From a Distance

Remote Sensing of Planet Earth

SCOTT BAUER (K9528-1)

On the Jornada Experimental Range in New Mexico, physical scientist Thomas J. Schmugge (background) and Frederick Jacobs, a visiting scientist from France, measure thermal and moisture flux.

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Loading equipment on a twin-engine Cessna 404 Titan for a flight over the Jornada Range. The equipment measures visible and thermal reflectance of ground vegetation.

The future of weather forecasting is rapidly changing. By the year 2008, we may have weather maps that can detect a flood in its infancy.

These maps will be generated from 20-foot-diameter microwave dishes spinning rapidly on platforms attached to satellites. These dishes capture the natural microwave emissions from soil as a measure of moisture. The rapid spinning is the secret to the complete coverage the dish provides of each area the satellite passes over. A U.S.-European pair of satellites for long-range weather forecasting may be launched by 2008 and will have the dishes.

It's all part of a "Soil-Moisture Observing System" envisioned by hydrologist Tom Jackson, who is with ARS' Hydrology and Remote Sensing Laboratory in Beltsville, Maryland. His soil-moisture remote-sensing work in joint projects with the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration is paving the way for that launch. Already, NASA is set to launch a satellite named "Aqua," which monitors the planetary water cycle with a version of the spinning-dish sensor tested in airplane and satellite flyover campaigns in Arizona, Oklahoma, and soon in Iowa. Aqua is the water-targeted match to Terra, a land-monitoring satellite already in orbit.

With the Aqua satellite set to launch, Jackson must soon verify its microwave-dish data with data from tests on Earth's soil. To do this, he'll use instruments at four of ARS' watershed centers—in Arizona, Georgia, Oklahoma, and Idaho—as well as the USDA Natural Resources Conservation Service's network of 40 ground-monitoring stations across the country. The service's data, available on the World Wide Web at http://www.wcc.nrcs.usda.gov/scan/, can be read 1 hour after being collected, 24 hours a day.

Jackson, his colleagues, and scientists from around the world have developed and tested various sensors in the flyover campaigns. They've looked at small-scale, land- and airplane-based monitoring and global-scale satellite monitoring. From this research, techniques have emerged that will be used to translate Aqua's data into maps.

Jackson cites the recent flooding in Mississippi as an example of an event that could have been predicted weeks earlier. His analysis of 2 weeks of satellite data shows the April 12 flood started in the Dakotas. On March 29, it appeared on the map as a small blue area of oversaturated soil. "Knowing the terrain and water systems, it isn't hard to predict where all that water will end up—maybe 1,000 or more miles away," he says.

Beyond the Clouds

An atmospheric region Jackson and colleagues call the boundary layer plays an important role in cloud development and in determining where rainfall is likely to occur. "It is becoming more evident that reliable predictions of the growth rate and ultimate depth of this layer are important for accurate weather forecasts," says ARS physical scientist Tom Schmugge. He, ARS hydrologist Bill Kustas, and Andy French, a Ph.D. candidate from the University of Maryland, are using thermal infrared sensors to measure variation in surface temperature, which is key to defining regions of high and low evaporation that affect boundary layer growth.

They are using the temperature data collected from aircraft to develop a computer model to predict patterns of evaporation for eventual use with Terra's infrared sensors. The present sensor has a 90-meter resolution, perfect for precision farmers who are interested in monitoring crop growth, which is strongly affected by surface temperature and moisture variations. The sensor can also spot areas of drought and crop damage.

Schmugge and other ARS colleagues participated in a recent flyover campaign over the ARS Jornada Experimental Range in Las Cruces, New Mexico. The flyovers occur twice a year, before and after the summer rainy season. Some planes fly as low as 750 to 1,000 feet, and some (U-2 spy planes from the Cold War) go up to 70,000 feet. Some data is obtained from up to 220 miles into space with satellites. The researchers also have thermal infrared and other sensors on towers 100 feet above the desert, as well as hand-held devices that provide a close-up look. Similar sensors are on the airplanes and satellites.

Jerry Ritchie, an ARS soil scientist at Beltsville, participates in the flyover campaigns by using an airborne laser altimeter to profile landscapes. "This gives us a better understanding of the effect of plant canopy and landscape roughness on evaporative losses, soil water infiltration, surface water movement, and rangeland conditions," Ritchie says.

