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 substances. The permanently shadowed regions of the Moon are truly cold traps, collecting and preserving material over billions of years."

There was not an "aha moment" regarding the discovery, Colaprete said. "It has been a 'holy cow' moment every day since impact."

LCROSS and its companion rocket stage hit the Moon within 200 meters of their targets, according to Colaprete. The LCROSS mission was launched on 18 June as a companion mission to the Lunar Reconnaissance Orbiter. It follows other missions that also have detected evidence of water on the Moon.

For more information, visit http://www.nasa.gov/lcross. LCROSS-related sessions at the AGU Fall Meeting in San Francisco include "Lunar Reconnaissance Orbiter/LCROSS: New Insights Into the Moon" sessions U21C, U22A, U331, and U31B (http://agu-fm09.abstractcentral.com/planner). Among the oral presentations is U22A-07, "An Overview of the Lunar Crater Observation and Sensing Satellite (LCROSS) Post-Impact Results," by Colaprete and others.

—Randy Showstack, Staff Writer

FORUM

Lies, Damned Lies, and Statistics (in Geology)

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According to Karl Popper's epistemology of critical rationalism, scientists should formulate falsifiable hypotheses rather than produce ad hoc answers to empirical observations. In other words, we should predict and test rather than merely explain [*Popper*, 1959]. Sometimes, statistical tests such as chi-square, *t*, or Kolmogorov-Smirnov are used to make deductions more "objective." Such tests are used in a wide range of geological subdisciplines [see *Reimann and Filzmoser,* 2000; *Anderson and Johnson,* 1999; *Lørup et al.*, 1998; *Sircombe and Hazelton,* 2004].

However, "statistically significant" is not the same as "geologically significant." I will illustrate this point with a geophysical example, in which Pearson's chi-square test implies that earthquakes are unevenly distributed throughout the week, with seismic activity being particularly high on Sunday.

Statistics Invalidates Likely Hypotheses

According to the so-called Neyman-Pearson paradigm of statistics, theories can be tested by formulating a null hypothesis H_0 (e.g., average global temperature has remained constant since 1900) and an alternative hypothesis H_a, which can be either "two-sided" (e.g., global temperature has changed since 1900) or "one-sided" (e.g., global temperature has risen since 1900). Given a quantitative data set D (e.g., a time series of temperatures), the decision whether or not to reject H_0 in favor of H_a is made on the basis of $S(D)$, the so-called test statistic. If $S(D)$ is "unlikely" to occur under H_0, then H_0 is rejected. The probability of observing a value at least as extreme as $S(D)$ under H_0 is called the "*p* value," and a cutoff value of $p = 0.05$ is often used to make a decision on a 95% confidence level.

One problem with this approach is that it lumps together two factors: effect size and sample size. Given a large enough data set, statistical tests (especially the two-sided ones) will pick up any departure from the null hypothesis, no matter how small. The result is that geological hypotheses are never "true"—they will always be rejected if lots of data are available.

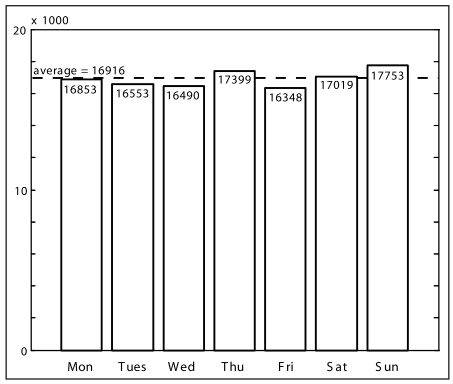

Fig. 1. Histogram of 118,415 earthquakes occurring globally between 1999 and 2009, grouped by weekday.

Consider the following seemingly plausible null hypothesis: The occurrence of earthquakes does not depend on the day of the week. To test this hypothesis, a global database of 118,415 earthquakes of magnitude 4 or greater and occurring between Friday, 1 January 1999, and Thursday, 1 January 2009, was compiled from the U.S. Geological Survey Web site (http://earthquake.usgs.gov). The earthquakes were tallied by weekday, resulting in a seven-bin histogram with bin counts $D = \{D_1, D_2, \ldots, D_7\}$ varying between 16,348 (Friday) and 17,753 (Sunday), and an average of 16,916 (Figure 1). Our null hypothesis is mathematically equivalent to saying that this histogram is uniformly distributed. A chi-square test was used to evaluate the statistical significance of the observed scatter and the departure from uniformity. Given a set of expected and observed events (E_i and D_i, respectively, for $1 \leq i \leq 7$), Pearson's chi-square statistic is given by $S(D) = \sum (D_i - E_i)^2/E_i$, which can be shown to follow a chi-square distribution with 6 degrees of freedom [*Rice*, 1995]. For the earthquake database, $S(D)$ is 94. The likelihood of observing a result at least as extreme as this under the null hypothesis (i.e., the *p* value), is only 4.5×10^{-18}. Because this is much less than 0.05, the null hypothesis has been clearly rejected.

Finding Geological Significance

Why did the earthquake data fail the test for uniformity? After all, Pearson's chi-square test should work particularly well on very large databases like ours. The answer is that this, actually, is exactly the problem: The test is too sensitive. Using the same proportions of earthquake occurrences but reducing the sample size by a factor of 10 results in a 10 times smaller chi-square value ($S(D) = 9.4$), corresponding to a *p* value of 0.15, which is greater than 0.05 and fails to reject the null hypothesis.

In conclusion, the strong dependence of *p* values on sample size makes them uninterpretable. The nonuniformity of the earthquake distribution could have a number of causes. Is it that background noise is perhaps lower on weekends, leading to an increased sensitivity of the seismometers? Or does the tolling of church bells on Sunday trigger false positives? Whatever the reason is, it is unlikely to be a geological one.

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