# Cracking the carbon code

With a research focus on the role of soil in carbon cycling, soil scientist **Dr Jennifer Harden** is deciphering how these processes govern carbon exchange over both spatial distributions and temporal scales

**Why is it necessary to combine field research with scientific modelling to achieve the results you are looking for?**

Combining these techniques is a priority for our current research, in part because computer modelling is the "currency" of the global climate research community. These computer models are required to assess the complex and interconnected interactions among biologic and inorganic processes in nature that occur over a wide range of spatial and time scales. All of our field- and experimental-based data contributes to a deeper understanding that must eventually be put in context of many other types of data, perspectives, regions and timescales. Also, it is critical not to 'stove-pipe' our thinking within our own expertise. Modellers should visit field sites and explore the issues while seeing and touching the materials they are trying to model. Similarly, field scientists must use conceptual and mathematical tools to contribute perspectives that are transferable to computer modelling.

**How are you involving collaborators and graduate students in your work?**

Our lab has many collaborators, most of whom are co-investigators on specific grants or research topics. These scientists are often associated with relevant agencies and departments, who share common interests and goals and exchange information in many forms. We share research concepts, data, and insights with member-based science organisations, such as the United States Permafrost Association. Graduate students are absolutely essential to our research and are actively engaged in hypothesis formulation and testing. All of our students are encouraged to incorporate both field and modelling approaches to their research problems and this information contributes to various models in the community at large. Mentoring of students who can think comprehensively across spatial and temporal scales is a priority of our research programme.

**Some of your latest research looks at the effect of wildfires in the region, which are inextricably linked to climate change. How can this be applied to help make predictions on the full impact of wildfires and climate change on carbon emissions?**

The importance of wildfires in shaping the boreal landscape is well established. However, previous research has focused largely on the burning of upland forests, and thus less is known today about the prevalence of peat fires and how emissions from these smouldering fires influence atmospheric emissions at regional to continental scales. We are analysing annual burn area, burn severity, and post-fire ecosystem succession in peatlands and permafrost forests in Alaska and Canada. Our latest results show that drought and deeper thawing are likely to increase burning of thick peat layers. This will influence carbon emissions as well as a number of other aspects of human and ecosystem health.

**How do you intend to communicate your research, and is it something that you are hoping will engage policy makers on climate issues?**

Firstly, we are training scientists to improve communication skills by offering seminars and short courses at some of our member-based science organisations. Secondly, we encourage students to engage with other communities by forming student partnerships with media majors or non-science majors. With regard to policy development, many of our networks, such as the Research Coordination Network on permafrost carbon, are aimed toward contributing to the Intergovernmental Panel on Climate Change (IPCC) in a meaningful way. Of course the IPCC is one of the most comprehensive attempts to align our science to societal needs for informed decision-making.

**What are the next steps that you have planned for your research?**

We are just beginning to understand the complexity of ground ice distribution, which fundamentally affects how terrain collapses after thaw and whether soils become wetter or drier. Our collaborations with other projects are helping to improve mapping capabilities for landcover, soils, and permafrost characteristics and also the link among these entities. Ultimately, it is the processes that are fundamentally important, and because of this, we emphasise spatial distributions, as well as temporal perspectives, that help formulate how form and function are connect.

# A **hotspot** for collaborative science

By researching how permafrost landscapes affect and respond to a warming climate in Alaska, scientists are using field measurements and computer models to build a picture of how ecosystems may contribute to global warming

**MEMBERS OF THE** US Geological Survey's (USGS) Soil Biogeochemistry group are conducting various research projects on permafrost, fire, soil microbiology, and soil development to understand more about soil processes. By characterising and studying soil processes, they hope to understand more about the role of soils in climate change, water quality, and the management of ecosystems.

The Impact of Permafrost Degradation on Carbon and Water in Boreal Ecosystems is a project co-funded by USGS and the National Science Foundation, in which USGS researchers, along with science collaborators and students, are digging into a number of landscapes underlain by permafrost. One such landscape is located in Alaska's Innoko Flats National Wildlife Refuge, where researchers are keen to gain an understanding of how Alaskan wetlands respond to climate warming. They want to find out if these landscapes release or sequester carbon dioxide during thaw, thereby acting to either accelerate or retard warming of the atmosphere.

The Innoko Flats National Wildlife Refuge is an extensive wetland that formed after the last ice age when lakes were more extensive in the region. Over time, lakes filled up with peat and partially decomposed plant debris, forming a frozen permafrost landscape. Recently, the permafrost has been thawing and collapsing into numerous moss-rich bogs of differing age: we study these bogs as a time series from young to old in order to understand how soil carbon responds to permafrost thaw.

