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STUDY TITLE: Mapping and Characterization of Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas.

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BACKGROUND:
Dramatic changes have occurred in the US Arctic where the loss of summertime sea ice extent has been most pronounced and operations associated with oil and gas exploration have been most active. Persistent openings, or leads, occur in the ice cover every year in the Chukchi and Beaufort Seas. These leads coincide with spring migration routes of bowhead whales and are also heavily used by spring migrating waterfowl. Since such openings also offer paths of least resistance for vessels transiting the ice cover, the spatial and temporal distribution of leads in the Chukchi and Beaufort Seas is a critical consideration for management of the region. Interaction between these leads in a moving ice field is also key to assessing the risk to local biota from spilled oil. Size, frequency, and latitudinal extent of these leads in the northeastern Chukchi and Beaufort Seas were the subject of a previous study (MMS 2005-068) characteristics of leads in the remainder of the Chukchi Sea are poorly known. The location of leads near the coast is related to the presence and extent of landfast ice, which represents a stable extension of the land and is used as platform for hunting and travel. The seaward limit of stable fast ice is also a key management consideration as it defines the limit of stationary ice relevant for on-ice operations and spill-response planning. It is also the extreme landward boundary of possible whale migration routes during the spring. Landfast ice is not well mapped using passive microwave satellite data, due to insufficient spatial resolution and problems of pixel contamination near coastlines. Although landfast ice is typically identified in operational products such as the National Ice Center ice charts, these charts are not ideal for long-term analysis due to their subjective and adaptive nature.

OBJECTIVES:
The goal of this project was to update the results of MMS OCS Study 2005-068 with current data and to extend the study area to include the Chukchi Sea coasts of Alaska and the Chukotka Peninsula of eastern Siberia. Note that the study area for MMS OCS Study 2005-068 included the Beaufort Sea coast from MacKenzie Bay to Point Barrow and then southwest along the Chukchi Sea coast to about Icy Cape (Figure 1). The specific objectives for the entire study area and time period are to:
1) Document and map the spatial distribution and extent of recurring leads, lead systems and polynyas along the Alaska coast of the Beaufort and Chukchi Seas and their extension into the Chukchi Sea, and develop terminology to describe and classify lead patterns;
2) Document and map the extent of the stable landfast ice along the Beaufort and Chukchi Sea coasts of Alaska and the northern coast of the Chukotka Peninsula in eastern Siberia;
3) Determine monthly mean, minimum and maximum landfast ice extents;
4) Develop and evaluate efficacy of methods to delineate landfast ice extent and deformation based on interferometric synthetic aperture radar data analysis;

5) Determine and grid monthly lead and polynya occurrence probabilities;
6) Summarize statistics of lead morphology and recurrence;
7) Interpret the lead patterns and polynyas as indicators of ice dynamics;
8) Interpret landfast ice variability in the context of atmospheric and oceanic forcing and bathymetric constraints.

DESCRIPTION:
We present results from an extensive analysis of remote sensing data spanning more than a decade. Using clear-sky Advanced Very High Resolution Radiometer (AVHRR), we have qualitatively identified a number of distinct recurring patterns of leads and quantified the number, size, mean areal fraction and probability of occurrence of openings in the ice cover. We also mapped landfast sea ice extent through analysis of consecutive mosaics of Radarsat synthetic aperture radar (SAR) data and determined mean occurrence dates of key stages within the landfast ice annual cycle on local and regional bases.
We also present results from an alternative approach to delineating landfast ice extent using L-band SAR data as means of extending the landfast ice record beyond April 2008 when a change in the Radarsat data sharing policy rendered imagery prohibitively expensive for such purposes.

SIGNIFICANT CONCLUSIONS:
1) Significant differences in the number and nature of recurring lead patterns between the Chukchi and Beaufort Seas can be explained through regional differences in coastal orientation, prevailing currents, storm tracks and ice thickness.
2) Landfast ice extent is controlled by the combination of coastal bathymetry, heat exchange with the atmosphere (and to a lesser extent atmospheric circulation) and ice-pack interaction, all of which vary regionally and locally within the study area.
3) A marked shift in ice behavior in the Beaufort Sea occurred around 2006 (after MMS OCS 2005-068), resulting in greater similarity in lead characteristics between the Chukchi and Beaufort Seas.
4) Certain sections of coastline exhibit trends toward later formation and earlier breakup of landfast ice, similar to data from the1970s. However, other sections exhibit opposite trends.
5) L-band SAR offers promise as a means of identifying landfast ice at regional scales. The robustness of the interferometric method used holds promise for automation of the technique and the potential for application at global scales.

