Acoustic Thermometry in the Arctic Ocean

…following Ira to the Arctic

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OUTLINE

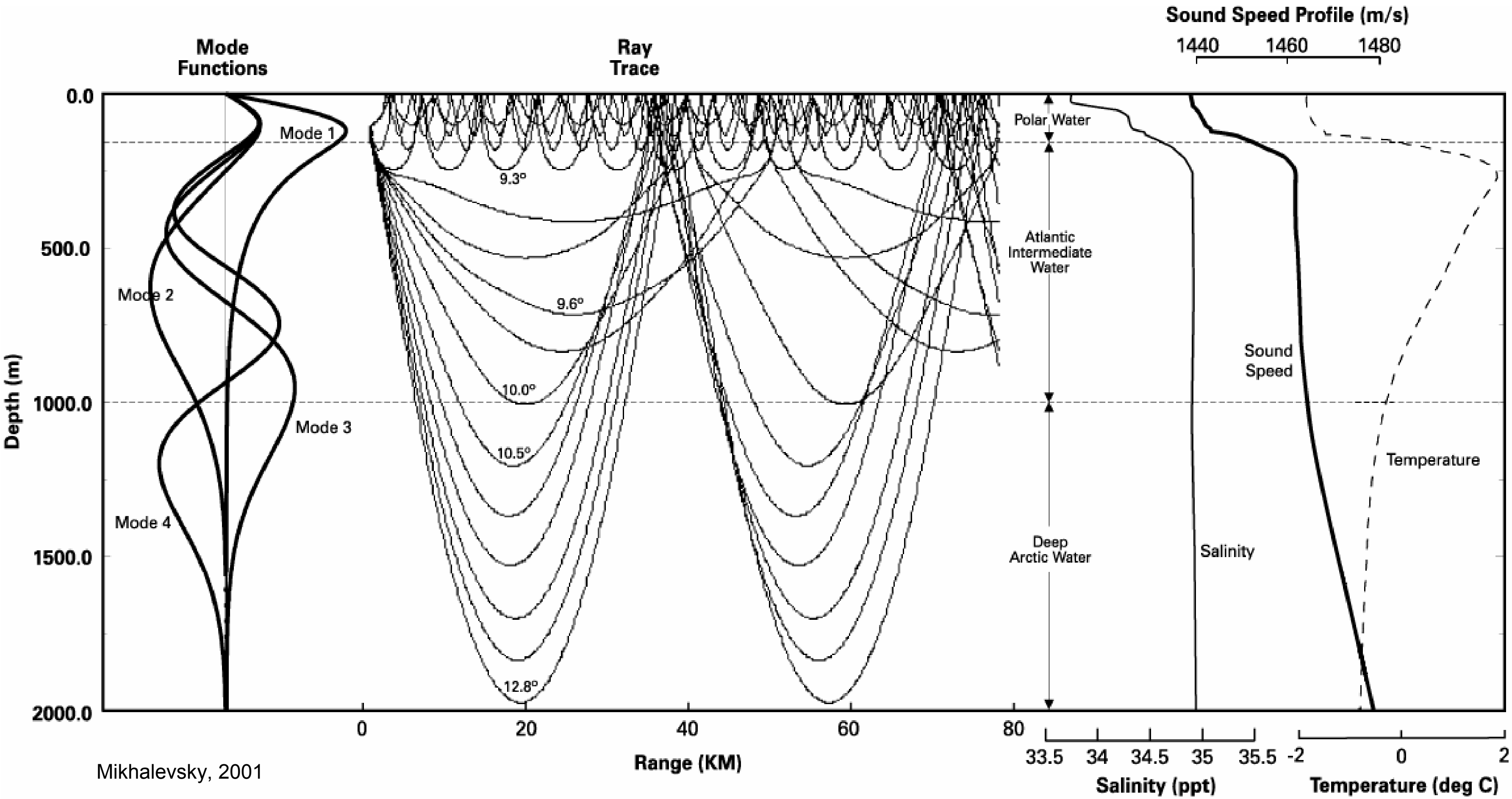
- Acoustic thermometry and the Arctic Ocean – a little background
- ACOUS (Arctic Climate Observations using Underwater Sound)
  - The Trans-Arctic Acoustic Propagation (TAP) Experiment 1994
  - Continuous acoustic section from Oct.1998 through Dec. 1999
  - Measurements at Ice Camp APLIS during SCICEX 1999
- SCICEX Cruises from 1995-2000
  - Repeated Trans-Arctic CTD section shows increased warming of AIW
  - Sections used to model acoustic response
- Ocean Observatories and Long term observations in the Arctic Ocean - update

Acoustic Thermometry

Speed of sound dependent on water temperature

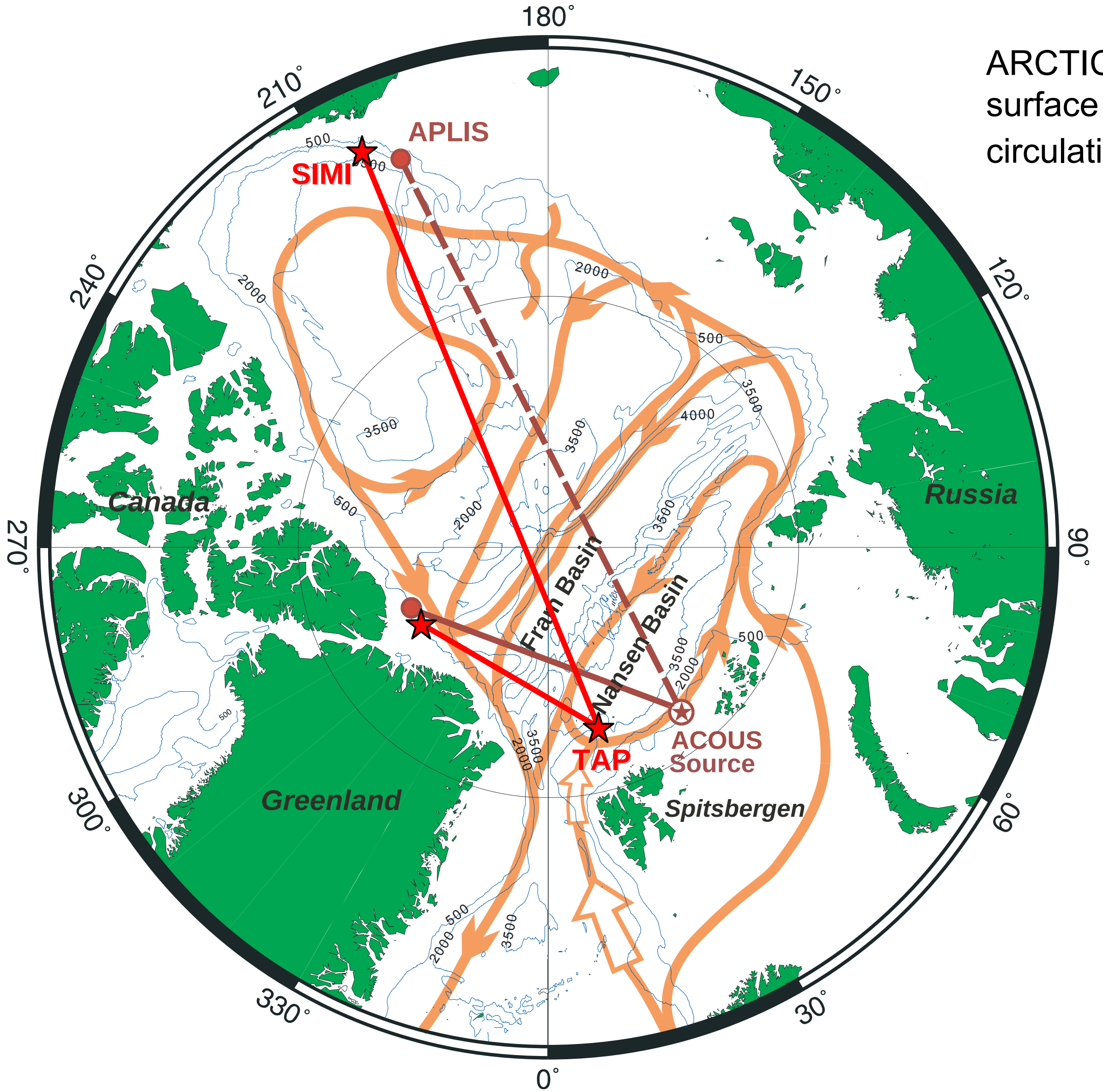
- **Acoustic Thermometry**
  - Average temperature along a propagation path derived from travel time changes between the source and receiver
  - Reciprocal transmissions can resolve average net current along the path
  - Arctic Ocean uniquely suited for acoustic thermometry due to good coupling of acoustic modes and major Arctic water masses

ACOUSTIC THERMOMETRY in the ARCTIC OCEAN



MAJOR ARCTIC OCEAN WATER MASSES ARE WELL SAMPLED BY ACOUSTIC MODES/RAYS (Modes shown for 20 Hz)

ATLANTIC INTERMEDIATE WATER (AIW) CIRCULATION in the ARCTIC OCEAN and Acoustic Thermometry Sections



ARCTIC OCEAN influences Earth's surface heat balance and the thermohaline circulation of the world's oceans

Significant change in the Arctic Ocean in the last 20 years:

- Temperature increase in AIW
- ~40% loss in sea ice mass

Forecasts of ice-free summer in this century

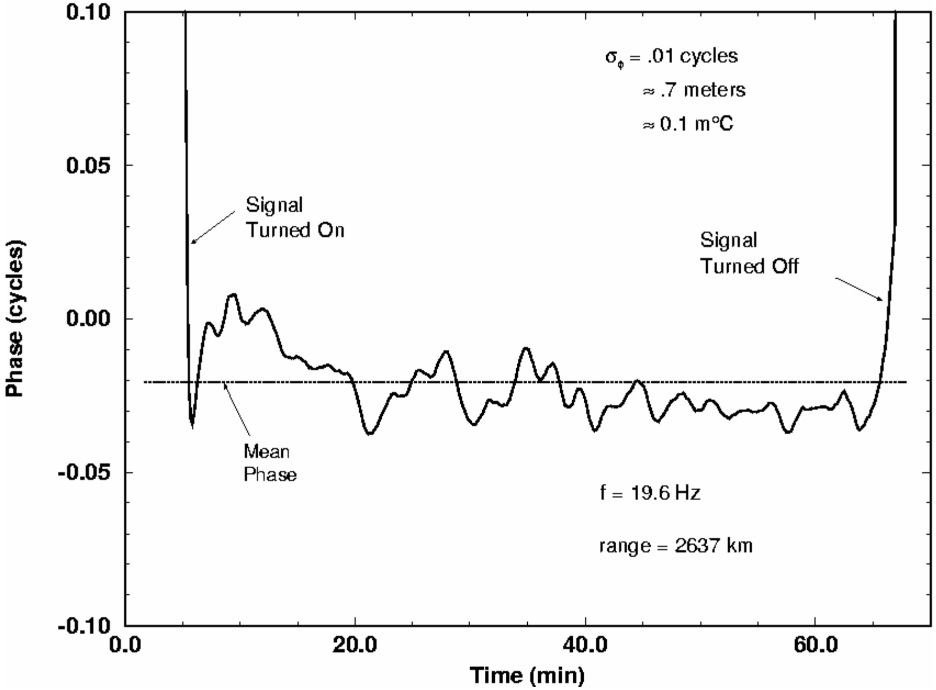
TAP Acoustic Section: Ice deployed source to the Lincoln Sea ice camp and the ONR Sea Ice Mechanics Initiative (SIMI) ice camp in the Beaufort Sea April, 1994 – A feasibility test

