The Russian–American Initiative for Land–Shelf Environments in the Arctic

Contributions to Arctic System Science

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The Russian–American Initiative for Land–Shelf Environments (RAISE) is unique among research program and project components supported by the National Science Foundation's (NSF) Arctic System Science Program (ARCSS). RAISE project implementation has been explicitly international, and the program is the only cooperative, bilateral research program supported by both NSF and its Russian counterpart agency, the Russian Foundation for Basic Research (RFBR).

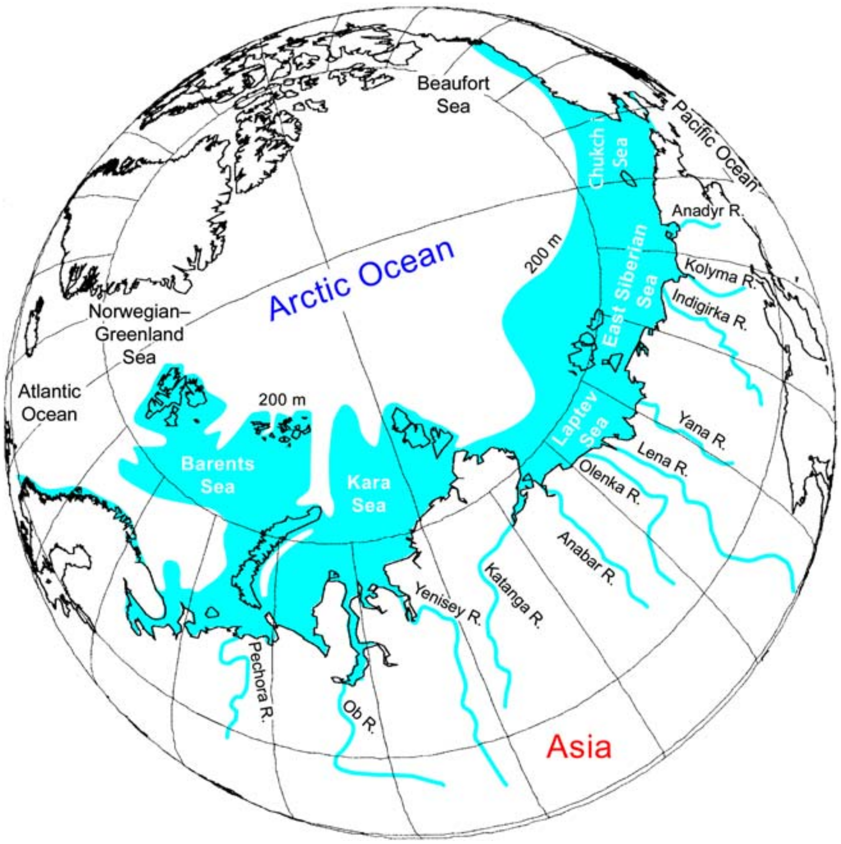
The goal of RAISE is to facilitate bilateral (U.S.–Russian) research at the land–sea margin in the Eurasian Arctic, focusing on the scientific challenges of environmental change in human and biological communities and related physical and chemical systems. The RAISE program has historically been one of the key ARCSS mechanisms for supporting global change research beyond the relatively small portion of the Arctic shared by the United States. A more general objective of RAISE specifically has been to facilitate cooperation between Russian and U.S. scientists that would improve knowledge of Arctic system science on both land and sea in the large portion of the Arctic that is in the Russian Federation.

The scientific justifications and bases for the RAISE umbrella of research priorities were identified by participants in three international workshops held in Columbus, Ohio; St. Petersburg, Russia; and Arlington, Virginia in 1995 and in annual follow-up meetings of RAISE investigators and the RAISE International Science Steering Committee over the past eight years. The results of these scientific deliberations are available from the RAISE web site (http://arctic.bio.utk.edu/RAISE/index.html) or from the RAISE project office at the Department of Ecology and Evolutionary Biology at the University of Tennessee.

Since the publication of the RAISE prospectus that resulted from these science planning efforts, a number of land- and sea-based, remotely sensed, or archived data recovery research projects involving both U.S. and Russian scientists have been initiated. Summaries of many of these projects, both Russian and U.S. based, are also available at http://arctic.bio.utk.edu/#raise, and a summary in written form has also been recently published.

Despite this progress, the scale of research supported through RAISE has been limited by the complexities of undertaking bilateral research in the Russian Federation. Changing political realities in both the United States and Russia, economic dislocations that have affected the abilities of Russian scientists to pursue their vocations, logistical challenges in the Russian Arctic, and the lack of high-level governmental agreements between the Russian and U.S. governments that would facilitate bilateral research have resulted in RAISE projects that are largely scientist-to-scientist in implementation. Although this orientation towards supporting individual projects has been effective, there have also been no large-scale multi-investigator projects such as Surface Heat Budget of the Arctic (SHEBA) and Shelf–Basin Interactions (SBI) that have been coordinated through the Ocean–Ice–Atmosphere Interactions (OAII) Management Office of ARCSS.

The lack of coordinated projects within RAISE may be ending. Many projects recently funded through the Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) are utilizing research priorities identified in the RAISE prospectus and involve coordinated teams of Russian and U.S. investigators studying runoff impacts from Eurasian rivers on the climate-linked thermohaline processes in the world ocean. Also, science planning is underway for a coordinated Land–Shelf Interactions (LSI) initiative that has a goal of providing a coordinated, interdisciplinary research opportunity in the Arctic that would focus on the coastal zone and would support land-, river-, and sea-based researchers who would take advantage of coordi-



these changes in the past. Within the past decade, RAISE researchers have contributed several key insights to our understanding of past Arctic climate and its relationship to biogeochemical processes at high latitudes and the processes that link with the world climate system.

One uncertainty in interglacial paleoclimatic reconstruction is the extent to which ice sheets were present at the time of the Last Glacial Maximum (LGM) in northeastern Siberia and their extent in general in the Northern Hemisphere. The presence or absence of such ice sheets geographically is important for validating atmospheric global circulation models during both glacial and interglacial periods, which depend on accurate sea-level reconstructions and accurate estimates of glacial ice volume. Knowledge of the extent of glacial ice is also important for evaluating global ice balance and the mechanisms for transitions between glacial and interglacial periods. RAISE-related research efforts in particular have been important for defining the limits of glaciation over a wide geographical region of the Russian Arctic.

