# *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.*

The DOD Arctic research program seeks to enhance our understanding of basic and applied phenomena that directly affect military activities and operations. Some specific focus areas for these research studies include but are not necessarily limited to:

- The interaction of the Arctic environment with military systems, facilities, other infrastructures, personnel, and operations;
- Energy exchange and ocean–atmosphere interaction dynamics;
- The structure and physics of the middle and upper atmosphere, and the impact of energy exchange processes on global circulation of the atmosphere; and
- The impact of extreme cold on biophysical phenomena and human biology, and methods to optimize human performance in these extreme environments.

The DOD Arctic Research Program is conducted by the military services. Each service is responsible for the conduct of its own, coordinated research program to meet service-specific and joint research and technology objectives. An overview of some of the primary activities and major accomplishments for each service is provided in the following paragraphs.

| | Funding (thousands) | |
|---|---|---|
| | FY 02 | FY 03 |
| Arctic Engineering | 2,750 | 1,246 |
| Permafrost/Frozen Ground | 430 | 500 |
| Snow and Ice Hydrology | 1,485 | 1,877 |
| High Latitudes Program | 3,030 | 3,050 |
| Lower Atmosphere | 100 | 269 |
| High-Freq Active Auroral Program | 10,700 | 7,600 |
| Medical and Human Engineering | 898 | 700 |
| Total | 19,393 | 15,242 |

## Army

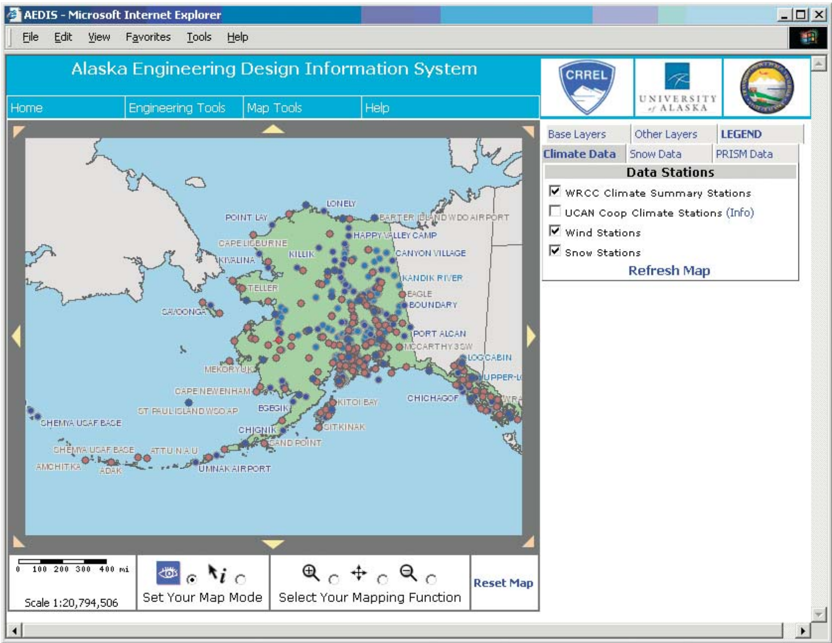
### *Biomedical Research*

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 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 for predicting 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 nonintrusive, ambulatory, real-time monitoring of warfighter physiological status during military operations in cold conditions.

### *Medical and Human Engineering*

USARIEM maintains an active research program in the area of human physiological responses to cold. A current emphasis concerns the extent to which factors expected to be encountered by warfighters in an Objective Force scenario affect the ability to sustain thermoregulation, physical performance, and immune function in cold environments. Studies demonstrated that multiple days of exertional fatigue impairs vasoconstrictor responses




*Screen image of the Alaska Engineering Design Information System.*

to cold and increases a soldier's susceptibility to hypothermia. These studies also showed that immune function is not degraded by the combination of exertional fatigue and cold, wet environments. The combination of physical fatigue, sleep deprivation, and caloric restriction, as encountered on a sustained operation, increases the risk of hypothermia.

