The Switchyard Project:
A modular approach to building an Arctic Observing System for the IPY and beyond in the Switchyard region of the Arctic Ocean
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1. Project Summary

The Switchyard project samples the marine environment in the Lincoln Sea (just north of northern Ellesmere Island, Canada and Greenland) north to the Pole. We call this the "Switchyard" region because like a train switching yard, different water masses and sea ice types converge into this region and are sent on their way, with some recirculating back into the Arctic Ocean's Beaufort Gyre and the rest into the North Atlantic Ocean on different "tracks" to the west of Greenland via Nares Strait and to the east of Greenland via Fram Strait. This is the water that influences the downstream deep water formation and thus global ocean circulation, and so it is crucial to document interannual changes in this region to achieve both understanding and a predictive capability.

The project consists of 4 main components:

1) Hydrochemical section: This is a section between the Lincoln Sea and the North Pole, consisting of 5-8 stations taken annually in early May. A Twin Otter aircraft lands on an ice floe, a hole is drilled, and a winch with conducting wire is used to lower a CTD-O (i.e., a suite of digital temperature, salinity, and dissolved oxygen sensors) and 1-3 specialized rosettes of 4 Niskin bottles (for measuring various chemical constituents) each to a depth of about 600 m. This section cuts across the Transpolar Drift Stream and several segments of the deeper Atlantic Water circulation.
2) Hydrochemical survey: This is a regional survey of the Lincoln Sea of maximum radius 500 km, consisting of 10-16 stations taken at the same time as the section, using another Twin Otter aircraft. A much lighter winch is used to lower a CTD-O to 500 m or 1000 m depth (depending on bathymetry), and a single ocean surface Niskin bottle sample is taken. This activity takes about half the time of a "section" station and thus we get about double the stations, for a complete sample of the regional hydrography.
3) Shelf-slope mooring line: This is a growing activity to observe the eastward-flowing waters along the continental shelf and slope of Northern Ellesmere Island, an extension of such boundary currents found elsewhere in the Arctic Ocean. At this point there are 3 moorings deployed, with 3 more planned for spring 2010. The moorings use an innovative acoustic data downlink, eliminating the need for

expensive mooring recovery operations. Moorings are deployed by Twin Otter and data are downloaded by landing nearby, using a helicopter.

4) Sea ice remote sensing studies: This activity has focused on an analysis of sea ice fluxes through the Canadian straits, including Nares Strait, using remote sensing.

2. Technology Highlights

- *Hydro section*: We have developed a Modular Rosette System that includes: (i) a Seabird CTD (SBE 19+), (ii) a Seabird dissolved oxygen sensor (SBE 43), and (iii) a series of 1-3 new 4-bottle Niskin rosettes that can fit through a 12" diameter hole drilled through the sea ice. Development of this instrument took a few years of trial and error, but it is now working quite reliably with generally 90% or more successful tripping of bottles on each station.
- *Hydro survey*: Seabird electronics is no longer making a 1000 m pressure case for their CTDs, only 500 m and 5000 m. For our 1000 m casts with small winches, we require a new model. Thus we special-ordered a 1000 m Delrin plastic case that worked well in 2009, and plan to order another back-up unit in the future.
- *Moorings*: Our switchyard moorings represent a new philosophy, with acoustic downloading of all data that eliminates expensive recovery operations.

3. Science Highlights

- *Oxygen minimum waters*: Using dissolved oxygen data from the hydro section and survey, K. Falkner et al. (2005) described and explained the presence of water layers with low oxygen values relative to those immediately above and below. These layers originate on the Arctic shelves, circulating within the basin in complex ways dependent on the depth at which they inject into the interior flow.
- *Ice flux through Nares Strait*: Kwok (2005) showed that the annual total sea ice flux through Nares Strait is less than 10% of that through Fram Strait, with a strong seasonal amplitude. No particular interannual trend was found from the six years of RADARSAT data analyzed.
- *Modification of waters within Nares Strait:* Munchow et al. (2006) used hydro survey data to determine that waters within the strait are substantially modified, relative to that which enters the northern end of the Strait in the Lincoln Sea.
- *Hydrographic relaxation:* Morison et al. (2006) used hydro section data to determine that central Arctic Ocean hydrographic conditions in the early-mid 2000s had relaxed back to a condition very similar to that in the 1980s, i.e., before the large shifts seen in the 1990s.
- *Freshwater build-up in the Canadian Basin*: McPhee et al. (2009) used hydro section and survey data to show how the freshwater content of the Canadian Basin was much higher in 2008 than in the historical climatology.
- *Freshwater outflow from the Arctic Ocean*: de Steur et al. (2009) used CTD data from both the hydro survey and hydro section to show that recent freshwater build-up in the Beaufort Gyre is "leaking" into the Lincoln Sea and thus may indicate a coming freshwater export into the North Atlantic Ocean (Figure 1).