## SOIL, WATER AND GAS EXCHANGES

The Innoko crew is led by USGS research soil scientist Dr Jennifer Harden and Mr Torre Jorgenson, from Alaska Ecoscience, with assistance from the US Fish and Wildlife Service. Dr Mikhail Kanevskiy, from the University of Alaska Fairbanks is also contributing to this project by mapping permafrost ice structures in a manner that reveals the history of burial and the filling of pores with ice during the onset of freezing. This is important because once those ice structures thaw, the land collapses and the liquid water allows bogs and open water bodies to form. Dr Stephanie Ewing from the USGS and Montana State University is leading students and technicians in sampling water chemistry and measuring the flux of $CO_2$ and $CH_4$ gases from the soil surface to the atmosphere. With float planes and help from US Fish and Wildlife service, crews set up camps in remote territories, construct a canvas tent for base camp and use solar panels and a generator to power their instruments and computers. From May through September 2011 they were able to capture gas exchange while water and plants underwent their dramatic changes from thaw to freeze-up.

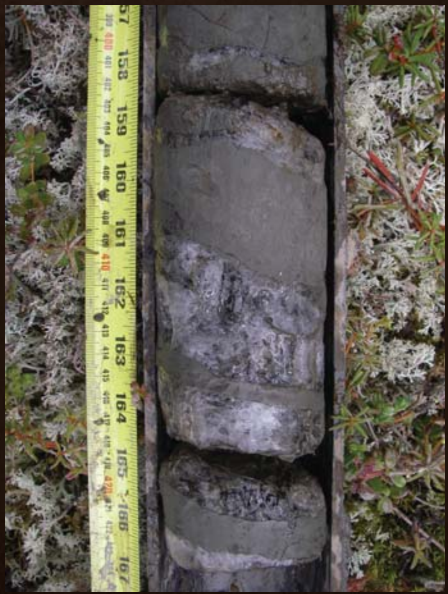
## ALASKAN PEATLAND EXPERIMENT (APEX)

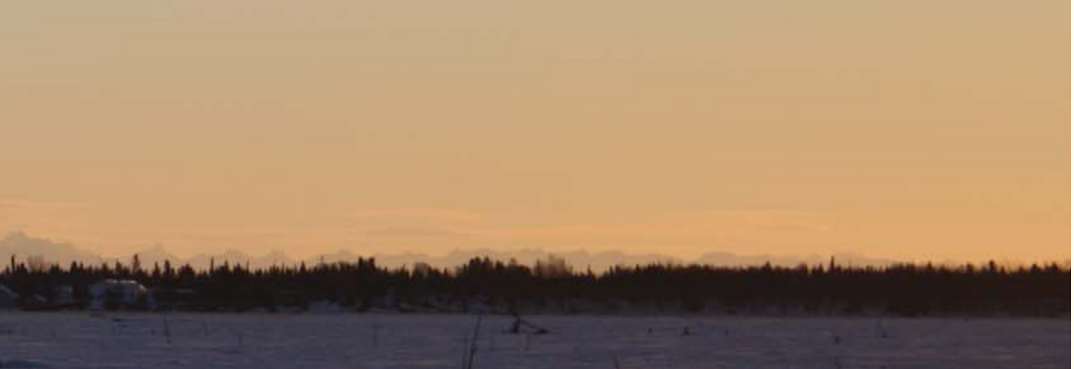
The Bonanza Creek Long-term Ecological Research (LTER) site, located southwest of Fairbanks, Alaska, has some of the longest-term datasets available on northern ecosystems and how they have responded to climate over the past 25 years. In 2005, a group of researchers led by Dr Merritt Turetsky (now a Canada Research Chair at the University of Guelph) established an experimental framework for examining climate controls on northern wetland carbon cycling. Water tables are being lowered and raised to separate the effects of hydrology from thaw cycles, and warming chambers are being used to warm surface soils and ground ice. At APEX, numerous graduate and undergraduate students are able to learn and refine their techniques before contributing to more remote campaigns such as Innoko.

