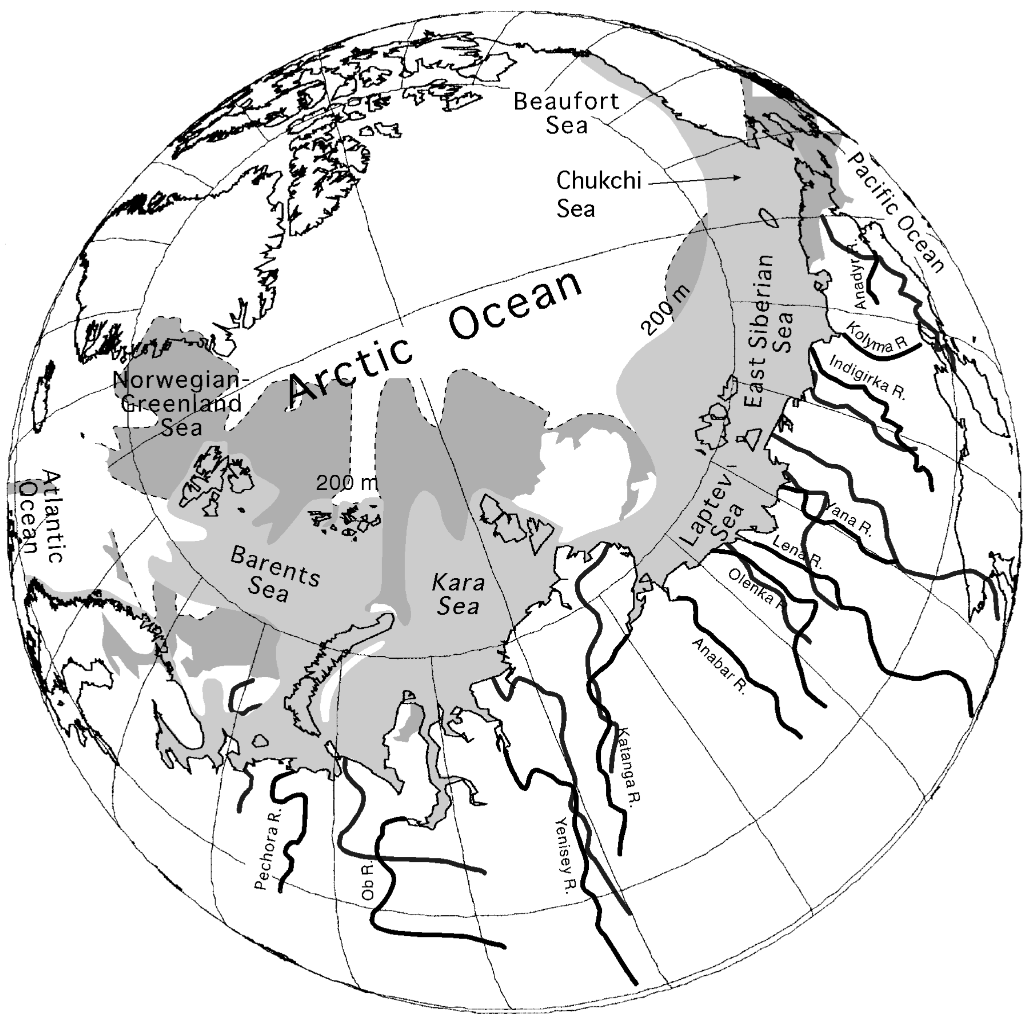
Prospectus

for the Russian-American Initiative on Shelf-Land Environments in the Arctic (RAISE)



Cover figure: Northern Eurasia “half hemisphere” showing major rivers and extensive shallow continental shelf.

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Steven L. Forman and G. Leonard Johnson, editors.

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Overview

The objective of RAISE (Russian-American Initiative on Shelf-Land Environments in the Arctic) is to facilitate collaborative research between Russian and American scientists in order to understand processes and events in terrestrial, shelf, and ocean environments in northern Eurasia. This program focuses on the dynamics of the coupled Arctic land-shelf system in response to external forcing and internal variability on a variety of temporal and spatial scales. Through the generation of data and analysis of the environmental response across the land-shelf system and through experimentation with models, new knowledge will be obtained on the role and response of the Eurasian arctic to global change. This initiative will yield improved understanding of the processes endemic to the Arctic shelf-land interface on decadal, centennial, and millennial timescales and, through modeling, provide insight on future environmental change.

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Foreword

The recently improved access to the vast polar seas and lands of northern Eurasia provides unparalleled opportunities to heighten understanding of Arctic environmental processes and events. However, there has been little coordination within the North American scientific community and with Russian and European colleagues in defining and executing research priorities in the Russian half-hemisphere of the Arctic. Thus, three workshops sponsored by the Arctic System Science Program of the National Science Foundation were convened in 1995 to prioritize research on land-shelf interactions in the Eurasian north. The initial workshop was held in Columbus, Ohio, in January, 1995 and attended by approximately forty biological, physical and social scientists from institutions in Russia, Latvia, the U.S., Canada, Germany, and Norway (Appendix 1). Workshop discourse concentrated on defining major research questions for four broad topics: 1) flux of sediment, water and ice; 2) biogeochemical cycling and ecosystem dynamics; 3) cryospheric interactions; and 4) human and biotic interactions. A follow-up workshop in Arlington, Virginia, in October, 1995 attended by about twenty scientists, provided additional definition on research strategies prior to a workshop in Russia. The final workshop, co-organized by Russian colleagues at the Arctic and Antarctic Research Institute, St. Petersburg, Russia, in November, 1995, was attended by over 100 Russian colleagues (Appendix 2) and gave a perspective on research priorities of former Soviet Union colleagues.

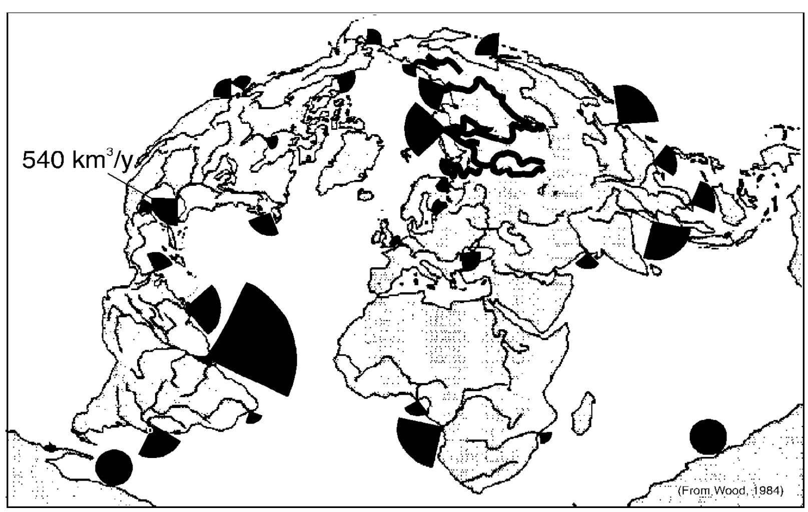
The reports of the three workshops serve as a nucleus of ideas in this program plan. The program was further refined and research priorities evaluated with input from a binational steering committee (Appendix 3), which met to address the program plan in December, 1996. The program plan in early draft stage (November 1996) and in a later form (April 1997) was circulated for comment to the steering committee and other interested members of the Arctic community in the USA and Russia. Drafts of the program plan were translated into Russian by colleagues at the Arctic and Antarctic Research Institute, St. Petersburg, to promote binational evaluation of this initiative. This program plan serves as a guide for American and Russian scientists to propose collaborative research to their respective agencies, the U.S. National Science Foundation and the Russia Foundation for Basic Research.

We would like to thank Wendy Warnick and the Arctic Research Consortium of the U.S. (ARCUS) for publishing this prospectus. Anne Sudkamp prepared the layout and design and Milo Sharp and Alison York provided technical assistance. Finally we would like to thank the National Science Foundation for financial support and the opportunity to participate in the development of this important initiative.

