Collection of Arctic Ocean Data from US Navy Submarines on the New SCICEX Program

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I. Introduction

The U.S. Navy's SCience ICe EXercise (SCICEX) program originated in the 1990s when six *dedicated science cruises* were conducted in the Arctic Ocean aboard US Navy Sturgeon class submarines. After these cold war era submarines were retired, several *Science Accommodation Missions* (SAMs), on which a few days for civilian science were added to submarine transits through the Arctic Ocean, were carried out as opportunities arose. Interest in conducting SAMs on a regular basis to document and understand how the Arctic Ocean responds to climate change resulted in publication of a scientific plan in 2010 (http://www.arctic.gov/publications/scicex_plan.pdf). In support of future SAMs, data collection and water sampling methods aboard newer Seawolf and Virginia class submarines were tested on transits from a Navy ice camp in the Beaufort Sea in March, 2011.

This poster presents the results of the 2011 sampling that are available to date to test the collection methods and identify sampling protocols that may need improvement. The available data include:

- Under-ice submarine-launched eXpendable Condutivity Temperature Depth (XCTD) probes were deployed from the USS Connecticut (SSN-22), a Seawolf class submarine, that were compared with profiles from CTD casts during the APLIS ice station and historical profiles.
- Discrete samples for chemical and tracer measurements were collected by the Connecticut and the New Hampshire, a Virginia class boat. Although these were not calibrated against standard Niskin collections, replicate samples reflected the precision of the underway sampling system as well as the integrity of the samples during storage and shipping for laboratory analysis.
- Ice draft measurements also were taken in the vicinity of the ice camp and near the North Pole to evaluate new data collection systems.

II. Prior SCICEX Results

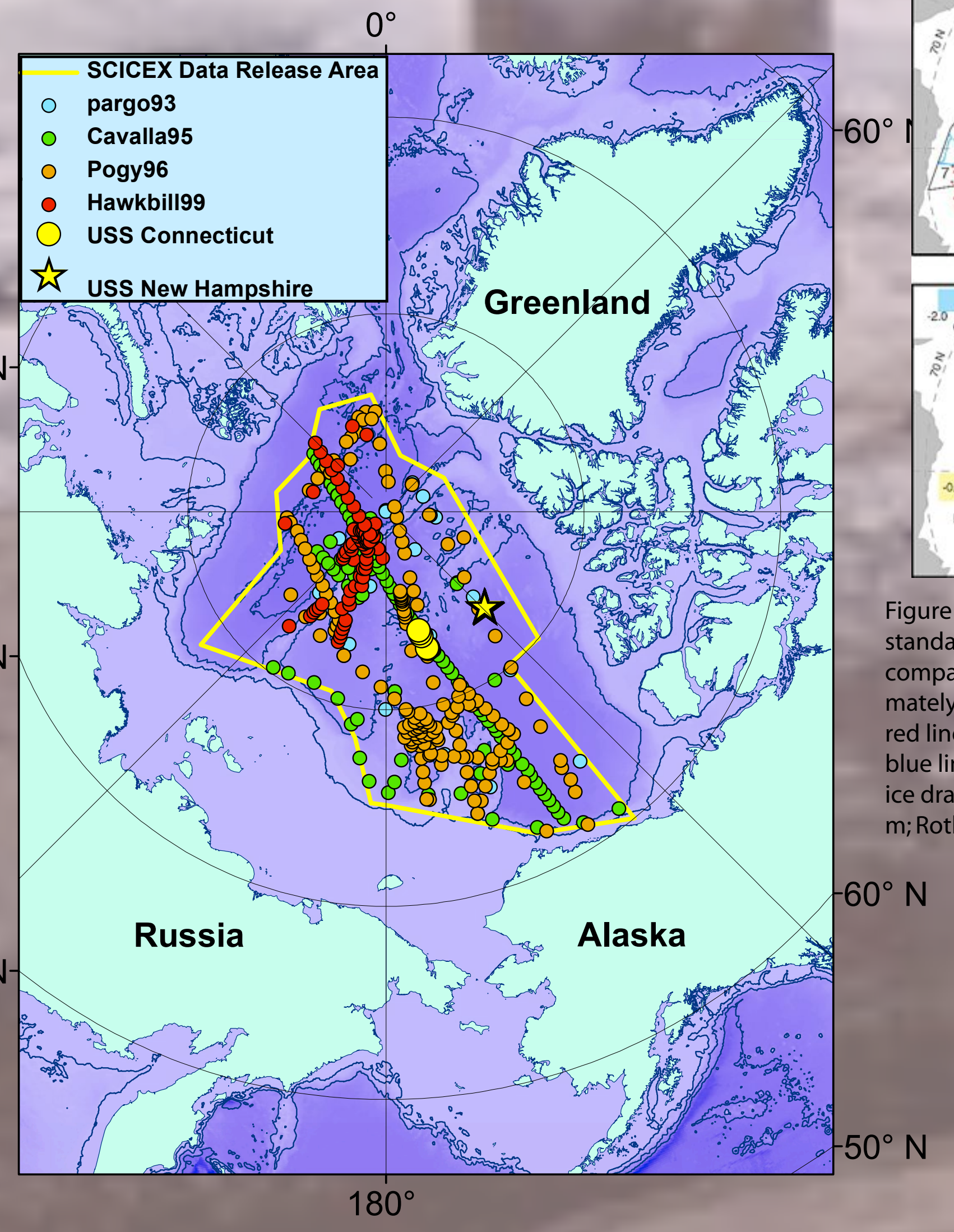


Fig.ure 1. Selected previous SCICEX cruise tracks as represented by missions aboard the U.S.S. Pargo, the U.S.S. Cavalla, the U.S.S. Pogy, and the U.S.S. Hawkbill. All sampling is restricted to the SCICEX Data Release Area. Stations in yellow were sampled on March 31st, 2011 aboard the U.S.S. Connecticut and the U.S.S. New Hampshire, and are the basis for the evaluation of protocols on the new submarines.