Inferences for significant glacial ice volumes in the Wrangel Island and East Siberian Sea region at the time of the last glacial maximum have been directly tested during field studies by RAISE investigators on Wrangel Island. Studies using the cosmogenic radionuclides ^{10}Be and ^{26}Al, which provide a time history of atmospheric exposure, and field studies on the island that have documented the paucity of glacial geomorphological features (such as landforms, moraines, and glacial erratics) have led the RAISE investigators to conclude that Wrangel Island remained free of extensive glacial ice during the LGM. The lack of moisture caused by the continental climate on the emergent Bering Land Bridge is the most likely reason for limited ice in this part of the Arctic during the LGM.

Additional work on this project is documenting Pleistocene marine transgressions on Wrangel Island. The Tundrovayan Transgression (459,000–780,000 years ago) is represented by raised marine deposits and landforms that are 15–41 m above the current sea level and up to 18 km inland. Evidence of a high sea level between 64,000 and 73,000 years ago is preserved in deposits and landforms 4–7 m above the current sea level in the Krasny Flag valley on Wrangel Island. These deposits and landforms were mapped, dated, and described using amino acid geochronology, radiocarbon, optically stimulated

nated logistical capabilities that would otherwise be unavailable. This new research initiative also has a goal of transcending the traditional geomorphic boundaries separating marine and terrestrial lines of inquiry in Arctic system science. Development of the initiative and identification of key research priorities are being coordinated by the RAISE/LSI Project Office at the University of Tennessee.

Despite the relatively modest financial investment in the RAISE effort, the initiative has been effective in coordinating bilateral U.S.–Russian research of importance to understanding and predicting the impacts of global change in the Arctic. In the following discussion, research highlights from selected RAISE projects are outlined, with time scales of interest in the past and present, as well as predictive modeling for future environmental change.

RAISE Research Highlights

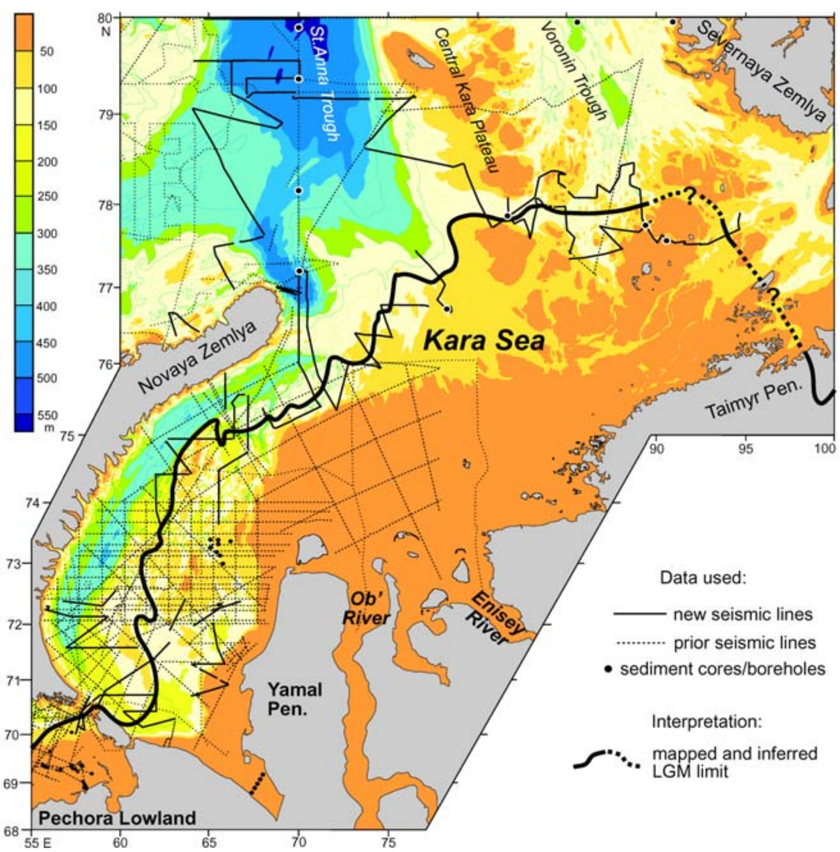
Paleoclimate

One of the key aspects for understanding the global environment impacts of environmental change in the Arctic is the scope and scale of luminescence, electron spin resonance, oxygen isotopes, micropaleontology, paleomagnetism, and soil grain sizes. The marine deposits reflect past sea levels and have not been uplifted. The presence of marine deposits that predate the LGM also indicates that neither Wrangel Island nor the East Siberian or Chukchi Seas experienced extensive glaciation over the last 64,000 years.

In a parallel RAISE-supported effort, the extent of Arctic ice sheets during the LGM is also being studied in the Kara and Barents Sea region using sediment coring and seismic profiling. The extent of glaciation here is an issue of intense debate, involving a question of whether the West Siberian rivers have been blocked by glaciers from discharging into the Arctic Ocean. Characterization of subbottom sediment structure and stratigraphy is providing initial supporting evidence that major Siberian river runoff was blocked or dammed on the Kara Sea shelf at the time of the LGM, followed by a rapid inundation of the continental shelf. Both of these events can be expected to have had a significant impact on climate. Glaciation limits and Holocene peat accumulation has also been studied on the Yamal Pensinula.

A separate, more recently funded project is investigating the glacial history of the Severnaya Zemlya Archipelago during the LGM and earlier glacial periods. This project closely complements the marine efforts in the adjacent Kara Sea, discussed above, and will help constrain the extent, volume, and timing of ice sheets in the northern Kara Sea and adjacent land areas. Preliminary stratigraphic and geomorphic data from a first field season on Severnaya Zemlya in the summer of 2002 provide evidence for three Late Quaternary glaciations on southern October Revolution Island. Significant isostatic depression associated with at least two of these glaciations caused subsequent deposition of marine sediments and the formation of raised beaches at altitudes up to approximately 130 m above current sea level, suggesting regional glaciation, not just expansion of local glaciers. Ice directional indicators (glaciotectonic structures, clast fabrics, and striations) associated with these two glaciations show southerly flow into the Kara Sea. Numerous samples were collected to constrain the age of the glaciation events, the oldest of which may predate the Last Interglacial (more than 130,000 years ago). As had been reported by prior investigators, the LGM glaciation is poorly expressed and may not have expanded much beyond the present ice limits. A second field season in 2003 is planned to better define the LGM limits, adding to the many RAISE-related research efforts that are delimiting glaciation over a wide geographical region of the Russian Arctic.