## FILLING A GLOBAL CLIMATE RESEARCH GAP

This spectrum of field work is expected to lead researchers to an understanding of how permafrost is changing and what Harden and other scientists call the 'climate regulation services' provided by the boreal forest biome: "In simpler terms, the boreal forest region has been sequestering $CO_2$ for thousands of years - as evidenced now by the large amount of carbon stored in soils. Because of this carbon uptake, and by influencing permafrost, wildfire, and vegetation, boreal forests and wetlands have played an important role in regulating the climate system for the planet," she explains. The

Permafrost with high ice content: silt-rich lake sediments were separated by lens of ice near Innoko flats NWR





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concern is that the boreal biome is now suffering from some very rapid and dramatic changes, but the reasons are complex. What is known is that as permafrost thaws, one of two responses can emerge: the water from ice-rich permafrost can pool and settle into bogs or lakes, or water can end up draining away from the surface of the land. "From these complex soil and vegetation patterns we hope to establish some clear trends about how vast amounts of carbon stored in soils will be impacted," Harden states. The goal is to establish whether soil carbon currently frozen in permafrost will be released to the atmosphere, and thus contribute to more warming, or if new patterns will emerge to protect and sequester that carbon into other forms and places. "I really want to understand whether the CO2 sinks or sources will ultimately be most pervasive," underlines Harden.

These projects will fill significant gaps in knowledge as the research teams look to establish field studies that supply data on permafrost, carbon, vegetation and water and translate those studies into complex models. "There is ample field evidence that permafrost is changing rapidly in some northern regions," asserts Turetsky. "We cannot wait for a century to see how these large stockpiles of soil carbon will respond as permafrost thaws. We need to develop techniques to study this now". One such approach is to examine trends across sites that vary in time since the initiation of permafrost thaw. Referred to as a space for time substitution or 'thaw chronosequence', this approach offers insights into how a landscape has been thawing over time and what impacts this has on vegetation and soils. "Field approaches like the chronosequences at the Innoko and APEX sites are important if we want to understand how high latitude landscapes are evolving in a changing climate," emphasises Turetsky.

## THE THAWING AND FREEZING CYCLE

Previous research has shown that permafrost in the north has been in existence for many thousands, if not millions, of years. In response to climate variability, permafrost has gone through a number of phases of thinning and thickening. In its simplest form, the biologically active layer is the top of the soil that thaws seasonally from the surface down, which translates to thicker active layers under warmer conditions. But as Jorgenson elaborates: "The system is much more dynamic and complex, in part because the soil organic matter acts like a sponge". These spongy organic soil layers can be wet or dry, thick or thin. They generally insulate the permafrost from warm summers and protect the deep soil from deep thawing. But organic soils can be vulnerable to accelerated decomposition and burning during wildfire events. If these losses occur more frequently in a changing climate, then soils will lose their stores of carbon, and this will cause increases in atmospheric CO2, contributing to global warming.

Today, northern permafrost regions are warming at a faster pace, and are experiencing very different snow and thaw regimes than in preceding centuries. This leads to the areas burning far more severely than has previously been seen. And as fire emissions increase, so will other constituents. For example, mercury is released by biomass burning along with carbon. This has the potential to influence not just ecosystems but also human health, as Turetsky clarifies: "Over the long term, because of these interactions between fire and permafrost, we anticipate a younger forest and thinner organic soil cover, both of which indicate that northern forests and wetlands will store less carbon and serve a less important role in climate regulation in the future".

## INTELLIGENCE

### COLLABORATIVE RESEARCH: IMPACT OF PERMAFROST DEGRADATION ON CARBON AND WATER IN BOREAL ECOSYSTEMS

### OBJECTIVES

To generate a new approach to modelling boreal forest systems by research tasks designed to:

(1) assess interactive effects of climate change and fire on permafrost stability
(2) quantify how the varying modes of permafrost degradation initiate various thaw regimes on the landscape by affecting the microtopography, drainage, and soil thermal regimes of boreal systems
(3) determine how various thaw regimes such as drained or ponded systems affect carbon loss or accumulation in biomass and soils
(4) characterise the export of dissolved organic carbon from watersheds in an effort to fingerprint the various thaw regimes induced by permafrost degradation.

### KEY COLLABORATORS

**Dr Merritt Turetsky**, University of Guelph
**Dr Torre Jorgenson**, Alaska Ecoscience

### PARTNERS

APEX • Bonanza Creek LTER • Permafrost Carbon RCN • National Soil Carbon Network

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**JENNIFER HARDEN** completed her PhD in Soil Science at the University of California, Berkeley in 1982. She has been a research Soil Scientist at the US Geological Survey since 1982.

**MERRITT TURETSKY** is an Associate Professor of Ecosystem Ecology at the University of Guelph and a Canada Research Chair in Integrative Ecology.

**TORRE JORGENSON** runs Alaska Ecoscience and is an Adjunct Professor of the Department of Civil Engineering, University of Alaska Fairbanks.