Arctic Acoustics at MIT

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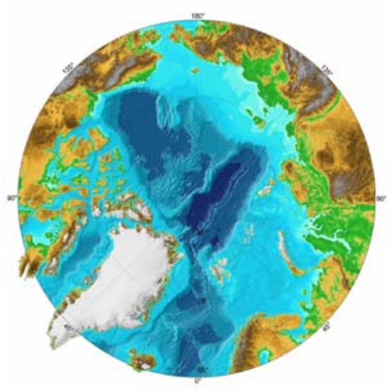
Dyer Symposium

14 June 2007

Preface

- 30 years since inception of the Arctic Program at MIT
- Changes
  - Arctic Ocean Basin has increased in size by 1-2 feet
  - Arctic ice cover has been dramatically changed by air and sea temperatures
- Arctic Acoustics Research
  - Scaled-back in mid-'90s due to fall of Soviet Union
  - Glimmers of new initiatives
    - International Polar year
    - Increased US Navy (surface?) operations may be needed—soon!
      - Much SHALLOW WATER → Ira is on the mark, as usual



Outline

- Review accomplishments of Arctic Acoustics work at MIT
  - ONR Sponsorship

- Subsequent work:
  - BBN/ONR AEAS Program Arctic Low-Frequency Active

- Show how it was done: a few pictures (if time permits)
  - Pre-GPS
  - Pre-Iridium/Globalstar
  - 1940's Airframes

  - POST-DIGITAL!

MIT Arctic Program

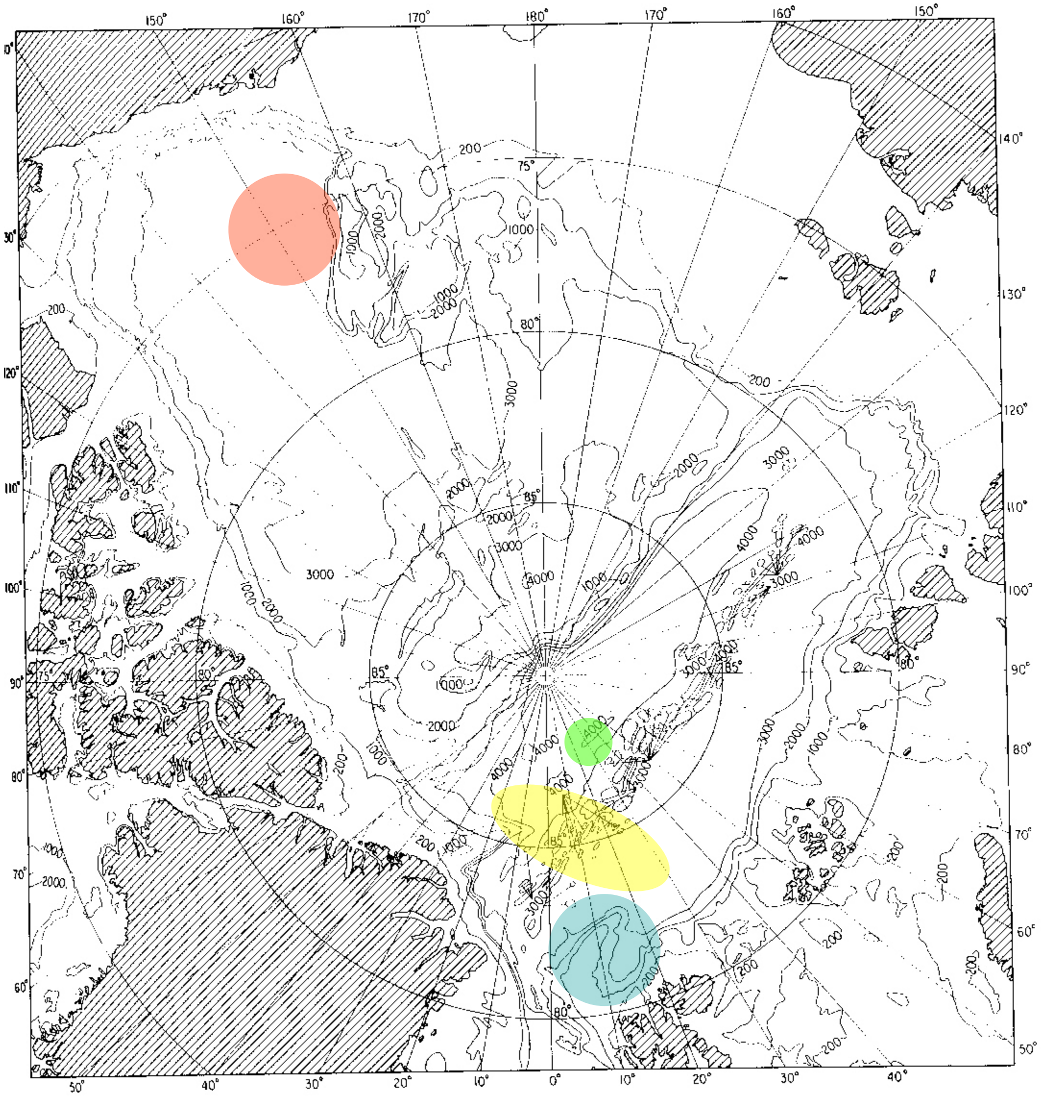
- What I heard:
  - Dyer: We should do basin acoustics. The MED is a good basin.
  - ONR: Good idea, but we have another basin in mind…

- → Multi-faceted ONR Arctic Program:

Acoustical Tools

	Ice Science	Oceanography	Crustal Geophysics	SONAR
Ambient Noise acoustic seismic	X	X	X	X
Reverberation basin meso-scale direct path	X	X	X	X
Propagation loss stability structure	X	X	X	X
Seismic reflection refraction	X	X	X	X

Experimental Program



- CANBARX ('78)
- Fram II ('80)
- Fram IV ('82)
- MIZEX 83
- MIZEX 84
- PRUDEX 87
- CEAREX 89

- AREA 92

What is unique about the Arctic?

- It's cold (for now)
- Surface Duct
- Frozen rough surface
- Very stable water column
- Ice cracking noise

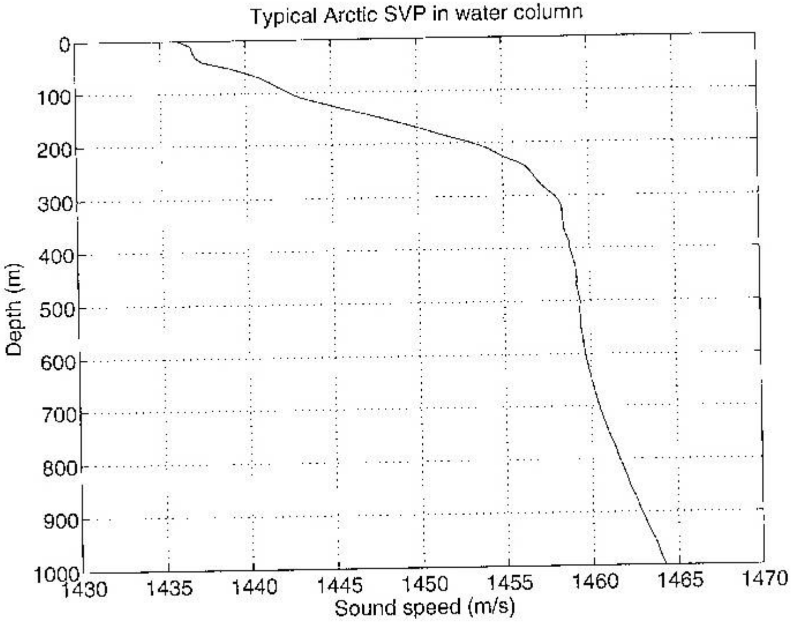
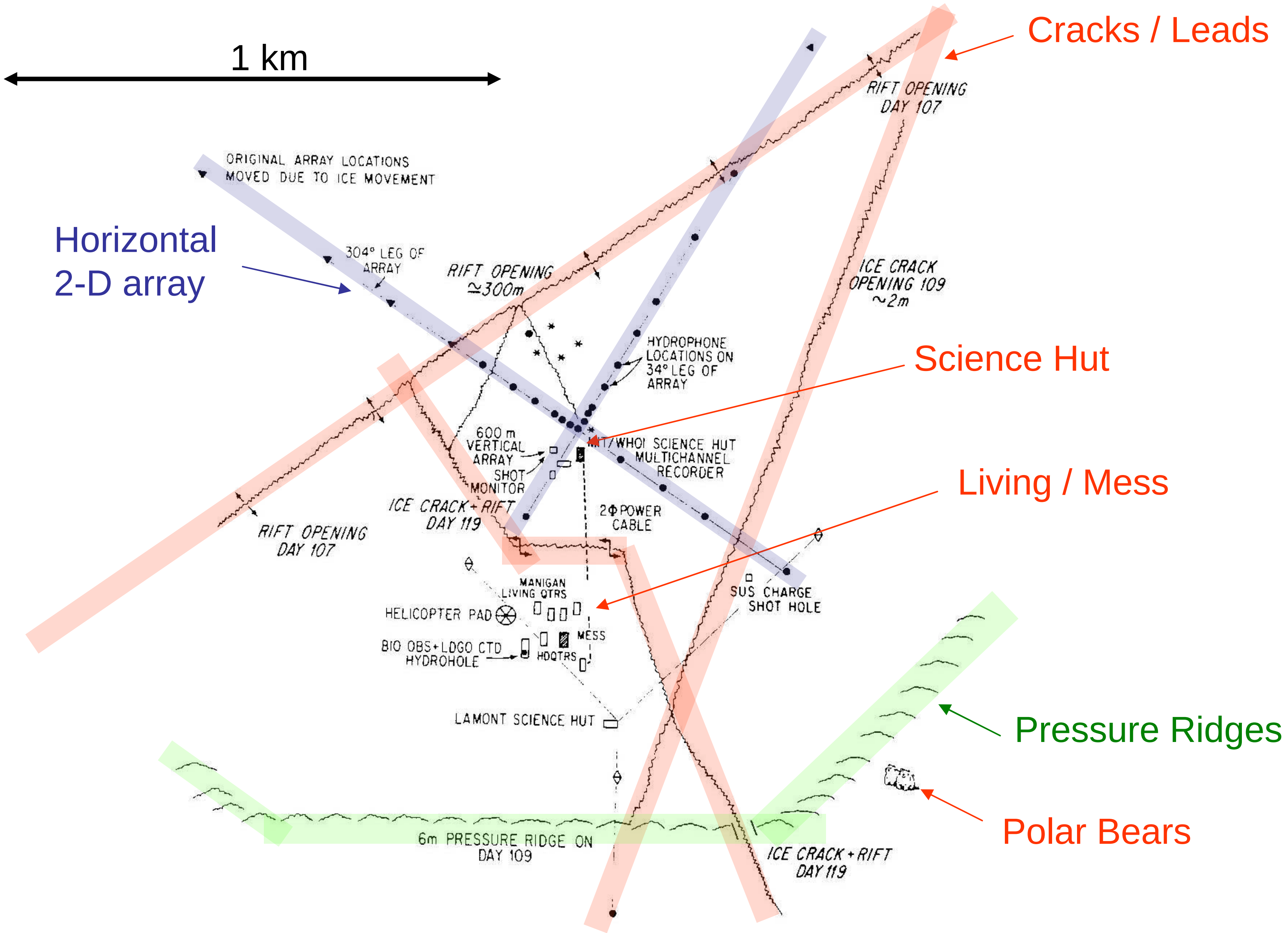


