Witness The
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Coincidence and Contradiction in the Warming Boreal Forest

By Glenn Patrick Juday

This is the second article in an occasional series by authors invited to trace how their personal thinking about their research has changed over time.

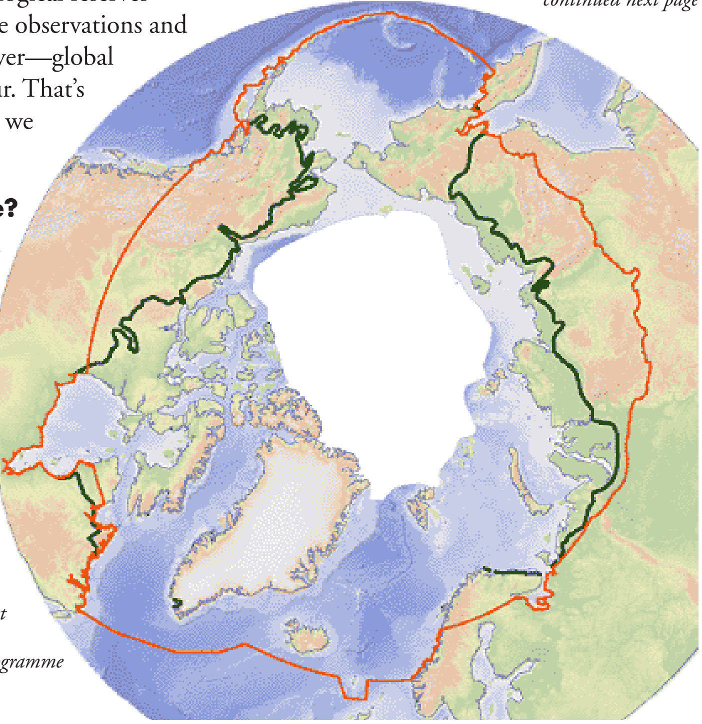
After its purchase in 1867, for most of a century Alaska was a vast expanse of unclassified federal public lands, but in the late 1970s the U.S. government began classifying areas for their long-term management. Early in this process, a far-sighted group of scientists and resource managers developed a plan for a network of ecological reserves, envisioned as experimental treatment areas, as baseline sites for long-term studies needed to inform management, and as sites to protect key biodiversity resources. I began work as the first Alaska Ecological Reserves Coordinator in 1977, and almost immediately climatic oddities with implications for the network began to come to my attention.

Tundra fires, always uncommon, burned a record high area on the Seward Peninsula during a record warm August 1977. In 1978 mean annual temperature at Fairbanks was second only to 1926 in an observational record back to 1904, as was Anchorage with a record back to 1916. Then came the spectacular warmth of January 1981. The mean monthly temperature at Fairbanks was 16.7°C (30.0°F) above normal, the greatest departure from normal of a weather station in the history of North America to that time. Maybe these were all coincidences, but it seemed like rolling dice and always seeing fours or fives come up. We now know that the Pacific climate regime shift from 1976 to 1977 was one of the most powerful influences on the condition and functioning of ecosystems across a vast area of western North America (Ebbesmeyer et al. 1990) and that these effects were particularly noticeable in Alaska.

At the time, although I considered global warming from human-caused increases in greenhouse gas as an explanation, something as dramatic as global-scale climate and ecosystem change seemed like a distant prospect, not something likely actually to be important in my career. Maybe, I thought, the odd weather events were just cyclic variability. But if these events really were an early expression of global greenhouse warming, I wanted the areas chosen for the ecological reserves network to have baseline observations and data in case—or whenever—global climate change did occur. That's one of the main reasons we were establishing them.

Beyond Coincidence?

On one hand, the physics of how increases in greenhouse gasses retain more heat in a system seemed virtually certain. On the other hand, maybe some process such as enhanced carbon sequestration would operate to dampen any warming effect to the point it would be negligible. In any event, how would we recognize global warming effects if we saw them? A good answer to that question was not available at the time.



Boreal forest is found south of arctic treeline (dark green line). The orange line indicates the Arctic, as defined by the Arctic Council's Arctic Climate Impact Assessment (ACIA) and Arctic Monitoring and Assessment Programme (AMAP). Graphic from UNEP/GRID Arendal (2002).

To address that question, a group of faculty at the University of Alaska Fairbanks (UAF) planned a scientific meeting to evaluate the evidence from the atmosphere, cryosphere, oceans, and land systems and gain a bigger perspective about environmental change in Alaska. I joined the conference organizing committee, which included Jenifer McBeath (Agricultural and Forestry Experiment Sta-

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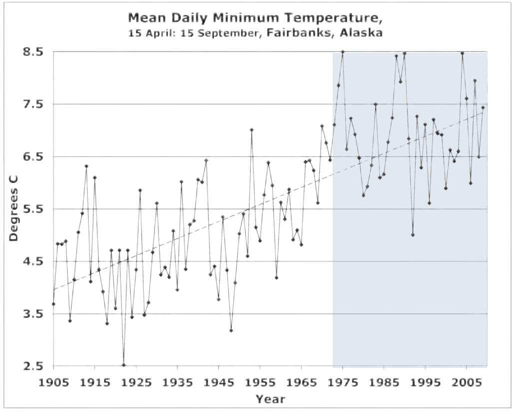
tion), Gunter Weller and Tom Osterkamp (Geophysical Institute), and Richard Neve (Marine Science). We agreed to consider both what the science could tell us and what the implications of a warmer Alaska would be for society in general.

With support from the UAF School of Agriculture and Land Resources Management and funding from the Alaska Humanities Forum, one of the first national meetings to consider climate change evidence in a specific region, including human implications, convened in April 1982 (McBeath et al. 1984). Charles Keeling of the Scripps Institution of Oceanography presented his atmospheric CO_2 concentration measurements (at that time about 341 ppm, in 2008 386 ppm). Climatologist Will Kellogg of the National Center for Atmospheric Research noted that models based on simple representations of heat flux showed that if CO_2 concentrations continued to increase at anticipated rates, "…the Arctic Ocean will become ice-free with a relative modest warming, one that could occur very early in the next century…." Current evidence suggests that his prediction was accurate.



Above: Immediate aftermath of the Rosie Creek Fire, June 1983. A severe convective firestorm generated hurricane-force winds of flame that toppled and snapped the trees in this area. Warming and drying of Alaskan boreal forests has led to increased area burned and high fire severity. Left: Mean daily low temperatures during the warm season at Fairbanks. Summer temperatures have remained at elevated levels since the mid-1970s (shaded). A greater magnitude of warming in the daily low vs. high temperatures is pronounced and consistent with the mechanism by which greenhouse gasses work. Figures courtesy of G.P. Juday.

My paper analyzed temperature trends in the Alaska climate record. My office at the Institute of Northern Forestry (INF) had two tools that helped greatly. First, INF's small library held the nearly complete National Weather Service Climatological Data and Local Climatological Data publication series for Alaska. Second, INF had just obtained a computer with a pen plotter. Today, access to data or the ability to manipulate and display information on an affordable device seems trivial, but they were big challenges at the time.

As I analyzed the Alaska temperature data, the pile of squiggly lined graphs grew higher and higher, and nearly all displayed a sharp upswing at the far right of the page, representing the high temperatures of the most recent years. Again, this sounds elementary today, but at the time it was a noteworthy trend—seeing the hard data at so many stations going up to such high levels was compelling (see figure this page).

My results also showed a strong cyclic feature in the record, which was partly related to the solar cycle and to El Niño, as a few others had suggested earlier. In addition to giving a summary perspective on about 80 years of climate data, I was looking for a reasonable and specific test that would address the question of greenhouse gas warming. I concluded that "if, as expected, CO_2 begins to overwhelm the natural range of climate variability between now [1982] and the end of the century, Alaska would experience a stairstep increase in temperatures, the peaks of which would reach unprecedented highs." That basically describes what happened, but, of course, I wasn't certain at the time.

I had unilaterally defined my work on the conference topic as part of my ecological reserve duties. Fortunately, my boss, Ken Wright (associate director of the U.S. Forest Service Pacific Northwest Research Station), was very understanding. He thought that this global warming issue might eventually be important (a brave admission at the time), but probably only in the long-term future. My administrators and funding sources were anxious for me to get back to "real work," so I returned to selecting, documenting, and establishing ecological reserves and starting monitoring to enable us to detect important ecological changes if they occurred.

Burning Questions

In 1983, an external review panel from the National Science Foundation (NSF) met in Fairbanks in late May to assess the accomplishments of the Taiga Biome project and identify priorities for future boreal forest research. Recognizing the good progress the project had made in understanding fire ecology and the black spruce ecosystem, the panel recommended that the next phase of research focus on higher productivity white spruce forests. As the group was meeting, the fast-moving Rosie Creek wildfire burned across 8,600 acres just west of Fairbanks, including about one third of the Bonanza Creek Experimental Forest, one of my ecological reserve sites. The fire burned a significant amount of productive white spruce forest and displayed particularly severe fire behavior because of the warm, dry conditions (see photo this page). Another coincidence, it seemed.

