



# global glimpses

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## The Role of Wildfire in Alaska: *Frostfire*

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### What is Frostfire?

Frostfire is an experiment to investigate the behavior and effects of forest fire in a small research watershed near Fairbanks, Alaska. Firefighters from the Bureau of Land Management's Alaska Fire Service and the Alaska Department of Natural Resources Division of Lands will burn about 2,000 acres in the summer of 1999 or 2000, weather permitting. The window for 1999 is June 23–July 31.

Frostfire is of great interest to a large cooperating group of investigators from universities, research institutes, and federal and state agencies, and will contribute to the knowledge of many fields, as well as to the overall knowledge of how our planet works and how human activities might be changing how it works. Information gained from the prescribed fire will further research in several areas, including (1) long-term effects of wildfire on the surface energy balance and feedback mechanisms to global climate; (2) better prediction of fire behavior, which will help fire managers better predict wildfire and use prescribed fire as a land management tool; and (3) studies of the effects of the fire on permafrost, water chemistry, nutrient dynamics, vegetation, climate, hydrology, small mammals, and other aspects of the forest ecosystem.

### Boreal Forests and Global Climate

Forests are highly sensitive to climate change, and global climate change is likely to have its greatest impact on boreal forests (Kirschbaum and Fischlin 1996). Boreal forests account for about one-third of the carbon sequestered in terrestrial ecosystems, so changes in the function or the distribution of boreal forests will modify important feedbacks to the climate system. The rate of change in boreal forests is governed by the frequency and severity of fire, and fire has immediate as well as long-term effects on the carbon and energy flows in the boreal system. Data collected from Frostfire will be used to measure the carbon storage and flux in a boreal forest and measure the direct and indirect effect of fire on that system.

Models are also important to understanding the role of boreal forests in global climate. Predicting the future role of boreal and other terrestrial ecosystems in global climate change requires an understanding of the major terrestrial processes that affect climate. Models that incorporate these terrestrial feedbacks to climate have rapidly improved in recent years and now include temperature and moisture controls over trace gas fluxes and changes in surface properties of land-atmosphere exchange. The success of these global models in estimating future impacts on climate depends on our ability to include all the major processes, including those related to forest fires, that will have significant effects on the ocean-land-atmosphere system (see Figure 1). Processes that are not incorporated in the model constitute "surprises" that the model cannot predict. Thus, an important strategy for improving global climate models is not only to refine our understanding of those processes that we know to be important but also to develop a predictive understanding of major "surprises" that might overwhelm the processes incorporated in, and predicted by, current global models.

Fire return time in the boreal forest ranges from 50 to 500 years (Kasischke et al. 1995). This fire regime is variable because of its sensitivity to vegetation, topography, climate

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### Inside this Issue:

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## Frostfire... (from p. 1)

(especially short-term extreme fire-weather events), and human activities (both as a source of ignition and an agent of fire control). Some fire models that include CO<sub>2</sub>-induced climatic warming predict a 46% increase in fire severity and a 40% increase in area burned (Van Wagner 1988, Flannigan and Van Wagner 1991). However, the correlation between weather and area burned cannot be linearly extrapolated into the future, because many factors (e.g., level of protection) confound the current correlation between fire and climate, and because it is quite likely that there are important thresholds and non-linearities in the causes and consequences of fire. Frostfire will help to improve our understanding of the causes and consequences of fire regime, thus improving models of the role of boreal forest in climate feedbacks.

### Fire Behavior Prediction

Another goal of Frostfire is better prediction of fire behavior in interior Alaska. Interior Alaska is a fire-dominated ecosystem where fire controls much of the pattern of vegetation