Map of the Kara Sea with reconstruction of the probable LGM ice sheet limit. Bathymetry is from navigational charts detailed using seismic reflection data.

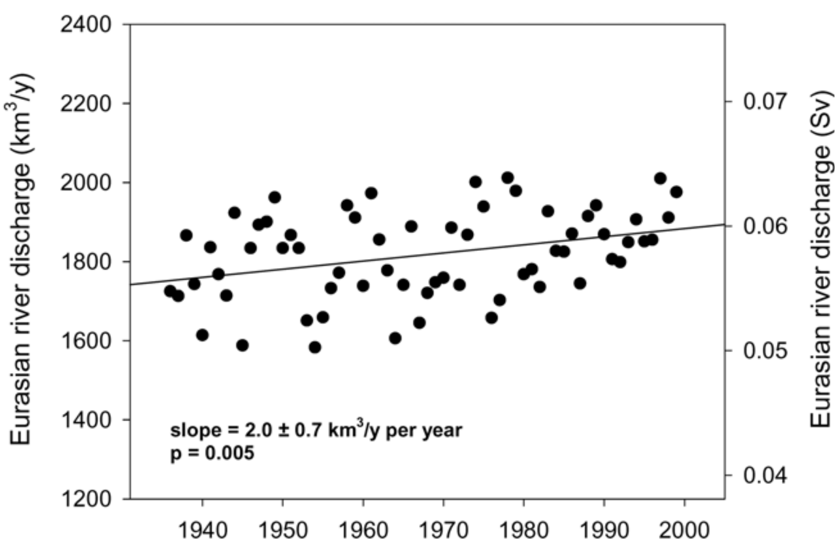


Following de-glaciation at the start of the Holocene, large amounts of carbon were synthesized and remain stored as peat in the West Siberian lowlands (WSL) in the Ob' and Yenisey River basins. U.S. and Russian investigators have been working together to reconstruct the history of this carbon sequestration using radiocarbon dating as well as geographic information systems and remote sensing tools. The WSL is the world's highest-latitude wetland, covering nearly two thirds of West Siberia. The carbon sequestered in the WSL has been conservatively estimated at more than 10% of the global carbon pool stored in soils. Much of this peat accumulation initiated over a wide range of latitudes and geographical area approximately 8,000–10,000 years ago. This timing of peat accumulation is consistent with studies on the Yamal Peninsula, where a prominent birch horizon is also present below peat that is approximately 9,000 to 10,000 years old. This vegetation change is consistent with a northward shift of the treeline of more than 200 km from the present limits, corresponding to a 2–4°C summer warming across northern Eurasia. Improved estimates of the WSL carbon pool and documentation of changes in drainage and carbon sequestration patterns are additional expected outcomes of this RAISE research project.

Contemporary and Historical Processes

Historical hydrographic records collected during the Soviet era are also being used in syntheses of runoff data. Recently reported results indicate that the average annual discharge of fresh water from the six largest Eurasian rivers to the Arctic Ocean increased by 7% from 1936 to 1999. The average annual rate of increase has been 2.0 ± 0.7 cubic kilometers per year. As a result the average annual discharge volume from these six rivers is currently about 128 cubic kilometers per year greater than it was when discharge monitoring began in the 1930s. This RAISE project has also correlated annual discharges with changes in the North Atlantic Oscillation and increases in global mean surface air temperatures. The observed large-scale change in freshwater influxes to the Arctic could ultimately have important implications for ocean circulation and climate. If the warming trend and correlated increase in runoff continue, the higher runoff fluxes into the North Atlantic and Arctic Oceans could affect ocean circulation and northern climate by reducing North Atlantic deep-water ventilation.

Related RAISE-supported research is evaluating historical runoff data quality, and more detailed studies are determining the highly variable nutrient fluxes associated with Arctic rivers, which in turn impact marine productivity. Fluvial sediment flux data from many of these rivers are also being synthesized to establish more accurate estimates of sediment fluxes. This is fundamentally important for understanding land–ocean linkages in the Arctic.



Combined annual discharge from the six largest Eurasian Arctic rivers for 1936 to 1999. [Reprinted with permission from Peterson et al. (2002) Science*, vol. 298, p. 2171, which gives details about the data sources. © 2002 American Association for the Advancement of Science.]*

Another RAISE-related research project that is being supported jointly by the RFBR and NSF is contributing additional linked insights on interannual seasonal variability of Russian river discharge over the past 50 years. In this case, NSF support is being provided indirectly through its grant that supports the International Arctic Research Center (IARC) at the University of Alaska Fairbanks. In this research project, which includes investigators from the Pacific Oceanological Institute in Vladivostok, historical records have been used to document a significant positive trend for winter discharge from the three largest Siberian rivers over the past several decades. In the last three decades the mean winter discharge (November–April) has increased by 13% for the Ob', 45% for the Yenisey, and 25% for the Lena Rivers compared with prior periods. The total annual Siberian runoff into the Arctic has increased only 4.5% since the early 1970s, so this finding indicates a partial redistribution of runoff from summer to winter since the end of the 1960s. This change in the seasonal patterns of Siberian rivers discharge may be related to a periodic atmospheric climatic shift observed in the early 1970s over northeastern Asia as air and soil temperatures increased during winter.