Studies also showed that moderate altitude exposure (6,000 feet) impairs the shivering and vasoconstrictor response to cold. Epidemiological studies performed by USARIEM showed that women and African–Americans have an increased risk of cold injury. Studies demonstrated that dehydration does not increase the risk of peripheral cold injury. Studies were also completed to evaluate the use of a cold-weather index for use in the Warfighter Physiological Status Monitor program. Biophysical modeling studies were also conducted to examine heat exchange in extremities. Planned research on responses of humans to cold exposure include the effect of exercise intensity, water depth, and water temperature on the risk of hypothermia as well as the role of low body temperatures on cognitive and physical performance.

*Arctic Engineering*

The U.S. Army has peacetime responsibility for developing, operating, and maintaining military and civil facilities in Arctic regions, ranging from military test and evaluation facilities to commercial energy transportation systems. During armed conflict the Army must be prepared to deploy forces, sustain forces and equipment, and conduct a wide variety of operations in hostile Arctic environments.

One effort being pursued to meet this need seeks to develop new engineering analysis tools to support both peacetime and wartime civil engineering tasks. In cooperation with the University of Alaska, the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) is developing a web-accessible Alaska Engineering Design Information System (AEDIS), which is an analysis toolkit for engineers. It presents a broad array of geospatial terrestrial, oceanic, and atmospheric environmental data based on a geographic information system (GIS). In its current state of development, AEDIS contains permafrost distribution, soil distribution, towns and roads, digital elevation and aspect, and other environmental and geographic data. The web site includes climate summaries for over 200 sites in Alaska that include snow depth, load information, and recurrence intervals. Automated toolbox algorithms are available for calculating mean freezing, thawing, and heating indices. Other calculators are available for the length of daylight and a variety of climate statistics. Mean monthly maps of precipitation and temperature for Alaska are included.

Planned improvements to AEDIS include adding more geospatial environmental data and expanding the engineering tools to enable engineers to estimate soil bearing capacity; climate trends; depths of freezing and thawing; statistics for wind, precipitation, and snow load; and other engineering parameters derived from calculations requiring geographical and climate data.

While the data incorporated into AEDIS are specific to Alaska, the enhanced engineering analysis tools available through this system can be applied to problems of Arctic engineering in other locations.

A second effort on Arctic engineering tool development is the application of advanced discrete element modeling methodologies. These developments now allow an ice model to be combined with an unsteady flow model for simulating ice conditions in natural channels. Because the ice model also provides a means for simulating ice jams and ice interaction with structures, it can provide estimates of ice forces on river structures in a reasonable time and at low cost.

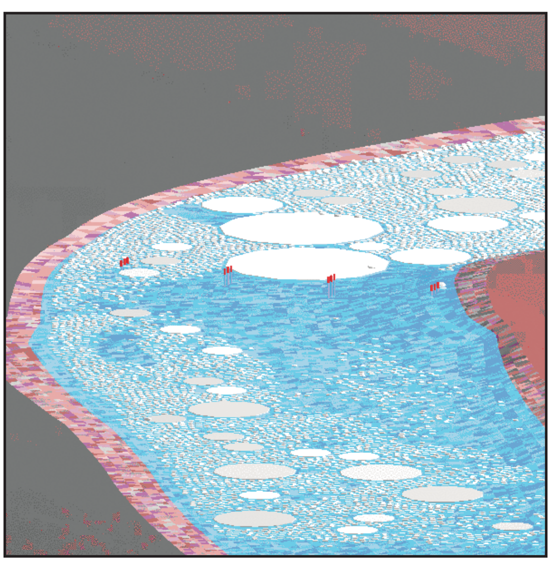
With these tools USACRREL created powerful three-dimensional river ice models to simulate the effects of ice interaction with the piers of a proposed bridge on the Buckland River in Buckland, Alaska. In this project for the Alaska Department of Transportation, USACRREL investigated ice forces on three designs for the proposed bridge piers and the effect of the piers on passing ice. While the results of this particular study are specific to Alaska, the analytic tools employed can be applied to any similar ice-choked waterway.

*Environmental Remediation in Permafrost and Frozen Ground*

The challenging conditions and problems in the Arctic require an increased understanding of fundamental soil phenomena such as freeze–thaw cycles, phase changes, and biological adaptations. These conditions make the already complicated problem of environmental remediation even more difficult. USACRREL 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 natural plants and indigenous microbial communities. Secretions from the plant's root system stimulate the microbes to more rapidly 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.