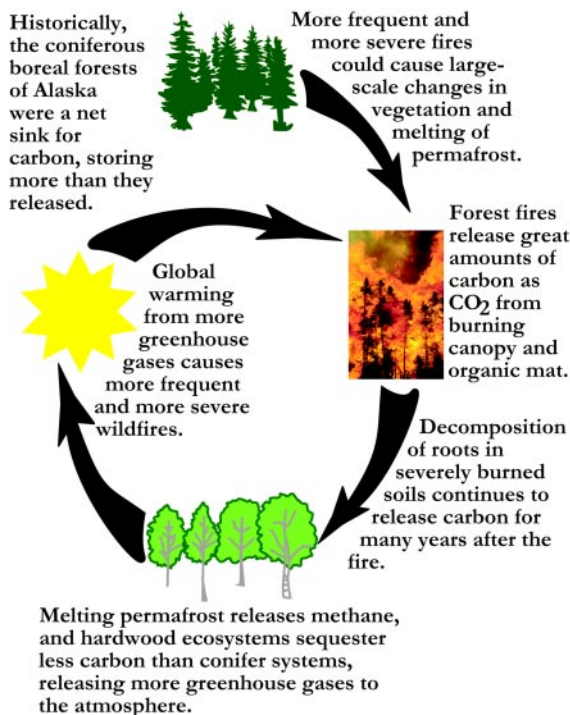


Figure 1: Hypothesis: The greatest carbon loss due to fire results from post-fire decomposition rather than combustion during the fire. The high decomposition rate is caused by both improved environment (moisture and temperature) and massive carbon inputs from root mortality. This causes high CO<sub>2</sub> efflux in well-aerated sites and large efflux of methane and N<sub>2</sub>O where thawing of the permafrost creates waterlogged soils. Nitrogen retention initially depends more on retention in microbial biomass than on regrowing vegetation.

distribution. The State of Alaska Division of Forestry and the Bureau of Land Management spend roughly \$40 million in fire suppression activities every year and an additional \$150,000 to \$200,000 in activities related to prescribed fires. In many states, prescribed burns are generally accepted as an ecologically sound land management technique. In Alaska, land management specialists generally believe prescribed burns are a viable approach for protecting the interface between human habitation and wildlands and for improving wildlife habitat. However, current models for predicting fire behavior (an essential tool for any burn plan) have been developed primarily for more temperate regions, where forests are taller and organic soils are thinner. Frostfire can provide data to improve fire behavior predictability for Alaska.

### Frostfire Process Studies

In addition, Frostfire includes many research projects examining processes in the forest ecosystem affected by fire. See article in the Autumn 1998 issue of *Witness the Arctic* (ARCUS, 1998).

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An important aspect of Frostfire continues to be an active public information process. This multi-agency, multi-disciplinary experiment will continue to provide information for years to come. For more information, see <http://www.fsl.orst.edu/fera/frostfire.html>, or contact F. Stuart Chapin ([fschapin@lter.uaf.edu](mailto:fschapin@lter.uaf.edu)) or Larry Hinzman ([ffldh@uaf.edu](mailto:ffldh@uaf.edu)).

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## News from the Center for Global Change and Arctic System Research

### 1999 Student Research Grants

Congratulations to the following winners of the annual Student Research Grant competition sponsored by the Center for Global Change:

**Anne Thomas Beesley, Institute of Marine Science**

*Northeast Pacific Retrospective Study: Long-term Variability in Salmon Abundance in the Gulf of Alaska and California Current Systems*

**John Chythlook, Department of Biology and Wildlife**

*The Impact of Coastal Glaciation and Sea Level Change on Genetic Variation in the Threespine Stickleback*

**Michael S. Koskey and Susan Yamin, Department of Anthropology**

*Climate Variability in the Bering Strait Region: Written Sources and the Detection of Arctic Climate Change*

**Heather C. L. Peat, Department of Biology and Wildlife**

*Nitrogen Fluxes and Carbon Sequestration: A Stable Isotope Study*

**Jason Vogel, Department of Forest Sciences**

*Soil Carbon and Nitrogen Dynamics in Logged Versus Burned Stands*

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### Barb Severin Joins Center Staff

Barb Severin joined the Center staff in July 1998 as Meetings and Publications Coordinator. Previously, Barb worked as project coordinator for the Alaska SAR Facility for three years. In addition to her other Center activities, Barb organizes and publishes the UAF Weekly Science Calendar, which announces science-related activities across campus. Her participation in the UAF and Fairbanks community includes singing in the Alaska Chamber Chorale.

