CReSIS Technology

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- Objectives
- Requirements
- Strategy
- Status

NATIONAL SCIENCE FOUNDATION :: KANSAS TECHNOLOGY ENTERPRISE CORPORATION :: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The University of Kansas | The Ohio State University | Pennsylvania State University
The University of Maine | Elizabeth City State University | Haskell Indian Nations University

Centre for Polar Observation and Modelling | University of Copenhagen
Technical University of Denmark | Antarctic Climate & Ecosystems CRC

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Science-driven technology requirements

Polar research has unique and demanding technology requirements

The needs of the science community will drive the center's technology program

A system-level approach will address requirements at all levels

- Integrating antennas with UAV platforms
- Communication needs of radar sensors on UAVs

Technology Objectives for Year 2 (& 3)

Design and develop technologies for collecting science data

Sensors:

–radar: for characterizing the ice column and bed condition

–seismic: for characterizing the subglacial conditions

–shallow ice-core system: for depth profiles of density, temperature, and layer characterization within the top 100 m

Platforms:

–uncrewed-aerial vehicle (UAV): supports airborne radar

–ground-based vehicle: supports seismic and surface-based radar

Involve undergraduate and graduate students in research

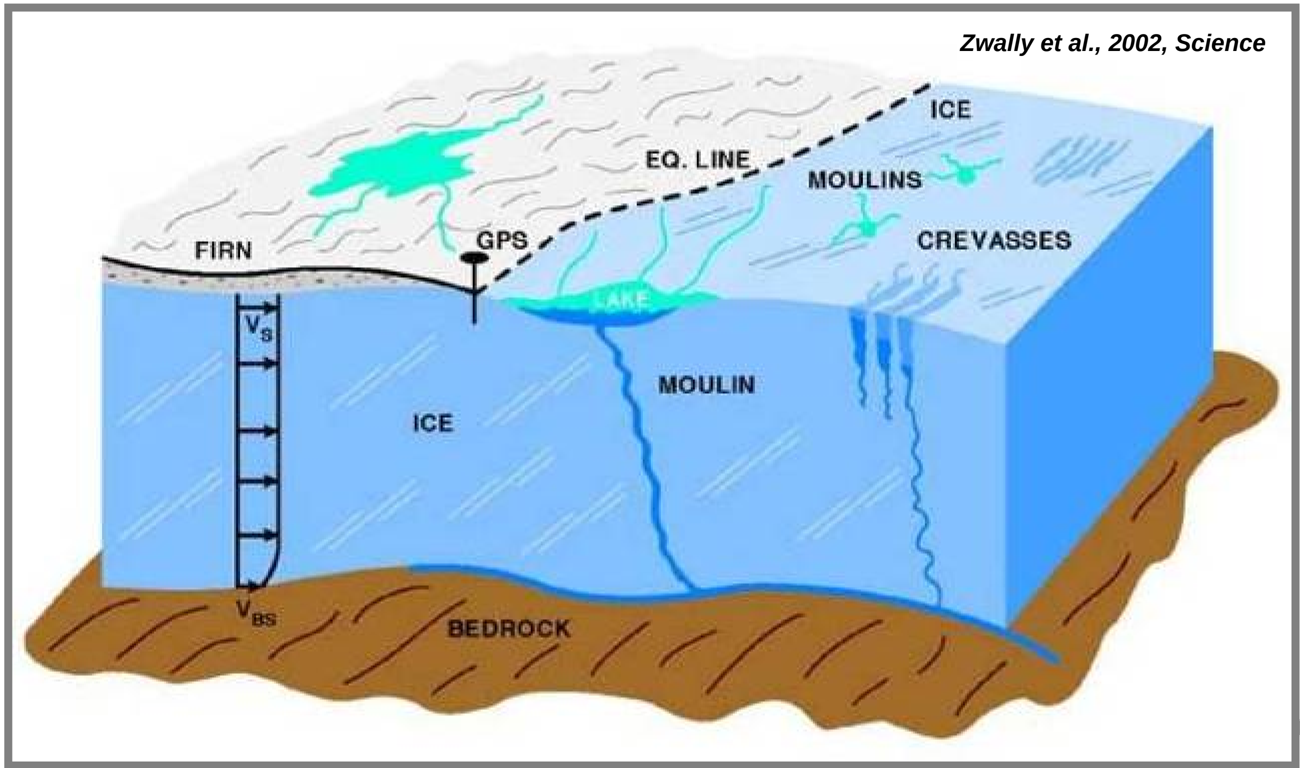
137 students involved in overall research activities

34 @ ECSU (28 undergraduate), 11 @ Haskell (all UG),
74 @ KU (26 UG), 10 @ OSU (3 UG),
2 @ Maine (0 UG), 6 @ PSU (0 UG)

Science requirements

Example: Intensive study of outlet glacier

Detailed outlet glacier characterization need:
ice thickness, strain, basal conditions, …



<u>Glacier extent:</u>
5 to 80 km width
100^+ km length
0.3 to 3 km thickness

<u>Examples</u>
Jakobshavn glacier, Greenland

Pine Island Glacier, Antarctica

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Technology requirements

Characterize the ice column and bed conditions

Radar

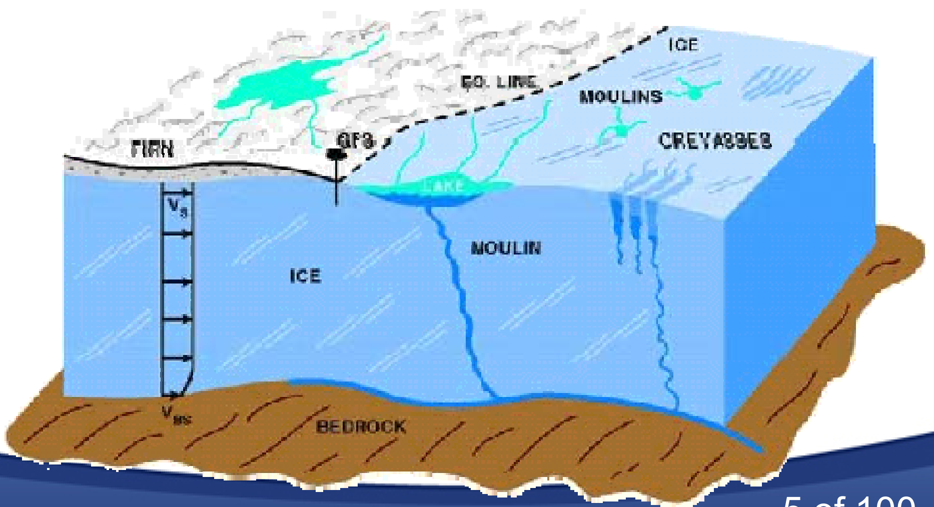
ice thickness, map internal layers, crystalline orientation fabric, englacial temperature profile, map englacial moulins, map basal water layers, bed roughness

Seismic

ice thickness, map basal water layers, bed roughness, subglacial characterization (stratigraphy, faulting, geology)

Shallow ice-core

snow-firn core sampling and density profiles



Technology strategy

Sensors

Radar – 3 different systems deployed

ground-based operation, manned aircraft, UAV

Seismic – conventional seismic technology used, new techniques to improve measurement efficiency

Shallow ice-coring – Speedograph system under development for rapid, fine-resolution density profiling

Platforms

Rover – supporting seismic mission

Twin Otter – supports regional- and local-scale radar surveys

UAV – supports fine-scale surveys

Radar development timeline

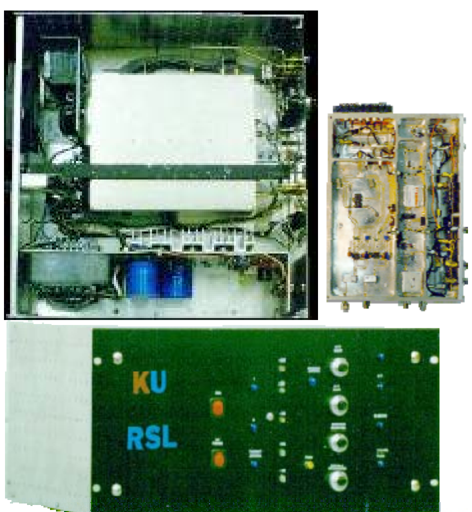
Continuous improvements on depthsounder system. Annual measurement campaigns of Greenland ice sheet.
1993 - 2001

More advanced and compact radar systems developed as part of the PRISM project.
2001 - 2005

New radar systems developed to meet science needs. Radar systems modified and miniaturized for UAV use.
2005 - 2010

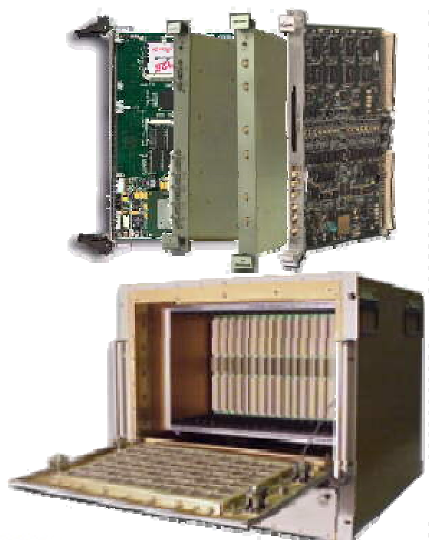
Radar system size and weight reduction continues. Imaging radars developed.
2010 - 2015

