Infrared Cloud Imager Deployment at the North Slope of Alaska During Early 2002

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Introduction

Starting in February 2002, we deployed a new cloud-radiation sensor called the infrared cloud imager (ICI) at the North Slope of Alaska (NSA) site near Barrow, Alaska (71.32 N, 156.62 W). ICI records radiometrically calibrated images of the thermal infrared sky radiance in the 8µm to 14 µm wavelength band, from which spatial cloud statistics and spatially resolved cloud radiance can be determined.

Infrared Cloud Imager

The ICI is designed for simultaneously studying the spatial and radiative properties of clouds, especially in the Arctic atmosphere. The initial scientific objective in developing the ICI system was to provide spatial cloud statistics that could be used to complement the single-point-in-space but spectrally resolved sky emission data from a fourier transform infrared spectro-radiometer (FTIR). These two sensors are part of a large instrument suite deployed at Poker Flat Research Range near Fairbanks, Alaska, as part of a Japan and United States collaborative program to study the Arctic atmosphere (http://www2.crl.go.jp/dk/c216/index_e.html). Whereas visible-wavelength imagers use cloud texture or topology to distinguish cloud types, relying on scattered sunlight to illuminate the cloud (e.g. Buch et al. 1995), the ICI system identifies and classifies clouds directly from their emitted infrared radiance. Because the cloud emission signature is the same in day and night, ICI provides a significant advantage over visible-wavelength imagers in being able to produce a continuous day-night data stream with no change in sensitivity or cloud-detection algorithm.

One of the initial applications of the ICI system is to help determine how well cloud statistics from zenith-viewing, single-pixel instruments agree with cloud statistics from spatially resolving instruments.

Most currently operational cloud radars and lidars use a single vertically pointing beam and rely on advection of the cloud field over the instrument to build up space-time cloud statistics. This approach assumes ergodicity, or that ensemble, time, and space averages are equivalent. Taylor's hypothesis states that when the turbulence is small compared with the mean wind, temporal statistics at a single point in space can be used to infer spatial statistics. However, Sun and Thorne (2000) showed that Taylor's hypothesis usually does not hold for cirrus clouds and broken stratus, both cases of great importance in the Arctic. ICI was deployed during February – May 2002 at the NSA Atmospheric Radiation Measurement (ARM) site near Barrow, Alaska, with nearby cloud radar, cloud lidar, and other sensors to study how Arctic cloud statistics might vary between point-sensors and imaging sensors.

Long-term, unattended deployment of an infrared imager previously was impractical because of the need to regularly fill liquid nitrogen dewars or provide an alternate form of cooling the detector array to cryogenic temperatures. However, recently developed micro-bolometer detector arrays (Kruse 2001) provide an excellent solution to this problem because of their relatively high sensitivity without cryogenic cooling. The cost of cameras based on these detector arrays is falling steadily, so a network of these infrared cloud imagers is a practical goal for studying cloud variability throughout the world, at much higher spatial resolution and with improved radiometric contrast between cloud and background than can be achieved with satellites.

Infrared Cloud Imager Hardware

At the heart of the ICI system is a commercial infrared camera that uses an uncooled micro-bolometer detector array, technology only available to the military until recently. These detectors offer reasonably high sensitivity without the troubling need for liquid nitrogen cooling. Because these detector arrays are fabricated with technology similar to that used for standard silicon electronic chips, infrared cameras are beginning to be available at much lower cost.

The ICI system records radiometrically calibrated images of the sky with 320 × 240 pixels in the thermal infrared window band of 8 to 14 µm. The camera generates 30 frames per second, but the ICI only acquires a frame once every few minutes to avoid excessive redundancy. The original camera has a full-angle field of view of approximately 18° horizontal ×13.5° vertical, which is not as wide as is desirable for cloud measurements, but it allowed us to demonstrate the feasibility of this technique. Future versions of the ICI will use a wide-angle lens to achieve a wide field of view of up to 100°, which is nearly optimal for spatial cloud statistics (Long 2002).

As is illustrated in Figure1, the infrared camera looks horizontally at a beam-steering mirror (M) mounted on a stepper motor (SM), which rotates alternately between a blackbody (BB) calibration source and a sky port covered by a hatch that opens for image collection when a precipitation sensor (PS) shows no precipitation. The camera, blackbody, stepper motor, hatch, system diagnostics sensors, control electronics, and precipitation sensor all are mounted in the optics box which sits outside, controlled by a computer that sits in a nearby building or shelter (Figure 2 is a photograph of the optics box interior). The system is controlled via an internet connection, avoiding the need for an on-site operator. Each pixel of the calibrated sky images gives an absolute radiance or brightness temperature, from which clouds are identified and classified in categories such as clear, high, mid, and low.

