Summit, Greenland Observatory and ISI Station

Serving Scientific Research into the 21st century

An updated outline for an extended 5-year plan

January, 2014

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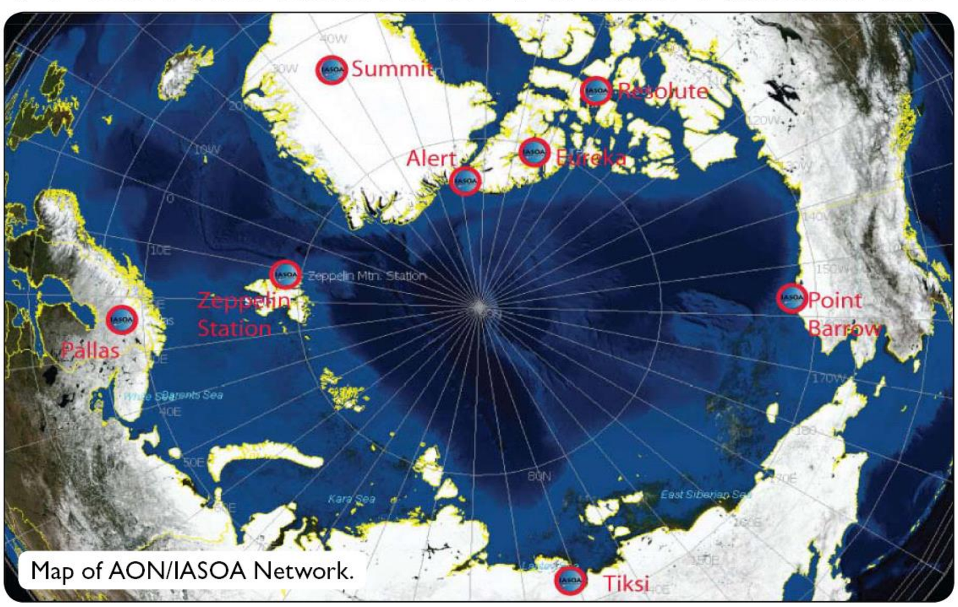
Summary

Summit is a unique observatory that will serve a critical role in understanding arctic and global climate change over the next several decades. ***As the only dedicated, staffed observatory operating year-round at high altitudes in the Arctic, Summit offers easy and immediate access to the free troposphere, is relatively free of local influences that could corrupt climatic records, traces averaged trends in the northern hemispheric troposphere, and captures rare phenomena that can represent climatic trends and help scientists understand the impacts of climate change.*** Summit is situated ideally for studies aimed at identifying and understanding long-range, intercontinental transport and its influences on air and snow chemistry and albedo. For radiation measurements, it is the only arctic site with a year-round dry snow and ice background. Recent pilot studies have also demonstrated that Summit is one of the best sites in the northern hemisphere for submillimeter and terahertz astronomy and may be the best site on earth for radio detection of high energy neutrinos.

While other research observatories in the Arctic such as those at Barrow, Alert, Ny-Alesund, Tiksi, and Chersky lie at sea level near coastal and continental influences, Summit will remain free of regional effects from increased shipping, melting ice, and thawing permafrost – changes that are likely to be observed across the Arctic in the near future. Summit records would not be corrupted by such influences unless they represent widespread Arctic trends or are sufficiently significant to have large-scale effects. Summit thus serves as a reference site, analogous to a white cell in a spectrometer, for arctic measurements of climate change. Process studies targeting aspects of the climate system (e.g., atmospheric chemistry, air-snow exchange, boundary layer dynamics, energy balance, cloud physics/microphysics and radiative impact) conducted at Summit benefit from the suite of long-term, continuous measurements that can help in identifying questions and interpreting and understanding results, something that is not available at temporary or seasonal field sites. Because Summit is largely free of impacts from regional activities, great care must be taken to ensure that local activities at, and to support, the station do not jeopardize the unique characteristics of the site.

Vision: *Summit station will be a pre-eminent polar research station in coming decades, integrated into an arctic network of observations and supporting cutting edge research in a variety of disciplines by international teams from the US, Europe and Asia. Investigations into tropospheric chemistry, snow chemistry, air-snow exchange and climate change will remain prominent at the facility, but other geophysical fields (e.g., seismic, stratospheric, ionospheric, space weather, particle physics, astronomy, astrophysics) will also be represented. In addition, Summit will increasingly serve as a test bed for new sensors and technology designed for remote operation or autonomous exploration in isolated regions and harsh environments. Continued improvements in communications technology will allow for scientists and the general public to fully participate in experiments and events at Summit from their desks back home around the world.*

A Cornerstone of Arctic Research



Map of AON/IASOA Network.