In an Oklahoma flyover, as rains came and went, Jackson and his Maryland colleagues, including Kustas and Schmugge, studied the effects as vast areas of surface soil quickly changed from hot and dry to cool and wet, followed by rapid evaporation. Significant soil-moisture variations over a large expanse can create a surface-temperature differential that encourages the development of storms, including tornadoes. Jackson foresees soil-moisture data from Earth being part of daily weather forecasts of floods, drought, tornadoes, and hurricanes.

A Global Look at Climate

The desert team has been working with the Beltsville lab since 1995, helping NASA gather data on global climate change as part of that agency's long-term environmental health checkup of Earth from space. The program, named "Mission to Planet Earth," takes a broad look at the planet's land, water, and atmosphere. ARS has the lead role in the soil-hydrology part of the project.

The Jornada's desert site is a good stand-in for similar sites throughout the world, that is, semiarid areas further desertified

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Jacobs (left) and soil scientist Jerry C. Ritchie take spectral reflectance measurements at the Jornada Experimental Range.

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Schmugge sets up a thermal instrument to measure temperature on the Jornada Range.

by overgrazing and drought. As a large land mass with changing vegetation, it is a perfect outdoor lab for using remote sensing to measure such changes.

In fact, there is a relationship between the water cycle and global change. For example, warming could speed up the evaporation and precipitation cycle, causing droughts in some areas and dumping more rain and snow in other areas.

The Jornada work helps NASA evaluate the interaction between desert landscapes and climate. Changes in vegetation over such vast landscapes can have a more lasting effect on climate and weather than temporary shifts in moisture and temperature. For example, as the desert is taken over by shrubs, there could be a rise in erosion and wind-blown dust. Once this dust goes into the atmosphere, it could accelerate the Earth's warming. In turn, a cooling or warming of the planet affects these landscapes. There is preliminary evidence from ARS scientists that global warming may be responsible for the increased pace at which grasslands are being overtaken by mesquite and other shrubs.

The Jornada site has large parts of desert land covered with grass, large parts where brush has replaced the vegetation, and large areas of a grass/brush mix. "This helps us validate the NASA satellite sensors under three different landscapes," says Kris Havstad, the head of the Jornada Experimental Range.

Schmugge says that measuring surface temperature will provide a "more realistic view of surface variability and its relationship to regional climate change. For example, when water evaporates from large areas of rainforests, it can affect climate and weather. If a large section of rainforest were to be removed in a short time, that would change the evaporation pattern—and the climate and weather—dramatically. Likewise with any similar large-scale land-use changes."

Angling to Beat Reflectance

James McMurtrey, with the Beltsville lab, is testing the use of fluorescence—natural emission of light or colors—rather than microwave sensors to spot vegetation from afar. He and colleagues studied 45 soil series types across the United States and found that when the soils were bare they had very low fluorescence. This encouraged them to proceed further in trying to develop a way to distinguish bare ground from ground protected by plants or harvested crop residue.

"Methods like this, plus my colleague Craig Daughtry's reflectance work, help with conservation tillage surveys," McMurtrey says. Reflectance uses sunlight reflected from plants to distinguish bare land from plant and crop residue cover.

This will be useful to NRCS inventories of land use and the Conservation Technology Information Service's annual surveys of conservation tillage usage. Conservation tillage typically requires at least 30 percent of the land to be covered with residue from a previous crop. This can cut soil erosion by 90 percent.

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Agricultural meteorologist Paul Doraiswamy (right) and Paul Cook of the National Agricultural Statistics Service observe a remote-sensing map of a field study of corn and soybean crop yields in McLean County, Illinois.

SCOTT BAUER (K9526-2)

At the Jornada Range, airplane pilots follow flight-line markers during remote-sensing flyovers. Here, Mark Chopping secures a marker in place.

SCOTT BAUER (K9536-2)

ARS pilot Michael René Davis flies the Cessna over the Jornada Range as researchers collect light-reflectance data.

McMurtrey and colleague Paul Doraiswamy, an agricultural meteorologist with the Beltsville lab, are also working with scientists in Nebraska to use reflectance to develop a "nitrogen needs index" to spot how much nitrogen plants really need.

Light, Shadows, and Angles

An example of the close cooperation between the Beltsville lab and other ARS labs is the recent transfer of Al Rango and Mark Chopping from Beltsville to the Jornada. Rango is a hydrology expert who has developed ways to estimate annual snowmelt and studied the effects global warming could have on these estimates. Chopping is a remote-sensing scientist who is testing ways to make "surface corrections." These adjust for errors in remote measurements caused by shadows of plants and clouds and other light distortions caused by the sun-target-satellite sensor alignment. Light reflects off plant leaves at different angles, which contributes to a scattering of light that can cause the radiation measured by sensors to be significantly overestimated or underestimated. Semiarid regions like the Jornada are so bright that plant canopy shadowing has a more significant effect on remote-sensing measurements than in humid regions, Chopping says.