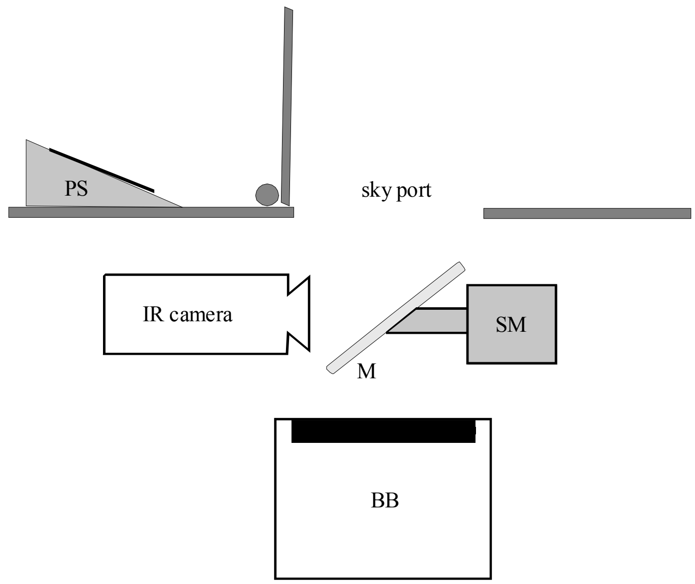

Figure 1. Illustration of the infrared camera looking horizontally at a beam-steering mirror (M) mounted on a stepper motor (SM).

Figure 2. Photograph of the optics box interior.

As is so often the case in passive remote sensing, making ICI work successfully is largely a problem in radiometric calibration. The calibration requirements for cloud identification and classification are far less demanding than those for most other atmospheric sensing applications [such as clear-sky absolute radiometry with FTIR spectro-radiometers, which require uncertainties < 1% (e.g., Shaw et al. 1999; Feltz et al. 1998). The ICI radiometric calibration has an uncertainty of approximately 2 to 6%, generally being largest at the cold clear-sky measurement range. The calibration relies on a linear fit between band-integrated radiance and voltage on each pixel, measured with the camera viewing a blackbody source at different temperatures. A least-squares fit provides a linear calibration equation of the form $L = G*V+C$, where L is the radiance measured in the camera's optical bandwidth, G is the radiometer gain (change in radiance for a given change in voltage), and C is an offset that describes the voltage output from the detector caused by thermal radiation within the instrument. The current ICI prototype uses only one blackbody calibration source, from which the offset, C, is updated for each image; the gain, G, is determined in a laboratory calibration and assumed to remain constant throughout the deployment. This assumption appears to remain sufficiently valid under typical conditions to allow the ICI to achieve the 2 to 6% calibration uncertainty that is good enough for cloud identification and classification. A second blackbody calibration source can be added if lower uncertainty is required in future deployments.

Radiometric Images from ICI

Figure 3 is a radiometrically calibrated image from the ICI, recorded with thin clouds overhead at the NSA site on March 19, 2002. The image was calibrated in radiance units [W/(m^2 sr μm)] and subsequently converted to band-averaged brightness temperature (K) for display. The display is color coded according to brightness temperature, ranging from –90°C at the bottom (dark blue) to +20°C at the top (dark red). The infrared emission signature makes the clouds stand out against the cold, clear background, although these thin clouds were not at all obvious to a visible-wavelength camera. The extremely low water vapor content of the wintertime Arctic atmosphere allows ICI to see an extraordinarily high radiometric contrast between the clear sky and thin clouds. In other locations with higher water vapor content, thin clouds will be more difficult to see with ICI (this will be the topic of future research at the ARM Southern Great Plains [SGP] site).

