A Case Study of a High-Latitude, Towed Streamer 3-D Seismic Survey*

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Introduction

In the summer of 2009, CGGVeritas collected a towed seismic streamer survey in the Canadian Beaufort Sea for BP. This was the highest latitude (>71 degrees) towed streamer 3-D survey collected by both companies, and possibly the industry. The presence of first-year and multi-year sea ice dominated the operation and taught both companies a great deal about high latitude seismic operations.

Geologic and Environmental Setting

The Mackenzie Delta is the second largest Tertiary delta in North America. To date, 250 wells have been drilled in the delta testing delta plain, delta front and upper slope reservoirs. The wells drilled to date established the presence of a prolific petroleum system in the Canadian Beaufort Sea. The lower slope/basin floor reservoirs have never been tested due to their remote location and challenging operating environment. BP Exploration's licences sit in water depths ranging from 40 m – 1200 m over the present day continental shelf edge (Figure 1). The exploration licences sit in a highly sensitive natural arctic environment with the challenge of ice infested waters.

In any given year, there is no assurance that passage from the Bering Sea into the Beaufort Sea without ice-breaker support can be made. The ice pack can prevent eastbound entry or westbound exit at any number of sites, most notably at Point Barrow, Alaska (Figure 2). When the passage does open, there are normally only some weeks of open water (<1/10 sea ice coverage) before new ice formation begins and one must wait until the next summer for another opportunity to collect data. To date the BP licences are the most northern licenses awarded and hence have the least number of open water days on average.

Method

Seismic surveying in constricted waters is often more easily accomplished by using sea floor nodes or ocean bottom cable. However, the robustness of these techniques in the presence of surface obstacles yields much lower productivity than the streamer method. BP's exploration license terms require the first well to spud within 5 years. With no assured access to the Beaufort Sea or to the survey area, and the very short annual acquisition window, it was clear that the best method to collect the 1600 sq km required to site a well was the streamer method.

Decades of ice history led the team to assume sea ice would be present in the survey area at all times and most locations within the survey would open briefly during the few weeks of "summer" (typically September). The challenge would be to identify and predict those areas and develop a flexible operations plan so they could be quickly surveyed before being covered by sea ice once again.

The geophysical requirements dictated a minimum offset of 7.35 km and a subsurface bin width of 37.5 m or less. The limited window for operations dictated as wide a swath as could be towed. Eight streamers at 150 m separation were deployed. A relatively wide streamer spacing maximized daily production and minimized the risk of lost time due to a tangle and damage as turns were sometimes very tight to save time and space in constricted waters.

The greatest threat to the operation was collision between sea ice and the streamer front end. It was assumed (little field experience to support), that the paravanes could survive infrequent collisions with relatively soft first year floes a few meters in diameter. Detachment or destruction of a paravane or a streamer head float could result in catastrophic damage or loss to much of the streamer spread that would require a retreat until the next summer. Strikes by ice along the streamers and detachment or damage to tail buoys were of little concern; that damage could be repaired or accommodated. Of course, the ship had to guard against towing streamers into an area that was too constricted to execute a prudent 180° turn, risking a streamer tangle. (Optimum turn diameter was approximately 10 km.) For these reasons, an accurate and timely knowledge of the sea ice distribution and movement was of prime importance in the management of the survey.

Sea ice moves in response to wind, surface current, and ice pack pressure. Each floe responds to the wind and current individually depending upon its sail profile and keel. Floe movement at its fastest reached a few tens of km per day. Predicting sea ice movement was one of the biggest challenges the operation faced. The use of support ships to map and track the ice which was inadequate on its own as they could not cover such a large area where ice drift in different places was occurring at varying rates and azimuths. Prediction of ice movement based upon such incomplete observations was a frustrating endeavour.