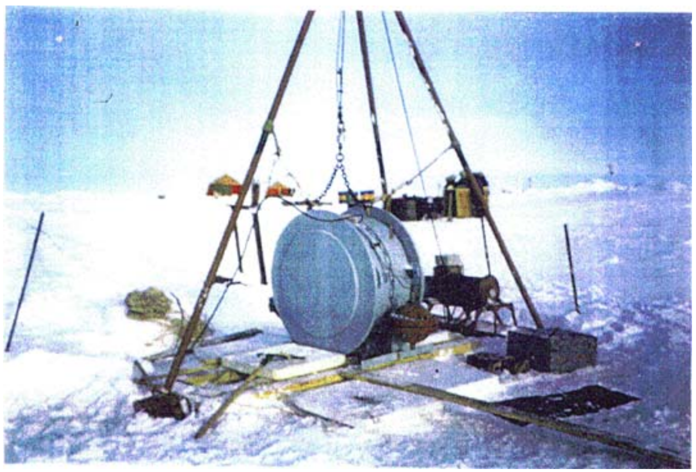
ACOUS Acoustic Section: Moored source to the APLIS ice camp in the Chukchi Sea April, 1999 and to bottom moored vertical array in the Lincoln Sea Oct. 1998 to Dec. 1999

Arctic Climate Observations using Underwater Sound (ACOUS)

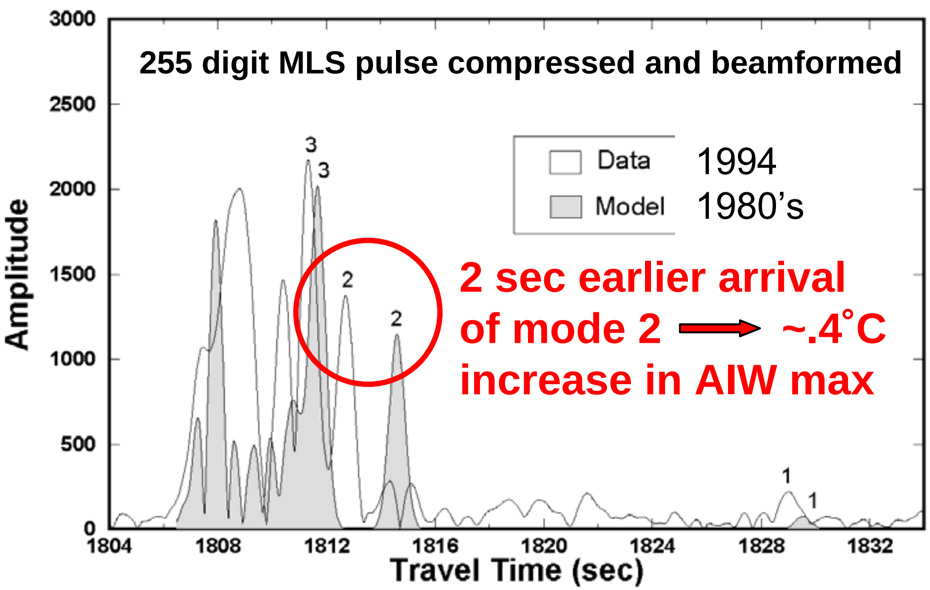
- US/Russia bilateral program started in 1992
- Use acoustic thermometry to measure Arctic Ocean temperature and derive heat content
- TAP Feasibility exp. in 1994 showed strong coupling between travel times and AIW temp., observed basin scale AIW warming (~.4 °C avg. max)
- Source installed in Oct. 1998 with transmissions every 4 days to receive array in Lincoln Sea
- Reception of source signals at APLIS ice camp in April 1999 showed continued warming in AIW consistent with SCICEX CTD’s (~.5°C avg. max)

TAP Experiment CW and MLS Transmissions





RUSSIAN SOURCE 19.6 Hz,195 dB



CW signals show the exceptional stability of the Arctic acoustic channel and Rician statistics first observed in 1980 (but not at trans-basin range!)

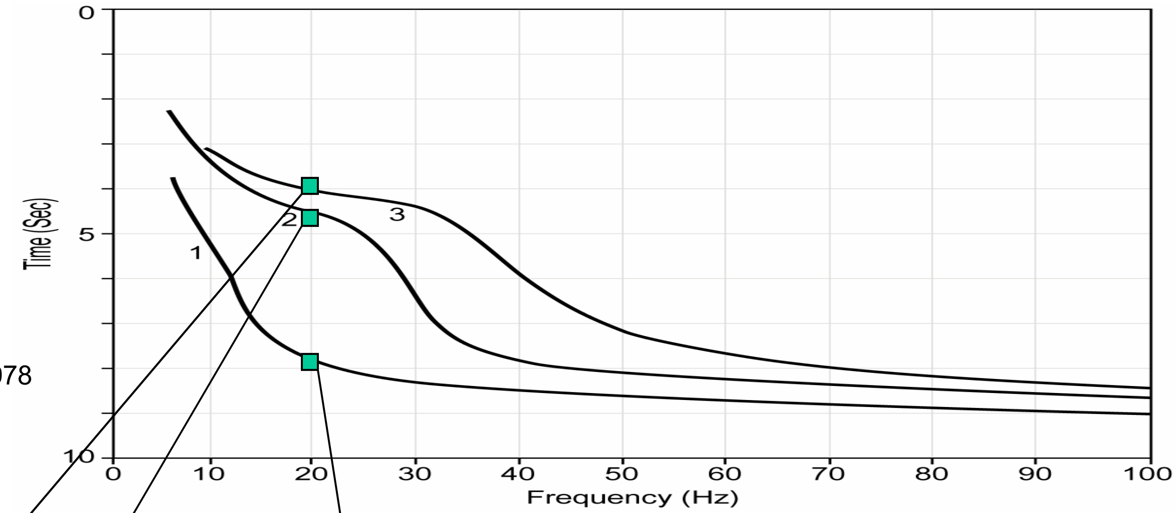
Maximal Length Sequences pulse compressed and coherently averaged achieved theoretical compression gains

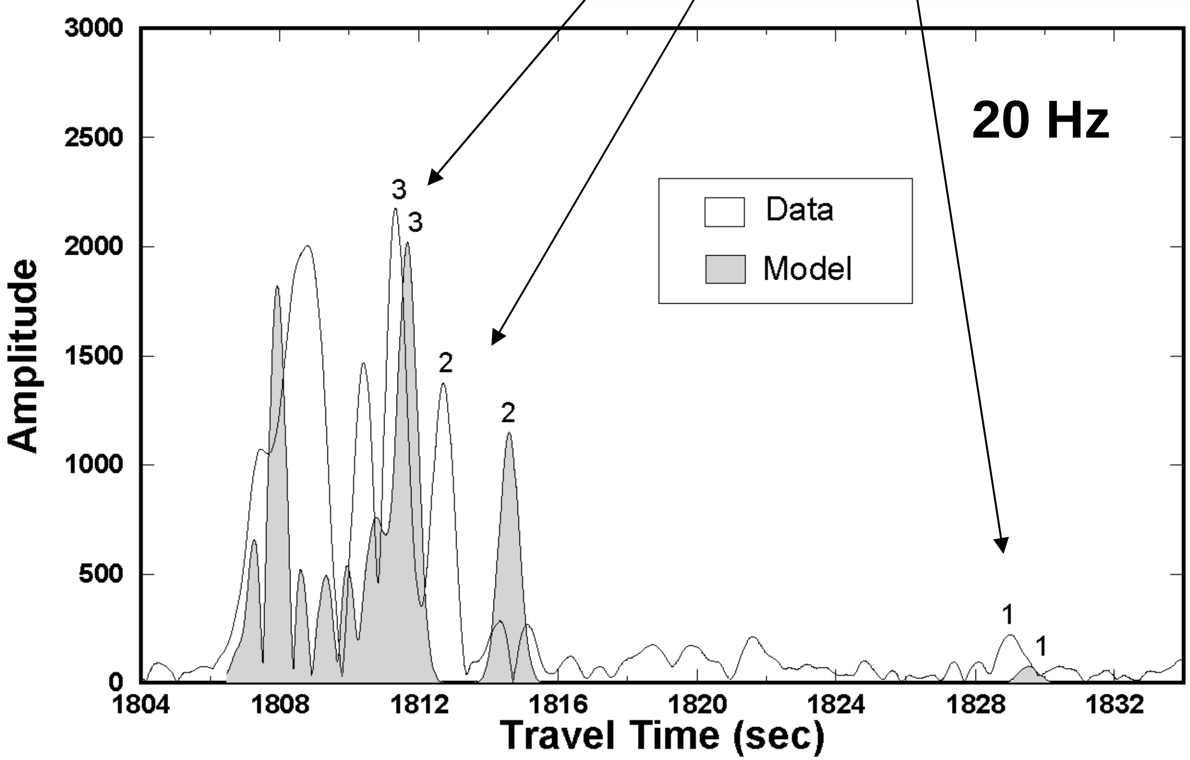
Time measurement resolution of ~22msec by peak picking and ~0.5msec by phase in agreement with theory

Mikhalevsky, 1981
Mikhalevsky, Baggeroer, Gavrilov, and Slavinsky, 1995
Mikhalevsky, Gavrilov, and Baggeroer, 1999

