Supersite at Iqaluit

The Canadian Arctic Weather Science Project

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Developmental pressures, combined with social-cultural, technological, and climate-environmental changes are increasing human activity in the Canadian Arctic. The Northwest Passage is expected to become a prime shipping corridor. Transpolar flights have increased from nearly 400 in 2000 to 12,759 in 2014, with annual projected growth of 3.5%. Such changes are going to require considerable planning and development on many fronts including infrastructure for increased navigation and improved search and rescue (SAR) capabilities.

Weather hazards, including blizzards, high winds, and low visibility, are expected to become less predictable, more frequent, and longer-lasting as climate changes, presumably also requiring even more SAR support and expanded observational and weather forecasting capabilities. Currently, the Canadian Arctic (Nunavut, the Northwest Territories, and Yukon Territory) is only sparsely observed. Research in the region to date has mainly focused on short weather projects, air quality, or climate. Findings include: (i) precipitation is very light but ubiquitous, (ii) the radiative effects of persistent light precipitation can lead to cold air outbreaks in the midlatitudes, and (iii) changes in precipitation are early indicators of climate warming.

✱ Iqaluit CAWS reference site (circled in red) amid major storm tracks (large yellow arrows; ECCC training materials/Ed Hudson) and marine transportation routes (www.espg.ca) for fishing (orange), cargo (black), passenger ships (red), and pleasure boats (green). In the complex topography (inset) around Iqaluit (red-yellow marker), the highest terrain is to the north-northwest at 550 m.

Environment and Climate Change Canada (ECCC) has begun defining weather monitoring requirements for the Arctic within the constraints of complex logistics and high operating costs. This has involved a project, Canadian Arctic Weather Science (CAWS), hypothesizing a network of a limited number of surface and radiosonde stations, satellite observations, and reference stations. Canadian Arctic Weather Science (CAWS) coincides with a new responsibility for ECCC to provide meteorological services (METAREAs) in the Arctic. We will discuss here the first CAWS supersite, operating

Looking eastward to the CAWS Iqaluit site and farther to the T121 Doppler lidar site along a ridgeline where it can detect flows across the shallow valley. ✱

CAWS priorities

One priority of CAWS is to understand Arctic weather and its impact on observation and prediction requirements. For example, fog is a frequent transportation hazard at sea (with sea ice present), and is a major concern for navigation and SAR operations. Blizzards reduce visibility and can disrupt air traffic for days at a time. Strong winds also affect sea travel, particularly by small vessels; sea ice movement; and most significantly, hunting, which is critical for the diet of the indigenous people.

CAWS also aims to identify and test future operational monitoring technologies for the

Arctic. Due to the high cost of operations and maintenance, developing technology to replace radiosondes is also a significant focus of CAWS. Satellites are a key to network design because they measure phenomena over broad areas. Therefore, a prime interest is validation of satellite precipitation products and temperature, wind, and humidity profile products, including from missions such as CloudSat, the Global Precipitation Mission, Aeolus, and EarthCARE.

Numerical model predictions are also part of the network design, as CAWS has a priority of developing, validating, and verifying prediction products for high-impact local weather—specifically, products from high-resolution coupled atmosphere–ocean–sea ice models. Effective communication of information that scientific products provide is a recognized issue to all end users. This will involve codesign of prediction and warning communication strategies with the indigenous community—in particular risk communication—as well as demonstrating societal impact and benefits.

Iqaluit site and instruments

ECCC has established a meteorological reference site at Iqaluit, the capital and largest city of Nunavut in the eastern Canadian Arctic (63°45'N, 68°33'W). A large majority of Iqaluit's 8,000 residents are Inuit. This is the primary gateway for air traffic for the eastern Arctic and is near many current and planned primary transportation corridors for seafaring vessels, and the region is influenced by a diversity of synoptic storms originating from across the Arctic. It has

