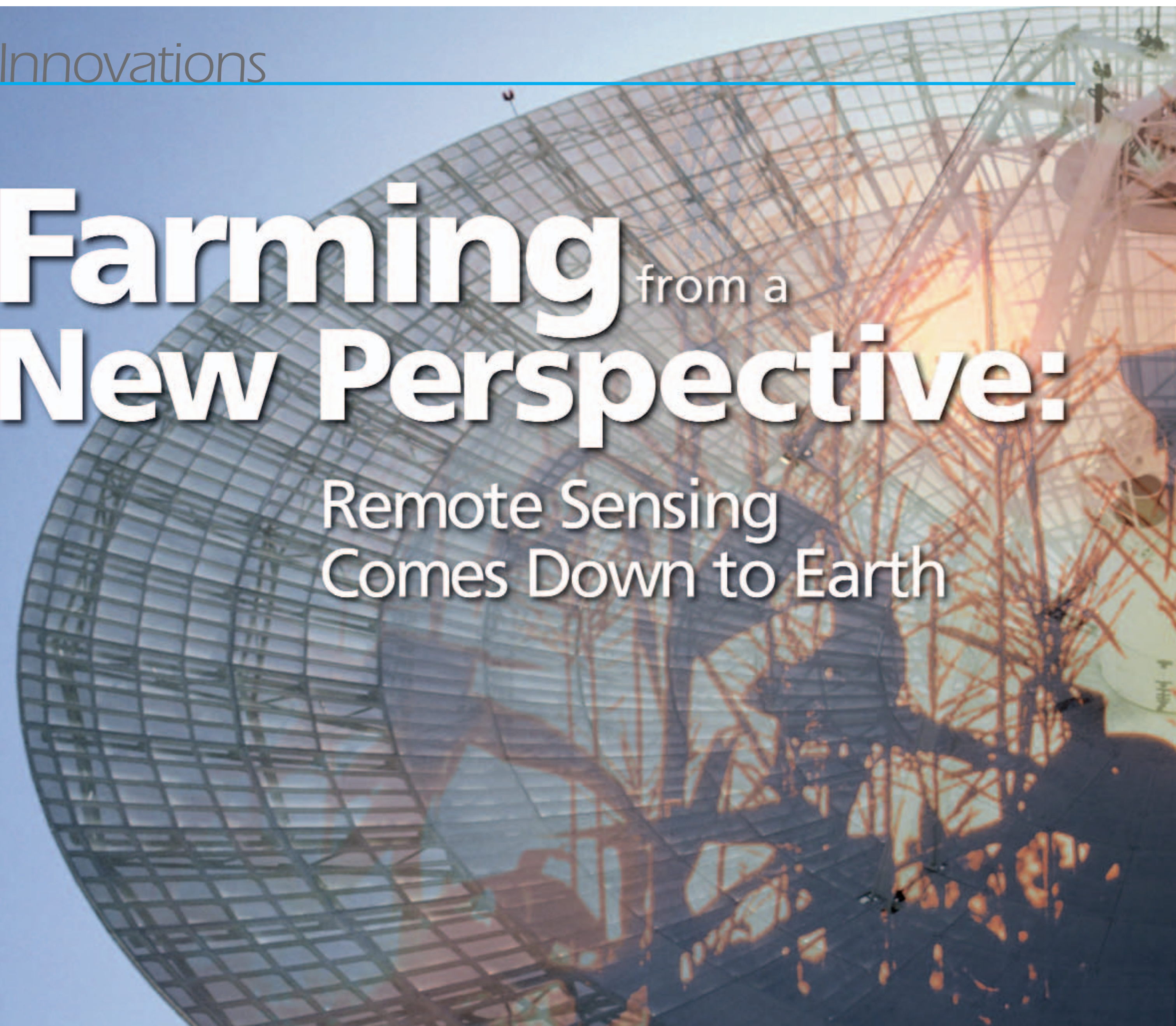
