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Research

Deadly Tsunami Hits Solomon Islands

By Helen Gibbons and Eric Geist

A powerful tsunami struck the western Solomon Islands on April 2, 2007 (7:40 a.m., local time), washing away hundreds of homes and taking numerous lives; the death toll was 34 at press time and is expected to rise. Triggered by an offshore earthquake of magnitude 8.1, the deadly waves were part of a so-called near-field or local tsunami. A tsunami typically begins as a single wave that, within minutes after the triggering earthquake, splits into two: a transoceanic tsunami that travels outward to the deep ocean, and a local tsunami that travels toward the nearby coast. The local-tsunami waves that crashed into the Solomon Islands reportedly reached heights of as much as 9 m (30 ft) and extended as far inland as 200 m (650 ft). According to one resident of Gizo, the largest town in the area swamped by the tsunami, the first wave came "almost instantaneously" after the earthquake shaking.

Deep-ocean Assessment and Reporting of Tsunami (DART) stations—operated by the National Oceanic and Atmospheric Administration (NOAA) and described in the article "Tsunami-Forecasting System Tested by Recent Subduction-Zone Earthquakes" (this issue)—are designed to detect transoceanic tsunamis, so that alerts can be sent to areas which would otherwise have no warning. After the earthquake in the Solomon Islands, NOAA's Pacific Tsunami Warning Center used sea-level measurements from tide gauges, DART stations, and other sources to issue a tsunami warning for numerous areas in the South Pacific (for example, see URL **http://www.prh.noaa.gov/ptwc/messages/pacific/2007/pacific.2007.04.02.015800.txt**). This warning enabled countries at a distance from the earthquake to prepare for a possibly damaging transoceanic

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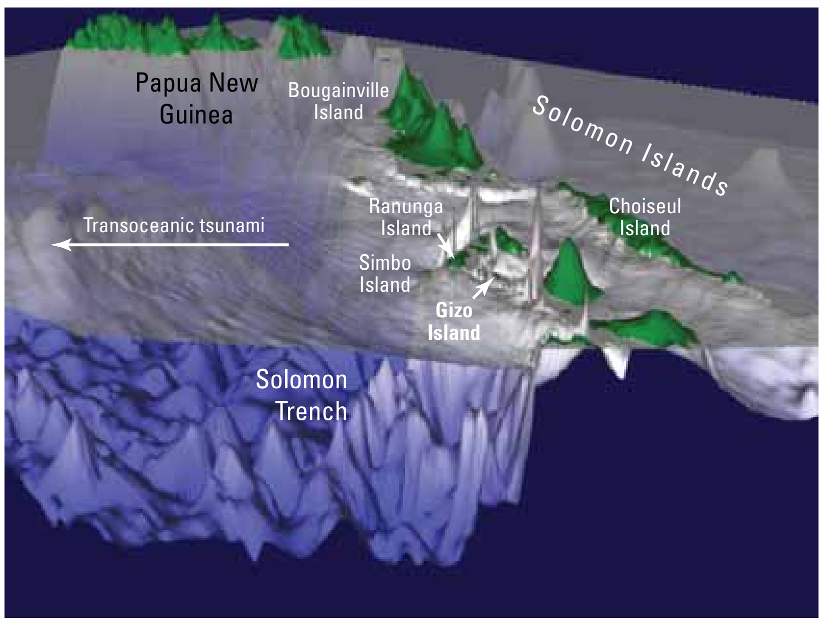
Solomon Islands, showing epicenter (red star, approximately located) of magnitude 8.1 earthquake that triggered a deadly tsunami on April 2, 2007. (Note: Bougainville is geographically part of the Solomon Islands volcanic arc and politically part of Papua New Guinea.)



*Wave heights are highly exaggerated in this computer simulation of the tsunami 16.9 minutes after the earthquake; view northwestward. This frame comes from an animated movie posted at URL **http://soundwaves.usgs.gov/2007/04/**. Damaging local-tsunami waves were reported on each of the labeled islands. Note the transoceanic tsunami moving southwestward toward Australia (to left in this view). Vertical exaggeration is approximately 10:1 for features on the land (green) and sea-floor (purple); wave heights (gray) are greatly exaggerated with respect to topography for visualization purposes.*

Sound Waves

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tsunami; Australia, for example, closed beaches along its east coast until the warning was lifted. The tsunami caused limited damage at sites across the Solomon Sea from the earthquake epicenter, but otherwise no serious effects were reported from the transoceanic tsunami.

Local tsunamis reach nearby shores too quickly for official warnings to be practical. For some local tsunamis, the only warning is the strong ground-shaking generated by the earthquake that triggers the tsunami. Commonly, the ocean recedes far from shore before the first local-tsunami wave strikes, as happened in Thailand, for example, during the 2004 Indian Ocean tsunami. Early reports are unclear as to whether this phenomenon occurred along all the affected coasts in the Solomon Islands.

The earthquake that triggered the Solomon Islands tsunami originated approximately 10 km (6 mi) beneath the sea floor. Its epicenter was 345 km (215 mi) west-northwest of Honiara, the Solomon Islands' capital on the island of Guadalcanal, and just 10 km (6 mi) south-southeast of Gizo, a small fishing and diving center in the New Georgia Islands archipelago. Like most tsunami-generating earthquakes, the Solomon Islands earthquake occurred at a subduction zone, which is somewhat complex here, where the Australia, Woodlark, and Solomon Sea tectonic plates dive beneath the Pacific plate (for maps and more information, visit URL **http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/us2007aqbk.php**). The earthquake occurred during the day; if the quake and tsunami had struck at night, the loss of life might have been even greater.

For information about tsunami safety, please read the sidebar accompanying "Indian Ocean Earthquake Triggers Deadly Tsunami" in *Sound Waves*, December 2004/January 2005, at URL **http://soundwaves.usgs.gov/2005/01/**. To learn some basic facts about how tsunamis are formed and how they change shape as they cross the ocean and run up on shore, read "Life of a Tsunami" at URL **http://walrus.wr.usgs.gov/tsunami/basics.html**. To view preliminary computer models and animations of the Solomon Islands tsunami, visit URLs **http://walrus.wr.usgs.gov/tsunami/** and **http://nctr.pmel.noaa.gov/solomon20070401.html**. ☸

Tsunami-Forecasting System Tested by Recent Subduction-Zone Earthquakes

By Eric Geist, Vasily Titov (NOAA/PMEL), Annabel Kelly, and Helen Gibbons

A tsunami-forecasting system being developed by the National Oceanic and Atmospheric Administration (NOAA) got a good test in recent months when two great earthquakes generated small tsunamis that spread across the Pacific Ocean basin. Both earthquakes—a magnitude 8.3 on November 15, 2006, and a magnitude 8.1 on January 13, 2007—originated in the Kuril subduction zone, seaward of the Kuril Islands, which stretch between Japan and Russia.

