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STUDY TITLE: Idealized Process Model Studies of Circulation in the Landfast Ice Zone of the Alaskan Beaufort Sea

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KEY WORDS:

BACKGROUND:
Winds and river runoff influence the dynamics and circulation pathways over the innermost portion (water depths < ~ 20 m) of most continental shelves. While this is true for Arctic shelves as well, the effects of wind stress and buoyancy are substantially modulated by the annual freeze/thaw cycle, which controls the phasing and duration of the landfast ice season and river discharge (Weingartner et al., 2009). Nearshore circulation processes on arctic shelves differ from ice-free seas because of the presence of landfast ice, which inhibits the transfer of momentum from the wind to the ocean and is frictionally coupled to the underice flow. Consequently, dynamical principles gleaned from ice-free shelves are not completely applicable to the landfast ice zones surrounding the Arctic Ocean.

OBJECTIVES:
The aim of this project is to develop a first order understanding of the circulation dynamics of the landfast ice zone of arctic shelves. It is hoped that the models are useful for response planning in the event of an oil spill under a landfast ice cover.

DESCRIPTION:
Idealized analytical and numerical models are used to illuminate the effect of a landfast ice cover on under ice circulation. Landfast ice is included in the models as a surface stress, exactly analogous to placing a bottom boundary on the surface of the ocean. To investigate the effects of spatial variations in ice roughness, the linear ice ocean drag coefficient was varied to test whether spatial variations in the ice ocean friction coefficient exerted a torque on the water column under the ice.

Three forcing mechanisms were investigated: first we used vertically averaged analytical and numerical simulations to study the effect of a landfast ice cover on a lateral inflow (an elevated sea level at the western boundary of the shelf). Second, we investigated the effect of an upwelling wind stress along a seaward landfast ice edge to determine the response of the under-ice circulation. Both vertically averaged analytical and numerical simulations were used. Unstratified numerical simulations that allowed for vertical variations were used to study exchange across the ice edge. Third, we studied the fate of a buoyant inflow under an ice cover generated by a river that discharges into the model domain through the southern coastal wall. In this case we used three dimensional numerical simulations to study the effect of landfast ice on a buoyant plume and to determine the differences between ice free plume behavior and ice covered buoyant plume behavior.

SIGNIFICANT CONCLUSIONS:
Lateral inflow experiments show that spatial variations in the frictional coupling between the ice and the ocean exert a vorticity torque on the water column. For a very wide ice cover where the ice-ocean friction coefficient increases with increasing distance from the coast (mimicking the offshore increase in roughness of the Beaufort Sea landfast ice cover), the result is an increase in offshore spreading of the inflow (versus the ice free and uniform ice cover scenarios) while for a narrow ice cover (<40 km), the effect of the surface stress curl across the ice edge (ice covered to ice free) exerts a vorticity torque in the opposite sense of bottom and under ice friction (and the cross-shore increase in the under ice frictional strength). The ice edge stress curl restricts flow under the ice in the same sense that Coriolis and the sloping bottom due in the simplified scenario we examined.

Wind driven experiments show that an along-shore upwelling-favorable wind at the seaward landfast ice edge leads to a lowering of the sea level at the ice edge. As a result, a cross-shore sea level slope develops between the coast and the ice edge with the sea level at the coast being higher than that at the ice edge. This slope drives an upwind, geostrophically balanced, under-ice flow, whose magnitude is largest near the ice edge and negligible at the coast. The upwind flow initially increases but then begins to decrease after several days (the timing differs with different values of the ice-ocean friction coefficient). After ten days, the upwind flow is weak (0.01 cm s^{-1} or less) and the sea level under the ice has decreased by >1.3 m (with a 7 m s^{-1} blowing continuously seaward of the ice edge). Cross-shore variations in the ice change the spin up and spin down time of the cycle whereas along-shore variations in the ice (along-shore variations in the ice-ocean friction coefficient and changes in ice coverage) can lead to along-shore sea level slopes that drive significant currents near the coast (>0.05 m s-1) after ten days.