I. Arctic Change as an Indicator and Feedback of Climate Change

The Arctic region is currently undergoing profound atmospheric, terrestrial, and oceanic changes related to notable variations in climate. In many cases, observed changes do not represent and frequently exceed model projections and predictions. The Arctic is not just an indicator of climate change, but also provides numerous feedbacks. These feedbacks are associated with unique Arctic characteristics, such as those associated with reductions in sea ice cover, increasing coastal water temperatures, pronounced continental warming, potential release of carbon and methane associated with permafrost thaw, and rising sea level. The changes are further complicated by social adjustments that accompany them – adjustments that may further modify the Arctic system such as expanded maritime and land transportation, fisheries, resource exploration and extraction. Environmental changes due to climate change and human responses to those changes in the Arctic already are having, and will continue to have, significant ramifications for marine and land ecosystems, indigenous human populations, societal human health and infrastructure, and international maritime water column and sea bed claims. Some projections suggest that Arctic system adjustments to global climate change may be modifying northern hemispheric mid-latitude weather patterns, or will soon be. Immense effort in the future will be aimed at studying these phenomena and understanding their effects and global impacts.

Amid these Arctic changes and efforts, Summit Station in coming decades will become a critical, perhaps the sole, background site in the northern hemisphere for studies of global climate change, as it will remain free of local and regional influences for decades to come. Precisely because it is not located in a coastal area that is subject to nearby climate change events, Summit Station will become an increasingly important site for studies that need to be free of significant local effects. For those trying to separate local change from large-scale phenomena, whose studies simply require being free of regional effects, who might need to observe long term change in the free troposphere, who will be studying the exchange between the stratosphere and troposphere and its linkage to climate, or who wish to study extraterrestrial phenomena, Summit will be the increasingly favored site or at least a necessary component for their work.

II. Near Term Opportunities for Science to be Conducted at Summit

Summit supports a mixture of long-term observation programs that are building extended time series for detection and quantification of large scale changes in the Arctic system. In addition, Summit supports an ever changing set of short term "campaign-based" investigations that are expected to yield insight or resolution through intensive but short observational or experimental efforts. In recent years many campaigns have focused on air/snow exchange, both to more fully exploit the glaciochemical records recovered from the Summit ice cores (GISP2 and GRIP) and to elucidate the impact of snow photochemistry on the overlying atmosphere. Other teams have collected new shallow ice cores for targeted investigations responding to open questions raised by the deep ice cores, or because new analytical techniques have been developed that allow measurements not possible 15 years ago. Advances in methods to measure stable isotopes in very small samples have lead to several recent studies generating time series in snow and ice cores, and also using isotopic tools to understand air/snow exchange processes. Several teams have conducted deep firn air sampling from the new bore holes to further our understanding of recent changes in atmospheric composition and to refine understanding of the processes controlling the mixing of air within the firn and trapping of that air in ice, in order to make full use of existing and future measurements of trapped gases in deep glacial ice. Several campaigns have made measurements relevant to glacier dynamics (e.g., densification, vertical strain) using new techniques including satellite borne sensors; results from these studies add to knowledge about the history of the Greenland ice sheet and perhaps will inform simulations of the large scale impact of the recent dramatic increase in the discharge rates of several large outlet glaciers. Another important group of Summit users is made up of those testing new concepts and designs; in recent years these have included examples ranging from "green" infrastructure like the wind turbine and electric snow machines, ice core drills designed for deep coring in Antarctic and shallow coring on Europa and perhaps other bodies in the solar system, several different new ice penetrating radar systems, to autonomous rovers for exploration in remote regions of Greenland, Antarctica, and also other planets and moons.

Similarly wide ranging studies are ongoing or have been proposed for the near future. The exact mix of users moving forward is impossible to predict since this will depend on funding decisions, and also new issues posed by the many currently active science communities as new discoveries are made at Summit and elsewhere. However, it is safe to state that interest in Greenland and Summit station will grow as climate change focuses ever more attention on the Arctic.

