Arctic Climate Observations Using Underwater Sound (ACOUS)

Dr. Peter N. Mikhalevsky
Science Applications International Corporation (SAIC)
1710 SAIC Drive, M/S 1-11-15
McLean, VA 22102
Phone: 703-676-4784 fax: 703-893-8753 email: peter@osg.saic.com

Contract Number: N00014-97-C-0205

LONG TERM GOALS

The Arctic Climate Observations using Underwater Sound (ACOUS) Project is a joint US/Russian global climate change research program. The goal of the ACOUS Project is to monitor changes in water temperature in the Arctic Ocean through the use of underwater acoustic remote sensing technology, exploiting the fact that the speed of sound propagation in water is a function of the water temperature.

OBJECTIVES

The objective of the ACOUS Project is to advance the understanding of short and long-term variability in the Arctic Ocean and its relation to global climate trends. Acoustic measurements made in 1994 and again in 1998/99 have shown significant warming of the Arctic Ocean with average maximum temperature increases of 1°C since the early 1990's. These results are consistent with direct temperature measurements made by the SCICEX Arctic submarine cruises that have validated the acoustic method.

APPROACH

ACOUS ocean temperature data will augment and complement data acquired from other programs using satellite temperature, altimeter and synthetic aperture radar as well as direct ocean measurements planned using moorings, drifting buoys and AUV's. Methods will then be developed to incorporate measurements supplied by the ACOUS Project into databases supporting models for Arctic Ocean-ice-atmosphere interactions, Arctic Ocean circulation, and climate prediction. By improving supporting databases, the predictive capabilities of these models will be enhanced, thus enabling more accurate forecasts of Arctic environmental changes, which are important indicators of environmental changes occurring on as global scale.

WORK COMPLETED

A field effort was conducted in March 2001 to recover an autonomous vertical acoustic receive array and recording package that was deployed in the Lincoln Sea in October 1998, about 100 miles north of Ellesmere Island, Canada, at 84-03.4 N / 066-24.9W. The array recorded a signal transmitted by a Russian acoustic source located near Franz Josef Land (over 1250 km away), which transmitted an M-sequence acoustic signal at 20.5 Hertz for 20 minutes every 4 days. Examination of the signal recordings on the array showed that the source operated successfully for 14 months from October 11, 1998 until December 8, 1999. For this time period the source transmitted 107 signals. During the past year, initial analysis has been conducted of the data recorded by the array.

RESULTS

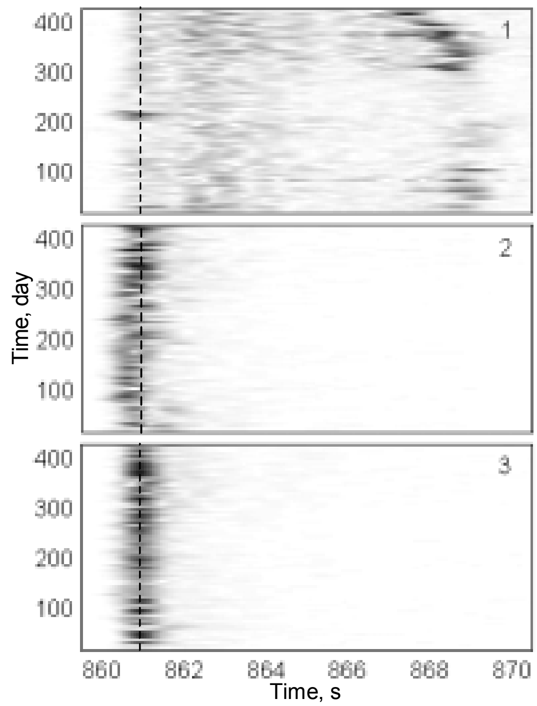

Figure 1. Gray-scale intensity plot of the modal arrival pulses (modes 1-3) as a function of the travel time and the day of measurements. The signals are synchronized with the arrival time of mode 3 shown by a dashed line.

Figure 1 from this year's work [1] shows the gray-scale intensity plot of the modal arrival pulses (modes 1-3) as a function of the travel time and day of measurements. Here all of the 107 received signals are synchronized with the arrival time of mode 3 that was measured at the energy center of the modal pulse. The absolute time is set corresponding to the time scale of the first signal recording. The amplitude, energy, and shape of the modal pulses underwent considerable variations during the period of observations. The short-term variations (from one transmission to the next) were, most likely, the result of sound speed variations at the beginning of the acoustic path over the shallow-water section of the continental slope, which influenced strongly the energy exchange of coupled modes. Modes 3 and 4 were less variable than the other modes.

