National Ocean Partnership Project Advances Real-time Coastal Ocean Forecasting

PAGES 145, 150

A 1999-2000 National Ocean Partnership Project (NOPP) has demonstrated highly accurate predictions of ocean temperatures, currents, and surface elevation through a model that integrates the state of the ocean to routinely produce real-time nowcasts and forecasts. The success is attributed to a new technology for model-assimilation of satellite-derived surface observations with observations from in situ equipment.

Because the Chesapeake Bay and the northwestern Atlantic boarding the east coast of the United States is an area of intense ocean harvest, recreational boating, and major shipping —activities that depend on near-term prediction of near-surface conditions of the waters off the eastern coast—it served as the test-bed for the "Coastal Marine Demonstration Project" (CMDP). The project showed that the assimilation of data available in real-time can produce ocean fields that agree well with independent observations, which is an exciting development for mesoscale ocean forecasting.

Successful prediction of the ocean state with a numerical model has lagged far behind atmospheric weather prediction despite the availability of satellite measure-ments and imagery of ocean surface conditions. This has been due to the lack of subsurface data and the need for a suitable method-ology for multi-level assimilation of available observations.

Knowledge of present and near future temperatures in the upper, nutrient-rich levels of the ocean is of vital interest to the fishing industry. Knowledge of near-surface currents and sea-surface height is vital for the navigation planning of recreational boaters, ocean transport vessels, and Coast Guard search and rescue operations.

Obtaining accurate nowcasts and forecasts by effectively coupling high-resolution models with real-time data from atmosphere- and ocean-observing platforms has been a challenging problem both scientifically and technically. High-resolution ocean modeling and the assimilation of ocean data are extremely complex undertakings, especially for the Atlantic with the strong gradients of the Gulf Stream. Direct measurements of ocean currents are virtually nonexistent and reports from subsurface observing platforms are few and far between.

Space-based observing platforms provide much of the available information about ocean conditions, and inferential/statistical relationships between remotely observed and ocean variables allow this data to be interfaced with ocean models using newly developed data assimilation technology.

Impacts of Assimilating Satellite Altimetry and Gulf Stream Location Data

The NOPP-funded partnership enabled a model-based coastal ocean forecast system, which has been running semi-operationally at NCEP with assimilation of surface-only temperatures, to be enhanced with the ingestion of satellite-derived data for adjustment of subsurface temperature and salinity values. The new algorithm assimilates data on the location of the north wall of the Gulf Stream (NWGS) and sea-surface height anomalies (SSHAs) derived from TOPEX altimeter reports, in addition to sea-surface temperature data. In the deep ocean, changes in SSHAs reflect internal changes in vertical temperature structure. The SSHA assimilation algorithm is based on the statistical, vertical coupling of SSHA with subsurface temperature anomalies, where the immediate impact of the assimilation is felt. Model dynamics distribute the anomalies' influence back toward the surface.

The surface height field, the 1-m current field, and the 100- and 200-m temperature fields show significant impact of the newly ingested data. Most profound is the appearance of cold and warm pools in nowcast and forecast temperature fields and eddies in 1-m velocity fields; these are not evident in the control-model output. The existence of the cold and warm pools was verified through comparison with GOES images.