As the panel continued its work, I talked with the local investigators attending the review to define the research topics they thought were important now that the fire had occurred. We quickly developed a research plan, which we sent to local members of the state legislature as the legislative session in Juneau was ending and final agreements on appropriations were being made. The Fairbanks delegation arranged an immediate appropriation for the Rosie Creek Fire Research plan. The contributing scientists and I were amazed that it happened at all, let alone so quickly. The fire effects studies added to the considerable research history in the Bonanza Creek Experimental Forest, and in 1987 the area became one of the early sites in the NSF-supported Long Term Ecological Research (LTER) network.

During a sabbatical leave, the strong El Niño of 1987–88 kept climate anomalies before me as I visited five Canadian provinces in addition to 20 U.S. states and began to see firsthand the practical challenges of managing areas for biodiversity in a changing environment. I spent time with Gary Davis, biologist for Channel Islands National Park in southern California, who had developed what was universally recognized as the model environmental monitoring program for parks or nature reserves. I helped him record data in intertidal plots, documenting huge ecological effects cascading through the marine ecosystem—ultimately triggered by an exceptional warm water anomaly. Another coincidence?

As I returned from my sabbatical, a flurry of events related to global warming culminated in the Yellowstone fires of 1988 and James Hansen's testimony to Congress, which news media saw as the first unequivocal statement by an eminent scientist that ongoing temperature anomalies could be interpreted as human-caused global warming. But record warmth did not continue uninterrupted, and by the early 1990s it seemed that climate change had faded on the national agenda. I had to consider whether I would continue doing climate change work at that stage in my career. For me personally, the decision came down to this: how would I feel if the biggest change to affect northern forests in the past several thousand years occurred, and I was too busy to notice? I decided that even if the time scale of change put the confirmation of global warming effects past my retirement, I would go ahead and focus on the potential effects of warming on boreal tree growth and forest health.

Contradictory Tree-Ring Results

To complement the forest monitoring (looking forward in time) I had been doing, I wanted to study the history of forest growth and development (looking backward in time). So I began to learn tree ring analysis, with great help from Gordon Jacoby and Rosanne D'Arrigo of the Lamont-Doherty Tree Ring Laboratory of Columbia University. At that time, I wasn't interested in dendroclimatology, which involves using tree rings to reconstruct past climates, because reconstructions based on Alaska tree rings had been published for a number of years, and those questions seemed fairly settled.

For my first big tree ring sample, I used a chain saw to cut off stump sections from 100 large white spruce trees killed in the Rosie Creek Fire, a stand of some of the biggest, fastest growing trees in interior Alaska, and definitely not the kind of cold treeline site typically used for a tree ring-based climate reconstruction. Les Viereck's work at Bonanza Creek LTER had previously shown that, as you might expect, total productivity (ability to grow plant matter) was greatest on sites with warm soils and least on sites with cold soils (Viereck et al. 1986). Just for due diligence, I plotted my ring-width sample data against Fairbanks climate data, expecting to see no relationship. I was quite wrong, however, because the year-to-year change in temperatures and growth of my white spruce sample showed a strong relationship—only it was a negative relationship (see figure next page).

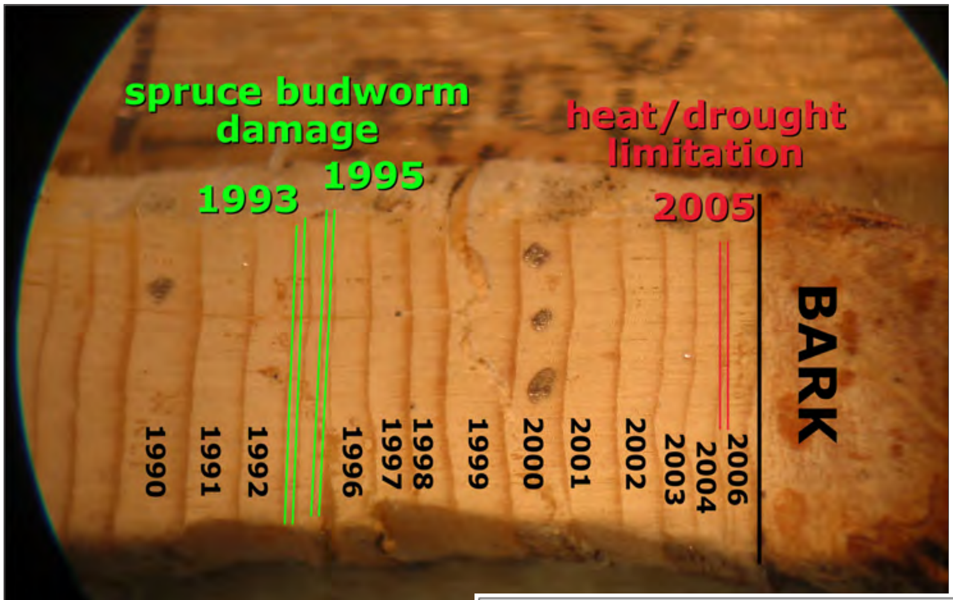
This meant that as summer temperatures increased the trees grew less, and as summer temperatures decreased the trees grew more. That just seemed the wrong result in Alaska, where all the published papers from "properly" collected tree samples at cold treeline sites show a positive relationship. I was concerned I might have made a mistake. A negative relationship between growing season temperatures and tree ring width, I knew, mainly happened on hot, dry sites as a result of drought stress limiting tree growth. If I had a valid result, the implications were very great for the boreal forest.

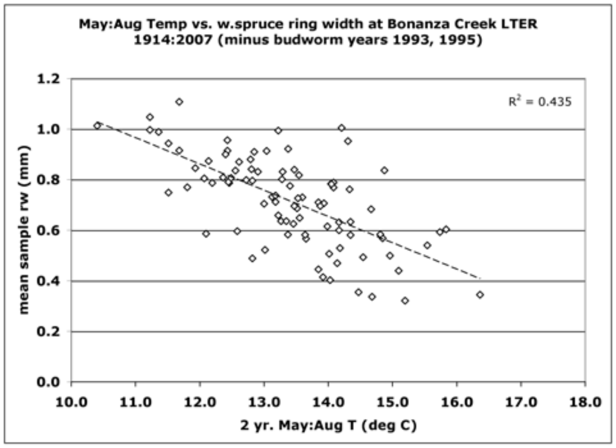
I increased my white spruce tree ring sampling effort with the same result. The trees were definitely not growing well in the regime of increasing summer temperatures that had begun in 1977 and strengthened since. But I wanted evidence about the mechanism causing the common growth signal in the trees.

About that time Valerie Barber, now at the UAF-Palmer Center for Sustainable Living, started a Ph.D. program, working with me and Bruce Finney, who ran a paleoecological lab in the Institute of Marine Science with expertise in stable isotopes. Val thought we might be able to use the carbon-13 (^{13}C) in the wood to measure moisture stress. From my samples, she painstakingly harvested the wood from each year's ring from several trees. Her lab was soon filled with little jars holding ground-up wood samples for later cellulose digestion and extraction.

I distinctly remember the moment Val brought all the data, and we sat down to plot isotopes versus ring width and temperature. If we were right about drought stress, ^{13}C would be related to temperature and ring width, and if we were wrong they would be unrelated. When the graphs appeared on the screen, the relationship was so strong that we laughed.

We knew that we had to get this story right, so Val went to the Lamont-Doherty Tree Ring Lab to measure wood density with x-ray. In most conifers if a tree has experienced high temperatures and/or drought, more of the year's growth is produced as dense latewood. Val did another meticulous job of preparing wood slices for analysis, and we found that the density data agreed with our ring width and ^{13}C results. Finally, I compared the isotope and density results to ring width during the 20th century in 269 white spruce trees from 20 stands across central Alaska. The relationship, which was the same for all the stands and nearly all the trees, was as strong in the first half of the 20th century as in the second half. Temperature-induced drought stress controlled the growth of these trees, which were representative of stands with the greatest value for timber production and the most active in taking up atmo-





Increased temperatures reduce growth of productive white spruce stands both directly and indirectly. Right: Growth of a monitored stand at the Bonanza Creek LTER is directly proportional to summer temperatures, and highest temperatures are the least favorable. Above: Record high temperatures in 2004 and 2005 led to severe reduction of the 2005 ring from drought stress; warm weather favorable to the spruce budworm led to growth reduction from defoliation in 1993 and 1995. Figures, this and facing page, courtesy of G.P. Juday.

spheric CO_2. Many, if not most, ecosystem or general circulation models had boreal trees grow more as temperatures increased, but we showed that these trees would do the opposite (Barber et al. 2000).