In recent years, the enormous benefits of the Summit Station site have come to the attention of the astrophysics community. Summit Station provides a unique high elevation site in the Northern hemisphere. Millimeter-wave telescopes rely on high, dry sites with a stable atmosphere to make high-quality measurements of the millimeter-wave sky. A consortium led by the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics has acquired a 12-meter radio telescope and has advanced plans to install it at Summit to become part of the Millimeter VLBI Network. As interest continues to develop over the coming years in making full-sky maps of the Cosmic Microwave Background from the ground, Summit Station would be a natural candidate site for a CMB telescope.

Summit Station is perhaps the best site on Earth for radio detection of high energy neutrinos, folding in ice properties and logistical considerations. Summit Station could prove to be the most practical place to build a large radio array for detecting these elusive particles. In the coming years, Summit could be home to a large facility for radio detection of neutrinos, with many autonomous radio-detector modules operating through the winter.

The new interest in Summit from the astrophysics community is exciting, but clearly could result in larger populations of researchers visiting the site, increasing the need for power and infrastructure. Accommodating such growth, without degrading the value of the region for the ongoing clean air and clean snow studies will be a challenge but also a priority.

III. Operational and Scientific Advantages of the Summit Observatory

As the only high elevation year-round observatory north of the Arctic Circle, Summit has proven to be a valuable location for numerous multidisciplinary investigations including: sampling of globally transported atmospheric compounds, investigation of the snow-to-air transfer of atmospheric compounds, investigation of the complex photochemical cycling of reactive nitrogen and other short-lived species, detailed studies of the boundary layer and energy fluxes over the ice sheet, seismic measurements, magnetic measurements of the ionosphere, and also testing of remotely operated vehicles for glaciological and other autonomous measurements. Recent pilot studies have also established that atmospheric conditions are ideal for millimeter and microwave astronomy, and that the snow and firn characteristics uniquely allow for installation of radio antennas at or near the surface to detect very high energy neutrinos created by cosmic rays.

Providing the highest quality records available for the evaluation of climate change in the northern hemisphere is a core component of Summit as a research platform. Data sets produced from Summit provide a long term record of free tropospheric conditions in the northern hemisphere free of impact from local or regional pollution sources. The station will continue to contribute to established monitoring networks such as GAW, AMAP and IASOA. The National Oceanic and Atmospheric Administration (NOAA) formally added Summit to its atmospheric baseline observatory network in 2010. Support from NSF's Arctic Observing Network (AON) program will extend observations of UV radiation, long range transport and deposition of aerosol-associated compounds, and impacts of clouds on radiative budget at least through 2016. Summit is expected to be incorporated into the Baseline Surface Radiation Network, extending these 10+ year long climatically relevant data series into the future as well. NOAA's recent addition of measurements of aerosol optical properties (initiated in 2011) will provide unparalleled observations of the agents forcing climate change in the Arctic.

Unique to Summit

High Elevation

- Surface measurements representative of Arctic free troposphere
- Low water vapor supports measurements of upper atmosphere

High Latitude

- Combined with high elevation yields extreme cold temps for monitoring ozone depletion
- Strong seasonal radiation cycle

Pristine/Remote

- Background levels of important atmospheric components can be characterized

Dry Snow/Accumulation Region

- Dry ice sheet location supports intercomparison studies with Antarctica (Dome C, WAIS)
- High snow accumulation provides high annual resolution for ice core interpretation

Year-round Science

- Access to seasonal data

"Summit is the best place in the Northern Hemisphere for long-term solar observations given its clean air, high elevation and cold environment."
-Koni Steffen, Summit PI

A core value of the station is the availability of year-round baseline measurements of climate and chemical variables in the atmosphere. These measurements are used by numerous investigators working both on the station as well as incorporating the data into larger scale 'pan Arctic' and Arctic systems science analyses. Summit is also the location of the GISP2 ice core, which was completed in 1993, and provides a continuous paleoclimate record reaching back 110,000 years ago, to date the deepest ice core retrieved from the Greenland Ice Sheet. Along with the companion GRIP core, drilled 28km to the west, the two ice cores represent a unique high resolution climate record. Extracting deeper understanding of the records of past atmospheric chemistry preserved in these ice cores motivates many of the process studies conducted at Summit. However, in the remote environment of Summit, the slightest pollution can cause ‘noise’ in the signal creating a challenge to evaluate long term changes, and can cast doubt on the extent to which present day air-snow exchange processes represent the natural system as it operated in the past. As such, a critical requirement of the facility is to remain a ‘clean air’ station and to utilize best practice approaches to minimize the generation of pollution and to mitigate impacts when practical.