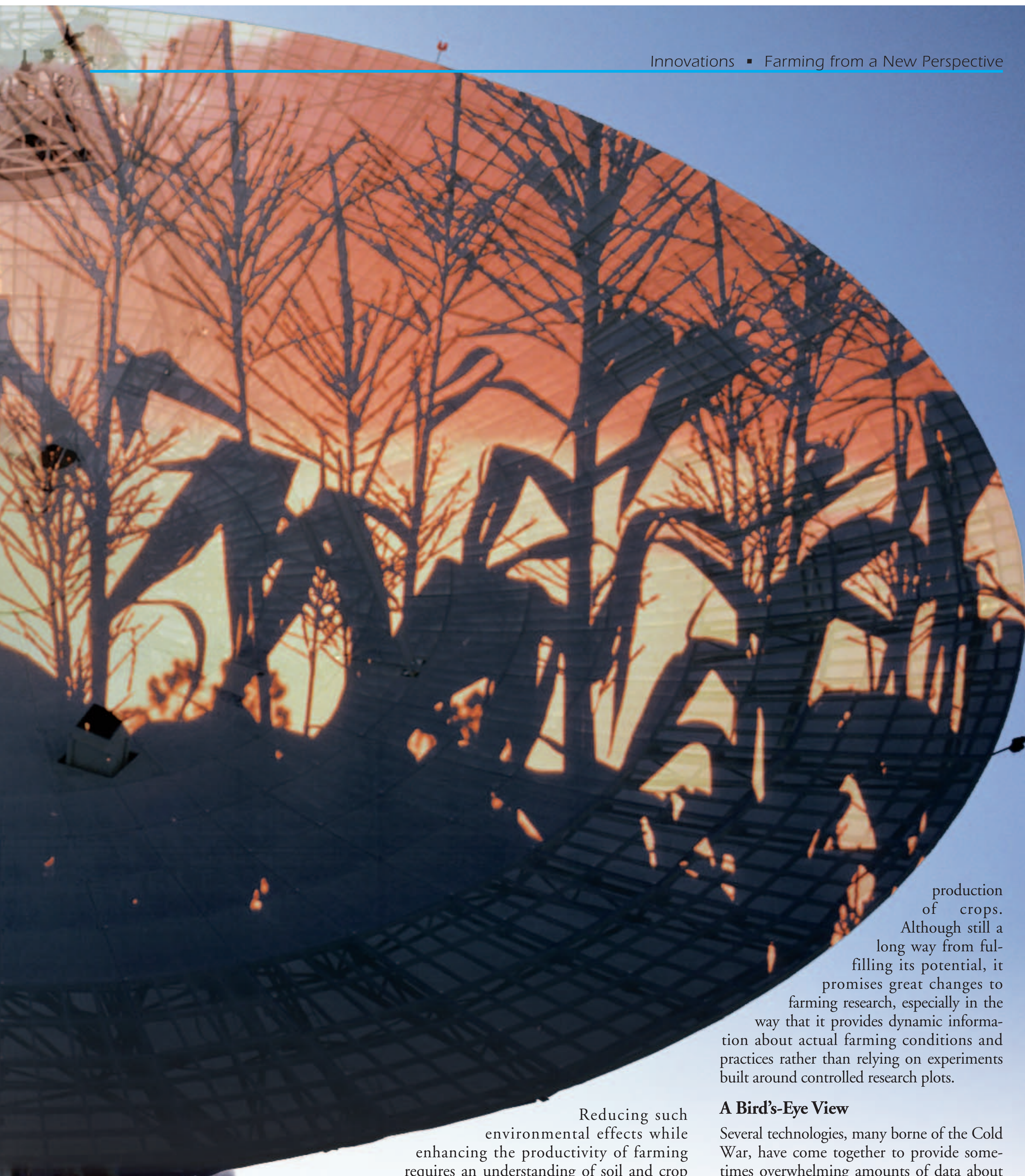


