check samples collected during each rosette cast.

Final pressure, temperature and conductivity corrections were determined during post-cruise processing.

ODF CTD #6 was used during stations 1-35 and station 36, cast 1. The conductivity sensor displayed erratic behavior during cast 1 for station 36. The CTD was not used for several days between stations 35 and 36 and even though precautions were taken to avoid freezing, it is believed that the conductivity sensor froze and was damaged. The conductivity sensor was replaced for cast 2 but then it was thought that the primary temperature sensor malfunctioned. It was then decided to replace CTD #6 with CTD #1 for the remainder of the cruise (stations 37-39). For stations 37 and 38, CTD #1 did not have a secondary temperature channel as the CTD would not function with it in place. After consultation with personnel on shore, the FSI secondary temperature sensor was successfully put in place for station 39.

#### **1.8.1. Pressure and Temperature**

A second Rosemount PRT sensor was deployed for CTD #6, and the secondary temperature channel for CTD #1 was an FSI PRT temperature module/OTM. These were compared with the primary PRT channel on all casts during this expedition (except for stations 37 and 38) to monitor for drift. The response times of the sensors were first matched, then preliminary corrected temperatures were compared for a series of standard depths from each CTD down-cast.

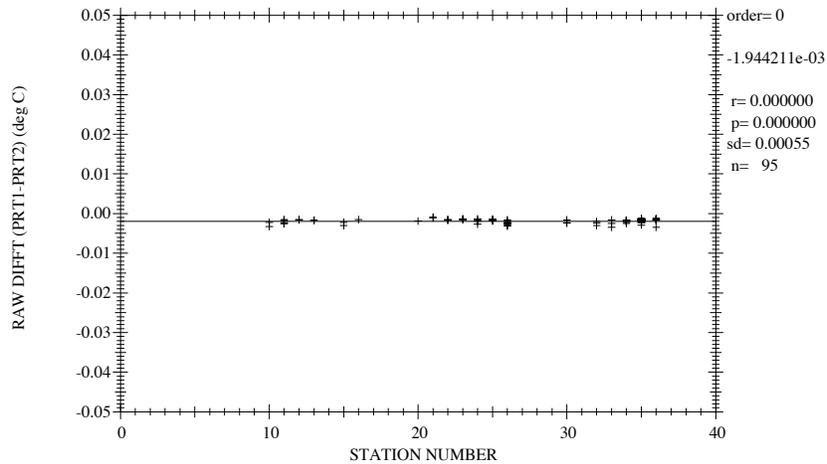
#### **CTD #6**

There was essentially no change between the pre- and post-cruise pressure laboratory calibrations, so the pre-cruise pressure calibration was applied for CTD #6.

The CTD #6 primary temperature sensor (PRT1) used during Arctic 94 was believed to be ruined during station 36, cast 2. The CTD #6 conductivity sensor was changed after station 36, cast 1, and during cast 2, it was thought that the primary PRT was malfunctioning. Upon its return to La Jolla, PRT1 was worked on. There was no post-cruise calibration for the primary temperature sensor.

The CTD #6 secondary temperature sensor (PRT2) was not affected by the changed conductivity sensor because it was mounted in a different turret. Using the PRT2 sensor for reporting CTD data was not a reasonable solution because its distance from the single conductivity sensor would cause an unacceptable level of noise in CTD salinity. Since PRT1 was not destroyed until after its use during the cruise, a comparison of shipboard PRT1 and PRT2 data, combined with changes in the PRT2 laboratory calibrations, was used to decide if any further correction was required for PRT1.

There was a constant offset maintained between the two PRTs on CTD #6. [Figure 1.8.1.0](#) summarizes the shipboard comparison between the primary and secondary PRT channels for CTD #6 for all CTD casts, including the casts which were not processed.



**Figure 1.8.1.0** Shipboard comparison of CTD #6 primary/secondary PRT channels, pressure>1000db.

The pre- and post-cruise laboratory calibrations showed a shift of  $-0.0018^{\circ}\text{C}$  in the PRT2 correction over the temperature range of the cruise. During pre-cruise laboratory calibrations, the PRT1-PRT2 difference was  $-0.003^{\circ}\text{C}$ . CTD #6 deep shipboard raw PRT1-PRT2 differences held steady at  $-0.0015$  to  $-0.0020^{\circ}\text{C}$ . If the PRT2 pre-cruise laboratory calibration was in effect for the whole cruise, then by station 10, the first station for which we have deep data, PRT1 must already have changed at least  $0.001^{\circ}\text{C}$  (since the difference was already  $-0.0015$  to  $-0.0020^{\circ}\text{C}$  rather than the  $-0.003^{\circ}\text{C}$  seen during the pre-cruise calibration). Assuming that the PRT2 post-cruise laboratory calibration was in effect for the whole cruise (i.e. changes occurred during shipping out for the cruise) means that by station 10, PRT1 had already changed by  $0.003^{\circ}\text{C}$ . As there was no way to tell when the change occurred, it was decided to split the difference and offset the pre-cruise PRT1 correction by  $-0.002^{\circ}\text{C}$  and apply this temperature correction to the Arctic 94 CTD #6 data.

### CTD #1

There was an average  $\sim 0.6$ -db offset between the pre- and post-cruise pressure laboratory calibrations. This is a negligible difference, so the pre-cruise pressure calibration was applied for CTD #1.

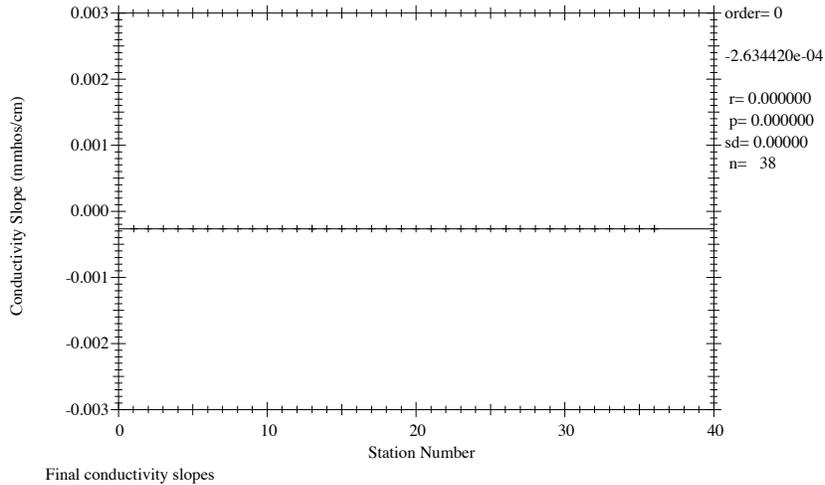
The pre- and post-cruise laboratory calibrations for the CTD #1 primary temperature sensor (PRT1), showed an average shift of  $+0.0018^{\circ}\text{C}$  in the PRT1 correction. The secondary temperature sensor showed a shift of  $+0.0020$  to  $+0.0026^{\circ}\text{C}$ .

There was only one cast with a working secondary PRT for this CTD, as PRT2 would not function with the CTD for the first 2 CTD #1 stations. The PRT1-PRT2 difference was  $-0.518^{\circ}\text{C}$  pre-cruise,  $-0.517^{\circ}\text{C}$  post-cruise and  $-0.518^{\circ}\text{C}$  for the third station below 500 db. Shipboard DSRT-PRT1 differences were not helpful as only one cast had deep usable data. As there is no way to determine when the shift occurred, it was decided to split the difference between pre- and post-cruise PRT1 corrections and offset the pre-cruise PRT1 correction by  $+0.0009^{\circ}\text{C}$  for stations 37 through 39.

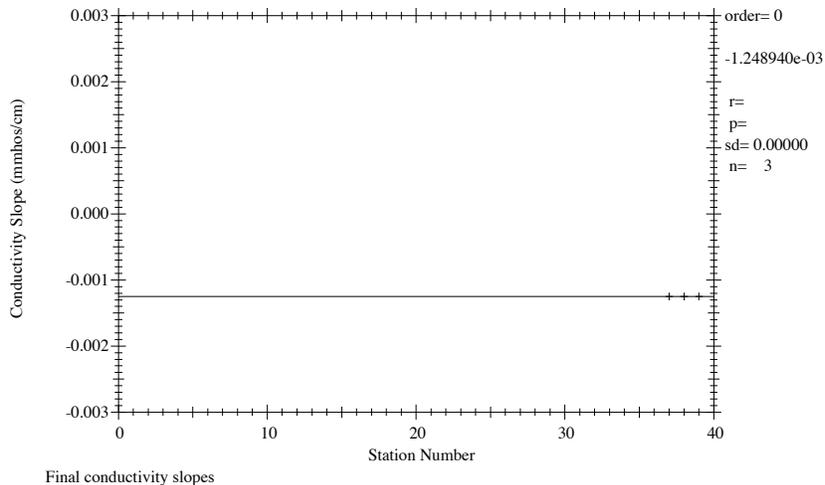
### 1.8.2. Conductivity

The corrected CTD rosette trip pressure and temperature were used with the bottle salinity to calculate a bottle conductivity. Differences between the bottle and CTD conductivities were then used to derive a conductivity correction. This correction is normally linear for the 3-cm conductivity cell used in the Mark III CTD. Cast-by-cast comparisons showed only minor conductivity sensor offset shifts, and no sensor slope changes. This part of the ocean has a very narrow range of conductivities, so the conductivity slope correction does not have a great effect on the data.

The conductivity slopes for stations 1-36 for CTD #6 and stations 37-39 for CTD #1 were fit to station number, with outlying values (4,2 standard deviations) rejected. Even though there was a change of conductivity sensor for station 36 cast 2, the calculated slopes for both casts for that station were so similar that it was decided to use the same slope correction for all CTD #6 casts. Conductivity slopes were calculated from the 0-order fit for each CTD and applied to each Arctic 94 cast. Figure 1.8.2.0. summarizes the final conductivity slopes for CTD #6 (stations 1-36) and Figure 1.8.2.1 for CTD #1 (stations 37-39).



**Figure 1.8.2.0** CTD #6 conductivity slope corrections by station number.

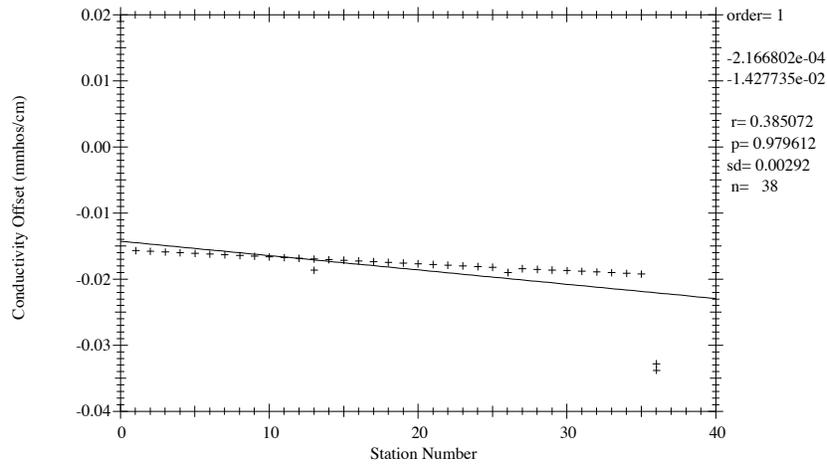


**Figure 1.8.2.1** CTD #1 conductivity slope corrections by station number.

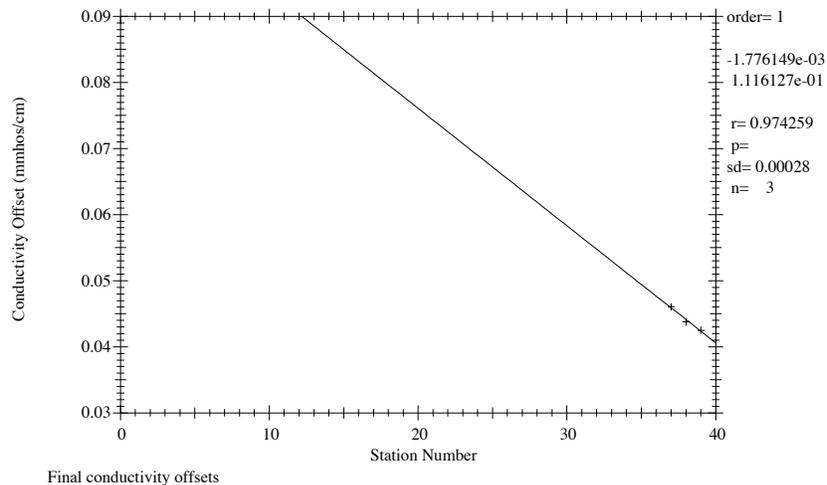
Once the conductivity slopes were applied, residual CTD conductivity offsets were calculated for each cast using bottle conductivities deeper than 500 db. Casts were grouped together based on CTD and known CTD conductivity shifts to determine average offsets. This also smoothed the effect of any cast-to-cast bottle salinity variation. The conductivity offsets for CTD #6 (2 groups: stations 1-35 and station 36, casts 1 and 2) and for CTD #1 (stations 37-39) were fit to station number, with outlying values (4,2 standard deviations) rejected. Conductivity offsets were calculated from the first-order fit for each station group for both CTDs and applied to each Arctic 94 cast. An average of the calculated offsets for the 2 casts of station 36 was used, then the offset for cast 1 was adjusted, as the

up-cast was reported.

Smoothed offsets were applied to each cast, then some offsets were manually adjusted to account for discontinuous shifts in the conductivity transducer response or bottle salinities, or to maintain a consistent deep T-S relationship from station to station. Figure 1.8.2.2. summarizes the final applied conductivity offsets for CTD #6 (stations 1-36) and Figure 1.8.2.3 for CTD #1 (stations 37-39).



**Figure 1.8.2.2** CTD #6 conductivity offsets by station number.

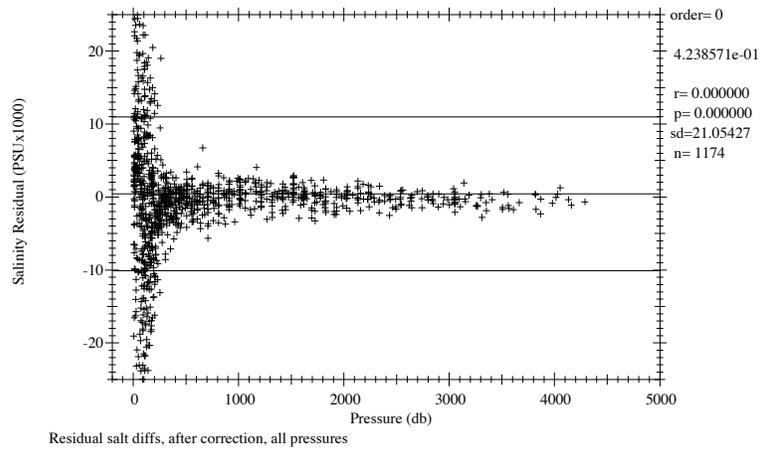


**Figure 1.8.2.3** CTD #1 conductivity offsets by station number.

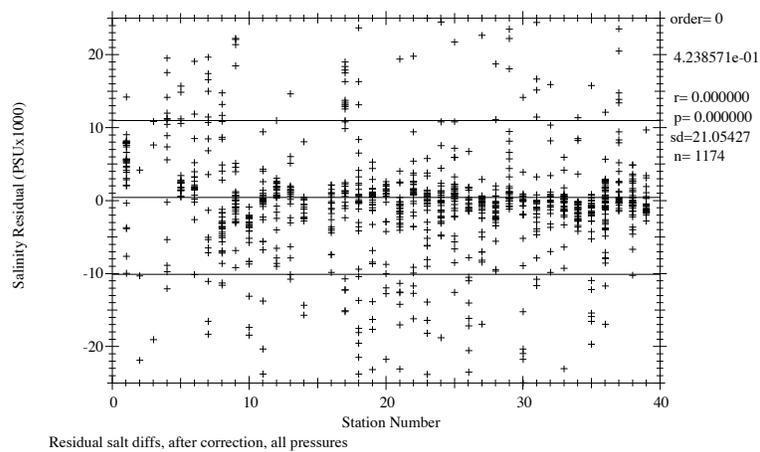
Arctic Ocean 94 temperature and conductivity correction coefficients are also tabulated in [Appendix A](#).

