stepped in to provide these services because doing so will result in an overall enhancement of the data environment:

• *New data:* A number of VxOs are involved in non-VxO tasks: holding and storing data. The discipline-specific nature of the VxO is partly the reason; the VxO leads have close contacts with scientists in the field and interact with them at meetings. Another reason is that some data do not have permanent homes after a project has ended. The VxOs have stepped up to provide one.

• *New products:* Scientists who have data sets for a paper want to make them available to their community, and they realize that their discipline's VxO would be a natural place for storage. In the past a scientist who developed a specialized data product as a part of a proposal would post it on a personal home page. Besides the obvious problems with longevity of personal pages, visibility and searchability of these data products are reduced. VxOs ease this problem.

• *New code:* A number of scientists realize that the best way to introduce and promote software codes is through their discipline's virtual observatory. Rather than storing it on a generic software repository, they make the primary storage point the virtual observatory.

The eventual goal of the virtual observatory is to allow high-level science analysis. Now that the infrastructure is in place, the next step is to bring in the users. In the next few years, VxO users are expected to gradually change their familiar methods of data access and exchange to methods that leverage the new technologies and services available through the VxO.

What Can Be Expected for the Future?

Consider how a photo gallery was displayed in the early days of the Internet on a personal Web page. For the early Internet adopters, it was straightforward to write html and upload files to a Web page. New photo-sharing sites made this process even easier and allowed nontechnical experts to do it with ease. The major benefit of such sites is the aggregation of community resources that allowed for a single application programming interface (API) and user interface for searching, tagging, sharing, and commenting on photos. Although standard Web searches on images still work, domain-specific image services provide an even higher level of utility. The same applications hold true for virtual observatories, and heliophysics community members are now becoming more aware of how to use the added-value services developed by VxOs.

The most important task for virtual observatories is to integrate new services that meet a discipline-specific science need. Further, there is a growing understanding in the VxO developer community of the importance of interoperability at the data level. A number of existing APIs for data, including the Open-Source Project for a Network Data Access Protocol (OPeNDAP; http://opendap.org/), appear to satisfy many of these needs, and several heliophysics VxOs plan on providing their data using this protocol, which has extensive support and use in the climate and atmospheric sciences community.

The long-term success of the virtual observatory depends on the close interaction with the science community. The separation of the virtual observatories into subdomains will help foster that interaction and at the same time make data accessible from other subdomains through an interface at a VxO relevant to another subdomain. Through these links, the collection of VxOs will form one conglomerate, the "Heliophysics Great Observatory." With the metadata and software infrastructure maturing, the next phases involve (1) the iterative process of refinement and revision based on user needs and expectations, (2) the continual addition of new services and data resources, and (3) the promotion of communication and data sharing through virtual observatories and within subspecialty communities of the HPDE.

References

Baker, D. N., and S. P. Worden (2008), The large benefits of small-satellite missions, *Eos Trans. AGU*, *89*(33), 301, doi:10.1029/2008EO330001.

Baker, D. N., C. E. Barton, W. K. Peterson, and P. Fox (2008), Informatics and the 2007–2008 Electronic Geophysical Year, *Eos Trans. AGU*, *89*(48), 485, doi:10.1029/2008EO480001.

Moretto, T., and R. M. Robinson (2008), Small satellites for space weather research, *Space Weather*, *6*, S05007, doi:10.1029/2008SW000392.

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Field Geophysics Class at Volcán Tungurahua, Ecuador

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Ecuador's erupting Volcán Tungurahua was the recent site of a 3-week graduate-level geophysical course on volcanoes, hosted by Ecuador's Instituto Geofisico of the Escuela Politecnica Nacional (IG-EPN) and the Department of Earth Science at the New Mexico Institute of Mining and Technology (NMT). Sixteen students from 12 universities and four countries participated in the intensive course, which entailed broadband seismometer and infrasound sensor deployment followed by subsequent data processing, analysis, interpretation, and result synthesis. Hardware for the course was provided by the Incorporated Research Institutes for Seismology (IRIS) through the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) as well as the IG-EPN and NMT geophysics programs.

Since the start of its most recent eruptive period (in 1999), Tungurahua has proved itself a reliable source of both seismicity and infrasound radiating from its typically open vent. As such, Tungurahua provides the ultimate outdoor teaching laboratory where students can deploy instruments for just a few days and then collect earthquake and explosion data. Tungurahua's activity in June 2009 did not disappoint class participants: Frequent earthquakes included long-period and volcano tectonic events, various types of tremor events, and explosion earthquakes manifested by booming "cannon-shot" blasts. Some of the explosion shock waves were recorded 10 kilometers from the vent with excess pressure amplitudes greater than 50 pascals in the infrasonic band. Had these intense sounds been audible, their sound pressure levels at 10 kilometers would have been in excess of about 130 decibels!

The manifestation of the seismic tremor events was equally dramatic. One of these tremor events was witnessed up close and personal by the class as they approached a field site just in time to watch a torrential lahar of rain-mobilized ash flow down one of Tungurahua's drainages. Small explosive (Vulcanian) and lava fountain (Strombolian) eruptions were common daily and were especially satisfying to watch while knowing that the corresponding elastic wave radiation was being recorded.