Buoyancy forced experiments demonstrate that a landfast ice cover significantly alters the behavior of a buoyant plume from the ice free scenario. The plume (and the anti-cyclonic bulge at the river mouth) are spread significantly further offshore than the ice free plume (up to 9 times the local baroclinic deformation radius or 40 km versus <30 km for the ice free plume). The ice cover also widens the downstream coastal current compared to the ice free scenario. When the ice cover is narrow and the plume interacts with the ice edge; the change in surface stress across the ice edge leads to vertical circulation at the ice edge. The experiments demonstrate that Yankovsky and Chapman's 1997 scaling is not valid for an ice covered plume although it is not clear if an alternate scaling appropriate for under-ice plumes can be developed.

STUDY RESULTS:
This work represents the first comprehensive step towards developing a basic theoretical understanding of Arctic shelf circulation. The results have suggested explanations to features of observed currents underneath the Alaskan Beaufort landfast ice cover (Weingartner et al., 2009). The results also demonstrate why a landfast ice cover is important to under ice circulation and how profoundly different ice covered shelf circulation is from the shelf circulation under ice free and/or freely-drifting ice conditions. Study results suggest that more research should be conducted on the frictional coupling between the ice and the ocean, including more detailed knowledge of the ice-thickness distribution of the landfast ice zone. Also further theoretical work is recommended to develop more complete conceptual models describing circulation under a landfast ice cover.

STUDY PRODUCTS:

Kasper, J., Idealized models of Circulation in the Landfast Ice Zone, University of Alaska, PhD. Thesis, 200 pages.
Kasper, J. and T. Weingartner. The effect of landfast ice on a lateral inflow to a shelf sea. (in prep for submission to Continental Shelf Research)
Kasper, J. and T. Weingartner, Wind forced circulation under a landfast ice cover. (in prep for submission to Continental Shelf Research)
Kasper, J. and T. Weingartner. The spreading of a buoyant river plume beneath a landfast ice cover. (in prep for submission to Continental Shelf Research)
Weingartner, T., Kasper, J., 2010, Idealized process model studies of circulation in the landfast ice zone of the Alaskan Beaufort Sea, Coastal Marine Institute University of Alaska Annual Report, in review
Weingartner, T., Danielson, S., Kasper, J., Okkonen, S., CIRCULATION AND WATER PROPERTY VARIATIONS IN THE NEARSHORE ALASKAN BEAUFORT SEA (1999 – 2007), Final Report, MMS Contract M03PC00015.
Kasper, J, Weingartner, T., 2009, Modeling Circulation in the Landfast Ice Zone, Alaska Marine Science Symposium Abstract, page 210.
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Weingartner, T., Kasper, J., 2008, Idealized process model studies of circulation in the landfast ice zone of the Alaskan Beaufort Sea, Coastal Marine Institute University of Alaska Annual Report No. 15
Kasper, J., Weingartner, T., 2008, Modeling circulation in the landfast ice zone, Ocean Sciences Meeting Abstracts, page 201
Weingartner, T., Kasper, J., 2007, Idealized process model studies of circulation in the landfast ice zone of the Alaskan Beaufort Sea, Coastal Marine Institute University of Alaska Annual Report No. 14., pages 90-98
Kasper, J., Weingartner, T., Danielson, S., 2007, Modeling circulation in the landfast ice zone, Alaska Marine Science Symposium Abstract Book, page 29
Kasper, J., Weingartner, T., 2006, Modeling circulation in the landfast ice zone, Eos Trans. AGU, Fall Meet. Suppl., Abstract C33B-1269