Farming from a New Perspective: Remote Sensing Comes Down to Earth

Manure, and what to do with it, has been much on the mind of James Schepers, a soil scientist and agronomist at the U.S. Department of Agriculture's (USDA) Agricultural Research Service in Lincoln, Nebraska. "The problem is where to put it," he says. "It's not something that's given a lot of thought and so it often ends up poorly spread on fields or in large piles that leach into the groundwater."

Making matters more challenging, Schepers adds, is the fact that "not only do farmers not know where to put it, most farmers don't know what mixture is in their manure piles, so spreading it uniformly often makes matters worse by increasing the [fertility] variability of the soil." He thinks that if farmers could combine their crop yield maps with soil survey maps and remote sensing, they would be able to apply the manure to less-fertile areas. "This approach requires more time and effort, but those farmers that have done it are fighting to get more manure because it's a slow-release form of nutrient," he says.

In an age-old battle, farmers strive to increase the yield of their fields by adding nutrients and water and controlling pests and disease. The results of their endeavors—in addition to bountiful harvests—may include elevated levels of fertilizers in surface waters and aquifers and potential risk to themselves and their neighbors from exposure to pesticides. The application of fertilizers can result in high nitrate concentrations in residential wells in farming areas. Excess phosphate from fertilizers and other sources is a major cause of eutrophication in lakes, which leads to oxygen depletion and environmental



disruption. Farmers, their families, and neighbors of farms have shown some adverse health effects associated with exposure to pesticides, including some types of cancer, neurotoxicity, and reproductive problems.

Reducing such environmental effects while enhancing the productivity of farming requires an understanding of soil and crop conditions, and a knowledge of where to apply fertilizers and pesticides most effectively. The term "precision agriculture" is now widely used to describe a strategy that uses information technology to bring together data from many sources so that systematic decisions can be made affecting the production of crops. Although still a long way from fulfilling its potential, it promises great changes to farming research, especially in the way that it provides dynamic information about actual farming conditions and practices rather than relying on experiments built around controlled research plots.

A Bird's-Eye View

Several technologies, many borne of the Cold War, have come together to provide sometimes overwhelming amounts of data about farm conditions. Geographic information system (GIS) technology has provided the computer-based mapping capability to integrate different layers of information into multidimensional views that can then be analyzed for many purposes. The Global Positioning System (GPS) makes use of military satellites

Manure marks the spot. Farmers are combining new technologies such as crop yield and soil survey maps to pinpoint exactly where to apply manure (e.g., only to less-fertile soil) in order to increase its effectiveness and reduce leaching of fertilizer into groundwater.

and commercial receivers to locate objects within 1 meter (m) of the actual site, be it an irrigation ditch or a tractor moving across a field of alfalfa.

The chief data-gathering technique, also a product of the Cold War, is remote sensing from airplanes and satellites. Remote sensing encompasses a group of sensing technologies including photography, multispectral scanning, and infrared imaging. In one way or another, most take advantage of spectral signatures (or reflected wavelengths), with different wavelengths being the mark of different soil or plant types or conditions. For example, vegetation has a very strong reflectance feature at 0.7 micrometers (µm). Spectral bands detected by satellite include the visible (0.5–0.6 µm and 0.6–0.7 µm) and the near-infrared (0.7–0.8 µm and 0.8–1.1 µm), with additional bands becoming available in the mid-infrared.

Multispectral photography records a number of spectral bands separately on film, the bands being selected to show the greatest contrast. Multispectral scanning systems use an array of optical detectors to simultaneously detect a number of spectral bands from the visible into the infrared. The resulting electronic data are transmitted to the ground, where they are reconstructed into images. Thermal infrared radiation images are also created by scanners, but are recorded on film or videotape across a wide band in the infrared.

An advocate of precision agriculture, Schepers is working to identify the spectral signatures of the phosphorus and nitrogen needed to fertilize fields. His partners include the National Aeronautics and Space Administration (NASA) and a commercial spinoff company based in Englewood, Colorado, called Resource21, which currently uses a small plane to conduct its surveys but plans to launch up to four remote sensing satellites in 2003. The information should tell Schepers more about the organic content of the soil and its water-holding capacity—and thus which areas need fertilization and irrigation.

Research of this type is part of the USDA's Integrated Agricultural Systems National Program, which in large measure reflects a report prepared by the National Research Council titled *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. The report captured for public policy makers much of the strategy's development as well as several potential benefits and drawbacks in this approach to farming.

Spinning Off

As the agency with its eyes on the sky, NASA has long played a role in supporting U.S. agriculture. The Commercial Remote Sensing Program (CRSP), run out of Stennis Space Center, Mississippi, has the charter to take what has been a duel military/civilian technology and target its commercial uses. Nathan Sovik, manager of applications research and development at the CRSP, says that NASA can help private companies develop and prove their remote sensing technology and can develop new applications on its own. "Geological exploration and vegetation mapping have been the traditional civilian applications for remote sensing," he says. "Now we're looking to open up new areas such as high-resolution forest inventory and precision farming."