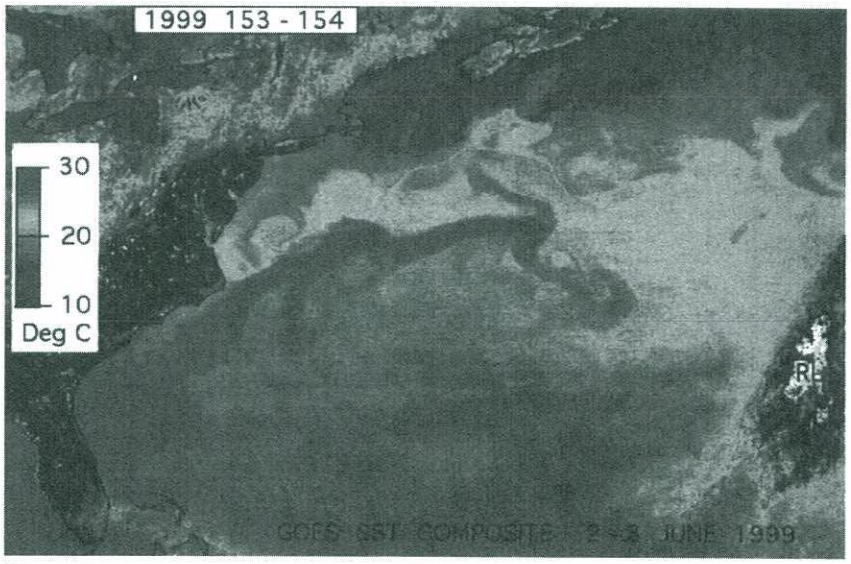
Figures 1a and 1b show velocity fields for the two versions of the model. Figure 1a shows the 1-m velocity field produced by the control run with temperature-only assimilation, and Figure 1b displays the product of the run with additional assimilation of SSHA- and NWGS-location data. Figure 1c shows independent data from the imager on the GOES-8 satellite. The surface velocity field derived after inclusion of the TOPEX data reveals an anti-cyclonic eddy just north of the Gulf Stream, centered at 39.5°N and 65°W, which is not present in the control-run velocity field. In the GOES image for the same date this eddy appears as a meander about to pinch off from the Gulf Stream.

The positive impact of the assimilation of SSHA- and NWGS-location data on subsurface temperatures has also been verified by comparing model-temperature profiles with temperature profiles from independent bathythermograph reports (For example, see Figure 2). For the model that assimilates TOPEX data through the correlation structure of SSHA and subsurface temperature anomalies, model-temperatures at greater depth are significantly closer to the direct measurements of subsurface instruments than those derived by the model that uses surface-only assimilation.

Both results signify that a major step has been made in real-time ocean prediction, through the cooperative efforts of NCEP and Princeton University.

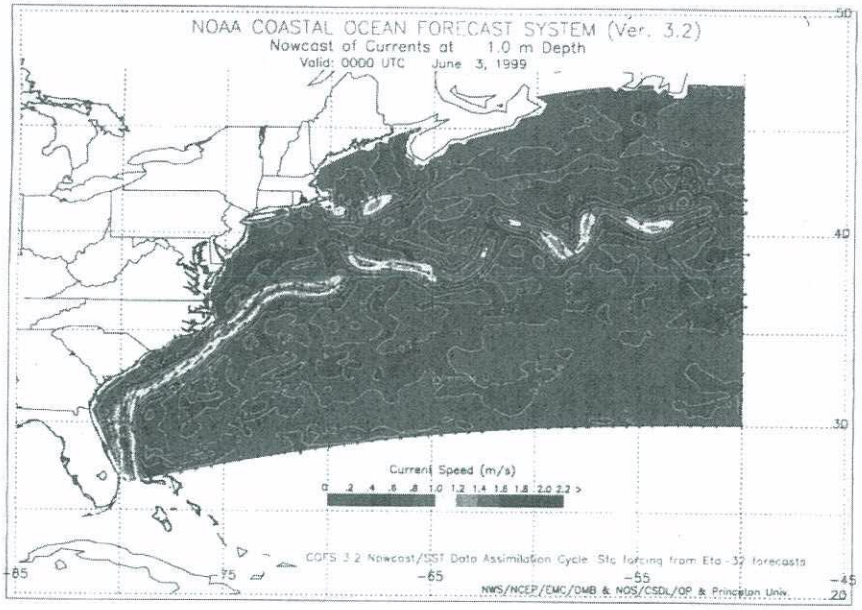
In the first demonstration period, which took place in June and July of 1999, real-time ocean nowcast and forecast products were provided on a public-access Web site and practical evaluation of their utilities was solicited from the marine community. A second demonstration period, scheduled for February and March of 2000, will allow winter testing with product and delivery improvements based on the feedback of the first period.

