NSF Annual Progress Report

0856733 to University of Idaho
0904152 to University of Wisconsin
0856559 to University of Colorado

"*Collaborative Research: An Integrated Characterization of Energy, Clouds, Atmospheric State, and Precipitation at Summit (ICECAPS)*"

Period covered: 1 May 2013 - 30 September 2013

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Matthew D. Shupe, PI, University of Colorado

ACCOMPLISHMENTS

What are the major goals of the project?

This project was terminated early on 30 September 2013 (instead of 30 June 2014) in accordance with the guidelines of the American Recovery and Reinvestment Act (ARRA).

The main objective of the ICECAPS project is to produce atmospheric thermodynamic state, cloud, cloud-radiation, and precipitation data sets at Summit that can be used to address the following scientific questions and serve additional community research needs:

1) How do cloud properties and precipitation properties vary seasonally at Summit?
2) What are the effects of clouds and atmospheric state on the ice sheet surface radiation budget?
3) What is the sensitivity of radiative fluxes to perturbations in atmospheric state, cloud properties, and surface properties?
4) How are cloud and precipitation properties associated with local and regional weather and climate variables, such as winds, temperature, turbulent heat fluxes, radiative fluxes, and synoptic activity?
5) How do cloud and atmospheric state properties, as well as radiative fluxes, vary among different Arctic sites? In particular, how do these conditions vary among Barrow, Eureka, and Summit?

To accomplish this objective, programmatic goals are to:

1) Deploy and operate a suite of cloud and atmosphere sensors at Summit, Greenland, including: infrared interferometer, microwave radiometers, cloud radar, depolarization lidar, ceilometer, precipitation sensor, sodar, and twice-daily radiosondings
2) Produce data products from these instruments that are quality controlled and publicly archived for public usage. Such products include: all quality-controlled measurement streams, atmospheric thermodynamic properties and water vapor

amount, cloud occurrence and boundaries, cloud compositional properties such as liquid water path and phase, precipitation rate, and other properties.

3) Facilitate the usage of ICECAPS data by the broader research community via a project web page, through publicly available data archives, and by engaging in active collaborations with research colleagues.

What was accomplished under these goals? (Required to complete at least 1 of following 4 sections)

1/4: *Major Activities*

1) The operational activities of the ICECAPS experiment continued from spring 2013 to autumn 2013 at Summit Station, Greenland. The primary activities were field operations, data quality assurance, and analysis of observations. During the reported time period, the project maintained a full-time technician on site. During the summer of 2013, there were six ICECAPS visits to Summit by PIs, engineers, and students to fix equipment, perform instrument maintenance, and ensure the consistent operation of the instrument suite. The majority of ICECAPS instruments are still in operation at the Mobile Science Facility (MSF) at Summit since funding for this project was renewed for an additional five years as of 1 October 2013. Special considerations for each instrument are outlined below.

- *Polar Atmospheric Emitted Radiance Interferometer (PAERI).* The PAERI has been operating nearly continuously since July 2010. There were very few issues with the instrument throughout the past year. Additional insulation was provided for the PAERI's scene mirror to allow operation at extremely low temperatures (< -55 C). The "uptime" of the PAERI over this reporting period has been about 97%.
- *Microwave Radiometers (MWR).* The MWRs have also been collecting data in an almost uninterrupted fashion for the past year. The MWRs "uptime" over the past year has exceeded 95%. The instrument alterations made after the first winter (i.e., Nov 2010-Mar 2011) alleviated the technical issues related to extremely cold conditions that occur during the winter season, and our data quality in the winter is much improved. New blower fans were also installed during the past year and have operated nominally. Successful liquid nitrogen calibrations were also performed last summer and in late April.
- *Millimeter Cloud Radar (MMCR).* Cloud radar operations in general have been a challenge at Summit as the system includes a number of delicate parts that can fail and it is difficult for standard technicians to address these issues. However, during the past year the radar has been more stable than any time during the ICECAPS deployment to date. Since a component was repaired in April 2012, the system has operated consistently with more than 95% uptime.
- *MicroPulse Lidar (MPL).* Over the course of the first two years of operation during ICECAPS, where was a slow drift in the MPL's depolarization channel. To rectify this, the system was swapped out with a replacement MPL in the late

summer of 2012. That system has operated relatively consistently since that time, with few issues (>95% uptime).