MEASURED
MODAL ARRIVAL
PATTERN **1962**
BEAUFORT SEA

Dinapoli, Viccione, and Kutschale, 1978

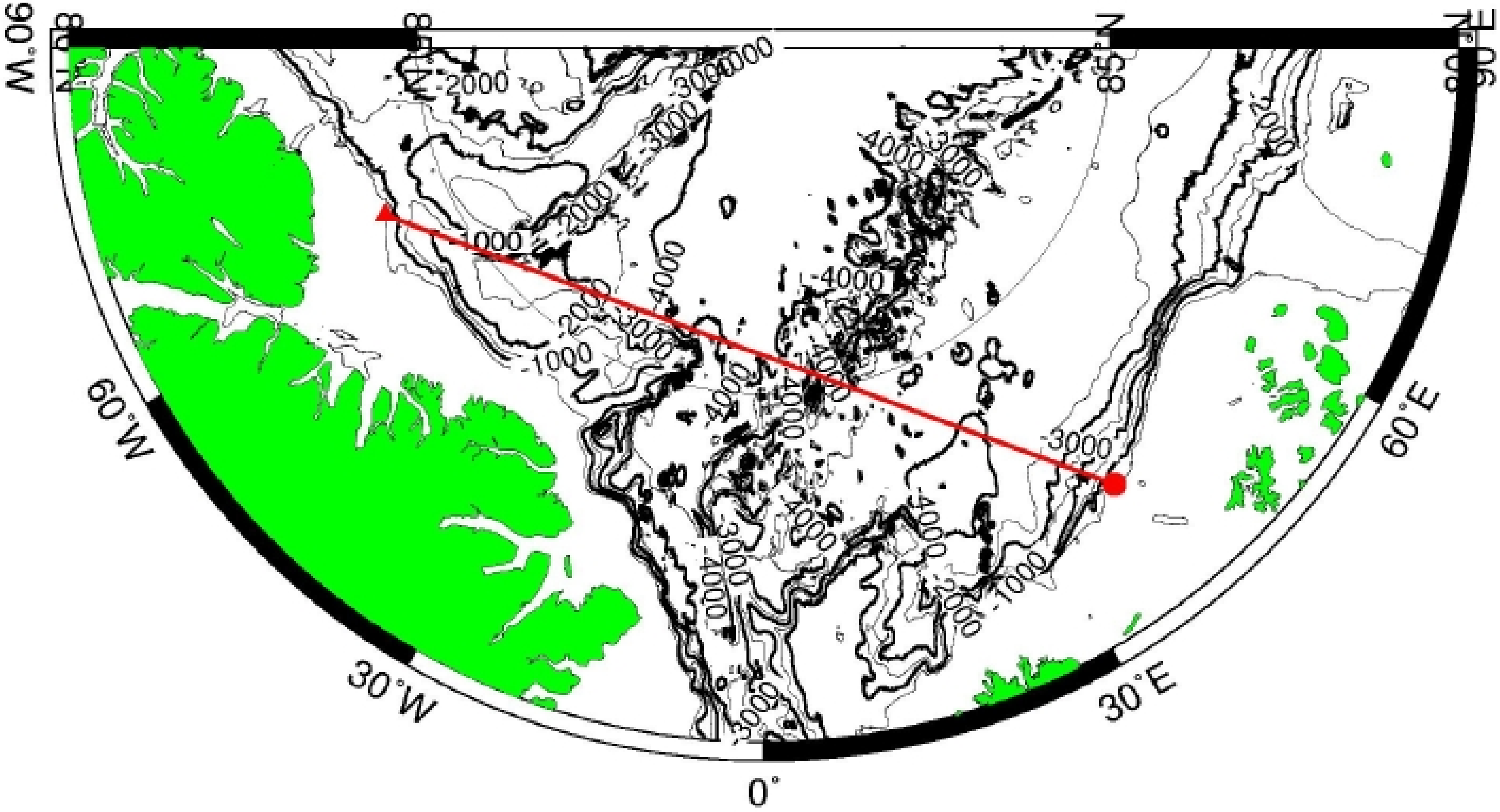




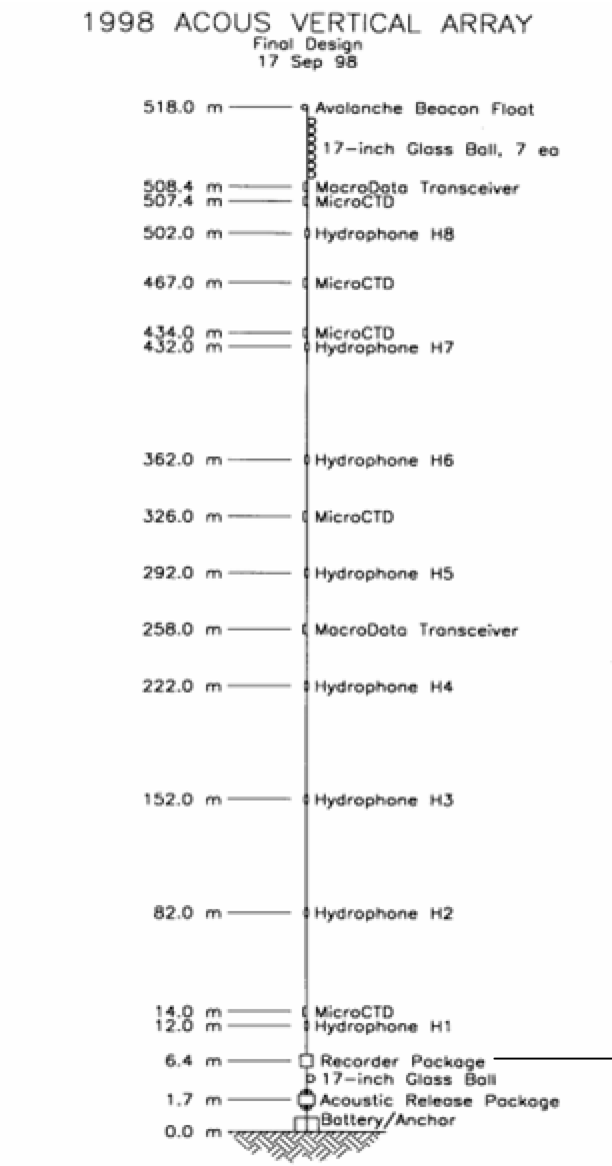
MODAL ARRIVAL
PATTERN **1994**
TRANS-ARCTIC
PROPAGATION
EXPERIMENT

Mikhalevsky, Gavrilov, and Baggeroer, 1999

ACOUS - LINCOLN SEA EXPERIMENT



ACOUS SOURCE – Franz Victoria Strait
ACOUS RECEIVE ARRAY - Lincoln Sea
Oct. 10, 1998 to Dec. 8, 1999



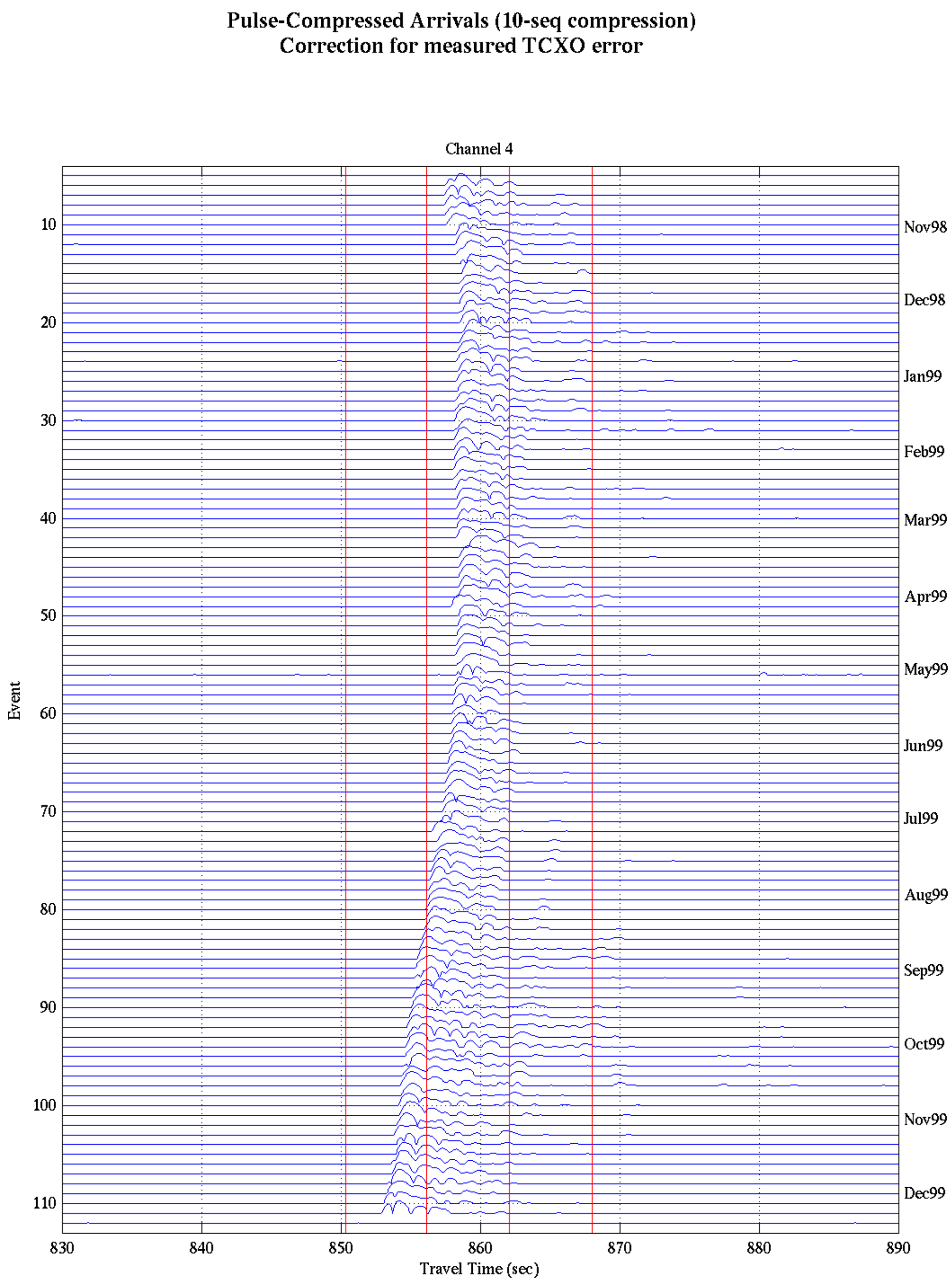
R/V Akademik Fyodorov

ACOUS SOURCE Deployed OCT. 1998

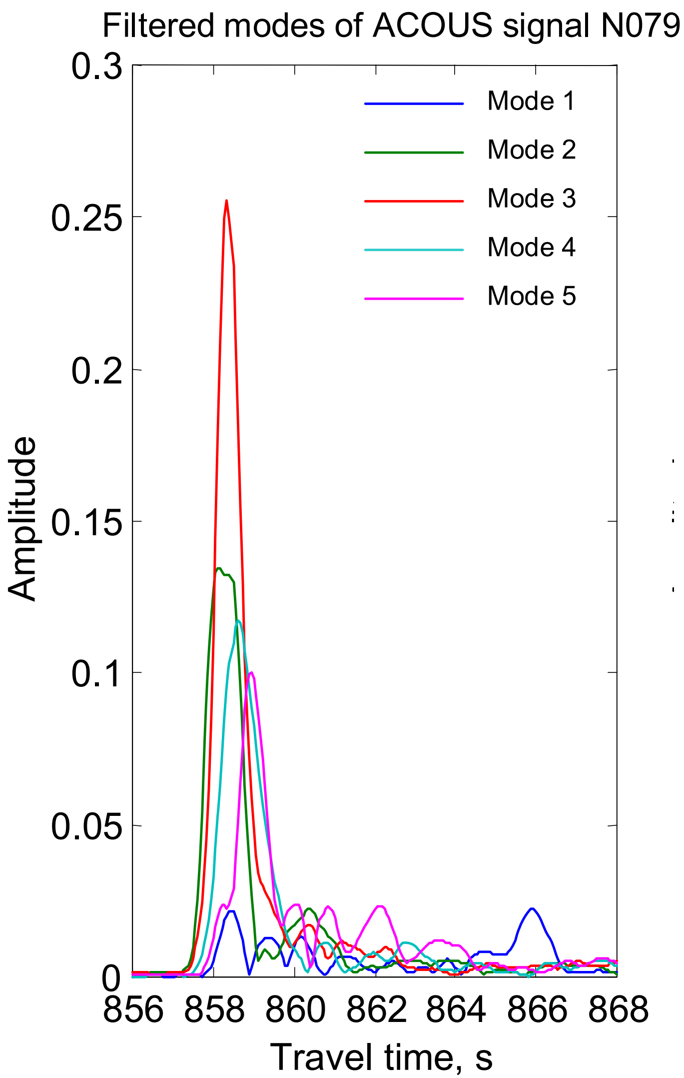
20.5 Hz center frequency
Q~8, 195 dB source level