Ice forecasts were supported by an average of two satellite images per day in the optical and radar bands. Not only was that an inadequate number to optimise the management of the survey, the resolution of the satellites only permitted gross mapping, not the detection of isolated floes. The radar satellites operating in the C-band (5.331 GHz) had pixel resolutions between 30 m and 150 m, depending upon subscribed swath widths. The optical satellites were more frequent, but of course useless in poor visibility (night, fog, clouds) and resolved down to only 500 m. (Ice floes as small as 2 meters in diameter were considered a threat to the paravanes and head floats.)

Given an approximation of the sea ice distribution from satellite and surface observations, prediction was made on a near-constant basis onboard the ship by metocean specialists with local experience. The deepwater Beaufort Sea is devoid of current buoys so there was no source of current data, other than from the ship itself. Meteorological measurements were available from the only 5 coastal sites along the 900 km of Alaskan and Canadian Beaufort Sea, clearly a spatially under-sampled dataset, with expected unreliable predictions of wind speeds and azimuth.

The ships' radars were supplemented with real-time processing (stacking and spatial filtering) of the sea clutter to enhance detection of small floes. A network allowed the ships to acquire one another's radar images, thus extending the view. Aircraft observations were used to tie all data together and resolve conflicts amongst different data sources.

The predictions were used to identify subsequent sail lines that would have the highest probability of being ice-free. A scout boat approximately 5 km ahead of the streamer vessel made a visual and radar/ice processor check for the presence of floes. Despite these efforts, most sail lines were completed piece-meal, taking advantage of temporary clearings of the ice.

Aside from the standard conflicts amongst data quality, schedule and budget, this survey required operational flexibility to meet the following operational priorities:

1. Collect the northern-most portion of the survey at every opportunity, since it was least likely to be ice-free (Figure 3).
2. Collect the sail lines over the most important subsurface geology first since there was no assurance of having enough time to complete the survey.
3. Collect in the most efficient manner (using racetracks) since the arctic summer is short.
4. Do not use racetracks as an unpredictable ice incursion could force the ship to depart the Arctic Ocean, leaving a hole in the data coverage.

These four, sometimes conflicting, priorities were a result of the constant and always changing ice forecasts and were resolved on a daily basis by maintaining operational flexibility. It was critical to the subsurface team to collect the most important sail lines when ice forecasts threatened a possible end of season.

The ship was driven by major sea ice incursions to open water outside the survey area on the average of every two weeks, any one of which could have signalled the close of the open water season and the beginning of freezeup (Figure 4). The ship's DNV Ice-C classification provided minimal protection against hull damage.

It was essential that the demobilization decision was made early enough to retrieve the in-water gear and transit out of the Arctic Ocean before an ice incursion closed the Beaufort Sea for shipping until the next summer. That decision needed to be made at least five days before any choke-point along the route prevented safe passage. Five days is considerably longer than reliable weather and ice forecasts can be made in the poorly-instrumented Arctic.

Sea ice forecasts included the escape route extending 900 km to the west, to Point Barrow, Alaska USA to the open waters of the Bering Sea, and ultimately, the Pacific Ocean (Figure 2). There are no harbours in the Beaufort Sea to accommodate a deep draft ship, no shelter from an encroaching ice pack and no possibility of escape eastward through the Northwest Passage in October without ice-breaker support.

The water temperature (measured approximately 10 m beneath the surface) ranged between -1ºC and +4ºC. The freezing temperature of seawater at the standard salinity of 35 is -1.8ºC. The Beaufort, being a Mediterranean Sea with ample river discharge and limited circulation with the world's oceans, has a salinity at and near the surface of approximately 27 and a freezing point of -1.1ºC. The in-water streamer bird and tail buoy batteries, new at the beginning of the survey and hazardous to change in production from a small boat in the Arctic, were approaching depletion at survey end.