Steven L. Forman and G. Leonard Johnson, U.S. co-chairs
Igor Melnikov and Sergey Priamikov, Russian co-chairs

Introduction and Goals

The Eurasian arctic, spanning from the Atlantic to Pacific oceans and fringed by the Arctic Ocean, is a critical area for the flux of water and ice that modulate Earth's climate. A unique feature of the Eurasian arctic is its vast watershed, draining from the Himalaya Range to the arctic shore, that contributes freshwater to the shelf from three of the ten largest river systems on Earth. This river discharge flows into the world's largest area of contiguous continental shelf, an area equal to 25% of the global shelf. Much of this shelf is relatively shallow (<100 m deep), and underlain by permafrost and one consequence is that river water and constituents have significant impacts across the shelf and into adjacent oceans. New knowledge is needed of the interaction between present and past terrestrial, shelf, and ocean environments in northern Eurasian to understand the role and response of the Arctic to global change.



Freshwater inputs to the world ocean. Note the voluminous discharge from Eurasian rivers (after Carmack, 1990).

Global change may lead to major disturbances at the land-shelf interface, and several of these changes are unique to the Arctic. For example, accelerated warming and thawing of permafrost, on land and sub-sea, coupled with sea level rise creates massive coastline erosion and provides significant inputs of sediment and nutrients to the shelf. The degradation of permafrost, associated with sea level rise and warming, may lead also to the rapid release of large amounts of greenhouse gases from deposits within and beneath permafrost. Recent measurements place the planetary maximum of CO_2 and CH_4 over arctic/subarctic latitudes (Conway *et al.*, 1994) which may reflect processes endemic to the Arctic (Semiletov *et al.*, 1996; Zimov *et al.*, 1993).

Another important parameter is variability in sea ice formation and export, which is intrinsically linked to fresh water contributions from rivers and to large-scale patterns of ocean circulation. River-diluted sea waters originating on the shelf exert important control over the formation of North Atlantic deepwater which affects ventilation rate of the global ocean. Basic environmental data on distribution of sea ice, thermohaline structure of the oceans, course and discharge of rivers, and the configuration of past ice sheets are needed to constrain predictions of global sea level (Peltier and Tushingham, 1989), ice sheet history (Lambeck, 1995; Peltier, 1996), boundary conditions for general circulation models (Kutzbach *et al.*, 1994), and to evaluate migration and evolution of biota in the Northern Hemisphere (Vartanyan *et al.*, 1993).

The Russian-American Initiative Shelf-Land Environments in the Arctic (RAISE) is a program to facilitate collaborative research between Russian and American scientists to gain a better understanding of environmental and climate components endemic to the Arctic and those that modulate the Earth's climate. The program focuses on determining the sensitivity of and feedbacks within the Arctic land-shelf system that affect such important forcing factors such as atmospheric composition, thermohaline structure of the oceans, and global radiative balance. To achieve this goal we must understand the Arctic land-shelf system on a range of time scales, encompassing phenomena such as river discharge, permafrost dynamics, and continental ice sheets. The RAISE initiative stresses the importance of the hydrologic system in northern Eurasia in controlling glacier extent, sea-ice production and flux, and stratification and productivity of northern oceans. A better understanding of the Arctic land-shelf system will allow an evaluation of the sensitivity of arctic climate and environments to human activities in the context of natural variability.

There is a strong geographic focus, the Eurasian arctic, in this initiative because of its recent accessibility for collaborative Russian-American research and the dominance of continental-scale watersheds, broad lowlands, and epicontinental seas that have received insufficient attention for understanding the Arctic as a system. Fortunately, this focus on the Eurasian north can be used to arrange cost-effective logistics with European and Canadian partners, that serve to address many of the program elements. Research should focus on obtaining new insight on environmental processes and events in northern Eurasia, that integrated with knowledge of other Arctic areas, yields new understanding for arctic system science.

Goals

The RAISE elements are scientific themes for pursuing collaborative research between Russian and American scientists. This initiative recognizes the need to study and model both modern and past arctic systems in order to fully evaluate the causes and effects of natural environmental and climate variability. The RAISE program focuses on determining how the Arctic land-shelf system responds to and drives climate change in the present and recent past (20,000 years). Based on an improved understanding of processes and past responses to climate change, the program seeks to develop better predictive models for future change. To achieve this progress, new data sets are critically needed from northern Eurasia to refine climate, hydrologic and ice sheet models and to forward understanding of the processes, feedbacks, forms of climate and environmental variability and associated human-societal interactions.

The RAISE prospectus identifies three elements of highest priority for joint Russian-American research:

1. Effects and feedbacks of global change on the hydrology, biogeochemistry, ecosystem dynamics and biodiversity of the Eurasian land-shelf region.
2. Response and feedbacks of glaciers, sea ice, and permafrost to global change on decadal, centennial and millennial timescales.
3. Human impacts of global change, cultural adaptation and response to environmental change in the past 20,000 years.

Element 1: Effects and feedbacks of global change on the hydrology, biogeochemistry, ecosystem dynamics and biodiversity of the arctic land-shelf region

Shelf-Basin Interactions

The Eurasian shelf is closely coupled to the global ocean through exchange of shallow waters via the Bering Strait, the East Greenland Current, the Canadian Archipelago, and surface and deep-water exchange through Fram Strait (*e.g.*, Aagaard *et al.*, 1985; Aagaard *et al.*, 1991; Bånisch and Schlosser, 1995). Ventilation of the deep ocean occurs with cooling of North Atlantic waters in the Norwegian/Greenland Sea and with the lateral flux of dense, brine-enriched water from the Eurasian shelf into the Arctic Ocean (Aagaard *et al.*, 1985; Carmack, 1990). The spatial and temporal variability in the influx of North Atlantic waters is an important control on the extent of sea ice, poleward heat flux, and climatology of the Arctic. The advection of North Atlantic waters into the Arctic affects also the lateral exchange of water masses between the Arctic Ocean and the adjacent continental shelf. The inflow of Pacific waters through the Bering Strait, the outflow of intermediate and deep water from the Arctic Ocean, and the fresh water input from Siberian rivers can strongly influence the advection of Atlantic waters into northern seas (Bryan, 1986; Reason and Power, 1994). In turn, freshwater input from northern seas may slow or shut down North Atlantic deep water formation (Rahmstorf, 1994).

Approximately 10% of the upper 100 m of the Arctic Ocean consists of river water, essentially forming a diluted river plume originating on the continental shelf of northern Eurasia and extending across most of the central Arctic basin (*e.g.*, Østlund and Hut, 1984; Schlosser *et al.*, 1994). This river-dominated surface water

Key objectives

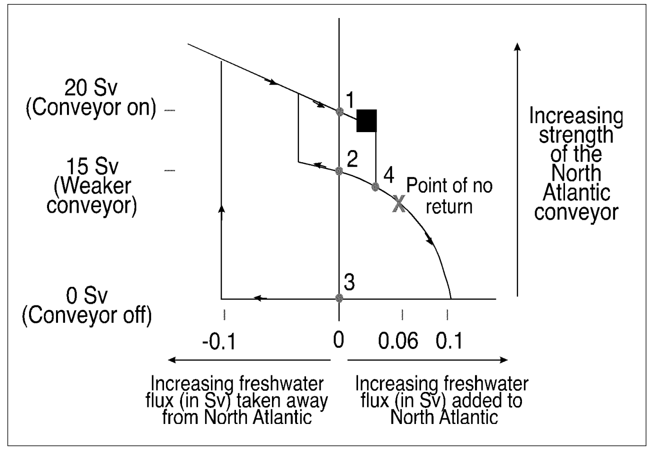
- Document historic variations in terrestrial water balance and freshwater discharge, including seasonal components of precipitation, evapotranspiration, and water resources from permafrost terrains. Develop biotic and geochemical proxies and watershed-to-shelf models to evaluate water balance variations on decadal to millennial timescales.
- Determine the effects of global change on river-mouth environments, such as deltas and estuaries, including transformation of suspended and dissolved constituents; changes in geomorphology and productivity, and location of river-marine frontal zones. Evaluate the variations in material transport to the shelf system from river input, coastal erosion, eolian fluxes and determine concomitant changes in biologic productivity.
- Evaluate changes in sea level on the Eurasian shelf, including eustatic and isostatic elements, and resulting bathymetric evolution over the past 20,000 years. Information is needed on the co-evolution of river discharge foci, coastal geometry, degradation of permafrost and changes in course of shelf currents with sea level variations.
- Determine the formation, extent and variability of sea-ice cover on annual to millennial scales. Inquiry should consider the entrainment, transport and fate of biological, geological, and chemical materials in sea ice.
- Evaluate the spatial and temporal variations in shelf-water transformations in Eurasia. Knowledge is needed of the routing of Atlantic and Pacific derived-waters and, mixing processes with freshwater, whether contributed through river discharge, precipitation or sea-ice melt. In turn, changes in the structure and distributions of biological communities affected by changing circulation should be evaluated.

has a characteristic salinity, alkalinity, carbonate, and oxygen-isotopic signature and has been traced as a sharp front extending through the Nansen Basin into Fram Strait (*e.g.*, Anderson *et al.*, 1989; Schlosser *et al.*, 1995a). Downward mixing of fresh water is inhibited by buoyancy of the water mass and the persistence of sea-ice cover, which reduces wind-induced surface turbulence and leads to a stable pycnocline. Approximately equal amounts of this river-enriched surface water flow through the Canadian Archipelago and Fram Strait (Schlosser *et al.*, 1995b). The distinct freshwater character of surface water and the relatively unaltered state of this input with transit across the Arctic basin is unique to the Arctic Ocean. Additional knowledge is needed on the fate of freshwater exported from the Eurasian shelf.