In follow-up work, Val and I isolated the oldest trees in our data set, extended the climate sensitivity analysis back another century, and performed a formal temperature reconstruction for central Alaska during the 1800s (Barber et al. 2004). We found signals in the 19th century of the Pacific Decadal Oscillation (PDO), as well as two unexpected periods of warm summers that were likely accompanied by large-scale fires (Juday et al. 2003). Overall, we could say that summer temperatures since the 1976–77 regime shift were the warmest in the past 200 years. In fact, given that mature spruce trees are often about 200 years old, the great majority of these trees probably had not experienced temperatures as warm in their lifetimes.

These results raised other issues as well. As I mentioned earlier, dendroclimatologists typically collect samples from “limiting stands” such as treeline, where trees are at their margin of cold tolerance and temperature effects on ring width should be less confounded by other factors; presumably, warming should mitigate, if not completely overcome, temperature limitation to growth. Yet accumulating evidence suggested that the relationship between site-based tree-ring chronologies and temperature predictions of growth became weaker around the mid-20th century (Briffa et al. 1998). If tree-rings don’t respond consistently to climate forcing functions, then the entire field of reconstructing past climates from tree-rings might need to be re-evaluated.

Doctoral student Martin Wilmking, now at the University of Greifsvald in Germany, did a comprehensive assessment of the relationship of white spruce trees to environmental characteristics at treeline. The published literature actually used relatively small samples, typically a few dozen trees carefully selected by the investigator based on a judgment that they were the most likely to contain a climate signal. The samples Martin and I analyzed ultimately totaled about 2,600 trees from 15 treeline and near-treeline locations in the Brooks Range and Alaska Range. A bit less than 40% of our treeline trees had a positive growth response to warming, as expected. In all but the coolest years, however, the growth of over 40% of the sampled trees was negatively related to midsummer temperatures (Wilmking et al. 2004). Once a threshold temperature was reached, additional warming reduced growth in these negative responders. So the apparent weakening of treeline response to recent temperature increases came from mixing samples in which growth responses to temperature varied, with some increasing and some decreasing (Wilmking et al. 2005). By using only one consistent responder type, tree ring temperature reconstructions could be reliable.

Obviously if global climate change was in fact occurring, its effects should also become evident on a larger scale. In 2004, the Arctic Council sponsored the Arctic Climate Impact Assessment, a major international collaborative study and synthesis of climate change and its effects across the circumpolar north. I was given the task of pulling together information on forests, land management, and agriculture with a large author team (Juday et al. 2005). It became clear that a period of major, sustained temperature increases was, in fact, underway in the North. In parts of the boreal forest with greater precipitation, such as eastern Canada, western Russia, and the Nordic countries, tree growth generally increased with increasing temperatures, but in the Russian Far East and central and western North American boreal region, temperature increases were often (but not exclusively) decreasing tree growth and increasing fire and insect outbreaks. I reported that in addition to white spruce, growth of some black spruce and Alaska birch populations responds negatively to warming.

The Changing Future

In assessing boreal forest response to warming, it had been assumed that forest fires and tree-damaging insect outbreaks, which are warm temperature phenomena, would increase as well. By the 1990s, the extent of fire in the global boreal forest had increased, but it was difficult to see the trend in the Alaska wildland fire record until 2004—then the fires of 2004 and 2005 burned over 4.2 million hectares in Alaska, equivalent in size to Sri Lanka. The unexpectedly large fire season of 2009 burned an additional 1.2 million hectares, resulting in a cluster of record or near-record fire years closely spaced over a mere six years. This rapid transformation of the landscape appears to be beyond previous disturbance regimes, taking us into an unknown future boreal forest.

Multiple and simultaneous outbreaks of forest damaging insects have occurred to greater extents as temperatures increased in the past 20 to 30 years in Alaska. In some cases, such as spruce budworm in central Alaska or the spruce bark beetle in south-central Alaska, outbreaks are clearly related to increasing temperatures. In others, such as aspen leaf miner, the cause is not known. There seems little doubt that continued temperature increases would allow the survival and successful reproduction of a greater variety of potentially forest-damaging insects, while the process of forest tree adaptation or addition of species is likely to be markedly slower.

The strong trend of increasing temperature and the variety and vast scale of major effects of warming on Alaska boreal forests are so obvious today that the continuing change is now impossible to ignore. But when did I become convinced?

I found myself facing that question a couple of years ago in an interview with the Finnish newspaper *Helsingin Sanomat*, and I realized that no single piece of evidence was responsible. From the beginning of my work, I knew that the temperature anomalies in Alaska might be an effect of global warming, but also that I might be wrong. I felt the need to test my interpretations and use the objections of those who disagreed to come back with more convincing evidence. After enough specific effects that were anticipated—if not predicted—had occurred, I just got to the point that it was unreasonable to me to believe that the global warming explanation was wrong. During the opportunities we have had to explain our results, my colleagues and I have always tried to convey that sense of how science works. We constantly have to test our ideas and look for consistency in our explanations. And when we find it, we need to draw the conclusions that are the most reasonable. ■

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A spruce budworm feeding on a tree on the University of Alaska Fairbanks campus in 2008. Outbreaks of this insect were rare or unknown in Alaska until temperature increases created favorable conditions.

Further Reading

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PRB Study Leads to Release of Arctic Sea Ice Imagery

In July 2009, the Polar Research Board (PRB) issued a report, *Scientific Value of Arctic Sea Ice Imagery Derived Products*, recommending the release of a suite of arctic sea ice images collected by U.S. government intelligence sources. The PRB report committee determined that the images could help scientists examine the effects of climate change and the impacts of diminishing sea ice and lead to significant improvements in the development of climate models. Shortly after the report was released, the U.S. Geological Survey's (USGS) Civil Applications Program launched a website to disseminate a selection of these sea ice images.

During the 1990s, the U.S. government's Medea program brought together scientists and members of the intelligence community to apply classified information and data to further the understanding of environmental change. Under Medea auspices, the Global Fiducials program enabled participating scientists to request collection of classified images at environmentally sensitive locations around the globe. The term "fiducials" refers to the fact that the classified images were to be kept "in trust" in classified archives, with the eventual goal of declassification and release to the broader scientific community for research purposes. In 1999, scientists requested that the intelligence community collect images of sea ice at four locations in the Arctic Basin during the summer months; two additional locations were added in 2005 (see box). Images have been collected at these sites during the summer months until the present day.

Location	Year Collected and Number of Images Available
Barrow (71°N, 156°E)	2005–2006: 18 images 2007–2008: 8 images
Beaufort Sea (73°N, 150°W)	1999: 12 images 2000: 33 images 2001: 27 images 2002–2005: 19 images 2006–2008: 19 images
Chukchi Sea (70°N, 170°E)	2005–2006: 20 images 2007–2008: 7 images
Canadian Arctic (85°N, 120°W)	1999: 12 images 2000: 31 images 2001: 30 images 2002–2006: 16 images 2007–2008: 20 images
Canadian Fram Strait (85°N, 0°E)	1999–2000: 28 images 2001: 46 images 2002–2006: 19 images 2007–2008: 14 images
East Siberian Sea (82°N, 150°E)	2000: 32 images 2001: 32 images 2002: 23 images 2005–2007: 20 images 2008: 25 images

In later years of the program, images called Literal Imagery Derived Products (LIDPs) were produced from the classified data at a resolution deemed suitable for unclassified release. To date, several hundred unclassified LIDPs have been produced from the images collected at the six arctic sites and will continue to be produced from classified sources in the future.

To assist in the process of making the unclassified derived imagery more widely useful, the PRB committee reviewed the images and considered their potential uses for scientific research. The resulting report contains information on the importance of sea ice in the Arctic and illustrates possible uses of the derived images.

Projections of future arctic ice cover are hampered by poor understanding of sea ice physical processes because few observations exist at appropriate times and scales. Readily available satellite images are too coarse to capture the details, the report says. In addition, collecting ground-based data by maintaining manned-drifting stations is challenging due to rapidly changing environmental conditions and the weak platform of ice, and collecting data from observational aircraft flights is difficult and expensive.

The U.S. Geological Survey's Civil Applications Program recently launched a website to disseminate a selection of aerial sea ice images, which were derived from satellite imagery classified by the U.S. government. The box at left shows the location, year collected, and number of sea ice images available on the site (note that some of the LIDP images listed here are a compilation of several smaller LIDP images). The images at left, taken in July 2006 and 2007 over Barrow, Alaska, are available on the site as well.

Committee members identified immediate priorities for dissemination: all data from 2007–2008, which would enhance the value of a broad range of intensive ground-based observations carried out during the International Polar Year, as well as all images from both the Barrow and Beaufort Sea locations. The data from Barrow will provide information that may help inform coastal communities on ecosystem shifts as they adapt to a changing climate, and the images from the Beaufort Sea depict a broad range of ice types and ages that can add to scientists' ability to monitor and forecast ice movement.

