Center for Remote Sensing of Ice Sheets: Introduction

George Tsoflias
Department of Geology &
Center for Remote Sensing of Ice Sheets

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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

Center for Remote Sensing of Ice Sheets

- Established in 2005; one of seventeen active Science and Technology Centers sponsored by the National Science Foundation
- Initial grant from 2005-2010, renewable in 2009 for another five years
- Headquartered at the University of Kansas
  - Five other domestic university partners
    - Elizabeth City State University (North Carolina) – HBCU
    - Haskell Indian Nations University (Kansas) – MSI
    - University of Maine
    - The Ohio State University
    - Pennsylvania State University
  - Three international universities
    - University of Copenhagen
    - Technical University of Denmark
    - University of Iceland
  - Two international research centers
    - Centre for Polar Observations & Modeling (CPOM) (United Kingdom)
    - Antarctic Climate and Ecosystems Cooperative Research Centre (ACE) (Tasmania, Australia)
  - Multiple domestic/international collaborators
    - NASA – Goddard Space Flight Facility
    - NASA – Jet Propulsion Laboratory
    - University of Washington
    - Lamont-Doherty Earth Observatory – Columbia University

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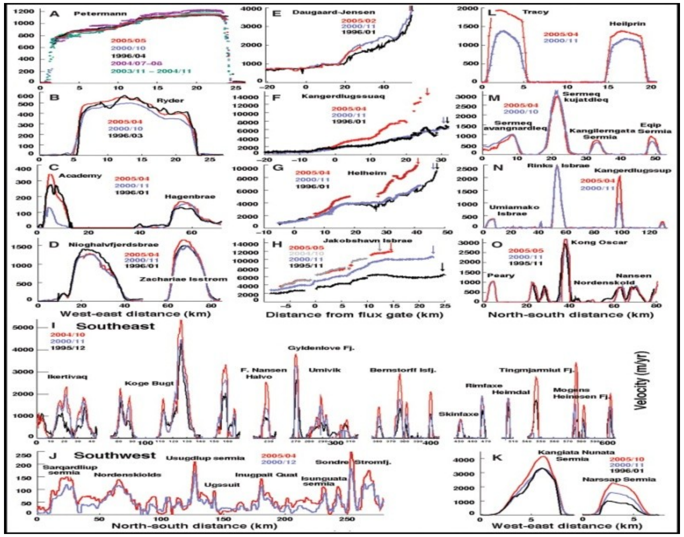
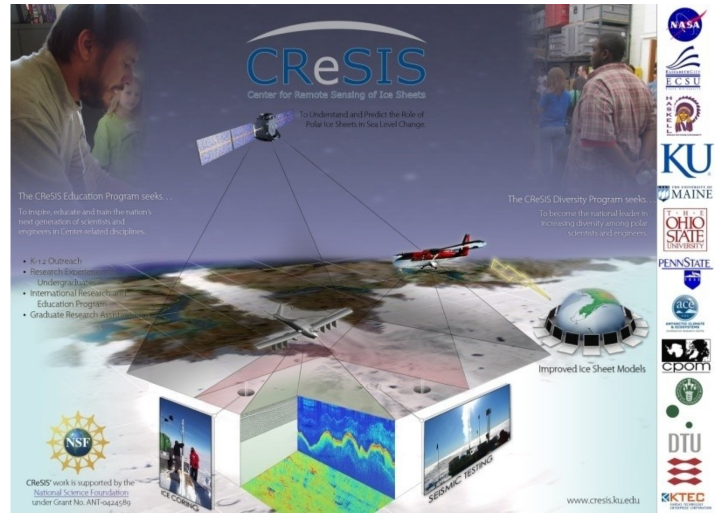
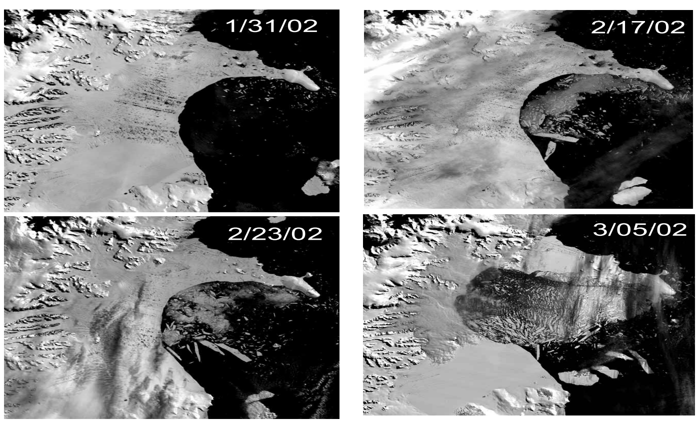
Introduction – Rapid Changes



Rignot and Kanagaratnam, Science 17 February 2006



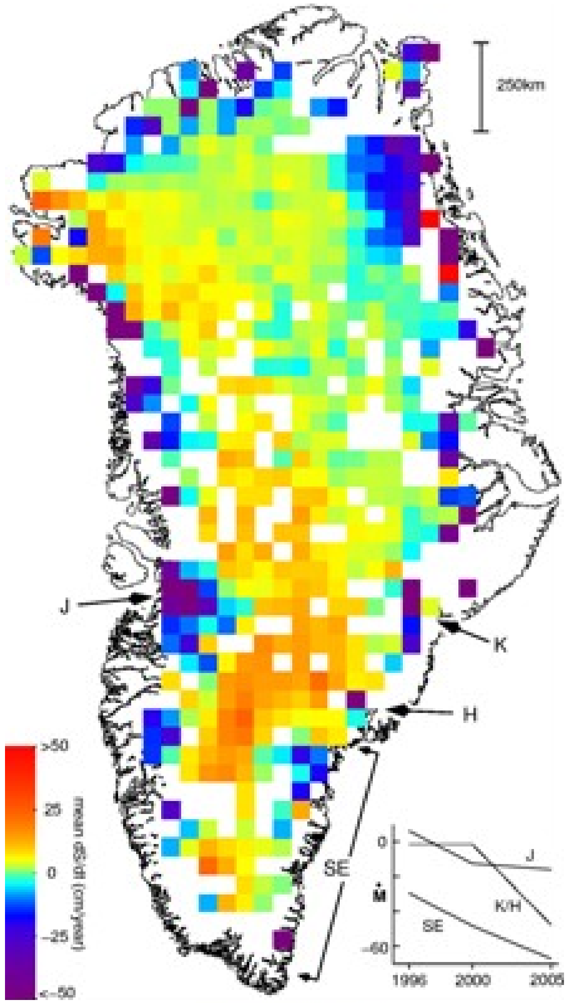


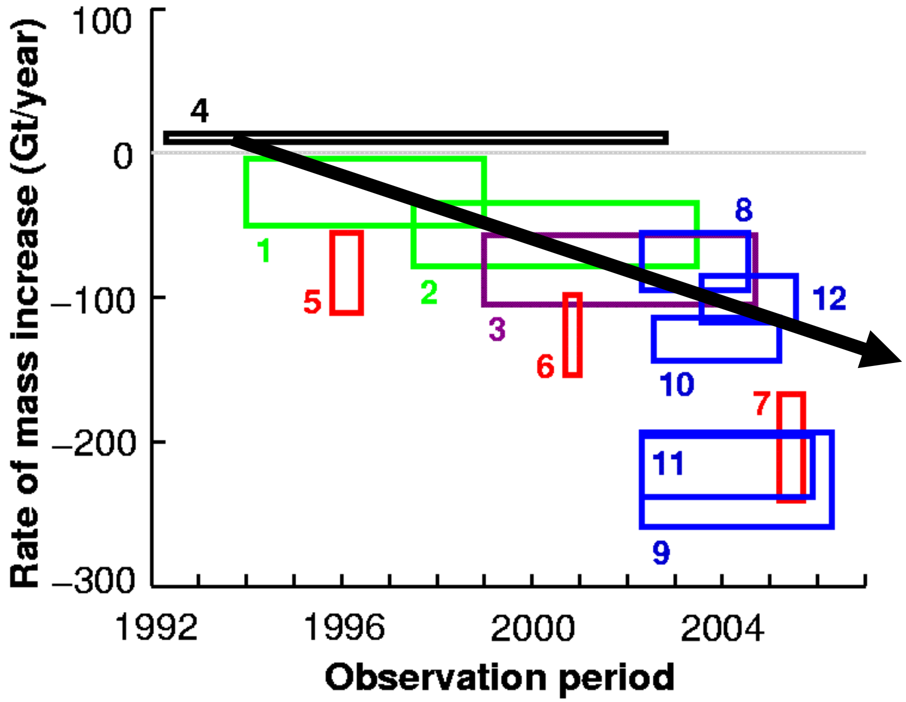
Scambos, 2002

Rignot et al, *GRL* October 2004

- Satellites are revolutionizing the study of ice sheets
- Rapid changes
  - –Breakup of floating tongues
  - –Changing basal conditions
  - –3-D view of the ice sheet
- Fine resolution in transition areas

Greenland Mass Balance





Black:	**ERS radar altimeter data**
Green:	**ATM laser-altimeter surveys**
Purple:	**ATM/ICESat comparisons**
Red:	**Mass-budget estimates**
Blue:	**GRACE gravity estimates**

