Cosmic rays detect soil moisture

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(PhysOrg.com) -- An instrument that uses cosmic rays to measure the moisture content in soil ultimately could prompt major improvements in weather forecasting and irrigation practices, and provide a wealth of new data about land density and the impacts of climate change. The University of Arizona's Marek Zreda is leading the project.

A novel instrument that uses cosmic rays to measure the moisture content in soil ultimately could prompt major improvements in weather forecasting and irrigation practices, and provide a wealth of new data about land density and the impacts of climate change.

In many parts of the country, water in the soil influences weather and climate, said Marek Zreda, associate professor in the University of Arizona's department of hydrology and water resources, who is leading the project. "The local weather is controlled by the recycling of the water from the soil back into the atmosphere, evaporated, then falls back as precipitation," he said. "If this is the case, then we can talk about seasonal climate and weather forecasting."

The device, called a "cosmic ray moisture probe," is new, but is based on existing technology that dates back to the 1950s, and "comes from cosmic physicists interested in high energy cosmic rays," Zreda said.

It is an above-ground probe inserted into the earth that calculates low-energy cosmic-ray neutrons above the soil level. The number of neutrons in the air above the soil surface is inversely related to soil moisture, which affects absorption.

The research, known as the Cosmic-Ray Soil Moisture Observing System (COSMOS), is supported by $5.5 million over four years from the National Science Foundation as part of the American Recovery and Reinvestment Act of 2009. Zreda is working with three other University of Arizona scientists, including Xubin Zeng, a professor of atmospheric sciences, W. James Shuttleworth, Regents professor of hydrology and water resources, and Chris Zweck, an assistant research professor in the department.

The probes, which look like white electric boxes mounted on poles, were designed by a former University of Arizona student, and cost about $20,000. Zetetic Institute and Quaesta Instruments, LLC, both located in Tucson, and Hydroinnova of Albuquerque, N.M., were involved in designing and manufacturing them.

The technology could, among other things, have important economic implications for agriculture, in particular, irrigation practices. Water is costly, and often in short supply. If the research proves successful, the probes could help manage irrigation so that it is not wasteful, Zreda said.

"Today, farmers often irrigate on a timer, whether it's needed or not," he said. "But it makes sense not to irrigate if the soil already is wet. A probe can send a signal for irrigation to start if it is needed."

The probe also may prove valuable in "quantifying the density of forests and other vegetation, and understanding the biomass and how it changes over time," Zreda said, as well as more accurately measuring the snow pack, that is, "the amount of snow on the ground," he added. It also could provide important new data about climate change. Ecosystem processes such as the activity of soil organisms, the growth of plants and the carbon cycle are all linked to soil moisture.

"The plan is for these probes to be there indefinitely," Zreda said. "In ten years, we could see whether the soil moisture levels, on average, have changed. If the climate is the same, they should remain the same. If the climate is warming up, we'll have more precipitation, and the soil will be wetter."

Here's how the instrument works: Cosmic rays constantly bombard the planet. Neutrons from the upper atmosphere cascade to the ground, producing—in the air and in the ground—so-called "fast" neutrons, which are sensitive to hydrogen atoms and which are immobilized when they collide with them.

Keeping in mind that the makeup of water is two-thirds hydrogen, "if you have a large number of hydrogen atoms in the soil, they will suck in a large number of neutrons, and decrease the concentration of neutrons in the soil," Zreda said. Thus, when neutrons in the soil diffuse into the atmosphere, "if we have fewer of them in the soil, then fewer will be diffused into the air, and we will have a lower measurement of them in the air," he added.

Put another way, "the more water in the ground, the lower the concentration of neutrons in the air," Zreda said. "The probe gives us the number of neutrons per unit of time, typically one hour. The instrument is out there and counts them, and every hour sends the information to our computers."

The probe itself is a tube filled with a proportional gas, such as helium-3. Once a neutron enters the tube and interacts with gas molecules, it creates a shower of electrons. (A proportional gas is one in which the number of electrons produced is proportional to the number of neutrons that enter the tube. This is what makes the neutron detector work.)

"We don't have a way of detecting neutrons, but electrons are charged so we can see them," Zreda explained. "The number of electrons increases in proportion to the number of neutrons."

This method is a vast improvement over existing soil moisture measuring approaches, he said. Until now, measuring soil moisture typically involved digging up soil and drying it.

"You would take a physical sample, bring it to the lab, weigh it, put it in the oven to evaporate the water, then weigh it again—the difference is the moisture," Zreda said. "It was standard procedure for 100 years. But it is labor intensive, and destructive. Also, you can't collect another sample at the same point tomorrow, which defeats the purpose, if you can't calculate the differences from one day to the next."

Another method of detection requires burying wires in the soil and measuring electrical impulses. If researchers want to get soil moisture over a large area, they would have to measure hundreds of these points, a process that also is labor-intensive, time consuming and expensive.

Finally, scientists also can use satellite images to get average soil moisture for county-sized areas, but only to a soil depth of about one inch.

"People have been looking for a way to replace these labor intensive, destructive methods with some kind of geophysical method that would allow for long-term measurement," Zreda said.

The COSMOS project can deploy sensors that can detect soil moisture as deep as two feet over an area as large as 720 yards in diameter.

Currently, there are two probes in Hawaii, and a dozen more across the United States. Phase I of the project calls for 50 probes. Once the testing is finished--and with additional funding—the researchers hope to expand the network to 500 probes.

"Once we demonstrate the scientific value of our data, we hope go to sites with weather stations, and get many more people on board," Zreda said.

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