- *Ceilometer*. This system has operated continuously and robustly for the duration of the project with very few interruptions in the measurement stream; this is perhaps the most robust system in the ICECAPS suite.
- *Precipitation Occurrence Sensor System (POSS).* This X-band radar precipitation system has operated without major issues since it was installed in summer 2010, attaining >98% uptime
- *Radiosonde program*. Twice daily radiosonde profiles have continued throughout the course of the campaign. All soundings measure temperature and humidity, while a single sounding per day also measures wind speed and direction. Information from these measurements is automatically uploaded to the Global Telecommunications System where it is assimilated by operational weather prediction models. Within the past year there have been a few missed or faulty radiosonde launches; these are typically related to weather conditions (very high winds), glitches in the radio communications, or potential contamination of the balloon leading to early burst. Additionally, there are occasional issues with the relative humidity measurements that appear to be related to cold temperatures and perhaps icing on the sensor.
- *Ice Particle Imaging Camera (IcePIC).* Ice particle images have been taken periodically over the course of the past year, giving a nice sampling of the types of ice crystals that occur at Summit. This instrument is not operational, but instead requires manual user operation and therefore images are only captured when the technicians have sufficient time.
- *Cloud, Aerosol Polarization And Backscatter Lidar (CAPABL).* CAPABL had some interruptions in data collection over the past year due to a slowly failing laser. These issues were addressed during summer 2013 when a new laser and data system were installed. A paper on this lidar system and its application for observing oriented ice crystals was published in the *J. Atmos. Oceanic Technology* (Neely et al. 2013).
- *Sodar*. This instrument has operated nearly continuously over the past year with very few issues or outages and a total uptime exceeding 98%
- *Onsite Data Archive System*. Data archival and transmission has been very successful for ICECAPS with all data being stored redundantly on site and most data being transferred daily down to Boulder, Colorado for intermediate term data storage at the SEARCH/IASOA (Study of Environmental Arctic Change / International Arctic Systems for Observing the Atmosphere) archive at NOAA. From this location the appropriate data is distributed to individual investigator institutions for data quality control and higher order processing. There have been a few maintenance issues with the archival system over the past year related to failed hard drives and networking problems, but all have been resolved without the loss of data.
- *Data Archival*. Long-term data archival is an important activity for the ICECAPS observational campaign, and there is currently a multi-tiered archival system in place at Summit. All ICECAPS data are currently stored on a SEARCH/IASOA server at NOAA-ESRL in Boulder, Colorado. At this location, it is readily

available to ICECAPS PIs and the general public via anonymous FTP. Additionally, quicklook plots of the data streams are updated daily on an ICECAPS web page (http://www.esrl.noaa.gov/psd/arctic/observatories/summit), where interested parties can look at all measurements from the ICECAPS project to date. Periodic updates are made to the web page to enhance content and provide more information to the data user community. For long term archival, the NSF AON-supported Cooperative Arctic Data and Information Service (CADIS) data portal is unable to accommodate the size of the ICECAPS data streams (~10GB/day). However, metadata describing the appropriate ICECAPS data sets is served at CADIS.

2) ICECAPS data through the end of this project (30 September 2013) have already gone through quality control. The final data sets are in the process of being archived at the Department of Energy's Atmospheric Radiation Measurement Program archive (http://www.archive.arm.gov) under the "External data collections" heading. This archive includes most of the core ICECAPS data streams (radar, lidar, ceilometer, microwave and infrared radiometers, radiosondes) that are similar to the data streams from other ARM sites around the globe that already exist at the ARM archive. ICECAPS data formatting has been intentionally modeled after the ARM conventions to facilitate broader, coordinated use of both data streams. The ARM archive is ideal for ICECAPS data because the system is robust and well-maintained, and the data are exposed to a wide range of climate scientists.