Some of the freshwater discharge from Siberian and North American rivers may be entrained in the Beaufort Gyre, where it can accumulate for years, forming a large freshwater-enriched lens (Aagaard and Carmack, 1989). Although little is known about the variability of the Beaufort Gyre, it may reverse direction of movement with a change in wind trajectories during the summer (McLaren *et al.*, 1987; Serreze *et al.*, 1989). On decadal timescales there may be even larger variability, with changes in the size and location of the gyre (*e.g.*, Kotchetov *et al.*, 1994). These changes in circulation may force relatively low salinity water “stored” in the Beaufort Gyre through channels in the Canadian Archipelago or Fram Strait to generate phenomena like the “great salinity anomaly” (Dickson *et al.*, 1988; Macdonald, 1996).

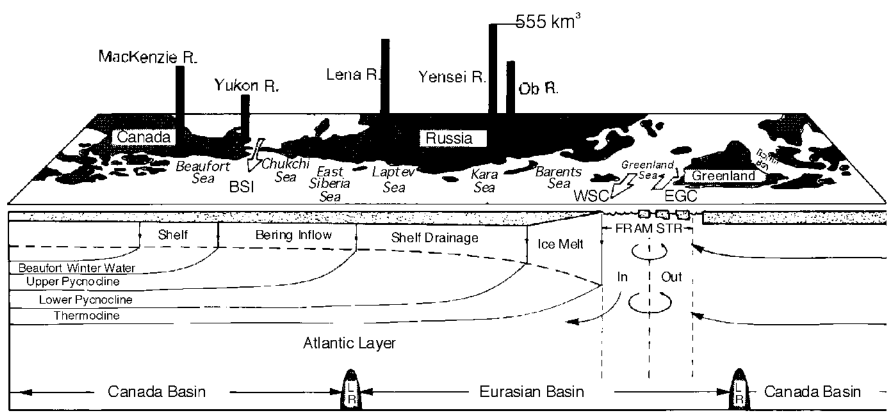
Land-Shelf Coupling

The epicontinental Barents, Kara, Laptev, East Siberian and Chukchi seas bordering northern Eurasia comprise 25% of the total continental shelf area of the world's oceans, and with the exception of the Barents Sea and part of the Kara Sea, lie principally at depths of <50 meters. These shallow shelf seas are a major hemispheric source of sea ice, intermediate and deep waters, and buoyant riverine waters. The shelves act as positive estuaries during the summer, with a net outflow of low density water at the surface. A reverse estuary outflow of dense, saline waters at depth is sustained during the winter, associated with sea ice formation (Midttun, 1985; Carmack, 1990). Penetration of warm surface Atlantic waters is limited to the southern Barents Sea (Loeng, 1991). However, transformed Atlantic water at intermediate depths (150 to 400 m) penetrates to an unknown extent into Eurasian shelf seas, importing heat and nutrients (Aagaard *et al.*, 1985).



Schematic diagram showing the behavior of the North Atlantic Conveyor as freshwater perturbation is slowly varied (Weaver, 1995).

The Eurasian continent is a major source of freshwater input into the Arctic Ocean. Approximately 70% (2960 km^3) of the riverine inflow is derived from three Eurasian rivers, the Ob, Lena and Yenisey (Carmack, 1990; Gordeev *et al.*, 1996). Much of this freshwater is exported as sea ice and comprises up to 10% of the surface waters of the Transpolar Drift Stream. This voluminous freshwater discharge reflects the large catchment area (13054 x 10^6 km^2) for rivers draining into the Kara, Laptev, and East Siberian seas. Catchments east of the Ural Mountains receive relatively low precipitation of 100 to 600 mm/yr (Gordeev *et al., 1996).* Thus, a small change in regional precipitation across continental Russia or impoundment of drainages could significantly alter the delivery of freshwater to northern seas. Siberian river systems exhibit large interannual variability ($\pm$ 50% of the mean) in discharge reflecting large-scale changes in synoptic elements (Antonov and Morozova, 1957). In turn,



Schematic drawing of circulation and stratification patterns associated with river inflow and halocline ventilation in the Arctic Ocean (modified from Carmack, 1990). Shown is river runoff scaled to average annual discharge of 555 km^3 of the Yenisei river.

the cross-shelf movement of water, nutrients and sediments are also influenced strongly by variations in river input.

The Eurasian shelf seas, except for the Barents Sea, are usually stratified during the summer, reflecting the high input of riverine water (*cf.* Aagaard and Carmack, 1989). The freshwater delivered to the shelf is generally deflected eastward along the coast by Coriolis forcing and confined shoreward by shallow bathymetry. In the Kara Sea, discharge from the Ob, Yenisey and Piasina rivers exits the sea both north and south of Severnaya Zemlya, flowing into the Laptev Sea, with partial entrainment by the Transpolar Drift Stream. Waters from the Khatanga, Lena and Yana rivers discharge into the Laptev Sea. This freshwater is transported also eastward, toward the New Siberian Islands, where much of the flow is diverted to the north and entrained into the Transpolar Drift Stream. The average residence time of water on the shelf is approximately three years (*e.g.*, Schlosser *et al.*, 1994; Pavlov and Pfirman, 1995). Water on the vast shelf area is usually mixed on a seasonal basis primarily by surface density flux associated with sea-ice formation. These dense waters flow laterally off the shelf and ventilate the Arctic Ocean, circumventing the strong upper ocean stratification (Aagaard and Carmack, 1994).

Rivers of the Eurasian north exhibit extreme seasonal variability, with up to 90% of discharge occurring in summer months and often confined beneath river or land-fast ice (Pfirman *et al.*, 1995). The spring breakup of river ice propagates downstream and can be highly turbulent with successive ice jams and overbank floods, enhancing channel erosion. River discharge frequently flows over the sea ice surface, extending far out onto the fast ice. Ponded freshwater on the ice surface can break through, forming a whirlpool that penetrates to the sea floor, resuspending sediments (and contaminants) for cross-shelf transport (Reimnitz *et al.*, 1994). There is a need to better understand the seasonal, annual, and decadal variability of river systems in northern Eurasia to elucidate the controlling processes on variations in sediment, nutrient, and contaminant delivery to the shelf (*e.g.*, Macdonald and Brewers, 1996).

Sea-Ice Dynamics

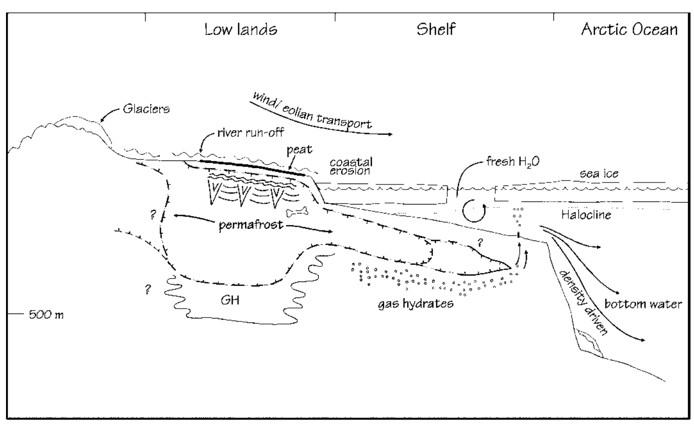
The broad shelves of the Kara, Laptev, East Siberian, and Chukchi seas are often covered by sea ice for 10+ months/year and are source areas for much of the sea ice in the Transpolar Drift Stream. Sea ice often forms in association with persistent polynyas over the continental shelf, demarking the limit between the land-fast and drifting sea ice. Heat transfer to the arctic atmosphere above the polynay can be one to two orders of magnitude greater than the surrounding sea ice (*e.g.*, Aagaard *et al.*, 1987). The size and duration of winter polynays have a significant effect on the heat budget of the Arctic. In turn, the seasonal variability in sea-ice coverage affects planetary albedo.