FIG. 5. Central Arctic sound speed profile obtained from CTD measurement taken at the ZIRCON camp.

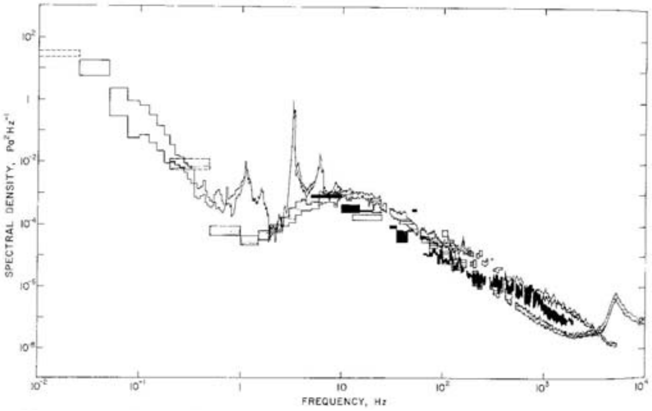
Fram II Camp Layout (& hazards)



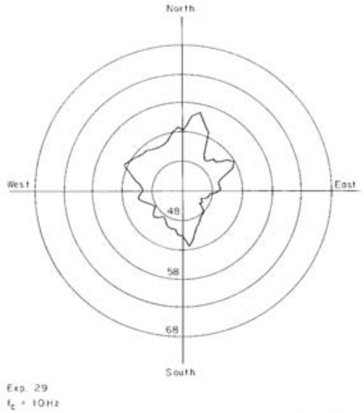
Ambient Noise: Ice Cracking

- Goals
  - Ambient noise statistics
  - Ambient noise understanding
    - Postulate and verify ice-cracking mechanisms and relation to sea-ice strength
    - Seismic noise from mid-ocean ridge
- Methods
  - Validate models for individual ice-crack events and aggregate spectral observations
  - Specific ice propagation studies with geophones and sources on the ice
  - Measure and localize earthquake events from the mid-ocean ridge
- Results