Conclusions

A 2-D program (1459 km) was collected in August while waiting on enough open water to deploy the eight streamers; 1564 sq km of full fold 3-D were collected in 29 days of September, including three retreats for ice incursions. Multi-streamer surveys in the marginal ice zone between seasonal ice coverage and permanent ice coverage are possible with significant operational flexibility, but some enhanced remote sensing of ice is required to be reliable and predictable. The enhancement, if not from more frequent passes of satellites providing wide swath-high resolution radar imagery, might come from UAS (unmanned aircraft systems, i.e. drones) carrying side-looking airborne radar with near-real time telemetry to the seismic fleet. Secondly, the prediction task would be enhanced by a denser grid of meteorology stations and ocean current meters.

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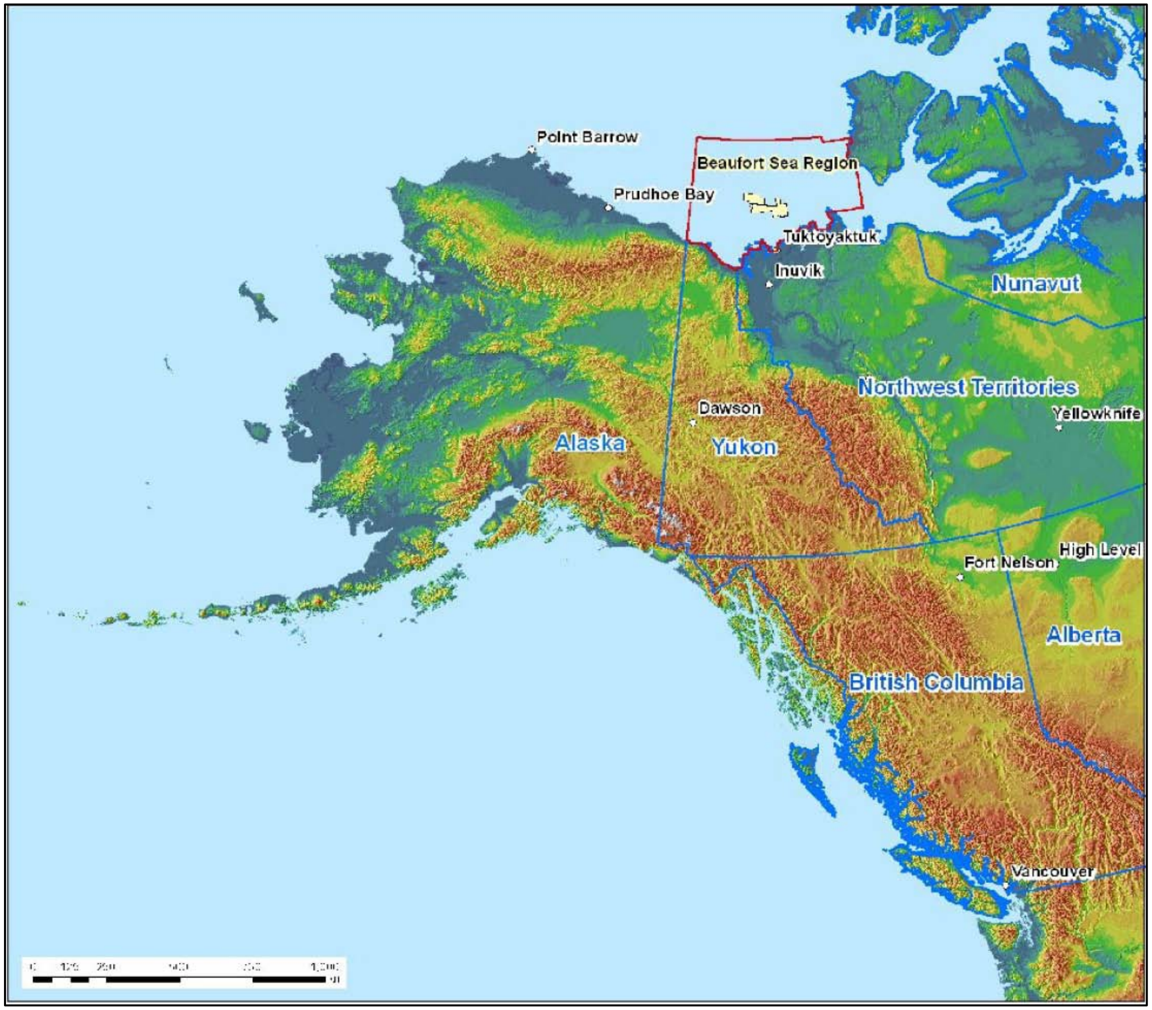

Figure 1. Survey Location.