*Snow and Ice Hydrology*

The snow distribution throughout Alaska is heterogeneous, primarily because of drifting that redistributes the fallen snow. Shrubs trap snow, thereby increasing the snow depth and creating warmer conditions in the underlying soil. Such snow accumulations benefit the shrubs by potentially enhancing their growth. USACRREL, in efforts funded by the NSF Arctic System Science Program and the NASA Land Surface Hydrology Program, has been investigating the patterns of snow distribution using end-of-winter aerial- and ground-based measurements in conjunction with a physics-based computer model for blowing snow (SnowTran-3D). Snow–shrub interactions may have important potential for climate feedback. They may also play a vital role in the transition of tundra regions to scrublands; such transitions would have significant climatic and hydrologic ramifications. Recent results also suggest that shrubs and snow interact in an important way to affect the snow albedo.



*A computer-generated scene showing a simulated ice cover on the Buckland River near Buckland, Alaska, interacting with four proposed bridge pylons (in red).*

In an associated effort, USACRREL has examined the relationship between the SeaWinds satellite scatterometer data and spring snow cover dynamics to monitor freeze/thaw processes in high-latitude boreal and Arctic landscapes. Seasonal freeze–thaw transitions represent the closest analog in nature to a biospheric and hydrologic on/off switch. Surface-level meteorological conditions, ecological trace gas dynamics, and hydrologic activity all respond profoundly to freeze/thaw transitions. Advanced Very High Resolution Radiometer (AVHRR) satellite data were employed to create a series of maps showing the percentage of snow-covered area between Anchorage and the north coast. These maps served as ground truth for evaluating evidence in the scatterometer data for the disappearance of spring snow, a proxy for thaw.

Concurrently, employing a one-dimensional mass and energy balance model called SNTHERM, USACRREL calculated surface energy exchange and associated snow cover dynamics for a portion of the boreal forest of Saskatchewan, Canada. The SNTHERM predictions across the modeling region provided regional-scale, multi-temporal maps of snowpack properties to compare with the scatterometer data. Accurately monitoring and modeling snow conditions and forest energy budgets over large areas will assist in predicting long-term changes to the boreal forest.

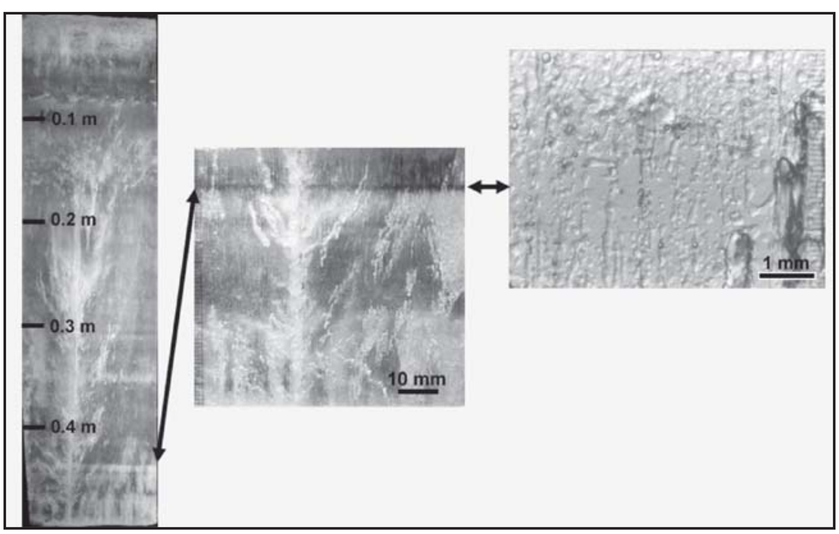
Also, under funding provided by the NSF Arctic Natural Sciences Program, USACRREL is collaborating with Dartmouth College faculty and students on a study of the mechanisms of deformation of pure and debris-laden ice. The project seeks to enhance understanding of the physical mechanisms that underlie the flow of large ice sheets (glaciers) and how such sheets of ice might respond to rapidly changing temperatures. The program involves laboratory experiments and the application of a constitutive model for ice developed at USACRREL.