A. Ice volume

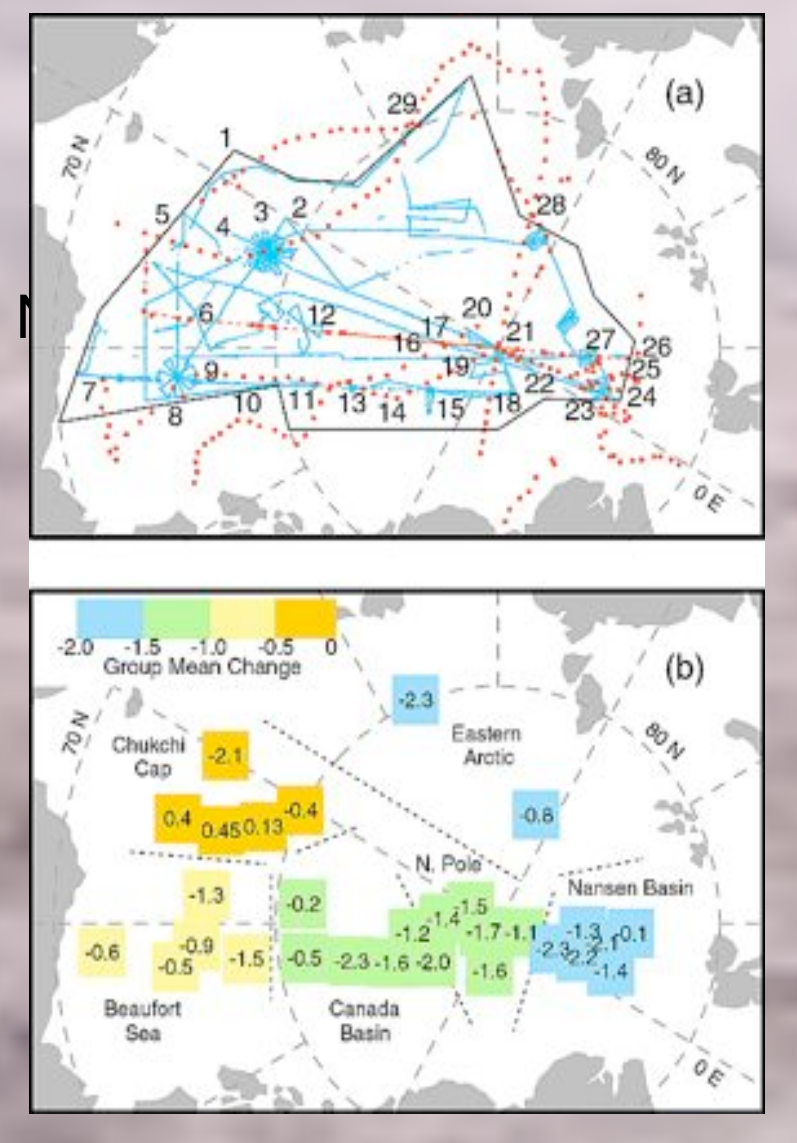


Figure 2. Ice draft measurements are a standard feature of Arctic crossings. This comparison of sea ice thickness approximately 30 years apart [1958–1976 (dotted red lines in top panel) vs. the 1990s (solid blue lines)] revealed the changes in mean ice draft during this period (bottom panel, m; Rothrock et al., 1999).

B. Hydrography

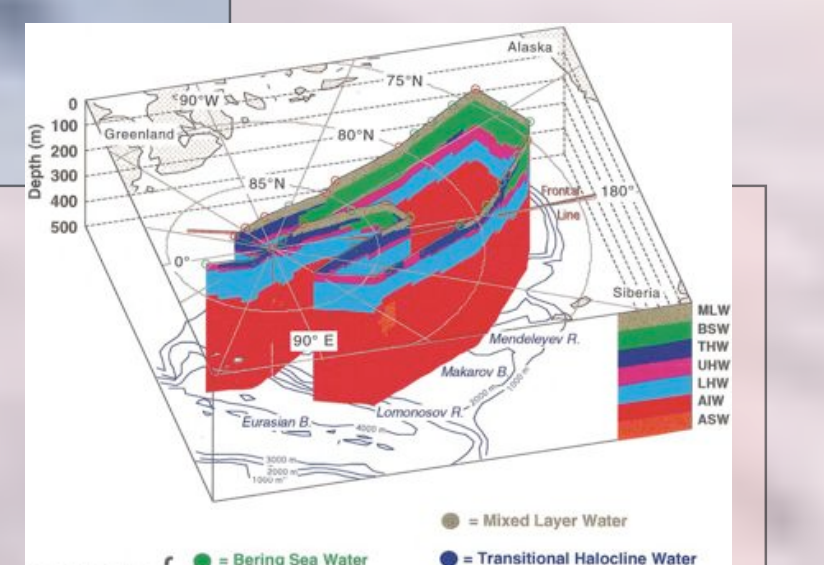


Figure 2. Water types of the Arctic Ocean characterized in August - September 1992 from submarine XCTD measurements. Bering Sea Water characterizes the Western Arctic. The Transitional Halocline Water occupies the Eastern Arctic. Upper Halocline Water appears at the surface in the Makarov Basin. (Morison et al., 1998).