Landsat satellites have been the most consistent suppliers of information to the agricultural research community, from the 1972 launch of the first one, which carried a four-band multispectral scanner, to the launch in April 1999 of Landsat 7 with an eight-band scanner. Resolution from the most recent satellite varies between approximately 15 and 60 m, depending on the spectral band. Approximately 80 more Earth-observing satellites are scheduled to be launched in the next 15 years. The IKONOS satellite, launched in September 1999 by Space Imaging of Thornton, Colorado, is authorized by the U.S. government to release images at 1-m resolution and is the first of several commercial imaging satellites scheduled to be launched.

Sovik says that NASA is also contributing the latest in remote sensing capability by using the Advanced Thermal and Land Applications Sensor (ATLAS), installed on a Lear 23 jet. ATLAS can scan 15 spectral bands and is capable of 2-m resolution. It has proven its value in numerous agricultural settings, from tracking drought conditions on farms to testing for atmospheric effects of moisture and aerosols on images collected by remote sensing equipment and compared to data collected by satellites or ground-based systems.

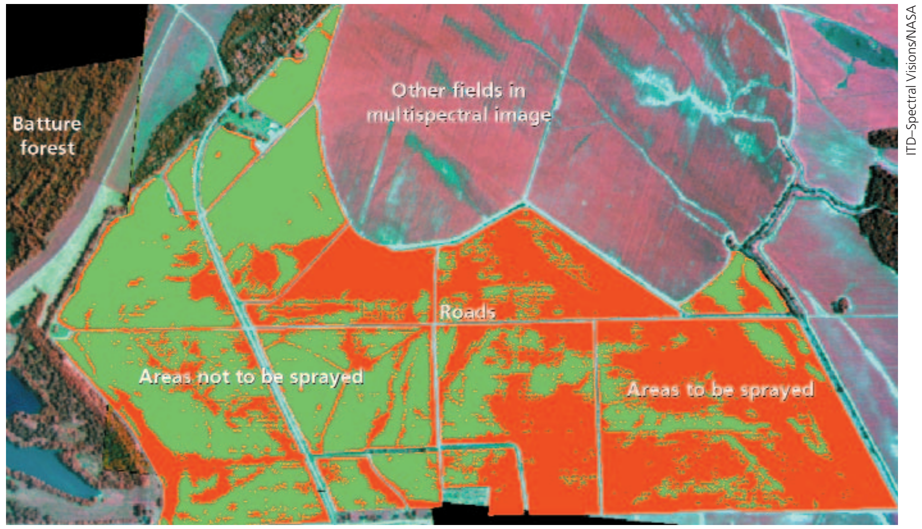
Sovik says an application being considered is the use of remote sensing to enforce environmental standards compliance by farmers. For example, he asks, "If a farm field abuts a stream and you get an algal bloom downstream, how do you know whether it is a natural occurrence or caused by the farmer's behavior? Unless you are flying over at exactly the right moment, it's very difficult to determine."

Stennis Space Center has been a breeding ground for new commercial remote sensing companies that focus on agriculture. Its contractor, Spectral Visions, has been conducting studies to reduce the use of insecticides in controlling the cotton-damaging plantbug on 1,000 acres of a farm in Mississippi. Insecticides represent approximately 18% of the annual production cost of growing cotton, so reducing their use could help farmers better compete in a market that is suffering a downturn from rising production costs and foreign competition, as well as impart clear environmental health benefits.

"To determine when and where to apply insecticides, some people claim that the spectral signal can be correlated to the stress on a plant, but that is very tough to do, given that images are taken at different times and in different terrain," says Richard Campanella, a remote sensing GIS specialist at Spectral Visions. Instead, Campanella looks at the health of the cotton plants as indicated by their water content to identify when they are most likely to be attacked by the plantbug.

In one experiment, 20 sets of images were gathered by a NASA CRSP plane carrying a multispectral sensor comprising three Kodak charge-coupled device cameras with a narrow-band filter on each camera. These data, when combined with information gathered from the ground on existing infestations, led to insecticide applications that varied by location. Early results show a 30–40% decrease in overall chemical use.

