CReSIS

Center for Remote Sensing of Ice Sheets

Annual Progress Report

I. GENERAL INFORMATION

1a. Provide the following general information:

Date Submitted	April 14, 2014
Reporting Period	March 19, 2013 through April 11, 2014
Name of the Center	Center for Remote Sensing of Ice Sheets (CReSIS)
Name of the Center Director	Dr. S. Prasad Gogineni
Lead University	University of Kansas
Address	Nichols Hall 2335 Irving Hill Road Lawrence, Kansas 66045-7612
Phone Number	(785) 864-4390
FAX Number	(785) 864-7753
E-Mail Address of Center Director	gogineni@cresis.ku.edu
Center URL	www.cresis.ku.edu
PARTICIPATING INSTITUTIONS	
Elizabeth City State University	Dr. Linda Hayden
Address	Mathematics and Computer Science Department Box 672 ECSU 1704 Weeksville Road Elizabeth City, NC 27909
Phone Number	(252) 335-3696
Fax Number	(252) 335-3790
Email Address of Center Director	haydenl@mindspring.com
Role of Center in Institution	The Center of Excellence in Remote Sensing Education and Research (CERSER) at ECSU contributes its expertise in analyzing satellite data and generating high-level data products.
The Pennsylvania State University	Dr. Sridhar Anandakrishnan
Address	Department of Geosciences

	EMS Environment Institute 442 Deike Building University Park, PA 16802
Phone Number	(814) 863-6742
Fax Number	(814) 863-7823
Email Address	sak@essc.psu.edu
Role of Center in Institution	PSU participates in technology development for seismic measurements, field activities, and modeling.
University of Washington	Dr. Ian Joughin
Address	Polar Science Center Applied Physics Lab University of Washington 1013 NE 40th Street Seattle, WA 98105
Phone Number	(202) 221-3177
Fax Number	(206) 616-3142
Email Address	ian@apl.washington.edu
Role of Center in Institution	UW provides expertise in satellite observations of ice sheets and participates in process-oriented interpretation and model development.
Indiana University	Geoffrey Fox
Address	Pervasive Technology Institute 2719 E. 10th Street Bloomington, IN 47408
Phone Number	(812) 856-7977
Fax Number	(812) 846-0927
Email Address	gcf@indiana.edu
Role of Center in Institution	IU provides world-class expertise in CI and high-performance computing, addresses challenges in data management, processing, distribution, and archiving, and contributes to high-performance modeling requirements.
Los Alamos National Laboratory	Dr. Steven Price
Address	Los Alamos National Laboratory Building 123, Room 273 Bikini Atoll Road., SM 30 Los Alamos, NM 87545
Phone Number	(505) 665-1000
Fax Number	(505) 665-5926
Email Address	sprice@lanl.gov
Role of Center in Institution	LANL contributes to ice sheet modeling.

Association of Computer and Information Science Engineering Departments at Minority Institutions	Dr. Andrea Lawrence
Address	Spelman College 350 Spelman Lane S.W. Atlanta, GA 30314-4399
Phone Number	(404) 681-3643
Email Address	lawrence@spelman.edu
Role of Center in Institution	ADMI provides outreach and supports student development

1b. Provide, in one page or less, brief biographical information for each *new* faculty member *by institution*. Attach as Appendix A.

Institution	Name
University of Kansas	Haiyang Chao
Elizabeth City State University	None
The Pennsylvania State University	None
University of Washington	None
Indiana University	None
Los Alamos National Laboratory	None
Association of Computer and Information Science Engineering Departments at Minority Institutions	None

1c. Provide the name and contact information for the primary person to contact with any questions regarding this report.

Name of the Individual	Jennifer Laverentz
Center Role	Administrative Manager
Address	see above
Phone Number	(785) 864-7722
Fax Number	(785) 864-7753
E-Mail Address	jenlav@ku.edu

2. Context Statement (maximum of 20 pages). The Context Statement should include a brief overview of the vision, goals plans, and performance and management indicators for the Center. Any significant changes from the original plans for the Center should be described. This section also reports on progress toward meeting the goals set for the Center (described in detail in the remaining sections) and provides an overview of significant accomplishments during the reporting period. The Context Statement also should contain a discussion of how the Center's accomplishments in the past year fit within the overall Center accomplishments since the Center's inception. In addition, the Context Statement should situate the work of the Center within the context of the disciplinary field(s) at large.

The Center's vision is to understand and predict the role of polar ice sheets in sea level change. Over 100 million people live within a 1 m elevation of the present sea level [Rowley et al., 2007]. The IPCC's recent report states that expected sea level rise will be between 18 and 59 cm by 2100, but it acknowledges that large uncertainties exist in estimates of contribution from ice sheets. In the next few years, 20 of 30 mega-cities will be on the coast, with many low-lying locations vulnerable to rising sea level [WCRP, 2006]. As coastal development expands with a growing population and increased urbanization, a rapid increase of sea level will have a large impact on society. There is an urgent need to improve the knowledge of ice dynamics and improve ice-sheet models to predict their response in a warming climate. In particular, the Center's mission is to develop technologies, to conduct field investigations, to compile data to understand why many outlet glaciers and ice streams are changing rapidly, and to develop models that explain and predict ice sheet response to climate change. The Center's mission is also to educate and train a diverse population of graduate and undergraduate students in Center-related disciplines and to encourage K-12 students to pursue careers in science, technology, engineering and mathematics (STEM-fields).

The Center has developed technologies and techniques to sound ice in areas undergoing rapid changes, a major challenge in radio glaciology, and image the ice-bed interface to generate fine-resolution bed topography and determine basal conditions. The Center successfully applied these techniques for sounding and imaging major glaciers in Greenland and for producing first-generation bed topography maps for these glaciers. The Center also demonstrated that fine-resolution 3-D topography can be generated from data collected using synthetic aperture radars (SAR) equipped with cross-track arrays. The Center recently completed an extremely successful field campaign over Byrd Glacier using multi-frequency radars, processed collected data, and produced and distributed a detailed bed map. Our data analysis revealed a 2.7 km deep sub-glacial trench – the deepest sub-glacial trench located so far. The Center has continued to make its data products, data, and tools available to the broader science community through its website and through National Snow and Ice Data Center (NSIDC). The science community has begun to use the bed topography maps generated by CReSIS to produce results that can explain observed rapid changes.

The Center's goals and mission in research, education and diversity, and knowledge-transfer areas are described in detail in the strategic and implementation (S&I) plan. The plan is updated annually based on Center progress and recommendations from the site-visit panel and advisory boards.

References

- Rowley, R. J., J. C. Kostelnick, D. Braaten, X. Li, and J. Meisel (2007), Risk of Rising Sea Level to Population and Land Area. *EOS Trans. AGU*, 88(9), 105.
- WCRP (2006). Understanding Sea-level Rise and Variability, Workshop Report. IOC/UNESCO, Paris, France, June 6-9, 2006.

II. RESEARCH

1a. The Center's long-term goals are to perform a four-dimensional — space and time – characterization of rapidly changing ice-sheet regions, develop diagnostic and predictive ice-sheet models, and contribute to future assessments of sea level change in a warming climate.
Our proposed research is aimed at addressing the following objectives:

- Document existing data for target areas and identify observational and technological requirements to improve and validate models;
- Design and develop technologies for collecting and processing necessary data;
- Conduct field investigations to collect required data sets;
- Process, analyze, and distribute data to modeling groups and the scientific community;
- Integrate data and models using state-of-the-art computing, storage, and networking cyberinfrastructure;
- Develop diagnostic models identifying processes leading to rapid ice sheet change; and
- Incorporate an improved understanding of physical processes into predictive ice-sheet models.

1b. Discuss any problems you have encountered in making progress toward the Center's research goals/objectives during the reporting period as well as any problems anticipated in the next period. Include your plans for addressing these problems.

The two major issues we had to deal with are the delay in further flight testing of the Meridian UAS and advanced signal processing of data from Jakovshavn and other challenging areas of the ice sheet to improve current bed maps. We could not deploy the Meridian UAS because the manufacturer could not return the upgraded auto pilot system in time to ship the aircraft to Antarctica. However, we developed small UAS integrated with a dual-frequency radar sounder and used the auto pilot on the UAS to evaluate its performance. The delays in developing advanced signal processing algorithms were caused by two factors: (1) key personnel with expertise in signal processing were involved in the field activities in Antarctica and reluctance of the EECS department to hire new faculty in areas on interest to CReSIS. We improved signal processing algorithms as soon as key personnel returned from the field. Now we are reprocessing data from Jakobshavn and Byrd glaciers with these improved algorithms. We will releasing new data products over these two glaciers in the next few weeks.

2a. Briefly describe the research thrust areas at the Center. Please provide basic information for each thrust area and details of significant accomplishments during the reporting period, including any research partnerships and their contributions to the Center (*do not include publications, presentations, etc., that are reported in Section VIII, Center-wide Outputs and Issues*). Include in the narrative a discussion of the goals, activities, and outcomes and/or impacts in the current reporting period, if changed from the previous reporting period. Be sure to discuss how the activities in the various research thrust areas enable the Center to meet its goals/objectives described above.

The Center has organized its expertise into six research thrusts: (1) Sensors and Signal Processing; (2) Uninhabited Aerial Vehicles (UAV); (3) Field Activities; (4) Satellite Measurements; (5) Cyberinfrastructure; and (6) Analysis and Modeling. These research thrusts encompass the diverse scientific and technical expertise required to achieve the Center's goals and are closely integrated, both providing information to and receiving information from, one or more of the other focus areas. Education, training, diversity, and knowledge transfer permeate all focus areas.

Thrust Area	Sensors and Signal Processing
Lead	Fernando Rodriguez-Morales and John Paden (KU)
Core Participants	Gogineni, Leuschen, Hale, Wang, Yan, Li, Gomez-Garcia, Carabajal, Townley, Lewis, Mahmood, et al.

Sensors

We completed the development of the HF and Wide Band (WB) radar depth sounders. We continued the optimization and refinement of the existing radars for airborne operation; in particular important upgrades were completed on the Ku-band and Snow radar systems. The HF radar sounder, the WB radar depth sounder, and the Ku-band/Snow radar were successfully tested and used in a major field experiment conducted in the vicinity of Subglacial Lake Whillans in West Antarctica for collecting data over ice streams. In addition, we modified two of the existing radars for surface-based operation in support of local and remote field experiments, including two NSF-funded efforts in Greenland and Antarctica. Finally, we conducted other projects including a study on the effect of wing flexure in the formation of the beam pattern of wing-mounted antenna arrays.

UWB Radar Depth Sounder Development

Radars

We developed a WB radar depth sounder for sounding and imaging ice sheets with fine resolution [1]. We designed, built, and tested a multi-channel data acquisition system integrated with analog receivers and a multi-channel high-power transmitter equipped with fast, wideband transmit/receive (T/R) switches. This development was partially funded by a Major Research Instrumentation (MRI) grant from the NSF.

The operating frequency range of the radar is currently 150-450 MHz and supports eight T/R channels. The waveform generator is the 8-channel direct digital synthesizer (DDS) that was previously developed to operate at 1 GSPS. The data acquisition system uses a 500-MHz sampling clock and employs sequential in-phase/quadrature (I/Q) sampling to achieve an effective sampling rate of 1 GSPS. The analog receivers have a variable gain between -10 dB and 50 dB, which can be digitally controlled in 0.5 dB steps. The transmitter has a gain close to 50 dB and is capable of producing approximately 250 Watts of peak output power per channel (2 kW with eight channels combined). The T/R switches were developed using the technique described in the last annual report, which utilizes two quadrature hybrids and diode elements. The duplexer design reported last year was

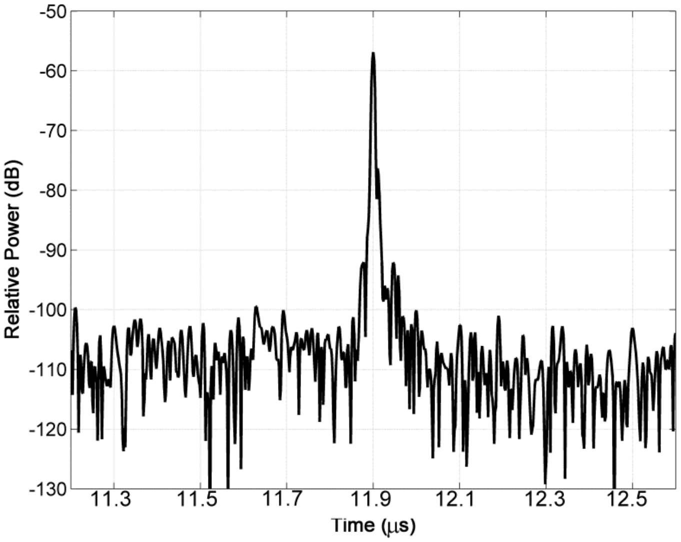


Figure 1: Radar impulse response measured with a synthetic target for one of the channels of the UWB radar depth sounder.

optimized to operate in the 100-300 MHz range and had a maximum of 2.5 dB loss in the receive path. For WB radar, we optimized the circuit to operate in the 100-450 MHz range with less than 1 dB for both transmit and receive paths and less than 150 ns switching speed at the maximum RF power. Both RF and digital sections are currently being upgraded to operate with up to 24 channels in the 150-600 MHz range.

The complete radar system was characterized in the laboratory after each section was tested individually. We measured the impulse response of each channel the using a synthetic target composed of high-power and low-power attenuators, a directional coupler, and a fiber optic delay line with a measured delay close to 12 μs. The radar was operated in the 200-450 MHz range to match the frequency range of the antennas during this field season, as discussed below. Figure 1 shows a plot of the response for one of the channels obtained after 1,000 coherent integrations [1].

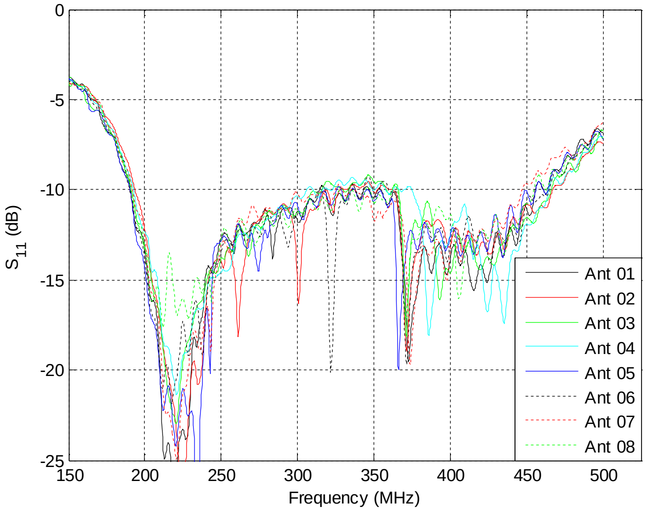


Figure 2: Measured return loss for individual elements in the antenna array for the UWB radar depth sounder.

Antenna Array

We also developed an 8-element antenna-array for use with this radar onboard the BT-67 Basler aircraft. The antenna-array is composed of eight uniformly-spaced bays that house the individual antenna elements. The antenna elements are printed dipoles on a dielectric (FR4) substrate. We used resistive loading and combined two printed dipole antennas by using a microstrip power combiner. A passive impedance matching network is used to provide a return loss of at least 10 dB over the 190-450 MHz range, which ultimately set the bandwidth used with the radar system. Figure 2 shows the measured S_{11} the eight-antenna elements in the array after it was integrated into the Basler aircraft.

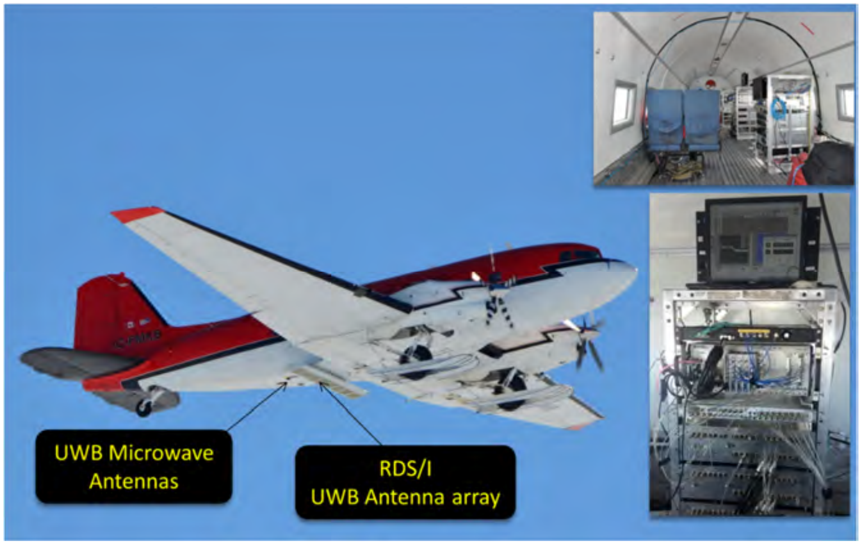


Figure 3: Photograph of the BT-67 platform equipped with antenna array for the UWB radar depth sounder/imager and microwave antennas for the Ku-band/Snow radars. The top inset shows a photograph of the cabin equipped with the instrument package. The bottom inset shows a photograph of the rack containing UWB radar depth sounder electronics.

Field Testing

The WB radar-depth sounder and its array were installed on the BT-67 Basler, along with the Ku-band/Snow radar (discussed in the next section of the report), and flight tested in Calgary, Canada during September/October, 2013. A high-resolution imaging camera, provided by Google, Inc., completed the instrument package onboard this aircraft.

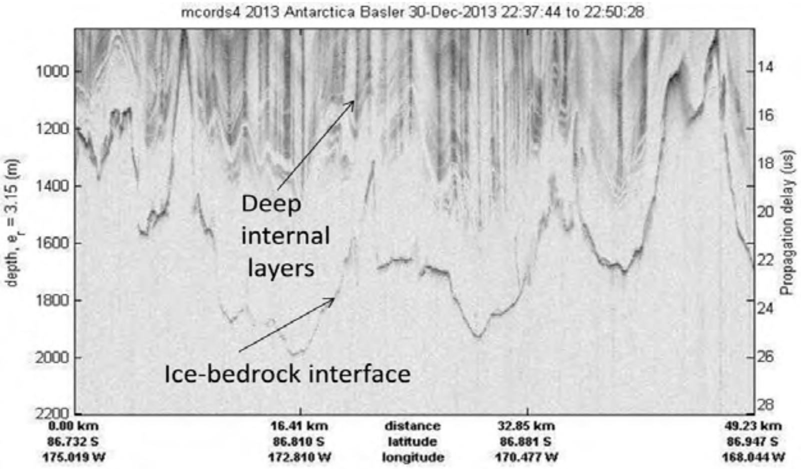


Figure 4: Sample echogram obtained from data collected with the UWB radar depth sounder during the 2013/2014 field season in Antarctica.

The integrated system including three radars, camera and GPS-INS equipment was deployed to Antarctica during the 2013/2014 Austral Summer field season. We used the system for extensive surveys over the Ice Streams in West Antarctica from the Sub-glacial Lake Whillans (SLW) field camp. Figure 3 shows photographs of the Basler aircraft and its cabin during a flight. Figure 4 shows a sample echogram produced with data from the WB radar-depth sounder, demonstrating the capability of the system to image deep internal layers with fine vertical resolution of about 1 m or less and sound 2-km thick ice [2]. Additional products derived from data collected with this radar will be presented in the Signal Processing section of this report.

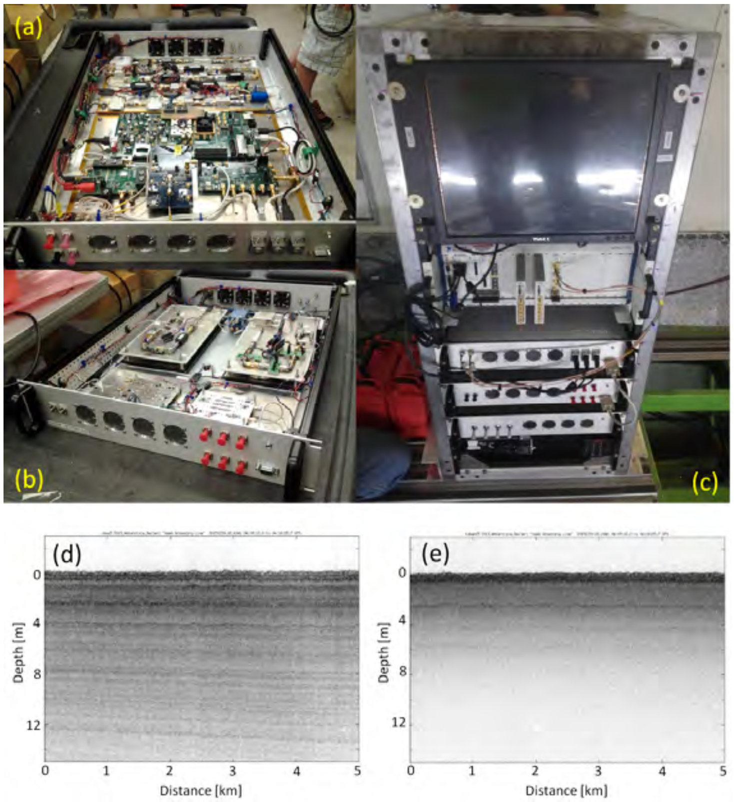


Figure 5: Photographs of the Snow/Ku-band electronics showing the new chirp generator (a) and RF section of the radar (b); (c) photograph of the complete system racked onboard the BT-67 Basler aircraft; (d) sample preliminary results obitaned at the WISSARD site with the Snow Radar that incorporates the new chirp generator; and (e) sample preliminary results obtained over the same area using the Ku-band altimeter.

Ku-Band/Snow Radar Development

In the last annual report, we presented preliminary results obtained with an improved microwave chirp generator based on a custom-designed direct digital synthesizer (DDS) and a frequency multiplier chain. The DDS provides a 1.5-2.25 GHz chirp signal that gets multiplied up to the 12-18 GHz frequency range. The DDS has the capability of providing phase and amplitude corrections to the 1.5-2.25 GHz signal to increase the linearity of the final chirp [3]. We have since completed and optimized the design and incorporated it into the Ku-band and Snow radar systems as their primary transmit signal source. Several other improvements were incorporated to these radars. These include electronic sampling band selection, the capability of digital down-conversion (DDC), and an automated flight altitude tracker [4]. The electronic sampling band selection allows extending the operational altitude range of the radar from 1200-5000 ft AGL without using multiple analog-to-digital converter (ADC) channels; the DDC allows reducing the data rate by a selectable factor of 2, 4, or 8; and the altitude tracker automatically adjusts the DDC parameters for in-flight data display and data recording, which minimizes the user interaction.

Figure 5 shows some photographs of the Ku-band/Snow radar electronics along with preliminary radar echograms produced with data collected with these systems in the vicinity of the Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) site.

HF Sounder

Radar System

In the last annual report we discussed the progress made toward the design of this radar and its integration with a modified YAK platform, called G1X . We had indicated that our target weight for the system was 7 kg (15.4 lbs). We have since completed the design, laboratory characterization, and field testing of the system in Antarctica. Remarkably, we achieved a weight close to 3 kg (6 lbs) for the initial prototype system and close to 2 kg (4 lbs) for the final version. Figure 6 shows a photograph of the radar electronics.

Figure 6: Photograph of the HF sounder electronics.

The radar is capable of transmitting approximately 100 Watts peak power signal and its average DC power consumption is close to 20 Watts. Its operating frequency is fully programmable and

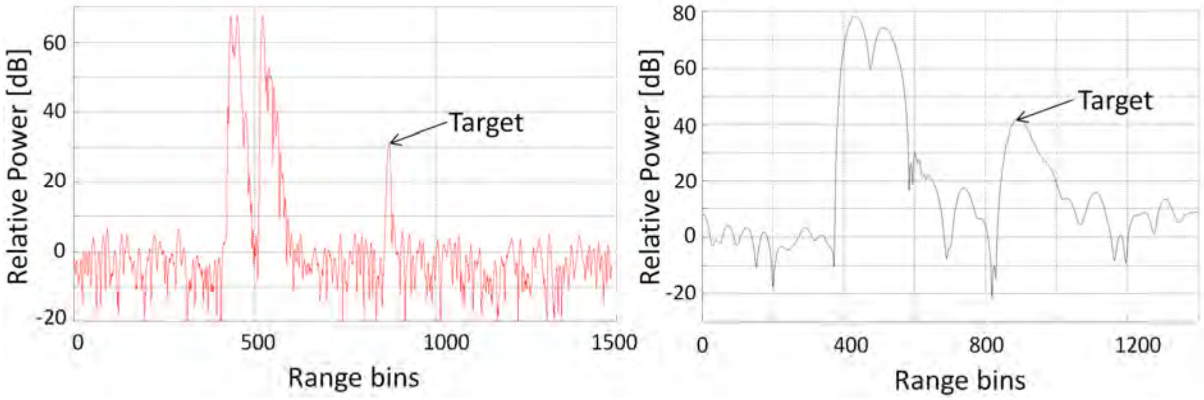


Figure 7: Laboratory tests results obtained with the HF sounder operating at 35 MHz (left) and 14 MHz (right).

currently supports two frequency ranges: 12-15 MHz (lower frequency range) and 30-40 MHz (upper frequency range). The data are stored to an on-board secure digital (SD) card.

We conducted laboratory tests to determine the impulse response and loop sensitivity of the system. The radar was operated s in the vicinity of 35 MHz and 14 MHz, respectively. Figure 7 shows the results obtained using a synthetic target built with a 12-μs delay line and high-power attenuators. The target was used to simulate the propagation of the radar signal including loss it experiences through approximately 1 km of ice. The total attenuation in the test setup was approximately 120 dB. With 256 presums, the signal from the target is approximately 40 dB above the average noise. This translates to a loop sensitivity close to 160 dB. As discussed below, additional signal processing gain can obtained by integrating close to 20,000 pulses in the along-track direction and by using data collected over multiple lines in the cross-track direction. The signal-to-noise ratio improvement obtained from the additional processing is estimated to be more than 30 dB. This will result in a loop sensitivity close to 190 dB, which is required to sound lossy ice in fast-flowing glaciers like Jakobshavn.

Integration and Field Tests

We integrated the system into the aircraft and deployed to Antarctica during the 2013/2014 Austral summer field season. We conducted several measurements at the Sub-glacial Lake Whillans (SLW) field camp on the Whillans Ice Stream in Antarctica [5]. The measurements included: (1) surface-based tests using sleds to test the functionality of the system and to demonstrate bi-static measurements; (2) in-flight return loss measurements to optimize impedance matching with the antenna over both operating bands; and (3) fully autonomous flights onboard the G1X UAS.

Surface-based tests

We conducted two types of radar functionality checks on the surface. We first installed the radar on a dielectric sled and used a simple antenna structure made with conductive tape to verify the system functionality. Figure 8 shows a photograph of the system setup and sample results obtained during these tests, where the radar was configured for operation at about 35 MHz. The ice thickness at this location is close to 800 m.

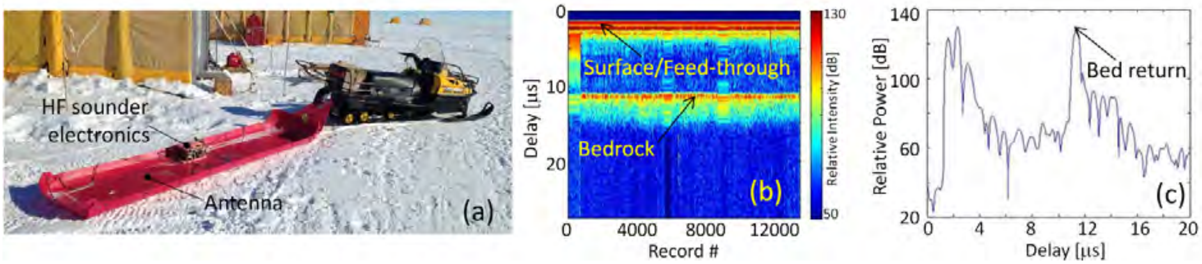


Figure 8: HF sounder ground tests in Antarctica: (a) test setup; (b) sample radar echogram obtained with the system operating at 35 MHz; and (c) sample A-scope showing a high signal-to-noise ratio for the bed return.

Next, we installed the HF sounder radar on the G1X UAS and mounted the aircraft on a wooden Nansen sled, which was towed by a snowmobile. A multi-pass survey was performed on the ice runway with the radar configured to operate at about 13.5 MHz. This was done as a performance verification check and to establish the coherence of the bedrock return over closely spaced grid lines. High coherency and stability are required to demonstrate synthetic aperture radar (SAR) processing in both the along-track and cross-track directions. Figure 9a shows the results obtained during a single pass, while Figures 9b-c show the phase and amplitude of the bedrock reflection over 11 passes. These results demonstrate remarkable coherence of the bedrock return signal over the surveyed grid, indicating the feasibility of SAR processing [5].

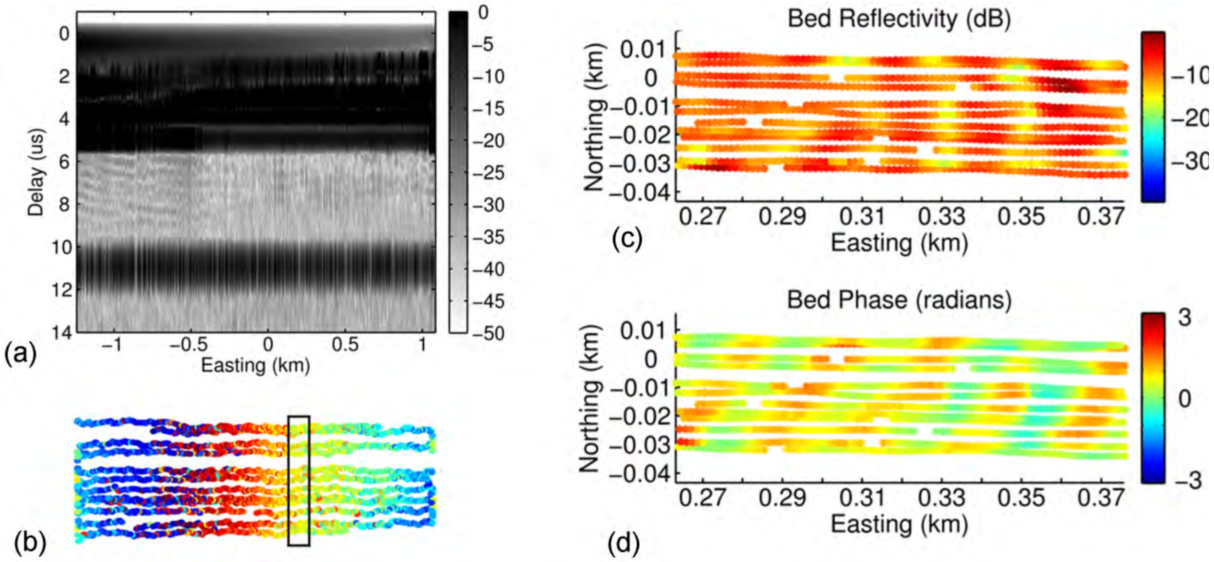


Figure 9: Test results from a multi-pass sled survey at the SLW camp: (a) Echogram produced from single-pass data; (b) Phase of the bedrock signal over the 11 passes in the survey; (c) Zoomed view of the amplitude and (d) phase of the bedrock return signal over the rectangular area marked in (b).

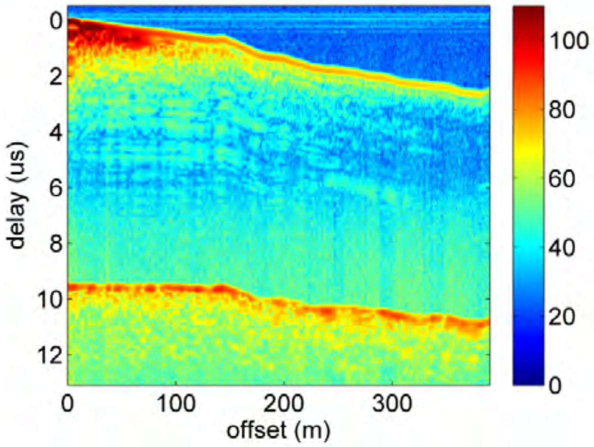


Figure 10: Test results obtained operating two HF sounder systems on the ground in a bi-static configuration.

We also conducted bi-static measurements using a dual-sled configuration. This was done by configuring one system as a transmitter and keeping it stationary, while the other was configured as a mobile receiver. A GPS-based oscillator was used to derive the sampling clock for both the mobile and the fixed system. Figure 10 shows sample preliminary results from these measurements with the radar operating near 35 MHz. The first echo in the top 3 μs corresponds to the transmit feed-through signal; its location changes as the receiver moves away from the transmitter. The location of the bedrock return in the echogram (around 10 μs in the vertical scale) varies much less because of the more constant distance to the target. This is a key result for the future demonstration of surveys conducted with multiple UAS.

Airborne measurements

In the last annual report we described the dual-frequency antenna design proposed for the YAK platform. We finalized the design, which consists of a resistively-loaded dipole for the 14 MHz and a tapered planar-dipole for the 35 MHz. After integrating the antennas with the aircraft in the field, we configured the radar to perform in-flight antenna impedance measurements. We used the inflight measured data to design and optimize a passive impedance-matching network for

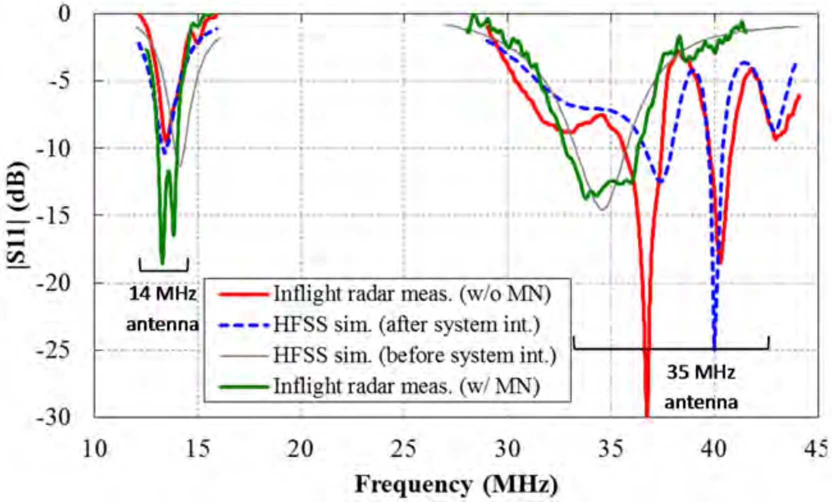


Figure 11: Computer simulation results and in-flight measured HF sounder antenna performance [4].

each band. A return loss of at least 10 dB was obtained over a 1 MHz bandwidth at the lower operating frequency of 14 MHz while a bandwidth of 4 MHz was obtained at higher operating frequency of 35 MHz. The resulting fractional bandwidth for the two bands is within a few percent of the predictions presented in the last annual report. Figure 11 shows a plot of the simulated magnitude of the scattering parameter S_{11} for the two operating bands before and after system integration. The computer simulations were performed using Ansoft's High Frequency Structure Simulator (HFSS). The plot also shows the in-flight measured response of the antennas with and without the matching networks.

The radar system was tested with the UAS operating in three different modes: remote-controlled (RC) mode; fully autonomous line-of-sight mode; and fully autonomous over-the-horizon mode. The radar was setup to use the 900-MHz communication link to provide real-time display of the data being collected to verify the operation of the radar during flight. Multiple survey passes were completed over the runway using the first two modes. Finally, a survey of the WISSARD drill site was completed using the fully autonomous over-the-horizon mode.

Figure 12 shows sample results obtained with the radar configured for operation in the 35 MHz band. The left inset of Figure 12(a) shows an echogram obtained after combining

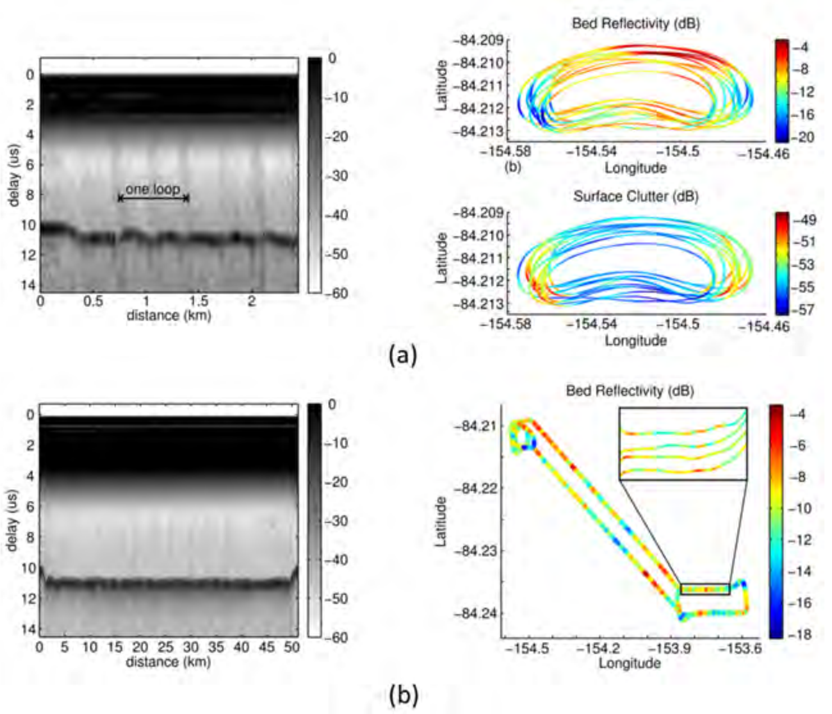


Figure 12: Sample preliminary results obtained with the HF sounder radar configured for 35-MHz operation flying on the G1X UAV on different modes: (a) RC-mode survey of the ice runway; and (b) Fully autonomous over-the-horizon mode survey of the WISSARD site [4].

data from a several runway passes with the aircraft operating in RC mode. The ice-bedrock interface is located about 800-m below the ice surface. The top right inset of Figure 12(a) shows the amplitude of the bedrock return signal over 15 passes. This plot indicates that the amplitude of the bedrock echo decreases during roll maneuvers, as expected from the antenna radiation pattern. The bottom right inset shows the opposite effect for the surface clutter power during roll maneuvers, as the surface clutter power which reaches its maximum when the bedrock signal reaches its minimum.

The left inset of Figure 12(b) shows a sample echogram from a fully autonomous flight over the WISSARD site. This survey flight was conducted over the horizon. The measured ice thickness was close to 800 m, which agrees with the information provided in the WISSARD project's website (http://www.wissard.org/about/study-area). The right inset of Figure 12(b) shows the measured bed reflectivity over the survey area. The significant correlation of the bedrock return over multiple passes is an indication of the feasibility of two-dimensional aperture synthesis. The data are currently being further processed, and they will be used to fully demonstrate this capability.

Radars for Surface-based Experiments

Snow Measurements at Summit, Greenland

We provided a version of the CReSIS Snow Radar to perform measurements as a part of a NSF-funded project led by Dr. M. Albert at Dartmouth University. The project was funded through two

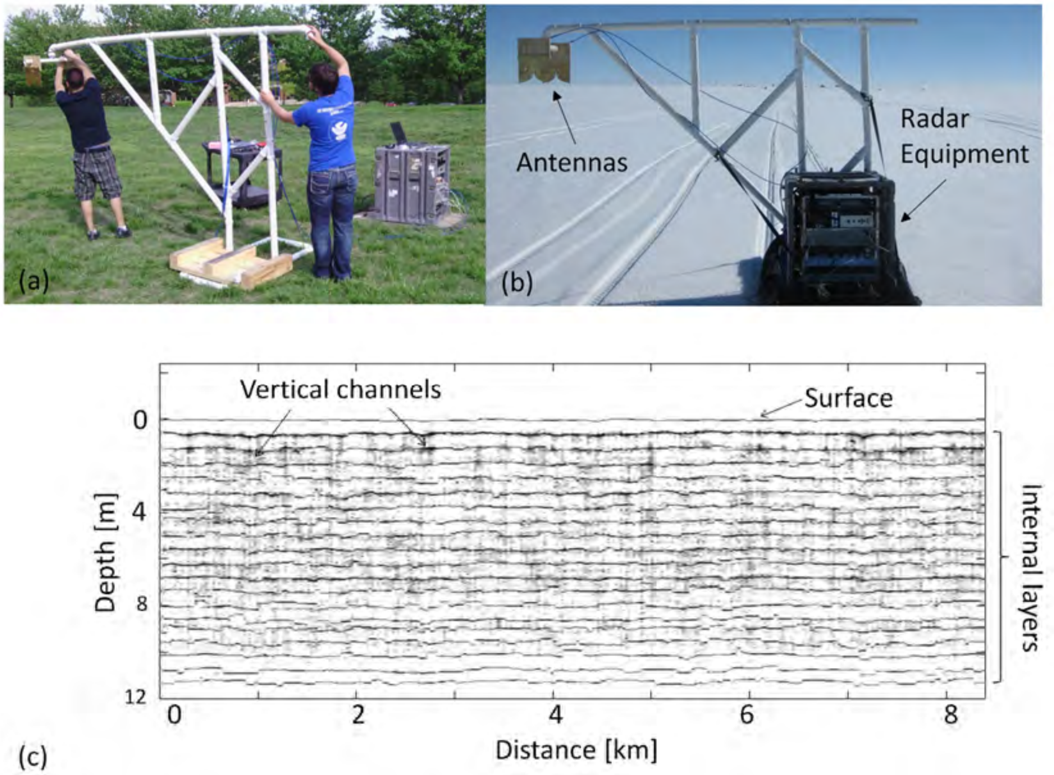


Figure 13: Snow Radar for surface measurements provided by CReSIS to support of a field experiment conducted by Dartmouth University at Summit Camp, Greenland: (a) System setup in Kansas; (b) Survey operations at Summit Camp and; (c) Sample radar echogram showing internal layers and vertical channels.

grants: (1) IGERT: Polar Environmental Change, and (2) a NSF Polar Programs Arctic grant for robotics, “Collaborative Research: Cool Robot to Support Greenland Field Science Campaigns”. The radar was used to look at the ice structure that formed as a result of the widespread 2012 Greenland melt event, **which resulted in the** formation of horizontal layers and vertical columns of ice that connected the horizontal layers within the snow pack. The goal of the project was to map the continuity of the horizontal ice layers and determine the spatial variability of the vertical ice columns. We adapted the radar to operate from a sled, provided the antenna mounts, and trained a graduate student from Dartmouth University as an operator.

Since Summit camp is a clean-air station, the radar had to be modified to support continuous operation for up to 8 hours using rechargeable batteries. The required modifications to the radar system were completed by a CReSIS doctoral student (Electrical Engineering) overseen by faculty and staff members. The antenna mounts were designed by a junior graduate student (Aerospace Engineering) also supported through CReSIS.

The radar was operated with 7.5 GHz of bandwidth (0.5-8 GHz) at Summit Camp during the 2013 summer season. A few 100-m x 100-m grid surveys with 10 m spacing were completed. The grids

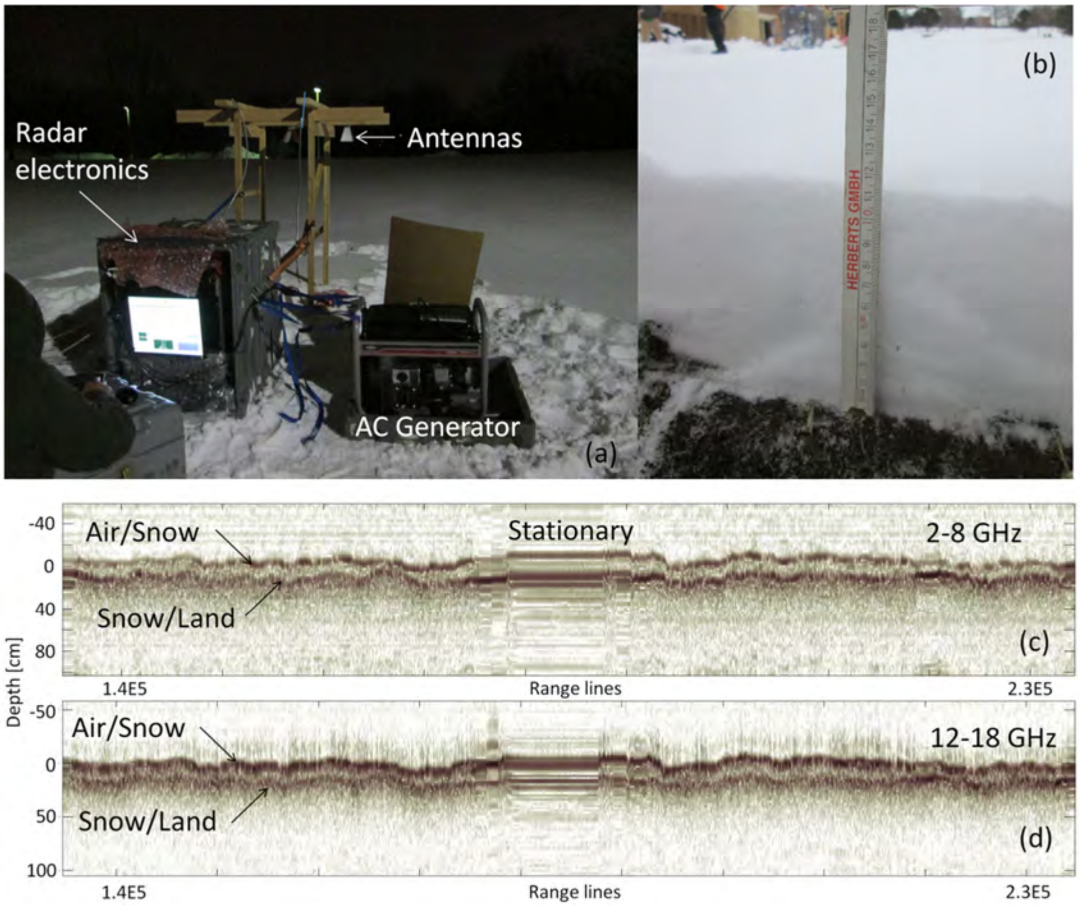


Figure 14: Radar experiment to measure snow cover over land: (a) Measurement setup being operated by CReSIS doctoral student D. Gomez-Garcia; (b) in-situ measurement to determine snow cover thickness at one of the survey points; (c) sample radar echogram obtained with the 2-8 GHz Snow Radar and; (d) sample radar echogram obtained with the 12-18 GHz radar altimeter.

were comprised of North/South transects and East/West transects. The field team also conducted excavations to map the location of the vertical and horizontal ice structures over a smaller survey area. A photograph the system during setup and test operations in Kansas is shown in Figure 13(a). A photograph of the system being pulled by a snowmobile during survey operations at Summit camp, Greenland is shown in Figure 13(b). Sample preliminary results obtained from radar data are shown in Figure 13(c). These results reveal internal layers in the upper part of the ice sheet and the presence of some vertical flow channels. The data are currently being further processed and analyzed at CReSIS.

Measurements of Snow Cover Over Land

We took a recent opportunity to conduct local measurements on snow over land using both the Snow Radar and the Ku-band radar altimeter. To obtain the best chirp linearity performance, we adapted the airborne version of these two radars for surface operation. The antennas were mounted on a simple wood sled structure. The radars were first operated in nadir-looking mode for snow thickness measurements along 100-m lines of undisturbed snow. Next, we collected off-nadir radar measurements at select locations at different angles (up to 70 degrees) for three different polarizations: V-V, H-H, and H-V. We assumed that the backscattering obtained for H-V will be same as for V-H, so we did not collect data for V-H. These measurements were conducted a part of two Ph.D. dissertations and the data will be used to estimate snow water equivalent (SWE) and snow density from radar data employing a technique similar to that used by Rott et al. [6]. The inversion of radar data to estimate SWE would reduce the need for extensive in-situ snow density measurements required to convert radar measured electrical range into snow thickness or depth.

Figure 14(a) shows a photograph of the measurement setup being operated by a CReSIS doctoral student. Figure 14(b) shows a photograph of an in-situ measurement verifying the snow cover thickness. Figure 14 (c) and 14 (d) show preliminary results obtained from radar data in nadir-looking mode operating over two different frequency ranges: 2-8 GHz and 12-18 GHz, respectively. The air/snow and snow/land interfaces are clearly resolved using both frequency bands. The data are currently being processed for further analysis.