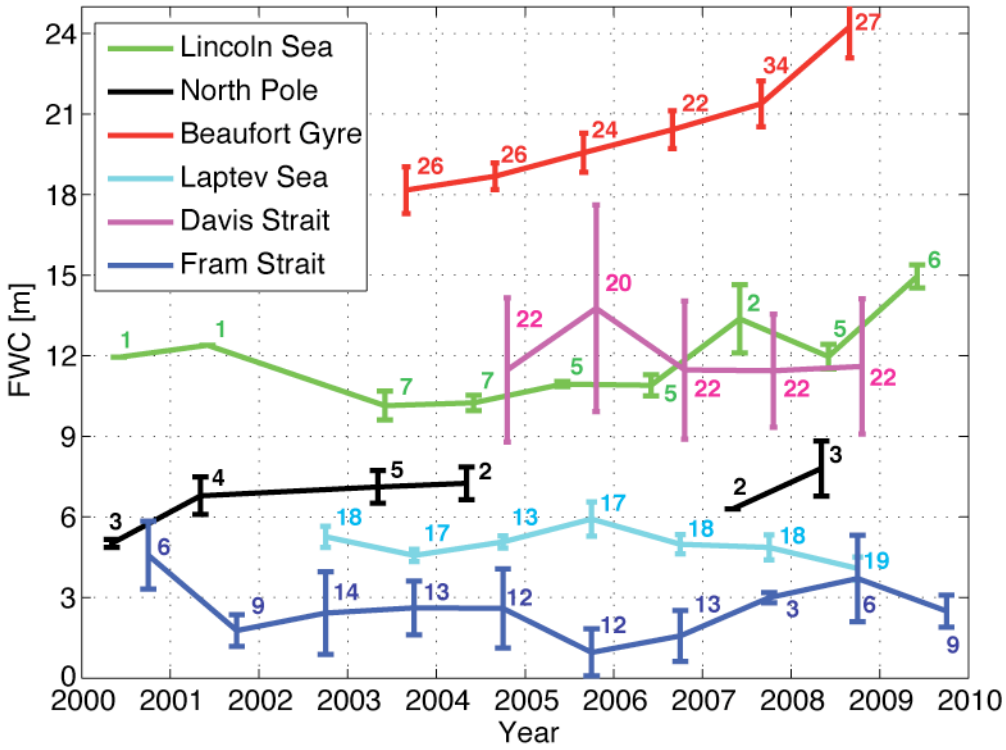

Figure 1. *From de Steur et al. (2009):* Freshwater Content (FWC) for six regions of the Arctic Ocean over the 21st century, using annual hydrographic survey data in each case. The large build-up in the Beaufort Gyre is obvious and has been the subject of very recent papers by Proshutinsky et al. (2009) and McPhee et al. (2009). Increasing FWC in the Lincoln Sea (as observed in the Switchyard project) indicates that this freshwater may be "leaking" toward the North Atlantic Ocean. Relatively flat trends in Fram and Davis Straits indicate that this freshwater pulse has not yet reached these exit points. Vertical lines indicate +/- 1 standard deviation of FWC within one or more 150 km box, except for Davis and Fram Straits, where the boxes are 50 km. Small numbers indicate the total number of hydrographic profiles used for each point on the graph.

- *Black carbon*: Hegg et al. (2009) show that black carbon found in snow on Arctic Ocean sea ice (including data from Switchyard) comes not from biomass burning, but rather from "pollution," the source of which was not determined in this analysis. A follow-up manuscript soon to be submitted stresses the relatively clean nature of the Arctic Ocean snow cover.
- *General freshening of the Switchyard region*: Survey data from 2008 and 2009 indicate that there has been a general freshening of all water types in the Switchyard region, including Eurasian water mass assemblies. The chemical signature indicates that these are meteoric waters, as opposed to sea ice melt.
- *Seasonality of Lincoln Sea shelf waters*: The first year of mooring data (spring 2008 – spring 2009) indicates a substantial seasonal variation,s which will be explored further using data from the three mooring deployed over the following year (to be downloaded in spring, 2010).