### NOAA Arctic Research Initiative Continues in FY2000

The Cooperative Institute for Arctic Research (CIFAR), co-located with the Center for Global Change, administers the NOAA Arctic Research Initiative. This initiative, begun in 1997, funds research on natural variability and anthropogenic influences on Bering Sea/Western Arctic ecosystems. Twenty-three projects were funded for 1998-1999, several led by UAF investigators (see <http://www.cifar.uaf.edu> for details). The Arctic Research Initiative will likely be funded at the \$2 million level for FY 2000, and a new announcement of opportunity will be released later this year.

### David Schimel Visits UAF

The Center, in conjunction with the Institute of Arctic Biology, sponsored a visit to UAF in March by Dr. David Schimel, a nationally recognized climate change expert from the National Center for Atmospheric Research in Boulder, Colorado. Dr. Schimel presented a Life Sciences seminar entitled *The Observed Variability of Climate and the Global Carbon Cycle*, and also gave a well-attended public lecture at the Fairbanks Princess Hotel, *Is the Climate Changing?* In addition, Dr. Schimel met with a number of students and faculty.

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### Research Awards to UAF Faculty and Staff

The Center for Global Change and the Cooperative Institute for Arctic Research recently held a grant competition open to UAF faculty and staff for small projects addressing global change issues. The following projects received awards:

**James Begét, Department of Geology & Geophysics**

*Correlations Between High Resolution Lacustrine and Ice Core Records of Volcanic Eruptions and Climate Change in the Arctic*

**Richard Collins, Geophysical Institute**

*Smoke Lidar Measurements During Frostfire*

**George Divoky, Institute of Arctic Biology**

*Black Guillemots as Indicators of Long-term Climate Change in the Bering and Chukchi Seas: Continuation of a Multi-decadal Demographic Database and Assessment of Feathers as Monitors of Oceanographic Change*

**Glenn P. Juday, Department of Forest Sciences**

*Drought Stress in Southcentral Alaska Trees: A Climatic "Crunch" Explanation for the Current Large Spruce Bark Beetle Outbreak?*

**Gerald A. McBeath, Department of Political Science**

*Regulatory Regimes and Arctic Environmental Change*

**Peter Schweitzer, Department of Anthropology**

*Ethnohistory and Global Change: A Preliminary Assessment of Social Science Methods in the Reconstruction of Past Climate Change*

**Lewis Shapiro, Geophysical Institute**

*Timing and Patterns of Ice Formation in the North Bering and Chukchi Seas as Indicators of Variations in Oceanic and Atmospheric Conditions*

## Remote Sensing of Water Cloud Properties in the Arctic from AVHRR Measurements

by Wei Han, Physics Department and Geophysical Institute; now at Lockheed Martin Co., Arlington, Virginia

It is well known that clouds strongly modulate the energy balance of the Earth-atmosphere system through their interaction with solar and terrestrial radiation. Clouds reflect part of the energy back to space and thus have a cooling effect on the Earth-atmosphere system. On the other hand, clouds can also have a greenhouse effect. They absorb part of the longwave radiation from the Earth's surface, re-emit about half of the absorbed energy back to the Earth's surface and thus warm the Earth's surface and lower atmosphere. The arctic region constitutes a radiative energy sink whereas the equatorial region is a source. The persistent presence of snow/ice cover in the Arctic may change the cooling effect of clouds to a slight heating due to the generally higher albedo of snow/ice as compared with clouds.

Cloud properties are of great interest for understanding the global radiation budget and climate change. The arctic region has received more and more attention by climate researchers because it is believed to be particularly sensitive to climate change due to greenhouse warming.

However, the spatial coverage of ground-based radiation measurements in the Arctic is sparse as compared with mid- and low latitudes. Cloud measurements by aircraft are also sparse. With their considerable spatial and temporal variability, clouds are among the most difficult components of the climate system to study. Satellite-borne sensors, on the other hand, can, at least in principle, provide continuous and global measurements with high temporal and spatial resolution.

The Earth's lower atmosphere is composed of gas molecules, cloud droplets and aerosol particles. The interaction between solar radiation and the Earth-atmosphere system includes absorption, scattering, and reflection. The Earth surface, clouds, aerosols, and molecules in the atmosphere also absorb and emit thermal radiation.

