Advancing Arctic observations

Dr Kimberly Strong is dedicated to understanding the changing composition of the Arctic atmosphere. Here, she discusses how issues concerning the Arctic environment impact the wider biosphere

To begin, what led to your interest in physics and the Arctic region?

I was attracted to physics as an undergraduate because I liked how it could be used to investigate the world in a rigorous and quantitative way. I chose to specialise in atmospheric physics because it is both scientifically intriguing and of great importance. I want to understand what is happening in our atmosphere and why, and how natural causes and human activity may lead to future changes. Measurements are essential to this understanding, so I am involved in running instruments that allow us to detect gases in the atmosphere. We make measurements from remote locations such as the Arctic, deploying huge balloons carrying instrument packages as high as 40 km above the surface and sending our instruments into space on satellite missions to study the planet. We then analyse data from these sources and use it to unravel the complex physical and chemical processes occurring in the Earth's atmosphere.

Could you highlight some of the most significant achievements in your field to date? Have these shaped your research focus?

The discovery of the ozone hole in 1985 and the subsequent research that took place in the late 1980s and early 1990s, which led to the Montreal Protocol, sparked the interest of many atmospheric scientists and brought new people into the field – myself included. While the evolution and recovery of the ozone layer remains a topic of interest, there are also many fascinating scientific questions related to air quality and climate. Improving our understanding of these issues is driven by both scientific curiosity and recognition of their importance to the health of our planet.

How have advances made in research techniques applicable to extreme environments helped your field grow over the past few decades?

Instrumentation and research techniques are continually evolving. The ability to automate instruments, and control them remotely, significantly increases the amount of data we can acquire, particularly in environments like the high Arctic. There is always room for improvement, as we strive to increase the accuracy and precision of our measurements to meet the needs of their scientific application.

Funding is often touted as a major concern for researchers. How has this impacted your research, and are you working to address the situation?

Finding funding can be a challenge. This is particularly true for research in the high Arctic, which is difficult and expensive, given the remote location and unpredictable and extreme weather conditions. The collection of even a small amount of data requires considerable effort. To collect and study measurements, we have to find funding to operate the Polar Environment Atmospheric Research Laboratory (PEARL) facility, on top of the more usual costs of research.

More than CAD $25 million has been invested in PEARL, through grants and contracts from numerous funding agencies. Most recently, we were successful in our application to the Natural Sciences and Engineering Research Council of Canada (NSERC)'s new Climate Change and Atmospheric Research Program; this will enable us to continue science research at PEARL for the next five years.

As it is difficult to locate the source of pollutants, how can we ensure nations take ownership of their emissions?

Improvements in measurement and modelling capabilities are making it easier to track the location of some pollutants. For example, when we measure enhanced concentrations of biomass burning products at PEARL, we can combine these with satellite observations and models of atmospheric transport to trace the trajectories of the smoke plumes back to the forest fires that emitted them.

How does Canada exercise its sovereignty over the Arctic? What is your hope for the future of the Arctic in terms of scientific and societal use?

Dramatic changes are occurring in the Arctic, including increasing temperatures, degradation of permafrost, melt-back of glaciers and rising sea levels. The impacts of climate change pose threats and opportunities. For example, the anticipated opening of the Northwest Passage has major implications for Canada's sovereignty, security and access to natural resources. The Arctic is a critical component of the global climate system; it is vital that we monitor changes as they occur and provide communities, policy makers and industry with the information they need for wise decision-making, planning and investment.

The Arctic is seeing dramatic losses in sea ice extent. How might we resolve this problem?

There is clear evidence of dramatic losses in Arctic sea ice; in September 2012, Arctic sea ice extent was the smallest observed in the satellite record. Observing sea ice decline is relatively easy, but resolving it is not. Arctic sea ice extent is tied to the global climate system so stopping or reversing future decline will depend on how we deal with the larger challenge of global climate change.

