Flow of dense water through Herald Canyon: Results from the 2004 RUSALCA Hydrographic survey

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Introduction

In summer 2004 the Russian icebreaker *Khromov* carried out the inaugural cruise of the Russia-US Long-term Census of the Arctic (RUSALCA) program. The expedition was a great success, consisting of multi-disciplinary sampling from Bering Strait northward into the Chukchi Sea. Part of the hydrographic component consisted of a detailed survey of the flow through Herald Canyon (Figure 1a). This is the first time that the canyon has been sampled at high cross-stream resolution (station spacing less than the Rossby radius of deformation), enabling us to fully resolve the currents and water masses. This in turn offers the first opportunity to investigate the dynamics of the flow of dense water through the canyon, and the impact that this may have on the ventilation of the western Arctic. Furthermore, it will provide clues on how various canyon processes, such as hydraulic control, may modulate the response of this region to climate change. This report summarizes the initial results from the Herald Canyon conductivity/temperature/depth (CTD) survey.

Hydrography of the overflow

A. Source water

At the time of the hydrographic survey in late August, there were two main water masses present in Herald Canyon: warm Bering summer water (temperatures as warm as 8^{o}C), and cold winter-transformed Pacific water (< -1.6^{o}C). The focus of this study is on the latter, which, after exiting the canyon, ventilates the upper halocline of the western Arctic Ocean. The winter-transformed water was likely formed the previous winter due to strong surface buoyancy loss over the Chukchi Sea, both before the onset of the ice, and during polynya events throughout the season. (Influx of winter water from the Bering Sea likely contributed as well.) During the ensuing spring and summer months most of this winter water drained off the shelf—much of it through Herald Canyon—and the Chukchi Sea was largely replaced by warmer Bering summer water. During the RUSALCA survey, however, there was still some dense water present in the canyon, adjacent to the warm Bering water. These two water masses were separated by a sharp front at the head of Herald canyon (Figure 1b, near x=35 km). Note that the dense water was located on the right side of the canyon (looking upstream), which is not what one would expect for water originating from the Bering Strait area or central Chukchi. It is believed that there was a reservoir of winter-transformed water located to the south and west of Wrangel Island still present this late in the season, draining into Herald Canyon. Inspection of AVHRR images from the previous winter suggests significant polynya activity in this area, which would form such dense water. Since the ice cover here persisted into August, this would limit solar heating and allow this reservoir to remain intact. Hence, the belief is that during the time of the RUSALCA survey, dense water was draining from the East Siberian Sea (via Long Strait) through Herald Canyon, while buoyant water originating from the Bering Strait area was flowing adjacent to it. Whether or not this situation is common in summertime remains to be determined.

(b) Evolution of dense water through the canyon

The sequence of vertical sections across the canyon (Figure 1b-e) indicates that the conditions in Herald Canyon evolved significantly from the head of the canyon to the mouth. Of particular note is that the dense winter-transformed water (marked by the magenta shades in the figure) moved progressively down-slope, and most of it crossed over to the other side of the canyon by the last section. This has important ramifications, since the water will subsequently follow the isobaths to the east along the Chukchi shelfbreak, instead of flowing in the opposite direction towards the Lomonosov Ridge. Why did the water switch sides of the canyon? This could be due to due hydraulic effects (it happens frequently in hydraulic models) or it could be due to the dynamics that control geostrophic adjustment in a channel. The velocity data collected during the cruise will shed light on this, but at this point the lowered ADCP data have only just been processed and the analysis is in its initial stages. There is, however, indication in the hydrographic data that hydraulic control was active during the time of the survey. By constructing a vertical section along the path of the dense overflow (using the stations marked by red stars in Figure 1a), it is revealed that the deep density surfaces deflect sharply upwards at the last section (not shown). This is indicative of a hydraulic jump located where the canyon descends steeply near the mouth. Several tracers (turbidity, fluorescence, buoyancy frequency) indicate that water from offshore is being drawn upstream near the top of this feature, which is also suggestive of hydraulic behavior.

(C) Far-field

Roughly a month after the RUSALCA survey, a hydrographic section was occupied across the Chukchi shelfbreak at 166^{o}W as part of the Western Arctic Shelf-Basin Interactions Program (SBI). If one assumes an advective speed of 10-15 cm/s for the water exiting Herald Canyon (a plausible speed based on previous SBI measurements), it means that the 166^{o}W section likely sampled the same water measured during the RUSALCA survey. This gives us the opportunity to investigate the far-field product. An analysis in T-S space (not shown) reveals that the water became warmer, fresher, and less dense, along the same mixing line that was observed in the canyon. Overall, however, relatively little mixing occurred over this large distance of approximately 350 km, indicating that the evolution of the dense water within Herald Canyon sets, to first order, the properties of the water that eventually ventilates the upper halocline. This will be investigated further using the multitude of chemical tracers collected during the RUSALCA survey.