C. Mixing rates

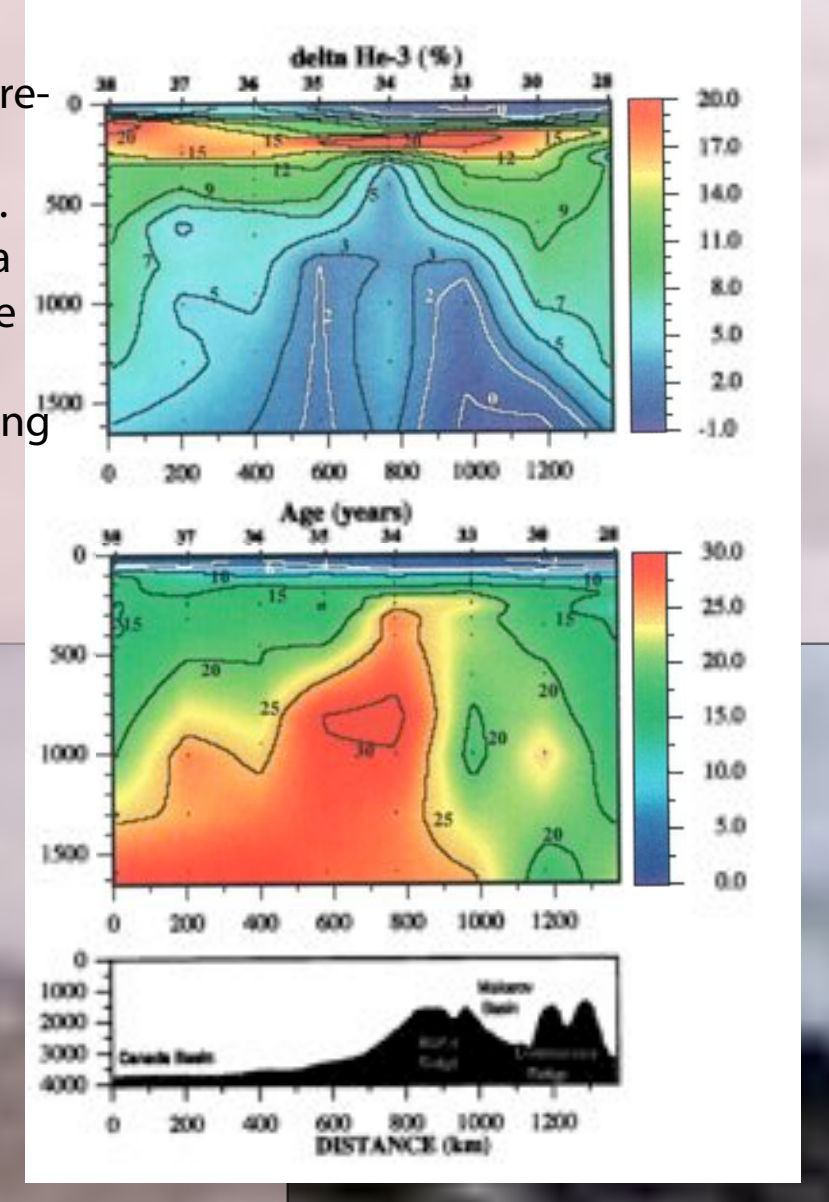


Figure 4. Through-hull measurements permit a variety of discrete samples to be collected. Here, vertical sections of delta He-3 (%) and tritium/He-3 age (years) along the SCICEX 96 cruise track reflect water mixing rates (Smethie et al., 2000).

D. Microbial diversity

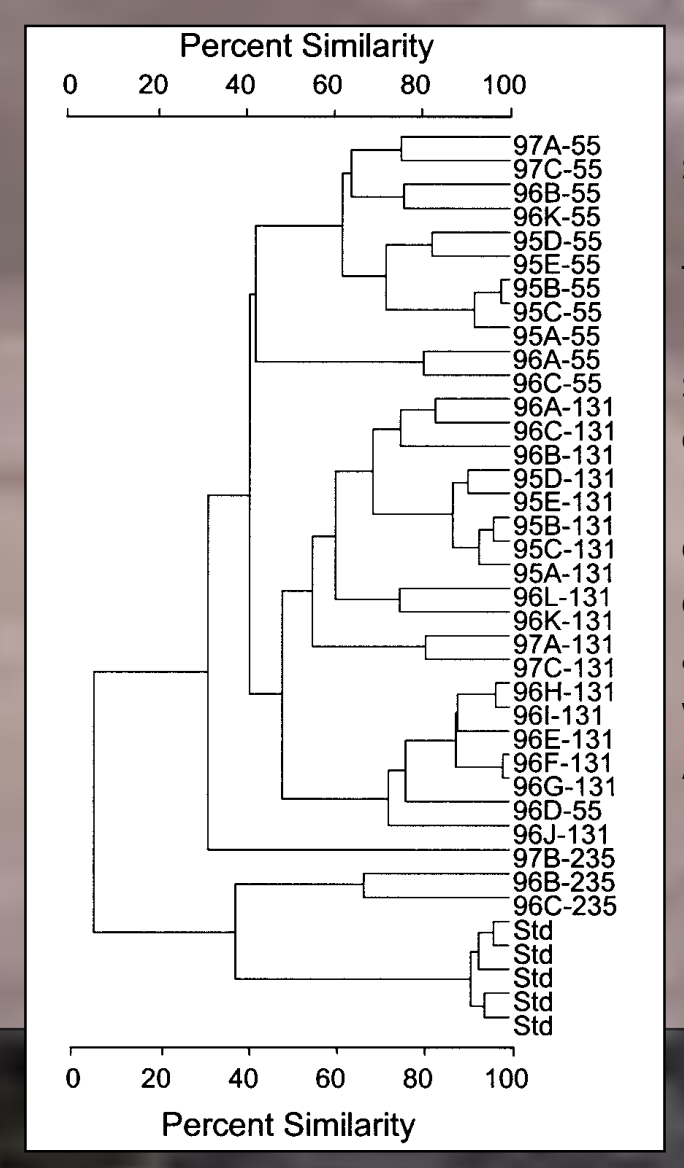


Figure 5. Submarine samples provide valid biological material for detailed analysis. Here, genetic patterns of bacterial samples indicate that the differences among bacterial communities with depth are greater than the difference due to location and season. These samples were also used to compare Arctic and Antarctic bacteria. (Bano et al., 2004).