Both source and receive array used rubidium standard for timing control

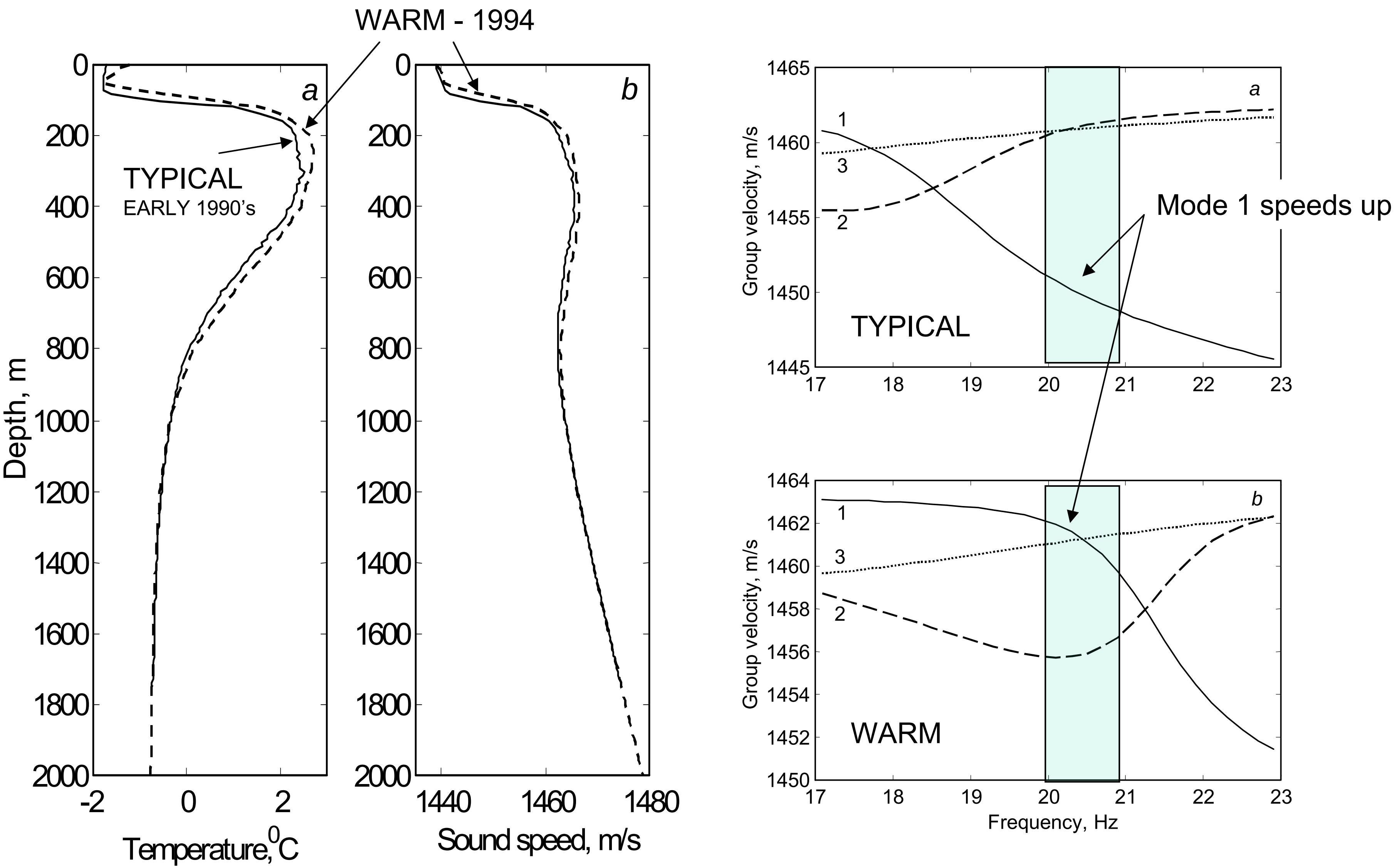
ACOUS VLA Deployed OCT. 1998 Recovered MAR. 2001



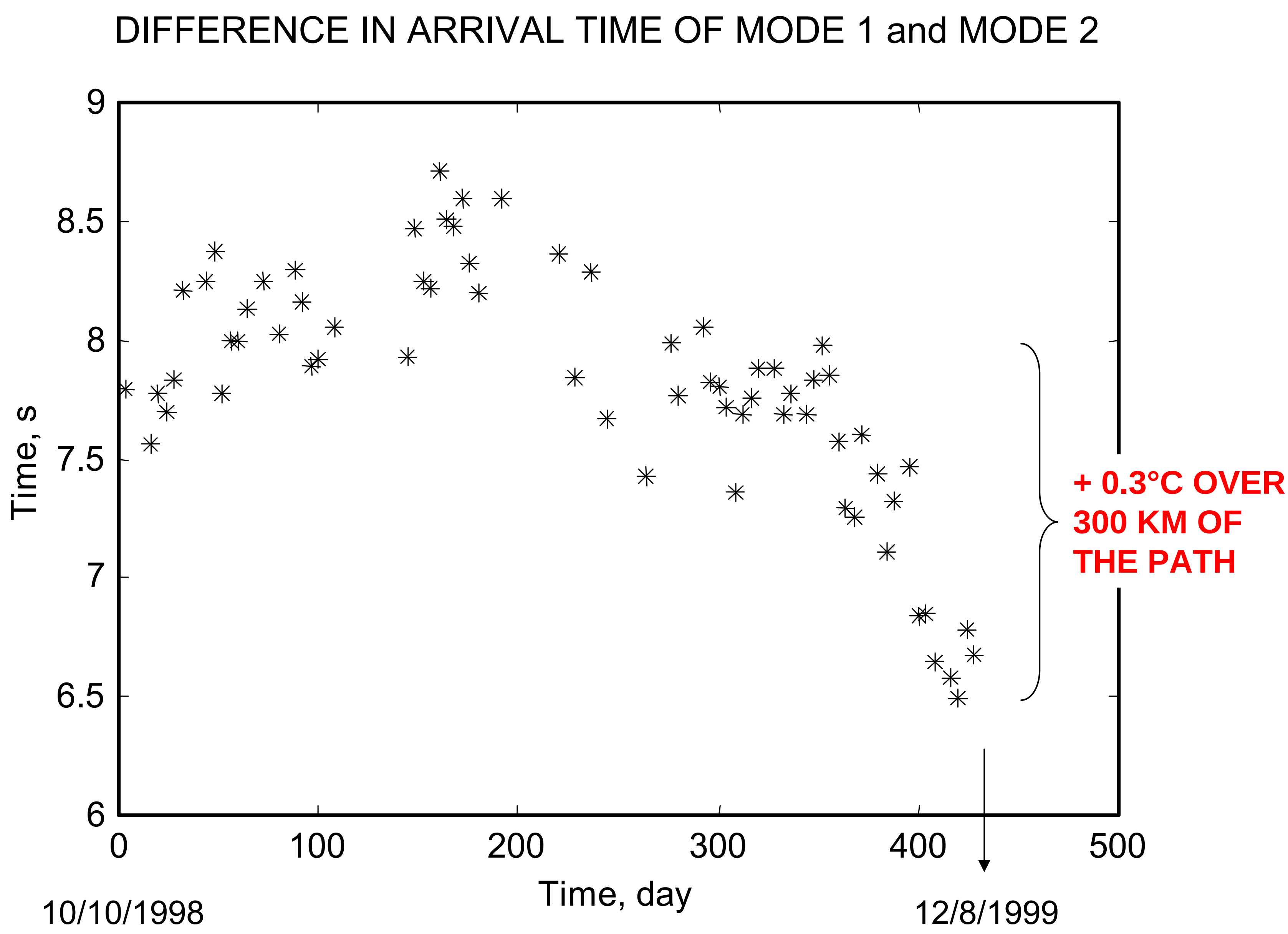
10 repetitions of 255 digit MLS sequence
20.7 min total duration every 4 days, 107 transmissions

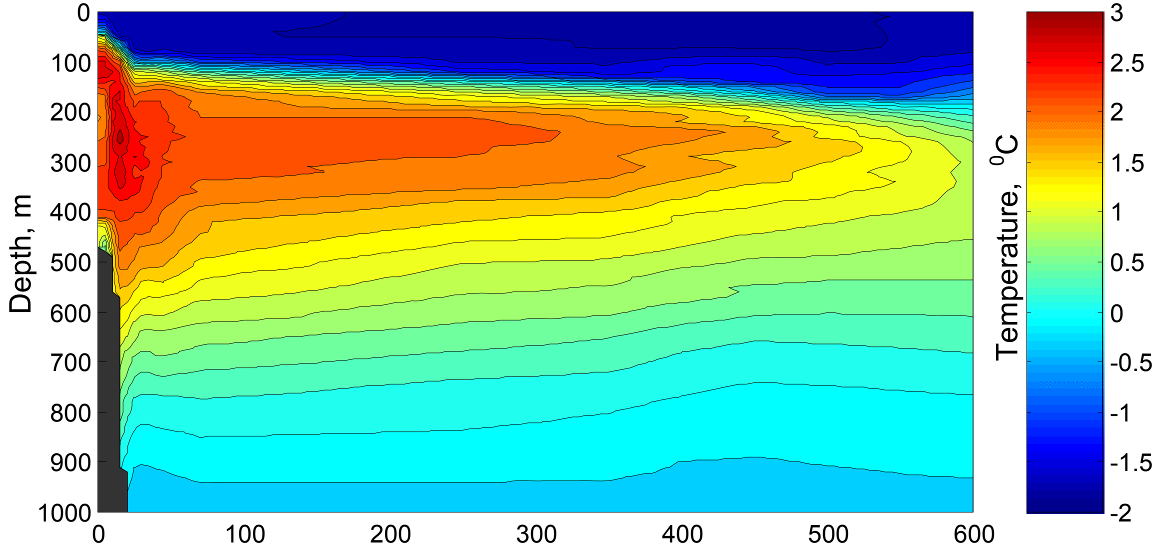


TEMPERATURE, SOUND SPEED and MODAL GROUP VELOCITIES

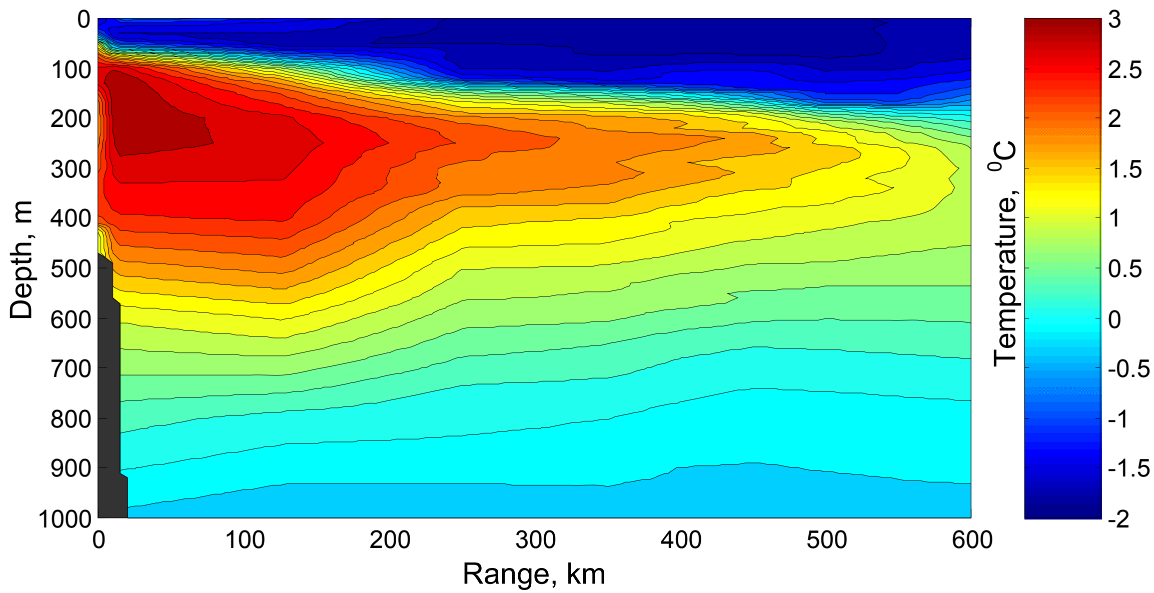


Gavrilov and Mikhalevsky, 2002


DIFFERENCE IN ARRIVAL TIME OF MODE 1 and MODE 2
9
8.5
8
7.5
7
6.5
6
Time, s
0
100
200
300
400
500
Time, day
10/10/1998
12/8/1999
+ 0.3°C OVER
300 KM OF
THE PATH