Ice Shelf Measurements in Antarctica

In the last annual report we provided an update on the upgrades completed on the Accumulation Radar and described the modifications done to support surface operation as a part of a NSF-funded field experiment around the Pirrit Hills in Antarctica (2012/2013). This year we

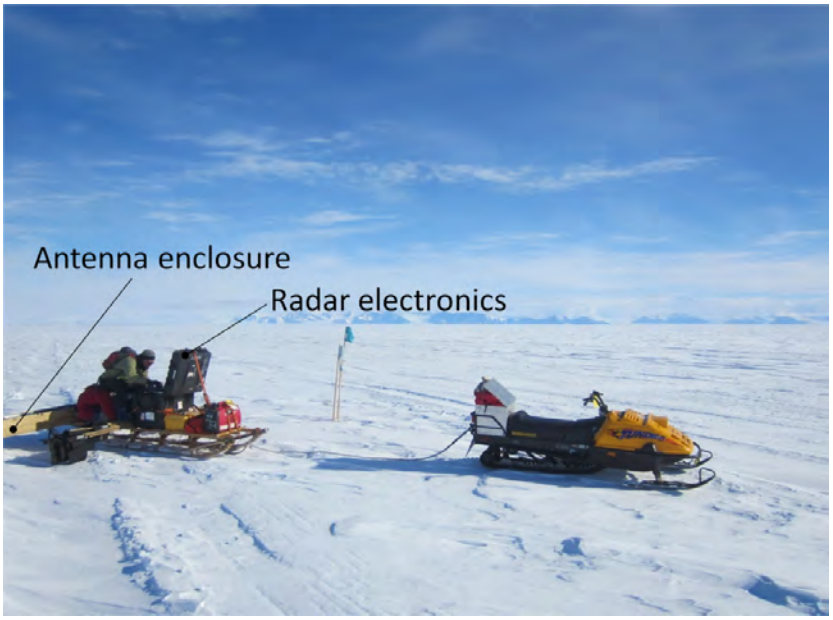


Figure 15: Photograph of the Accumulation radar setup for melt-rate measurements in Antarctica.

provided a similar version of the same radar to support a different NSF-funded effort in Antarctica during the 2013/2014 field season (field event number I-188-M). The radar electronics and antennas were re-packaged to support easy transportation and set-up. A small team flew from the CReSIS camp on Whillans Ice Stream to different locations along the Ross Ice Shelf, where they used the radar to measure the ice thickness at two different points in time. The data are currently being processed and analyzed and will be used to infer ice shelf melt rates. Figure 15 shows a photograph of the radar measurement setup during field operations.

Other Projects

Wing Flexure Studies

As a part of a doctoral dissertation, we performed a study of the effects of wing flexure on beam formation for the radar depth sounder that was previously deployed onboard the DHC-6 Twin Otter [7]. The study consisted of computer simulations of a full-scale model of the wing-mounted array and measurements on a scale model demonstrator. The simulations were completed using Ansoft's HFSS while the scale-model measurements where completed in an anechoic chamber. The scale-model was designed to include six dipole-antenna elements, and several components of the aircraft wing including a control surface. The size of the antenna elements was scaled down to operate at 1.2 GHz instead of the 195 MHz used with the depth sounder radar. The measurements were completed using the EMQuest antenna measurement software and using a version of the Multichannel Coherent Depth Sounder (MCoRDS). In the latter case, a custom-design module was used to: (1) up-convert the 180-210 MHz chirp signal from the MCoRDS waveform generator to the 1.18-1.21 GHz range for transmit and (2) down-convert the signal back to the 180-210 MHz range for receive. The up-converter/down-converter module was designed and built as an undergraduate research project. The results were included in two different papers, which present a detail discussion of this study and were recently accepted for publication [8-9]. Figure 16(a) shows a photograph of the array scale model during measurements at the anechoic

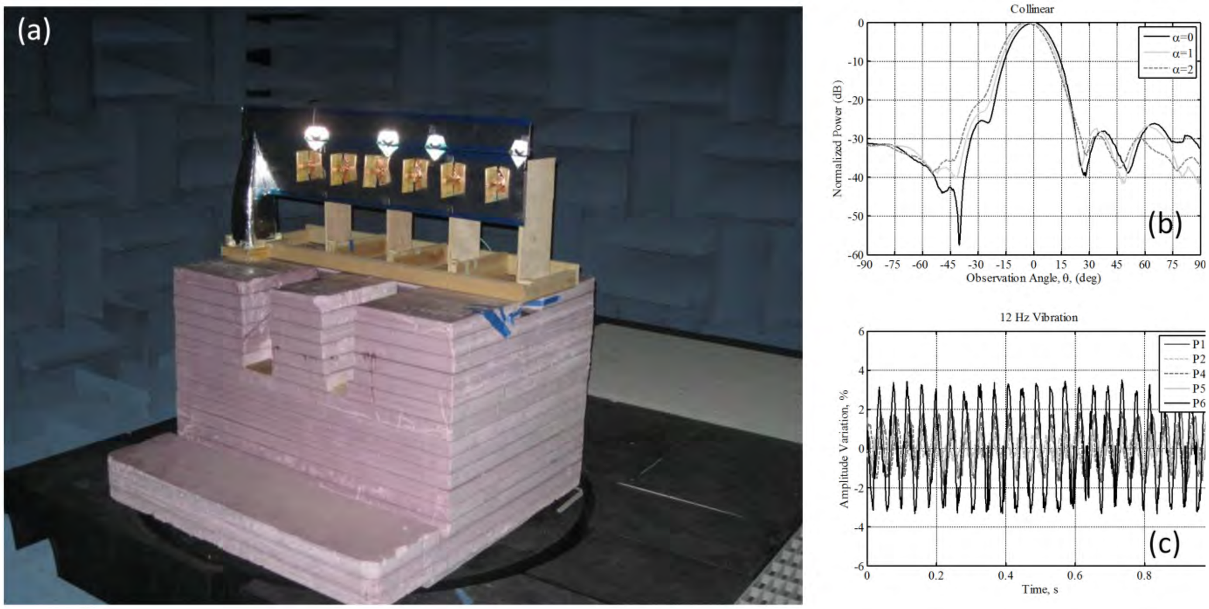


Figure 16: (a) Antenna array scale model during vibration tests; (b) Measured collinear array patterns with Chebyshev weights for three displacement levels; (c) Amplitude variations measured for each element in the scale array for a 12-Hz vibration.

chamber. Figure 16(b) and (c) show some example results obtained for measurements of the array radiation pattern when the structure is subject to flexing.

1-kW T/R modules

In the last annual report we presented the progress toward the implementation of transmit/receive modules for very high power (>1kW per channel). We improved the design of the T/R switch and were able to optimize its attenuation characteristics as a function of frequency for both transmit and receive paths. The typical output power obtained from the transmit chain using the Freescale Semiconductor amplifier reported last year is approximately 1100 W after losses. Figure 17 (a) shows a typical waveform at the output of the transmitter after a high-power attenuator chain with 60.35 dB of loss. Figure 17(b) shows the gain and delay characteristics for the complete transmit chain measured with a vector network analyzer capable of pulsed measurements. The increasing delay at the band edges is related to the response of the high-power band-pass filter installed at the antenna port of the duplexer. This filter is used for harmonic-suppression on transmit and pre-selection on receive. The information provided from these measurements will be used to pre-distort the phase and amplitude of the transmit signal and optimize the range sidelobe performance.

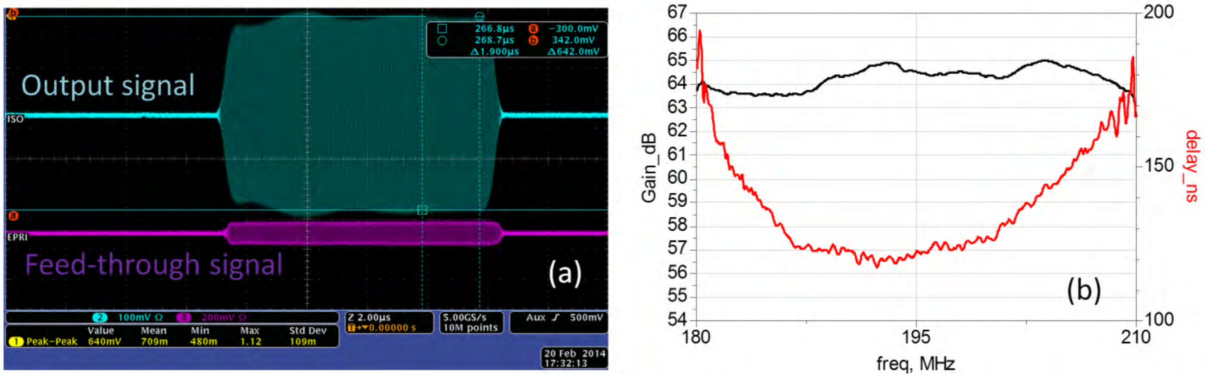


Figure 17: (a) Typical transmit waveform (green) and transmit feed-through signal of the 1-kW T/R module; (b) Measured gain and delay characteristics of the complete transmit chain.

References

[1] S. Gogineni, J.B. Yan, R. Hale, C. Leuschen, F. Rodriguez-Morales, Z. Wang, J. Paden, B. Townley, D. Gomez-Garcia, L. Stearns, C. Carbajal, R. Willer, S. Child, and D. Braaten, Ultra-Wideband Radar for Measurements over Ice Sheets in Antarctica and Greenland, to be presented as Invited Paper at the *10th European Conference on Synthetic Aperture Radar*, *EUSAR*, Berlin, Germany, Jun. 2014.

[2] Z. Wang, S. Gogineni, F. Rodriguez-Morales, J.B. Yan, R. Hale, J. Paden, C. Leuschen, C. Carabajal, D. Gomez-Garcia, B. Townley, R. Willer, L. Stearns, S. Child, and D. Braaten, Ultrawideband Imaging Radar for Cryospheric Remote Sensing, Submitted to the 2014 IEEE international Geoscience and Remote Sensing Symposium, Quebec City, Canada.

[3] D. Gomez-Garcia, C. Leuschen, F. Rodriguez-Morales, S. Yan, and P. Gogineni, Linear Chirp Generator based on Direct Digital Synthesis and Frequency Multiplication for Airborne FMCW Snow Probing Radar, to be presented at the 2014 *IEEE International Microwave Symposium*, Tampa Bay, FL, USA, Jun. 2014.

[4] D. Gomez-Garcia, CReSIS Internal Report, October 2013.

[5] C. Leuschen, R. Hale, S. Keshmiri, J.B. Yan, F. Rodriguez-Morales, A. Mahmood, and S. Gogineni, UAS-Based Radar Sounding of the Polar Ice Sheets, *IEEE Geoscience and Remote Sensing Magazine*, to appear, Mar. 2014.
[6] H. Rott, M. Heidinger, T. Nagler, D. Cline, S. Yueh, Retrieval of Snow Parameters from Ku-Band and X-Band Radar Backscatter Measurements, *IEEE International Geoscience and Remote Sensing Symposium*, Cape Town, Sudafrica, Jul. 2009, pp. II-144-147.
[7] E. Arnold, Development and Improvement of Airborne Remote Sensing Radar Platforms, Ph.D. Dissertation, Aerospace Engineering, University of Kansas, June 2013.
[8] E. Arnold, J.B. Yan, R. Hale, F. Rodriguez-Morales, P. Gogineni, J. Li, and M. Ewing, Effects of Vibration on a Wing-Mounted Ice Sounding Antenna-array, *IEEE Antennas and Propagation Mag.*, accepted, 2014.
[9] E. Anold, J.B. Yan, R. Hale, F. Rodriguez-Morales, and P. Gogineni, Identifying and Compensating for Phase Center Errors in Wing Mounted Phased Arrays for Ice Sheet Sounding, *IEEE Trans. Ant. Prop.*, accepted, 2014.

Signal and Data Processing

Layer Database

The first version of the CReSIS geospatial database system for storing layer information has been completed. This system is being used to store our flight line and layer data for all sensor systems and is named the Open Polar Server (OPS). A block diagram of the system in shown in Figure 18. This system was built with several key features in mind:

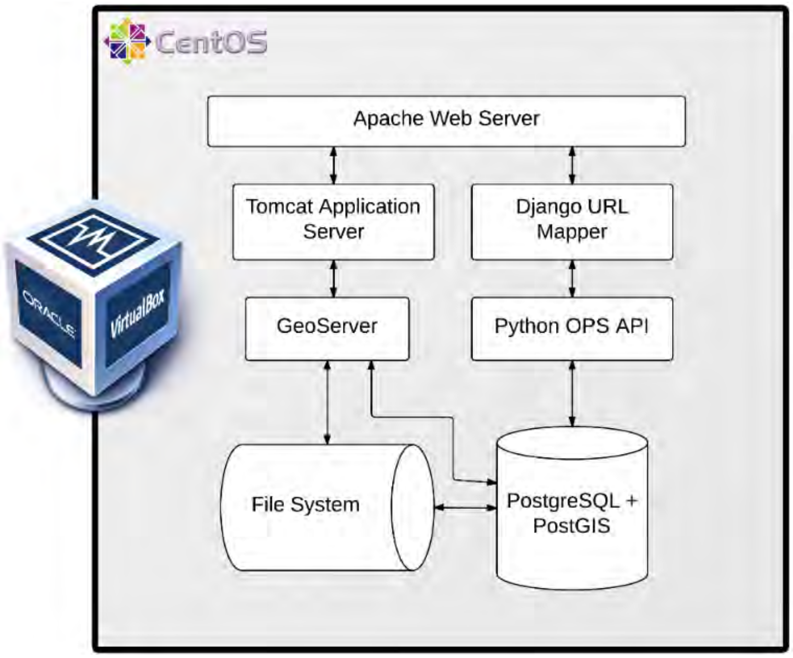
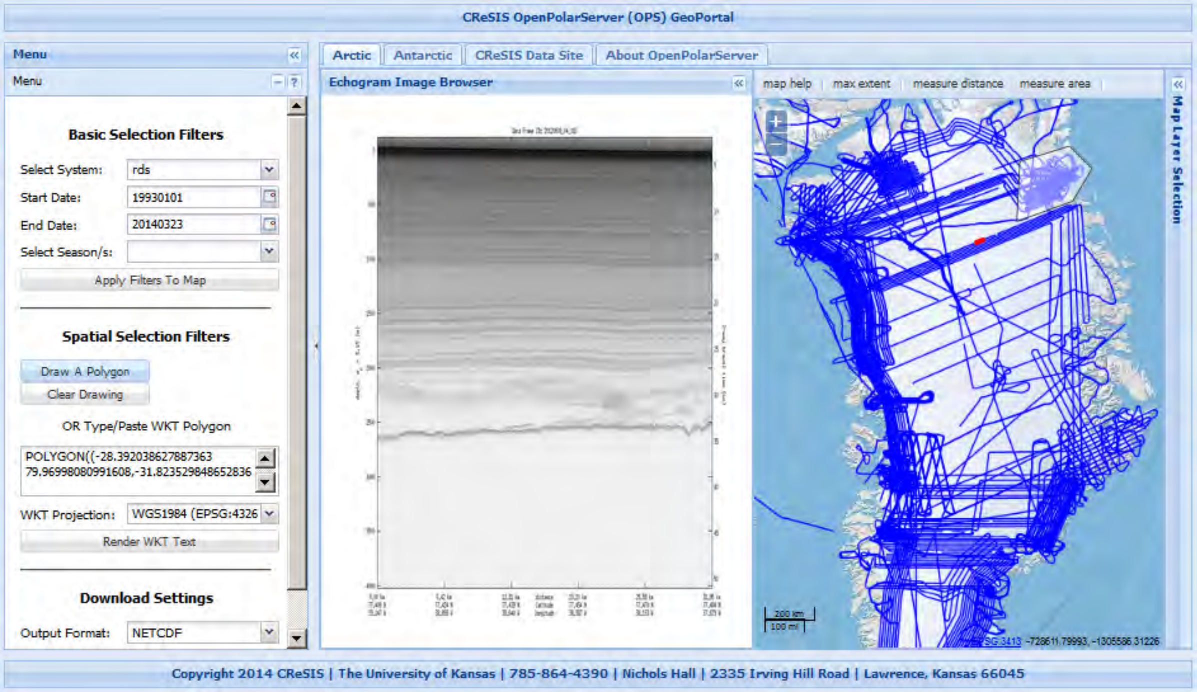


Figure 18: Block diagram of OPS.

- Handle all CReSIS sensors and seasons in a scalable and integrated fashion
- Easily installable mobile version for field work where internet access is limited or nonexistent
- Integrated map server
- Support unlimited layers and several different layer relationships
- Convenient geographic browsing and data download interfaces from the web for layer and echogram data
- Open source to encourage the international science community to both use and develop the system
- Design not started yet: ability to ingest and manage raster data

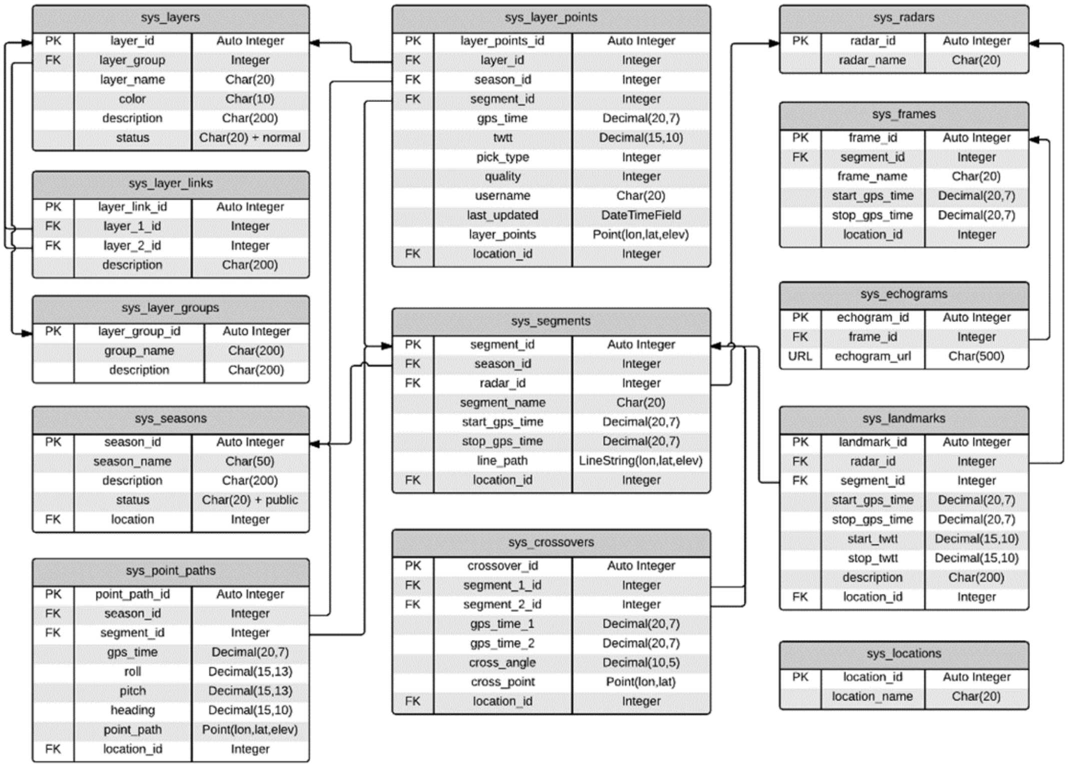
Each of the components in the system use open source software and the first version is released on the GitHub open source server at https://github.com/kpurdon/OPS. We have adopted the use of a virtual machine framework to enable mobility across platforms (e.g. the VirtualBox virtual machine is supported on Linux, Windows, and MacOS) and to limit installation issues since we can fully control the environment on the virtual machine. We use Vagrant, a virtual machine wrapper, to ease creation of field deployable versions of OPS. The primary interface is through the web server. This allows us to leverage web authentication, open source frameworks and map servers. Also, web access is generally the least access-restricted service on the internet. The web address for the primary server is https://ops.cresis.ku.edu/. A snapshot of the web interface is shown in Figure 19. A number of basic features, such a date, season, and sensor filtering are possible. The geographic search allows the user to draw a polygon on the map or to paste in a WKT polygon. The download interface supports multiple formats and multiple download requests can be made simultaneously since these are processed in the background.



Select System: rds
Start Date: 19930101
End Date: 20140323
Select Season/s:
POLYGON((-28.392038627887363 79.96998080991608,-31.823529848652836
WKT Projection: WGS1984 (EPSG:4326
Output Format: NETCDF

Figure 19: Snapshot of web interface to OPS.

We use PostgreSQL database with the PostGIS geospatial extension to support scalability, layer organization, and geographic searches. The entity relationship diagram is shown in Figure 20. The database supports individual layer details, grouping of layers, and linking of layers. For tracking layers over a large area, it is useful to be able to link and unlink layers when trying to determine the relationships between disconnected layers. One of the layer datasets that we have tested with is the LAYERMAP project lead by Macgregor et al. 2013. We are also using the system to track internal layers in the accumulation radar data. We will eventually include snow thickness on sea ice data products as well.



sys_layers

PK	layer_id	Auto Integer
FK	layer_group	Integer
	layer_name	Char(20)
	color	Char(10)
	description	Char(200)
	status	Char(20) + normal

sys_layer_links

PK	layer_link_id	Auto Integer
FK	layer_1_id	Integer
FK	layer_2_id	Integer
	description	Char(200)

sys_layer_groups

PK	layer_group_id	Auto Integer
	group_name	Char(200)
	description	Char(200)

sys_seasons

PK	season_id	Auto Integer
	season_name	Char(50)
	description	Char(200)
	status	Char(20) + public
FK	location	Integer

sys_point_paths

PK	point_path_id	Auto Integer
FK	season_id	Integer
FK	segment_id	Integer
	gps_time	Decimal(20,7)
	roll	Decimal(15,13)
	pitch	Decimal(15,13)
	heading	Decimal(15,10)
	point_path	Point(lon,lat,elev)
FK	location_id	Integer

sys_layer_points

PK	layer_points_id	Auto Integer
FK	layer_id	Integer
FK	season_id	Integer
FK	segment_id	Integer
	gps_time	Decimal(20,7)
	twtt	Decimal(15,10)
	pick_type	Integer
	quality	Integer
	username	Char(20)
	last_updated	DateTimeField
	layer_points	Point(lon,lat,elev)
FK	location_id	Integer

sys_segments

PK	segment_id	Auto Integer
FK	season_id	Integer
FK	radar_id	Integer
	segment_name	Char(20)
	start_gps_time	Decimal(20,7)
	stop_gps_time	Decimal(20,7)
	line_path	LineString(lon,lat,elev)
FK	location_id	Integer

sys_crossovers

PK	crossover_id	Auto Integer
FK	segment_1_id	Integer
FK	segment_2_id	Integer
	gps_time_1	Decimal(20,7)
	gps_time_2	Decimal(20,7)
	cross_angle	Decimal(10,5)
	cross_point	Point(lon,lat)
FK	location_id	Integer

sys_radars

PK	radar_id	Auto Integer
	radar_name	Char(20)

sys_frames

PK	frame_id	Auto Integer
FK	segment_id	Integer
	frame_name	Char(20)
	start_gps_time	Decimal(20,7)
	stop_gps_time	Decimal(20,7)
	location_id	Integer

sys_echograms

PK	echogram_id	Auto Integer
FK	frame_id	Integer
URL	echogram_url	Char(500)

sys_landmarks

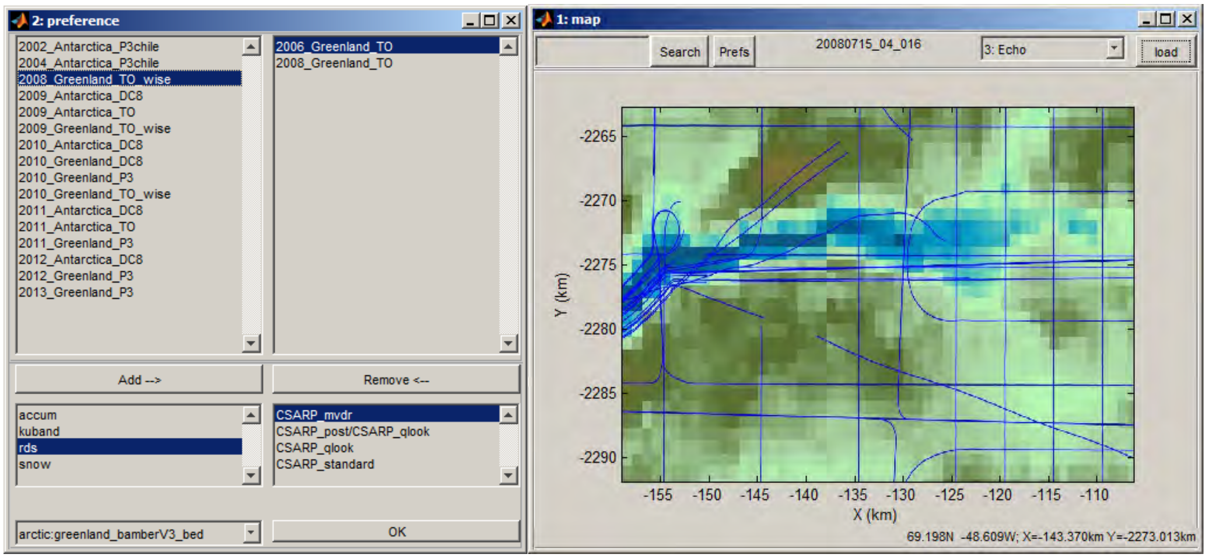
PK	landmark_id	Auto Integer
FK	radar_id	Integer
FK	segment_id	Integer
	start_gps_time	Decimal(20,7)
	stop_gps_time	Decimal(20,7)
	start_twtt	Decimal(15,10)
	stop_twtt	Decimal(15,10)
	description	Char(200)
FK	location_id	Integer

sys_locations

PK	location_id	Auto Integer
	location_name	Char(20)

Figure 20: Entity-Relationship diagram for OPS.

Most of the data processed by the current CReSIS SAR processor have been ingested into the system. Older data (2005 and prior) collected with the ACoRDS and ICARDS systems, are being reprocessed. Because of the improved organization and analysis tools, we are performing a global quality control task across all seasons and regions that will be completed in the coming year. We are also comparing the picking against other datasets which we have ingested, including



2: preference

2002_Antarctica_P3chile
2004_Antarctica_P3chile
2008_Greenland_TO_wise
2009_Antarctica_DC8
2009_Antarctica_TO
2009_Greenland_TO_wise
2010_Antarctica_DC8
2010_Greenland_DC8
2010_Greenland_P3
2010_Greenland_TO_wise
2011_Antarctica_DC8
2011_Antarctica_TO
2011_Greenland_P3
2012_Antarctica_DC8
2012_Greenland_P3
2013_Greenland_P3

2006_Greenland_TO
2008_Greenland_TO

accum
kuband
rds
snow

CSARP_mvdr
CSARP_post/CSARP_qlook
CSARP_qlook
CSARP_standard

arctic:greenland_bamberV3_bed

1: map

20080715_04_016
3: Echo

69.198N -48.609W; X=-143.370km Y=-2273.013km

Figure 21: Preference and map windows for Matlab based image browser.

the mass conservation map produced by Morlighem 2014 and the Warm Ice Sounding Explorer (WISE) radar depth sounder dataset from Mouginot 2014. The ability to handle multiple seasons and layers facilitates these comparisons.

Although the web interface provides access to browse echogram images and to download layer data, it does not allow editing of the layer data and only supports JPEG radar echogram browsing. Our internal Matlab based browser and layer tracker was overhauled to utilize OPS and will continue to be the primary tool for editing layer data. This new browser has not been released to the public yet, but we have been using it for the past 6 months as the primary layer tracking tool and will release it during the coming year as a complementary tool for use with the OPS. Figure 21 shows the map and preference window of the new picker. The map window interfaces to the OPS map server and the preference window queries the database and map server to get a list of seasons, sensors, and maps that are available. Multiple seasons can be browsed at the same time due to the scalability of the database and map server. Figure 22 shows an echogram loaded from the map display with LAYERMAP layers shown.

Three Dimensional Ice Bed Imaging

Maximum Likelihood Estimation Algorithm

To produce digital elevation models (DEMs) of the ice bed , we use the radar depth sounder cross-track arrays to determine the direction of each pixel in the radar echogram. This process, known as direction of arrival (DoA) estimation or spectral estimation, has been implemented in the literature in many ways. The maximum likelihood estimation method is currently the best performing direction of arrival estimation technique in the literature, but also requires a substantial increase in computational resources because of the N-dimensional nonlinear optimization steps required. We implemented the (MLE) algorithm for the direction of arrival estimation using the alternating projection technique to make the algorithm efficient as outlined in Ziskind et al. 1988 and Wu et al. 2011. We compared the performance of this MLE implementation with two other algorithms. The first, Multiple Signal Classification (MUSIC) used the approach detailed in Paden et al. 2010. The second algorithm for comparison was the Re-Iterative Super Resolution (RISR) algorithm developed in Blunt et al. 2011. The MLE and MUSIC performance were found to be nearly identical in terms of cross over analysis (i.e. the error is computed by comparing the algorithm results using two orthogonal flight tracks over the same terrain) and both

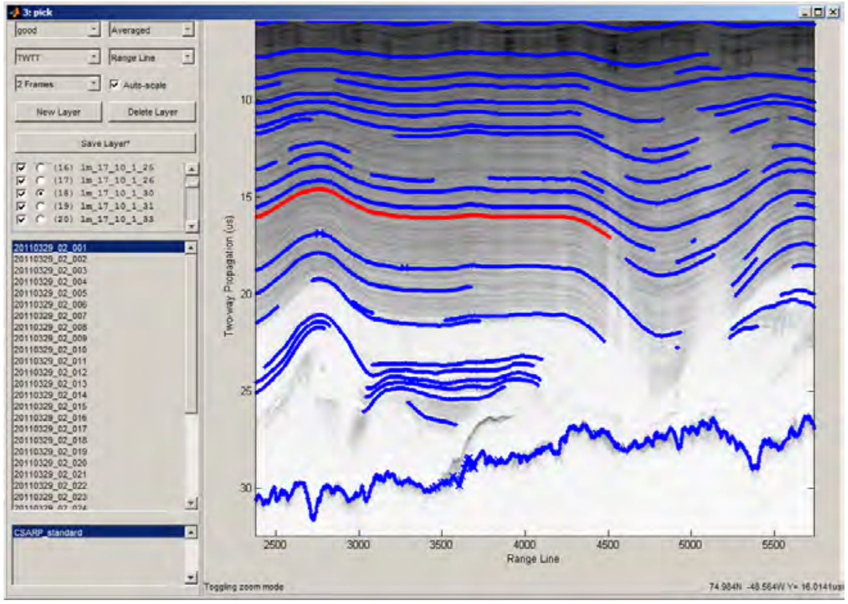


Figure 22: Matlab based echogram window with LAYERMAP layers from MacGregor et al. 2013 displayed.

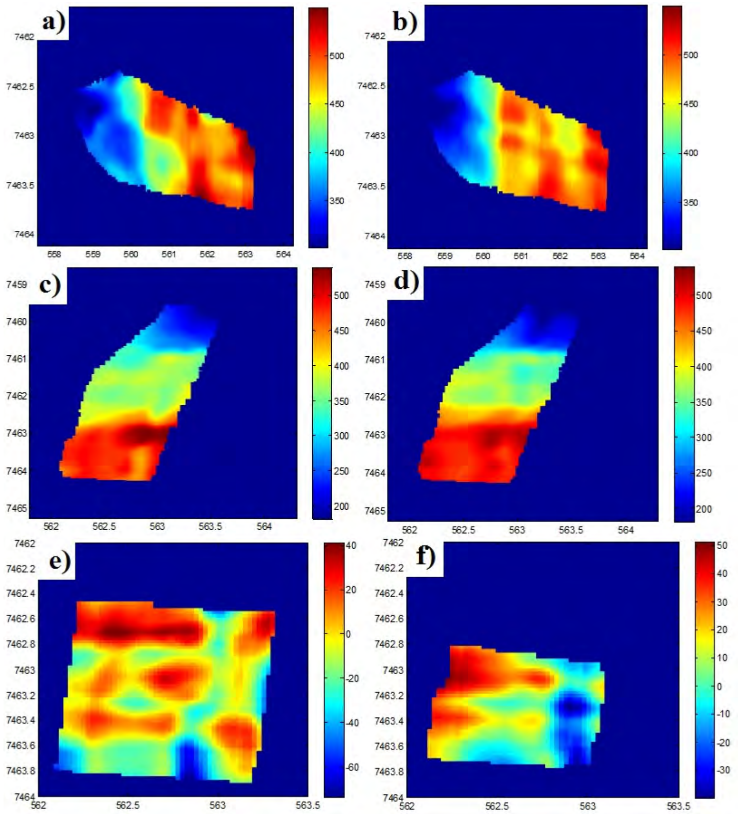


Figure 23: (a) MLE and (b) MUSIC DEMs for flight track 1 and c) MLE and d) MUSIC DEMs for flight track 2. Colorbars are WGS-84 elevation. e) MLE and f) MUSIC cross over errors in meters. X and Y axes are in km.

substantially outperformed RISR. For this comparison, only angles close to nadir were used since the surface extraction algorithm used did not work well for large incidence angles. Figure 23 shows the comparisons of the DEMs and cross overs with both producing an RMS error of about 20 meters (Raghunandan 2013). We plan to further investigate the MLE and MUSIC algorithms with improved surface extraction techniques and over a much larger region.

Surface Extraction

To deal with the surface extraction problem for large incidence angles, we implemented a hybrid approach where near-nadir angles used the existing beam-forming approach discussed in Paden et al. 2010 and targets at large incidence angles use the approach discussed in Wu et al. 2011. To constrain both search techniques, a flatsurface is used to predict where the surface will lie and the peak value in the neighborhood around this flat-surface is used to estimate of the actual surface. This helps isolate the bed return from the surface return clutter and sources of noise which may dominate for weak returns from the bed.

Figure 24 shows the surface extraction technique using the two different techniques and the neighborhood about the flat surface that was used. Further image filtering is applied to remove outliers and average the data to reduce the variance at the expense of resolution.

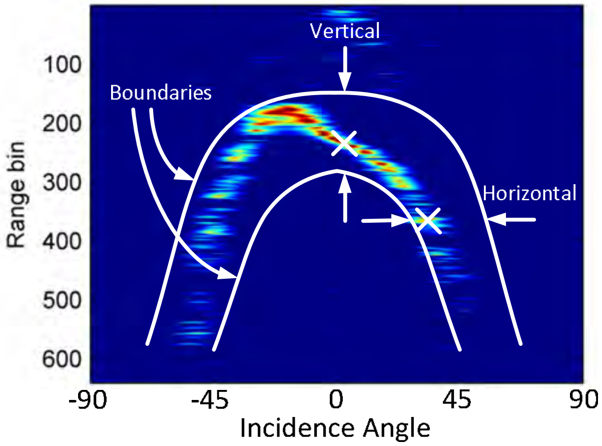


Figure 24: Surface extraction takes the peak value between the boundaries. For incidence angles close to 0 a vertical peak search is done. For large incidence angles a horizontal peak search is done.

Three Beam Tomography

During the 2013 Antarctica Basler mission, we took high-altitude (6000 ft AGL) three-beam data over the Whillans and Kamb Ice Stream grounding lines, portions of a subglacial lake and the northern margin of the Whillans Ice

Stream. Using the MUSIC algorithm and the hybrid surface extraction approach we extracted the surface for the center beam using the vertical search and for the left and right beams, we extracted the surface using the horizontal search. The results were then mosaicked together by averaging the elevation values in the beams' overlapping areas.

Figure 25a shows preliminary results from the three beam mode over the Kamb grounding line. The large bottom crevasses are evident in the DEM. A single side looking intensity image, before geocoding, is shown in 25b and a cross track nadir profile is shown in 25c. The strong lines of scattering in 25b follow the ridges of the bottom crevassing and are caused by the basal surface tilting so that it is normal to the radar system and results in a mirror like reflection back toward the radar.

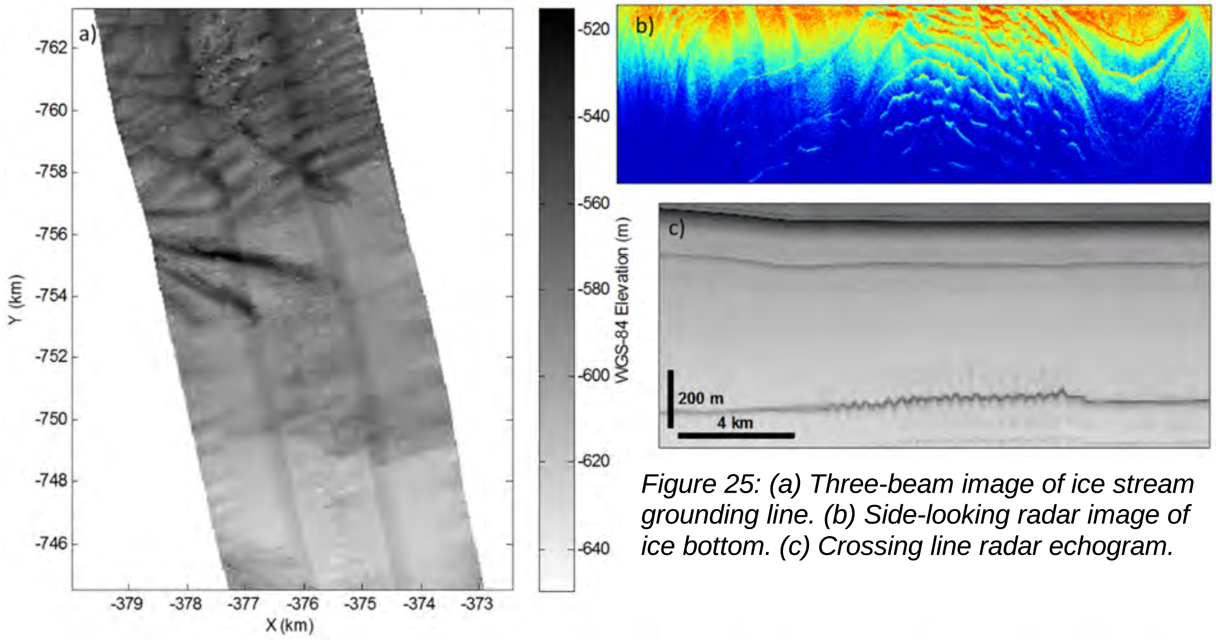


Figure 25: (a) Three-beam image of ice stream grounding line. (b) Side-looking radar image of ice bottom. (c) Crossing line radar echogram.

Internal Layer Processing

The LAYERMAP project is tracing internal layers throughout the Greenland ice sheet using CReSIS radar echograms. To improve internal layer tracking, we have investigated a new SAR processing technique adapted for internal layer targets instead of point targets. Point targets produce hyperbolas in the raw radar data because the time delay to the target is a hyperbolic function. Specular targets, like internal layers, produce linear features where the time delay is related to the surface slope, α, by the linear equation $t_d(x) = \frac{2}{c}\frac{H-\alpha x}{\sqrt{1+\alpha^2}}$ where H is the slope height at the origin, x is the along-track offset, and c is the speed of light. Figure 26 shows the response from a point target and a specular target with zero slope. The new SAR processor uses a tracking algorithm to estimate the slope using a matched filter for linear features rather than hyperbolic features. To reduce the search space, the internal layer slope is assumed to change slowly. This is a reasonable assumption since a slowly changing slope is required to produce a specular return. Useful byproducts of this new SAR processor are an internal layer slope map and easier tracking of layers due to the flattening. An example of the processor output is shown in Figure 27. This technique breaks down for rough internal layers such as is found in the deformed ice near the base of the ice sheet in some locations and along the ice-sheet margins. In the coming year,

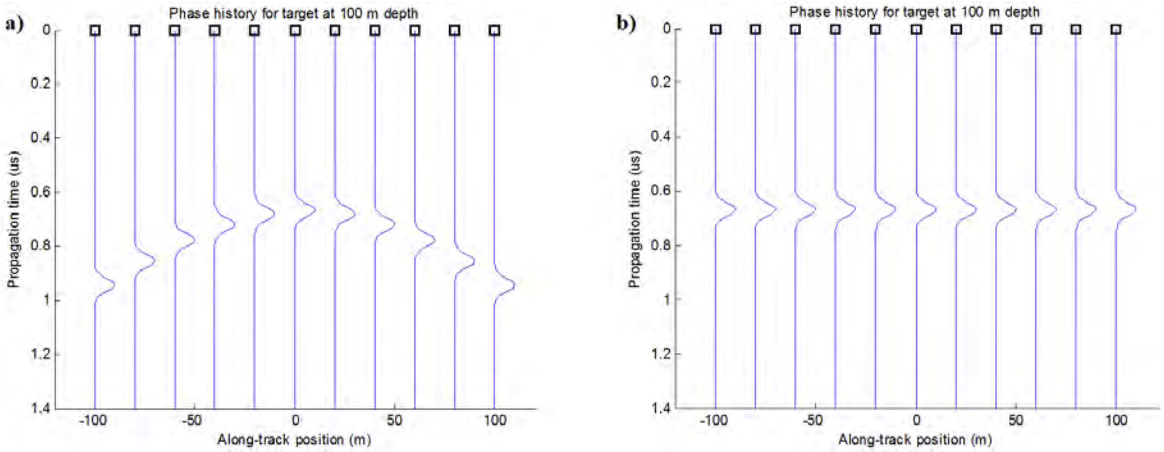


Figure 26: (a) Point target hyperbolic response and (b) internal layer linear response.

we plan to investigate hybrid SAR processing approaches which fall between a purely point and purely specular target approach since these rough layers are of critical interest to ice core site selection and may play an important role in understanding basal melting and ice flow.

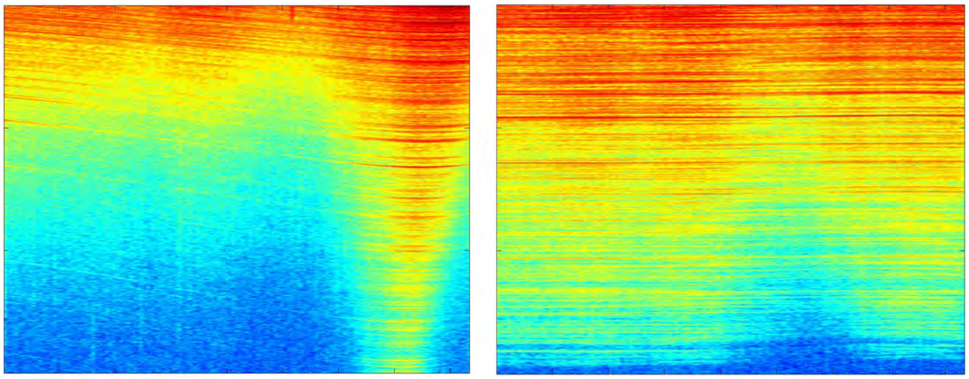


Figure 27: Starting with the left image, after matched filtering to a tracked slope, the SAR-image on the right shows enhanced internal layers and is flattened.

References

[1] S.D. Blunt, Tszping Chan, and K. Gerlach. Robust doa estimation: The reiterative superresolution (risr) algorithm. Aerospace and Electronic Systems, IEEE Transactions on, 47(1):332{346, 2011. ISSN 0018-9251. doi: 10.1109/TAES.2011.5705679.

[2] Joseph A. MacGregor, Mark A. Fahnestock, Ginny A. Catania, John D. Paden, Sivaprasad Gogineni, Susan C. Rybarski, S. Keith Young, Alexandria N. Mabrey, Benjamin M. Wagman, Radiostratigraphy of the Greenland ice sheet, Abstract 67A007, International Glaciological Society Radioglaciology 2013 Meeting, Sept 9-13.

[3] M. Morlighem personal communication, 2014.

[4] J. Mouginot personal communication 2014.

[5] J. Paden, T. Akins, D. Dunson, C. Allen, and P. Gogineni. Ice-sheet bed 3-D tomography. Journal of Glaciology, 56:3{11, April 2010. doi: 10.3189/002214310791190811.

[6] Sahana Raghunandan, “Analysis of Angle of Arrival Estimation Algorithms for Basal Ice Sheet Tomography,” CReSIS Technical Report 158, 2013, p. 57.

[7] Xiaoqing Wu; Jezek, K.C.; Rodriguez, E.; Gogineni, S.; Rodriguez-Morales, F.; Freeman, A., "Ice Sheet Bed Mapping With Airborne SAR Tomography," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.10, pp.3791,3802, Oct. 2011 doi: 10.1109/TGRS.2011.2132802.
[8] Ziskind and M. Wax, “MUSIC, maximum likelihood localization of multiple sources by alternating projection,” IEEE Trans. Acoust., Speech, Signal Process., vol. 1553, no. 1560, pp. 1553–1560, Oct. 1988.

2013 Antarctica Basler Field Season

The field program for 2013-2014 season consisted of three components: (1) Airborne measurements with the wideband radar on a BT-67 aircraft, surface-based measurements with a phase-sensitive 600-900 MHz radar; and flight tests of a small UAS integrated with a low-frequency sounder that operates at about 14 and 35 MHz. The airborne measurements with BT-67 were aimed at characterizing the grounding zones of ice streams— B/Whillans, C/Kamb, and D/Bindschadler—along the Siple Coast. Figure 28 shows flight lines over which we collected data with the radar package on the BT-67 aircraft. These data will be processed and data products for use the CReSIS science team and broader science community will be generated in the 6-9 months. Here we provide a few samples to show that we collected a very interesting and useful data.

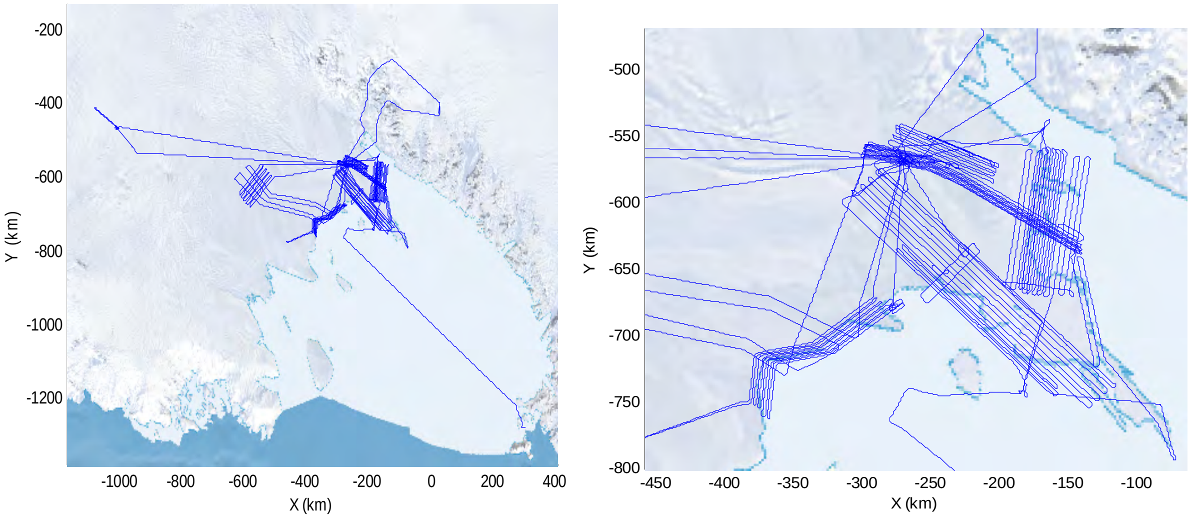


Figure 28: Coverage maps for the twelve 2013 Antarctica Basler missions.

Radar Depth Sounder

As mentioned previously, the radar depth sounder was operated with an 8-element fuselage mounted array and over the frequency range of 200-450 MHz. Figure 29 and 30 show typical results obtained with the radar. Figure 29 shows data collected over 2000 m thick ice and the results in echogram show quality of data collected for sounding thick ice and mapping internal layers with fine resolution. Figure 30 shows data collected over Kamb ice stream.in mapping internal layers with fine resolution in the top 20-30 m of ice.

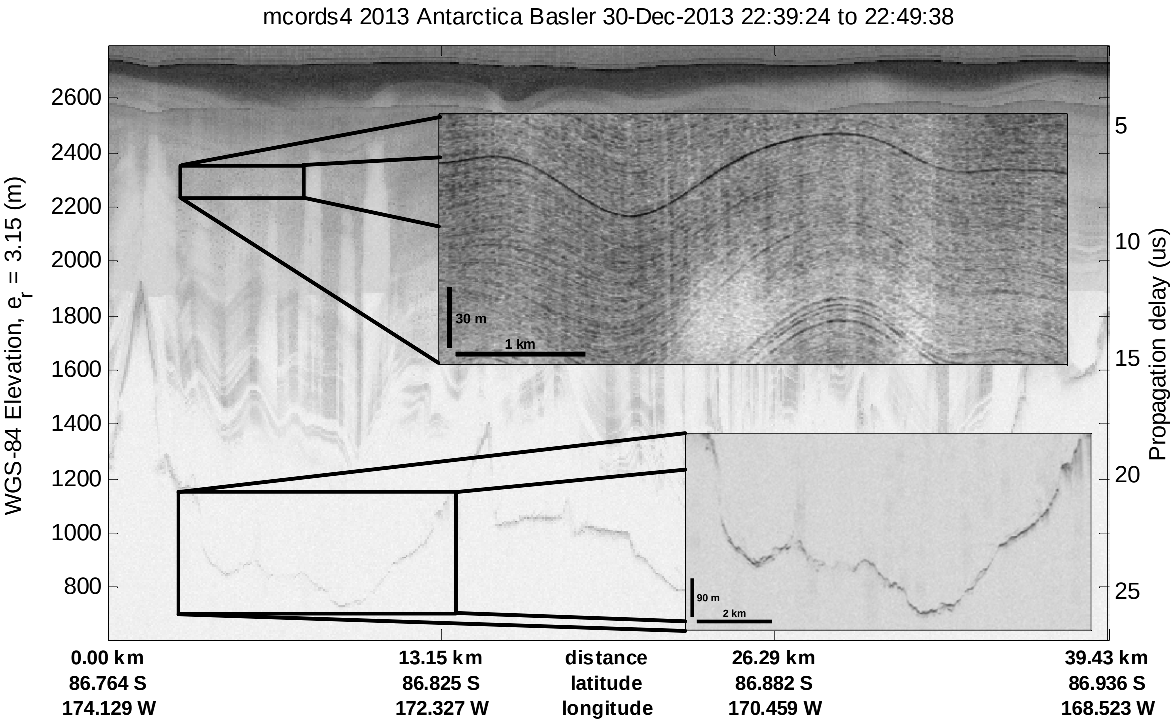


Figure 29: Radar echogram collected south of the Transantarctic Mountains. The top inset shows the fine resolution imaging of internal layers. Many layers merge and reemerge, but a few layers are traceable over long distances. The bottom inset shows the ice bottom for 2000 m thick ice with the dynamic range rescaled.