III. Protocol Tests Results from 2011

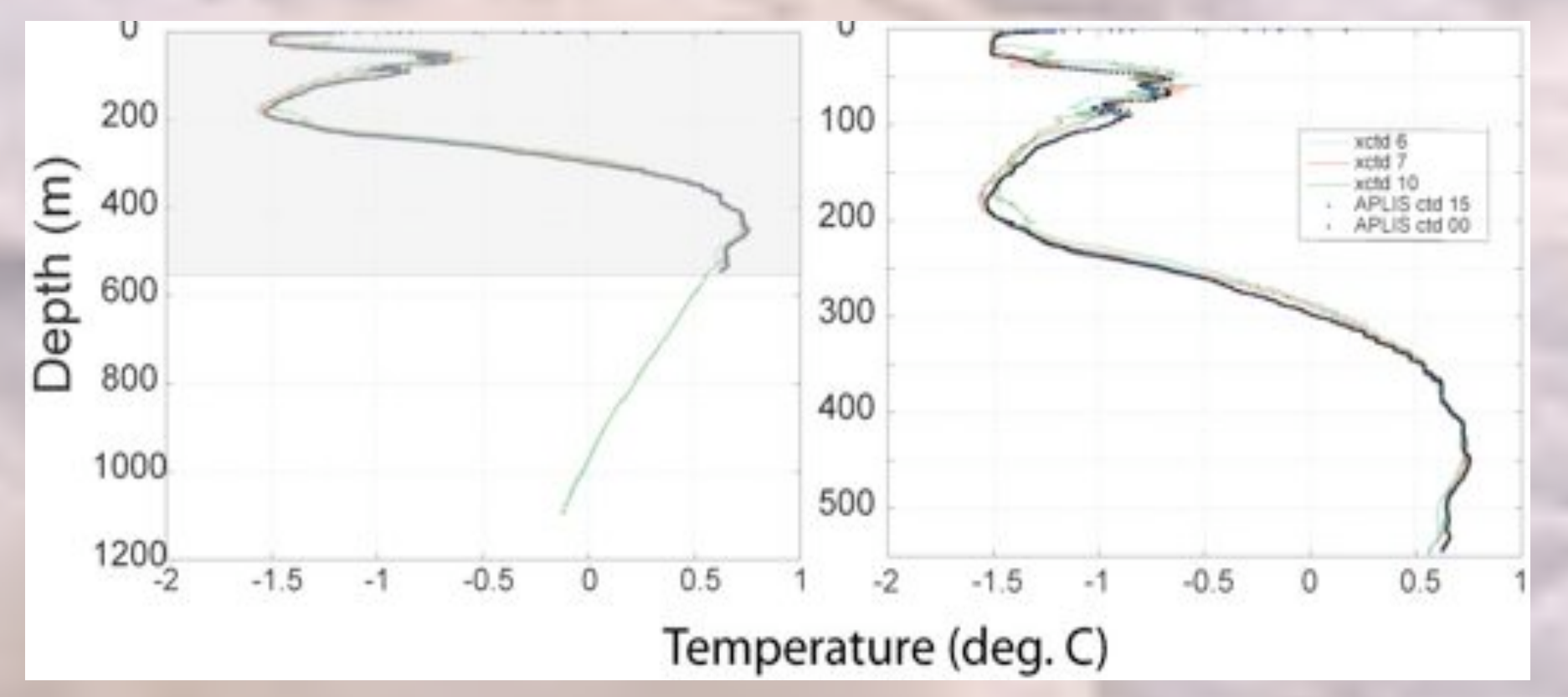


Figure 6. Results of 3 XCTD deployments from Connecticut (Seawolf class) submarine in March 2011. These are compared to 2 contemporaneous CTD casts from the APLIS ice station. The left panel shows the full depth of the CTD casts and panel B shows the upper 550 m of the XCTD deployments.

- There has been a significant improvement in the rate of success for probes to achieve the designed maximum depth and this no longer appears to be a significant problem.
- A high rate of failure of probes (out-of-the-box) to pass pre-launch tests remains unacceptable.
- Calibration of XCTD salinity measurements indicate that the XCTD salinities typically differ by less than 0.02 with the CTD, and meet the design XCTD conductivity accuracy for this pressure and temperature range.
- Calibration of XCTD temperature measurements at local minima and maxima are very close to the design criteria of ± 0.02 °C for XCTD temperature.
- The most significant limitation of the XCTD data derives from depth errors. Derived XCTD depths are biased by up to 10 m shallow relative to CTD pressure sensors within the depth range of the halocline. This limits the ability of XCTDs to resolve the small scale variability within fine scale vertical structures associated with T/S steps in the upper ocean.