### Summary of Residual Salinity Differences

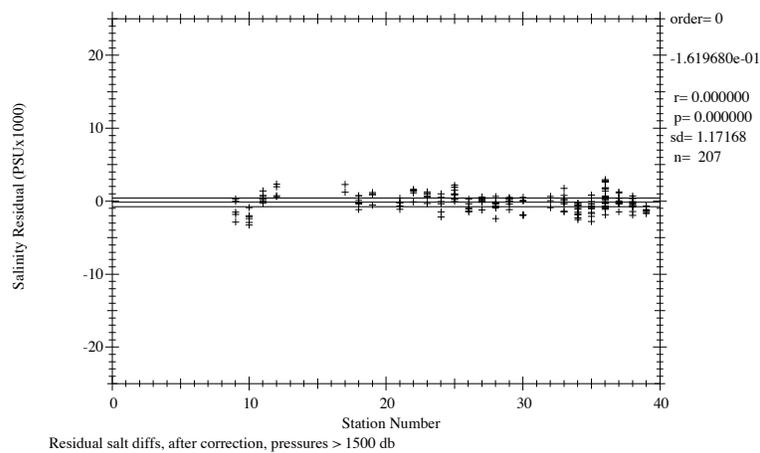
Figures 1.8.2.4, 1.8.2.5 and 1.8.2.6 summarize the residual differences between bottle and CTD salinities for all casts after applying the conductivity corrections.



**Figure 1.8.2.4** Salinity residual differences vs pressure (after correction).



**Figure 1.8.2.5** Salinity residual differences vs station # (after correction).



**Figure 1.8.2.6** Deep salinity residual differences vs station # (after correction).

The CTD conductivity calibration represents a best estimate of the conductivity field throughout the water column.  $3\sigma$  from the mean residual in [Figures 1.8.2.5](#) and [1.8.2.6](#), or  $\pm 0.0211$  PSU for all salinities and  $\pm 0.0012$  PSU for deep salinities, represents the limit of repeatability of the bottle salinities (Autosal, rosette, operators and samplers). This limit agrees with station overlays of deep Theta-Salinity. Within most casts (a single salinometer run), the precision of bottle salinities appears to be better than 0.001 PSU. The precision of the CTD salinities appears to be better than 0.0005 PSU.

Arctic 94 data were compared with final calibrated CTD data from Arctic 91. Preliminary calibrated CTD data from Arctic 96 were also compared (Makarov basin stations only). Deep Theta-Salinity comparisons were made for casts in the Fram, Makarov and Nansen basins and along the Lomonosov Ridge. Only the North Pole casts from Arctic 91 and Arctic 94 were in the same geographical location, although station 30 from Arctic 94 and station 24 from Arctic 91 were extremely close (Lomonosov Ridge). The two North Pole stations showed less than 0.001 PSU difference. The Lomonosov Ridge stations looked the same. The variation in the Nansen basin stations was about .0015 PSU as well as in the Makarov basin stations. The Makarov basin stations for Arctic 96, had much variability in the bottle salts and only 1 CTD cast. The variability within the Arctic 91 CTD stations alone is at least .001 PSU for this basin, with the bottle salts variability being twice that much. The standard seawater batches from Arctic 91 (P-115) and Arctic 96 (P-125) have not been cross-calibrated with other batches, so no corrections for standard seawater batch differences have been considered. A cross-calibration of standard seawater batches is planned for mid-1998 [Mant97].

During the Arctic 94 cruise, a question was raised concerning the temperature calibration correction used for final processing of Arctic 91 data. The data were re-examined and it was determined that it was possible that the main PRT had shifted 2 millidegrees during pre-cruise shipping and that the rest of the shift occurred during post-cruise shipping (another 4.6 millidegrees). This determination was based on PRT1 minus PRT2 differences during both the cruise and pre/post-cruise calibration, as well as the fact that there was no shift pre/post for PRT2. Such a correction would move the Arctic 91 temperatures 2 millidegrees warmer. This would mean that the deep basin thetas for Arctic 91 and Arctic 94 would then be within 1 millidegree of each other.

### 1.8.3. CTD Dissolved Oxygen

Please note that the CTD oxygen data for Arctic 94 are not calibrated. Working in high latitudes provides extremely harsh conditions for CTD dissolved oxygen sensors. Their performance is severely impacted due to the extreme cold. In addition, the CTD oxygen sensor was malfunctioning off and on throughout the cruise, thus making it extremely difficult if not impossible to calibrate the CTD oxygen. The data reported are the preliminary data automatically generated shipboard. They are provided only to suggest the gross oxygen features.

There are a number of problems with the response characteristics of the Sensormedics  $O_2$  sensor used in the NBIS Mark III CTD, the major ones being a secondary thermal response and a sensitivity to profiling velocity. Stopping the rosette for as little as half a minute, or slowing down for a bottom approach, can cause shifts in the CTD  $O_2$  profile. Winch stops longer than .5 minute and deeper than 5 db which may have affected CTD oxygen data are documented in [Appendix B](#). Most launches had pauses of between .5 to 1 minute at or just below the surface. In two cases, this pause lasted up to 2 minutes.

Because of these problems, up-cast CTD rosette trip data cannot be optimally calibrated to  $O_2$  check samples. Instead, down-cast CTD  $O_2$  data are derived by matching the up-cast rosette trips along isopycnal surfaces. When down-casts were deemed to be unusable (see [Appendix B](#)), up-cast CTD  $O_2$  data were processed despite the signal drop-offs typically seen at bottle stops. The differences between CTD  $O_2$  data modeled from these derived values and check samples are then minimized using a non-linear least-squares fitting procedure.

The general form of the ODF  $O_2$  conversion equation follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. ODF does not use a digitized  $O_2$  sensor temperature to model the secondary thermal response but instead models membrane and sensor temperatures by low-pass filtering the PRT temperature. *In-situ* pressure and temperature are filtered to match the sensor response. Time-constants for the pressure response  $\tau_p$ , and two temperature responses  $\tau_{Ts}$  and  $\tau_{Tf}$  are fitting parameters. The  $O_c$  gradient,  $dO_c/dt$ , is approximated by low-pass filtering 1st-order  $O_c$  differences. This gradient term attempts to correct for reduction of species other than  $O_2$  at the

cathode. The time-constant for this filter,  $\tau_{og}$ , is a fitting parameter. Oxygen partial-pressure is then calculated:

$$O_{pp} = [c_1 O_c + c_2] \cdot f_{sat}(S, T, P) \cdot e^{(c_3 P_l + c_4 T_f + c_5 T_s + c_6 \frac{dO_c}{dt})} \quad (1.8.3.0)$$

where:

$O_{pp}$	= Dissolved $O_2$ partial-pressure in atmospheres (atm);
$O_c$	= Sensor current ( $\mu$ amps);
$f_{sat}(S, T, P)$	= $O_2$ saturation partial-pressure at S,T,P (atm);
$S$	= Salinity at $O_2$ response-time (PSUs);
$T$	= Temperature at $O_2$ response-time ( $^{\circ}$ C);
$P$	= Pressure at $O_2$ response-time (decibars);
$P_l$	= Low-pass filtered pressure (decibars);
$T_f$	= Fast low-pass filtered temperature ( $^{\circ}$ C);
$T_s$	= Slow low-pass filtered temperature ( $^{\circ}$ C);
$\frac{dO_c}{dt}$	= Sensor current gradient ( $\mu$ amps/secs).

### 1.9. Bottle Sampling

At the end of each rosette deployment water samples were drawn from the bottles in the following order:

- CFCs;
- $^3He$ ;
- $O_2$ ;
- Total  $CO_2$ ;
- Alkalinity;
- Trace Metals;
- Tritium;
- Nutrients;
- Salinity;
- HCH;
- $^{18}O$ ;
- HC;
- Radionuclides;
- Methane;
- Barium.

Some properties were sampled by cast or by station, so the actual sequence of samples drawn was modified accordingly.

One member of the sampling team was designated the *sample cop*, whose sole responsibility was to maintain the sample log and insure that sampling progressed in the proper drawing order. The numbers of the individual sample containers, and the rosette bottle from which the samples were drawn, were either recorded on the sample log for the cast, or, in the case of samples taken by/for groups other than ODF, maintained by pre-numbered adhesive labels attached to each Niskin bottle prior to a cast, and to the sample containers to be used for sampling from each Niskin. Thus each Niskin bottle, and each sample from that bottle, shared a common, unique number (the Bedford Institute of Oceanography numbering system). In the latter case, the sample log was simply checked as the sample was drawn. The sample log also included any comments or anomalous conditions noted about the rosette and bottles.

Normal sampling practice included opening the drain valve before opening the air vent on the bottle, indicating an air leak if water escaped. This observation and/or other diagnostic comments (e.g., "lanyard caught in lid", "valve left open") that might later prove useful in determining sample integrity were routinely noted on the sample log.

Drawing oxygen samples also involved taking the sample draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful as an indicator of leaking or mis-tripped bottles.

### 1.10. Bottle Data Processing

Bottle data processing began with sample drawing, and continued until the data were considered to be final. One of the most important pieces of information, the sample log sheet, was filled out during the drawing of the many different samples, and was useful both as a sample inventory, and as a guide for the technicians in carrying out their analyses. Any problems observed with the rosette before or during the sample drawing were noted on this form, including indications of bottle leaks, out-of-order drawing, etc. Oxygen draw temperatures recorded on this form were at times the first indicator of rosette bottle-tripping problems. Additional clues regarding bottle tripping or leak problems were found by individual analysts as the samples were analyzed and the resulting data were processed and checked by those personnel.

The next stage of processing was accomplished after the individual parameter files were merged into a common station file, along with CTD-derived parameters (pressure, temperature, conductivity, etc.). The rosette cast and bottle numbers were the primary identification for all ODF-analyzed samples taken from the bottle, and were used to merge the analytical results with the CTD data associated with the bottle. At this stage, bottle tripping problems were usually resolved, sometimes resulting in changes to the pressure, temperature and other CTD properties associated with the bottle. All CTD information from each bottle trip (confirmed or not) was retained in a file, so resolving bottle tripping problems consisted of correlating CTD trip data with the rosette bottles.

Diagnostic comments from the sample log, and notes from analysts and/or bottle data processors were entered into a computer file associated with each station (the "quality" file) as part of the quality control procedure. Sample data from bottles suspected of leaking were checked to see if the properties were consistent with the profile for the cast, with adjacent stations, and, where applicable, with the CTD data. Various property-property plots and vertical sections were examined for both consistency within a cast and consistency with adjacent stations by data processors, who advised analysts of possible errors or irregularities. The analysts reviewed and sometimes revised their data as additional calibration or diagnostic results became available.

Based on the outcome of investigations of the various comments in the quality files, WHP water sample codes were selected to indicate the reliability of the individual parameters affected by the comments. WHP bottle codes were assigned where evidence showed the entire bottle was affected, as in the case of a leak, or a bottle-trip at other than the intended depth.

WHP water bottle quality codes were assigned as defined in the WOCE Operations Manual [Joyc94] with the following additional interpretations:

- |   |   |
|---|---|
| 2 | No problems noted.  |
| 3 | Leaking. <i>An air leak large enough to produce an observable effect on a sample is identified by a code of 3 on the bottle and a code of 4 on the oxygen. (Small air leaks may have no observable effect, or may only affect gas samples.)</i> |
| 4 | Did not trip correctly. <i>Bottles tripped at other than the intended depth were assigned a code of 4. There may be no problems with the associated water sample data.</i>  |
| 5 | Not reported. <i>No water sample data reported. This is a representative level derived from the CTD data for reporting purposes. The sample number should be in the range of 80-99.</i>   |
| 9 | The samples were not drawn from this bottle.  |

WHP water sample quality flags were assigned using the following criteria:

- 1 | The sample for this measurement was drawn from the water bottle, but the results of the analysis were not (*yet*) received.
- 2 | Acceptable measurement.
- 3 | Questionable measurement. *The data did not fit the station profile or adjacent station comparisons (or possibly CTD data comparisons). No notes from the analyst indicated a problem. The data could be acceptable, but are open to interpretation.*
- 4 | Bad measurement. *The data did not fit the station profile, adjacent stations or CTD data. There were analytical notes indicating a problem, but data values were reported. Sampling and analytical errors were also coded as 4.*
- 5 | Not reported. *There should always be a reason associated with a code of 5, usually that the sample was lost, contaminated or rendered unusable.*
- 9 | The sample for this measurement was not drawn.

WHP water sample quality flags were assigned to the CTDSAL (CTD salinity) parameter as follows:

- 2 | Acceptable measurement.
- 3 | Questionable measurement. *The data did not fit the bottle data, or there was a CTD conductivity calibration shift during the up-cast.*
- 4 | Bad measurement. *The CTD up-cast data were determined to be unusable for calculating a salinity.*
- 7 | Despiked. *The CTD data have been filtered to eliminate a spike or offset.*

WHP water sample quality flags were assigned to the CTDOXY (CTD O<sub>2</sub>) parameter as follows:

- 1 | Not calibrated. *Data are uncalibrated.*
- 2 | Acceptable measurement.
- 3 | Questionable measurement.
- 4 | Bad measurement. *The CTD data were determined to be unusable for calculating a dissolved oxygen concentration.*
- 5 | Not reported. *The CTD data could not be reported, typically when CTD salinity is coded 3 or 4.*
- 7 | Despiked. *The CTD data have been filtered to eliminate a spike or offset.*
- 9 | Not sampled. *No operational CTD O<sub>2</sub> sensor was present on this cast.*

Note that all CTDOXY values were derived from the down-cast pressure-series CTD data. CTD data were matched to the up-cast bottle data along isopycnal surfaces. If the CTD salinity was footnoted as bad or questionable, the CTD O<sub>2</sub> was not reported.

Table 1.10.0 shows the number of samples drawn and the number of times each WHP sample quality flag was assigned for each basic hydrographic property:

Rosette Samples Stations 001-039								
	Reported Levels	WHP Quality Codes						
		1	2	3	4	5	7	9
Bottle	1269	0	1207	5	29	27	0	1
CTD Salt	1269	0	1262	0	7	0	0	0
CTD Oxy	1227	1227	0	0	0	42	0	0
Salinity	1229	0	1181	42	6	3	0	37
Oxygen	1072	0	1059	8	5	4	0	193
Silicate	1095	0	1037	53	5	0	0	174
Nitrate	1095	0	1084	6	5	0	0	174
Nitrite	1091	0	1086	0	5	4	0	174
Phosphate	1095	0	1090	0	5	0	0	174

**Table 1.10.0** Frequency of WHP quality flag assignments.

Additionally, all WHP water bottle/sample quality code comments are presented in [Appendix C](#).

### 1.11. Pressure and Temperatures

All pressures and temperatures for the bottle data tabulations on the rosette casts were obtained by averaging CTD data for a brief interval at the time the bottle was closed on the rosette, then correcting the data based on CTD laboratory calibrations.

The temperatures are reported using the International Temperature Scale of 1990.

### 1.12. Salinity Analysis

#### Equipment and Techniques

Two Guildline Autosol Model 8400A salinometers were used to measure salinities. The salinometers were modified by ODF and contained interfaces for computer-aided measurement. Autosol #55-654 was used for stations 007-011, 015-016 and 019. Autosol #57-396 was used on the other stations. The salinity analyses were performed when samples had equilibrated to laboratory temperature, usually within 8-20 hours after collection. The salinometers were standardized for each group of analyses (typically one cast, usually 36 samples) using at least one fresh vial of standard per cast. A computer (PC) prompted the analyst for control functions such as changing sample, flushing, or switching to "read" mode. At the correct time, the computer acquired conductivity ratio measurements, and logged results. The salinometer cell was flushed until two groups of readings met software criteria for consistency, both within and between groups; the two averages of the groups of measurements were then averaged for a final result.

#### Sampling and Data Processing

Salinity samples were drawn into 200 ml Kimax high-alumina borosilicate bottles, which were rinsed three times with sample prior to filling. The bottles were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to collecting each sample, inserts were inspected for proper fit and loose inserts were replaced to insure an airtight seal. The draw time and equilibration time were logged for all casts. Laboratory temperatures were logged at the beginning and end of each run.

PSS-78 salinity [UNES81] was calculated for each sample from the measured conductivity ratios. The difference (if any) between the initial vial of standard water and one run at the end as an unknown was applied linearly to the data

to account for any drift. The data were added to the cruise database. 1229 salinity measurements were made and 110 vials of standard water were used. The estimated accuracy of bottle salinities run at sea is usually better than 0.002 PSU relative to the particular Standard Seawater batch used.

### **Laboratory Temperature**

The ship had no air-conditioned spaces, because it normally worked only in cold environments, and the salinometer laboratory varied widely in temperature, from 23-31°C. Bath temperatures were switched around from time to time, to try to keep up with room temperature. One Autosal bath temperature was normally set 3°C higher than the other so that hopefully at least one would be close enough to run salts. The salinometer laboratory normally changed several degrees depending on whether the ship was stopped or underway; however, under steady conditions, the temperature stability was fair, with the lab temperature generally within 1-2°C of the Autosal bath temperature.

### **Standards**

IAPSO Standard Seawater (SSW) Batch P-120, was used to standardize the salinometers.

### **1.13. Oxygen Analysis**

#### **Equipment and Techniques**

Dissolved oxygen analyses were performed with an ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC software. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml buret. ODF used a whole-bottle modified-Winkler titration following the technique of Carpenter [Carp65] with modifications by Culberson *et al.* [Culb91], but with higher concentrations of potassium iodate standard (approximately 0.012N) and thiosulfate solution (50 gm/l). Standard solutions prepared from pre-weighed potassium iodate crystals were run at the beginning of each session of analyses, which typically included from 1 to 3 stations. Several standards were made up during the cruise and compared to assure that the results were reproducible, and to preclude the possibility of a weighing or dilution error. Reagent/distilled water blanks were determined, to account for presence of oxidizing or reducing materials.