Thomas, 2008

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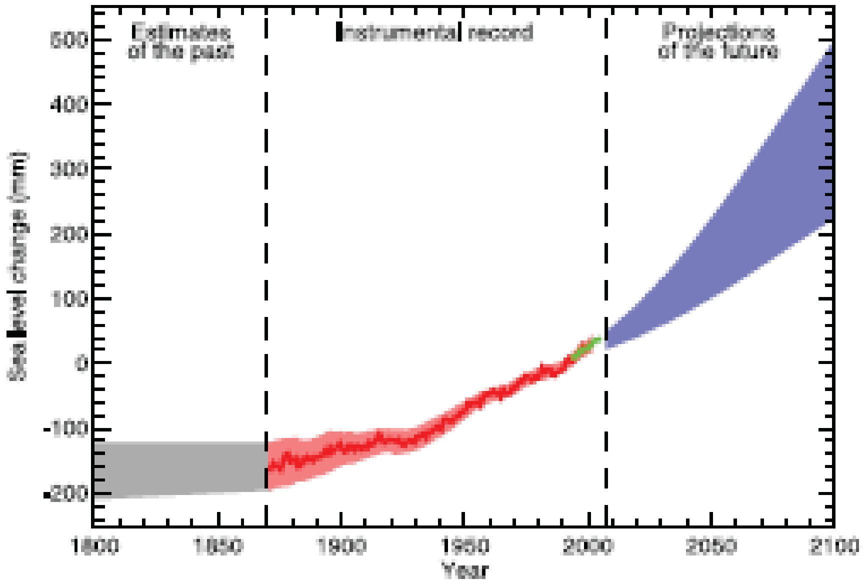
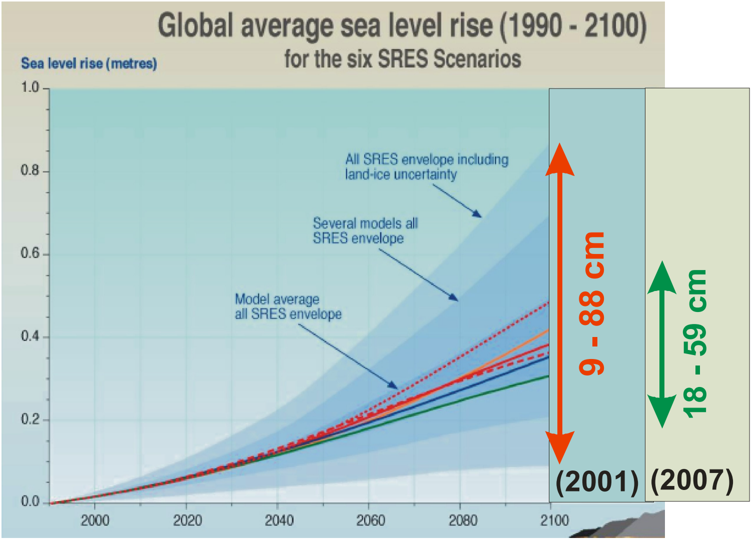
Sea Level Rise





"Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude." *IPCC Summary For Policy Makers (2007)*

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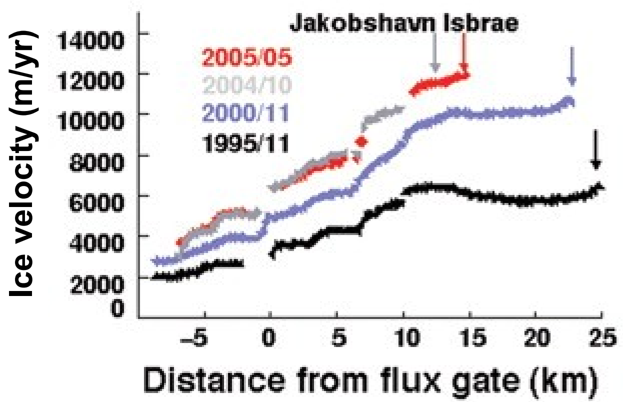
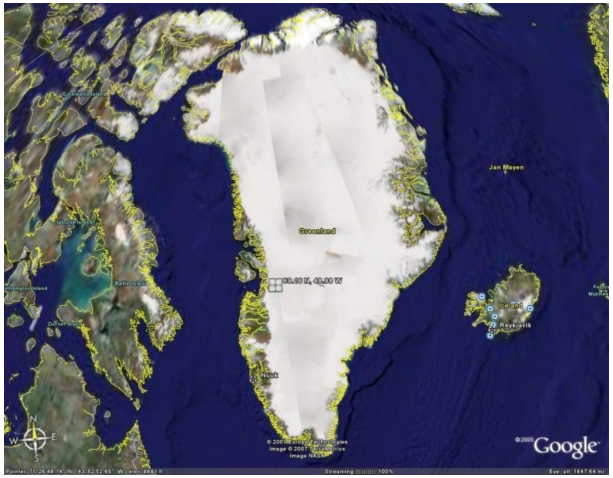
Introduction – Rapid Changes

Understand & predict the behavior of outlet glaciers

- Jakobshavn Isbrae, Greenland, 1996 – 2005
  - 95% increase in frontal speed
  - discharge from 24 km^3/yr to 46 km^3/yr



(Rignot and Kanagaratnam, 2006, Science)



- Ice properties:
  - Elevation, thickness, temperature, internal layers
- Properties of glacier bed:
  - Topography, meltwater, bedrock vs. till

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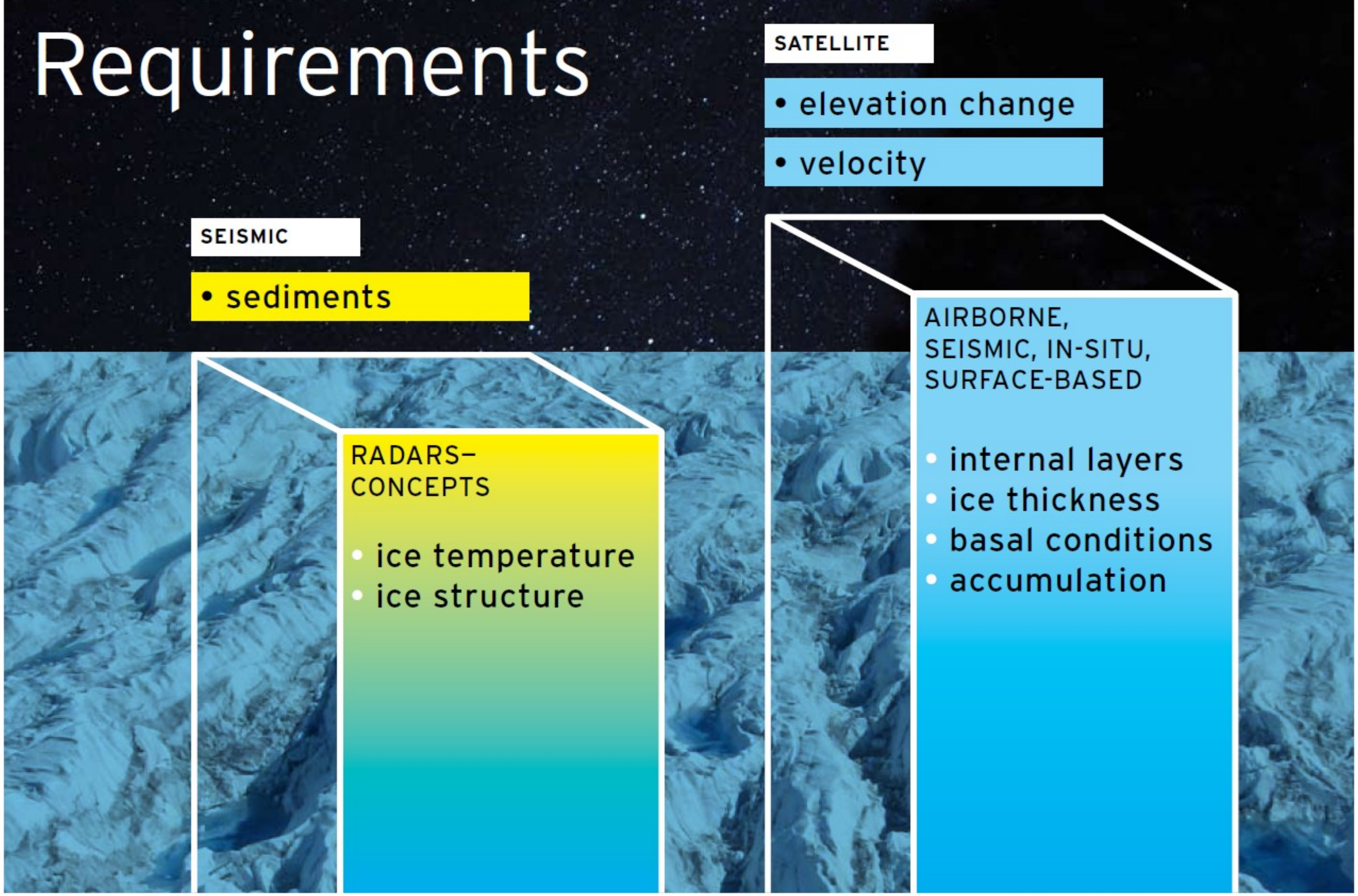
Data Requirements