2/4: Specific Objectives

Nothing to Report

3/4: Significant Results

ICECAPS measurements continue to establish a baseline of many important characteristics of the atmospheric state, clouds, and precipitation at Summit and to provide an unprecedented view of cloud-atmosphere processes over the Greenland Ice Sheet. Below is a list of papers published by the ICECAPS research team; these have been documented in prior annual reports. Additionally, new papers that are at various stages in the publication process are listed along with their abstracts. These new papers help to demonstrate some of the significant scientific results that the ICECAPS measurements are contributing to regarding Greenlandic climate and broader topics

Published.

Bennartz, R., M.D. Shupe, D.D. Turner, V.P. Walden, K. Steffen, C.J. Cox, M.S. Kulie, N.B. Miller, and C. Pettersen, 2013: July 2012 Greenland melt extent enhanced by low-level liquid clouds. *Nature*, 496, 83-86, doi:10.1038/nature12002.

Miller, N.B., D.D. Turner, R. Bennartz, M.D. Shupe, M.S. Kulie, M.P. Cadeddu, and V.P. Walden, 2013: Surface-based inversions above central Greenland. *J. Geophys. Res.*, 118, 1-12, doi:10.1029/2012JD018867.

Neely, R.R., M. Haymans, R. Stillwell, J.P. Thayer, R.M. Hardesty, M. O'Neill, M.D.

Shupe, and C. Alvarez, 2013: Polarization lidar at Summit, Greenland, for the detection of cloud phase and particle orientation. *J. Atmos. Oceanic Technol.*, **30**, 1635-1655, doi:10.1175/JTECH-D-12-00101.1.

Shupe, M.D., D.D. Turner, V.P. Walden, R. Bennartz, M.P. Cadeddu, B.B. Castellani, C.J. Cox, D.R. Hudak, M.S. Kulie, N.B. Miller, R.R. Neely III, and W.D. Neff, 2013: High and dry: New observations of tropospheric and cloud properties above the Greenland ice sheet. *Bull. Amer. Meteo. Soc.*, 94, 169-186, doi:10.1175/BAMS-D-11-00249.1.

<u>In Press.</u>

Kneifel, S., S. Redl, E. Orlandi, U. Loehnert, M.P. Cadeddu, D.D. Turner, and M.-T. Chen, 2013: Absorption properties of supercooled liquid water between 31 and 225 GHz: Evaluation of absorption models using ground-based observations. *J. Appl. Met. Clim.*, accepted.

Microwave radiometers (MWR) are commonly used to quantify the amount of supercooled liquid water (SLW) in clouds; however, the accuracy of the SLW retrievals is limited by the poor knowledge of the dielectric properties of supercooled liquid water at microwave (MW) frequencies. Six liquid water permittivity models were compared with ground-based MWR observations between 31 and 225 GHz from sites in Greenland, the German Alps, and a low-mountain site; average cloud temperatures of observed thin cloud layers range from 0 to -33 degC. A recently published method to derive ratios of liquid water opacity was employed in this analysis. These ratios are independent of liquid water path and equal to the ratio of mass absorption coefficient at two different frequencies, and can thus be directly compared to the permittivity model predictions.

The observed opacity ratios from all sites show highly consistent results that are generally within the range of model predictions; however, none of the investigated models are able to approximate the observed opacity ratios over the entire frequency and temperature range. Findings in earlier published studies were used to select one specific model as a reference model for the mass absorption coefficient at 90 GHz; together with the observed opacity ratios, the temperature dependence of mass absorption coefficients at 31.4, 52.28, 150, and 225 GHz was derived. The results clearly reveal that two models fit the opacity ratio data better than the other four models, with one of the two models fitting the data better for frequencies below 90 GHz and the other for higher frequencies. These findings are relevant for the development of liquid water retrievals of supercooled clouds and radiative transfer in the 31 - 225 GHz frequency region.

Van Tricht, K., I.V. Gorodetskaya, S. Lhermitte, D.D. Turner, J.H. Schween, and N.P.M van Lipzig, 2013: An improved algorithm for cloud base detection by ceilometer over the ice sheets. *Atmos. Meas. Technol.*, submitted.