The committee concluded that the images should be released to the public as soon as possible and outlined what information should be included in the metadata. The committee recognized the need for additional observations at the North Pole as well as dynamic image collection designed to enable scientists to track specific ice floes and to study how their features change over time; this would complement the existing system whereby images are taken at a particular point in space as various ice features pass through. The committee also noted that any corresponding radar data should be made available as well.

In response to the report recommendations, the USGS Civil Applications Program made the images and accompanying metadata publicly available on the Global Fiducials Library website at: http://gfl.usgs.gov/ArcticSeaIce.shtml. The site currently contains a total of 700 LIDP images produced from imagery at the arctic sites (see box and images at left), and USGS plans to continue to publish LIDP images online as new observations are collected.

The PRB is a unit within the National Academies and is responsible for studies related to the Arctic, Antarctic, and cold regions in general. The report is available online at: www.nap.edu/catalog/12631.html. For more information, contact study director Curtis Marshall (cmarshall@nas.edu; 202-334-3533).

Study Explores Inuit Hunting and Economic Strategies

The subsistence practices of arctic peoples have long occupied the attention of social scientists working in the north. Research over the past four decades has established the continued importance of subsistence hunting to both the economies of northern communities and the maintenance of Inuit identity at a time of rapid social change. Generally speaking, this research has documented that subsistence hunting continues to be an important source of food for Inuit, but hunting from a modern settlement requires access to a variety of resources. Hunters require money, obtained through wage labor, to acquire the equipment and fuel used for hunting, as well as access to traditional capital (tools and kin connections) to engage effectively in the subsistence economy. Successful hunting also requires a significant store of traditional knowledge about animals and the environment.

As part of a project funded by the NSF Arctic Social Sciences program, Peter Collings of the University of Florida and George Wenzel of McGill University have been conducting fieldwork in two Inuit communities, Ulukhaktok (formerly Holman) in the Western Canadian Arctic and Clyde River on Baffin Island, to collect comparative data on contemporary Inuit hunting and economic strategies. Their research, which focuses on a cohort of adults born between 1955 and 1970 and raised primarily in these communities, is aimed at understanding the challenges that this generation of Inuit have faced as they confront a rapidly changing economy, society, and climate while retaining their cultural identity.

Collings and Wenzel worked with the same group of people between 1992 and 1994 in another study exploring the same issues, which has allowed for an understanding of how these communities have changed over time and how those changes affect Inuit. Initial results from Ulukhaktok suggest that over a 15-year period, Inuit have faced increasing economic burdens in terms of the stagnation of real wages and increases in the costs of living. Economically, Inuit in this cohort are considerably worse off today than they were when Collings and Wenzel initially began their work in the 1990s.

While data collection continues in Clyde River, initial analysis of food sharing data from Ulukhaktok has focused on the patterns of food sharing between hunters and recipients that differ in degree of relatedness (kinds of kin) and how different strategies for generating money result in different patterns of interaction between community residents. Preliminary analysis of connections between economic strategies and kinds of kin demonstrate that Inuit who self-identify as hunters while pursuing a strategy of casual wage labor and/or provide guide services to sport hunters commonly share subsistence food with their extended families and more distantly related kin. Inuit who are engaged in full-time employment, on the other hand, tend to focus their subsistence food exchanges within their nuclear families.


Larry Olifie, a resident of Ulukhaktok butchering a muskox on Holman Island in March of 2007. Meat from this animal was given to his father and siblings, and some of the animal was used to feed his father's dog team. Photo courtesy of Peter Collings.

Study results also suggest that, on one level, engaging in full-time wage labor as an economic strategy is socially isolating when it comes to the movement of country food and, by extension, limits access to knowledge and material items used in subsistence. On the other hand, hunters who connect with a larger number of distant kin and non-kin can use those connections to gather and share information and material related to successful hunting.

These differences in sharing patterns also have deeper implications, especially in the context of a rapidly changing climate. If the ability for a settlement to adapt is predicated upon the ability of a group of people to act collectively, for example, then contemporary economic trends that encourage wage labor and discourage subsistence hunting are troubling, since wage employment fosters the isolation of individuals within the community. Furthermore, although it seems that an economic strategy focusing on subsistence hunting at the expense of wage labor might provide the flexibility to adapt to changing circumstances, such as those presented by climate change, social forces may effectively prevent many Inuit from pursuing such a strategy.

Detailed analysis of food networks in Ulukhaktok continues, and the results will be compared with data currently being collected in Clyde River. Once complete, a comparison between the settlements at both times (1992–1994 and 2007–2009) will allow for a more complete understanding of changing patterns over time and specific social and economic conditions that may influence decisions about sharing.

In May 2009, an article describing Colling's experiences with participant observation as a research strategy in these communities appeared in the journal *Field Methods.* A paper on this project is also under review at the journal *Arctic,* and final reports will be made to the communities of both Ulukhaktok and Clyde River.

For more information, contact Peter Collings (collings@anthro.ufl.edu, 352-392-2253, Ext. 239). ■

Project Investigates Fire Behavior of the Past and Future

Over the past 40 years, fire activity in the boreal forests of North America has increased dramatically, and this increase can be attributed primarily to anthropogenic climatic change; the annual area burned increased from an average of ~12,000 km² per year in the 1960s to ~30,000 km² per year in the 1990s. Such short-term historic observations, however, do not capture the full spectrum of boreal fire responses to climate change, and predictive models based on historic observations may be constrained by assumptions derived from climate-fire relationships over the observational record. Holocene paleorecords provide a longer-term perspective on fire-climate relationships, including evidence that changes in the composition of vegetation and abundance of fuels play a key role in shaping fire regimes in Alaska.

In a project funded by the NSF Arctic Natural Sciences program, Feng Sheng Hu (University of Illinois) and Scott Rupp (University of Alaska) are integrating paleoecological analysis and ecosystem modeling to elucidate the linkages between fire regimes and climate change. They are interested in understanding boreal fire regime dynamics from the past 6,000 years and using this information to simulate possible future trends in the 21st century. Hu and Rupp are working with scientists from the University of Washington and the University of Idaho and graduate students from the University of Illinois.

The research team has conducted field work in the Copper River and Yukon-Old Crow basins, which are located in south-central and interior Alaska, respectively. These two ecoregions have similar physiography and vegetation but differ in terms of modern fire regime and climate trends.

The researchers extracted sediment cores from more than 30 lakes in the two regions and conducted charcoal analysis of each core to reveal past fire events around each lake. They then statistically interpreted the results to derive the fire history of the two ecoregions during the past 6,000 years. Hu and Rupp also reconstructed climate and vegetation change using paleoecological and isotopic analyses, which allowed examination of fire regime response to a range of temperature and moisture combinations within the context of vegetation change.

The team found that, in certain areas, recent fire regimes are not representative of long-term patterns. For example, over the past 55 years, during which time observations have been collected by the Alaska Fire Service, the boreal forests of the Copper River Basin rarely burned, whereas interior Alaska was characterized by high fire frequency. Over the past 6,000 years, however, the Copper River Basin burned as frequently as interior Alaska. This result implies a dramatic shift in the mechanisms controlling fire occurrence over recent decades, possibly linked to changes in atmospheric circulation patterns affecting storm frequency and/or intensity and duration of summer drought.

The team then used the Alaskan Frame Based Ecosystem Code (ALFRESCO) model to evaluate causal relationships among fire, climate, and vegetation and to simulate regional fires in boreal forests under 21st century climate scenarios. ALFRESCO simulations showed that a change to black spruce dominance around 5,000 years ago led to more frequent fires, despite the development of cooler and wetter conditions.

Preliminary results also suggest that climate warming during the 21st century will initially increase fire frequency and area burned. This increase in fire activity could lead to a shift from conifer-dominated to broadleaf-dominated vegetation. Since deciduous stands have lower flammability than conifers, the increased dominance of broadleaf species would have significant impacts on the structure and function of the boreal forest by the middle of the 21st century. These impacts include changes in vegetation distribution, increases in fire frequency, and changes in the spatial dynamics of vegetation. These changes could shift the boreal forest in interior Alaska into a novel state where smaller, more frequent fires are most common. The simulations suggest that this trend continues until the last several decades of the 21st century, when even deciduous trees burn readily under exceptionally warm and dry climate conditions. This outcome is consistent with the five General Circulation Models that best depict historical climate in Alaska and three emission scenarios from the most recent Intergovernmental Panel on Climate Change report.

The team completed their final field season in summer 2009. Findings are being shared with multiple stakeholders, including the U.S. Fish and Wildlife Service, Bureau of Land Management Alaska Fire Service, National Park Service, Bureau of Indian Affairs, State of Alaska, and private citizens.

For more information, contact Feng Sheng Hu (fshu@life.illinois.edu) or Scott Rupp (scott.rupp@uaf.edu).

Sediment records from lakes like this one, located north of Fairbanks in interior Alaska, reveal the local fire history and vegetation and climate conditions associated with fire. This site burned in 2004, which was a record setting fire season in Alaska—over 2.6 million hectares burned. While any individual year cannot be associated with predicted changes, the activity seen in 2004 is consistent with the trend of increasing fire activity in the boreal forests of North America. Photo courtesy of P. Higuera.