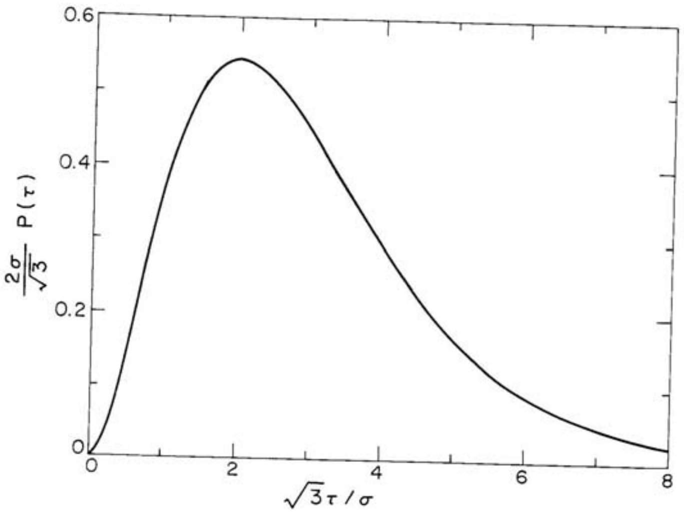
Ambient Spectrum



Horizontal Directivity

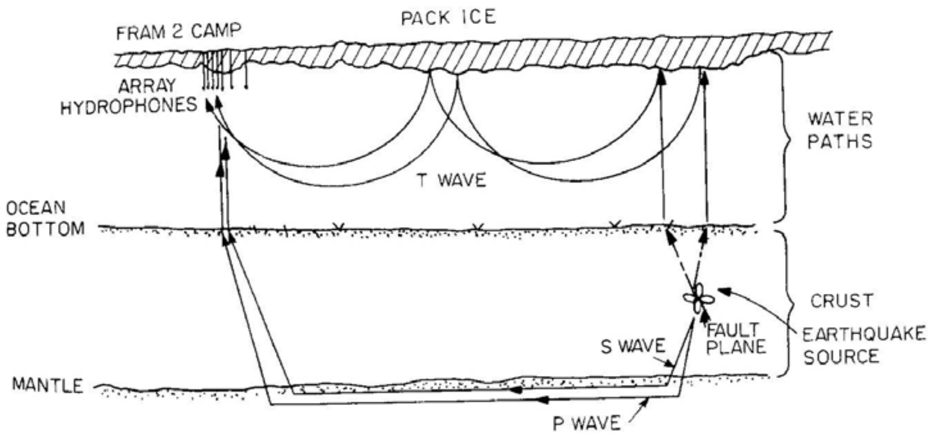


Ice Stress Distribution



Ambient Noise: Seismic

Geometry

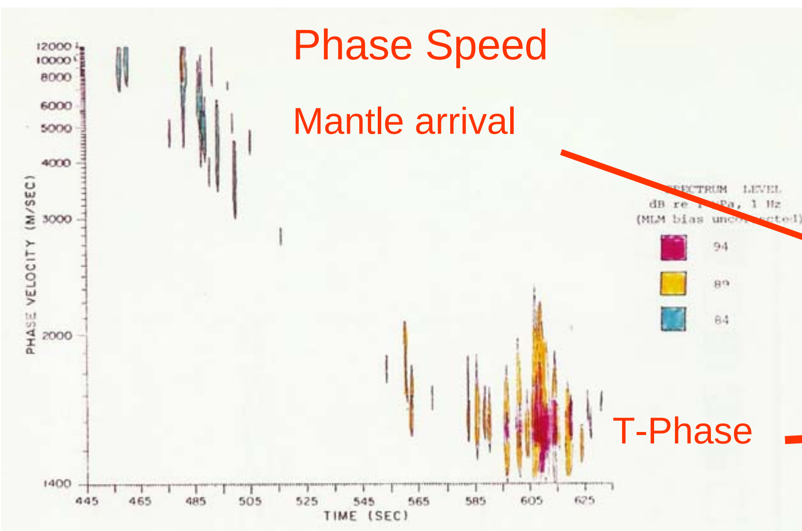


Phase Speed

Mantle arrival

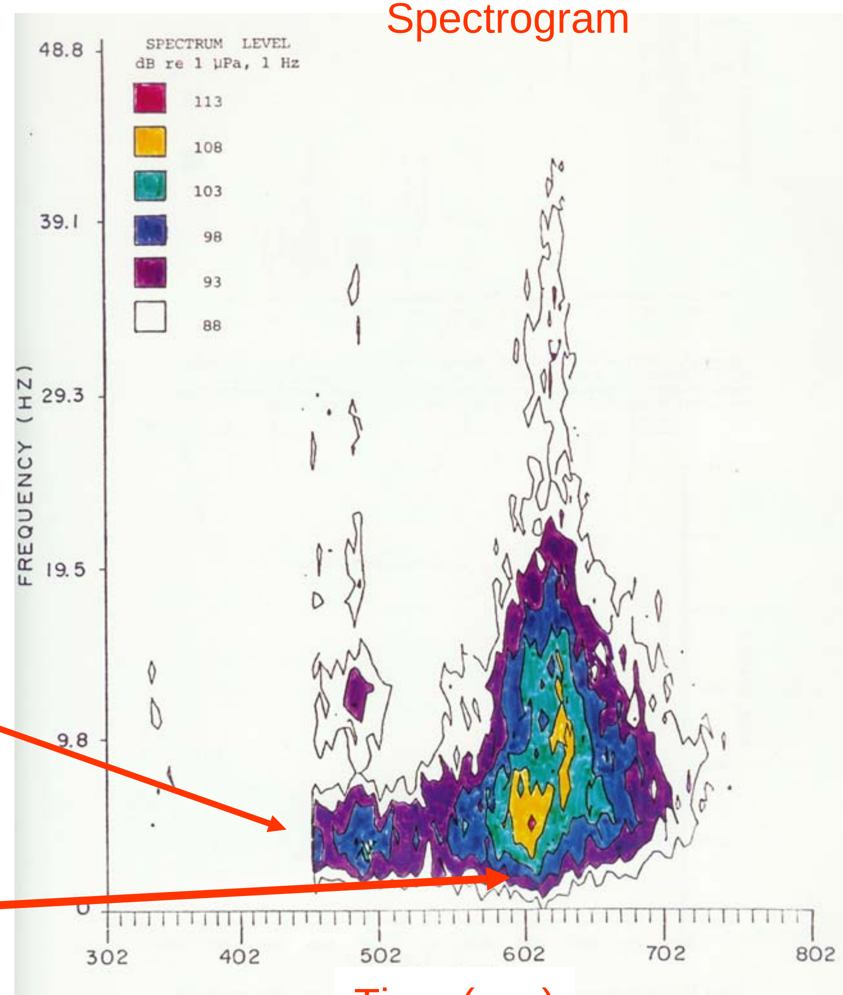
T-Phase

Phase Speed (m/s)



Time (sec)

Spectrogram

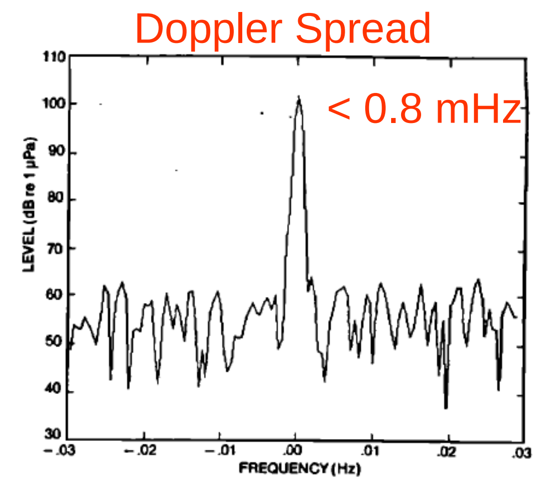


Time (sec)

- Precision Localization of earthquakes in Rift zone to within 5 km.

Propagation Stability

- Goal
  - Determine the stability of the multi-path Arctic propagation channel
- Method
  - Transmit LF CW tones over 300 km paths
  - Receive on array and beamform
  - Measure fluctuation statistics
- Results
  - Stability greater than measurable with available 25 dB SNR (15-40 Hz) and time windows



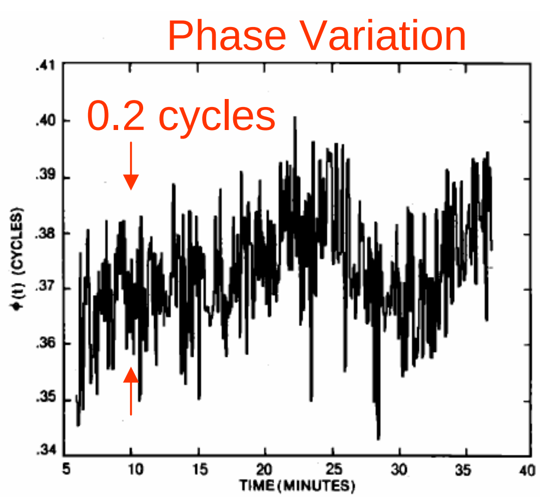


FIG. 3. Phase of the 30-Hz received tone versus time for record 1.

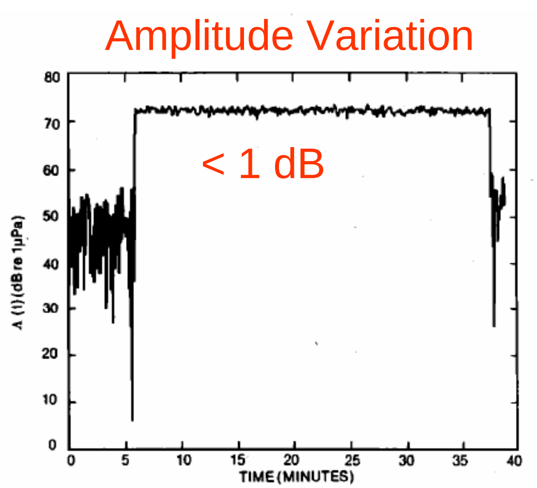
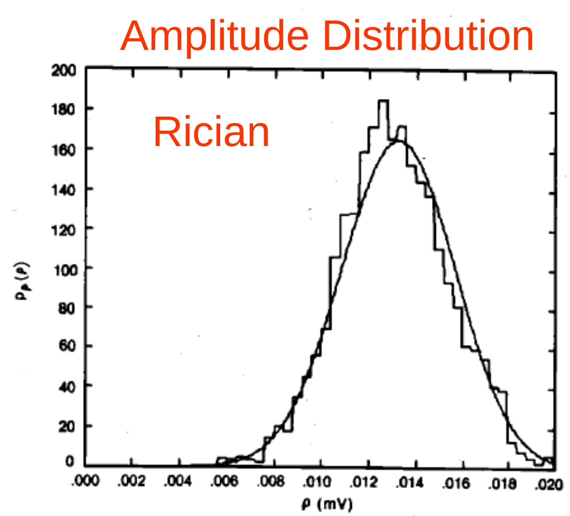
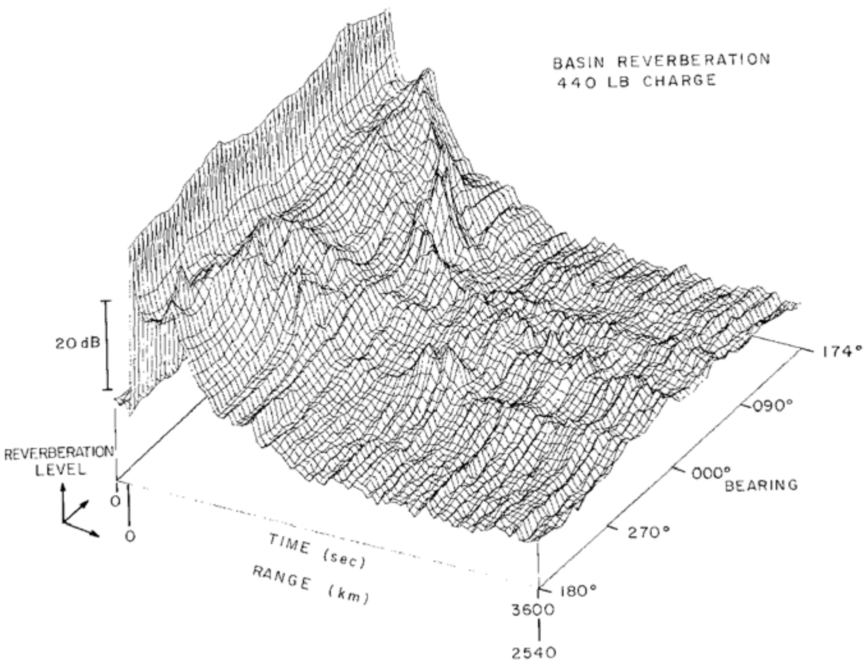


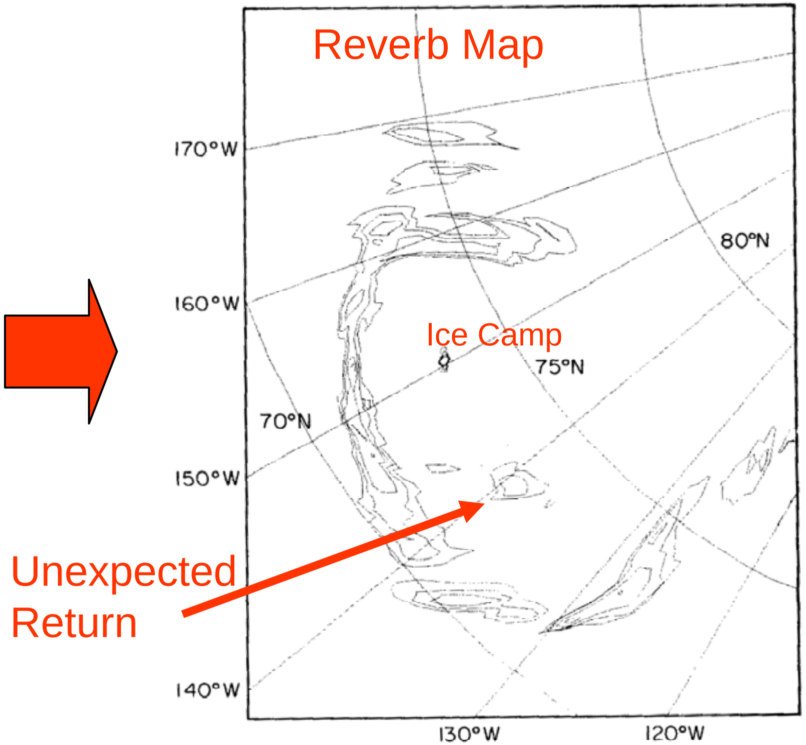
FIG. 4. Level in dB's re 1 μPa of the square of the amplitude of the tone versus time for record 1.