The basinwide tsunamis were detected by many sea-level recorders, including NOAA's Deep-ocean Assessment and Reporting of Tsunami (DART) stations, which are critical elements of NOAA's tsunami-forecasting system. Each DART station consists of a bottom-pressure recorder, or tsunameter, that measures the tsunami's wave height and related parameters, and a surface buoy that communicates the information to NOAA's Tsunami Warning Centers. The tsunami-forecasting system now in development will combine earthquake information (such as location and magnitude) calculated from seismograms, real-time sea-level information measured by DART stations, and numerical modeling to predict tsunami wave heights and other characteristics before landfall in threatened coastal areas.

Currently, tsunami alerts issued by NOAA's Tsunami Warning Centers identify areas likely to be affected by the

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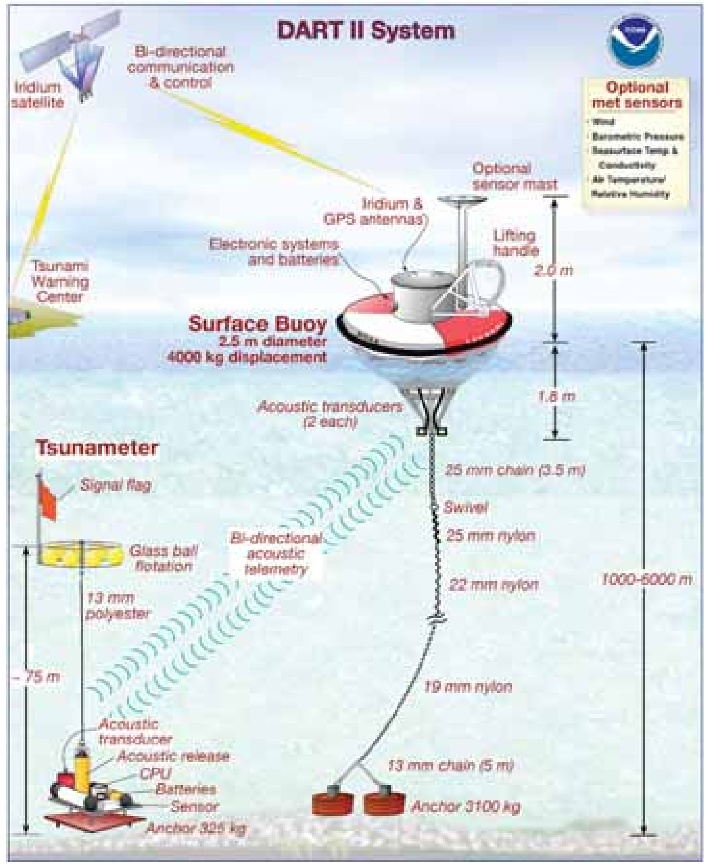
(Tsunami Forecasting continued from page 2)

tsunami and list estimated arrival times of the first tsunami waves (for example, see alert posted at URL **http://www.prh.noaa.gov/ptwc/messages/pacific/2007/pacific.2007.01.13.043435.txt**). Shortly after the November 2006 earthquake, NOAA's Alaska and West Coast Tsunami Warning Center (Palmer, Alaska) and Pacific Tsunami Warning Center ('Ewa Beach, Hawai'i) issued tsunami warnings for countries and islands near the earthquake and for the part of Alaska along the Aleutian Island chain. Other parts of Alaska, Hawai'i, Canada, and Washington State, as well as island nations and countries around the western Pacific Ocean, were issued a tsunami watch: A tsunami warning indicates an imminent threat of a destructive tsunami; a tsunami watch provides advance alert of the possibility of a destructive tsunami (see URL **http://wcatwc.arh.noaa.gov/frequently.htm**). The January 2007 earthquake resulted in a tsunami warning for countries including Russia, Japan, and Vietnam, and a tsunami watch for Hawai'i and several countries in the western Pacific. After each earthquake, the alerts were refined and eventually canceled on the basis of sea-level measurements at DART stations and coastal tide gauges.



Second-generation DART station, or DART II. The first-generation DART design featured automatic detection and reporting of tsunamis triggered by a threshold wave-height value. The DART II design incorporates two-way communications that enable tsunami-data transmission on demand; this capability ensures the measurement and reporting of tsunamis with amplitudes below the auto-reporting threshold. The next generation DART ETD (Easy To Deploy) buoy is currently under development at PMEL.