Study Reveals How Glacial Lakes Influence Ice Sheet Flow

Along its western margin, the Greenland Ice Sheet flows seaward at speeds of roughly 100 m/yr. Embedded within the ice sheet are faster flowing (200–15,000 m/yr) outlet glaciers that discharge ice directly to the ocean. Each summer the ice sheet surface melts at rates that can exceed 2.5 m/yr. When glacial mass balance is negative, the excess ice and water lost to the ocean contributes to sea level rise. Recent changes—in particular, increased rates of speed (50–100%) for many large outlet glaciers—have amplified Greenland's contribution to sea-level rise from near zero in the 1990s to a current imbalance of roughly 150 to 250 Gtons/yr (equivalent to 0.4–0.7 mm of sea level rise per year).

Glacial motion results from a combination of internal deformation of ice under its own weight, sliding at the ice-bed interface, and deformation of underlying sediments. Basal sliding over a well-lubricated bed is often the source of fast (>100 m/yr) ice motion. Greenland's large coastal melt rates have prompted widespread speculation that a warmer climate will increase melting, which, in turn, will enhance basal lubrication and hasten ice-sheet retreat. Poor knowledge of this process, though, limits quantitative prediction of future ice sheet contribution to sea level rise, as noted by the Intergovernmental Panel on Climate Change.

To address such uncertainties, the NSF Arctic Natural Sciences program and the National Aeronautics and Space Administration jointly funded Ian Joughin of the University of Washington and Sarah Das of the Woods Hole Oceanographic Institution to investigate the role of Greenland's supra-glacial lakes (see top image) in influencing ice sheet flow.

Joughin and Das initially focused on determining how water can make its way to the base of the ice sheet through ice more than 1 km thick. Several theoretical studies had suggested this could be accomplished through hydro-fracturing. Such fractures were thought to occur when water on the surface penetrates a crevasse or other surface crack. Because water is denser than ice, pressure at the bottom of a water-filled crack is higher than in adjacent ice, so the water effectively acts as a "wedge" driving the crack farther into the ice. If the water level drops as the crack opens, the pressure is relieved, and the crack stops propagating. If, however, the crack stays full, then it should propagate all the way through even the thickest ice. Supra-glacial lakes provide a large reservoir of water that could keep such propagating cracks filled.

While the hydro-fracturing process was well established in theory, it was not clear whether it actually occurred in nature. To investigate this process, Joughin, Das, and their research team instrumented two lakes on the west coast of Greenland with Global Positioning Systems (GPS), seismometers, lake-level loggers, and weather stations. The instruments have been in place since 2006, and, over the three summer seasons thus far, data have been collected during six lake drainages. While it was known from satellite images that large lakes could drain overnight, the data indicated that the lakes could completely drain in 90 minutes or less, with flow into the crack exceeding the rate of flow over Niagara Falls (8,700 m^3/s). The GPS also recorded uplift of the ice surface during the drainage events as the water flooded beneath the ice sheet, indicating it made it all the way to the glacial bed.

Although data from the lake sites clearly established that water does reach the bed, this investigation demonstrated that one of the more dire scenarios of run-away ice loss as surface melt lubricates the base of the ice sheet is unlikely to occur. Using a combination of GPS data and satellite images, the researchers showed that summer increases in speed averaging 50–100 m/yr occur over a broad area along the margin of the Greenland Ice Sheet. On the slow moving ice sheet (~100 m/yr), this increase represents almost a doubling in speed. On fast moving glaciers (500 to 15,000 m/yr), which move the bulk of the ice to the ocean, however, the effect of the seasonal increase in speed is small in a relative sense, having little effect on sea level.

The top image shows a supra-glacial melt lake on the Greenland Ice Sheet at ~950 m elevation. The lake is ~1.5 km wide and ~10 m deep. The bottom image shows a lake bed bisected by an ~3 km long crack through which the lake drained in ~90 minutes. Photo courtesy of Ian Joughin.

Nevertheless, a sudden transition from a frozen to melted bed could have a substantial influence on flow. The base of an ice sheet can either be frozen so that ice must deform over it or melted so that ice can slide over it. A warming climate will likely cause inland migration of the zone where supra-glacial lakes form. If hydro-fracturing at these lakes can breach the thicker ice in the interior regions, where the ice is currently frozen to the bed, the heat delivered by the surface melt could thaw and lubricate the bed over a wide area, potentially destabilizing the ice sheet. Whether this represents a minor or major effect remains uncertain.

For more information, contact Ian Joughin (ian@apl.washington.edu) or Sarah Das (sdas@whoi.edu).

ARCSS Announces Awards for Seasonality Research

Awards were announced in July and August 2009 for the Arctic System Science (ARCSS) Program's most recent solicitation, Changing Seasonality in the Arctic System (CSAS). NSF received 71 individual proposals in response to the solicitation, representing approximately $30 million in requested funding—40 awards totaling $14.3 million were made (see facing page for details). More than 85% of the funding for the 17 projects was provided through funds from the American Recovery and Reinvestment Act.

Awards were also recently announced for ARCSS research funded through the Arctic Research Opportunities solicitation. A total of 19 awards were made totaling $5.6 million—all of the funds for these awards were provided through the American Recovery and Reinvestment Act. Information on these projects appears in the box on this page and more information about the Arctic Research Opportunities solicitation is available at: www.nsf.gov/funding/pgm_summ.jsp?pims_id=5521&org=OPP.

Other recent ARCSS activities include discussions with the Study of Environmental Arctic Change (SEARCH) Science Steering Committee about improved integration between ARCSS and SEARCH activities.

For more information, go to: www.arcus.org/arcss/index.html, or contact Neil Swanberg (nswanber@nsf.gov), Josh Schimel (schimel@lifesci.ucsb.edu), or Helen Wiggins (helen@arcus.org). ■

2009 ARCSS Projects Funded through Arctic Research Opportunities Solicitation

Analysis and Attribution of Changes in Siberian Hydroclimate and Implications for the Future.

Judah Cohen (Atmospheric and Environmental Research Inc). #0909457, *$180,389.*

Jessica Cherry, Vladimir Alexeev (University of Alaska Fairbanks [UAF]). #0909525, *$283,374.*

Mathew Barlow (University of Massachusetts Lowell). #0909272, *$175,150.*

Arctic Research Using the Community Climate System Model.

Peter Gent, Marika Holland (University Corporation for Atmospheric Research). #0908675, *$776,475.*

Environmental Changes Alter the Carbon Cycle of High Arctic Ecosystems: Shifts in the Ages and Sources of CO_2 and DOC.

Claudia Czimczik (University of California Irvine). #0909514, *$617,647.*

Jeffrey Welker, Patrick Sullivan (University of Alaska Anchorage). #0909538, *$502,530.*

Joshua Schimel (University of California Santa Barbara). #0909510, *$301,642.*

Nonlinearities in the Arctic Climate System During the Holocene.

Darrell Kaufman (Northern Arizona University). #0909332, *$315,789.*

Gifford Miller, Scott Lehman, Yarrow Axford (University of Colorado at Boulder). #0909347, *$685,013.*

Jason Briner (State University of New York at Buffalo). #0909334, *$209,379.*

Raymond Bradley (University of Massachusetts Amherst). #0909354, *$209,087.*

Mark Abbott (University of Pittsburgh). #0908200, *$141,355.*

Bruce Finney (Idaho State University). #0909310, *$136,780.*

Zicheng Yu (Lehigh University). #0909362, *$128,175.*

Feng Sheng Hu (University of Illinois at Urbana-Champaign). #0907986, *$120,784.*

Matthew Wooller (UAF). #0909523, *$119,999.*

Michael Loso (Alaska Pacific University). #0909322, *$79,786.*

Regional Climate Modeling of Volcanic Eruptions and the Arctic Climate System.

Alan Robock (Rutgers University). #0908834, *$342,401.*

Troposphere-Stratosphere Coupling and Linkages to High Latitude Climate Variability.

Judah Cohen (Atmospheric and Environmental Research Inc). #0909459, *$299,940.* ■

Edmonds Joins OPP as New Arctic Natural Sciences Program Director

Henrietta (Hedy) Edmonds joined the Office of Polar Programs in April 2009 as the Arctic Natural Sciences program director, replacing Jane Dionne, who retired in 2008. Edmonds' appointment is a permanent staff position. In addition to working with Bill Wiseman on the diverse Arctic Natural Sciences program, Edmonds will also manage the Postdoctoral Fellowships in Polar Regions Research.

Edmonds is a marine chemist with research interests in both tracer oceanography and hydrothermal geochemistry. She earned a B.S. in Chemistry from Yale in 1991 and a Ph.D. in Oceanography from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in 1997. She did postdoctoral work at the University of Rhode Island and at the Southampton Oceanography Center in the U.K. before joining the faculty at the Department of Marine Science and Marine Science Institute at the University of Texas at Austin in 1999.