Basin Reverberation

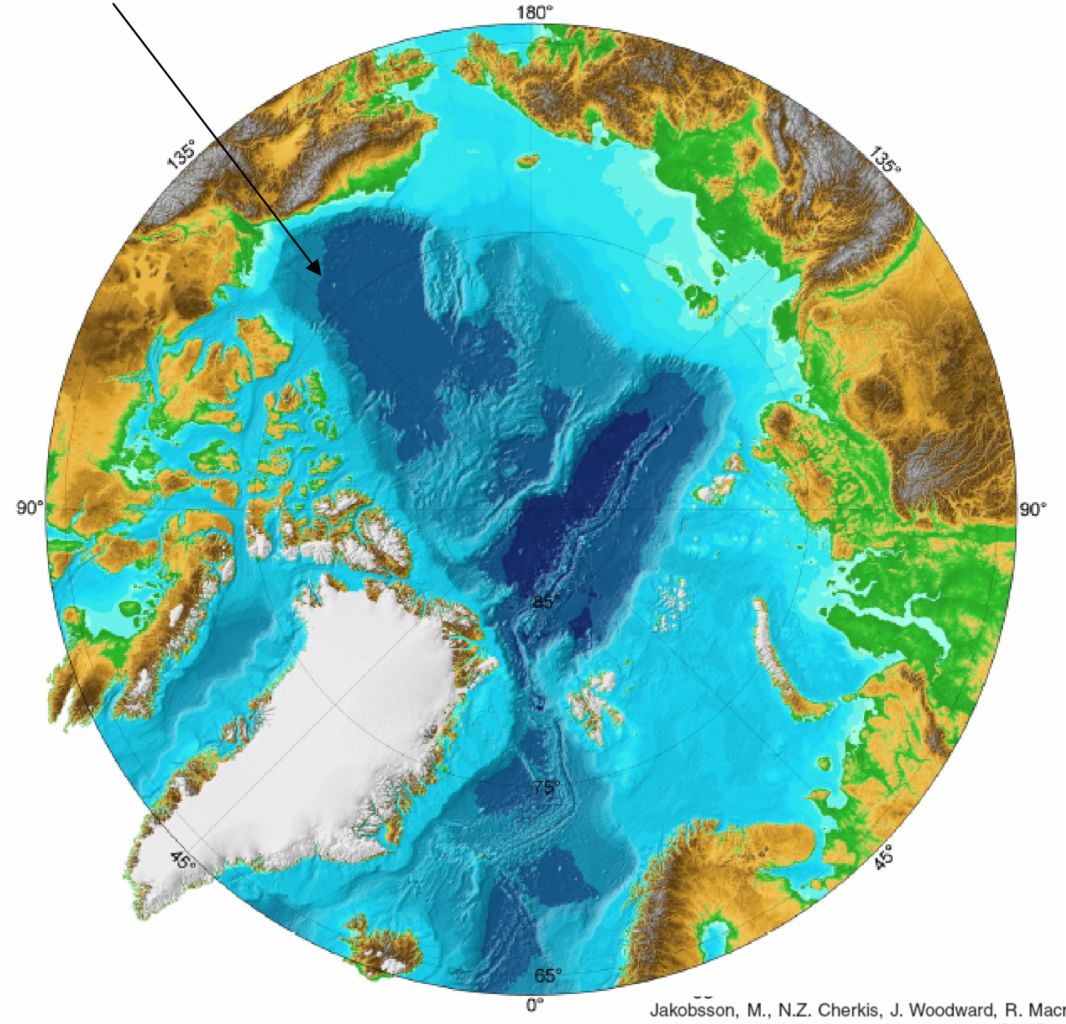
- Goal
  - Probe the basin margins and everywhere in-between with a very-low-frequency active sonar → estimate backscatter strength
- Method
  - 8-10 Hz active sonar. 24 element 2-D logarithmic array (1 km aperture)
  - 440-1600 lbs TNT source at 800’ depth
  - > 1 hour listen time for 2500 km range
- Results: Backscatter strength + a new feature!





Basin Reverberation

- Seamount “G. Leonard Johnson”
  - 73.2 N   139.0 W

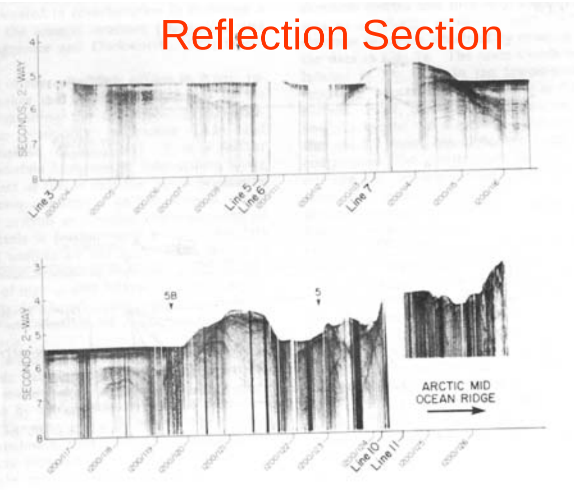


Jakobsson, M., N.Z. Cherkis, J. Woodward, R. Macnab, and B. Coakley. New grid of Arctic bathymetry aids scientists and mapmakers; Eos, Transactions, American Geophysical Union, v. 81, no. 9, p. 89, 93, 96.

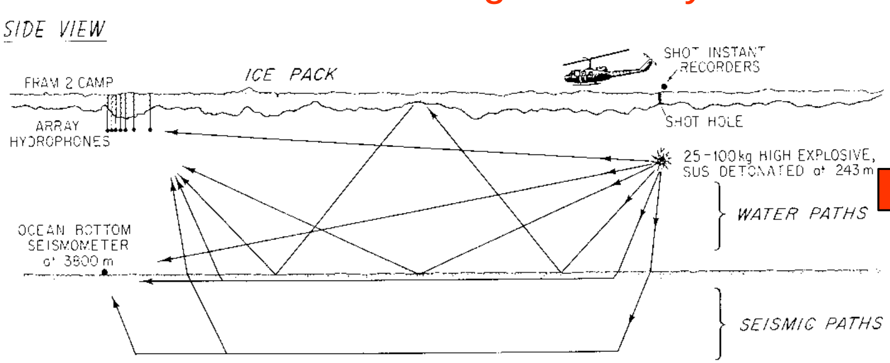
Seismic Reflection / Refraction

- Goal
  - Understand the crustal structure of the Arctic basins down to the mantle
- Method
  - Reflection: Air gun / SUS
  - Refraction:
    - Fly transects away from array at camp with helicopter
    - Drop 25-100 kg charges @ 800' depth
    - Velocity analysis and inversion
    - Exploit extensive multiple arrival structure
- Results
  - Well-constrained sediment / igneous crust velocities down to mantle

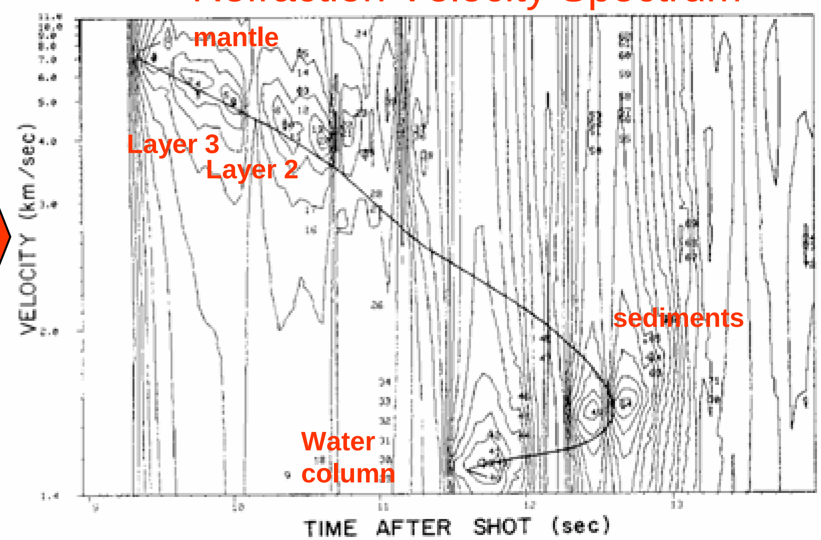
Reflection Section



Refraction Shooting Geometry



Refraction Velocity Spectrum



Seismic Refraction Results

Refraction Migrations

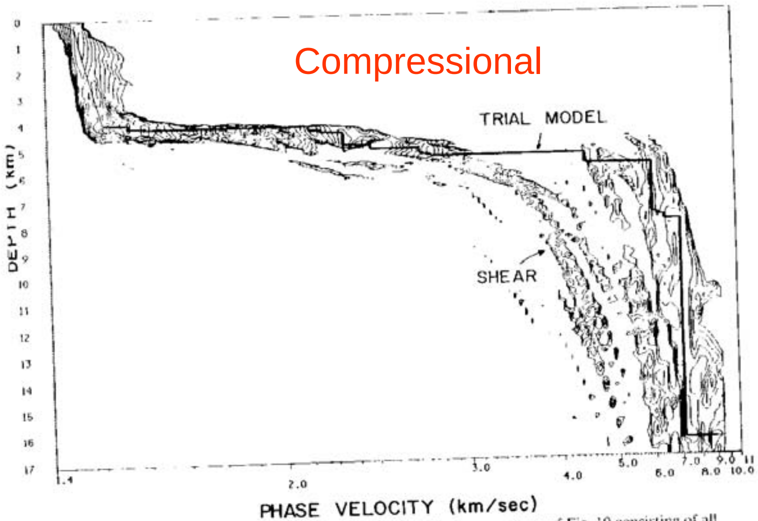


Fig. 12. Compressional velocity/depth migration image of τ-slowness spectrum of Fig. 10 consisting of all multiples from all six offsets in line 1 at 14 Hz. Contour intervals are 10 dB.

