Department of Defense

The Department of Defense conducts military operations and maintains military facilities in the Arctic. As a consequence the DOD conducts a broad-based research program that extends from the ocean floor to the magnetosphere.

Army

	Funding (thousands)	
	FY 04	FY 05
Arctic Engineering	1,150	1,138
Permafrost/Frozen Ground	400	327
Snow and Ice Hydrology	1,900	1,187
High Latitudes Program	2,959	0
Lower Atmosphere	100	0
High-Freq Active Auroral Prog	5,000	5,500
Medical and Human Engineering	700	512
Total	12,209	8,664

U.S. Army Research Institute of Environmental Medicine

The U.S. Army Research Institute of Environmental Medicine (USARIEM), located in Natick, Massachusetts, conducts basic and applied biological and biophysical research to elucidate novel approaches for sustaining health and optimizing the performance of humans exposed to cold environments. USARIEM research findings provide the biomedical basis for Army doctrine to minimize adverse effects of cold on individual military personnel, crews, and troop populations deployed in cold climates, including Arctic regions. USARIEM employs multidisciplinary teams of scientists using human, animal, tissue, cellular, and mathematical models to delineate pathophysiological mechanisms of cold injury, identify biomedical risk factors influencing susceptibility to cold injury, and provide physiologic data for developing and validating mathematical models that predict human cold tolerance. Additionally, USARIEM formulates and validates exposure guidelines and safety limits to prevent cold injury during military training, develop strategies to safely extend cold tolerance and work capabilities in cold climates, and provide biomedical support for cold-stress Health Hazard Assessment and MANPRINT efforts of Army materiel/clothing developers. USARIEM research capabilities include state-of-the-art technology for collecting human thermoregulatory data in the laboratory and non-intrusive, ambulatory, real-time monitoring of warfighter physiological status during military operations in cold conditions.

USARIEM maintains a very active research program in the area of human physiological responses to cold. A current emphasis concerns establishing guidance for soldiers in order to prevent cold injury and maintain physical and cognitive performance. A series of studies have demonstrated that dehydration does not adversely impact thermoregulation, cardiovascular strain, and physical performance during exercise in the cold. Studies were also conducted to examine the effect of exercise intensity, water depth, and water temperature on the risk of hypothermia. The studies demonstrated that a slight increase in exercise intensity significantly reduces the risk of hypothermia. Those studies also determined that a USARIEM biophysical model better predicted the core temperature response during light exercise than currently used thermoregulatory models. Studies have also determined that the nutritional supplement tyrosine can ameliorate the decline in cognitive performance that occurs when humans are hypothermic. Furthermore, tyrosine supplementation attenuated the decline in marksmanship performance in hypothermic humans. USARIEM also recently updated TB MED 508 – Prevention and Management of Cold Weather Injuries. This document is the Army's medical doctrine for cold weather operations.

Cold Regions Research and Engineering Laboratory

The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) of the Corps of Engineers, Engineer Research and Development Center (ERDC), is recognized as a primary Federal

Winter field test of Stryker vehicle mobility impacts at Donnelly Training Area, Alaska.

source for Arctic and Subarctic expertise. It is an internationally recognized center of excellence in polar science and applied cold regions engineering research with a host of unique research laboratory facilities in Hanover, New Hampshire, and offices in Fairbanks and Anchorage, Alaska. CRREL advances and applies cold regions science and engineering technologies and leverages this knowledge to provide all-season solutions to a wide range of environmentally driven problems. The CRREL research program responds to the needs of Army, the Corps of Engineers, and the Department of Defense, but much of the research it performs also benefits the Nation and the private sector. In recent years, CRREL has placed greater emphasis on environmental physics, with a goal of understanding the dynamic processes that govern the character and appearance of the natural and man-made environments and their impacts on military activities. This transition contributes to high-priority defense needs while exploiting the physics-based talents that cold regions process research require. CRREL has sustained and extended its Arctic and cold regions research efforts and capabilities through reimbursable and collaborative work with other cold-focused DOD users, NASA, NSF, and academia. CRREL also continues to maintain the world's foremost library of cold regions scientific and technical literature. Highlights of some of the recent research follow.