*High Latitudes Program*

In a recently completed three-year study sponsored by the NSF Arctic Natural Sciences Program, USACRREL and the Geophysical Institute, University of Alaska Fairbanks, examined the microstructural features and brine drainage networks in first-year sea ice. Extensive field work in the Alaskan Arctic supplied new knowledge about the physical properties of first-year sea ice. Monitoring sites in the Chukchi Sea and on Elson Lagoon, near Barrow, Alaska, provided continuous records of the ice growth and thermal regime and opportunities to conduct detailed studies of the microstructure and brine inclusion structure of sea ice on scales ranging from individual inclusions to the full thickness of the ice sheet. Image-processing techniques were employed on a comprehensive set of microstructure photos to quantify the inclusions in three dimensions and to study the horizontal banding features that are frequently observed in sea ice and that seem to be related to under-ice currents.

Recent evidence indicates that the sea ice cover of the Arctic Ocean has been thinning and decreasing in extent. Currently the only reliable method of assessing ice thickness throughout the Arctic Ocean is to analyze ice draft profiles collected by transiting submarines. Under a project sponsored by the NSF, USACRREL has archived and made publicly available formerly classified sonar profiles of ice draft collected by U.S. Navy submarines under the Arctic ice cap between 1976 and 1994. Data from fifteen such cruises between 1986 and 1994 are now available from the National Snow and Ice Data Center. Analysis of these ice draft data revealed rapid thinning in the western Arctic in the late 1980s. That thinning has been attributed to a major shift in the atmospheric circulation in the Arctic and the resultant weakening of the Beaufort Gyre, the large, clockwise ocean circulation system in the western Arctic.

*Sequence of vertical sections of sea ice obtained from the Chukchi Sea in December 1999. The increasing magnification focuses on a type of narrow, very-low-porosity band often observed in sea ice.*




USACRREL has modeled Arctic sea ice and climate on spatial scales from centimeters to thousands of kilometers and on temporal scales from microseconds to a century. For example, USACRREL performed a year-long simulation of the mass balance during the SHEBA year, driving the Community Climate System Model (CCSM), a sea ice thermodynamics model, with meteorological and oceanic data gathered in and around the SHEBA ice camp. SHEBA was the 1997–1998 experiment to study the Surface Heat Budget of the Arctic Ocean. USACRREL also has used global climate simulations of the 20th and 21st centuries with the Parallel Climate Model (PCM) from the National Center for Atmospheric Research (NCAR) to show that trends in present-day greenhouse gases produce a decrease of 1 million square kilometers in the simulated area of Arctic sea ice, a decrease similar to that seen in satellite data.

In other sea ice modeling work, USACRREL is developing a high-resolution Lagrangian model of the ice pack on the Arctic Ocean for NASA. In this model the ice pack is composed of discrete parcels that converge to form pressure ridges and separate to form leads. Though high resolution, the current model is capable of covering the entire ocean. Simulations begin with a continuous, frozen ice pack that covers the basin; wind drag then causes the pack to move. Stress builds up in the model ice, it breaks, and fracture lines propagate through the pack. The result is an aggregate plate structure that determines paths for subsequent deformation. Because the modeled ice pack displays linear kinematic features like those seen in satellite imagery of the Arctic Ocean, the conclusion is that large-scale wind stress, not regional topography, creates Arctic leads and ridges.

*Lower Atmosphere*

During the third and final phase of SHEBA in 2003, USACRREL maintained a 20-m meteorological tower in the main SHEBA camp and four instrumented remote meteorological sites at distances of 0.5–10 km. The main tower and three of the remote sites operated continuously for almost 11 months, yielding long time series of the turbulent and radi-

*Ice physicists making mass balance measurements near Barrow, Alaska, June 2001.*

ative components of the surface heat budget over diverse ice types.

In addition, from 2000 through 2002, USACRREL and other institutions examined the seasonal evolution of albedo and the snow and ice mass balance in the coastal region near Barrow, Alaska. This complex region of tundra, lake ice, and sea ice is an excellent location to examine interactions among the terrestrial, ocean, ice, and atmosphere environments. The field program included tundra, lake, lagoon, and sea ice study sites. Automated stations monitored conditions throughout the winter, when the snow and ice are spatially uniform and temporal variations are relatively modest. Intensive field work was also performed each year from late May through the end of June during the critical melt season when spatial variations are large and interactions among the ice, ocean, and atmosphere are greatly amplified.