The movement of sea ice conveys large amounts of freshwater between shelf seas and to the Arctic and Atlantic oceans. There is a need to reconstruct changes in sea-ice flux and coverage on decadal and millennial time scales, particularly to areas in the Barents Sea and Fram Strait where there are interactions with warm North Atlantic surface waters (Rudels *et al.*, 1994; Pfirman *et al.*, 1989) or where shelf brines form (Midttun 1985; Quadfasel *et al.*, 1988). These water mass transformations have a profound effect on circulation, ventilation, and nutrient supply to northern oceans and shelf seas (Aagaard *et al.*, 1981; Aagaard and Carmack, 1989; Rudels *et al.*, 1994; Schlosser *et al.*, 1995a). Measurements and models should focus on elucidating the links between air temperature and river run off and variations sea-ice formation, conveyance and coverage in northern oceans and seas.

Numerous observations document the presence of dirty sea ice emanating from the arctic shelves (Nurnberg *et al.*, 1994 and references within). A small percentage of the sediment in sea ice is probably eolian. Although some of the sediment is probably derived from direct freezing of bottom sediments into sea ice, most of the particles may be incorporated into sea ice by super-cooling of wave suspended sediment in polynyas. The primary source for sediment released from sea ice into the Arctic Ocean and for contaminant-bearing particles released near Fram Strait is probably the Russian shelf (Pfirman *et al.*, 1989; Pfirman *et al.*, 1996).

Winter sea ice formation over the shallow shelves results in brine ejection which enhances density-driven deep-water flow into the Arctic Ocean (Midttun 1985; Quadfasel *et al.*, 1988). These deep waters are inferred to carry shelf-derived, productivity-limiting nutrients into the central Arctic Ocean. Density-driven circulation in the northern shelves is a poorly known parameter in global thermohaline circulation.

Beyond historic observations, little is known about changes in extent and thickness of sea ice and associated processes. Primary productivity is linked to sea ice coverage and thus, sediment records from the Eurasian shelf can provide new proxies of past sea-surface conditions (*e.g.*, Keigwin and Gorbarenko, 1991). The loci of sea-ice formation during the last glacial maximum possibly shifted, with a eustatically depressed sea level, to deeper water over the slope and/or basin of the Arctic Ocean, significantly reducing the availability of sediment and nutrients for entrainment in the ice. Sediment records from the Arctic Ocean during the last glacial maximum document a near cessation of sedimentation and dramatically reduced productivity, possibly reflecting greater sea-ice thickness and a less mobile pack (Stein *et al.*, 1994; Jones, 1994a). The deglacial rise in sea level progressively shifted sea-ice formation to the shelf, providing more sediment for entrainment (Pfirman *et al.*, 1989). Sea level rise also opened Bering Strait, allowing the flux of nutrient-rich waters into the Arctic Ocean and establish a new hemispheric max flux between Pacific and Atlantic waters



Schematic representation of land-shelf processes in the Eurasian north.

(Reason and Power, 1994). Elevated summer sea-surface temperatures inferred for Nordic seas during the early Holocene, *ca.* 9000 to 6000 yr. B.P. (Salvigsen *et al.*, 1992; Jones, 1994b), imply greater Atlantic water input, leading to significantly reduced sea-ice cover, probably less than the historic minima. Conversely, the southern limit of permanent sea ice may have extended onto the Eurasian shelf seas during the Little Ice Age or other neoglacial events.

Paleohydrologic Uncertainty

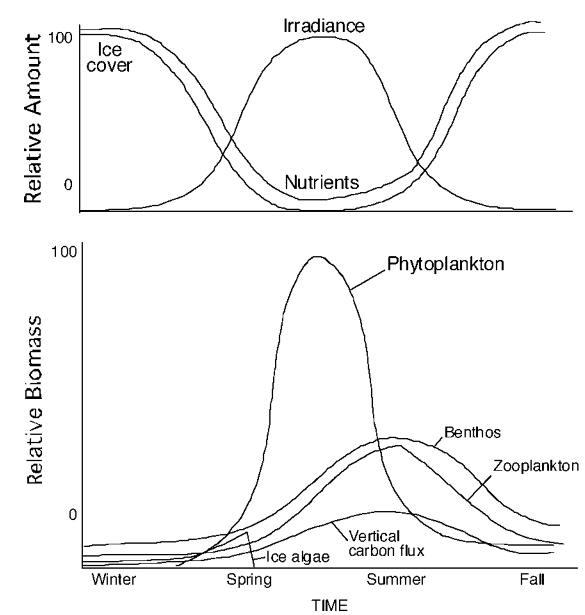
Dramatic changes in the hydrology of Eurasia occurred during the past 20,000 years. Discharge of many Eurasian rivers was probably reduced during the last glacial maximum, reflecting colder and dryer climates of the Siberian lowlands (Ukraintseva, 1993). Potentially, some drainages were dammed by advancing glaciers, diverting discharge from the Arctic Ocean to the Mediterranean Sea (Rudoy and Baker, 1993). Thus, during the last glacial maximum, freshwater discharge from Russian rivers into the Arctic Ocean may have been dramatically reduced, affecting sea-ice production, sediment and nutrient fluxes, halocline formation and thermohaline circulation. The deglacial rise in sea level and glacier retreat may have lead to a rapid increase in freshwater input into shelf seas, heralded by depleted ^{18}O values in planktonic foraminifera records from the eastern Arctic Ocean (Stein *et al.*, 1994). Full rise in sea level by the middle Holocene and degradation of permafrost may also be associated with maximum fresh water and nutrient inputs into northern oceans.

The shallow continental shelf seas of northern Eurasia are sensitive to changes in sea level, particularly during glacial/interglacial transitions. Epicontinental seas of northern Eurasia may not have existed during the last glacial maximum when ice sheets occupied most, if not all, of the Barents and Kara seas. Available evidence indicates that the Laptev, East Siberian, and Chukchi seas and adjacent lowlands were largely unglaciated, with large shelf areas exposed with a ~ 120 m fall in global sea-level (Fairbanks, 1989). Thus, many of the processes unique to the present shelf environment, such as sea-ice formation and concomitant brine ejection, may not have been fully operative during glacial periods. The Laptev, East Siberian and Chukchi seas are particularly sensitive to post-glacial sea level rise, with much of the shelf <100 m deep. Sea level rise may accelerate already rapid rates of coastal retreat of 1 to 10 m/year on many arctic coastlines and through this erosion provide organic matter and nutrients to support shelf productivity (Reimnitz *et al.*, 1994; S. Soloman, L. Timokov and E. Reimnitz, pers. comm., 1994).

Shelf Productivity and Nutrient Sources

Understanding changes in shelf productivity is critical for assessing terrestrial and marine sources, sinks, and transformations of carbon, nitrogen and release of greenhouse gases. The shallow shelf seas of Eurasia support a diverse ecosystem limited by the availability of light and nutrients (*e.g.*, Grebmeier *et al.*, 1995). Light, in turn, is modulated by sea-ice extent and thickness, by turbidity arising from runoff, by melting of sediment-laden sea ice, and by resuspension events.

The inflow of Pacific waters through the Bering Strait and terrestrial inputs from the Eurasian margin are sources of carbon and nutrients for shelf seas and the Arctic Ocean. Biogeochemical cycling in shelf sediments is both a significant source and sink for nutrients to and from the overlying waters (Codispoti *et al.*, 1991). Surface productivity often peaks with maximum nutrient availability at the sea-ice edge and in areas of river discharge. River input of nutrients are usually focussed in the near-shore zone and are areas if maximum productivity (Gordeev *et al.*, 1996). Areas of high primary productivity support benthic amphipod and bivalve communities that nourish marine mammals, fish stocks and bird populations which in turn are utilized by indigenous human populations.