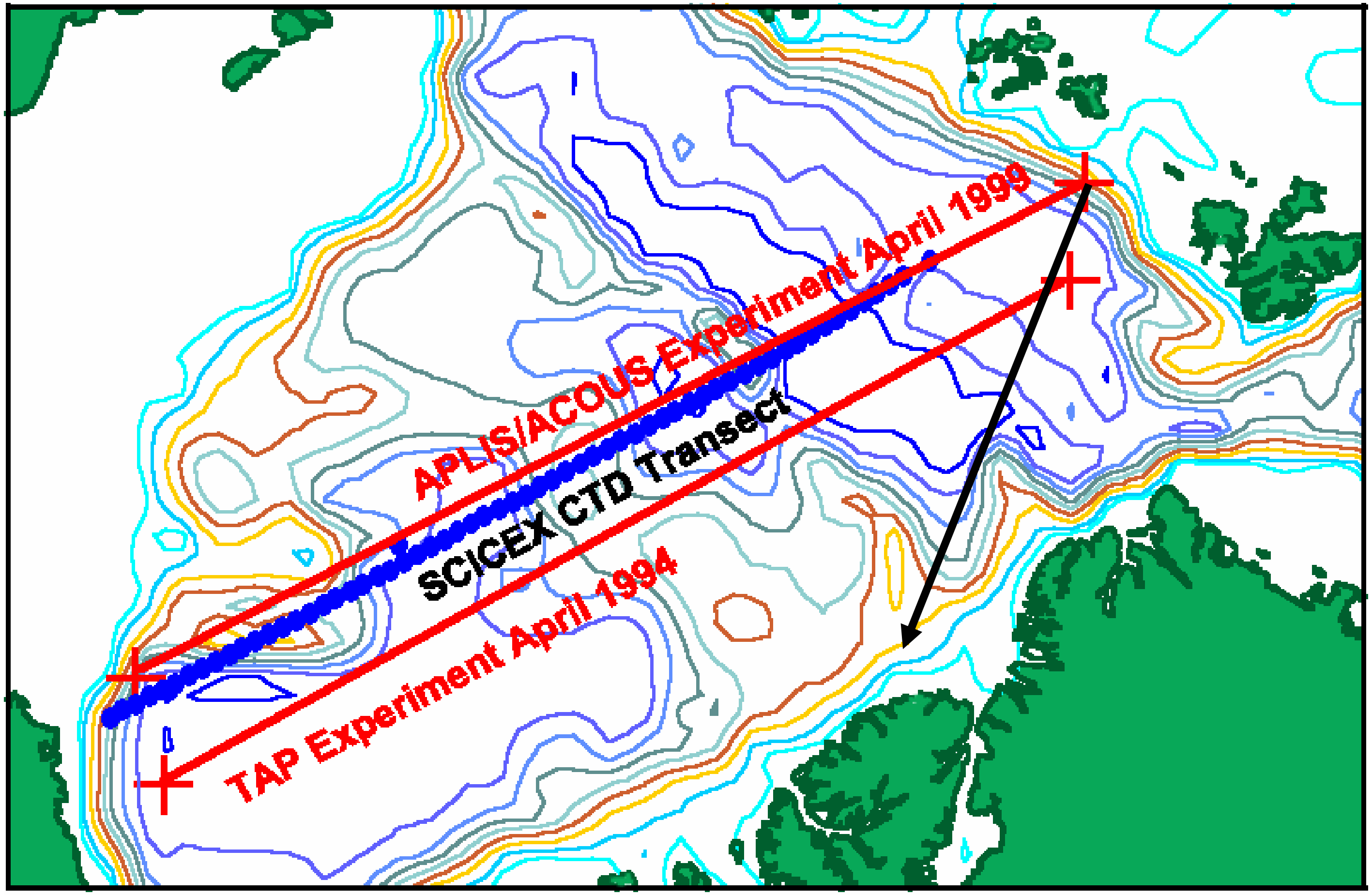


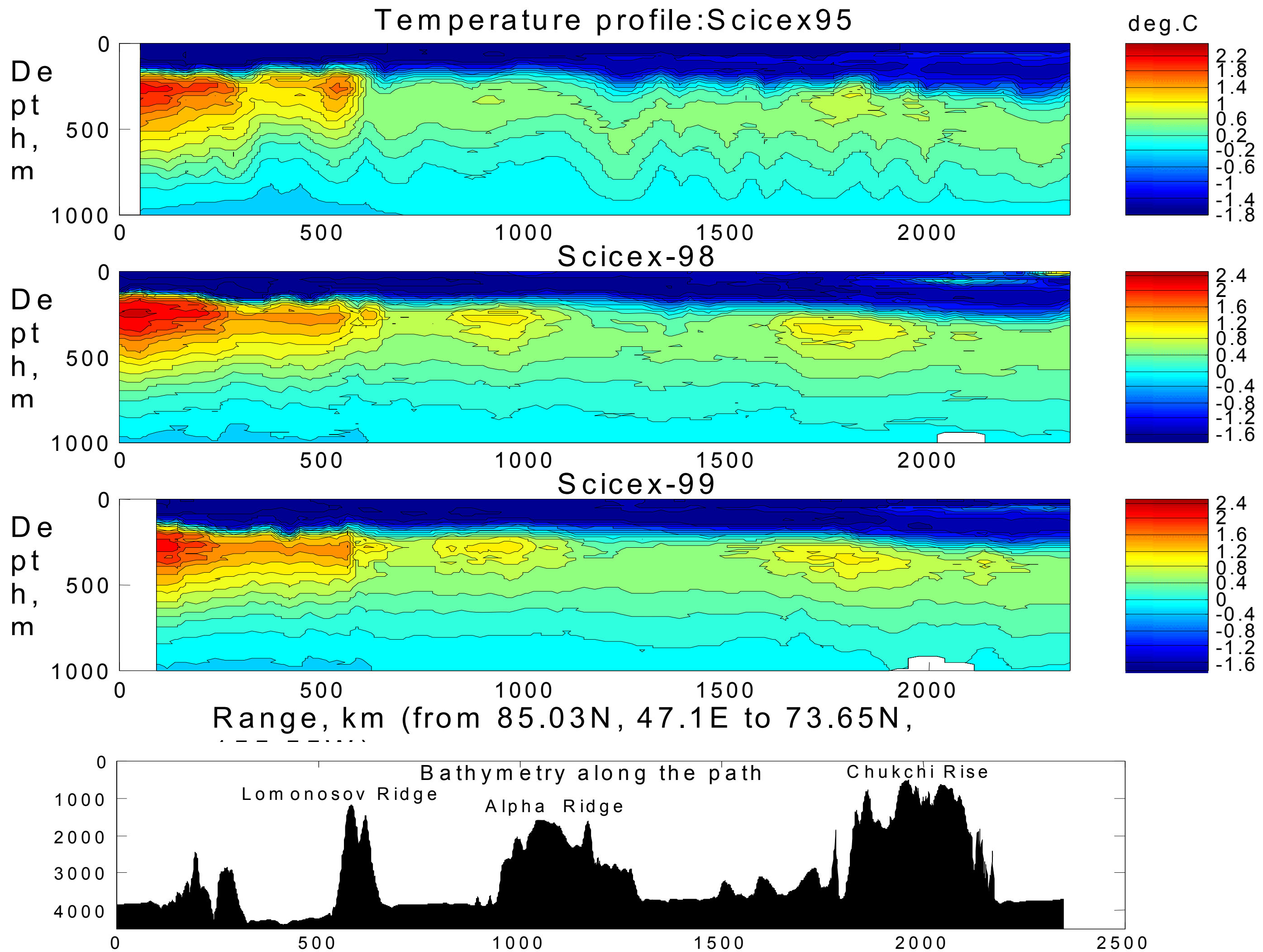
Temperature section using climatology and profiles from the early 1990’s



Temperature section using profiles from mid 1990’s perturbed to fit late 1999 “warm” part of acoustic record

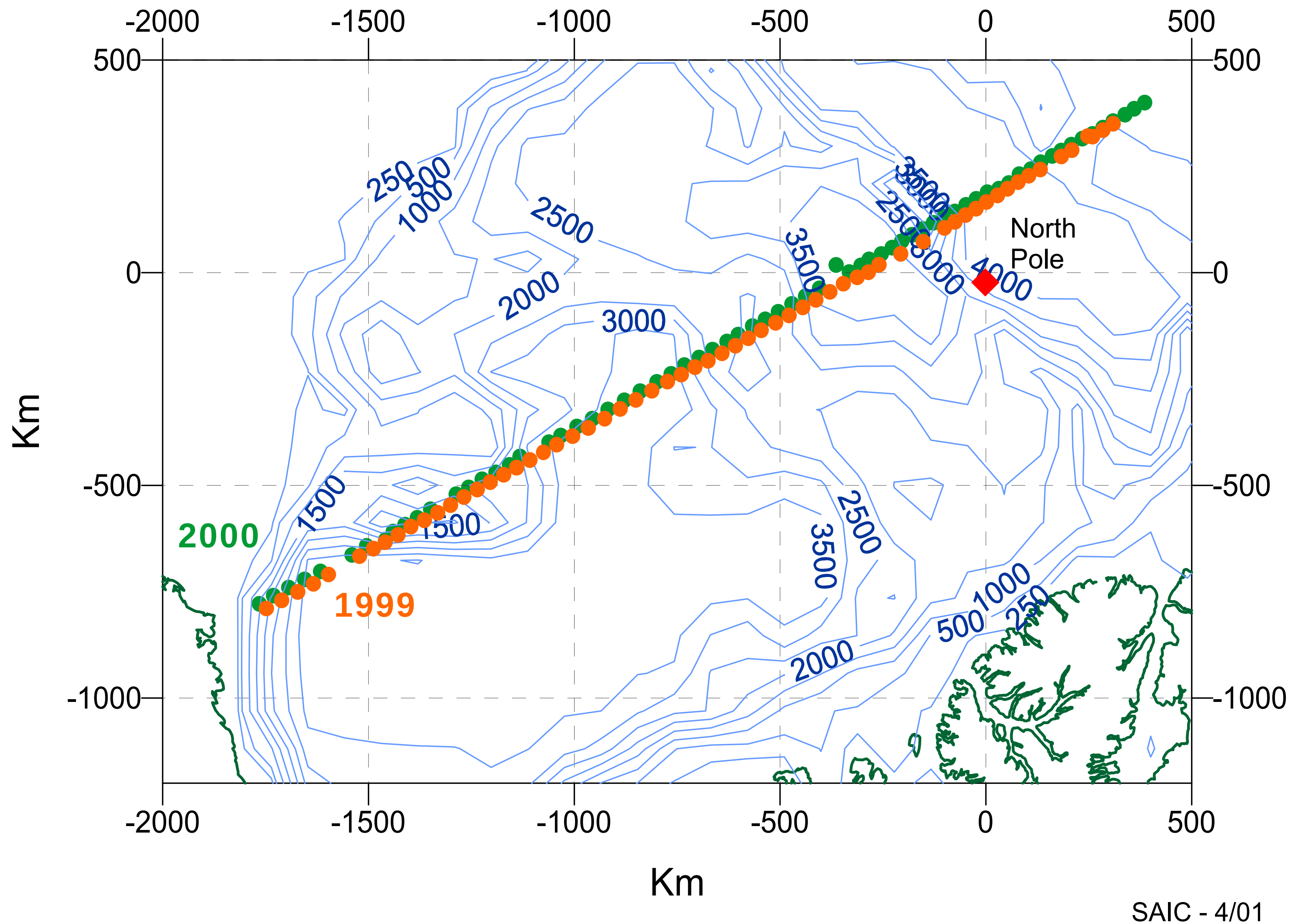
SCICEX / TAP / APLIS-ACOUS Transarctic Sections