The atmospheric boundary layer during SHEBA was often stably stratified and frequently near quasi-equilibrium, a condition seldom seen in the more ephemeral stable boundary layers at lower latitudes. This data set, collected in almost laboratory-like conditions, is yielding new insights into the turbulent structure of the atmospheric boundary layer during stable stratification. For example, two new turbulence regimes in very stable stratification have been defined. In one, the atmosphere is still intermittently turbulent. In the second, an even more stably stratified case, the turbulence has been damped out by the stratification. In both regimes, though, the effects of Ekman turning are obvious even within 20 m of the surface. Although these results were obtained over sea ice, they are relevant also to terrestrial surfaces at lower latitudes, where stable stratification occurs almost every night.

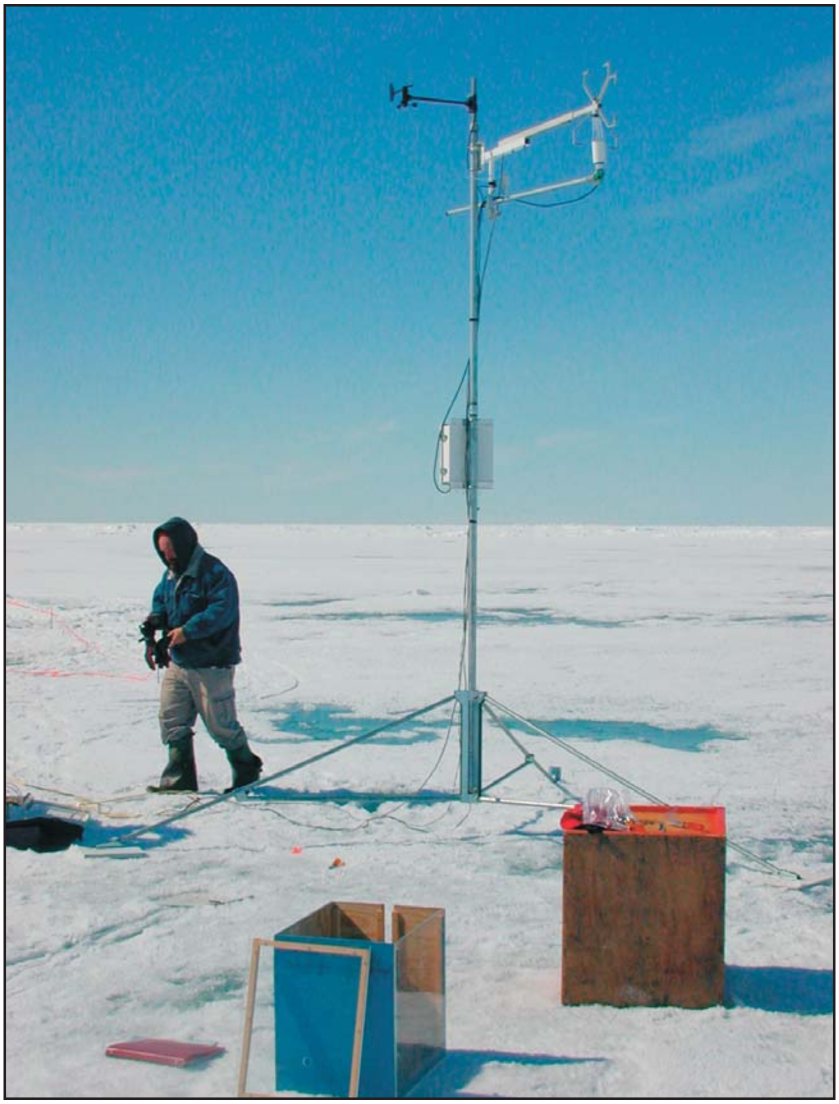
The areally averaged albedo decreased and the spatial variability increased at all sites as the melt season progressed. Comparing results from this study with data collected in the central Arctic during SHEBA showed that albedos of fast ice in the coastal regime evolve significantly faster than albedos in the central pack. In particular, the evolution of the albedo of the lagoon ice was sensitive to the amount of sediment entrained in the ice during freeze-up.