Satellite sensors detect a combination of radiation emitted and reflected from the surface of the Earth and transmitted by the atmosphere, as well as radiation emitted by the atmosphere or scattered into the field of view of the satellite sensor by particles and molecules in the atmosphere. The task is to determine what part of the radiation comes from the ground and what part comes from various regions in the atmosphere, and to use this information to deduce surface and atmospheric conditions from satellite measurements.

The above physical processes of absorption, emission, and scattering determine the transport of radiation throughout the Earth-atmosphere system. This transport is described quantitatively by radiative transfer equations. The radiance measured by satellite sensors can be used in conjunction with radiative transfer calculations to infer some important features of cloud particles, such as optical depth and

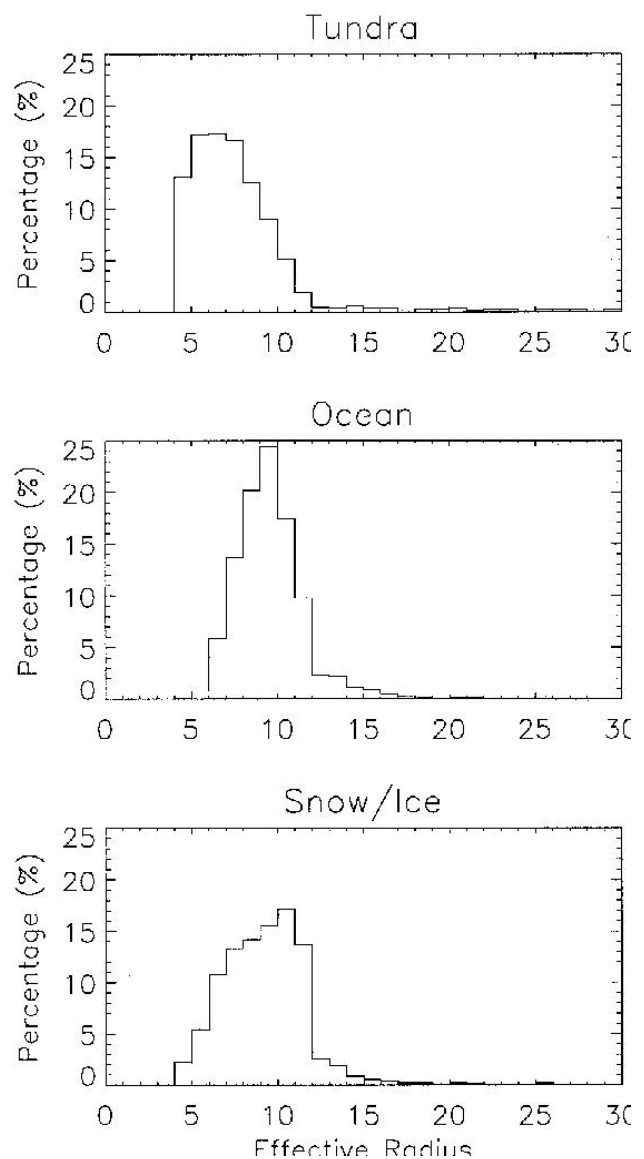


Figure 1: Frequency distributions of retrieved cloud effective radius (in mm) for three cases with tundra, ocean and snow as underlying surfaces, respectively.

effective radius, which determine how much energy a cloud can absorb and how a cloud scatters solar radiation.

The techniques of retrieving optical depth and the effective particle size of water clouds from remote sensing data have been developed since the 1980s. However, most of the work has focused on mid- and low latitudes. The principle behind the retrieval methods are that the reflection function of a cloud at a nonabsorbing channel in the visible spectral region is primarily a function of cloud optical depth, whereas the reflection function at a water-absorbing channel in the near-infrared spectral region is primarily a function of cloud droplet size. These techniques are followed, making appropriate modifications to account for the arctic conditions. Based on a comprehensive radiative transfer model, algorithms are generated to retrieve optical depth and

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effective particle size of water clouds using data collected in the Barrow area in 1992 by Advanced Very High Resolution Radiometers (AVHRR) which were on board the National Oceanic and Atmospheric Administration (NOAA) series satellites. Three areas of  $1^\circ \times 1^\circ$  each which have ocean, snow and tundra as their underlying surface are selected for data processing. A look-up table procedure is employed to speed up the data processing.

