the middle dilutes and bends the slick near the bottom. Furthermore, on the right-hand side of the slick, a small eddy of 10 kilometer size can be identified from its cyclonic circulation. These results indicate that multiple SAR images overlapped in a short time can be used to derive ocean surface drift, and can help to identify oceanic processes such as currents and eddies. Since there are no in situ measurements or drifter buoy data in this Philippines coast water, further validation and calibration are definitely warranted for future study.

Other Applications

This wavelet tracking technique has the potential to be used on a variety of sensors besides SAR, under different ocean conditions, from monitoring algal blooms to ice flow drift. For these studies, several comparisons have been made with analyses from other datasets, in order to demonstrate the validity of the wavelet tracking method. For example, wavelet analysis of NSCAT, QuikSCAT backscatter and Special Sensor Microwave/Imager (SSM/I), and Advanced Microwave Scanning Radiometer (AMSR) radiation data have been used to obtain daily sea ice drift information for both the northern and southern polar regions [*Liu et al.,* 1998, 1999; *Zhao et al.*, 2002]. Overall, the comparison of scatterometers and radiometer-derived ice motion with Arctic buoy data shows good agreement.

Chlorophyll-*a* concentration images provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) and Sea-viewing Wide Field-of-View Sensor (SeaWiFS) can also be used to derive surface layer drift at a large scale [*Liu et al.*, 2002]. The surface layer drift has been derived by wavelet tracking, and major oceanographic features, such as the Gulf Stream boundary and a large cold-core cyclonic eddy south of the Gulf Stream, have been clearly identified. To validate the drift results, data from several drifter buoys were compared with the satellite-derived flow field. The qualitative comparison showed a generally consistent pattern over the east coast of the United States.

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Education and Science Connect at Sea

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In the past several decades, the scientific community's collective understanding of Earth's history and the processes that shape this dynamic planet has grown exponentially. Yet communicating the current understanding of Earth systems to the community outside of science (educators and students, policy makers, and the general public) has lagged.

In 1995, the U.S. National Academy of Sciences (NAS) led the effort to establish National Science Education Standards (http://www.nap.edu/readingroom/books/nses/), with the goal of helping all students achieve scientific literacy. Earth and space sciences are one of the eight categories of content standards. Clearly the establishment of science education standards alone will not foster a scientifically literate society, as indicated in the NAS report "Rising Above the Gathering Storm" (http://www.nap.edu/catalog/11463.html). This report, released last fall, warns that without strong steps to improve federal support for science and technology research, and science and technology education, the quality of life in the United States is threatened as the country loses its competitive edge.

Reports such as this raise awareness that the U.S. science community needs to communicate the relevancy, if not the urgency, of Earth system science to the country's youth and the broader population. Federal funding agencies have also recognized this problem, and in doing so have challenged us as scientists with a fundamental question: How can you and how do you broaden the impact of your research?

Answers could include engaging students with real data: our own, from the published literature, or from an online database. This

Fig. 1. Roberta Young (Gunn Junior High School, Arlington, Tex.), Heather Kortlandt (Ostego High School, Ostego, Mich.), and Jerry Cook (Phoenix Country Day School, Paradise Valley, Ariz.) work together to describe a sediment core, while Sharon Cooper (National Museum of Natural History, Smithsonian Institution, Washington, D.C.) and teammates (background) describe another core.

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would nurture their problem-solving skills as they learn how to evaluate and analyze data and their significance. This may also contribute to a culture of capturing and utilizing legacy data collected during research, and then made accessible in online databases.

By reaching out to teachers and informal educators, active research could reach a broader audience; kindergarten through high school (K-12) classrooms and facilities that promote lifelong learning, such as museums, nature centers, and national parks.

Lastly, providing college and university faculty with periodic release time—an occasional reduction in teaching or service responsibilities—for curriculum development that includes scientific problem–based learning activities would send a message that quality instruction is as valuable as quality research.