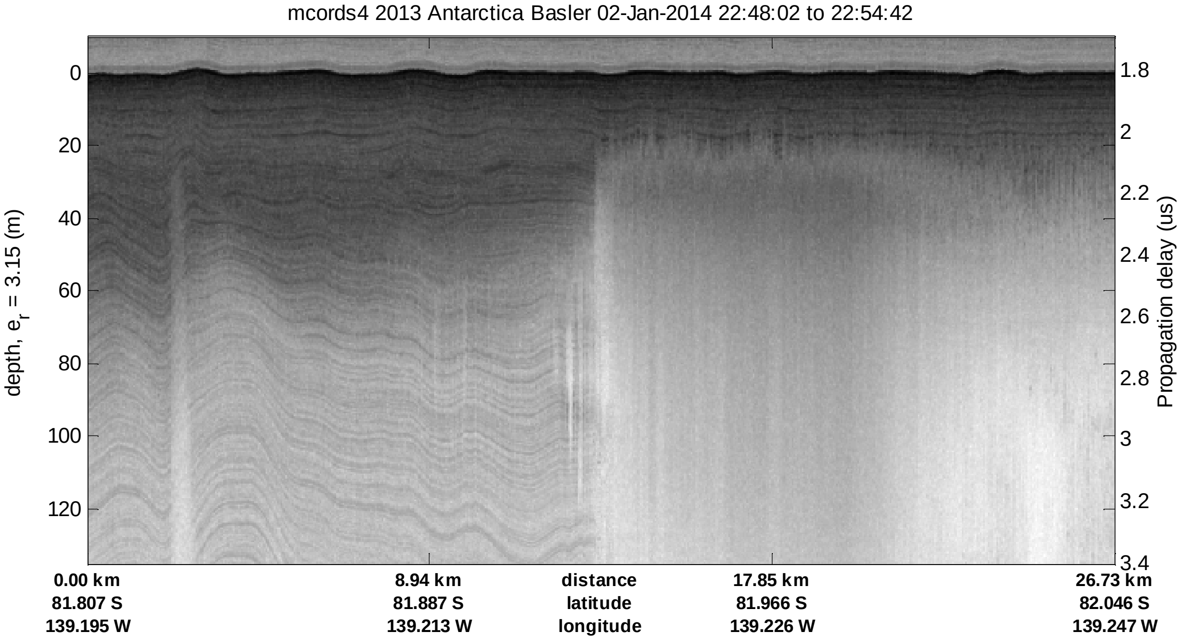


Figure 30: Upper Kamb Ice Stream margin showing the sudden onset of fast flow (where the layers disappear). The top 20 to 30 meters (solid ice equivalent) are layered on Kamb Ice Stream due to the recent slowdown of the ice stream which now permits layers to form.

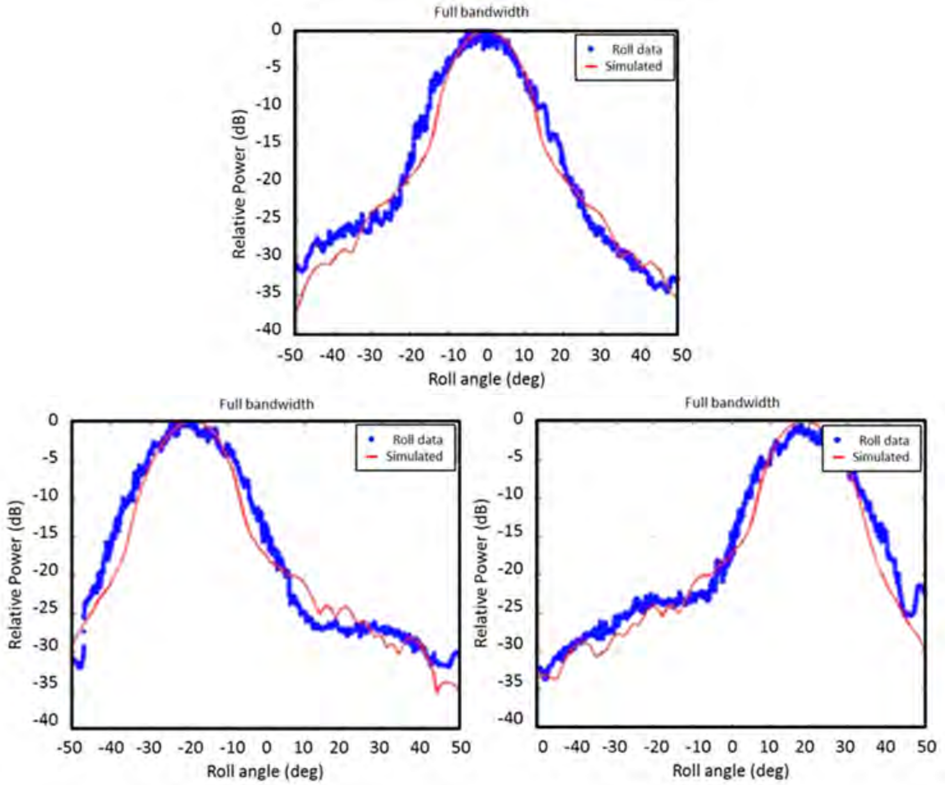


Figure 31: Simulated and measured transmit radiation patterns for three beam data collection mode using true time delays for beam steering of -20 deg, 0 deg, and +20 deg. These are the broadband (200-450 MHz) beam patterns using 35 dB Chebyshev window weighting on transmit.

We also performed measurements with time-multiplexed beams to demonstrate wide-swath imaging with our ultra-wideband radar. The sensitivity of any radar is directly proportional to the power-aperture product.The radar transmit power must be increased to illuminate a large swath with a small aperture (large beamwidth) antenna. This is difficult to accomplish with limited resources. We can use multiple beams generated from a large aperture to illuminate a wide swath. We designed and simulated multi-beam configuration and collected data to verify beam patterns as shown in the Figure 31. The multi-beam data collected with the wideband radar will be a part of the dissertation of Ms. Theresa Stumpf.

Snow and Ku-band Radars

In addition, we collected data with ultra-wideband microwave radars operating over the frequency range of 2-8 GHz and 12-18 GHz. The 2-8 GHz radar is referred to as the snow radar and 12-18 GHz radar as the Ku-band altimeter. Figures 32-34 show sample results from these radars over the Siple dome and Whillans ice stream. The results show that snow radar can map internal layers to a depth of about 45 m over areas with smooth surface and low-loss firn/ice. In areas with rough surfaces weak returns from internal layers are generally masked by off-vertical returns as shown in Figure 35. Only two layers located at about 10 m and 12 m below the surface are visible because these returns from a layers with strong dielectric contrast. The Ku-band altimeter returns are dominated by the surface, a few layers near the surface and volume scatter from firn. We will be using these data to estimate snow accumulation and interpret data from satellite altimeters such as Cryosat-II during the next and final reporting period.

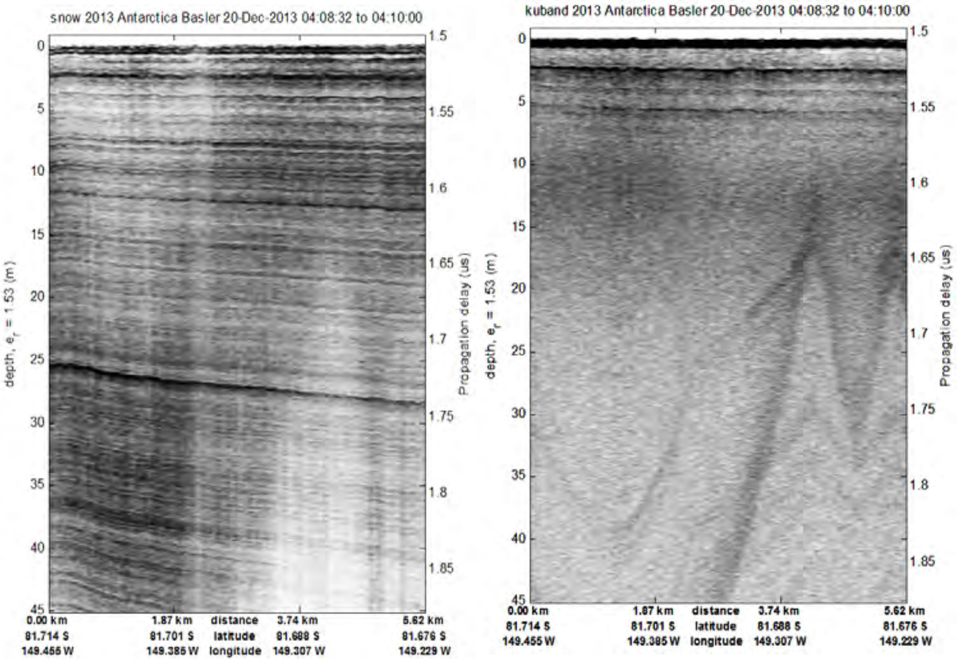


Figure 32: Snow radar and Ku-band radar images taken near Siple Dome.

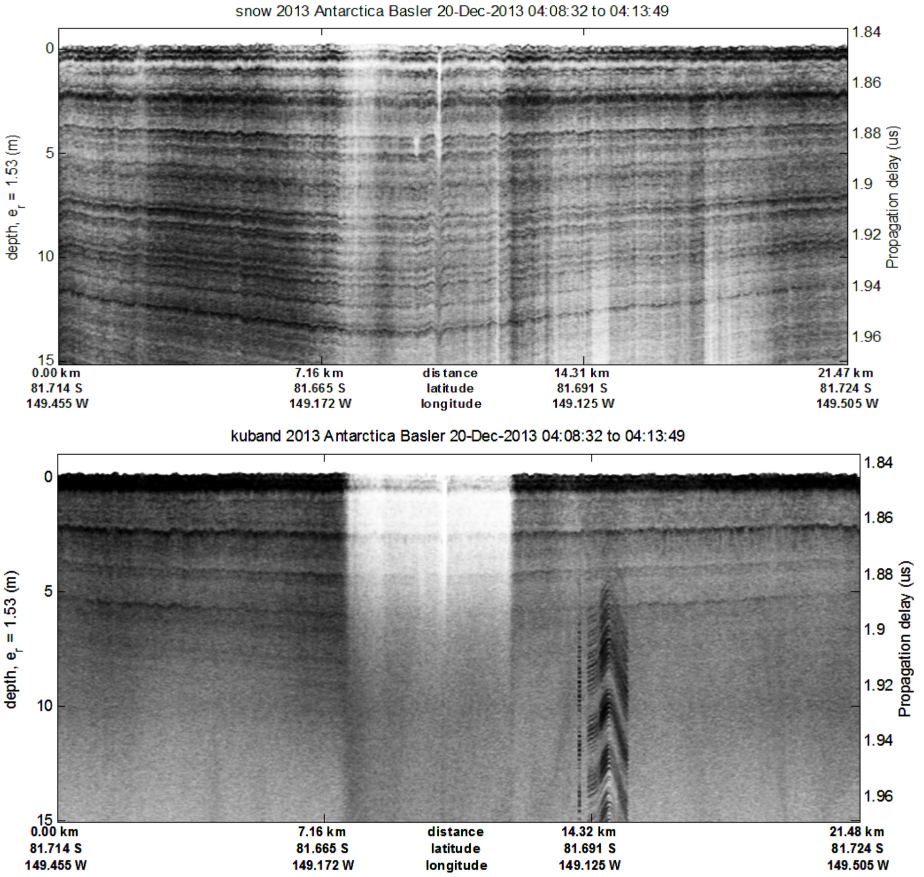


Figure 33: Snow radar and Ku-band radar images from Siple Dome. Ku-band radar signal power fades during the aircraft turn in the center of the image.

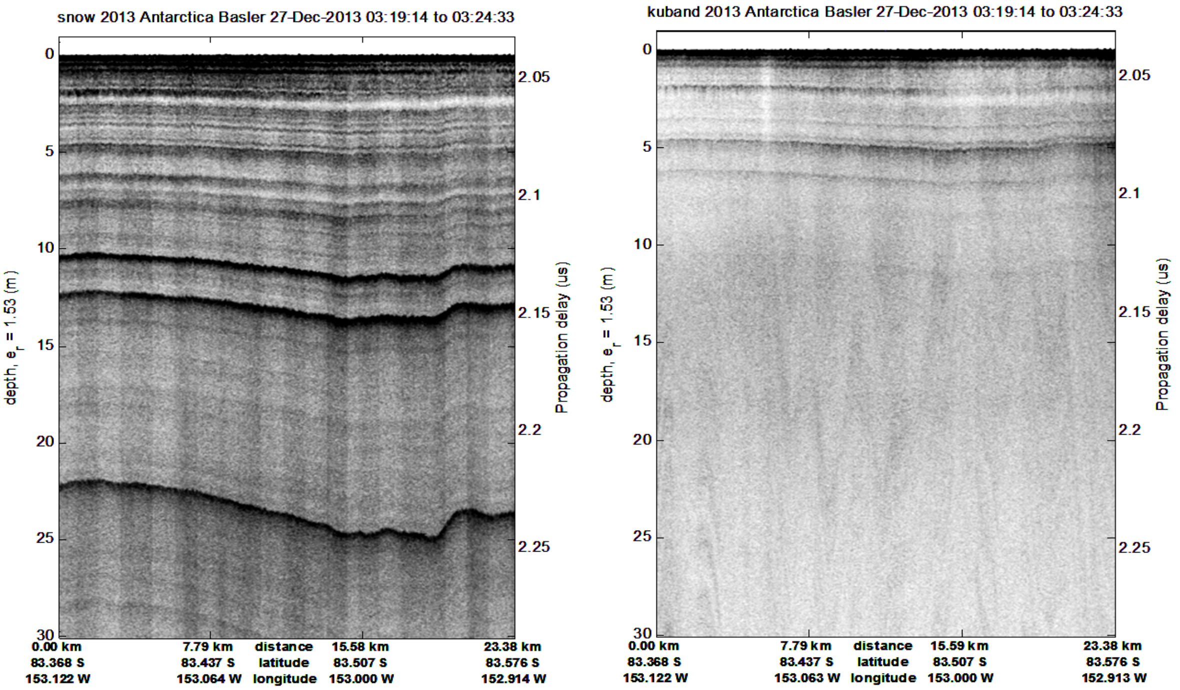


Figure 34: Snow radar and Ku-band radar images from the dome between Whillans and Kamb Ice Streams.

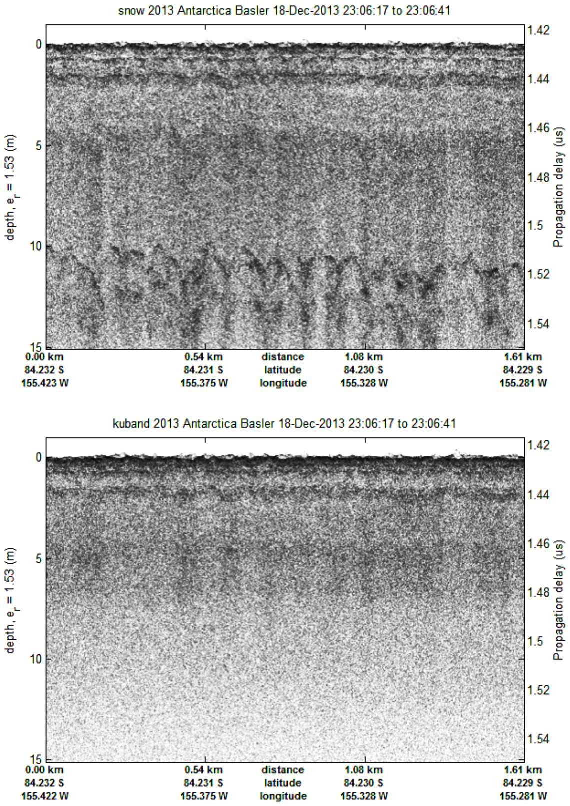


Figure 35: Interesting feature in Snow radar data collected on Whillans Ice Stream. The feature is not visible in the Ku-band radar data.

Google Camera System

A camera system, borrowed from Google, was installed and operated during seven of the twelve Basler missions. Four days were lost due to initial software issues and one day was lost due to cloud cover. The specifications for the camera and a picture of the installation are shown in Figure 36. The frames are GPS time tagged and an IMU and GPS receiver is used to provide precise attitude and trajectory information. Google is processing the data to geocode the images and to apply photogrammetric processing if possible. Figure 37 shows an image of the camp from 800 ft with a magnified inset to show the detail and quality of focus. The second image is from 6000 ft and shows that snow texture is still captured. During the 7 missions, 3.4 TB of data were collected in total.

Camera	Nikon D800E
Mount Angle	0 deg roll 4 deg pitch
Lens	Zeiss Distagon 2.0/35ZF-I 35 mm
Pixels	7360 pixels cross-track 4912 pixels along-track
Data format	Compressed 12 bit raw
Field of view cross-track	54.4 deg 822 ft at 800 ft AGL 6167 ft at 6000 ft AGL
Field of view along-track	37.8 deg 547 ft at 800 ft AGL 4108 ft at 6000 ft AGL
Frame Rate	0.5 Hz at 6000 ft AGL 1 Hz at 800 ft AGL

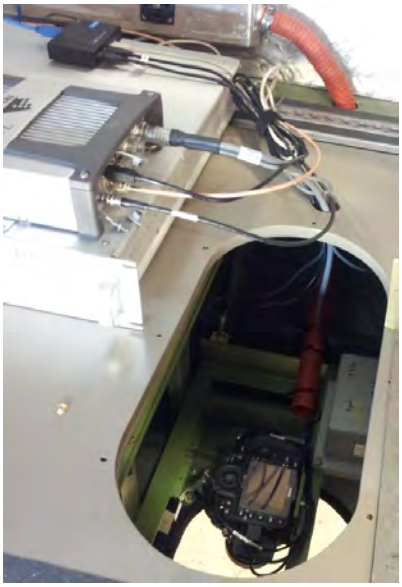


Figure 36: Camera and frame specifications and picture of installation.

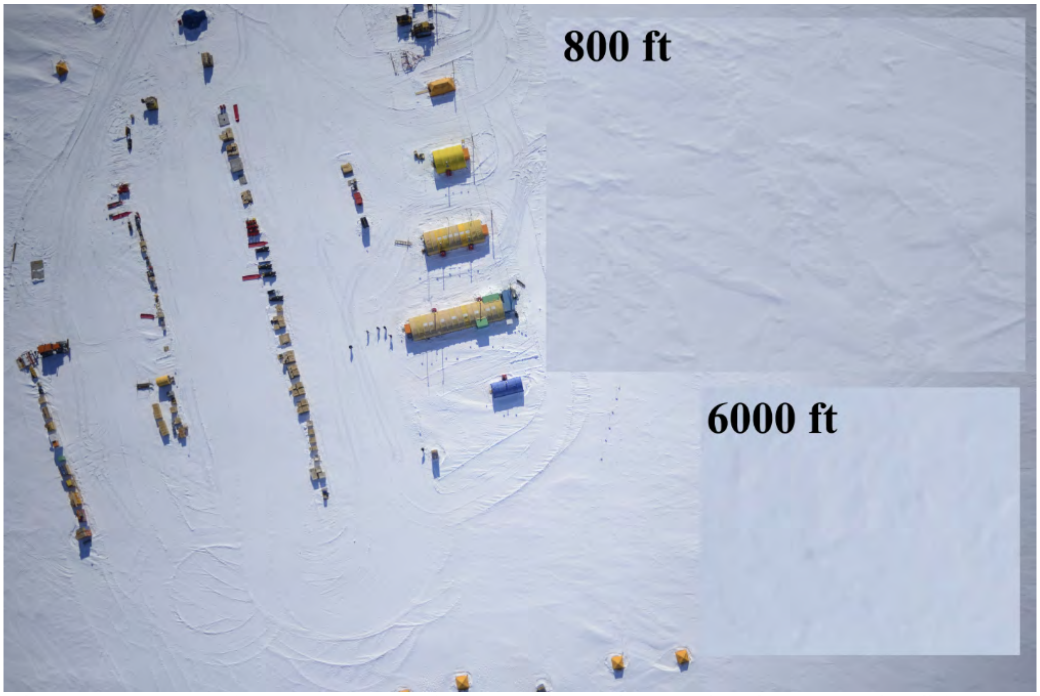


Figure 37: Image of camp from 800 ft AGL with two insets showing snow detail from 800 ft and 6000 ft. Snow features are very crisp in 800 ft imagery and appear blurred, but still visible, in 6000 ft imagery.

Ground Based Accumulation Radar

The PSU team operated a CReSIS developed 600-900 MHz radar, referred to as the accumulation radar, for surface-based measurements. Data were collected with an element for 6-element antenna array so 3-D image processing techniques can be applied to generate bottom topography of ice streams and also develop and test techniques for estimating bottom melt rates of ice shelves.

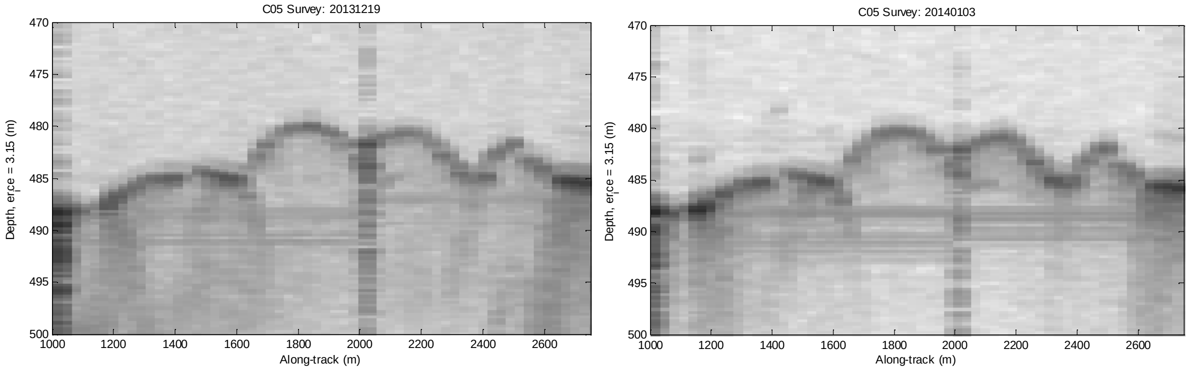


Figure 38: SAR processed images of the ice bottom from two different days for the C05 accumulation radar ground survey on the Ross Ice Shelf in front of the Kamb Ice Stream. The six receive channels were focused at nadir during processing. These images have not been registered, but the structure in the two images clearly shows high correlation.

Thrust Area	UAVs
Lead(s)	Dr. Rick Hale (KU), Dr. Shahriar Keshmiri (KU), Dr. Mark Ewing, (KU)
Core Participants	Yan, Leuschen, Rodriguez-Morales, Paden, Gogineni and Braaten (KU);

The main focus of this thrust area is to develop UAVs integrated with radars for polar research. The primary tasks addressed during the reporting period are to develop a small UAS integrated with a light weight and compact low-frequency radar to fly over closely spaced grid lines to synthesize a large 2-D aperture for sounding and imaging of fast-flowing glaciers, and to improve control and command systems for more precise positional control of those sensor-equipped platforms. We recently completed several successful test flights of the UAS equipped with the dual-frequency radar at a field camp in Antarctica. The radar measurements performed as a part of these test flights represent the first-ever successful sounding of glacial ice with a UAS-based radar.

G1X Platform

We designed and developed the Meridian UAS to accommodate an 8-element VHF antenna array for sounding of ice sheets. We have been using commercial off-the-shelf (COTS) scaled aircraft models as test vehicles for CReSIS UAS avionics and flight control systems since 2007. We have been using a 40% Yak-54 aircraft as a test vehicle for Meridian UAS for training of the CReSIS UAV Flight Test crew. The 40% Yak allowed integration, tests and evaluation of the Meridian UAS avionics systems. We explored whether or not a low-frequency radar sounder can be operated on the small UAS such as a 40% YAK starting in 2011. The miniaturization of the radar and close collaboration between the sensor and platform teams have contributed to the development of a modified fiberglass aircraft to serve as a science-payload carrying platform for CReSIS, named the G1X UAS. It is a mid-wing, semi-autonomous, high aspect ratio aircraft developed by CReSIS starting with a 40% YAK fuselage to operate a compact low-frequency radar sounder that operates at about 14 and 35 MHz as well as test UAS command, control and navigation systems.

The G1X is piloted by the Supplemental Pilot on takeoff, landing and in the vicinity of the runway in the “third person” or “external” pilot mode using a line-of-sight R/C link. Optionally, the G1X is commanded by the Pilot Operator using the WePilot 2000 autopilot through the implementation of GPS-based state estimations. This is the identical system originally developed for the larger Meridian UAS. The airborne WePilot communicates with the WePilot Ground Station via a telemetry transceiver and an Iridium satellite link. On uplink, the WePilot Ground Station operator has the capability of selecting the autopilot mode of operation, to kill the engine and to upload a new set of GPS waypoints, speed and altitudes. The Automatic Flight System (AFS) includes an on-board health-monitoring unit which communicates with the AFS Ground Station via a telemetry transceiver and an Iridium satellite link. On uplink, the AFS Ground Station operator only has the capability to control the payload and to select the autopilot “home” mode of operation.

The aircraft is configured with high-aspect-ratio extended wings with the dimensions listed in Table 1. The integration of HF/VHF antennas for operating the radar on a small UAS drove aircraft design requirements. The antenna’s physical length demanded a relatively high-aspect- ratio and wing span. The required extension of wing sets, to meet the radar-antenna requirements, was done in the absence of any changes to the aircraft’s empennage. Tables 2-4 show modal analyses of the G1X at different weights and different center of gravity (c.g.) positions. As it is shown the G1X had Level I handling quality in all important categories however the Phugoid mode was found to be Level II in low speed (30 knots) and the spiral mode was found to be Level III (Poor Quality) in the aircraft flight envelope. That meant landing in cross wind would be very challenging for the pilot.

Table 1: G1X Geometry/Dimension/Performance Parameters

PARAMETER	VALUE	UNITS
Dimensions/Geometry		
Length	9.33	Feet
Height	3.67	Feet
Wing		
Area	22.28	Feet2
Span	17.36	Feet
Aspect Ratio	11.75	Feet
Taper Ratio	0.3	
Sweep (c/4)	1.5	Degree
Airfoil	NACA 0012	
t/c	12	Percent
Dihedral	0	Degree
Horizontal Tail		
Area	4.11	Feet2
Span	3.92	Feet
Aspect Ratio	3.73	Feet
Taper Ratio	0.75	
Sweep (c/4)	8.4	Degree
Airfoil	NACA 0012	
t/c	12	
Dihedral	0	Degree
Vertical Tail		
Area	2.49	Feet2

Span	2.05	Feet
Aspect Ratio	1.69	Feet
Taper Ratio	0.51	
Sweep (c/4)	7.6	Degree
Airfoil	NACA 0012	
t/c	12	
Dihedral	0	Degree
Weights		
Fuel	6	Lb
Payload	10	Lb
Empty	64	Lb
Takeoff	80	Lb
Performance		
Stall Speed (baseline)	25	Knot
Cruise Speed	55	Knot
L/DCR	15.9	
Range	120	Nautical Mile
Endurance	1.5	Hour
Takeoff/Landing Distance	300	Feet (sized)
Power Plant		
Engine	Desert Aircraft 100cc	
Max Power	9.8	Horsepower

Level II and Unstable or Level III

Table 2: No Fuel, Light Radar – 83.4lbs, CG @ 2.94' aft of tip of spinner

Mode\Airspeed	30kts	50kts	70kts
Roll (T_R)	0.040 s	0.023 s	0.027 s
Spiral (T_D)	3.21 s	14.24 s	39.8 s
Dutch Roll (ω_n, ζ)	3.137 rad/s, 0.556	4.592 rad/s, 0.295	6.176 rad/s, 0.259
Short Period (ω_n, ζ)	4.011 rad/s, 0.814	6.448 rad/s, 0.826	8.942 rad/s, 0.820
Phugoid (ω_n, ζ)	0.604 rad/s, 0.027	0.376 rad/s, 0.062	0.273 rad/s, 0.109

Level II and Unstable or Level III

Table 3: Full Fuel, Light Radar – 88.3lbs, CG @ 2.90' aft of tip of spinner

Mode\Airspeed	30kts	50kts	70kts
Roll (T_R)	0.041 s	0.023 s	0.027 s
Spiral (T_{2S})	3 s	13.29 s	37.04 s
Dutch Roll (ω_n, ζ)	3.1418 rad/s, 0.594	4.655 rad/s, 0.301	6.226 rad/s, 0.260
Short Period (ω_n, ζ)	4.1696 rad/s, 0.773	6.678 rad/s, 0.784	9.335 rad/s, 0.774
Phugoid (ω_n, ζ)	0.6365 rad/s, 0.011	0.387 rad/s, 0.05	0.2895 rad/s, 0.095

Level II and Unstable or Level III

Table 4: Full Fuel, Heavy Radar – 91.3lbs, CG @ 2.86' aft of tip of spinner

Mode\Airspeed	30kts	50kts	70kts
Roll (T_R)	0.041 s	0.023 s	0.027 s
Spiral (T_D)	2.87 s	-12.71 s	35.36 s
Dutch Roll (ω_n, ζ)	3.15 rad/s, 0.621	4.7095 rad/s, 0.306	6.276 rad/s, 0.261
Short Period (ω_n, ζ)	4.341 rad/s, 0.74	6.9417 rad/s, 0.750	9.746 rad/s, 0.738
Phugoid (ω_n, ζ)	0.660 rad/s, 0.00	0.4128 rad/s, 0.043	0.3011 rad/s, 0.087

Table 5: Lateral-Directional Modal Analysis @ 65 knots

Mode	**Eigenvalue**	**Damping**	**Frequency (rad/sec)**
Dutch-Roll	-4.473-001±3.94e+000i	1.13E-01	3.97
Spiral	-2.28E-07	1.00E+00	0

To mitigate the undesirable control aspects induced by the longer wing, two winglets were designed, manufactured and installedd as shown in Figure 39. The physics-based model, pilot rating, and system identification analysis all show that the G1X UAS now satisfies every Level I handling quality requirement. The post flight test dynamic analysis shows that the solution worked and the aircraft had Level I Dutch-Roll and spiral modes characteristics (Table 5). Figure 40 shows system identification results using the G1X flight test data. As shown in Figure 41, the validation process of the developed dynamic model with an independent portion of flight test showed 94.69% accuracy.

The G1X aircraft can be configured with either wheels or skis. For all flights during this field season the ski configuration was chosen. This is the first time we have ski-equipped one of the smaller UAS platforms. We found that these skis performed well both on the ground and in the air (Figure 39). We verified the takeoff and landing performance at 90 m or less. The skis were designed, fabricated, aerodynamically characterized and integrated with the vehicle during this reporting period. In addition, new high-capacity landing gears were designed, fabricated, structurally characterized and integrated with the aircraft in this reporting period. The new gear was required to accommodate the larger landing loads for the heavier aircraft equipped with all sensors and avionics, as well as the increased loading by skis. There is no anti-ice/deice capability with this initial prototype, except for the heated pitot tube, and consequently the vehicle is not operated in icing conditions. The heated pitot tube is also new, however, and was specified and integrated with the airframe in this reporting period. This probe is evident in the top of

Figure 39: G1X UAS on approach to land at SLW site in Antarctica.

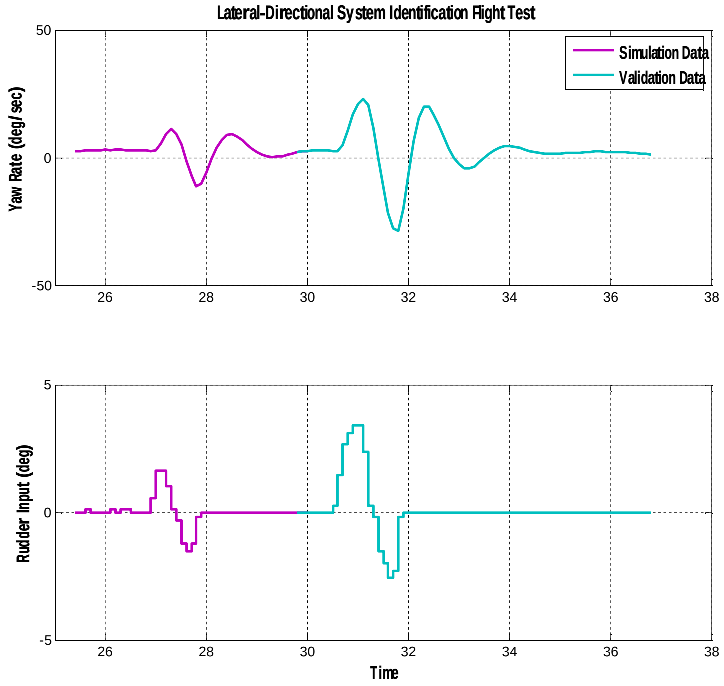


Figure 40: G1X Lateral Directional Performance Meets Design.

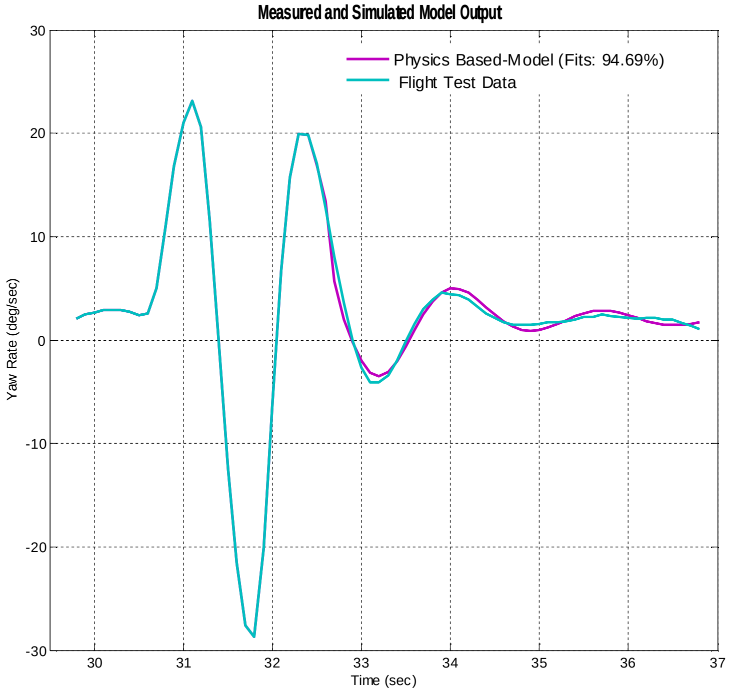


Figure 41: G1X Dynamic Model is 94.69% Accurate in System ID Flights.

Figure 39, protruding from the canopy. This fuselage mount was necessary to remove the associated cabling from the wings, as these interfered with the antenna patterns. To minimize vibration, the pitot tube is mounted with two dielectric structural frames bridging the base as well as arching across the canopy. The probe performed well in the field after the initial calibration flights, and we experienced no icing of this probe during the Antarctic campaign. The heating elements did not adversely affect antenna performance.

All fuel is contained in a central fuel cell in the center fuselage (no wing fuel cells). The aircraft operates on a 50:1 two-stroke mixture, with the fuel being high-quality unleaded gasoline and the oil being high performance synthetic oil. Wings are detachable to facilitate shipment, movement into/out of the UAS hangar, and for flexibility in wing-mounted science payload. In this field season, the wings were removed each day to enable outdoor wing storage, using the original shipping containers.

Initial G1X ground tests were completed at the University of Kansas, Lawrence Municipal Airport between June and August 2013. Tests were performed to ensure all flight critical systems were functioning properly. The systems tested included mechanical systems, electrical systems, flight control systems, communications, accessory subsystems and avionics. Additional tests to check for electromagnetic interference were also completed. Ground handling quality tests were completed in low speed tests, up to 15 knots, and at high speeds, from 20-30 knots.

First flight of the G1X was performed at Fort Riley, KS in August of 2013. This flight was fully manual with the pilot in the loop and was used to assess aircraft stability and handling qualities. Subsequent flight tests were completed testing the communications, control transition between manual and autonomous flight, and radar antenna performance and functionality.

G1X Avionics Development and Integration

When the airframe for the glass 40% Yak-54 UAS was originally received, it did not have any stock components for integration of radar system, avionics, and other subsystems. Many shelves and internal supporting structures were designed and integrated in the fuselage. Additional fuel capacity was added to extend the flight time using a custom made fuel tank, though this larger fuel tank further complicated avionics placement. One of the largest challenges faced in the development of G1X was the interference d between the onboard radar system and the aircraft's electrical systems (EMI issues). Each component had to be positioned in such a way that they would not significantly affect antenna performance. In addition, components also had to be appropriately distributed throughout the aircraft i to maintain the appropriate weight and balance for safe flight. To keep the aircraft's static margin in the desired range, many components had to be positioned in such a way that they are easily accessible for retrieving data and at the same time keep the aircraft center of gravity in an acceptable position. These competing tasks were accomplished using solid modeling software to position components virtually inside the fuselage, while simultaneously considering aircraft and sensor performance, and designing custom support structure to mount the items in the aircraft. Considerable effort and time went into mitigating this issue in this reporting period. Multiple wiring iterations were manufactured and subsequently tested in the KU-CReSIS Anechoic Chamber to find a suitable solution to the EMI problem. The final solution involved a combination of wire shielding, modification of placement plan, and increasing wire lengths. Finally, the original airframe for the G1X was designed to be a strictly radio controlled aircraft. To turn this aircraft into an autonomous UAS, other modifications such as the PWM calibration of servos had to be made.

Power Distribution

The aircraft was outfitted with a more fuel efficient engine than originally specified for the airframe to increase the range and reduce the fuel consumption ratio. System power is provided by the on-board 26 Volt battery and a 28 Volt alternator driven by that new engine. The alternator is a new development, and generates a significant Radio Frequency Interference (RFI) that degrades radar performance. . Whileground tests addressing this were performed and we could not find a solution to reduce RFI for 2013-2014 deployment. , We operated systems with 12-V backup power system. Also the engine ignition system is powered by a separate 4.8V NiCd battery and did not receive power via the alternator. The engine cavity is shielded using a copper lining and an aluminum ground plane within the cowling.

WePilot 2000

A commercial, off-the-shelf autopilot system, the wePilot 2000, is used for assisted and autonomous operation. As previously mentioned, this autopilot is identical to that flown on the larger Meridian UAS, so the only development for this reporting period was the specific control software for this G1X platform. The autopilot assumes control of the UAS upon command from the WePilot Ground Station, either line of sight or over the horizon. After takeoff, the autopilot can maintain control during routine operations, requiring intervention only for landing or as an exception. Real-time modifications to the UAS flight path when under wePilot control are possible through the Ground Station, should they become necessary.

WePilot missions are defined by a series of waypoints which are referenced from the “start” waypoint, which is simply a position in space, and is usually near the pilot’s location during flight. The three types of waypoints used for mission planning are “cruise”, “circle”, and “home”. Cruise waypoints are defined by a position in space and an airspeed, while “circle” and “home” waypoints are defined by a position in space, airspeed, as well as a circle radius and direction. The wePilot system has been ground and flight tested on the G1X UAS in both line of sight and over the horizon conditions. Every function available on the wePilot, including emergency functions, has been tested and verified in the G1X UAS in this reporting period.

Automatic Flight System (AFS)

The KU Automatic Flight System (AFS) is primarily a real-time health monitoring system including an on-board unit and a Ground Station. The AFS Ground Station provides beyond line-of-sight and over-the horizon situational awareness required for monitoring and/or altering the progress of the mission. From the AFS Ground Station, the operator can monitor UAS position and attitude plus the health of the UAS. On-board, the AFS receives commanded control deflections, GPS position, angular rates, and attitude information from the NAV 420 IMU/GPS/EKF, plus monitors selected power buses within the avionics package. Primary developments for this reporting period are to enable variants of the AFS which for future use will enable a more robust nonlinear predictive model controller integration for future missions involving simultaneous flights of multiple platforms. The theoretical development of this was addressed in the last annual report, and this year activities were predominantly in hardware development and integration. Flight testing of the new AFS system will occur in the next reporting period.

Automated Flight Follower

The G1X aircraft is equipped with a Guardian 3 Iridium flight following system which transmits in the 1616 to 1626.5 MHz band. This is the first time we have flown such equipment in one of our small UASs, although we have previously flown it on the Meridian UAS. This GPS-based system transmits position, altitude, bearing, and speed every two minutes, in compliance with USDA AFF requirements. The information is transmitted to USDA-AFF to enable continuous tracking of the aircraft. This system was shown to be effective in the field, allowing ATC as well as other air operators to maintain knowledge of G1X position at all times, thus helping to ensure separation of manned and unmanned aircraft.

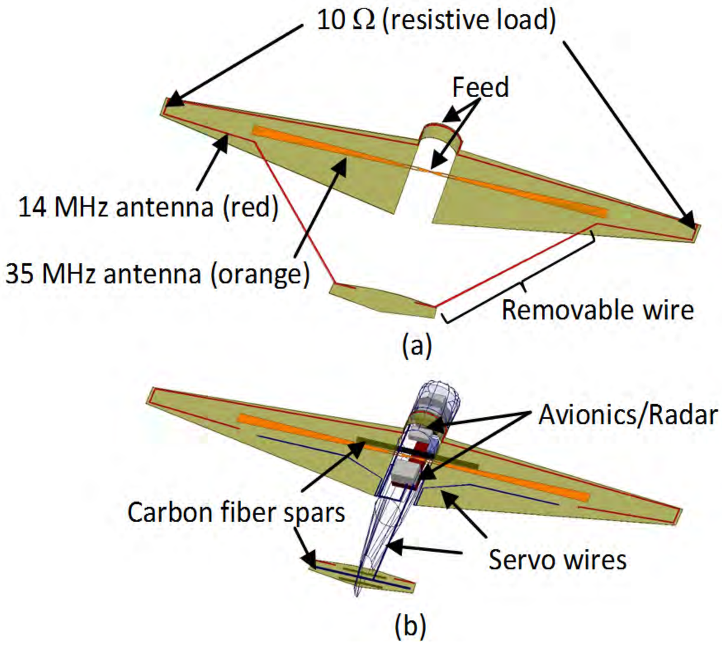


Figure 42: HF/VHF radar antennas implemented on the G1X platform (a) before system integration and (b) after system integration.

G1X Antenna Structures

The G1X carries two separate antennas integrated onto its wings and airframe, as shown in Figure 42. The 14 MHz structure is a resistively-loaded dipole implemented with copper tape and removable wires that run around the perimeter of the airframe. The 35-MHz antenna is a tapered planar dipole implemented with copper tape. While additional details of the antenna and radar systems are provided in the sensor section, we note here that the antennas are integrated into the structure. As such, considerable time and effort were invested in this reporting period in iterating on the specific antenna shapes and patterns as the performance changed with vehicle integration. The simulated return loss before integration was obtained using a High Frequency Structure Simulator (HFSS) from ANSYS, and these simulations were compared with experiments performed in our anechoic chamber (and then again later in the Antarctic field trials). The close proximity of the servo wires and other conductive objects resulted in frequency shifts and bandwidth limits which needed to be compensated in design. In addition, numerous iterations on the aircraft system cabling routing as well as shielding concepts were performed in an effort to reduce noise for the radiated patterns.

Field Test Planning and Air Space Coordination

We interacted with various federal agency representatives to comment on drafts of the emerging US Antarctic Inter-agency Air Operations Manual (AOM) and the emerging United States Antarctic Program (USAP) guidelines to define operations of unmanned aircraft. Our detailed Concept of Operation document for the G1X UAS has been developed in accordance with these emerging guidelines and demonstrates significant steps towards compliance with Chapter 4 of the US Antarctic Inter-agency Air Operations Manual (AOM).

IAW established USAP AOM separation guidelines between manned and unmanned flights were coordinated between the National Science Foundation (NSF), Lockheed-Martin Polar Services Corporation (LMPSC), Space and Naval Warfare Systems Command (SPAWAR), other manned aircraft operators (109th ANG, PHI, KBAL, etc.) and other research teams. In the field, the CReSIS team scheduled missions to de-conflict with manned fixed and rotary wing flights to the maximum extent possible, coordinated with the Fixed Wing Coordinator 24 hours prior to any UAS mission, monitored air to ground communications for the duration of all missions, coordinated with air traffic control (ATC) for special use airspace and special use airspace NOTAMs, establish and published lost communication and lost data link procedures, and developed emergency recovery procedures for: a) loss of aircraft control, b) aircraft crash on runway c) aircraft crash near runway and d) aircraft crash beyond line of sight. This resulted in seamless integration of manned and unmanned aircraft at the SLW field camp.

We have drafted applications for a Certificate of Authorization (COA) to operate both the autopilot-equipped 33% Yak and the autopilot-equipped 40% Yak outside of restricted airspace, namely in a somewhat remote tract of land owned by the University of Kansas. The COA application for the former is approved, enabling our team for the first time to legally operate our smaller UASs in the national airspace.

UAS Field Tests

Test flights and data collection with the radar-equipped UAS, including airborne and surface-based measurements, were carried out as a part of ongoing research at CReSIS during the 2013-2014 field season. In terms of the UAS mission, we have repeated the initial flight test in the field to ensure all flight-critical systems were functioning properly in local conditions. Phase I field testing began with line-of-sight flight tests and included additional flight tests to assess and verify communications, control the transition between manual and autonomous flight, and assess and verify radar antenna performance and functionality. Phase II flight tests were autonomous, included over-the-horizon flight functionality, and focused on improving ground track accuracy of the aircraft flight path and enhancing the performance of both the HF and VHF sounders. The G1X UAS was flown 14 times at the SLW field camp. In all flights, the aircraft was instrumented with the dual-frequency HF/VHF radar. Seven of those flights were autonomous, including an over-the-horizon flight. The radar measurements performed as a part of these test flights represent the first-ever successful sounding of glacial ice with a UAS-based radar. The post flight test dynamic analysis shows that the G1X aircraft satisfies every Level I handling quality requirement. Additional details of the field program are summarized in the Field Program section of this report, and additional details of the science mission outcomes are summarized in the Sensors section of this report.

Flight Test Results

Post flight test analysis of the original 33% Yak-54 trainer showed that in some portions of flight the autopilot's Extended Kalman Filter (EKF) had large errors in estimation of some parameters such as the pitch and roll attitude angles and forward and vertical accelerations in the body coordinate system. Although such errors did not have a major effect on the aircraft overall stability they could reduce the ground tracking accuracy of aircraft and consequently would affect the radar performance. There were two main hypotheses explaining such errors: (1) Nonlinearities in aerodynamic parameters due to external disturbances such as cross- wind and (2) Large modeling errors in the aircraft physics based model and non-Gaussian propagation through the system dynamics. After rigorous analysis performed in this reporting period, it was concluded a combination of errors in the Physics Based model of the UAS and axisymmetric vibration of the autopilot box were the main source of errors. The axisymmetric vibration of box added a high level of unmolded noise to the EKF and could cause divergence in estimations. To avoid such issues in the G1X UAS autopilot, the goal was set to improve the physics based model through the following steps:

1. A high fidelity CAD model of the G1X was developed and exported to the Advanced Aircraft Analysis (AAA) software to avoid any source of error which might result from the high sensitivity AAA has to the geometry input data.
2. The AAA results were checked with other approximation methods to verify the quality of stability and control derivatives.
3. A 2nd order thrust model was used for modeling the G1X engine model.
4. 3DoF vibration isolators were utilized for the G1X autopilot box.

The EKF operates using a propagation of a Gaussian random variable through the aircraft dynamics. In the EKF, the state distribution is approximated using Gaussian distribution assumptions, which is then propagated analytically through the first-order linearization of the aircraft nonlinear aerodynamics. In instances of large and fast nonlinearities in the aircraft dynamic model such assumptions can introduce large errors in the true posterior mean and covariance of the transformed Gaussian random variable, which may lead to sub-optimal estimation and poor performance and sometimes divergence of the filter. To validate our hypothesis, an unscented Kalman filter (UKF) for nonlinear estimation was designed. The state distribution in UKF is also approximated by a Gaussian distribution, however it is represented using a minimal set of sample points. These sample points (sliding window) completely capture the true mean and covariance of the Gaussian distribution, and when propagated through the aircraft nonlinear model, capture the posterior mean and covariance accurately to the 3rd order (Taylor series expansion) for any nonlinearity. If the improvement of the physics based model was insufficient to improve the EKF estimations then major differences would be evident between EKF and UKF.