The results of this investigation show that: (1) accounting for bidirectional reflectance of snow in the retrieval algorithm significantly improves the quality of the retrieval results in the case of low sun elevation, which happens frequently in the Arctic, as compared with the retrieval results using the assumption that snow is an isotropic reflector, which is commonly used. (2) In three cases selected for cloud retrieval, the effective radius of clouds over tundra lies primarily between 4 and 11 mm, with a peak occurrence of 18% at  $r_e = 7\text{--}8$  mm. Over the ocean surface, the effective radius of a cloud is slightly larger, lying primarily between 6 and 12 mm with a peak occurrence close to 25% at  $r_e = 9\text{--}10$  mm. Over the snow surface, the effective radius lies primarily between 5 and 12 mm, and the peak occurrence is about 17% at  $r_e = 10\text{--}11$  mm. These results are also shown in Figure 1 (previous page). These values are generally smaller than those at mid- and low latitudes reported by other investigators.

Downwelling irradiances at the surface calculated using the retrieved cloud optical depth and effective radius are compared with field irradiance measurements, and encouraging agreements are found.

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## **Modeling Study of Climate Feedbacks in the Arctic, which Involves the Cloud-Capped Boundary Layer**

by Qiuqing Zhang, Geophysical Institute; now at Meteorology Department, University of Utah, Salt Lake City, Utah

Arctic Stratus Clouds (ASCs) are important modulators of local climate, and perhaps even global climate. One of the most significant features of ASCs is that they can persist for several days. Nevertheless, the mechanism responsible for their persistence remains unknown.

Modeling of ASCs during the past years was developed essentially in two main directions. The first makes use of integrating mixed-layer models. The second makes use of one-dimensional ensemble-averaged models. Nevertheless, the complicated features such as the inversions of temperature and humidity, as well as the existence of multiple layers, make it difficult to develop models based on the simplifying assumption of a well-mixed boundary layer. In this study, a Large Eddy Simulation (LES) model is developed and used to study the persistence and evolution of ASCs. LES is a useful tool to investigate the turbulence on the boundary layer. The concept of LES is to explicitly simulate the large

eddies, which contain most of the energy and dominate turbulent fluxes within the planetary boundary layer, and to parameterize the subgrid-scale motions, which contain less energy and are less important. A well-tested radiative model was installed in the LES model for calculating the solar radiative effect.

With the LES model, we simulate an ASC case, which was observed on June 28, 1980 during the Arctic Stratus Cloud Experiment, with two nearly parallel layers of clouds. The persistence of the clouds is investigated.

Based on the results, the model is able to simulate reasonably well the case observed on June 28, 1980. The results suggest that the dynamics of the two cloud layers were decoupled and the evolution mechanisms of the two cloud layers were different. The turbulence within the upper layer cloud is maintained by the cloud top radiative cooling, and that of the lower layer cloud is maintained by the buoyancy production and wind shear. After the upper layer clouds initially formed near the peak of the temperature inversion, vertical mixing caused large amounts of heat and water vapor to be transported upward, and thus led to the further development of the cloud. The longwave cooling then increased and had a positive feedback on the cloud development. Vertical heat fluxes had an effect of decreasing the evolution of the upper layer cloud.

The role of both solar and terrestrial radiation are examined. The cloud turbulence is maintained by the cloud top radiative cooling. The effect of solar radiation helps the lifting of the upper cloud layer. By comparing simulations with different large-scale vertical velocities, we find that large-scale vertical motion has some influence on the cloud evolution. The upper cloud layer develops most rapidly when there is a small downward large-scale subsidence.

A one-dimensional radiative-convective model with detailed cloud microphysics was also developed to study the role of radiation and microphysics in the formation of arctic stratus clouds. The results suggest that radiative cooling plays a most important role during the initial stage of cloud formation.