The amplitude of mode 1 experienced strong short-term fluctuations superimposed on noticeable long-term variations due to seasonal changes of sea ice characteristics along the path. The Arctic ice cover is usually significantly thicker and rougher during so-called Arctic winter (January-June, days 80-260 in Fig. 1), which results in higher propagation loss of the modes, mainly mode 1, due to ice scattering. The difference between the travel times of modes 1 and 3 on the ACOUS path was expected to be about 8.0-8.5 seconds, predicted from the results of the Transarctic Acoustic Experiment (TAP) and the results of numerical modeling of the acoustic propagation for the typical oceanographic conditions along the path. The travel time difference of Mode 1 and 3 measured in the ACOUS signal recordings was varying between 7.5 and 8.5 seconds for the first ten months of observations, which roughly corresponds to the expected numbers. However, from August 1999 this difference was rapidly decreasing and had fallen to 6.0-6.5 seconds by the end of observations. These variations were not gradual. The pulse of mode 1 was considerably expanded, deformed and sometimes broken into partly overlapping peaks. The pulse width of this mode exceeded 1 second, and the peak maximum and pulse energy center were fluctuating in time within the expanded modal pulse.

In contrast to modes 3 and 4, the parameters of the lower modes, especially mode 1, were varying for the last months of acoustic observations so greatly that this must indicate significant changes in the environmental characteristics that occurred on the ACOUS path during this time period. Until August 1999 the modes propagated in the oceanographic conditions nearly typical for this path in the 1990s. Mode 1 was slower than modes 2 and 3 everywhere along the path except, probably, in a very narrow zone over the Eurasia continental slope. However, from August the zone of “warmer” sound speed profiles, in which mode 1 was as fast as mode 3, began to progressively expand and had spread over an abnormally wide region by the end of acoustic observations. In order to arrive 1.5 seconds faster than in typical conditions, mode 1 should have propagated in “warmer” conditions.

It is obvious that this anomalous water mass structure rose in the initial part of the acoustic path in the Nansen Basin. Indeed, the Atlantic waters in the Nansen Basin are considerably warmer, lie much closer to the sea surface, and undergo larger variations than that in the Fram Basin and the Lincoln Sea. Warming of Atlantic waters over 2.5° C and rising of the thermocline about 100 meters in this basin are abnormal, but likely, while such changes in the environmental conditions of the Fram Basin seem impossible. Moreover, the expansion of the main pulse of mode 1 to approximately 1.5 seconds indicates that a frontal zone of warmer Atlantic water mass extended to ranges of 250-300 km from the acoustic source.

The observed change in the Atlantic Intermediate Water (AIW) layer was rapid for such a broad region so that it was, most likely, a result of a wide frontal zone propagating across the acoustic path rather than a gradual spread of the warmer Atlantic water core from the continental slope to the central part of the basin. The rise of the warmer and expanded Atlantic water mass in this region might also be a result of interaction between the primary and recirculating flows of the warmer Atlantic waters in the Nansen Basin.

The termination of acoustic observations in December 1999 did not allow us to track the back of the warmer Atlantic water mass that passed across the acoustic path. However, the abruptness of change observed in the ACOUS experiment is most likely a consequence of pulsating intrusions of warm North Atlantic water into the Arctic Basin through the Fram Strait [1] rather than gradual warming of the incoming water masses. Occasional oceanographic measurements from research vessels may not be capable of detecting the appearance and investigating the characteristics of such rapidly varying, spot-like features of the water mass.

IMPACT

The acoustic observations taken by the ACOUS Lincoln Sea Array during the period October 1998 to December 1999 indicate a strong and extended warming of Atlantic waters that occurred in the Nansen Basin by the end of 1999. This acoustic measurement is consistent with the continued warming of the

AIW in the Arctic Ocean observed during the SCICEX-2000 cross-basin transect. These measurements and the modeling show that acoustic thermometry can also be used to monitor average thermocline depth along the propagation path.

The warming of the AIW in the Arctic Ocean that started in the early 1990's has continued through the fall of 2000. With the end of the dedicated SCICEX cruises one of the most fruitful eras of data collection that has driven much of our newly formed understanding of the Arctic Ocean is at a close. New technologies are needed. Acoustic thermometry can provide long-term high-resolution time series of changes in the Arctic Ocean temperature, heat content, and thermocline depth. It is remarkable that the linear relationship between the section-average AIW temperature and heat content, and the mode 2 and 3 travel times is not only consistent with the recent SCICEX measurements but the 40 year average climatology as well. An acoustic thermometry network of sources and receivers collocated on bottom mounted Arctic Ocean moorings as proposed in several new initiatives could provide spatially synoptic time series measurements in the post SCICEX era.

TRANSITIONS

None

RELATED PROJECTS

Submarine Science Expeditions (SCICEX) starting in 1993 and extending through 2001.

REFERENCES

[1] A.N. Gavrilov, and P.N. Mikhalevsky, "Recent Results of the ACOUS (Arctic climate Observations using Underwater Sound) Program", European Acoustic Journal, Acta Acoustica/Acoustica, in press, June 2002.

PUBLICATIONS

A.N. Gavrilov, and P.N. Mikhalevsky, "Recent Results of the ACOUS (Arctic Climate Observations using Underwater Sound) Program", European Acoustics Journal, Acta Acoustica/Acoustic, in press, June 2002.

A.N. Gavrilov, "Study of Acoustic Propagation Loss in the Arctic Ocean using the data of the ACOUS Experiment", Technical Report, June 2002, for the Office of Naval Research.

PATENTS

None