Arctic Engineering

Arctic engineering has an emphasis on operating in harsh conditions with little infrastructure. Understanding how to modify traditional equipment and procedures to enhance their suitability for use in extreme environments has strong relevance for today's expeditionary military. CRREL has a long history of performing such research on the design and construction of Arctic infrastructure and facilities and supporting military and logistics operations in the polar regions.

The training lands utilized by U.S. Army Alaska (USARAK) include more than 1.6 million acres of widely varied terrain, including areas of continuous and discontinuous permafrost subject to climate and weather extremes. These training lands are primarily used by light tracked vehicles associated with light infantry units. Military vehicle operations on these training lands during spring thaw can cause significant disturbance to soil and vegetation. The military training lands in Alaska have experienced thermokarst erosion caused by the loss of insulating vegetation in permafrost zones. The need to maximize training capacity is important for the Army, but environment disturbance must be kept to a minimum to reduce environmental consequences and terrain reclamation or restoration needs.

The transformation of the 172nd Brigade to a Stryker Brigade Combat Team required re-equipping the unit with the 20-ton Stryker wheeled vehicle. To gain a better understanding of the terrain disturbance generated by Stryker vehicles on training lands, USARAK and CRREL, in cooperation with the Army's Cold Regions Test Center, conducted Stryker impact tests at Alaska's Donnelly Training Area in late winter and spring. The winter test was conducted when the ground was frozen and coverd by approximately six inches of snow. Follow-on Stryker impact tests were performed on various terrains during spring breakup.

The sites of the winter and spring tests were revisited later in the summer to evaluate the soil and vegetation recovery. Because the ground was frozen, the winter maneuvers caused no rutting; the impact to vegetation was minimal, and all roots were intact. Rutting that occurred during the spring test was closely related to thaw depth, which ranged from 0 to 15 inches in that location. Terrain disturbance varied from minimal (tire imprint with vegetation still intact) to severe (deep ruts, piles, and clumps of dirt on the side of the ruts). A follow-up site visit was conducted after one year to survey and quantify the recovery from the terrain disturbances. This research supported an environmental assessment of impacts of proposed range expansion projects and helped quantify the disturbance that the Stryker vehicle will be generating on the terrain for planning and sustainable land management.

The Alaskan Arctic has several coastal communities that are being threatened by shoreline erosion. Mitigation options are being studied for cities and villages such as Barrow, Kivalina, and Shishmaref. Virtually all northern Alaska construction sites are remote, and the season for completing work is short, resulting in high construction costs and logistical challenges. The permafrost regime at these coastal sites adds to the problems faced by engineers and designers. Ways to improve the durability and long-term performance of these erosion control structures are important to the impacted communities and supporting agencies.

The Corps of Engineers Alaska District recently completed the construction of 230 feet of shore protection at Shishmaref, a Native Alaskan community on Sarichef Island. Sarichef is one of a chain of barrier islands in the Chukchi Sea located on the north coast of the Seward Peninsula, about 100 miles southwest of Kotzebue. The soils of Sarichef Island are primarily fine-grained sand permafrost that is highly erodible when thawed. The most common mechanism by which shoreline banks fail is when permafrost thaws and is washed away at the water line. This results in an undercut bank with large blocks of permafrost soil breaking off and falling onto the beach. This behavior is accelerated by storm erosion events.

Intense fall storms prior to the establishment of shore ice have become more frequent, resulting in severe erosion and adverse impacts on the integrity of the Shishmaref School, teacher's quarters, and commercial and private buildings in the community. The recently completed Corp of Engineers shore protection project tied together a prior shore protection project constructed by the Natural Resources Conservation Service (NRCS) and another project currently under construction by the city of Shishmaref funded by the Alaska Department of Commerce, Community, and Economic Development.

Installation of a thermistor during the Shishmaref shoreline protection project.