### **We've Moved!**

The Center for Global Change is now located in Room 306 of the International Arctic Research Center (IARC), adjacent to the Geophysical Institute on the West Ridge of the UAF campus.

We invite you to drop by, introduce yourself, and browse through available publications from the Center and from the Arctic Research Consortium of the U.S. (ARCUS).

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## Ice-Wedge Networks in Alaskan Permafrost

by Lawrence J. Plug, Alaska Quaternary Center and the Department of Geology and Geophysics, University of Alaska Fairbanks; now at Complex Systems Laboratory, Cecil and Ida Green Institute for Geophysics and Planetary Physics, Scripps Institution of Oceanography, La Jolla, California

Patterns formed by interconnected wedges of ice originate with the fracture of frozen ground during the winter season. Low and rapidly falling ground temperatures, driven by changes in air temperature, give rise to tensile stress. A fracture opens at a position where this stress exceeds strength and propagates downward and horizontally through frozen ground, its path determined by variations in stress and by heterogeneity in strength of frozen ground. As stress increases, more fractures initiate and propagate. By reducing and changing the orientation of maximum stress in the surrounding frozen ground, open fractures affect the position and orientation of subsequent fractures. Most fractures fill with ice, which is generally weaker than frozen ground, causing fractures to follow the same paths from winter to winter. Over many winters, repeated fracturing leads to wedges of ice up to tens of meters deep and broad. The growth of these wedges deforms the surrounding frozen ground, generating patterns of mounds and ridges at the surface that reveal the position of fracture paths below (Figure 1a). Such patterns adorn lowland landscapes of northern and Interior Alaska and similar regions in the circumarctic. The fading impact of now-melted Pleistocene networks is found in regions as far south as the midwestern U.S. and central England.

Although the thermal contraction origin for an ice-wedge has been well documented (e.g., Black 1974; MacKay 1986), ice-wedge networks continue to present intriguing questions. These include: (1) How do orderly networks, characterized by consistent distance and relative orientation between ice wedges, emerge out of interactions between individual fractures, via stress, in the context of frozen ground with heterogeneous strength? (2) What is the relationship between the geometry of networks and the climatic conditions under which they formed? If understood, could we use this relationship to interpret past winter conditions from relict ice-wedge networks?

One model for ice-wedge networks has focused on the position where a new parallel fracture can initiate, given a calculated distribution of stress around an earlier single long straight fracture (Lachenbruch 1962). No models have explicitly addressed the development of a network pattern composed of many interacting fractures in a heterogeneous medium, or the horizontal propagation of fractures. Propagation might be important to the geometry of networks because fractures can propagate through regions where stress is insufficient to initiate a new fracture.

To examine issues of the spacing and orientation of ice-wedge networks, a rule-based model that encapsulates elastic

fracture mechanics and stress on a lattice in plan view is employed. Inherent in this rule-based approach (e.g., Werner 1999) are the hypotheses that precise determination of the effect of open fractures on stress is irrelevant, and that the morphology of networks transcends details of fracture tip behavior. In the model, the tensile stress in frozen ground due to cooling is represented by applying a uniform, isotropic stress to the lattice. Fractures are added sequentially, with the location and orientation of fracture initiation determined by patterns of modeled stress imposed by earlier fractures and by a parameterization of frozen ground heterogeneity. Once initiated, a fracture in the model propagates as long as the strain energy released through propagation (a function of fracture length and the distribution of stress along the fracture path) exceeds a material-dependent threshold. A fracture propagates along an angle that maximizes the rate of modeled strain energy release. Parameters for strength and stress/strain behavior are chosen to be similar to what is known about ice-rich frozen silt. These values, some poorly constrained, form a starting point for examining the behavior of modeled networks across a wide range of parameters.

Modeled networks of interconnected fractures develop through addition of fractures to the network. Early fractures are long and have irregular paths due to properties of the substrate, whereas the orientations of later fractures are dominated by preexisting patterns of stress. Most fractures intersect at orthogonal angles because of anisotropy of modeled stress around an earlier fracture. Steady-state modeled networks (those in which no new fractures can occur for a given stress) are characterized by multisided enclosed regions. The dimensions of these regions are greater than is predicted by the stress-based initiation criteria mentioned above. This is hypothesized to be due to suboptimal placement of fractures and because the last fractures added to a network (those which determine the size of the enclosed regions at steady-state) initiate and propagate under stresses influenced by two or more fractures.