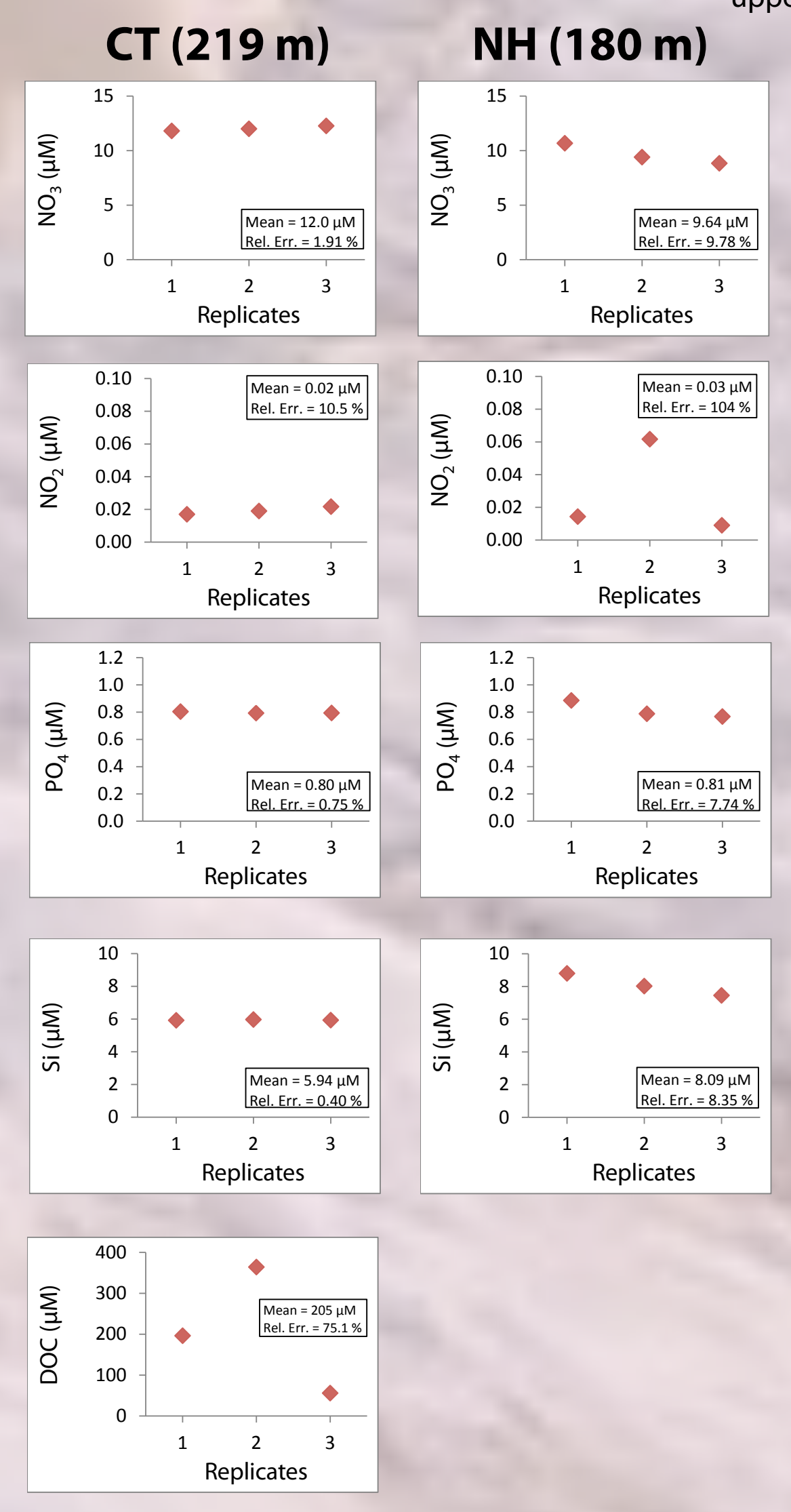


Figure 7. Results of nutrient and dissolved organic carbon analyses. All of the analyses for the major inorganic nutrients produced values in the range of what would be expected at the depths and locations sampled and changed smoothly along track. (The variations in nitrite are small compared to the nitrate pool).

The measurments of dissolved organic carbon (DOC; lower panel in CT data) varied by 6-8x in a region where nutirnets changed little. These measurements were not considered to be reliable and to be an artifact of contamination during sampling in the boat.

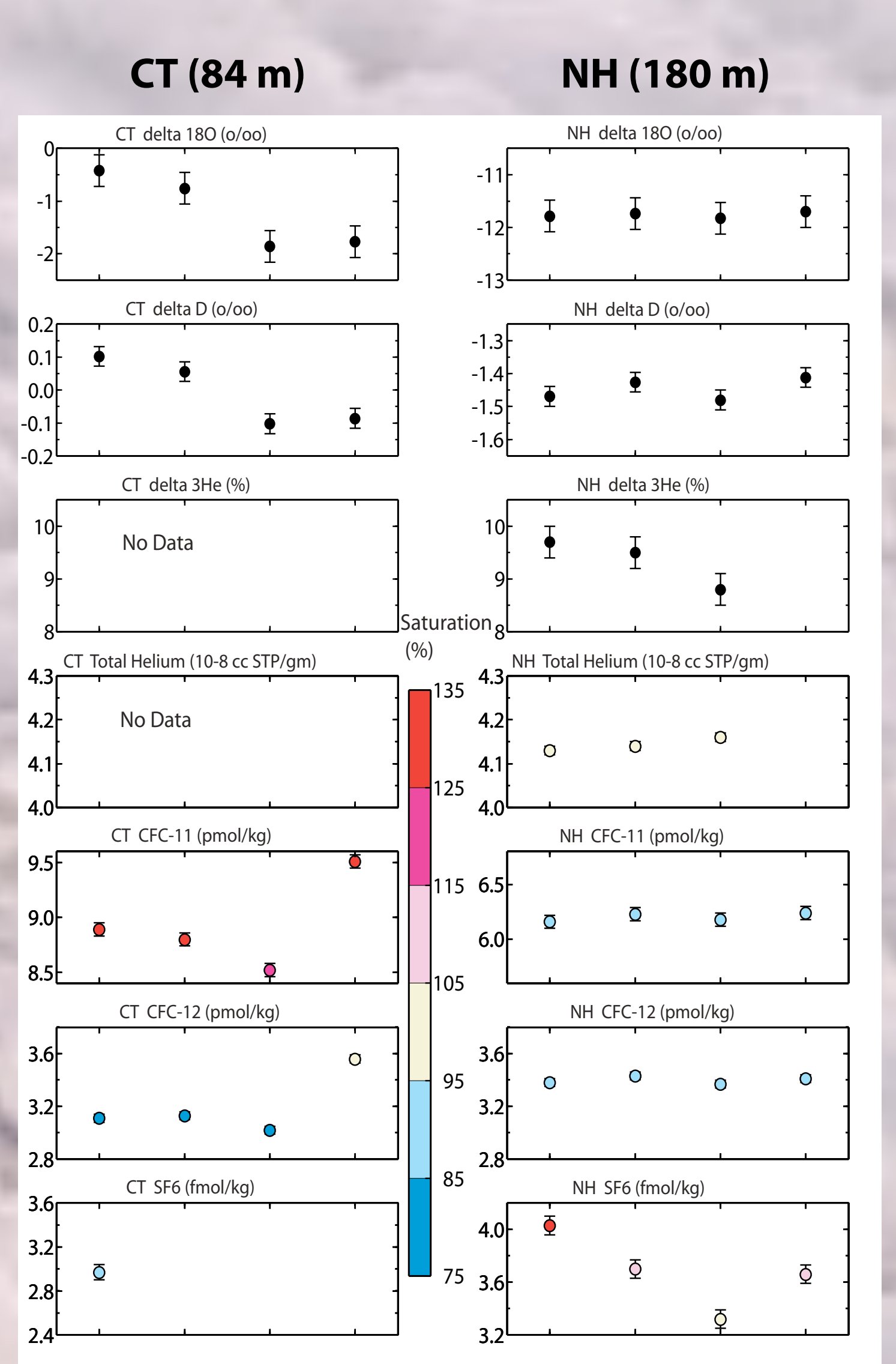


Figure 8. Results of analyses for several geochemical tracers. Important isotopic tracers such as δ18O of seawater (that reflects water sources) and hydrogen and helium (that reflect water age) work well on samples obtained from the submarines. There was less uniformity in the results of the CFCs and SF6 tracers. On the NH (Virginia class) boat, CFC levels were below saturation, while the SF6 levels were above. CFC-11 samples from the CT (Seawolf) were inecplicably large, while the SF6 values were undersaturated and similar to expected values. These results suggest that the composition of the boat's atmosphere and storage conditions are critical.