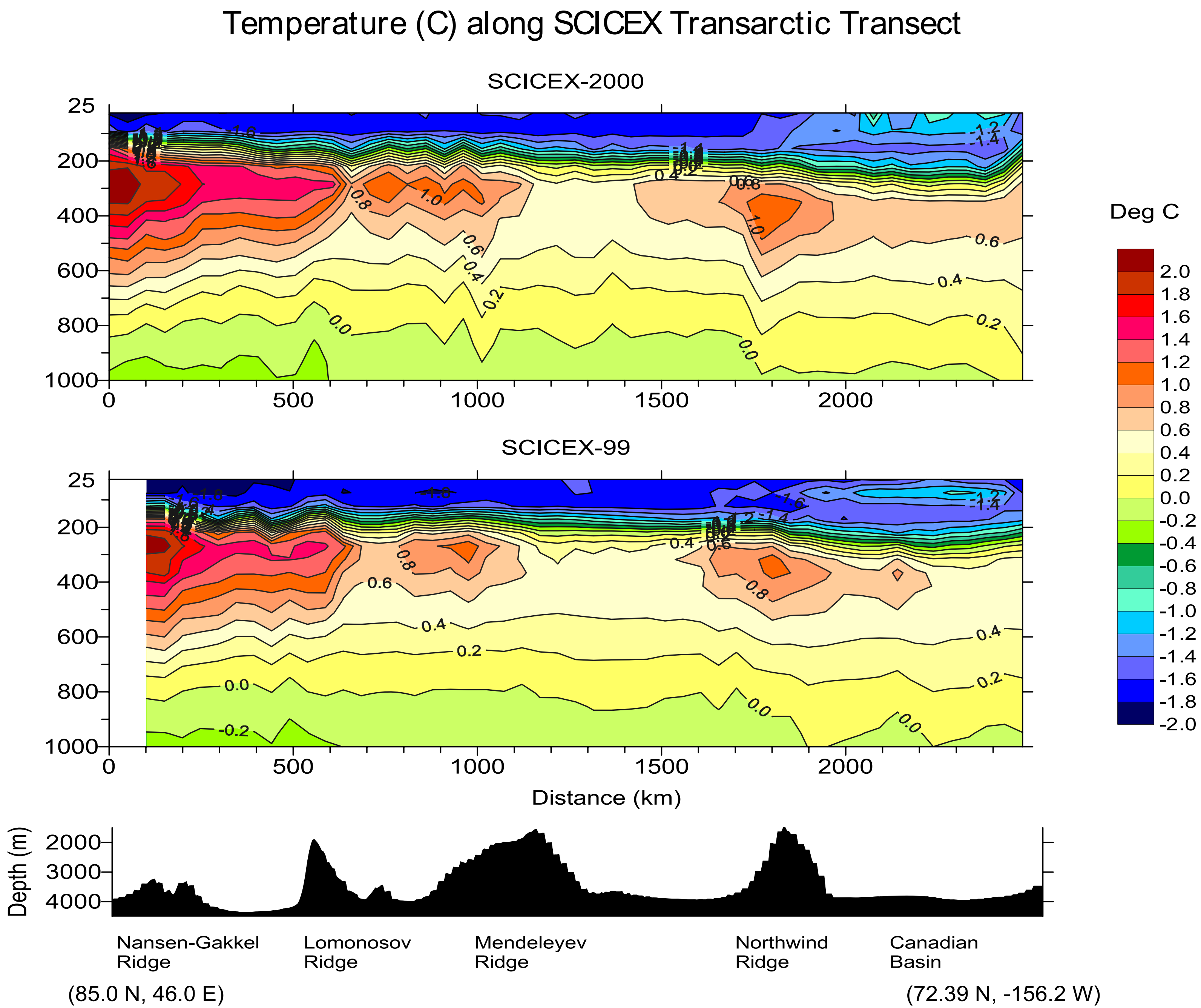




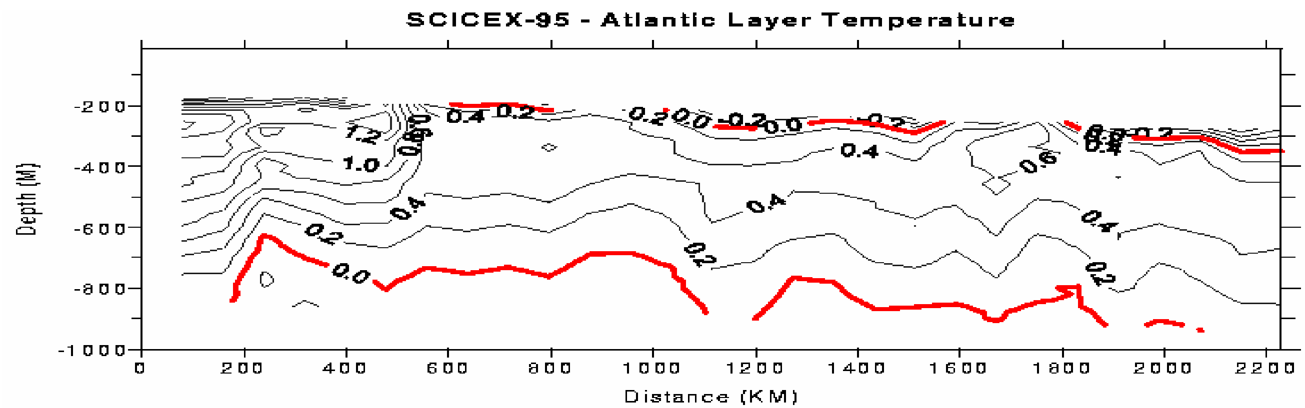
TEMPERATURE SECTIONS FROM SCICEX 1995, 1998, AND 1999 ACROSS THE ARCTIC BASIN WITH CORRESPONDING BATHYMETRY. WARMING IN THE ATLANTIC LAYER IS EVIDENT IN TOPOGRAPHICALLY GUIDED EXTENSIONS OF THE ATLANTIC WATER CIRCULATION.

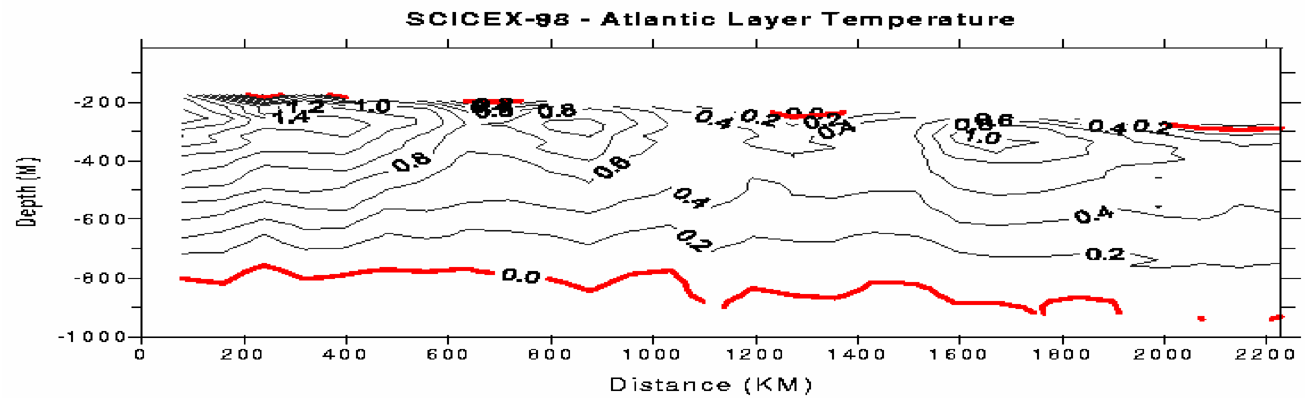
SCICEX-1999/2000 Transarctic Transect CTD Sample Locations