Another topic of importance identified within the RAISE prospectus is coastal erosion. It has become evident that coastal erosion in some Arctic marginal seas is at least as important a source of sediment fluxes as is river runoff. This topic is also being addressed by RAISE research projects through both coordinated and individual efforts. The Arctic Coastal Dynamics (ACD) program (http://www.awi-potsdam.de/www-pot/geo/acd.html) is an international, coordinated effort, supported in part and sanctioned through the International Arctic Science Committee (http://www.iasc.no), that provides a multidisciplinary, multinational forum for exchanging and synthesizing ideas, data, and information related to erosion and sediment transport. The ACD was recently designated as a regional project of the International Geosphere–Biosphere Programme's Land–Ocean Interactions in the Coastal Zone project. Many of the project elements were formulated at the NSF-funded RAISE workshop in Woods Hole in November 1999 and are being carried out under the auspices of the International Permafrost Association (IPA) through its working group on Coastal and Offshore Permafrost and its coastal erosion subgroup.

Arctic Coastal Dynamics is focused on the processes that occur along permafrost-affected coasts. Of particular note are the influences of ice and permafrost (massive terrestrial ground ice, subsea permafrost, and sea ice). Results and recommendations of the Woods Hole workshop included:

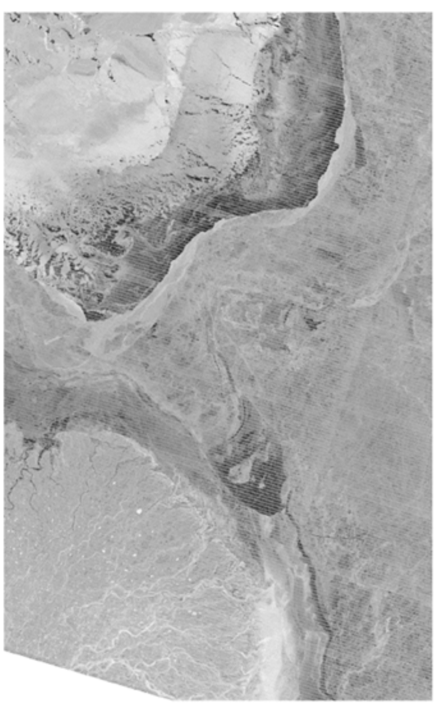
- Development of a metadata form for selecting and establishing key monitoring sites;
- Establishment of a consistent and generalized coastal classification scheme based on morphology and materials;
- Consensus on direct and indirect methodologies for estimating ground ice volumes and presentations of data on maps; and
- Preparation of a suite of standard tools and techniques for developing long-term coastal monitoring sites, including local community-based observations.

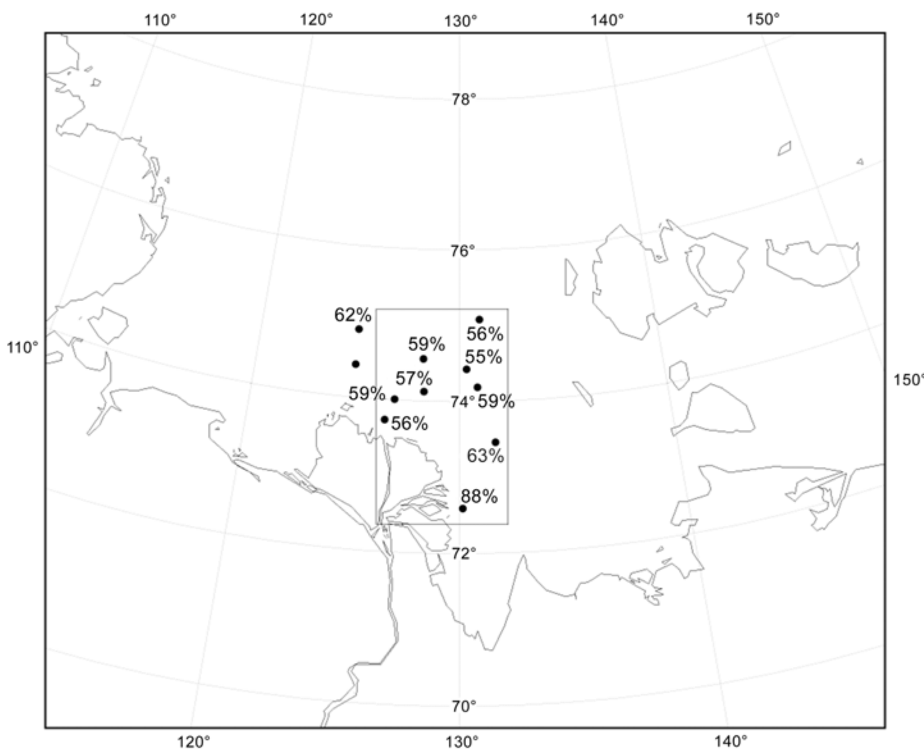
Additional workshops have been held subsequent to the original RAISE-supported workshop in Woods Hole, and the abstracts and results of these workshops are being published in *Berichte zur Polar-und Meeresforschung* (*Reports on Polar Research*). A five-year ACD Science and Implementation Plan guides the current international effort, and the program is also strongly supported by bilateral German–Russian cooperative agreements. The objectives are to improve our understanding of circumarctic coastal dynamics as a function of environmental forcing, coastal geology, cryology, and morphodynamic behavior. The science plan consists of two interrelated components:

- A series of coordinated, synthesis activities; and
- Proposed focused-research projects and long-term observations.

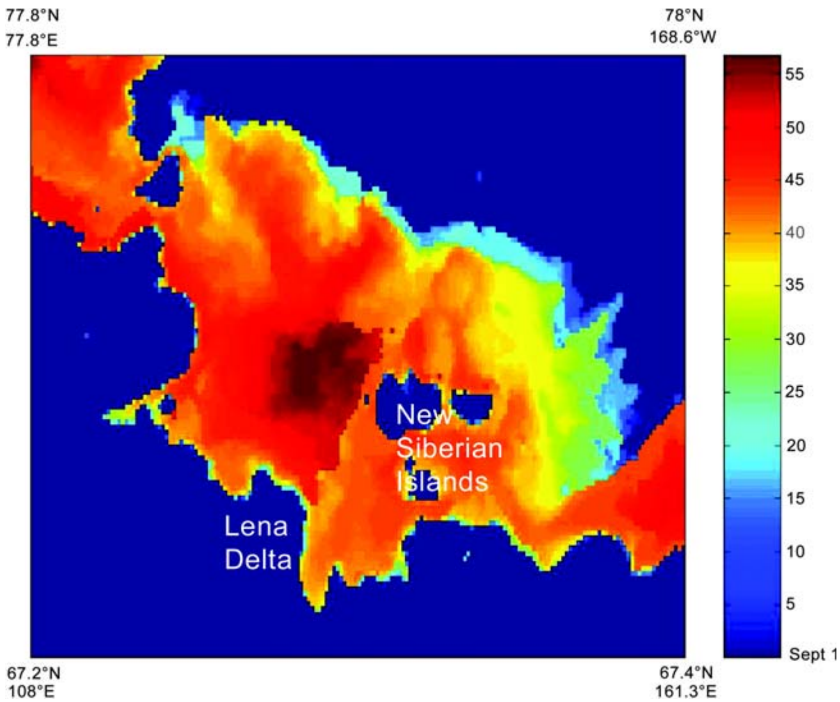
Specific scientific goals for ACD are to:

- Establish the rates and magnitudes of erosion and accumulation of Arctic coasts;
- Develop a network of long-term monitoring sites, including local community-based observational sites;
- Identify and undertake focused research on critical processes;
- Estimate the amounts of sediment and organic carbon derived from coastal erosion;
- Refine and apply an Arctic coastal classification (including ground ice, permafrost, geology etc.) in a digital form applicable to geographic information systems;
- Extract and utilize existing information on relevant environmental forcing parameters (for example, wind speed, sea level, fetch, and sea ice);

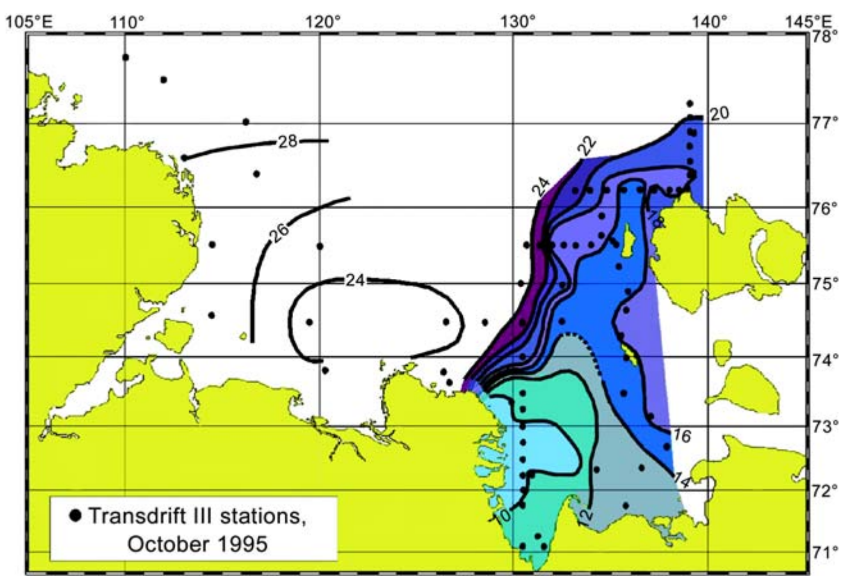




Contribution of riverine fresh water to the fast ice cover of the southern Laptev Sea. The Radarsat SAR scene (left) is coincident with the sampling program carried out in April and May 1999 (right). Locations of coring and hydrographic measurement sites are indicated along with the fraction of riverine fresh water incorporated into the fast ice cover as derived from a linear mixing model. The box on the right outlines the coverage of the SAR scene at the left.



Progression of fall freeze-up during October 1995 in the Laptev and western East Siberian Seas. The colors indicate the number of days of open water or temporary ice before final freeze-up at each location (starting September 1). Note the comparatively early onset of ice formation in waters surrounding the New Siberian Islands, bordering against a region in the west with open water persisting into late October. These patterns correspond closely to the distribution of the freshwater plume from the Lena River as shown in the panel below.



Surface salinity field of the Laptev Sea as measured during the Transdrift III ship expedition in October 1995. The numbers indicate salinity in practical salinity units (psu).

- Produce a series of thematic and derived maps (for example, coastal classification, ground ice, and sensitivity); and
- Develop empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts.

Parallel to these coordinated, synthesis activities, focused process studies in the international program have been recommended to address varied topics, including:

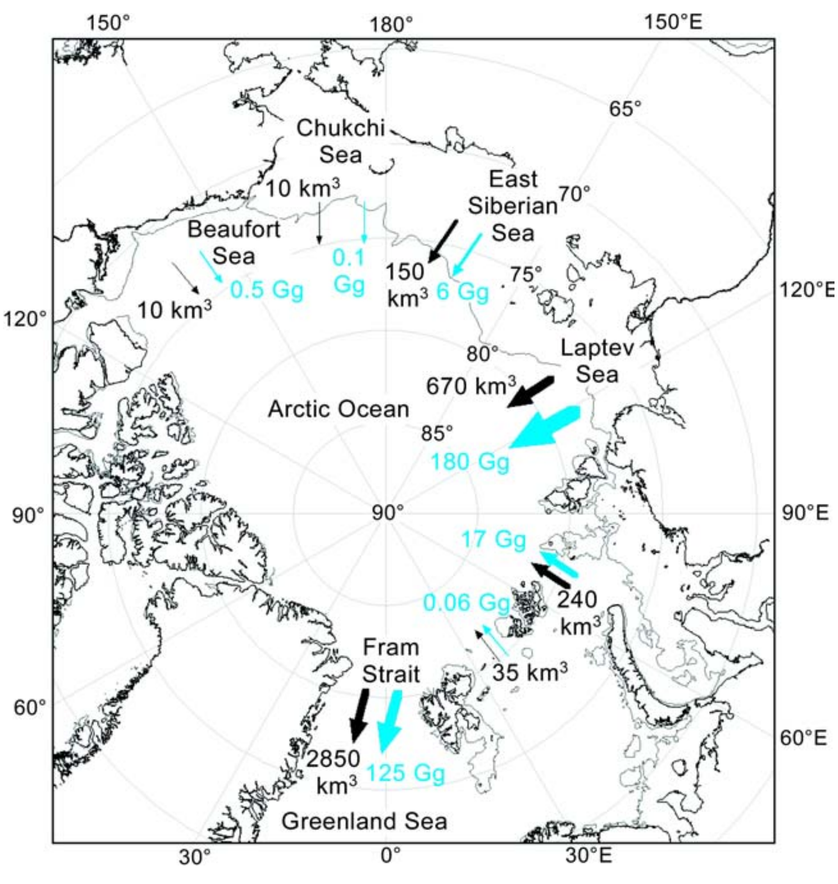
- Thaw consolidation of subsea permafrost and its role on coastal erosion;
- Weathering and erosion of bedrock;
- The fate of eroded organic carbon and sediments;
- Natural hazards and effects of human activities; and
- The role of sea ice processes in erosion and sediment transport and the influence of sea level on sediment dynamics.