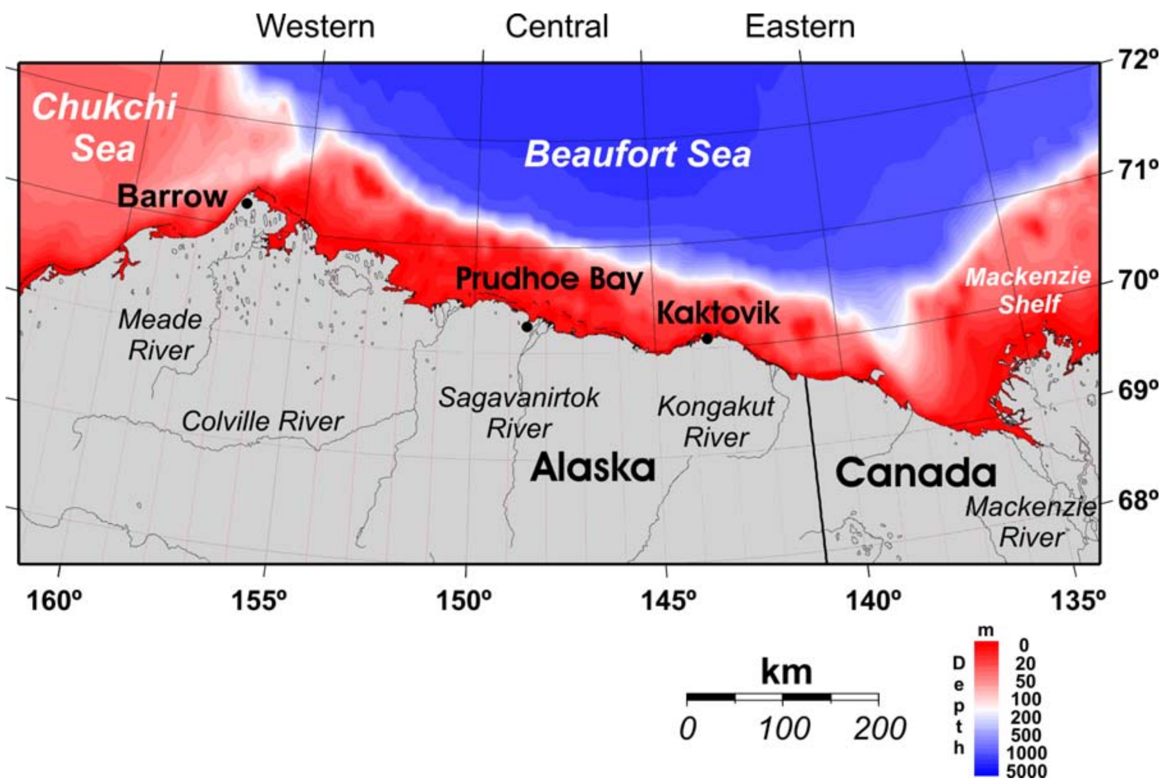
Presentations

"Modeling the Effects of a Landfast Ice Cover on Arctic Shelf Circulation", Oral Presentation, Ocean Sciences Meeting, February 2010
"Modeling the Effects of a Landfast Ice Cover on Arctic Shelf Circulation", Oral Presentation, Institute of Marine Science Seminar, February 2010
"Modeling circulation in the landfast ice zone", Poster Presentation, Gordon Research Conference of Coastal Ocean Circulation, June 2009
"Modeling the Effects of Wind Stress and Sea Ice on Arctic Coastal Circulation", Oral Presentation, UA Computational Science Symposium, February 2009
"Modeling Circulation in the Landfast Ice Zone", Poster, 2009 Alaska Marine Science Symposium
"Idealized Process Model Studies of Circulation in the Landfast Ice Zone of the Alaskan Beaufort Sea", Oral Presentation, CMI Annual Research Review, December 2008
"Modeling Circulation in the Landfast Ice Zone", Invited Speaker, Annual Information Transfer Meeting, Anchorage, October 2008
"Modeling Circulation in the Landfast Ice Zone", Invited Speaker, Annual UAF School of Fisheries and Ocean Sciences Advisory Committee Meeting, April 2008
"Modeling Circulation in the Landfast Ice Zone", Poster, 2008 Ocean Sciences Meeting
"Modeling Circulation in the Landfast Ice Zone", Oral Presentation, CMI Annual Research Review, February 2008
"Modeling Circulation in the Landfast Ice Zone", Institute of Marine Science Seminar, April 2007
"Modeling Circulation in the Landfast Ice Zone", Poster, 2007 Alaska Marine Science Symposium
"Modeling Circulation in the Landfast Ice Zone", Poster, 2006 American Geophysical Union Fall Meeting

References

Weingartner, T. J., S. L. Danielson, et al. (2009). Circulation and water property variations in the nearshore Alaskan Beaufort Sea (1999-2007). [Anchorage, Alaska], US Dept. of Interior, Minerals Management Service, Alaska Outer Continental Shelf Region: xi, 154 p.
Yankovsky, A. E. and D. C. Chapman (1997). "A Simple Theory for the Fate of Buoyant Coastal Discharges." Journal of Physical Oceanography 27(7): 1386-1401.

*P.I.'s affiliation may be different than that listed for Project Manager(s).



Map of the Alaska Beaufort Sea (ABS) showing major rivers and geographic names.