The observed rates of sea ice surface melting were typically at least twice as high as rates observed in the pack ice during SHEBA. This difference indicates the possible role, in the coastal regime, of advective heat transfer from the tundra to the nearby sea ice. The accelerated melting in the coastal Arctic that has been observed in recent years could, therefore, amplify a warming signal as it propagates from the land over the coastal ocean.

The role of the Arctic Ocean in the regional budget of $CO_2$ is largely unknown but is often presumed to be unimportant under the assumption that sea ice impedes gaseous exchange between the atmosphere and the ocean. To address this uncertainty, in the summer of 2002 USACRREL collaborated with scientists from the International Arctic Research Center (IARC), Fairbanks, to make the first direct (eddy-correlation) measurements of the turbulent flux of carbon dioxide over sea ice.

These direct measurements were complemented with more traditional geochemical sampling that involved placing large and small chambers on the sea ice and monitoring the $CO_2$ in the headspace in the chambers as a function of time. The measurements were all on the fast ice near Barrow. During these June measurements the ice had begun to melt, and melt ponds eventually formed. It was found that, in general, the surface was taking up atmospheric $CO_2$. The melt ponds seemed to be especially active; as ponds deepened, the partial pressure of $CO_2$ in them decreased, presumably as a consequence of photosynthesis. The sea ice, however, was also a sink for $CO_2$. Not only was photosynthesis active in the ice, but also the warming ice became more permeable to gases and permitted coupling between the atmospheric and oceanic $CO_2$ reservoirs. The USACRREL/IARC team has concluded that the ice-covered Arctic Ocean could be an important missing link for balancing the global $CO_2$ budget.

Understanding the dispersion, persistence, fate, and environmental impact of airborne pollutants in Arctic conditions is increasingly important. USACRREL 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



*Eddy-correlation measurements of the carbon dioxide flux and other turbulence quantities on the fast ice near Barrow, Alaska, June 2002.*

dispersion and deposition of petroleum-aerosol-based fogs used for military training. Such aerial plumes behave differently in winter and summer; both predicting their deposition area and monitoring the process have environmental and homeland defense applications.

## *Navy*

The Navy conducts several research programs for the purpose of understanding the Arctic environment and its interaction with Navy materiel, personnel, and operations. As part of these efforts, the Navy provides platforms and support to other agencies to conduct research in collaboration with or on a "non-interference" basis with the Navy. In recent years (although not in the past two years), the Office of Naval Research (ONR) has conducted the Submarine Arctic Science (SCICEX) Program. Short, 2- to 10-day periods of data collection were incorporated into portions of submarine cruises. Navy personnel assisted the research crews with data collection. During the spring of 2003, the Navy operated an ice camp in the Beaufort Sea in support of operational testing. During this period the camp also was made available for unclassified research. ONR handled the selection of experiments for the unclassified camp research and funded the additional camp logistics costs.

## *Air Force*

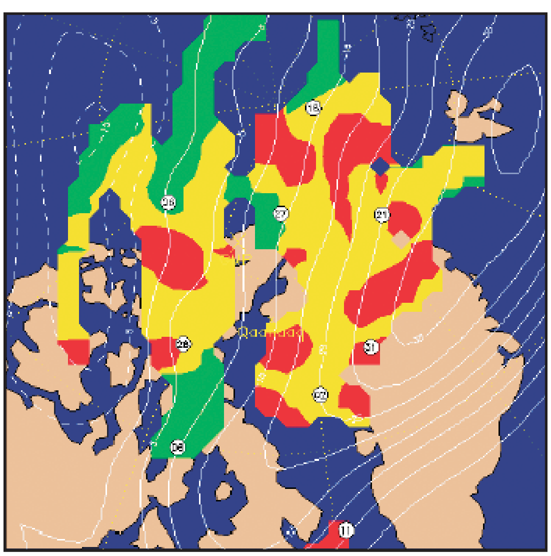
The Air Force conducts research in upper atmospheric and ionospheric physics. These efforts are primarily performed by the Air Force Research Laboratory (AFRL) Space Vehicles Directorate, Battlespace Environment Division, and by the Air Force Office of Scientific Research (AFSOR). The goal of the research is to understand the basic physical and chemical processes and dynamics of the polar ionosphere, with the main objectives to specify, predict, and mitigate disruptions to DOD communications, navigation, and surveillance systems. To actively pursue and maintain a well-rounded program, the research includes experimental measurements to determine specific physical processes and first-principles numerical modeling efforts, with a strong connection to ongoing theoretical research.