2000 *2005* *2010* *2015*

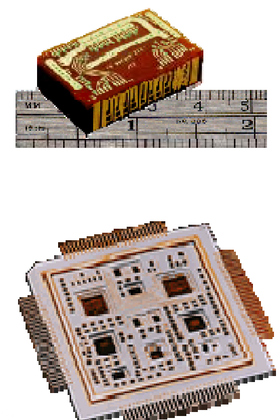


7.1 ft^3

2001



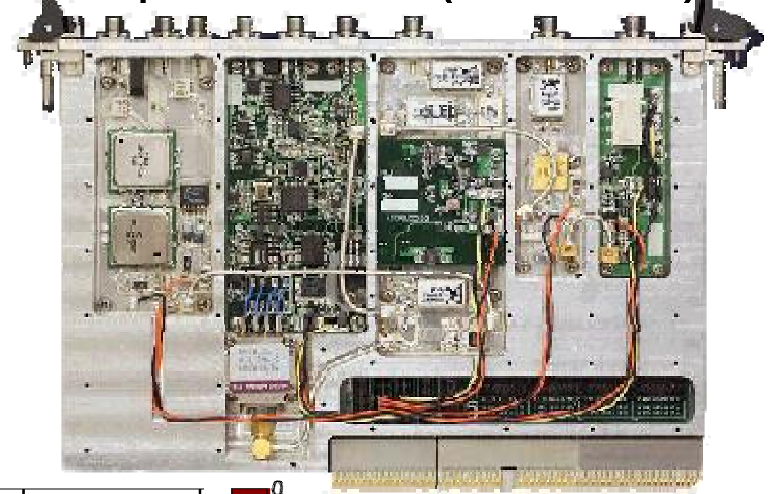
2004



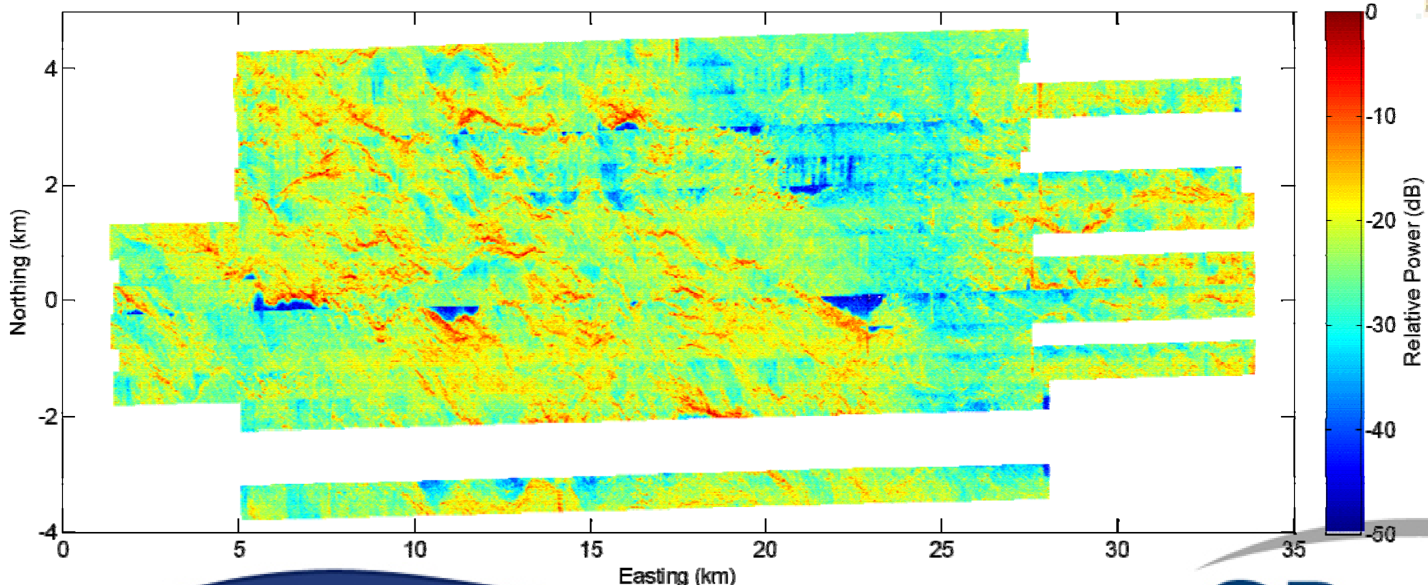
2015

Sensors – Ground-based radar

Compact PCI module (9” x 6.5” x 1”)



Synthetic-aperture radar data from Summit, Greenland in summer 2005



SAR mosaic of ice bed. Origin is Summit Camp, Greenland.
Data parameters:
120 to 200 MHz,
VV polarization,
10 to 30 m cross-track and 30 m along-track resolution with 15 looks.

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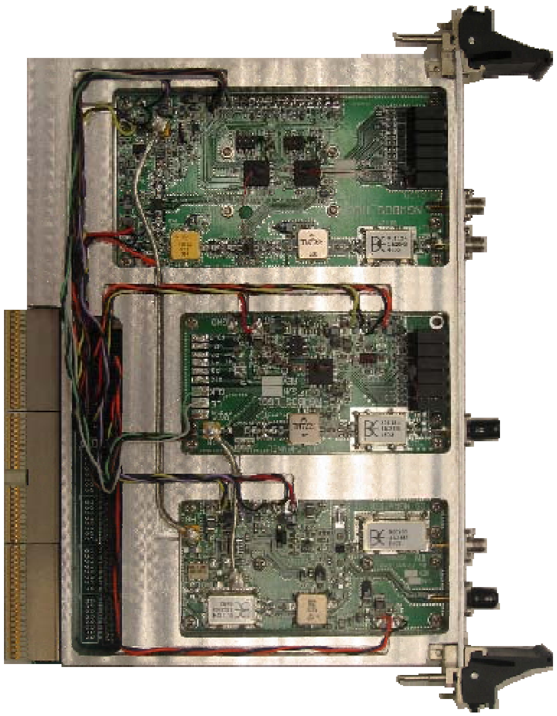
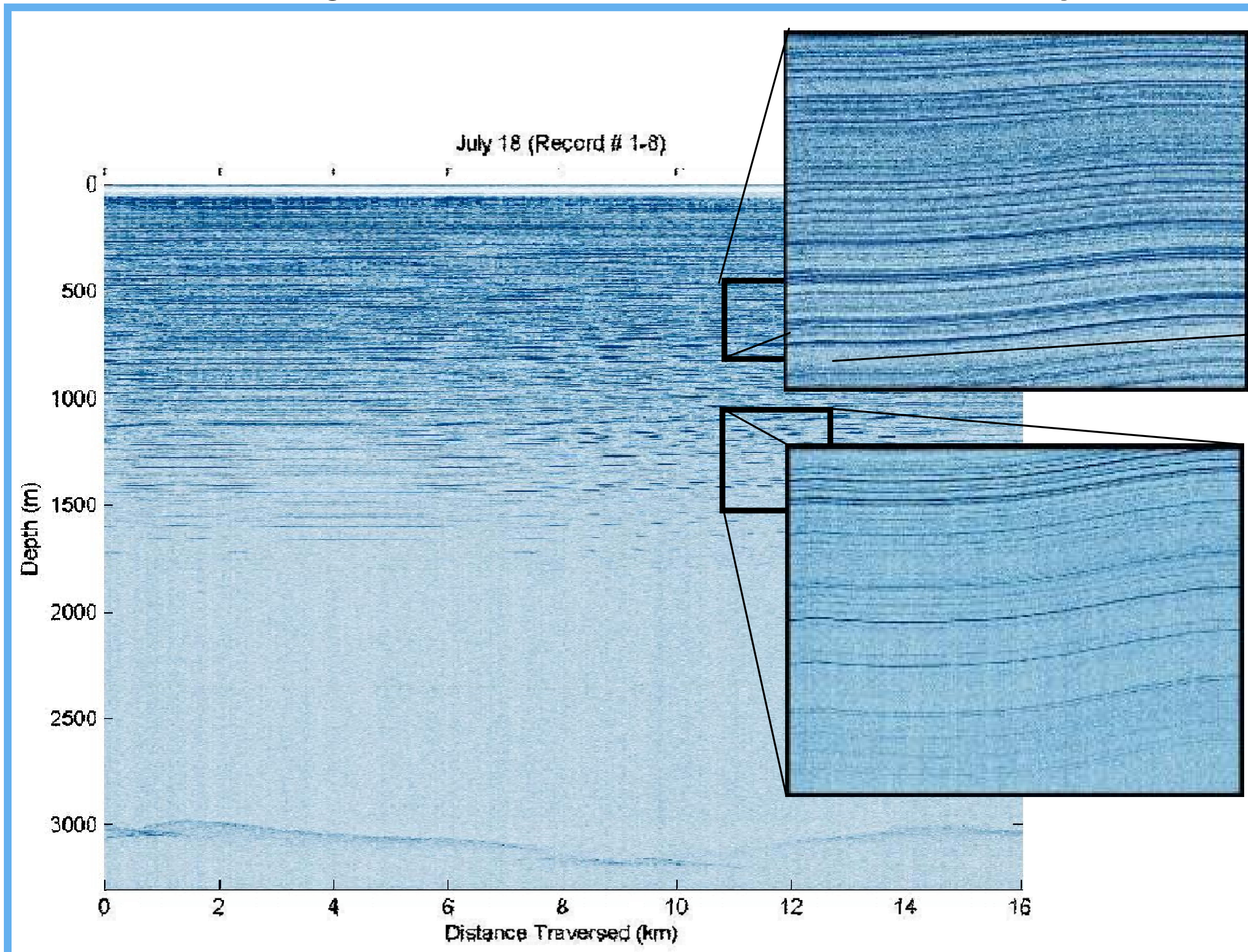
Sensors – Ground-based radar



Radar echogram collected at Summit, Greenland in July 2004



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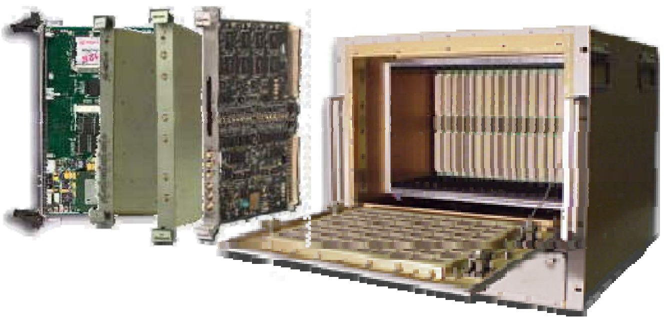
Sensors – Ground-based radar

Existing wide-bandwidth radar (1 existing system)

Frequency range	Resolution in ice
120 to 300 MHz	0.5 m

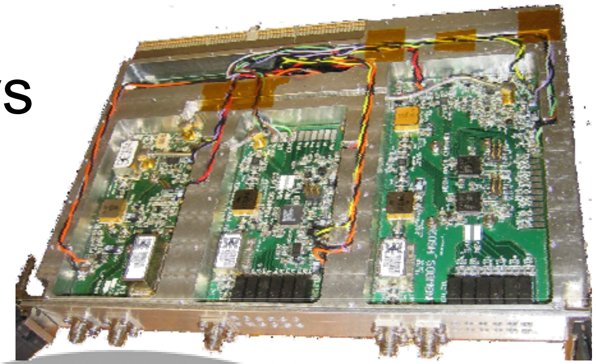
Eight independent receive channels
- digital beamsteering and interferometry