Schematic representation of processes operative on the continental shelf seas of northern Eurasia (after Grebmeier et al.*, 1995).*

Summer river run-off from northern landscapes dominated by organic-rich soils and mires is probably an important source of organic carbon and nutrients for shelf seas. Rivers of Eurasia with catchment areas > 1000 km^2, such as the Ob, Lena, and Yenisey rivers, serve to focus continental runoff and nutrients into restricted estuaries and deltaic environments, which are areas of high summer productivity. Changes in the melt season, precipitation patterns and permafrost degradation in northern Eurasia could substantially alter the amount and seasonality for delivery of fresh water and associated nutrients into arctic seas.

The collapse of coastal cliffs containing ground ice is a pervasive phenomenon along northern seas, providing a less focused nutrient source than fluvial input. Coastal retreat of 1 to 10 m/year has been documented for select areas in the Kara and Laptev seas (Are, 1988). During periods of rapid sea level rise, rates of coastal retreat may have been substantially greater. Most cliff retreat occurs during the open water season delivering particulate and dissolved organic matter to the near-shore zone with productivity peaking.

The sequestering and dissemination of nutrients from continental shelves into the Arctic Ocean basin is linked to halocline formation and biologic activity. The highest productivity on the continental shelf is often where river and marine waters mix, supporting phytoplankton blooms. However, some of the dissolved nutrients delivered by rivers descend into the halocline and are advected into the central Arctic Ocean. These shelf-borne nutrients within the upper halocline can enhance Arctic Ocean productivity if mixed into the surface water by wind-driven mixing, ice-keel stirring, and shelf-edge breaking of internal waves.

The productivity of the Arctic Ocean and adjacent shelf seas is projected to increase with global warming. Future scenarios portray reduced sea-ice cover as increasing light availability and nutrient flux with enhanced wind mixing over shelf seas (Walsh, 1989). However, this assessment does not fully consider the effect of greater precipitation or changes in river discharge on shelf processes and nutrient availability. There is added importance in understanding the fate of particulate and dissolved matter from Eurasian rivers because some drainages may deliver substantial amounts of radionuclide, metal, and organochlorine constituents. There is uncertainty about the fate of these contaminants and their effects on shelf productivity, arctic biodiversity, and the sustainability of human populations.

Terrestrial Ecosystem Dynamics

Arctic ecosystems are particularly vulnerable to climate change due to the large carbon stocks in soils and the predominance of permafrost. Northern landscapes, though comprising 14% of the global land area, contain 25% of the global soil-carbon pool (Oechel and Vourlitis, 1994). The degradation of permafrost and the drying of soils may lead to new sources of greenhouse gases (Oechel *et al.*, 1993). About 9600 Gt of organic carbon (~ 13 times more than in the atmosphere) is estimated to be buried in the upper 100 m of permafrost and may be a future source of CH_4 and CO_2 particularly with expansion of thaw lakes (Semiletov, 1995). In turn, changes in landscape conditions will alter river runoff and nutrient availability on the shelf. There is a need to understand the links among terrestrial ecosystem change, variations in land-to-shelf fluxes, and the resultant effects on shelf biotic and physical processes. The development of integrated watershed-to-shelf models will assist in exploring the effects of land to sea fluxes on shelf stratification and productivity and also provide improved boundary conditions for global oceanographic and climate models.

The position of the northern treeline provides first-order paleoclimatic information because it is coincident with the mean July position of the atmospheric polar front (Krebs and Barry, 1970). Vegetation distribution in northern Eurasia, particularly the poleward extent of forests, may have a profound influence on radiative balance (Foley *et al.*, 1994). During the Holocene, the northern limit of forests may have varied by hundreds of kilometers, with changes in continentality, controlled by sea level, and variations in insolation and synoptic patterns (McDonald *et al.*, in review). Treeline movement across Eurasia should result in other landscape changes, such as changes in permafrost distribution, surface run-off and hydrologic response of rivers.

Research Priorities

1. Document changes in the northern Eurasian terrestrial ecosystems during the past 20,000 years, assess the concomitant response of the hydrologic system, and through modeling, evaluate the role of Arctic vegetation, soils, and permafrost in global change.
2. Understand the cycling of carbon in northern Eurasia for evaluation of CO_2 and CH_4 sources and sinks. Quantify particulate and dissolved organic matter and nutrient fluxes from rivers and from coastal erosion, and determine their fate in deltaic environments, estuaries and shelves.
3. Maintain and further develop data bases and models of river discharge, sediment load, and geochemistry for the Eurasian arctic watershed. Efforts should focus on accessing long time series (>25 years long) for rivers in the Eurasian north.
4. Develop and apply remote sensing tools to detect variations in river discharge, sea-ice conditions, coastal erosion, vegetation changes, fires and sea-level changes. Time-series images should be linked to field measurements to ascertain seasonal and yearly changes in the hydrologic system.
5. Obtain measurements and further develop models to assess how changes in river water, Atlantic water and Pacific water inputs affect water mass exchange between the Eurasian shelf and the Arctic Ocean.
6. Develop and evaluate proxy indicators (*e.g.*, Si, REE, $^{87}Sr/^{86}Sr$, ^{13}C, ^{18}O, and biomarkers) of riverine water, dissolved and particulate matter input into northern seas. Geochemical indices are also needed to fingerprint major fresh water sources from the Ob, Yenisey, Lena and other river systems.
7. Obtain sediment cores from estuarine and shelf environments to understand past changes in sediment flux, river discharge and chemistry, sea-ice cover and sea level. Use biotic and geochemical indices to quantify changes in water mass structure and circulation.
8. Determine the linkages between changes in watershed-to-shelf transport processes and primary productivity. Evaluate how changes in productivity will effect trophic structure and biodiversity in the Arctic.
9. Evaluate the spatial and temporal variability of biological productivity in estuary, delta and shelf environments. Inquiry should focus on the natural states of productivity and potential response with environmental contamination (*e.g.*, nutrient loading, heavy metals and organochlorines) and climate change.

Element 2: Response and feedbacks of glaciers, sea ice, and permafrost to global change on decadal, centennial, and millennial time scales.

Climate Change

Paleoclimatic records from the Greenland Ice Sheet and the deep North Atlantic Ocean divulge rapid fluctuations in the ocean and the atmosphere system within time scales of human generations, underscoring the sensitivity of the climate system beyond historic variability (*e.g.*, Taylor *et al.*, 1993). There is a clear need to define climate boundary conditions on longer timescales of the Holocene (10,000 yr. B.P.), the last deglaciation (20,000 yr. B.P.), and the last interglaciation (150,000 yr. B.P.) to understand better the response of the climate system to rapidly changing forcings. Questions remain regarding if and how the extreme climate variability identified on Greenland (GRIP, 1993; Taylor *et al.*, 1993) and in the North Atlantic (*e.g.*, Lehman and Keigwin, 1992) in the past 20,000 years propagated across the Arctic. New decadal to millennial scale records are needed from shelf and terrestrial environments in

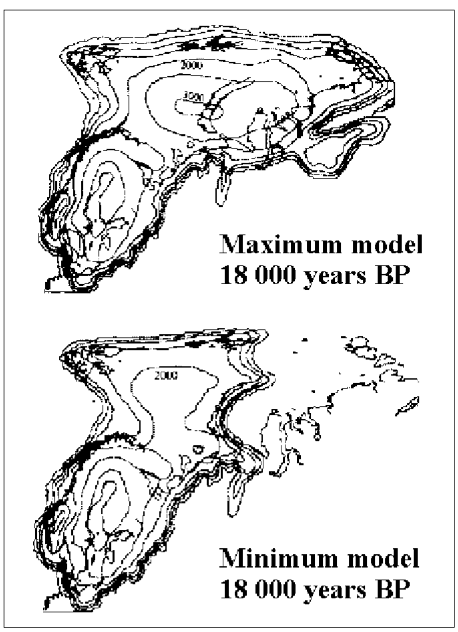
Key Objectives

- Determine how the dynamics of sea ice, glaciers and permafrost respond to and drive climate change on different time scales and, based on improved understanding of these processes, develop better predictive models for future change.
- Better define the extent, thickness, and timing of past ice sheets and associated changes in sea level and permafrost and further develop glaciological models to understand internal dynamics and climate sensitivity.
- Document the interactive response of riverine, shelf, and ocean systems to glaciation, sea level rise, and abrupt climate change during the past 20,000 years and provide improved boundary conditions for climate models.
- Document land-to-ocean response to extreme climate events during the Holocene.

northern Eurasia to better understand spatial and temporal variability of climate change.