Students' perspectives

Five students from the **NSERC CREATE Training Program in Arctic Atmospheric Science** comment on the value of research and the opportunities presented by this adventurous mission to the Canadian north

Cristen Adams, former PhD student, University of Toronto, Toronto, Ontario

As a CREATE PhD student, I gained a well-rounded perspective on science that has benefited my current work as a postdoctoral fellow at Environment Canada. During my PhD, I enjoyed six field campaigns at PEARL, where I collected measurements of stratospheric trace gases with two UV-visible spectrometers. With this unique dataset, I performed an early study on the unprecedented 2011 Arctic ozone depletion, which won the Roger Daley Post-Doctoral Publication Award from the Canadian Meteorological and Oceanographic Society. The CREATE Exchange Program also funded my presentation of this work at the 2011 American Geophysical Union Fall Meeting, where the unexpected Arctic ozone loss was a major topic of scientific discussion. Furthermore, I gained a 'bigger-picture' view of science as a member of the Trainees' Advisory Committee (TAC) and as the trainees' representative on the Training Program Committee (TPC). In short, PEARL and CREATE gave me a very interesting dataset and the best learning experience of my graduate years.

Jonathan Franklin, PhD student, Dalhousie University, Halifax, Nova Scotia

My PhD work at Dalhousie University with CANDAC/PEARL Principal Investigator Jim Drummond involves investigating issues of atmospheric pollution transport using a newly commissioned Fourier transform spectrometer. In 2011, the CREATE Exchange Program enabled me to travel to the University of Toronto Atmospheric Observatory to work with colleagues operating a similar instrument. Later, thanks to funding provided by the CREATE Industrial Partnership Program, I was able to present my research at the 2012 Workshop in Infrared Remote Sensing Applications, hosted by ABB Inc. in Quebec City. I am currently participating in an outreach trip to the northern hamlet of Igloolik, Nunavut, where four members of the CREATE team are visiting local classrooms to help the next generation learn about our atmosphere.

Liviu Ivanescu, PhD student, Université de Sherbrooke, Sherbrooke, Québec

Pursuing a PhD in the remote sensing programme at the University of Sherbrooke, I have had the opportunity to study the semitransparent ice clouds at PEARL during the polar night. Our instrument, a star-photometer, measures the attenuation of star-light at several visible channels in order to infer the cloud and aerosol features. The CREATE Summer Schools and Research Symposia enabled me to improve the scientific interpretation of those observations, identify similar features observed by other groups, and find the external expertise and support I needed. In return, I'm involved in the TAC, particularly through the think tank on Summer School activities, as well as posting blogs on my own Arctic experiences, contributing to the CREATE Facebook page and conducting outreach presentations.

Emily McCullough, PhD student, University of Western Ontario, London, Ontario

I am a PhD candidate in Astronomy with Specialization in Planetary Science at the University of Western Ontario. I use the CANDAC Rayleigh-Mie-Raman Lidar's green laser beam and polarisation-sensitive detectors to study the properties of cold Arctic clouds. Through several extended stays (up to two months at a time) at PEARL, I have contributed to instrument development and testing, as well as making atmospheric measurements. These have been the most rewarding experiences of my education. I have been fortunate to receive support from CREATE through the Exchange Program, which has allowed me to meet and discuss scientific findings with international colleagues at two Fall Meetings of the American Geophysical Union, and I have contributed to the Program through my former roles as Chair of the TAC and trainees' representative on the TPC.