### *High-Latitude Scintillation Studies*

Research expanded in the past two years to characterize and quantify the occurrence and impact of ionosphere scintillation, using a variety of optical and radio frequency sensing techniques. The observations spanned a variety of frequencies and propagation geometries, making use of signals from both low-earth-orbit satellites and higher-altitude (quasi-stationary) satellites, including the global positioning system (GPS) constellation. Observational campaigns in northern Greenland and Svalbard were conducted in coordination with incoherent scatter measurements from radars in Kangerlussuaq, Greenland, and Longyearbyen, Svalbard, to observe the formation of scintillation-producing regions near the dayside cusp of the auroral zone and their subsequent evolution and drift across the high-latitude region.

These ionospheric disturbances can lead to rapid fluctuation or scintillation of satellite signals at or near the earth's surface. This phenomenon is most intense at night within 20 degrees of the earth's magnetic equator, which occupies more than one-third of the globe's surface. Affecting radio signals, scintillation seriously disrupts navigation and communication satellites signals. The Scintillation Network Decision Aid (SCINDA) was developed to advise operational users in real time when and where scintillation is likely to occur.

These ionosphere disturbances can lead to rapid fluctuation or scintillation of satellite signals at or near the earth's surface. This phenomenon is prevalent throughout the high-latitude regions, especially during winter. Scintillation of radio signals can severely disrupt navigation and communications relying on satellite links. Based on the results of these measurements, the Air Force has developed a prototype high-latitude scintillation specification tool, SCINDA-P, to advise operational users in real time when and where scintillation is likely to be encountered. The model, which follows the concept of SCINDA developed for equatorial regions, uses measurements from ground-based receivers and ionosphere radars to determine where scintillation-related difficulties or system outages can be expected in the polar regions. Ground-based receivers monitor signals from GPS satellites, measure the amount of scintillation at the GPS frequency directly or estimate it at other frequencies based on the strength of the observed ionosphere irregularities, and then combine that information with real-time measurements or models of the high-latitude convection pattern, which indicates where the observed disturbances will be traveling. The result is a map, updated every five minutes, showing the expected degree of system effects in a tri-color red–yellow–green scheme. By combining scintillation measurements with information on the movement of the ionosphere, the map helps users understand how scintillation structures develop and enables operators to determine practical strategies for maintaining system performance.



*Scintillation Network Decision Aid for the Polar Regions.*

*High-Frequency Active Auroral Research Program*

Under the High-Frequency Active Auroral Research Program (HAARP), jointly managed by the Air Force Research Laboratory and the Office of Naval Research, a major facility is being developed in Gakona, Alaska, for conducting ionosphere/radio science research. The facility includes a high-power, high-frequency (HF) transmitting system and a suite of radio and optical diagnostic instruments. The present HF transmitting system includes a phased-array antenna, 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 HAARP 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 facility is scheduled for completion in 2006.

HAARP is located on a DOD site near Gakona, Alaska, about 180 miles northeast of Anchorage. Research is conducted primarily via four- to five-month-long campaigns each year, with emphasis on studies relating to the generation of Extremely Low Frequency/Very Low Frequency (ELF/VLF) waves in space via modulation of auroral currents with the 960-kW HF transmitter; the production of geomagnetic-field-aligned irregularities and their effects on radio wave scattering; and the generation of optical emissions in space.

A variety of experiments have been conducted in conjunction with space platforms, including the CLUSTER, IMAGE, and WIND 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 CLUSTER observations demonstrate that ELF/VLF signals generated in the ionosphere, by modulating HAARP's HF transmissions, can be routinely received in deep space. These results have led to the initiation of research programs to study the interactions of ELF/VLF radio waves with charged particle populations in the earth's radiation belts and their subsequent effects, including guided (ducted) propagation and wave amplification in the magnetosphere.