Figures 43-44 show the comparison between the G1X's autopilot EKF and UKF estimations. As shown, a more accurate physics based model of the aircraft and utilization of 3DoF vibration isolators improved the overall performance of the G1X EKF and there is no divergence in the attitude or acceleration results. Analyses using the line of site and over the horizon flight test data demonstrated that the nonlinear UKF and EKF results agree in all portions of flight with the exception of very tight turns in the presence of high cross-wind. Such aggressive flight maneuvers will only be performed when transitioning between radar target flight lines (eg during tight turns to enable closely spaced flight lines), and as such the deviation will not be a concern for radar performance during these maneuvers, since recovery is quick. The differences in the EKF and UKF estimations of attitude or acceleration are not significant considering the latencies are very short. Such small mismatches will not degrade the UAS ground tracking performance required by the radar system. The comparison of EKF/UFK in the over the horizon flight demonstrates even better performance by the autopilot; it can be concluded that the G1X can reliably perform medium range Earth and Science missions with reliable performance.

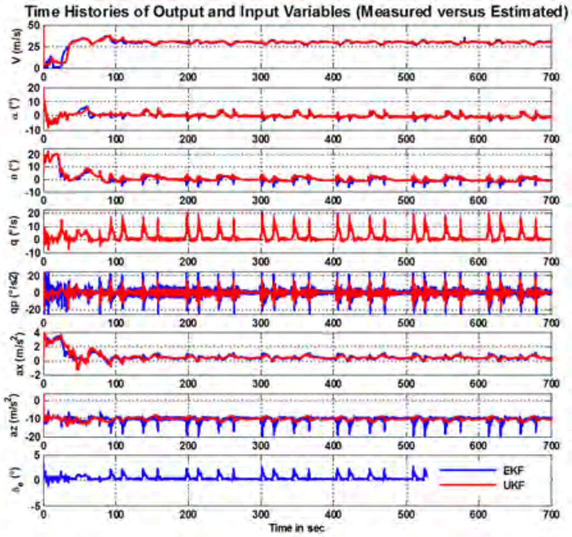


Figure 43: Comparison of EKF and UKF (G1X Line of Sight Flight Test).

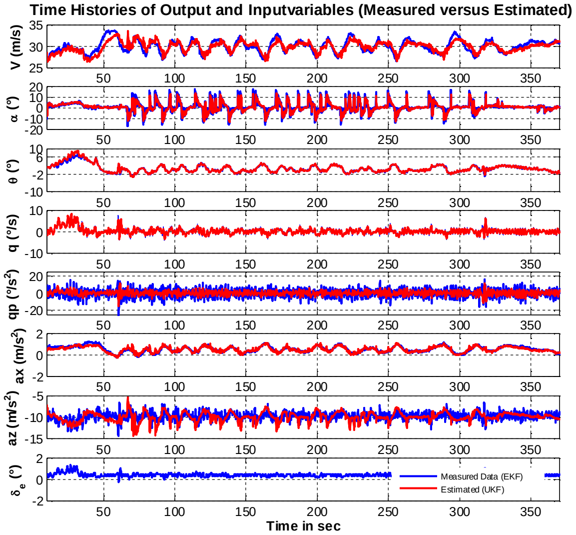


Figure 44: Comparison of EKF and UKF (G1X Over the Horizon Flight Test).

Thrust Area	Field Activities
Lead(s)	Ms. Judith Riley (KU), Dr. Rick Hale, Dr. Carl Leuschen
Core Participants	All Center Members from University of Kansas, Indiana University, and Pennsylvania State University

During the second phase of the CReSIS award, we are conducting field activities in Greenland and Antarctica to accomplish the following objectives:

1. To collect focused data sets in areas of current or expected significant glacier change; and
2. To test and optimize sensors and platforms at established field stations.

We solicited input from the modeling community through a CReSIS-sponsored meeting during the 2010 AGU meeting in San Francisco and took this input into consideration to plan our field activities. Then in September 2013, CReSIS hosted the International Glaciological Society (IGS) Symposium on Radioglaciology to allow polar researchers from various scientific disciplines to interact with sensor and platform technology representatives and to prioritize the key scientific questions that would drive Antarctic manned and unmanned airborne remote sensing missions. We are also coordinating our field activities with the NASA OIB program to collect data sets that complement and supplement the large volume of data being collected through OIB-sponsored field programs. Our airborne surveys are aimed at measuring surface elevation and ice thickness, imaging the ice-bed interface, and mapping deep and near-surface internal layers. Our field programs are supplemented by satellite measurements that provide ice surface velocity. Our *in situ* measurements are targeted at collecting information on subglacial sediment structure and water content from seismics, as well as information on fine-resolution spatial and temporal variations in accumulation rate with surface-based ultra-wideband accumulation radar.

The main CReSIS field program during this reporting period are airborne and surface-based measurements over ice streams on Siple Dome, and flight tests of a small UAS equipped with a low-frequency radar sounder. Our additional field activities for Spring/Summer 2013 included participating in two NASA-funded missions and loaning CReSIS radar systems for collaborative research. In Fall/Winter 2013-2014, our field activities included participating in an airborne NASA OIB mission to Antarctica and in three NSF-funded Antarctic missions involving manned aircraft, unmanned aerial systems, and surface-based systems. In Spring 2014, our field activities included participating in an airborne NASA OIB mission to Greenland and loaning CReSIS radar systems for collaborative research. For completeness all our field activities for last year are discussed below.

Antarctica, Winter 2013-2014: Airborne Radar Survey Project with Manned Basler Aircraft (NSF I-189-M)

From November 29, 2013 to January 18, 2014, five CReSIS personnel [Carl Leuschen (KU), John Paden (KU), Stephen Yan (KU), Zongbo Wang (KU), and Aaron Wells (IU)] participated in an airborne radar survey project (event/project number I-189-M) using an instrumented Basler aircraft over the Siple Coast of Antarctica. The major objective of the field program was to collect fine-resolution radar data with our ultra-wideband (UWB) UHF/VHF radar depth sounder in conjunction with data from our ultra-wideband microwave radars [Ku-band Altimeter (12-18 GHz) and Snow Radar (2-8 GHz)] over the Whillans (B) (highest priority), Kamb (C), and Bindschadler (D) Ice Streams on the Siple Coast of West Antarctica. These data will be used to generate fine-resolution maps of bedrock topography and internal-ice stratigraphy (layers), which will lead to a more realistic estimate of the hydropotential field at the base of the ice sheet and a better understanding of the subglacial hydrology.

In the past we operated our radar systems on a Twin Otter aircraft (“CKB” from Kenn Borek Air, Ltd.) with wings that had been specially modified with hardpoints to mount folded-dipole antennas. However, after learning that the Twin Otter wings had essentially reached their maximum wing life (flying hours) and could no longer be used, we requested to use a Basler aircraft instead. We were approved to use Kenn Borek’s “MKB” Basler; however, modifications to the aircraft were required to allow for the use of the full CReSIS sensor suite. Hardpoints (same as on the “JKB” Basler) were added to the fuselage to allow for the installation of a newly developed center antenna array for the UWB VHF/UHF Radar. In addition, 2 nadir ports in the aft location were added to the MKB Basler to allow for the installation of the horn antennas for the Ku-band Altimeter and Snow Radar. Please refer to the Sensors and Signal Processing section for more information about the UWB VHF/UHF Radar and antenna array, and Ku-band/Snow Radar.

CReSIS' radar suite, antenna systems, and a digital camera (provided through a collaborative agreement with Google, Inc.) were shipped to Kenn Borek's facility in Calgary, and installed on the MKB Basler in September 2013. After conducting test flights, the equipment was removed, packed, and shipped to Port Hueneme for transport to Antarctica. When the Government Shutdown occurred in October 2013, it was uncertain which missions would be supportable with the reduced resources. We were excited and thankful when the NSF told us that the CReSIS Antarctic missions were allowed to deploy. The Government Shutdown caused a 3-week shift in the mission dates, but the length of survey time at the field camp (4 weeks) remained the same. We are very grateful to everyone at NSF, USAP, and ASC that worked so long and hard to make it possible for our teams to conduct research in Antarctica in 2013-2014.

Figure 45: Photo of MKB Basler in flight with CReSIS radar and antenna configuration. The fuselage-mounted antenna array for the UWB UHF/VHF Radar System can be seen mounted to the fuselage just aft of the wings. (Photo courtesy of Alec Bowman).

The field team departed the United States on November 29, arrived in Christchurch on December 1, and after 2 weather delays, flew to McMurdo on December 5. Beginning on December 11, the team installed the radar systems, antenna systems, and Google camera on the Basler in McMurdo and conducted 3 days of test flights from McMurdo Station, before departing for the field camp on December 18. The field camp was located near Subglacial Lake Whillans (SLW) on the Whillans (B) Ice Stream on the Siple Coast of West Antarctica. The team conducted survey flights for 4 weeks based from the field camp. Figure 45 shows the MKB Basler in flight with CReSIS' radar antenna systems. The team conducted survey flights on 12 days out of the 16 proposed flight days. They also collected data during the return transit flight from the field camp to McMurdo. They collected airborne radar survey data over Whillans (B), Kamb (C), and Bindschadler (D) Ice Streams, with the focus on Whillans. Figure 28 (see: *Signal Processing*) shows the survey flight lines flown during this field program. New flight lines crossed historical survey lines, thus improving the reliability of the historical data and expanding the effective survey area when both datasets are combined. In addition, data was collected over Operation IceBridge flight lines, ice-core drilling sites, and sites sounded by the surface-based Accumulation Radar that was being used

Figure 46: Photo of rac tent at field camp where the data storage/management system and servers (inside the orange cases) were set up and where the team processed data. Shown are John Paden (foreground) and Aaron Wells (background) working with data on their laptops. (Photo courtesy of Alec Bowman).

by the I-188-M team, so that internal layers mapped by the radars could be cross-correlated and validated.

The data were stored and archived after each flight by our IU field team member and processed by KU field personnel (see Figure 46). During the 12 survey flight days and 77.67 survey flight hours, the UWB UHF/VHF Radar collected 43.07 terabytes of data, and the Ku-band and Snow Radars each collected 2.16 terabytes of data. The Google camera collected 3.4 TB of fine-resolution imagery of the ice surface along the flight path during 7 flights.

Antarctica, Winter 2013-2014: Airborne Radar Survey Project with Unmanned Aerial System (UAS) (NSF I-185-M)

From December 1, 2013 to January 18, 2014, five CReSIS personnel [Rick Hale (KU), Shawn Keshmiri (KU), Alec Bowman (KU), T.J. Stastny (KU), and Nicholas Brown (KU)] participated in an airborne radar survey project (event/project number I-185-M) using an unmanned aerial system over the Siple Coast of Antarctica. The major objectives of the field program were to extensively flight test a small UAS, G1X, equipped with low—frequency radar sounder and to collect radar data to develop the concept 2-D aperture synthesis by flying the UAS along closed spaced lines in the cross-track direction.

The G1X UAS used in this field project was originally a 40%-scale Yak-54 model, which CReSIS modified to accommodate the avionics systems, a dual-frequency radar that operates at about 14 and 35 MHz, and radar antennas. The G1X UAS has a fiberglass frame, a 208-inch wingspan, 15-pound payload capacity, 1.5-hour cruise endurance, and 125 nautical mile range. The team also shipped a wooden frame UAS called “W1” as a backup UAS system. More information about the G1X UAS system is provided in prior annual reports, as well as in the UAS section of this report.

Figure 47: Photo of ground test of dual-frequency radar installed inside G1X UAS with antennas integrated in wings. The UAS was attached to a sled and towed behind a snowmobile to measure the runway’s ice thickness. In this photo, Carl Leuschen is conducting the radar test and Nicholas Brown is driving the snowmobile. (Photo courtesy of Alec Bowman).

The field team departed the United States on December 1, arrived in Christchurch on December 3, and flew to McMurdo on December 5. After receiving the cargo (which required special handling because of the temporary export licenses covering ITAR-controlled items), the team spent several days sorting and repacking the cargo for transport on the LC-130 to the field and participating in required deep field training, before flying to the SLW/CReSIS field camp on the Whillans (B) Ice Stream on December 18. Also at camp were the CReSIS I-189-M Basler and I-188-M surface-based project teams.

Figure 48: Photo of radar ground test setup. See G1X UAS (with radar inside) attached to sled on left, with UAS ground control station in center/right of photograph. (Photo courtesy of Alec Bowman).

Figure 49: Photo of Nicholas Brown (pilot) bringing the G1X UAS in for a landing. (Photo courtesy of Carl Leuschen).

The team spent 4 weeks at the SLW/CReSIS field camp, from December 18 to January 13. First, the team conducted ground tests with the UAS/Radar, such as testing communication links, performing UAS ski taxi tests, testing UAS engine performance, and testing radar functionality and performance. The I-189 Basler team members worked with the I-185 UAS team members to ground-test the radar system at the camp. The UAS/Radar was attached to a sled and towed behind a snowmobile to measure the runway's ice thickness (see Figures 47 and 48). On December 27, flight testing and airborne radar data collection with the G1X UAS began (see Figure 49). Flight tests with the UAS/Radar were first conducted within line-of-sight in manually-piloted mode and then in autonomous mode. Then, over-the-horizon test flights in autonomous mode were conducted. The longest over-the-horizon mission flown by G1X was 11 km (5.9 nautical miles) from camp. Flying in autonomous mode allowed for greater precision while flying flight lines, which made it possible to collect radar data in closely spaced grids. Overall, 14 flights occurred while the team was at the field camp, covering a total distance of 30 km. The UAS/Radar system collected airborne radar data over areas in and around camp as well as over areas near a WISSARD drill site. ***The radar measurements performed as a part of these test flights represent the first-ever successful sounding of glacial ice with a UAS-based radar.*** For more information about the results from this mission, please refer to the UAS section and the Sensors and Signal Processing section of this report.

Antarctica, Winter 2013-2014: Surface-based Radar and Seismic Survey Project (NSF I-188-M)

From November 29, 2013 to January 22-23, 2014, two CReSIS personnel [Sridhar Anandakrishnan (PSU) and Peter Burkett (PSU)] participated in a surface-based radar and seismic survey project (event/project number I-188-M) on the Siple Coast of Antarctica. The primary research objective was to estimate basal melt rate, an important factor in glacier flow modeling, ice sheet stability, and ocean-water circulation beneath ice shelves. Basal melt rate beneath the Ross Ice Shelf can be estimated by accurately measuring the change in ice shelf thickness by collecting data with CReSIS' surface-based Accumulation Radar System in the same locations every other week over a multi-week period. PSU's seismic equipment can be used to determine water thickness.

In September 2013, PSU personnel visited KU to be trained to setup and operate the surface-based Accumulation Radar System. Prior to their visit and in preparation for this field mission, personnel at KU modified the surface-based Accumulation Radar System to fit inside a 27 x 27 x 26 inch pelican case that could be unloaded from a utility Twin Otter, and quickly and easily attached to a Nansen sled. Radar operation could be monitored and data quality could be verified through the use of a computer monitor mounted inside the lid of the pelican case. The antenna array and mounting structure were also modified to be easily transported and quickly assembled and attached to the back of a Nansen sled. Figure 50 shows the surface-based Accumulation Radar System inside the pelican case, and the assembled antenna array and mounting structure. More information about the surface-based Accumulation Radar System can be found in the Sensors and Signal Processing section of this report.

Figure 50: Photo on left is the surface-based Accumulation Radar System inside the pelican case. Photo on right is the assembled antenna array and mounting structure. (Photos courtesy of Judith Riley).

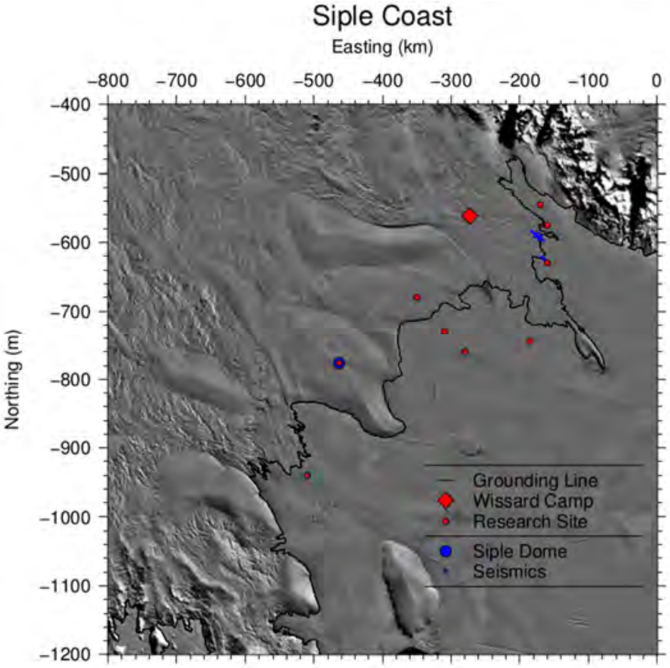


Figure 51: Graphic showing proposed measurement locations. The SLW/CReSIS field camp was located near the previous "Wissard Camp" location. Small red dots represent "super sites", where there were three landing sites (measurement sites) within a 15 km radius of the red dot location. Siple Dome and Whillans Ice Stream locations were highest priority. Siple Dome was the calibration site because of the known ice thickness, temperature, and impurities. (Graphic provided by Sridhar Anandakrishnan).

The field team departed the United States on November 29, arrived in Christchurch on December 1, and after 2 days of weather delays, transited to McMurdo on December 5. After receiving and repacking cargo and participating in training, the field team transited on December 16 to the SLW/CReSIS field camp on the

Whillans (B) Ice Stream on the Siple Coast of West Antarctica. Also at camp were the I-189-M Basler and I-185-M UAS CReSIS teams. Every other week over a 5-week period, the field team traveled on a utility Twin Otter to measurement sites on the Ross Ice Shelf and grounding line, and setup the surface-based Accumulation Radar System and seismic equipment to collect data. Figure 51 shows the proposed measurement locations on the Siple Coast. During the measurement week, they visited multiple landing sites each day, spending 1 hour at each landing site (or up to 4 hours at a "super site"). At each location, they measured the thickness of the ice shelf with the surface-based Accumulation Radar System (Figure 52) and they measured the water thickness by occupying a seismic line. If needed, a radar engineer from the I-189 Basler team was available to travel with the team. Then, after waiting a week, they revisited the same sites again and repeated the measurements. During the week between the flight periods, the field team conducted seismic and surface-based radar measurements at and around the field camp (Figure 53). After collecting two to three datasets at each location over the 5-week period, the field team left the field camp and returned to McMurdo Station. On January 22-23, 2014, the field team flew from McMurdo to Christchurch, and then returned home to the United States.


Figure 52: Photo of Peter Burkett working with the surface-based Accumulation Radar on the Ross Ice Shelf, with Transantarctic Mountains in the background. The radar antennas (in box at rear of sled) and the antenna hardware (in black case on sled) were transported by Twin Otter aircraft and towed by skidoo. (Photo courtesy of Sridhar Anandakrishnan)


Figure 53: Photo of seismic testing at SLW/CReSIS camp. The shelter contains the seismic recording equipment, and the cable in the foreground connects to buried geophones. (Photo courtesy of Sridhar Anandakrishnan)

Greenland, Spring 2013: NASA Operation IceBridge (OIB) Mission using P-3 Aircraft

From March to May, 2013, CReSIS personnel from both KU and IU participated in NASA's Operation IceBridge (OIB) spring deployment over the Arctic Ocean and the Greenland Ice Sheet. CReSIS supports the OIB program by deploying radar instrumentation and personnel on NASA

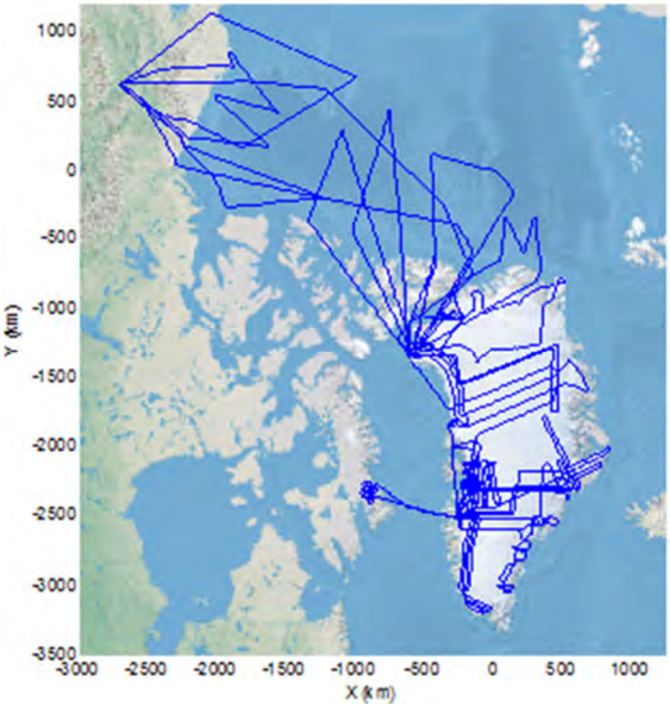


Figure 54: Surveyed flight lines during the spring 2013 OIB P-3 mission to Greenland and Alaska.

aircraft to collect data for monitoring land ice and sea ice in the cryosphere during the gap in satellite coverage between ICESat-1, which failed in 2009, and ICESat-2, planned for launch in late 2015. From February 25 to March 14, prior to the 2013 deployment, CReSIS personnel were involved with the antenna installation, radar installation, and test flights at NASA Wallops Flight Facility (WFF) in Virginia. CReSIS radar systems included the MCoRDS/I Depth Sounder/Imager, Accumulation Radar, Ku-band Altimeter, and Snow Radar. Also installed was IU's Forward Observer data management system. On March 18, four CReSIS personnel (3 from KU, 1 from IU) flew on the NASA P-3 aircraft from WFF to Thule Air Base in Greenland. Within a few days of their arrival in Thule, the team flew to Fairbanks, Alaska and conducted survey flights over sea ice for several days before returning to Thule. Survey flights were conducted while based out of Thule until April 2, when the team transited on the P-3 from Thule to Kangerlussuaq, Greenland. The team conducted survey flights while based out of Kangerlussuaq until April 19. On April 19, the team transited on the P-3 from Kangerlussuaq back to Thule where they conducted survey flights until May 3. On May 3, the team transited on the P-3 from Thule to Wallops. The team then removed the radar equipment from the P-3 before returning home to KU or IU. Figure 54 shows the flight lines that were surveyed during this mission. During the 46-day deployment, the team conducted a total of 26 science flights and flew a total of 146.4 science hours. The MCoRDS/I system collected 12.90 TB of data on 19 flights. The Snow and Ku-Band Radars both collected 7.14 TB each on 26 flights. The Accumulation Radar collected 3.54 TB of data on 26 flights. The total data collected over the current project period was approximately 30.74 TB. Please refer to the Sensors and Signal Processing section for more information.

Greenland, Summer 2013: Collaborative research involving the use of CReSIS Surface-based Snow Radar System at Summit Camp by Dartmouth

CReSIS provided the surface-based Snow Radar System and antenna mounting structure to Dr. Mary R. Albert from the Thayer School of Engineering at Dartmouth for use by her field team during their deployment to Greenland in June-July 2013. CReSIS also provided computing equipment and quick-look software scripts written by CReSIS for the team to use in the field to assess data quality and to produce first-order results. The equipment was used to collect surface-based radar survey data for the purpose of investigating the impacts of melt in the dry snow zone in the APEX area of Summit Camp in Greenland, in conjunction with Dr. Albert's NSF-funded research. One of Dr. Albert's students visited CReSIS in May 2013 to be trained in the assembly and operation of the radar system and antenna mounting structure. Equipment traveled on the ANG 109th aircraft from the United States to Kangerlussuaq, Greenland on May 28, 2013 and then from Kangerlussuaq to Summit Camp around June 4. The radar system components were

Figure 55: Dartmouth field team member, Alden Adolph, conducting a radar survey at Summit Camp in Greenland with the CReSIS surface-based Snow Radar System. (Photo courtesy of Allison Morlock from Dartmouth). Source: https://dartmouthigert.wordpress.com/category/igert-fellows/alden-adolph/page/7/, post by Alden Adolph on June 27, 2013)

shipped in a racked configuration inside a hardigg container. Once at Summit Camp, the hardigg container was strapped to a sled; the antennas were attached to the mounting structure and then mounted to the sled; and the sled was towed by a snowmobile (see Figure 55). The surface-based Snow Radar System was used at Summit Camp until late June, and then it returned on the ANG 109th aircraft to the United States by late July 2013. Radar data collected during the experiment was shared with CReSIS. Please refer to the Sensors and Signal Processing section for more information.

Antarctica, Winter 2013-2014: NASA OIB Mission to Antarctica using P-3 Aircraft
In November-December 2013, CReSIS personnel from both KU and IU participated in NASA's OIB winter deployment to Antarctica. For the first time, the NASA OIB P-3 aircraft was based at McMurdo Station to support the mission.

The mission start date and mission duration were significantly impacted by the Government Shutdown in October 2013. However, NASA was thankful to learn from the NSF that this mission was deemed to be supportable, especially after the Shutdown had reduced so many resources. Mission activities started 3 weeks later than originally scheduled. From October 23 to November 1, CReSIS personnel from KU and IU installed the CReSIS radar suite (MCoRDS/I Depth Sounder/Imager, Accumulation Radar System, and combined Ku-band and Snow Radar Systems) and associated antenna systems, as well as IU's Forward Observer data management system on the NASA P-3 aircraft at NASA Wallops Flight Facility (WFF) in Virginia. CReSIS personnel from KU and IU also participated in test flights at WFF from November 7-9. The OIB field team, including four CReSIS personnel (3 from KU and 1 from IU), left the United States on November 7, arrived in Christchurch on November 9, and flew to McMurdo Station on November 11. The NASA P-3 arrived in McMurdo on November 16. There was one test flight on November 18 from McMurdo (with only NASA crew allowed aboard).

In the original schedule, before the Shutdown, there were 24 potential science flight days. However, after the Shutdown, there were only 5 potential science flight days, because the mission end date was fixed. The P-3 was required to use the Sea Ice Runway and therefore the P-3 had to depart McMurdo before the move to Pegasus Runway occurred at the beginning of December. The OIB team was able to collect survey data during a total of 6 flights—5 science flights plus the transit flight from McMurdo to Christchurch—for a total of 43.1 science flight hours. Figure 56 shows the flight lines that were surveyed during the mission. The MCoRDS/I system collected 9247.5 GB of data; the Snow and Ku-Band Radars each collected 1052.1 GB of data; and the

Accumulation Radar collected 858.5 GB of data. The total data collected was approximately 12210.3 GB. The P-3 departed McMurdo on November 28 to return to WFF by early December. The field team departed McMurdo on December 2 and flew to Christchurch, before flying back to the U.S. on December 4. CReSIS personnel from KU and IU participated in the removal of the equipment from the NASA P-3 aircraft at WFF in early December. Please refer to the Sensors and Signal Processing section for more information.

Figure 56: Flight lines from Antarctic OIB P-3 deployment. (Source: OIB 2013 Annual Final Report submitted by NASA)

Greenland, Spring 2014: NASA OIB Mission using P-3 Aircraft

From March 10 to May 23, 2014, CReSIS personnel from KU and IU participated in NASA's Operation IceBridge (OIB) spring campaign over sea ice off the northern coast of Alaska and in the Arctic Ocean, and over land ice on the Greenland Ice Sheet. Figure 57 shows the proposed flight lines for 53 land ice missions and 19 sea ice missions for this deployment. Prior to the 2014 Arctic deployment, CReSIS personnel were involved with the antenna installation, radar installation, and test flights at Wallops Flight Facility (WFF) in Virginia from Feb. 24 to March 9. CReSIS' MCoRDS/I Depth Sounder/Imager, Accumulation Radar, Ku-band Radar, and Snow Radar as well as IU's Forward Observer data management system were installed on the NASA P-3 aircraft. On March 10, four CReSIS personnel (3 from KU including 2 radar operators and 1 data processing person, and 1 data

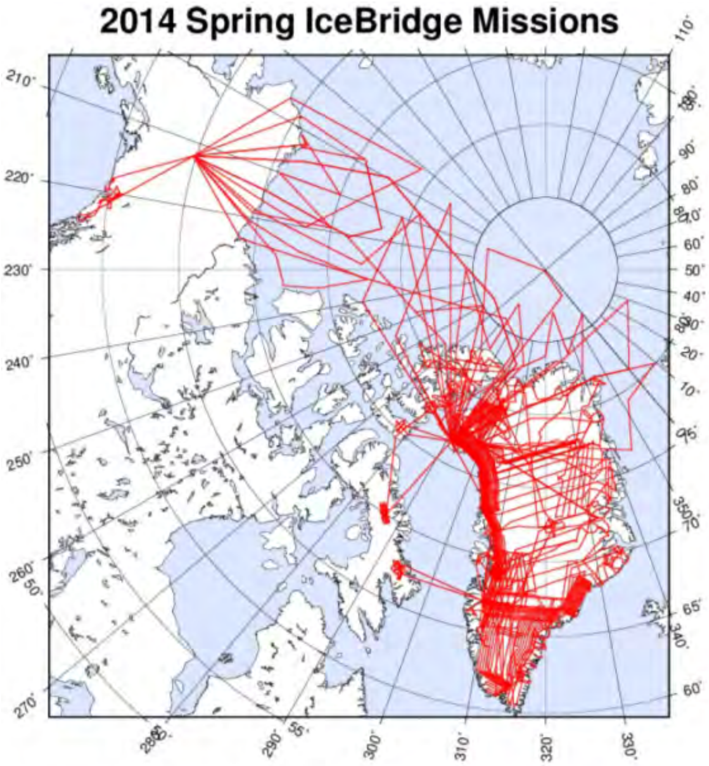


Figure 57: Proposed flight lines for 2014 Spring OIB deployment. (Source: Spring 2014 IceBridge P-3 Flight Plans, 10 March 2014 Draft, compiled by John Sonntag, NASA)

management person from IU) flew on the NASA P-3 from WFF to Thule Air Base in Greenland. From March 10 to April 4, the team conducted airborne radar surveys from the NASA P-3 aircraft while based out of Thule and out of Fairbanks, Alaska. On April 4, the team transited on the NASA P-3 from Thule to Kangerlussuaq in Greenland, and conducted survey flights from this location until April 25. Team members rotated in and out once for each of the positions on the team. On April 25, the team transited on the NASA P-3 from Kangerlussuaq to Thule. The team conducted survey flights from Thule until May 23, when the team transited back to WFF on the P-3 aircraft. On May 24-26, the team removed the equipment from the NASA P-3 and packed it for the return shipment to KU and IU.

Alaska, Spring 2014: Loan of Ku-band and Snow Radar Systems to Naval Research Laboratory (NRL) for Alaskan Sea Ice Surveys using Twin Otter

CReSIS loaned a version of the Ku-band and Snow Radar Systems to the Naval Research Laboratory (NRL) in March 2014 to collect radar data over sea ice off the northern coast of Alaska. This activity is part of an NRL-funded project with CReSIS (Dr. Stephen Yan, PI). From March 3-7, 2014, three CReSIS personnel installed the Ku-band and Snow Radar Systems on an NRL-contracted Twin Otter aircraft at the Twin Otter International office/hangar in Grand Junction, Colorado. CReSIS obtained a Special Temporary Authority license from the FCC to authorize CReSIS to operate the radars during the test flights on March 8-9, 2014 in Colorado. From March 15-31, 2014, the NRL team conducted survey flights over sea ice off the northern coast of Alaska, while based out of Barrow, Alaska.

Thrust Area	Cyberinfrastructure
Lead(s)	Dr. Geoffrey Fox (IU)
Core Participants	All Center Members

Glacier Bed Layer Identification

Our efforts to improve accurate selection of the bed and surface features in radar imagery include the following: a level set technique, which evolves two geometric functions as initial estimates of a layer's position and depth until a gradient-based cost function was minimized [1].

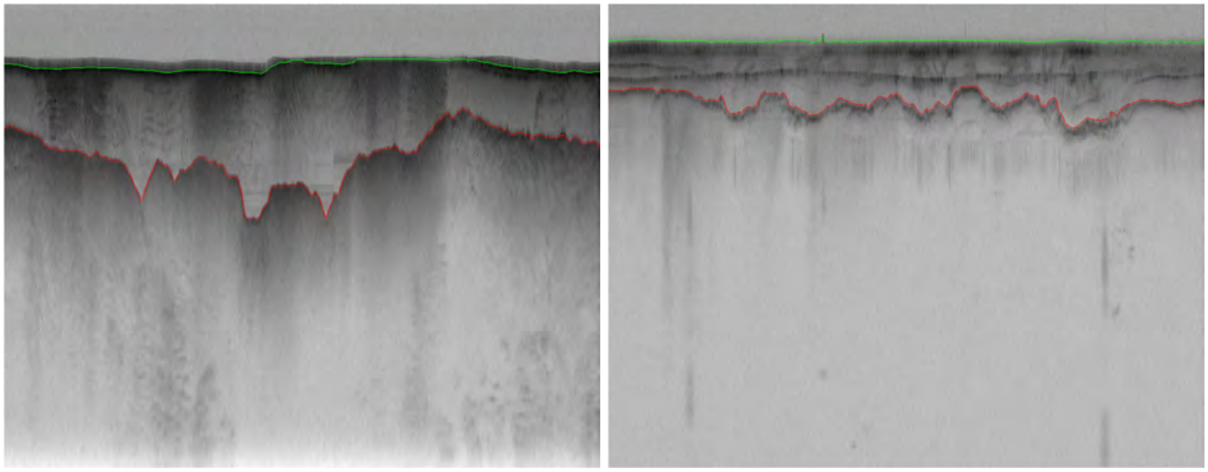


Figure 58: Semi-automatic technique using an active contours model ("level sets"). Estimates of bedrock and surface layers are shown in red and green, respectively.

Another technique, uses a Markov Chain Monte Carlo to sample from the joint distribution over all possible layers conditioned on the radar image. The layer boundaries can be estimated from

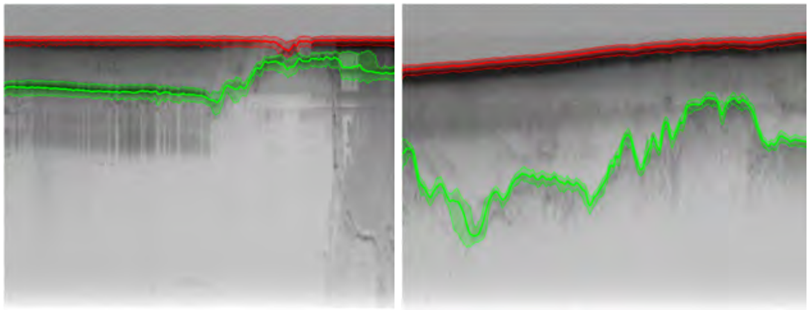


Figure 59: Automatic technique using a Markov Chain Monte Carlo method. Estimates of bedrock and surface layers are shown in green and red, respectively. The shaded regions represent 95% confidence bands of probable layer locations.

the expectation over this distribution, and confidence intervals can be estimated from the variance of the samples [2].

Snow Layers

Our efforts to improve accurate selection of the near surface internal features in polar radar imagery focuses on developing an active contour ("snakes") model to find high intensity edges likely to correspond to layer boundaries, while simultaneously imposing constraints on smoothness of layer depth and parallelism among layers

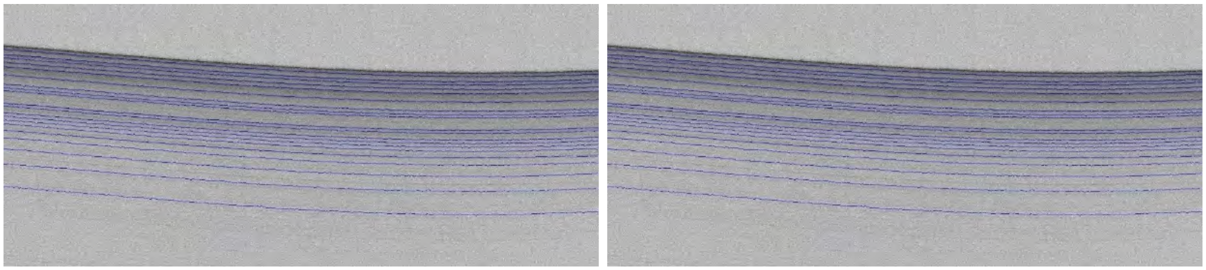


Figure 60: Semi-Automatic technique using active contours model ("snakes"). Near surface estimates are shown in blue.

We have also presented our basic work on layer identification at the International Glaciology Society (more information in Section IV: Knowledge Transfer) and the Radio Echo Sounding Workshop.

Figure 61: Forward Observer Heads-Up Display in use.

Integrated Layer Determination

Currently images are processed individually but we are preparing a more powerful approach that determines 2D surfaces (not just layers) by simultaneous analysis of many flight paths incorporating continuity and models for background. This has obvious scientific value and very interesting algorithmic and parallel computing issues [4].

Figure 62: Ground lab at Crary Lab at McMurdo station.

Batch Processing and Expedition Cyberinfrastructure

IU provided field support for CReSIS missions, including the Forward Observer In-Flight system for real-time backup and processing of radar systems. IU oversaw the backup and processing of 97TB of radar data across three field missions. For Operation IceBridge missions, data were captured on the Forward Observer system during science flights and processed as they were collected. Additional initial processing was handled in a ground lab. Figure 61 shows the FO system in use on the NASA Orion P-3. Figure 62 shows IU equipment in use at the McMurdo Crary Lab. For the I-189 mission at WISSARD camp, IU field staff received data drives after flights were completed and completed data back up and processing with ground lab equipment.

After completion of field missions, mission drives were shipped to IU, where they were installed on the Polar Research Operations Center (PROC). Data were made available from PROC systems to IU's Quarry and Big Red II systems. IU assisted CReSIS in migrating Matlab codes to the Big Red II system, where CReSIS was one of the first early users of the system. IU assisted CReSIS staff with archiving processed data to the Scholarly Data Archive at IU. IU's Data Capacitor team worked with CReSIS staff to migrate data from the original Data Capacitor system to the new Data Capacitor II storage system. During this time, IU also created a web site to highlight involvement in CReSIS activities: http://proc.pti.iu.edu. [5].

References

[1] Mitchell, J.E., D.J. Crandall, G.C. Fox, M. Rahnemoonfar, and J.D. Paden (2013). A Semi-Automatic Approach for Estimating Bedrock and Surface Layers from Multichannel Coherent Radar Imagery, *SPIE Remote Sensing Conference,* Dresden Germany, September 23-26, 2013, ttp://grids.ucs.indiana.edu/ptliupages/publications/articleSPIEfinal.pdf.

[2] Lee, S., J. Mitchell, D. Crandall, and G. Fox (2014). Estimating Bedrock and Surface Layers Boundaries and Confidence Intervals in Ice Sheet Radar Imagery using MCMC, *International Conference on Image Processing* [submitted].

[3] Mitchell, J., D. Crandall, G. Fox, and J.D. Paden (2013). A Semi-Automatic Approach For Estimating Near Surface Internal Layers From Snow Radar Imagery, *International Geoscience and Remote Sensing Symposium*, Melbourne, Australia, July 21-26, 2013, http://grids.ucs.indiana.edu/ptliupages/publications/IGARSSMitchellv2.pdf.

[4] Rahnemoonfar, M., G. Fox (2013). Ice Layer Detection from RADAR Depth Sounder Data using Novel Approach based on theory of Electrostatics, *International Glaciological Society International Symposium on Radioglaciology,* Lawrence, Kansas, September 9-13, 2013, http://grids.ucs.indiana.edu/ptliupages/publications/Abstract-IGS%202013-v2.pdf.

[5] Knepper, R., Standish, M. (2013). Forward Observer In-Flight Dual Copy System, *Polar Technology Conference*, Annapolis, MD, April 3, 2013, http://polarpower.org/PTC/2013_pdf/PTC_2013_Knepper.pdf.

Thrust Area	Satellite Measurements
Lead(s)	Dr. Ian Joughin (UW)
Core Participants	Hayden (ECSU); Bindschadler (NASA); Shepherd (CPOM); Dahl-Jensen (UC)

Activity at the University of Washington over the last year focused on fundamental observations of ice-sheet change and on using the combination of satellite and airborne observations (CReSIS radar and NASA lidar) to constrain models to understand the fast flow and potential retreat of Thwaites Glacier, Antarctica. Much of this work relies on maps of velocity we have derived for Thwaites glacier for the 1990s, 2006 through 2010.

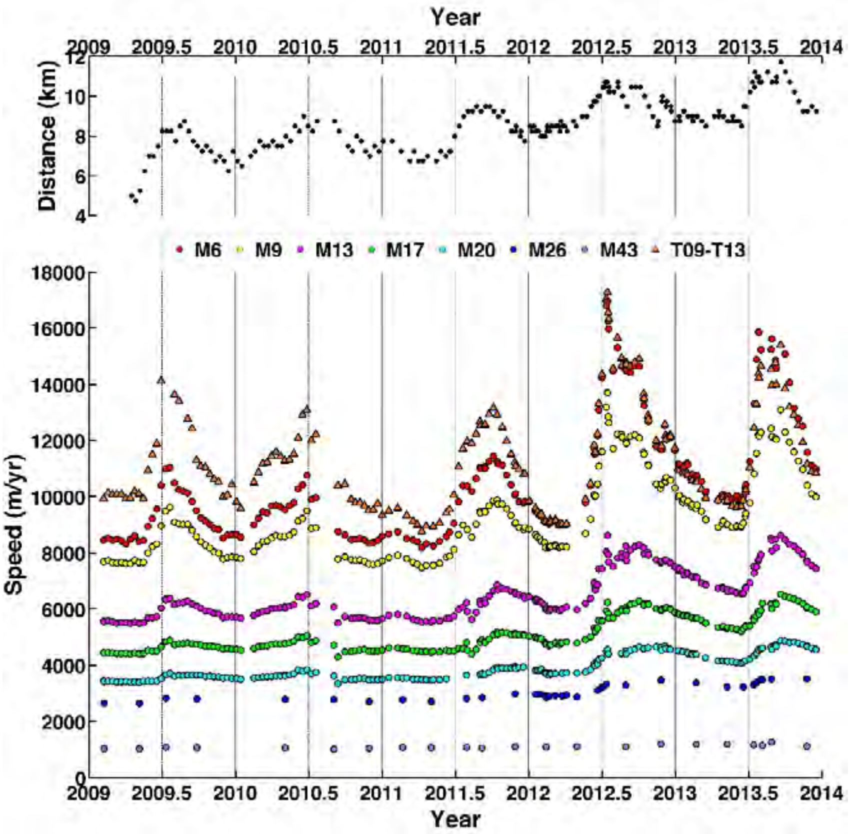


Figure 63: Plots of (top) terminus position and (bottom) speed through time for Jakobshavn Isbræ determined from TerraSAR-X data collected from 2009 to 2013. Terminus position was digitized where it intersects the white profile shown in Figure S1. The color circles (M6-M43) show the speed at several points along the glacier's main trunk. Each point's numerical designation (e.g., M6) gives the approximate distance in kilometres from the glacier terminus in late summer 2003 and these points are used for consistency with earlier records. Additional markers, T09-T13 (orange triangles), are each situated 1-km upstream of the terminus at its position of maximum retreat for the years 2009-2013. Each year, speeds are plotted for the corresponding point (T09-T13).

During the summer of 2012 there was remarkable transient speedup on Jakobshavn Isbrae (Figure 62), with speeds well in excess of previous summer (17 km/yr near the terminus). A similar speedup is in progress in summer 2013 as the calving front continues to recede. Once we have a complete summer record (through September 2013). We published a description of this speedup in the Cryosphere [1]. This paper was highlighted by EGU with a press release and generated more than 150 online posting of news stories. Joughin did radio interviews for NPR (2), BBC, and CBC.

References

[1] Joughin, I., Smith, B. E., Shean, D. E., & Floricioiu, D. (2014). Brief Communication: Further summer speedup of Jakobshavn Isbræ. *The Cryosphere*, *8*(1), 209–214. doi:10.5194/tc-8-209-2014.

Thrust Area	Analysis and Modeling
Lead(s)	Dr. David Braaten and Dr. Kees van der Veen (KU)
Core Participants	Gogineni (KU); Joughin (UW); Price, Lipscomb (LANL); Alley, Anandakrishnan, Pollard (PSU); Allison (ACE); Dahl Jensen (UC); Sheperd (CPOM)

The modeling and analysis goals during this reporting period have been to assess factors that control glacier stability, ice sheet mass balance, surface velocity, and observed transient behavior of ice sheets. A strength of the Center is in coupling ice sheet observations with theoretical processes through numerical modeling to provide informed assessments to modelers coupling ice sheet models into earth system models. Accurate sea level rise predictions from coupled earth system models will depend on a true depiction of glacier dynamics. The accomplishments during this reporting period have incrementally moved us toward this goal.

University of Washington

After our recent modeling efforts aimed at understanding sensitivity of Pine Island Glacier to a warming ocean [UWR1], in this reporting period we have focused our Antarctic modeling efforts on the other rapidly thinning ice streams in the Amundsen Sea Embayment (Thwaites, Smith, Pope, and Kohler). We are continuing to use velocity data to constrain a model of Thwaites Glacier. This model also is heavily constrained by thickness and bed data collected with CReSIS developed radars as well as accumulation estimates shown in Figure 64. We have used these data to constrain a numerical model to investigate the sensitivity of Thwaites Glacier to ocean melt and whether unstable

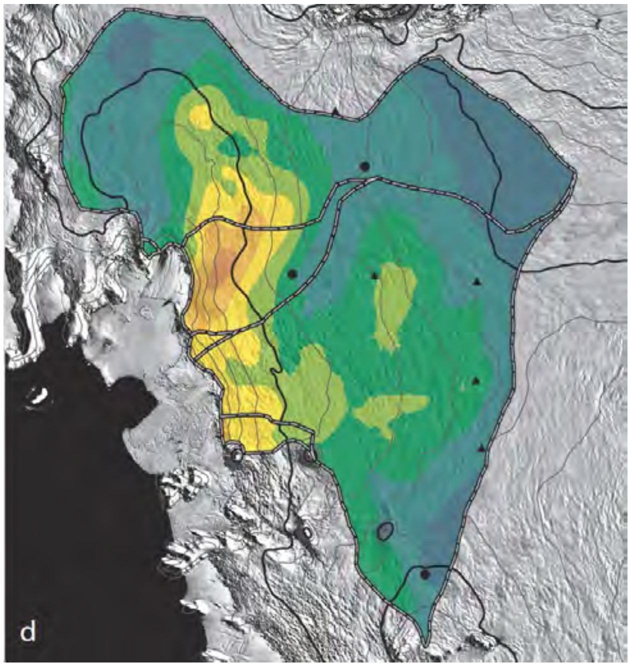


Figure 64: Mean accumulation for the Pine Island and Thwaites Glacier basins derived using CRESIS snow- and accumulation-radar data [Medley et al, in prep].

retreat is already underway. Our model reproduces observed losses when forced with ocean melt comparable to estimates. Simulated losses are moderate (<0.25 mm/yr sea level) over the 21st Century, but generally increase thereafter. Except possibly for the lowest-melt scenario, the simulations indicate that early-stage collapse has begun. Less certain is the timescale, with onset of rapid (>1 mm/yr sea level) collapse for the different simulations within the range of two to nine centuries. This work is described in a paper currently in revision at Science. We also collaborated with Faezeh Nick on model outlet glacier response to warming [2].

Kristin Poinar, a CReSIS-funded student at the University of Washington, is continuing with a variety of process models to understanding how englacial temperature influences the flow of the Greenland Ice Sheet. Currently she is focusing on how crevasses can hydrofracture down several hundred meters to deliver latent heat to the middle of the ice sheet.

The University of Washington also had a separately-funded project (NSF Antarctica Glaciology) that uses the CReSIS accumulation and snow radars to study accumulation in the drainage basins of Thwaites and Pine Island glaciers. We currently are extending this work through CReSIS funding. We recently published a paper in GRL [3] demonstrating that annual layers can be resolved with the snow radar. Furthermore, the snow radar data show strong agreement with results from reanalysis models, validating the use of these models in regions where no other data exist. Brooke Medley, a CReSIS funded graduate student, graduated with her Ph.D. in October 2013 and has accepted a Post Doc position at NASA. Her recent work focused on using the CReSIS accumulation radar to measure accumulation and mass balance of the Pine Island and Thwaites glacier basins. Figure 65 illustrates a map of multi-decadal averaged accumulation produces as part of this effort. This work is described in a paper in review for the Cryosphere [4].

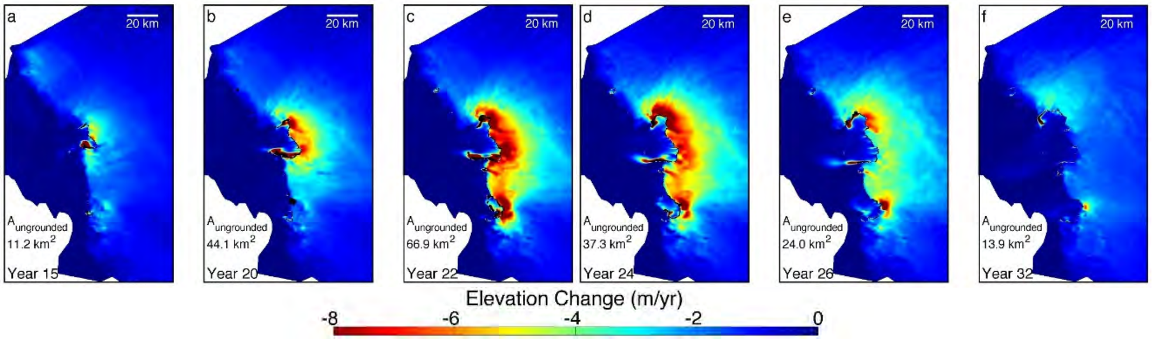


Figure 65: Simulated thinning rates for years a) 15, b) 20, c) 22, d) 24, e) 26, f) 32 showing evolution of thinning during a period ungrounding in the m=3x simulation. For each year the corresponding panel includes the area that ungrounded ($A_{ungrounded}$).