4. Lessons Learned

- *New technology takes time to develop and test*. The Modular Rosette System used in the hydro section took a few years of field work to develop into the robust system it is today. This success might have been much more difficult if the project had been funded on a typical 3-year cycle, or within a broad program like ANS instead of a dedicated observational program like AON.
- *We must be responsive to weather/marine conditions*. The hydrochemical survey was originally conceived as an annual high-resolution survey across the continental slope, using a helicopter and our small winch. This worked well for the first few years of our program. However, in recent years an increase in low clouds and fog in our operating window (i.e, May) have severely limited the days on which a helo can fly. As a result, we shifted our focus to a large-scale hydro survey using the more weather-resistant Twin Otter aircraft. This has proved very successful. As the arctic climate changes, other AON projects may also need to modify their observational strategies to adapt.

5. Interactions with other projects

- *NPEO*: We have a strong collaboration with the North Pole Environmental Observatory, which consists in part of hydrochemical surveys similar to those conducted during Switchyard. One of our Twin Otters comes south from the Pole, saving staging costs. We also share some equipment and personnel. NPEO used to do our Lincoln Sea – North Pole section, but now we coordinate with them to create even longer sections that start in the Lincoln Sea and extend through the Pole and into the Canadian or Eurasian Basins.
- *Black carbon surveys*: For the past 3 years we have collected snow samples for an NSF project led by T. Grenfell and S. Warren to determine the distribution of black carbon ("soot") across the arctic marine and terrestrial environments. Our data are some of the cleanest in the arctic, providing an important baseline point.
- *IABP*: We annually deploy ice-drifting buoys for the International Arctic Buoy Program, both from the section and survey flights. Our deployments are important for determining the characteristics of the bifurcation seen in the Switchyard region, i.e., where some sea ice recirculates back southwestward into the Beaufort Gyre, some finds its way through Nares Strait, and some heads southeastward into Fram Strait and then the East Greenland Current.

6. Data use

- See Section 3, Science Highlights, and Section 5, Interactions with Other Projects.

7. Publications

deSteur, L., M. Steele, J. Morison, I. G. Rigor, C. M. Lee, and E. Hansen, Recent changes in Arctic Ocean freshwater distribution, Geophys. Res. Lett., submitted, 2009.

Falkner, K., M. Steele, R. Woodgate, J. Swift, K. Aagaard, and J. Morison, Dissolved oxygen extrema in the Arctic Ocean halocline from the North Pole to the Lincoln Sea, Deep-Sea Res. I, 52, 1138-1154, 2005.

Hegg, D. A., S. G. Warren, T. C. Grenfell, S. J. Doherty, T. V. Larson, and A. D. Clarke, Source attribution of black cargon in arctic snow, Environ. Sci. Technol., 43, 4016-4021, 2009.

Kwok, R., Variability of Nares Strait ice flux, Geophys. Res. Lett., 32, L24502, doi: 10.1029/2005GL024768, 2005.

McPhee, M., A. Proshutinsky, J. Morison, M. Steele, and M. Alkire, Rapid change in freshwater content of the Arctic Ocean,.Geophys. Res. Lett., 36, L10602, doi:10.1029/2009GL037525, 2009.Morison, J., M. Steele, T. Kikuchi, K. Falkner, and W. Smethie, Relaxation of central Arctic Ocean hydrography to pre-1990s climatology, Geophys. Res. Lett., 33, L17604, doi: 10.1029/2006GL026826, 2006.

Morison, J., M. Steele, T. Kikuchi, K. Falkner, and W. Smethie, Relaxation of central Arctic Ocean hydrography to pre-1990s climatology, Geophys. Res. Lett., 33, L17604, doi: 10.1029/2006GL026826, 2006.

Munchow, A., H. Melling, and K. K. Falkner, An observational estimate of volume and freshwater flux leaving the Arctic Ocean through Nares Strait, J. Phys. Oceanogr., 36, 2025-2041, 2006.

8. Web site

http://psc.apl.washington.edu/switchyard

9. International Cooperation

- We operate out of Alert, Nunavut, Canada. Our operations are at the discretion of the Canadian military, which permit our access to facilities and even provide some personnel support. This could change at any time, for example if territorial tensions over the Canadian Archipelago were to escalate.
- We have plans to share data with a joint British-Danish hydrographic and sea ice experiment that operated in spring 2009 on the northern coast of Greenland.
- We have made inquiries with NOAA and NASA teams that occasionally fly a P3 aircraft over the Lincoln Sea for sea ice surveys, with a goal of deploying some expendable CTD probes into open water in the area.

10. Education/Outreach

- In our first year, we took Dan Dyer, a graduate student in videography, to the field. He used footage shot in that trip to make an educational DVD that also contained an interview with M. Steele.
- We will take a US grade school teacher to the field in 2010, via the PolarTREC program.
- Our field scientist and data analyst Roger Andersen acted as “beta tester” for the fall, 2009 update to the CADIS data portal web site.