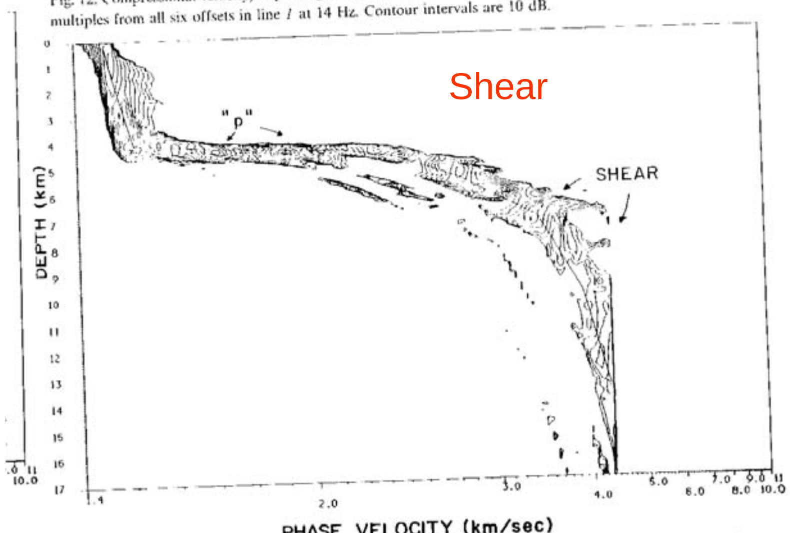
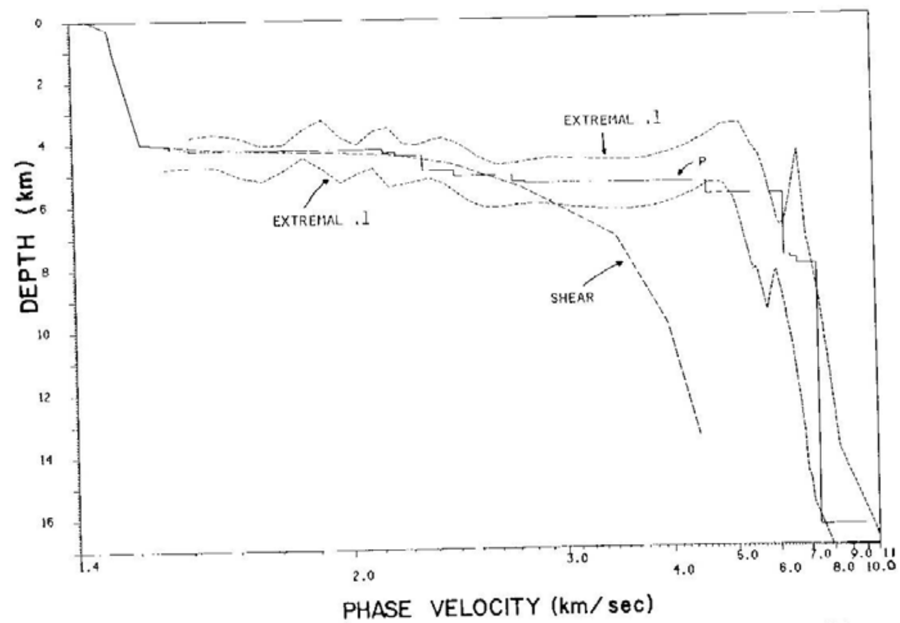


Fig. 13. Shear wave velocity/depth migration image of Fig. 10 consisting of all multiples from all six offsets in line 1 at 14 Hz. Contour intervals are 10 dB.

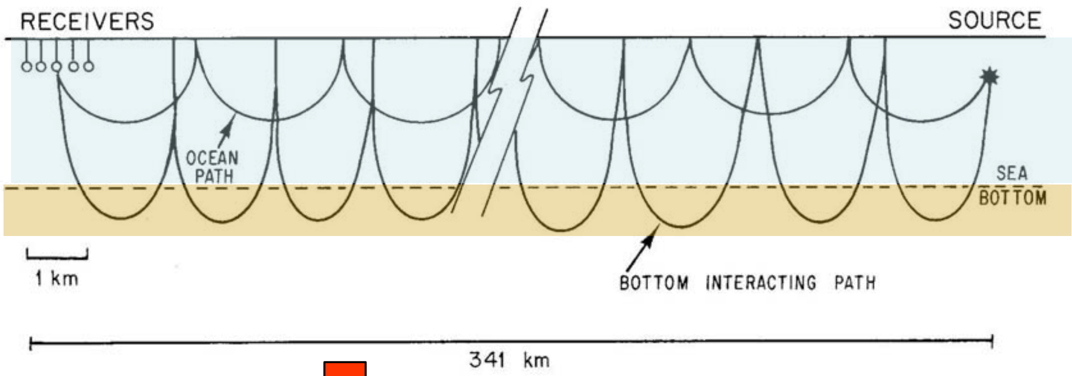
Pole Abyssal Plain Crustal Velocity Structure



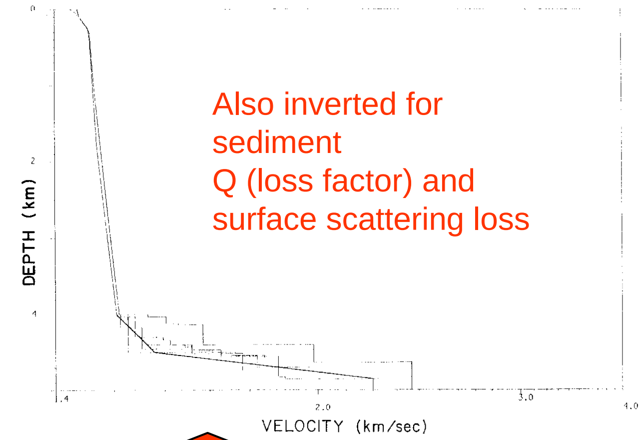
Key: Invert all direct and multiple arrivals to make up for the sparse shooting geometry

Sediment Refraction

341 km shot geometry

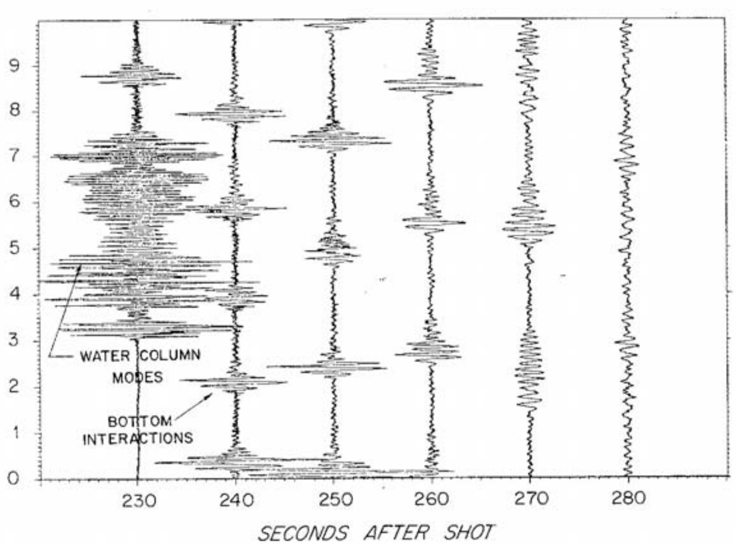


Sediment Velocity Structure



Also inverted for sediment
Q (loss factor) and
surface scattering loss

22 Sediment Penetrating Multiples



Velocity Analysis → tau-p inversions

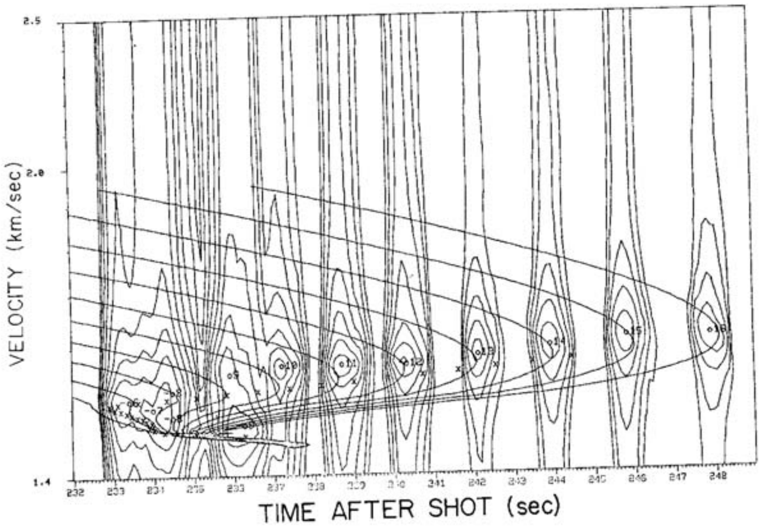


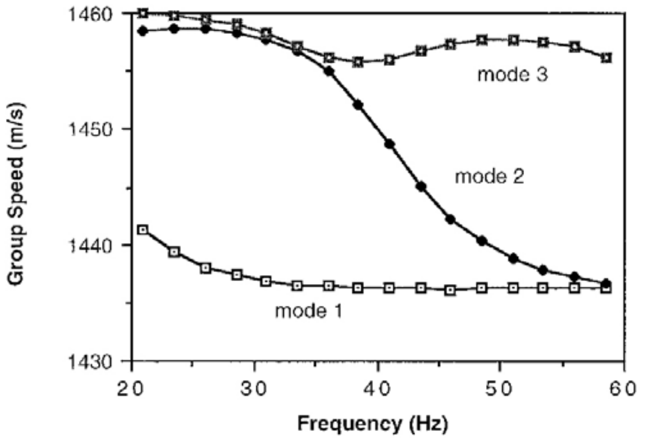
Fig. 6.15) The 16 Hz velocity spectrum of the data and the normal mode and WKBJ predictions. See the text for a discussion of this plot.