Josh Carmichael, who has been funded over the last couple of years through CReSIS, successfully defended his Ph.D. dissertation on August 23rd, 2013 and began a Post Doc position at Los Alamos National Laboratory in September, 2013. His work has focused on detection of seismic signals collected around a supra-glacial lake in Greenland (Figure 66), using data acquired under a separately funded (NSF ANS) project. The primary finding of his work is that 95% of the seismicity observed in this region is the result of surface waves, resulting small fractures at the ice sheet surface. He is in the process of finalizing two manuscripts describing this work.

References

[1] Joughin, I., B. E. Smith, and D. M. Holland (2010), Sensitivity of 21st century sea level to ocean-induced thinning of Pine Island Glacier, Antarctica, *Geophys Res Lett*, *37*(20), L20502–, doi:10.1029/2010GL044819.

[2] Nick, F. M., Vieli, A., Andersen, M. L., Joughin, I., Payne, A., Edwards, T. L., et al. (2013). Future sea-level rise from Greenland's main outlet glaciers in a warming climate. *Nature*, *497*(7448), 235–238. doi:10.1038/nature12068.

[3] Medley, B., Joughin, I., Das, S. B., & Steig, E. J. (2013). Airborne-radar and ice-core observations of annual snow accumulation over Thwaites Glacier, West Antarctica confirm the spatiotemporal variability of global and regional atmospheric models. *Geophysical Research Letters*, *40*, 1–6. doi:10.1002/grl.50706.

[4] Medley, B., Joughin, I., Smith, B. E., Das, S. B., Steig, E. J., Conway, H., et al. (2014). Constraining the recent mass balance of Pine Island and Thwaites glaciers, West Antarctica with airborne observations of snow accumulation. *The Cryosphere Discussions*, *8*(1), 953–998. doi:10.5194/tcd-8-953-2014.

CReSIS continues to produce data products that enable detailed investigations into ice sheet dynamics that were not previously possible without making wide-ranging assumptions. These investigations have often led to many follow-on questions, which often return Center investigators back to a reexamination of the CReSIS data sets. A healthy exchange of ideas and modeling results across the Center partners has taken place during this reporting period, allowing concepts developed through process modeling to contribute to efforts to parameterize of ice dynamics in an ice sheet model coupled to an earth system model. Process modeling efforts include force balance calculations along rapidly changing outlet glaciers, the impact of overdeepened beds on basal conditions and ice dynamics, processes at the

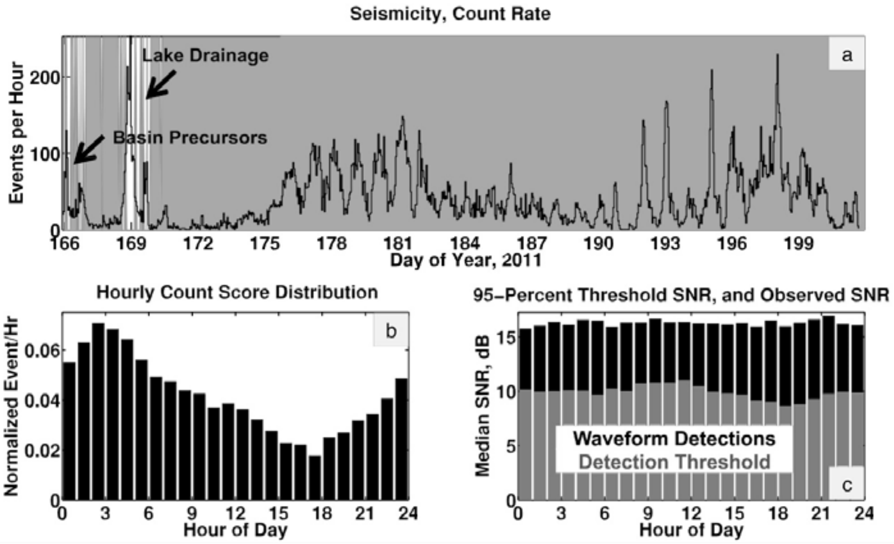


Figure 66: A summary of icequake seismicity and corresponding detection statistics [Carmichael et al., in prep]. All dates indicate local time. (a) Number of icequakes detected per hour (seismicity) on any 3 or more operational geophones within the network. The dominant peaks preceding and during drainage and labeled for reference. The gray shading indicates bins where the STA/LTA detector statistic's predicted null distribution fit the observed distribution with less than 20% error. (b) Seismicity binned by hour of day. Days preceding drainage were removed from counting. Some counts exceeding 23.5hr were not included due to truncated data volumes. (c) Median signal-to-noise ratio (SNR) of detected icequakes (black) compared with the median, unbiased SNR threshold required to achieve a 95% detection probability in that hour. This threshold SNR was conditional upon several noise statistics that were estimated within each detection window.

grounding line that could lead to destabilization, and water at the ice-bed interface.

University of Kansas

The CReSIS Byrd Glacier data set from 2011-2012 has enabled a reexamination of flow dynamics within the lower Byrd catchment Byrd Glacier is a fast-moving outlet glacier that transects the Transantarctic Mountains, funneling an estimated 20.6 ± 1.7 Gt/yr of ice into the Ross Ice Shelf, a number that will now need revision due to the CReSIS discovery that the main glacier channel is much deeper than originally thought. The glacier has been the subject of glaciological investigations since the early 1960s (Whillans et al. [1989]) using surface elevations and ice velocities derived from repeat photogrammetry in the late 1970s. Earlier studies, as well as subsequent studies, have been limited by a lack of detailed information on the bed topography under the glacier that has now been obtained by CReSIS.

New force-balance calculations from the CReSIS data set reveal large variations in the along-flow component of driving stress that are muted by gradients in longitudinal stress such that basal drag is somewhat less variable spatially. Several persistent sticky spots have been identified, and on a large scale, gradients in longitudinal stress seem to play a small role in balancing the driving stress, and flow resistance seems mainly associated with basal drag. Lateral drag seems to be approximately constant along the lower trunk at ~30 kPa. Despite high values of basal drag, ice flow is due mostly to basal sliding and concentrated vertical shear in the basal ice layers, indicating the bed is at or close to the pressure-melting temperature. Confirming earlier results, there is a significant component of driving stress in the across-flow direction resulting in non-zero basal drag in the direction perpendicular to ice flow. This is an unrealistic result that can be

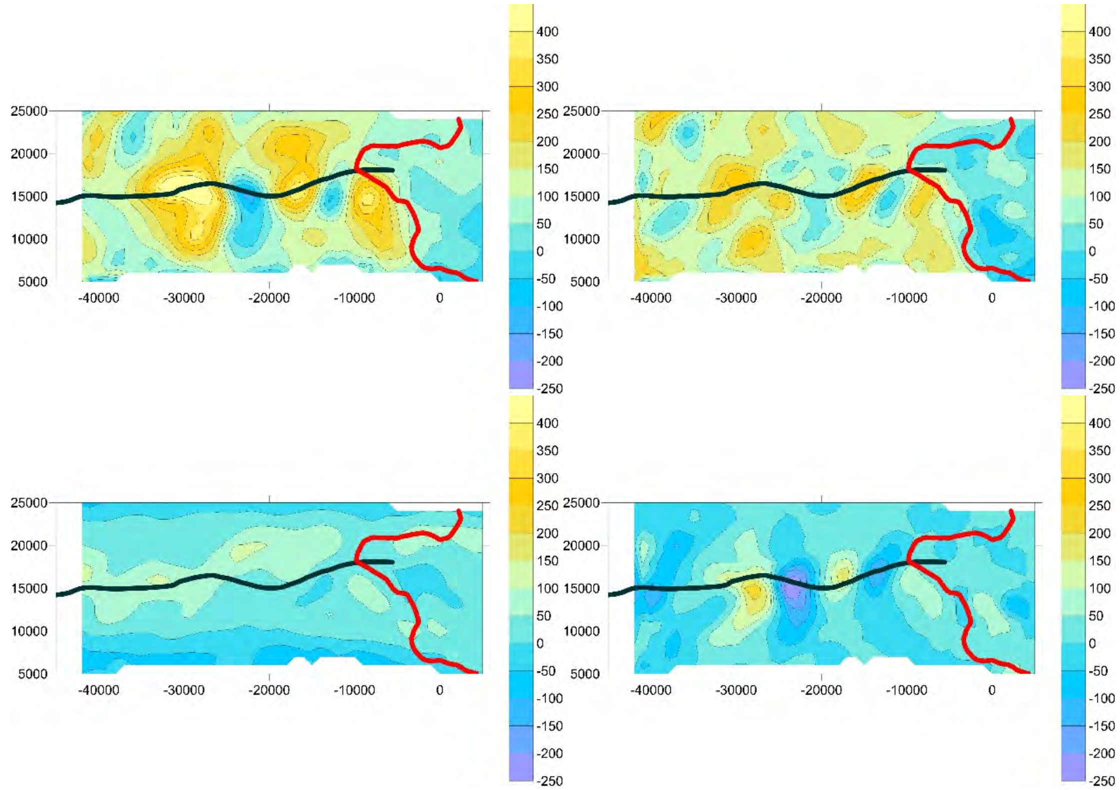


Figure 67: Terms in the along-flow balance of forces (in kPa): driving stress, basal drag, lateral drag, and gradients in longitudinal stress.

resolved with improved bed topography information, which can be obtained through a return to the CReSIS data set for reprocessing and analysis of select flight lines.

The grounding line of Byrd Glacier is located in a region where the bed slopes upward from an over-deepened trench. Such a configuration is often associated with transient outlet glacier behavior, and can lead to instabilities due to small perturbations at the grounding line causing irreversible retreat of the grounding line. There is no current evidence of this, despite a 10% increase in ice discharge between December 2005 and February 2007, following a suspected subglacial lake drainage event in the glacier catchment area. The CReSIS data set provides new detailed information on grounding zone position and characteristics, and will allow a reassessment of grounding zone stability. The new data set is also permitting a reexamination of evidence for subglacial water in the Byrd catchment, and the locations of potential hydrologic channels.

Observations of outlet glacier behavior in Greenland and Antarctica seem to be closely associated with changes at the ice-ocean interface, where. a large reduction of the floating ice tongue is associated with large-scale changes in flow dynamics upstream of the floating ice tongue. Many outlet glaciers underwent changes in the extent of their floating ice tongue, which was coincident with a sudden outlet glacier acceleration and thinning. In this canonical view, a perturbation in the balance of stresses at or near the grounding line has a cascading effect to subsequent acceleration upglacier; without the support, or "back-stress" provided by the ice shelf, the ice sheet rapidly relaxes to a new equilibrium characterized by a lower surface elevation throughout the drainage area. Numerical modeling studies appear to support this theory, and further indicate that small changes in the force balance at the ice-ocean interface gives rise to velocity increases that are consistent with observations.

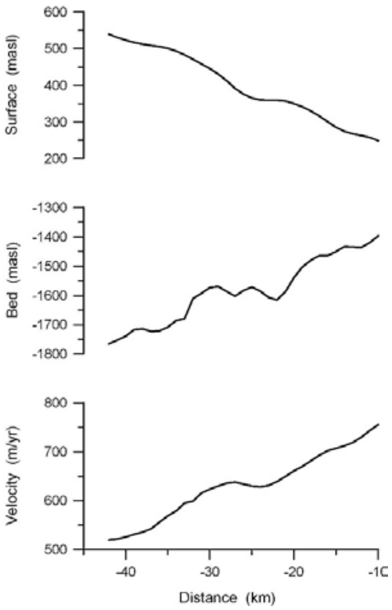


Figure 68: Width-averaged surface and bed elevation (in masl) and surface velocity along the trunk of Byrd Glacier.

Using CReSIS data sets from outlet glaciers to better constrain ice thickness and bed topography has enabled the use of a simplified "back-stress" model to better understand all of the force balance components and their role in the rapid accelerations seen several tens of km inland. More detailed ice thickness and bed topography information have led to a reassessment of quantitative force balance analysis on rapidly changing outlet glaciers, identifying the important control on glacier dynamics.

Numerical models used to investigate potential physical forcing mechanisms responsible for dramatic glacier changes have recently increased in sophistication , and now include many key processes. In particular, flowband models incorporate explicit inclusion of gradients in longitudinal stress, as well as physically-based treatment of iceberg calving at the glacier terminus. Application of these models to specific Greenland outlet glaciers has shown that observed glacier changes can be modeled satisfactorily by selecting the appropriate combination of essentially unconstrained model parameters. However, because of the multitude of non-linearly interacting processes included in these model simulations, it remains somewhat unclear as to what is the cause of glacier change and what may be feedback mechanisms amplifying initially small perturbations. Application of flowband models have been helpful in examining the role of "back stress" and longitudinal stress gradients in regulating glacier flow as shown in Figure 69. A series of flowband model runs for idealized geometries have been conducted, comparing scenarios that have longitudinal stress gradients to those with a balance between driving stress and resistance from basal and lateral drag. These flowband model results show that gradients in longitudinal stress do not play an important role in the large-scale flow dynamics of outlet glaciers. CReSIS is continuing to improve the bed maps of rapidly changing outlet glaciers near the calving front, and as bed geometry improvements are made, flowline model sensitivity to these changes will be assessed.

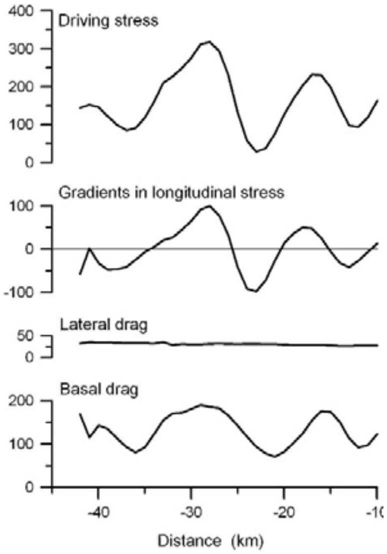


Figure 69: Terms in the width-averaged along-flow balance of forces (in kPa): driving stress, gradients in longitudinal stress, lateral drag, and basal drag.

Los Alamos National Laboratory

Overview

At LANL, CReSIS modeling partners Price, Lipscomb, and Hoffman have continued to develop and test the Community Ice Sheet Model (CISM), improve its representation of important physical processes and its computational performance and robustness, and couple it to the Community Earth System Model (CESM). In addition, they have continued to work with colleagues at the Nat. Center for Atmos. Res. (NCAR) and other Dept. of Energy (DOE) labs on the development, testing, and application of new ice sheet dynamical cores for use within next-generation climate models, such as the Model for Prediction Across Scales (MPAS) climate modeling framework.

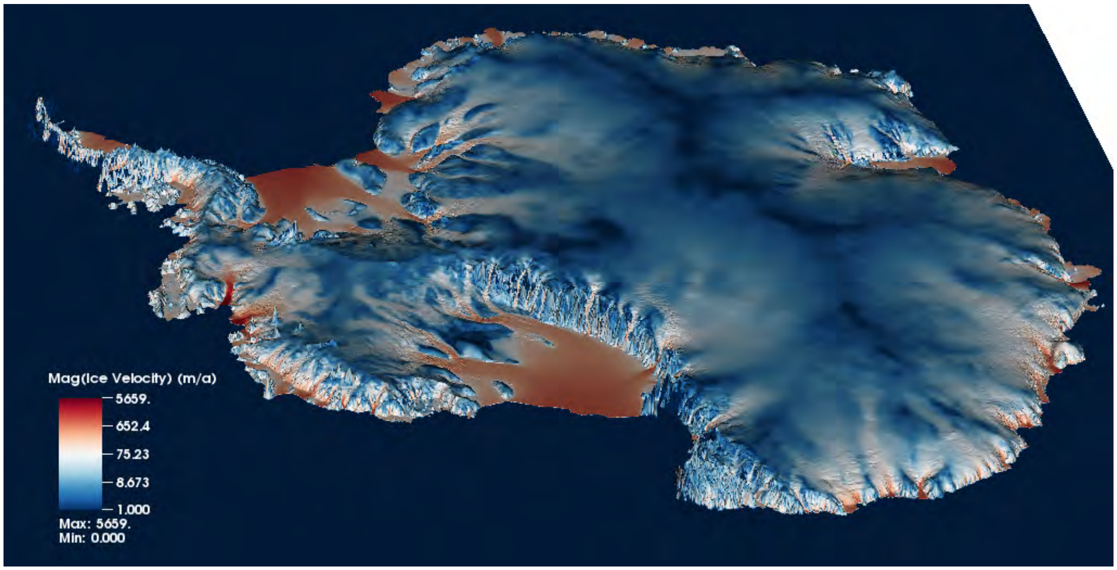


Figure 70: Antarctic ice sheet surface speed modeled by CISM-BISICLES with adaptive mesh refinement at 8, 4, 2, and 1 km resolutions. This optimized initial condition is being coupled with a regional version of the POP2x ocean circulation model to conduct large-scale, high-resolution, ice-ocean coupled simulations for all of Antarctica and the Southern ocean. Figure courtesy of Dan Martin (LBNL).

Recent Progress

During the past year, LANL and colleagues at Lawrence Berkeley Nat. Lab. (LBNL) have coupled the higher-order BISICLES dynamical core, which uses adaptive mesh refinement (AMR) to focus resolution near grounding lines and other regions of dynamical complexity, to CISM (CISM-BISICLES; Figure 70). In collaboration with NYU/PIK, we have coupled CISM-BISICLES to "POP2x", a version of the POP ocean circulation model (the ocean model component of CESM) that has been modified to allow for circulation beneath ice shelves. This work has led to the first ever (to our knowledge) large-scale, high-resolution, coupled simulations of Antarctic ice sheet and Southern ocean evolution, initial results of which were presented at the 2013 AGU meeting as part of an invited presentation (Price et al., 2013a) (Figure 71).

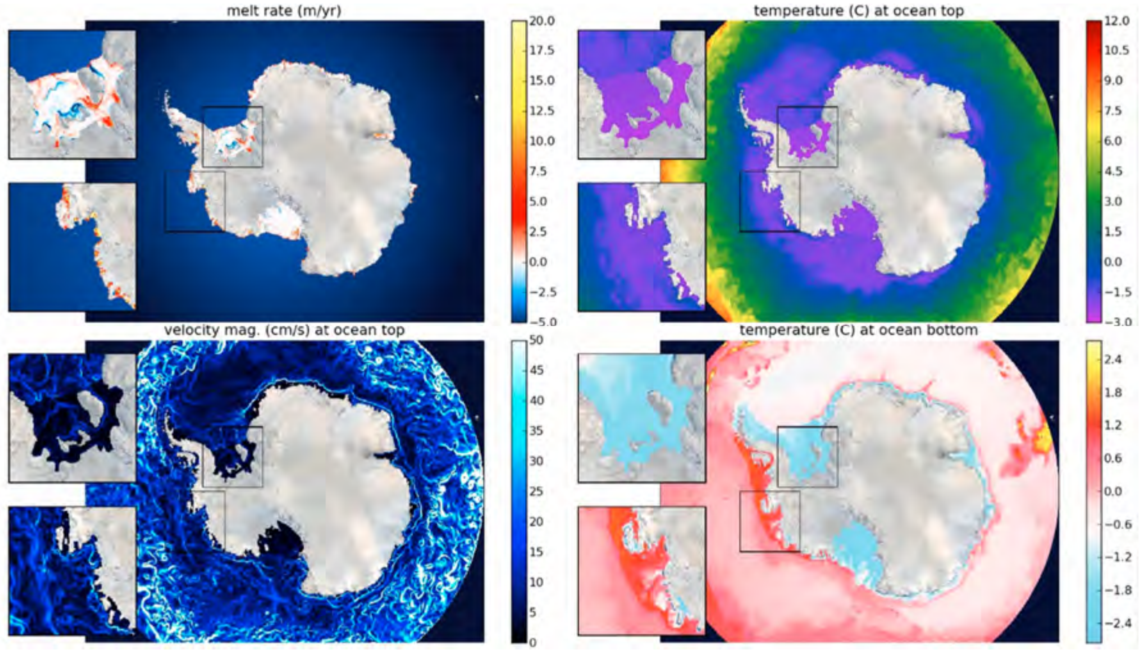


Figure 71: Snapshot from a 10 yr simulation with coupling between CISM-BISICLES and POP2x, showing sub-ice shelf melt rates (upper-left), ocean temperatures at the uppermost (upper-right) and lowermost (lower-right) ocean grid cells, and velocity magnitude at the uppermost ocean grid cell (lower-left). Figure courtesy of X. Asay-Davis (NYU / PIK).

Along with colleagues at Sandia Nat. Lab. (SNL) and the Univ. of Texas at Austin (UT), we have made significant progress on an ice-sheet model optimization method that allows for both realistic initial conditions (e.g., good matches to observed velocity fields and ice sheet geometry) and smooth coupling to forcing from a climate model. The problem and our solution are demonstrated below in Figures 72(a) and 72(b). In Figure 72a, the left panel shows ice sheet surface speeds from an initial condition in which sliding parameters are optimized to provide a best match to observed surface velocities (obtained using InSAR, by project partner Joughin). The right panel in Figure 72(a shows a surface mass balance (SMB) field for the present-day obtained from the RACMO regional climate model (representative of the type of SMB forcing that would be provided by CESM). When integrating forward in time under such SMB forcing, the model flux divergence would initially need to match this SMB field as closely as possible; mismatches between the two lead to undesirable transient "shocks", which both force the initial ice sheet state (e.g., geometry and velocity) away from its present day configuration and mask the ice sheet response to secular climate forcing. In the 1st panel of Figure 72(b), we show the flux divergence associated with an initial condition where only the fit to observed velocities is accounted for during optimization. When integrated forward in time with realistic SMB forcing (the right panel in Figure 72(a)), the result is large and unphysical transients in ice thickness change, as shown in the 2nd panel of Figure 72b).

We expanded the optimization approach most commonly used to additionally minimize the mismatch between the model flux divergence and a target SMB field and to allow for the model ice thickness field to vary within its stated observational uncertainties (as provided by CReSIS). The results of this optimization are shown in the 3rd and 4th panels of Fig. 3b. The flux divergence associated with this new optimized initial condition (3rd panel in Figure 72(b)) is a much better approximation of the SMB field from the climate model (right panel in Figure 72(a)). As a result, the resulting changes in ice thickness after integrating forward in time with realistic SMB forcing are also significantly smaller (4th panel in Figure 72(b)). Notably, the optimized velocity field remains a good match to the observations. This new optimization method will allow for realistic initial conditions that provide a good match to present day observations, and smooth coupling to climate models, so that transients related to ice sheet model initial conditions are minimized or removed. In turn, this will allow for a more straightforward quantification of the ice sheet's response to forcing as a result of climate change. Importantly, the optimization framework can easily ingest improved ice thickness data and/or error estimates, and can be used to assess where additional or improved measurements are needed (e.g., the undesirable transient thickness change in central south-east Greenland in the 4th panel in Figure 72(b) suggest that additional thickness and velocity observations, or at least reduced uncertainties, are desirable there).

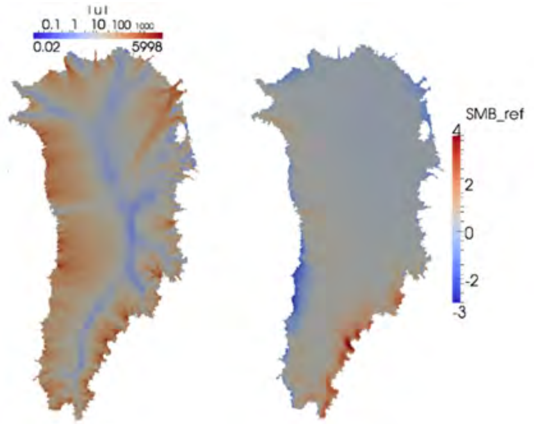


Figure 72(a): Modeled Greenland surface speed, optimized to fit observed velocities (left). The present-day surface mass balance (SMB) for Greenland, as simulated by RACMO (right).

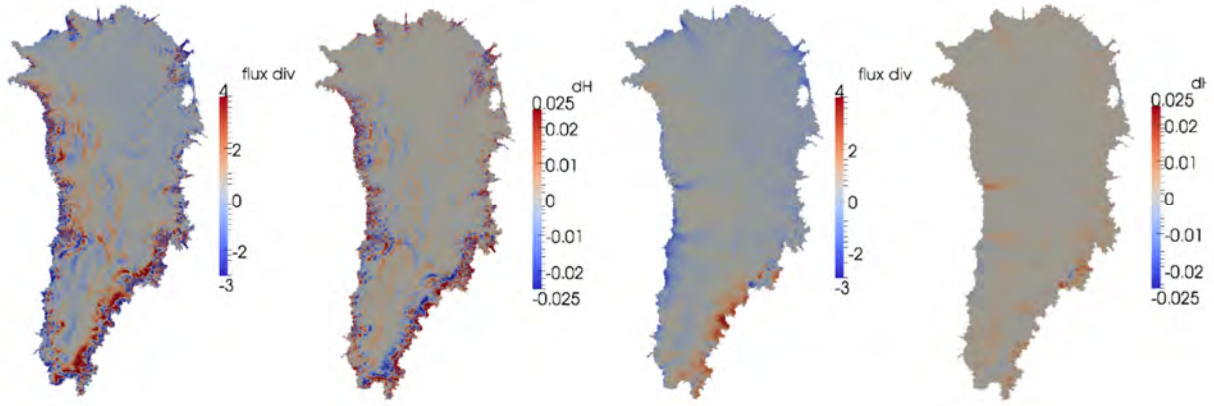


Figure 72(b): Modeled flux divergence (m/yr; 1st panel) and change in ice thickness (km; 2nd panel) after 5 yrs of forward model integration when optimization target only includes observed surface velocities. Modeled flux divergence (m/yr; 3rd panel) and change in ice thickness (km; 4th panel) after 5 yrs of forward model integration when optimization accounts for surface velocities, SMB forcing (i.e., the SMB field shown in Fig. 3a above), and uncertainties in ice thickness observations.

Publications

The evolutionary subglacial hydrology model development work done by CReSIS sponsored LANL postdoc M. Hoffman was published in *JGR Earth Surface* in January of this year. Future work will consist of parallelizing this model, linking it to a modern solver library (e.g., *Trilinos*), and coupling it to CISM2 so that it can be used in large-scale ice sheet simulations, both in stand-alone mode and as a coupled component within CESM.

As of January 2014, all papers from LANL's collaborations with the *SeaRISE* and *Ice2Sea* projects (both of which make heavy use of improved ice thickness data courtesy of CReSIS and NASA OIB) have been published.

2b. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

Research indicators/metrics are unchanged and are outlined in our Strategic and Implementation Plan. Table 2 (below) outlines objectives, metrics, and Center progress for each objective.

Table 2: Research Objectives/Metrics/Progress

Objective	*Metrics*	*Center Progress*
A. Document existing data for target areas and identify observational and technological requirements to improve and validate models.	▪ Develop technical report addressing observational and technical requirements for target areas; incorporate this information into Science, Sensor, and UAV Project Plans.	We have developed a project plan that defines these requirements. These plans refined and updated annually.
B. Design and develop technologies for collecting and processing necessary data.	▪ Develop technical report addressing observational and technical requirements for target areas; incorporate this information into Science, Sensor, and UAV Project Plans. ▪ Center products (number of technical reports, conference papers, presentations, etc.) outlining sensor, platform, and cyberinfrastructure requirements and specifications; design definitions; and analysis of test results.	We developed techniques and data processing techniques, and produced first and only bed maps for three glaciers. We also produced 3-D images of ice bed and reported in the open literature
C. Conduct field investigations to collect required data sets.	▪ Assessment of scientific/technical objectives against field accomplishments in recurring progress reports.	We conducted three major field campaigns in Antarctica in December 2013 to January 2014. Radar survey data of the Siple Coast were collected from a Basler aircraft platform, unmanned aerial system (UAS)

		platform, and surface-based platform. We participated in the NASA OIB campaigns to collect data over Greenland and Antarctica. We also loaned our radars to partners to conduct collaborative research. These data are useful to the CReSIS science team and broader science community.
D. Process, analyze, and distribute data to modeling groups and the scientific community.	▪ List of new data sets generated and archived, including data volume. Assessment includes an estimated number of researchers using or citing the Center-generated data sets. ▪ Time to distribute data sets (from collection to distribution) is less than two years.	We have generated data products and distributed them both through our website and NSIDC. New updated bed map of the Greenland ice sheet was generated by Bamber et al. [2013]. 85% of the data for this map came from CReSIS. We have also upgraded our online distribution tool to include full geographic search capabilities with the release of our Open Polar Server https://ops.cresis.ku.edu. We have continued to provide assistance in data usage and analysis to groups using the data.
E. Integrate data and models using state-of-the-art computing, storage, and networking cyberinfrastructure.	▪ List of new data sets generated and archived, including data volume. Assessment includes an estimated number of researchers using or citing the Center-generated data sets. ▪ Time to distribute data sets (from collection to distribution) is less than two years.	This is being accomplished through LANL and in collaboration with broader science community.
F. Develop diagnostic models identifying processes leading to rapid ice sheet change.	▪ Summary of achievements in ice sheet modeling (models developed or integrated, conference or journal publications, presentations, etc.) as outlined in recurring progress reports.	The results of CReSIS work are reported in major conferences and workshops.

G. Incorporate improved process understanding into predictive ice sheet models.	▪ Summary of achievements in ice sheet modeling (models developed or integrated, conference or journal publications, presentations, etc.) as outlined in recurring progress reports.	Significant progress has been made. The results of CReSIS work are reported in major conferences and workshops.
H. Involve undergraduate and graduate students in research activities.	▪ List of graduate and undergraduate students (including student demographics) that participated in research activities.	A first draft of the student project mapping is completed.

2c. Describe your research plans for the next reporting period with attention to any major upcoming changes in research direction or level of activity. Also, list plans for developing new research partnerships, if any, for the next reporting period.

These bullets outline Center focus for the next reporting period:

Sensors and Signal Processing

Sensors

- Extend the bandwidth of the Ultra-Wideband (UWB) radar electronics and antenna array from 150-450 MHz (190-450 MHz for the antenna array) to 150-600 MHz.
- Continue the development of a multi-channel/polarimetric UWB 2-18 GHz radar (including antennas) as an extension of the work done with the Ku-band/Snow Radars.
- Conduct field tests of the above two systems in Greenland during August 2014.
- Further miniaturization and improvement of the HF Sounder (in particular design of a more efficient, higher power transmitter).
- Improve calibration support for all the radars.
- Continue enhancing sensor performance through CAD tools and hardware refinements.
- Continue the development of radar control interfaces to enable a more autonomous operation of the radars.

Signal Processing

- OPS/layer tracker related:
    - Finish ingest of legacy data and several external layer datasets such as LAYERMAP, snow thickness, and accumulation layers.
    - Support for live cross over and layer elevation/depth information.
    - Support for raster imagery in the database.
    - Complete field deployable support.
- Continue work on array processing:
    - A routine robust minimum variance distortionless response (MVDR) product. This is derived from ice thickness and bed topography for the most challenging areas of ice sheets.
    - Multi-beam tomography including investigation of multiple input multiple output (MIMO) concept.
    - Internal layer synthetic aperture radar (SAR) processor.
- Continue work on radar system deconvolution, electromagnetic interference (EMI) suppression, calibration and simulation.

UAVs

Field deployments of the G1X UAS have validated the aircraft design performance, however we seek to enable longer range for science missions by simultaneously pursuing further miniaturization of sensors, better integration of subsystems and cabling, and reduced airframe structural weight. Of particular note is the need to reduce radio frequency interference which still persists in the currently implemented alternator. Lessons learned from the field season for improved positioning of subsystems will guide the developments of instrumentation rails and cable routing channels to ensure that daily removal of the wings, as required for overnight protected storage, does not require daily removal of critical subsystems. Vehicle changes engineered within this grant will be implemented through manufacturing two additional G1X platforms enabled by additional support received from the Paul Allen Foundation. Additional ground testing of all electronic subsystems and cabling will continue in the anechoic chamber to reduce the noise signature and thus improve the radar performance. We anticipate a significant amount of local flight test hours will be required for these modified aircraft and sub-systems. Initial flight tests are planned at the Ft. Riley restricted airspace. We will continue the application for the G1X Certificate of Authorization (COA) to enable us to flight test at designated locations outside of restricted airspace. We will perform flights for our 33% Yak-54 trainers at the local Sunflower range under an approved COA both to train our student flight test teams and to streamline the COA application for the larger G1X.

To improve reliability and ground track accuracy of the G1X UAS in over-the-horizon missions, an onboard adaptive, resilient, and robust flight control system is required, and this control system will continue to be developed and implemented in the coming year. The KUAFS system will be fully implemented in the G1X UAS, including support for differential GPS in the KUAFS ground station which will be shared with the radar instruments. These control system developments are key to future applications of remote sensing simultaneously using multiple UAS platforms, or small swarms. We are currently seeking supplemental research support to demonstrate this swarming concept for polar remote sensing.

Cyberinfrastructure

- Improve and compare different approaches to both glacier bed and snow layer determination using traditional image at a time approach
- Develop a multi-image large geographic area coupled approach to bed and layer determination
- Continue investigation of GPU's for field infrastructure

Field Activities

- August to September 2014: NSF MRI mission to Greenland using AWI Basler. The team will install and flight-test the CReSIS UWB UHF/VHF Radar, CReSIS Ku-band/Snow Radar, and Google Camera on AWI's Basler aircraft in Muskoka, Canada, before flying to Greenland for approximately 4 weeks of airborne radar surveys while based from Kangerlussuaq, Constable Point, and Station Nord.
- Participate in NASA OIB deployments. Funding for this activity is provided by NASA
    - October to November 2014: NASA OIB mission to Antarctica using DC-8 aircraft, based out of Punta Arenas, Chile
    - March to May 2015: NASA OIB mission to Greenland (Thule and Kangerlussuaq). Aircraft platform is TBD.
    - October to early December 2015: NASA OIB mission to Antarctica using P-3 aircraft, based out of McMurdo Station

Satellite Measurements

Work at UW will continue to observe rapidly changing glaciers (e.g., Thwaites and Jakobshavn) and use CRESIS related data sets to constrain models to better understand fast flow. In particular, we will begin developing the ability to use ELMER/ICE - a finite element ice sheet model package.

Analysis and Modeling

Analysis and modeling work will continue at the University of Kansas, University of Washington, Penn State University and LANL. We will process data collected over ice streams in Siple Dome area. We will generate data products including ice thickness, bed topography and basal conditions, and distribute these to CReSIS science team as well as broader science community.

KU**:** Continue model experiments assessing the role of membrane stresses in modulating response of marine outlet glaciers and ice streams to external forcings and conduct a systematic suite of model experiments to investigate the stability of grounding lines and to test the Marine Instability Hypothesis.

UW: Work at UW will continue to observe rapidly changing glaciers (e.g., Thwaites and Jakobshavn) and use CReSIS related data sets to constrain models to better understand fast flow. In particular, we will begin developing the ability to use ELMER/ICE – a finite element ice sheet model package.

LANL: In June of 2014, we anticipate the release of CISM 2.0 (CISM2), which will include a 3d, 1st-order accurate, FEM-based dynamical core that is robust, parallel, and highly scalable. For a range of standard test problems and realistic problems on high-resolution meshes (e.g., 1 km resolution Greenland, 5 km Antarctica) it has proven to be much more robust and scalable than a previously developed FDM-based dynamical core, which was originally planned for release with CISM2. Initial tests show strong scaling on up to as many as 4096 cpus. During the spring of 2014, we will focus on development and testing necessary to support this public code release.

Around the same time, we anticipate that full two-way coupling between CISM and the land and atmosphere components of CESM will be complete (ocean coupling work is ongoing, as discussed above). Testing of this coupling using both the shallow-ice version of CISM and using the newer CISM2 will take place during the summer and fall of 2014. In winter and spring of 2015, work will focus on scientific validation of CISM2 within CESM, after which we anticipate releasing CISM2 as a coupled component of CESM under the CESM 1.3 release in May of 2015.

In addition to the above noted model development and testing efforts, we anticipate devoting more future effort to model validation in Greenland, largely as a result of data made available through CReSIS. These data include (1) significantly improved spatial and temporal observations of outlet glacier discharge (Enderlyn et al., *GRL*, **41**, 2014) and (2) a comprehensive database of dated internal layers (MacGregor et al., *AGU*, 2013). We plan to apply (1) to develop a standardized validation test case for Greenland, whereby models are forced over the past few decades using the outlet glacier discharge time series and observed surface mass balance, and model output is compared to observations of ice sheet mass loss over the same time period (i.e., using time series from ICESat and GRACE). By adding the capability to generate model internal layers (isochrones), we will use (2) for validating optimized and spun up model initial conditions. In the future, we anticipate that (2) will also be used as time-dependent constraints taken into account during the model initialization procedure.

III. EDUCATION

1a. Describe the Center's overall education goals and/or objectives. If the Center's overall education goals/objectives changed since the last reporting period, how did they change and why? [In section 2 below, please describe progress the Center has made toward reaching these goals and/or objectives.]

The goals of the education program are to educate a diverse group of graduate and undergraduate students on engineering and science topics related to ice sheets, climate change and remote sensing, and to inspire and encourage students in K-12 to pursue education in STEM fields. The objectives of the education program reproduced below remain the same as those stated in our renewal proposal.

The objectives, approach and metrics are discussed in the Center's Strategic and Implementation Plan. The specific objectives are as follows:

1. Develop and teach courses that broaden technical and scientific education across partner institutions using video-conferencing facilities;
2. Integrate Center research into science and engineering undergraduate and graduate courses;
3. Expand these courses to other disciplines by leveraging a new KU NSF-IGERT program known as *Climate Change, Humans, and Nature in the Global Environment* (C-CHANGE);
4. Educate students in subjects outside their primary discipline, such as geoinfomatics, glaciology and remote sensing;
5. Provide internship opportunities in industry;
6. Organize monthly "all-hands" meetings that include presentations on some aspect of the Center's mission;
7. Engage graduate and undergraduate students in Center decisions through the CReSIS student organization; and
8. Increase the pool of underrepresented graduate students through an exchange program, such as REU's between research universities and minority-serving institutions.

1b. Inform us of the performance and management indicators the Center has developed to assess progress in meeting its education goals/objectives, if changed from the previous reporting period.

Internal program evaluation for the 2013 CReSIS REU program has been completed and the CReSIS K-12 Ice, Ice Baby program evaluation will be completed by March 2014.

1c. Discuss any problems you may have encountered in making progress toward the Center's education goals/objectives during the reporting period as well as any problems anticipated in the next period. Include your plans for addressing these problems.

Funding for the 2013 REU program was provided by ADMI, CReSIS and remaining funds in the CReSIS-REU grant #ANT-0944255. The new three year REU grant PLR-1263061 began July 1 and is funded through the Arctic and Antarctic office of Polar Programs at NSF.

2a. Describe the Center's internal educational activities in the reporting period. Include in the narrative a discussion of how the various internal education activities enable the Center to meet its education goals/objectives described above.

A. To educate a diverse group of graduate and undergraduate students on engineering and science topics related to ice sheets, climate change and remote sensing

- CReSIS Student Organization (CSO)
- National/International Technical/Scientific Conferences
- Summer Internships and Training
- Center Subject Related Courses
- Research Experience for Undergraduates (REU) Program
- International Research and/or Study Abroad
- CReSIS All-Hands Meetings
- Cloudy View of Computing Summer Workshop at ECSU

B. To inspire and encourage students in K-12 to pursue education in STEM fields

- Classroom Visit/Informal Science & Engineering Activities
- Teacher Workshops/Support
- CReSIS Middle School Program
- Inquiry-based Science Curriculum

The Center’s education program is based on the stated goals and objectives of the Strategic and Implantation Plan. We developed and offered several graduate courses to provide multidisciplinary education and training focused on ice sheets, climate change, remote sensing and cyber-infrastructure. We continue to involve undergraduate students in research during the academic year and will also continue with the Research Experience for Undergraduates. We also provided graduate and undergraduate students with internship opportunities, as well as opportunities to attend major international conferences and workshops.

Table 6 below shows course(s) offered to students by CReSIS affiliated faculty to support their research and educational activities during Academic Year 2013-2014.

Table 6: Center Subject Related Courses

Activity Name	Center Subject Related Courses		
Led by	Center Faculty		
Course	Professor/Instructor	Intended Audience	Enrollment
AE 421 - Aerospace Computer Graphics	Rick Hale, KU	Undergraduate Students	26
AE 430 – Aerospace Instrumentation Labr	Shawn Keshmiri, KU	Undergraduate Students	20
AE 508 – Aerospace Structures II	Rick Hale, KU	Undergraduate Students	30
AE 592 – Spcl Prjct Arspc Eng Ugdl Stds	Rick Hale, KU	Undergraduate Students	1
AE 592 – Spcl Project Arspc Eng Ugdl Stds	Shawn Keshmiri, KU	Undergraduate Students	1
AE 507 – Aerospace Structures I	Mark Ewing, KU	Undergraduate Students	33
AE 508 – Aerospace Structures II	Rick Hale, KU	Graduate Students	30
AE 592 - Spcl Prjct Arspc Eng Ugdl Stds	Shawn Keshmiri, KU	Graduate Students	1
AE 790 – Spcl Prblm Arspc Engr Mst Stds	Shawn Keshmniri, KU	Graduate Studies	2
AE 709 – Structural Composites	Rick Hale, KU	Graduate Students	7
EECS 825 – Radar Systems	Prasad Gogineni, KU	Graduate Students	5
GEOL 791 – Advanced Topics in Geology	Leigh Stearns, KU	Graduate Students	7

Activity Name	Research Experience for Undergraduates (REU) Program
Led by	Dr. Linda Hayden and Dr. S. Prasad Gogineni

During 2013, REU students participated in research at ECSU, PSU, IU and KU. KU and ECSU coordinate recruitment of students and placed them at collaborating institutions based on student's interest and availability of an advisor to mentor the student. The total number of students involved in the REU program included 26 undergraduate students. Thirteen students participated at ECSU, two students were on-site at PSU for 1 week and spent the remainder of their time at ECSU, five students attended KU, and six students were placed at IU during June and July. Twenty-five of the twenty-six participants were funded through National Science Foundation REU supplement awarded to ECSU. Of the five students at KU, one student was funded by the School of Engineering at KU. Funds were also provided by the KU SELF program to support REU students activities.

Figure 73: KU CReSIS REU students participating in the 2013 Self Fellows Poster Symposium.

Students were teamed with faculty, staff, and graduate students in carrying out research with "deliverables". This year, the KU

CReSIS program worked specifically with 3 students who were math education majors in developing lesson plans for secondary students. Center staff at each of the host institutions organized a schedule that included Matlab tutorials, guest speakers, professional development activities and student research presentations and social activities/events.

CReSIS faculty, staff and GRA mentors worked with student(s) to define and develop their research projects, meeting with students on a weekly basis to discuss issues, concerns and information related to research, reviewing and providing feedback on research poster and oral presentation.

Table 7: 2013 REU Program Demographics (CReSIS only):

	Number	Percent
Women	13	50%
White	3	12%
Black	21	81%
Hispanic	0	0%
Asian	0	0%
Native American	2	8%
Total	**26**	

Table 8: REU Projects included (Name/Project Title):

Name	School	Mentor(s)	Title	REU
Maya Smith	WSSU	Dr. John Paden	Analysis Functionality to enhance MATLAB default interpolation schema using mGstat	KU
Bernard Aldrich Jr.	JSU	Dr. John Paden	Implementing a Snake Tool to Track the Ice Surface and Ice Bottom in a Radar Echogram	KU
Renee Butler	HINU	Dr. David Braaten	Accumulation Layer Picking	KU
Tyler Berry	HINU	Dr. Fernando Rodriguez-Morales	Dielectric measurements using a vector network analyzer	KU
Tamara Gaynes	KU	Dr. Fernando Rodriguez-Morales	Measurements and simulations for the optimization of a microwave FMCW radar	KU
Justin Deloatch	ECSU	Dr. Geoffrey Fox	Utilizing HUBzero to Create an Educational Hub for CReSIS Educational Data Sets	IU
Derek Morris Jr.	ECSU	Dr. Gregor van Laskewski	From 0 to 100: Cloud computing for the Non-Programmer	IU
Dorias Brown	Spelman	Mr. Jerome Mitchell	Estimating Surface and Bedrock layers in Polar Radar Imagery using Active Contours	IU
Zazie Lumpkin	Spelman	Mr. Jerome Mitchell	Estimating Surface and Bedrock layers in Polar Radar Imagery using Active Contours	IU
Donquel Davis	WSSU	Mr. Jerome Mitchell	Estimating Surface and Bedrock layers in Polar Radar Imagery using Active Contours	IU

Malcolm McConner	ECSU	Dr. Darnell Johnson	Using Common Core State Standards of Seventh Grade Mathematics in the Application of NXT LEGO® Robotics for CReSIS Middle School Students	ECSU
Jessica Hathaway	ECSU	Dr. Darnell Johnson	Using Common Core State Standards of Seventh Grade Mathematics in the Application of NXT LEGO® Robotics for CReSIS Middle School Students	ECSU
Ricky Dixon	MVSU	Dr. Darnell Johnson	Using Common Core State Standards of Seventh Grade Mathematics in the Application of NXT LEGO® Robotics for CReSIS Middle School Students	ECSU
Kelechi Onyiriuka	ECSU	Dr. Malcolm LeCompte	Early North Carolina Colonial and Native American GPR Site Surveyal	ECSU
Michael Cobb	ECSU	Dr. Malcolm LeCompte	Early North Carolina Colonial and Native American GPR Site Surveyal	ECSU
Rashad Williamson	MVSU	Dr. Malcolm LeCompte	Early North Carolina Colonial and Native American GPR Site Surveyal	ECSU
Dorothy Brice	VUU	Jeff Wood	A comparative study of the 2011/2013 water quality assessments in the Pasquotank Watershed in Northeastern North Carolina	ECSU
Robin Brice	FSU	Jeff Wood	A comparative study of the 2011/2013 water quality assessments in the Pasquotank Watershed in Northeastern North Carolina	ECSU
Anthony Lynn	WSSU	Jeff Wood	A comparative study of the 2011/2013 water quality assessments in the Pasquotank Watershed in Northeastern North Carolina	ECSU
Courtney Farmer	ECSU	Je'aime Powell	Terascan Curriculum Development and Integration of Remote Sensing Technology into the Classroom	ECSU
Kalyx McDonald	MVSU	Je'aime Powell	Terascan Curriculum Development and Integration of Remote Sensing Technology into the Classroom	ECSU
Jazette Johnson	Spelman	Je'aime Powell, Jerome Mitchell (IU)	Developing a Remote Sensing and Cloud Computing Curriculum for the Association of Computer/Information Sciences and Engineering Departments at Minority Institutions	ECSU
Jimil Perkins	NSU	Je'aime Powell, Jerome Mitchell (IU)	Developing a Remote Sensing and Cloud Computing Curriculum for the Association of Computer/Information Sciences and Engineering Departments at Minority Institutions	ECSU
Michael Chamberlain	UC Berkley	Peter Burkett, Dr. Sridhar Anandakrishnan	Using CReSIS airborne RADAR to constrain ice-volume influx across lateral shear margins into the Northeast Greenland Ice Stream.	Penn State
Emma Reeves	Hamline	Peter Burkett, Dr. Sridhar Anandakrishnan	Using CReSIS airborne RADAR to constrain ice-volume influx across lateral shear margins into the Northeast Greenland Ice Stream.	Penn State

Former CReSIS REU Students Update

Joyce Bevins and Jean Bevins, two former REU students have matriculated into graduate programs at Indiana University. They began their respective programs in the fall 2013.

Tyler Berry, KU CReSIS REU student, was accepted into the KU School of Engineering, Mechanical Engineering program and will begin his coursework in the Fall 2013. Tyler and another REU student Tamara Gaynes are now employed as Undergraduate Student Research Assistants at CReSIS KU.

Andrew Brumfield, former ECSU CReSIS REU student, began his graduate program in remote sensing program in the fall 2013 at ECSU.

Activity Name	International Research and/or Study Abroad
Led by	Dr. Prasad Gogineni (KU); Dr. A.R. Harish (IIT-Kanpur), Carlos Cárdenas (Universidad de Magallanes)
Intended Audience	Select Faculty/Staff, Graduate/Undergraduate Students
Approx Number of Attendees (if appl.)	3-5 per year

CReSIS hosted two international students for the spring 2013 semester. Ulrik Nielsen, a Ph.D. student at the Technical University of Denmark (DTU), specializes in electromagnetics, signal processing, mathematics, and radar systems. His Ph.D. research focuses on surface clutter suppression techniques for radar ice sounding. Christian Panton, a Ph.D. student at the University of Copenhagen, also spent time at CReSIS to further his work on automated internal layer tracing. His research interests are in mapping internal ice layers to understand ice sheet dynamics and mass balance, and his work intersects the fields of computer science and climate research.

Another international student, Abhishek Awasthi from IIT-Kanpur will spend two months during spring 2014 at CReSIS KU working on the effects of mutual coupling of antenna arrays with CReSIS researchers Prasad Gogineni and Stephen Yan.