Figure 4 is a radiometrically calibrated image from ICI of scattered medium-level clouds with a mean band-average brightness temperature near –30°C. Especially on the left-hand side of the image, thin spots are visible as bluish areas in the image, indicating that ICI is seeing higher into the atmosphere through the cloud. When we process ICI images to derive spatial cloud statistics, each pixel is classified into a category of clear, high and thin, medium, or low clouds (or similar categorization, depending on the specific application) and cloud fraction is determined as the number of pixels containing clouds relative to the total number of pixels

Summary and Future Plans

The ICI system was deployed from February through May 2002 at the NSA site in Barrow, Alaska, performing satisfactorily in a wide range of conditions in a harsh environment. The prototype instrument achieves a radiometric uncertainty of approximately 2 to 6%, which is sufficient for cloud

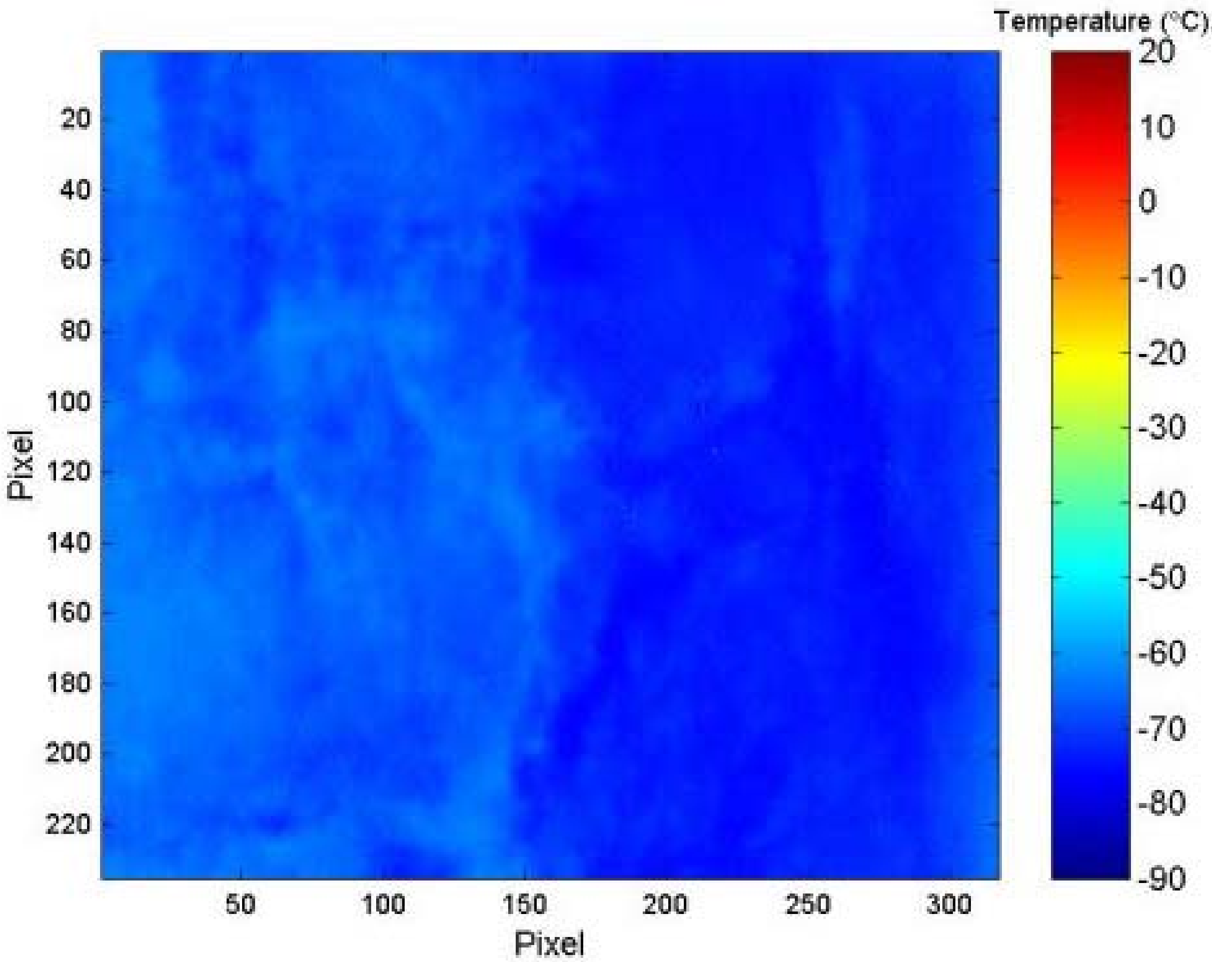

Figure 3. Radiometrically calibrated image from the ICI, recorded with thin clouds overhead at the NSA site on March 19, 2002.

identification and broad classification. The calibration uncertainty can be reduced with simple instrument modifications if it becomes necessary or desirable. The images from NSA demonstrate that the ICI has a high sensitivity to thin clouds in a cold, dry Arctic atmosphere. Future research will be conducted to quantify this capability in both Arctic and more humid atmospheres. The plans for the immediate future are to use the ICI data collected during this 2002 deployment to determine cloud statistics and to study the potential difference between cloud statistics measured with single-pixel and imaging sensors.