Compact PCI system

Data acquisition
- Two channels
- 10-bit quantization
- 720-MHz sampling rate

Will be used next for ground-based surveys in Greenland during summer 2007



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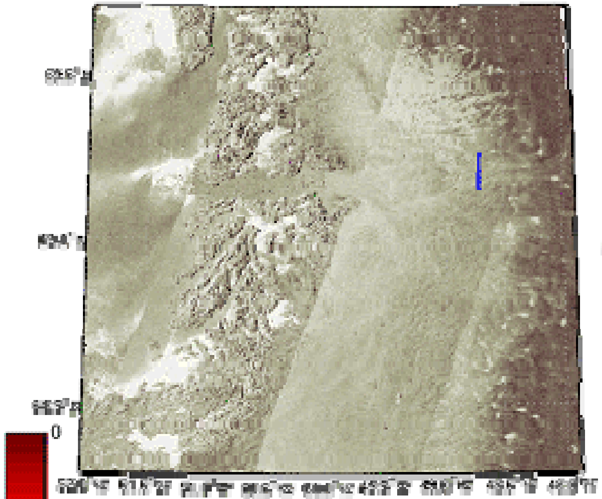
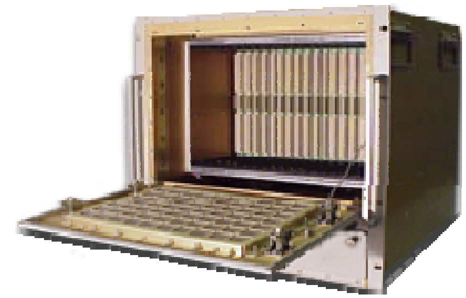
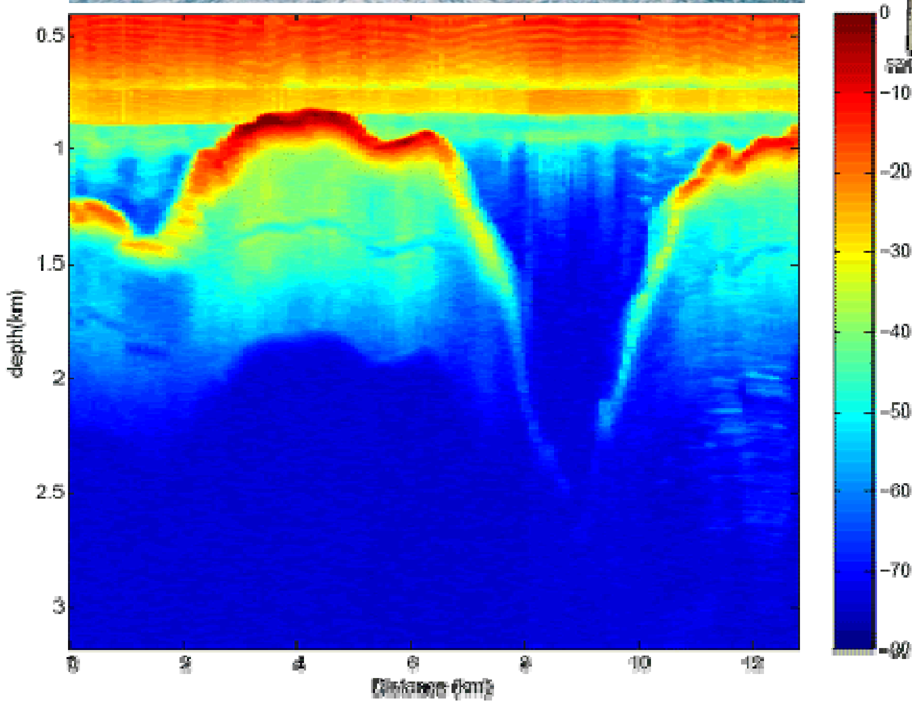
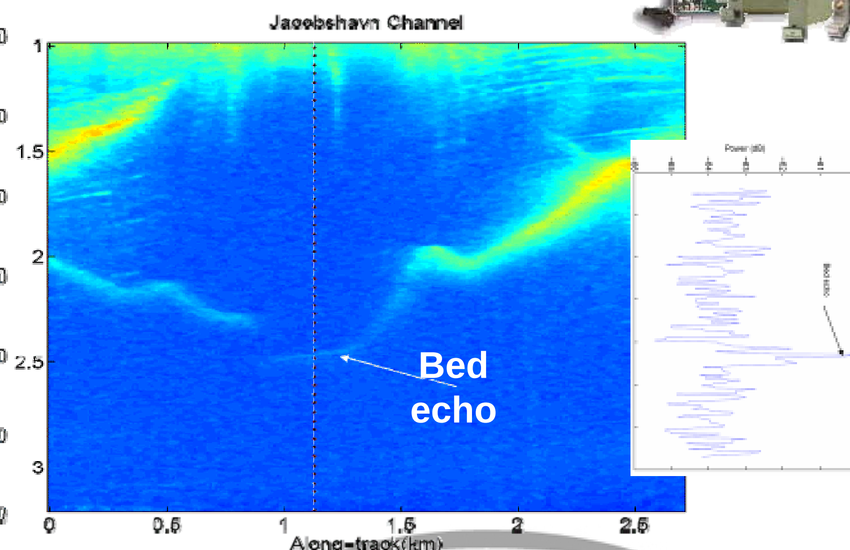
Sensors – Twin Otter-based radar





Compact PCI system





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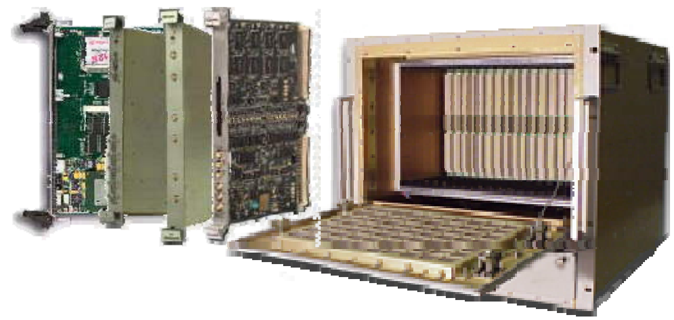
Sensors – Ground- and Twin Otter-based radar

New dual-band radar (2 copies to be produced)

Frequency	Bandwidth	Resolution in ice
150 MHz	20 MHz	4.2 m
450 MHz	50 MHz	1.7 m



Compact PCI system

Six independent receive channels

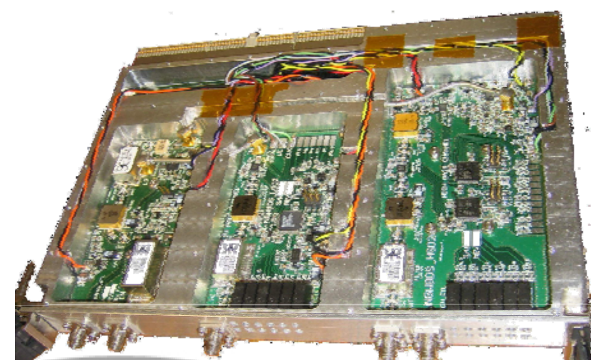
- digital beamsteering and interferometry

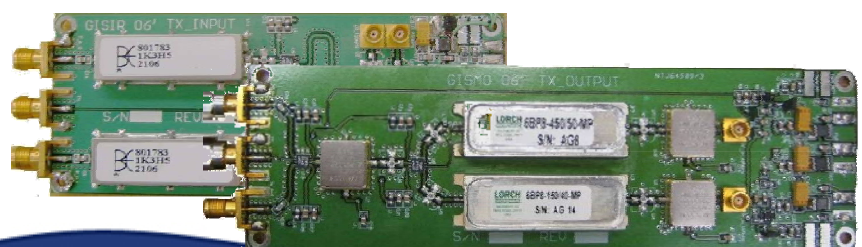
Data acquisition

- Six channels
- 12-bit quantization
- 120-MHz sampling rate

Will be flight tested summer 2007

- on NASA P-3 over Greenland





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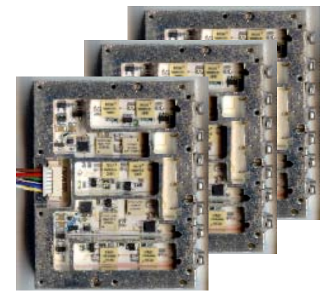
Sensors – UAV-based radar

Design is ongoing

- Eight receive channels
  - digital beamsteering and interferometry
- Eight data acquisition channels
- Volume: 50 x 50 x 20 cm
- Mass: 55 kg (120 lbs)
- Input power: 300 W
- 3U format for digital modules
- Small form factor for RF modules
- Custom antenna elements
  - constrained to 50 x 50 x 3 cm
  - Vivaldi antenna development underway
- Frequency selection will follow
  - summer 2007 field results



Seismic sensors

Seismic offers fine-resolution stratigraphy of material beneath the ice

- Requires small, lightweight, lower-power sensors that are easily deployed
  - MEMS-based low-noise accelerometer
  - Wireless network to get rid of cables
  - Distributed system processing
  - Enables spatial and temporal beamforming for improved resolution, directivity, and penetration
  - 3-D arrays and imaging possible

Seismic development timeline

Current Practice

<u>Instrumentation</u>: Has changed little in last 30-50 years.
<u>Seismic sources</u>: High energy impulsive (explosive or weight drop) or vibratory; commonly a single source.
<u>Receivers</u>: Analog geophones used in arctic.
<u>Seismic imaging</u>: Recent advancements in 3D seismic visualization (1980s-present). In polar research current practice is 2D seismic surveys due to the labor intensive nature of seismic acquisition. Each geophone is planted and retrieved by hand.

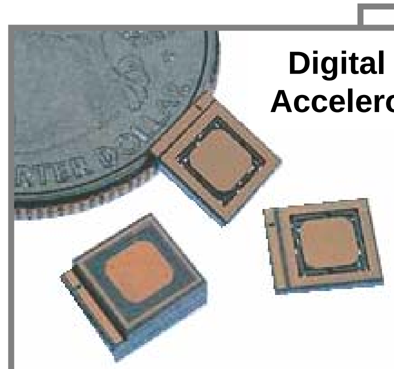
Research Goals

<u>Instrumentation</u>: Development of MEMS digital sensors combined with wireless technology. Deployed manually or with an autonomous rover, allowing 3D subsurface imaging.
<u>Source</u>: Development of low-energy low-impact vibratory seismic sources.
<u>Seismic imaging</u>: Develop 3D imaging of the subsurface with automated geophone array placement.

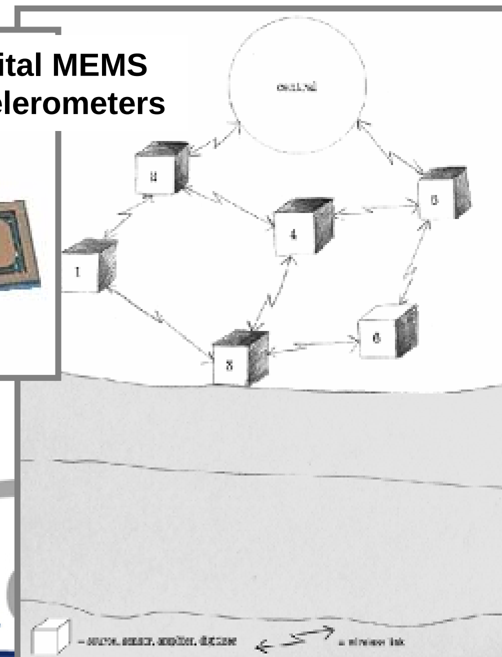
2000 — 2005 — 2010 — 2015

Large, Heavy Seismic Sources

Analog Geophones



Digital MEMS Accelerometers



Sensor development
Seismic sources

Current technology uses high-energy impulsive (explosive or weight drop) or vibratory; commonly a single source.

Investigating use of controlled acoustic sources to generate seismic waves, such as:

- 1-kW, woofer/sub-woofer loudspeakers, 15-18" diameter to launch a swept-frequency from 4 Hz to 400 Hz
- controlled vibration sources (hammer drill), with good seismic efficiency, but problems with source non-linearity and firn crushing

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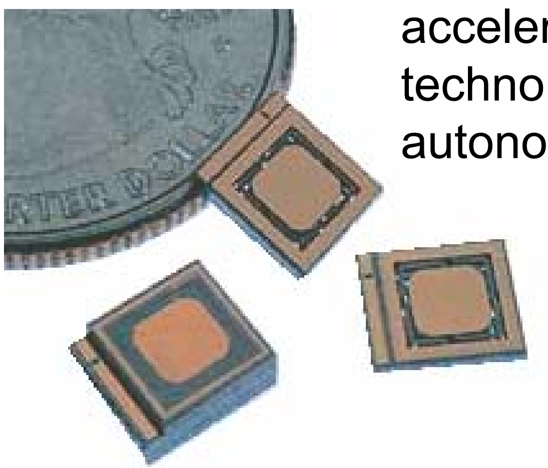
Sensor development
Seismic receivers

Current geophone technology has sensors connected with heavy cable for labor-intensive sensor deployment.