STUDY RESULTS:
The analysis of lead distributions shows a distinct seasonal cycle in the lead fraction as well as lead size and number density. A key event in the seasonal cycle is the transition between the regime of distinct linear leads in winter and the ubiquitous appearance of patches of open water surrounding floes in spring (“spring ice”), typically occurring in late April or early May. Monthly maps of lead occurrence probability reflect the key processes controlling lead patterns, including flaw leads and polynyas resulting from seaward ice motion near coasts, advection of floes past grounded ice on Hanna and Herald Shoals, the appearance of arced leads that radiate from Point Barrow and arched lead structure that propagate north from Bering Strait under southward drift conditions. Approximately a dozen recurring patterns were characterized in the Beaufort Sea as part of MMS OCS Study 2005-068. In this study, we found such characterization more difficult for Chukchi Sea and describe a similar number of classes of lead pattern associated with recurring patterns of ice motion. Examination of lead statistics shows a marked contrast between the Chukchi and Beaufort Seas, with the former having significantly higher number and areal fraction of leads than the latter. This difference can be attributed to an overall thinner and more mobile ice pack in the Chukchi Sea than the Beaufort Sea, which results from differences in latitude and ocean heat transport and a coastline in the Chukchi Sea that promotes the creation of open water under almost directions of ice drift. However, our results also point to a dramatic change beginning in the early 2000s such that lead patterns in the Beaufort Sea have more closely resembled those in the Chukchi Sea in recent years. The extent and timing of landfast sea ice also differs between the two seas, with landfast ice in the Beaufort Sea being generally more extensive and longer lasting than that in Chukchi Sea. However, we find that local variability is of a similar magnitude to regional-scale differences and can be linked to specific coastal morphologies such as lagoons and headlands. In the Beaufort Sea, we find a relatively robust relationship between the location of the seaward landfast ice edge (SLIE) and bathymetry such that the 20 m isobath offers a reasonable approximation for the stable location of the

SLIE. However, in the Chukchi Sea, we find greater overall variability and no such isobath that can be used universally. Time series analysis reveals significant trends toward later formation and earlier breakup of landfast ice along certain sections of coast. This is in agreement with a comparison with data from the1970s. However, we also found other sections exhibiting opposite trends. In general, we find that the extent of landfast ice has remained relatively constant over time, but there are notable cases where landfast ice extent was anomalously low, such as in the Beaufort Sea following the pronounced loss of multiyear ice in the Arctic in 2006.

STUDY PRODUCTS:
Mahoney, A.R., H. Eicken, L.H. Shapiro, R. Gens, T. Heinrichs, F.J. Meyer, A. Graves Gaylord, 2012, Mapping and Characterization of Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Alaska Region, Anchorage, AK. OCS Study BOEM 2012-067. 179pp.

The following products can be accessed through BOEM, Alaska OCS or the Geophysical Institute, University of Alaska, Fairbanks: bibliographic database, catalogues of AVHRR imagery, RADARSAT SAR imagery, geodatabases of landfast ice, Geotiffs , grids and shapefiles of landfast ice and leads, summary statistics of lead data, monthly averages of landfast ice, metadata templates, monthly lead occurrence probability maps.

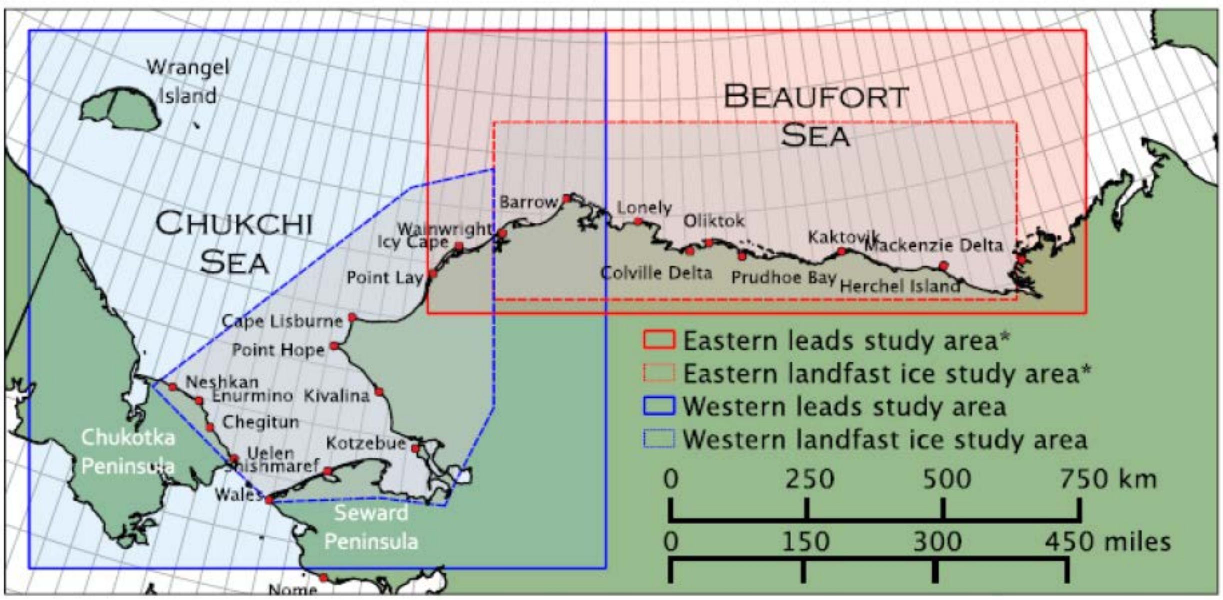

Figure 1: Study areas for the leads and landfast ice components of this study