Dan Weaver, PhD student, University of Toronto, Toronto, Ontario

The CREATE Program has enriched my graduate school experience at the University of Toronto, where I study water vapour and climate change using atmospheric measurements made with a infrared spectrometer at PEARL. When I helped build a new sun-tracking instrument, the CREATE Exchange Program funded me for a visit to Dalhousie University. The opportunity to see their instrument in operation and discuss the details of their software was extremely valuable. It helped me move forward in my work and build working relationships with researchers in my field. As a member of the TAC, I've engaged the public with the work done by our CREATE team using social media (eg. our Twitter and blog). I also moderate a career panel at the annual Summer School, providing me and attendees with insights into future job options. These experiences have valuably extended my communication and organisational skills. In addition, the CREATE Exchange Program provided funding for me to attend an international meeting of atmospheric scientists in Japan this June, where I presented my research and received specialised training on cutting-edge data analysis software, equipping me with the knowledge I need to be at the forefront of my field.

DR KIMBERLY STRONG

CREATE-ing potential

The **NSERC CREATE Training Program in Arctic Atmospheric Science** at the University of Toronto has gained many important insights into the complexities of the Arctic environment. More importantly, it continues to promote world-class education in Arctic atmospheric science, providing its trainees with access to a world-class facility, unique datasets, and a large team of highly qualified researchers

CLIMATE CHANGE IS an ever-growing global concern, but nowhere is more rapidly or severely affected than the Arctic. In fact, the Arctic is warming at almost double the rate of the global average. Consequently, sea ice is diminishing; last year Arctic sea-ice extent was recorded at its lowest ever level. The continuance of such temperature increases will have profound effects on the Arctic environment; melting glaciers and sea ice will further contribute to rising sea levels and Arctic marine ecosystems will be disrupted, while storm damage to Arctic coastlines and melting permafrost will affect local communities. Exacerbating all of this, the melting of snow and ice reduces the Arctic's ability to reflect sunlight, thus accelerating the overall rate of global warming.

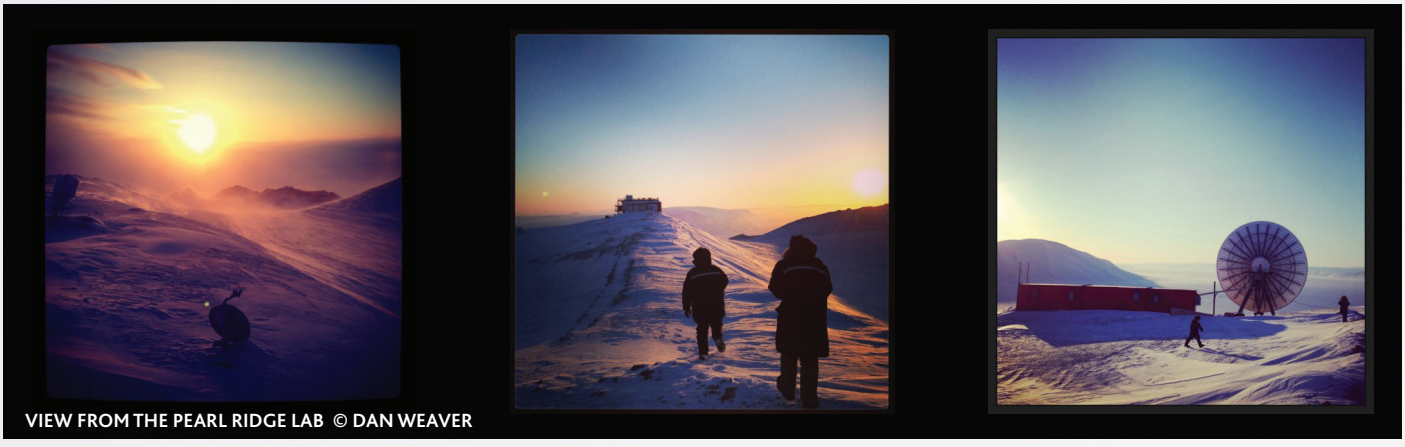
Even small increases in temperature can alter the character of the region. It is, therefore, vitally important that scientists are able to quickly and successfully detect and respond to such changes as and when they happen. The Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Training Experience Arctic Atmospheric Science (CREATE-AAS) Program, an initiative run by a number of collaborating academic institutions in Canada, is preparing its students to do just that. By providing students and postdoctoral fellows with comprehensive training in Arctic atmospheric science, CREATE-AAS hopes to equip the next generation of scientists with all the skills necessary to understand and respond to the effects of global warming.