Although not explicitly a part of the ACD international effort, several RAISE projects funded through NSF have addressed some of these recommended topics. For example, in one collaborative project conducted jointly with Russian scientists, the interannual variability in entrainment and transport of sediments by sea ice was investigated in the Siberian Arctic using field measurements, remote sensing, and numerical modeling (http://www.gi.alaska.edu/~eicken/he_proj/RAISE/intro. htm). In this research it was found that freshwater dispersal from the Lena and other major rivers contributes substantially (more than 60% in 1999) to the Laptev Sea fast ice cover, impacting entrainment of sediments and shelf hydrography. Overall sediment entrainment was controlled by the combination of river discharge and meteorological conditions that impact vertical mixing and lateral dispersion of low-salinity water over the shallowest portions of the shelf. While only a fraction of the sediment-laden ice is actually exported into the deeper basins, this fraction still accounts for a substantial portion of the basin-wide transport of particulates and particulate organic carbon.

Among the major accomplishments of this research was the demonstration that the combination of synthetic aperture radar (SAR) and visible- and infrared-range remote sensing can allow discrimination between the principal ice types in the coastal environment affected by substantial river runoff (freshwater ice, brackish ice, sea ice, bottom-fast ice). The combination of this comprehensive remote-sensing approach with water and ice sampling and measurements during the Russian–German Transdrift VI expedition was used to develop a first conceptual model of the transfer and interaction of freshwater and dissolved and particulate matter with the ice cover of the southern Laptev Sea and other marginal seas affected by strong freshwater input. Ice-core analyses (textural stratigraphy, salinity, and stable isotope measurements) in conjunction with sequential SAR images indicate distinct zones with a near-shore belt of freshwater and brackish ice with very low particulate and dissolved matter concentrations.

The distribution of bottom-fast ice over a broad platform extending out from the Lena River delta to the 2-m bathymetric contour is a recurring feature for the years studied with SAR data (1997–1999) and plays an important role in maintaining the location of the delta coastline. The stable isotope data clearly show that most of this near-coastal delta ice is composed of more than 80% river water. Remarkably, however, river water fractions of well above 50% were found several hundred kilometers away from the source throughout the southeastern Laptev Sea. On average, the fast ice cover in this region is made up of roughly 60% river discharge. Modeling and analysis of forcing data indicate that 1999 was not an extreme year, suggesting that a significant fraction, possibly as much as half of the total annual discharge from the Lena River, is eventually incorporated into the fast ice cover.

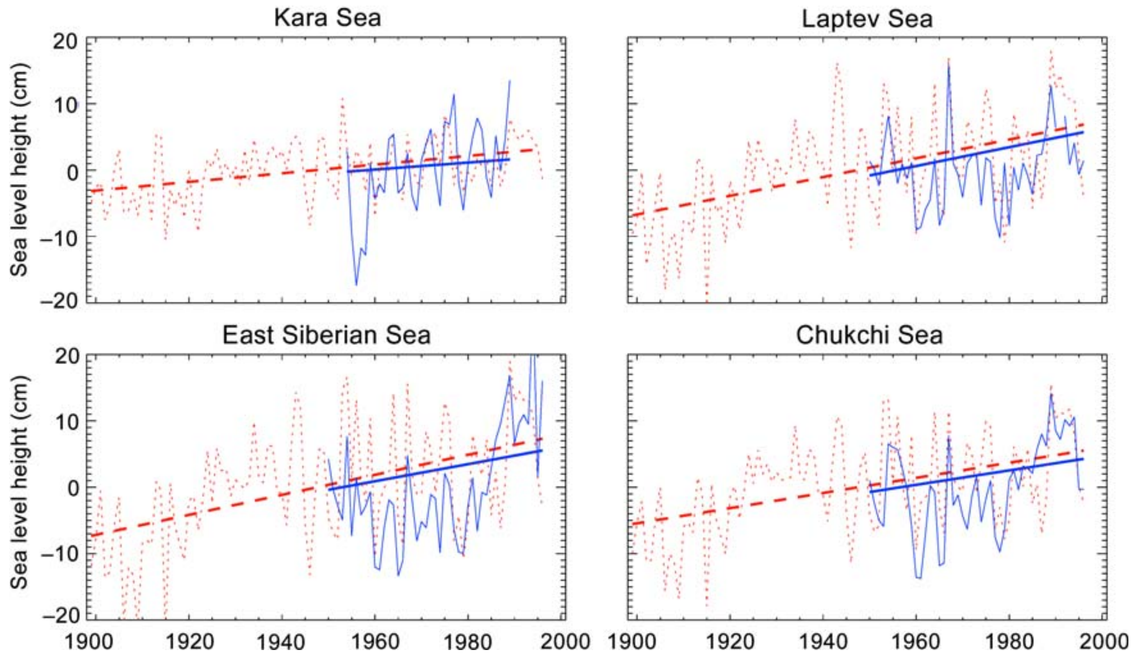
Annual export of first-year sea ice (black arrows and numbers) and terrigenous particulate organic carbon transported by sea ice (blue arrows and numbers).



This retention of fresh water on the shelf is significant not only for the entrainment of sediment into the sea ice cover but also for thermohaline mixing over the shelves and the adjacent basin. As further supported through the analysis of freeze-up data and the corresponding hydrography, the atmospheric circulation regime and the degree of wind mixing can determine to what extent the freshwater signal from river discharge is either released as a single pulse into the Arctic Ocean or retained and obliterated through incorporation and delayed release from the fast ice cover. At the same time, sea ice and hydrographic data analyzed as part of this study indicate that reduced mixing of fresh water and incorporation of freshened surface waters into the ice cover reduce the likelihood for sediment entrainment, underscoring the importance of a brief period during fall freeze-up for entrainment and export events.