Wireless node development using MEMS digital accelerometer sensors combined with wireless technology. Deployed manually or with an autonomous rover, allowing 3D subsurface imaging.



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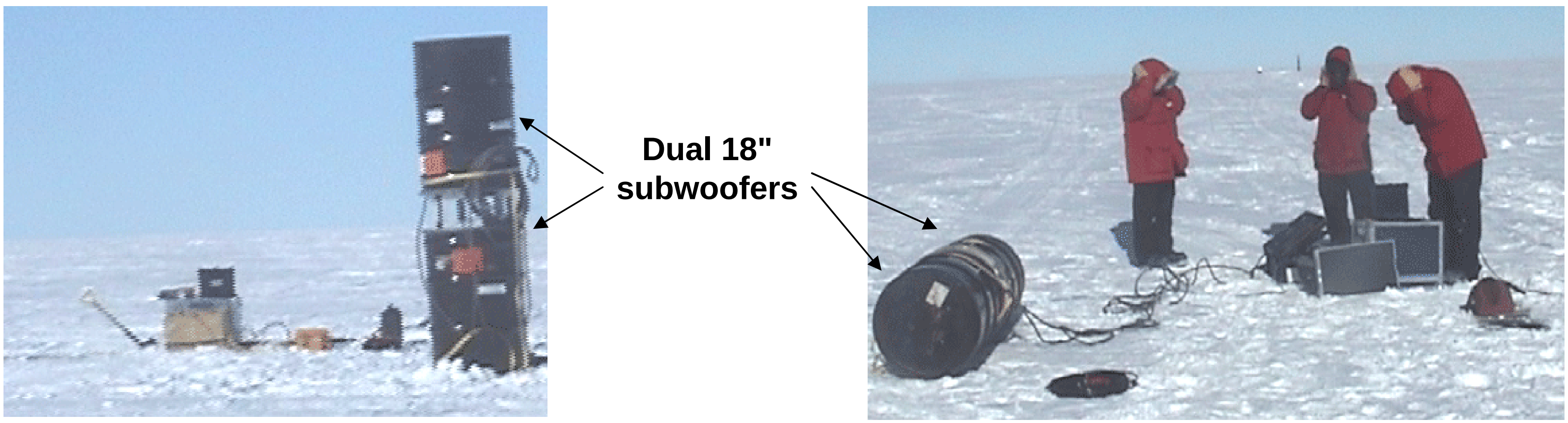
Sensor development – Seismic sources

Designed, built, tested acoustic source

- 2-kW loudspeaker, 40- to 200-Hz chirp waveform
- Recorded on both microphones and geophones
- Usable for 1-km target range
- Adding speakers will extend range



Viable replacement for explosives eventually

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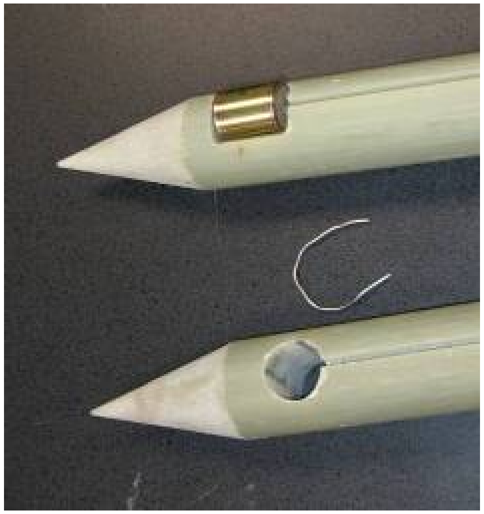
Sensor development – Seismic receivers

Designed, built, tested “GeoRods” (modified geophones)

- Conventional geophones designed for soil emplacement
- Firn can be penetrated more easily
  - 4x improvement in signal;
  - 10x improvement in time to deploy



Very successful - ready for production

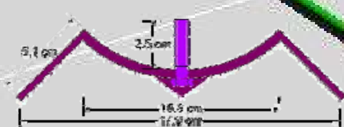
Hybrid Streamer Concept

Goals

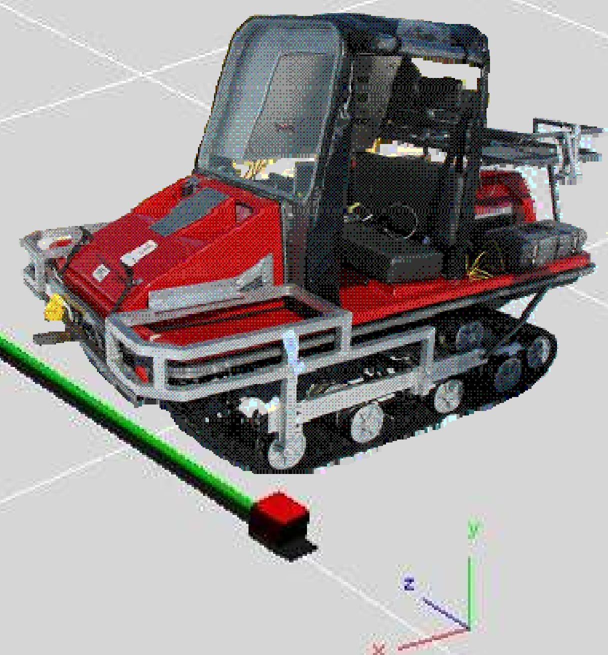
- **Reduce time, effort, and cost of collecting seismic data**
- **Gather more data while reducing the human effort**

Commercial off-the-shelf seismograph (Geometrics Geode)

- **24-channels**
- **24-bit (110 dB) A/D**
- **20-kHz bandwidth**



Streamer Plate



3 geophones per plate (P, SH and SV)

8 plates with 20 m spacing (24-channel streamer)

160-m streamer per 24-channel seismograph

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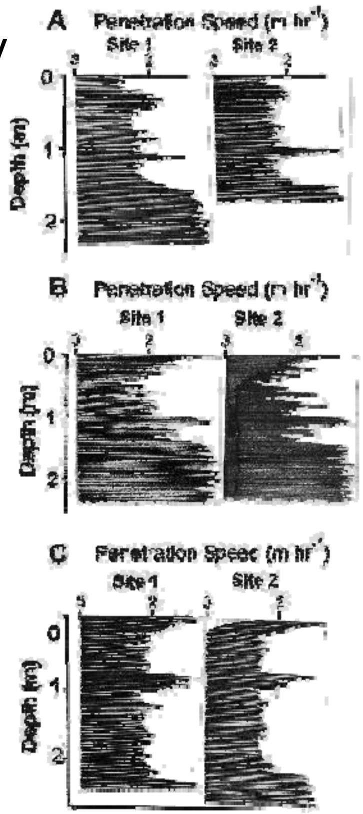
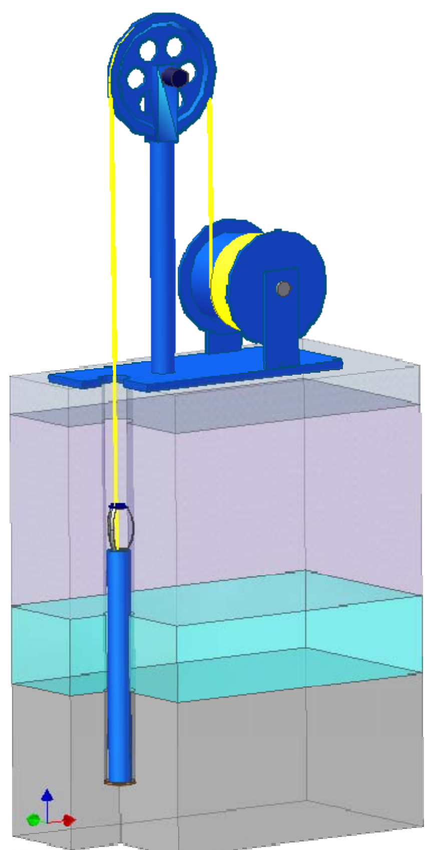
Speedograph measures density variations

In situ, **continuous density variations are measured with a Speedograph: the penetration rate of the thermal drill at constant power depends on the density of the melted material.**

Reproducibility of Speedograph





$\rho = P/S*L*V$

- ρ – ice density
- V – drill penetration rate
- S – borehole cross section
- L – melting latent heat
- P – drill power

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Speedograph status

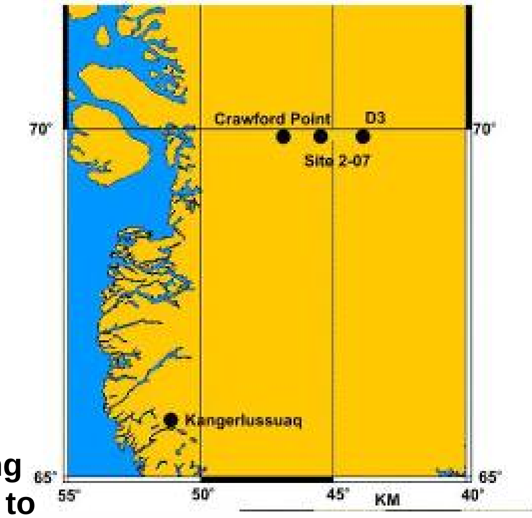
OSU Field Program: May – June 2007

Field sites (see map):

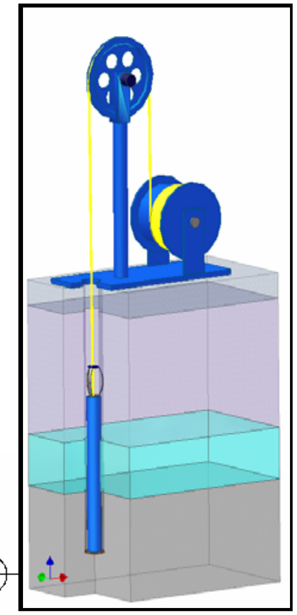
Crawford Point
69.9ºN; 47ºW; 2046 masl
Site 2-07
69.9ºN; 45.5ºW; 2300 masl

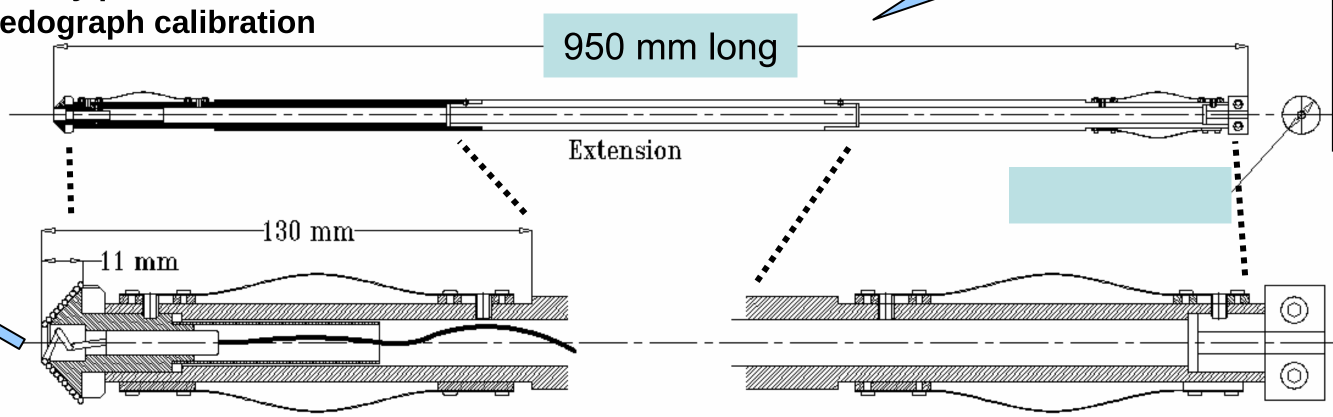
Objectives at Each Site:

Test speedograph:
~ 24 profiles
Drill 150-m core
multi-century record of annual accumulation
Drill 10-m core & Pit sampling for detailed density profiles to help with speedograph calibration



High vertical resolution density profiles:
Speedograph penetration is a f (density)





Heater tip

Centralizer

Stabilizer

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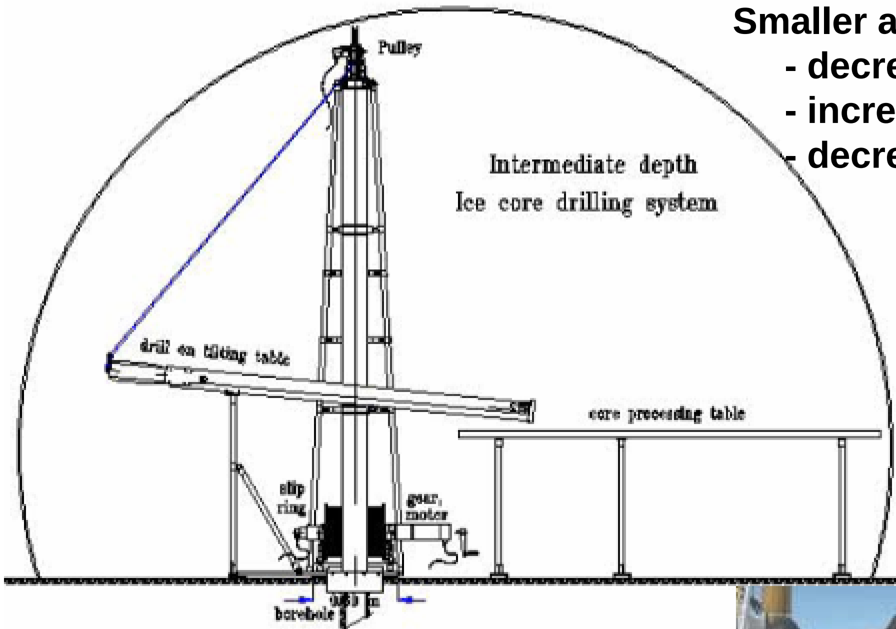
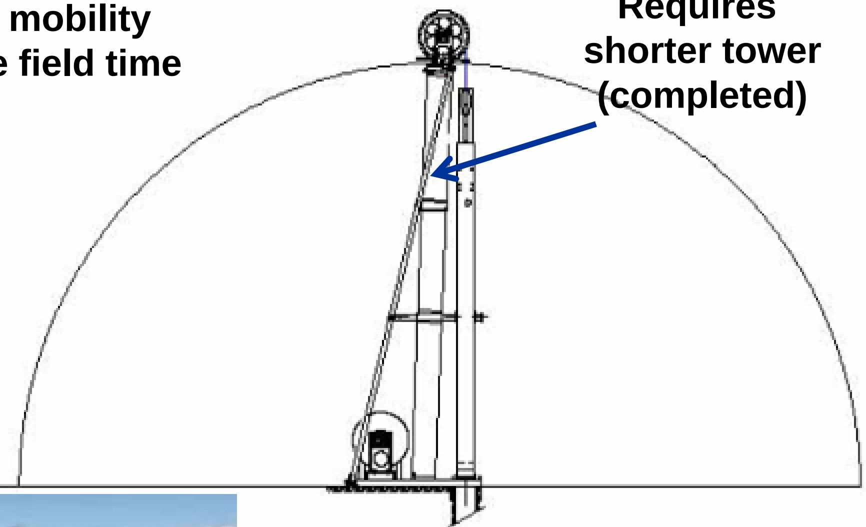
Ice Core Analysis System (ICAS)



Smaller and lighter domes:
- **decrease logistical requirements**
- **increase mobility**
- **decrease field time**



Requires shorter tower (completed)

OSU Geodesic Dome: 350 kg; 30.2 m^2
16 man hrs to install

Mountain Hardware Dome:
22 kg; 28.3 m^2 2 man hrs to install

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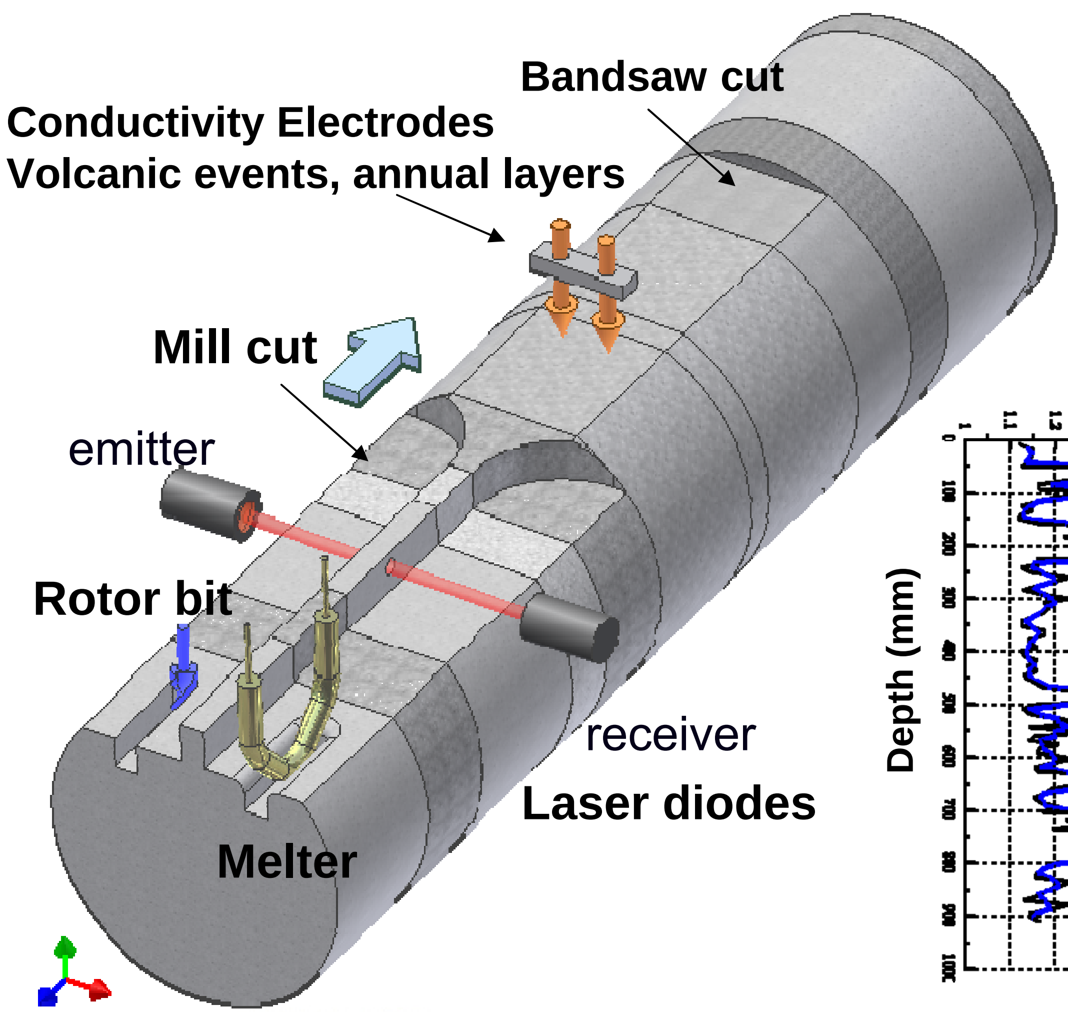
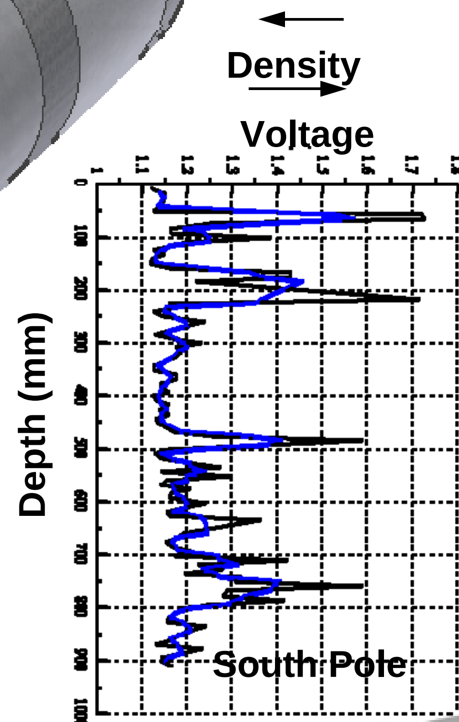
Ice Core Analysis System (ICAS)



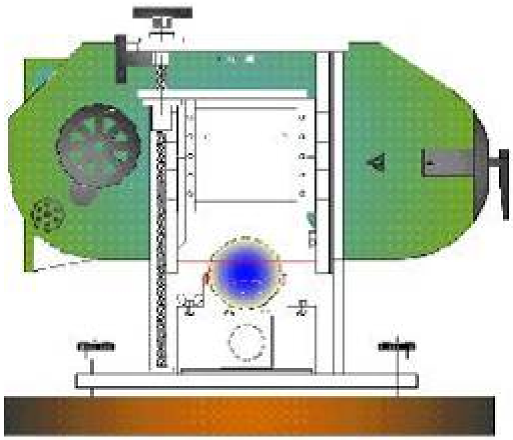


3 Proxies for Density

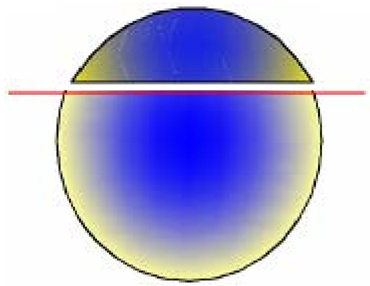
- **Light diffusion**
- **Rotor bit (hardness)**
- **Volume melted (depth of groove)**