For more information, go to www.nsf.gov/div/index.jsp?org=ARC or contact Hedy Edmonds (hedmonds@nsf.gov, 703-292-8029). ■

2009 Changing Seasonality in the Arctic System (CSAS) Awards

A Change of Seasonality of the Upper Arctic Ocean in Response to Atmospheric and Sea Ice Forcing.

Jiayan Yang (Woods Hole Oceanographic Institution [WHOI]). #0902090, *$497,366.*

Changing Seasonality of the Arctic: Alteration of Production Cycles and Trophic Linkages in Response to Changes in Sea Ice and Upper Ocean Physics.

Jinlun Zhang, Michael Steele (University of Washington [UW]). #0901987, *$391,639.*

Yvette Spitz (Oregon State University). #0901924, *$248,347.*

Carin Ashjian (WHOI). #0901131, *$152,342.*

Robert Campbell (University of Rhode Island). #0901926, *$108,539.*

Diamonds and Oil from the Tundra: A System Study on the Impact of Changing Seasons on Mining and Oil Exploration.

Matthew Sturm, Thomas Douglas (U.S. Army Cold Regions Research and Engineering Laboratory [CRREL]). #0902130, *$250,164.*

Michael Goldstein (Babson College). #0902066, *$173,191.*

Effects of Lengthening Growing Season and Increasing Temperature on Soil Carbon Fluxes and Stocks in Arctic Tundra.

Jianwu Tang (Marine Biological Laboratory [MBL]). #0902109, *$99,879.*

How Does Changing Seasonality Affect the Capacity of Arctic Stream Networks to Influence Nutrient Fluxes from the Landscape to the Ocean?

William Bowden (University of Vermont). #0902106, *$549,581.*

Michael Gooseff (Pennsylvania State University [PSU]). #0902029, *$373,268.*

Wilfred Wollheim (University of New Hampshire). #0902113, *$340,920.*

How the Timing of Summer Precipitation Affects the Responses of Boreal Forest to Climate Change.

Daniel Mann, T. Scott Rupp, Paul Duffy (University of Alaska Fairbanks [UAF]). #0902169, *$797,130.*

Elise Pendall (University of Wyoming). #0902180, *$149,961.*

Andrea Lloyd (Middlebury College). #0902088, *$143,937.*

Impacts of the Changing Seasonality of Wind-Driven Mixing on the Arctic System.

Luc Rainville, Rebecca Woodgate, Muyin Wang (UW). #0901407, *$518,993.*

Amala Mahadevan (Boston University). #0901650, *$201,559.*

Patricia Matrai (Bigelow Laboratory for Ocean Sciences). #0901438, *$104,337.*

Pan-Arctic Climate and Ecosystem Response to Historical and Projected Changes in the Seasonality of Sea Ice Melt and Growth.

Bonnie Light (UW). #0902040, *$279,690.*

Donald Perovich (CRREL). #0902020, *$197,188.*

Marika Holland (University Corporation for Atmospheric Research [UCAR]). #0902068, *$134,733.*

Jefferson Moore (University of California Irvine). #0902045, *$91,955.*

Seasonality of Circumpolar Tundra—Ocean and Atmosphere Controls and Effects on Energy and Carbon Budgets.

Howard Epstein (University of Virginia). #0902152, *$358,777.*

Uma Bhatt, Donald Walker (UAF). #0902175, *$369,016.*

Michael Steele (UW). #0902042, *$192,833.*

Seasons of Change in the Arctic Environment.

Mark Serreze, Tingjun Zhang, Andrew Slater, Oliver Frauenfeld, Kevin Schaefer (University of Colorado Boulder [CU]). #0901962, *$862,974.*

Shifting Seasonality of Arctic River Hydrology Alters Key Biotic Linkages Among Aquatic Systems.

Linda Deegan, Bruce Peterson (MBL). #0902153, *$1,317,687.*

Alexander Huryn (University of Alabama Tuscaloosa). #0902126, *$307,269.*

Shifting Seasonality of Northern Forest Response to Arctic Environmental Change.

Rosanne D'Arrigo, Kevin Anchukaitis (Columbia University). #0902051, *$381,154.*

Scott Goetz, Pieter Beck (Woods Hole Research Center). #0902056, *$221,838.*

The Changing Seasonality of Tundra Nutrient Cycling: Implications for Ecosystem and Arctic System Functioning.

Michael Weintraub (University of Toledo). #0902096, *$461,684.*

Heidemarie Steltzer, Matthew Wallenstein (Colorado State University). #0902030, *$409,117.*

Joshua Schimel (University of California Santa Barbara). #0902038, *$313,386.*

Patrick Sullivan (University of Alaska Anchorage). #0902184, *$225,072.*

Edward Rastetter (MBL). #0902102, *$180,926.*

The Seasonal Response of the Arctic and Global Climate System to Projected Sea Ice Loss within the Context of GHG-Induced Climate Change.

Clara Deser, Marika Holland, David Lawrence (UCAR). #0902065, *$670,103.*

Andrew Slater (CU). #0902057, *$114,868.*

Timing is Everything: Seasonality and Phenological Dynamics Linking Species, Communities, and Trophic Feedbacks in the Low- vs. High-Arctic.

Eric Post, Mads Forchhammer (PSU). #0902125, *$363,137.*

Tracking the Seasonal Contribution of Algal Fatty Acids to the Arctic Marine System.

Matthew Wooller, Rolf Gradinger, Gay Sheffield, Katrin Iken, Larissa Dehn (UAF). #0902177, *$617,856.*

Understanding Climate-Driven Phenological Change: Observations, Adaptations, and Cultural Implications in Northeastern Siberia and Labrador/Nunatsiavut.

Susan Crate (George Mason University). #0902146, *$620,822.*

Astrid Ogilvie (CU). #0902134, *$566,517.*

NSF Awards $35 Million in AON Projects

In July 2008, NSF released a solicitation for the Arctic Observing Network (AON). Proposals were due 30 September 2008, and the agency anticipated making 15–20 awards totaling $18–24 million over 3–5 years. NSF received 57 proposals requesting $69 million for 36 projects. In June 2009, NSF announced funding totaling $35 million for 20 AON projects (see box, facing page). Nine awards fund five projects that have not previously received AON Program funds, and 23 awards support the continuation of 15 existing AON projects. The current Arctic Research Opportunities solicitation invites AON proposals (www.nsf.gov/funding/pgm_summ.jsp?pims_id=5521&org=OPP).

In July 2009, NSF released a solicitation for Organization of Projects on Environmental Research in the Arctic (OPERA). This solicitation seeks proposals for activities to foster and sustain collaboration among projects funded by NSF that contribute to the U.S. arctic environmental change research effort, many of which are affiliated with the AON and the interagency Study of Environmental Arctic Change (SEARCH). NSF anticipates making 1–4 awards totaling $10–15 million over three years. Proposals are due 11 December.

AON Meetings

Principal investigators of AON projects will hold their annual meeting in Boulder, Colorado, on 30 November–2 December. Craig Lee of the University of Washington will chair the meeting. Goals include:

- reviewing AON science achievements, network layout and scope, lessons learned, and evolution following the International Polar Year;
- beginning a broad evaluation of AON network design;
- evaluating current and future AON integration and cooperation with interagency and international efforts; and
- evaluating the flow and dissemination of AON data, with emphasis on access and usage by the science community and stakeholders.

The AON PI meeting will be followed by a workshop of the new AON Design and Implementation (ADI) task force, chaired by Hajo Eicken of the University of Alaska Fairbanks, on 2–4 December. NSF has tasked the ADI task force with developing

- guidance on coordinating, consolidating, and optimizing the existing observing system elements; and
- a broader strategy that includes more detailed design studies to enhance and sustain the observing system.

The ADI task force is composed of researchers with observing system expertise both within and outside of the Arctic. Plans include a combination of virtual and in-person meetings, two workshops, and a small array of proof-of-concept or exploratory studies overseen by the task force, culminating in a summary report with recommendations for the next steps in optimizing, coordinating, and enhancing the existing components of an international arctic environmental observing system, with emphasis on the U.S. AON.

More information is available through the following links or by contacting AON program director Martin Jeffries at NSF (mjeffrie@nsf.gov; 703-292-7442).

AON: NSF website (www.nsf.gov/funding/pgm_summ.jsp?pims_id=503222&org=ARC&from=home) or the Cooperative Arctic Data and Information Service (CADIS) website (www.aoncadis.org).

AON Meetings: Joint Office of Science Support website (www.joss.ucar.edu/events/2009/aon/index.html).