Means and Extremes

Selected climate normals for Iqaluit, 1981–2010

Daily average temperature, for February: -27.5°C

...for July: 8.2°C

Daily average minimum, for February: -31.7°C

Daily average maximum, for July: 12.3°C

Extreme minimum, for February: -45.6°C

Extreme maximum, for July: 26.1°C

Annual average days with minimum below -30°C : 62.8

...below -10°C : 182.4

Annual snowfall: 229.3 cm

Average snow depth on April 30: 29 cm

Annual precipitation: 403.7 mm

Month with highest average precipitation: August, with 69.5 mm

Months averaging less than 20 mm precipitation: 4 (December–March)

Mean wind: 15.7 km/h

Average annual hours with 1–9 km visibility: 1,187.4

...less than 1 km: 138.7

Annual hours with 8–10 tenths cloud cover: 5,163.3

...with less cloud cover: 3,601.7

From ECCC, http://climate.weather.gc.ca/climate_normals/index_e.html#1981

The CAWS logo, codesigned with Inuit representatives.

an operational radiosonde site and existing, substantial facilities for instrument testing.

Temperatures below -20°C are very common but not a significant concern for the indigenous people in their daily lives, but the cold is a major concern for operating and repairing instruments, limiting deployment and maintenance to summer. Blizzard watches or warnings are issued when 8 consecutive hours of visibility less than 0.5 or 0.25 mi are expected, respectively. Of 196 days in the CAWS project period, 25% had near-blizzard visibility (<0.5 mi) and 53 days (6%) had blizzard conditions (<0.25 mi).

Early results from CAWS confirm that very light (less than -10 dBZ) and deep (>5 km in height) precipitation (diamond dust ice crystals) is ubiquitous, and appears to have significant impact on the radiation budget. Calibration of such light precipitation measurements is a challenge. For example, radars must be very sensitive (at least -35 dBZ) to detect it. Lidar was able to detect light precipitation but at a limited range. In addition, blowing snow was observed to several hundreds of meters in

height by the lidar and radar, and may have similar impact on the radiation budget.

With one exception, the instruments used in the project were commercial off-the-shelf purchases and not specified to operate in Arctic environments. Despite this, the instruments operated normally even in extreme circumstances except for a few computer errors attributed to normal failure modes and power interruptions.

The CAWS Iqaluit site has continually evolved. The extremely limited Internet bandwidth and associated data transfer constraints governed the design of the data collection, processing, and archiving. A limited suite of image products is created on-site and transferred to a web server in the south for access by researchers and forecasters. Raw data are stored on-site and manually retrieved a few times a year during maintenance or repair visits.

ECCC designed, built, and deployed the CAAAL (Canadian Autonomous Arctic Aerosol Lidar) for atmospheric profiling of aerosols and water vapor in an Arctic environment. In practice, aerosols were observed to approximately 10-km altitude. The CAAAL operates continuously except during precipitation and when aircraft are overhead as detected by radar.

CAAAL observations reveal water vapor inversions during winter. These inversions are thought to be a function of dominant forcing by the surface during the Arctic winter combined with meridional transport. The extent and frequency of these events and their relationship to the height of the mixing layer needs further investigation. Moreover, the addition of CAAAL to existing 50- or 400-MHz wind profilers and development of temperature profilers with comparable resolution and coverage provide a

⚠️ Radar data revealing significant layering of the atmosphere with up to seven wind direction shifts in the lowest layers of the atmosphere, in this case (below 5 km AGL) for a blizzard at 1420 UTC 20 Mar 2016. Radial velocity from the scanning Ka-band Doppler polarization radar is shown (left) in PPI at 5° elevation angle and (right) in RHI scan along azimuth 135°. Reflectivities are very low (from -30 to -10 dBZ), indicating ice crystals. Negative (blue/green) radial velocities indicate flow toward the radar and vice versa for positive (red) velocities. The RHI scan is at constant azimuth angle from horizon to horizon (over the top).

genuine opportunity to consider replacing radiosondes with remote-sensing technologies.

The CAWS project continues to add new and improved instrumentation. For example, in September 2018 a new differential absorption lidar was installed to continuously measure water vapor profiles up to 3 km AGL, and comparisons with radiosonde data, NWP model output, and CAAAL are currently underway. Additionally, the site was equipped with a Drop-let Measurement Technologies fog-measuring device, a radiation flux sensor suite, snow depth sensors, soil moisture and temperature probes, and a far-infrared radiometer.