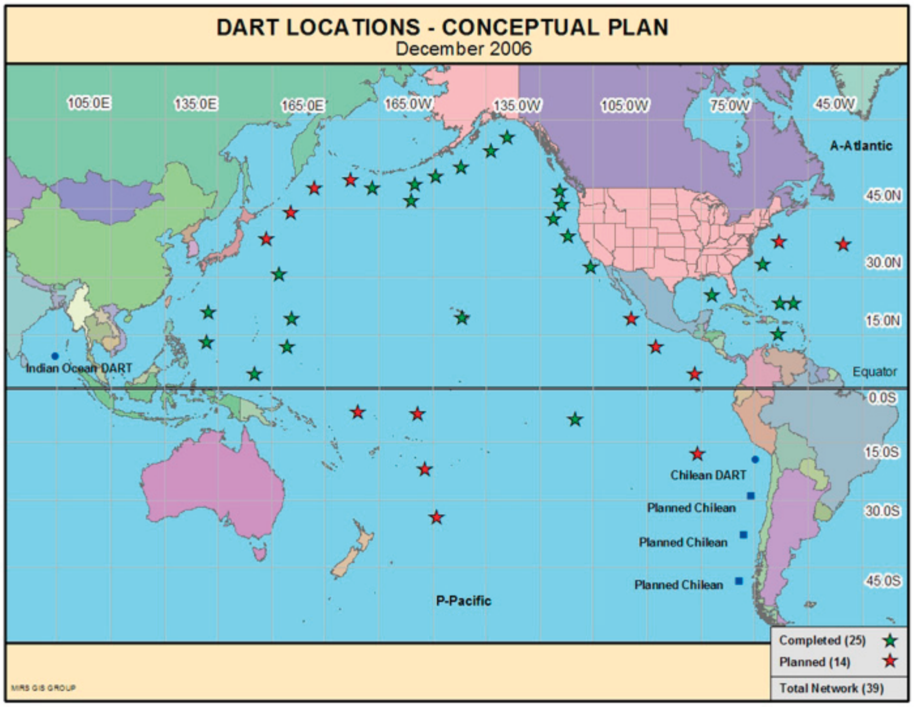
Because DART stations are critical to tsunami forecasting, NOAA has been working to increase the number of DART stations in the Pacific, Atlantic, and Indian Oceans, the Gulf of Mexico, and the Caribbean Sea, at sites chosen with the assistance of U.S. Geological Survey (USGS) scientists (see "Workshop on Optimizing the DART Network for Tsunami Forecasting," in *Sound Waves*, October 2005, at URL **http://soundwaves.usgs.gov/2005/10/meetings.html**). The DART stations are becoming not only more numerous but also more sophisticated, thanks to continuous design improvements by NOAA's Pacific Marine Environmental Laboratory (PMEL). For example, the second-generation, or "DART II," stations are designed for two-way communications that enable Tsunami Warning Centers to request data from the DART II station, ensuring the measurement and reporting of tsunamis with amplitudes too small to trigger the automatic detection and reporting built into first-generation DART stations. PMEL is currently developing the next-generation DART ETD (Easy To Deploy) buoy. (For more information about DART stations, visit URL **http://nctr.pmel.noaa.gov/Dart/**.)

Along with increasing the number of DART stations and improving their tsunami-measuring capabilities, NOAA scientists are also improving numerical models that predict how tsunami waves will behave in the open ocean and at coastlines. NOAA's plan for providing reliable tsunami forecasts is to combine measurement and modeling techniques (see URL **http://nctr.pmel.noaa.gov/tsunami-forecast.html**). The recent tsunamis gave NOAA scientists a good opportunity to test such combinations. For example, they used initial measurements of the November 2006 earthquake to predict the tsunami waveform at DART stations south of the Aleutian Islands; here, the tsunami-waveform modeled solely on earthquake magnitude and location was close to the measured waveform.

Map of northwestern Pacific Ocean, showing epicenters (approximately located) of two great earthquakes—in November 2006 (square) and January 2007 (circle)—that triggered small tsunamis across the Pacific Ocean basin.

(Tsunami Forecasting continued on page 4)

(Tsunami Forecasting continued from page 3)



Pacific Ocean basin, showing locations of current (green stars) and planned (red stars) DART stations as of December 2006. Visit URL ***http://nctr.pmel.noaa.gov/Dart/*** *for more information.*

An important next step in the tsunami-forecasting process is to "invert," or work backward from, the real-time waveforms measured at DART stations to determine the amount of slip on the causative fault—for the November 2006 earthquake, the giant fault that separates the two tectonic plates at the Kuril subduction zone, termed the interplate thrust or "megathrust." From the refined estimate of the fault motion that caused the tsunami, predictions of tsunami wave heights at selected coastal sites can be made by using NOAA's Short-term Inundation Models (SIMs). Predictions of the November 2006 tsunami wave heights at four coastal sites in Hawai'i (Honolulu, Nawiliwili, Kahului, and Hilo) are posted on PMEL's Web site at URL **http://nctr.pmel.noaa.gov/kuril20061115.html**. These predictions are extremely useful as a test of the SIMs models. Graphs comparing the modeled to measured wave heights show that the SIMs work well for predicting the heights of the first few tsunami waves to arrive at these sites.

The January 2007 earthquake was unusual in that it occurred seaward of the oceanic trench marking the boundary between the Pacific oceanic plate and the overriding Okhotsk plate. Most great earthquakes at subduction zones, such as the November 2006 earthquake, occur on the interplate thrust that separates the two plates. The January 2007 earthquake, in contrast, occurred on a fault in the downgoing Pacific plate; such faults result from bending and breaking of the plate as it enters the subduction zone. Though rare, these earthquakes can also generate highly destructive tsunamis, as did the 1933 Sanriku earthquake, magnitude 8.4, which occurred east of Japan and generated a tsunami that killed more than 3,000 people. The NOAA tsunami-forecasting system proved that it can accommodate these unusual events through inversion of real-time sea-level data recorded at the DART stations.

The Kuril Islands tsunamis illustrated two wave characteristics that are important for estimating tsunami severity: preferential beaming of tsunami energy and site response. In the open ocean, tsunami wave heights are highest along azimuths approximately perpendicular to the subduction zone where the triggering earthquake occurred—a phenomenon termed "tsunami beaming." This beaming pattern is modified by refraction caused by large-scale variations in water depth as the tsunami travels across the Pacific Ocean basin, similar to how light is refracted by a prism. Tide-gauge measurements of the November 15, 2006, tsunami show that tsunami wave heights were substantially larger at sites along the main beam of tsunami energy (for example, at Hawai'i, where the tsunami caused one injury) than at sites off the main beam (for example, at Japan). A minor beam aimed

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Damage to floating docks at the Citizens Dock boat basin, Crescent City, California, caused by November 2006 tsunami. Photograph by ***Lori Dengler****, Humboldt State University.*

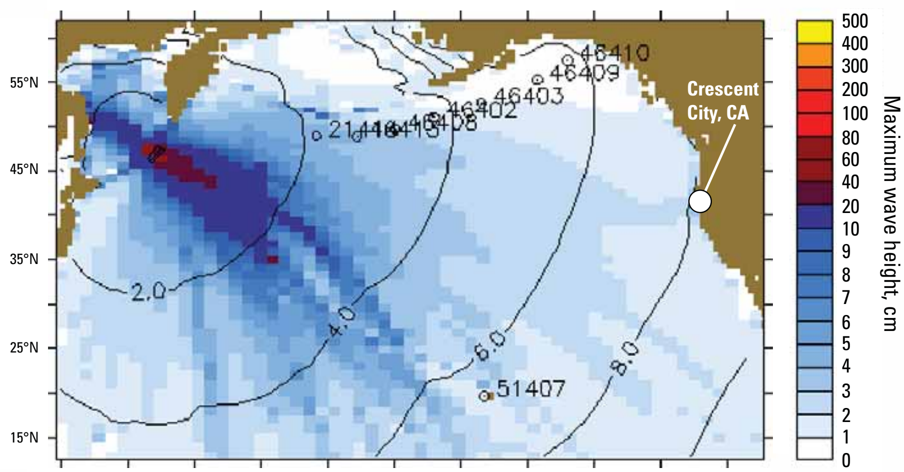
(Tsunami Forecasting continued from page 4)