NCEP's Coastal Ocean Forecast System (COFS) is an experimental system based on the Princeton Ocean Model [*Blumberg and Mellor*, 1987], with wind forcing and energy fluxes from NCEP's high resolution, regional atmospheric Eta model [*Black*, 1994]. Assimilation of surface temperatures from the Advanced Very High Resolution Radiometer ships and buoys uses the technique of Kelley, Behringer, and Thiebaux [1999]. Altimeter and NWGS-location data is assimilated with an

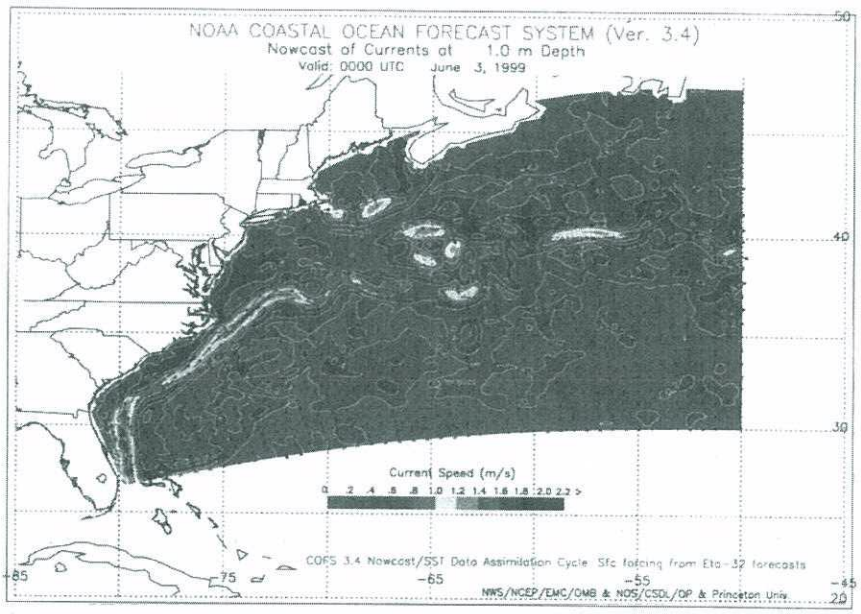


a

Fig. 1. (a) Velocity field at 1 m depth, June 3, 1999, produced by COFS with surface temperature assimilation only. Original color image appears at the back of this volume.



b



c

Fig. 1. (b) Velocity field at 1 m depth, June 3, 1999, produced by COFS with additional assimilation of surface heights derived from TOPEX altimeter data and the NWGS-location data. (c) GOES-8 composite temperature image for the northwest Atlantic, with June 2 and 3 data, from Richard Legeckis, Office of Research and Applications, NESDIS. Original color image appears at the back of this volume.