Modeled networks (Figure 1b) are compared to digitized images of ice-wedge networks near Cape Espenberg on the northern Seward Peninsula (Figure 1a) and on the Arctic Coastal Plain, Alaska. Parallel fractures in modeled networks have a characteristic spacing of 20–25 m, comparable to those in sampled ice-wedge networks. In more rigorous comparisons, frequency distributions of the spacing and relative orientation (Figure 2) between ice wedges in field networks are compared to similar distributions for fracture segments in modeled networks. These comparisons show field networks are not statistically consistent with a sample population of twenty modeled networks. However, the differences between ice-wedge networks are similar to the mean of the differences between ice-wedge networks and each of twenty realizations of the model (Plug and Werner 1998). Despite these similarities, modeled networks do not display features that occur in some ice-wedge networks, such as three-way nonorthogonal intersections.

The model briefly described here forms the beginning of ongoing investigations into the geometry of ice-wedge networks. These investigations include quantifying the sensitivity of modeled networks to parameters representing temperature and the rheology of frozen ground.

### Acknowledgments

This material is based on work supported by a Student Research Grant Award from the Center for Global Change and Arctic System Research (UAF); the National Science Foundation, Arctic Natural Sciences Program (OPP-9530860); and the National Park Service, Bering Land Bridge National Preserve, Beringian Shared Heritage Program.

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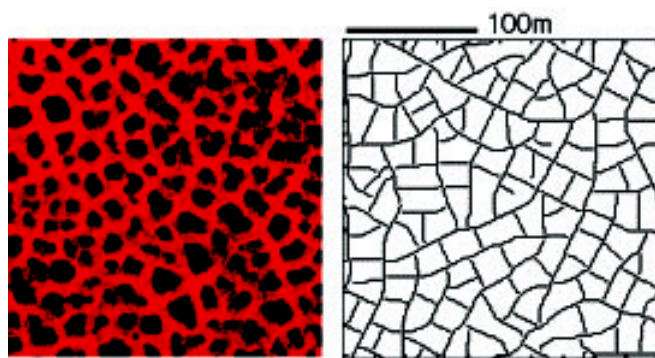
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a) Ice-wedge network on the Seward Peninsula      b) Modeled fracture network

Figure 1: a) A near-infrared aerial photograph of an ice-wedge network that has developed in ice-rich frozen silt near Cape Espenberg, Alaska; and b) a model network near steady-state (see text).

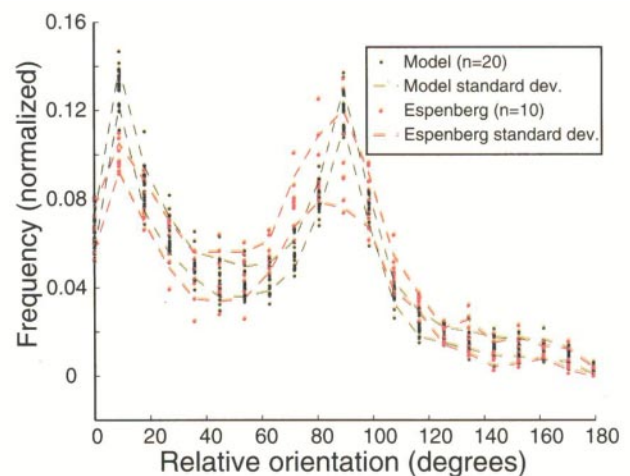


Figure 2: Distributions of relative orientation between fractures in modeled networks and between ice-wedges in digitized Espenberg networks. Observations of relative orientation are collected along sample lines that cross a network at randomly selected angles (Plug and Werner 1998). The two peaks in distributions occur because intersections are commonly orthogonal and more distant fractures (ice wedges in the case of Espenberg) tend to be parallel.

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***Implications of Global Change in Alaska and the Bering Sea Region***

Proceedings of a Workshop  
University of Alaska Fairbanks  
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***Global Warming in Alaska***

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