*Crescent City Harbor, showing interior boat basin. Aerial photograph by **Rick Hiser**, provided by Harbor Master **Richard Young**. This and additional photographs of the harbor are posted on the University of Southern California's Tsunami Research Center Web site at URL **http://cwis.usc.edu/dept/tsunamis/2005/tsunamis/Kuril_2006/**.*

at Crescent City, California (see tsunami-beam map, below), partly explains damage to that city's harbor during the November 2006 tsunami. USGS seismologist **Annabel Kelly** and her colleagues summarized the tsunami damage at Crescent City in the December 12, 2006, issue of *Eos* (Transactions of the American Geophysical Union). The Citizens Dock and boat basin sustained approximately $1 million in damage to floating structures. This damage was caused by strong currents generated by focusing of the 15- to 20-minute-period tsunami waves (which reached a maximum of 1.76-m peak-to-trough amplitude in the outer harbor) through the narrow entrance to the boat basin. The highest wave was seen at 2 p.m. (PST), 1 hour and 40 minutes after the arrival of the first wave. (Additional information is posted on the University of Southern California's Tsunami Research Center Web site at URL **http://cwis.usc.edu/dept/tsunamis/2005/tsunamis/Kuril_2006/**.)

Clearly contributing to the damage at Crescent City was the second wave characteristic illustrated by the Kuril Islands tsunamis, called "site response." The bathymetry off some coastal sites, such as Crescent City, produces an accentuated site response in tsunami waves: certain bathymetric features focus the wave energy (the way a lens focuses light) and produce secondary waves that propagate up and down the coast after the initial waves strike. These secondary waves are termed coastal "trapped waves" or "edge waves." (For more information about edge waves and how local topography affects tsunamis, see sidebar "Topography—Natural and Altered—Affects Tsunami's Severity" in *Sound Waves* article posted at URL **http://soundwaves.usgs.gov/2005/02/**.) Crescent City's harbor, which opens to the south-southwest, is particularly vulnerable to trapped and reflected waves originating south of the harbor and propagating northward. The largest tsunami wave to hit Crescent City after the November 2006 earthquake was this type of secondary wave. More information and animations illustrating the persistence of tsunami-wave activity along the central and northern California coast are available on a new USGS Web page at URL **http://walrus.wr.usgs.gov/tsunami/persistence.html**.

A USGS-sponsored workshop on tsunami sources was held April 21-22, 2006, with a focus on research efforts in support of NOAA's tsunami-forecasting system. For information about this workshop, visit URL **http://walrus.wr.usgs.gov/tsunami/workshop/**. To learn more about NOAA's tsunami-forecasting efforts, visit NOAA's Center for Tsunami Research Web site at URL **http://nctr.pmel.noaa.gov/**. ☸



North Pacific Ocean, showing predicted maximum wave heights (indicated by color) and arrival times (contour lines labeled with numbers representing hours after the triggering earthquake) of tsunami waves generated by November 15, 2006, earthquake near Kuril Islands. Predicted wave heights illustrate "tsunami beaming"—the tendency of tsunami waves in the open ocean to be highest along azimuths approximately perpendicular to the subduction zone where the triggering earthquake occurred. Note minor beam aimed at Crescent City, California, where the boat harbor was damaged, largely by secondary tsunami waves (see text).

Sub-Sea-Floor Methane in the Bering Sea—USGS Emeritus Describes Possible Gas-Hydrate Accumulations to the Geophysical Society of Alaska

By David Scholl, Ginger Barth, Jonathan Childs, and Helen Gibbons

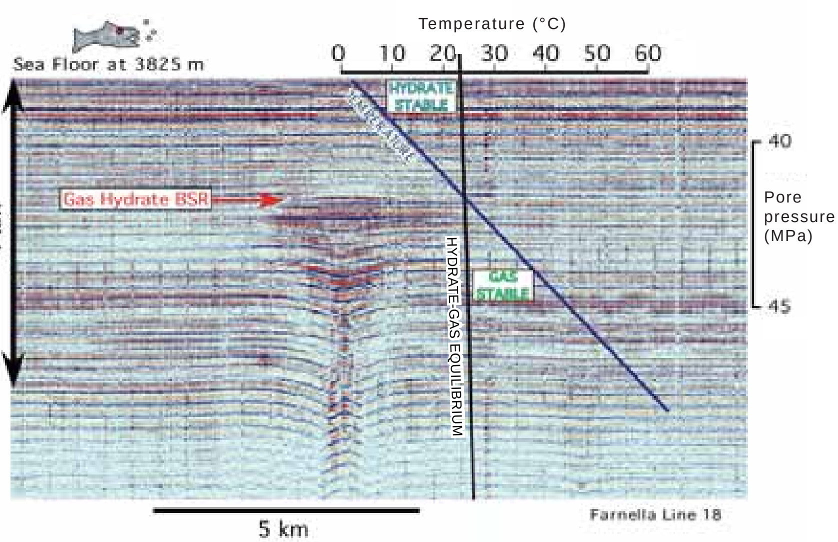
U.S. Geological Survey (USGS) emeritus scientist **Dave Scholl** described evidence for large accumulations of methane hydrate beneath the floor of the Bering Sea in an invited talk at a January 11 meeting of the Geophysical Society of Alaska in Anchorage. Methane hydrate is a naturally occurring crystalline substance in which molecules of methane—a primary component of natural gas—are trapped in a lattice of water molecules. Common in Arctic permafrost environments as well as in sea-floor sediment, methane hydrate interests scientists for numerous reasons, among them its potential as a future source of fossil fuel, and its potential to cause submarine landslides and to release large volumes of methane—a greenhouse gas—when conditions cause it to dissociate into free gas and water.