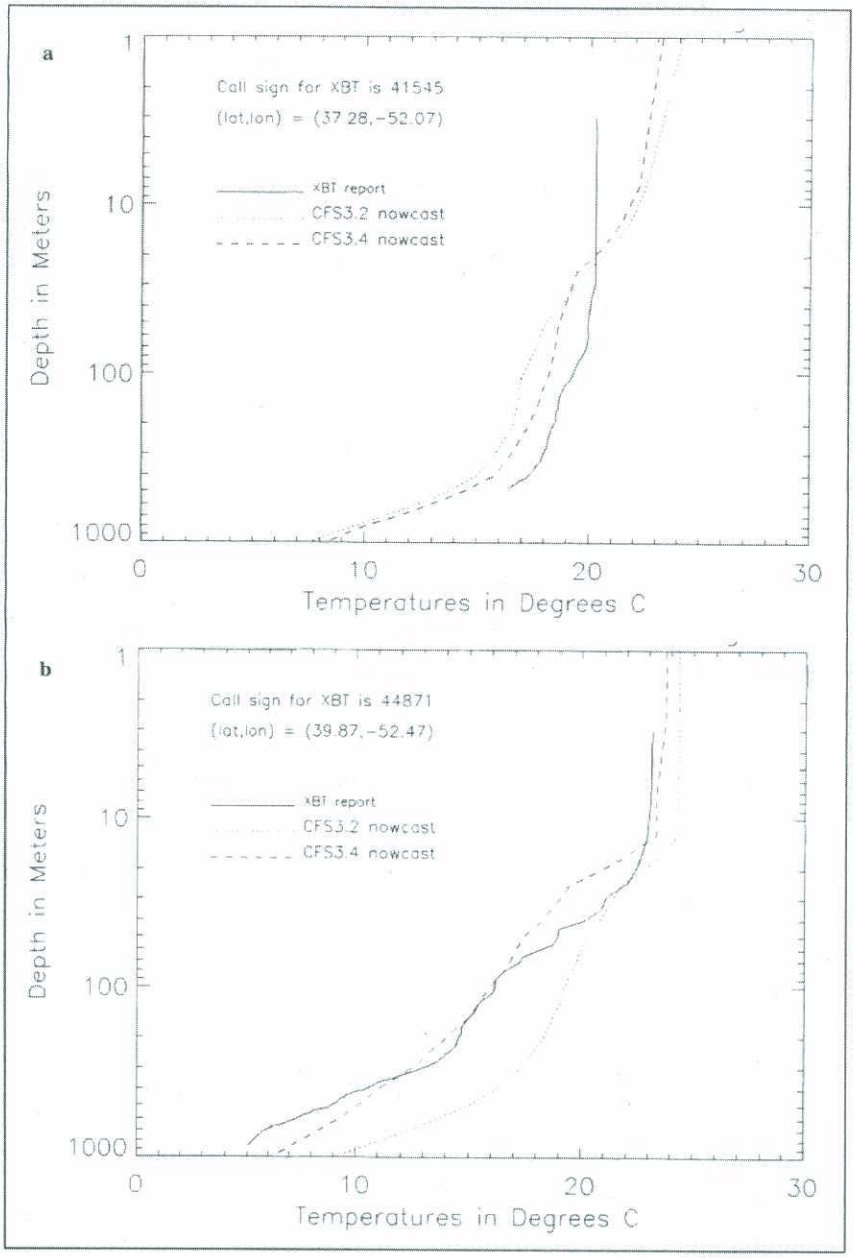


Fig. 2. XBT and COFS temperature soundings, in which CFS3.2 is the control, with assimilation of surface temperatures only and CFS3.4 is run with addition of TOPEX and NWGS data. a) Data for 37.28°N, 52.07°W, on May 17, 1999; b) Data for 39.87°N, 52.47°W, on July 5, 1999.

algorithm developed by G. L. Mellor, T. Ezer, and N. Kim (personal communication, 1998).

Acknowledgments

This work was supported in part by the National Ocean Partnership Program in a cooperative agreement with the University of Maryland, Horn Point Laboratory, Princeton University, and the National Ocean Service.

We are pleased to acknowledge the excellent cooperation of NOAA's Laboratory for Satellite Altimetry, from which we now receive timely, quality-controlled data; the input of the Princeton team that created a smooth transition to a combined assimilation system; Richard Legeckis, Ocean Research and Applications Division, NESDIS, for the confirming evidence of his composite, cloud-cleared images.

Authors

Jean Thiebaux, Bert Katz, John Kelley, Laurence Breaker and Bhavani Balasubramaniyan
For more information, contact Jean Thiebaux, National Centers for Environmental Prediction, 5200 Auth Rd., Camp Springs, Md., 20746 USA; E-mail: Jean.Thiebaux@NOAA.gov. Thiebaux is a senior scientist with NCEP, which is an NOPP partner in this project.

References

Black, T. L., The new NMC mesoscale Eta model: Description and forecast examples, *Weather and Forecasting, 9*, 265-278, 1994.

Blumberg, A. F., and G. L. Mellor, A description of a three-dimensional coastal ocean circulation model, Three-Dimensional Coastal Ocean Models, *Coastal Estuarine Science, Vol. 4*, AGU, Washington, D.C., pp. 1-16, 1987.

Kelley, J. G. W., D. W. Behringer, and H. J. Thiebaux, *Description of the SST data assimilation system used in the NOAA Coastal Ocean Forecast System (COFS) for the U.S. East Coast*, Technical Note, U.S. Department of Commerce, NOAA, National Weather Service, Washington, D.C., 1999.

U.S EPA Science and Technology Efforts Come Under Scrutiny

PAGE 146

Two U.S. Congressional hearings in mid-March put the heat on some science and technology efforts of the U.S. Environmental Protection Agency (EPA). First, a March 22 House of Representatives Science Committee hearing focused on EPA's management of a ruling about sludge treatment and disposal. The hearing examined whether the agency has failed to foster sound science, while also allegedly harassing agency whistleblowers and some private citizens.

Then, a March 23 House Science Subcommittee hearing scrutinized the fiscal year 2001 budget authorization request for EPA's science and technology budget.

During the March 22 hearing on sewage sludge, or "biosolids," Committee Chair James Sensenbrenner, Jr. (R-Wis.) said his committee has questioned EPA's scientific process on several occasions. The committee, he said, had raised questions concerning the agency's handling of the high-production volume chemical-testing program, and whether EPA had ignored scientific evidence about the potential harm the gasoline additive MTBE—methyl tertiary butyl ether—can cause to public health and the environment.