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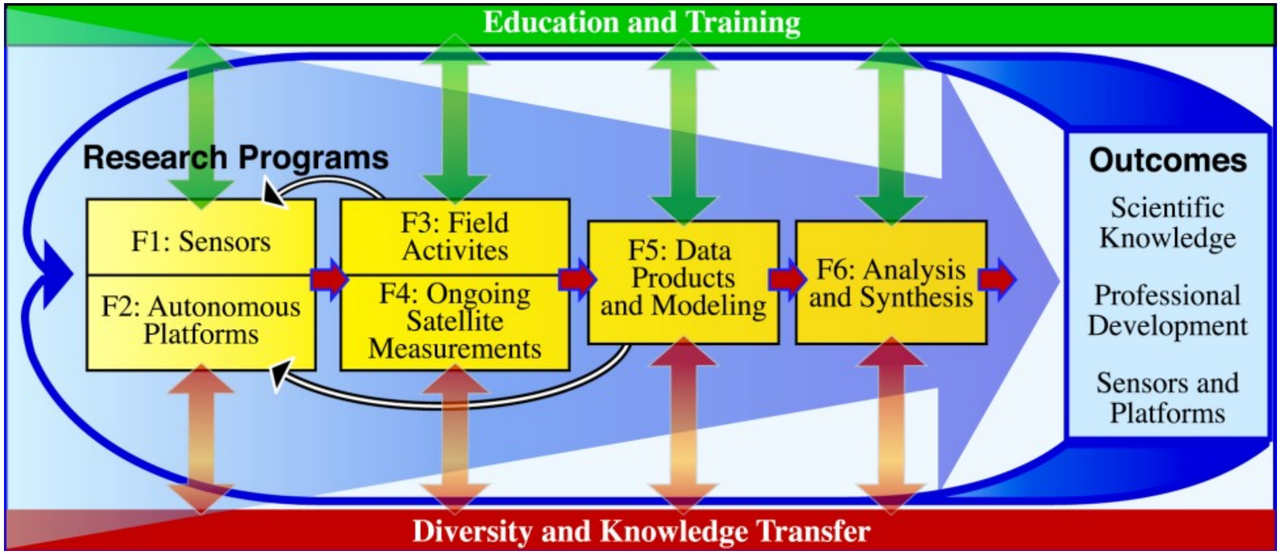
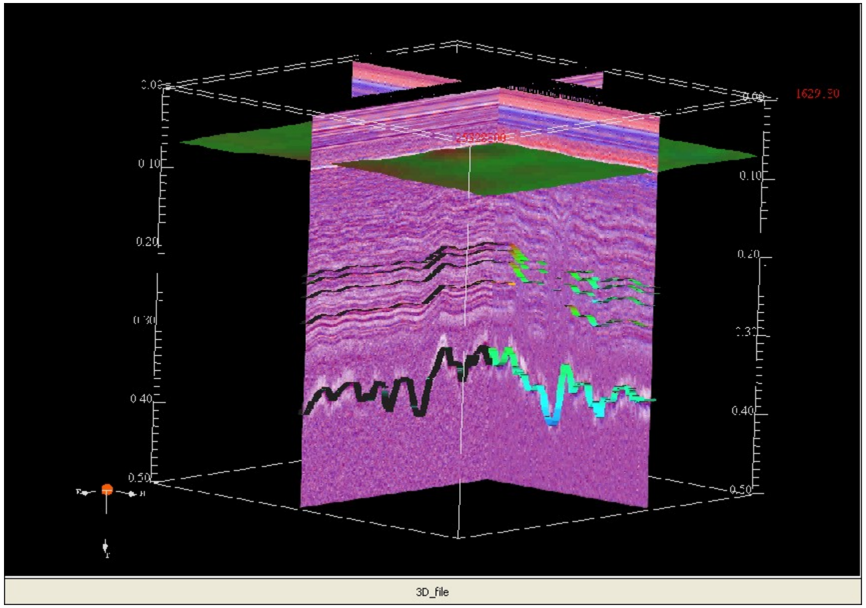
- To understand and interpret the observed changes from satellite data sets.
- To develop models to explain observed changes and predict future behavior, we need additional airborne and in-situ observations.
- The Center will systematically address the technological, observational, modeling and infrastructure needs for studying ice-sheet drainage in regions that are currently undergoing rapid changes.



CReSIS Research

- Sensors Development
  - Radar
  - Lidar
  - Seismics
- Meridian UAS
- Field Programs
  - Greenland
  - Antarctica
- Data Products



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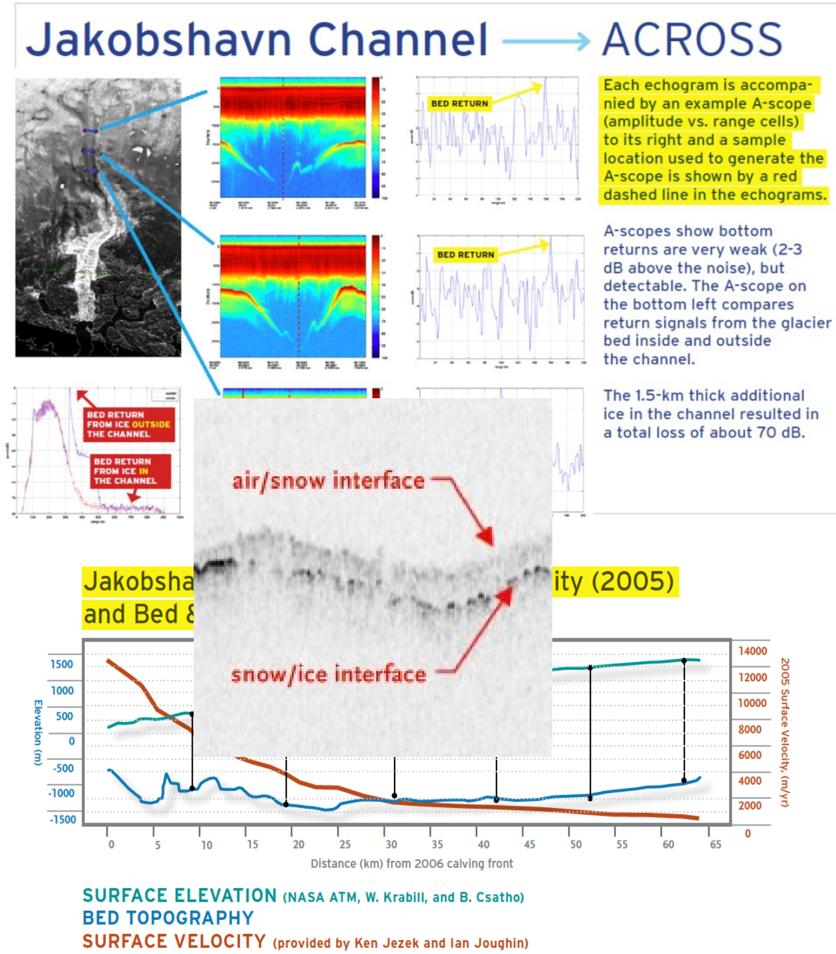
Sensor Development – Radar & Lidar

Sensor	Freq/BW	Purpose
Radar Sounder/Imager	150 / 20 MHz 195 /30 MHz 7.7& 14/1 MHz	Ice thickness Bed topography Basal conditions Internal Layers
UHF Radar	750 /300 MHz	Accumulation rate Shallow-ice thickness
Radar Altimeter (RA)	15/4 GHz	Ice-surface elevation Accumulation rate Snow thickness
Pulse-Compression LIDAR (PCL)	1054 nm BW = 4 GHz	Ice-surface elevation Snow thickness in conjunction with RA
Microwave Ultra-wideband Radar	2.5-7 GHz	Snow thickness over sea ice
Low-Freq Ultra-wideband Radar	100-1200 MHz	Sea Ice thickness



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Meridian UAS

Active Source Seismic Methods for Exploration of the Cryosphere

George Tsoflias
Department of Geology &
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Objective

- Improve the efficiency of seismic reflection data acquisition by developing a streamer
- Evaluate active source seismic surface wave methods for polar firn and shallow ice imaging

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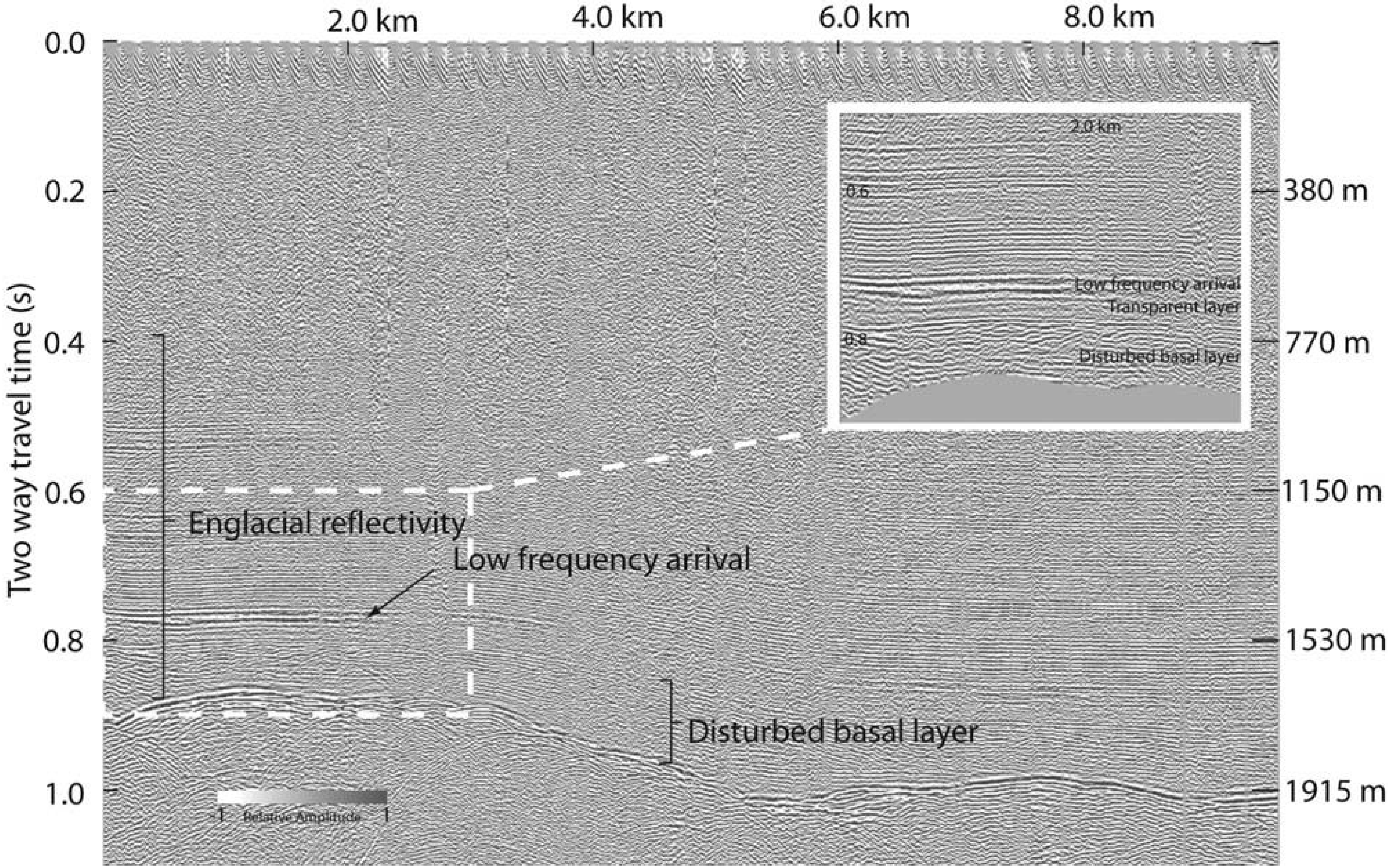
2-D Seismic Line, Jakobshavn Glacier