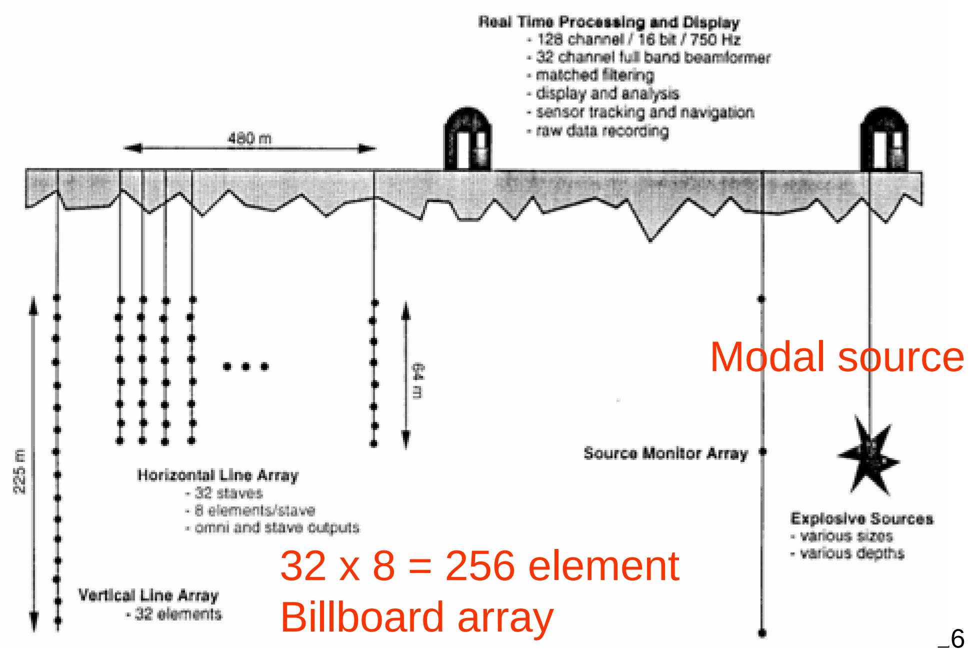
Post-MIT: Arctic LFA (Low Frequency Active)

- Goal
  - Design and Test LFA Sonar for the Arctic
- Method
  - Exploit Surface Ducted Energy
    - Low dispersion
    - Low backscatter (low grazing angle)
    - Continuous coverage (no CZs)
- Results
  - LFA Performance (classified)
  - Surface Backscatter model
  - Ice Deformation Tracking
  - Potential for coherent clutter subtraction demonstrated

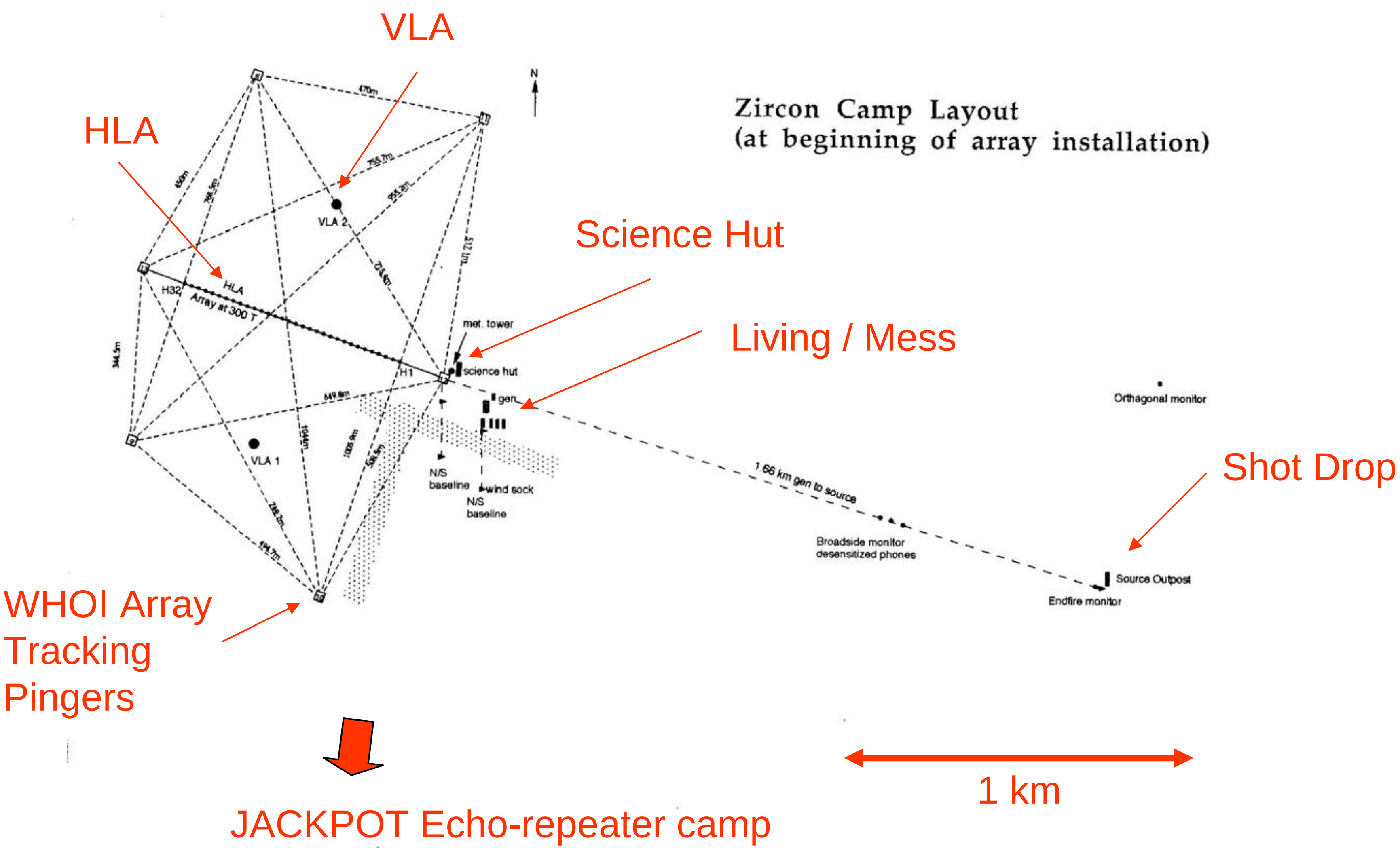
Dispersion

- 0.03 seconds at 100 km for 30-60 Hz band
- 0.24 seconds at 100 km for 20-60 Hz band





Typical Camp Layout: ZIRCON (AREA-92)