"In both these instances, EPA appeared to care more about protecting its own regulations than ensuring adequate protection for the environment and the public's health," Sensenbrenner said. "Without confidence in EPA's scientific process, states, localities, and wastewater treatment plants will have an increasingly difficult time convincing farmers and the public to accept EPA's word on the safety of land application of processed sewage sludge."

Several witnesses, though, vigorously defended EPA's scientific process. They also supported the sludge rule—enacted in 1993 and commonly referred to as the Part 503 rule of Section 405 of the Clean Water Act—and land application as one good way to handle some of the eight million dry metric tons of biosolids produced annually in the United States.

"EPA is implementing an effective program to assure the safe and proper management of biosolids generated by the nation's sewage treatment plants," said Charles Fox, EPA assistant administrator for water. "The agency used the best available science to implement Section 405 of the Clean Water Act." Fox described the agency's complex risk assessment of sludge and internal and external review processes. He added that the agency had followed a deliberative and open process to develop national regulations for biosolids use and disposal to protect public health and the environment, and that EPA is open to further discussion on the issue.

At the March 23 hearing, the House Science Subcommittee considered EPA's science and technology budget request. That request includes $492 million—a 7.8% reduction from last year's enacted budget—for EPA's Office of Research and Development (ORD). The number increases by $35.9 million when funding allocated for the Superfund Program to locate, investigate, and clean up hazardous waste sites is figured in.

EPA's total science and technology budget request calls for $674.3 million—a decrease of 1% before Superfund money is added—of the agency's overall $7.3 billion budget request.

Chair Ken Calvert (R-Calif.) criticized EPA's budget request and its adherence to the 1993 Government Performance and Results Act (GPRA), which requires agencies to establish goals for program performance.

The budget request, he said, "somewhat shortchanges science and technology at the agency.

"While the overall [science and technology] amounts are up, there are still many areas of critical research that are being shortchanged. ORD is flat-funded for FY 2001," even after some adjustments for Superfund funding, he said. Calvert contrasted ORD with the Office of Air and Radiation (OAR), whose budget would increase by $21.6 million or 20% above last year's appropriation.

Agency Defends Science Research

Norine Noonan, assistant administrator for research and development at EPA, said ORD resources focus on a carefully targeted research program. Clinton Administration research priorities for fiscal year 2001 include chronic epidemiology research concerning particulate matter; drinking water research into unregulated contaminants; and global change research assessments on human health, air and water quality, and ecosystem health.

ORD, she added, also maintains goals in other areas, including preventing pollution and reducing risk, better waste management, reducing global and transboundary environmental risks, research into emerging risks such as endocrine disrupting chemicals and mercury, and sound science.

"I would like to emphasize ORD's commitment to not only provide the sound science to support EPA's regulatory mandates, but to assume the national leadership in producing the knowledge that will help us solve the critical problems of the 21st century," Noonan told the committee. "Sound science, on a founda-tion of rigorous peer review, remains a critical mainstay of our work," she added. "While conducting sound science is the foundation for our success, producing results in a timely fashion to solve problems is the measure of our success."

In his testimony, William Seeker, chair of EPA's Research Strategies Advisory Committee (RSAC), gave the agency generally high marks for its budgetary priorities, efforts toward reaching decisions based on sound science, and progress in following GPRA standards.

Seeker agreed with the agency's increased science emphasis on the epidemiology of particulate matter, drinking water Candidate Contaminant List (CCL) pollutants, ecosystem research and monitoring, global change assessment, and other issues.

However, he said the advisory committee is concerned about whether EPA's overall science and technology budget is adequate to address complex environmental issues, including research into tropospheric ozone, combustion science, and ecosystems.

Seeker also expressed concern about insufficient funding for several potentially high-risk areas—including naturally occurring radioactive material, and non-aqueous phase liquids remediation technologies—and an overemphasis on shorter-term issues in the yearly budget planning process.

RSAC "believes that emerging issues need to have ongoing stable support, because EPA is the key agency responsible for aggressively watching for critical new environmental threats to human health and to ecosystems," he said.