ADI Task Force: ARCUS website (www.arcus.org/search/aon.html). ■

State of the Arctic Conference Set for March 2010

Planning continues for the State of the Arctic Conference, which will be held 16–19 March 2010 at the Hyatt Regency Miami in Miami, Florida. The main goal of the conference is to review our understanding of the arctic system in a time of rapid environmental change. It will provide an open international forum for discussion of future research directions aimed toward a better understanding of the arctic system and its trajectory. Topics will range from basic understanding of the Arctic and system-wide change to developing response strategies to adapt and mitigate change.

Community input is being integrated into the conference program, which will be available soon on the conference website. Major science themes include:

- Advances in arctic system understanding—the basic functioning of the arctic system, including all of its human dimensions;
- Arctic change—rapid, system-scale changes and the capability to project future states of the arctic system under various scenarios;
- Linkages to the Earth system—linkages and feedbacks between the arctic system and the Earth system; and
- Translating research into solutions—informed solutions to the problems caused by environmental change.

Major funding for the conference is provided by NSF, with several U.S. and international partners and co-sponsors, including: the National Oceanic Atmospheric Administration (NOAA), the U.S. Arctic Research Commission (USARC), the International Study of Arctic Change (ISAC), the Canadian ArcticNet Network of Centres of Excellence, and the European Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) program. The Arctic Research Consortium of the U.S. (ARCUS) is organizing the conference on behalf of the arctic community and sponsoring organizations.

Additional sponsors are invited, and interested parties are encouraged to contact Helen Wiggins at ARCUS (helen@arcus.org). More information is available on the State of the Arctic Conference website (http://soa.arcus.org). ■

2009 Arctic Observing Network Awards

Note that awards listed under the categories of atmosphere, ocean and sea ice, hydrology/cryosphere, terrestrial ecosystems, and data and information management are continuing projects.

New Projects

An Interdisciplinary Monitoring Mooring in the Western Arctic Boundary Current: Climatic Forcing and Ecosystem Response.

Robert Pickart (Woods Hole Oceanographic Institution [WHOI]. #0856244, *$2,317,495.*

Kathleen Stafford (University of Washington [UW]). #0855828, *$271,917.*

Jeremy Mathis (University of Alaska Fairbanks [UAF]). #0856210, *$195,417.*

Fire in the Arctic Landscape: Impacts, Interactions, and Links to Global and Regional Environmental Change.

Gus Shaver (Marine Biological Laboratory). #0856853, *$911,715.*

Integrated Characterization of Energy, Clouds, Atmospheric State, and Precipitation at Summit (ICECAPS).

Von Walden (University of Idaho). #0856773, *$898,408.*

Matthew Shupe (University of Colorado [CU]). #0856559, *$598,504.*

David Turner (University of Wisconsin [UWisc]). #0904152, *$421,158.*

The Circumpolar Active Layer Monitoring Network—CALM III (2009–2014): Long-term Observations on the Climate-Active Layer-Permafrost System.

Nikolay Shiklomanov, Fritz Nelson (University of Delaware). #0856421, *$1,662,201.*

UpTempO: Measuring the Upper Layer Temperature of the Arctic Ocean.

Michael Steele, Ignatius Rigor (UW). #0856177, *$875,222.*

Atmosphere

A Replacement Laser for the Arctic High Spectral Resolution Lidar.

Ed Eloranta (UWisc). #0856503, *$88,773.*

Continued Core Atmospheric and Snow Measurements at the Summit, Greenland Environmental Observatory.

Joe McConnell, Roger Bales (Desert Research Institute). #0856845, *$1,254,266.*

Ultraviolet Radiation in the Arctic.

John Frederick (University of Chicago). #0856268, *$696,904.*

Ocean and Sea Ice

An Array of Autonomous Ocean Flux Buoys to Directly Observe Turbulent Vertical Fluxes of Heat, Salt, and Momentum as a Component of the Arctic Observing Network.

Timothy Stanton, Richard Krishfield, William Shaw (Naval Postgraduate School). #0856868, *$390,107.*

An Ocean Observing System for the Bering Strait, the Pacific Gateway to the Arctic—An Integral Part of the Arctic Observing Network.

Rebecca Woodgate, Ronald Lindsay (UW). #0855748, *$1,224,449.*

Thomas Weingartner, Terry Whitledge (UAF). #0856786, *$772,111.*

Autonomous Ice Mass Balance Buoys for an Arctic Observing Network.

Jacqueline Richter-Menge, Donald Perovich (U.S. Army Cold Regions Research and Engineering Lab [CRREL]). #0856376, *$445,555.*

Bering Sea Sub Network: A Distributed Human Sensor Array to Detect Arctic Environmental Change.

Victoria Gofman, Patricia Cochran (Aleut International Association). #0856774, *$2,499,989.*

Lilian Alessa, Andrew Kliskey (University of Alaska Anchorage [UAA]). #0856305, *$545,143.*

Collaborative Research on the State of the Arctic Sea Ice Cover: Sustaining the Integrated Seasonal Ice Zone Observing Network (SIZONET).

Hajo Eicken, Mark Johnson, Amy Lovecraft, Thomas Heinrichs, Christian Petrich (UAF). #0856867, *$251,913.*

Don Perovich, Matthew Sturm (CRREL). #0856377, *$188,231.*

Continuation of the Ice-Tethered Profiler Contribution to the Arctic Observing Network.

John Toole, Carin Ashjian, Andrey Proshutinsky, Richard Krishfield, Mary-Louise Timmermans (WHOI). #0856479, *$4,622,113.*

Continuing the Beaufort Gyre Observing System to Document and Enhance Understanding Environmental Change in the Arctic.

Andrey Proshutinsky, John Toole, Richard Krishfield, Mary-Louise Timmermans (WHOI). #0856531, *$5,274,224.*

Coordination, Data Management, and Enhancement of the International Arctic Buoy Programme.

Ignatius Rigor (UW). #0856292, *$1,000,000.*

Sustained Observations of the North Pole Environment to Characterize Ongoing Arctic Change.

James Morison, Richard Moritz, Andreas Heiberg, Michael Steele (UW). #0856330, *$1,050,346.*

Robert Collier (Oregon State University). #0856808, *$104,428.*

Miles McPhee (McPhee Research Company). #0856214, *$34,201.*

Hydrology/Cryosphere

Thermal State of Permafrost (TSP) in North America and Northern Eurasia: The U.S. Contribution to the International Network of Permafrost Observatories (INPO).

Vladimir Romanovsky, Sergey Marchenko (UAF). #0856864, *$1,859,861.*

Terrestrial Ecosystems

Sustaining and Amplifying the ITEX AON through Automation and Increased Interdisciplinarity of Observations.

Steven Oberbauer, William Gould (Florida International University). #0856710, *$1,137,831.*

Jeffrey Welker, Patrick Sullivan (UAA). #0856728, *$591,914.*

Robert Hollister (Grand Valley State University). #0856516, *$502,600.*

Craig Tweedie (University of Texas El Paso). #0856628, *$400,471.*

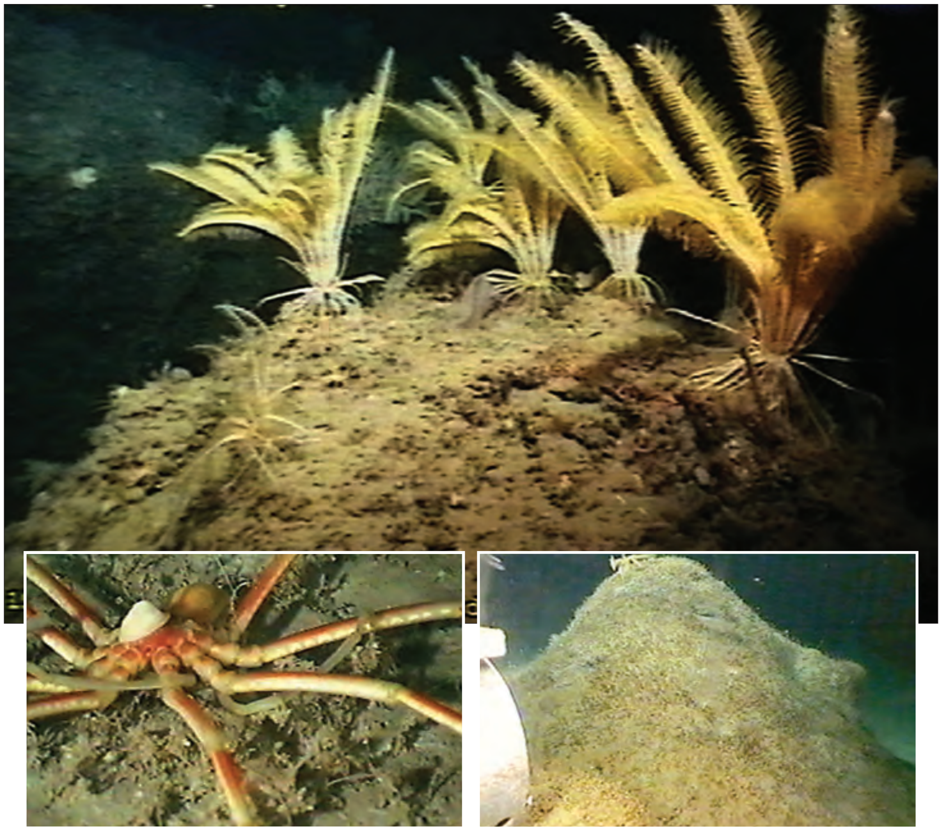
Data and Information Management

ELOKA Phase II: Toward Operational Data Management Support for Community-Based Observations Contributing to the Arctic Observing Network.