#### **Sampling and Data Processing**

Samples were collected for dissolved oxygen analyses soon after the rosette sampler was brought on board, and after CFC and helium were drawn. Nominal 125ml volume-calibrated iodine flasks were rinsed twice with minimal agitation, then filled via a drawing tube, and allowed to overflow for at least 3 flask volumes. The sample temperature was measured with a small platinum resistance thermometer embedded in the drawing tube. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice to assure thorough dispersion of the precipitate, once immediately after drawing, and then again after 20 minutes. The samples were usually analyzed within a few hours of collection and the data were then merged with the cruise database.

Thiosulfate normalities were calculated from each standardization and corrected to 20°C. The 20°C normalities and the blanks were plotted versus time and were reviewed for possible problems. New thiosulfate normalities were recalculated after the blanks had been smoothed as a function of time, if warranted. These normalities were then smoothed, and the oxygen data were recalculated.

Oxygens were converted from milliliters per liter to micromoles per kilogram using the *in-situ* temperature. Ideally, for whole-bottle titrations, the conversion temperature should be the temperature of the water issuing from the bottle spigot. The sample temperatures were measured at the time the samples were drawn from the bottle, but were not used in the conversion from milliliters per liter to micromoles per kilogram because the software for this calculation was not available. Because of the very small slope of the density vs. temperature curve at the temperatures encountered on this cruise, and the small range of water temperatures encountered, no significant error was introduced by this method of conversion. Aberrant drawing temperatures provided an additional flag indicating that a bottle may not have tripped properly.

1072 oxygen measurements were made with no major problems with the analyses. The auto-titrator generally performed very well.

### **Volumetric Calibration**

Oxygen flask volumes were determined gravimetrically with degassed deionized water (DIW) to determine flask volumes at ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect bottle volume is detected. The volumetric flasks used in preparing standards were volume-calibrated by the same method, as was the 10 ml Dosimat buret used to dispense standard iodate solution.

### **Standards**

Potassium iodate standards, nominally 0.42 to 0.45 grams, were pre-weighed in ODF's chemistry laboratory to  $\pm 0.0001$  grams. The exact normality was calculated at sea after the volumetric flask volume and dilution temperature were known. Potassium iodate was obtained from Johnson Matthey Chemical Co. and was reported by the supplier to be >99.4% pure. All other reagents are "reagent grade" and are tested for levels of oxidizing and reducing impurities prior to use.

## **1.14. Nutrient Analysis**

### **Equipment and Techniques**

Nutrient analyses (phosphate, silicate, nitrate and nitrite) were performed on an ODF-modified 4-channel Technicon AutoAnalyzer II, generally within a few hours after sample collection. With only one nutrient analyst aboard, it was necessary on occasion to refrigerate some samples at 2 to 6°C for up to 12 hours.

The methods used are described by Gordon *et al.* [Gord92], Hager *et al.* [Hage72], Atlas *et al.* [Atla71]. The analog outputs from each of the four channels were digitized and logged automatically by computer (PC) at 2 second intervals.

Silicate was analyzed using the technique of Armstrong *et al.* [Arms67]. An acidic solution of ammonium molybdate was added to a seawater sample to produce silicomolybdic acid which was then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. Tartaric acid was also added to impede  $PO_4$  color development. The sample was passed through a 15mm flowcell and the absorbance measured at 820nm. ODF's methodology is known to be non-linear at high silicate concentrations ( $>120 \mu M$ ); a correction for this non-linearity is applied through ODF's software.

A modification of the Armstrong *et al.* [Arms67] procedure was used for the analysis of nitrate and nitrite. For the nitrate analysis, the seawater sample was passed through a cadmium reduction column where nitrate was quantitatively reduced to nitrite. Sulfanilamide was introduced to the sample stream followed by N-(1-naphthyl)ethylenediamine dihydrochloride which coupled to form a red azo dye. The stream was then passed through a 15mm flowcell and the absorbance measured at 540nm. The same technique was employed for nitrite analysis, except the cadmium column was not present, and a 50mm flowcell was used for measurement.

Phosphate was analyzed using a modification of the Bernhardt and Wilhelms [Bern67] technique. An acidic solution of ammonium molybdate was added to the sample to produce phosphomolybdic acid, then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The reaction product was heated to  $\sim 55^\circ C$  to enhance color development, then passed through a 50mm flowcell and the absorbance measured at 820m.

### **Sampling and Data Processing**

Nutrient samples were drawn into 40 ml polypropylene, screw-capped centrifuge tubes. The tubes were cleaned with 10% HCl and rinsed with sample twice before filling. Standardizations were performed at the beginning and end of each group of analyses (typically one cast, usually 36 samples) with an intermediate concentration mixed nutrient standard prepared prior to each run from a secondary standard in a low-nutrient seawater matrix. The secondary standards were prepared aboard ship by dilution from dry, pre-weighed primary standards. Sets of 5-6

different standard concentrations were analyzed periodically to determine the deviation from linearity as a function of concentration for each nutrient.

After each group of samples was analyzed, the raw data file was processed to produce another file of response factors, baseline values, and absorbances. Computer-produced absorbance readings were checked for accuracy against values taken from a strip chart recording. The data were then added to the cruise database. 1095 nutrient samples were analyzed. No major problems were encountered with the measurements, other than a continuing difficulty in holding the lab temperature constant, and a rapidly changing range of concentrations over the first few stations. These changes resulted in a few off-scale peaks, which required gain-setting changes and re-runs of several samples at each station where this occurred. The pump tubing was changed once.

Nutrients, reported in micromoles per kilogram, were converted from micromoles per liter by dividing by sample density calculated at 1 atm pressure (0 db), *in-situ* salinity, and an assumed laboratory temperature of 25°C.

### **Standards**

$Na_2SiF_6$ , the silicate primary standard, was obtained from Fluka Chemical Company and Fisher Scientific and was reported by the suppliers to be >98% pure. Primary standards for nitrate ( $KNO_3$ ), nitrite ( $NaNO_2$ ), and phosphate ( $KH_2PO_4$ ) were obtained from Johnson Matthey Chemical Co. and the supplier reported purities of 99.999%, 97%, and 99.999%, respectively.

## **Total Carbonate and Total Alkalinity: Tracers of Shelf Waters in the Arctic Ocean**

*(E. Peter Jones)*

Modern oceanographic measurements include a suite of many tracers, each of which often has a significance in determining the origin of a particular water mass and tracing its circulation. In the Arctic Ocean, total carbonate and total alkalinity have been shown to be effective tracers of waters that have flowed into central regions from the continental shelves. In addition, these measurements are an integral part of an assessment of carbon fluxes into and within the Arctic Ocean.

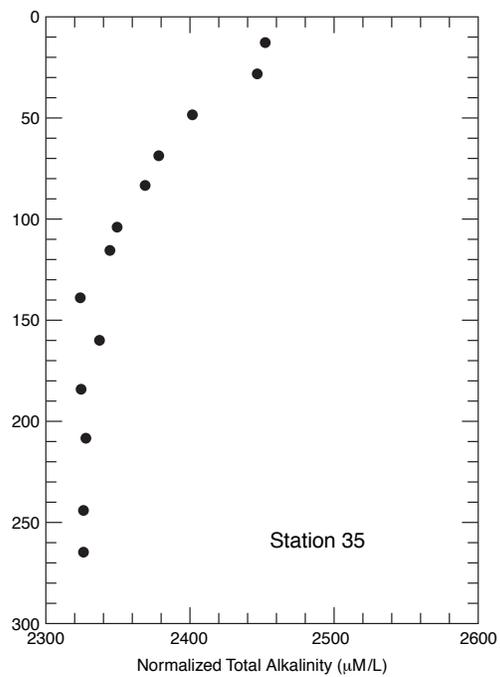
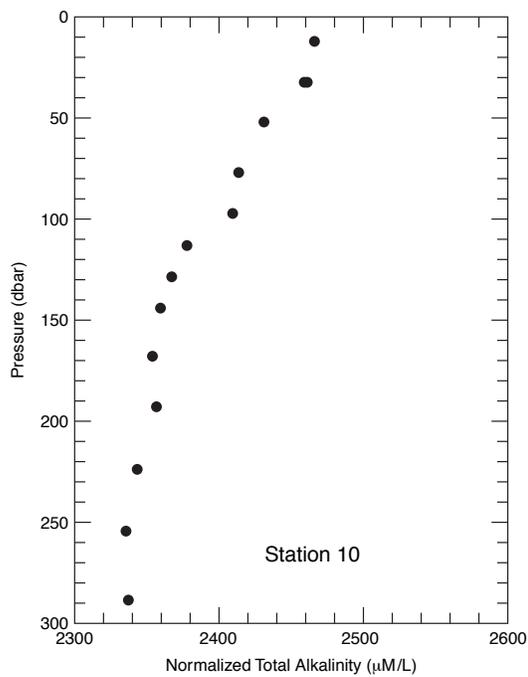
Total alkalinity and total carbonate in seawater are closely related to salinity, with small deviations from a linear relationship resulting primarily from the dissolution or precipitation of calcium carbonate. In near-surface water, carbon from biological decay can also be a significant contributor to changes in total carbonate. Biological productivity can be assessed with the aid of total alkalinity and nutrient measurements, and the total carbonate and total alkalinity data will contribute to an assessment of the carbon budget of the Arctic Ocean.

Total alkalinity and total carbonate analyses are best carried out on “fresh” samples: the analyses were done onboard ship within about 20 hours after they were collected, using standard techniques (potentiometric titration and coulometry). Samples were collected at almost all oceanographic stations at almost all sampling depths, typically 36 from the surface to the bottom, using the rosette sampler. The time between stations did not allow water from every sampling depth to be analyzed, though more than 90% of them were. The quality of the data is high, reflected in replicate analyses with an average difference of just over 1 part per thousand for total alkalinity and 0.9 parts per thousand for total carbonate.

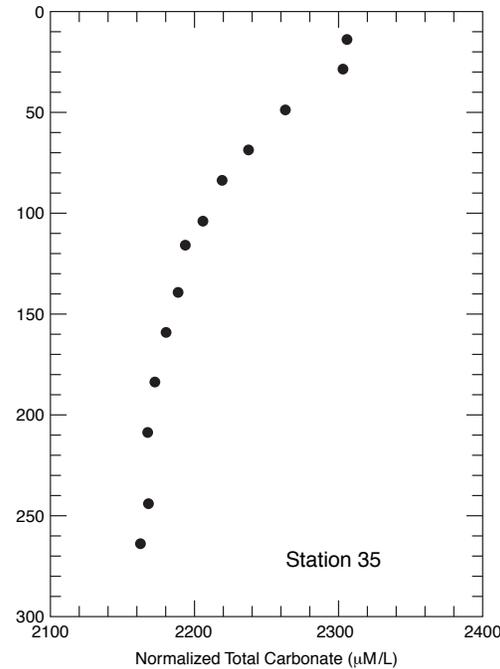
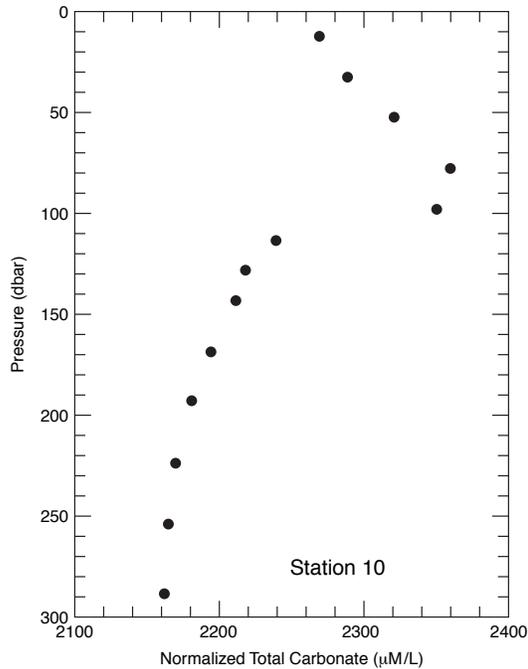
Higher total alkalinity values observed in the near-surface water at many stations during AOS-94 are attributed to dissolved calcium carbonate brought into the Arctic Ocean by runoff. This signal helps to determine the sources of fresh water by separating river runoff from sea ice meltwater, and it helps in tracing the circulation pattern of river runoff. Near-surface “excess” alkalinity, indicating the presence of river runoff, was found at all stations in the Canada Basin and in the Amundsen Basin. In the Nansen Basin the “excess” total alkalinity was much reduced or not present, indicating that most of the nearsurface fresh water in these regions of the AOS-94 path comes from melting sea ice.

High values of total carbonate were also observed near the surface. These correspond to the total alkalinity maximum and are consistent with dissolved calcium carbonate being brought into the Arctic Ocean by river runoff. There are also high total carbonate values in the halocline (depth about 100 m) of the Canada Basin that correspond closely with the nutrient maximum, consistent with the “excess” total carbonate being regenerated along with nutrients during the decay of biogenic matter. These high values were not present after Station 14, where the nutrient maximum also disappeared. The total carbonate in the near-surface water and in the halocline can be used to assess the amounts of carbon entering the Arctic Ocean from the Siberian tundra (river runoff) and the amount entering as a result of carbon fixation on the continental shelves.

Profiles of both total alkalinity and total carbonate show small variations in deeper water that are greater than the precision of these measurements. These structures may be interpretable in terms of the water masses present and processes such as the sequestering of anthropogenic carbon dioxide, but any definitive interpretation will have to await more detailed data analysis, not to mention inspired thought.



Upper profiles of total alkalinity at Stations 10 and 35 (the North Pole).



Upper profiles of total carbonate at Stations 10 and 35 (the North Pole). The maximum values in total carbonate at Station 10 correspond to maximum values in the nutrient profile and minimum values in the oxygen profile.

## **Transient Tracers: Chlorofluorocarbons and Carbon Tetrachloride**

*(E. Peter Jones and Fiona A. McLaughlin)*

The cloud of international concern over the growing anthropogenic releases of refrigerants, aerosols and solvents and their impact on climate and the ozone layer, ironically, has had a silver lining for oceanographers. The measurement of chlorofluorocarbons (CFCs) and carbon tetrachloride (CCl<sub>4</sub>) in seawater, from the surface to the bottom, provides a tool for tracing water masses since they were last at the sea surface with a time clock that spans most of this century. Such data give important information about the various layers within the ocean, for example: Are they rapidly flushed or isolated? Are the waters transported from other oceans or nearby shelves? These are important questions in Arctic Ocean research, as they relate directly to the transport of contaminants— such as organochlorines and radionuclides—to the Arctic food chain.

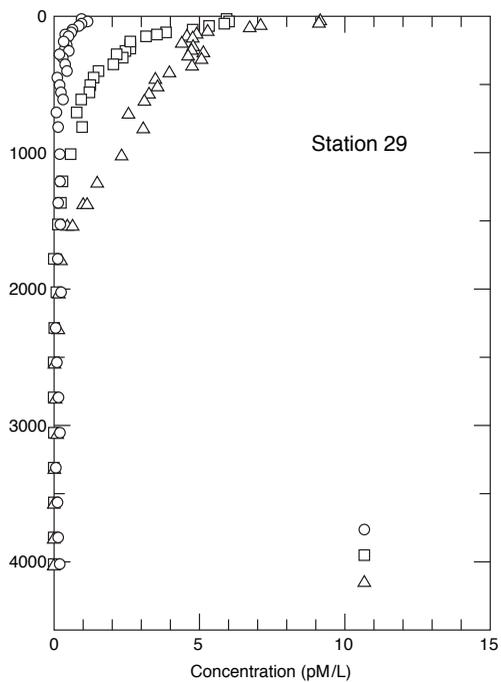
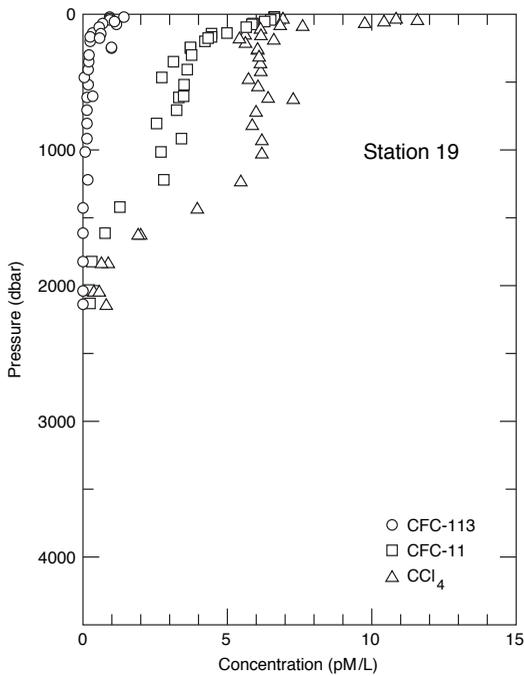
Measuring CCl<sub>4</sub> may also contribute to understanding the ocean's ability to absorb carbon dioxide, a critical question for those attempting to predict global warming. CCl<sub>4</sub> can be used as a surrogate for estimating levels of atmospheric carbon dioxide, as both compounds have been increasing in the atmosphere in a similar fashion since the turn of the century. The depth at which CCl<sub>4</sub> is found in the ocean thus signals the depth at which anthropogenic carbon dioxide, produced in the twentieth century, is found.

