

Update of the River Overflow on Sea Ice and Strudel Scour in the U.S. Beaufort Sea

Technical Summary

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ABSTRACT: The U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Alaska Outer Continental Shelf Region commissioned a study designed to map the extent of peak river overflow onto the landfast sea ice in the nearshore region of the Alaskan Beaufort Sea during the 13-year period from 2008 to 2020. The study builds on, updates, and supersedes all products generated as part of a similar study published in 2009 (the “2009 Study”) in the framework of the U.S. Department of the Interior, Minerals Management Service (MMS) project *Mapping Sea Ice Overflow Using Remote Sensing: Smith Bay to Camden Bay* (covering the period from 1995 to 2007; Hearon *et al.*, 2009). The combined dataset, presented in a geodatabase, includes satellite imagery, interpreted overflow boundaries, isolines of probability of overflow occurrence, strudel drain and scour data, and an inventory of offshore ice roads for the 26-year period from 1995 to 2020. The geodatabase can be used by BOEM, the Bureau of Safety and Environmental Enforcement (BSEE), and the State of Alaska to assess the potential environmental hazards associated with present and future oil and gas facilities that may be located within the study area.

BACKGROUND: River overflow on the sea ice occurs annually in the nearshore region of the Beaufort Sea during a brief period in the spring when river break-up precedes the break-up of the landfast sea ice. Upon arrival at the coast, the river water flows on top of the grounded and floating sea ice, spreading up to 10 km offshore. This brief but energetic phenomenon constitutes a potential hazard to offshore oil and gas development in that it can impede access to facilities, disperse spilled oil, and expose buried subsea

pipelines through strudel scouring.

This study was designed to map the extent of peak river overflow onto the landfast ice in the nearshore region of the Alaskan Beaufort Sea during the 13-year period from 2008 to 2020. The present effort builds on, updates, and supersedes all products generated as part of a similar study published in 2009 (the “2009 Study”) in the framework of the U.S. Department of the Interior, Minerals Management Service (MMS) project *Mapping Sea Ice Overflow Using Remote Sensing: Smith Bay to Camden Bay* (covering the period from 1995 to 2007; Hearon *et al.*, 2009).

OBJECTIVES: The specific objectives of this study are as follows:

1. Document the maximum river overflow boundaries (peak seaward extent) from Admiralty Bay to Camden Bay between 2008 and 2020 using remote sensing and historical helicopter-based surveys;
2. Update the overflow information in the 2009 Study geodatabase, where applicable, based upon newly available data;
3. Develop isolines of annual overflow occurrence probability based on the expanded dataset;
4. Update the strudel scour information in the 2009 Study geodatabase by incorporating information acquired since 2007;
5. Evaluate the environmental factors that contribute to river overflow and any changes in overflow extent or timing that have occurred over the study period; and
6. Combine the 2009 Study geodatabase with the river overflow boundaries and strudel scour information derived for the present study.

RESULTS: The primary components of the study are a data product and a synthesis report. The data prepared as part of this study were compiled in a geodatabase that includes satellite imagery, interpreted overflow boundaries, isolines of probability of overflow occurrence, strudel drain and scour data, and an inventory of offshore ice roads for the 26-year study period from 1995 to 2020. The principal study findings from the report are summarized below:

1. **Overflow Boundary Mapping:** A total of 274 overflow boundaries were mapped over the 13-year period from 2008 through 2020. The peak overflow extents between 1995 and 2007 mapped as part of the 2009 Study were refined, as needed, based on newly available imagery. In addition, overflow boundaries missing from the 2009 Study due to lack of imagery at the time were mapped. Aside from one instance in 2019, the overflow edge was mapped for all watercourses in the study area over the 21-year period from 2000 through 2020.
2. **Overflow Occurrence Probability:** Isolines of overflow probability were developed using the overflow extents mapped during the 21-year period from 2000 through 2020. The immediate region fronting all but one of the thirteen major rivers in the study area (Topagoruk River) flooded annually (100% probability of occurrence). In the central portion of the study area, between Cape Halkett and the Staines River, the entire coast flooded 25% of the time. Elsewhere, the flooded areas were discontinuous.
3. **Correlation of River Overflow with Environmental Variables:** Consistent with the 2009 Study findings, no meaningful correlations were identified between the annual overflow areas of

