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SUPER-SEEING SITES IN THE CANADIAN HIGH ARCTIC

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ABSTRACT

The potential of polar regions for astronomy has long been recognized and first highlighted with measurements of exceptional seeing in Antarctica. On the basis of satellite data and topography we identified the western part of Ellesmere Island as having potential comparable to the Antarctic sites. Preliminary site seeing measurements find that Ellesmere has sites superior to the best known mid-latitude ones and does not suffer from the substantial ground layer of Antarctic plateau sites. The site characterization is ongoing and is a very high priority, but it is clear that Canadians have an opportunity to develop an internationally competitive observatory site in the High Arctic. One immediate possibility is to develop an essentially diffraction limited optical infrared 2m class telescope. The site itself would be beneficial for telescopes of a wide range of apertures operating in the optical, IR, and sub-mm, and radio spectrum, although the increased costs will always need to be considered.

Subject headings: site testing - telescopes - instrumentation:adaptive optics

1. INTRODUCTION

Essentially all astronomical observations are improved with better resolved images, stable PSFs, and lower backgrounds.The potential of the Arctic and Antarctic as sites for astronomical observatories has long been recognized on the basis of very low precipitable water vapor and that the inversion layer in the atmosphere is at very low elevation. A recent development is experimental proof that the astronomical "seeing" (the image motion due to small turbulence induced index of refraction changes in the air) is exceptionally good in the Antarctic above the ground layer (Lawrence et al. 2004). It was subsequently determined that the flat terrain that surrounds the domes of Antarctica created an unfortunate, but fully expected, turbulent ground layer that degraded the seeing below 100 to 200m to good but not truly exceptional seeing.

Mountains in the Canadian Far North have conditions comparable to the antarctic ice plateau, and in some ways are superior. Mountain ranges in the Eastern Arctic archipelago are of particular interest, having many summits between 1000 and 1900 m that project into the free atmosphere, thus mitigating boundary effects. None are as high as Dome C, but Barbeau Peak (82N, 2616 m) on Ellesmere Island is almost as high as Cerro Pachon (2715 m). And in cold, dry air the effective altitudes at the peaks increase. Being located as far North as a latitude of 82 degrees they offer the advantage of long arctic nights, superior to sites further from the poles. The other distinct advantage of a mountain site over the Antarctic glacial plateau (or the Greenland ice-cap) is a solid, rock foundation on which to install a telescope. And equally significant are the existence of substantial scientific base-facilities already at Resolute Bay (76N), Eureka (80N), and Alert (82N). These are sites for environmental and weather-data gathering, operated by the Federal government and Canadian universities, served year-round by commercial air transport and in summer by sea. Notably, the Polar Environment Atmospheric Research Laboratory (PEARL) operates on a 600 m ridge accessible by road from Eureka. Remote mountain sites can be accessed via helicopter. One route is through logistical support from Natural Resources Canada through the Polar Continental Shelf Program (PCSP).

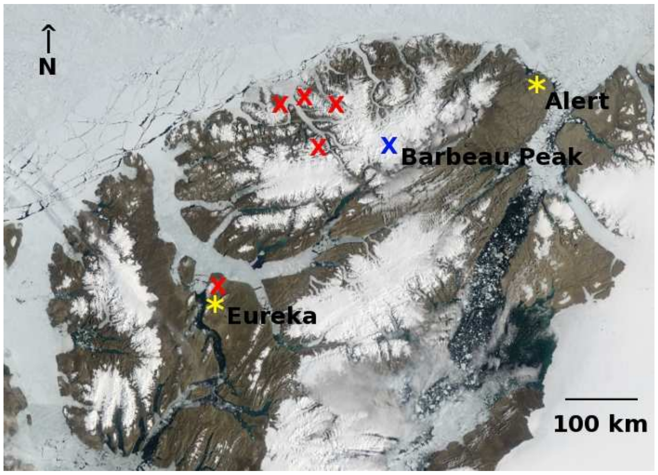

FIG. 1.— A MODIS satellite image showing northern Ellesmere Island. Sites are indicated by red crosses.

2. ACCESS TO SITES IN CANADA'S HIGH ARCTIC

Our group has been investigating the PEARL site near Eureka and four remote mountain locations along the northwestern shore of Ellesmere. The advantages of PEARL are its easy access and existing infrastructure. There are already many atmospheric instruments in operation, including LIDAR and RADAR. It is also a base facility from which we can access the mountain sites. We have gained access to the remote sites through standard arctic field logistics: Twin Otter bushplane and Bell 206L helicopter, courtesy of NRCan/PCSP. There are larger aircraft in routine operation in the North, but already these modest resources have allowed us to deploy compact autonomous instrumentation at three sites. These are wind-powered robots we call Inuksuit (Steinbring et al. 2008; Wallace et al. 2008). We have also experimented with more sophisticated equipment, including an all-sky camera and power supplementation with a small commercially-built fuel-cell electrical generator (see Fig-

FIG. 2.— The PEARL research station, near Eureka on Ellesmere Island.