Prediction and products

Wind and blizzard forecasts in addition to fog are primary weather products for the Nunavut region. ECCC runs several NWP systems for the Arctic region, all based on the Canadian Global Environmental Multiscale (GEM). Two deterministic systems have complete coverage

Instrument	Measurement(s)	Temporal sampling cycle and resolution
NASA Wallops precipitation imaging package	Particle imagery, drop size distribution, precipitation rate, and density estimation	1 min; surface observation
Four Campbell Scientific cameras	Ka-radar, lidar, and sky-view images	5 min; 1,080 pixels
METEK Ka-band dual-pol Doppler radar	Line-of-sight wind speed and direction, cloud and fog backscatter, depolarization ratio	10 min; 10-m resolution up to 25-km range
Vaisala ceilometer CL31—pulsed diode lidar	Cloud intensity, cloud octa and height, aerosol profiles, mixing-layer height	5 min; 5-m resolution up to 7.5 km
Vaisala PWD 52 present weather detector and visibility sensor (×2)	Visibility, precipitation type	1 min; surface observation only
HALO Doppler lidar	Line-of-sight wind speed and direction, aerosol backscatter, depolarization ratio	5 min; 3-m resolution up to 3-km range
Rosemount icing detector	Detects ice, frost	—
Surface meteorological observations	Surface temperature (T), relative humidity (RH), pressure, winds, precipitation	1 min; surface observations
Vaisala Radiosondes	Profiles of T, RH, pressure, winds	12 h; ~15 m resolution up to 30 km
Axis 4k Pantilt camera	Automated pivoting camera provides images of site in all directions	5 min; 4k
Canadian Autonomous Arctic Aerosol Lidar (CAAAL)	Aerosol and water vapor profiles; particle size and shape information	1 min; 3-m resolution up to 15 km
Halo Doppler lidar: Ridge (T121)	Line-of-sight wind speed and direction, aerosol backscatter, depolarization ratio	5 min; 3-m resolution up to 3-km range
Scintec scintillometer	Turbulence, crosswind, heat flux	5 min; maximum 6-km pathlength
Droplet Measurement Technologies fog measuring device	Fog intensity, water vapor at surface	1 min
LR Tech. far-infrared radiometer	Downwelling infrared radiation, cloud microphysics	10 min
Campbell Scientific surface radiation fluxes	Shortwave and longwave up, down, and horizontal radiation	1 min
Vaisala water vapor lidar	Profiles of aerosols, 24-h water vapor profile	20 min; 10-m resolution up to 3 km
ECCC precipitation occurrence sensor system (POSS)—bistatic X-band Doppler radar	Precipitation type, rate, particle distribution	1 min

of the Arctic: the operational Global Deterministic Prediction System (GDPS), with 15-km horizontal grid spacing and the experimental Canadian Arctic Prediction System (CAPS; 48-h forecasts), with 3-km grid spacing, downscaled from the GDPS. Both are coupled to ice–ocean prediction models. The Regional (RDPS; 10-km resolution, 84-h forecasts) and High Resolution Deterministic Prediction System (HRDPS; 2.5-km resolution, 48-h forecasts) models are operational local area models also downscaled from the GDPS and used extensively in the

Iqaluit site instrumentation

CAWS project. Forecasts are produced from operational model runs at 0000 and 1200 UTC.

New guidance products for warnings are created by postprocessing basic and derived NWP output, such as temperature, wind, and visibility in snow or blowing snow. This includes three blizzard products. First, the Blizzard Potential derives from forecaster expert's rules for land and ice-covered areas with at least 1 cm of snow on the ground, up to a few days in advance. Second, a regression analysis of blizzard conditions uses nearly 40 years of surface observations of visibility,

10-m wind speed, and surface temperature. It assumes a “perfect prognosis” forecast of the probability of visibility ≤ 1 km due to blowing snow. The number of hours since the last snowfall is included as a proxy for snowpack condition. Finally, the “time-offset model output statistics” prediction uses the Random Forest machine-learning algorithm for classifying events, and predicts the likelihood of blizzard conditions using two winters of observations matched with RDPS output. Similarly, the likelihood of dense fog and low stratus clouds is predicted using RDPS.