Optically thin ice clouds play an important role in polar regions due to their effect on cloud radiative impact and precipitation on the surface. Cloud bases can be detected by lidar-based ceilometers that run continuously and therefore have the potential to provide basic cloud statistics including cloud frequency, base height and vertical structure. Despite their importance, thin clouds are however not well detected by the standard cloud base detection algorithm of most ceilometers operational at Arctic and Antarctic stations. This paper presents the Polar Threshold (PT) algorithm that was developed to detect optically thin hydrometeor layers (optical depth $\tau \geq 0.01$). The PT algorithm detects the first hydrometeor layer in a vertical attenuated backscatter profile exceeding a predefined threshold in combination with noise reduction and averaging procedures. The optimal backscatter threshold of 3×10^{-4} km^{-1} sr^{-1} for cloud base detection was objectively derived based on a sensitivity analysis using data from Princess Elisabeth, Antarctica and Summit, Greenland. The algorithm defines cloudy conditions as any atmospheric profile containing a hydrometeor layer at least 50 m thick. A comparison with relative humidity measurements from radiosondes at Summit illustrates the algorithm's ability to significantly differentiate between clear sky and cloudy conditions. Analysis of the cloud statistics derived from the PT algorithm indicates a year-round monthly mean cloud cover fraction of 72% at Summit without a seasonal cycle. The occurrence of optically thick layers, indicating the presence of supercooled liquid, shows a seasonal cycle at Summit with a monthly mean summer peak of 40%. The monthly mean cloud occurrence frequency in summer at Princess Elisabeth is 47%, which reduces to 14% for supercooled liquid cloud layers. Our analyses furthermore illustrate the importance of optically thin hydrometeor layers located near the surface for both sites, with 87% of all detections below 500 m for Summit and 80% below 2 km for Princess Elisabeth. These results have implications for using satellite-based remotely sensed cloud observations, like CloudSat, that may be insensitive for hydrometeors near the surface. The results of this study highlight the potential of the PT algorithm to extract information in polar regions about a wide range of hydrometeor types from measurements by the robust and relatively low-cost ceilometer instrument.

Submitted.

Neff, W., G. Compo, F. M. Ralph, and M. D. Shupe, 2014: Continental heat anomalies and the extreme melting of the Greenland ice surface in 2012 and 1889. *J. Geophys. Res.*, submitted.

Recent decades have seen increased melting of the Greenland ice sheet. On 11 July 2012, nearly the entire surface of the ice sheet melted; such rare events last occurred in 1889 and, prior to that, during the Medieval Climate Anomaly. Studies of the 2012 event have associated the presence of a thin, warm elevated liquid cloud layer with surface temperatures above the melting point at Summit Station, some 3212 m above sea level. Here we explore other potential factors in July 2012 associated with this unusual melting. These include 1) warm air originating from a record North American heat wave, 2) transitions in the Arctic Oscillation, 3) transport of water vapor via an Atmospheric River over the Atlantic to Greenland, and 4) the presence of warm ocean waters south of Greenland. For the 1889 episode, the Twentieth Century Reanalysis and historical records showed similar factors at work. From other reports, markers of biomass burning were evident in ice cores from 1889 which may reflect another possible factor in these rare events. We suggest that extreme Greenland summer melt episodes, such as those recorded recently and in the late Holocene, could have involved a similar combination of slow climate processes, including prolonged North American droughts/heat waves and North Atlantic warm oceanic temperature anomalies, together with fast processes, such as excursions of the Arctic Oscillation, and transport of warm, humid air in Atmospheric Rivers to Greenland. It is the fast processes that underlie the rarity of such events and influence their predictability.

In Preparation.

Cox, C.J., V.P. Walden, G.P. Compo, P.M. Rowe, M.D. Shupe and K. Steffen: 2014. Downwelling longwave flux over Summit, Greenland: Analysis of surface observations and validation of ERA-Interim using wavelets. To be submitted to *J. Geophys. Res*.