FIG. 3.— A compact autonomous observatory deployed at a remote coastal mountain site.

ure 3). These data provide "ground-truth", compared to satellite observations, and long-temporal baseline data at Eureka and Alert, where continuous weather records date back roughly 50 years. We find that weather conditions are as expected: daily climate normals are -30C for winter and 5C in summer. Winds follow a remarkably consistent pattern associated with the Arctic vortex, winds are almost always from the west in winter. These sites reach above a low-altitude atmospheric thermal inversion. Figure 4 shows the results of visual sky clarity during the winter of 2008/09 (Steinbring et al. 2010).

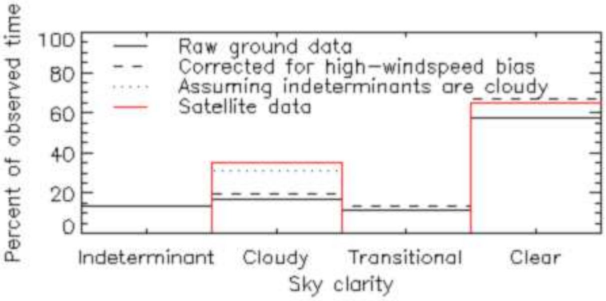

FIG. 4.— Sky clarity measurements for a remote mountain site for winter 2008.

3. EVIDENCE OF EXCELLENT BOUNDARY-LAYER SEEING

As a first step in investigating the optical seeing quality of high-arctic sites, our team has installed two Sonic Detection and Ranging systems (SODARs) and a lunar scintillometer, the Arctic Turbulence Profiler (ATP), at PEARL, near Eureka. These instruments are designed to measure turbulence profiles in the planetary boundary layer, within the lower kilometre of the atmosphere. They are not sensitive to high-level turbulence. At the time of writing, initial results are available only from the ATP.

The ATP is based on a lunar scintillometer that UBC has operated successfully at Cerro Tololo (CTIO) for several years, redesigned for operation in the harsh arctic environment. By recording fluctuations in the lunar flux received by photodiodes over a range of baselines, one can reconstruct the C_N^2 profile, and from this determine the seeing as a function of height above ground (Beckers 1993; Hickson & Lanzetta 2004; Hickson, Pfrommer, & Crotts 2008; Tokovinin et al. 2010). To provide an independent check, a second scintillometer was built. The Portable Turbulence Profiler (PTP) is less complex than the ATP, but uses the same optical elements and preamplifiers. It was taken to Mauna Kea (MK) and operated at CFHT at a location adjacent to their facility seeing monitor, a combination Differential-Image-Motion Monitor (DIMM) and Multi-Aperture Scintillation Sensor (MASS) previously used in TMT site testing. The very good agreement between the scintillometer and DIMM-MASS instruments strengthens confidence in our results from the arctic.

About 6 hours of photometric data were obtained with the ATP, over a 72 hr period in November, 2009, before it was damaged by a severe storm. Repairs have been made, and more data are being collected. The ground-layer seeing statistics measured by the ATP at PEARL and the PTP at MK are shown in Figure 6. These initial results clearly indicate that the ground layer (GL) at PEARL is weaker than at MK. The median GL seeing is $0\farcs28$ compared to $0\farcs45$ for MK. We must also consider high-level turbulence not sensed by the scintillometer. For MK, the median free atmosphere (FA) seeing is $0\farcs33$ (Schoeck et al. 2010). Adding this to the GL seeing values gives a median total seeing of $0\farcs46$ for PEARL and $0\farcs59$ for MK. However, there is good reason to believe that the FA seeing may be better at PEARL than at MK. MASS observations from Dome C in Antarctica indicate unusually-weak FA turbulence (but a strong ground layer) (Lawrence et al. 2004; Aristide et al. 2009).

FIG. 5.— The ATP mounted on the roof of PEARL.

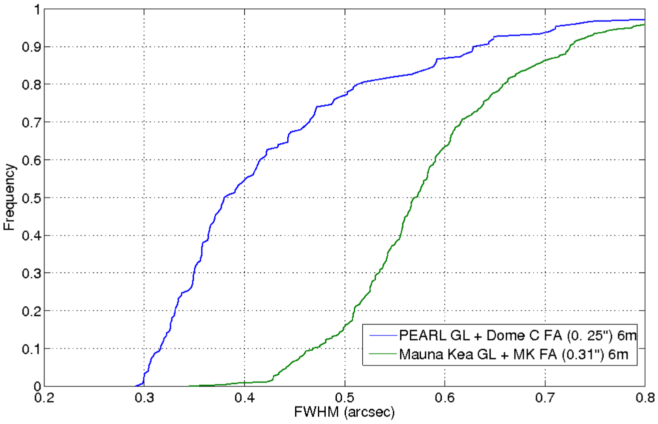

FIG. 6.— Ground-layer plus free-atmosphere seeing at PEARL and Mauna Kea, referred to zenith and 500 nm, from a height of 6 m AGL.