(Horgan et al., 2008)

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I. Snow Streamer

King and Bell, 1996: Standard geophone elements encapsulated in polyurethane, resembling a “long flexible ski”

Eiken et al., 1989; Anandakrishnan et al., 1995: Drag cable with gimbal-mounted geophones

“Although over-snow streamers have seen some success, problems with coupling still limit their use when studying basal conditions” and “burying each geophone a short depth below the snow surface protects it from noise induced by light winds and appears to give good, repeatable coupling with the snow” (Smith, 2007, JEEG)

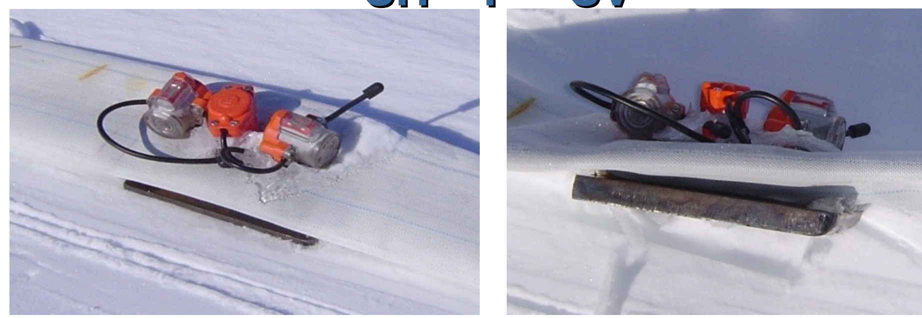
Why another streamer?

- Majority of streamer testing in Antarctic
- Appeal of potentially significant efficiency gains
- Perhaps, there is still room for improvement of streamer technology

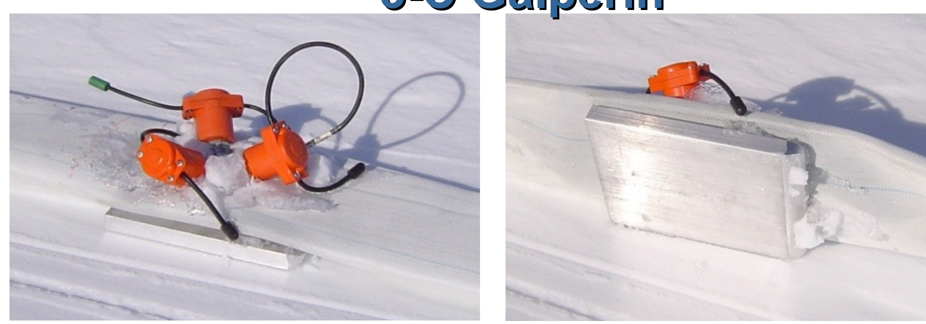
Streamer Design

- Use of conventional seismic components for "streamer" and "manual" deployment
- Full wavefield (3-Component) recording

SH – P – SV



3-C Galperin



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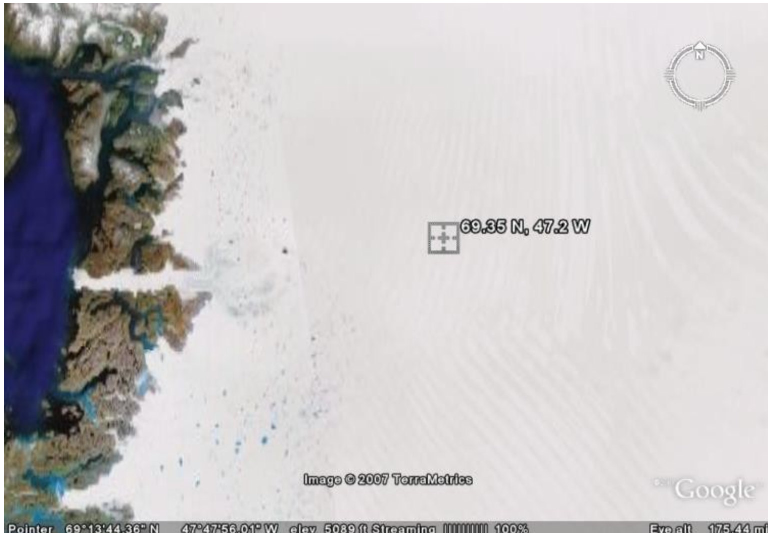
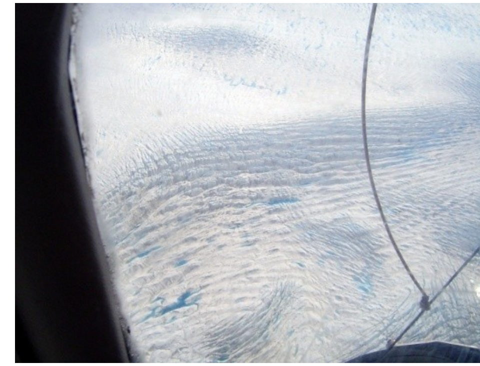
Seismic Tests – Jakobshavn Glacier, May 2007





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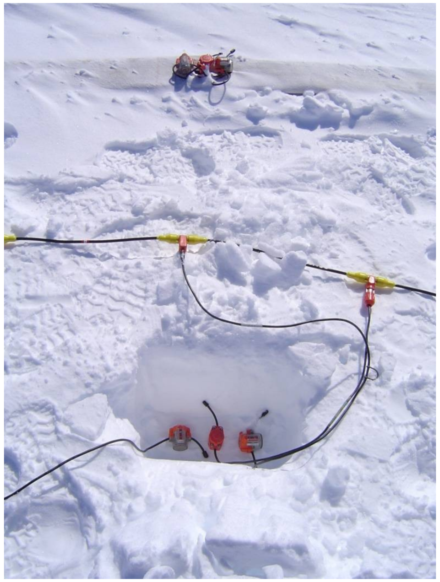
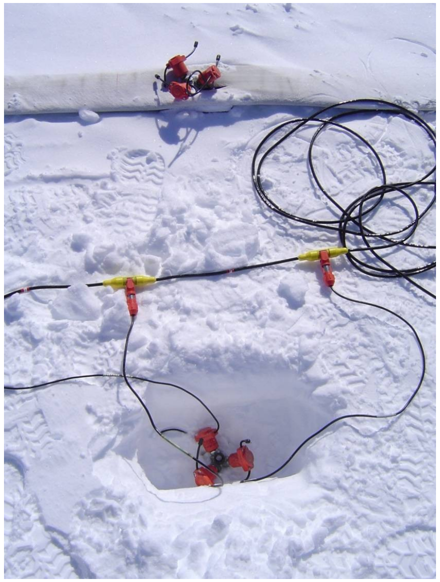
Streamer Tests