IV. Future SCICEX Sampling Opportunities

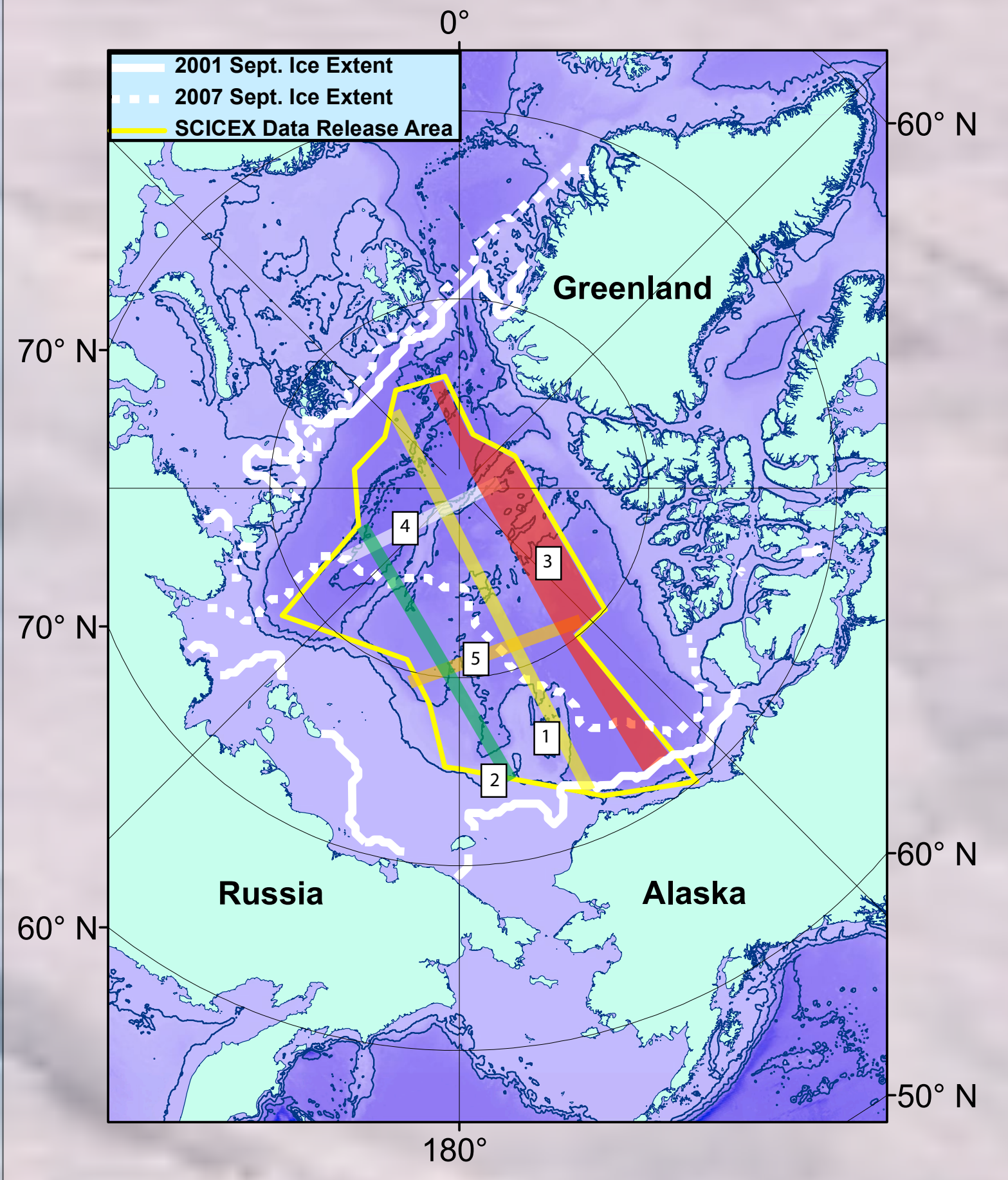
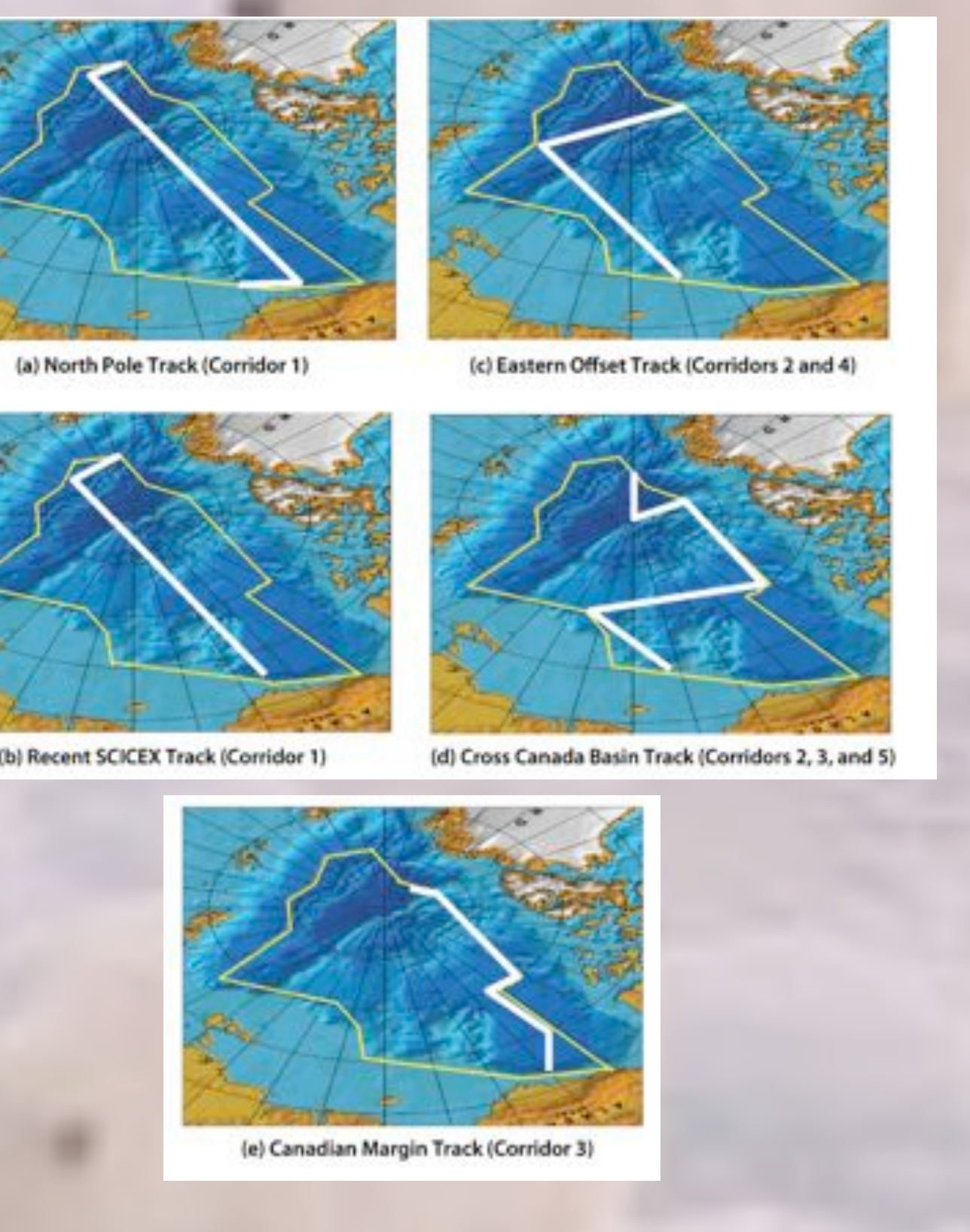