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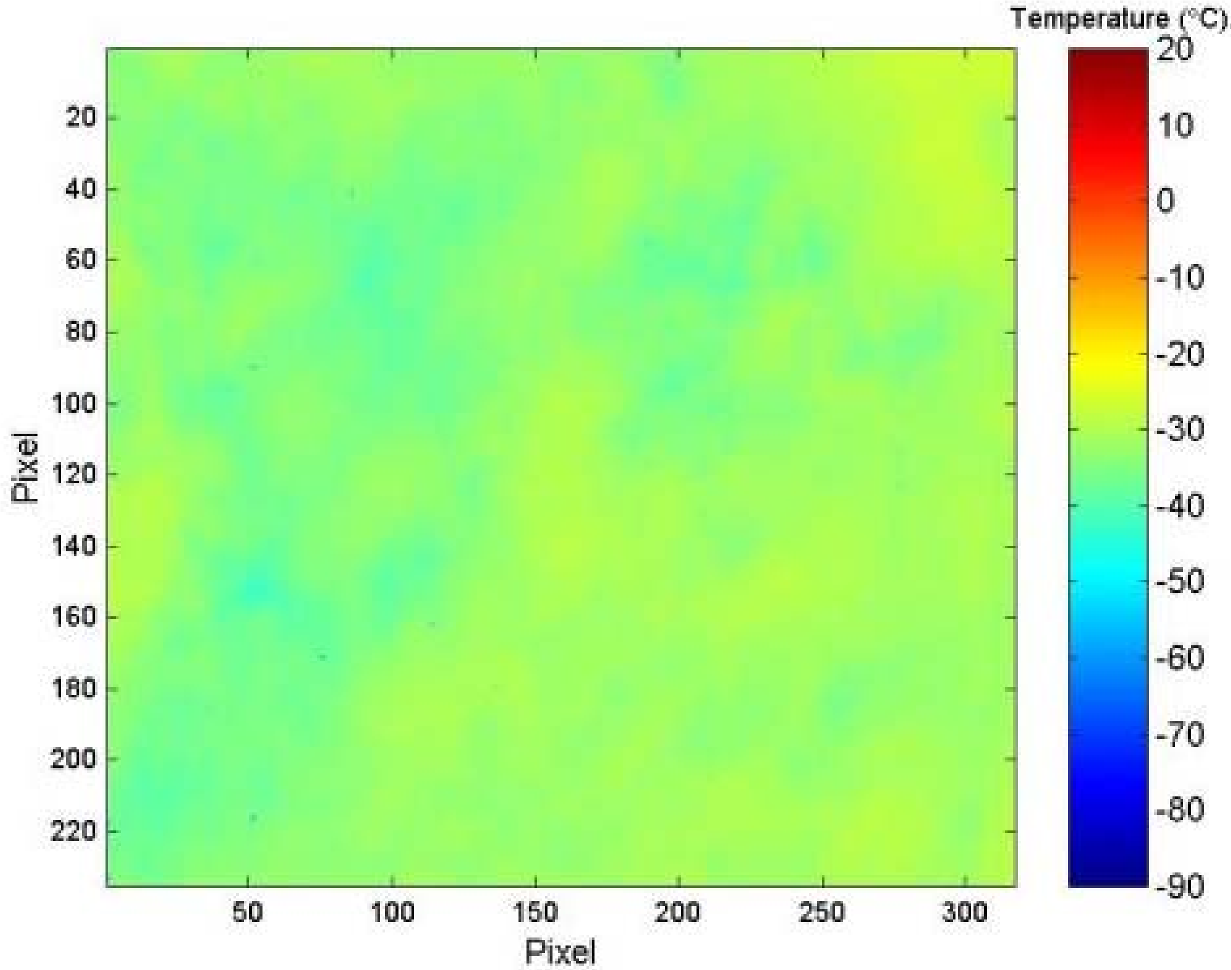

Figure 4. Radiometrically calibrated image from ICI of scattered medium-level clouds with a mean band-average brightness temperature near –30°C.

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