During his talk, **Scholl** showed seismic-reflection data collected by the U.S. Navy in the 1960s during antisubmarine-warfare research that revealed unexpected features beneath the floor of deep basins (3,500- to 4,000-m water depth) in the Bering Sea. The features, which range from 2 to 8 km in width, look like giant mushrooms in the seismic-reflection records. The "cap" of the mushroom is a stack of upward-arched seismic-reflection horizons with its top approximately 200 m below the sea floor. The "stem" of the mushroom is a continuous column of downward-arched horizons, extending from about 360 to at least 2,000 m below the sea floor. Using modern tools to re-analyze data in which the mushroom-like structures appear, USGS scientists have extracted new details about these features, now interpreted as natural-gas chimneys overlain by deposits of methane hydrate.

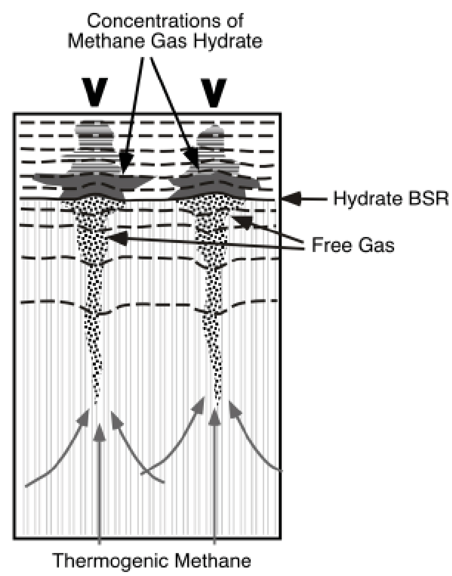
Seismic-reflection data are produced by bouncing acoustic (sound) energy off layers of sediment beneath the sea floor and recording the returning echoes. Some acoustic energy is reflected at any horizon where certain physical properties change—at the boundary between different sedimentary layers, for example. In the Bering Sea data, flat-lying horizons predominate, indicating that deep Bering Sea basins are filled with 2 to 4 (or more) km of sediment in little-deformed horizontal beds. The enigmatic "mushrooms" amid the flat-lying beds were dubbed "acoustic Velocity-AMPlitude (VAMP) anomalies" in the 1970s by USGS scientists examining both Navy and USGS seismic-reflection data from the Bering Sea.

Continuing research on the origin of VAMP structures brought recognition that the transition from upward-arching horizons to downward-arching horizons occurs at the same depth—approximately 360 m below the Bering Sea floor—as the predicted transition from stable methane hydrate (above) to stable methane gas (below). The

(Bering Sea Methane continued on page 7)



Conspicuous VAMP anomaly in seismic-reflection image from the central Aleutian Basin (star on map, next page). Overlying the image is a plot of temperature versus pore pressure, here assumed to be equal to hydrostatic pressure, or the weight of the overlying water. (1 MPa = 10 bars or approx 10 atm.) Nearly vertical line labeled "Hydrate-gas equilibrium" separates lower-temperature region where methane occurs as methane hydrate (left of line) from higher-temperature region where methane occurs as pore-filling gas (right of line). Line labeled "Temperature" shows expected increase of temperature with depth in sediment. Point where temperature line crosses equilibrium line marks transition depth above which hydrate is stable and below which free gas is stable; this depth is marked by gas-hydrate BSR (bottom-simulating reflection).



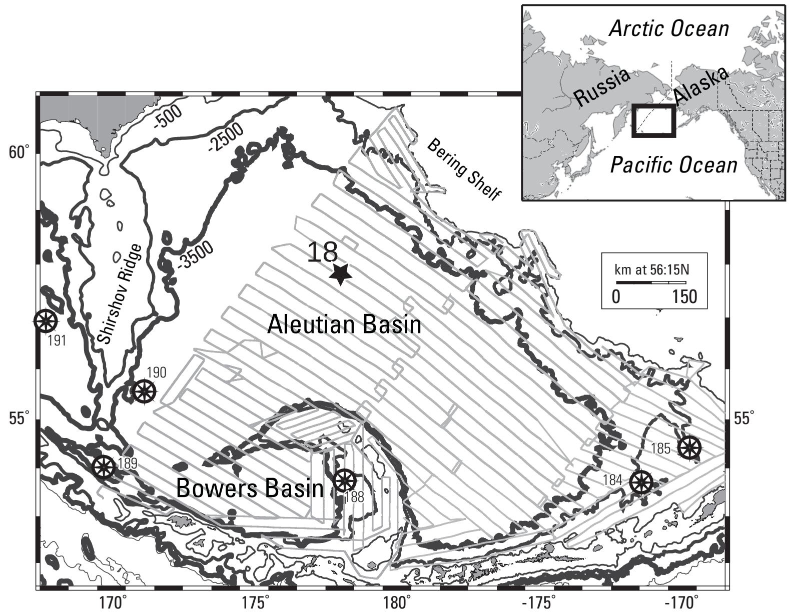
VAMP anomaly interpretation. Sedimentary horizons (dashed lines) are drawn as they appear in seismic-reflection data. Scientists attribute horizon distortions largely to variations in velocity of sound through layers. BSR, bottom-simulating reflection, above which methane occurs as methane hydrate, and below which it occurs as pore-filling gas. Methane hydrate forming "cap" of mushroom (gray shading) is generally most concentrated (darkest shading) just above BSR.

(Bering Sea Methane continued from page 6)

form in which methane is most stable is determined by pressure and temperature. In the Bering Sea, the pressure at about 360 m below the sea floor is approximately 400 bars, and the temperature approximately 24°C. Below this “transition depth,” higher temperatures cause methane to exist as a gas in pores in the sediment. Above the transition depth, lower temperatures and moderate pressures cause methane to exist as methane hydrate.

A white, icelike solid, methane hydrate yields about 164 volumes of free gas per unit volume of hydrate at room temperature and pressure (where the hydrate is unstable). Where temperature and pressure conditions are favorable, methane hydrate occurs in marine sediment as either massive accumulations (as shown in photograph) or pore-filling deposits.

Sound waves travel faster through methane hydrate than through water-filled sediment, and slower through gas-filled sediment than through water-filled sediment. Because of these acoustic-velocity differences, seismic-reflection horizons appear to bow upward where methane hydrate occurs, and downward where pore-filling methane gas occurs. The mushroom-like VAMP structures are thus believed to be acoustic images of large deposits of methane hydrate (the cap of the mushroom) directly overlying chimneys of ascending fluids carrying methane gas (the stem of the mushroom). The methane that forms VAMP structures is believed to be generated largely by thermal decomposition of organic matter in sedimentary deposits deeper within the sedimentary basin.