- Coupling to the snow/ice surface
- Wind and snow drift noise

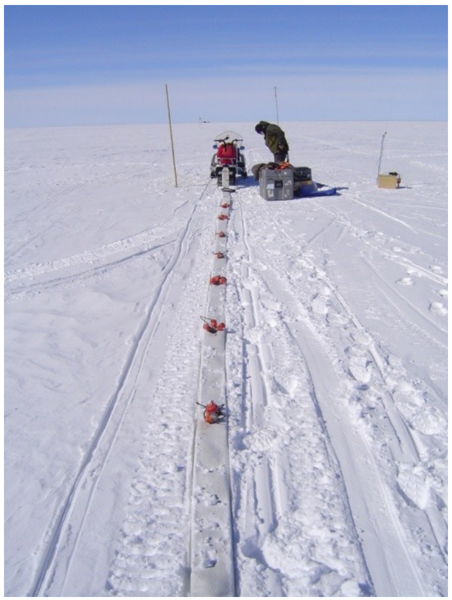
SH – P – SV

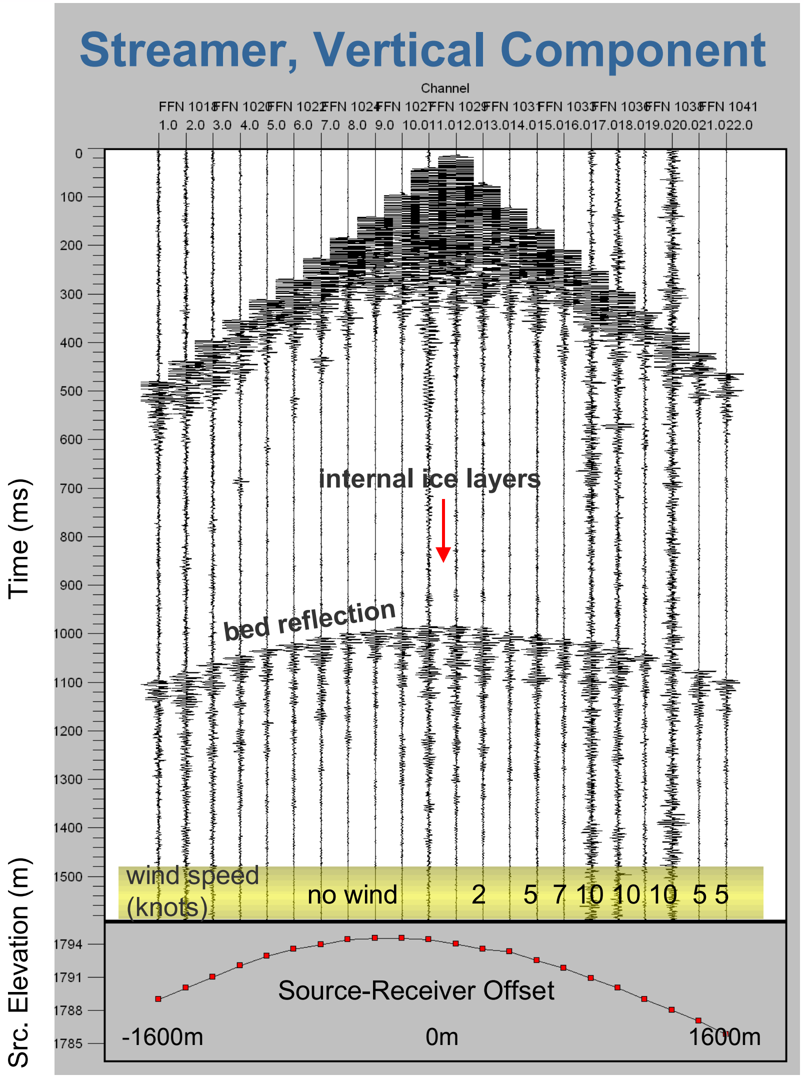


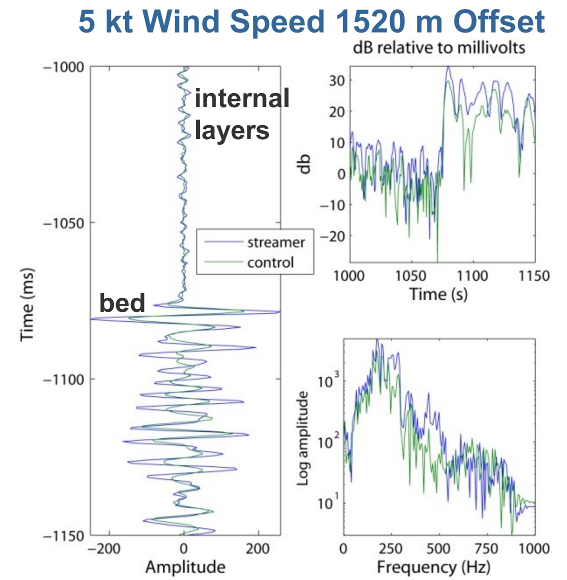
3-C Galperin

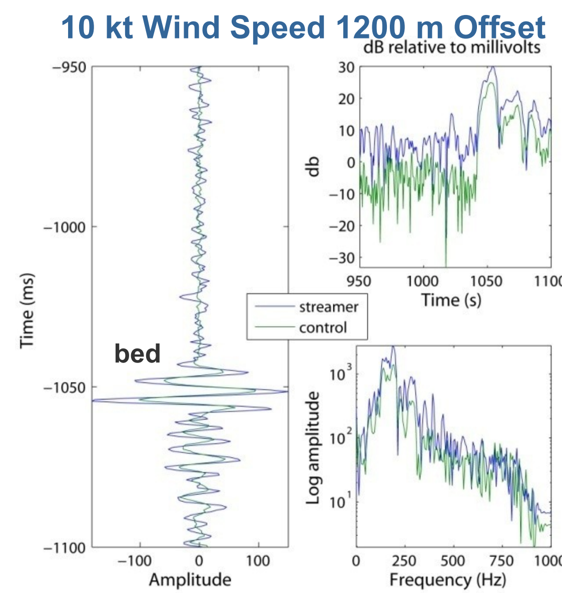


Seismic Streamer Tests: Jakobshavn Glacier, May 2007









- Streamer data virtually identical to buried geophones for wind conditions under 10 kt; Loss of internal ice layer reflections at 10+ kt wind; Bed imaged at all wind conditions
- Estimated 10-fold efficiency increase in seismic data acquisition (3D?)

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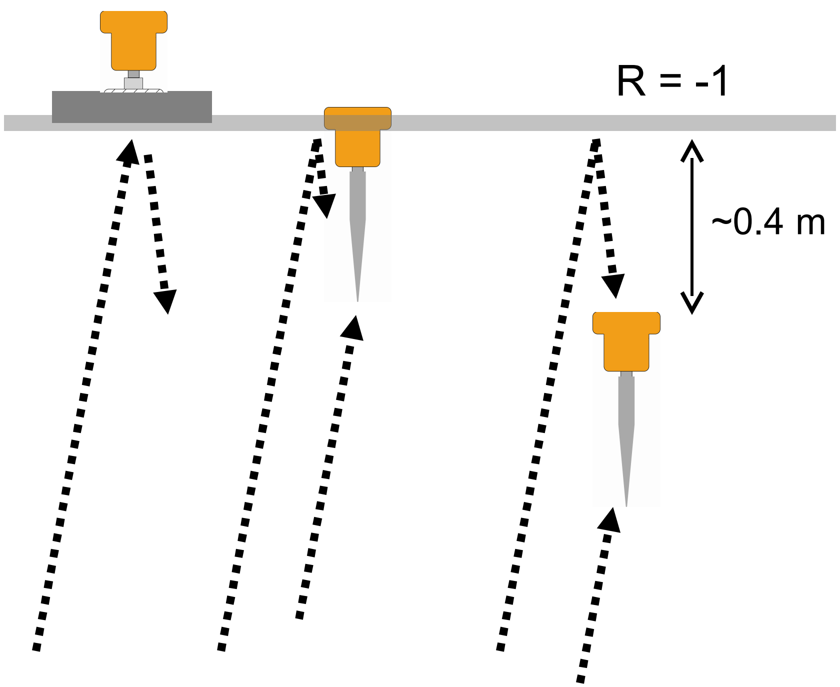
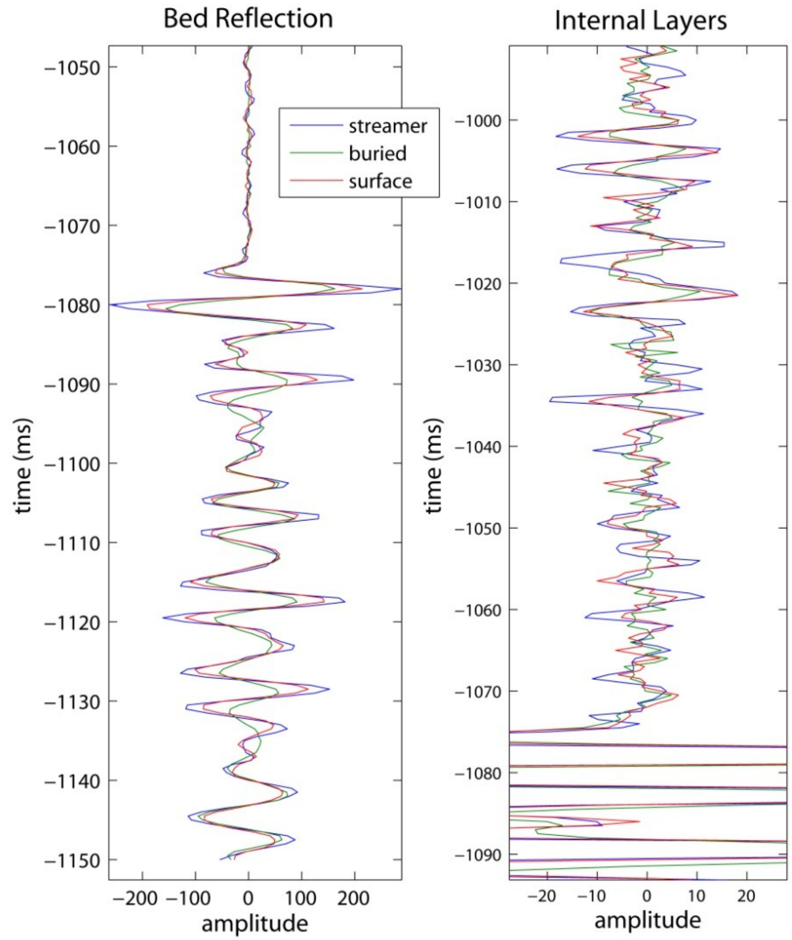
Streamer vs. Surface vs. Buried Vertical Component



v = 1500 m/s
f = 200 Hz
λ = 7.5 m

5 kt Wind Speed 1520 m Offset



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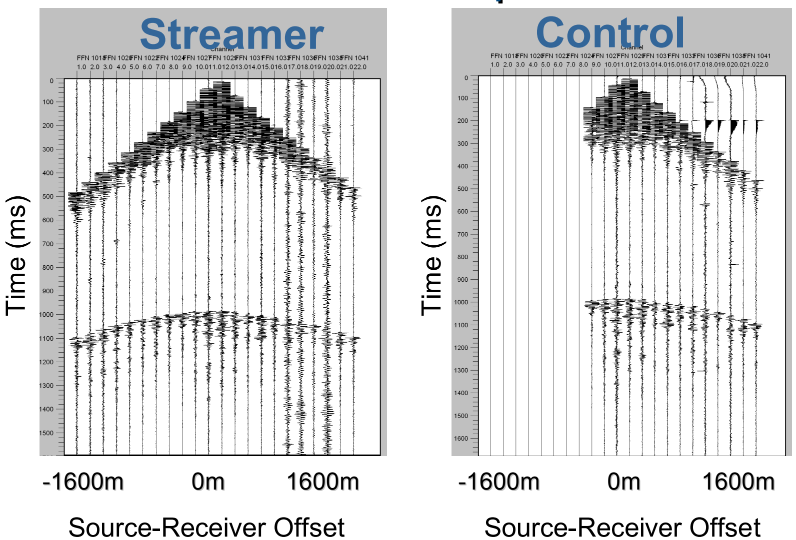
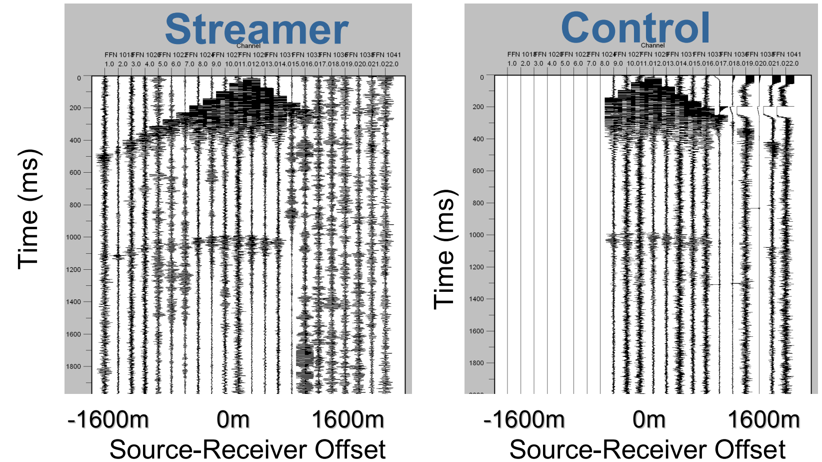
Seismic Streamer Full Wavefield Recording