Observations revealed persistent (tens of hours) multiple wind layers in the lowest 2–3 km, and about 40% of the time these layers were associated with light precipitation. Preliminary NWP model evaluation (2016–17) indicated a cold temperature bias and also

underforecasting of surface winds during these events. Climate model studies have indicated the importance of the radiative effects of such layers and their role in the development of cold-air outbreaks affecting midlatitudes.

Discussion

As part of CAWS, many efforts and community events have been undertaken to bridge not

An example of a probability visibility forecast ≤ 1 km. It is the maximum of (i) the probability of visibility ≤ 1 km in blowing snow or (ii) the probability of visibility ≤ 1 km in concurrent blowing snow and precipitating snow, valid at 1600 UTC 11 Feb 2019 from the operational RDPS. Red circle indicates the location of Iqaluit. *

only the research-to-operations gap but the science-to-society gap. This includes ongoing meetings with government departments (ECCC staff and forecasters, national defense), industry (terminal operations, airlines, pilots), the research community (Nunavut Research Institute, universities in the south), SAR teams, and students, as well as ongoing government-wide open town halls with the public.

In a broader international context, the CAWS Iqaluit site aims to contribute to the

International Arctic Systems for Observing the Atmosphere observatories and the WMO Polar Prediction Project with new technology measurements (only a few of which we've highlighted here) to complement traditional observation instruments and to enhance monitoring and understanding of Arctic weather. This is particularly important in anticipation of the increased population and development of the Canadian Arctic associated with a warming climate. ♣♣

≡ METADATA

BAMS: What's an important take-away message for readers?

Paul Joe: *ECCC and other countries are addressing the needs of the Arctic communities with sophisticated coupled atmosphere-ocean-sea ice and high-resolution weather prediction programs with advanced artificial intelligence-based products.*

BAMS: What are some of the improvements you are striving for?

PJ: *Enhancement of the current sparse observational monitoring program is needed to understand the Arctic weather, initiate the models, and validate them. Climate change models indicate that precipitation will increase, but disagree on the magnitude. Cold-season precipitation is very sensitive to small changes in environmental conditions such as temperature and humidity. The Arctic weather and environment is different from that in the south and therefore have different observation requirements and monitoring support strategies as well as improvements to the physics of the models.*

BAMS: Can you give an example of those differences from cold-season precipitation farther south?

PJ: *Previous studies have indicated the different physics of the*

precipitation processes that lead to cold-air outbreaks due to anthropogenic midlatitude aerosols, and also to long-lived ubiquitous very light diamond dust events.

BAMS: How are your project's new observations of the multilayering of that diamond dust surprising?

PJ: *My previous impression was that this was fog-like and surface-based and so confined to the lowest few hundred meters of the atmosphere. To see it up to 5 to 7 kilometers meant that there was something else going on that we don't understand at all. I have not seen the multilayering events in such a way in the data that I am familiar with at midlatitudes and again it is something that we don't understand.*

BAMS: What are some other interesting developments in the observations so far?

PJ: *I am not a lidar expert, but the operational program has been looking for a radiosonde replacement for some time to replace the current technology and with higher performance (more frequent observations for high-resolution forecasts). With Doppler lidars, or wind profilers and the CAAAL, we have wind and water vapor. The only missing parameter is temperature at a comparable resolution. Radiometers*

can produce such measurements, but the key is to be able to capture the sharpness of the inversion that controls the precipitation growth in a confident way.

BAMS: What was the biggest challenge you encountered while doing this work?

PJ: *Given that the observations in the Arctic are costly, there are a lot of challenges on many fronts that are compelling challenges. It is new territory. One of the challenges is coming to grips with the lack of internet. We rely on it so much for off-site support getting people peripherally involved—such as IT support, centralized and automated data archiving/storage, trouble shooting—that we kept revisiting this issue over and over again. In developing countries without good internet, they have data access via cell phones.*

BAMS: How about the challenge of extreme climate itself?

PJ: *Working in the harsh conditions meant that equipment installation, support, and maintenance could only be done in a two-month window or so. The logistics and planning takes longer, and installation can be delayed by one or two years if there are any hiccups due to weather or logistics.*

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