Bering Sea, North Pacific Ocean. Bathymetric contour lines are in meters, with the darkest line representing 3,500-m water depth. The deep Aleutian and Bowers Basins lie at approximately 3,600- to 3,900-m water depth. Star, location of VAMP example; circled stars, nearest drilled wells, from Deep-Sea Drilling Program (DSDP) leg 19. Tracklines (gray) represent approximately 24,000 km of digitally recorded USGS single-channel seismic data.

Chunks of gas hydrate recovered from the Gulf of Mexico in 2002 (see “Gas Hydrate Studied in the Northern Gulf of Mexico” in Sound Waves*, September 2002, at URL* ***http://soundwaves.usgs.gov/2002/09/****). Photograph by* ***Bill Winters****, USGS.*

Thousands of VAMPs occur in the Bering Sea. New analyses by the USGS show that a single large VAMP structure involves a volume of methane equivalent to that of a large conventional gas field (approx 0.6-0.9 trillion ft^3). If the hydrate hypothesis is correct and VAMP structures do indeed represent occurrences of methane hydrate and gas, then the potential total inventory of natural gas in the deep Bering Sea is enormous. The remoteness and depth of these deposits, however, make economic extraction implausible in the foreseeable future.

For more information about USGS study of the Bering Sea VAMPs, see “Possible Deep-Water Gas Hydrate Accumulations in the Bering Sea,” by **Ginger Barth**, **Dave Scholl**, and **Jonathan Childs**, in the Fall 2006 issue of *Fire in the Ice*, the National Energy Technology Laboratory’s Methane Hydrate Newsletter (URL **http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/newsletter/newsletter.htm**). In addition, an informative article about **Scholl’s** talk to the Alaska Geophysical Society was written by **Alan Bailey** for the January 21, 2007, issue of *Petroleum News* (URL **http://www.petroleumnews.com/pnfriends/286678373.shtml**). ☸

Outreach

From the Beach to Broadway—USGS Extreme Storm Group Donates Equipment to Local Nonprofit Theater

By Dennis Krohn

Aerial view of the Strand in Myrtle Beach, S.C., in 1996, shot during an early USGS storm-response mission, using the donated video camera. The USGS storm-response team has been conducting aerial surveys for more than 10 years (see URL ***http://coastal.er.usgs.gov/hurricanes/oblique.html****).*

The U.S. Geological Survey (USGS) was able to donate some of its older, professional-grade video equipment to a local nonprofit theater in St. Petersburg, Fla. "That is exactly the kind of video equipment we have been looking for," said **Andy Orrell**, marketing director of the American Stage Theatre Company. "It has been on our wishlist for a long time."

The large camera was used in some of the earliest flights by the USGS Hurricane and Extreme Storm Impact Studies project to map coastal features altered by Hurricanes Fran and Bertha. It was later replaced by a smaller digital video camera that works better within the confined spaces of an aircraft. Donation of the older camera to the local theater company was made possible by provisions in USGS regulations that allow donations to schools and educational nonprofit organizations. The donated camera will be used to make high-quality videos of the theater group's productions for archival, educational, and promotional use.

For more information about the American Stage Theatre Company, visit URL **http://americanstage.org/**. For more information about oblique aerial and video photography by the USGS Hurricane and Extreme Storm Impact Studies project, visit URL **http://coastal.er.usgs.gov/hurricanes/oblique.html**.

Meetings

Getting to Know ET (Evapotranspiration)—USGS Shares Expertise About this Important Component of the Hydrologic Cycle in Florida

By David Sumner and Ann Tihansky

The hydrologic cycle describes the various states of water as it moves through a landscape, transforming from liquid to gas and back to liquid again. Water moves from precipitation as rain, snow, and fog into ponds, lakes, and rivers; some infiltrates into the ground as ground water. Most precipitation in Florida returns to the atmosphere by way of evapotranspiration (ET), a term for the combined processes of evaporation and transpiration. Evaporation occurs directly from free-water surfaces, such as lakes, streams, and temporary rainfall accumulations (puddles on a sidewalk, for example, or droplets on top of a leaf); transpiration occurs as plant roots extract water from the soil and release water vapor into the atmosphere through plant-leaf stomata.

ET rates can vary depending on meteorological conditions, the type of land-surface cover (paved, wetland, wooded, agricultural, and others), the time of day, the time of year, and soil moisture. In spite of the relative importance of ET within the

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Typical ET tower; the USGS maintains stations like this in several different types of landcover. Here, ***Amy Swancar*** *services an ET field-data station in an orange grove in Arcadia, Florida.*

(ET in Florida continued from page 8)

hydrologic cycle—after rainfall, it is the largest component of the water budget—reliable data for ET have historically been scarce. Strategic water management requires quantification of ET for reliable hydrologic analyses. The U.S. Geological Survey (USGS) currently operates 13 ET stations throughout Florida in various environmental settings; the stations measure ET at daily or shorter time scales. Another 6 stations are scheduled for installation in 2007.

The USGS Florida Integrated Science Center (FISC) office in Orlando hosted an ET workshop on November 13, 2006, to share ET information and to discuss plans for future partnerships and collaboration. More than 40 scientists, regulators, and technical managers representing the USGS, the Florida Water Management Districts, the Florida Department of Environmental Protection, Tampa Bay Water, and eight universities attended the meeting. They gathered to discuss the results of an effort to estimate ET rates throughout Florida, using a combination of satellite- and weather-station meteorological data.