The sensitivity of the earth system to climate change cannot be completely assessed without a better knowledge of the past extent of Arctic sea ice and land ice. Changes in sea ice and glacier coverage in the Arctic may result in fundamental shifts in the climate system by increasing global albedo and altering the planetary wave pattern (Kutzbach *et al.*, 1994; Ruddiman and Kutzbach, 1989). Sea ice, meltwater and iceberg discharge from the Arctic can lead to dramatic changes in the ventilation rate of the deep ocean, altering the global ocean heat budget, $C0_2$ uptake, and nutrient balance (Charles and Fairbanks 1992; Veum *et al.*, 1992). Our understanding of the climatic links between the cryosphere, atmosphere, and oceans is hampered because of an incomplete knowledge of the distribution of past ice sheets, sea ice and permafrost in the Arctic.

Large amplitude changes in the arctic climate are characteristic of glacial to interglacial transitions (Taylor *et al.*, 1993). There may have been an extreme climatic response during interglacial intervals (the Holocene and the last interglacial), particularly in northern Eurasia. For example, ocean temperatures warmed during the Holocene, reducing sea-ice cover to allow the migration of Atlantic and Pacific biota into arctic shelf seas (Salvigsen *et al.*, 1992; Polyak, pers. comm, 1995). There is a wealth of potential sediment archives from shelf, land, and lacustrine environments in northern Eurasia that offer new records on how the Arctic responded to extreme climate events during interglaciations.



Maximum and minimum ice sheet models for northwest Eurasia for the last glaciation (from Lambeck, 1995).

Glaciation of the Eurasian Shelf

One of the largest uncertainties in ice-volume changes during the late Quaternary is the areal and vertical extent of ice sheets over the extensive shallow shelves bordering northern Eurasia. Glacial-maximum ice sheet reconstructions range from nearly complete glacier coverage of northern Eurasia by a contiguous marine-based ice sheet (*e.g.*, Grosswald, 1993; Peltier, 1996) to individual ice sheets/caps centered on the arctic archipelagos and advancing onto the adjacent shelf (*e.g.*, Velichko, and Nechayev, 1984; Siegert and Dowdeswell, 1995). The discrepancy between reconstructions is equivalent to the volume of two Greenland ice sheets.

Equally uncertain is whether these ice sheets blocked major rivers, such as the Ob and Yenisey, creating sub-continental scale proglacial lake systems that drained through the Mediterranean Sea (*e.g.*, Arkhipov *et al.*, 1995; Tveranger *et al.*, 1995). These lakes would provide an atmospheric moisture source proximal to the ice sheet. Iceberg calving may have occurred when proglacial lake basins attained depths of 100's m. The presence of sizable bodies of water adjacent to ice sheet termini may lead to rapid glacier response resulting in mega-floods (*e.g.*, Rudoy and Baker, 1993), extensive deformational flow at the bed (*e.g.*, Boulton, 1996) or surging.

The damming of Eurasian rivers by Pleistocene ice sheets would alter the hemispheric hydrologic cycle by diverting freshwater from the Arctic Ocean to the Mediterranean Sea through a series of spillways across Eurasia (Rudoy and Baker, 1993). An important implication of this discrepancy is that ice sheet extent and height parameters and surface hydrologic parameters for the latest generation of general circulation models may be in error and offer an unrealistic paleoclimate assessment.

The distribution of glaciers and sea ice has had significant impact on human adaptations in Arctic regions. The growth of ice sheets both blocked and, through sea level lowering, facilitated the movement of humans and biota across the Arctic into lower latitudes. The extent and seasonality of sea-ice coverage has controlled the movement of marine mammals and the development of indigenous fisheries, critical resources for human survival.

Equally unresolved are the climatic conditions conducive for inception and disintegration of ice sheets and glaciers in northern Eurasia. An important observation is the apparent difference in magnitude of Late Weichselian and older glaciations across Eurasia. Large marine-based ice sheets may have been confined to the Barents and Kara seas. In contrast, glaciation of the eastern arctic was more restrictive, characterized by ice cap and valley glacier expansion, with vast shelf areas of the Laptev, East Siberian, and Chukchi seas exposed.

Knowledge of the timing and volume changes of ice sheets over the continental shelves of Russia between 15,000 and 10,000 yr. B.P. are insufficient to understand the links between the episodic rise in global sea level, potentially related to iceberg discharge events of Laurentide and Fennoscandinavian ice sheets to the demise of northern Eurasian glaciers (Broecker *et al.*, 1992). Marine margins of shelf-based ice sheets, at least in the Barents Sea, are particularly susceptible to sea-level rise, with outlets terminating in the >500 m deep troughs feeding into the Arctic Ocean. The balance between glacial isostasy and global eustasy during the Holocene is poorly known for many continental shelves in the Eurasian north (Forman *et al.*, 1995), which is necessary to evaluate the spatial and temporal variations of coastal erosion and present stability of subsea permafrost.

Permafrost Dynamics

Drilling in the eastern Siberian lowlands reveals permafrost extending to >500 m depth. Temperature profiles through the permafrost provide integrated temperature histories on time scales of decades to millennia (*e.g.*, Lachenbruch and Marshall; 1986; Osterkamp *et al.*, 1994; Osterkamp and Romanovski, 1996). Areas of higher geothermal heat flux, particularly associated with tectonic plate margins or zones of recent faulting along the Laptev Sea coast results in decreased permafrost thickness and heightened instability with future changes (Imaev *et al.*, 1994). Massive ground ice of various origins (*e.g.*, segregation, intrusive, or glacial) is often

Permafrost exposed along 5 to 7 m high coastal cliffs on Bolshoy Yahovsky Island, Laptev Sea, Russia (photo: I.P. Semiletov).

enclosed by ice-bonded marine and glacial sediments in west Siberia, while syngenetic ice wedges are more common east of the Taimyr Peninsula.

The "Yedoma Formation" is a common near-surface, permafrost-dominated deposit in eastern Eurasia that attains thicknesses of 50 to 60 m. This ice-rich (up to 80-90%) substratum contains organic, fluvial, lacustrine, and eolian sediments deposited between >100,000 yr. B.P. and 10,000 yr. B.P. (*e.g.*, Popov, 1983; Konishchev, 1983; Kaplina and Lozhkin, 1985). Within the frozen sediment is a rich archive of past environmental conditions recorded in the physical structure (*e.g.*, crystal size and structure) and chemical signature (*e.g.*, oxygen and hydrogen isotopes) of the ice, and by superbly preserved flora and fauna (Sher, 1997), and viable microorganisms (Gilichinsky *et al.*, 1995).

Subsea permafrost occurs widely in the Laptev, East-Siberian, and Chukchi seas, extending to depths of 130 m and probably formed with lower eustatic sea levels during the past 150,000 years (*e.g.*, Baranov 1960, 1965; Fartyshev 1983; Soloviev and Ginsburg, 1989). Large areas of the shelf, beyond ice-sheet limits, were subaerially exposed during the last glaciation and into the Holocene. The exposure of continental shelf during the last glacial cycle promoted permafrost expansion with syn-deposition of eolian and colluvial "Yedoma" sediments. The emerged shelf hosted a treeless arctic grassland, which supported herds of mammoths and other cold-climate mammals (Vereschchagin and Baryshnikov, 1982; Sher; 1997).

Permafrost occurs sporadically beneath the Barents and Kara seas, often as massive ice bodies (Melnikov and Spesivtsev, 1995). This off-shore permafrost reflects subaerial exposure during eustatic lowering of sea level or freezing and dislocations beneath an ice sheet (Romanovskii, 1993; Astakhov *et al.*, 1996). Coastal exposures along the Kara Sea reveal ground ice of various origins, with the deepest ice exhibiting large scale deformational structures, a relict of glacier ice, and reflecting the movements of an ice sheet in the past 100,000 years (Astakhov and Isayeva, 1988; Astakhov *et al.*, 1996).