AOS-94 provided an opportunity to measure a suite of CFCs (CFC-12, CFC-11 and CFC-113) and CCl<sub>4</sub> on a transect crossing the Arctic Ocean. Samples were collected at almost all oceanographic stations at almost all sampling depths, typically 36 from the surface to the bottom, using the rosette sampler. The samples were analyzed using a standard purge-and-trap gas chromatograph.

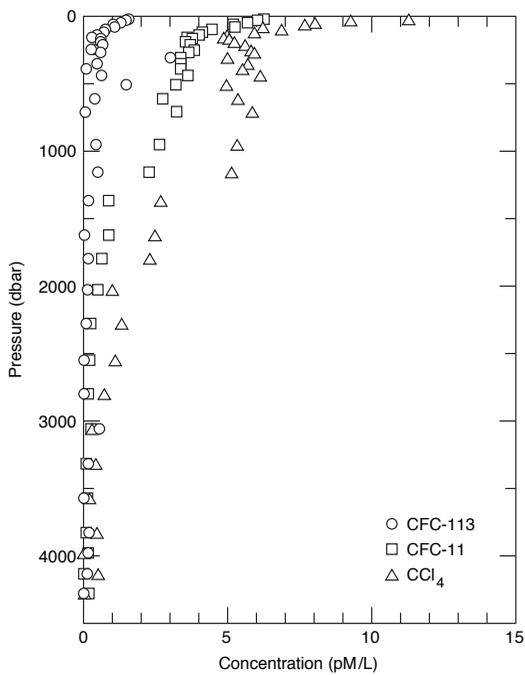
Previous cruises sampled different regions in different years: the Nansen Basin in 1987, the Nansen and Amundsen Basins and the North Pole in 1991, and the southwestern Canada Basin in 1993. The latter cruise yielded information suggesting that the structure and circulation of water masses in the Arctic Ocean may be undergoing a major change. AOS-94 CFC data will allow us to determine the rate, magnitude and extent of these changes.

Although results are preliminary, certain key features are evident. CFC and CCl<sub>4</sub> profiles obtained at Station 19 above the Mendeleev Ridge, where boundary currents are believed strong, and at Station 29 in the central Makarov Basin, where flows are believed to be weak, show important differences in both the concentrations and the penetration depths of all the compounds. This suggests that transport mechanisms are stronger around the basin's exterior than at its interior and that bathymetry plays a major role in the circulation of the Arctic Ocean.

Furthermore, Station 35, east of the Lomonosov Ridge in the central Amundsen Basin, shows higher values of CFCs and CCl<sub>4</sub> in intermediate water layers compared to the central Makarov Basin. This suggests a closer connection with laterally transported incoming source waters. In the deep waters of the Makarov Basin, greater than 2000 m, concentrations of CFCs and CCl<sub>4</sub> are below detection limits, indicating that these waters have a residence time longer than a century. In the Amundsen Basin the penetration is deeper, with CCl<sub>4</sub> values above the detection limit to beyond 3000 m, signaling that these waters are less isolated than those in the Makarov Basin. A mesoscale feature is apparent from temperature and salinity measurements and is confirmed by CFC concentrations at Station 22 between 900 and 1400 m, about 20% higher than nearby stations. This eddy-like structure is evidence of a mechanism whereby waters from the Siberian Shelf are transported into the interior of the Makarov Basin.



Profiles of CFC-11, CFC-113 and CCl<sub>4</sub> at Station 19 above the Mendeleev Ridge and Station 29 in the central Makarov Basin.



Profiles of CFC-11, CFC-113 and CCl<sub>4</sub> at Station 35 in the Amundsen Basin.

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## Air-Water Gas Exchange of Hexachlorocyclohexanes in the Arctic

(Liisa Jantunen and Terry Bidleman)

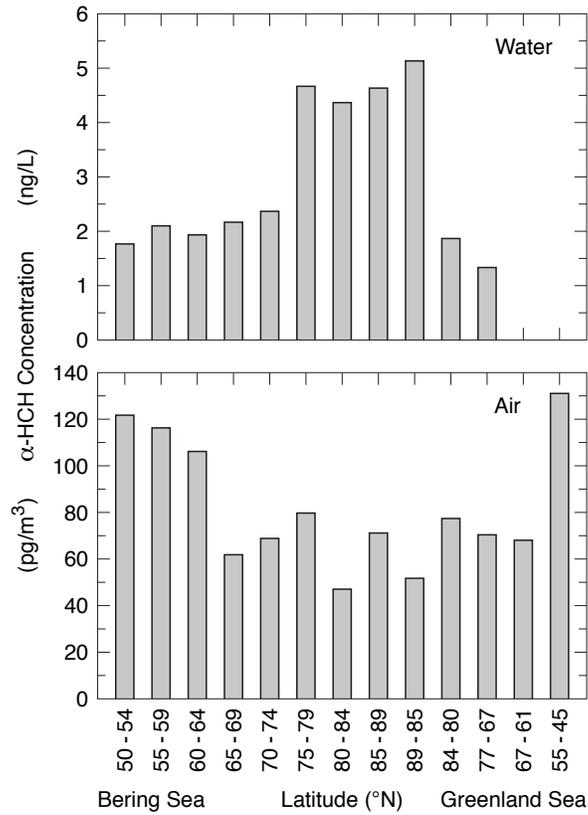
Our objectives for the AOS-94 cruise were to measure the transfer of chlorine-containing pesticides between the atmosphere and the Arctic Ocean. The focus was on pesticides that have largely been banned in Canada and the United States but are still used in other countries. These chemicals are emitted into the atmosphere through current usage and volatilization of old residues from soils. Air currents carry them to remote areas worldwide, including the Arctic. One pesticide of special interest was hexachlorocyclohexane (HCH).

HCH is applied as a technical mixture that contains several isomers, largely  $\alpha$ -HCH (60–70%),  $\beta$ -HCH (5–12%) and  $\gamma$ -HCH (10–15%) (Iwata et al. 1993). The active ingredient,  $\gamma$ -HCH, is also produced in pure form and sold as the pesticide Lindane. Both insecticides were produced during World War II and are still in large-scale use today. Canada banned technical HCH in 1971, followed by the United States in 1978. Lindane is still registered for restricted applications in these countries and is the main HCH product used in Europe (Barrie et al. 1993, Hinckley et al. 1991). Technical HCH was heavily used in Asian countries throughout the 1980s. Reports from India range from 20,000 to 47,000 tons/year (Iwata et al. 1993, Hinckley et al. 1991). It is estimated that the cumulative worldwide use since the introduction of HCH products is over 500,000 tons (Voldner and Li 1995). Because of their widespread usage and ease of transport, HCHs are the most abundant pesticides in the Arctic air and surface waters.

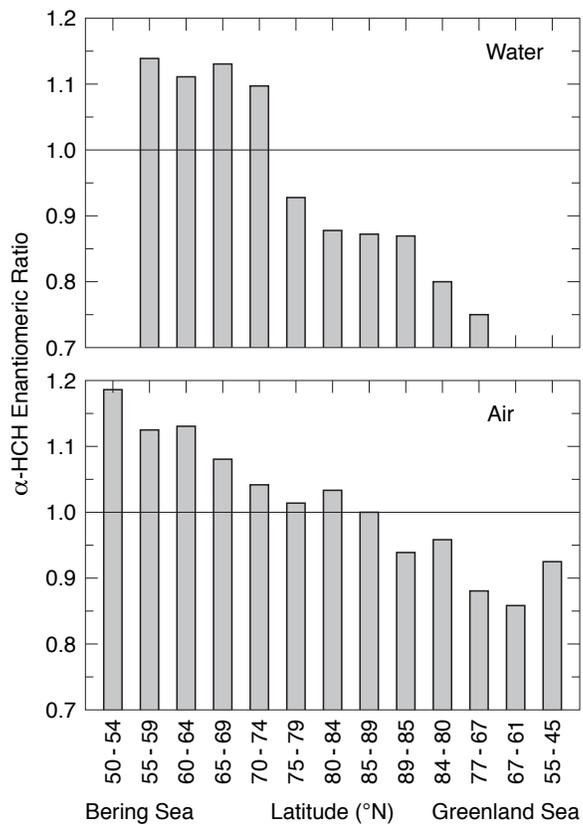
Air was sampled by drawing approximately 700 m<sup>3</sup> per day through a filter followed by a polyurethane foam cartridge. HCHs were extracted from water by passing 4–20 L through a filter followed by a C8-bonded silica cartridge. Analysis was done in the home laboratory, using capillary gas chromatography with electron capture detection and negative ion mass spectrometry.

The accompanying figures show the results of air and water sampling for  $\alpha$ -HCH; they also contain data collected in the Bering and Chukchi Seas in 1993 aboard the Russian R/V *Okeah* to complete the overall picture. The figures show the spatial distribution of  $\alpha$ -HCH, from the Bering Sea to the Greenland Sea over the North Pole. Concentrations of  $\alpha$ -HCH in water of the Bering and Chukchi Seas averaged  $2.00 \pm 0.48$  ng/L (Jantunen and Bidleman 1995), increased in the Arctic Ocean to  $4.61 \pm 0.45$  ng/L and decreased in the Greenland Sea to  $1.52 \pm 0.33$  ng/L. The trend of  $\alpha$ -HCH in air was opposite to that found in the water. The concentrations were highest over the Bering and Chukchi Seas ( $123 \pm 16$  pg/m<sup>3</sup>) and the Greenland Sea ( $119 \pm 16$  pg/m<sup>3</sup>) but decreased dramatically over the Arctic Ocean ( $57 \pm 20$  pg/m<sup>3</sup>). The dip over the polar ice cap may be due to rain scavenging by fog and drizzle and inhibited revolatilization from surface water by the ice cap.

The water/air fugacity ratio can be calculated from the  $\alpha$ -HCH concentrations in air and water and the temperature-dependent Henry's Law constant. The fugacity ratio expresses the saturation state of surface water relative to the partial pressure of the  $\alpha$ -HCH in air. In the 1980s fugacity ratios of  $\alpha$ -HCH were less than 1.0 in Arctic and sub-Arctic waters, indicating that the surface water was undersaturated and the net flux was air to sea. Our measurements in the Bering and Chukchi Seas (Jantunen and Bidleman 1995) and on the AOS-94 cruise show that concentrations of  $\alpha$ -HCH in the air have decreased by three-fold since 1990. Reducing the partial pressure of  $\alpha$ -HCH in air has raised fugacity ratios to above 1.0. Thus the surface waters are now oversaturated and volatilizing  $\alpha$ -HCH.



Surface water and air concentrations of  $\alpha$ -HCH measured on BERPAC93 and AOS-94, averaged within bands of 5° latitude.



Enantiomeric ratios of  $\alpha$ -HCH in surface water and air in the same bands of 5° latitude.

Release of a-HCH from the ocean can be sensed by following the proportion of its two enantiomers in water and air. Enantiomers are mirror-image molecules that have the same physicochemical properties but that often differ in their biochemical characteristics. Right- and left-handed amino acids are familiar examples, and a-HCH is similar. The enantiomeric ratio (ER) of a-HCH is defined as (+)a-HCH /(-)a-HCH. The ER in the manufactured pesticide is 1.00 (racemic) and is not changed by abiotic reactions such as hydrolysis and photolysis. However, enzymes can and frequently do react selectively with one enantiomer, leading to ERs that differ from 1.00 (Buser and Muller 1995). We have found selective depletion of either (+) or (-) a-HCH in surface water, presumably the result of microbial degradation. These enantiomeric “signatures” of a-HCH are reflected in the overlying air, providing a direct indication of sea-to-air transfer.

The figures above show the ERs of a-HCH in water and air with latitude. In the Bering and Chukchi Seas the ERs are greater than 1.00, indicating a degradation of (-)a-HCH relative to (+)a-HCH. Selective breakdown of (+)a-HCH in the Arctic Ocean and the Greenland Sea reverses the ERs to less than 1.00. These enantiomeric profiles are also found in air samples collected over open-water regions, indicating volatilization of a-HCH from surface water. The a-HCH in air over the ice cap was near racemic. Fugacity ratios at higher latitudes also show the potential for a-HCH to volatilize (this work and Falconer et al. 1995), but fluxes are probably inhibited by the ice cover.

Using the ER of a-HCH provides a way of distinguishing a-HCH that has been microbially processed and recycled to the atmosphere by the oceans from “fresh” a-HCH that has undergone aerial transport from source regions. Enantiomers of chiral pesticides, such as a-HCH, chlordanes and heptachlor, may also prove useful for tracing water masses with different ER signatures when employed with traditional tracers such as salinity, temperature, nutrients and dissolved oxygen.

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## **Volatile Halomethanes**

*(Robert M. Moore and Charles Geen)*

Volatile organohalogenes have an important influence on atmospheric chemistry. In particular, halogenated methanes provide a source of atmospheric chlorine and bromine radicals, which can affect ozone concentrations. There has been shown to be a strong correlation between elevated atmospheric concentrations of brominated substances and sudden tropospheric ozone depletion events, especially during the Arctic spring. There are also indications that brominated compounds play a significant role in stratospheric ozone destruction.

It is important to distinguish between natural and anthropogenic inputs of these compounds. In attempting to understand the ozone depletion events in the Arctic boundary layer, there has been considerable interest in examining the natural Arctic marine origins of volatile bromine compounds (bromoform in particular) as potentially significant sources of gaseous halogens to the atmosphere. Our research group has previously found evidence of an ice-algal source of bromoform and dibromomethane in the Arctic. Evidence also exists in northern waters for a phytoplankton source of volatile iodine compounds, which can play a role in the biogeochemical cycling of iodine and in atmospheric chemistry.

Our objective in participating in the AOS-94 cruise was to extend the database of measurements of distributions and concentrations of brominated, chlorinated and iodinated methanes in the Arctic Ocean. This would contribute to the goal of determining the natural origins of these compounds; in fact, this expedition was the culmination of a five-year, Arctic-wide study of the sources of such substances. Measurements were also made of the trace gas concentrations in seawater that had been allowed to equilibrate with the atmosphere; these are needed for calculating fluxes of the gases between the ocean and the atmosphere.

Almost 500 seawater samples were analyzed by gas chromatography during the cruise. Vertical profiles from many stations provided further general oceanographic knowledge of water column distributions of the halomethanes and generally showed the concentrations of the halocarbon gases of interest to be higher in the surface waters and to decrease with depth. However, since our interests were principally the origins and behavior of naturally produced volatile halocarbons in the upper ocean, the work focused on surface-water distributions and the results from the equilibration experiments. Initial data analysis centered on the primary compounds of interest—bromoform ( $\text{CHBr}_3$ ), dibromomethane ( $\text{CH}_2\text{Br}_2$ ) and chloriodomethane ( $\text{CH}_2\text{ClI}$ )—but data are being processed for other compounds in our suite of analytes, including bromodichloromethane ( $\text{CHBrCl}_2$ ), chlorodibromomethane ( $\text{CHBr}_2\text{Cl}$ ), methyl iodide ( $\text{CH}_3\text{I}$ ) and diiodomethane ( $\text{CH}_2\text{I}_2$ ).

The results of the equilibration experiments indicate that the direction of flux will be from the ocean to the atmosphere, since the water is supersaturated with respect to the air. The water column is stably stratified, so there is little downward mixing. Other dissipation processes, such as hydrolysis and substitution reactions, are relatively slow, so ventilation to the atmosphere is likely to be the main short-term removal mechanism for any of these dissolved gases in the seawater.

The results of our seawater measurements during AOS-94 indicate that some of the halomethane concentrations in the upper water column at these high latitudes beneath the polar ice pack are relatively high, even during late summer and early fall. For example, bromoform concentrations at most stations are equal to or greater than any others that we have previously measured from spring to autumn in the open ocean waters or beneath the ice of several Arctic regions, including Baffin Bay, Alert, Resolute Bay, the Beaufort Sea, the

Bering Sea and the Chukchi Sea. It would appear that while temporal variations may be relatively large in open ocean areas and in regions where the ice cover melts for part of the year, they may not be as great in permanently ice-covered regions.

The unexpected picture emerging from the AOS-94 expedition—that halomethane concentrations remain high beneath the polar ice cap throughout the summer and into the fall—means it is likely that even in winter, when such substances may not be produced, large amounts would still be present in surface waters. If in fact there is a fairly constant source of halomethanes beneath the ice pack, any lead, crack, polynya or open water could provide a flux of these gases to the atmosphere at any time. In this case the question of the possible origins of the Arctic springtime atmospheric pulse of bromine then becomes one of physics and ice dynamics. That is, how often, and for how long, are open-water areas present in the Arctic during the dark winter and early spring?