Galperin Configuration

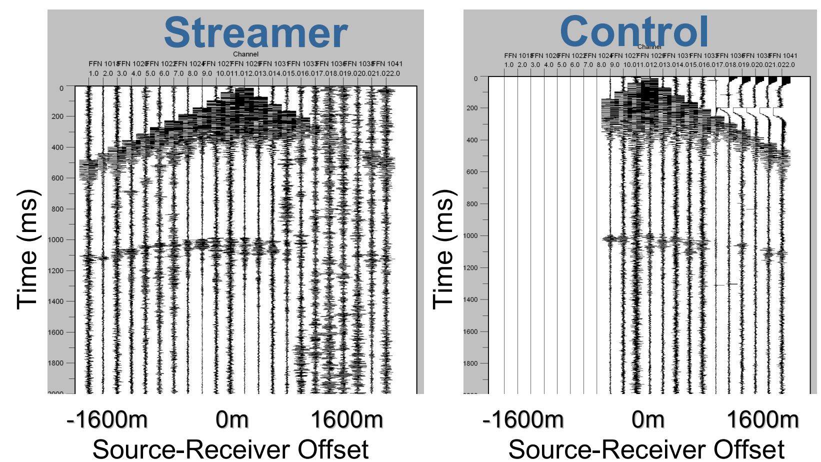
Vertical Component



SH Component



SV Component



- High quality 3-C recording at low wind conditions
- Vertical component signal recorded at all wind conditions
- Horizontal component signal recorded at wind speeds up to 7 knots
- Potential for detection of ice and bed seismic anisotropy

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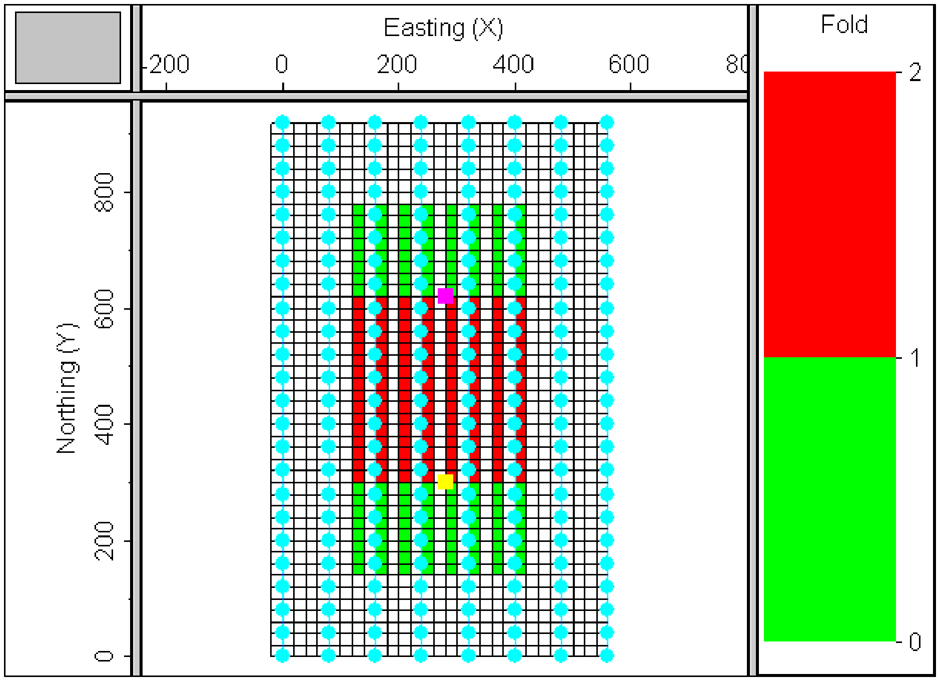
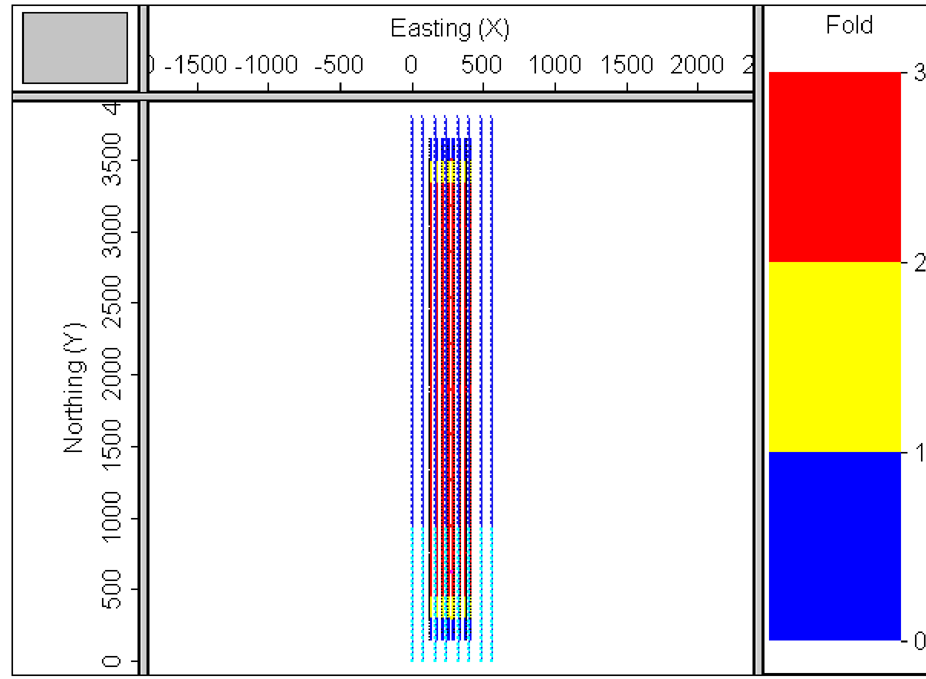
3-D Streamer Deployment



40 m geophone spacing
80 m line spacing
560m X 920 m spread



10 moves at ½ spread length

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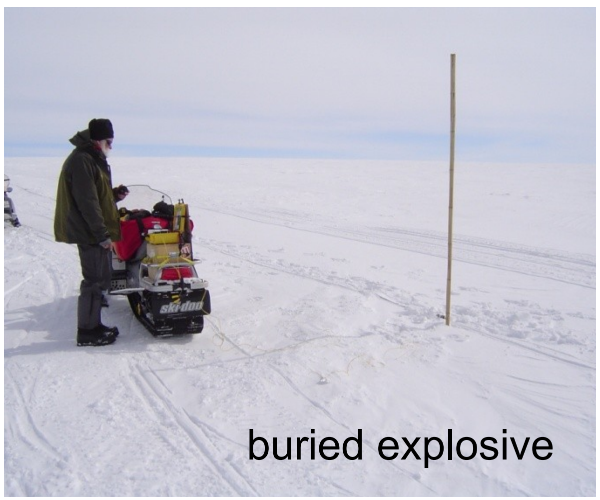
II. Investigate the Use of Seismic Surface Waves for Polar Firn and Shallow Ice Imaging