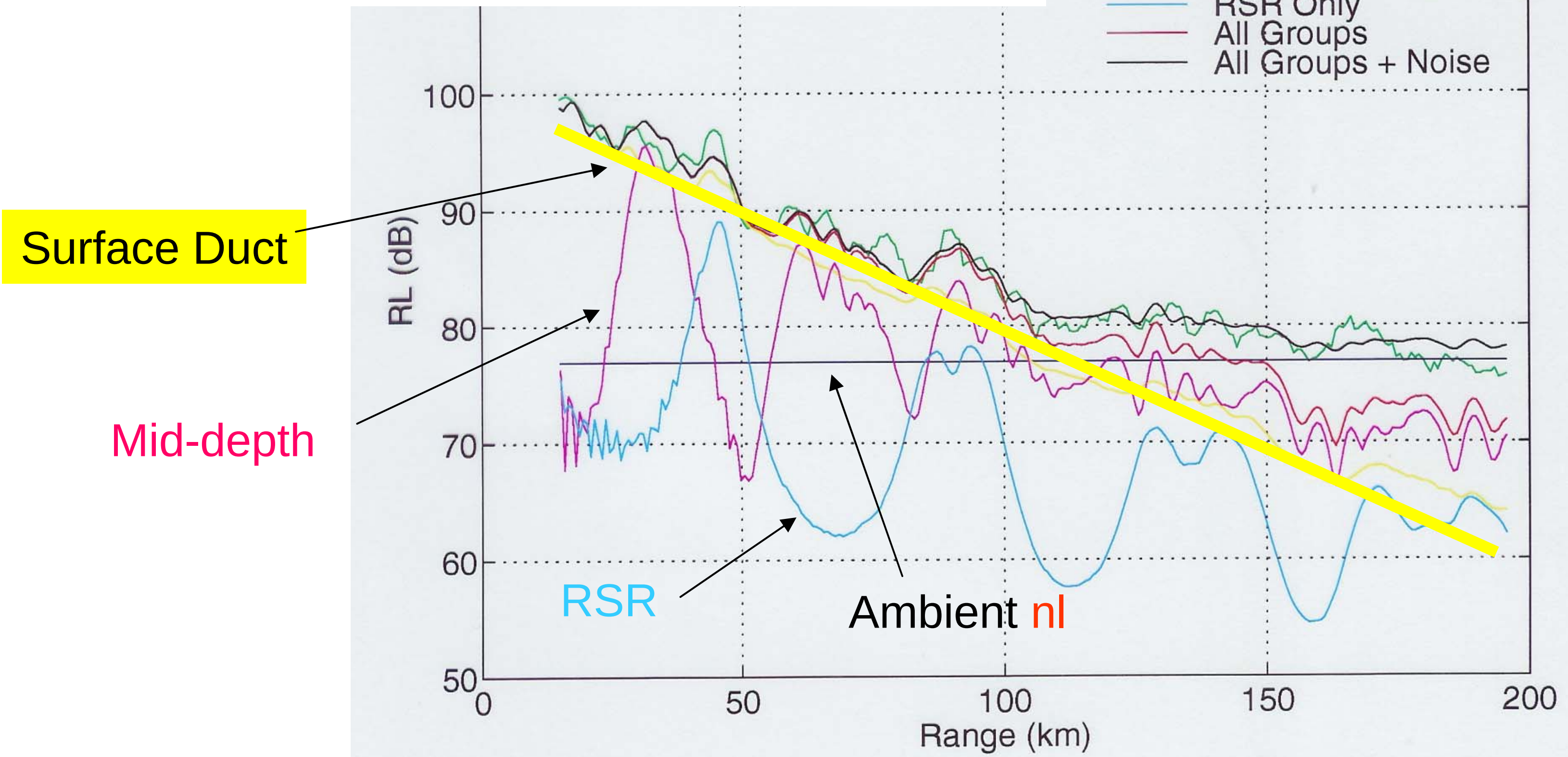
Reverberation Analysis

$$rl(t) = esl \sum_{\substack{m \\ \text{groups} \\ \text{out}}} \sum_{\substack{n \\ \text{groups} \\ \text{in}}} [tg1_m(r_{mn}(t)) \;\; a_{mn} \;\; ss_{mn} \;\; tg2_n(r_{mn}(t))] + nl$$

$$ss_{mn} = \alpha(\sin\theta_m \sin\theta_n)^\gamma$$

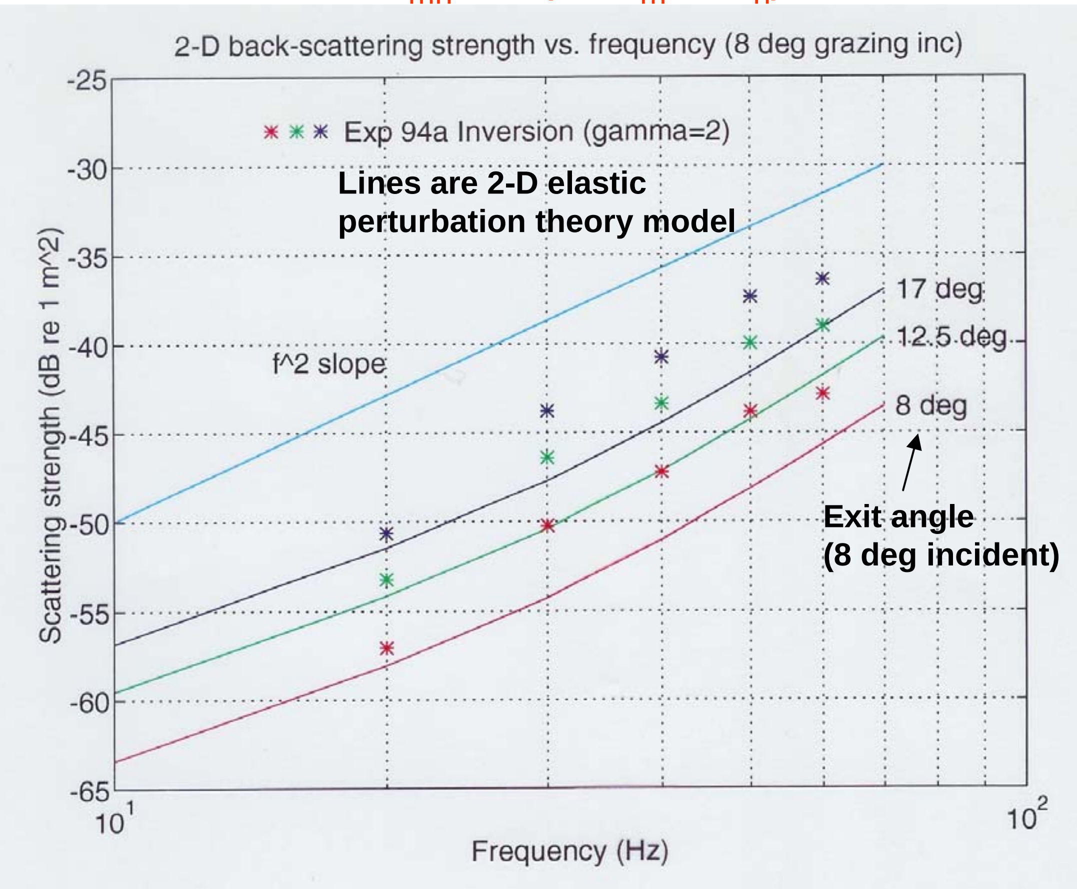
Unknowns: nl, α, γ

Group	Grazing Angle at Surface (degrees)	Normal Modes Included	Group Speed (m/s)	Turning Depth (m)
1 = Surface Duct	8.4 +/- 2	1-2	1442	210 +/- 100
2 = Mid Depth	12.5 +/- 1.3	3-17	1457 +/- 1.5	1527 +/- 506
3 = deep RSR	17.5 +/- 0.63	20-40	1465 +/- 1.4	3937 +/- 327

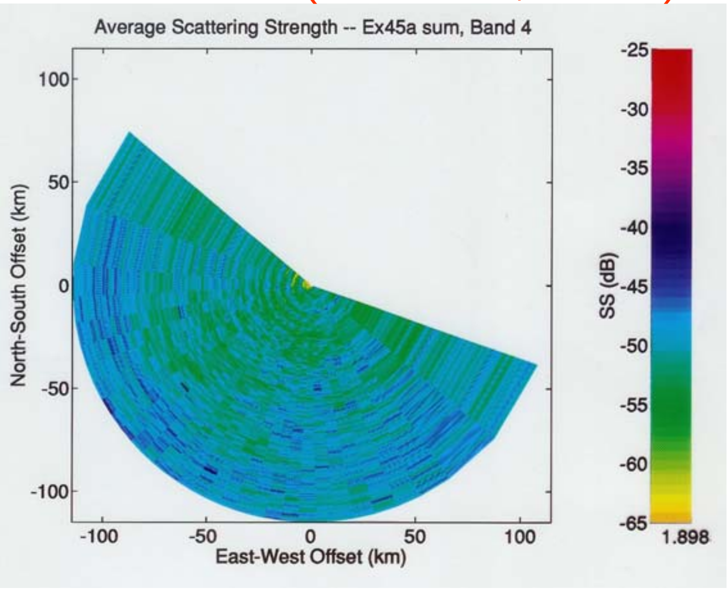


Backscatter Strength Results

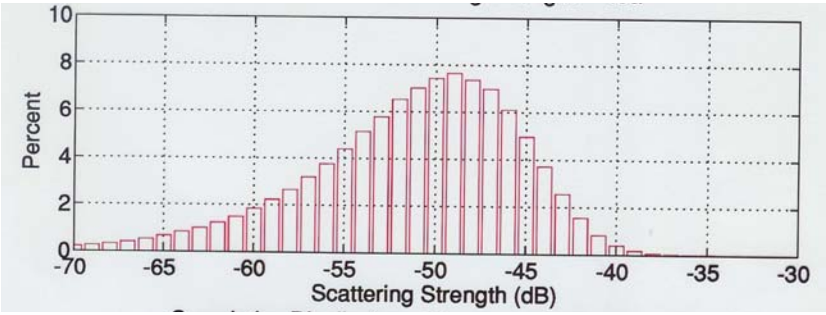
$ss_{mn} = \alpha(\sin\theta_m \sin\theta_n)^{\gamma}$



Reverb Rose (tuned LFA, 1s ave)