Like Dome C, PEARL is located inside the polar vortex (PEARL is in fact closer to the pole than is Dome C) and may also have weak FA turbulence. In that case, the median total seeing will be less than $0\farcs46$, and potentially as low as $0\farcs28$ (and lower still at heights greater than 6 m). These results suggest that Ellesmere Island has seeing that may be the best in the world, and is likely superior to any established site.

4. FUTURE DIRECTION

Our preliminary data indicate that the mountains of north-west coast of Ellesmere Island have astronomical sites better than the truly exceptional sites of northern Chile and Hawaii. Moreover, we have established that we can build and operate equipment in the challenging environment of the Arctic using the relatively modest resources available to us. The Ellesmere sites are at least comparable in optical quality to those of the South Pole, but allow building on rock, and have nearby summer sea access and year-round air access, via commercial operators.

It is essential to fully characterize the astronomical properties of several Ellesmere sites and their operational feasibility before undertaking any major astronomical development. Our preliminary seeing results are acquired near the PEARL lab, a relatively low elevation inland site, but with year round technicians and good power. The mountain sites on the western coast of Ellesmere require remote operation and are only partially characterized. Satellite data indicates that they have better overall sky transparency and as relatively isolated peaks should have reduced ground layer turbulence. PEARL is an invaluable resource for commissioning equipment and is suitable for a range of less demanding astronomical observations. Our group plan to expand our studies to include 20 micron measurements and a DIMM-MASS, as funding allows. Assuming that our preliminary analysis is verified, the high quality of NW Ellesmere Island as an astronomical site makes it suitable for essentially any astronomical observation from the radio to the optical. One consideration is higher costs, although there is commercial air service to Eureka and PCSP provide superb support at remarkably economical rates. The second is the difficult operating conditions which are best suited for largely robotic observatories, which are now routinely operated at the 2m scale at mid-latitudes. We currently plan to run a DIMM-MASS in a campaign mode, which will require an on-site operator over the winter, which will provide invaluable knowledge of conditions.

A 2m-class robotic high-resolution telescope, to some extent a revival of Racine's High Resolution Telescope idea, would make an interesting first step. Thermal background is greatly reduced compared to MK. The telescope would be essentially diffraction limited at K, achieving a Strehl-ratio of about 0.5 in the J band with tip-tilt alone. A prime scientific use would likely be planetary transit/eclipse monitoring. A modern AO system would be able to provide high-Strehl diffraction-limited images well into the optical bands with a good field of view. A 2m class telescope and enclosure can be procured for approximately \$5-10M. Tip-tilt correction is relatively cheap and even with median seeing gives significant Strehl values shortward of 1 μm. A new possibility is that a relatively low cost Rayleigh beacon system with a 12×12 DM can be developed for about \$1M (Britton et al. 2008). With reasonable assumptions for residual wavefront errors this could extend 0.5 Strehl-ratio performance into V band (Racine 2010), becoming essentially an HST on the ground. At the 2m scale the telescope should have a focused scientific mission and limited but powerful instrumentation. This level of funding is within the grasp of a consortium of Canadian universities and is not necessarily a national facility although if there is sufficient interest a national facility should be entertained. An alternate possibility would be to build a large aperture mid-infrared telescope using high precision radio-telescope manufacturing techniques. The very cold, dry, "super-seeing" sites of Ellesmere can support many interests and offers the possibility of attracting new resources into Canadian astronomy.

A diverse group has joined forces on this effort, bringing together scientists, engineers, and experts in arctic logistics. In particular, Greg Fahlman, Brian Leckie, Tim Hardy, Kris Caputa, and Matthias Schoeck, and the HIA ATRG-V, its shop and purchasing department have been instrumental in making it work, as have Thomas Pfrommer and the Physics and Astronomy Department at UBC. Other contributors to this work are Rene Racine, Tony Travouillon, and Liviu Ivanescu. Undergraduate summer students from UofT have assisted with field work, and collaborators and technicians at the PEARL lab carried out setup and help operate the ATP and SODARs. Logistical support has come from Environment Canada, which operates the weather station at Eureka, as well as Natural Resources Canada through the PCSP arctic-fieldwork base in Resolute Bay.

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