It is the collective responsibility of the science community to share science discoveries and advances with the public, and to show the excitement and value of the scientific process.

As an example of what can be done, the Joint Oceanographic Institutions (JOI) is actively working to facilitate and promote the links between research data and Earth system science education from the unique perspective of scientific ocean drilling. The JOI-sponsored 'School of Rock Expedition' is one model for bringing scientific discoveries and research data to the broader public through student-active learning.

The School of Rock Expedition

The School of Rock Expedition, which took place 31 October–12 November 2005, was a seagoing, hands-on discovery expedition that connected scientists and educators

Table 1. Scientific Ocean Drilling Practices and Discoveries: Connecting Themes for Educational Inquiry

Curricula Developed by Scientists for Educators	Activities Developed by Scientists for Educators	DSDP-ODP-IODP Data Used in Activities	
		Leg/Expedition	Site-Hole
1. Plate tectonics – paradigm overview *History of a program/Test of a hypothesis*	*Our Dynamic Planet* - CD* Going back to original data	DSDP 3	14, 15, 16, 17, 18, 19, 20, 21
2. Marine sediments - Lithostratigraphy *Group inquiry: what criteria would you use to describe sediment cores?* *Drilling, receiving, describing sediment core*	Intro to core flow - tour of core lab Describing core: visual core description, smear slides, *AppleCore* data entry (creation of barrel sheets) Sampling core: micropaleontology Sampling core: carbonate Marine sediments lecture	ODP 130, 145, 206 ODP 204, IODP 303 ODP 130, 145, 206	807A, 887C, 1256B 1245D**, 1308A*** 807A, 887C, 1256B
3. Microfossils - Biostratigraphy *Group inquiry: what do you need to know next?* *How old is it? Part 1*	Biostratigraphy exercises: construction of age-depth plots, calculation of sedimentation rates Sample processing in paleo lab Sand fraction under the microscope Photomicroscopy of smear slides	ODP 198, 202 ODP 204, IODP 303 ODP 204, IODP 303 ODP 130, 145, 206	1208, 1237A, 1237B 1245D, 1308A 1245D, 1308A 807A, 887C, 1256B
4. Paleomagnetism - Magnetostratigraphy *Group inquiry: what do you need to know about Earth's magnetic field?* *How old is it? Part 2* *Geomagnetic Polarity Time Scale (GPTS)*	Paleomagnetism - tour of paleomag lab Polarity reversal stratigraphy exercises: correlation to GPTS, construction of age-depth plot	ODP 198, 199, 202	1208, 1218, 1237 (1237A, B, C, D)
5. Geohydrology - Introduction to CORKS *Monitoring fluid flow at spreading centers*	CORK (Circulation Obviation Retrofit Kit) 101 lecture - Juan de Fuca Ridge	IODP 301	
6. Geophysics - Seismic stratigraphy *Why did they drill here? Site selection* *Sea level change*	Seismic reflection lecture Underway geophysics lab tour Site selection exercise 1 Site selection exercise 2 Seismic stratigraphy/Sequence stratigraphy and sea level exercise	ODP 149, 173 ODP 208 ODP 150, 174A	900, 901, 1067, 1068 1263, 1264, 1265, 1266 seismic line: 1071, 1072, 1073
7. Carbonate geochemistry	Percent carbonate analysis	ODP 130, 145, 206	807A, 887C, 1256B
8. Ocean crust *Group inquiry: what criteria would you use to describe basement cores?* *Drilling, curating, describing basement core*	Ocean crust structure lecture Describing core: visual core description, thin section photo-microscopy	ODP 206	1256D
9. Abrupt events - Deep time examples *Cretaceous/Paleogene (K/P) boundary* *Paleocene/Eocene Thermal Maximum (PETM)* *Eocene/Oligocene (E/O) boundary interval*	Abrupt events of past 71 Ma discussion K/P exercise PETM exercise E/O boundary and Oi1 event	ODP 171B, 198, 207, 208 ODP 198, 199, 208 ODP 189, 198, 199, 208	1049, 1209-1212, 1257-1261, 1262, 1267 1208-1212, 1220, 1221, 1262, 1263, 1265-1267 1168-1172, 1208, 1209-1211, 1217-1221, 1262, 1263, 1265-1267
10. Climate cyclicity *Milankovitch (orbital) cycles* *Suborbital cycles (Heinrich events, Dansgaard-Oeschger oscillations)*	Climate cyclicity discussion Milankovitch cyclicity exercises Suborbital cyclicity exercises	ODP 108, 154, 162, 177, 198, 199 DSDP 94, ODP 143B, 165	659, 929A, 983, 1089, 1208, 1218 609, 893A, 1002C
11. Post-cruise research example *Reconstructing paleoclimate*	Sediment point-count analysis and interpretation	ODP 152	919A