Activity Name	CReSIS All-Hands Meetings
Led by	Selected Faculty, Invited Presenters, Staff and Students
Intended Audience	CReSIS staff, faculty, students and partner organizations
Approx Number of Attendees	Varies; average of 20-30

The purpose of the All Hands presentations include: (1) to connect CReSIS partner organizations through our Polycom system so they can share their areas of expertise; (2) to provide students an opportunity to improve their oral presentation skills and; (3) to provide staff, students and faculty opportunities to learn about ongoing Center research and/or topical issues related to CReSIS research. Presentations held Spring 2013 through Spring 2014 are listed (April-March) and future presentations are currently being scheduled.

Table 9: CReSIS All Hands Meetings

Date	Title	Name	Affiliation	External/ Internal
3/6/13	*Insights Into Ice-Sheet Dynamics from Radar Sounding*	Joe MacGregor	University of Texas at Austin	External
4/10/13	*Tracing Internal Layers from Radio Echo Sounding*	Christian Panton	University of Copenhagen	External
4/29/13	*Antarctic Sea Ice Thickness and Iceberg Distributions from Satellite and Airborne Altimetry in the Bellinghausen and Amundsen Sea*	Steve Ackley	University of Texas at San Antonio	External
5/24/13	*How Ice Sheets Work*	Patrick Applegate	Penn State	External (hosted by CSO)
6/6/13	*Surface Clutter Suppression Techniques for Radar Ice Sounding*	Ulrik Nielsen	Denmark Technical University	External
6/19/13	*The Effects of Changing Climate on Future Fire Regimes in Yellowstone*	Erica Smithwick	Penn State	Internal (hosted by CSO)
6/20/13	*Climate Change and CReSIS*	Richard Alley	Penn State	External
7/25/13	*2013 KU CReSIS REU Students Research Presentations*	Aldrich, Berry, Butler, Gaines, & Smith	CReSIS REU Students	External
7/19/13	*Applying for a NASA Fellowship*	Theresa Stumpf & Jerome Mitchell	CReSIS, University of Kansas & Indiana University	External
10/17/13	*Isotopes and impurities (including volcanic eruptions), and dating of ice cores*	J.P. Steffensen	The Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen	External
10/18/13	*Future Plans for the Center*	Prasad Gogineni	CReSIS, University of Kansas	Internal
11/7/13	*Preferred Ice Crystal Orientation Fabric Measurements within the Greenland Ice Sheet Using Multi-Polarization Radar Data*	José Vélez González	CReSIS, University of Kansas	External
3/8/14	*REU Mentoring/ OpenPolarServer, a New Face for CReSIS Data*	Kyle Purdon	CReSIS, University of Kansas	External
4/22/14	*Active-Target Multistatic Receiver Digital Section for CReSIS Radar Calibration*	Sam Buchanan	CReSIS, University of Kansas	Internal

Activity Name	CReSIS Student Organization (CSO)
Led by	Darryl Monteau

The CReSIS Student Organization (CSO) has been active for the spring 2013 and fall 2013 semesters. The group has been working to include students at partnering campuses to participate in more interactive events/activities.

CSO Activities from March through December 2013:

- Monthly breakfast socials
- REU Meet and Greet
- Royals Game with CSO and REU students
- Professional Development Workshops held – “Time and Stress Management” October 2013 and “Using Social Media/Linked In for Job Search” November 2013

Current Activities/Future Plans:

- Coordinating a speaker series (fall 2013/spring 2014).
- Refreshments (morning/afternoon) for students
- More social events and activities depending on funds
- Virtual meetings/social networking with CSO students at partnering institutions

Officers for Spring 2013: Brandon Gillette, President, Steve Foga, Vice-President and Kyle Purdon, Social Activity Chair

Officers for Fall 2013: Theresa Stumpf, President, Open - Vice-President

2b. Summarize the participation of Center students in professional development activities in the reporting period. Include in the narrative a discussion of how the various professional development activities enable the Center to meet its goals/objectives and produce meaningful results.

Activity Name	Regional/National/International Technical/Scientific Conferences
Led by	Select Graduate/Undergraduate Students

CReSIS GRA Jerome Mitchell delivered two presentations at the **Radio Echo Sounding Layer Tracing Workshop** in Copenhagen, Denmark in May 2013. His presentations were titled “*Automatically Estimating Near Surface Layers from Polar Radar Imagery*” and “*Visions - Mapping Greenland's radiostratigraphy efficiently and prediction, flattening and quality control.”*

JerNettie Burney and Robin Evans, IU CReSIS graduate students, participated in the ADMI/Science Gateway institute. The ADMI Introduction to **Science Gateways Workshop was held August 6-8, 2013** on the campus of Elizabeth City State University in the Center of Excellence in Remote Sensing Education and Research and featured speakers included Dr. Michael McLennan of Purdue University’s Rosen Center for Advanced Computing, Dr. Rion Dooley of the Texas Advanced Computing Center, and Dr. Stephanie Barr of the National Center for Atmospheric Research. This workshop introduced participants to common uses of Science Gateway, highlighted several approaches to modern gateway design, and walked them through the process of building and customizing gateways science discipline using existing platforms while learning from others who are doing the same thing.

Figure 74: ADMI graduate students, IT personnel and faculty are shown during the summer science gateway workshop.

Jerome Mitchell, CReSIS GRA and Indiana University Ph.D. candidate, represented CReSIS at the **IGARRS 2013 annual conference held in Melbourne, Australia in August 2013**. He presented a poster titled “A semi-automatic approach for estimating near surface internal layers from snow radar imagery”.

Jose Velez-Gonzalez presented a talk titled “Preferred Ice Crystal Orientation Fabric Measurements within the Greenland Ice Sheet Using Multi-Polarization Radar Data” at the 2013 AGU meeting in San Francisco.

Maya Smith and Bernard Aldrich, 2013 CReSIS REU students, were invited to serve as volunteers during SuperComputing 2013 in November in Denver, Colorado.

The Center for Remote Sensing of Ice Sheets (CReSIS) at the University of Kansas hosted the **International Glaciological Society’s (IGS) International Symposium on Radioglaciology in Lawrence, Kansas, September 9-13, 2013.** Several CReSIS students participated though both oral presentations and a student poster session.

Oral Presentations

- **Jerome Mitchell:** *A survey of techniques for detecting layers in polar radar imagery*
- **Kiya Riverman:** *North East Greenland Ice Stream basal conditions from reflection seismology and ice-penetrating radar*
- Nicholas Holschuh-Nicholas: *The Implications of Reflector Geometry on Radar Data Acquisition*
- **Brooke Medley:** *Constraining the recent sea-level contributions of Pine Island and Thwaites glaciers, West Antarctica, using CReSIS ultra-wideband airborne radar systems*
- **Aqsa Patel:** *Interpretation of CryoSat-2 waveforms using CReSIS Ku-band altimeter data*

Posters Session

- **Emily J. Arnold:** *Challenges and Limitations in Designing and Integrating Airborne Antenna Arrays Used for Remote Sensing*
- **Tyler Berry:** *Dielectric Measurements Using A Vector Network Analyzer for Greenland and Antarctica Ice Sheets*

- **Sarah F. Child:** *Insight into the existence and possible implications of "surface waves" on Byrd Glacier*
- **Donquel Davis (WSSU):** *Estimating Surface and Bedrock layers in Polar Radar Imagery using Active Contours*
- **Michael Jefferson, III (ECSU):** *Survey of the NASA basal stress boundary in the vicinity of Elizabeth City State University Bay and West Antarctic Peninsula*
- **Cameron Lewis:** *Sounding of Subglacial Nunatak Ridges in West Antarctica Using a UHF Radar*
- **Ali Mahmood:** *Development of High Frequency Radar Depth Sounder*
- **Jimil Perkins (NSU):** *Developing a Remote Sensing and Cloud Computing Curriculum for the Association of Computer/Information Sciences and Engineering Departments at Minority Institutions*
- **Kyle Purdon:** *OpenPolarServer: An open source, field deployable, spatial data infrastructure*
- **Soroush Rezvanbehbahani:** *Improving the geothermal heat flux estimates in Greenland Ice Sheet using radar detected basal water*
- **Kiya Riverman:** *Ice thickness and density of the Pine Island Glacier floating ice shelf*
- **Maya Smith (WSSU):** *Analysis Functionality to enhance MATLAB default interpolation schema using mGstat*
- **Theresa Stumpf:** *UWB MIMO SAR for Imaging the Ice-Bed Interface of Polar Ice Sheets over a Wide Swath*
- **Jose Velez:** *Using Seismic Observations to Detect Deformable Ice Layers at the Base of Jakobshavn Glacier and Comparison to Radar Imaging*

The IGS Symposium included presentations from international researchers and provided a forum for participants from around the world to exchange scientific information. The symposium involved technological improvements in radars and signal processing techniques for exploring ice-sheets, glaciers and their geophysical settings. CReSIS co-hosted the symposium with the University of Kansas, the KU School of Engineering and the National Science Foundation (NSF). The symposium included a banquet and a trip to the Kansas Flint Hills, a prairie and nature preserve outside Lawrence. An article on the event can be found at: https://www.cresis.ku.edu/news/icebreaker/2013/cresis-reu-students-participate-2013-igs-symposium and additional information can be found in Section IV: Knowledge Transfer.

The **2013 WAIS Workshop was held at the Algonkian Meeting Center in Sterling, Virginia September 29th through October 2, 2013**. This multidisciplinary Earth system science workshop focused on the distinctive glaciological, geological, oceanographic, and climatic aspects of the West Antarctic Ice Sheet. The West Antarctic Ice Sheet (WAIS) initiative is a multidisciplinary research program designed to answer two critical, interrelated climate questions: How will the unstable West Antarctic ice sheet affect future sea level? How do rapid global climate changes occur?

The Center of Excellence in Remote Sensing Education and Research (CERSER) at Elizabeth City State University was represented by Dr. Malcolm LeCompte (Research Fellow, retired) and Mr. Michael Jefferson (Grad Student) who presented their research titled “Survey of the NASA basal stress boundary in the vicinity of Elizabeth City State University Bay and West Antarctic Peninsula” during the poster session. This research focuses on the gradual reduction of a small ice shelf in the Pine Island Bay area which was discovered and examined using eleven Landsat images spanning 1972 to 2003 by Dr. LeCompte and his students. Dr. Sridar Anandakrishnan, from Penn State University, representing the Center for Remote Sensing of Ice Sheets (CReSIS) also presented "New constraints on the ocean cavity beneath the Pine Island Glacier Ice Shelf, Antarctica." Webpage: http://nia.ecsu.edu/ur/1314/130929wais/

Activity Name	CReSIS Student Professional Presentations and Publications
Led by	Select Graduate/Undergraduate Students

Xiushan Jiang and Brandon Gillette (CReSIS Education GRAs) presented at the 2013 American Educational Research Association (AERA) annual conference in April 2013. The title of the presentation is “How Effective Is Problem-based Learning in K-12 STEM Education Compared to Lecture-based Learning? A Meta-analysis of Quantitative Studies from 1990 to 2012.”

Xiushan Jiang (CReSIS Education GRA) presented at the 2013 American Educational Research Association (AERA) annual conference in April 2013. The title of his presentation is “A Meta-analysis of the Effectiveness of the Problem-based Learning in College STEM Education Compared to Lecture-based Learning.”

Kuang Chen-Hsu’s (CReSIS Education GRA) had his publication titled “Implementation of an E-book in the Facilitation of Polar Science Education: A case study” accepted to the E-Learn 2013 World Conference for presentation. The conference was held October 21-24, 2013 in Las Vegas, Nevada.

Levi Houk (CReSIS Student Education Employee), Brandon Gillette (former CReSIS GRA/KU ABD), and Cheri Hamilton (CReSIS K-12 Educational Outreach Coordinator will have their article titled “Modeling the physical properties of glaciers" published in *Science Scope* later this year.

Activity Name	Research and Training Opportunities
Led by	Select Graduate/Undergraduate Students

Jerome Mitchell and Theresa Stumpf were awarded the NASA Earth and Space Science Fellowship (NESSF) and Emily Arnold’s fellowship, which was first awarded last year, was renewed for another year. Fewer than 17 percent of all applicants were selected for the Earth Science research award this year. The fellowship provides $30,000 to recipients, which includes funds for living expenses, research materials, travel funds and university expenses.

- Mitchell, a Graduate Research Assistant (GRA) at Indiana University, is a Ph.D. student in Computer Science. The fellowship will support Mitchell’s research project, called “Developing Machine Learning Algorithms to Access Bedrock and Internal Layers in Polar Radar Imagery.”
- **Stumpf** is a GRA at the University of Kansas, where she is a Ph.D. student studying Electrical Engineering and Computer Science. Her project is entitled “Ultra-Wideband, Wide-Swath Radar Imaging of the Ice-Bed Interface for Generating Fine Resolution Bed Topography and Quantifying Basal Conditions.”
- Arnold’s NASA fellowship was renewed for a second year. She completed her dissertation, “Development and Improvement of Airborne Remote Sensing Radar Platforms,” and is working at MITRE Corp. Her dissertation dealt with how to integrate large antenna arrays on aircraft and how to correct errors introduced by wing flexure and other effects.

Je'aime Powell was awarded the Student Leadership-Graduate Level award during the National Black Engineer of the Year Awards (BEYA) HBCU Engineering Deans' Power Breakfast held during the BEYA Science, Technology, Engineering, and Mathematics (STEM) Global Competitiveness Conference which took place in Washington, D.C., February 7-9, 2013. The BEYA Awards Ceremony recognized the achievement of African-American leaders in the STEM fields.

Sam Buchanan, an undergraduate research assistant at the Center for Remote Sensing of Ice Sheets (CReSIS), was awarded the KU Undergraduate Research Award (UGRA) for the 2014 spring semester. The award, which has been around for over 20 years, provides $1,000 of support for independent, original research, scholarship, or creative work by undergraduates at the University of Kansas Lawrence Campus. Sam's research project involves the implementation of the digital signal processing section of CReSIS' Active Target Multistatic Receiver (ATMR) system, which will be deployed in the field this August, according to Buchanan. His mentor is Dr. John Paden, KU CReSIS Assistant Research Professor.

CReSIS student researcher Kyle Purdon was awarded first prize at the University of Kansas' (KU) 2013 GIS Day for a paper on an open source field deployable spatial data infrastructure. His paper, "OpenPolarServer: An open source, field deployable, spatial data infrastructure," won first place. "The OpenPolarServer (OPS) project aims to develop a free and open source spatial data infrastructure (SDI) to store, manage, analyze, and distribute data collected by CReSIS," according to Purdon's paper.

2c. Describe the Center's external educational activities in the reporting period. Include in the narrative a discussion of how the various external educational activities enable the Center to meet its goals/objectives and produce meaningful results.

Activity Name	Classroom Visit/Informal Science & Engineering Activities
Led by	Select Participants

Education outreach activities were expanded to find creative ways to engage high school students. Although the majority of our efforts remain in the elementary classrooms, due to long term partnerships with these schools and teachers, a greater emphasis was placed on high-school curriculum development and outreach.

Our K-12 outreach coordinator and the K-12 team continues to focus on making community connections, assisting with online high-school curriculum expansion, and concentrating on article submissions and presentations at conference such as National Science Teacher Association (NSTA). The three schools the CReSIS K-12 Educational Outreach are working with include John Fiske Elementary in Kansas City, KS (68 4th grade students; 79% free and reduced lunch, 67.6.% Hispanic,10.8% % black, 16% white,3.4% Asian, ELL 70%), Whittier Elementary in Kansas City, KS (107 students 4th grade, and 110 students 5th grade 97 % Free and reduced lunch, 73.6 % Hispanic, Black 11.9%, White 8.3% 5.4% Asian and ELL 63.8%), and Mark Twain Elementary in Kansas City, Kansas (46 students in 4th grade, 65.2% Hispanic, 16.74% African American, 10.57 White, and ELL 65%).

Table 10: KU CReSIS K-12 Educational Outreach Programs/Events/Presentations

Date	Activity Name	Location	Presenters	Target	#	Activity
4/1/2013	Whittier Elementary	KCK (Garcia, Hathaway, Quinteros)	Hamilton	4th	64	Water displacement
4/6/2013	Blue Springs High School	KU	TJ Stastny	High school	10	CReSIS information, airport, UAV lab
4/8/2013	Whittier Elementary	KCK (Donaldson, Conover)	Hamilton	4th	66	Water displacement
4/11/2013	John Fiske Elementary	KCK (Flores, Skipton, Hull)	Hamilton	4th	62	Water displacement
4/16/2013	Southwest Middle School	Lawrence, KS	Marcie Leuschen	6th	35	Remote Sensing IIB
4/18/2013	Southwest Middle School	Lawrence, KS	Marcie Leuschen	6th	32	Ice Bridge- Communicating with flight
4/20/2013	KATS Camp	Rock Springs, KS	Leinmiller-Renick	teachers	45	Grounding line lesson and sea level rise
4/26-30/2013	AERA Presentations	San Francisco, CA	Gillette, Xiushan	college students and professors	46	*How Effective is Problem-Based Learning in K-12 STEM Education Compared to Lecture-Based Learning?*
4/30/2013	Santa Fe Trail Science Night	Olathe, KS	Hamilton	middle school	225	CReSIS Information and glaciers with goo
5/6/2013	Whittier Elementary	KCK (Garcia, Hathaway, Quinteros)	Hamilton	4th	64	Ice Cores and Greenland Field Experience
5/9/2013	John Fiske Elementary	KCK (Flores, Skipton, Hull)	Hamilton	4th	62	Ice Cores and Greenland Field Experience
5/13/2013	Whittier Elementary	KCK (Donaldson, Conover)	Hamilton	4th	66	Ice Cores and Greenland Field Experience
5/16/2013	NSTA Conference	St. Louis	Gillette	teachers	13	On line data portal lessons
5/17/2013	NSTA Conference	St. Louis	Hamilton and Teri Fulton	teachers	6	Science is Elemantary-CReSIS information
6/5/2013	KU Engineering Camp	Lawrence, KS	Hamilton	6th and 7th	72	Glaciers and CReSIS information
6/8/2013	Natural History Museum	Lawrence, KS	Hamilton, Xiushan, Kuang	K-6 and parents	150	Ice Ice Baby Actvities and CReSIS information
6/19-20/2013	ECSU Middle School Workshop	Elizabeth City, NC	Hamilton	6th	12	Glacier Goo Inquiry and CReSIS field work
7/8/2013	Discover Technology Summer Camp	Lawrence, KS	Hamilton	7th	43	Climate change and glacier goo

9/9/2013	Whittier Elementary	KCK	Hamilton	4th	56	Water Demo and Earth Ball Toss- CReSIS Pieces
9/10/2013	John Fiske Elementary	KCK	Hamilton	4th	66	Water Demo and Earth Ball Toss- CReSIS Pieces
9/11/2013	Eisenhower Middle School	KCK	Hamilton	Middle and high teachers	75	Science Questioning- Questioning Formula Technique
9/16/2013	Whittier Elementary	KCK	Hamilton	4th	38	Water Demo and Earth Ball Toss- CReSIS Pieces
9/18/2013	Quindaro Elementary	KCK	Hamilton	Elementary teachers	34	Science Questioning- Questioning Formula Technique
9/19/2013	Mark Twain Elementary	KCK	Hamilton	4th	67	Water Demo and Earth Ball Toss- CReSIS Pieces
9/27/2013	STEM Career Fair	Dulles, VA	ECSU Grad students	K- adult	1,000	Glaciers and CReSIS information
9/27/2013	STEM Career Fair	Dulles, VA	ECSU Grad students	Pre-service teachers	35	CReSIS information and Glacier animation
9/28/2013	STEM Career Fair	Dulles, VA	ECSU Grad students	K- adult	1,000	Glaciers and CReSIS information
10/7/2013	Whittier Elementary	KCK	Hamilton	5th	64	Global warming-IIB # 5.1
10/14/2013	Whittier Elementary	KCK	Hamilton	4th	57	Water Properties- IIB # 3.1
10/15/2013	John Fiske Elementary	KCK	Hamilton	4th	66	Water Properties- IIB # 3.1
10/17/2013	Mark Twain Elementary	KCK	Hamilton	4th	38	Water Properties- IIB # 3.1
10/18/2013	Robinson Middle School	Topeka, KS	Houk	7th	152	Freezing Friday Remote Sensing of Ice Sheets
10/21/2013	Whittier Elementary	KCK	Hamilton	4th	38	Water Properties- IIB # 3.1
10/28/2013	Whittier Elementary	KCK	Hamilton	5th	67	Global warming-IIB # 5.1
11/1/2013	West Middle School	Lawrence, KS	Houk	6th	70	Freezing Friday Remote Sensing of Ice Sheets
11/4/2013	Whittier Elementary	KCK	Hamilton	5th	69	Global Warming- IIB # 5.2
11/7-8/13	NSTA Conference	Charlotte, NC	Hamilton, Fulton	Middle school teachers	8	Remote Sensing IIB #6.1
11/8/2013	West Middle School	Lawrence, KS	Houk	6th	70	Freezing Friday Glacier Goo
11/11/2013	Whittier Elementary	KCK	Hamilton	4th	68	States of Matter- IIB #3.2
11/12/2013	John Fiske Elementary	KCK	Hamilton	4th	68	States of Matter- IIB #3.2

11/14/2013	Mark Twain Elementary	KCK	Hamilton	4th	42	States of Matter- IIB #3.2
11/15/2013	West Middle School	Lawrence, KS	Houk	6th	70	Freezing Friday, Salt Ice experiment with Polar Food Chain
11/18/2013	Whittier Elementary	KCK	Hamilton	4th	38	States of Matter- IIB #3.2
11/21/2013	Quindaro Elementary	KCK	Hamilton, Fulton	K-5	320	Science Fair judging and commenting
11/22/2013	Olathe North High School	Olathe, KS	Hamilton	High School students, families	300	Glaciers and CReSIS information
11/25/2013	Whittier Elementary	KCK	Hamilton	5th	46	Global warming-IIB # 5.2
12/9/2013	Whittier Elementary	KCK	Hamilton	4th	69	Glacier Dynamics- IIB #2.5
12/10/2013	John Fiske Elementary	KCK	Hamilton	4th	68	Glacier Dynamics- IIB #2.5
12/12/2013	Mark Twain Elementary	KCK	Hamilton	4th	42	Glacier Dynamics- IIB #2.5
12/13/2013	Robinson Middle School	Topeka, KS	Houk	7th	152	Freezing Friday Glacier Goo
1/20/2014	John Fiske Elementary	KCK	Hamilton	4th	68	Glacier Dynamics- IIB #2.5
1/9/2014	Mark Twain Elementary	KCK	Hamilton	4th	43	Glacier Dynamics-IIB# 2.2
1/27/2014	Whittier Elementary	KCK	Hamilton	4th	69	Glacier Dynamics- IIB #2.2
1/28/2014	Whittier Elementary	KCK	Hamilton	4th	46	Glacier Dynamics- IIB #2.2
1/31/2014	French Middle School	Topeka, KS	Houk	7th	174	Freezing Friday Remote Sensing of Ice Sheets
2/8/2014	Southwest Middle School Science Expo	Lawrence, KS	Hamilton	Middle school and families	250	CReSIS Information and glaciers with goo
2/10/2014	Whittier Elementary	KCK	Hamilton	4th	69	Glacier Dynamics- IIB #2.6
2/11/2014	John Fiske Elementary	KCK	Hamilton	4th	68	Glacier Dynamics- IIB #2.6
2/13/2014	Mark Twain Elementary	KCK	Hamilton	4th	43	Glacier Dynamics-IIB# 2.6
2/13/2014	Mark Twain Elementary Science Night	KCK	Hamilton	K-5 and families	250	Glacier Dynamics and CReSIS
2/20/2014	Westridge Middle School Family Fun	Overland Park, KS	Hamilton	Middle school and families	300	CReSIS Information and glaciers with goo
2/24/2014	Whittier Elementary	KCK	Hamilton	5th	73	Glaciers and slope

**Activity key: Pink – grade school; Purple – middle school; Blue – high school; Green – K-12; Red – teachers.*

Total number of outreach participants = 6,879

Additional K-12 outreach activities include:

- Continued partnership with the Science Museum of Minnesota to produce content for a Science Buzz Kiosk that is currently housed at the Natural History Museum in Lawrence, KS. Revised content and photos have been uploaded in response to shortened viewing at the museum. The content is also available on the Science Buzz website: http://www.sciencebuzz.org/kiosks/future/cresis/ice.
- The interactive media for use in the *Ice, Ice, Baby!* lessons is completed and available on the CReSIS website. The flash animation is titled "Glaciers in Motion" and is ready for public use. Feedback on the animation is now available and will be used to assist K-12 in making improvements to the content. (*Ongoing) Polar Opposites, an online game teaching about polar opposites is now available on our site as well.*

Activity Name	Teacher Workshops and Support
Led by	Select Center Faculty, Staff, and Students at KU, ECSU, and PSU

K-12 Educational Outreach staff gave presentations at national conferences, workshops for K-12 science educators and facilitated in-service training days for teachers (refer to Table 4). Several presentations to elementary, middle and high-school teachers were on teaching students to ask their own science questions through the question formula technique. This year "Freezing Friday's" continues to travel to middle school classrooms for CReSIS related science lessons taught by a pre-service KU student.

Activity Name	CReSIS Middle School/High School Programs
Led by	Select Center Faculty, Staff, and Students at ECSU

CReSIS High School Robotics Program: During summer 2013, students at I.C. Norcom High School in Portsmouth, Virginia explored the use of autonomous robotics in industry and research; the engineering design cycle and the fundamentals of robot design and worked with a team mentor on projects which involved learning the fundamentals of earth science. Participants also learned analysis and robot prototyping, testing and optimization of robot design, and VRC Gateway game rules.

CReSIS Middle School Program: During summer 2013, selected students worked with a Team mentor on projects that involved learning the fundamentals of earth science. Participants also learned about remote sensing and satellite imagery, how to take atmosphere and hydrology measurements, learned about the Polar Regions, published their research projects and collaborated with scientists and faculty.

2013 NASA Summer of Innovations at Elizabeth City Middle School The NASA 2013 Summer of Innovation (SOI) project challenged middle-school students across the United States to share in the excitement of scientific discovery and space exploration through unique, NASA-related science, technology, engineering and mathematics, or STEM, opportunities. The Center of Excellence in Remote Sensing Education and Research (CERSER) sponsored by Dr. Linda B. Hayden at Elizabeth City State University welcomed the opportunity to implement SOI NASA Robotics with students at Elizabeth City Middle School.

Figure 75: (Left) CReSIS educator Cheri Hamilton is shown teaching middle school students about glaciers. (Right) High School Robotics team shares information with local elementary school students.

In partnership with 8th grade science teacher Mrs. Wanda Hathaway students were selected to participate in the NASA Summer of Innovation Mini-Awards program after school three times per week. Student participants were exposed to 20 hours of Robotic based instruction. NASA SOI robotics lessons, robotics engineering using LEGO MINDSTORMS, and electronics demonstrations from Virginia Air and Space Center were all incorporated through the NASA SOI session which lasted from early October to mid-December. Webpage: http://nia.ecsu.edu/ur/1314/131216nasasoi/

On September 27th and 28, 2013, representatives from Elizabeth City State University's Center of Excellence in Remote Sensing Education and Research (CERSER) presented at the National Science Foundation's "Change the World" Science and Engineering Career Fair as part of the Center for the Remote Sensing of Ice Sheets (CReSIS) Education Outreach program. CERSER staff and students presented interactive lessons ranging from "Ice, Ice, Baby" lessons utilizing "Goo" to represent glacier movement to online tutorials and quizzes presenting knowledge of the Antarctic, Arctic, and Greenland ice masses. Dr. Linda Hayden, Director of the CERSER program and CReSIS Associate Director – Education and ECSU Operations supervised the presentation and assisted a group of elementary, high school, college students, and teachers from the Elizabeth City area who arrived on Saturday for the presentations.

The Celebration of Women in Mathematics was held on October 15, 2013 at Elizabeth City State University with 368 girls and 40 teachers attending. This event is sponsored by the Center for the Remote Sensing of Ice Sheets (CReSIS), NASA NICE Program, and the Center of Excellence in Remote Sensing Education and Research (CERSER). Celebration of Women in Mathematics consists of a program of workshops, talks, and math competitions for middle/high school girls and their teachers. The purpose of the program is to encourage young women to continue their study of mathematics and to raise the level of mathematics competency in Northeastern North Carolina. Webpage: http://nia.ecsu.edu/nrts/2013events/131015cwm/
Schools represented at this year's event included: Bertie Early College High School, Bertie High School, Bertie STEM High School, Camden County High School, Camden County Middle School, Central Middle School, Creswell High School, Elizabeth City Middle School, Gates County High School, H.L. Trigg Community School, Hertford County High School, Hertford County Middle School, Perquimans County Middle School, Plymouth High School and River Road Middle School

Activity Name	Inquiry-based Science Curriculum
Led by	Select Center Faculty, Staff, and Students

By year nine, five new online inquiry-based STEM curriculum lessons have been developed, focusing on grades 9–12. These lessons are designed to use real-world scientific data and allow for students to manipulate data to arrive at their own conclusions about climate change and other global environmental concerns. Topics include: sea level rise, atmospheric CO_2 concentrations, and glacier mass balance, to name a few. The goal is to continue expanding and revising these lessons as teacher input and pilot testing data are received. Areas of further development include: GIS mapping activities and remote sensing analysis. A new evaluation was added to the website for teachers who use our lessons in their classrooms. A new Ice Ice Baby lesson about glacial erosion was also added to make the total curriculum of 27 hands-on lessons.

2d. Describe and discuss the ways in which the Center integrated research and education in the reporting period, with examples as appropriate.

Many of the education programs discussed above integrate Center research. The following programs exemplify integration of research and education:

- ECSU Middle School Program – sea level rise, glacier mass balance, climate change
- K-12 Educational Outreach – Freezing Fridays and Ice, Ice Baby
- CReSIS-related courses

2e. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

- 4 Student papers
- 26 Student presentations/conference attendance
- 26 REU participants – 81% students from underrepresented groups (21 African American, 2 Native American); 50% women
- 12 ECSU Middle-school program participants
- 24 ADMI Conference student participants - 100% African American

2f. Describe your plans for internal and external educational activities for the next reporting period with attention to any major changes in direction or level of activity. Also, list plans for developing new educational partnerships, if any, for the next reporting period.

Internal Initiatives/Direction

- Continue to recruit underrepresented students, especially through the summer REU program, and other applicable KU departments. Continue building partnership with the School of Engineering recruitment team to ensure CReSIS continues to be represented in their recruitment events/outreach efforts;
- Expand student tracking mechanism to include all partner institutions to provide a clearer overall picture of recruitment, retention, demographics, research efforts, conference attendance, papers/publications, etc. for all CReSIS graduate and undergraduate students.

External Initiatives/Direction

- Continue to leverage the success of “Ice, Ice, Baby” lessons to reach more teachers and students through in-class visits, teacher training, and other activities;

- Continue “Freezing Fridays” program for middle schools allowing pre-service teachers to gain classroom experience.
- Enhance education resources available online through CReSIS Website. Continue bolstering 9-12 web-based lesson-plans;
- Begin targeted recruitment efforts by building relationships with local/regional colleges, universities, and community colleges; attend conferences/events that target underrepresented populations.
- CReSIS Education team has partnered with Dr. Ashanti Johnson and the Institute for Broadening Participation in an NSF proposal titled Pathways to Research on Diversity in Recruitment and Retention. CReSIS committed to participate in this project using data from REU program for an intensive evaluation effort.
- CReSIS Education worked with other STC Education and Diversity programs to develop a ‘white paper’ focusing on best practices for new Education and Diversity administration and staff. This effort was led by Barb Bruno, C-MORE Education Director and the final copy was shared with NSF directors and program officers in February 2014.

New Partnerships
CReSIS Education has joined with the Institute for Broadening Participation led by Dr. Ashanti Johnson in a proposal titled "Pathways to Research on Diversity in Recruitment and Retention!" The proposal was submitted to NSF Education and Human Research program with the goal of increasing the capacity of researchers to assess the impact of programs and program elements on the success and career trajectories of diverse STEM students. The project focuses on creating a Data and Research Management System (DRMS). The system would be useful to small student support programs in higher education for collecting data and conducting research on the impact of program elements on diverse students' success. The DRMS will also collect l data on program applicants and participants, and will be accessible to participating programs via a secure and user-friendly web-based interface. CReSIS REU is one of 5 existing student support programs that will participate in the grant.

Continued Partnerships
Continue relationship with Minnesota Science Museum “Science Buzz” program, which is a National Science Foundation funded program. The Museum contacted the Center to develop a Science Buzz Kiosk that is currently housed at KU Natural History Museum. The kiosk is currently operational.

ECSU serves as a TeraScan Remote Sensing training and satellite data collection facility for SeaSpace customers and clients on the East Coast. SeaSpace will set up and maintain its TeraScan equipment at ECSU's Center of Excellence in Remote Sensing Education and Research (CERSER). In exchange, ECSU faculty and students will be included in the training SeaSpace provides to its clients. The university also will receive software upgrades and support for the new antennas, servers and equipment at no charge.

Our K-12 Educational Outreach staff are currently working with Haskell Indian Nations University Teacher Education program in sharing information and materials for their pre-service teachers.

IV. KNOWLEDGE TRANSFER

1a. Describe the Center's overall knowledge transfer goals and/or objectives. If the Center’s overall knowledge transfer goals/objectives changed since the last reporting period, how did they change and why? [In section 2 below, please describe progress the Center has made toward reaching these objectives.]

The Knowledge Transfer goals of CReSIS are to:

- Transform a large volume of remotely-sensed data on ice sheets into new knowledge that can be readily shared.
- Assist in the professional growth of Center participants.
- Stimulate regional and national economic growth resulting from Center-developed, marketable technologies and capabilities.
- Inform the public and policymakers of significant ice-sheet changes and outline the implications of these changes on sea level.

The Knowledge Transfer objectives of CReSIS are to:

- Disseminate scientific and technical knowledge to peers.
- Commercialize Center-developed technologies and encourage entrepreneurial activities.
- Interact with, and provide information to, the general public on ice sheets – their importance and vulnerabilities.
- Provide information and expertise on climate change issues and their impacts to policymakers and the policy-development process at the state and federal levels.
- Provide Center participants with unique learning opportunities.

1b. Inform us of the performance and management indicators the Center has developed to assess progress in meeting its knowledge transfer goals/objectives.

In the second phase, the Center has continued to build on previously-established knowledge transfer initiatives, improved various tools related to the program (i.e., website, project plans, and quarterly newsletters), and expanded outreach. We updated the Strategic and Implementation Plan, including metrics, to determine our progress in meeting the stated goals and objectives of the knowledge transfer team.

Table 14. Knowledge Transfer Objectives/Metrics

Objective	*Metrics*
Disseminate scientific and technical knowledge to peers	• Invited presentations • Scientific/technical journal publications • Requests for CReSIS-generated data • Data sets archived/data volume • Estimated researchers using CReSIS-generated data
Commercialize Center-developed technologies and encourage entrepreneurial activities	• Commercialization contacts • Patent disclosures and awards • Start-up companies • Attendance and feedback on CReSIS-sponsored entrepreneurial workshops and technology expositions
Interact with, and provide information to, the general public on ice sheets – their importance and vulnerabilities	• Invited presentations • Outreach events conducted • Newsletter distribution, requests, feedback • Website inquiries/volume • Media events related to Center activities
Provide information and expertise on climate change issues and	• Policymaker participation in workshops • Congressional inquiries/Center visits

their impacts to policymakers and the policy-development process at the state and federal levels	
Provide Center participants with unique learning opportunities	• Distinguished Lecturer/All-Hands series presentations • Staff short courses, seminars, and workshops attended • Internship participation • International exchange/travel opportunities (incl. field work)

1c. Discuss any problems you have encountered in making progress toward the Center's knowledge transfer goals/objectives during the reporting period as well as any problems anticipated in the next period. Include your plans for addressing these problems.

We have encountered no major problems in making progress toward the Center's knowledge transfer goals or objectives.

2a. List organizations with which knowledge transfer occurs and the frequency and type of interactions. Describe the Center's knowledge transfer activities in the current reporting period and discuss how they enable the Center to meet its knowledge transfer goals/objectives listed in 1a above.

Disseminate Scientific and Technical Knowledge to Peers		
Led by	Center Faculty/Staff/Students	
Organizations Involved (add rows as necessary)		
Name		Address
1	5/6-5/10 – Prasad Gogineni (KU) presented "Ultra-Wideband Radar for Fine Resolution Mapping of Internal Layers from the Surface to the Bed" at the Radio Echo Sounding Layer Tracing Workshop	Copenhagen, Denmark
2	5/6-5/10 – D. Crandall, G.C. Fox, and J. Paden presented Automatic Identification of Ice Layers in Radar Echograms" at the Radio Echo Sounding Layer Tracing Workshop	Copenhagen, Denmark
3	5/6-5/10 – J. Mitchell, D. Crandall, G. Fox, and J. Paden presented "(Semi) Automatically Detecting Layers from Polar Radar Imagery" at the Radio Echo Sounding Layer Tracing Workshop	Copenhagen, Denmark
4	5/21 – Prasad Gogineni (KU) gave a presentation at the National Science Foundation.	Washington, D.C.
5	8/14-8/16 – Prasad Gogineni (KU) presented "UltraWideband Radars (FM-CW) for Snow Thickness Measurements" at the NASA Snow Remote Sensing Workshop.	Boulder, CO
6	9/2-9/4 – Prasad Gogineni (KU) presented "Radar Instrumentation for Polar Research: Status and Future" at a British Antarctic Survey Seminar	Cambridge, UK
7	9/29-10/2 – Ian Joughin (UW) presented "Sensitivity of Thwaites Glacier to Ice Shelf Melting at the WAIS Workshop	Sterling, VA

8	2/3-2/5 – K. Poinar and I. Joughin presented "How deep does a typical crevasse in Western Greenland carry meltwater?" at the IASC Workshop on the Dynamics and Mass Budget of Arctic Oceans	Ottawa, Canada

Outreach Efforts to Enhance Public Awareness of Climate Change and its Effects		
Led by	Center Faculty/Staff/Students	
Organizations Involved (add rows as necessary)		
Name		Address
1	11/9 – Ian Joughin (UW) Vanishing Ice Speaker Series: Getting to the Bottom of the Greenland Ice Sheet	Whatcom Museum Bellingham, WA

Conduct Center-Sponsored Workshops and Seminars at PSU, ECSU, and Other Partner Institutions		
Led by	Center Faculty/Staff/Students	
Organizations Involved (add rows as necessary):		
Name		Address
1	2/4/14 – 2/7/14 ECSU Research Week	ECSU
2	6/17/13 – 6/28/13 2013 CReSIS Middle School Program	ECSU
3	7/8/13 – 7/19/13 2013 CReSIS High School Program	ECSU
4	2013 NASA Summer of Innovations at Elizabeth City Middle School	ECSU
5	10/15/13 Celebration of Women in Mathematics	ECSU

Activity Name	Requests for CReSIS-Generated Data	
Led by	CReSIS Knowledge Transfer Team	
Intended Audience	Public	
1	Steve Roof requested information regarding how we archive data.	University of New Hampshire
2	Timothy D. James requested information about Helheim data set and requested custom radar imagery for a publication he was working on.	Swansea Univeristy
3	Joe Macgregor requested information on datasets and support for Layermap	University of Texas at Austin
4	Jacob Wang requested information about raw data usage.	Unknown
5	Rick von Flatem requested permission to use radar imagery in a publication.	Oilfield Review Magazine
6	Judith Nathaniel requested information about the sea level rise datasets.	Unknown
7	Wei Jiang requested access to CReSIS source codes.	Unknown

8	Alex Brisbourne requested SEGY converter codes.	British Antarctic Survey
9	Kamal Chapagain requested information about data ftp access and loading and displaying snow radar data.	Western Region Campus, Nepal
10	Bill Rymer requested publication references for radar depth sounder and tomographic processing.	IEEE
11	Rose Goina requested sea level rise maps and references.	Pacific Climate Change
12	Josh Macy requested help with KML files and finding datasets.	Unknown
13	Wesley Van Wychen and David Burgess requested updated and picked datasets in Canada that had not yet been picked and reposted.	Unknown
14	Konstantin requested access to Helheim and Kangerdlugssuaq glacier ice bottom DEMs.	University of Bremen
15	Robin Bell requested a search for layers in ice shelves.	Doherty Earth Observatory
16	Indrani Das requested code for elevation compensation and unpacking of snow radar imagery.	Doherty Earth Observatory
17	Paul Holland requested a repacking of ice shelf data to be more accurate and consistent.	British Antarctic Survey
18	Ute Herzfeld requested information about data access and use of layer data for gridding.	University of Colorado.
19	Mary Randolph requested use of the GIS data for sea level rise via ArcMap.	Unknown

2b. Describe any other outcomes or impacts of knowledge transfer activities not listed above. Discuss, in particular, applications of Center research in industry, Federal Laboratories or elsewhere not discussed above.

CReSIS Website:

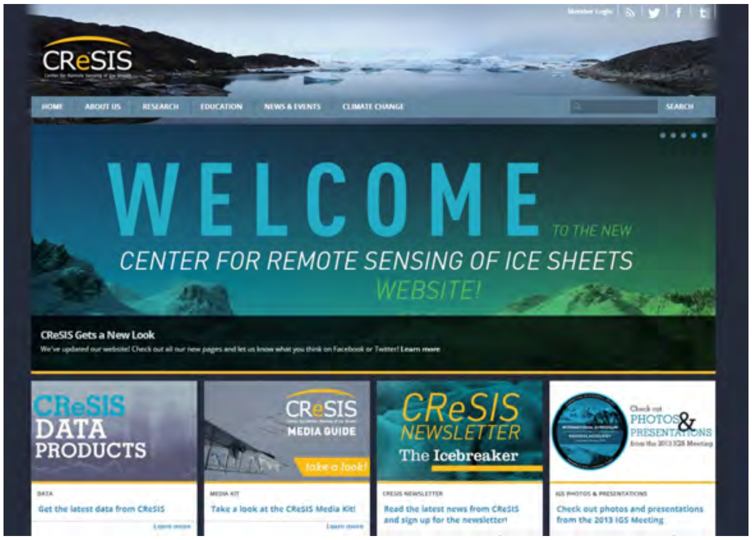
CReSIS Website Statistics	
Unique Visitors	29,311

CReSIS Website DATA PRODUCTS Statistics	
GB Transferred	3,554.08 GB
Files Downloaded	822,692
Unique Visitors	3,362

The statistics posted above reflect the amount of data (in GB) transferred from the site, the number of files downloaded, and the number of unique visitors. The website did not experience a significant increase in total visits over the last year. However, there was growth in our data products area over last year along with a much higher bandwidth utilization (e.g. more data products downloaded) on our dedicated data.cresis.ku.edu website. We anticipate that the ease of use with the new website will encourage additional visits as a result of key search terms, including sea level rise, sea level rise map, ice sheets, and CReSIS.

Data Storage: We have added a new file system called Quantum StorNext that we intend to replace our existing HDS BlueArc based file system. It greatly increases the speed to about 2-3 times our existing system and an expectation that as we migrate to it there will be an increase of about 10 times. The new system is expandable to about 10 times the capacity as our existing file system as well. It adds tape as an in line affordable mechanism for storage of older data sets as well for an expected reduction in our overall storage costs to as much as 40% less than our existing system over the next several years.

Website Redesign: Following a recommendation from the Year 7 Review, we have completed a restructuring and redesign of the CReSIS website with the help of local design firm Miller Meier's, Inc. The new site, which went live on April 2, 2014, should increase global visibility, usability, and search engine optimization. It features a look more closely aligned with the CReSIS Media Guide and offers sectional "call-outs" for ease of navigation and promotional opportunities. The Knowledge Transfer team recently underwent a training session for updating procedures.



CReSIS Gets a New Look

We've updated our website! Check out all our new pages and let us know what you think on Facebook or Twitter! Learn more

Get the latest data from CReSIS

Take a look at the CReSIS Media Kit!

Read the latest news from CReSIS and sign up for the newsletter!

Check out photos and presentations from the 2013 IGS Meeting

Figure 76: The new CReSIS website, live as of April 2014.

In addition to the website, the look and feel of our social media assets, including the CReSIS Facebook page logo and banner image, as well as our Twitter and YouTube accounts, have been redesigned to be consistent with the new website.

Figure 77: The 2013 CReSIS Media Guide.

Media Kit: The 2013 Media Kit was released in early April, 2013. Our goal is to maintain the Kit as a live, dynamic online document that captures and promotes ongoing developments as they occur at the Center. No changes have yet been made to the Media Guide for 2014.

Technology Transfer: As a leader in the field of polar remote sensing technologies, CReSIS systems are used by the global polar research community to better understand the basic science of various complex issues relating to glaciology, sea-level rise, etc. The demand for our technologies and our software has risen steadily over the past few years, as evidenced by our collaboration with the following entities:

- Alfred Wegener Institute for Polar and Marine Research (AWI) Germany, http://www.awi.de/en

- British Antarctic Survey (BAS), United Kingdom, http://www.antarctica.ac.uk/
- Dr. Peter Jensen, Antarctic Climate & Ecosystems Coperative Coperative Research Center (ARC-CRC) University of Tasmania, Australia, http://www.acecrc.org.au/
- Dr. Lora Koenig, NASA, USA, http://www.nasa.gov/centers/goddard/news/releases/2012/12-070.html.
- Dr. Kirsty Langly, Norwegian Polar Institute, Norway, http://www.npolar.no/en/
- Dr. John Stone, Earth and Space Siences, University of Washington, USA, http://depts.washington.edu/cosmolab

*These CReSIS collaborations are in addition to the array of national and international collaborators listed on our website.

In 2012, CReSIS was awarded an MRI to support the development of a new antenna array for the Basler aircraft. Year 9 saw the continuation of this award. In conjunction with this support, the Alfred Wegener Institute for Polar and Marine Research (AWI) in Germany is funding the duplication of CReSIS radars to be installed on AWI's Basler.

In 2013, CReSIS began a partnership with the U.S. Naval Research Laboratory (NRL) to enhance several of the radar technologies developed by CReSIS, particularly for duplication of the Snow Radar for use an aircraft used for measurements over sea ice. CReSIS research Dr. Stephen Yan is the PI on this project.

IGS International Symposium on Radioglaciology 2013: CReSIS and the International Glaciological Society hosted a conference on radioglaciology at the University of Kansas from September 9-13, 2013. The conference, which was attended by delegates from 15 countries, took a comprehensive look at developments in radar, signal processing, and seismic technologies; previewed the latest results and technical advances; and identified gaps in observations to improve ice-sheet models. Topics for the meeting included:

- Radars and signal processing techniques for sounding and imaging of polar ice sheets.
- Recent radar observations and results over the Greenland and Antarctic ice sheets.
- Using radar observations to improve ice sheet models.
- Quantifying ice physical properties and basal conditions with radar techniques.
- Validating radar measurements with seismic observations and modeling techniques.
- Quantifying the geometry of temperate and debris-covered glaciers.

During the 11 oral sessions and student poster session, the IGS meeting provided participants with an opportunity to discuss observational requirements for radars, including gaps in the current data, which will assist modelers with the development and validation of the next generation of ice-sheet models. The meeting sought to achieve the integration of ice-core science, subglacial hydrology, flow dynamics, snow densification physics, change detection and characterization and the invention of the next generation of field techniques.

The Symposium featured meeting of APECS for young career scientists and a workshop devoted to polar aircraft and their use in conducting glaciological research.

In addition to the scientific elements of the meeting, participants attended several social activities, including an icebreaker and registration event at the Oread Hotel, a tour of the Tallgrass Prairie National Preserve, a visit to the Nelson-Atkins Museum of Art in Kansas City and the U.S. National World War One museum, a barbeque and pow-wow at Haskell Indian Nations University, and the

Figure 78: Dr. Gogineni opens the 2013 IGS Symposium on Radioglaciology at the University of Kansas.

IGS Symposium Banquet at the Alumni Center, which featured a lecture by KU professor of history, Dr. Jonathan Earle.

Photos and presentations from the 2013 International Glaciological Society Symposium on Radioglaciology are available on the CReSIS website at http://www.cresis.ku.edu/content/news/cresis-meetings/igs-conference-2013.

Social Media Networking: During the reporting period, CReSIS has continued to expand its use of social media networking. CReSIS continues to maintain a *CReSIS Facebook* fan page and a CReSIS Twitter page. These sites allow CReSIS to disseminate *The Icebreaker* newsletter and *Climate Change News* across new platforms and to a wider audience. We post content from the CReSIS website and articles found through news search engines at least once a week on both sites. CReSIS also offers a Tumblr page that features current external and internal content about local activities and the climate change community. Through these sites we also interact with other climate institutions, scientists, journalists, and the general public. Overall, social media has improved the public awareness of CReSIS activities and stimulated discussions on climate topics. Crosslinks on our news website now allow both CReSIS members and non-CReSIS visitors the chance to interface with the Center beyond the website through these social media platforms.

CReSIS on the Cover: In March 2014, a CReSIS article was featured on the cover of the IEEE Geoscience and Remote Sensing Magazine. The article, “UAS-Based Radar Sounding of the Polar Ice Sheets,” provides a brief overview of why radar soundings of fast-flowing glaciers ta low-frequencies is needed, along with a short description of the UAS and radar. IEEE GRSM is published quarterly and seeks to inform readers of activities in the GRSM Society, its technical committees, and chapters.

