The Impact of Changing Cloud Cover on the High Arctic's Surface Cooling-to-space Windows

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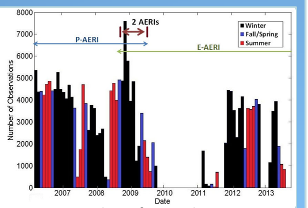
Objectives

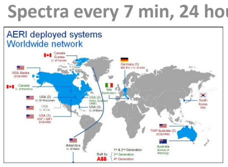
- Investigate the impact of clouds on the radiative budget in the high Arctic
- Compile measurements of the two main atmospheric windows at 10 and 20 µm, where most of the infrared energy emitted by the surface escapes to space in the high Arctic
- Investigate high-Arctic brightness temperature distributions and radiance trends; compare to an existing climatology at the Southern Great Plains (SGP)

Combined Eureka AERI Dataset

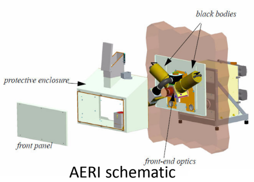
- AERI = Atmospheric Emitted Radiance Interferometer
- Two AERIs at Eureka (Polar AERI & Extended-range AERI)
- Infrared Fourier Transform Spectrometer (FTS) with **1 cm^{-1} resolution** (max OPD = 1 cm)
- Wavelength range covers 400 (E-AERI) or 500 (P-AERI) to 3000 cm^{-1} (**3-25 µm**)
- Measurement of accurately calibrated **downwelling infrared thermal emission from the atmosphere** [DOE, 1990, Knuteson *et al.*, 2004a,b]
- **Spectra every 7 min, 24 hours a day, 365 days a year** (precipitation permitting)



Number of AERI observations



Network of AERI instruments deployed worldwide (Image: ABB)

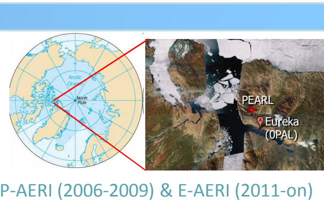


AERI schematic (Image: ABB)

Front-end of the E-AERI mounted thru-wall at 0PAL

Measurement Site: Eureka

- Ellesmere Island, Nunavut (80°N, 86.2°W)
- Deployed 2 AERIs to 2 Facilities:
  - -PEARL = Polar Environment Atmospheric Research Laboratory → E-AERI (2008-2009)
  - -0PAL = Zero-altitude PEARL Auxiliary Laboratory → P-AERI (2006-2009) & E-AERI (2011-on)



PEARL Ridge Lab (Alt. = 610 m)

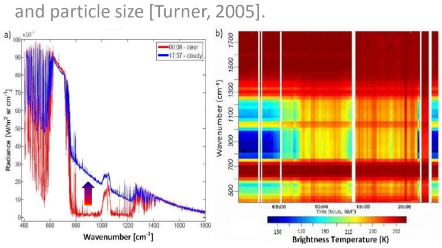
0PAL (Alt. = 10 m)

Sundogs at Eureka

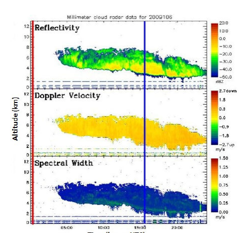
View from PEARL

Impact of Clouds on the high-Arctic's Radiative Budget

Measurements of radiance from the AERI can be grouped based on cloud cover to ascertain the corresponding forcing. As seen in the figures below, the E-AERI's radiance increases significantly when clouds are present; for instance, in the afternoon of April 16, 2009 in the 400-600 cm^{-1} and 750-1400 cm^{-1} regions due to cloud particle emission. This correlates with the Millimeter Wave Cloud Radar's (MMCR) detection of a low-altitude cloud that first appeared above Eureka at 04:00 UTC. The brightness temperature increases 44% at the same time; these increases are several times greater than at southern latitudes. Thus the impact of clouds on the radiation budget is greater in the Arctic than in other more humid regions due to the main atmospheric window being more transparent. Such large increases in radiance provide a proxy for cloud detection and analysis of cloud optical depth, phase, and particle size [Turner, 2005].



(a) E-AERI measurements of radiance on 16 April 2009 at 00:08 UTC (red) and 17:57 UTC (blue). **(b)** Brightness temperatures measured throughout 16 April 2009. White spaces correspond to periods of no measurement.



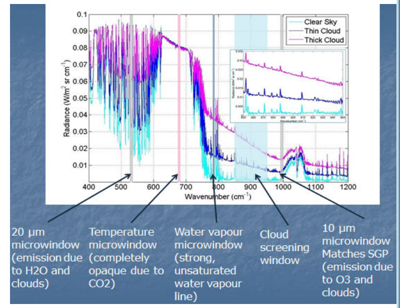
MMCR reflectivity, Doppler velocity, and spectral width plots for April 16, 2009. Red and blue vertical bars correspond to the time of E-AERI measurements, at 00:08 UT and 17:57 UT, respectively.