The shallow continental shelf of northern Eurasia developed with an approximately 120 m rise in postglacial sea level starting prior to *ca.* 15,000 years ago. The maximum rate of coastal retreat probably occurred between 12,000 and 7,000 years ago, when global sea level rose approximately 75 m (Fairbanks, 1989). The rapid rise in sea level and relatively cold sea-surface temperatures led to the wide-spread preservation of submerged permafrost across the northern Eurasian shelf, which is in thermal disequilibrium with the overlying waters (Neizvestnov and Semenov, 1973). Beneath off- and on-shore permafrost are gas hydrate concentrations, trapped by laterally continuous bodies of permafrost (*e.g.*, Kvenvolden, 1988; Soloviev and Ginsburg, 1989). Melting of sub-sea permafrost will lead to development of the lateral discontinuities in the permafrost layer (open taliks) and provide conduits for the release of greenhouse gases to the atmosphere, if not assimilated by bacteria (Soloviev and Ginsburg, 1989; Osterkamp and Fei, 1993). On land, the expansion of thaw lakes and general degradation of permafrost may lead also to open talik conditions and an increase in greenhouse gas emissions.

Degradation of permafrost, indicated by thermokarst development, commenced sometime in the late Pleistocene to early Holocene, reflecting greater summer precipitation and/or warmer air temperatures. Thermokarst expansion during the early Holocene accelerated the formation of thaw lakes, alass valleys, and the expansion of peat bogs. These changes in permafrost dynamics and rapid expansion of shelf seas are coincident with a major environmental shift in the Eurasian north, heralded by the demise of steppe-tundra, extinction of mammals, and the onset of the northern movement of treeline (Velichko, and Nechayev, 1984: Sher, 1997; McDonald *et al.*, in review). Landscape-scale changes in permafrost may have increased subsurface and surface water flow, accelerating stream-bank erosion of frozen sediments; rising sea level may have lead to a similar response in coastal areas. The flux of fresh water to the shelf may have increased with permafrost deterioration, heightening the potential for sea-ice formation. Recent modeling indicates that the landscape response to future projected warming and sea-level rise may be similar in magnitude to widespread thermokarst expansion during the early Holocene (Anisimov and Nelson, 1996).

Degradation of permafrost (thermokarst) on Bykovsky Peninsula, Laptev Sea, Russia (photo: I.P. Semiletov).

Research Priorities

1. Gather evidence to evaluate the spatial and temporal variations in ice sheet and glacier coverage over the Kara, Laptev, and East Siberian seas and adjacent terrestrial areas through marine and terrestrial geologic studies. Integrate new ice sheet reconstructions with global ice sheet and climate models to evaluate feedbacks.
2. Determine variations in shelf geometry, loci of river discharge, and coastal circulation and erosion. Knowledge is needed of the spatial and temporal limits of glacial-isostatic compensation and eustatic sea-level oscillations for lowlands, islands, and shelf seas.
3. Evaluate the many terrestrial interglacial sites in the Eurasian north to ascertain synchroneity of records and magnitude of environmental response. Application of multiple geochronologic methods (^{14}C, amino acid racemization, ESR and luminescence dating and other isotopic methods) is needed to constrain the age of biotic and geochemical proxies to evaluate the nature of interglacial conditions.
4. Sedimentary time series spanning the past 20,000 years are needed to evaluate the nature of abrupt climate change in northern Eurasia. A priority is the retrieval of annual to millennial scale sedimentary records from shelf basins, troughs, or lakes that reflect changes in climate, glaciers, permafrost conditions and sea ice cover. AMS ^{14}C resources are needed to constrain the time-series of climate proxies.
5. Determine present and past changes (20,000 years) in the distribution of subsea and terrestrial permafrost, open and closed taliks and gas hydrate concentrations for land and shelf. Measure CH_4 and CO_2 flux from shelf, lake, and tundra areas and develop hydrologic-vegetation models to further evaluate spatial and temporal variations in trace gas balance. Evaluate Arctic contributions of greenhouse gases associated with permafrost degradation for the past, present and future.
6. Monitor changes and evaluate the role of permafrost degradation and active layer variations on vegetation composition, run-off, sediment delivery to the shelf, and coastal erosion.
7. Evaluate the large scale geothermal controls on permafrost distribution, type, and thickness. Relate permafrost state to underlying tectonic elements and identify areas that are most susceptible to future perturbation because of heightened geothermal flux.

Element 3: Human impacts of global change, cultural adaptation, and response to environmental change in the Eurasian Arctic for the past 20,000 years.

Adaptive Responses to Global Change

Human studies, past and present, are an effective venue for integrating natural, physical, and biological components of the Arctic system through analyses of environmental records, settlement patterns, and modern adaptations. The holarctic occurrence of historic and prehistoric archives provides a unique capacity to evaluate human-environmental interactions. Arctic systems can be investigated through records of human-environmental interactions over time scales from the present to beyond 50,000 years ago. The pattern of human adaption can be assessed from a variety of scales, ranging from an individual valley to an integrated watershed.

Paleoenvironmental and archaeological data from prehistoric sites provide needed understanding about how humans adapt to changes in the arctic ecosystems with global change. As a case-in-point, only in the Arctic have human hunting societies endured to the present; and only here have ice-age fauna (*e.g.*, mammoths on Wrangel Island; Vartanyan *et al.*, 1994) persisted later than anywhere else on Earth. The identification of bird, fish, and mammal remains within archaeological sites and extra-site information from

Key Objectives

- Determine what environmental changes and/or cultural adaptations faciliated human colonization and movements in the Eurasian north and migration to the Americas.
- Assess how indigenous populations altered and adapted to resource availability (*e.g.*, fisheries) with climate change in the past 20,000 years.
- Evaluate the range of adaptive strategies of arctic populations to global change, and through modeling evaluate the feedbacks within the Arctic and Earth systems.

pollen, wood-remains, phytoliths, and landscape associations (paleoshorelines, terraces, etc.) provide complimentary data sets for detailed reconstruction of past ecosystems, important boundary conditions for the next generation of climate models (Foley *et al.*, 1994). These integrated data sets are necessary to evaluate the effects of climate and environmental change on human and non-human systems. There is an urgent need to recover paleoenvironmental and archaeological data due to the rapid pace of coastal and riverine erosion, modern development, and the loss of native knowledge. Finally, such studies have significant relevance to the present and future lives of arctic residents.

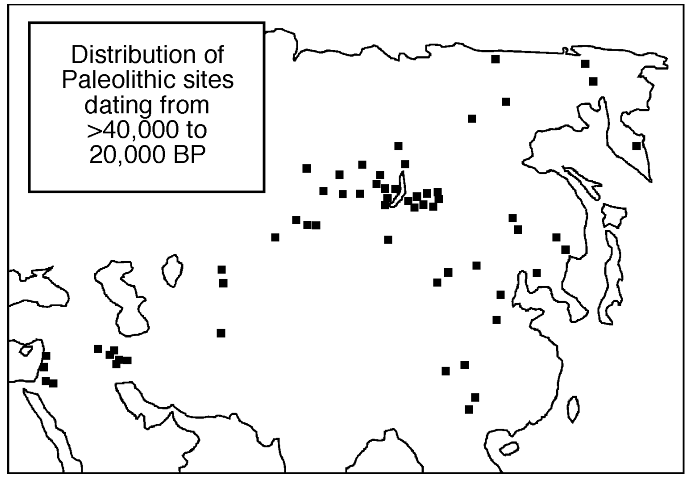
A heightened understanding of environmental and cultural change in northern Eurasian is critical to assess past and present human adaptations and population patterns in the Arctic and lower latitudes. There is a rich history of human habitation in the Eurasian arctic spanning much of the late Quaternary. The watersheds and continental shelf seas of northern Eurasia provide a variety of natural resources for sustenance of past and future human populations. Environmental and climate changes, particularly in the past 20,000 years, have had significant impacts on human, animal, and plant populations inhabiting northern Eurasia. This region was mostly ice-free during the late Quaternary, serving as a refugium for ice-age biota in the Holocene, and a staging area for human dispersal into the Americas.