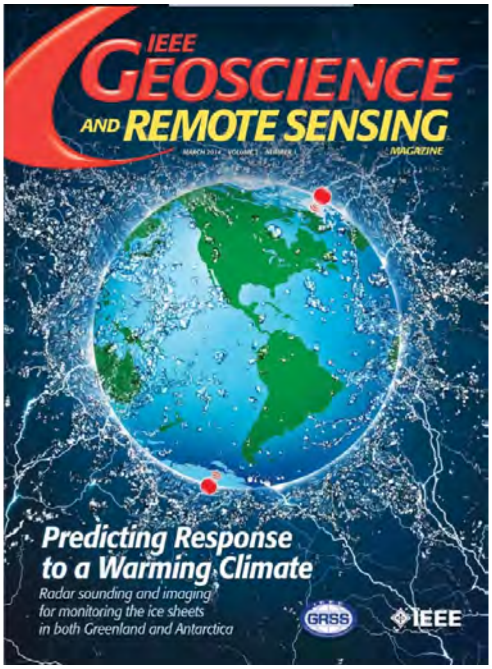


Figure 79: IEEE GRSM cover for March 2014.

In addition, a CReSIS article entitled "Advanced Multifrequency Radar Instrumentation for Polar Research," will be featured on the May 2014 cover of IEEE Transactions on Geoscience and Remote Sensing. This paper presents a radar sensor package specifically developed for wide-coverage sounding and imaging of polar ice sheets from a variety of aircraft.

Figure 80: The 2013 Fall Icebreaker.

CReSIS Quarterly Newsletter: The Icebreaker: The CReSIS *Icebreaker* newsletter has continued to include in-depth feature articles and general stories pertaining to CReSIS. Affiliated website components like the Climate Change Policy Timeline complement newsletter reporting. Four newsletters have been published during the reporting period, and one is in progress:

The Winter 2013 Icebreaker article titles [published April 2013]:

- Research Week 2013 fosters educational growth
- Visiting Researchers Utilize CReSIS Expertise
- NSIDC launches 'Greenland Ice Sheet Today'
- Student Spotlight: Lauren Brown
- Student Spotlight: Ryan Ondracek
- CReSIS welcomes New Staff
- CReSIS joins IceBridge Mission in Arctic
- Get your Abstracts in for the 2013 IGS Symposium on Radioglaciology
- Je'aime Powell Honored at Black Engineer of the Year Awards

The Spring 2013 Icebreaker article titles [published June 2013]:

- Professor Stearns recognized with NSF CAREER Award
- CReSIS attends national and international conferences
- CReSIS welcomes new staff
- CReSIS technology contributes to new Antarctic map
- IGS Conference updates
- New Media platforms support education outreach
- Research Week 2013 fosters educational growth
- CReSIS Students Awarded NASA Fellowships

The Summer 2013 Icebreaker article titles [published October 2013]:

- CReSIS Co-Hosts International Research Conference
- Education Outreach at CReSIS
- CReSIS REU Students Participate in 2013 IGS Symposium
- An Exchange of Research and Culture – Dr. Dorthe Dahl-Jensen
- CReSIS Welcomes New Staff
- Q & A with Dr. Richard Alley
- New NRL Project to Improve CReSIS Radars
- CReSIS Students and Team Members attend the 2013 STC Directors Meeting

The Fall 2013 Icebreaker article titles [published December 2013]:

- CReSIS Deploys to Antarctic
- Educational Outreach Update
- Government Shutdown Delays and Cancels Antarctic Research
- Research Experience for Undergraduates (REU)
- CReSIS Student Awarded First Prize in GIS Competition
- Greenland Canyon Discovered with CReSIS Data

The Winter 2014 Icebreaker will include the following articles [to be published April 2014]:

- CReSIS graduate student receives CSO Mentoring Award March 6
- A Wideband Airborne Ice Sounding/Imaging Radar Deployment – KU CReSIS
- CReSIS Student Receives Undergraduate Research Award
- Unmanned Aircraft System for Radar Sounding and Imaging of Ice Sheets

2c. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

The Center continues to monitor and address all of the Knowledge Transfer indicators/metrics listed in the CReSIS Strategic and Implementation Plan.

2d. Describe your plans for knowledge transfer activities for the next reporting period with attention to any major changes in direction or level of activity. Include plans for new knowledge transfer partnerships, if any.

Monitoring the New Website: Efficiency of the new CReSIS website will be evaluated and necessary adjustments will be made to increase the impact of the website to targeted audiences. Surveys will be conducted every six months to update the effectiveness of the website.

Other Tasks

- Continue disseminating data sets to the scientific community.
- Continue aggressive outreach efforts to all Center audiences reflected by our Knowledge Transfer objectives.

V. EXTERNAL PARTNERSHIPS

1a. Describe the Center's overall goals and/or objectives for developing external partnerships. If the Center’s overall partnership goals/objectives have changed since the last reporting period, how did they change and why? [In section 2a below, please describe progress the Center has made toward reaching these goals/objectives.]

Core Partnerships:

The Center’s core partners and international collaborators have changed during the second phase. Core partners are selected to accomplish the Center research, education and diversity objectives. Core partners for Phase II are the University of Kansas, Elizabeth City State University, Indiana University, Pennsylvania State University, the University of Washington and Los Alamos National Laboratory (LANL), and the Association of Computer and Information Science/Engineering Departments at Minority Institutions (ADMI). The Pennsylvania State University (PSU) will continue to participate in technology development for seismic measurements, field activities, and modeling. The Center of Excellence in Remote Sensing, Education and Research (CERSER) at Elizabeth City State University (ECSU) will contribute its expertise to analyzing satellite data and generating high-level data products. ECSU will bring to the Center their extensive experience in mentoring and educating traditionally under-represented students. Indiana University (IU) provides world-class expertise in CI and high-performance computing to address challenges in data management, processing, distribution and archival, and high-performance modeling requirements. The University of Washington (UW) provides expertise in satellite observations of ice sheets and process-oriented interpretation and model development. Los Alamos National Laboratory (LANL) will contribute in the area of ice sheet modeling. Partnership with ADMI expands the Center's outreach to more underrepresented groups in Science and Engineering.

Collaboration with industry includes the Kansas City Plant (KCP), a National Nuclear Security Administration (NNSA) facility operated by Honeywell.

Our international partners include the Center for Polar Observations and Modeling (CPOM) in the United Kingdom, the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE-CRC) at the University of Tasmania, the University of Copenhagen Glaciology Group, and the Indian Institute of Technology-Kanpur. CPOM will collaborate in field experiments and ice sheet and sea ice models, as well as participate in faculty and student exchanges. With the launch of Cryosat and CReSIS participation in NASA OIB program, there has been excellent cooperation between these two centers. ACE-CRC will cooperate with the Center in conducting field experiments (including aircraft and ships), ice sheet modeling, and interpretation of data, and will participate in faculty and student exchanges. The University of Copenhagen Glaciology Group will collaborate in field experiments, provide ice core expertise, assist in ice sheet modeling, participate in faculty and student exchanges, and assist in coordinating IPY activities. The Indian Institute of Technology-Kanpur collaborates in sensor development, particularly in the area of antennas and antenna arrays, and signal processing.

1b. Inform us of the performance and management indicators the Center has developed to assess progress in meeting its partnership goals/objectives.

We have no existing performance and management indicators to assess this area. After an attempt to develop metrics, we identified that *quality* of the partnership is the most critical consideration and virtually impossible to measure with numbers.

1c. Discuss any problems you have encountered in making progress toward the Center's partnership goals/objectives during the reporting period as well as any problems anticipated in the next period. Please include your plans for addressing these problems.

We have encountered no significant challenges in this area.

2a. Describe and discuss the activities that are conducted as part of partnerships, which are *not listed in another section of this report*. Be sure to discuss how the Center's partnership activities enable the Center to meet its partnership goals/objectives listed above.

Weekly Teleconferences/Monthly Videoconferences		
Led by	Center Management, University of Kansas	
Organizations Involved (add rows as necessary)		
Name of Organization	Shared Resources (if any)	Use of Resources (if applicable)

1	Elizabeth City State University	▪ Guest Speakers ▪ Faculty/Student Research ▪ Center-Wide Management Discussions and Decision-Making ▪ Center-Wide Education Team Planning ▪ KU-based videoconferencing equipment (Polycom)	
2	The Pennsylvania State University		
3	Indiana University		
4	University of Washington		
5	Los Alamos National Laboratory		
6	Association for Departments of Computer Science and Engineering at Minority Institutions		

These events provide us the recurring opportunity to participate in Center activities from geographically dispersed locations. Most importantly, they provide Center personnel access to resources physically available to only one partner (e.g. guest speakers are able to influence seven campuses rather than only the campus they happen to be visiting).

Short-Term Faculty/Staff/Student Exchanges			
Led by	Exchanging Partners		
Organizations Involved (add rows as necessary)			
Name of Organization		Shared Resources (if any)	Use of Resources (if applicable)
1	Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen to KU	Ph.D. Student Christian Panton	Christian spent Spring 2013 at CReSIS KU working on automated internal layer tracing.
2	Technical University of Denmark (DTU)	Ph.D. Student Ulrik Nielsen	Ulrik spent Spring 2013 at CReSIS KU working on Surface Clutter Suppression Techniques for Radar Ice Sounding
3	Indian Institute of Technology-Kanpur	Abhishek Kumar Awasthi	Abhishek will spend two months at CReSIS KU working on the effects of mutual coupling of antenna arras with CReSIS researchers Dr. Prasad Gogineni and Dr. Stephen Yan.

In addition to the knowledge transfer involved, these activities are particularly important to enhancing integration across the core partners.

2b. Describe any other outcomes or impacts of partnership activities not listed elsewhere.

None

2c. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

See discussion in 1b above.

2d. Describe your plans for partnership activities for the next reporting period with attention to any major changes in direction or level of activity.

In Year 9 we will expand our partnership with the Alfred Wegner Institute through a series of meetings and researcher exchanges, continue to expand our collaborations with IIT-Kanpur and work to establish a long-term relationship with Naval Research Lab. We also hope to build on our international student exchanges (detailed in Section III - EDUCATION) by increasing the number of researchers participating in short- and long-term exchanges with the Center for Ice and Climate and DTU in Denmark.

VI. DIVERSITY

1a. Describe the Center's overall goals and/or objectives related to increasing diversity at the Center. If there have been any changes in the Center's overall goals/objectives and plans related to increasing diversity since the last reporting period, please discuss these changes and the reasons behind them. [In section 2a below, please describe progress the Center has made toward reaching these goals/objectives.]

The Center's overall Diversity objectives and goals remain unchanged and we have continued to make measurable progress.

Vision Statement for Diversity: To become a national leader in increasing diversity among polar scientists and engineers.

Mission Statement for Diversity: Increase the number of students, staff, and faculty from underrepresented groups in science and engineering by fostering an interest in science throughout the K-16 minority community, and among women and individuals with disabilities. Ensure diversity in all aspects of the Center.[1]

Encourage and facilitate involvement of students at our partner and minority serving institutions to pursue graduate education in science or engineering.

1b. Inform us of the performance and management indicators the Center has developed to assess progress in meeting its diversity goals/objectives.

The following metrics were updated in our last Annual Report and have been unchanged since that time. They were reviewed when the Strategic and Implementation Plan was revised in 2010 and remain unchanged.

Table 15: Diversity Objectives/Metrics/Assessment Indicators

Objective	*Metric*	*Assessment Indicators*
▪ Recruit and mentor graduate students from a diverse undergraduate population. Retain 20% of	▪ Number of Center students who were recruited by	▪ Numbers and kinds of recruitment initiatives (e.g.: conferences, ads, talks, etc.).

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[1] The Higher Education Act defines the term "underrepresented minority" as an American Indian, Alaskan Native, Black (not of Hispanic origin), Hispanic (including persons of Mexican, Puerto Rican, Cuban, and Central or South American origin) and Pacific Islanders (http://www.ed.gov/about/offices/list/ocr/edlite-minorityinst-list.html).

the Center's students from underrepresented groups.	Center recruiting activities.	▪ Demographics of recruited Center students. ▪ GPA and GRE of recruited students. ▪ Numbers and demographics of students contacted in recruiting efforts (measured as those requesting more information). ▪ Track students to determine participation and effects of Center recruitment on educational and career choice. ▪ Demographics of school districts supported by Center K-12 outreach. ▪ Numbers and demographics of students supported by the Center.
▪ Provide research opportunities for the underrepresented student populations at our partner institutions.	▪ Number of outreach activities conducted and their assessments in promoting diversity.	▪ Number and demographics of students reached via middle school outreach and enrichment programs. ▪ Numbers and demographics of students participating in summer research experience programs, exchange programs, and other Center education opportunities.
▪ Provide financial resources for underrepresented groups to pursue graduate education.	▪ Amount of Center and external funds that are used to provide educational opportunities to underrepresented groups.	▪ Numbers and kinds of opportunities provided to students. ▪ Demographics of student recipients.
▪ Establish distinguished scientist and engineer lecture exchange program, allowing educators and researchers at all partner institutions to give seminars and encourage undergraduate students to pursue graduate education.	▪ Distinguished scientist/engineer lecture program.	▪ Lecture title, location, and number of participants. ▪ Number of Center faculty participating in the program.
▪ Conduct outreach by participating in conferences, meetings, and science fairs attended by large numbers of underrepresented students to discuss the Center's research	▪ Activity at appropriate conferences and meetings.	▪ Numbers of conferences, meetings, and science fairs attended, including associated activities at those events. ▪ Numbers and demographics of students and educators contacted (measured as those requesting more information).

program and opportunities.		
▪ Assure diversity efforts address issues in K-12 education.	▪ Effectiveness in reaching a diverse student and teacher population.	▪ Participation of underrepresented students and teachers in workshops and student activities. ▪ Number and attendance of summer school activities for middle school and high school students.
▪ Maintain a diverse staff of scientists, engineers, managers and administrators throughout the Center.	Demographics of staff and professional personnel in and associated with, the Center.	

1c. Discuss any problems you have encountered in making progress toward the Center's diversity goals/objectives during the reporting period as well as any problems anticipated in the next period. Include your plans for addressing these problems.

There have been no new challenges to the Center in meeting stated diversity goals. Diversity goals have been met and in most cases exceeded.

Partnerships
All Center partner universities have complementary recruiting and outreach efforts. Participation by Elizabeth City State University and ADMI specifically provides CReSIS with networking opportunities with other organizations also focused on increasing participation by underrepresented groups in STEM fields.

As a core partner, ADMI receives a full budget to support students and outreach programs in STEM. In addition, CReSIS provides leadership for graduate success services at the annual ADMI conference.

A number of Center-supported activities contribute, both directly and indirectly, to our diversity objectives. These include:

- University Outreach and Student Recruiting
- Research Experience for Undergraduates (REU) Program
- CReSIS Pre-service RET program
- ADMI Annual Symposium
- K-12 Outreach Program:
    - CReSIS Middle School/High School Programs
    - Freezing Fridays
    - Hispanic School Visitations

Activity Name	University Outreach and Student Recruiting
Led by	Center Faculty, Staff, and Students

Recruiting activities at CReSIS includes campus visits, disseminating information to partner institutions, other STC's and universities regarding opportunities for students (via website, emails), and sharing information about CReSIS at local, regional, and national conferences/events. CReSIS is currently accepting applications for Graduate Research Assistant positions and will continue to actively recruit students who have a strong interest in polar studies and climate change. The REU program continues to draw an array of student applicants and is one of our most diverse programs with a high number of underrepresented students participating in past programs.

CReSIS Education staff and Faculty work with the KU School of Engineering recruitment staff and the Diversity office to provide materials on the REU program and opportunities for graduate students and participate in visits to high schools, engineering expos and other outreach activities to increase student interest in science and engineering.

Activity Name	Research Experience for Undergraduates (REU) Program
Led by	Center Faculty, Staff, and Students at ECSU, KU, IU and UW

Details of this activity have been discussed previously in Section III – EDUCATION. Participants from this program have been included in demographic information presented in conjunction with an assessment of our diversity metrics.

Of the 26 REU participants in 2013 we had:

- 50% Women
- 81% Black
- 4% Hispanic
- 8% Native American
- 100% US citizens/permanent residents

Activity Name	ADMI Annual Symposium
Led by	ADMI

ADMI 2014
Host: Norfolk State University and Hampton University
Virginia Beach, VA
April 3-6, 2014

The 2014 ADMI conference, “Surfing through a Sea of Data,” provided a showcase for innovative graduate and undergraduate research. Two 2013 REU students had oral presentations and two presented posters. Twenty-four (24) African American students were supported to attend ADMI and present their research projects (7 females/ 17 males/ 24 undergraduates/ 0 grads). All were US Citizens. Maya Smith 2012 and 2013 CReSIS REU alumni received first place for oral presentations. The title was Analysis Functionality to enhance MATLAB default interpolation schema using mGstat (mentor was John Paden, KU).

Ricky Dixon 2012 and 2013 CReSIS REU alumni received second place for poster presentations. The title was Using Common Core State Standards of Seventh Grade Mathematics in the Application of NXT LEGO® Robotics for CReSIS Middle School Students (mentor was Dr. Darnell Johnson, ECSU).

Activity Name	*High School Summer Program*
Led by	ECSU

The Middle School Summer Program was discussed in Section III – EDUCATION.

Activity Name	*Middle School Summer Program*
Led by	ECSU

The Middle School Summer Program was discussed in Section III – EDUCATION.

Activity Name	*Hispanic School Visitations*
Led by	KU

CReSIS K-12 Educational Outreach continued its outreach to elementary schools with large percentages of Hispanic students. The three schools the CReSIS K-12 Educational Outreach are working with include John Fiske Elementary in Kansas City, KS (68 4th grade students; 79% free and reduced lunch, 67.6.% Hispanic,10.8% % black, 16% white,3.4% Asian, ELL 70%), Whittier Elementary in Kansas City, KS (107 students 4th grade, and 110 students 5th grade 97 % Free and reduced lunch, 73.6 % Hispanic, Black 11.9%, White 8.3% 5.4% Asian and ELL 63.8%), and Mark Twain Elementary in Kansas City, Kansas (46 students in 4th grade, 65.2% Hispanic, 16.74% African American, 10.57 White, and ELL 65%). More details of this activity are available in Section III – EDUCATION.

2b. Discuss the impact of these programs or activities on enhancing diversity at the Center.

During the last nine years the center has made significant strides towards increase diversity.

Last year Emily Arnold was one of only two female Aerospace Engineering PhD students to graduate from KU since 2004. She began working at CReSIS as an undergraduate. CReSIS has three female or minority PhD students who have been awarded NASA fellowships.

From 2006 to 2013 CReSIS has awarded 21 females and 12 minority students with Master's or Ph.D. degrees. 8 female and 9 minority students are currently working toward degrees with CReSIS.

Nine female or minority students who were originally introduced to CReSIS through the REU Program have gone on to pursue graduate work at a CReSIS partner institution.

2c. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

A table showing the breakdown of underrepresented undergraduates, graduate students and REU participants can be found at the end of this section. The table shows that from Year 2 to Year 9 the Center increased its graduate student enrollment from 7% to 29%. Minority undergraduate participation has fluctuated from a high of 61% to a low of 42% and REU minority participation has steadily increased to 78% from 88% since the REU site was awarded.

Table 16: Diversity Objectives/Metrics (w/ Indicators)/Performance

Objective	*Metric/Indicators*	*Performance*
A. Recruit and mentor graduate students from a diverse undergraduate population. Retain 20% of the Center's students from underrepresented groups.	▪ Number of Center students who were recruited by Center recruiting activities.	▪ Of the Center's graduate student's 29% are women, 21% Black, 7 % Hispanic and 0% are Native American. 71.43 % are US citizens or permanent residents. ▪ Of the Center's undergraduate students (including REUs) 45% are women, 52% Black, 3% Hispanic and 2% Native American. 93.75% are US citizens or permanent residents.
B. Provide research opportunities for the underrepresented student populations at our partner institutions.	▪ Number of outreach activities conducted and their assessments in promoting diversity.	▪ Demographics of our most-often visited K-12 destinations are presented in Section III – EDUCATION. ▪ 26 REU Participants; 88% students of underrepresented groups; 50% women ▪ ECSU middle school research program – 92% African American; 75% women
C. Provide financial resources for underrepresented groups to pursue graduate education.	▪ Amount of Center and external funds that are used to provide educational opportunities to underrepresented groups.	▪ Exact dollars are not available, but there are NO qualified underrepresented students who have not been offered support to attend graduate school at one of the research partners. ▪ Graduate students at ECSU receive $16,000 per year with tuition assistance provided through the NOYCE scholars program.
D. Establish distinguished scientist and engineer lecture exchange program, allowing educators and researchers at all partner institutions to give seminars and encourage undergraduate students to pursue graduate education.	▪ Distinguished scientist/engineer lecture program.	▪ The CReSIS All-Hands seminar series had 28% of presenters from underrepresented groups.
E. Conduct outreach by participating in conferences, meetings, and science fairs	▪ Activity at appropriate conferences and meetings.	▪ Visit to Haskell Highlight Night (standing invitation to attend; held at the beginning of each semester). ▪ Work with Haskell instructors in the Math and Science departments and make

attended by large numbers of underrepresented students to discuss the Center's research program and opportunities.		classroom visits to promote REU program; CReSIS faculty/GRAs also make presentations. ▪ KU School of Engineering and other NSF STC Education teams help promote CReSIS programs at local, regional and national conferences such as AISES and SACNAS (e.g. brochures, printed materials) . ▪ CReSIS set up a table at the 2013 KU GIS day in November. ▪ K-12 CReSIS Education Outreach Staff share information about all programs (K-12, undergraduate, graduate) at presentations and events they attend locally, regionally and nationally. ▪ Information about graduate student opportunities is disseminated to regional universities on annual basis.
F. Assure diversity efforts address issues in K-12 education.	▪ Effectiveness in reaching a diverse student and teacher population.	▪ Demographics of our K-12 focus schools were presented in Section III – Education.
G. Maintain a diverse staff of scientists, engineers, managers and administrators throughout the Center.	▪ Demographics of staff and professional personnel in, and associated with, the Center.	▪ Faculty are 23% Female and 23% underrepresented groups. Staff is 31% female and 16% from underrepresented groups.

2d. Describe your plans for programs, activities, or partnerships to enhance diversity for the next reporting period with attention to any major changes in direction or level of activity. Be sure to discuss how the planned activities will enable the Center to meet its diversity goals/objectives.

K-12 classroom visits will continue in Year 10 at John Fiske and Whittier Elementary. We will also continue the Freezing Fridays program, which has allowed additional outreach to 6th-8th graders. The REU site renewal proposal was renewed for an additional 3 years. It will continue to support up to 20 REU student and includes funding to expand the RET program.

The table below shows the comparison of Year 2 through Year 9 for diversity of undergraduates, graduates and REU CReSIS students.

	UNDERGRADUATES	**Women**	**% Women**	**White**	**% White**	**Black**	**% Black**	**Hispanic**	**% Hispanic**	**Asian**	**% Asian**	**Native American**	**% Native American**	% Underrepresented
Year 2	59	26	44%	22	37%	24	41%		0%	4	7%	9	15%	53%
Year 3	32	12	38%	13	41%	11	34%	1	3%	2	6%	5	16%	53%
Year 4	51	26	51%	19	37%	22	43%	3	6%	4	8%	6	12%	61%
Year 5	38	18	47%	13	34%	14	37%	3	8%	3	8%	3	8%	53%
Year 6	39	17	44%	18	46%	18	46%	2	5%	1	3%	0	0%	51%
Year 7	45	20	44%	20	44%	20	44%	3	7%	2	4%	0	0%	51%
Year 8	62	22	35%	37	60%	15	24%	3	5%	6	10%	1	2%	31%
Year 9	50	22	44%	26	52%	17	34%	4	8%	3	6%	0	0%	42%

	REU (all CReSIS)	**Women**	**% Women**	**White**	**% White**	**Black**	**% Black**	**Hispanic**	**% Hispanic**	**Asian**	**% Asian**	**Native American**	**% Native American**	% Underrepresented
Year 2	3	1	33%	1	33%	1	33%	1	33%		0%	0	0%	67%
Year 3	15	6	40%	7	47%	3	20%	4	27%		0%	1	7%	53%
Year 4	20	6	30%	6	30%	10	50%	4	20%		0%	0	0%	70%
Year 5	6	4	67%	3	50%	1	17%		0%	2	33%	0	0%	17%
Year 6	26	11	42%	7	27%	14	54%	1	4%	1	4%	0	0%	58%
Year 7	35	22	63%	12	34%	21	60%	1	3%	1	3%	0	0%	63%
Year 8	23	13	57%	5	22%	16	70%	1	4%	0	0%	1	4%	78%
Year 9	26	13	50%	3	12%	21	81%	0	0%	0	0%	2	8%	88%

	GRADUATES	**Women**	**% Women**	**White**	**% White**	**Black**	**% Black**	**Hispanic**	**% Hispanic**	**Asian**	**% Asian**	**Native American**	**% Native American**	% Underrepresented
Year 2	71	19	27%	42	59%	1	1%	4	6%	24	34%	0	0%	7%
Year 3	57	11	19%	35	61%	2	4%	2	4%	16	28%	2	4%	11%
Year 4	62	16	26%	43	69%	5	8%	3	5%	12	19%	2	3%	16%
Year 5	60	13	22%	41	68%	6	10%	7	12%	6	10%	2	3%	25%
Year 6	40	9	23%	24	60%	4	10%	3	8%	7	18%	2	5%	23%
Year 7	47	11	23%	21	45%	12	26%	3	6%	10	21%	1	2%	34%
Year 8	43	12	28%	21	49%	8	19%	3	7%	9	21%	0	0%	26%
Year 9	42	12	29%	19	45%	9	21%	3	7%	11	26%	0	0%	29%

II. MANAGEMENT

1a. Describe the Center's organizational strategy and its underlying rationale, if changed since the last reporting period. To assist in your description, attach the organization chart of the Center during the reporting period as Appendix B (if changed from last period). If there have been any changes in the Center's organization or management since the last reporting period, discuss these changes and the reasons behind them.

There have been no changes to the organizational structure during Year 8. Dr. Gogineni serves as PI and is assisted by the Associate Directors (Education, Knowledge Transfer, Technology and Science) and a Deputy Director. An organization chart is attached as Appendix B.

1b. Inform us of the performance and management indicators the Center has developed to assess its progress in organizational and management goals/objectives.
The following metrics remain unchanged through Year 7.

Table 17: Management Functional Area Assessment Strategy

ADMINISTRATIVE AREA	*INDICATOR*	*OBJECTIVE*	*ASSESSMENT MECHANISM*
Financial Management	Matching dollars lost each year to fiscal year anniversaries	$0	Direct Measurement through Year-End Account Reconciliation
	Value of misplaced/lost property each year	$0	Direct Measurement through recurring 100% Property Inventory (captures losses associated with property subject to "tagging")
	Number and Value of Audit Findings	$0	Direct Measurement via internal/external, formal/ informal financial audits
Personnel Management	Staff Overtime Hours	<10%	Direct Measurement through the Payroll Reporting System
	Training Courses Obtained of Training Required (%)	>90%	Direct Measurement
Communication Management	Recurring Report Submissions – Days Late	< 7 from Due Date	Direct Measurement

1c. Describe how the Center is doing with respect to the indicators/metrics listed above. Include any data that have been collected on the indicators/metrics.

Table 18: Management Functional Area Progress against Performance Indicators

ADMINISTRATIVE AREA	*INDICATOR*	*OBJECTIVE*	*CENTER PROGRESS*
Financial Management	Matching dollars lost each year to fiscal year anniversaries	$0	▪ University-match state funds = $0 ▪ Industry (KTEC)-match funds = $0
	Value of misplaced/lost property each year	$0	▪ The University of Kansas requires that we track all items with a value > $5,000; during Year 9, none of these items were misplaced or lost.
	Number and Value of Audit Findings	$0	▪ In FY 2013 CReSIS had 0 external audits and had no findings during the yearly internal audit of KUs sponsored programs.
Personnel Management	Staff Overtime Hours	<10%	▪ Overtime for the period was 4.7%
	Training Courses Obtained of Training Required (%)	>90%	▪ 100% for FY13 consisting of new staff training, HR upgrade training, and participation in the steering committee for KU Financials upgrades
Communication Management	Recurring Report Submissions – Days Late	< 7 from Due Date	▪ NA

1d. Discuss any problems (e.g., technical, personnel, communication) you may have encountered in realizing the Center's organizational strategy or management goals/objectives in the reporting period as well as any problems anticipated in the next period. Include your plans for addressing any problems.

We have not encountered any problems in realizing the Center's organizational strategy or management goals/objectives during this reporting period.

2. Describe and discuss the management and communications systems being used to develop a fully integrated STC as well as any problems encountered in achieving this integration, if changed from the previous reporting period.

CReSIS uses both email and weekly meetings to coordinate among the partners. The list below details some of the recurring meetings. These are held using both video and voice conferencing systems. This is unchanged from previous years.

	Name	*Frequency*
1	Management Meeting	Bi-weekly
2	Education meeting	Bi-weekly
3	Technology meeting	Bi-weekly
4	Knowledge Transfer meeting	Weekly
5	Polar Grid Meeting (Computing)	Weekly
6	Signal and Data Processing Group Meeting	Weekly

3. Provide a list of names and affiliations of the Center's internal and external advisors or advisory bodies in the reporting period. Attach summary minutes of advisory committee meetings as Appendix C.

Advisory Board 2013— External

	Name	*Affiliation*
1	Dr. Jonathan Bamber	Bristol Glaciology Centre, University of Bristol
2	Dr. Scott Beaven	Space Computer Corporation
3	Mr. Steve Ericson	Lockheed-Martin Aeronautics Company
4	Dr. Roger Hathaway	NASA Langley Research Center
5	Dr. Tony Hey	External Research Division, Microsoft Research
6	Dr. David Holland	CAOS, Courant Institute of Mathematical Sciences
7	Mr. Charles Luther	Retired/Formerly Office of Naval Research
8	Dr. Carl Person	NASA, Minority University Research and Education Programs
9	Mr. Suresh Ramamurthi	BC Capital, Inc.
10	Dr. Christopher Shuman	NASA/GSFC
11	Mr. Jeffrey Stepp	Honeywell Federal Manufacturing Technologies
12	Mr. Herb White	W. Herbert White & Co., Inc.

Academic Advisory Council — Internal

The Academic Advisory Council (AAC) of the Center for Remote Sensing of Ice Sheets (CReSIS) was established to guide and advise the CReSIS director on administrative issues. The AAC is chaired by the Dean of the School of Engineering at the University of Kansas—Dr. Michael Branicky. Although the CReSIS AAC existed during the first phase of the Center, it only included senior administrators at the University of Kansas. At the suggestion of the 2010 Site Visit Panel, the AAC has been expanded to include all partner institutions. A meeting is held semi-annually during which the CReSIS director provides a detailed overview of the Center and seeks input on issues requiring guidance and help from senior administrators; additional meetings are scheduled as necessary. The AAC is also provided with quarterly e-mail updates regarding Center activities.

Name		*Affiliation*
1	Dr. Michael Branicky	Dean, School of Engineering
2	Dr. Steven Warren	Vice-Chancellor, Research and Graduate Studies and President of the University of Kansas Center for Research
3	Dr. Danny Anderson	Dean, College of Liberal Arts and Sciences, University of Kansas
4	Dr. Robert Goldstein	Associate Dean, College of Liberal Arts and Sciences, University of Kansas
5	Dr. Bob Odom	Assistant Director for Education and Development, Principal Physicist, University of Washington
6	Dr. Bill Easterling	Dean, College of Earth and Mineral Sciences, Penn State University
7	Dr. Harry Bass	Dean, School of Mathematics, Science and Technology, Elizabeth City State University
8	Dr. Robert Schnabel	Dean, School of Informatics and Computing, Indiana University
9	Dr. Philip Jones	Deputy Group Leader, Climate, Ocean and Sea Ice Modeling, Los Alamos National Laboratory

4. Describe and discuss any changes to the Center's strategic plan since its last submission.

No changes were made to the strategic plan during the Year 9 reporting period.

VIII. CENTER-WIDE OUTPUTS AND ISSUES

1a. List all Center publications in the reporting period using a standard citation format.

Peer-Reviewed Publications

[1] E. Arnold, J. B. Yan, R. Hale, F. Rodriguez-Morales, and P. Gogineni, "Identifying and Compensating for Phase Center Errors in Wing-Mounted Phased Arrays," *IEEE Antenna and Propagation,* vol. submitted, 2013.

[2] J. L. Bamber, J. A. Griggs, R. T. W. L. Hurkmans, J. A. Dowdeswell, S. P. Gogineni, I. Howat, J. Mouginot, J. Paden, S. Palmer, E. Rignot, and D. Steinhage, "A new bed elevation dataset for Greenland," *The Cryosphere,* vol. 7, pp. 499-510, 2013.

[3] R. A. Bindschadler, S. M. J. Nowicki, A. Abe-Ouchi, A. Aschwanden, H. Choi, J. Fastook, G. Granzow, R. Greve, G. Gutowski, U. Herzfeld, C. Jackson, J. Johnson, C. Khroulev, A. Levermann, W. H. Lipscomb, M. A. Martin, M. Morlighem, B. R. Parizek, D. Pollard, S. F. Price, D. Ren, F. Saito, T. Sato, H. Seddik, H. Seroussi, K. Takahashi, R. T. Walker, and W. L. Wang, "Ice-sheet model sensitivities to environmental forcing and their use in projecting future sea-level (The SeaRISE Project)," *Journal of Glaciology,* vol. 59, pp. 195-224, 2013.

[4] R. Forster, J. Box, M. van den Broeke, C. Miege, E. Burgess, J. van Angelen, J. Lenaerts, L. Koenig, J. Paden, C. Lewis, S. Gogineni, C. Leuschen, and J. McConnell, "Extensive liquid meltwater storage in firn within the Greenland ice sheet," *Nature Geoscience,* vol. accepted, 2013.

[5] P. Fretwell, H. D. Pritchard, D. G. Vaughan, J. L. Bamber, N. E. Barrand, R. Bell, C. Bianchi, R. G. Bingham, D. D. Blankenship, G. Casassa, G. Catania, D. Callens, H. Conway, A. J. Cook, H. F. J. Corr, D. Damaske, V. Damm, F. Ferraccioli, R. Forsberg,

S. Fujita, Y. Gim, P. Gogineni, J. A. Griggs, R. C. A. Hindmarsh, P. Holmlund, J. W. Holt, R. W. Jacobel, A. Jenkins, W. Jokat, T. Jordan, E. C. King, J. Kohler, W. Krabill, M. Riger-Kusk, K. A. Langley, G. Leitchenkov, C. Leuschen, B. P. Luyendyk, K. Matsuoka, J. Mouginot, F. O. Nitsche, Y. Nogi, O. A. Nost, S. V. Popov, E. Rignot, D. M. Rippin, A. Rivera, J. Roberts, N. Ross, M. J. Siegert, A. M. Smith, D. Steinhage, M. Studinger, B. Sun, B. K. Tinto, B. C. Welch, D. Wilson, D. A. Young, C. Xiangbin, and A. Zirizzotti, "Bedmap2: improved ice bed, surface and thickness datasets for Antarctica," *The Cryosphere,* vol. 7, pp. 375-393, 2013.

[6] M. Hoffman, "Feedbacks between coupled subglacial hydrology and glacier dynamics," *Journal of Geophysical Research: Earth Surface,* vol. accepted, 2013.

[7] M. Hoffman and S. Price, "Effect of uncertainty in surface mass balance elevation feedback on projections of the future sea level contribution of the Greenland ice sheet, Part I: Parameterisation," *Cryosphere,* vol. accepted, 2013.

[8] Joughin, B. E. Smith, D. E. Shean, and D. Floricioiu, "Brief Communication: Further speedup of Jakobshavn Isbrae," *The Cryosphere,* vol. 8, pp. 209-214, 2014.

[9] S. A. Khan, K. H. Kjær, N. J. Korsgaard, J. Wahr, I. R. Joughin, L. H. Timm, J. L. Bamber, M. R. van den Broeke, L. A. Stearns, G. S. Hamilton, B. M. Csatho, K. Nielsen, R. Hurkmans, and G. Babonis, "Recurring dynamically induced thinning during 1985-2010 on Upernavik Isstrøm, West Greenland," *Journal of Geophysical Research: Earth Surface,* vol. 118, pp. 111-121, 2013.

[10] J. Kostelnick, D. McDermott, R. Rowley, and N. Bunnyfield, "A Cartographic Framework for Visualizing Risk," *Cartographica,* vol. 48, pp. 200-224, 2013.

[11] N. Kurtz, J. Richter-Menge, S. Farrell, M. Studinger, J. Paden, J. Sonntag, and J. Yungel, "IceBridge Airborne Survey Data Support Arctic Sea Ice Predictions," *EOS Trans. AGU,* vol. 94, p. 41, 2013.

[12] B. Medley, I. Joughin, S. Das, E. J. Steig, H. Conway, S. Gogineni, A. Criscitiello, J. McConnell, B. Smith, M. Van den Broeke, J. Lenaerts, D. H. Bromwich, and J. P. Nicolas, "Airborne-radar and ice-core observations of the snow accumulation rate over Thwaites Glacier, West Antarctica validate the spatio-temporal variability of global and regional atmospheric models," *Geophysical Research Letters,* vol. 40, 2013.

[13] A. Muto, S. Anandakrishnan, and R. B. Alley, "Subglacial bathymetry and sediment layer distribution beneath the Pine Island Glacier ice shelf, West Antarctica, modeled using aerogravity and autonomous underwater vehicle data," Annals of Glaciology, vol. 54, pp. 27-32, 2013.

[14] F. M. Nick, A. Vieli, M. L. Andersen, I. Joughin, A. Payne, T. L. Edwards, F. Pattyn, and R. S. W. van de Wal, "Future sea-level rise from Greenland's main outlet glaciers in a warming climate," *Nature,* vol. 497, pp. 235-238, 2013.

[15] S. M. J. Nowicki, R. A. Bindschadler, A. Abe-Ouchi, A. Aschwanden, E. Bueler, H. Choi, J. Fastook, G. Granzow, R. Greve, G. Gutowski, U. Herzfeld, C. Jackson, J. Johnson, C. Khroulev, E. Larour, A. Levermann, W. H. Lipscomb, M. A. Martin, M. Morlighem, B. R. Parizek, D. Pollard, S. F. Price, D. Ren, E. Rignot, F. Saito, T. Sato, H. Seddik, H. Seroussi, K. Takahashi, R. T. Walker, and W. L. Wang, "Insights into spatial sensitivities of ice mass response to environmental change from the SeaRISE ice sheet modeling project I: Antarctica," *Journal of Geophysical Research - Earth Surface,* vol. accepted, 2013.

[16] S. M. J. Nowicki, R. A. Bindschadler, A. Abe-Ouchi, A. Aschwanden, E. Bueler, H. Choi, J. Fastook, G. Granzow, R. Greve, G. Gutowski, U. Herzfeld, C. Jackson, J. Johnson, C. Khroulev, E. Larour, A. Levermann, W. H. Lipscomb, M. A. Martin, M. Morlighem, B. R. Parizek, D. Pollard, S. F. Price, D. Ren, E. Rignot, F. Saito, T. Sato,

H. Seddik, H. Seroussi, K. Takahashi, R. T. Walker, and W. L. Wang, "Insights into spatial sensitivities of ice mass response to environmental change from the SeaRISE ice sheet modeling project II: Greenland," *Journal of Geophysical Research: Earth Surface,* vol. accepted, 2013.

[17] B. Panzer, D. Gomez-Garcia, C. Leuschen, J. Paden, F. Rodriguez-Morales, A. Patel, T. Markus, B. Holt, and P. Gogineni, "An ultra-wideband, microwave radar for measuring snow thickness on sea ice and mapping near-surface internal layers in polar firn," *Journal of Glaciology,* vol. 59, pp. 244-254, 1/13 2013.

[18] K. Player, T. Stumpf, J. B. Yan, F. Rodriguez-Morales, J. Paden, and P. Gogineni, "Characterization and Mitigation of RFI Signals in Radar Depth Sounder Data of Greenland Ice Sheet," *IEEE Transactions on Electromagnetic Compatibility,* vol. 55, pp. 1060-1067, 2013.

[19] S. R. Shannon, A. J. Payne, I. D. Bartholomew, M. R. van den broeke, T. L. Edwards, X. Fettweis, O. Gagliardini, F. Gillet-Chaulet, H. Goelzer, M. J. Hoffman, P. Huybrechts, D. W. F. Mair, P. W. Nienow, M. Perego, S. F. Price, C. J. P. Paul Smeets, A. J. Sole, R. S. W. van de Wal, and T. Zwinger, "Enhanced basal lubrication and the contribution of the Greenland ice sheet to future sea-level rise," *Proceedings of the National Academy of Sciences (PNAS),* 2013.

[20] B. Medley, I. Joughin, B. E. Smith, S. B. Das, E. J. Steig, and H. Conway, "Constraining the recent mass balance of Pine Island and Thwaites glaciers, West Antarctica with airborne observations of snow accumulation," *The Cryosphere Discussions,* vol. 8, pp. 953-998, 2014.

[21] M. Perego, S. F. Price, and G. Stadler, "Optimal ice sheet model initial conditions for coupling to climate models," *Journal of Geophysical Research - Earth Surface,* submitted 2014.

[22] F. Rodriguez-Morales, S. Gogineni, C. Leuschen, J. Paden, J. Li, C. Lewis, B. Panzer, D. Gomez-Garcia, A. Patel, K. Byers, R. Crowe, K. Player, R. Hale, E. Arnold, L. Smith, C. Gifford, D. Braaten, and C. Panton, "An Advanced Multi-Frequency Radar Instrumentation for Polar Research," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 52, no. 5, 2014.

[23] S. Chakrabarti, C. Axel, and P. Gogineni, "Application of Special Purpose Artificial Neural Networks for the Speckle Reduction from SAR Images," *Journal of Remote Sensing,* vol. 35, pp. 1804-1828, 2014.

[24] T. L. Edwards, X. Fettweis, O. Gagliardini, F. Gillet-Chaulet, H. Goelzer, J. M. Gregory, M. Hoffman, P. Huybrechts, A. J. Payne, M. Perego, S. Price, A. Quiquet, and C. Ritz, "Probabilistic parameterisation of the surface mass balance - elevation feedback in regional climate model simulations of the Greenland ice sheet," *The Cryosphere,* vol. 8, pp. 181-194, 2014.

[25] T. L. Edwards, X. Fettweis, O. Gagliardini, F. Gillet-Chaulet, H. Goelzer, J. M. Gregory, M. Hoffman, P. Huybrechts, A. J. Payne, M. Perego, S. Price, A. Quiquet, and C. Ritz, "Effect of uncertainty in surface mass balance - elevation feedback on projections of the future sea level contribution of the Greenland ice sheet," *The Cryosphere,* vol. 8, pp. 195-208, 2014.

[26] C. Leuschen, R. Hale, S. Keshmiri, J. B. Yan, F. Rodriguez-Morales, A. Mahmood, and S. Gogineni, "UAS-Based Radar Sounding of the Polar Ice Sheets," IEEE Geoscience and Remote Sensing Magazine, vol. 2, pp. 8-17, 2014.

[27] M. J. Hoffman and S. F. Price, "Feedbacks between coupled subglacial hydrology and glacier dynamics," *Journal of Geophysical Research - Earth Surface,* vol. 119, 2014.

[28] Joughin, B. E. Smith, and B. M. Medley, "Has a marine ice sheet collapse begun in the Thwaites Glacier basin, West Antarctica?," Science, in revision.

Other Non-Peer-Reviewed Publications

[1] S. Raghunandan, "Analysis of Angle of Arrival Estimation Algorithms for Basal Ice Sheet Tomography," 09/2013 2013.
[2] P. S. Tan, "Study Conducted on Robust Adaptive MVDR Beamforming for Processing Radar Depth Sounder Data," 6/2013 2013.

Theses/Dissertations

[1] E. J. Arnold, "Development and Improvement of Airborne Remote Sensing Radar Platforms," Ph.D. Dissertation, Aerospace Engineering, University of Kansas, Lawrence, KS, 2013.
[2] S. Chen, "Synoptic Scale Weather Patterns Associated with Annual Snow Accumulation Variability in North-Central Greenland," M.S. Thesis, Atmospheric Sciences and Meterology, University of Kansas, Lawrence, KS, 2013.

1b. List all conference presentations in the reporting period using a standard citation format.

[1] S. Gogineni, D. Gomez, A. Patel, J. Paden, F. Rodriguez-Morales, D. Braaten, and C. Leuschen, "Ultra-wideband Radars for Measuring Snow Thickness Over Sea Ice and Mapping Internal Layers in Firn," presented at the EGU Gernal Assembly, Vienna Austria, 2013, 2013.
[2] R. Knepper and M. Standish, "Forward Observer In-Flight Dual Copy System," presented at the Polar Technology Conference, Annapolis, MD, 2013.
[3] S. Lee, J. Mitchell, D. J. Crandall, and G. Fox, "Estimating Bedrock and Surface Layers Boundaries and Confidence Intervals in Ice Sheet Radar Imagery Using MCMC," presented at the International Conference on Image Processing [submitted] Paris, France, 2014.
[4] B. Medley, I. Joughin, B. E. Smith, I. Das, E. J. Steig, H. Conway, P. Gogineni, A. Criscitiello, J. McConnell, M. Van den Broeke, J. Lenaerts, D. H. Bromwich, and J. Nicholson, "Constraining the recent sea-level contribution of Pine Island and Thwaites glaciers using CReSIS airborne radar systems," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[5] B. Medley, I. R. Joughin, B. E. Smith, S. B. Das, E. J. Steig, H. Conway, P. S. Gogineni, A. Criscitiello, J. R. McConnell, M. R. van den Broeke, J. Lenaerts, D. H. Bromwich, and J. P. Nicolas, "Constraining the recent mass balance of Pine Island and Thwaites glaciers, West Antarctica with airborne observations of snow (invited)," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[6] J. Mitchell, D. J. Crandall, G. Fox, and J. Paden, "A Semi-Automatic Approach for Estimating Near Surface Internal Layers From Snow Radar Imagery," presented at the International Geoscience and Remote Sensing Symposium, Melbourne, Australia, 2013.
[7] J. Mitchell, D. J. Crandall, G. Fox, M. Rahnemoonfar, and J. D. Paden, "A Semi-Automatic Approach for Estimating Bedrock and Surface Layers from Multichannel Coherent Radar Imagery," presented at the SPIE Remote Sensing Conference, Dresden, Germany, 2013.

[8] J. Mitchell, D. J. Crandall, and G. C. Fox, "A Survey of Techniques for Detecting Layers in Polar Radar Imagery," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[9] J. Mitchell, G. C. Fox, and J. Paden, "Automatic Identification of Ice Layers in Radar Echograms," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[10] F. M. Nick, A. Vieli, M. L. Andersen, and I. R. Joughin, "Effect of fjord geometry on Greenland mass loss in a warming climate (invited)," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[11] K. Poinar and I. Joughin, "How deep does a typical crevasse in western Greeenland carry meltwater?," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[12] K. Poinar and I. Joughin, "Sensitivity of Thwaites Glacier to Ice Shelf Melting," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[13] S. F. Price, X. S. Asay-Davis, D. F. Martin, M. E. Maltrud, and M. J. Hoffman, "Simulations of coupled, Antarctic ice-ocean evolution using POP2x and BISICLES," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[14] S. F. Price, M. J. Hoffman, M. Gunzburger, L. Ju, I. Kalashnikova, W. Leng, M. Perego, M. Petersen, T. Ringler, A. Salinger, and G. Stadler, "Simulating Land Ice Evolution within the MPAS Climate Modeling Framework," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[15] M. Rahnemoonfar and G. Fox, "Ice Layer Detection from RADAR Depth Sounder Data using Novel Approach based on theory of Electrostatics," presented at the International Glaciological Society International Symposium on Radioglaciology, Lawrence, KS, 2013.
[16] F. Rodriguez-Morales, P. Gogineni, C. Leuschen, D. Gomez-Garcia, B. Panzer, C. Lewis, J. Paden, J. B. Yan, Z. Wang, B. Townley, C. Carbajal, E. Arnold, and R. Hale, "Airborne Radar Sensor Package for Coincidental Multi-Frequency Measurements of the Cryosphere," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[17] A. Patel, J. Paden, C. Leuschen, B. Panzer, and P. Gogineni, "Interpretation of SIRAL waveforms using CReSIS altimeter data," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[18] D. Dahl-Jensen, C. Panton, and S. Gogineni, "Deformation and folds of the basal ice under the Greenland ice sheet," presented at the IGS International Symposium on Radioglaciology, Lawrence, KS, 2013.
[19] M. Truffer, D. B. Podrasky, M. A. Fahnestock, R. J. Motyka, and I. R. Joughin, "The effects of Jakobshavn Isbrae's acceleration on the surrounding ice," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[20] M. A. Werder and I. R. Joughin, "Fast flow of Jakobshavn Isbrae and its subglacial drainage system," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[21] J. A. Velez-Gonzalez, J. Li, C. Leuschen, P. Gogineni, C. J. Van der veen, G. P. Tsoflias, R. Drews, and A. R. Harish, "Preferred Ice Crystal Orientation Fabric Measurements within the Greenland Ice Sheet Using Multi-Polarization Radar Data," presented at the 2013 Fall Meeting, AGU, San Francisco, CA, 2013.
[22] S. Gogineni, J. B. Yan, D. Gomez, F. Rodriguez-Morales, J. Paden, and C. Leuschen, "Ultra-Wideband Radars for Remote Sensing of Snow and Ice," presented at the International Microwave and RF Conference, New Delhi, India, 2013.