*CD by Don Prothero (http://oceanography.geol.ucsb.edu/Support/ODP/ODP_Description.html) **dropped core ***missed mudline core in a pilot opportunity to delve into one of the largest, yet largely untapped, geoscience databases available. It was sponsored by JOI in alliance with Texas A&M University and the Lamont-Doherty Earth Observatory of Columbia University, who jointly operate and staff the research drilling vessel *JOIDES Resolution*.

The School of Rock Expedition brought together a small but diverse group of 13 formal and informal educators in the high-powered scientific setting of the *JOIDES Resolution*. The educators were selected from a pool of 60 applicants from 37 states. The intention of the School of Rock Expedition was to expose educators to (1) the nature of scientific ocean drilling research, which depends on inquiry, technology, and teamwork of people with diverse talents and backgrounds; and (2) the wealth of data collected and discoveries made over nearly four decades of scientific ocean drilling. These educators discovered for themselves that published scientific data are accessible and applicable to the Earth system science curricula they teach in the classroom and present in museum displays.

The School of Rock Expedition was carried out during a transit of the *JOIDES Resolution* from Victoria, British Columbia, Canada, to Acapulco, Mexico, at the start of Integrated Ocean Drilling Program (IODP) Expedition 312. In addition to the 11 days at sea, the School of Rock Expedition educators and staff participated in two additional days of concluding education and assessment activities on shore. While at sea, the educators were introduced to the research tools on the *JOIDES Resolution* and were briefed on the legacy of scientific ocean drilling discoveries and results. This is a major advancement in the promotion of JOI's education and outreach goal of Teaching for Science, Learning for Life™, for which previous activities had included educational CDs and posters based on scientific ocean drilling discoveries and data, workshops, and online educational activities.

The educators worked with previously recovered sediment and basement cores and with published data from 56 drill sites from 26 scientific ocean drilling cruises to investigate a range of scientific procedures used by shipboard scientists (Table 1). These included (1) core description (lithostratigraphy; Figure 1); (2) age model development (biostratigraphy and magnetostratigraphy); (3) geophysical methods used for site selection and studies of global sea level change (seismic stratigraphy); and (4) the use of multiproxy data sets to discover past global climate change, including abrupt events, and orbital and suborbital cyclicity (using proxy data such as stable isotopes, magnetic susceptibility, and carbonate content).

The educators were also introduced to the procedures and equipment used by the ship's crew and technical staff in the course of a typical two-month expedition. They learned about (1) drilling operations; (2) core recovery, handling, and curation; and (3) the sequence of measurements, description, and analyses that constitute 'core flow.' The educators received instruction from a staff that included two scientists with extensive scientific ocean drilling experience and four education and outreach specialists, together with a team of professional marine technicians. The ship's crew and support staff shared additional insights into life at sea and the day-to-day workings of the drill ship.

Making Broader Connections

During the School of Rock Expedition, the teachers and informal educators not only were given inquiry-based experiences utilizing diverse data sets, but they also drew on their own educational expertise to transform materials developed for a college/university level into materials appropriate for the ages and audiences they teach.