Figure 9. Recommended sampling corridors within the SCICEX Data Release Area. Note their placement with respect to the receding summer ice extent as observed between September 2001 and September 2007.

Figure 10. Example SAMs cruise tracks chosen from Sampling corridors. Science cruise time needed in addition to the basic crossing time for each track varies, with a minimum requirement of up to three days. The minimum time required is referenced to the time to complete the direct crossing for either the Atlantic-Pacific transit or the ice camp transit. (SCICEX Phase II Science Plan).


(a) North Pole Track (Corridor 1)
(c) Eastern Offset Track (Corridors 2 and 4)
(b) Recent SCICEX Track (Corridor 1)
(d) Cross Canada Basin Track (Corridors 2, 3, and 5)
(e) Canadian Margin Track (Corridor 3)

Near-term Sampling Priorities by Discipline:

Ice draft profiling: Priority regions – North Pole for historical comparison; Cross Canada Basin – from Lincoln to East Siberean; 50 km intervals for sampling

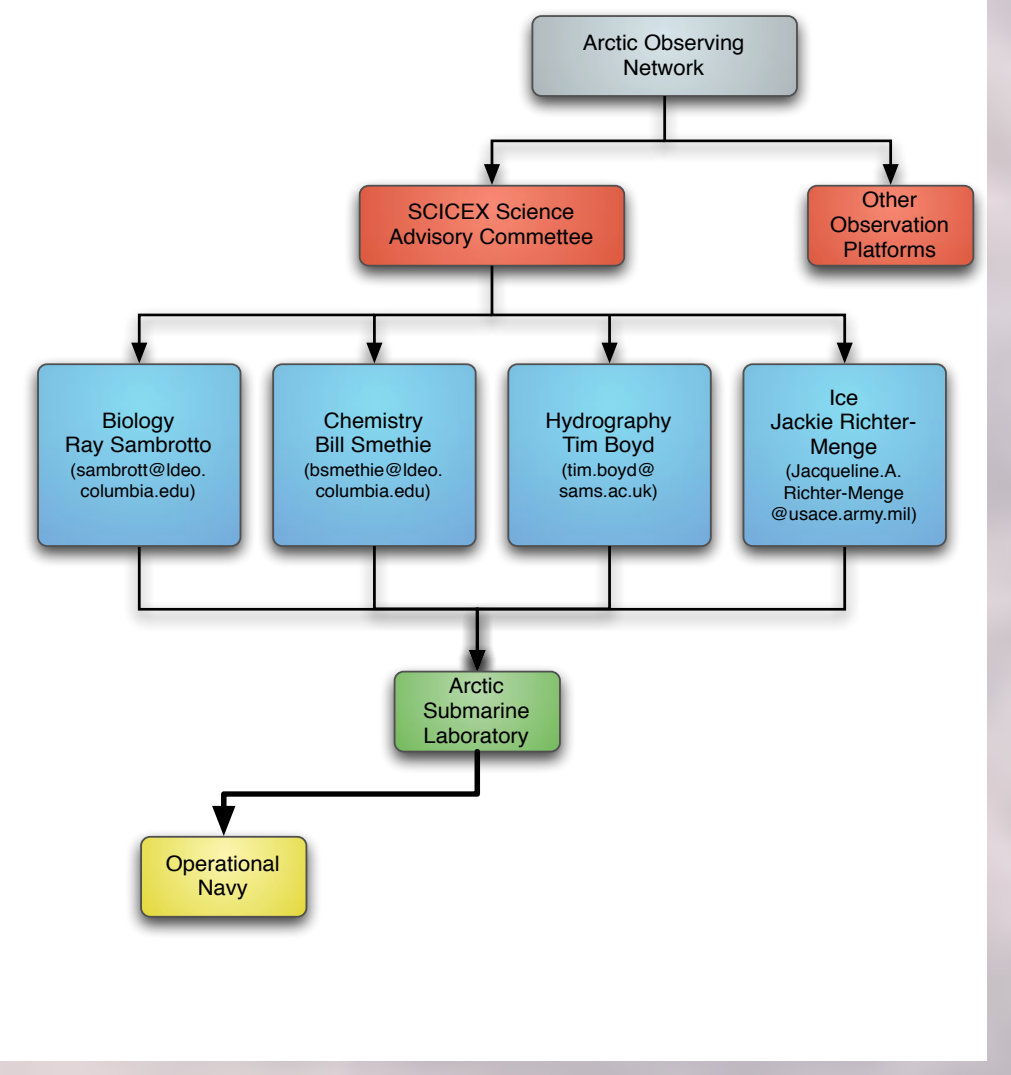
Hydrography: Water mass distributions, surface water changes; XCTD surveys