[23] S. Gogineni, J. B. Yan, F. Rodriguez-Morales, C. Leuschen, B. Panzer, D. Gomez-Garcia, A. E. Patel, J. Paden, and M. A. Aziz, "Airborne Ultra-Wideband Microwave Radars for Snow Measurements," presented at the URSI Commision F Microwave Signatures 2013: Specialist Symposium on Microwave Remote Sensing of the Earch, Oceans and Atmosphere, Espoo (Helsinki), Finland, 2013.

2. List all awards and other honors with names of those honored and source in the reporting period. Please classify the award type indicating whether the award or honor is scientific, education-related, industry-related, a fellowship, or other.

Recipient		*Award Name and Sponsor*	*Date*	*Award Type*
1	Je'aime Powell	Student Leadership at the graduate level, 2013 Black Engineer of the Year Awards	February 2013	Education-related
2	Leigh Stearns	CAREER Award, NSF	June 2013	Scientific
3	Emily Arnold	Earth and Space Science Fellowship Renewal, NASA	June 2013	Fellowship
4	Theresa Stumpf	Earth and Space Science Fellowship, NASA	June 2013	Fellowship
5	Jerome Mitchell	Earth and Space Science Fellowship, NASA	June 2013	Fellowship
6	Kyle Purdon	First Prize, KU 2013 GIS Day	December 2013	Scientific
7	Sam Buchanan	Undergraduate Research Award, KU	January 2014	Scientific
8	Kyle Purdon	CSO Mentoring Award, KU CReSIS	March 2014	Education-related

3. List any undergraduate, M.S. and Ph.D. students who graduated during the reporting period. Include their current placement. Include the number of years taken since entering graduate school to complete the Ph.D. List postdoctoral associates who left the STC during the reporting period, and include their current placement.

	Student Name	*Degree(s)*	*Years to Degree*	*Placement**
1	Kelsey Leinmiller-Rennick	B.S. Environmental Studies	4	Intern at Disney Animal Kingdom
2	Ashley Detmering	B.A. Graphic Design	4	Colorado Mountain News Media
3	Lynsey Metz	B.S. Electrical Engineering	4	Unknown
4	David Jones	B.S. Computer Science	4	IBM
5	Zhang Zengxin	B.S. Electrical Engineering	4	Master's Program, University of Texas at Austin

6	Amir Bachelani	B.S. Aerospace Engineering	4	Graduate Program, University of Kansas
7	Matthew Elijah Patterson	B.S. Aerospace Engineering	4	Graduate Program, University of Kansas
8	Ya'Shonti Bridgers	B.S. Mathematics Education	4	Anticipated graduation May 2014
9	Michael Cobb	B.S. Chemistry	4	Anticipated graduation May 2014
10	William Daehler	M.A. Political Science	2	Chapman and Cutler LLP
11	Lauren Brown	M.Arch.	2	Kohn Pedersen Fox Associates (KPF)
12	Ali Mahmood	M.S. Electrical Engineering	2	Unknown
13	Nick Roberts	M.Sc. Aerospace Engineering	2	Goodyear
14	Shu Chen	M.S. Atmospheric Sciences and Meteorology	2	Unknown
15	Michael Jefferson	M.S. Mathematics with Remote Sensing Concentration	2	Anticipated graduation May 2014
16	Justin Deloatch	M.S. Mathematics with Remote Sensing Concentration	2	Anticipated graduation May 2014
17	Emily Arnold	Ph.D. Aerospace Engineering	4	MITRE Corporation
18	Cameron Lewis	Ph.D. Electrical Engineering	3	Anticipated graduation September 2014

4a. List, to the extent known the general outputs of knowledge transfer activities since the last reporting period.

Production detail is outlined in this and Section IV – Knowledge Transfer.

4b. Describe any other outputs of knowledge transfer activities made during the reporting period not listed above.

Press Releases/Media Exposure

- KU's CReSIS Tests UAS for Measuring Changes in Polar Ice Sheets
  - http://www.infozine.com/news/stories/op/storiesView/sid/58535/
- Antarctic trench named after KU professor: April 4, 2014
  - http://6lawrence.com/news/education/9635-arctic-trench-named-after-ku-professor
- KU water conference aims to find out what Midwest can learn from rest of world about drought: April 11, 2013

  - http://www2.ljworld.com/news/2013/apr/10/ku-water-conference-aims-find-out-what-midwest-can/
- ‘Seeing’ Into the Ice: April 18, 2013
  - http://www.polartrec.com/expeditions/airborne-survey-of-polar-ice-2013/journals/2013-04-17-0
- IU innovations continue to help NASA manage big data: May 2, 2013
  - http://ovpitnews.iu.edu/news/page/normal/24020.html
- NASA Polar Ice Flyover: One Bumpy Big Data Project: May 13, 2013
  - http://www.informationweek.com/big-data/news/big-data-analytics/nasa-polar-ice-flyover-one-bumpy-big-data-project/240154755
- NASA’s IceBridge mission contributes to new map of Antarctica: June 5, 2013
  - http://environmentalresearchweb.org/cws/article/yournews/53676
- NASA fellowship will help KU student develop better polar ice radar: July 3, 2013
  - http://news.ku.edu/2013/07/02/nasa-fellowship-will-help-ku-student-develop-better-polar-ice-radar
- KU student gets 3-year, $90K NASA fellowship: July 8, 2013
  - http://www.kctv5.com/story/22779995/ku-student-gets-3-year-90k-nasa-fellowship
- KU graduate student wins $90,000 NASA fellowship: July 10, 2013
  - http://www2.ljworld.com/news/2013/jul/08/ku-graduate-student-wins-90000-nasa-fellowship/
- Ph.D. student Jerome Mitchell receives 2013 NASA Earth and Space Science Fellowship: July 17, 2013
  - http://www.soic.indiana.edu/discover/news-events/news/jerome-mitchell-nasa-2013.shtml#
- NASA awards grant to graduate student: July 22, 2013
  - http://kansan.com/news/2013/07/22/nasa-awards-grant-to-graduate-student/
- NASA reveals ‘mega-canyon’ under Greenland ice sheet: September 4, 2013
  - http://www.komonews.com/home/video/NASA-reveals-mega-canyon-under-Greenland-ice-sheet-221840151.html
- NASA’s Operation IceBridge data shows Large Canyon underneath the Greenland Ice Sheet: September 6, 2013
  - http://www.komonews.com/home/video/NASA-reveals-mega-canyon-under-Greenland-ice-sheet-221840151.html
- NASA Data Reveals Mega-Canyon under Greenland Ice Sheet: September 6, 2013
  - http://alaska-native-news.com/science_news/9218-nasa-data-reveals-mega-canyon-under-greenland-ice-sheet.html
- Effects of federal shutdown being felt in Lawrence, Douglas County: October 11, 2013
  - http://www2.ljworld.com/news/2013/oct/09/effects-federal-shutdown-being-felt-lawrence-dougl/
- Antarctic research plans on ice: October 11, 2013
  - http://www2.ljworld.com/weblogs/heard_hill/2013/oct/10/plans-on-ice/
- University research suffers through sequester, shutdown: October 16, 2013
  - http://cjonline.com/news/2013-10-16/university-research-suffers-through-sequester-shutdown
- Government reopens, Antarctic research yet to thaw: October 17, 2013
  - http://kansan.com/news/2013/10/17/government-reopens-antarctic-research-yet-to-thaw/

- NASA IceBridge campaign to be based out of McMurdo Station for first time: November 18, 2013
    - http://antarcticsun.usap.gov/science/contenthandler.cfm?id=2937
- NASA Radar Peers Through Polar Ice to Help Predict Future Melting and Movement: December 3, 2013
    - http://www.scienceworldreport.com/articles/11334/20131203/nasa-radar-peers-through-polar-ice-help-predict-future-melting.htm
- Airborne radar looking through thick ice during NASA polar campaigns: December 3, 2013
    - http://phys.org/news/2013-12-airborne-radar-thick-ice-nasa.html
- Airborne Radar looking Through Thick Ice During NASA Polar Campaigns: December 3, 2013
    - http://www.nasa.gov/content/goddard/airborne-radar-looking-through-thick-ice-during-nasa-polar-campaigns/#.Up3I5MRDsvp
- Radar Cuts Through the Polar Ice Caps: December 9, 2013
    - http://www.brightsideofnews.com/news/2013/12/4/radar-cuts-through-the-polar-ice-caps.aspx
- IceBridge wraps up successful Antarctic campaign: December 12, 2013
    - http://phys.org/news/2013-12-icebridge-successful-antarctic-campaign.html
- Students Skype with Ku researchers in Antarctica: December 18, 2013
    - http://www2.ljworld.com/news/2013/dec/17/students-skype-ku-researchers-antarctica/
- Extensive liquid meltwater storage in firn within the Greenland ice sheet: December 23, 2013
    - http://www.nature.com/ngeo/journal/vaop/ncurrent/full/ngeo2043.html
- Greenland's Snow Hides 100 Billion Tons of Water: December 23, 2013
    - http://www.livescience.com/42172-greenland-snow-aquifer-found.html
- Enormous Aquifer Discovered Under Greenland Ice Sheet: December 23, 2013
    - http://www.nasa.gov/content/goddard/enormous-aquifer-discovered-under-greenland-ice-sheet/#.UriCF_RDvnh
- Small Drone Probes Antarctic Ice With Radar: January 6, 2014
    - http://spectrum.ieee.org/tech-talk/robotics/aerial-robots/small-drone-probes-antarctic-ice-with-radar
- Glacier Blamed for Berg That Sank Titanic Unleashes More Ice: February 3, 2014
    - http://www.npr.org/blogs/thetwo-way/2014/02/03/271148468/iceberg-blamed-for-sinking-titanic-pushing-more-ice-into-ocean
- Greenland's Fast-Moving Glacier Speeds Up: February 7, 2014
    - http://www.sciencefriday.com/segment/02/07/2014/greenland-s-fast-moving-glacier-speeds-up.html
- KU-based team conducts research in Antarctica: February 19, 2014
    - http://cjonline.com/life/arts-entertainment/2014-02-15/ku-based-team-conducts-research-antarctica
- Ku assistant professor awarded grant to aid research on melting glaciers: March 6, 2014
    - https://news.ku.edu/2014/03/04/research-will-boost-knowledge-melting-antarctic-glaciers-and-sea-level-rise
- Antarctic trenched named for professor, CReSIS researcher: April 2, 2014
    - http://news.ku.edu/antarctic-trench-named-ku-professor-researcher
- Antarctic trench named after CReSIS director: April 3, 2014
    - http://www2.ljworld.com/news/2014/apr/02/antarctic-trench-named-after-cresis/

5. List all participants in Center activities alphabetically classified by the categories and demographic characteristics listed below the table. Center affiliates may also be included in this table, but MUST be distinguished from participants.

Last Name	First Name	Middle	Category	Partner Institute	Department	Citizenship Status	Ethnicity	Gender
Ahmed	Syed	Faiz	Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male
Aldrich	Bernard		REU	Jackson State University	Computer Science	US Citizen	Black	Male
Alley	Richard		Faculty	Pennsylvania State University	Geosciences	U.S. Citizen	White	Male
Anandakrishnan	Sridhar		Faculty	Pennsylvania State University	Science/Geosciences	Permanent Resident	Asian	Male
ARNOLD	Emily	Julianna	Graduate	KU	AE	U.S. Citizen	White	Female
Aziz	Masud	Al	graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male
BACHELANI	Amir	Ali	Undergraduate	KU	AE	U.S. Citizen	Asian	Male
Baltrop	Jamika		Graduate	ADMI	MCS	U.S. Citizen	Black	Female
Barmore	Nyema		REU	ADMI	MCS	U.S. Citizen	Black	Female
Bass	Harry		Faculty	ECSU	MCS	U.S. Citizen	Black	Male
BERGLUND-RILEY	Judith	A.	Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Berry	Tyler		REU	Haskell Indian Nations University	Environmental Science	US Citizen	Native American	Male
Biggers	Maureen		Faculty	Indiana University	Diversity and Education	U.S. Citizen	White	Female
Bly	Patrina		Graduate	ECSU	MCS	U.S. Citizen	Black	Female
Bowman	Alec	D	Graduate	KU	Aerospace	U.S. Citizen	White	Male
BRAATEN	David		Faculty	KU	Geography	U.S. Citizen	White	Male
Brice	Dorothy		REU	Virginia Union University	Math	US Citizen	Black	Female
Brice	Robin		REU	Fayetteville State University	Biology/Chemistry	US Citizen	Black	Female
Bridgers	Ya'Shonti		REU	ADMI	MCS	U.S. Citizen	Black	Female
Brown	Dorias		REU	Spelman College	Computer Science	US Citizen	Black	Female
BROWN	Lauren	Leigh	Undergraduate	KU	Architecture	U.S. Citizen	White	Female
Brown	Nicholas	J	Other Participant	KU	CReSIS	U.S. Citizen	White	Male
Brumfield	Andrew		Graduate	ECSU	MCS	U.S. Citizen	Black	Male
BUCHANAN	Sam		Undergraduate	KU	Electrical Engineering	U.S. Citizen	White	Male
Burkett	Peter		Other Participant	Pennsylvania State University	Earth & Engineering Sciences	U.S. Citizen	White	Male
Burney	JerNettie		Graduate	Indiana University	CS	U.S. Citizen	Black	Female
Burns	Zachary	Brian	Undergraduate	KU	Mechanical Engineering	U.S. Citizen	White	Male
Burton	Kathryne A.		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Butler	Renee		REU	Haskell Indian Nations University	Environmental Science	US Citizen	Native American	Female
Caldwell	Rebecca		Faculty	ADMI	MCS	U.S. Citizen	Black	Female
Camps-Raga	Bruno		Other Participant	KU	CReSIS	Non-U.S. Citizen	Hispanic	Male
Carabajal	Calen	Lee	graduate	KU	Electrical Engineering	U.S. Citizen	Hispanic	Male
Carmichael	Joshua		graduate	University of Washington	Geopysics	U.S. Citizen	White	Male
Chakrabarti	Swapan		Faculty	KU	Electrical Engineering	U.S. Citizen	Asian	Male
Chamberlain	Michael		REU	UC Berkley	Geophysics	US Citizen	White	Male
Chao	Haiyang		Faculty	KU	Aerospace	Non-U.S. Citizen	Asian	Male
CHILD	Sarah	F.	Graduate	KU	Geology	U.S. Citizen	White	Female
Cobb	Michael		REU	Elizabeth City State University	Chemistry	US Citizen	Black	Male
Cobb	Michael		Undergraduate	ECSU	chem	U.S. Citizen	Black	Male
COLLINS	Jenna	Ann	Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Constant	Katie	Leigh	undergraduate	KU	Aerospace	U.S. Citizen	White	Female
Cornet	Erik		Other Participant	Indiana University	Research Technologies	U.S. Citizen	White	Male
Daehler	William	Lawrence	graduate	KU	Journalism	U.S. Citizen	White	Male
Davis	Danielle		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Davis	Donquel		REU	Winston Salem State Univeristy	Computer Science	US Citizen	Black	Male
Deloatch	Justin		Graduate	ECSU	MCS	U.S. Citizen	Black	Male
Deloatch	Justin		REU	Elizabeth City State University	Remote Sensing	US Citizen	Black	Male
Denny	Marisol		Undergraduate	ECSU	MCS	U.S. Citizen	Hispanic	Female
Detmering	Ashley	Grace	Undergraduate	KU	Graphic Design	U.S. Citizen	White	Female
Diaz-Camacho	Maricel	Victoria	Undergraduate	KU	Journalism	U.S. Citizen	Hispanic	Female
Dixon	Ricky		REU	Mississippi Valley State University	Math Education	US Citizen	Black	Male
Doyen	Katharine	Suzanne	Undergraduate	KU	Aerospace	U.S. Citizen	White	Female
Epperson	Riley	James	Other Participant	KU	CReSIS	U.S. Citizen	White	Male
Escalera Mendoza	Alejandra	Stefania	Undergraduate	KU	Aerospace	Non-U.S. Citizen	Hispanic	Female
Evans	Robin		Graduate	Indiana University	CS	U.S. Citizen	Black	Female
Evers	Justin	W.	Undergraduate	KU	Electrical Engineering	U.S. Citizen	White	Male
Ewing	Mark		Faculty	KU	AE	U.S. Citizen	White	Male
Farmer	Courtney		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
Farmer	Courtney		REU	Elizabeth City State University	Math Educaiton	US Citizen	Black	Female
Feng	Boyu		Graduate	KU	Geography	Non-U.S. Citizen	Asian	Female
Finley	Gale		Faculty	ADMI	CS	U.S. Citizen	Black	Female

Last Name	First Name	Middle	Category	Partner Institute	Department	Citizenship Status	Ethnicity	Gender
Fox	Geoffrey		Faculty	Indiana University	Pervasive Technology Institute	U.S. Citizen	White	Male
Freeman	Evan	Christopher	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
FULLER	Jay	W.	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Male
GARCIA-GOMEZ	Daniel	Alvestegui	Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Hispanic	Male
Gaynes	Tamara		REU	University of Kansas	Electrical Engineering	US Citizen	White	Female
GEE	Carson	M	Other Participant	KU	CReSIS	U.S. Citizen	White	Male
GILLETTE	Brandon	A.	Graduate	KU	Geography	U.S. Citizen	White	Male
GOGINENI	Prasad		Faculty	KU	Electrical Engineering	U.S. Citizen	Asian	Male
Gronek	Jeffrey		Other Participant	Indiana University	Research Technologies	U.S. Citizen	White	Male
Guion	Antonio		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
HALE	Richard		Faculty	KU	AE	U.S. Citizen	White	Male
HAMILTON	Cheri		Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Hartman	Ryan		Other Participant	Indiana University	Pervasive Technology Institute	U.S. Citizen	White	Male
Hathaway	Joal		Other Participant	ECSU	MCS	U.S. Citizen	Black	Male
Hathaway	Jessica		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Hathaway	Jessica		REU	Elizabeth City State University	Math Education	US Citizen	Black	Female
Hayden	Linda		Faculty	ECSU	MCS	U.S. Citizen	Black	Female
Hicks	Stephen	Albert	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
Hoffman	Matthew		Other Participant	LANL	Fluid Dynamics and Solid Mechanics	U.S. Citizen	White	Male
Holschuh	Nick		Graduate	Pennsylvania State University	Geosciences	U.S. Citizen	White	Male
Houk	Levi	Read	Undergraduate	KU	Education	U.S. Citizen	White	Male
Hsu	Kuangchen		Graduate	KU	Education	Non-U.S. Citizen	Asian	Male
Hunter	John		Other Participant	KU	AE	U.S. Citizen	White	Male
HYLAND-SIDENER	Sorcha		Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Jefferson	Michael		Graduate	ECSU	MCS	U.S. Citizen	Black	Male
JIANG	Xiushan		Graduate	KU	Education	Non-U.S. Citizen	Asian	Male
Johnson	Darnell		Faculty	ECSU	MCS	U.S. Citizen	Black	Male
Johnson	Jazette		REU	Spelman College	Computer Science	US Citizen	Black	Female
Jones	Kevin		Graduate	ECSU	MCS	U.S. Citizen	Black	Male
Joughin	Ian		Other Participant	University of Washington	Polar Science Center (PSC)	U.S. Citizen	White	Male
Kehl	Laura		Graduate	University of Washington	Polar Science Center (PSC)	U.S. Citizen	White	Female
Kennedy	Katelyn	Delaney	Undergraduate	KU	Geography	U.S. Citizen	White	Female
KESHMIRI	Shahriar		Faculty	KU	AE	U.S. Citizen	White	Male
Knepper	Richard		Other Participant	Indiana University	Research Technologies	U.S. Citizen	White	Male
LAVERENTZ	Jennifer	Racine	Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Lawrence	Andrea		Faculty	ADMI	CS	U.S. Citizen	Black	Female
LeCompte	Malcolm		Faculty	ECSU	MCS	U.S. Citizen	White	Male
LEUSCHEN	Carl		Faculty	KU	Electrical Engineering	U.S. Citizen	White	Male
LEWIS	Cameron	S.	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Male
LI	Jilu		Faculty	KU	CReSIS	Permanent Resident	Asian	Male
Link	Matthew		Other Participant	Indiana University	Research Technologies	U.S. Citizen	White	Male
Lipscomb	Bill		Faculty	LANL	Fluid Dynamics and Solid Mechanics	U.S. Citizen	White	Male
Luke	Autumn		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Lumpkin	Zazie		REU	Spelman College	Computer Science	US Citizen	Black	Female
Lykins	Ryan		Graduate	KU	Aerospace	U.S. Citizen	White	Male
Lynn	Anthony		REU	Winston Salem State Univeristy	Computer Science	US Citizen	Black	Male
Mahmood	Ali		Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male
Matthews	Tatyana		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
McCafferty	Julian	Patrick	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
McConner	Malcolm		REU	Elizabeth City State University	Math Education	US Citizen	Black	Male
McDaniel	Jay	William	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Male
McDonald	Kalyx		REU	Mississippi Valley State University	Computer Science	US Citizen	Black	Female
McGuire	Michael	Raymond	Undergraduate	KU	Computer Sciences	U.S. Citizen	White	Male
Meadows	Anthony		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
Medley	Brooke		Graduate	University of Washington	Polar Science Center (PSC)	U.S. Citizen	White	Female
Metz	Lynsey	Marie	Undergraduate/REU/graduate	KU	Electrical Engineering	U.S. Citizen	White	Female
Miksik	Gary		Other Participant	Indiana University	Pervasive Technology Institute	U.S. Citizen	White	Male
Mishra	Sanjay		Faculty	KU	Business	U.S. Citizen	Asian	Male
Mitchell	Jerome		Graduate	Indiana University	Computer Science	U.S. Citizen	Black	Male
Monteau	Darryl		Other Participant	KU	CReSIS	U.S. Citizen	Native American	Female
Morgan	Kevin	Ralph	Undergraduate	KU	CReSIS	U.S. Citizen	White	Male

Last Name	First Name	Middle	Category	Partner Institute	Department	Citizenship Status	Ethnicity	Gender
Morris	Derek		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
Morris	Derek	Jr.	REU	Elizabeth City State University	Math/Computer Science	US Citizen	Black	Male
Onyiriuka	Kelechi		REU	Elizabeth City State University	Computer Science	US Citizen	Black	Male
Paden	John	Drysdale	Faculty	KU	CReSIS	U.S. Citizen	White	Male
Paden	Aaron		Other Participant	KU	CReSIS	U.S. Citizen	White	Male
PANZER	Benjamin	Garrett	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Male
Parizek	Byron		Faculty	Pennsylvania State University	Geosciences	U.S. Citizen	White	Male
Penmetsa	Sreelakshmi		Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Female
Perkins	Jimil		REU	Norfolk State University	Computer Science	US Citizen	Black	Male
PLACE	Paulette	Linda	Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Poiner	Kristin		Graduate	University of Washington	Polar Science Center (PSC)	U.S. Citizen	White	Female
Pollard	David		Faculty	Pennsylvania State University	Earth & Engineering Sciences	U.S. Citizen	White	Male
Post	Elizabeth	Ann	Undergraduate	KU	Graphic Design	U.S. Citizen	White	Female
Powell	Je'amie		Other Participant	ECSU	MCS	U.S. Citizen	Black	Male
Price	Steve		Faculty	LANL	Fluid Dynamics and Solid Mechanics	U.S. Citizen	White	Male
Pugh	Nigel		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
PURDON	Kyle	W.	Undergraduate	KU	Geography	U.S. Citizen	White	Male
Qiu	Judy		Faculty	Indiana University	SALSA HPC Lab	U.S. Citizen	Asian	Female
Reeves	Emma		REU	Hamline University	Physics, Geology	US Citizen	White	Female
Reuter	Elise	Suzanne	Undergraduate	KU	Journalism	U.S. Citizen	White	Female
Reynolds	Alicia		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Rezvanbehbahani	Soroush		Graduate	KU	Geology	Non-U.S. Citizen	Asian	Male
Ridgeway	Jefferson		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
Rinkovsky	Joseph		Other Participant	Indiana University	Research Technologies	U.S. Citizen	White	Male
Riverman	Kiya		Graduate	Pennsylvania State University	Geosciences	U.S. Citizen	White	Female
RODRIGUEZ	Kelly		Undergraduate	KU	Mathmatics	Non-U.S. Citizen	Hispanic	Female
RODRIGUEZ-MORALES	Fernando		Faculty	KU	Electrical Engineering	Non-U.S. Citizen	Hispanic	Male
Rohde	Blake	Anthony	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
Satchell	Khaliq		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Male
SCHROER	David	Paul	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
Sheppard	Ian	Thomas	Undergraduate	KU	Aerospace	U.S. Citizen	White	Male
Smith	Maya		REU	Winston Salem State Univeristy	Information Technology	US Citizen	Black	Female
SMITH	Logan	S.	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Male
ST. AUBYN	Jackie		Other Participant	KU	CReSIS	U.S. Citizen	White	Female
Stafford	Trey	Michael	Undergraduate	KU	Geography	U.S. Citizen	White	Male
Stastny	Thomas	James	Undergraduate/Graduate	KU	Aerospace	U.S. Citizen	White	Male
Stearns	Stearns		Faculty	KU	Geology	U.S. Citizen	White	Female
Stumpf	Theresa	M.	Graduate	KU	Electrical Engineering	U.S. Citizen	White	Female
Syed	Ahmed	Faiz	Undergraduate	KU	Electrical Engineering	Permanent Resident	Asian	Male
Tan	Peng	Seng	Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male
Thompson	Emily	Christine	Undergraduate	KU	Aerospace	U.S. Citizen	White	Female
Townley	Brian	Curtis	Other Participant	KU	CReSIS	U.S. Citizen	White	Male
TSOFLIAS	Georgios		Faculty	KU	Geology	Permanent Resident	White	Male
VAN DER VEEN	Cornelis		Faculty	KU	Geography	Permanent Resident	White	Male
Velez	Jose	A.	Graduate	KU	Geology	U.S. Citizen	Hispanic	Male
Vincent	Stephen	Andrew	Graduate	KU	Mechanical Engineering	U.S. Citizen	White	Male
von Laszewski	Gregor		Other Participant	Indiana University	Pervasive Technology Institute	U.S. Citizen	White	Male
Wang	Zongbo		Faculty	KU	CReSIS	Non-U.S. Citizen	Asian	Male
Wang	Haiji		Undergraduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male
Warner	Christian	John	Undergraduate	KU	Computer Sciences	U.S. Citizen	White	Male
Wells	Bailey	Katherine	Undergraduate	KU	Graphic Design	U.S. Citizen	White	Female
Wieland	Tyler	Storm	Undergraduate	KU	Journalism	U.S. Citizen	White	Male
Wilbon	Tori S.		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Willer	Robert	Matthew	Undergraduate	KU	Electrical Engineering	U.S. Citizen	White	Male
Williams	Briana		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Williams	Rashida		Undergraduate	ECSU	MCS	U.S. Citizen	Black	Female
Williamson	Rashad		REU	Mississippi Valley State University	Math	US Citizen	Black	Male
Wood	Jeff		Other Participant	ECSU	MCS	U.S. Citizen	White	Male
XIUSHAN	Jiang		Graduate	KU	Education	Non-U.S. Citizen	Asian	Male
Yan	Jie	Bang	Faculty	KU	CReSIS	Non-U.S. Citizen	Asian	Male
Zhu	Yi		Graduate	KU	Electrical Engineering	Non-U.S. Citizen	Asian	Male

6. Provide a summary listing of all of the Center's research, education, knowledge transfer and other institutional partners (the total number of academic institutions and non-academic organizations, including industry, states, and other Federal agencies which work or share resources with the Center).

Table 19: Center Partners

	Organization Name	*Organization Type**	*Address*	*Contact Name*	*Type of Partner***	*160 hours or more? (indicate Y/N)*
1	See CReSIS partner list w/ contact information in Section I: General Information					
2	NASA – Jet Propulsion Lab	Federal Government	Pasadena, CA	Eric Rignot	research, education, knowledge transfer	N
3	NASA – Goddard Space Flight Center	Federal Government	Beltway, MD	Bob Bindschadler, William Krabill, Robert Thomas	research, education, knowledge transfer	N
5	Antarctic Climate and Ecosystems Cooperative Research Centre	International Research Center, University	Tasmania, Australia	Ian Allison	research, education, knowledge transfer	Y
6	University of Copenhagen	International Research Center, University	Copenhagen, Denmark	Dorthe Dahl-Jensen	research, education, knowledge transfer	Y
7	Technical University of Denmark	International Research Center, University	Lundtofte, Denmark	Erik Christensen, Niels Reeh	research, education, knowledge transfer	N
8	Centre for Polar Observations and Modeling	International Research Center, University	Cambridge, UK	Andrew Shepherd	research, education, knowledge transfer	N
9	University of Iceland	International Research Center, University	Reykjavík, Iceland	Jón Atli Benediktsson	research, education, knowledge transfer	N
10	Universidad de Magallanes	International Research Center, University	Punta Arenas, Chile	Carlos Cárdenas M.	research, education, knowledge transfer	N

11	Indian Institute of Technology Kanpur	International Research Center, University	Kanpur, India	Sanjay G. Dhande	research, education, knowledge transfer	N

7. For internal NSF reporting purposes, provide a Summary Table with the following information:

Table 20: Summary Table

1	The number of participating institutions (all academic institutions that participate in activities at the Center) This value should match the number of institutions listed in Section I, Item 1 of the report plus other additional academic institutions that participate in Center activities as listed in the table above.	16
2	The number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center) This value should match the number of partners listed in the table in Section VIII, Item 6 (above)	2
3	The total leveraged support for the current year (sum of funding for the Center from all sources *other* than NSF-STC) [Leveraged funding should include both cash and in-kind support that are related to Center activities, but not funds awarded to individual PIs.] This value should match the total of funds in Section X, Item 4 of "Total" minus "NSF-STC" for cash and in-kind support	$1,395,242
4	The number of participants (total number of people who utilize center facilities; not just persons directly supported by NSF); please EXCLUDE affiliates This value should match the total number of participants listed in Section VIII, Item 5 (above)	183

8. Describe any media publicity the Center received in the reporting period. Provide in Appendix D any appropriate media materials that can be used to disseminate information on Center accomplishments and activities to the public.

These are outlined in paragraph 4b above.

IX. INDIRECT/OTHER IMPACTS: Please describe any international activities in which the Center has engaged. If they are described elsewhere in the report, highlight them here without going into great detail.

- Daniel Shapero (UW GRA) traveled to Finland to attend the Elmer Ice Workshop.

- Kristin Poinar (UW GRA) traveled to Ottawa, Canada to attend at the IASC Dynamics and Mass Budget of Arctic Glaciers Workshop.
- Prasad Gogineni (Director) traveled to Cambridge, UK to present at the British Antarctic Survey.
- Prasad Gogineni (Director) and others traveled to Copenhagen, Denmark to present at the Radio Echo Sounding Layer Tracing Workshop

X. BUDGET

1. Unobligated Funds. Provide a statement of funds estimated to remain unobligated at the end of the current award year, and plans for use.

The current carry forward is 15.34% across all partners.

2. Requested Award Year. Provide a proposed total budget, and individual budgets for each subcontract, for the requested award year using NSF Form 1030 (10/97).

SUMMARY PROPOSAL BUDGET — FOR NSF USE ONLY

ORGANIZATION University of Kansas Center for Research, Inc.	PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR S. Prasad Gogineni	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)				RATE	%	NSF-Funded Person-Months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1	Gogineni, S. Prasad	PI	EECS	$ 12,423.48				1.75	$ 47,106	
2	Braaten, David	Co-I	CLAS	$ 4,724.77				1.75	$ 17,915	
2	Ewing, Mark	Co-I	AE	$ 5,461.00				0.00	$ -	
3	Hale, Rick	Co-I	AE	$ 5,881.38				1.50	$ 19,114	
4	Keshmiri, Shah	Co-I	AE	$ 4,446.46				0.00	$ -	
5	Leuschen, Carl	Co-I	EECS	$ 5,351.08				1.50	$ 17,391	
6	Mishra, Sanjay	Co-I	BUS	$ 6,716.69				0.00	$ -	
7	Paden, John	Co-I	CReSIS	$ 4,458.00				0.00	$ -	
8	Stearns, Leigh	Co-I	CLAS	$ 3,846.00				0.50	$ 4,167	
9	Rodriguez-Morales,	Co-I	CReSIS	$ 3,672.92				9.00	$ 71,622	
10	Tsoflias, Georgios	Co-I	CLAS	$ 4,923.91				0.50	$ 5,334	
11	van der Veen, Cornelis	Co-I	CLAS					0.00	$ -	
12	new AE Faculty member	Co-I	AE						$ -	
13									$ -	
14									$ -	
	(13) TOTAL FACULTY								$ 182,649	

		Funds Requested By Proposer	Funds Granted by NSF (If Different)
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)			
1 (0) POSTDOCTORAL ASSOCIATES		$ -	
2 (4) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)		$ 118,385	
3 (8+1) GRADUATE STUDENTS		$ 78,246	
4 (5) UNDERGRADUATE STUDENTS		$ 47,385	
5 (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)		$ -	
6 (4) OTHER		$ 127,949	
TOTAL SALARIES AND WAGES (A + B)		$ 554,614	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)	32% = faculty/staff 12% = 76% or more 4% = 75% or less	$ 142,300	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)		$ 696,914	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)			
Sensors - Seismics	$ 50,000		
Sensors - Radar	$ 50,000		
Platform - UAV	$ 25,000		
Data Processing - Computing/Storage	$ 80,000		
TOTAL EQUIPMENT		$ 205,000	
E. TRAVEL			
1 DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)		$ 35,000	
2 FOREIGN		$ 15,000	
F. PARTICIPANT SUPPORT			
1 STIPENDS	$ 600		
2 TRAVEL	$ 3,000		
3 SUBSISTENCE	$ 2,400		
4 OTHER	$ -		
TOTAL NUMBER OF PARTICIPANTS (12)	TOTAL PARTICIPANT COSTS	$ 6,000	
G. OTHER DIRECT COSTS			
1 MATERIALS AND SUPPLIES		$ 50,000	
2 PUBLICATION/DOCUMENTATION/DISSEMINATION		$ 15,000	
3 CONSULTANT SERVICES		$ -	
4 COMPUTER SERVICES		$ -	
5 SUBAWARDS		$ 1,052,992	
ADMI - Lawrence		$ 89,640	
Elizabeth City State University - Hayden		$ 281,000	
Indiana University - Fox		$ 179,280	
Los Alamos National Laboratory - Lipscomb		$ 66,400	
The Pennsylvania State University - Anandakrishnan		$ 287,272	
University of Washington - Joughin		$ 149,400	
6 TUITION		$ 35,918	
7 OTHER		$ 113,745	
Other Costs		$ 39,777	
Computing & Networking (7%)		$ 73,968	
TOTAL OTHER DIRECT COSTS		$ 1,267,655	
H. TOTAL DIRECT COSTS (A THROUGH G)		$ 2,225,569	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) rate = 46.5%			
TOTAL INDIRECT COSTS (F&A)		$ 430,431	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)		$ 2,656,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)		$ -	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$ 2,656,000	

M. COST SHARING PROPOSED LEVEL: $996,000	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE* S. Prasad Gogineni	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) ***Supersedes All Previous Editions*** *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

SUMMARY PROPOSAL BUDGET

	FOR NSF USE ONLY		
ORGANIZATION Elizabeth City State University	PROPOSAL NO.	DURATION (MONTHS)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR **Linda B. Hayden**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months			Funds Requested By Proposer	Funds Granted by NSF (If Different)
	CAL	ACA	SUMR		
1. Linda B. Hayden - PI	1.14			$14,200	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1-6)	1.14			$14,200	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES					
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.0			108,061	
3. (2) GRADUATE STUDENTS				15,000	
4. (4) UNDERGRADUATE STUDENTS				8,000	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				145,261	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				20,149	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				165,410	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					
2. FOREIGN				2,000	
F. PARTICIPANT SUPPORT 1. STIPENDS $ 7,000 2. TRAVEL 3. SUBSISTENCE 2,000 4. OTHER 21,922					
TOTAL NUMBER OF PARTICIPANTS (15) TOTAL PARTICIPANT COSTS				30,922	
G. OTHER DIRECT COSTS				8,332	
1. MATERIALS AND SUPPLIES				2,070	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				700	
3. CONSULTANT SERVICES					
4. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER				2,770	
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)				203,102	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) Rate 54.7% Base 142,410					
TOTAL INDIRECT COSTS (F&A)				77,898	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				281,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$281,000	$

M. COST SHARING: PROPOSED LEVEL $138,948	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) ***Supersedes All Previous Editions***

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

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SUMMARY PROPOSAL BUDGET

ORGANIZATION Indiana University	FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed	 Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR **Geoffrey C. Fox**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Geoffrey C. Fox - PI	.36			$8,754	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. (1) TOTAL SENIOR PERSONNEL (1-6)	.36			8,754	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES					
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	4.5			48,347	
3. (1) GRADUATE STUDENTS				22,980	
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				81,577	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				26,427	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				108,004	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,000	
2. FOREIGN					
F. PARTICIPANT SUPPORT 1. STIPENDS $ ________ 2. TRAVEL ________ 3. SUBSISTENCE ________ 4. OTHER					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS				8,332	
1. MATERIALS AND SUPPLIES					
2. PUBLICATION/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER				8,332	
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)				119,336	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) Rate 54% Base 111,004					
TOTAL INDIRECT COSTS (F&A)				59,943	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				179,279	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$179,279	$

M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) ***Supersedes All Previous Editions***

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

SUMMARY PROPOSAL BUDGET Year 5

	FOR NSF USE ONLY		
ORGANIZATION Pennsylvania State Univ University Park	PROPOSAL NO.	DURATION (MONTHS) Proposed	DURATION (MONTHS) Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Sridhar Anandakrishnan	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Sridhar Anandakrishnan - PI		0.50		$6,626	$
2. Richard B Alley – Co-PI		0.50		13,660	
3. Byron Parizek – Co-PI		1.00		8,236	
4. David Pollard – Co-PI	1.0			12,256	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. (4) TOTAL SENIOR PERSONNEL (1-6)	1.0	2.00		40,778	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	4.2			21,470	
3. (2) GRADUATE STUDENTS				52,544	
4. ( ) UNDERGRADUATE STUDENTS					
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				5,000	
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				119,792	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				30,802	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				150,594	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,000	
2. FOREIGN				3,000	
F. PARTICIPANT SUPPORT 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				10,000	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER				37,752	
TOTAL OTHER DIRECT COSTS				47,752	
H. TOTAL DIRECT COSTS (A THROUGH G)				206,346	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) mtdc (Rate: 48.0000, Base: 168594)					
TOTAL INDIRECT COSTS (F&A)				80,926	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				287,272	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$287,272	$

M. COST SHARING: PROPOSED LEVEL $175,481	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE* Sridhar Anandakrishnan	DATE	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) ***Supersedes All Previous Editions***

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

SUMMARY PROPOSAL BUDGET

YEAR 5

ORGANIZATION **University of Washington**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	 Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ian R Joughin**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Ian R Joughin - PI**	2.80	0.00	0.00	$ **45,349**	$
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	2.80	0.00	0.00	**45,349**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**1**) GRADUATE STUDENTS				**12,543**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**57,892**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**24,569**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**82,461**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**4,276**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,225**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,924**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**38,016**	
TOTAL OTHER DIRECT COSTS				**42,165**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**128,902**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 17.0000, Base: 120577)**					
TOTAL INDIRECT COSTS (F&A)				**20,498**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**149,400**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **149,400**	$

M. COST SHARING PROPOSED LEVEL $ **22,410** AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Ian R Joughin**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Barbara Armbrister**	Date Checked	Date Of Rate Sheet	Initials - ORG

5 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 5

ORGANIZATION **Los Alamos National Laboratory, Los Alamos National Security**	FOR NSF USE ONLY PROPOSAL NO. / DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **William Lipscomb**	AWARD NO.

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **William Lipscomb - PI**	0.00	0.00	0.00	$ **0**	$
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**1**) POST DOCTORAL SCHOLARS	4.44	0.00	0.00	**33,165**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**33,165**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**8,789**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**41,954**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**1,859**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**1,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**44,813**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **DOE overhead rate (Rate: 3.0000, Base: 64466) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS (F&A)				**21,587**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**66,400**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **66,400**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME **William Lipscomb**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. NAME* **Barbara Armbrister**	Date Checked / Date Of Rate Sheet / Initials - ORG

5 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 5

**** I- Indirect Costs**
G&A rate (Rate: 35.5000, Base 16615)
Infrastructure rate (Rate: 23.0000, Base 41954)
New Mexico Gross Receipts Tax (Rate: 5.5000, Base 54462)
Program rate (Rate: 2.0400, Base 54462)

SUMMARY PROPOSAL BUDGET

[redacted]

ORGANIZATION

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR
Dr. Andrea W. Lawrence

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)			NSF-Funded Person-Months			Funds Requested By Proposer	Funds Granted by NSF (If Different)
			CAL	ACAD	SUMR		
1	Andrea Lawrence	PI			1.00	$ 5,000	$
2							
3						$ -	
4						$ -	
5						$ -	
6	(2) TOTAL FACULTY					$ 5,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN	[redacted]						
1	(0) POSTDOCTORAL ASSOCIATES						
2	(0) OTHER PROFESSIONALS (TECHNICIAN,						
3	(0) GRADUATE STUDENTS						
4	(0) UNDERGRADUATE STUDENTS						
5	(0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					$ -	
6	(0) OTHER						
	TOTAL SALARIES AND WAGES (A + B)					$ 5,000	
C. FRINGE BENEFITS (IF CHARGED AS						$ -	
	TOTAL SALARIES, WAGES AND FRINGE					$ 5,000	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING						[redacted]	
	Mechanical		$ -				
	Platforms						
	Sensors						
	TOTAL EQUIPMENT					$ -	
E. TRAVEL						[redacted]	
1	DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					$ 3,000	
2	FOREIGN					$ -	
F. PARTICIPANT SUPPORT						[redacted]	
1	STIPEND	$ 31,000					
2	TRAVEL	$ 8,000					
3	SUBSIST	$ 22,460					
4	OTHER	$ 20,000	Scholarships for ADMI Conference				
	TOTAL NUMBER OF PARTICIPANTS (50)					$ 81,460	
G. OTHER DIRECT COSTS						[redacted]	
1	MATERIALS AND SUPPLIES					$ -	
2	PUBLICATION/DOCUMENTATION/DISSEMINATION					$ 180	
3	CONSULTANT SERVICES					$ -	
4	COMPUTER SERVICES					$ -	
5	SUBAWARDS					$ -	
6	OTHER					$ -	
	TOTAL OTHER DIRECT COSTS					$ 180	
H. TOTAL DIRECT COSTS (A THROUGH G)						$ -	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						[redacted]	
	TOTAL INDIRECT COSTS (F&A)					$ -	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)						$ 89,640	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG						$ -	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)						$ 89,640	$
M. COST SHARING: PROPOSED LEVEL	AGREED LEVEL IF DIFFERENT: $						
PI/PD TYPED NAME AND SIGNATURE*	DATE	[redacted]					
ORG. REP. TYPED NAME &	DATE						

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Center Support from All Sources.

	Current Award Year		*Requested Award Year*	
Award Source	Cash ($)	In-Kind	Cash ($)	In-Kind
NSF-STC Core (ANT-0424589)	$3,320,000		$2,656,000	
Other NSF (details in 5. below)				
Other Federal Agencies:				
▪ NASA Deployment of a radar instrumentation suite to monitor land and sea ice in support of Operation Ice Bridge	625,808			
▪ Deployment of CReSIS instrumentation and Data Management Activities in support of Operation Ice Bridge	1,588,594		1,598,465	
▪ NASA Subglacial Water and Antarctic ice dynamics	121,760	12,593		
▪ EcoSAR: The first P Band Digital Beamforming Interferometric SAR Instrument to measure Ecosystem Structure, Biomass and Water	95,595			
▪ Design and Development of an Ultra-Wideband Microwave Radar for Airborne Measurements of Thickness of Snow on Sea Ice	700,000			
▪ Earth and Space Science Fellowship 2013	30,000		30,000	
▪ Adaptation of the Snow Radar for NASA Global Hawk And Ikhana Unmanned Aircraft in Support of Operation Ice Bridge	160,000		150,000	
State Government (KTEC)	56,448		150,000	
Local Government				
Industry				
University:				
▪ STC Matching Funds to ANT-0424589 - KU	340,541	196,301	277,467	
▪ STC Matching Funds to ANT-0424589 - Partners	178,152	415,690	10,107	359,226
▪ Other Center Support		220,000		220,000
International				
Private Foundations				
▪ Allen Foundation	200,000			
▪ Self-Fellowship Support to REU activities	3,500		3,500	
▪ Other				
TOTAL				
	$7,420,398	**$831,991**	**4,875,539**	**$579,226**

4. Breakdown of Other NSF Funding. All Center-related NSF funding is reflected in the table above.

Several Center collaborators are funded under the following NSF programs as PIs or Co-Is:

Award	*This FY $*	*Next FY $*	*End Date*
Development of a high-power, large antenna array and ultra-wideband radar for a Basler for sounding and imaging of Fast-flowing Glaciers and Mapping Internal Layers	$580,639		9/30/2014
MRI: Development of an Anechoic Chamber	$177,820		7/31/2014
Byrd Glacier Flow Dynamics			11/12/2014
CAREER: Improving Understanding of Antarctic Glacier Dynamics Through an Interactive Numerical Flowline Model	$114,998	219,929	07/31/2018
Arctic and Antarctic CReSIS Project (AaA-REU) with Research Experience for Teachers (RET) Component	$326,718	$326,718	06/30/2016
TOTAL	**$1,200,175**	**$546,647**	

5. Cost Sharing. The amount of cost sharing must be documented (on an annual and cumulative basis), reported to NSF, and certified by an authorized institutional representative.

6. Additional PI Support from All Sources

All funding for Dr. Gogineni is included in the above tables.

Appendix A:

Haiyang Chao, Ph.D., Assistant Professor

Department of Aerospace Engineering, University of Kansas, 1530 W 15th St, Lawrence, KS 66045, Tel: (785) 864-2968, Fax: (785) 864-3597, E-mail: chaohaiyang@ku.edu

Professional Preparation

Utah State University	Electrical Engineering	Ph.D., 2010
Zhejiang University, China	Electrical Engineering	B.S., 2001

Appointment

08/13-present	Assistant Professor, Department of Aerospace Engineering, University of Kansas
2011-07/13	Post-Doc Fellow, Department of Mechanical & Aerospace Engineering, West Virginia University (2011 – July, 2013)

Relevant Publications

Chao, H. and Chen, Y.Q., "*Remote Sensing & Actuation Using Unmanned Vehicles,*" ISBN: 978-1-1181-2276-1, Wiley – IEEE Press, August, 2012.

Chao, H., Gu, Y., Gross, J., Guo, G., Fravolini, M.L., and Napolitano, M., "*A Comparative Study of Optical Flow and Traditional Sensors in UAV Navigation,*" American Control Conference, June, 2013.

Larrabee, T., **Chao, H.**, Mandal, T., Gururajan, S., Gu, Y., Napolitano, M., "*Design, Simulation, and Flight Test Validation of a UAV Ground Control Station for Aviation Safety Research and Pilot Modeling*," AIAA Guidance, Navigation, and Control Conference, August, 2013

Chao, H., Jensen, A., Han, Y., Chen, Y., and McKee, M., "*AggieAir: Towards Low- cost Cooperative Multispectral Remote Sensing Using Small Unmanned Aircraft Systems,*" Chapter, Advances in Geoscience and Remote Sensing, IN-TECH, 2009.

Chao, H., Luo, Y., Di, L., and Chen, Y.Q., "*Roll-Channel Fractional Order Controller Design for a Small Fixed-Wing Unmanned Aerial Vehicle,*" Control Engineering Practice, vol.18, 7:761-772, 2010.

Chao, H., Cao, Y., and Chen, Y.Q., "*Autopilots for Small Unmanned Aerial Vehicles: A Survey*", International Journal of Control, Automation and Systems, vol.8, 1:36-44, 2010.

Ren, W., **Chao, H.**, Bourgeous, W., Sorensen, N. and Chen, Y.Q., "*Experimental Validation of Consensus Algorithms for Multi-vehicle Cooperative Control,*" IEEE Transactions on Control Systems Technology, vol.16, 4:745-752, 2008.

Synergistic Activities

Co-inventor: AggieAir UAS with multispectral capabilities of RGB, NIR and thermal bands.

Grants

Co-PI (30%), $*200,000,* NASA LEARN Program Phase I, *"Gust Sensing and Suppression Control in Aircraft Formation Flight", Nov. 2012 – Dec. 2013*.

PI, $*20,000,* NASA West Virginia Space Consortium, *"Prevailing Winds and Gusts Estimation Using Small UAVs", May 2011 – Dec. 2012*.

Appendix B: Center Organizational Chart