The design of the Corps of Engineers shore protection project included several layers of varying rock size over a filter fabric to prevent the fine sand from washing away. As part of the project, CRREL designed and installed thermistor instrumentation beneath the filter fabric to provide information on changes in the permafrost temperature during fall storm events and the thickness of the active layer of soil freezing and thawing over the course of a year. CRREL is also investigating whether using a layer of 3- to 5-inch coarse rock can set up a thermal convection cell in the rock layer to increase the extent or thickness of the permafrost layer, making it more resistant to thawing and thus providing additional protection. A convection cell layer will be designed into future shore protection projects planned for Barrow, Alaska. If successful, this increase in the permafrost's resistance to thaw will improve the performance of the shoreline erosion control structures for these and other communities and result in significant long-term construction and maintenance savings.

Extreme conditions and problems in the Arctic require an increased understanding of fundamental soil phenomena such as freeze-thaw cycles, phase changes, and biological adaptations that vary with season. These conditions make the already complicated problem of environmental remediation even more difficult. CRREL has demonstrated that phytoremediation can be used to treat petroleum-contaminated soils in Arctic conditions in situations and locations where other options are severely limited. Phytoremediation capitalizes on the interaction between plant roots and indigenous microbial communities, known as the rhizosphere effect. Exudates from the plant's root system stimulate microorganisms to more rapidly and completely degrade contaminants in the soil. Because this innovative technique requires minimal equipment and energy, it is particularly well suited for locations that lack significant infrastructure. In a series of replicated Alaskan field studies at Barrow, Galena, Fairbanks, and Annette Island reported in 2004, CRREL has shown statistically significant enhancement effects as a result of

Fescue and ryegrass growing on petroleum-contaminated soil in test plots near the Naval Arctic Research Laboratory site at Barrow, Alaska.

incorporating rhizosphere phenomena into treatment strategies.

Robots have the potential to play increasingly important roles in support of polar science and operations. Mobile robots could significantly expand the scientific utilization of Antarctica and Greenland summit regions by creating networks of instruments that can be tailored to specific experiment plans. Potential missions include snow characterization and biological sampling along transects and upper atmosphere or magnetosphere observations using broadly spaced instrument arrays. Understanding the design and performance of polar robots for scientific use also has relevance to Army-funded research on the performance of robots in harsh environments.

Polar regions pose numerous challenges for mobile robots, including extremely low temperatures, blowing snow, and mobility over vast distances. Nevertheless, it is possible to capitalize on conditions unique to polar snowfields to design a simple robot capable of long-distance autonomous travel. During polar summers, the sun is above the horizon all day and the skies are frequently clear, making solar power an attractive power source. Firm snow permits the use of low-pressure wheels, which are preferred over tracks for simplicity and mechanical efficiency. Four-wheel drive provides good mobility and is consistent with high reliability and low cost. Vast areas of the Antarctic and Greenland plateaus are obstacle-free provided the vehicle can negotiate wind-sculpted sastrugi.

In collaboration with an NSF-funded effort at Dartmouth College's Thayer School of Engineering, CRREL supported the development and testing of a solar-powered rover, Cool Robot, designed to deploy instrument networks in polar regions. The Cool Robot performed well during mobility and cross-country traverse tests conducted this summer at Summit Camp, Greenland, verifying the key features of the design, including an ability to tow significant science payloads and the tools to optimize it for specific missions.

Permafrost and Frozen Ground

The challenging conditions in the Arctic offer exceptional opportunities to increase our understanding of the fundamental nature of soil phenomena such as freeze-thaw cycles, phase changes, and biological adaptations. Understanding these topics is critical not only for addressing cold regions problems, but also to provide insights valuable for understanding similar processes in less extreme conditions. Permafrost underlies 20% of the world's land and 85% of Alaska. In permafrost regions, remote geotechnical, geophysical, and environmental site assessments often need to be made before large oil, gas, and mining business infrastructure development can occur.