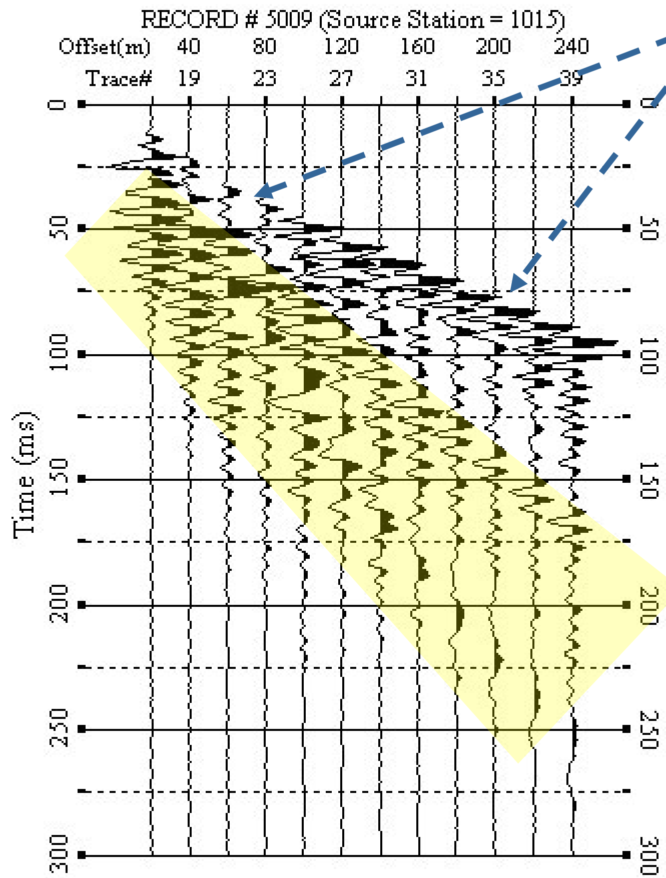
Firn

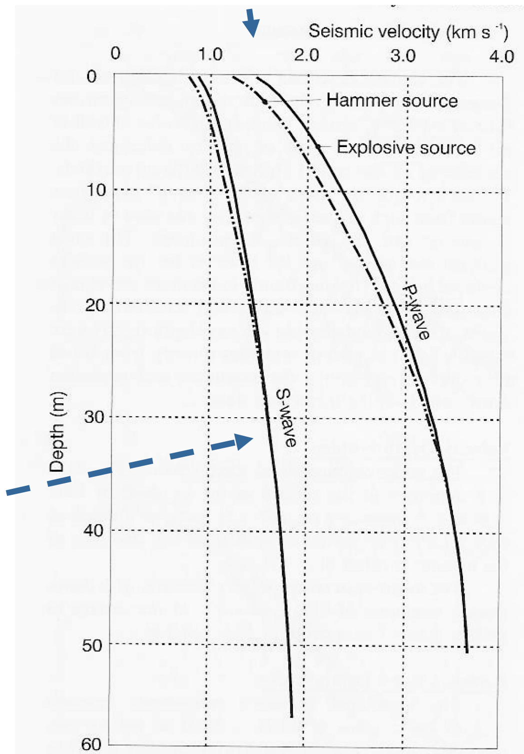
- Firn => near-surface, consolidated snow:
  - Smooth, exponential density, and P- and S-wave velocity increase with depth
  - Seismic velocity (Thiel and Ostenso, 1961):
    - P-wave 750 m/s – 3850 m/s
    - S-wave 400 m/s – 2000 m/s
  - Density (Patterson, 1994):
    - 300-400 kg/m^3 – 830 kg/m^3
  - Thickness
    - Varies with temperature and seasonal variations
    - Greenland: 60 – 80 m, ~100 – 400 years of burial time (Patterson, 1994)
- Use of firn properties
  - Seismic velocity indicator of firn / ice transition => thickness of firn
  - In situ measurement of firn mechanical properties; crevasse formation
  - Deep seismic and radar data processing

Surface Waves & MASW?



First arrivals





(King and Jarvis, 2007)

Is firn dispersive?
Can we extract usable dispersion curves?
How do different seismic sources compare?

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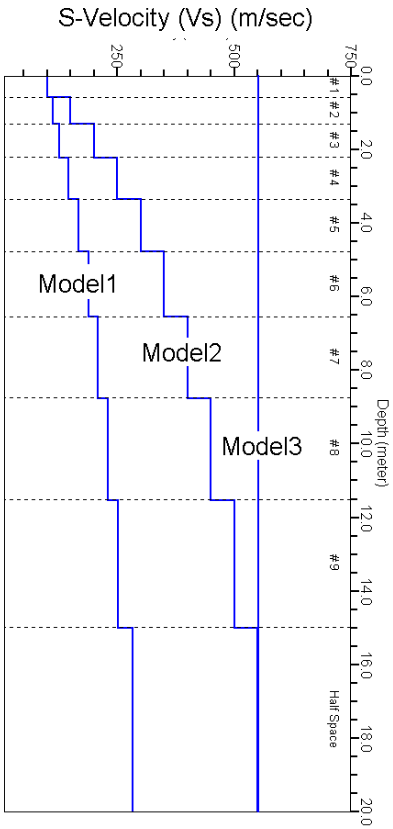
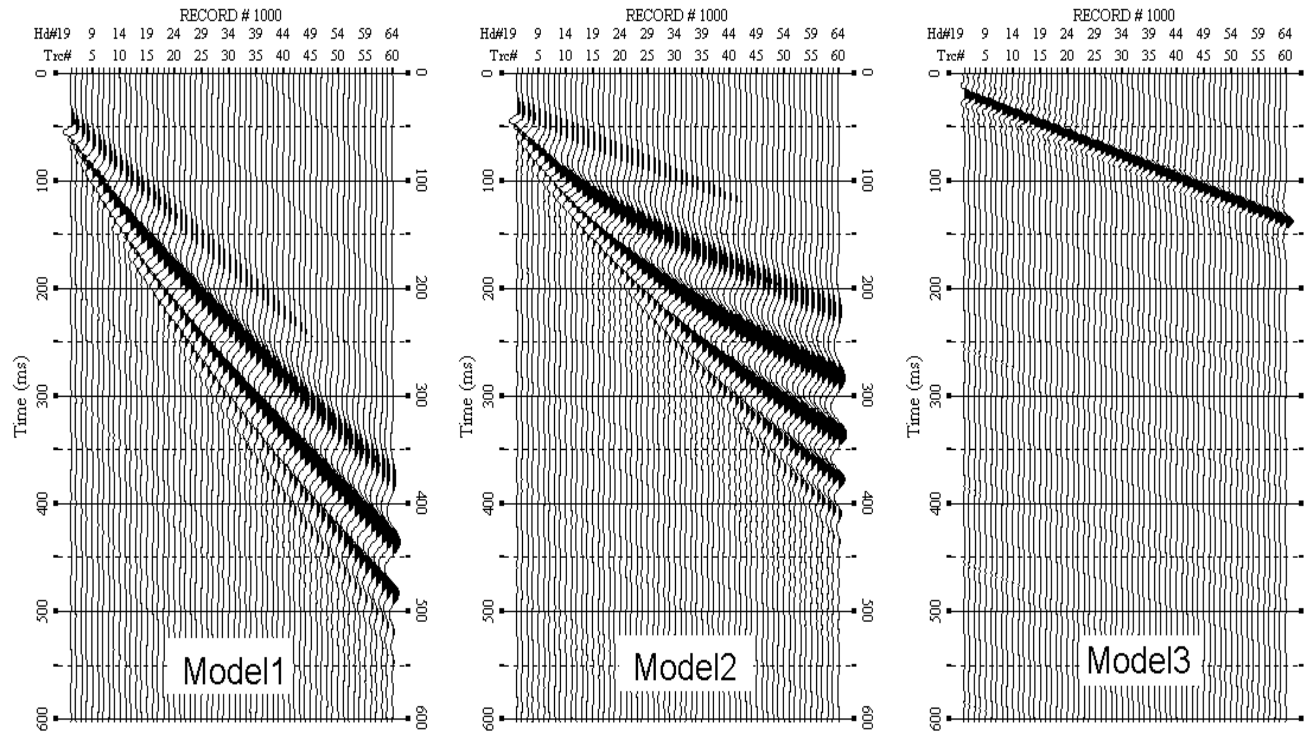
Dispersion Patterns on a Shot Record



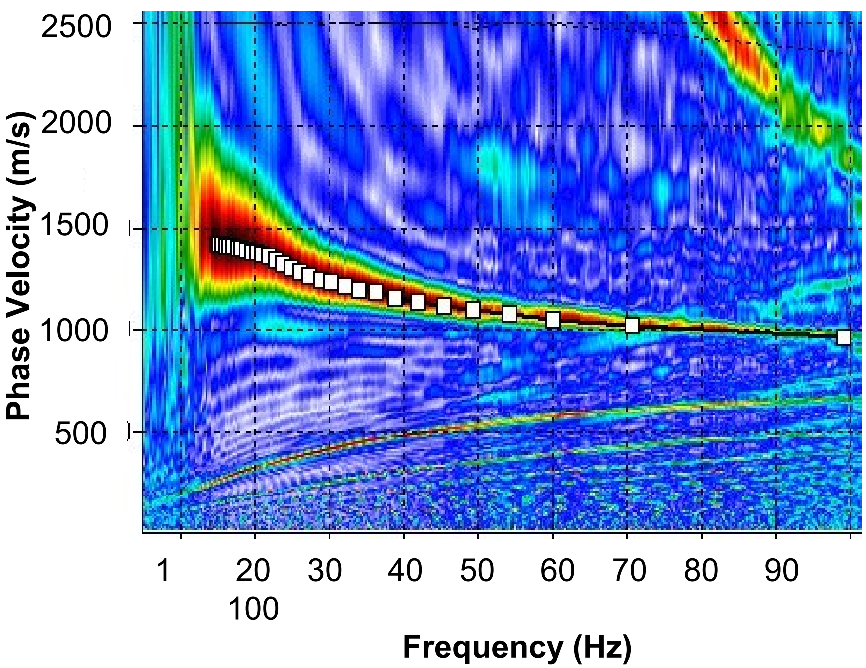


(from MASW manual, 2007)

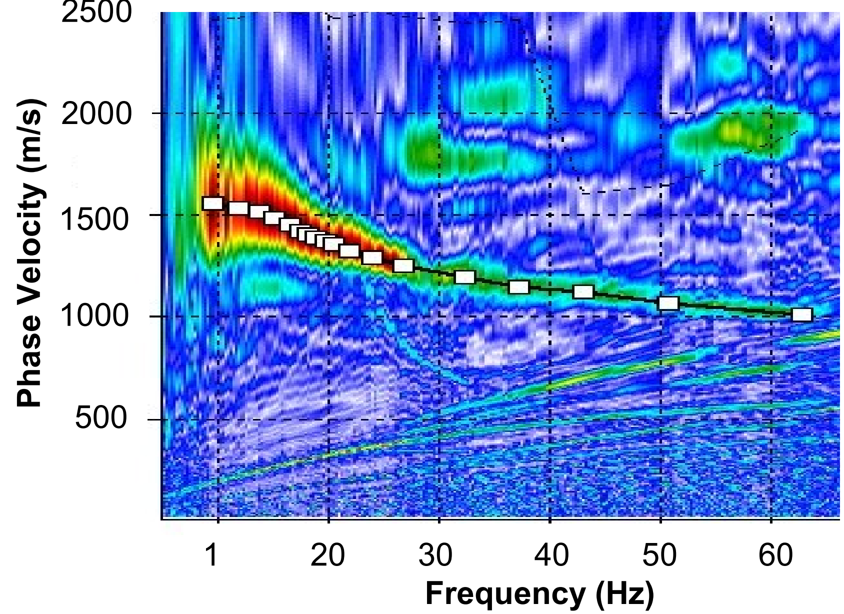
Multichannel Analysis of Surface Waves MASW: Park et al., 1999; Xia et al., 1999.