CREATE

CREATE-AAS is a six-year project that began in 2010. Supported by NSERC's CREATE Program, which promotes the development of new researchers in the fields of natural sciences and engineering, CREATE-AAS was designed to provide students and postdoctoral fellows with training in atmospheric science, including the use of cutting-edge instrumentation and analysis of large datasets, contributing to the Training Program's mission to enhance the educational opportunities available to young researchers interested in polar, atmospheric and climate sciences.

Currently, the Program is dedicated to understanding the changing state of the Arctic atmosphere; including the flows of energies that warm and cool the atmosphere, the differences between polar day and polar night, and the ability to verify and supplement satellite measurements in the Arctic.

This work is closely linked to the Probing the Atmosphere of the High Arctic (PAHA) project, recently funded under NSERC's new Climate Change and Atmospheric Research Program, which has three scientific themes – 'Polar Night', 'Satellite Validation' and 'Composition Measurements'. The latter theme, which is led by Dr Kimberly Strong from the University of Toronto, encompasses four distinct projects. One is investigating greenhouse gases related to the carbon cycle, while another is using measurements of ozone to assess changes in Arctic stratospheric composition and quantify the contributions from dynamics, chemistry and climate change to ozone depletion and recovery. The third project involves measuring pollutants to study the source(s), transport and variability of air quality in the Arctic, to assess the relative contributions of anthropogenic pollution and forest fires from different regions. Finally, the fourth project is characterising the



VIEW FROM THE PEARL RIDGE LAB © DAN WEAVER

properties of Arctic clouds and aerosols. These are but a few of the topics being investigated by CREATE trainees.

PEARL

Central to the Program is the uniquely equipped Polar Environment Atmospheric Research Laboratory (PEARL), located at Eureka, Nunavut in the High Arctic and led by Professor James R Drummond of Dalhousie University. Crucially, the suite of equipment installed at PEARL is a complete atmospheric monitoring system. The research of Strong and her colleagues relies upon roughly 20 instruments, including radars, lidars, spectrometers, radiometers, sample collectors and optical cameras. These instruments are providing a significant new dataset of Arctic measurements for studying atmospheric processes and long-term trends.

> CREATE's work has offered important insights into a number of Arctic issues

Without PEARL, it would be impossible to run these instruments and conduct programmes such as PAHA. Furthermore, PEARL is a vital facility for training CREATE students and postdocs. The facility provides hands-on training in research techniques applicable to remote and extreme environments, as well as access to the state-of-the-art instrumentation. In an area such as the Arctic, where the results can have substantial social and economic impacts, it is essential that future researchers are trained to make measurements of the highest possible quality. PEARL facilitates such training for a new generation of scientists, who are capable of understanding and responding to climate-related challenges – particularly those related to the rapidly changing conditions in the Arctic.

A WEALTH OF DISCOVERIES

Unsurprisingly, considering its wide-ranging aims, the work of CREATE-AAS has offered important insights into a number of Arctic issues. In terms of ozone studies, CREATE team members were on site and contributed to measurements taken during the large ozone depletion reported in spring, 2011 – the largest ever recorded in the Arctic. Two CREATE graduate students went on to publish papers on this work, with both subsequently receiving awards from the Canadian Meteorological and Oceanographic Society. PEARL has also been fundamental to studying air quality. For example, measurements using sun and star photometers, and direct particle measurements using an aerosol mass spectrometer have been used in combination with regional and global models to determine whether existing approaches provide realistic estimates of pollutant transport into the Arctic. This also helps to determine the sources of Arctic pollution; team members have detected plumes from forest fires from southerly latitudes and from as far away as Russia.