The goal of Summit Station is to become a ‘flagship’ Arctic observatory providing continuous year-round measurements of key climate variables while serving the needs of a diverse range of scientists. The long standing primary objective of the facility is to provide the highest quality long term year-round measurements of the free troposphere. While this initial objective requires Summit to be a ‘clean air’ facility, it is not intended to be exclusive, and serving the needs of multidisciplinary science can still be accomplished through innovative solutions and renewable energy utilization. Updating and expanding the infrastructure to allow support of the 12 m telescope while maintaining clean air and clean snow conditions is providing ample opportunity for such innovation.

IV. Operational Needs to Conduct These Studies & Intersection of Clean Energy with Science

Experiments in atmospheric chemistry have played a significant role in the development of Summit Station. A continuing objective of the facility is to provide a pristine sampling environment for measurement of trace gasses. Also, air-to-snow exchange of reactive compounds will likely continue to be investigated at Summit. Continued advances in analytical technology will create opportunities for more compounds to be measured both in the atmosphere and in ice cores at low concentrations. These new measurements may yield valuable proxies for climate reconstruction. Interpretation of the measurements will continue to rely on investigations of the preservation properties, and therefore, experimentation at Summit.

As with baseline observations, atmospheric measurements during many campaigns will rely on a sampling environment free of local sources of pollution. However, an additional challenge for air-to-snow exchange studies results from the ‘memory’ of the snow. That is, the snow surface is an integrative sampler of the local air. While observatory measurements may be flagged during pollution events, there is no such mechanism to prevent contamination from affecting the surface snow sample data. With more sensitive measurements, greater effort is required to reduce the impact from local pollutant sources – with the ultimate goal being a pollution-free infrastructure. ***It is anticipated that the National Renewable Energy Laboratory (NREL) will continue to provide invaluable advice regarding the most cost effective ways to further reduce fossil fuel use at Summit and lead to a cleaner research environment for all science groups.***

Pollution Impacts Science

» 15% down time in "clean air" measurements due to pollution from camp

A Clean Air Sector (CAS) was established and the prevailing winds at Summit are from the CAS more than 80% of the year. The CAS was established to preserve the unique atmospheric and terrestrial conditions found at the top of the Greenland ice sheet from Summit station influences. Except for special circumstances, access to the CAS is strictly prohibited. This includes foot and vehicle traffic. Aircraft activity is limited in the CAS, and guidelines for scientific or other activities have been established by the National Science Foundation (NSF) and CH2M-Hill Polar Services (CPS) in consultation with the Science Coordination Office (SCO). The pristine nature of the CAS is strictly preserved, not just for the current scientific activities, but also for future scientific interests at Summit.

V. Plan for Next Five Years (Science, Logistics and Interagency Support)

Summit station will be the pre-eminent polar research station in the world. It is likely that investigations into tropospheric chemistry, snow chemistry, air-snow exchange and climate change will remain prominent users of the facility, but other geophysical fields will also be well represented (e.g., seismic, stratospheric, ionospheric, space weather, particle physics, astronomy, astrophysics). In addition, Summit will also increasingly serve as a test bed for new sensors and technology designed for autonomous exploration on the moon, Mars and other objects in the solar system. And Summit will be the site of the 12 m telescope, defining the northern extent of the Millimeter VLBI Network. Positive decisions about proposals pending currently would also add radio detection of neutrinos and deployment of prototype telescopes mapping the CMB to the ever changing mix of research near the highest point of the Greenland ice sheet

- **Science**

As noted earlier, projections about future science activities are difficult in general, since they require assumptions about Federal funding at several levels. In the case of researchers supported by NSF, the fact that proposals are generated by numerous individual investigators and are submitted to multiple programs within the foundation limits the informed planning horizon to two or three years at best.