Finally, in pursuing our questions of possible biological sources of these gases, it will be of interest for us to examine our halocarbon data at particular stations in collaboration with information provided by other AOS-94 colleagues. While halomethane concentrations may not be directly correlated with bulk phytoplankton biomass, they might demonstrate some correlation with the presence or species abundance of particular ice algae or phytoplankton identified by other researchers during the expedition.

### **C2–C6 Hydrocarbons**

*(Peter C. Brickell and Jan W. Bottenheim)*

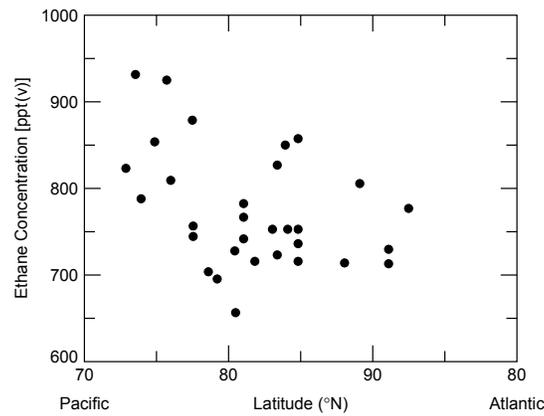
In recent years there has been growing concern about human impact on the high Arctic regions. Light hydrocarbons (C2–C6) in the environment include species that are primarily anthropogenic (for example, acetylene) and those that are primarily biogenic in origin (for example, isoprene). These species are of concern in the troposphere because they play a major role in ground-level ozone formation in urban and urbanimpacted regions. The study of the light hydrocarbon composition of the high Arctic troposphere can provide one more indication of human impact on the region. In addition, the study of light hydrocarbons in background environments can lead to a better understanding of photochemical reaction pathways occurring in these and other more polluted locations. The high Arctic environment is generally free of the myriad of local and regional anthropogenic hydrocarbon sources that complicate the study of hydrocarbon photochemistry in southern continental regions.

The goals of the light hydrocarbon measurement program during AOS-94 were to:

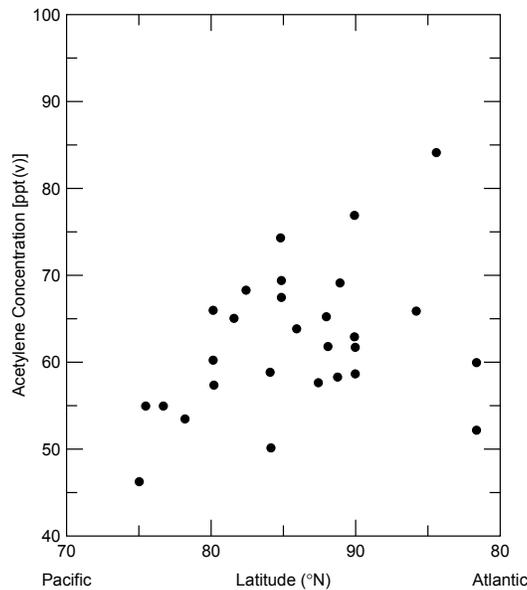
- Develop a reference light hydrocarbon database for the very high latitudes in summer;
- Compare these data with those previously taken from land-based sites in the high Arctic (for example, Barrow, Alaska; Alert, N.W.T., Canada; and the Norwegian Arctic);
- Look for evidence of unusual patterns of chemical processes in the Arctic troposphere; and
- Investigate the levels and patterns of anthropogenic light hydrocarbons at very high latitudes and compare these with the levels of other anthropogenic tracers measured during AOS-94.

Air for light hydrocarbon analysis was sampled in two ways. We collected air in electropolished stainless steel canisters using a battery-powered pump, and samples were stored for later analysis. Air was also drawn through a stainless steel sampling line mounted 22 m above the water line above the port flying bridge. The line was routed to the laboratory, where samples were preconcentrated and then immediately analyzed by in-situ gas chromatography. Canisters could also be analyzed by this system for intercomparison measurements with our laboratory in Toronto.

Because the location of the sampling line was fixed, this second method of sampling could only be used when a substantial breeze (more than 3 m/s) was blowing off the port side of the ship. This was necessary to avoid sampling emissions from the vessel itself, and it essentially limited sampling to times when the ship was stopped for science stations and when other sources of contamination (such as helicopters) were absent. Suitable conditions for sampling were determined by monitoring the real-time output of carbon monoxide and condensation nuclei counter instruments. Sampling with the portable canister system was more flexible and allowed air to be collected from any upwind location on the ship or even on the ice if conditions warranted it. In total 113 canister samples and 53 direct samples were collected; 40 of the canister samples were analyzed with the on-board gas chromatography system.



Ethane concentration vs. latitude during AOS-94.



Acetylene concentration vs. latitude during AOS-94.

Canister data are available for the lowmolecular-weight alkanes and acetylene. During AOS-94 the mean ethane concentration from 73 to 80°N was  $836 \pm 68$  pptv on the Pacific side of the Arctic Ocean. This agrees well with the concentrations observed during the 1988 ABLE 3A aircraft study based at Barrow, Alaska. Farther north, from 81 to 87°N, ethane concentrations dropped to  $726 \pm 36$  pptv. From 87°N through the Pole and down to 80°N on the Atlantic side of the Arctic Ocean, ethane concentrations rose slightly to  $765 \pm 51$  pptv. Propane concentrations followed a similar pattern for the three areas. Acetylene concentrations were initially  $56 \pm 6$  pptv and rose slightly to 64–65 pptv in the high-latitude and Atlantic-side areas. The Pacific-side data agree well with those from the 1988 ABLE 3A for Alaska, and the high-latitude and Atlantic-side concentrations compare very favorably with those for the Norwegian Arctic.

<b>AOS-94 light hydrocarbon concentrations and ratios compared with those from other researchers for Alaska and the Norwegian Arctic.</b>					
	Ethane (pptv)	Acetylene (pptv)	Propane (pptv)	Acetylene/ Ethane	Propane/ Ethane
Pacific (73–80°N)	$836 \pm 68$	$56 \pm 6$	$69 \pm 12$	0.061	0.084
High Latitude (80–87°N)	$726 \pm 36$	$64 \pm 7$	$64 \pm 8$	0.088	0.089
Atlantic (87–90–80°N)	$765 \pm 51$	$65 \pm 8$	$87 \pm 59$	0.085	0.113
Alaska*	$865 \pm 59$	$57 \pm 17$	$53 \pm 15$	0.066	0.061
Norwegian Arctic†	$1195 \pm 27$	$67 \pm 18$	$87 \pm 30$	0.056	0.073

\* From Blake, D.R., D.F. Hurst, T.W. Smith, W.J. Whipple, T. Chen, N.J. Blake and F.S. Rowland (1992) Summertime measurements of selected nonmethane hydrocarbons in the Arctic and Subarctic during the 1988 Arctic Boundary Layer Expedition (ABLE 3A). *Journal of Geophysical Research*, **97**: 16,559–16,588.

† From Hov, O., S.A. Penkett, I.S.A. Isaksen and A. Semb (1984) Organic gases in the Norwegian Arctic. *Geophysical Research Letters*, **11**: 425–428.

Ratios of acetylene and propane to ethane concentrations were also calculated for this data set. The acetylene-to-ethane ratio for the Pacific side data is consistent with the one for Alaska, but the Atlantic-side ratio is higher than for the Norwegian Arctic. This difference is due to the lower AOS-94 ethane results for the Atlantic side. Propane-to-ethane ratios are slightly higher than those reported by other researchers for both the Pacific side and Atlantic side. The difference on the Pacific side is attributable to the somewhat higher propane concentrations, and on the Atlantic side the difference is again due to lower ethane concentrations.

The preliminary data from the light hydrocarbon canister sampling program agree well with work that has been done previously in the Alaskan and Norwegian Arctic. The lower ethane concentrations on the Atlantic side of the Arctic Ocean are probably attributable to increased distance from terrestrial sources. The ethane concentrations observed in the high-latitude portion of the transect may be useful for determining the degree of aging of the air mass encountered in this area. These light hydrocarbon concentrations will provide additional data for estimating the background tropospheric volatile organic compound levels used to input advective inflows for continental atmospheric modeling. In addition, although only data from the high Arctic regions have been presented here, we collected hydrocarbon and some additional atmospheric data throughout the entire circumnavigation of the North American continent during AOS-94. This has yielded a unique data set for assessing the nature of continental and oceanic air masses, as well as providing an extended latitudinal profile from 7 to 90°N for these atmospheric species. Finally, once the Arctic data are available from all the compounds analyzed with the in-situ gas chromatograph, it is expected that an improved understanding of background atmospheric chemical processes will have been derived from the sampling carried out on this unique expedition.

## ***Cloud Radiation***

### **Atmospheric Radiation and Climate Program**

*(Dan Lubin and Robert H. Whritner)*

One of the major physical components of climate change is the way in which solar energy is redistributed in the Earth–atmosphere system. This subject also includes the simultaneous emission of thermal (infrared) energy from the Earth’s surface and its partial entrapment by the atmosphere (the “greenhouse” effect). Globally well-mixed increases in carbon dioxide abundance are believed by many to be enhancing the greenhouse effect and increasing the global surface temperature field. This could have serious repercussions for Arctic Ocean climate, as the Arctic Ocean surface exists for much of the year at temperatures just below the freezing point of water. A small increase in surface temperature could potentially have a large impact on the geographic extent of Arctic sea ice, with resulting changes to the energy balance between the atmosphere and ocean.

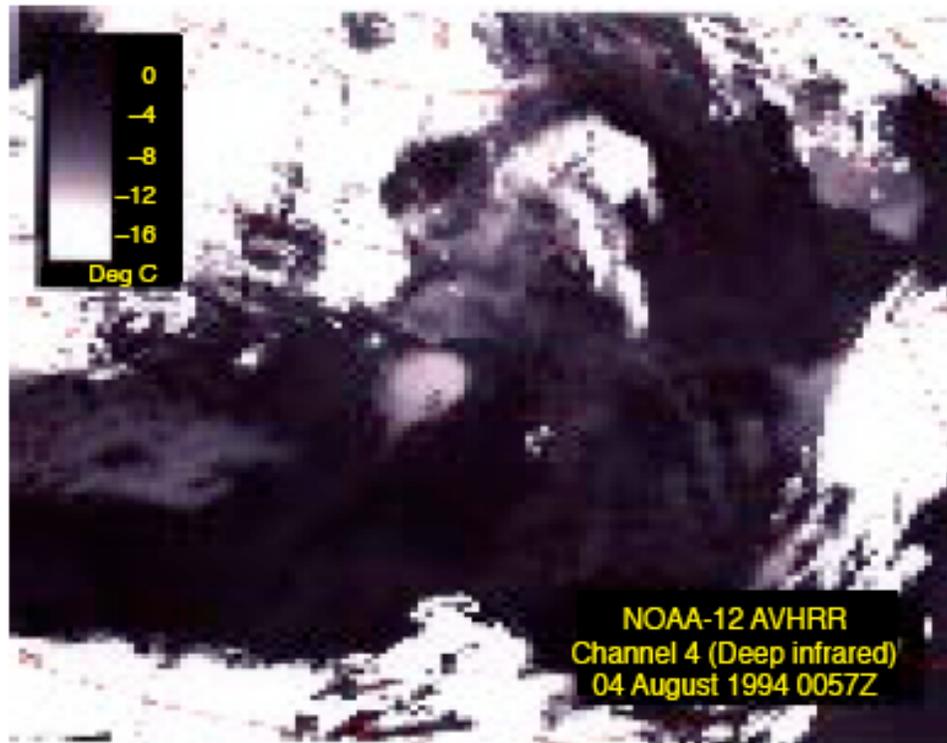
Most of the scientific community’s insight into potential “global warming” scenarios comes from large computer simulations called general circulation models (GCMs). The GCMs are quite sophisticated but often suffer from a lack of experimental input data and input physics from many remote regions throughout the world, particularly the Arctic. AOS-94 offered a unique opportunity to deploy state-of-the-art atmospheric radiation budget measurement apparatus in the high Arctic and to allow them to gather data continuously for several weeks. This was the first high-Arctic expedition to deploy these advanced optical instruments, and the large resulting data set should enable better representation of the Arctic atmosphere in the GCMs.

The California Space Institute project consisted of three major components, all deployed aboard the *Polar Sea*. The first was a battery of broad-band solar and infrared flux radiometers mounted above the pilothouse. Three Eppley Laboratory radiometers measured downwelling short-wave (0.28–2.8  $\mu\text{m}$ ), near-infrared (0.78–2.8  $\mu\text{m}$ ) and middle-infrared (4–50  $\mu\text{m}$ ) radiation reaching the Arctic Ocean surface. A Biospherical Instruments radiometer measured downwelling solar ultraviolet and visible radiation at 0.308, 0.320 and 0.380  $\mu\text{m}$ , as well as radiation in the intervals 0.580–0.680  $\mu\text{m}$  (to match a satellite radiometer) and 0.400–0.700  $\mu\text{m}$  (total photosynthetically active radiation). These radiometers operated automatically and recorded data in one-minute averages continuously throughout the cruise.

The second component consisted of the shipboard satellite tracking facility, the TeraScan system manufactured by the SeaSpace Corporation. In addition to providing weather and ice navigation for the expedition, the satellite tracking enabled this project to measure energy reflected and emitted to space at the same time that the shipboard instruments were measuring solar and terrestrial radiation impinging on the Arctic Ocean surface. The TeraScan system was used to track NOAA polar-orbiting satellites, obtaining 1.1-km spatial resolution images from the advanced very high resolution radiometers (AVHRR), which measure radiation at five visible and infrared wavelengths. The Defense Meteorological Satellite Program (DMSP) satellites were also tracked, giving this project access to the special sensor microwave imager (SSM/I), which was used to map sea ice along the expedition’s track. Throughout the cruise, the *Polar Sea* TeraScan facility tracked between five and ten satellite overpasses per day.

The third component consisted of a Fourier transform infrared (FTIR) spectroradiometer operating in the middle infrared (5–20  $\mu\text{m}$ ) with a spectral resolution of 1  $\text{cm}^{-1}$  (Lubin 1994). FTIR data collection was coordinated with the NOAA satellite overpasses, and a total of 178 sky scenes were studied with the FTIR instruments. This instrument made detailed

measurements of radiation trapped by the atmosphere in the middle-infrared window (8–13 mm). Under clear skies the atmosphere is relatively transparent in this wavelength range, and a large portion of the heat given off by the ocean surface escapes to space. Under cloudy skies, this window is mostly closed, meaning that far less radiation escapes to space and the greenhouse effect is enhanced. These greenhouse enhancements due to clouds are more than an order of magnitude larger than what is expected from a doubling of carbon dioxide in the atmosphere, so understanding the role of clouds in the atmospheric energy balance is critical before we can make meaningful “global warming” predictions with GCMs.



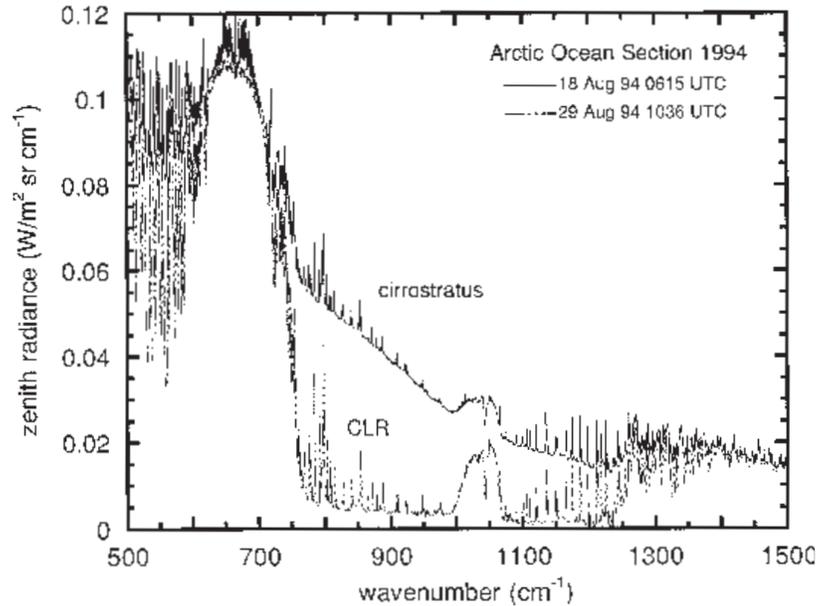
AVHRR image obtained from the shipboard TeraScan system on 4 August 1994 during AOS-94. Brighter shading refers to lower cloud top temperatures.