RSAC also reviewed whether EPA's science is strong enough to stand up to peer review. "The credibility of science used by EPA to support its decisions has been called into question over the last several years as more controversial issues and more subtle health and ecological effects have been investigated," Seeker said. "We found the EPA's peer review process to be well articulated and that it appears to be fundamentally sound and, with a few exceptions, working as intended."

Seeker told *Eos* that although the agency deals with many controversial issues, its current peer review policy—which he termed as "rigorous"—can help to circumvent criticism.

"One of the easiest things to attack is, 'is the science credible?' If you can attack that, that is a potential weak point of finally establishing the policy," said Seeker. "So, I think it is just a mechanism by which you can attack controversial issues."

One of those more controversial issues, Seeker added, has been the agency's regulatory efforts concerning particulate matter. Seeker said the agency's science, in this instance, was not attacked for lack of credibility. "But the fact that there was not enough science, perhaps, has resulted in some challenging policies and procedures," he said. "It is a matter of trying to make sure that we understand [potential scientific relationships between particulate matter and health effects], before a very expensive regulation could be established."

Seeker added that RSAC evaluates EPA's science process and provides advice for improving the process, but that the advisory committee has never questioned the credibility of EPA's science.

During the March 23 hearing, Rep. Calvert also criticized EPA's implementation of GPRA, and the agency's confusing budget reports. "As an experiment in strategic goal-based budgeting, perhaps [GPRA] has been a success. In providing the Congress and the American people with an informative and useful budget document, it has been, and continues to be, a failure," he said. "It is impossible to determine what each program will be spending and where."

Both Noonan and Seeker said EPA is making progress in implementing GPRA, though further steps need to be taken.

David Wood, associate director of environmental protection issues at the U.S. General Accounting Office, added, "It would behoove EPA, or other agencies, to say, 'will this be clear to people on [Capitol] Hill and any other users of the document?'"

For more information, visit the EPA Web site at http://www.epa.gov, and the House Science Committee Web site at http://www.house.gov/science.

Randy Showstack, Staff Writer

GEOPHYSICISTS

PAGE 149

Honors

Peter A. Rona has been awarded the Hans Pettersson Bronze Medal of the Royal Swedish Academy of Sciences. The medal recognizes a scientist who conducts work "in the spirit of Hans Pettersson." Pettersson directed the global Swedish Deep Sea Expedition, which is known as one of the foremost expeditions in oceanography history. Rona has also directed teams of scientists in exploring the deep sea floor. His work has led to the discovery of the first hot springs, new life forms in the deep Atlantic, and the development and application of methods to determine the impact of hot springs on the oceans.

Rona is professor of marine geology and geophysics at Rutger's Institute of Marine and Coastal Sciences with a joint appointment in the Geology Department. Rona is an AGU member (Oceanography–Marine Geology and Geophysics) who joined 1965.

The National Academy of Sciences will honor George W. Wetherill and Gilbert F. White at an awards ceremony on May 1, 2000. **George W. Wetherill** will be awarded the J. Lawrence Smith Medal, along with a prize of $20,000, for "his unique contributions to the cosmochronology of the planets and meteorites and to the orbital dynamics and formation of solar system bodies." The medal, presented since 1888, is given for recent original and meritorious investigations of meteoric bodies and was established as a gift from Sarah Julia Smith in memory of her husband. Wetherill is with the Department of Terrestrial Magnetism, Carnegie Institution of Washington. He is an AGU Fellow and has been a member (Planetology) since 1961.

Gilbert F. White will receive the 2000 Public Welfare Medal "for 65 years of educating colleagues, students, and governments—through research, institution-building, and policy analyses—on how to change the ways we manage water resources, mitigate hazards, and assess the environment, enabling people to aspire to a more humane coexistence with the natural world." This medal was established to recognize distinguished contributions in the application of science to public welfare and has been presented since 1914. White is Gustavson Distinguished Professor Emeritus of Geography, University of Colorado, Boulder. He is an AGU Fellow and has been a member (Hydrology) since 1936.

SECTION NEWS

HYDROLOGY

Editor: *Roger C. Bales, Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721-0011 USA; Tel: +1-520-621-7113; Fax: +1-520-621-1422;* **Section President**, *Soroosh Sorooshian;* **Section Secretary**, *Marc B. Parlange*

Outstanding Student Paper Awards

PAGES 148–149

The Hydrology Section presented fifteen outstanding student paper awards at the 1999 Fall Meeting in San Francisco, California, last December.