Global air temperatures have increased since the 1800s. Increases in the Arctic are significantly greater than those in the lower latitudes. For example, the 2002 *United States Climate Action Report* indicates that Alaska has experienced the greatest warming of any state, with a 3°C increase in aver-

Cool Robot climbing a 0.3-m-high, steep-faced snow berm at Summit Camp, Greenland.

age temperature since the 1960s. This has been accompanied by melting permafrost and related geotechnical problems. Consequently, permafrost engineering techniques must be adapted to account for such increases in temperature.

The CRREL Farmers Loop Road test site, near Fairbanks, Alaska, has been used for geotechnical research since the mid-1940s. Recently, the Farmers Loop Road permafrost site was established as a component of the National Geotechnical Experimentation Site (NGES) program. As a permafrost site, with its unique technical challenges, it adds geotechnical diversity to the NGES program. Data and results from studies performed at the site will become available to practitioners and engineering students nationally and internationally through the NGES public database. A preliminary version of an NGES bibliography covering previous and ongoing work conducted at the site is now available.

Farmers Loop Road is experiencing increased permafrost temperatures and permafrost melting. It has been proposed that the site be added to the CALM (Circumpolar Active Layer Monitoring) network by instituting a grid in a relatively undisturbed location where annual measurements can be made to determine the extent of the active layer. Data collection protocols and equipment are being established to provide the specific meteorological information required for a CALM site. The data collected will be uploaded to a database that currently contains more than 125 other locations around the circumpolar north. This will assist by giving a first indication of warming soils, which can lead to thawing of permafrost.

A collateral benefit of using the Farmers Loop Road site is that several older reports contain temperature data that provide a historical record for comparison to current conditions. Thus, Farmers Loop Road can be used to monitor temperatures as well as the performance of experimental geotechnical structures constructed on warming permafrost.

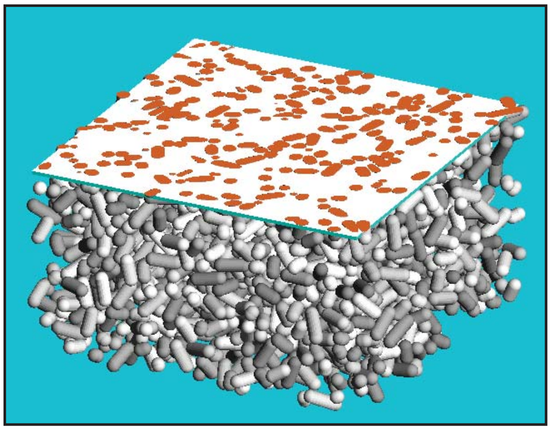
A July 2005 study to determine the suitability of the soils at the Alaska National Guard's Stewart River Training Area near Nome, Alaska, to allow a trail relocation was initiated to evaluate various geophysical tools. The area contains classic Arctic cryogenic features, including thermokarst ponds, ice wedge polygons, sorted circles, cobble pavement, and solifluction lobes. The soils range from silty gravel to clayey silt, typical of a glacial depositional environment. Discontinuous permafrost is present in the region.

Data were collected using 2D resistivity electrical imaging surveys and EM31 electromagnetic ground conductivity techniques on a study grid 525 m long by 300 m wide that was bisected north to south by a stream valley. Soil pits were excavated to determine the depth to the top of permafrost, measure soil horizontal thicknesses, and collect soil samples for water content measurements. Frost probes were also used to determine permafrost depth. Soil moisture content ranged from 47% by weight in frozen silt to 11% in thawed, poorly sorted silty gravel. The depth to permafrost ranged from 15 to 120 cm below the surface. Soil type appeared to be the dominant control on the presence of permafrost in the study area, with all permafrost found in silt and no permafrost found in gravels. The presence of willow thickets corresponded with thawed areas. Willows were absent in areas containing massive permafrost but were present in low numbers where permafrost was degrading. High resistivity anomalies correlated with frozen soil on the east side of the stream. On the west side of the stream, high resistivity associated with a cobble pavement and large gravel clasts had similar resistivity values as permafrost.