During the summer of 1994, the atmosphere over the Arctic Ocean exhibited a great deal of complexity, much more than is now represented in the GCMs. A common occurrence was multiple-layered cloud systems. The figure above is an image of terrestrial infrared radiation (10.5–11.5 mm) emitted by the Arctic ocean–atmosphere system to space, expressed in units of equivalent brightness temperature. At the time of this satellite overpass (4 August) the *Polar Sea* was at 78°N, roughly in the center of the image, where there were three distinct temperature ranges in the cloud fields corresponding to three distinct ranges in cloud top height. When the atmosphere contains a large amount of liquid or ice water, as is the case with these multiple-layered cloud systems, a large portion of the sun’s energy is reflected back to space or absorbed by the atmosphere before reaching the surface.

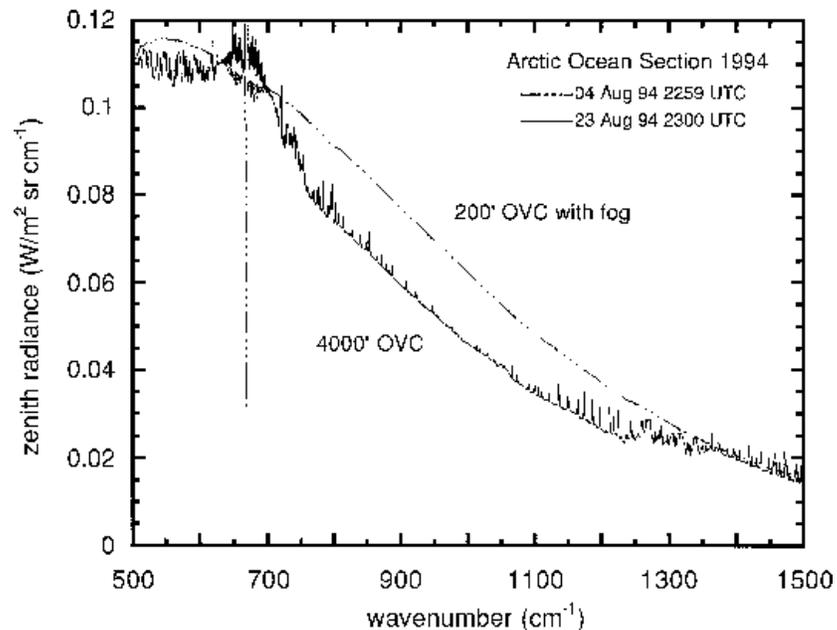
Two examples of atmospheric emission spectra from the CalSpace FTIR instrument are shown in the [figure](#) below, under low atmospheric opacity. Here the instrument is measuring terrestrial energy trapped by the atmosphere and emitted straight back down toward the ship. The middle infrared window exists between 800 and 1300  $\text{cm}^{-1}$  on this plot. The dotted curve, obtained under clear skies, shows that there is very little energy being trapped and re-emitted by the atmosphere in the window, meaning that most is escaping to space. For wave

numbers shorter than 800 and longer than 1300  $\text{cm}^{-1}$ , the atmosphere is largely opaque, and most of the energy emitted by the Earth's surface at these wave numbers is always trapped by carbon dioxide and water vapor. The upper (solid) curve was obtained under a high ice cloud, and we can see that in the window this cloud results in nearly an order of magnitude more energy at the ocean surface.

Atmospheric emission spectra measured by the CalSpace FTIR under conditions of low atmospheric opacity.



Atmospheric emission spectra measured by the CalSpace FTIR under conditions of high atmospheric opacity.



The figure above shows two FTIR emission spectra obtained under overcast skies (the most frequent sky condition during AOS-94). The upper (dotted) curve was obtained on 4 August, the same day as the AVHRR and solar radiometer data discussed above. At the time of this measurement there was so much liquid water in the atmosphere that the atmosphere radiated energy to the surface almost like a perfect blackbody, as signified by the smoothness of this curve. In this situation, when we have a combination of high cloud layers appearing very cold

in the satellite data (that is, they are radiating relatively little energy to space) and low cloud layers radiating nearly as much energy as possible to the surface, at nearly the surface temperature, the greenhouse effect of the atmosphere is nearly at a maximum. The lower (solid) curve was obtained under a single-layer stratus cloud. The middle infrared window is almost but not quite closed. This is because the cloud base is several degrees colder than the surface and because the cloud emissivity is less than one, meaning that the cloud does not contain enough liquid water to emit radiation like a perfect blackbody. A doubling of carbon dioxide in the Earth's atmosphere is expected to increase the flux of infrared radiation at the surface by 3–4 W/m<sup>2</sup>. The enhancements in surface infrared radiation related to changing cloud liquid water content and emissivity are on the order of tens of watts per square meter.

The FTIR cloud emission spectra can be used to estimate the effective radius of the cloud droplet size distribution (Lubin 1994), which in turn can indicate whether or not continental air masses are influencing cloud microphysics. Radiative transfer analysis of the AOS-94 cloudy sky emission spectra suggest that 30% of the stratiform clouds sampled have effective droplet radii of 7 μm or smaller, in which case they are probably influenced by continental air masses and aerosol concentrations. By showing this type of microphysical phenomenon, along with the large variability in cloud optical depth that can occur (0–50), this program has illustrated that the summer atmosphere in the high Arctic is as dynamically and radiatively complex as that over any other continent or ocean.

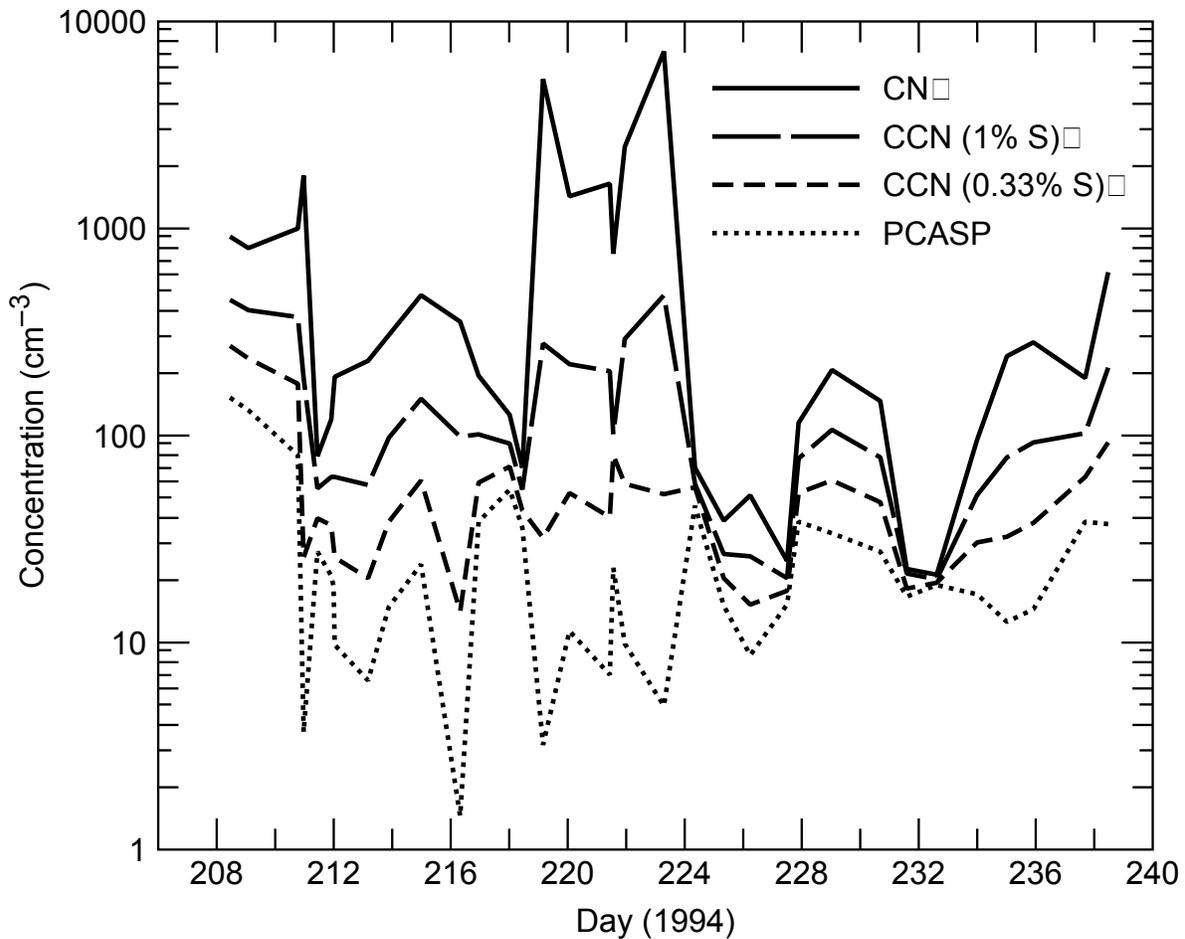
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#### Aerosols

*John D. Grovenstein, Richard Leitch and Fred Hopper*

Aerosols, especially those that influence cloud microphysics (droplet size spectra), are important in atmospheric research because they influence climate directly by backscattering and absorption of incoming solar radiation and indirectly by affecting cloud albedo. Wigley (1989) suggested that the latter effect could be the reason that the planet has not exhibited heating as predicted by global climate models of the “greenhouse effect.” Generally climate models are poorly parameterized for aerosol and cloud microphysics, especially in the remote Arctic. Therefore, it is necessary to measure these parameters to provide data sets for modelers and to diagnose future environmental change.

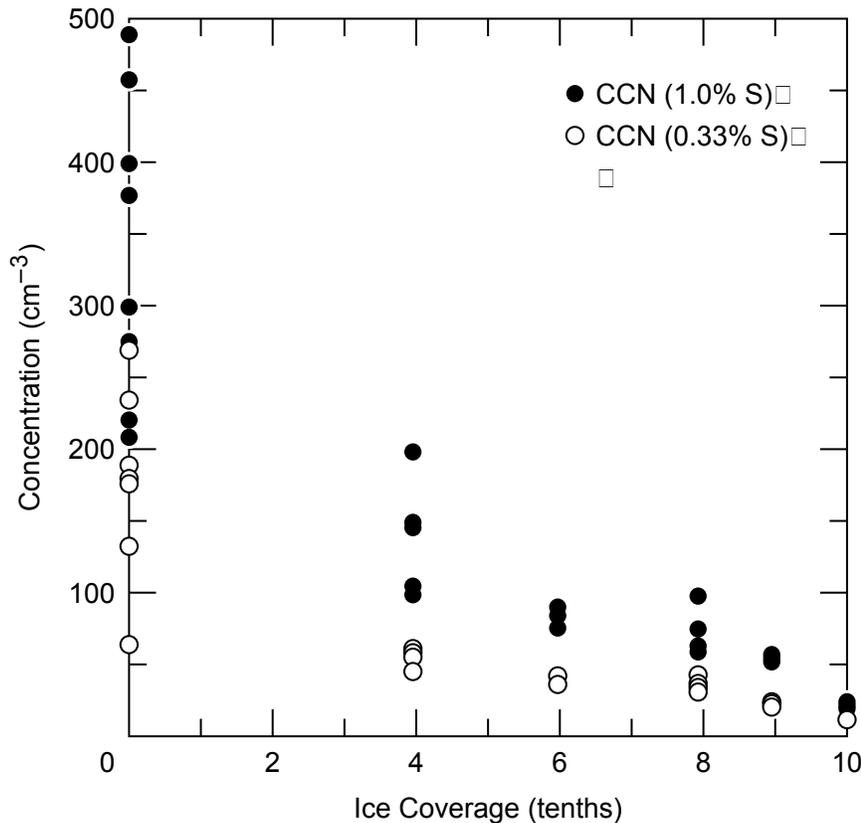


Time series of aerosol concentration for the AOS-94 expedition.

The figure above is a time series of aerosol concentration from AOS-94. The uppermost dotted line is the condensation nuclei (CN) concentration measured by TSI models 3025 and 3022 condensation nuclei counters. This number represents the concentration of the finest nuclei (nucleation mode) with a radius of 0.003  $\mu\text{m}$  to the larger aerosols up to a radius of 3  $\mu\text{m}$ . The uppermost solid line is the cloud condensation nuclei (CCN) concentration active at 1% supersaturation. These measurements were taken with an instantaneous CCN spectrometer introduced by Fukuta and Saxena (1979). For this study the spectrometer was operated at a range of 0.2–1.3% supersaturation. The spectrometer makes one spectral sweep every 15 s. The middle dotted line is the CCN concentration active at 0.33% supersaturation measured by the DH Associates cloud condensation nuclei counter. This instrument records the number of CCN active at a single supersaturation (set at 0.33% for this study). The lowermost dotted line is the large aerosol concentration (0.3–1.0  $\mu\text{m}$ ) measured with a Particle Measuring Systems passive cavity aerosol spectrometer probe (PCASP-100X). The instrument provides a histogram of aerosol concentration in 15 size ranges. The concentration from each size range is totaled to provide the concentration reported in the figure.

Sampling began on day 208 with instruments running on a continuous basis. The concentration of aerosols measured by all instruments decreased sharply upon entering the

ice. The concentration of CN, CCN (active at 1% supersaturation) and CCN (active at 0.33% supersaturation) “track” each other through the time series, with the PCASP-100X showing this trend but not as dramatically as the other measurements. Generally CCN concentrations in maritime air masses rarely exceed  $100 \text{ cm}^{-3}$ ; however, concentrations above  $100 \text{ cm}^{-3}$  were measured over a time of days in the remote Arctic Ocean (days 218–224 and days 228–232). These large CCN concentrations also accompanied large CN concentrations, which in one instance (day 224) exceeded  $7000 \text{ cm}^{-3}$ .



CCN concentration at two supersaturations plotted against ice coverage.

The concentrations of the larger aerosols, measured by the PCASP-100X and the CCN active at 0.33% supersaturation, never exceeded  $100 \text{ cm}^{-3}$  while we were sampling in the ice. The observations of the largest CN and CCN (active at 1% supersaturation) concentrations correspond to the lowest observed concentrations of the large aerosol with the PCASP-100X. This suggests that the elevated CN concentrations may be due to a local production mechanism. The reduction of the largest aerosol removes a significant surface area for the condensation of precursor gases. The concentration of these gases increases until, by the process of gas-to-particle conversion, they are converted into fine aerosol particles. Between days 218 and 224 the concentration of the finest aerosols are out of phase with the concentrations of the largest aerosols; the peaks in concentration of one corresponds to the minimums of the other. Although this scenario may not be the cause of the observed concentrations, the high concentrations of the precursor gases necessary have been recorded in the Arctic. The figure above shows the relationship between ice coverage and CCN concentration, illustrating the possible production of CCN from precursor gases. When the

gas supply is limited by ice cover, CCN concentration decreases. Regardless of the source, the particles are present and are modifying the climate of the remote Arctic.