Source Comparison for Dispersion Curve Generation

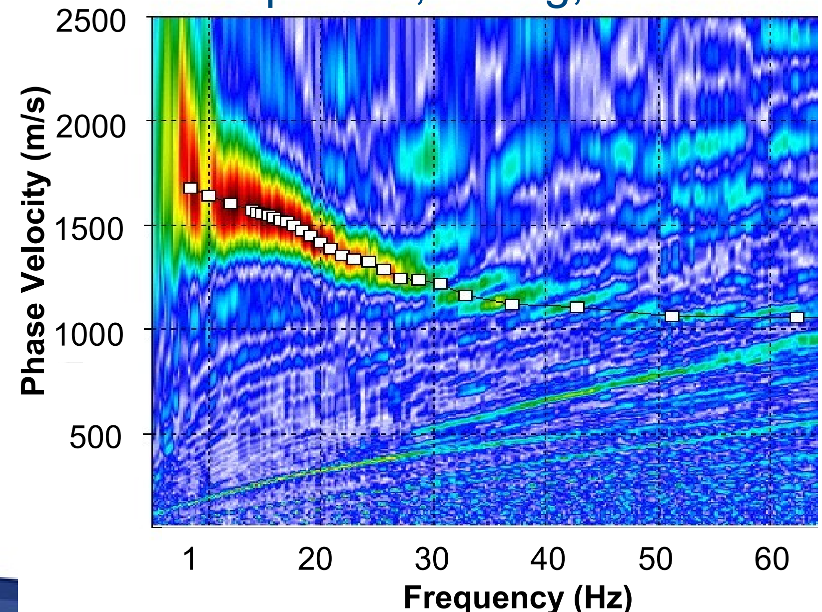
Sledge Hammer

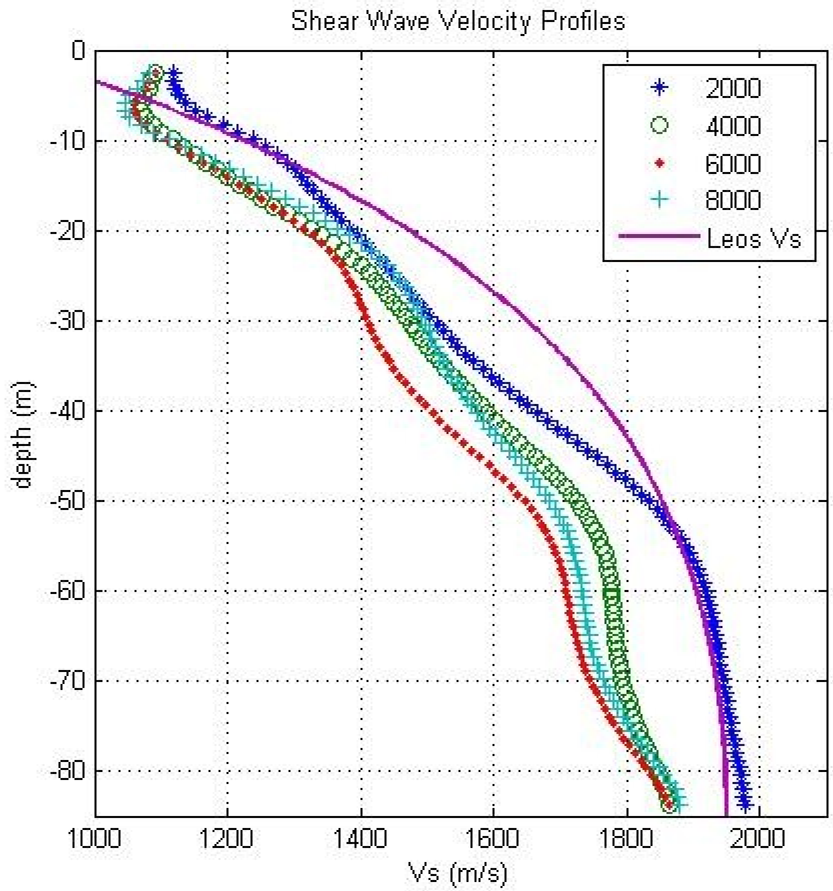


Explosive, 0.125 kg, 1 m



Explosive, 0.5 kg, 10 m

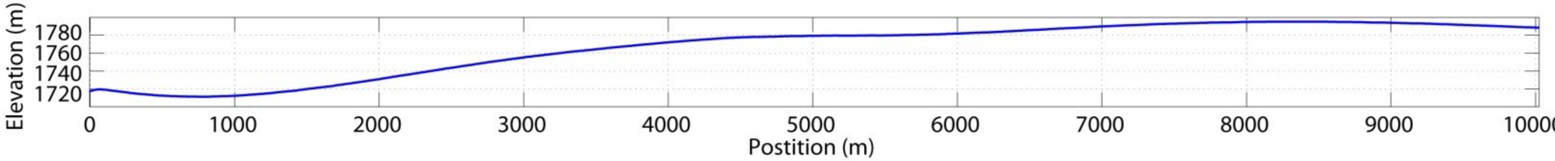




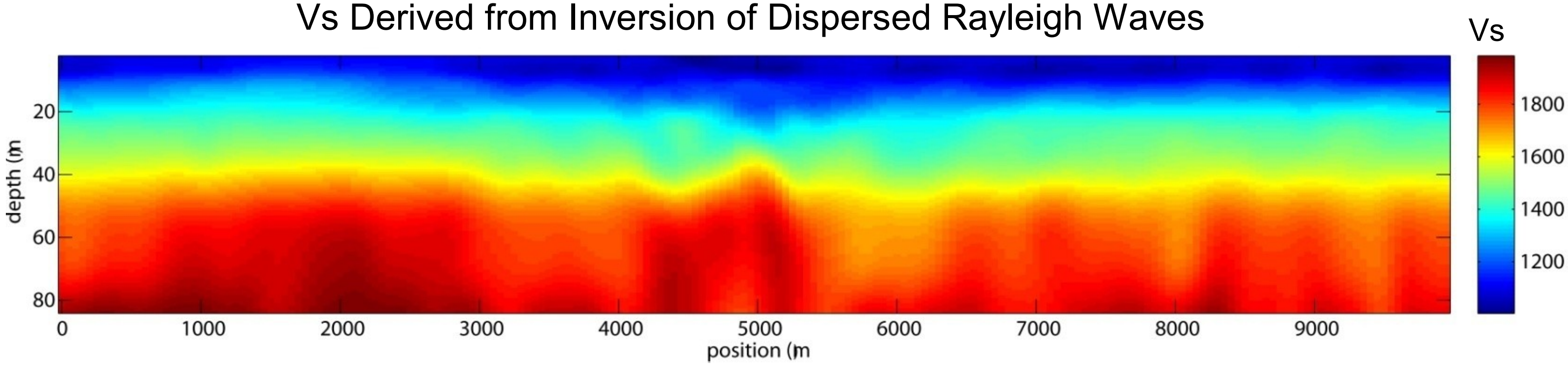
Vs derived from dispersion of surface waves along CMP line positions 2, 4, 6 and 8 km, and conventional shallow S-wave refraction data.

Development of Surface Wave Methods for Firn Imaging

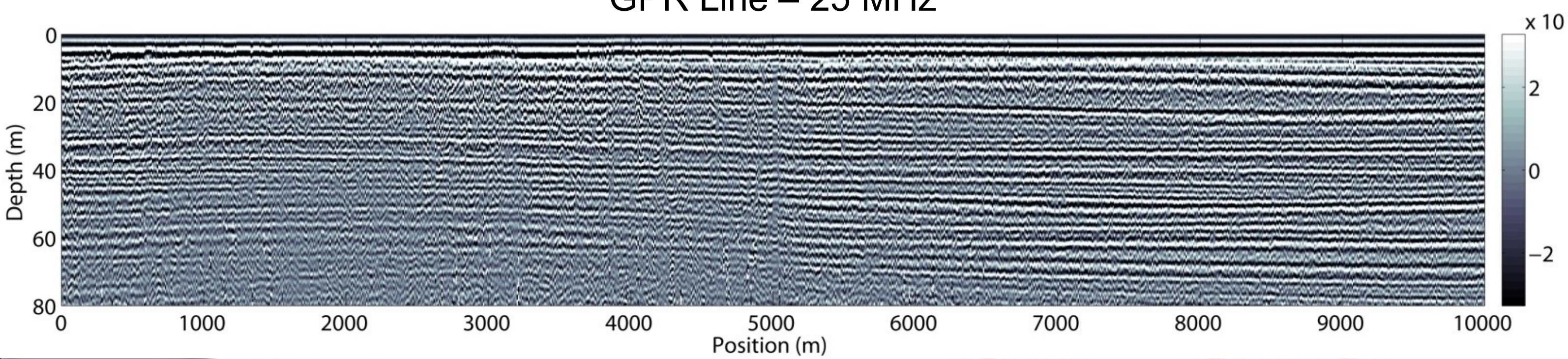
Jakobshavn Glacier, May 2007: DGPS Surface Elevation along Flow Direction



Vs Derived from Inversion of Dispersed Rayleigh Waves



GPR Line – 25 MHz



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Summary & Conclusions

- Streamer imaging of the bed and internal ice layers is comparable to conventional seismic for wind speeds up to 10 knots
- Under certain conditions burying geophones can degrade data quality
- Usable dispersion curves can be extracted from surface waves contained in polar seismic reflection records
- Firn exponential velocity increase with depth and laterally continuous velocity structure proved favorable for the MASW method, even when acquisition parameters were not “optimal”.
- The firn / ice transition varied considerably but was estimated to as shallow as ~60 m below surface on Jakobshavn Glacier, Greenland
- Surface waves can be used to characterize firn mechanical properties and could help study mechanisms of crevasse formation

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- Leo Peters
- Paul Winberry

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WHERE DISCOVERIES BEGIN

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