New cultural adaptations emerged during the latest period of rapid environmental and climate change, the transition from the Pleistocene to the Holocene *ca.* 14,000 yr. B.P. to 8,000 yr. B.P. Resource utilization shifted from a dominance of terrestrial mammal hunting to a greater exploitation of marine and riverine stocks. A reduction in sea-ice extent during the early Holocene allowed humans to occupy high arctic islands, such as Zhokhov Island at 77° N within the present limit of permanent pack ice (Makeyev *et al.*, 1993). Extended open water conditions facilitated the development of sea mammal hunting adaptations, enhancing the mobility of paleopopulations. The early Holocene expansion of whitefish and salmon stocks into arctic seas with increased river run-off and extended open water conditions provided new food sources for paleopopulations. Inferred climate cooling in the late Holocene, after 5000 yr. B.P., may have reduced marine and riverine food stocks, potentially leading to the out migration of paleopopulations from the Arctic. Cultural adaptations in the last few millennia, such as whaling and reindeer pastoralism, provide new opportunities for the sustenance of arctic populations.

Northern Eurasia: A Gateway for Human Expansion

The Bering Strait is recognized as a key migratory pathway of human populations and other biota, particularly during global low sea-level stands (*e.g.*, Hopkins, 1967; Hopkins *et al.*, 1982). Many critical cultural changes appear to have occurred first in the Eurasian north and spread later to North America. Outstanding questions on the timing and pathways of human migrations to the Americas, concomitant environmental/climatic controls and technological transfer cannot be addressed without a deeper understanding of Eurasian arctic cultural tradition. Therefore, greater knowledge of paleoenvironments and paleopopulations in northern Eurasia is essential for deciphering the climatic and/or cultural causation, routes, and timing of human migration across Beringia to North America.

The high arctic islands and coastal plains of the Laptev and East Siberian Seas have preserved unique records for studying early human occupations. The study of cultural adaptations over the past 20,000 years hold the greatest potential for advancing our knowledge of human-environmental interactions in the Eurasian north and to the early human entries to the North American continent. There are abundant archaeological sites that span from the late Pleistocene into the Holocene for which more valuable cultural information could be secured with modest reexcavations and additional radiocarbon control. Unlike Beringia, there is abundant evidence in the Russian arctic for occupation sites >20,000 years old. These sites offer an important perspective on the adaptation of people and biota to full glacial climate and earlier “warm” periods. The Diring Site, adjacent to the Lena River at 62° N, is of particular importance because this site provides insights on paleolithic human migration and adaptation in a subarctic environment (Waters *et al.*, 1997).



(modified from T. Goebel, pers. comm.)

Preservation of Environmental Knowledge and Lifeways of Local People

The local populations of northern Russia possess valuable knowledge of a variety of arctic phenomena such as weather extremes, sea-ice and permafrost conditions, coastal and river erosion rates, plant distributions, and game, fish and sea-mammal migration cycles. The intimate understanding of the environment held by indigenous people in North America has been acknowledged through various documentation programs. Similar recognition and new science partnerships are needed for Russian indigenous populations. There is concern that invaluable traditional perspective on arctic environments and lifeways will be lost through general cultural assimilation, passing of knowledgeable elders, and abandonment of native languages and subsistence activities by younger generations. Special efforts are needed to document native environmental and cultural wisdom, and to facilitate the integration of this information into scientific assessments.

Information on traditional subsistence provides important perspectives on past and future cultural changes in the Arctic. A case in point is the continuity of reindeer pastoralism for at least the past millennium in northern Eurasia and the

Research Priorities

1. Initiate new surveys to identify the distribution, history and paleoecological relations of early human occupations along the shores of the Laptev and East Siberian seas and high arctic islands. Undertake comparative regional studies (Lena River vs Indigirka River) of “key zones” as staging points for Asian entry into the New World.
2. Expand the radiocarbon and paleoecological database in order to build a continuous record of human settlement in the eastern Russian arctic.
3. Identify and catalogue Russian historical information and archival sources on environmental /human change and develop a fully accessible data base via a web site. This effort should include the gathering and preservation of traditional ecological knowledge.
4. Integrate historical and archaeological information into landscape/ecosystem models to gain a better understanding of how humans and their cultures responded to Pleistocene-Holocene environmental change and resource availability. Evaluate cultural processes and strategies for responding to future environmental/climate change.

possible resurgence of this lifeway in Russia with recent political changes (Krupnik, 1993). Beyond the need for ethnographic information, there is intrinsic value in facilitating the preservation and continuity of native lifeways in the Russian arctic. Many indigenous populations have survived centralized government control of the former Soviet Union, but their traditional lifeways are currently threatened by economic pressures and pollution. Hence, data on traditional responses to past environmental and cultural change may be crucial to reinvigorating local lifeways in the Eurasian north.

Framework

Data Management

A wealth of new data on a variety of present and past arctic phenomenon will be generated by RAISE research. RAISE will provide further access to a vast archive of arctic environmental data in Russia. This initiative will utilize existing data management structures at the Arctic System Science Data Coordination Center at the Snow and Ice Data Center (NSIDC) by ARCSS. For example, new river discharge data can be incorporated into preexisting Russian River Data Set at NSIDC; paleoclimatic time series will be integrated into PALE and CAPE data bases to achieve the greatest utility for the modeling community. Data submission will follow ARCSS guidelines and the American P.I. will be responsible for quality control of the submitted data.

Logistical Needs

Often a limitation for proposing and undertaking research in the Arctic is the challenge of arranging logistics or securing an appropriate sampling platform. Fortunately, collaborating with Russian investigators should provide access to established logistic systems, sampling platforms and field stations in northern Eurasia. Much of the Russian arctic is inhabited and is served by a rail system and local airports. A standard mode of transportation to more remote sites within the Russian Arctic is by voluminous “MI-8” helicopter from bases in Dickson, Vorkuta or other arctic towns. Field stations (*e.g.*, Marre-Sale on Yamal) in the Russian arctic, though fewer in number post-glasnost, can accommodate larger research groups (>5) and multiple year monitoring programs.

Studies on the broad sea-ice-dominated continental shelf of northern Eurasia requires ice-strengthened or ice-breaker class vessels. In the past decade there has been a number of international cruises into the Russian arctic, notably to the Laptev Sea in collaboration between Antarctic and Arctic Research Institute (AARI), St. Petersburg, Russia and GEOMAR, from Kiel, Germany. Future cruises could employ Russian or jointly deployed vessels, where a common border is shared in the Chukchi Sea. The RAISE initiative supports the recommendations of the logistics working group and underscore the need for additional funds to support ship and land-based research in the Russian Arctic.

RAISE and Other Initiatives

The RAISE initiative serves to complement existing scientific goals of Land-Ocean and Ocean-Atmosphere Interactions initiatives of ARCSS by linking the multitude of processes operating at the land-ocean interface, the continental shelf. Consideration of paleoenvironmental records in northern Eurasia broadens the scope of paleoclimatic inquiry beyond the purview of the Greenland Ice Sheet Program (GISP II) and Paleoclimate of Arctic Lakes and Estuaries (PALE) program. The RAISE program has been developed in light of SIMs (Synthesis, Integration and Modeling) initiative by stressing the continuity between contemporary arctic processes and environmental assessment derived from the paleorecord and by underscoring the need to interact with the modeling community. The human impacts component of RAISE parallel many priority research areas of the Human Dimensions of the Arctic System (HARC) initiative.

A number of international initiatives have recognized the primacy of the Eurasian Arctic for future research. The International Arctic Science Committee (IASC) supports the proposal for the development of a International Geosphere-Biosphere Project (IGBP) on Land-Ocean Interactions in the Russian Arctic (LOIRA). Another IGBP interest is Global Change and Terrestrial Ecosystems (GCTE), with a strong emphasis on biogeochemical cycling in Northern Eurasia. The Arctic Ocean Science Board has sponsored workshops on Arctic Paleo-River Discharge (APARD) and is in the process of developing a program plan. Other international initiatives within the World Climate Research Program recognize the prominence of the Mackenzie and Lena rivers watershed for global energy and water cycle experiments (GEWEX). The European community has developed and received funding to forward the Quaternary Environments of the European North (QUEEN) program, which has a strong focus in the Russian Arctic. IGBP-PAGES has recognized the primacy of integrating arctic paleorecords in climate research by establishing the CAPE (Circumarctic Paleoenvironments) organization. RAISE initiative has and will coordinate with European and international programs for exchange of information and coordinate logistics. Regularly scheduled (annual or biannual) meeting of RAISE and other investigators in Russia or in the U.S. would facilitate synthesis of data for model experiments.

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