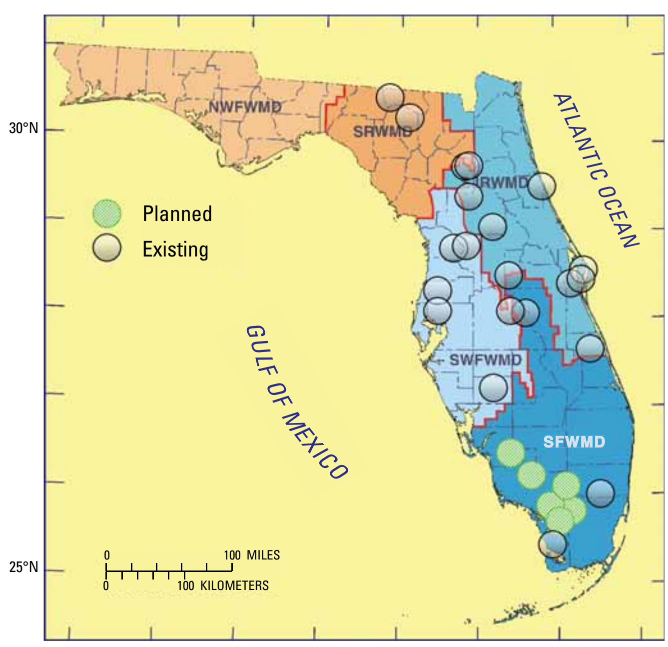
FISC director **Barry Rosen** opened the meeting with an overview of FISC, explaining how the center is organized and how it integrates geology, biology, and water science in studies that cover a range of topics—water quality and availability; the effects of invasive species; natural hazards and associated coastal processes; and interaction among ground water, surface water, and ecosystems, to name a few. After **Rosen's** welcome, USGS hydrologist **David Sumner** introduced the focus of the meeting with a comprehensive talk titled "Evapotranspiration Measurement and Estimation in Florida—State of the Art and Future Directions."

*Hydrologist **Ann Tihansky** uses climbing gear to access instrumentation on an ET tower. All staff who service these stations have been trained in climbing safety and use standard safety climbing gear.*

Sumner, who organized the meeting, has been managing a project to produce a database of daily ET rates covering the entire State of Florida at 2-km resolution; this database is expected to be used widely by water-resource planners and regulators. University scientists conducted the research used to generate the database, and several of them—**Jennifer Jacobs** of the University of New Hampshire, **Ellen Douglas** of the University of Massachusetts, and **John Mecikalski** and **Simon Paech** of the University of Alabama, Huntsville—presented results at the meeting. Validation data for the ET database project were provided primarily by USGS ET field stations operated by **Sumner**, **Ed German** (retired), **Amy Swancar**, and **Trey Grubbs**. Future plans are for the USGS to maintain and update the ET database in a Web-deliverable manner.

The November meeting was funded by all five Florida State Water Management Districts, which also provided funding for the ET database project. Representatives of three of the five districts gave talks at the meeting, including a proposal for State-wide coordination of ET research and data-collection programs.

Originally conceived as a simple project meeting, the November gathering ended up with a larger scope, providing a focal point to further the development of a State-wide, coordinated approach to ET research in Florida. ☸



Existing and planned evapotranspiration (ET) stations in Florida in May 2006. Each station is operated collaboratively or solely by the USGS, the Smithsonian Environmental Research Center, Dynamac Corp., the University of Florida, the University of New Hampshire, or the University of Virginia. Abbreviations: NWFWMD, Northwest Florida Water Management District; SRWMD, Suwannee River Water Management District; SJRWMD, St. Johns River Water Management District; SWFWMD, Southwest Florida Water Management District; SFWMD, South Florida Water Management District.

International Workshop on High-Seas Biogeography Held in Mexico

By Kathy Scanlon

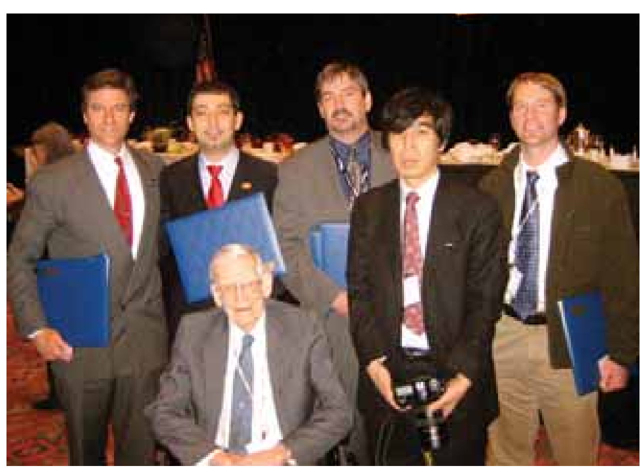
*Members of the "Benthic" working group at the Marine Biogeography Workshop pose around a projected map showing the rough results of the day's discussions on how to define biogeographic zones in the world ocean. USGS marine geologist **Kathy Scanlon** is second from right.*

A Scientific Experts' Workshop on Biogeographic Classification Systems in Open Ocean and Deep Seabed Areas Beyond National Jurisdiction was held at the Universidad Nacional Autónoma de México in Mexico City, Mexico, from January 22 to 24, 2007. U.S. Geological Survey (USGS) marine geologist **Kathy Scanlon** joined about 30 other scientists from around the world to begin developing a comprehensive biogeographic classification of open-ocean and deep-seabed areas beyond national jurisdiction, based on the latest information available from expert scientists. Establishing a biogeographic classification system is widely viewed as an essential first step toward integrated oceans management because it helps us understand how and where species are distributed, and provides a basis for the study, conservation, and management of ocean resources. In the open ocean and deep seabed, biogeographic classification systems are far less developed than in terrestrial, coastal, and continental-shelf areas, where biogeographic maps have long helped support ecosystem-based management.

Over the next year, the workshop participants will build on existing relevant global and regional data sets and utilize the experience of coastal states and regional management bodies to develop a worldwide high-seas biogeographic classification system. The resulting classification will assist international and regional management bodies to establish sound and equitable management policies with a scientific foundation.

The workshop was sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO)'s Division of Ecological and Earth Sciences (URL **http://www.unesco.org/science/earth/**), the Universidad Nacional Autónoma de México (UNAM, URL **http://www.unam.mx/english/**), Mexico's National Commission for the Knowledge and Use of Biodiversity (CONABIO, URL **http://www.conabio.gob.mx/**), UNESCO's Intergovernmental Oceanographic Commission (URL **http://ioc.unesco.org/iocweb/index.php**), and IUCN-The World Conservation Union (URL **http://www.iucn.org/**). The Governments of Australia and Canada and the J.M. Kaplan Fund (URL **http://www.jmkfund.org/**) provided financial support for the workshop. ☸

USGS Researcher Receives Award from the American Society of Civil Engineers



*Award recipients (standing, from left to right): **Rob Kayen**, **Onder Cetin**, **Les Harder**, **Kohji Tokimatsu**, and **Robb Moss**, with ASCE Honorary Member **Ralph Peck** (seated); not present: **Raymond Seed** and **Armen Der Kiureghian**.*

U.S. Geological Survey (USGS) scientist **Robert Kayen** was among a group of researchers who received the Thomas A. Middlebrooks Award, the highest award for geotechnical engineering research given by the American Society of Civil Engineers (ASCE). The researchers developed new correlations for probabilistic assessment of the likelihood of triggering earthquake-

(Middlebrooks Award continued on page 11)

(Middlebrooks Award continued from page 10)

induced soil liquefaction. These modeled relationships greatly reduce the uncertainty in predicting seismic soil liquefaction. The awardees represent a range of institutions in several countries: the Middle East Technical University (Ankara, Turkey), the University of California, Berkeley; the Tokyo Institute of Technology; the California Department of Water Resources; the USGS; and California Polytechnic State University, San Lius Obispo.