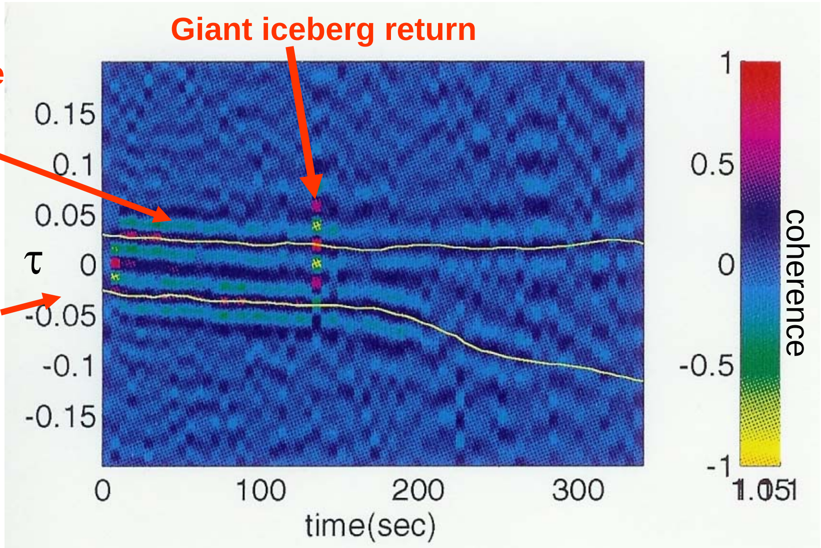
SS distribution (tuned LFA, 0.1s res)

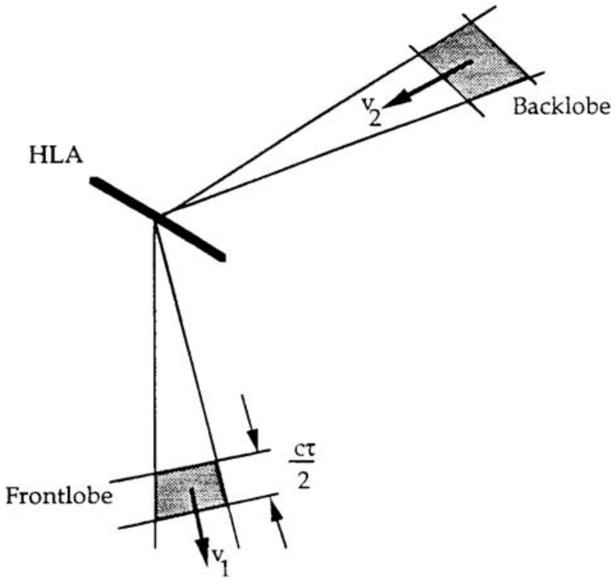


- Inversion Results and 2-D elastic perturbation theory in reasonable (3 dB) agreement

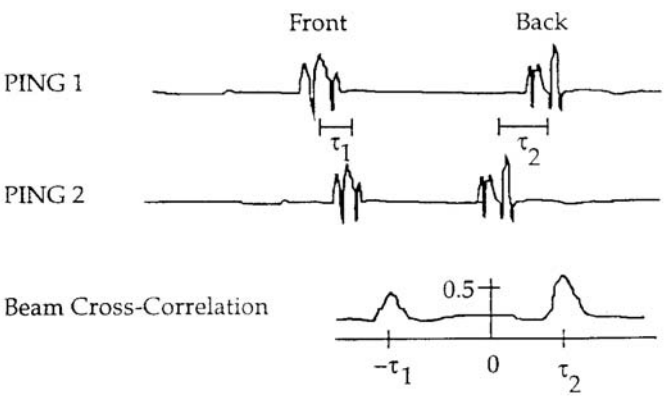
Fun with acoustics: Ice Floe Tracking

- Goal
  - Examine the stability of ping-to-ping clutter returns
  - Determine potential for coherent clutter subtraction
- Method
  - Track Individual Scattering Patches using ping-to-ping / beam-to-beam coherence
- Results
  - Can measure the deformation of the ice sheet for a radius of 150-200 km





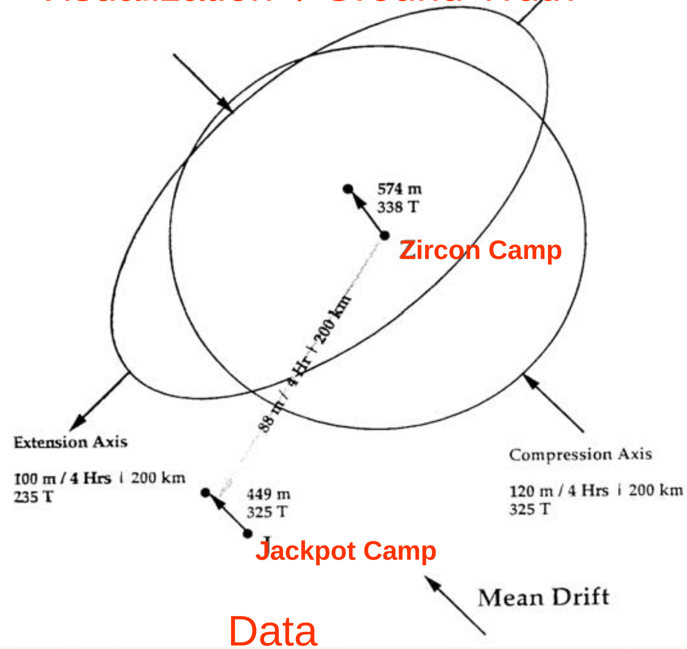
- Return from each patch will shift in time between pings due to differential ice motion
- One ping serves as "matched filter" for the other



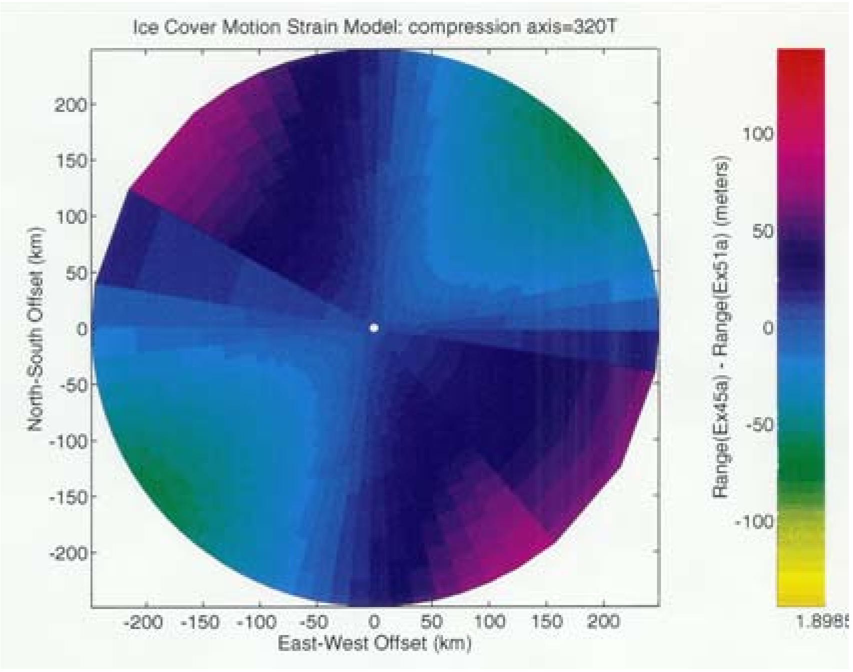
Ice Floe Tracking

- Floes can be tracked
- 4 hour strain shown
- Coherence threshold at 0.15 / 250 DOF

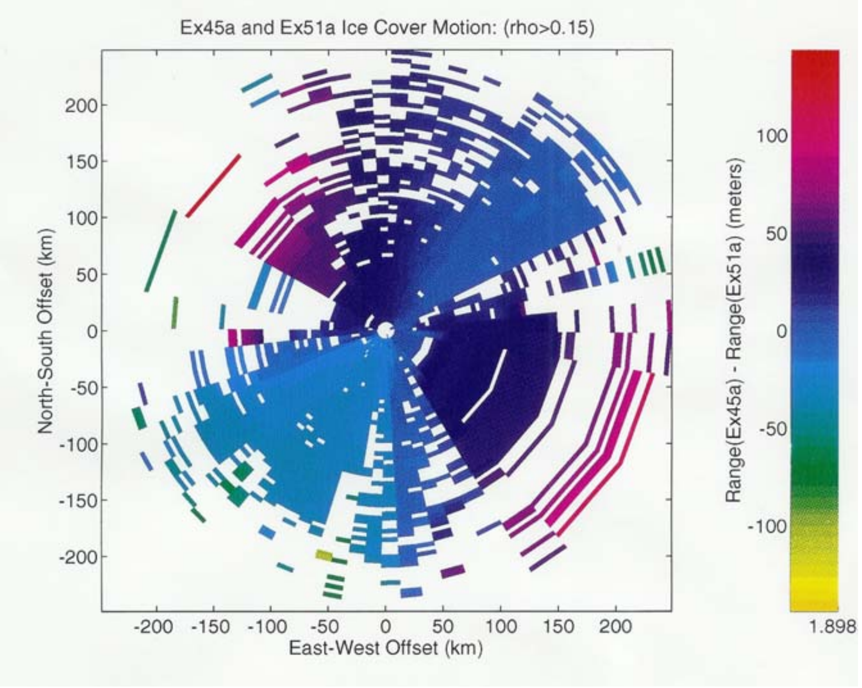
Visualization / Ground Truth



Uniform strain rate model
Exx = -.00015 /h Eyy = 0.00013 /h
(-30m/h @ 200km +25m/h @ 200km)



Data



Conclusions

- Acoustics is a fundamental tool for Arctic Geophysics and Ice Science

- Sheds light (sound!) on all areas
  - Ice properties and kinematics
  - Oceanography
  - Crustal structure and seismicity

- MIT contributed greatly to this work
  - Techniques
  - Results

- I am eternally grateful that I was in the right place at the right time
  - I apologize for much great work not represented today, and for the cursory and simplistic presentations of much of what was represented!