NOAA's near future plans are more specific, since they are formulated by a single group, but they are also uncertain due to the nature of the federal budget process. Growing societal concern about global change leads to optimism that NOAA will be supported at an increased level in the near future. The time line below is based on conservative estimates of NOAA budgets in the next few years, marked growth in the NOAA budget could compress the implementation (while reduced support could obviously extend the time line, or cause reassessment altogether).

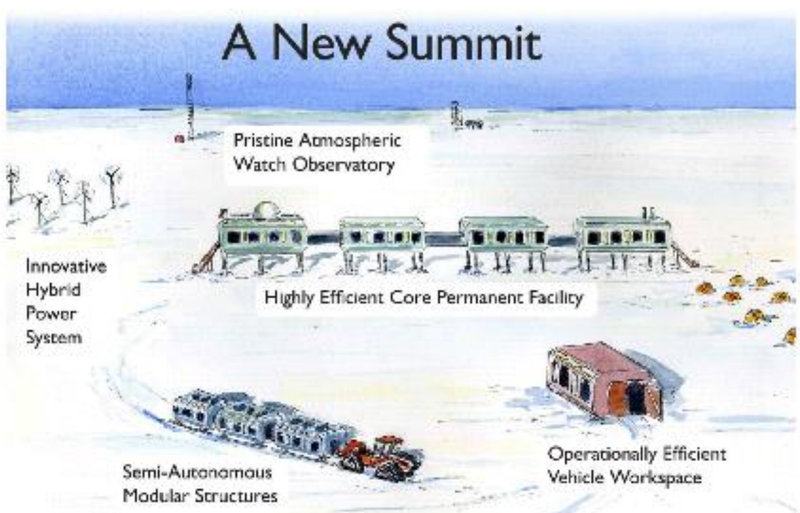
- Increased in-situ instrumentation: CO_2, CO, and CH_4.

- Add aerosol particle number and size distribution capabilities.
- Add NOAA solar tracker and instrumentation.
- Begin balloon-borne vertical profiles of stratospheric water vapor.
- Upgrade ozone balloon program to include plastic balloons flights.
- Upgrade meteorology suite and add horizontal visibility sensor.
- Enhanced data analysis and publications from Summit.

Smithsonian Astrophysical Observatory (SAO) and the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) likewise have focused plans, but their timeline is also subject to securing funding. This collaboration has the 12 m telescope in hand and is currently making modifications to allow operation in cold climates. They will assemble telescope in Thule and operate it for at least one year there, before transporting to Summit via the Greenland Inland Traverse (GrIT). Under the current timeline, preparation of a large snow foundation at Summit for the telescope will begin in 2016, and operations will begin in the winter of 2018/2019. SAO/ASIAA anticipates using the telescope as part of the VLBI Network for at least 15 years, they will provide year round staffing to maintain and operate the telescope, and will offer observing time to other investigators for different studies using the telescope.

- **Logistics**

Increasing fuel costs and changed priorities of the New York Air National Guard (ANG) are likely to cause changes in operations at Summit. Initiating a surface traverse program for major resupply of the station will most likely require investigators to adopt much longer planning horizons. To ensure delivery on site via the traverse, longer timelines will be required in order to get scientific cargo into the cargo system well in advance of deployment of personnel to Summit. In some cases the lead time could be nearly a year, in particular heavy and/or bulky cargo that will need to be transported by vessel to the traverse depot in Thule. On the plus side, lengthening the supply chain in this manner will reduce emissions on station (currently the LC-130 operations account for nearly 25% of all diesel burned at Summit, and contribute an even larger fraction of emissions of many pollutants). Optimistically, this change in operations will also hasten the adoption of energy conservation measures and use of renewable sources of energy at Summit. In some sense these changes are just a rather large step in the evolution of the culture at Summit, which has already adopted a pedestrian culture and aggressive measures to reduce energy use on the station.



In general, it is clear that increasing the thermal efficiency of all structures should be a priority (retrofit or replacement). Building as many year round structures as possible on jackable platforms will reduce the need for snow removal around camp, thereby limiting the area impacted by emissions from heavy equipment. This step could also reduce the operational workload for Summit staff, perhaps allowing smaller crew sizes. Proposed deployments of flexible work spaces mounted on sleds and including efficiency measures (high R values, passive solar heating, perhaps PV, day lighting) also appear likely to ease operational demands and reduce emissions. The cartoon (above) represents collective thoughts of SCO and CPS about the look of a future sustainable Summit station. Modularity should allow slow and steady progress toward this vision, with NREL pointing the way toward the most efficient elements that should be implemented first.