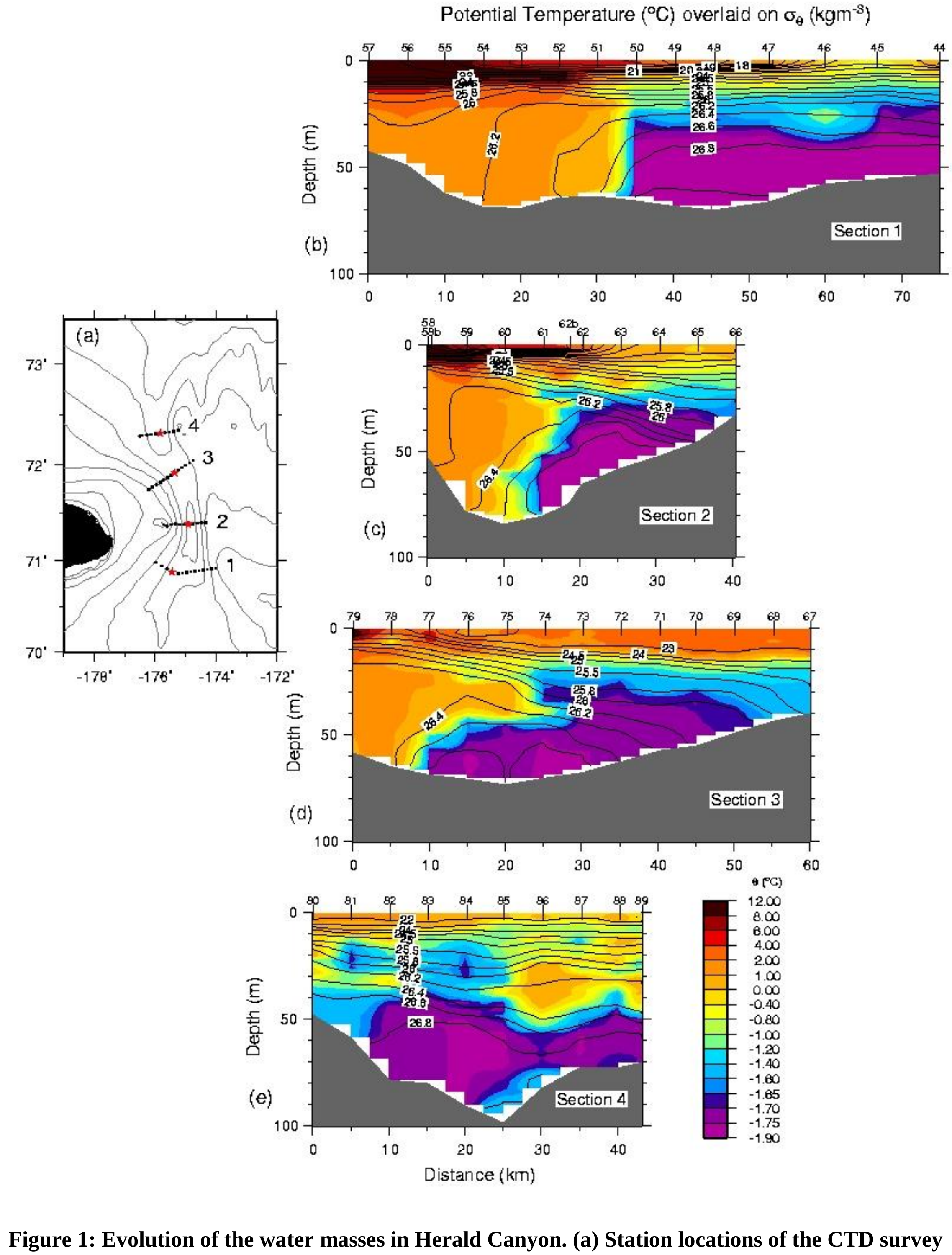

Figure 1: Evolution of the water masses in Herald Canyon. (a) Station locations of the CTD survey (black dots). The sections are marked 1-4, with section 1 at the head of the canyon. The location of the core of the dense overflow at each section is marked (red stars). (b-e) Potential temperature (color) overlaid on potential density (contours) for each section, looking upstream. The dense water corresponds to the magenta shades. The sections are placed laterally on the page so that the axis of the canyon is aligned.