Recent studies have shown that the downwelling longwave flux (DLW) is an important parameter in the Arctic surface energy budget. Changes in the DLW play a role in sea ice melt over the Arctic Ocean and in surface melt over the Greenland Ice Sheet (GIS). Surface-based observations provide accurate estimates of the DLW, but the network of observations is sparse and records are short, so it is necessary to include estimates of DLW from gridded data sets, such as reanalyses, for a comprehensive analysis. Surface observations of DLW are used from an infrared spectrometer that is part of the Integrated Characterization of Energy, Clouds, Atmospheric state and Precipitation at Summit station (ICECAPS) in Greenland obtained from 2010 to 2012. The DLW over Summit is then compared to observations from other Arctic locations. The ERA-Interim reanalyses are then used to gain insight into the spatial distribution of the DLW influence of clouds across the GIS. These analyses are then combined into a validation of the ERA-Interim DLW fields using a new method of time-frequency signal decomposition (wavelet analysis). The wavelet technique is capable of evaluating the reanalysis estimates of DLW at temporal scales from three hours through the annual cycle.

4/4: Key outcomes or Other Achievements

One important outcome of the ICECAPS project is its impact on the broader Arctic and Greenland research communities. The PIs and other ICECAPS team members have continued and started a number of scientific activities and collaborations using ICECAPS data during the past year.

- Field activities continue to be coordinated with Dr. David Noone (University of Colorado), as his project to study precipitation and water isotopes at Summit is complementary to ICECAPS measurements and objectives. A former graduate student funded by ICECAPS is now doing a post-doc with Dr. Noone and serves as a liaison between the projects.
- ICECAPS continues observational collaborations with Dr. Konrad Steffen (Swiss Federal Research Institute) and NOAA Global Monitoring Division through

sharing of meteorological and radiation measurements, operational support for a total sky imager, and intercomparisons of radiosonde measurements.

- Dr. Maria Cadeddu (Argonne National Laboratory) has provided tremendous support with the calibration and analysis of microwave radiometer measurements and conducted a recent analysis that compares cloud liquid water path observations from Summit with those from Barrow, Alaska.
- Dr. Stefan Kneifel and Dr. Ulrich Löhnert (University of Cologne), in collaboration with Dr. Cadeddu and ICECAP PI David Turner, have used ICECAPS microwave radiometer observations of supercooled liquid water clouds to characterize the accuracy of the temperature dependence of liquid water absorption in microwave radiative transfer models (paper has been accepted). They are currently using these observations, together with laboratory data collected by other investigators over the last few decades, to develop an improved liquid water absorption model that fits all of the available laboratory and field data and spans the entire temperature range from supercooled to warm liquid water clouds (paper in preparation).
- Drs. Gil Campo (NOAA-ESRL), Gijs de Boer (NOAA-ESRL) and Konrad Steffen (ETH) are collaborating with ICECAPS to evaluate Arctic reanalyses and climate model output using downwelling longwave fluxes derived from both broadband radiometers and the Polar Atmospheric Emitted Radiance Interferometer (P-AERI) at Summit.
- Dr. Jay Mace (University of Utah) and one of his graduate students (Kevin Hammonds) have worked with ICECAPS measurements to pursue their interests related to CloudSat measurements of ice clouds and snowfall over the Greenland Ice Sheet. Mr. Hammonds was the on-site ICECAPS technician for part of the summer of 2012.
- Drs. David Hudak and Brian Sheppard (Environment Canada) have similar interests and have been comparing ICECAPS precipitation measurements with those from other Arctic sites and working with a University of Colorado graduate student (Ben Castellani) to ensure robust precipitation measurements at Summit.
- Dr. Jeffrey Thayer (University of Colorado), and his graduate students, are utilizing ICECAPS measurements to understand lidar measurements of oriented ice crystals at Summit. This effort has resulted in a paper that was recently published (Neely et al. 2013).
- Dr. Michael Bergin (Georgia Tech University) and a graduate student are examining the radiative forcing of aerosols over Summit and have used ICECAPS cloud measurements to get a constraint on the cloud contribution to surface radiative measurements.
- Dr. Athanasios Nenes (Georgia Tech University) and a graduate student are using ICECAPS cloud and atmosphere measurements to understand the variability of cloud condensation nucleus measurements that were made at Summit during the summer of 2011.
- Dr. Claudio Tomasi (National Research Council of Italy) and colleagues have used ICECAPS radiosonde data, along with observations from other locations, to help them develop a new algorithm for calculating Rayleigh scattering optical depth from sun photometer measurements at Summit.