In 1962, in a previous incarnation, the Environmental Research Institute of Michigan (ERIM) in Ann Arbor was the site of the first civilian conference dedicated to remote sensing. One of the company's current research projects is to study crop stress in sugarcane near the Florida Everglades. According to Gregory White, program manager for terrestrial and wetlands applications at Veridian ERIM International, the hope is that aerial images, data collected on the ground, and computer modeling will lead to better yield management practices. "The sources and levels of pollution in the Everglades are debated greatly in Florida," he says. "Lowering the pesticides and fertilizers applied lowers the risk of water contamination and non–point source pollution." In addition, White hopes to help better manage water drainage canals, which would offer greater support to wildlife and fisheries.



Mississippi River delta mapping. Farmers use multispectral images of cotton fields to identify the location of fast-growing plants that are likely to attract insects (orange areas). These areas can then be targeted with pesticides and thereby reduce pesticide use considerably compared to blanket spraying, lessening the environmental impact and reducing costs.

Taking Stock

Remote sensing has applications for human health beyond precision farming. It has been used to track the movement of contaminants from hazardous waste sites, observe conditions leading to coastal algal blooms associated with cholera outbreaks in India, and identify habitats conducive to the spread of Lyme disease in New York and hantavirus in the Southwest. As the value of such applications became more apparent, NASA established a dedicated organization for its study: the Center for Health Applications of Aerospace Related Technologies, which is based at NASA's Ames Research Center at Moffett Field, California.

Yet, whether understanding the health effects of agriculture or of climate change, remote sensing as a tool is still far from ideal. There are challenges related to implementing the technology such as the difficulty of integrating GPS and remote sensing data into a GIS—although this obstacle is being overcome. In addition, interpreting images is very difficult and very much site-specific, with considerable input from ground observations required.

Time and thus cost become major constraints. One tool to deal with this problem has been developed by Susan Maxwell, deputy manager of the science and applications branch of Raytheon Company, which runs the Earth Resources Observation System Data Center in Sioux Falls, South Dakota, where Landsat data are processed. Maxwell and colleagues from Colorado State University and the National Cancer Institute propose a method for automating crop mapping using Landsat imagery. In health studies such as one of agricultural chemical use and the occurrence of cancer, accurate crop maps of large geographic regions are essential. Software developed by the team extracted spectral data from Landsat maps of 13 counties in Nebraska and produced a map for corn in less than 15 minutes. The classification accuracy of 89% was comparable to traditional methods requiring days of interpretation.

Maxwell says there is a shortage of GIS analysts and yet a vastly increasing supply of data coming in from satellite sensors. In an important sense, the means of processing the data is not keeping up with the ability of sensors to gather it. Indeed, in other ways as well, the cart is before the horse, observes William Suk, director of the Superfund Basic Research Program at the NIEHS. "We have the tools to characterize spatial relationships in front of the scientific understanding of the relationships we wish to model," he says. Suk believes that remote sensing is like an "orphan child" in that public health researchers are not always sure what to do with it. He would like to see more forums in which researchers from different disciplines could share skills and perspectives. "What's needed is the ability to use data and extrapolate from it in a meaningful way," he says.

It is true that sharing remote sensing data between different users can be very difficult—technically, professionally, and, increasingly, commercially. Yet the data will continue to stream in from planes, satellites, and new ground-based tools such as Light Detection and Ranging, which explores the physical and chemical properties of the atmosphere with a laser. It's all giving farmers a reason besides the weather for keeping an eye on the sky.

W. Conard Holton

Suggested Reading

Maxwell SK, Nuckols JR, Smith E, Ward MH, Hoffer RM. Automated crop type mapping from Landsat imagery. Presented at Pecora 14/Land Satellite Information III, 6–10 December 1999, Denver, CO.

National Research Council, Committee on Assessing Crop Yield. Precision agriculture in the 21st century: geospatial and information technologies in crop management. Washington, DC:National Academy Press, 1998.

National Research Council, Committee on the Human Dimensions of Global Change. People and pixels: linking remote sensing and social science. Washington, DC:National Academy Press, 1998.

Vine MF, Degnan D, Hanchette C. Geographic information systems: their use in environmental epidemiologic research. Environ Health Perspect 105:598–605 (1997).

Ward MH, Nuckols JR, Weigel SJ, Maxwell SK, Cantor KP, Miller RS. Identifying populations potentially exposed to agricultural pesticides using remote sensing and a geographic information system. Environ Health Perspect 108:5–12 (2000).