Provides density and conductivity data from core samples

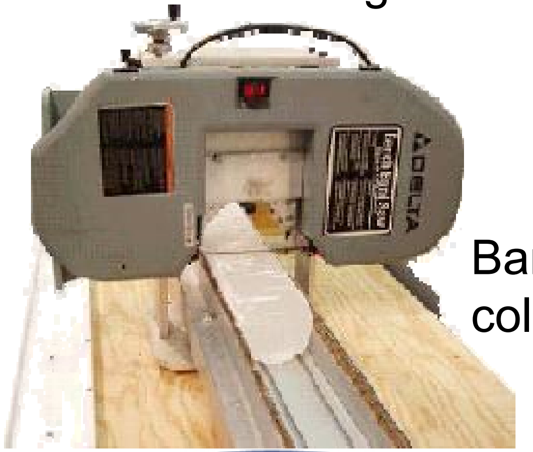
Sensor development
Firn-core analysis



Band saw design

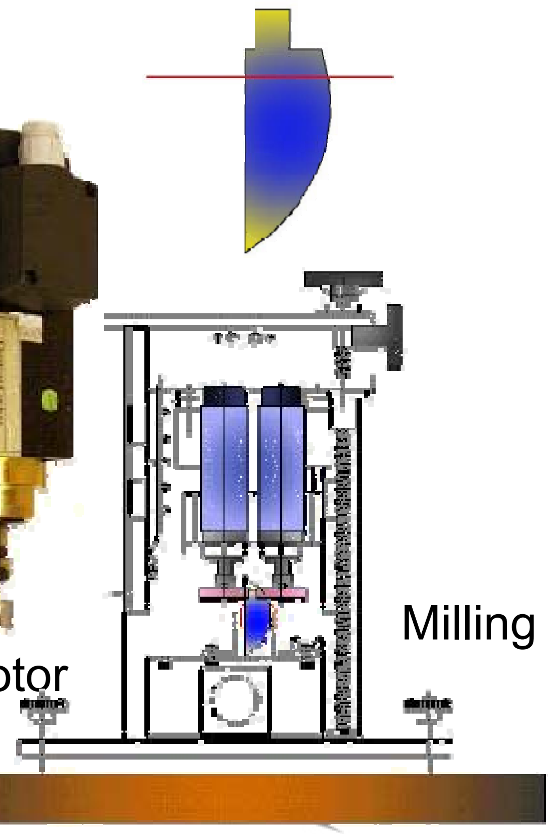


60/40% with high-speed horizontal band saw



Band saw in cold room

Milling spindle-motor



Milling

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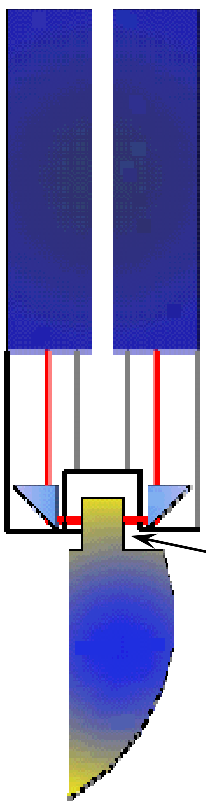
Sensor development
Firn-core analysis

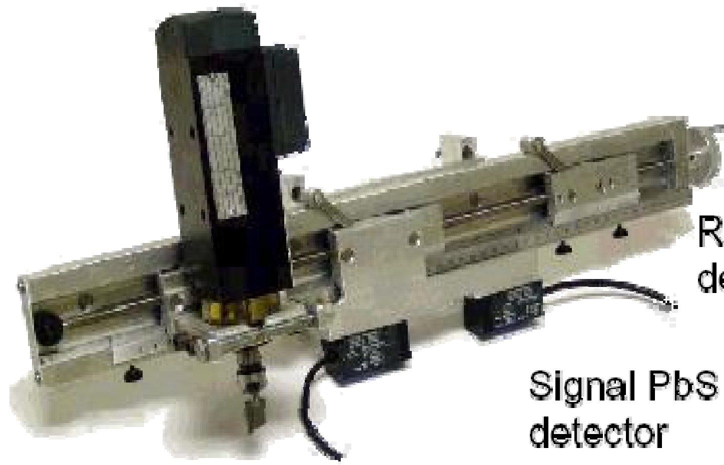


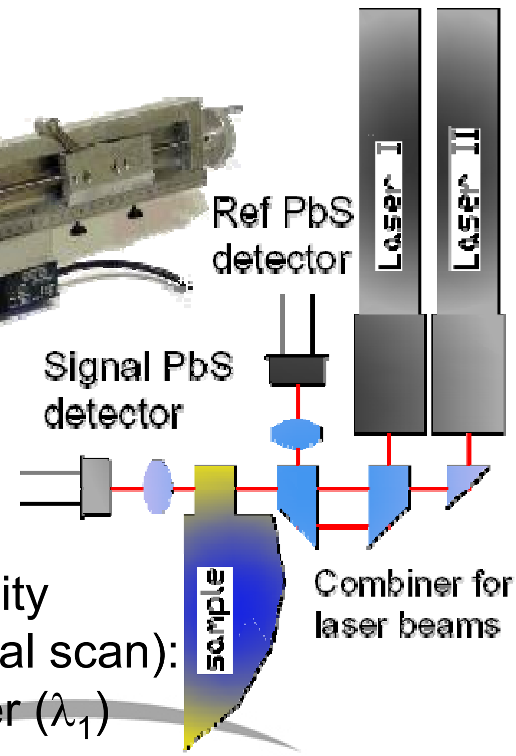
Snow-ice section
~ 10 mm

Optical sensors measure sample section thickness

Industrial proximity sensors

Positioning slides with spindle motor and laser sensors: tested prototype device





Fine-resolution optical density sensors (ice core longitudinal scan):
- light absorption and scatter (λ_1)
- light scatter (λ_2)

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Communications

Support operations with wide-bandwidth, mobile communications

- Local and regional links
  - Bluetooth, 802.11
- Global communications
  - Iridium

Support on-site data storage and processing

Platforms

Rovers

- Build on PRISM experience for surface-based robotic vehicle
- Support radar and seismic surveys and in-situ activities

Uncrewed Aerial Vehicles (UAVs)

- Develop flight control hardware and software
- Validate with simulator and flight tests
- Field test two sensor-equipped vehicles

Platform development – Rover

Previous vehicle:

- 27 HP
- gasoline-powered
- 125 mm ground clearance
- skid-steering
- 454-kg towing capacity

New vehicle specs:

- 34 HP
- diesel powered
- 233 mm ground clearance
- hydrostatic transmission
- 454 kg towing capacity

UAV development timeline

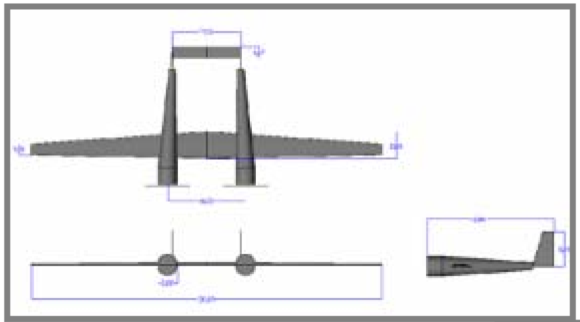
Sensor systems are large, heavy, power hungry, and require human operators.
- 2003

COTS UAVs evaluated and UAV testbeds developed
2003 - 2006

UAVs for polar field work developed
2006 - 2010

Second generation polar UAVs developed
2010 - 2015

2000 *2005* *2010* *2015*



UAVs as enablers

Capable of precise flight patterns supporting detailed surveys not possible with conventional aircraft

Supports wide-bandwidth RF sensors

- Avoids EMI issues with navigation and communication requirements on crewed aircraft

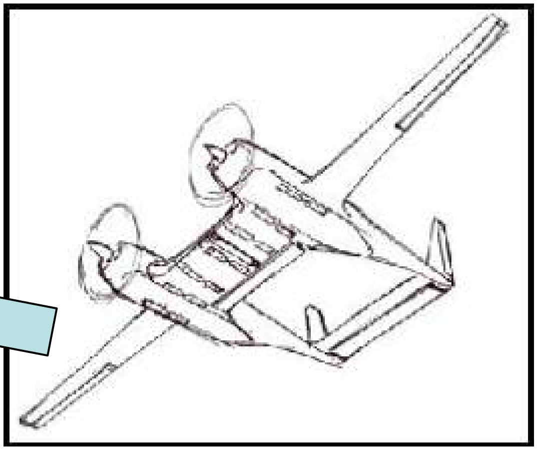
Able to operate (and sometimes land) in regions too hazardous for crewed aircraft

- Supports surface-based and in situ measurements

Platform development – UAVs

The Fall 2005 AE 721 class has designed and started construction of a half-scale demonstrator of a UAV concept, the Cryohawk.

Primarily to be used as a Stability and Control demonstrator.



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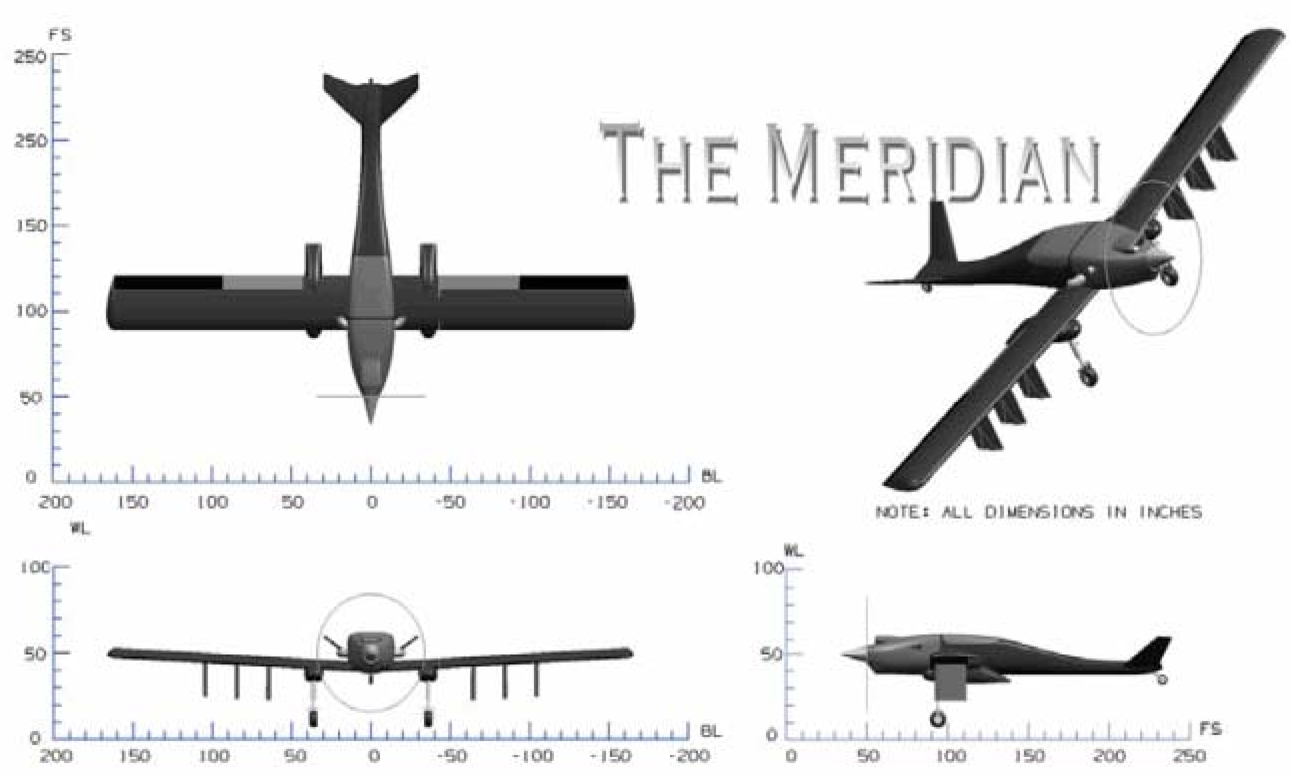
Platform development – UAVs

Aircraft summary:

- W_{TO} = 1,083 lbs
- W_E = 618 lbs
- W_F = 295 lbs
- W_{PL} = 165 lbs
- Wingspan = 26.4 ft
- Length = 17 ft
- Range = 1,750 km (950 nm)
- Endurance = 13 hours



The most critical design requirements are:

- Payload Integration (antenna size)
- Takeoff/Landing Distance
- Size limitations
- Shipping
- Hangar Size
- Fuel Type
- Cold Weather Requirements (Anti-Icing)

CReSIS

Platform development – UAV Autopilot selection

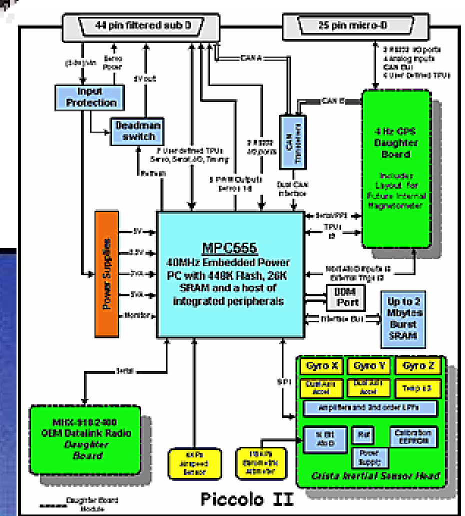
The Cloud Cap Piccolo II autopilot is currently being integrated into the existing Hawkeye UAV.