Chemistry: Atlantic – Pacific crossing ; Fresh water distribution; Carbonate chemistry of surface waters and halocline

Biology: Sampling of new open water region in western Canada Basin; Changes in productivity

Interested participants should contact the appropriate member of the SCICEX steering committe for further information. Detailed informationalso will soon be available on the SCICEX website -

http://nsidc.org/scicex



SAMPLE	PURPOSE	SIZE	COLLECTION PROCEDURE	ON BOARD PROCESSING	STORAGE REQUIREMENTS
UNDERWAY CONTINUOUS SAMPLING VIA SENSORS					
Temperature	Core water property	N/A	Hull-mounted CTD	None	N/A
Salinity	Core water property	N/A	Hull-mounted CTD	None	N/A
Oxygen	Water mass tracer; biological production andrecycling	N/A	Hull-mounted CTD	None	N/A
Nitrate	Water mass tracer; biological production andrecycling	N/A	Hull-mounted CTD	None	N/A
DOC	Water mass tracer	N/A	Hull-mounted CTD	None	N/A
Alkalinity, pH, pCO_2	CO_2 uptake, ocean acidification	N/A	Pumped stream from hull-mounted CTD	None	N/A
Chl a, variable fluorescence	Phytoplankton abundance, photosynthetic capacity	N/A	Pumped stream from hull-mounted CTD	None	N/A
Spectral radiometry, light scattering, and absorption	Chemical and biological properties (CDOM; overlying phytoplankton levels, particulate characterization)	N/A	Upward-looking sensors; pumped stream from hull-mounted CTD	None	N/A
DISCRETE WATER SAMPLES					
Salinity	Core water property; calibrate salinty sensor on CTD	200 ml	Rinse, fill, and cap a 200 ml glass bottle	Can be stored for shore-based measurement or measured on board with an Autosal	Room temperature
Oxygen	Water mass tracer; Biological production and recycling; calibrate O_2 sensor on CTD	120 ml	Rinse and fill 120 ml flask	Add reagents, follow Winkler titration procedures	Room temperature covered with water for up to one day prior to titration
Chl a, HPLC pigments	Phytoplankton levels and community composition; calibrate Chla fluorometer on CTD	500 ml (Chl a only) or 1–3 L for HPLC	Chl a—filter and place filter into 10 ml 90% acetone; HPLC samples—freeze filter	Chll a can be measured in an on-board fluorometer or stored for shore based measurement like HPLC	–20°C, must not thaw (–80° if possible for HPLC)
Flow cytometry	Microbial abundance	10 ml	Rinse and fill 15 ml tube	Add formalin and freeze	–20°C, must not thaw (–80° if possible)
Nutrients (PO_4, NO_3, SiO_2)	Water mass tracers; biological production andrecycling	50 ml	Rinse, partially fill, and cap a 50ml plastic tube; keep upright and ensure cap is tight	Quick freeze as soon as possible at –20°C	–20°C, must not thaw
^{18}O	Determine freshwater sources	100 ml	Rinse, fill, and cap 100 ml glassbottles	None	Room temperature
Alkalinity	CO_2 uptake, ocean acidification	250 ml	Rinse and fill 250 ml glass bottle with screw cap leaving a 2 ml headspace	None	Keep in dark at room temperature
SF_6, CFCs	Age information; calculation of anthropogenic CO_2 watermass tracer	1–2 L	Rinse and fill a 250–500 ml glass stoppered bottle, insert glass stopper, place the bottle in a jar and fill the jar with sample water	None	Refrigerated at a temperature of 0–2°C
Helium isotopes	Age information; watermass tracer	50 ml	Flush a 50 ml copper tube with the sample and crimp the ends of the tube with the water flowing; rinse the crimped ends with freshwater	None	Room temperature
Tritium	Age information; watermass tracer	500 ml	Fill a 500 ml bottle without rinsing and cap	None	Room temperature
^{129}I	Circulation time of Atlantic water	1 L	Rinse, fill, and cap a 1 L plasticbottle	None	Room temperature
Radium isotopes	Circulation of shelf water into the interior	130 L	Filter water through a cartiridge while the submarine is underway	Change cartiridge approx every three hours while submarine is underway	Room temperature

References

Bano, N., S. Ruffin, B. Ransom, and J.T. Hollibaugh. 2004. Phylogenetic composition of Arctic Ocean archaeal assemblages and comparison with Antarctic assemblages. Applied Environmental Microbiology 70:781–789.

Morison, J., M. Steele, and R. Andersen. 1998. Hydrography of the upper Arctic Ocean measured from the nuclear submarine U.S.S. Pargo. Deep-Sea Research I 45(357):15–38.

Rothrock, D., Y. Yu, G.A. Maykut. 1999. Thinning of the Arctic sea ice cover. Geophysical Research Letters. 26:3469-3472.

Smethie, W.M., P. Schlosser, G. Bonisch, and T.S. Hopkins. 2000. Renewal and circulation of intermediate waters in the Canadian Basin observed on the SCICEX 96 cruise. Journal of Geophysical Research 105:1,105–1,121.

SCICEX Science Advisory Committee. 2010. SCICEX Phase II Science Plan, Part I: Technical Guidance for Planning Science Accommodation Missions. US Arctic Research Commission, Arlington, VA, 76 pp