This linkage between the atmospheric circulation regime, surface hydrography, and freeze-up patterns is evident in the entire time series and at least to some extent correlated with the larger-scale circulation patterns over the Arctic Ocean (that is, cyclonic vs. anticyclonic). Statistical and principal component analyses of these freeze-up fields indicate that ice formation is dominated by meridional gradients associated with the position of the summer ice edge and land–ocean processes. Derivation of the areal fraction of sediment-laden ice over the fast ice belt of the Laptev Sea provides some indication that these atmospheric and oceanic processes, as well as the ice freeze-up patterns, are also reflected in the distribution of sediment-laden ice. While the latter also strongly depends on water depth and synoptic sea level and (tidal) currents, maps of the interannual variability of sediment-laden ice distribution essentially confirm the hypothesis that it is the combination of river discharge and atmospheric parameters (wind direction and wind stress) that determines entrainment of sediments. A synthesis of the data collected as part of this study, as well as modeling work and review of the existing literature, indicates that the central Siberian shelf, mostly because of the combined influence of riverine and coastal input and ice production and

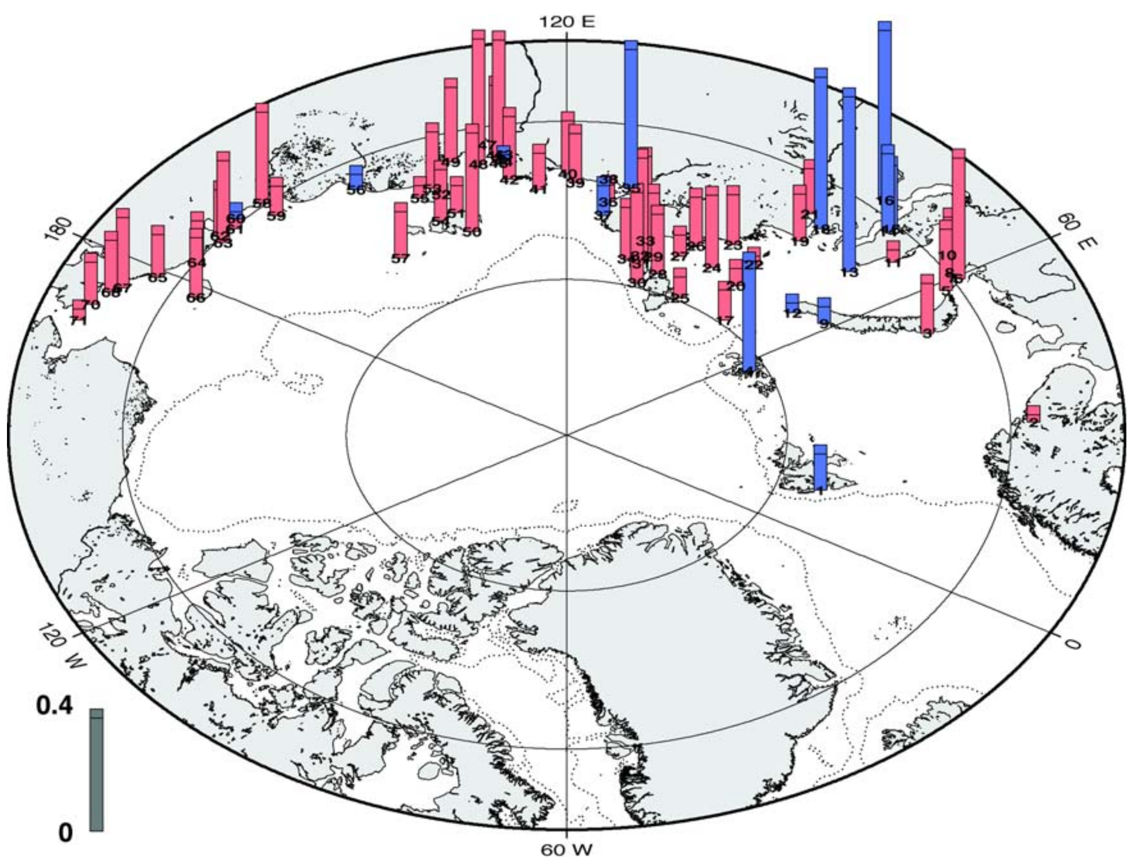
Sea level changes at some stations being used in a study of Arctic Ocean sea level change. In the graphs the solid lines show observations and the dotted lines show simulation results of a two-dimensional barotropic coupled ice–ocean model driven by monthly winds and atmospheric pressure gradients. The straight solid and dashed lines show linear trends for observed and simulated data, respectively.