This project has many goals:

- Develop a fully autonomous test vehicle that can be used to test small sensors
- Use the Hawkeye to validate new autopilot control schemes
- Develop experience with a commercial of-the-shelf autopilot system

Size - 4.8" x 2.4" x 1.5"
Weight = 212 grams (7.5 oz) with radio

Cloud Cap Technology, 2006
www.cloudcaptech.com

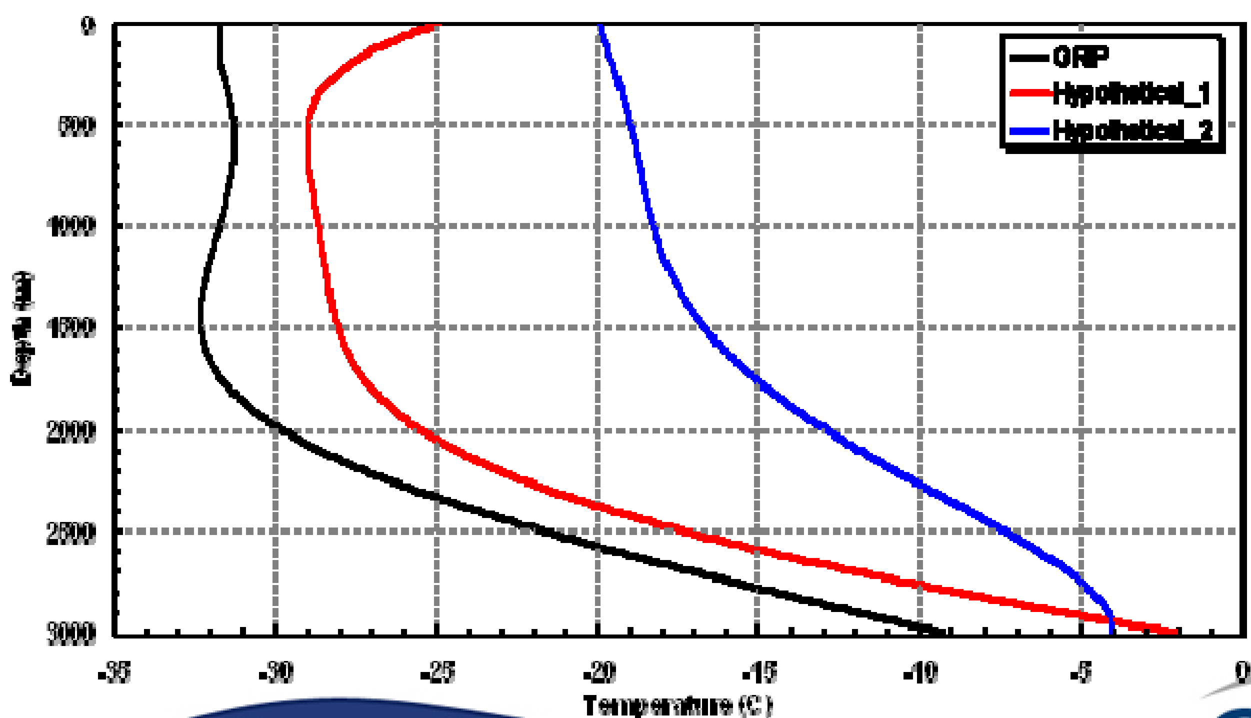


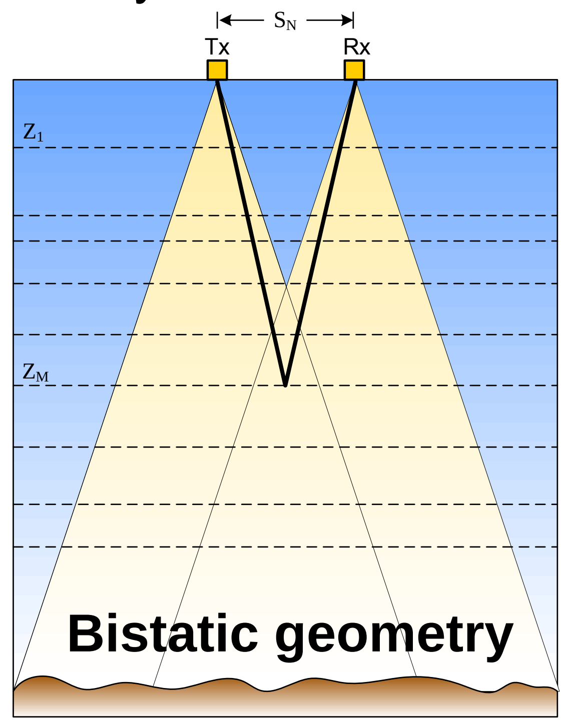
Hawkeye UAV

Incorporating research in education

Microwave Remote Sensing (Fall 2007 course example)

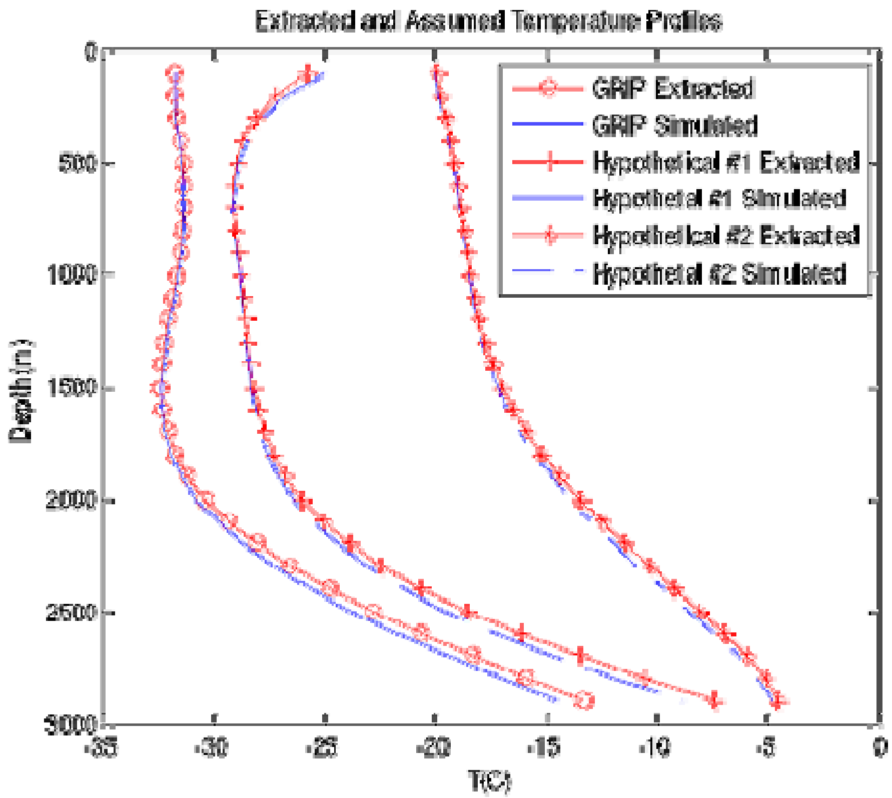
Englacial temperature requirement – The radar sensor shall measure ice attenuation with a depth resolution of 100 m and radiometric accuracy sufficient to estimate englacial temperature to an accuracy of 1 °C.

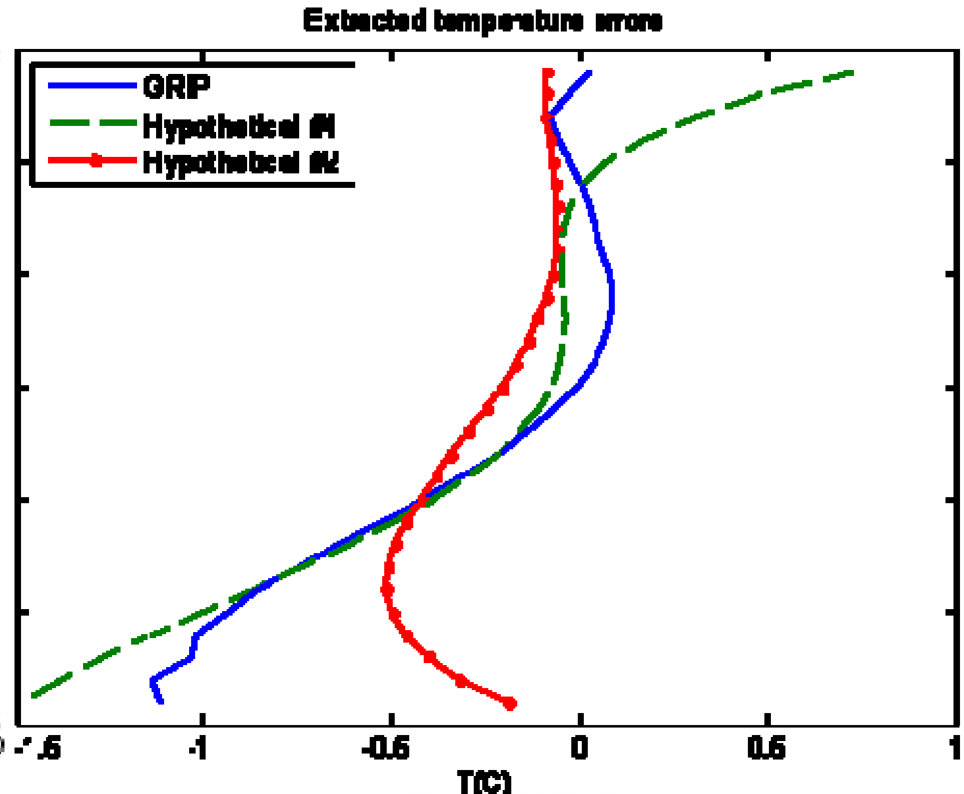




Incorporating research in education

Students' results show feasibility of extracting englacial temperature using existing radar hardware operated in bistatic configuration.