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## Appendices

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## Appendix A

### Arctic 94: CTD Temperature and Conductivity Corrections Summary

Sta/ Cast	PRT Response Time (secs)	ITS-90 Temperature Coefficients			Conductivity Coefficients	
		corT = t2*T <sup>2</sup> + t1*T + t0			corC = c1*C + c0	
		t2	t1	t0	c1	c0
001/04	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01571
002/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01581
003/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01591
004/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01602
005/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01612
006/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01623
007/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01633
008/02	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01643
009/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01654
010/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01664
011/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01675
012/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01685
013/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01695
013/02	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01865
014/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01706
015/02	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01716
016/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01727
017/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01737
018/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01747
019/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01758
020/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01768
021/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01779
022/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01789
023/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01799
024/02	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01810
025/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01820
026/04	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01901
027/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01841
028/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01851
029/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01862
030/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01872
031/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01883
032/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01893
033/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01903
034/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01914
035/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.01924
036/01	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.03281
036/02	.35	1.86300e-05	-5.81480e-04	-1.50150	-2.63442e-04	-0.03381
037/01	.3	1.83870e-05	-7.55550e-04	-1.48140	-1.24894e-03	0.04604
038/01	.3	1.83870e-05	-7.55550e-04	-1.48140	-1.24894e-03	0.04377
039/01	.3	1.83870e-05	-7.55550e-04	-1.48140	-1.24894e-03	0.04249

## Appendix B

### Arctic Ocean 94: CTD Shipboard and Processing Comments

Key to Problem/Comment Abbreviations	
CO	conductivity offset
RN	radionuclide cast
WS	winch slowdown/stop, potential shift in ctdoxy signal

Key to Solution/Action Abbreviations	
NA	no action taken, used default quality code 2
NR	cast not processed, not reported with final data
O9	blanked out CTD oxygen channel
OC	offset conductivity channel to account for shift/offset
S3	quality code 3 salinity in .ctd file for pressures specified
UP	used up-cast data for final pressure-series data

Cast	Problem/Comment	Solution/Action
001/04	TEST cast; O2 sensor guard on during cast	O9
005/01	WS/1.4 mins. at 174 db	NA
007/01	WS/0.9 min. at 251 db	NA
008/01	WS/0.8 min. at 303 db	NA
008/02	RN	NR
009/01	winch problems: stops/yos WS/1.9 mins. at 386 db, 3+ min. at ~1008 db, 1.8 mins. at 1693 db	NA
010/01	WS/0.6 min. at 1907 db	NA
011/01	WS/0.6 min. at 2257 db	NA
011/02	RN	NR
013/01	no bottles - pylon deck unit problem	NA
013/02	replaced pylon deck unit - tripping problems WS/1.4 mins. at 1163 db	NA
014/01	tripping problems	NA
015/01	RN	NR
015/02	tripping problems WS/1.3 mins. at 1863 db	NA
016/01	repaired original pylon deck unit back in	
017/01	WS/0.7 min. at 1624 db	NA
018/01	trouble with ice touching wire	NA
018/02	RN	NR
018/03	RN	NR
018/04	RN	NR
021/01	WS/1.8 mins. at 1649 db	NA
022/01	WS/1.3 mins. at 720 db	NA
024/01	RN	NR

Cast	Problem/Comment	Solution/Action
026/01	RN	NR
026/02	RN	NR
026/03	RN	NR
026/04	WS/1+ hour stop at 989 db up	replaced CTD deck unit (blown fuse)
027/01	WS/0.4 min at 3101 db, 0.4 min at 3201 db (ship propulsion problems - stops to pull A-frame in to avoid ice)	NA
031/01	CO 832-918 db down	UP
033/01	WS/0.9 min. at 2926 db, 0.6 min. at 2946 db	NA
035/01	North Pole station	
035/02	RN	NR
035/03	RN	NR
035/04	RN	NR
036/01	new CTD termination; top 300 db section of down-cast is bad; probable freezing of conductivity sensor causing bogus down-cast salinity conductivity strange - shape doesn't match bottles or surrounding casts	UP  S3 3202-3532db
036/02	new conductivity sensor	
037/01	switch to CTD #1; no 2nd temperature channel WS/1.4 mins. at 4054 db; 14.8 db yo-yo 3810-3795 db CO	NA  OC +.0035 mmho/cm 3743-3810 db
037/02	RN	NR
038/01	no 2nd temperature channel; sediments dumped from deck into water at cast start	NA
039/01	Greenland Basin station (only station not done in ice) up-cast offset from down by -0.0012 psu	adjusted cond offset coefficient for down-cast

## Appendix C

### Arctic Ocean 94: Bottle Quality Comments

Remarks for deleted samples, missing samples, PI data comments, and WOCE codes other than 2 from AO94/ArcticOcean 94. Investigation of data may include comparison of bottle salinity and oxygen data with CTD data, review of data plots of the station profile and adjoining stations, and rereading of charts (i.e., nutrients). Comments from the Sample Logs and the results of ODF's investigations are included in this report. Units stated in these comments are degrees Celsius for temperature, Practical Salinity Units for salinity, and unless otherwise noted, milliliters per liter for oxygen and micromoles per liter for Silicate, Nitrate, Nitrite, and Phosphate. The first number before the comment is the cast number (CASTNO) times 100 plus the bottle number (SAMPNO).

#### Station 001

- 435 Radionuclides(RN), hydrocarbons(HC) & salinity only. Footnote CTD oxygen not reported, oxygen and nutrients not drawn.
- 436 Sample log: "Vent open." Delta-S 0.003 low at 5db. Down T & S differ from up T & S. Other water samples okay for near surface.
- 424 Sample log: "Air leak" Delta-S 0.000 at 10db. No other samples drawn.
- 428 Sample log: "Air leak" Delta-S 0.009 low at 10db. Bottle salinity same as other bottle salinities this level.
- 421-433 Radionuclides(RN), hydrocarbons(HC) & salinity only. Footnote CTD oxygen not reported, oxygen and nutrients not drawn.
- 418 Radionuclides(RN), hydrocarbons(HC) & salinity only. Delta-S at 17db is -0.0303, salinity is 32.670. 0.016 difference with bottle 19 which was tripped at the same pressure. Suspect bottle salinity is acceptable. Footnote CTD oxygen not reported, oxygen and nutrients not drawn.
- 402-415 Radionuclides(RN), hydrocarbons(HC) & salinity only. Footnote CTD oxygen not reported, oxygen and nutrients not drawn.
- 401-436 CTD oxygen processor: "CTD oxygen values totally unreasonable, will not be reported." Footnote CTD oxygen not reported.

#### Station 002

- Cast 1 Autosol run has salt box 58 as Station 2 and box K as Station 3. Station 3 Sample log has salt box 58 and Station 2 sample log has no salt box nbr recorded. Data indicate Box 58 is Sta 3 and Box K is Sta 2. Delta-Ss erratic but reasonable per CTD except for 101. Used Box 58 for Sta 3 and Box K for Sta 2.  
LNSW lower than DDW on this station, reason unknown, and effect unknown. Either F1 factors or B and E base could be in error. Footnote nitrate questionable, samples 1, 4, 7-9,11.
- 112 Iodine only, No ODF samples. Footnote CTD oxygen not reported, salinity, oxygen and nutrients not drawn.
- 110 Delta-S at 10db is -0.0589, salinity is 32.135. Spike in CTD uptrace salinity. Footnote CTD salinity bad, CTD oxygen data not reported, oxygen and nutrients not sampled.
- 109 Delta-S at 10db is -0.0313, salinity is 32.131. Spike in CTD uptrace salinity. See Cast 1 nitrate comments. Footnote CTD salinity bad, CTD oxygen data could not be reported because the CTD salinity is bad, nitrate is questionable.
- 105-106 No oxygen or nutrients sampled. Footnote CTD Oxygen not calibrated, oxygen and nutrients not sampled.
- 102-103 No oxygen or nutrients sampled. Footnote CTD Oxygen not calibrated, oxygen and nutrients not sampled.

- 101 Delta-S 0.07 low at 49db, 6m above bottom. Autosal run ok other than Station mixup. CTD T & S show no change this level but salts 102 & 103 from 1m above are 0.5 higher. Other water samples show no change. Reason unknown. Footnote CTD oxygen not calibrated, salinity, silicate and nitrate questionable.
- 101-108 Original run offscale on these peaks. Analyst diluted these samples with equal volume LNSW and reran them. Several checks on LNSW gives sil = 2.8 uM/l. Reported concentrations for these samples calculated by hand. Overall effect of this process will be to reduce expected precision. Footnote silicate questionable, samples 1, 4, 7-8.
- 101-112 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

### Station 003

- Cast 1 Autosal run has salt box 58 as Station 2 and box K as Station 3. Station 3 Sample log has salt box 58 and Station 2 sample log has no salt box nbr recorded. Data indicate Box 58 is Sta 3 and Box K is Sta 2. Delta-Ss erratic, CTD S & T spikes. Bottom 2 salts low as on Station 2 bottom salt.
- 111 Oxygen was not drawn per sampling schedule. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 108 Oxygen was not drawn per sampling schedule. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 105 Sample log: "Small air leak." Delta-S 0.05 high, salinity 0.02 lower than 104 at same level(37db). No oxygen drawn this level. Nutrients agree with 104 nutrients. No freon or gas samples were drawn from this bottle. Will code bottle as leaking, if non-ODF samples are acceptable, then ODF suggests the bottle is acceptable. Footnote bottle leaking, CTD oxygen not calibrated, oxygen not drawn.
- 102 Oxygen was not drawn per sampling schedule. Footnote CTD oxygen not calibrated, oxygen not drawn. Delta-S at 59db is -0.0692, salinity is 32.762.
- 101-111 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

### Station 004

- 105 Sample log: "Leaking a little" Delta-S 0.008 low at 107db. Same scatter as other RN samples drawn this level. No other ODF samples drawn. Will code bottle as leaking, if non-ODF samples are acceptable, then ODF suggests the bottle is acceptable. Footnote bottle leaking, CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 103-113 No oxygen or nutrients drawn. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 102 No oxygen drawn. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 101-114 All other parameters have unusual slope and high T, S, PO4 & SIL values and low O2 values. NO3 values don't change. Special nutrient problems this station. Nutrient data processor says reruns confirm bottom NO3s. PI, Chris Measures, says mismatch between PO4 & NO3 typical on shelf. Data are acceptable, unless specifically noted.
- 101-120 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated. Delta-Ss are erratic, but reasonable per CTD. Autosal run okay. High gradient, less than 110db, steep slope. Salinity is acceptable.

**Station 005**

101-123 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

102-113 Sample log: "for radionuclides & salinity only." Oxygen and nutrients were not drawn. Footnote CTD oxygen not calibrated and oxygen and nutrients not drawn.

**Station 006**

124 Sample log: "Bottom end cap knocked during recovery" Delta-S 0.024 high at 26db. High gradient, up not equal down. Oxygen & nutrients also look good. Data are acceptable.

101-112 RN & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

101-126 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 007**

123-124 NO2 deleted by AA operator, "weird". Footnote CTD oxygen not calibrated, nitrite measurement not received, it will not be reported.

110-120 Radionuclides & salinity only. Delta-Ss erratic at 91db in high gradient area. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

101-127 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 008**

236 HC & salinity only. Delta-S at 12db is 0.1413, salinity is 31.313. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

234 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

232 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

230 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

228 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

225 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

223 HC only. Sample Log: "No water (left for salinity)." Footnote CTD oxygen not calibrated, salinity, oxygen and nutrients not drawn.

221 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

219 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

216 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

213 Sample log: "No water in 13, cap hung up on pinger" Footnote bottle no samples, CTD oxygen not calibrated.

212 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

204 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

201-236 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 009**

101-133 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

102-103 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

**Station 010**

- 101-131 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 102-103 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

**Station 011**

- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 102 Sample log: "Leaking from bottom end cap after air vent opened. Closed vent after salinity drawn." HC only other sample drawn. Delta-S 0.001 high at 2257db Will code bottle as leaking, if non-ODF samples are acceptable, then ODF suggests the bottle is acceptable. Footnote bottle leaking, CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 103 HC & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

**Station 012**

- 132 Delta-S 3.7 high at 31db. All water samples indicate NB32 closed at NB12 level, 632db. Footnote bottle did not trip correctly, CTD oxygen not calibrated, all samples bad. Delta-S at 31db is 3.6879, salinity is 34.857.
- 131 Delta-S 0.045 low at 52db. Other water samples okay. High T gradient and S step this level. Delta-S at 52db is -0.0561, salinity is 31.650.
- 122 Delta-S 0.025 low at 239db. Other water samples okay. High T gradient and S step this level. Salinity is acceptable. Delta-S at 239db is -0.0291, salinity is 34.697.
- 117 Sample log: "Vent open on 17". Delta-S 0.004 high at 375db. Other water samples also look okay.
- 101-133 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 013**

- Cast 1 No bottles closed. CTD Deck Unit problem. Replaced deck unit and relowered as cast 2.
- 209 Sample log: "major air leak" Delta-S 0.000 at 907db. Other water samples also look okay.
- 205 Sample log: "Small drip from bottom end cap." Delta-S 0.001 low at 1455db. Other water samples also okay.
- 201-211 Sample log: "Salt bottle 3 looks odd, draw dupe S into 36" Salt bottles in box X had brown algae in many bottles. Drew main salts for station 13 in box Y and saved box X draws for check. Box X had also been used on Stations 6/1, 8/2 & 11/2. Dupe runs agree well(-0.001 to 0.000) except Box X salt bottle 3 is 0.002 low and salt bottle 9 is 0.004 high. Delta-Ss on previous stations using these salt bottles okay. Salt bottle 9 on 8/3 is 0.003 low, others at or near 0.000.
- 201-223 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 101-123 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." This is CTD trip information, pressure, temperature, CTD conductivity and CTD oxygen. Bottles did not trip at these levels. Footnote bottles not reported, CTD oxygen not calibrated.

**Station 014**

- 119 Sample log: "Air leak" Delta-S 0.039 low at 62db. High CTD T, S & O2 gradients. Water samples look okay. Data are acceptable. Footnote CTD oxygen not calibrated. Delta-S at 62db is -0.0439, salinity is 33.293.
- 114 Delta-S 0.110 high at 167db. Calc okay. 16 salt has good match with 15 CTD level salt(138b) 15 salt has good match with 14 CTD level salt(167b) 14 salt doesn't match any level. Oxygens and

nutrients at all 3 levels very similar so difficult to use them to sort out trip levels. Intended 17 level had no confirm on first trip try, then used diagnostics to reset pylon to position 17. Data fits well IF ASSUME 14 closed on way up from 13 level(203db) to intended 14 level(167db), then 15 closed at intended 14 trip, and 16 closed at intended 15 trip(137db). The diagnostics "reset" put the trips back in order from 17 on up. Footnote bottle did not trip correctly, CTD oxygen not calibrated, all samples bad. Delta-S at 113db is 0.4936, salinity is 34.576.

- 116 Delta-S 0.228 high at 113db. Calc okay. See 114 note. Used intended 15 CTD trip data(137db) for 16. Footnote bottle did not trip correctly, CTD oxygen not calibrated.
- 115 Delta-S 0.161 high at 138db. Calc okay. See 114 note. Used intended 14 CTD trip data(167db) for 15. Footnote bottle did not trip correctly, CTD oxygen not calibrated.
- 101 O2 draw temp lower than expected. Delta-S 4.8 low at 956db. All water samples indicate 1 closed near surface. Footnote bottle did not trip correctly, CTD oxygen not calibrated, all samples bad. Delta-S at 956db is -4.8275, salinity is 30.047.
- 101-123 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

### Station 015

- Cast 2 Main Autosol run had drift of -0.00038, deeper samples run first. Begin Standard Dial low compared to other runs this bath temp, but confirmed with 2nd Wormley vial before starting samples. End standard agrees with other standards this bath temp. Recommend do not use Cast 2 bottle salinities for CTD adjustments. Footnote salinity questionable.  
Numerous apparent tripping problems this cast. Still using spare pylon Deck Unit as on Station 14 and 15/1. 1 & 2 tripped in air as rosette being lowered. Brought back on board, found trip arm at position 2, recocked, but pylon homed to position 2 only. Sent down with trip arm at position 2 but had no confirm at first trip attempt. Reset to position 1 with diagnostics and next trip attempt confirmed. Footnote bottles 4-7, 11-20, 24-29, and 31 did not trip as scheduled.
- 232 Delta-S 0.010 high at 13db. CTD T & S up differ from down. Other water samples look okay for near surface values. Footnote CTD oxygen not calibrated, salinity questionable.
- 231 Delta-S 0.436 low at 33db. All water samples indicate 31 closed about 55db, just below 30 at 53db. CTDO shows no S or O2 bump at 33db. Bottle did not trip at this level. This level is included to complete the profile for CTD pressure, temperature and salinity and to assist users in verifying that the pressure assignment was correct. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, samples bad.
- 230 Delta-S 0.016 low at 53db. Other water samples also look okay. Footnote CTD oxygen not calibrated, salinity questionable.
- 224 Delta-S 0.052 high at 145db. Salinity doesn't fit any tripped level. ASSUME 24 closed between 165db and 145db. See 225-229. Bottle did not trip at this level. This level is included to complete the profile for CTD pressure, temperature and salinity and to assist users in verifying that the pressure assignment was correct. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, samples bad.
- 225-229 Delta-Ss all high and moving all bottles down one level gives slightly low Delta-Ss corresponding to other Delta-Ss. 229 goes from 0.338 high to 0.020 high in high-gradient area and 229 low O2 matches CTDO better at lower level. Other water samples look reasonable at new levels. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.
- 223 Delta-S 0.004 low at 165db. Other water samples also look okay. Footnote CTD oxygen not calibrated, salinity questionable.
- 222 Delta-S 0.010 low at 185db. Other water samples also look okay. Footnote CTD oxygen not calibrated, salinity questionable.