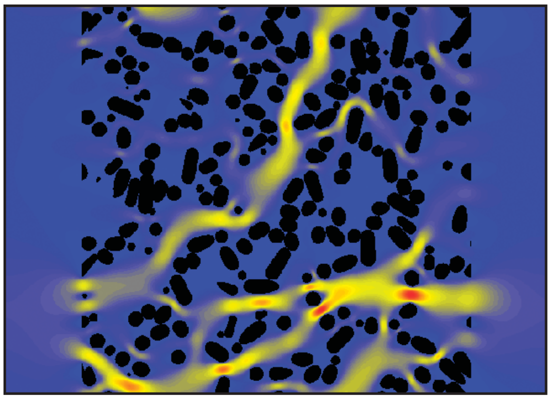
The EM31 data correlated well with permafrost and determined the location of a highly conductive area in the schistose bedrock. The results of this study suggest that a combination of geophysical tools and shallow ground truth explorations using probes and shovels can provide an accurate delineation of horizontal and vertical permafrost extent.

Snow and Ice Hydrology

CRREL has developed a virtual snow model laboratory. The snow model is based on a discrete element approach. The model snow has an explicit geometry composed of discrete particles or grains that are frozen together. The project has four main focus areas: snow dynamics, permeability, thermal conductivity, and electromagnetic interaction. The dynamics of model snow samples undergoing deformation are studied using the discrete element approach. Constitutive models have been developed to simulate freezing, creep and fracture between ice grains that allow simulation of shear, biaxial deformation, and settlement. Thermal conductivity is modeled using a coupled finite difference solver. Air flow through the complex pore space is modeled using a coupled lattice Boltzmann code. Albedo, transmissivity, and absorption of the model snow are modeled using a Monte-Carlo approach in which photons illumi-



Cross section through a model snow sample.



Two-dimensional lattice Boltzmann flow through the same cross section.

nate the snow sample. Morphological approaches are also being developed to characterize samples of real snow and incorporate them into the virtual snow framework. The goal is to be able to test samples of real snow in a virtual snow laboratory.

Understanding the dispersion, persistence, fate, and environmental impact of airborne pollutants in Arctic conditions is increasingly important. CRREL has worked with the Army Directorate of Public Works and the Alaska Department of Environmental Conservation to develop low-cost monitoring techniques for characterizing the dispersion and deposition of petroleum-aerosol-based fogs used for military training. Such aerial plumes behave differently in winter and summer. Predicting their deposition area and monitoring the process will enhance environmental monitoring and permitting of military training activities in sub-Arctic areas in Alaska.

Air Force

The Air Force conducts research in upper atmosphere and ionosphere physics. These efforts are primarily performed by the Air Force Research Laboratory (AFRL) Space Vehicles Directorate, Battlespace Environment Division, and by the Air Force Office of Scientific Research (AFSOR). The research goal is understanding the basic physical and chemical processes and dynamics of the polar ionosphere in order to identify, predict, and mitigate disruptions to DOD communications, navigation, and surveillance systems. The research program includes experimental measurements to determine specific physical processes augmented by first-principles numerical modeling efforts to correlate with ongoing theoretical research.

High-Latitude Ionosphere Studies

Recent efforts in polar ionosphere research have focused on additional capabilities made possible by new, more sensitive detectors, such as CCD (charged-couple device) cameras and the combined operation of instruments as networks rather than individual measurement tools. Experiments to test a specific theoretical mechanism for creation of polar cap patches were conducted at sites in Svalbard, Norway, and Greenland. This work demonstrated how reconnection of magnetic lines of force at the boundary between Earth's magnetosphere and the solar wind can result in the capture of higher-density ionosphere plasma from sunlit latitudes and transport it across the polar cap. The resulting kilometer-sized irregularities formed within these high-density patches can produce severe scintillation on trans-ionosphere radio wave signals. Another study comparing radar data with high-resolution optical images illustrated how this process can operate in two horizontal dimensions.