CReSIS

NSF NASA KTEC

Conclusions

The Center will provide science-driven technologies to meet the needs of the polar research community

Our team of researchers (university, industry, and government) are well-qualified to meet these needs

A dedicated technology development effort is required now to provide the capabilities needed in the near and distant future

National Science Foundation
WHERE DISCOVERIES BEGIN

KTEC
KANSAS TECHNOLOGY
ENTERPRISE CORPORATION

KU THE UNIVERSITY OF KANSAS

DTU

cpom

MAINE

THE OHIO STATE UNIVERSITY

PENNSTATE
1855

ELIZABETH CITY
ECSU

ace
CRC

NSF NASA KTEC

CReSIS

CReSIS Education Program Overview

Gary K. Webber
Education Coordinator

- Team and Objectives
- Meeting Our Objectives

NATIONAL SCIENCE FOUNDATION :: KANSAS TECHNOLOGY ENTERPRISE CORPORATION :: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The University of Kansas | The Ohio State University | Pennsylvania State University
The University of Maine | Elizabeth City State University | Haskell Indian Nations University

Centre for Polar Observation and Modelling | University of Copenhagen
Technical University of Denmark | Antarctic Climate & Ecosystems CRC

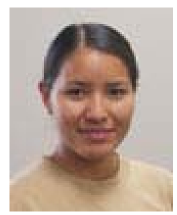
The CReSIS Education Team at KU

- Gary Webber – Education Coordinator

- Kelly Mason – Diversity/Recruiting /IREP/REU Coordinator

- Cheri Hamilton – K12 Outreach Coordinator

- Melanie Gile – GRA, K-12 Curriculum Development



- Nasbah Ben – GRA, Haskell Programs

- Dana Atwood Blaine – GRA, Evaluation

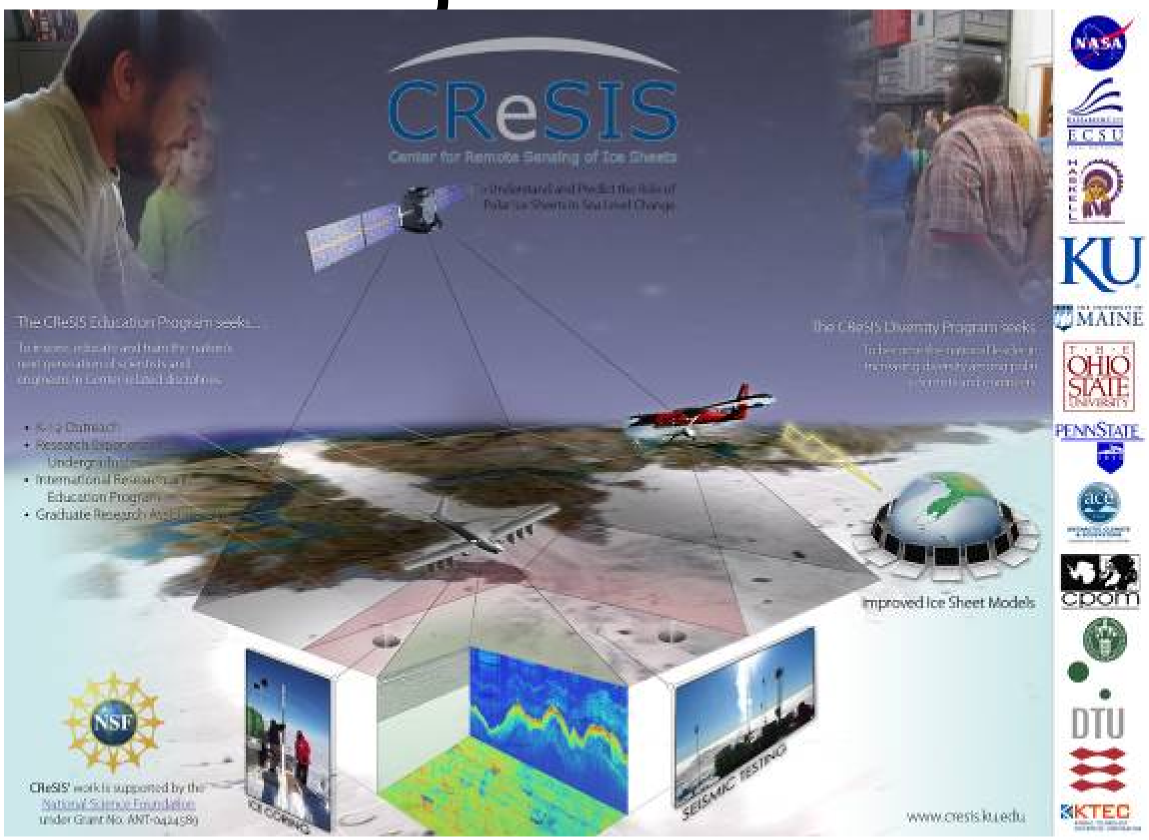
Vision and Mission for Education

- Vision
  - Inspire, educate and train the next generation of scientists and engineers for the Nation in Center-related disciplines.
- Mission
  - Educate and train a diverse population of graduate and undergraduate students in multi-disciplinary polar science research, provide research opportunities for undergraduate students as a pathway to graduate education, and reach out to encourage K-12 students to pursue careers in science and engineering.

Education Objectives

- For *graduate and undergraduate students* involved in CReSIS, we will provide the following skill set:
  - Appropriate theoretical and practical content knowledge.
  - Sufficient skills to conduct *independent* (graduate) or *supervised* (undergraduate) research.
  - Service orientation and global perspective.
  - Understanding of viable career paths available to scientists and engineers in STEM fields.

How Are We Meeting our Objectives?



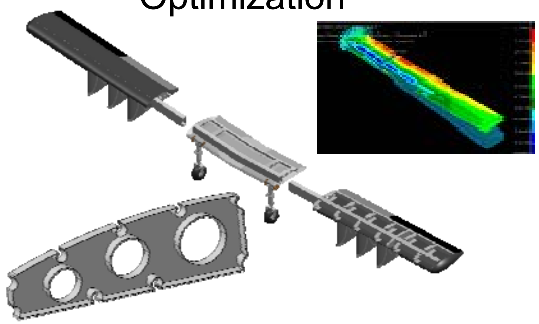
CReSIS

- Offering a Unique Graduate Curriculum
  - Advanced Glacier Dynamics
  - Business and Financial Issues of Climate Change
  - Geophysical Signal Processing
  - Glaciers and Landscape
  - Ice and Climate
  - InSAR and Applications
  - Principles of Microwave Remote Sensing
  - RF Circuit Design
  - Role of Continental Ice Sheets in Rapid Climate Change
  - Seismic Imaging Of and Beneath Glaciers
  - Teaching College-level Engineering and Science

CReSIS

- Integrating Research into Undergraduate Courses
  - Some of the eleven Aerospace Engineering courses modified to include CReSIS Research

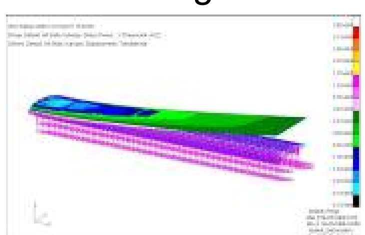
AE 709 – Structural Optimization



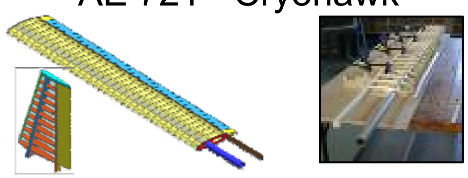
AE 510 – Manufacturing

AE 572/724 – Engine Performance and Testing

AE 507/508 – Structural Design



AE 721 - Cryohawk



AST4000 Flight Simulator – K12 Students

CReSIS

- Providing Undergraduate Research Experiences and More
  - Formal Research Experience for Undergraduates (REU) Supplement from the NSF supported seven (7) students on three (3) campuses last summer.
  - This summer, 19 students on two campuses supported.
  - Modeling Workshop at ECSU for Undergraduates (taught by Dr. Terry Hughes) summer 2006.
  - Dr. Arvin Agah will lead a workshop at ECSU this summer.

- Helping Students Gain Research Skills
  - Field work (Antarctica 2005/2006, Greenland 2006, and Antarctica 2006/2007) has involved thirteen graduate/undergraduate researchers.
  - Field work during 2007/2008 will involve approximately fifteen graduate/undergraduate researchers

- Helping Students Communicate Effectively
  - Poster and paper presentations at national conferences
  - Presentations at All-hands and Student/Faculty meetings
  - Presentations at university and community forums
  - Summer writing workshop and poster presentation

CReSIS

- Introducing Students to Career Opportunities
  - Internship and fellowship opportunities
  - Class on Teaching College-level Science and Engineering
  - Summer workshop on entrepreneurship
  - Visits and presentations by scientists, business leaders, and policy makers

CReSIS

- Providing Students With a Global Perspective

- International Research Experience Program (IREP)
- 2 month experiences with CReSIS International Partners
- Summer 2006: Two KU students visited the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE) at Tasmania, Australia
- Summer 2007: Six students:
  - 2 to the University of Copenhagen
  - 2 to the Danish Technical University
  - 1 to the University of Tasmania
  - 1 to the University of Edinburgh

CReSIS

- Involving Students in K-12 Outreach
  - Center students, faculty and staff have:
    - Made presentations to over 40 schools or groups
    - Involved over 2,100 K-12 students in presentations or hands-on activities
    - Presented to over 150 college students / teachers / adults
  - Plans for the future include:
    - Continued classroom or group presentations
    - Establishing a FIRST Lego Robotics program in the Topeka Public Schools
    - Supporting and expanding the FIRST Robotics program in Lawrence high schools

What Support is Available for Graduate Study?

CReSIS Student Pay Matrix

PhD-1 = Pre Qualifying Exam
PhD-2 = Pre Comp Exam
PhD-3 = Post Comp Exam

	MIN	AVG	MAX
PhD-1	$ 14.18	$ 17.19	$ 20.20
PhD-2	$ 14.95		$ 21.30
PhD-3	$ 16.24		$ 23.13

50% FTE Bi-Weekly	CURRENT		
	MIN	AVG	MAX
MS degree	$ 505.31	$ 612.50	$ 719.69
PhD-1	$ 567.19		$ 807.81
PhD-2	$ 598.13	$ 725.01	$ 851.88
PhD-3	$ 649.69		$ 925.31

50% @ 9 months	CURRENT		
	MIN	AVG	MAX
MS degree	$ 13,138.00		$ 18,712.00
PhD-1	$ 14,746.94		$ 21,003.06
PhD-2	$ 15,551.38		$ 22,148.88
PhD-3	$ 16,891.94		$ 24,058.06

	MIN	AVG	MAX
Undergraduate Research Assistant	$ 8.66	$ 10.50	$ 12.34

(hourly)

What Support is Available for Graduate Study?

- Additional Support available:
  - Undergraduate and Graduate Self Fellowships
  - Additional School and University scholarships
  - Internships and Fellowships

CReSIS

National Science Foundation

WHERE DISCOVERIES BEGIN

Questions?

CReSIS