- Dr. Richard Forbes (ECMWF) continues to provide ICECAPS with operational, 3-hourly forecasts for a region surrounding Summit that have provided useful context for the measurements at the site.
- Since the summer of 2012, ICECAPS personnel have worked with Dr. Murray Hamilton (University of Adelaide) to evaluate a polarization sonde that he has developed for detecting the presence of supercooled liquid water in the atmosphere. His "polar-sondes" are periodically attached to ICECAPS radiosondes to test their atmospheric profiling capabilities.
- Dr. Nicole van Lipzig and her colleagues (University of Leuven, Belgium) are using ICECAPS ceilometer, lidar, and radar data to evaluate their satellite-base cloud detection algorithm over high altitude ice sheets (a paper is currently under review). Kristof van Tricht and Irina Gorodetskaya from U. Leuven are also using longwave flux estimates from the PAERI to compare with satellite observations.
- Dr. Scott Paine (Smithsonian Astrophysical Observatory) and Dr. Ming-Tang Chen (Academia Sinica Institute of Astronomy and Astrophysics) continue to use 150-GHz brightness temperatures measured by the ICECAPS microwave radiometer to characterize the opacity of the atmosphere over Summit; this analysis supports planning for the deployment of a large 12-m submillimeter wavelength telescope to Summit station that will be used for wide range of astrophysical research.

ICECAPS radiosonde data are also being operationally uploaded to the WMO Global Telecommunications System (GTS) through an ingest portal at the Danish Meteorological Institute. The data are then available to a broad community included operational modeling centers. At present, the ICECAPS measurements are confirmed to be assimilated into operational models run by the European Center for Medium-range Weather Forecasts (ECMWF), the UK Meteorological Office, the Danish Meteorological Institute, the German Weather Service, and the US National Centers for Environmental Prediction.

What opportunities for training and professional development have the project provided?

The ICECAPS team includes a number of students who fill a variety of roles. Some are funded either part-time or full-time by the project to fill important operational roles, others have served as field technicians, and still others are not funded directly by ICECAPS but are conducting research that uses ICECAPS data.

Chris Cox received his Ph.D. in Environmental Science at the University of Idaho in July 2013. He also received the Doctoral Graduate Student Research and Creative Activity Award for the top Ph.D. at the University of Idaho in 2013 based on both his high-quality research and outreach efforts. Dr. Cox is now a postdoc at CIRES in Boulder Colorado working with Dr. David Noone, where he is continuing to analyze and use ICECAPS data. Dr. Cox published a manuscript on microphysical properties of clouds over Eureka to the *Journal of Applied Meteorology and Climatology* and plans to perform a similar analysis using ICECAPS data from Summit.

Nate Miller graduated with a Master's Degree from the Atmospheric and Oceanic Sciences Department at the University of Wisconsin-Madison and is now working on a Ph.D. with Dr. Matt Shupe at the University of Colorado. Nate continues to be an integral member of the ICECAPS team by helping to monitor, maintain, analyze, and quality-control the MWR data.

Claire Pettersen, a University of Wisconsin-Madison SSEC engineer and graduate student, continues to work on her Ph.D. using both radar and lidar data.

Ben Castellani, a Ph.D. student in the Atmospheric and Oceanic Sciences Department at the University of Colorado, continues to work on the ICECAPS project. Ben worked as the on-site ICECAPS technician from late April to June 2013. Ben continues to evaluate the performance of the active remote sensors (radar, lidar, ceilometer) to ensure their consistency with regard to observing clouds above Summit. Ben is also working on understanding the ICECAPS precipitation measurements and is improving retrievals of snowfall rate for the Summit location. He is evaluating the precipitation information from different sensors and comparing them with the surface accumulation measurements at Summit, to ensure consistency.

