HEARING THE OCEAN

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PHOTO: BILL WITTKOP

THE WORLD'S OCEANS, AND MATHEMATICS, have a lot to say to Eliza Michalopoulou, associate professor in the Department of Mathematical Sciences. They tell her about the location of submarines and whales, the earth's changing climate, even environmental contamination. Michalopoulou, who has a joint appointment in the Department of Electrical and Computer Engineering, hears what the ocean can communicate in these areas as a result of her math-based acoustical research — the investigation of sound as it travels from an underwater source to a detector and processing equipment.

Michalopoulou applies her expertise in both mathematical analysis and signal processing in pursuing this work, which has received major funding from the Office of Naval Research (ONR). In 1997, ONR also recognized her achievements in ocean acoustics with a prestigious Young Investigator Award.

Complex environments

The multifaceted potential of Michalopoulou's research arises from ONR's interest in better techniques for detecting submarines in water up to several hundred meters deep. Typically, these are coastal environments that tend to be especially complex when it comes to identifying the source of a sound and pinpointing its location. The challenge

$$t=f(m_0)+J\delta m$$

$$r(n)=\sum_{i=1}^{M} a_i s(n-n_i)+w(n)$$

$$C=(1/N)\sum_{i=1}^{N} d_i d_i^*$$

is compounded by the fact that submarines which may attempt to penetrate the nation's territorial waters are becoming much quieter, necessitating improved technology for detection and localization.

As Michalopoulou explains, many factors influence the propagation of sound in such environments. Among them are water temperature, the number of times sound waves bounce between the surface of the ocean and the earth below, the slope of the ocean floor and its subsurface geologic profile. It's also necessary to factor in the identifying characteristics of a sound source — sea life or submarine — and the noises of civilization emanating from shore and nearby surface vessels.

The raw material of Michalopoulou's oceanic insights is a growing body of data obtained from various sources, most notably ONR colleagues, to which she applies analytical techniques such as matched field processing and inversion analysis. These and other techniques help to address the problems of oceanic sound propagation and localization, including the influence of geologic features beneath the ocean's floor that must be acoustically imaged. The end products of her research are special algorithms, or precise mathematical tools, that may eventually be applied in next-generation systems for protecting the shores of the U.S. against unauthorized underwater incursions.

A warmer world?

While national defense is a primary focus of Michalopoulou's ONR-funded research, her efforts have very significant implications for other fields. One is the study of climatic trends and the continuing international dialogue on global warming. Detecting and localizing sound from any oceanic source requires a comprehensive understanding of the medium through which the sound travels. This includes the influence of temperature on sound propagation.

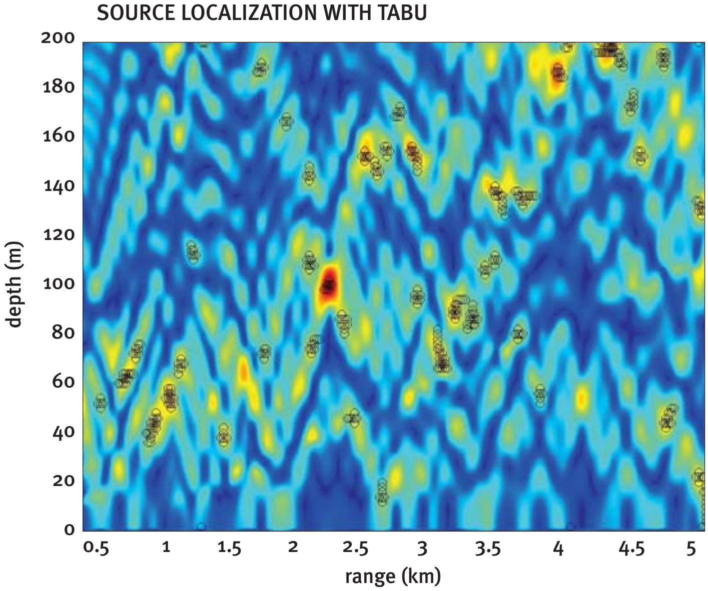
In general, the warmer the water, the faster sound will travel between a source and a detector. Accordingly, investigating oceanic sound propagation relative to historic seasonal variations for antisubmarine research also promises to yield insights into climate change — whether due to natural cycles or human activity. Sound propagation can be affected by the ocean's chemical composition as well. Therefore, in addition to climatic information, acoustic analysis can signal changes in the composition of water in a particular area, possibly due to the presence of harmful contaminants.

Although not part of her research plans at this time, Michalopoulou does mention the relevance of underwater acoustics to the detection of natural disasters like tsunamis, and to the development of warning systems that could help to prevent the

DEALING WITH OCEANIC AMBIGUITY

The illustration below, known as an ambiguity surface, plots likely locations of sound sources with respect to the depth of the ocean and range, or distance, from receiving sensors. Over the spectrum of colors used, red indicates that the source of a sound is very likely to be at that location, while blue corresponds to least likely locations. The black circles reflect application of an optimization technique called a tabu search — a phrase literally recalling the social concept of a tabu, which denotes activity that should be avoided. Calculating such ambiguity surfaces can be very time-consuming. The tabu search speeds this process by readily identifying the most likely source locations without wasting time on areas of high uncertainty.

SOURCE LOCALIZATION WITH TABU



loss of life such as that caused by the tsunami of December 2004. Indicative of this potential, the Acoustical Society of America scheduled discussion of tsunami acoustics for its spring 2005 meeting.