After deployment of a seven-station seismic array and a 10-component infrasonic network (see Figure 1), the class set out on a whirlwind volcano road trip while waiting for earthquake data to accumulate. With guest instruction from Pete Hall, Patty Mothes, and Patricio Ramon (IG-EPN) and Claude Robin (Institut de Recherche pour le Développement (IRD), France) the class toured the ash flow deposits of Quilotoa caldera, visited Cotopaxi National Park and Chacana caldera deposits, climbed to the rim of Guagua Pichinchas (which erupted in 1999–2000), and toured the currently erupting Reventador volcano in the eastern jungle lowlands. Stops at the Tungurahua and Quito volcano observatories and examination of devastation from recent eruptions at Tungurahua, Cotopaxi, and Reventador added cultural perspectives and an introduction to hazard monitoring in a country that is replete with threatening volcanoes.

After the road trip, students returned to the base town, Baños, at the foot of Tungurahua, for instrument redeployment and a final week of data synthesis and interpretation. Students divided into groups of two or three and utilized PASSCAL software and MATLAB™ tools to analyze seismic and infrasound array data. They then identified their own projects of interest, and on the final day of the course, they presented oral reports at the IG-EPN in Quito. Several students will present these results at the annual AGU Fall Meeting in San Francisco, and it is hoped that the excellent quality data collected by these students will lead to one or more journal publications in the coming months.

Fig. 1. Graduate students Aida Quezada Reyes (left) and Kirsten Chojnicki (middle), along with instructor Jeffrey Johnson (right), program a seismic station at one of the array sites located 5 kilometers from the Tungurahua vent.

The great success of this course was in the merger of geophysical education and research. All students developed familiarity with digital signal processing, seismic wave beamforming, and infrasound waveform modeling. Quantitative field volcano studies captured the imagination of students in large part because Earth processes occurred while they were watching and waiting. Future iterations of this course will be held domestically in alternating years starting at Kilauea in 2010 and returning to Ecuador in odd years. More information and a Web site for NMT's field course GEOP572 are available at http://nmtgeop.net/geop572/.

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NEWS

Water on the Moon Confirmed

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When NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) and a companion rocket purposely slammed into a crater at the Moon's south pole on 9 October, some observers on Earth lamented as anticlimactic the raised plumes of material that were partially blocked by a crater ridge and were difficult to see with backyard telescopes. However, it turns out that the projectiles struck it big.

"Indeed, yes, we found water. We didn't find just a little bit; we found a significant amount," said Anthony Colaprete, LCROSS principal investigator with the NASA Ames Research Center, Moffett Field, Calif. At a 13 November news briefing, Colaprete lifted a 2-gallon plastic bucket and said preliminary results indicate that instruments detected about a dozen buckets' worth of water in parts of the two plumes, the first generated by the spent Centaur upper stage of the Atlas V launch vehicle at 1131 UTC and the second generated by LCROSS about 4 minutes later. NASA described the two plumes as a high-angle plume of vapor and fine dust and a lower-angle ejecta curtain of heavier material. LCROSS and the Centaur upper stage hit the permanently shadowed Cabeus crater.

The new finding means there is a region of the Moon that is probably a little wetter than the driest desert on Earth, according to Colaprete. However, he added that it is unclear what conclusions to draw regarding water in other regions of the Moon. "Did we hit something typical or atypical? I don't know the answer just yet."

Several instruments—a near-infrared spectrometer and an ultraviolet/visible spectrometer—confirmed the presence of water in the plumes. "We were able to match the spectra from LCROSS data only when we inserted the spectra for water. No other reasonable combination of other compounds that we tried matched the observations," Colaprete said.

Significance of Finding Water

Greg Delory, senior fellow, Space Sciences Laboratory and Center for Integrative Planetary Science at the University of California, Berkeley, said that with this finding, researchers now can focus on other questions that could lead to a better understanding of the history of the Moon and of the solar system, including where the water came from, how long it has been there, and the processes of putting water there and removing it. The water could have originated from several different sources, including comets, the solar wind, giant molecular clouds that have passed through the solar system, the Earth, or internal activity on the Moon itself, he said.

The new findings are "giving us a surprising new picture of the Moon," Delory noted. "This is not your father's Moon. Rather than a dead and unchanging world, it could be a very dynamic and interesting one that could tell us unique things about the Earth-Moon system and the early solar system conditions."

Michael Wargo, chief lunar scientist for Exploration Systems at NASA Headquarters, said the water potentially could be used for drinking, be broken down for breathable air, or be a constituent for making potent rocket fuel.

"We are unlocking the mysteries of our nearest neighbor and, by extension, the solar system," he added. "As we find out more and more about the Moon, we find it is not a closed book but just the first chapter, and the rest of the chapters have yet to be written."

Colaprete told *Eos* that even though water has been confirmed, there is a very low possibility that there ever has been in situ life on the Moon. "The carbons, the nitrogens, the silicates, all of the building blocks for life are there," except for liquid water and an obvious energy source, he said.

"I would say it is very slim that there have been organisms living in the shadowed craters we explored," Colaprete added. He noted, though, that if the Moon transitioned through a series of orbital changes in the past, the lunar poles may have gotten sunlight periodically, which could have warmed ice deposits.

Not Just the Water

Colaprete said researchers also are combing through data for other clues about the Moon. "It's not just about the water," he said. "Along with the water in Cabeus, there are hints of other intriguing