The Thomas A. Middlebrooks Award is given to researchers by ASCE for a paper judged worthy of special commendation for its merit as a contribution to the field of geotechnical engineering. ASCE presents only one Middlebrooks Award annually. **Rob Kayen** and his colleagues received the award on February 21, 2007, in Denver, Colorado, at the national meeting of the GeoInstitute, one of seven specialty institutes of ASCE.

The citation of the paper for which the group received the Middlebrooks Award is:

Cetin, K. Onder, Seed, Raymond B., Der Kiureghian, Armen, Tokimatsu, Kohji, Harder, Leslie F. Jr., Kayen, Robert E., Moss, Robert E.S., 2004, SPT-based probabilistic and deterministic assessment of seismic soil liquefaction potential: Journal of Geotechnical and Geoenvironmental Engineering, v. 130, no. 12, p. 1314-1340.

USGS Sirenia Project Receives Manatee Hero Award

By Hannah Hamilton

The U.S. Geological Survey's (USGS) Sirenia Project was presented with the Save the Manatee Club's Manatee Hero Award in December 2006. The award was given in appreciation of the project's "contribution to the protection of manatees." As the club celebrated its 25th anniversary, it took the opportunity to "honor a select group of very special people and organizations who have contributed to the protection of manatees."

Established in 1981 by former Florida Governor and U.S. Senator **Bob Graham** and singer/songwriter **Jimmy Buffet**, the Save the Manatee Club was created so that the public could participate in manatee-conservation efforts to save endangered manatees from extinction. Federally listed as an endangered species in 1967 (under a law preceding the Endangered Species Act of 1973), West Indian manatees are also protected by the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973. Protection of the manatee at the State level began in 1893 when the Florida Legislature passed a law to protect these marine mammals.

"It has been my great pleasure to have worked for more than 30 years with the Sirenia staff," said **Patrick Rose**, Executive Director of Save the Manatee Club. "I find it hard to imagine a more committed, imaginative, or qualified group of scientists and associates who have contributed so much both to our base of knowledge and to the welfare of endangered manatees. They are true Manatee Heroes."

*Sirenia Project staff, from left to right: **Jim Reid, Howard Kochman, Cathy Beck, Brad Stith, Cathy Langtimm, Amy Teague, Gaia Meigs-Friend**, and **Bob Bonde**. Not pictured: **Susan Butler, Dan Slone**. Photograph courtesy of USGS Sirenia Project.*

This long-term relationship has been beneficial for both organizations.

"The club has been supportive of our research since their formation in 1981," said **Cathy Beck**, a Sirenia Project researcher with the USGS Florida Integrated Science Center. "They have assisted us on various research efforts and have forwarded relevant manatee observations and information from their members. The club staff has communicated with us over the years on numerous manatee-research issues, and their support of the efforts to document and better understand the challenges to manatee recovery is commendable."

According to **Beck**, "The many challenges facing manatees in their immediate and long-term future necessitates continued research. Limits to habitat availability and quality, and research on manatee population growth and distribution through analysis and modeling of genetic and photo-identification data, will likely be at the forefront of research efforts."

USGS Sirenia Project data are used in the implementation and assessment of Florida manatee-population-recovery plans. The USGS uses satellite telemetry and global-positioning-system (GPS)

(Manatee Heroes continued on page 12)

(Manatee Heroes continued from page 11)

technology, a digital catalog of individual manatees identified by their unique scars, genetic analysis, and microhistology to study:

- Movement patterns and identification of significant manatee habitats
- Reproduction and survival
- Population status and trends
- Population structure
- Diets of manatees in high-use habitats

Manatee moving along the bottom, using its flippers. Photograph courtesy of USGS Sirenia Project.

The USGS works in partnership with other Federal and State agencies, and private organizations such as the Save the Manatee Club, to study manatee life history, behavior, ecology, and population biology.

Save the Manatee Club is a membership-based, national nonprofit organization. Funds from the Adopt-A-Manatee program go toward public awareness and education projects, manatee research, rescue and rehabilitation efforts, and advocacy and legal action in order to ensure better protection for manatees and their habitat.

These large, gentle, herbivorous, and slow-moving mammals are entirely aquatic. The West Indian manatee has two subspecies: the Florida manatee (*Trichechus manatus latirostris*) and the Antillean manatee (*Trichechus manatus manatus*). West Indian manatees have a geographic range that includes the Southeastern United States, the Caribbean Islands, eastern Mexico, Central America, and the north coast and rivers of South America. Manatees cannot survive for extended periods in water colder than about 17°C (63°F), and prefer temperatures warmer than 22°C (72°F), which limits their habitat range.

Manatees and their closest relative, the dugong, are in the Order Sirenia; their ancestors evolved from four-footed land mammals more than 60 million years ago. The major threats to manatee survival are human activities: boat-related injuries and deaths, habitat loss or degradation, and, in some countries, hunting.

For more information about the Save the Manatee Club, visit URL **http://www.savethemanatee.org/**. For more information about the USGS Sirenia Project, visit URL **http://cars.er.usgs.gov/Manatees/manatees.html**. ☸

*A capture at Port of the Islands. Boat has been pulled stern-first into shore for processing (measurements, tagging, photographs, and so on). **Brad Stith** is at the stern in blue jacket and purple cap, **Susan Butler** is at the manatee's tail in USGS T-shirt, and **Jim Reid** is at the bow in T-shirt and cap.*

***Jim Reid** and **Susan Butler** fastening radio tag and belt to a scarred manatee in Everglades National Park.*

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