the Colville, Kuparuk, and Sagavanirktok Rivers and environmental data related to streamflow, precipitation, snowpack, and air temperature. This indicates that the extent of river overflow onto the sea ice cannot readily be predicted by any single environmental variable for which historical data currently exist. The overflow phenomenon appears to be governed by interactions between a number of environmental forces, some of which (*e.g.*, soil moisture at high elevations at the onset of snowpack thawing, ice jams in distributary channels, roughness and snow cover on the sea ice, wind events during flooding, and the density of drainage features on the sea ice) are complex, for the most part poorly understood, or lack sufficient data to evaluate their contributions to the overall overflow process. In the absence of such direct correlations, the detailed long-term mapping of overflow boundaries in this study provides a valuable probabilistic assessment of potential hazards to coastal facilities based on past events. Investigations into the complex interactions governing river overflow is a recommended area of further research.

4. **Long-Term Trends:** The environmental and overflow data sets exhibit considerable year-to-year variability. However, clear trends in several parameters are evident over the 26-year study period. Both the end-of-winter snow water equivalent and average air temperature generally increased over the study period, while the streamflow and precipitation data exhibited inconsistent and weak trends. The annual overflow area within the study region decreased with time (rate $\approx 18 \text{ km}^2/\text{yr}$) and both the start and peak of overflow occurred earlier in the year (rate $\approx 0.4 \text{ days/yr}$).
5. **Facility Hazards:** River overflow on the sea ice introduces two hazards to man-made facilities in the U.S. Beaufort Sea: interdiction of access to offshore facilities by flooding, and disturbance of the sea bottom above buried subsea pipelines by strudel scouring (which can compromise the integrity of the pipeline).

Rapid deterioration of the ice sheet can render ice roads impassable within the zone of river overflow, impacting both facilities access and oil spill response. At least some portion of every nearshore ice road mapped between 1995 and 2020 was located within the zone of river overflow and vulnerable to damage during break-up.

Strudel scouring can constitute a significant design consideration for subsea pipelines in nearshore areas adjacent to river and stream mouths. In the event that a strudel drain is located directly above a buried subsea pipeline, a sufficiently deep strudel scour may expose the pipeline and lead to an unsupported span. A strudel scour that forms directly over a buried pipeline also can remove the backfill material that is needed to prevent damage from ice keels and prevent upheaval buckling. An additional concern is that strudel drainage provides a potential mechanism to transport spilled oil below the ice sheet.

Strudel scour frequency and severity can be segregated into zones according to water depth. Strudel scouring typically is most common and severe in the Primary Strudel Zone, which extends offshore from the grounded landfast ice edge to approximately 6 m water depth. In the zone of grounded landfast ice (the “Secondary Strudel Zone”) and offshore of the Primary Zone (the “Tertiary Strudel Zone”), scouring tends to be more modest and occur less frequently. When the major rivers in this region were considered, the Secondary Strudel Zone accounted for the greatest portion of the overflow area in any given year. On average, this zone encompassed 62% of the total overflow area. The Primary Strudel Zone accounted for 37% of the total overflow area, while the Tertiary Zone accounted for a mere 1%. Strudel zone and overflow occurrence information should be used to assess the hazard to prospective pipeline routes posed by strudel scouring in different coastal areas.

STUDY PRODUCTS:

1. **BOEM study report:** Hearon G, Plana Casado A, Scott C, Dickins D (Coastal Frontiers Corporation, Moorpark, CA and DF Dickins Associates, LLC, Monterey, CA). 2022. Update of the river overflow on sea ice and strudel scour in the U.S. Beaufort Sea. Anchorage (AK): U.S. Department of the Interior, Bureau of Ocean Energy Management. 98 p plus appendices. Report No.: OCS Study BOEM 2022-044. Contract No.: M0121C0001.
2. **Geodatabase:** The geodatabase consists of two volumes:
 - OVERFLOOD_DATA.GDB: Primary geodatabase containing the river overflow data and auxiliary information compiled for the project.
 - IMAGERY_BANK.GDB: Supporting database containing the raw satellite imagery used to derive the overflow extents for the period 1995–2020.

MAP OF STUDY AREA: Figure 1 of report OCS Study BOEM 2022-044