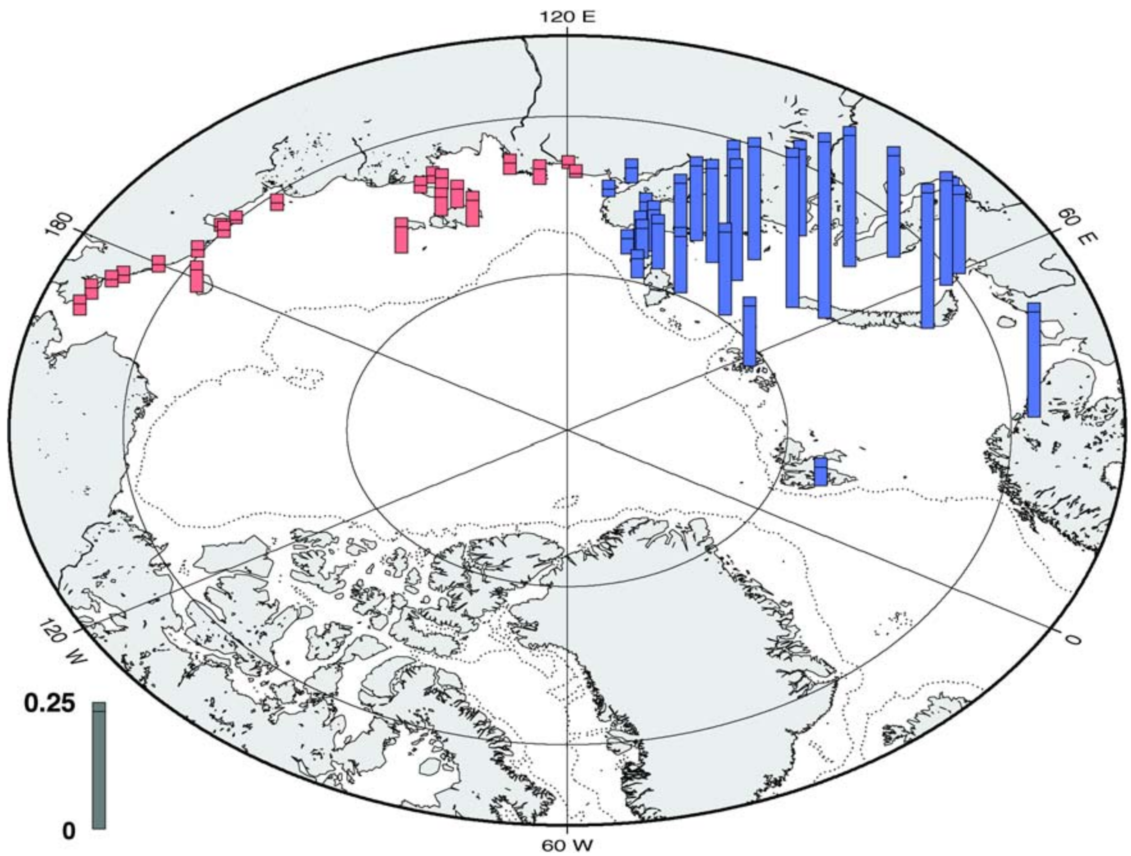
export, experiences some of the highest fluxes of particulate organic matter from the shelf into the basin observed in the Arctic.

Other research on this topic is being jointly supported through the IARC in Fairbanks and the RFBR, including studies of dissolved carbon dioxide in continental shelf waters that are establishing a link between Arctic coastal dynamic processes and the release of carbon dioxide from marine and terrestrial organic carbon.

Another aspect of coastal dynamics in the Arctic that is being addressed by a recently



Observed trends of sea level change (cm/year). Increases are in red; decreases are in blue.



Rate of sea level change caused by glacial isostatic adjustment (cm/year). The rebound of the earth surface following glacial retreat is greatest in the western portions of Eurasia that were glaciated during the Pleistocene. Increases are in red; decreases are in blue.

funded RAISE project is the significance of global warming and anticipated sea level rise impacts on shoreline erosion, sediment transport, navigation conditions, and oil and gas operations. This work is being based on analyses of existing but previously unavailable time series of sea level heights from Russian archives; atmospheric, cryospheric, terrestrial, and oceanic data sets; and the results of numerical modeling and data reconstruction. Goals include:

- Identifying links among sea level variability and atmospheric, hydrologic, cryospheric, and oceanic processes;
- Quantifying the regional and temporal variability of relevant processes in terms of sea level response; and
- Determining the relative importance of each factor influencing sea level change under global warming conditions.

There are two approaches being used:

- Investigation of the variability of sea level at seasonal and decadal time scales to estimate the secular sea level change and major factors responsible for this change; and
- Investigation of sea level variability at synoptic time scales (climatology of storm surges and their influence on coastal erosion).

Analyses of 50 years of monthly mean data from 57 tide gauges show that at the majority of stations the sea level has risen at a rate of approximately 1.4 mm/year. When the secular rates of change are corrected for the influence of glacial isostatic adjustment, the average rate of secular sea level rise is determined to be 2.3 mm/year, which is very close to the rate of 2.0 mm/year that has been determined from U.S. east coast data. Investigation of the decadal variability of sea level change using observational data and model results shows that the cumulative action of the wind-driven and thermohaline circulation may account for about 80% of sea level variance in the Arctic Ocean during 1950–1990. The most intriguing results were observed in the decade 1990–2000, when the rate of sea level rise was close to zero or became negative, contrary to the common expectation that the rate of sea level rise should increase uniformly as a consequence of global warming. This clearly warrants more detailed investigation.

Storm surge climatology of the Arctic marginal seas is being investigated based on observational data and two-dimensional coupled ice–ocean barotropic model results. The model was calibrated based on the strongest storm surges observed in the Kara, Laptev, East Siberian, Chukchi, and Beaufort Seas, and initial results show good reproducibility with observations. It is expected that the results can be used to aid current and future scenario risk assessments of coastal flooding and costal erosion rates.

Future Directions for RAISE

Individual project proposals for work under the RAISE research priorities continue to be accepted by the Office of Polar Programs of NSF on a rolling basis. In addition to the newly funded project on sea level rise described above, a recently initiated study is assessing the impacts of disturbances such as fire on trace gas exchange with the atmosphere in Siberia.

The project management office and international steering committee funded through RAISE also perform essential functions to facilitate the exchange of information between U.S. and Russian scientists and the Arctic research community as a whole, including providing information on Russian researchers, their contact coordinates, and the activities funded by the RFBR (see http://arctic.bio.utk.edu/RAISE/Russian_projects.html). In addition, the RAISE project office participates in the exchange of information with other countries having bilateral research programs in the Russian Arctic through the IASC's International Research Initiative in the Russian Arctic (ISIRA), Land–Ocean Interations in the Russian Arctic (LOIRA), and the ACD. The project office has also been involved in developing the new coordinated land–sea margins research project (LSI) in the Arctic, which is meant to better support interdisciplinary environmental change research in the Arctic coastal zone.

Although the scale of research funding for RAISE individual projects remains relatively small, the emphasis on bilateral research in the Russian Arctic has been crucial for providing a U.S. research presence in the large portion of the Arctic that is in the Russian Federation or its offshore waters. This presence and the accumulated experience of RAISE researchers should be of great value in the future as new Arctic hydrological research programs that include work with Russian investigators are initiated (Arctic-CHAMP) and as the potential for successful, coordinated near-shore research programs, such as LSI, are developed.

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