- 221 Delta-S 0.001 low at 215db. Other water samples also look okay. Footnote CTD oxygen not calibrated, salinity questionable.
- 290 This is only CTD trip information, pressure, temperature and CTD conductivity. Bottle did not trip at this level. This level (245 db), is added to complete the profile. See 201-232 CTD Oxygen comment. Footnote bottle not reported, CTD oxygen not calibrated, no samples drawn.
- 212-220 Delta-Ss all high and moving all bottles down one level gives slightly low Delta-Ss. 214, 215 & 216 are a toss- up, go from slightly high to slightly low after move. Other water samples have very little change these levels. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.
- 210 Delta-S 0.003 low at 964db. Other water samples also look okay. Silicate and PO4 more like 209 at 1116 db. It suggests there may be something questionable at 209, 210, and/or 211. Footnote CTD oxygen not calibrated, salinity questionable.
- 211 Delta-S 0.007 high at intended level 822db. All water samples same at 10 at level below 964db. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.
- 209 Sample log: "Air leak, lanyard okay." Delta-S 0.003 low at 1115db. Other water samples reasonable. Footnote CTD oxygen not calibrated, salinity questionable.
- 208 Delta-S 0.002 high at 1267db. Other water samples also look okay. Footnote CTD oxygen not calibrated, salinity questionable.
- 297 See 290 comment. This level (1419 db), is added to complete the profile. See 201-232 CTD Oxygen comment. Footnote bottle not reported, CTD oxygen not calibrated, no samples drawn.
- 207 Delta-S 0.010 high at 1419db but is 0.000 at intended 6 level 1571db. Other water samples look reasonable at either level. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.
- 205-206 Delta-S 0.004 low at 1697db. Oxygen and nutrients have same value as 6 at level above, while 6 salinity is 0.009 higher than 5 salinity whereas CTD trace indicates 6 salinity should be lower. Both runs for 6 salinity took more than 2 tries suggesting possible problem. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.
- 294 See 290 comment. This level (1799 db), is added to complete the profile. See 201-232 CTD Oxygen comment. Footnote bottle not reported, CTD oxygen not calibrated, no samples drawn.
- 201 Delta-S 0.001 high at 1865db(bottom trip level) using bottle salt calculated assuming high drift is linear. Other water samples also indicate 1 closed at bottom. Footnote CTD oxygen not calibrated, salinity questionable.
- 201-232 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 202 Delta-S 0.002 low at 1865db. Other water samples also indicate 2 closed at bottom. Footnote CTD oxygen not calibrated, salinity questionable.
- 203 Delta-S 0.002 low at 1865db. Other water samples also indicate 3 closed at bottom. Footnote CTD oxygen not calibrated, salinity questionable.
- 204 Delta-S 0.002 high at 1799db. Other water samples same as bottom samples from 1-3. Delta-S 0.004 low at 1865db. In view of salinity problems assume 4 closed at bottom when 3 tripped & no sample at 1799db as confirmed trip was for closed 4. Footnote bottle did not trip as scheduled, CTD oxygen not calibrated, salinity questionable.

#### **Station 016**

- 112 Sample log: "Souvenir samples for crew. No samples. Footnote CTD oxygen not calibrated, salinity, oxygen and nutrients not drawn.

- 113 Sample log: "Souvenir samples for crew. No samples. Footnote CTD oxygen not calibrated, salinity, oxygen and nutrients not drawn.
- 101 Sample log: "vent open (wide open). Spigot very loose." Delta-S 0.002 at salinity max, 1063db. Other water samples also okay. Salinity slightly high. Footnote bottle leaking, CTD oxygen not calibrated, and salinity bad.
- 101-126 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 017**

- 134 Seabird CTD on 34. No samples.
- 131 Sample log: "Salt 31 bottle chipped". Used salt btl 10 per sample log, salt btl 31 on salinity data sheet. Autosal operator says should be 10. Delta-S agrees with the other four Delta-Ss this level (162db) high gradient. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 132 Salts & RN only drawn. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 124-128 Salts & RN only drawn. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 116-120 Salts & RN only drawn. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 103 CTD Processor indicated that salinity was high. Salinity is within specs of the measurement. Salinity is acceptable. Footnote CTD oxygen not calibrated.
- 101 CTD Processor indicated that salinity may be high. Salinity is within specs of the measurement. Salinity is acceptable. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 018**

- 101 Sample log: "spigot loose" Delta-S 0.001 high at 2695db. Other water samples also look okay. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 019**

- 119 Oxygen sample lost due titration operator error. Footnote CTD Oxygen not calibrated, oxygen lost.
- 101-130 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 020**

- 101-127 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 021**

- 122 Computer crashed at overtitrate option "Illegal function call" First titration overshoot with no up slope on screen. Oxygen lost. Footnote CTD oxygen not calibrated, oxygen lost.
- 101-133 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 102-103 Toxiphene only. No ODF samples. Footnote CTD oxygen not calibrated, salinity, oxygen and nutrients not drawn.

**Station 022**

- 119 Stopper 1069 on flask 1293 this sample. Used 1293 for calc. Flasks volumes for 1069 & 1293 very similar. O2 values 0.01 different in area of little or no O2 change. Footnote CTD oxygen not calibrated, oxygen questionable.
- 118 Stopper 1293 on flask 1069 this sample. Used 1069 for calc. Flasks volumes for 1069 & 1293 very similar. O2 values 0.01 different in area of little or no O2 change. Footnote CTD oxygen not calibrated, oxygen questionable.
- 109 Silicate looks low on this sample, possibly 110 as well. This is the way it is on the chart, no calc errors. Silicate is acceptable.
- 101-133 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 023**

- 131-134 Sample log: "no samples on 31-34" Levels not reported.
- 135 Sample log: "test on new spring for TM & CFC. Footnote CTD oxygen not calibrated.
- 110 Sample log: "Air leak" Delta-S 0.000 at 911db. Other water samples also look okay. Data are acceptable. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 024**

- 223 Oxygen printout: "overshoot, op error, lost" Footnote CTD oxygen not calibrated, oxygen lost.
- 210 Sample log: "Accidentally discarded salinity 10, no sample" Only RN and salinity sampled. Footnote CTD oxygen not calibrated, salinity lost, oxygen and nutrients not drawn.
- 211-213 Only RN and salinity sampled. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 201-236 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 025**

- 130-131 RN & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 119 RN & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 120 Sample log: "Vent open (wide)." Delta-S 0.001 low at 305db. RN only other sample. Will code bottle as leaking, if non-ODF samples are acceptable, then ODF suggests the bottle is acceptable. Footnote bottle leaking, CTD oxygen not calibrated, oxygen and nutrients not drawn.
- 108 Sample log: "Air leak, vent closed" Delta-S 0.000 at 1726db. Other water samples also look okay. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 026**

- 415 CTD data taken about 45 minutes after tripping bottle. However, variability between down and up traces very small so no real problem expected. May be slightly degraded. Footnote bottle did not trip as scheduled, only code that is close to situation, CTD oxygen not calibrated.. Delta-S 0.005 high at 660db. Autosal run okay. CTD T&S inversion.
- 414 CTD data taken from down trace after checking up and down consistency at bottles 13, 15, and 16. Data should be good to 5 db, and 0.003 in T and C. Footnote bottle did not trip as scheduled, only code that is close to situation, CTD oxygen not calibrated..

- 409 Sample log: "Air leak" Delta-S 0.001 low at 1828db after salinity bottle order problem adjusted. Other water samples also look okay. Footnote CTD oxygen not calibrated.
- 407-413 Apparent trip problem from bottle 13 to deeper depths, but salinity operator reported realizing that bottle 13 was being analyzed while doing bottle 12. Suspect that this had been in progress for several bottles, but where it started is not certain. Not important as isohaline below bottle 6. Other properties verify a salinity problem rather than tripping. Footnote CTD oxygen not calibrated, salinity questionable.
- 401-436 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

#### **Station 027**

- 132 Oxygen sample lost, Titration system problem. PC stopped but Dosimat kept on dosing. Footnote CTD oxygen not calibrated, oxygen lost.
- 119 Sample log: "Air leak, air vent okay. no obvious problem with cap." Delta-S 0.001 at 395db. Other water samples also look okay. Footnote CTD oxygen not calibrated.
- 116 Sample log: "NB16 lanyard around top end cap NB15. No air leak 16 after lanyard freed." Delta-S 0.001 low at 632db. Other water samples also look okay. Data are acceptable. Footnote CTD oxygen not calibrated.
- 115 Sample log: "Air leak. NB16 lanyard around top end cap NB15. Delta-S 0.000 at 800db. Other water samples also look okay. Data are acceptable. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

#### **Station 028**

- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

#### **Station 029**

- 123 Dosimat kept dosing when PC stopped at speed 4 before window opened. Powered off Dosimat when refilling at 1 ml. Added 5 ml KIO<sub>3</sub>, restarted o2.exe, and retitrated. Over shot end point so used overtitrate option, adding 1 more ml KIO<sub>3</sub>. Resulting raw titer after OT calculation was 0.04381. Subtracting 0.1(raw std - blank)\*5ml from total thio, 1.04381 gives raw titer 0.76316 which calculates to 6.863 ml/L at 305db. Sample 124 at 279db is 6.859 and sample 122 at 354db is 6.873 in area of fairly smooth gradient. Used 6.863 ml/L for this sample. Footnote CTD oxygen not calibrated, oxygen questionable.
- 117 Delta-S 0.657 low at 606db. 0.005 higher than Sta 27, sample 317. Assume salt bottle mistakenly turned upright and no salt drawn from NB 17 this cast. Footnote CTD oxygen not calibrated, salinity lost.
- 109 Sample log: "leaking up top with vent closed" Delta-S 0.004 high at 2028db. Autosal run okay. Sample below (108) is 0.001 low at 2283db. If salt bottles were swapped, during run or draw, both Delta-Ss would look better. Day watch says didn't take two salt bottles at a time to fill, so possibly 109 salt is only problem. Other water samples okay. Delta-S at 2028db is 0.0034, salinity is 34.954. Footnote CTD oxygen not calibrated, salinity questionable.
- 108 Delta-S at 2283db is -0.003, salinity is 34.951. See 109 salinity comment. Footnote CTD oxygen not calibrated, salinity questionable.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 030**

- 190 This is only CTD trip information, pressure, temperature and CTD conductivity. Bottle did not trip at this level, and this level is just to complete the profile. See 101-130 CTD Oxygen comment. Footnote bottle is not reported, CTD oxygen not calibrated.
- 101-130 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.
- 120 O2, CFCs show this NB closed at bottom. Delta-S 0.303 high at 120db. Salinity & nutrients also same as bottom values. At reassigned bottom depth, data are acceptable. Footnote bottle did not trip correctly, CTD oxygen not calibrated. Delta-S at 184db is 0.3028, salinity is 34.950.

**Station 031**

- 124-131 No samples, levels are not reported.
- 122 Delta-S 0.087 low at 67db. CTD T spike on up trace. Salt is okay, CTD T may be wrong. Recheck CTD T. CTD Processor: "Agree with quality comment that CTD spike, and CTD salinity bad." Footnote CTD salinity bad, CTD oxygen data not be reported.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 032**

- 122-130 No samples taken, levels are not reported.
- 109 Sample log: "Air leak" Delta-S 0.000 at 608db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 033**

- 109 Sample log: "Air leak" Delta-S 0.000 at 1572db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 108 Sample log: "Air leak" Delta-S 0.000 at 1775db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 107 Sample log: "Drips from bottom end cap after air vent opened." Delta-S 0.000 at 1979db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 034**

- 119 Sample log: "Air leak" Delta-S 0.002 low at 607db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 109 Sample log: "Air leak" Delta-S 0.001 high at 2230db. Other water samples also okay. Footnote CTD oxygen not calibrated.
- 103 Sample log: "Bottom lid leak." Delta-S 0.000 at 3609db. Other water samples also okay. Data are acceptable. Footnote CTD oxygen not calibrated.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 035**

- 133-134 Bad NO2 peaks, Air?, No rerun. No NO2 values. Footnote nitrate lost. Footnote CTD oxygen not calibrated, nitrate lost.

109 Sample log: "Air Leak" Delta-S 0.000 at 2544db. Nutrients also okay. O2 may be slightly high (.002 ml/L) but was drawn late after helium. Footnote CTD oxygen not calibrated.

101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

**Station 036**

Cast 2 PO4 end DW is very strange, tailing off slowly. Leaves cast 2 PO4's not matching cast 1 (deep). PO4 are acceptable. Corrections were applied and PO4 data are acceptable. SiO3 Cast 1 and 2 not matching up. Run together, but not in usual order (Deep run first, then shallow). Footnote silicate questionable.

229 O2 Not drawn due HCH samples. Footnote CTD oxygen not calibrated, oxygen not drawn, silicate questionable.

220 Salinity and O2 not drawn due HCH samples. Footnote CTD oxygen not calibrated, salinity and oxygen not drawn, silicate questionable.

216 O2 drawn after 4L HCH sample. Value appears 0.006 high at 203db. Footnote CTD oxygen not calibrated, oxygen questionable, silicate questionable.

213 O2 drawn after 4L HCH sample. Value appears 0.006 high at 254db. Footnote CTD oxygen not calibrated, oxygen questionable, silicate questionable.

211 O2 drawn after 4L HCH sample. Value appears 0.01 high at 304db. Footnote CTD oxygen not calibrated, oxygen questionable, silicate questionable.

207 O2 drawn after 4L HCH sample. Value appears 0.01 high at 506db. Footnote CTD oxygen not calibrated, oxygen questionable, silicate questionable.

203 O2 drawn after 4L HCH sample. Value appears 0.016 high at 760db. Footnote CTD oxygen not calibrated, oxygen questionable, silicate questionable.

201-236 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." CTD conductivity offset continued. Found electrode peeling off ceramic prior Station 37. Bottle salinity is acceptable. See Cast 2 SiO3 comments. Footnote CTD oxygen not calibrated, silicate questionable..

136 HCH & salinity only. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

133-135 See 101 SiO3 comments. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, silicate questionable.

123-132 RN & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

127 Delta-S 0.02 high at 1522db. Autosal run okay. RN only other sample. Same value as bottom sample but also 0.004 higher than last cast this salinity bottle used. May have been mistakenly turned upright with no salinity sample from NB27 this cast. Thus uncertain whether RN sample okay. Footnote CTD oxygen not calibrated, salinity lost, oxygen and nutrients not drawn.

121-122 See 101 SiO3 comments. Footnote CTD oxygen not calibrated, silicate questionable.

120 HCH & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

116-119 See 101 SiO3 comments. Footnote CTD oxygen not calibrated, silicate questionable.

105 See 101 SiO3 comments. Footnote CTD oxygen not calibrated, silicate questionable.

106-114 RN & salinity only. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

109 Sample log: "Air leak" Delta-S 0.000 at 3053db. RN only other sample. Footnote CTD oxygen not calibrated, oxygen and nutrients not drawn.

115 Delta-S 0.003 high at 3053db. RN only other sample. No notes. Autosal run okay. Footnote CTD oxygen not calibrated, salinity questionable, oxygen and nutrients not drawn.

- 103-104 Footnote CTD salinity bad, CTD oxygen not reported, silicate questionable.
- 101 Silicates had a problem at end, ingesting a big slug of air, so that end F1 and base are a bit uncertain. Deep values appear too high relative to other stations and other properties on this station, but no way to recalc. Delta-S at 3533db is 0.0066, salinity is 34.939. See 101-104 CTD salinity comment. Footnote CTD salinity bad, CTD oxygen data could not be reported, silicate questionable.
- 101-104 CTD Processor: "Using the UP cast for final pressure-sequenced CTD data for this cast and noticed there appears to be a drift in conductivity over the bottom 300 db; the down cast is not any better." Footnote CTD salinity bad, CTD oxygen not reported.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated. CTD conductivity offset. Found electrode peeling off ceramic prior Station 37. Bottle salinity is acceptable.
- 102 HCH & salinity only. Delta-S at 3533db is 0.0056, salinity is 34.938. See 101-104 CTD salinity comment. Footnote CTD salinity bad, CTD oxygen data not reported, oxygen and nutrients not drawn.

### Station 037

- 120 No water for salinity after HC drawn.
- 116 No water for salinity after HC drawn.
- 109 Sample log: "Air leak" Delta-S 0.000 at 2236db. Other water samples look okay except oxygen possibly 0.002 ml/L high. Bottle is acceptable, oxygen is reasonable.
- 101-136 New CTD (Nbr 1) used in place of CTD 6 starting this cast. CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

### Station 038

- 121 Sample log: "Leaking on bottom" Delta-S 0.001 high at 358db. Other water samples also okay. O2 max, but adjacent levels agree. Bottle is acceptable.
- 109 Sample log: "Air leak" Delta-S 0.000 at 2135db. Other water samples also okay.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

### Station 039

- 133 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 127-128 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 122-124 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 120 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 114 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 112 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 107 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.

- 105 Delta-S 0.002 low at 2953db. Autosal run okay. Other water samples okay. Same value as NB 4 at level below. Possibly dupe draw or run. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, salinity questionable.
- 104 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 102 No oxygen drawn due HCH or HC samples. See 101-136 CTD oxygen comments. Footnote CTD oxygen not calibrated, oxygen not drawn.
- 101-136 CTD Oxygen processor: "CTD oxygens for AO94 will not be calibrated because the O2 sensor was obviously malfunctioning." Footnote CTD oxygen not calibrated.

## CCHDO Data Processing Notes

<b>Date</b>	<b>Contact</b>	<b>Data Type</b>	<b>Action</b>
2007-06-07	Key, Dr. Robert M.	ALKALI/TCARBN	Complete BTL file w/ new carbon params  Attached please find the updated cruise file the 1994 St Laurent data. Old TCO2 values have been replaced with values you sent earlier today. After replacement I did primary QC on the new TCO2 values. Please note in the README file (attached) that I still need information for the TCO2 and Alk values (was Jones really the PI?, CRM?, method?). Also note that I have updated the name (from 18SNA094 to 18SNA199407. This name does not include the sailing day since it is unknown. Also the "SNA" in the name is someone's guess since this vessel does not have an official code (that I could find).  Alex and CCHDO: These files are replacements for ones sent with the Jan. CARINA distribution. File name change and new TCO2 values in the data file.