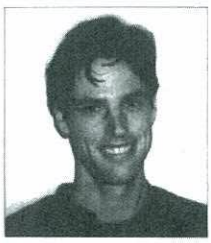
Ji Chen presented a poster titled "Influence of Topographic Attributes in the Prediction of Water and Energy Fluxes: A Study Using Large-Area Basin-Scale (LABs) Model." Ji received his B.E. and M.E. in hydraulic engineering from Tsinghua University, China, in 1993 and 1996, respectively. He is currently working toward his Ph.D. in the Department of Civil and Environmental Engineering under the supervision of Professor P. Kumar at the University of Illinois at Urbana-Champaign. Ji's research interests focus on land-atmosphere interactions and the global hydrologic cycle.

Alison K. Gee presented a paper titled "The Novel Use of Stable Isotopes and HR-ICPMS to Trace Adsorption/Desorption Equilibrium and Kinetic Partitioning of Ni, Cu, and Zn with Natural Particles from South San Francisco Bay, CA." Alison received her B.A. in environmental science from Wesleyan University in 1986. After working as an environmental consultant and a volunteer overseas, she returned to graduate school at the University of California, Santa Cruz. Alison is currently finishing her Ph.D. in the UCSC Earth Sciences Department, working with Professor Kenneth Bruland. Her research interests focus on the chemical controls of trace metal partitioning and cycling between dissolved and particulate forms in natural and contaminated aquatic systems.

Eric J. Henry presented a paper titled "Vadose Zone Drainage Caused by an Advancing Contaminant Plume." Eric received his B.S. and M.S. in civil engineering from the University of New Mexico. He is currently completing his Ph.D. under the supervision of James E. Smith and A. W. Warrick in the Department of Hydrology and Water Resources at the University of Arizona. His Ph.D. research focuses specifically on the effect of surface-active solutes on flow and transport in the vadose zone. Eric's research interests include contaminant hydrology and vadose zone processes.

Karl Niclas Hjerdt presented a paper titled "Spatial Measurements of Groundwater Levels Shed New Light on the Pathways of Water and Solutes during Snowmelt." Niclas received his M.S. in Earth sciences/hydrology from Uppsala University, Sweden, in 1997, and his thesis was awarded a prize by the Swedish Hydrologic Council (SHR). Niclas is currently a graduate student at SUNY-ESF, Syracuse, New York, where he expects to complete his Ph.D. in forest hydrology in the summer of 2001. His work is supervised by Jeff McDonnell, Oregon State University, and Elizabeth Boyer, SUNY-ESF.

Jörn Hoffmann presented a poster titled "Seasonal Subsidence Patterns in Las Vegas Observed by Interferometric Synthetic Aperture Radar." Jörn received his M.Sc. at Stanford University in 1999, for work on volume decorrelation effects in InSAR images of vegetated terrain. He completed



his undergraduate studies a the University of Karlsruhe, Germany, where he received his Vordiplom in 1996.

Jörn is currently pursuing his Ph.D. at Stanford University and investigating applications of interferometric Synthetic Aperture Radar (InSAR) to land subsidence problems.

Sarah K. Konrad presented paper titled "Rock Glaciers: Untapped Archives of Ice-Core Paleoclimate Data." Sarah

received an A.B. in Earth science from Dartmouth College in 1989, and spent the next 5 years as an instructor for the National Outdoor Leadership School, guiding mountaineering and sea kayaking trips in Wyoming, Alaska, and Chile. She then completed an M.S. in geological science at the University of Washington in 1997, and is actively pursuing a doctorate in geology at the University of Wyoming, advised by Neil Humphrey. Sarah's research interests include quaternary geomorphology and glaciology. When not pursuing her geological interests, Sarah competes in the national cross country ski racing circuit.

Kristine M. Kuhna presented a poster titled "Bridge Runoff from a Rural California Highway as a Source of Metal Contamination in Small Streams."

Kristine received her B.S. in physics in 1998, from Alma College in Alma, Michigan. She will obtain her M.S. in environmental engineering from the University of California, Davis, in September 2000. Kristine's current research focuses on determining the impact of trace metals in highway runoff on surface water quality. Further studies will identify the best management practices to maintain the integrity of the receiving water.