The enhanced understanding obtained by observing ionosphere processes over larger areas and multiple sites motivated efforts to better coordinate observations and fill coverage gaps between stations. To achieve this, DOD recently concluded an international agreement with the Home Rule Government of Greenland, the Denmark Ministry of Defence, and the Denmark Ministry of Transport and Energy to establish an ionosphere research site at Station Nord in northeast Greenland. The measurements from Nord will overlap with measurements from Svalbard to the east and the Thule area to the west, allowing the development, transport, and evolution of ionospheric structures to be observed continuously as the plasma travels from the auroral zone over the magnetic pole. The extremely high geographic latitudes of stations in the chain, all north of 77° latitude, will allow low-light optical observations to be made even at noon in the winter. This is crucial to determine processes operating in the cusp region of the auroral oval in the noon sector.

High-Frequency Active Auroral Research Program

A major facility for conducting ionosphere and radio science experimental research is being developed in Gakona, Alaska, under the High-Frequency Active Auroral Research Program (HAARP). The facility is jointly managed by the Air Force Research Laboratory and the Office of Naval Research. The facility includes a high-power, high-frequency (HF) transmitting system and a suite of radio and optical diagnostic instruments. Research has been conducted at the facility since 1999 using an HF phased-array antenna system consisting of 48 elements, with crossed-dipole antennas, driven individually by 10-kW transmitters, resulting in a maximum radiated power of 960 kW. In November 2002, a Memorandum of Agreement was signed by the Air Force, the Navy, and the Defense Advanced Research Projects Agency to complete the planned Gakona facility with the addition of 132 antennas and associated transmitters to form a 12 × 15 phased array with a radiated power of 3600 kW. The 40-acre antenna array and 15-MW power plant to achieve this capability were completed in 2004-2005, and installation of additional HF transmitters to drive the antenna array was initiated. The facility is scheduled for completion in 2006.

Significant additions to the facility's suite of radio and optical diagnostic instruments were also implemented over the past two years. New radio frequency diagnostic instruments include a 37-MHz imaging riometer to observe changes in the background galactic noise, and a phased-array UHF (446-MHz) diagnostic radar to study physical processes produced in the ionosphere by the facility's high-power HF transmissions. The UHF diagnostic radar, acquired in conjunction with the University of Alaska Fairbanks, comprises a small portion (8 panels, 256 antenna elements) of an innovative Advanced Modular Incoherent Scatter Radar (AMISR) (180 panels, 5760 elements) developed by the National Science Foundation with the Stanford Research Institute. State-of-the-art optical instruments employed at the facility include imagers, multi-channel photometers, telescopes, and sensitive webcams. These instruments are used to study artificial airglow produced by HF radio wave interactions in the ionosphere.

The suite of radio and optical diagnostic instruments provide important data to characterize the physical processes in the ionosphere produced during operation of the facility's high-power HF transmitter. When the HF transmitter is not in operation, they provide real-time data on geophysical parameters that characterize the state of the ionosphere and magnetosphere under both normal and disturbed (solar-related) conditions. As such, the instruments constitute a ground-based space weather station. The data are available on the internet at www.haarp.alaska.edu.

Recent optical research results include the creation of artificial spots in the natural aurora bright enough to be seen with the naked eye, a result that cannot be explained by existing ionosphere/radio theory. Other new results have been obtained by operating the facility's HF transmitter at the second harmonic of the local electron gyrofrequency (approximately 2.8 MHz), including the production of strong optical emissions and electron acceleration, even at very low transmitter powers.

A variety of experiments have been conducted in conjunction with space platforms, including the CLUSTER, IMAGE, WIND, and DEMETER satellites, primarily to investigate the degree and manner in which ELF/VLF and HF radio waves propagate from the ground or ionosphere into deep space. Recent research includes techniques to increase the efficiency of ELF/VLF wave generation in the ionosphere, and the observation of ELF/VLF waves in space at the conjugate point of the HAARP facility off the coast of New Zealand. These techniques are used to study the interactions of ELF/VLF radio waves with charged particle populations in Earth's radiation belts and their subsequent effects, including guided (ducted) propagation and wave amplification in the magnetosphere.