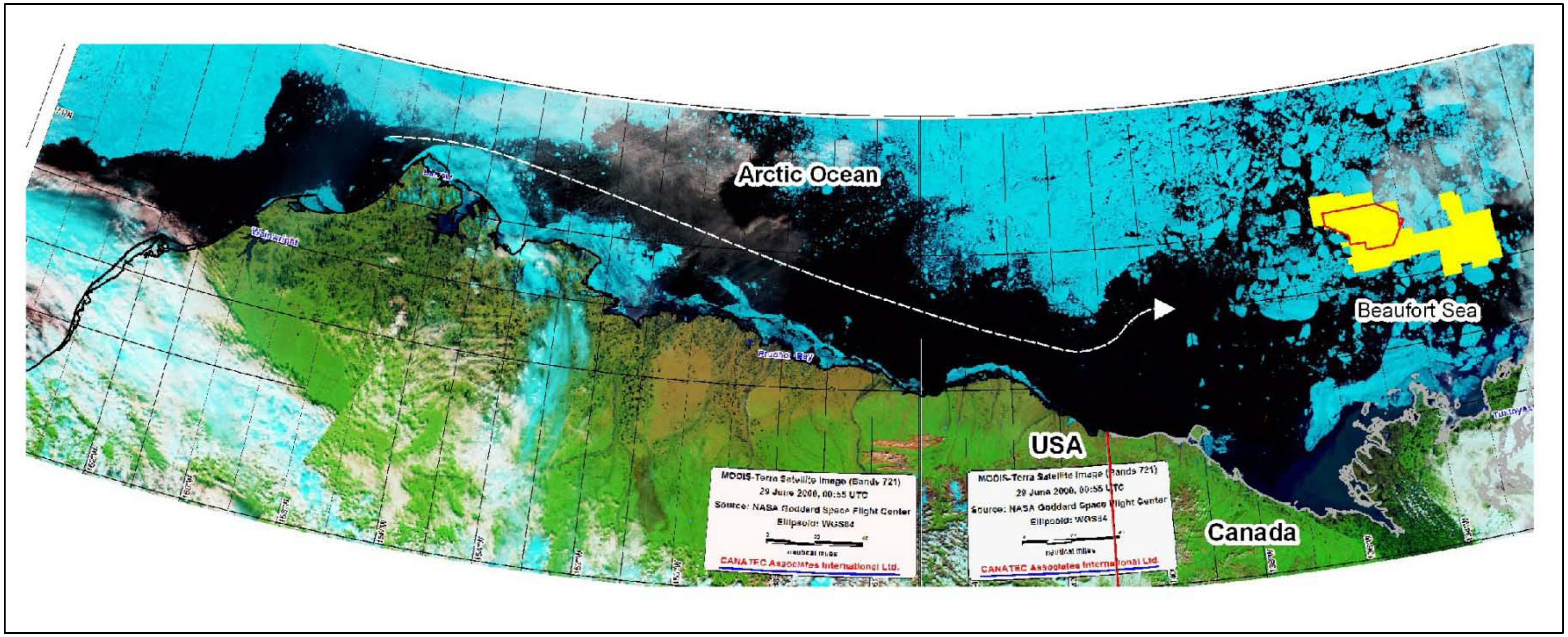

Figure 2. Modis satellite image 26 June 2009 Western entry and exit route of the Beaufort Sea. Distance between the survey (red polygon) and Barrow, Alaska is approximately 900 km.