Figures: Mariani *et al.*, *AMT,* 2012

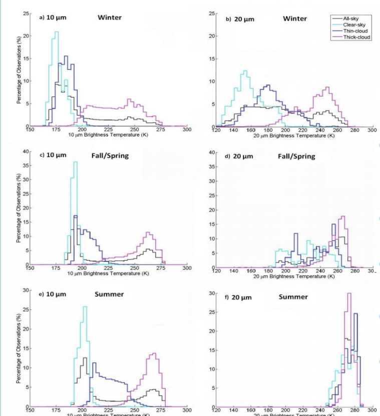
Measurements of Surface Cooling-to-space Windows

Characterizing Sky Scenes:

- Average radiance over the 850-950 cm^{-1} spectral region was used to determine the sky scene for >250,000 AERI spectra
- Allows optically thick and/or low-altitude 'warm' clouds and optically thin and/or high-altitude 'cold' clouds to be distinguished by the AERI using a set of radiance thresholds
- Radiance thresholds change depending on season (and, hence, water vapour)
- Sky scene classification validated against LIDAR and Millimetre Cloud Radar Data



E-AERI radiances measured on November 1, 2008 during clear-sky (cyan), thin-cloud (blue), and thick-cloud (magenta) conditions. The 4 microregions used in the trend analysis are shown.



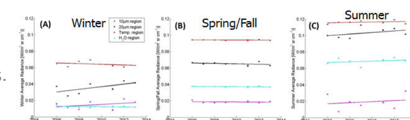
Distributions of brightness temperatures separated by season measured at 10 µm (985-998 cm^{-1}, left) and 20 µm (529.9-532 cm^{-1}, right) from the combined Eureka AERI dataset.

Brightness Temperature Distributions:

- Distributions calculated using 8-year dataset & separated based on cloud cover.
- Distinct increase in brightness temperatures is observed from winter to fall/spring to summer for both cooling-to-space windows.
- Brightness temps. @ 20 µm are independent of cloud thickness in the summertime.
- 20 µm window is saturated, or "closed," in the summer.
- 10 µm distributions are similar for Eureka and SGP in general.
- Eureka has shift to colder brightness temperatures at 10 µm compared to SGP.

Radiance Trends:

- Trends calculated within 4 microregions.
- Statistically significant radiance trends found in seasonal averages over 8 years.
- Statistically significant trends exist year-round at 20 µm.
- During the winter, trends at 10 µm are positive, in the opposite direction, and significantly larger (factor > 3) than SGP.
- Indicates changes are accelerated for the Arctic compared to southern latitudes.
- The large increase (> 4% / yr) in radiance at 10 and 20 µm during the winter is mainly attributed to increased thick-cloud cover at the expense of thin-cloud cover.



Seasonally-averaged AERI radiances at 0PAL over 8 years at the 4 microregions shown in the top Figure.

Measurement	Sky Conditions	Trend (% / yr)		
		Winter (Oct.-Apr.)	Spring/Fall (May/Sept.)	Summer (June-Aug.)
10 µm (985-998 cm^{-1})	All-sky	**+4.9 ± 4.5**	-0.4 ± 0.6	+3.4 ± 7.0
20 µm (529-532 cm^{-1})	All-sky	**+4.6 ± 2.6**	**-0.4 ± 0.3**	**+1.0 ± 0.8**
Temperature microregion (674-679 cm^{-1})	Clear-sky	-0.7 ± 0.7	-0.1 ± 0.1	**+0.2 ± 0.1**
Surface Temp. (met. obs.)	All-sky	-0.3 ± 0.7	-0.2 ± 0.8	-0.1 ± 1.5
Water vapour microregion (784-785 cm^{-1})	Clear-sky	**-1.2 ± 1.0**	-0.2 ± 0.2	+0.7 ± 0.9
Precipitable Water Vapour PWV (MWR)	All-sky	-2.5 ± 3.5	+0.4 ± 0.5	+2.5 ± 7.8
Clear-sky Observations	Clear-sky	-1.8 ± 2.4	-0.5 ± 0.8	+1.6 ± 2.1
Thin-cloud Observations	Thin cloud	**-6.1 ± 4.5**	-0.4 ± 1.0	+4.6 ± 6.0
Thick-cloud Observations	Thick cloud	**+7.2 ± 4.7**	**+0.8 ± 0.6**	-6.3 ± 6.3

Seasonal AERI radiance and cloud type trends (% /year) using the microregions illustrated in the top Figure.

Figures: Mariani *et al.,* in prep.

Conclusions and Future Work

Downwelling radiance and brightness temperature measurements have been collected by AERI instruments in the Canadian high Arctic over an eight-year period. Radiance thresholds that change with each season (and, hence, PWV) were used to characterize the sky scene. This dataset can be used to assess GCM simulations of brightness temperature distributions, cloud cover, and trends in radiance for the high Arctic's two surface cooling-to-space windows.

- Impact of clouds on the radiation budget is greater in the Arctic than in other more humid regions.
- 20 µm window is saturated during the summer.
  → *If the Arctic continues to warm at its current pace the duration of the 20 µm window being closed will increase, with important implications for the Arctic's energy balance.*
- Trends in seasonal averages at 10 µm during the winter are positive, in the opposite direction, & significantly larger (factor > 3) than any of the seasonal trends detected at the SGP.
  → *This indicates that changes in the downwelling radiance are accelerated in the high Arctic compared to lower latitudes.*
- The increase (> 4% / yr) in radiance at 10 and 20 µm during the winter is mainly attributed to increased thick-cloud cover at the expense of decreased thin clouds.
- Additional long-term measurements are necessary to determine statistically significant correlations between the two cooling-to-space windows and surface measurements of temperature and PWV.

Acknowledgements

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