One of the curriculum topics addressed in the School of Rock Expedition was History of a Program/Test of a Hypothesis (Table 1). Testing the hypothesis of seafloor spreading goes back to the start of the Deep Sea Drilling Project (DSDP), the first deep sea drilling program. But what were the initial discoveries or observations about the seafloor that were key contributions to the development of this theory? DSDP Leg 3 provided definitive proof of seafloor age relationships with respect to the mid-ocean ridge. (The undergraduate-level educational materials developed by the scientists for the School of Rock Expedition participants are available in the School of Rock Library on the JOI Learning Web page (http://www.joilearning.org), including a modified version of seafloor spreading activity adapted for middle-school students by a participating teacher.)

As part of their own learning and discovery process, the K-12 and informal educator participants themselves produced more than 15 classroom activities based on scientific ocean drilling cores, scientific procedures, and data. In addition, 20 career profiles, short biographies, were prepared based on interviews with a cross section of the ship's manifest, as well as three instructional lab demonstration videos. These materials are being field tested in the educators' classrooms and then will be made available on the JOI Learning Web page for other educators to utilize. In addition, a number of articles are being prepared that highlight several of the focused shipboard inquiries and the process of curriculum development, as well as participant feedback and program assessment. Links to these articles will also be made available on the Web page.

Although the seagoing part of the pilot expedition has been completed, the educational journey continues; more student-active learning materials using published data from scientific ocean drilling are being developed and posted online, and there are plans to continue the School of Rock Expedition learning experiences at core repositories, on port calls, and on future ship transits.

IODP and Earth System Science

Earth system science recognizes that the planet functions through the interactions of the geosphere, atmosphere, hydrosphere, biosphere, and cryosphere. The scientific goals of IODP and the past drilling programs [DSDP and the Ocean Drilling Program (ODP)] address all facets of Earth system science. The program exemplifies integrated scientific discovery through the application of geology, physics, chemistry, biology, mathematics, and engineering. Scientific ocean drilling is exemplary of a cooperative international cross-disciplinary approach to understanding Earth history and its processes. The work conducted on the *JOIDES Resolution* illustrates how Earth systems scientists use and integrate all sciences to achieve a shared scientific objective.

Earth systems science is accessible, rigorous, and timely. It:

- engages people's natural curiosity about the world in which they live
- connects people with the their home planet and their place in it
- promotes responsible stewardship
- bridges scientific disciplines
- increases the global knowledge base at the macro to micro level
- integrates and applies STEM (science, technology, engineering, and mathematics)
- enables informed decision-making, and
- encourages discourse and action among educators, scientists, and policy makers.

Collectively, the educators and staff who participated in the School of Rock Expedition recognize that there are some serious deficiencies in the way Earth system science is viewed and valued in the United States. The following recommendations made by the School of Rock Expedition educational party capture the spirit of the concerns shared by many Earth system scientists.

First, scientists need to make their published research data available in a form easily accessible to educators. In turn, educators need to actively explore ways to incorporate authentic scientific data into their teaching, especially at the middle-school level and above. Aggregating database efforts (such as CHRONOS, PetDB, PaleoStrat, JANUS) and encouraging these projects to refine database searchability and facilitate the accessibility of scientific data for educational purposes in parallel with research purposes will promote the connection between science research and science education.

In addition, the study of Earth systems is a good beginning-level science experience because it introduces children to major scientific themes concerning the world around us, and can serve as a foundational discipline from which other core sciences (e.g., chemistry, physics, and biology) can build.

However, Earth system science also has value as a capstone science experience for young adults because it facilitates synthesis and integration of the biological, chemical, and physical sciences in the context of the planet on which we live. The School of Rock Expedition's educators advocate for placement of greater emphasis on the Earth sciences in our K-12 science curricula.