Elena Willmot is an M.S. student at the University of Wisconsin-Madison working with Dr. Ralf Bennartz. Elena served as the on-site ICECAPS technician from June through August 2013.

In addition to these active students, the ICECAPS project has utilized a number of additional students and early career scientists as field technicians. These field experiences have proven to be valuable opportunities to broaden horizons and enhance skill sets. In one case while serving as the ICECAPS technician a student was able to clarify his future education path, build appropriate connections to a potential research advisor, and has since been accepted into a graduate program.

How have the results been disseminated to communities of interest?

In addition to Elena Willmot's many tasks as ICECAPS technician, she helped out with the Joint Science Education Project (JSEP) students when they visited Summit in July 2013. In particular, she helped the JSEP students launch a radiosonde.

Additionally, PI Matthew Shupe has incorporated observations and experiences from Summit, Greenland into classroom lectures that he has given at Chinook West High School in Nederland, Colorado. PI David Turner has also given several presentations regarding Arctic science and his experiences during ICECAPS to students at Mount St. Mary High School in Oklahoma City, Oklahoma.

What do you plan to do during the next reporting period to accomplish the goals?

This is the final progress report for the initial ICECAPS project. However, the project will continue via a renewal grant. As part of the renewal project, all observations will be continued at Summit and will be augmented by new precipitation measurements that are aimed at better quantifying the precipitation mass and constraining precipitation retrievals from active sensors. Ongoing data streams will continue to be archived at both NOAA and the long-term, publicly-available data archive at the Department of Energy Atmospheric Radiation Measurement Program.

Supporting Files

None.

PRODUCTS

Publications

Technologies or Techniques

Nothing to Report

Inventions, patent applications, and/or licenses

Nothing to Report.

Websites

http://www.esrl.noaa.gov/psd/arctic/observatories/summit/

This is the ICECAPS web page, containing background on the project, details on the instruments, and acknowledgement of support. Additionally there is a "Browser" link to a calendar and menu driven browser of quicklook images from the various instrument and measurement data streams. Over the past year some changes have been implemented with the way that different data streams are visualized and additional information has been added. This site continues to be under development as new derived products are produced and additional web page enhancements are implemented.

http://www.esrl.noaa.gov/psd/people/matthew.shupe

This site lists projects, overarching results, and publications from Dr. Shupe.

http://vw1.ce.wsu.edu/

This site lists recent publications from Dr. Walden and provides a brief description of this NSF project.

http://www.nssl.noaa.gov/~dturner/

This site lists Dr. Turner's publications and research interests.

http:// https://my.vanderbilt.edu/ralfbennartz/

This site lists recent publications from Dr. Bennartz and provides a brief description of this NSF and other projects.

Other products

Nothing to Report

PARTICIPANTS

What individuals have worked on this project? (UW-Madison part only)

- David D Turner [co-PI]: Microwave radiometers and micropulse lidar contact.
- Ralf Bennartz [co-PI]: Project oversight at UWisc.
- Erik Olson [Engineer]: Helps diagnose issues with microwave radiometers, radiosonde system, and other instruments
- Claire Pettersen [Engineer / graduate student]: Field technician, radar analysis
- Elena Willmot [graduate student]: Field technician
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What other organizations have been involved?

- NOAA-ESRL. [Facilities, Collaborative research, Financial support]. NOAA-ESRL provides equipment used for the ICECAPS project (cloud radar, sodar, lidar). It also provides engineering support, including travel and salary, for the radar engineer.
- DOE-ARM. [Facilities]. The Department of Energy Atmospheric Radiation Measurement Program has loaned the ICECAPS project a micropulse lidar and ceilometer. They also provide data archival services for ICECAPS data streams.
- Environment Canada [Facilities]. Environment Canada has let the ICECAPS project borrow a precipitation measurement system and has collaborated with us on operating, analyzing, and interpreting the data.
- NOAA-NSSL. [Financial support.] NOAA-NSSL provides support for Dr. Turner to continue his analysis and leadership activities of ICECAPS.
- University of Utah [Personnel exchanges]: Graduate student worked as the project's field technician

IMPACT

What is the impact on the development of the principle discipline(s) of the project?