Thomas S. Lowry presented a paper titled "An Improved Finite-Analytic Method for Contaminant Transport in Heterogeneous Porous Media."

Tom's educational background includes a B.A. in mathematics from the University of Colorado, and an M.S. in civil engineering from Portland State University. He is currently completing his Ph.D. in environmental engineering at Portland State. He also teaches groundwater-related courses at the university level and works part-time as a consultant. His research interests lie in developing modeling techniques to model the effects of physical and chemical heterogeneity on solute transport in saturated porous media. Tom's future plans include a position as postdoc at Lincoln Environmental in Christchurch, New Zealand.

Jeffrey M. McKenzie presented a poster titled "A High Basal Peat Hydraulic Conductivity: The Driving Mechanism for Vertical Recharge at Domed Bogs." Jeff received a B.Sc. in Earth and planetary sciences from McGill University in 1997. Currently, he is working toward his Ph.D. at Syracuse University, under the supervision of Donald Siegel. Jeff's research interests focus on wetland hydrogeology and geochemistry, solute transport, and water resources in developing countries.

Marie Mina Mitani presented a paper titled "Reactions of MTBE with Ozone and Ozone/Hydrogen Peroxide in Water: Stoichiometry, Kinetics, and By-Product Formation." Marie received a B.A. in chemistry at the University of California, Santa Cruz, and then went on to receive an M.A. in chemistry at the University of California, Santa Barbara. She is currently a Ph.D. student at UCSB in the School of Environmental Science and Management. Her research focuses on testing and creating new remediation technologies for contaminants prevalently found in the environment. Marie has tested the use of ozone and ozone/hydrogen peroxide for the oxidation of the gasoline additive MTBE, and is now working with the Materials Research Laboratory.

John M. Nadeau presented a poster titled "Stable Isotope and Herbicide Residues in Tile Drain Samples from Central New York State." John earned his B.S. in geological sciences at the University at Albany, SUNY, in May 1998, after transferring from Rensselaer Polytechnic Institute. He is currently finishing his M.S. in geological sciences at the University of Albany and intends to graduate in May. John's research project consist of two primary phases: the use of stable isotopes to trace agricultural pesticide movement in aquifers, and the use of stable isotopes to investigate localized versus regional variations of aquifer recharge. His research interests include the use of stable isotopes in hydrological applications as well as the use of conservative tracers to track groundwater containants.

Deborah K. Nykanen presented a paper titled "Nonlinear Propagation of Subgrid-Scale Rainfall Variability through the Land-Atmosphere System." Deborah received a B.C.E. in 1995, and her M.S. in 1997, from the University of Minnesota. She expects to complete her Ph.D. in civil engineering at the University of Minnesota in September 2000. Both her M.S. and Ph.D. research have been under the supervision of Efi Foufoula-Georgiou. Deborah gratefully acknowledges the support of a USDA Fellowship and the GEWEX Continental-Scale International Project.

Alyssa J. Olson presented a poster titled "Convective Transport in a Cavity/Chimney System After an Underground Nuclear Test." Currently, Alyssa is working as a graduate research assistant with Andrew Wolfsberg in the Geodynamics Group, Earth and Environmental Science Division of Los Alamos National Laboratory. Her poster presentation at the 1999 AGU Fall Meeting was co-authored with Lee Glascoe and Andrew Wolfsberg. This work is part of a large project examining contaminant transport in fractured tuff. Alyssa is also working on her M.S. in hydrology with Fred Phillips at the New Mexico Institute of Mining and Technology.

Douglas J. Sutton presented a paper titled "Interpretation of the Dipole-Flow with a Tracer Using a Streamtube Model." Doug graduated magna cum laude from Harvard University in 1994, with the highest honors in Earth and planetary sciences. He then worked for 2 years in the laboratory of Stephen Wofsy at Harvard where he managed an eddy-correlation field station as part of the BOREAS project, which studied the interaction of the boreal forest biome with the atmosphere. Doug then entered the Ph.D. program in civil and environmental engineering at Duke University where he now studies subsurface hydrology with Zbigniew Kabala.

Thorsten Wagener presented a poster titled "A Generic Rainfall-Runoff Modelling Toolbox." Thorsten obtained his B.S. and M.S. in civil engineering from the Universities of Siegen in Germany and Delft in The Netherlands, respectively. He is currently working toward a Ph.D. in hydrology