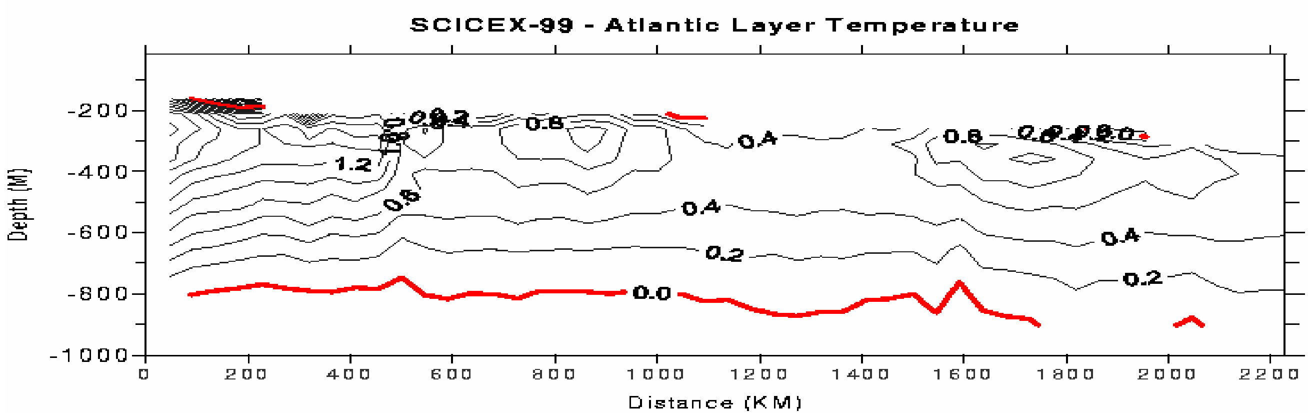




Mikhalevsky and Moustafa - SAIC - 4/01





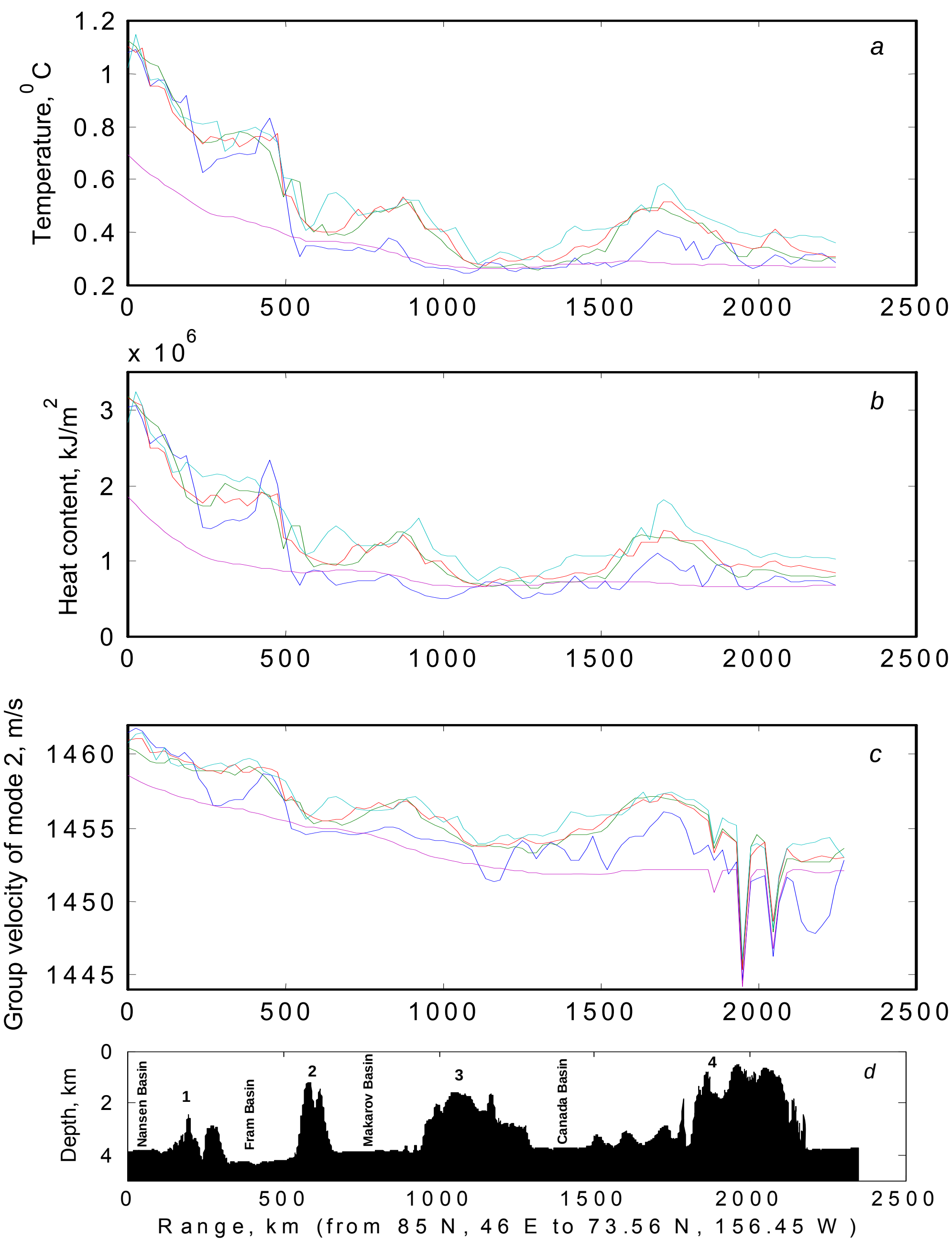


AVERAGE TEMPERATURE OVER RANGE and DEPTH BETWEEN 0°C ISOTHERMS:

1995 - .421°C

1998 - .478°C

1999 - .488°C

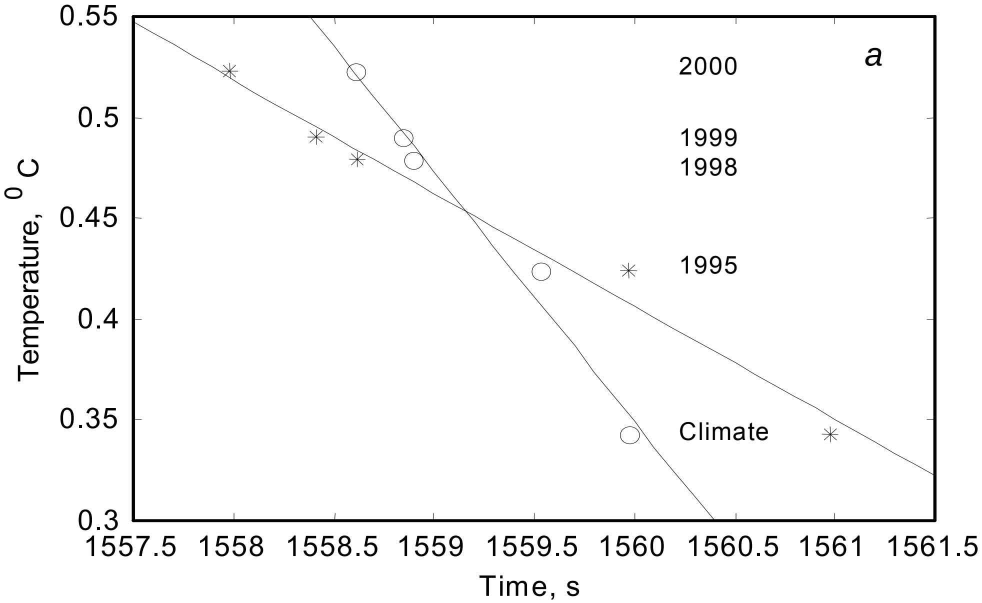


Temperature
vertical average vs range

Heat Content
vertical average vs range

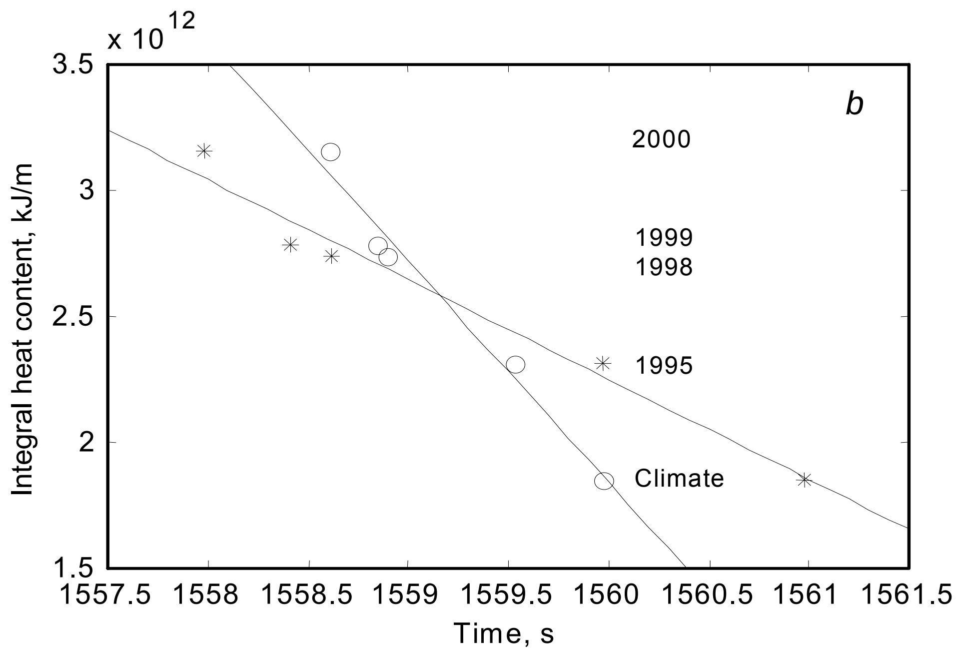
Mode 2 Group Velocity

EWG Climatology and
SCICEX 95, 98, 99, 00



Section Average Temp. vs Travel Time rms fit error ~ 9 m°C

Linear dependence on travel time of mode 2 (*) and Mode 3 (o)