"If you've ever taken off in a plane in a semiarid region, you may have noticed that as the plane gains altitude and your viewing perspective changes relative to the surface, what looked like a green field from the ground appears increasingly like bare soil. The vegetation cover is the same, but at higher viewing angles you—and the satellite sensor—see a smaller proportion of illuminated soil," Chopping says.

The Jornada scientists are using satellite data to map various types of vegetation, including creosote bushes, mesquite shrubs, and grasses. Chopping hopes to improve the accuracy of these maps by using multiangle sensing techniques and has tested these using data from two sites in the Chihuahuan Desert as well as over similar semiarid rangelands in Inner Mongolia.

Multiangle remote sensing has only recently been widely accepted as necessary, Chopping says. "Most satellites we use now for land remote sensing view only from one angle, covering about a 14-degree point of view." He is developing and testing mathematical equations to add more viewing and sun angles. NASA's Multiangle Imaging Spectro-Radiometer is an important recent addition to Terra, providing nine different views of the surface almost simultaneously.

In his recent light-reflectance experiments at the Jornada, Chopping relies on the skill of Cessna 404 pilot Michael René Davis (with ARS at Weslaco). Davis must fly with the sun directly behind him in relation to the target areas as the researchers photograph digital images at different viewing and sun angles. Practical applications that could come from these experiments, says Chopping, "are techniques to help ecologists and land-use managers identify areas that are critically threatened as well as those that are potentially suitable for remediation."

Working Together

The move of Chopping and Rango to the Jornada demonstrates the importance of the Jornada experiment as well as the scientists' determination to work in collaboration. For example, the National Science Foundation has several long-term ecological experiments at the Jornada and at the adjoining Chihuahuan Desert Rangeland Research Center.

Through a close relationship with nearby NASA's Goddard Space Flight Center, in Greenbelt, Maryland, the Beltsville lab's scientists contribute to the development of sensors for an ever-increasing number of NASA satellites. NASA's recently launched Earth Observing-1 satellite is serving as a prototype for the many commercial companies that intend to launch satellites for various purposes, some devoted solely to agricultural uses such as precision farming. One such company, Resource 21, provided ground-based light-sensing radiometers for an ARS-University of Nebraska study.

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A reflective tarpaulin on the ground is used to calibrate the visible and infrared spectrometers aboard the Cessna.

Far-Reaching Research

It isn't just rangeland or global issues or even hydrology that the Hydrology and Remote Sensing Lab gets involved with. The lab deals with a wide range of topics and landscapes.

At Beltsville, the lab has one of the most heavily instrumented watersheds in the world, with much of the instrumentation below ground, including automated soil-moisture sensors. The site has also been analyzed with ground-penetrating radar, the same type used to detect escape tunnels dug by prisoners. Scientists at this site are tracing the movement of soil water and chemicals below cornfields and under a nearby swamp and into a creek. NASA uses the site as one of its "ground-truth" stations to verify accuracy of the data from satellite microwave dishes.

SCOTT BAUER (K9518-1)

Probes like this one, held by soil scientist Tim Gish, monitor soil moisture. Soil-moisture data may one day help predict floods, drought, tornadoes, and hurricanes.

USDA is the single largest nonmilitary user of satellite data, says ARS physical scientist Charles Walthall, at Beltsville. He's benefiting from the rapid changes in satellite technology over the past quarter century. "It's a whole new ballgame," Walthall says. "Now, you can practically custom-order a satellite. That's been the major change I've seen in my career. Before, you had to stand in line for data from a few satellites. Now we have these multisensor flyover campaigns all over the United States and the world."

Walthall has spent hundreds of hours aboard NASA planes, operating remote sensors, but he is doing his research on the ground now. He has developed mathematical equations to make satellite data more accurate, including procedures for using images taken from different angles.

Doraiswamy has combined the traditional crop-yield models developed by USDA with climate data and data from satellite imagery to provide real-time crop conditions during the growing season. Also, over the past decade, Doraiswamy and his colleagues have worked with the research division of USDA's National Agricultural Statistics Service (NASS) to harness satellite remote-sensing technology to benefit and complement NASS's program to provide accurate reports of crop production for the United States.—By **Don Comis,** ARS.

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