CREATE-AAS researchers have also been responsible for several interesting climatological discoveries. A study on the climatology of surface temperature revealed a number of interesting phenomena and heightened scientists' interest in the dark months at Eureka. The study showed that the majority of warming observed over the past 30 years had occurred during the dark winter months, thus proving that sea-ice extent depends on temperatures year-round, not just in the summer. Another study on the impact of temperature inversions on Arctic warming analysed radiosonde data and showed that inversion layers have a substantial effect on 'Arctic Amplification' - the augmented warming observed in the Arctic. This is an important result, which has formed the basis of further studies on this topic.

EDUCATION

Aside from the important scientific discoveries facilitated by CREATE-AAS, education is the fundamental aspect of the Program. Indeed, it is specifically designed to support the training of teams of students and postdocs, with a focus on the development of collaborative approaches to address scientific challenges and the enhancement of professional skills.

The Program is hugely important as it enhances educational opportunities in polar, atmospheric and climate sciences, enabling its trainees to build collaborations and networks, and to develop the scientific, technical, communications and organisational skills necessary to pursue future activities in the field. These opportunities include undergraduate internships, an exchange programme, industrial partnership programme, summer schools, research symposia and outreach activities. The Summer Schools have been a real highlight, each bringing together ~40 students with experts from academia, government, industry and the media; in addition to lectures on a wide range of topics, they include broader training and networking opportunities through poster sessions, career panels and professional skills workshops. CREATE-AAS has engaged about 120 trainees in its various programmes, while directly funding the stipends of 17 graduate students and 27 undergraduate interns to date. "Education is essential to ensuring that we have a core of knowledgeable people whose understanding of the scientific issues will enable Canada to perform leading-edge Arctic climate research and develop rational environmental policies," states Strong. CREATE-AAS is certainly successful in this respect; so far, all of the Program's graduates have been successful in finding employment in atmospheric science.

NSERC CREATE TRAINING PROGRAM IN ARCTIC ATMOSPHERE SCIENCE

OBJECTIVES

- To train personnel in the use of state-of-the-art instrumentation and analysis of large datasets to address scientific questions
- To enhance educational and employment opportunities for young researchers interested in polar, atmospheric and climate sciences

KEY COLLABORATORS

The CREATE-AAS team: **Kimberly Strong**; **James R Drummond**; **Tom Duck**; **Alan Manson**; **Norm O'Neill**; **Marianna Shepherd**; **Jim Whiteway**; **Bob Sica**; **Jim Sloan**; **Kaley Walker**; **William Ward**

Collaborators: **Stephen Argall**; **Doug Degenstein**; **Pierre Fogal**; **Wayne Hocking**; **David Hudak**; **Kevin Strawbridge**; **Tom McElroy**; **Gordon Shepherd**; **Ed Eloranta**; **Taneil Uttal**; **Von Walden**

Additional team members: **Ashley Kilgour**; **Lisa LeBlanc**; **Yan Tsehtik**

The Training Program Committee: **Catharine Banic**; **Jacques Giroux**; **David Hik**; **Felicia Kolonjari**; **Michael Luke**

FUNDING

The Natural Sciences and Engineering Research Council of Canada

Aboriginal Affairs and Northern Development Canada, the Arctic Research Infrastructure Fund, Atlantic Innovation Fund/Nova Scotia Research and Innovation Trust, Canadian Foundation for Climate and Atmospheric Science, Canada Foundation for Innovation, Canadian Space Agency, Dalhousie University, Environment Canada, Government of Canada International Polar Year, the Northern Scientific Training Program, Ontario Innovation Trust, Ontario Research Fund, Polar Continental Shelf Program, the US Study of Environmental Arctic Change (SEARCH) and the University of Toronto.

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KIMBERLY STRONG has been a Physics Professor at the University of Toronto since 1996. In July 2013, she became the Director of the University's new School of the Environment.