A personal challenge

When asked what she considers to be the most significant, perhaps even surprising, outcome of her research to date, Michalopoulou speaks enthusiastically about how well the algorithms she is developing for oceanic sound propagation continue to reflect the growing volume of real-world data. But Michalopoulou's enthusiasm is not just for her immediate research. It clearly encompasses the entire field of applied mathematics, and the math program at NJIT that she helps to administer as coordinator for undergraduate degree programs.

Although all of Michalopoulou's degrees are in electrical engineering, she emphasizes that her field of specialization in graduate school at Duke University, signal processing, is computationally intensive. This led to a compatible post-doctoral research position in NJIT's math department, and to her current joint faculty appointment.

She also says that excelling in mathematics was a special personal challenge, even before embarking on her university studies. "I worked hard in every subject, from classical Greek to science," she says. "But I wanted to do especially well in mathematics, perhaps in reaction to the stereotype that women do not have the same potential for success in this field as men."

Michalopoulou is committed to encouraging other women to build careers in science and technology. She is a member of NJIT's Committee on Women's Issues and has co-chaired the Committee on Women in Acoustics of the Acoustical Society of America. Her personal page on the math department's Website also includes a link pointing the way to the university's Murray Center for Women in Technology, where she has been very active.

Exciting work

As supportive as she is of the young women who study at NJIT, Michalopoulou is equally positive about what the university offers to every student in mathematics and other disciplines. Continued development of the mathematical sciences program is one of the core objectives of NJIT's strategic plan, and Michalopoulou confirms that the department already has a national reputation for outstanding teaching and research. (See sidebar, "Continuing to Build on the Best in Math.")

"There is exciting work going on in many fields, and colleagues I meet at conferences know how well we are doing in mathematics," she says. "But this is only the beginning. We will be growing with new faculty, who will be working in even more areas of research."

Especially appealing to Michalopoulou are the many interdisciplinary aspects of the math program at NJIT, and the corresponding interfaces with the real world. She emphasizes that her own research spans electrical engineering, physical acoustics and oceanography as well as math. Working towards a degree in the Department of Mathematical Sciences fosters a comparable interdisciplinary perspective, with options for interaction with other departments and centers being virtually unlimited.

In recent years, Michalopoulou points out, mathematical biology has emerged as a field where cooperative engagement means not just interdepartmental work at NJIT. It encompasses research in which members of the math department are contributing their insights to joint efforts with institutions such as the University of Medicine and Dentistry of New Jersey. Areas of inquiry have ranged from basic research involving neuroscience to determining the optimal pattern for wound sutures.

For the immediate future, Michalopoulou plans to continue studying the propagation and localization of sound in the ocean, primarily with colleagues who also have ONR funding. Her work in this area includes active participation on three Acoustical Society committees — Underwater Acoustics, Signal Processing in Acoustics and Acoustical Oceanography.

Still, Michalopoulou has given some thought to other research horizons that might be explored with analytical techniques she now applies in the investigation of underwater sounds. For example, it's conceivable that the same techniques could be used to improve medical-imaging technology. Whatever the future direction of her research, though, it will undoubtedly continue to demonstrate the versatility of mathematics in helping to increase basic scientific knowledge and solve practical problems. ■

CONTINUING TO BUILD ON THE BEST IN MATH

The mathematical sciences comprise one of three core areas targeted for national prominence under the strategic plan that NJIT adopted in 2004. The Department of Mathematical Sciences in the College of Science and Liberal Arts already has the largest number of faculty working in applied math of any school in the U.S. Since 1986, the Center for Applied Mathematics and Statistics (CAMS) has promoted cooperative efforts among the academic community, industry and government geared toward meeting many real-world challenges. Recent departmental achievements, in concert with those of CAMS, have earned wide recognition today and indicate even greater potential for the future.

Highlights for math at NJIT over the past five years —

- The number of math majors, including PhD candidates, increased nearly ten percent.
- Annual grant funding rose from $892,000 to $1.2 million.
- New multi-year grants awarded in 2004-2005 added $1.6 million to the department's funding.
- Grants not only grew but came from increasingly diverse sources, reflecting the importance of mathematical research in the public and private sectors as well as NJIT's reputation in math. Among these sources: the Air Force Office of Scientific Research, the Fulbright Council for International Exchange of Scholars, the Mathematical Research Institute, the National Aeronautics and Space Administration, the Office of Naval Research, the National Institutes of Health, the National Science Foundation, the U.S. Department of Energy, the Whitaker Foundation.
- Department members teamed with colleagues from institutions such as California Institute of Technology and the University of California at Los Angeles in a national Focus Research Group to investigate key problems in fluid dynamics.
- The department was the recipient of the only 2004 Major Research Instrumentation award given by the National Science Foundation's Division of Mathematical Sciences, which will facilitate acquisition of one of the most powerful parallel supercomputers in the country.
- The National Science Foundation awarded the department one of just eight 2004 Undergraduate Biology and Mathematics Training grants to support participation by students in research related to mathematical biology — a discipline in which NJIT is a leader.
- Initiated in 2004, the annual Frontiers in Applied and Computational Mathematics conference is a unique event in the field, bringing together researchers engaged in pioneering work at universities and other institutions around the world.

Department of Mathematical Sciences: http://math.njit.edu

Center for Applied Mathematics and Statistics: http://math.njit.edu/CAMS/research.html

To read more about the Department of Mathematical Sciences in *NJIT Magazine*, **see the spring 2003 and winter 2004 issues in the online NJIT Publications Library at www.njit.edu.**