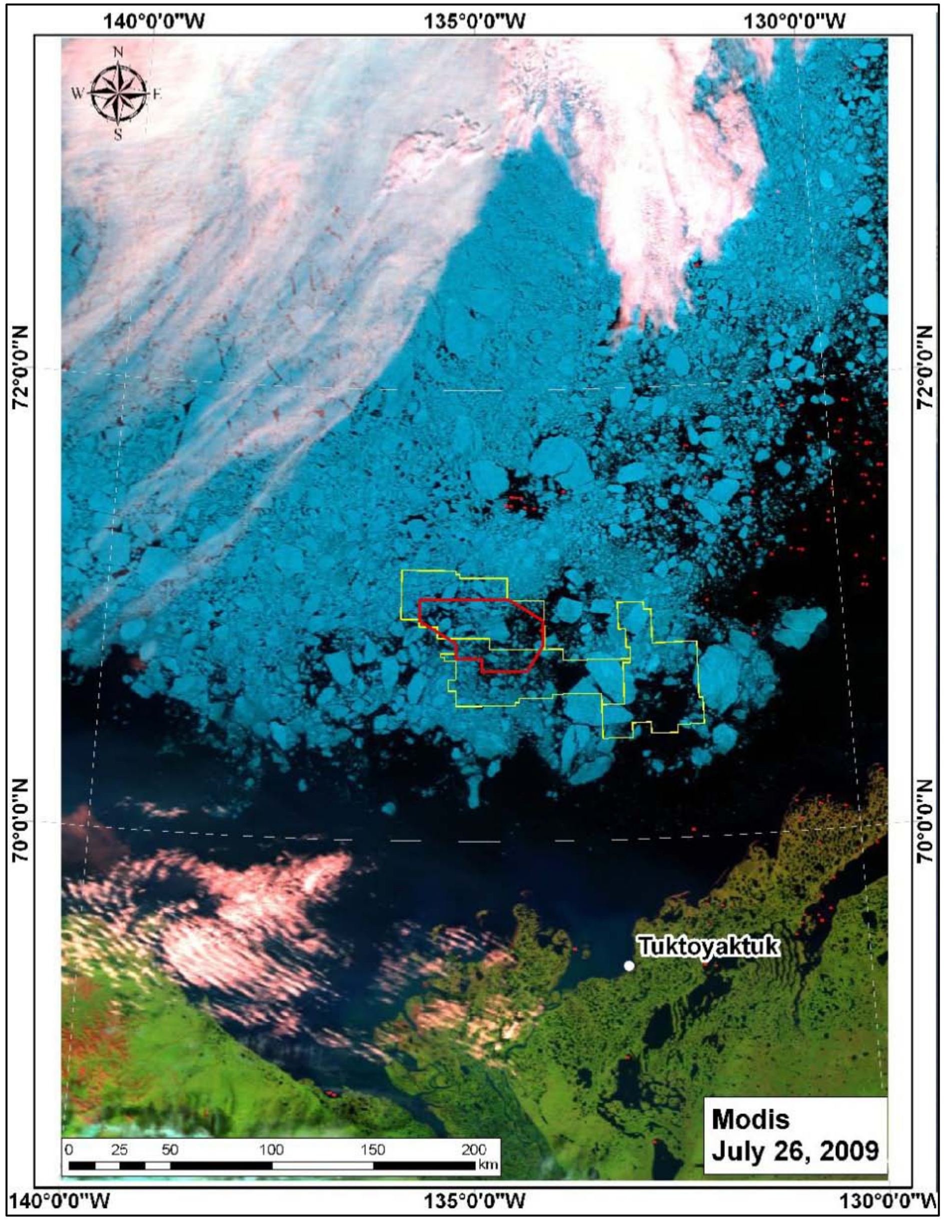

Figure 3. Modis (optical) image on arrival date 26 July 2009. 3-D polygon in red, licenses in yellow.

Figure 4. A frequent occurrence.