Furthermore, there is an urgent need for improved scientific literacy in the Earth sciences among the general public. A day does not pass without news-making stories concerning geologic hazards, nonrenewable resources, water, the environment, biodiversity, or global climate change. Earth system science is relevant to society and therefore vital to facilities that promote lifelong learning (e.g., museums, nature centers, and national parks). Thus it is important to involve informal educators, as the School of Rock pilot program did, in scientific outreach.

The legacy of scientific ocean drilling is enriched by education and outreach. The School of Rock Expedition demonstrated the vast educational potential that is embodied by IODP and its predecessor programs (DSDP and ODP). It actively engaged traditional and informal educators in scientific ocean drilling by (1) accessing and utilizing a broad sampling of the vast ocean drilling database, (2) developing a range of age-appropriate and audience-friendly Earth system science activities for classrooms and museums, and (3) recognizing that the findings of scientific ocean drilling have great relevance to understanding Earth history and its processes, including abrupt events from Earth's past that rival the rate of present-day global change. What the School of Rock Expedition accomplished was to connect educators with scientists and their research results and data sets. It is to be hoped that this type of connection is not the exception, but that it becomes the norm as the scientific community strives to have broader impact and create an Earth system science literate society.

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MEETINGS

Storm-Substorm Relations Workshop

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Magnetic storms in the magnetosphere can cause damage to communication satellites and large-scale power outages. The concept that a magnetic storm is a compilation of a series of substorms was proposed by *Akasofu* [1968]. However, *Kamide* [1992] showed that substorms are not a necessary condition for the occurrence of a magnetic storm. This controversy initiated a new era of research on the storm-substorm relation, which was the subject of a recent workshop in Banff, Alberta, Canada.

The main topics discussed during the meeting included a brief overview of what a substorm is, how quasiperiodic substorm events and steady magnetospheric convection (SMC) events without substorms contribute to storms, and how plasma flows enhanced by magnetic reconnection in the plasma sheet contribute to substorms and storms.

Working Definition of Substorms

Gordon Rostoker (University of Alberta, Canada) and Bob McPherron (University of California, Los Angeles; UCLA) presented an overview of substorm phenomenology to provide a common language for the workshop discussions. For many years, the definition by *Akasofu* [1964], which begins with the expansion phase, provided a template for substorms that contains no substorm growth phase. However, the growth phase is now understood to set the stage for the explosive development of the substorm expansion phase. Further, it is now understood that the auroral ovals do not represent a simple latitudinally confined distribution of luminosity and ionospheric currents.

Magnetic activity tends to be concentrated at the equatorward and poleward edges of the midnight and evening sector oval, giving rise to the term 'double oval.' The expansion phase onset and pseudobreakups occur on the equatorward branch of the oval while poleward boundary intensifications (PBIs) dominate activity on the poleward branch. During periods of sustained driving by the solar wind, the magnetosphere may go into a state characterized by quasi-steady convection (i.e., an SMC event) or may experience quasiperiodic substorm disturbances known as sawtooth events. The discussions of SMC and sawtooth events formed the focus for considerable discussion during this workshop.

The Cause of Substorms

McPherron and Bob Clauer (University of Michigan, Ann Arbor) led the discussion on substorms, solar wind triggering, and the development of moderate storms. A central question motivating this discussion was whether substorms, triggered by northward turning of the interplanetary magnetic field (IMF), were less intense at injecting energetic particles into the inner magnetosphere to build up the ring current than substorms associated with prolonged southward IMF.

Although workshop participants were unable to definitively answer that question, the topic motivated a detailed discussion of substorm triggering. There was some agreement on two points: the limited upstream measurements of the solar wind conditions make even the best triggering studies somewhat ambiguous, and for any given substorm, identification of a solar wind trigger is somewhat subjective. Nevertheless there was also general consensus among the participants that a majority of substorms are likely triggered by variations in the IMF.

Sawtooth Events of Quasiperiodic Substorms

A second topic that focused on 'sawtooth events' was facilitated by Mike Henderson