ICECAPS measurements provide the first, continuous and detailed perspective on cloud and atmosphere properties over the central Greenland Ice Sheet. These measurements will contribute to important understanding of how cloud and atmospheric processes impact the surface energy and precipitation budgets over the ice sheet. The detailed, process-level measurements are useful for evaluating model parameterizations and supporting improvements in representing cloud and atmosphere processes, particularly for mixed-phase clouds and low-level atmospheric boundary layer structure.

The ICECAPS radiosonde profiles are being ingested in real-time into the World Meteorological Organization's Global Telecommunications System (GTS). The addition of routine radiosonde information from atop the Greenland Ice Sheet will be useful for scientific research, data assimilation into weather and climate models, and for year-round logistical operations in Greenland. Operational models are assimilating these data, including European Center for Medium range Weather Forecasting, UK Meteorological Office, German Weather Service, Danish Meteorological Institute, and the US National Centers for Environmental Prediction.

What is the impact on other disciplines?

Dr. Ming-Tang Chen (Institute of Astronomy and Astrophysics Sinica - ASIAA), Dr. Scott Paine (Smithsonian Astrophysical Observatory - SAO), and colleagues used data collected by the ICECAPS project to perform a preliminary analysis of the Summit station for astronomy. The ICECAPS microwave radiometer observations of atmospheric opacity at 150 GHz over the annual cycle demonstrated that the atmosphere over Summit was very transparent in the submillimeter portion of the electromagnetic spectrum, Dr. Chen deployed an additional microwave radiometer that makes observations at 225 GHz to confirm the ICECAPS data. The observations from these two radiometers demonstrated that Summit station would be an excellent place for submillimeter astronomy, and efforts are underway to deploy a large submillimeter telescope to Summit. Furthermore, the additional 225 GHz observations provided by ASIAA are being used by the ICECAPS team to study the temperature dependence of liquid water absorption in the microwave/submillimeter portion of the spectrum; the 225 GHz observations are a critical part of this analysis and would not be possible without the collaboration between ICECAPS and ASIAA/SAO.

The ICECAPS project has also contributed to the evaluation of new "polarsonde" technology that is being developed by Dr. Murray Hamilton for identifying supercooled liquid water in clouds.

What is the impact on the development of human resources?

This project supported one graduate student each at the Universities of Idaho, Wisconsin, and Colorado. These students have all gained valuable experience at working with observational data, performing quality assurance, developing and applying higher-order data processing algorithms, and data archival. Many graduate students have received in-depth and specialized training for operating ICECAPS instruments and have spent time in the field being the ICECAPS technician. These include: Chris Cox (U. Idaho), Nate Miller (U. Wisconsin), Aronne Merelli (U. Wisconsin), Claire Pettersen (U. Wisconsin), Ben Castellani (U. Colorado), Ryan Neely (U. Colorado), Patrick Wright (U. Houston), Kevin Hammonds (U. Utah), and Elena Willmot (U. Wisconsin). These students have all received valuable field experience that has enriched their graduate education and will support their development as young scientists.

What is the impact on information resources that form infrastructure?

The ICECAPS project has collected and developed observational data on cloud and atmosphere properties over the Greenland Ice Sheet that are the first of their kind. More than three years of data have been archived at the Department of Energy Atmospheric Radiation Measurement Program's data archive for public usage.

What is the impact on technology transfer?

Nothing to report

What is the impact on society beyond science and technology?

Nothing to report

CHANGES/PROBLEMS

Changes in approach and reasons for change.
Nothing to Report

Actual or anticipated problems or delays and actions of plans to resolve them.
Nothing to Report

Changes that have significant impact on expenditures
Nothing to Report

Significant changes in use or care of human subjects
Nothing to Report

Significant changes in use or care of vertebrate animals
Nothing to Report

Significant changes in use or care of biohazards
Nothing to Report