Shari Gearheard, Roger Barry, Henry Huntington, Mark Parsons, Chris McNeave (CU). #0856634, *$1,968,040.*

Unusual Fauna Found on Ancient Underwater Landslide

The Storegga slide off the middle coast of Norway is one of the world's largest known underwater landslides. Discovered in the 1960s by Norwegian geologists, the slide occurred more than 8,100 years ago when an area of land approximately the size of Denmark slumped into the Norwegian Sea, triggering a very large tsunami. The Storegga slide was last in a series of huge underwater slides in this region during the past million years. The northern flank of the Storegga slide area (64°45'N, 5°E), which was fully surveyed by Statoil in 2004 using remotely operated vehicles, is known as Nyegga, or "new scarp", and sits at water depths of 600–800 meters.



*Images taken during the 2004 seabed survey of Nyegga. Top: Stalked crinoids on a carbonate rock 725 m below the surface. Although these invertebrates are passive suspension feeders, they can move through the water column and along the sea floor at speeds up to 1 meter per second. Bottom right: A typical hydrate pingo measuring approximately one meter in height. Observations suggest that the shape and appearance of these pingoes change from year to year as the gas hydrates within continually form and melt over time. Bottom left: A sea spider (*Collossendeis probiscae*) measuring 15 cm wide. Attached to its back is a large, white foraminifer. Photos courtesy M. Hovland.*

Statoil's detailed seabed survey revealed a rugged seafloor terrain consisting of large complex pockmark craters approximately 200–300 meters in diameter with thick piles of carbonate rocks and sediment mounds within them. The team also found surprisingly abundant fish and invertebrates, including giant deep sea spiders and stalked crinoids (see images), at sub-zero water temperatures (-0.7 C). The seepage of hydrocarbons through the seafloor explains both the locally diverse, dense biology and unique topography. These light hydrocarbons, dominated by methane but also including ethane, propane, and butane, originate at considerable depth below the Earth's surface in a thermogenic hydrocarbon-generating region where organic matter is turned into oil and gas at relatively high temperatures and pressures. These gases exit through the seafloor at distinct, focused vent sites where the immediately surrounding seafloor sediments are poisoned, becoming anoxic as the hydrocarbons are oxidized at the sediment-water boundary. These locations are made visible by bacterial mats forming at the oxylimnion (the boundary where anoxic and oxic conditions meet).

Fuelled by the hydrocarbons, the abundant marine life in these areas demonstrates that such "cold seeps" represent important nutrient hubs, where primary producers—bacteria, archaea, and viruses—turn hydrocarbons into proteins available for higher trophic levels. Methane, the hydrocarbon with the highest hydrogen-to-carbon ratio, represents a particularly high-energy substrate for some of the microorganisms—specifically, the methanogens, which synthesize the compound for growth in anaerobic conditions.

At such great water depths, high ambient pressure can also cause hydrocarbon gases to combine with water molecules to form ice-like gas hydrates. At seep locations where this occurs, the seafloor is locally unstable, and small sediment domes, or pingoes, are formed (see bottom right image). These hydrate-pingoes resemble pure ice pingoes known from terrestrial tundra areas. They may also manifest the exact locations where fluid flow through the seafloor is currently active and could be used as indicators of active seepage.

Since Statoil's 2004 discoveries at Nyegga, a series of international research teams and vessels have visited this site. Scientists aboard the Russian vessel *Professor Logachev* obtained samples of the gas hydrates within the pingoes in 2006. The same year, a British and French research team aboard the *Pourquoi Pas* documented small tubeworms (Pogonophora) at the site, which are totally dependent upon internal bacteria for sustaining life. The bacteria utilize the seeping methane in their metabolism and make up about 60% of the tubeworms' weight.

Currently Statoil has no plans for further research or development in the Nyegga area. For more information, contact Martin Hovland, Marine Geology Specialist at Statoil (MHOVLAND@StatoilHydro.com).

USFWS Plans for Studies of Wildlife in Changing Arctic

In August 2009, the U.S. Fish and Wildlife Service (USFWS) released a report identifying the priority research, modeling, and synthesis activities needed to predict climate-related impacts to fish and wildlife populations in the U.S. Arctic. The report builds on the findings from a November 2008 USFWS workshop, Wildlife Response to Environmental Arctic Change: Predicting Future Habitats of Arctic Alaska, held in Fairbanks, Alaska.

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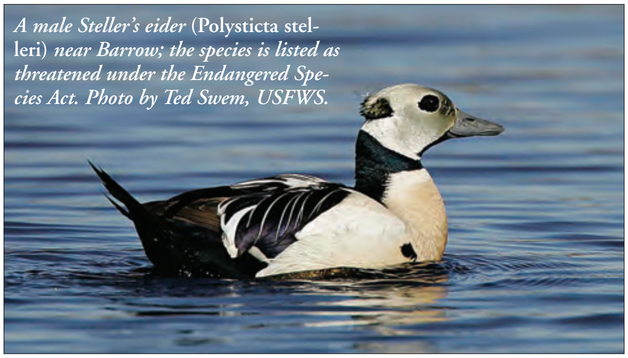
wit·ness (wit nis) *n.* **1.a.** One who has heard or seen something. **b.** One who furnishes evidence. **2.** Anything that serves as evidence; a sign. **3.** An attestation to a fact, statement, or event. —*v. tr.* **1.** To be present at or have personal knowledge of. **2.** To provide or serve as evidence of. **3.** To testify to; bear witness. —*intr*. To furnish or serve as evidence; testify. [Middle English *witnes(se)*, Old English *witnes*, witness, knowledge, from *wit*, knowledge, wit.]


A male Steller's eider (Polysticta stelleri) *near Barrow; the species is listed as threatened under the Endangered Species Act. Photo by Ted Swem, USFWS.*

The workshop was attended by over 100 participants representing federal and state agencies, academia, and commercial and nonprofit organizations interested in advancing understanding of the effects of climate change on birds, fish, and mammals of arctic Alaska. Focusing on terrestrial and freshwater systems, working groups used a conceptual modeling approach to identify the potential changes that would most strongly influence habitat suitability for a broad suite of arctic species.

The working groups emphasized that predictions of climate effects on fish and wildlife populations must be tentative, given the uncertainty surrounding climate forecasts and unavailability of models coupling climate, geophysical, and ecological processes at appropriate spatial and temporal scales. They also agreed that to predict climate change effects on species and habitats more accurately, multidisciplinary work is needed to improve understanding of underlying biological and physical processes that drive terrestrial and aquatic ecosystem function and the response of those systems to climate change. Hydrologic processes, in particular, are pivotal determinants of climate-related habitat change, and enhanced data collection and modeling in this area will benefit multiple users.

All participants emphasized that information available on life history, habitat requirements, distribution, abundance, and demography is inadequate for many arctic species. Basic biological studies, therefore, are also needed. Focal species should be chosen based on predicted vulnerability to climate change and potential to serve as indicators of hypothesized habitat changes.

USFWS Climate Change Planning

The Fish and Wildlife Service recently released a draft Climate Change Strategic Plan for public comment as part of developing an overarching Department of the Interior (DOI) framework to coordinate DOI climate change science and resource management strategies.

The USFWS plan, which is available for comment until 23 November, outlines commitments intended to enable USFWS to play a leading role in addressing the challenges of a changing climate system. These include building Landscape Conservation Cooperatives (LCC)—conservation science partnerships between federal agencies, states, tribes, and other entities within a defined geographical area that work together to develop regional and field technical capacity and provide spatially explicit, scientifically based analyses and tools to address climate change and other limiting factors at a landscape level. Guided by DOI's newly created Climate Response Council, the LCC will be closely integrated with the U.S. Geological Survey National Climate Change and Wildlife Science Center and its Regional Climate Change Response Centers; these will provide climate science information and data and work with LCC to develop modeling and decision support tools and conduct site-specific studies of climate impacts and species and habitat responses.

In the coming year, the USFWS Alaska Region, with its partners, plans to establish the Northern Alaska Landscape Conservation Cooperative office in Fairbanks to continue collaborative efforts initiated in 2009 to identify critical information needs in the Arctic.

For more information on:

The workshop, see www.arcus.org/alaskafws/, or contact Philip Martin (Philip_Martin@fws.gov, 907-456-0325);

The draft strategic plan, see www.fws.gov/home/climatechange/, or contact Charla Sterne (charla_sterne@fws.gov, 907-786-3471). ■