However, it should be clear that the arrival of the telescope near Summit will necessitate major upgrades to the year-round infrastructure. The power demands of the telescope are 3-4 times larger than the current load of the entire station, and the staff required to support and operate the telescope are estimated at ~10 individuals throughout the winter observing season, added to the current winter population. The increased activity, and especially the prospect of occasionally needing to run a 200 kw diesel generator to carry camp through periods of reduced renewable energy availability, threaten to jeopardize the clean air/clean snow qualities at Summit.

To minimize the impacts of the telescope (and other likely astrophysics investigations to follow) on the climate studies at Summit; NSF ARSL, CPS and SCO have planned to move all infrastructure except the Atmospheric Watch Observatory and the Summit Big House to a new station known as Isi 5 km to the north of Summit camp. The separation between AWO and core facilities at Isi will be > 6 km. Sustainable design and operation of these new facilities is essential, both to control long-term operational costs and to preserve the unique attributes that have attracted researchers to Summit since 1989. Key points in these plans include use of very efficient thermal envelopes on all structures, high RE penetration hybrid power system, elevating facilities on jackable platforms to reduce need to move snow, and increased reliance on GrIT for transport of materials and supplies to both Isi and Summit Observatory to reduce the number of flights into the region.

Expanding the capabilities of GrIT by introducing a split-fleet mode of operation is viewed as essential to accomplish the development of Isi and installation of the 12 m telescope on the ambitious timeline desired by SAO/ASIAA. Notably, these changes to GrIT will also enable support of science via surface traverse nearly anywhere on the Greenland ice sheet. Thule and Isi will serve as logistics hubs for science groups working well away from Summit, including investigations that make observations while traveling as well as short term occupation of remote camps delivered and then recovered by GrIT. For example, there is likely to be increased interest in determining the origins of the ice streams, understanding the bedrock topography, and validation of the IceSat2 and CryoSat2 instrumentation across the Greenland Ice Sheet.

It should be noted that Isi reflects evolution of planning that was already well underway before the prospect of a large telescope at Summit was even considered. The necessary expansion in the size of physical infrastructure required to support 3-fold higher population (and 3-4 fold greater power demand) made the decision to increase the distance between camp and the clean air science zone obvious, but this option was being considered even for redevelopment of Summit at present size.

- **Interagency support (e.g., NOAA, SAO/ASIAA, DOE, NASA/ESA)**

Interagency support is critical to the success and establishment of Summit as a preeminent Arctic research site. Interagency collaboration is mutually beneficial to all parties involved. NOAA considers a major part of its role at Summit to be one of support to the NSF and other research projects. NOAA provides a continuous long-term back bone to climate monitoring that includes gases such as CO_2, Methane, CO, CFCs, HCFCs, Ozone, and measurements of solar radiation, aerosols, and meteorology. This data set will enable other research groups to thrive and push the advancement of our understanding of the Arctic climate system. NOAA has a long history of expertise in providing baseline atmospheric observations in support of scientific research. The agency intends to continue to provide a similar service and product to all research groups at Summit.

SAO/ASIAA have accelerated a process that the Summit community had already begun. The change in scope of facilities required to house a large telescope has increased the magnitude of redevelopment required, but it has also imparted a faster pace to the planning process. The telescope will bring new and exciting high profile science to Summit, and also significant funds from sources beside NSF and the US government.

In the past, NREL has advised the NSF on measures to help make Summit infrastructure and operations both cleaner (less fossil fuel use leads to lower emissions of many pollutants) and more sustainable (lower long-term operating costs, but also an example of moving toward a reduced fossil carbon future). Current discussions about a more active collaboration between NREL and NSF DPP could lead to reductions in financial and environmental impacts of OPP supported research throughout the Arctic and Antarctic. Formalizing this collaboration must be a priority. Opportunities for partnership with other DOE programs are being cultivated, including possible shared funding of energy efficiency initiatives.

If NASA and ESA do support extensive ground validation of IceSat2 and CryoSat2, the central Greenland ice sheet would seem a priority target. Planned developments of Isi and GrIT should facilitate access for such studies, hence the space agencies should be cultivated as partners in the support of Greenland science, including investment in enabling infrastructure.