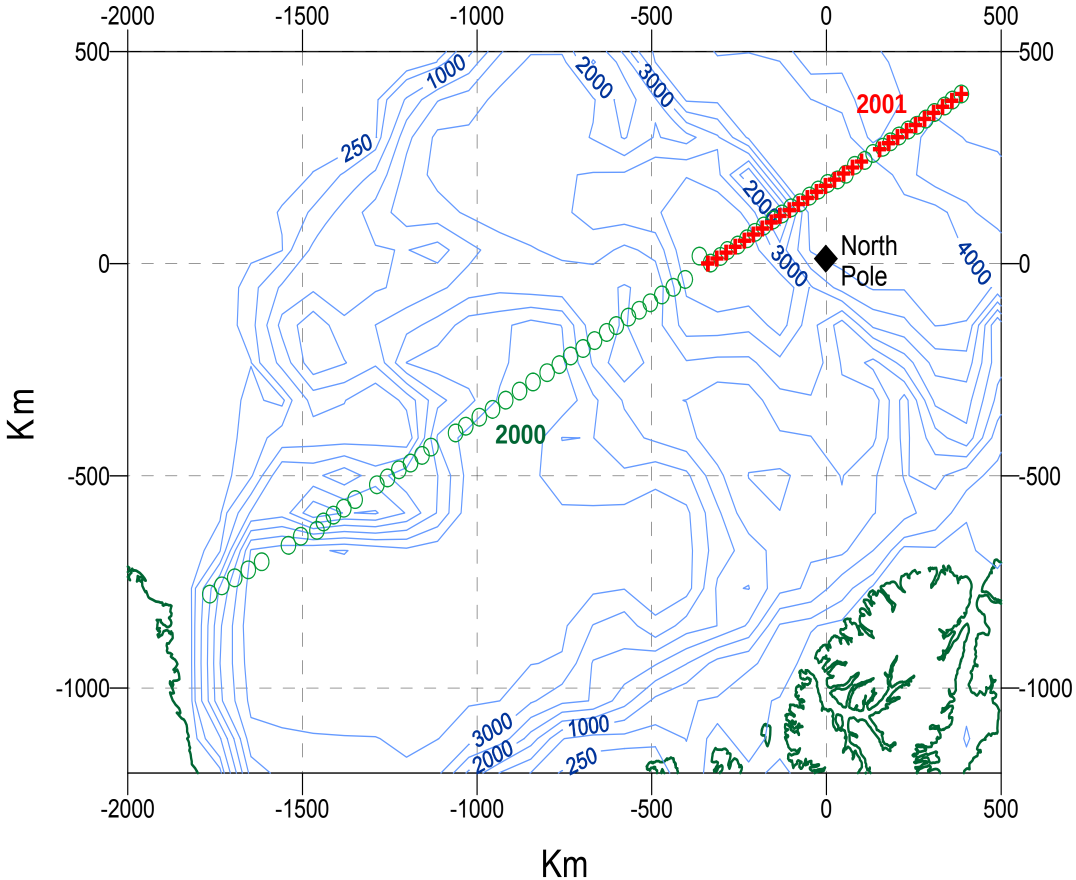


Integral Heat Content rms error ~ 7×10^{10} kJ/m

5 yr increase of ~10^{12} kJ/m over 2269 km path is 2.8 W/m^2 heat flux

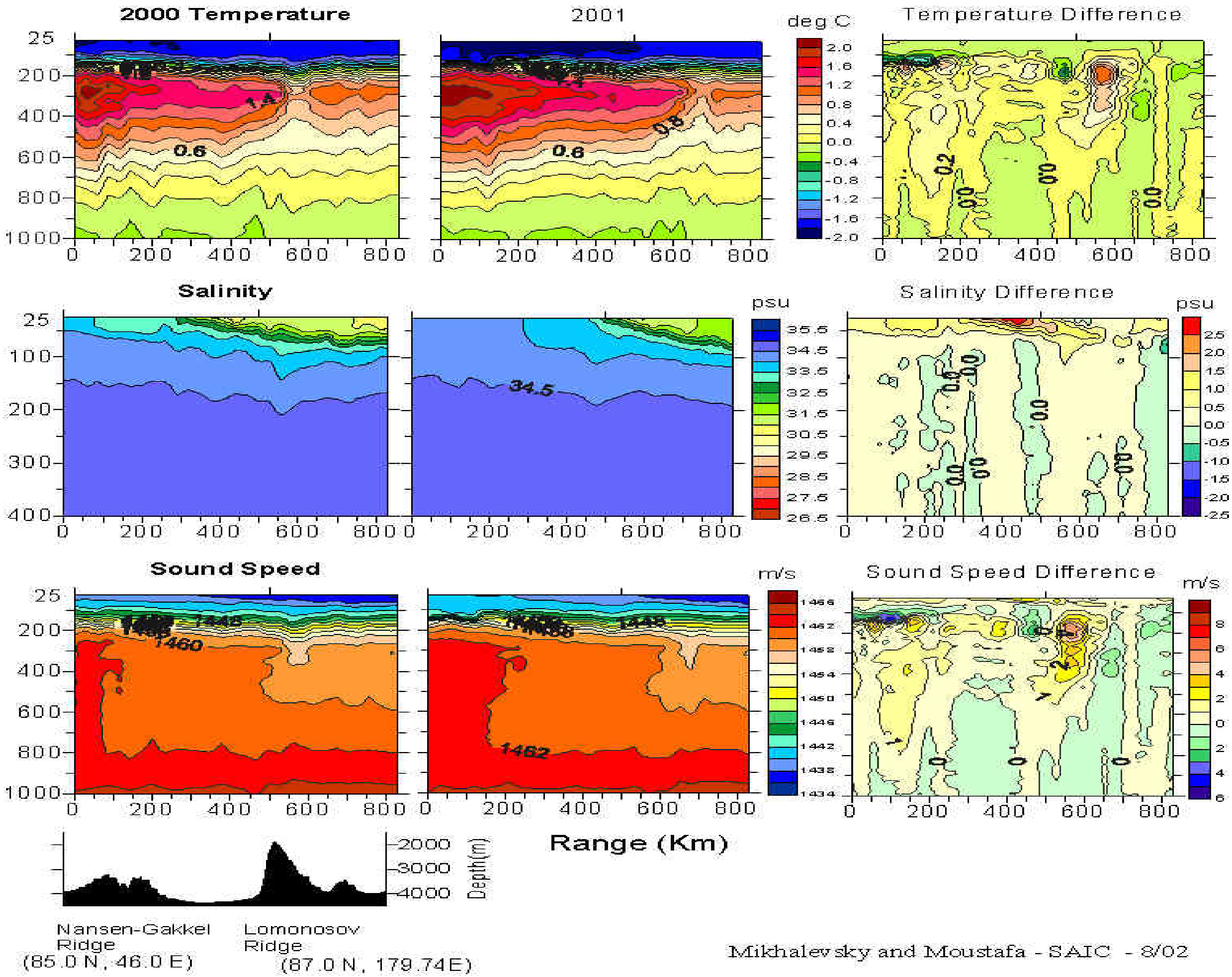
Mikhalevsky, Gavrilov, Moustafa and Sperry, 2001

SCICEX - 2000 / 2001 Transarctic Transect CTD Sample Locations

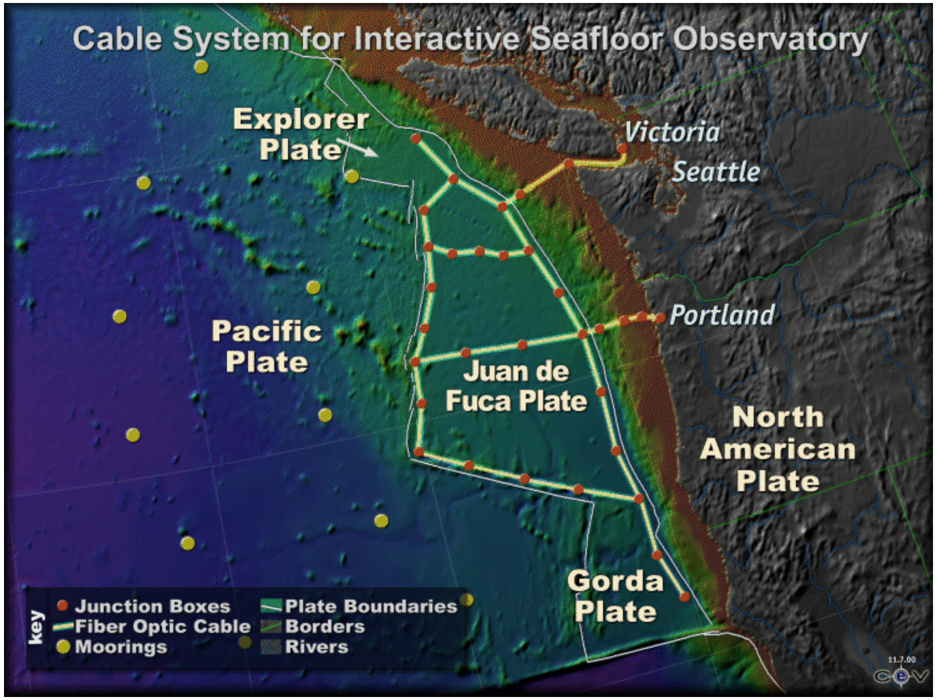


SAIC - 8/02

SCICEX 2000 and 2001 Transarctic Transects

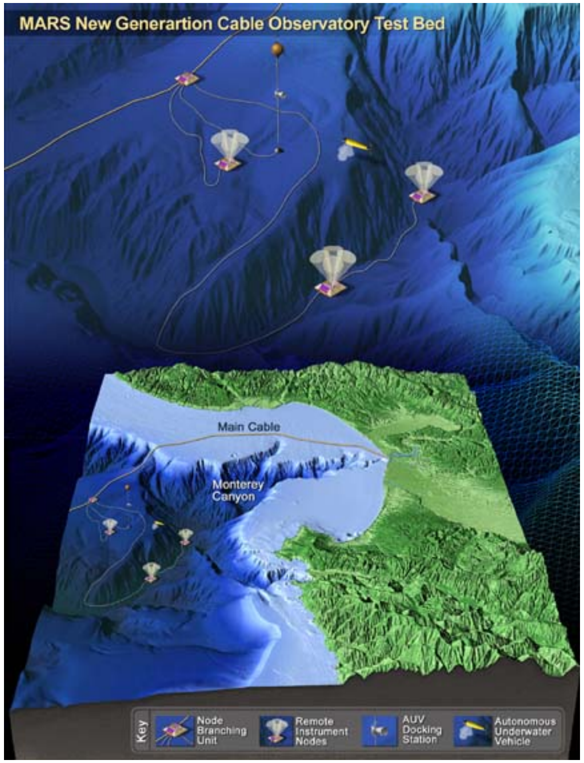


Undersea Cabled Observatories



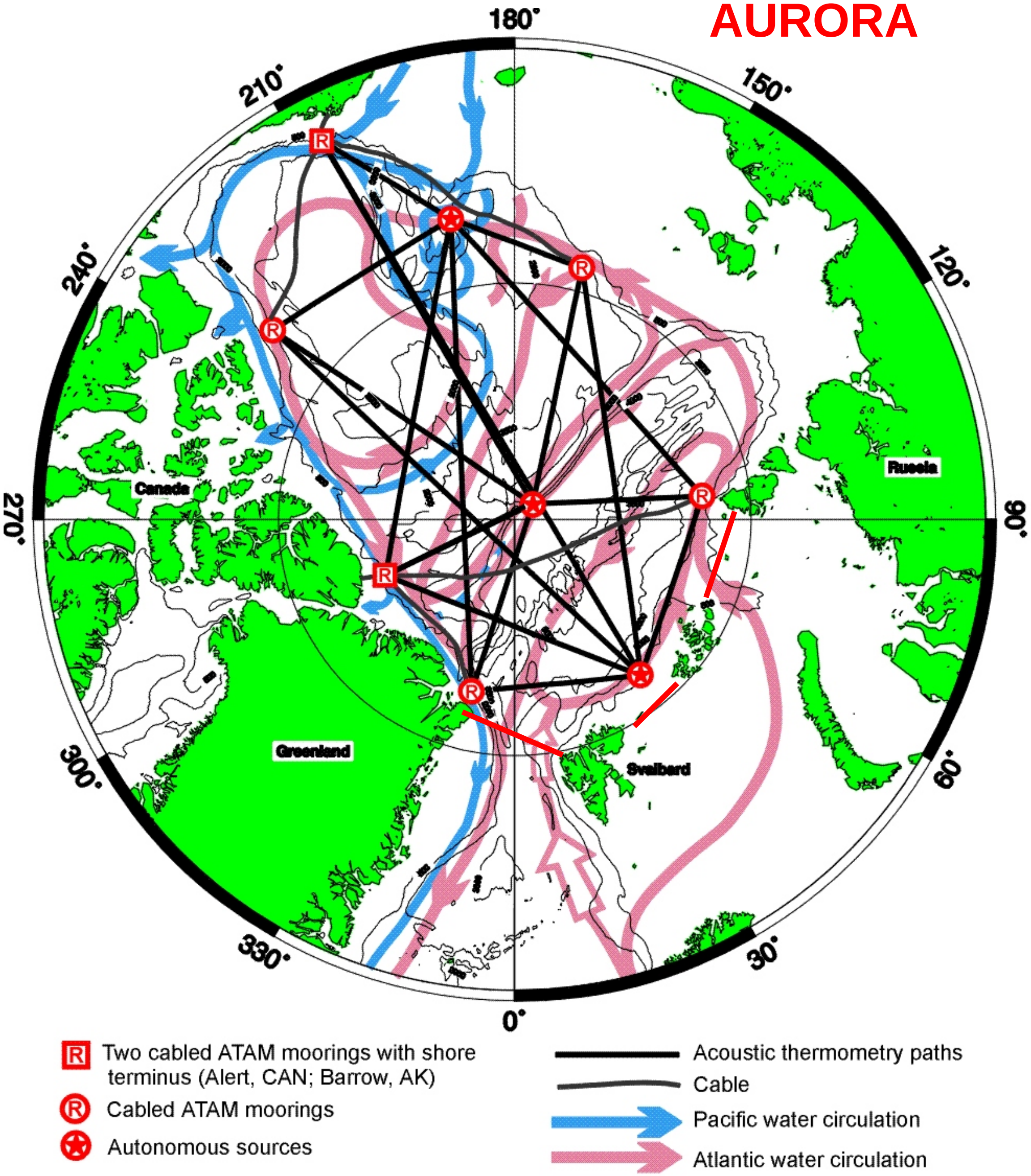
NEPTUNE Regional Cabled Observatory
Part of $350M NSF Ocean Observatories Initiative – 2008 start

MARS Cabled Observatory
Testbed in Monterey Canyon
First undersea node installation Fall 2007



ARCTIC REGIONAL UNDERSEA OBSERVATORY for RESEARCH and ANALYSIS

AURORA



VISION FOR EULERIAN ARCTIC MOORING GRID BASIN & STRAITS

Exact number, layout and mooring design determined by multidisciplinary requirements

Build in stages, Barrow Cabled Observatory, SEARCH, NPEO, and build on experience from MARS and NEPTUNE

International participation with cable terminations in Svalbard, Greenland, and Russia (as well as US and Canada) will greatly reduce undersea cable costs with cost sharing for system installation and operation

Conclusions and Future

- Acoustic modal travel times are an excellent proxy for the average temperature and heat content of the AIW in the Arctic Ocean
  - Monitoring of the average depth of the thermocline/upper mixed layer also possible
- Monitoring sea ice roughness/thickness by observing changes in acoustic propagation loss and monitoring salinity above the halocline using acoustic halinometry are under investigation
- Network of undersea moorings as contemplated by the Ocean Observatories Initiative will include acoustic sources and receivers that can provide synoptic real-time coverage

THANKS IRA!