Remote Sensing (I): Landsat Takes Hold in South America

São José dos Campos. An international meeting held here this month for operators of ground receiving stations for the U.S. Landsat satellite is indicative of the Brazilian commitment to remote sensing techniques as a means of gaining information about its huge wilderness regions. Remote sensing by airplane and satellite is profoundly changing the way geologists, hydrologists, land-use planners, and other resource specialists go about their work. The benefits of this new capability promise to be particularly significant in the developing countries of the world that lack other means of surveying and assessing their resources.

Nowhere is this promise clearer than here in South America, where remote sensing techniques have already made important contributions or appear to be on the verge of doing so in more than half a dozen countries. Brazil began early and has the largest effort, but programs are also under way in Bolivia, Venezuela, Colombia, Chile, Peru, and Argentina. The results of these efforts include mineral discoveries, the first accurate maps for large portions of the continent, and a new capability to plan and monitor development activities.

In Bolivia, for example, analysis of Landsat photographs of a huge salt flat resulted in the discovery of brine pools containing extremely high concentrations of lithium and potassium; Bolivia is now considering commercial production. In Brazil, the agency charged with monitoring the development of the Amazon Basin is using Landsat images to enforce laws restricting the amount of tree-cutting and land-clearing done on private ranches, and radar maps to plan the location of new ranches and other facilities. In Chile, hydrologic maps based on satellite photos are being used to estimate water availability in arid regions of the country. Although the pace of research and the application of these new techniques have proceeded slowly in recent years, there are now indications of a rapid acceleration.

These results and the ongoing programs depend heavily on two remote sensing techniques, both developed in the United States: airborne radar, which has permitted the mapping of otherwise impenetrable, cloud-covered jungle regions and hence the first systematic look at their resource potential; and satellite observing platforms, such as Landsat (formerly the Earth Resources Technology Satellite). This article reports on work with satellite systems, primarily the Brazilian program; an accompanying article considers radar mapping, again in Brazil; and a third reports on experimental efforts in the United States to combine and improve these two remote sensing techniques.

Brazil is unique among the developing countries of the world in having a Landsat ground station, one of only four permanent stations outside the United States. Brazil can thus receive information from the satellite directly as it passes overhead every 18 days. The station is located in the southern part of the country near São José dos Campos, the Brazilian aerospace center, and can provide Landsat images covering nearly all except the southernmost portions of the South American continent. Because of this, Brazil is now becoming a source of Landsat data and remote sensing expertise for other South American countries as well. But Brazilian interest in remote sensing techniques antedates Landsat, and the evolution of its program provides an example of what is often involved in introducing a novel technology in a developing country.

Brazil's space agency, the Instituto de Pesquisas Espaciais (INPE), has since its beginnings in 1962 been oriented to space applications, such as the use of satellites to broadcast educational programs to rural areas. According to Fernando Mendonça, INPE's former director and the person credited as the father of remote sensing in Brazil, remote sensing efforts began as early as 1967. At the time, however, there was little awareness of or interest in remote sensing in Brazil, laws governing resource exploration were prohibitive, and there was also considerable opposition from military officers concerned about aerial photos of strategic sites. INPE managed to get government permission for aerial surveys in a few limited areas with aircraft and sensing equipment loaned by the U.S. National Aeronautics and Space Administration (NASA). "Then we had something to show around," Mendonça says, and out of the interest generated came the beginnings of a remote sensing program. Nonetheless, INPE had to train not only its own specialists but also potential users of remote sensing data from other government agencies in such things as photo interpretation. One of the first results of the training program and Mendonça's proselytizing was a radar mapping program (see accompanying article). In 1970 INPE acquired its own plane for aerial surveys, and in 1973, a Landsat terminal.

The Landsat program has now grown to be a major remote sensing effort with hundreds of customers for the data it provides and a substantial research program. But the program has had a history of problems that are only gradually being resolved. The ground station and the associated processing equipment to produce photographs from the data radioed down from the satellite operated unreliably for the first couple of years, in part because film, replacement equipment, and other supplies had to come from the United States. "It's hard to run a high technology effort in Brazil," one INPE scientist says. Training technicians, potential users of Landsat data, and even their own remote sensing scientists has been and continues to be a major effort at INPE. Security restrictions imposed by the military until the beginning of 1976 required that the data be regarded as classified and released to potential users only after approval of the applicants and their purpose in seeking the data. Users in other countries (except NASA scientists) were prohibited access to Brazilian data. Even for Brazilian users the prices INPE charged were so high as to discourage wide use.

NASA officials were unhappy with the restrictions placed on access to Landsat data, since they run counter to the agency's stated policy. When the U.S.–Brazilian Landsat agreement came up for renewal in 1975, the agency imposed the condition that information for all of South America be made available to all comers at prices comparable to those charged by the EROS data center in Sioux Falls, South Dakota. The request was backed up by the tacit threat of cutting off Brazil's access to the satellite altogether. After considerable internal debate and, eventually, the direct intervention of President Ernesto Geisel, Brazil agreed to the new arrangements in May 1976. INPE was also given an additional $1 million by its parent agency, the Brazilian National Research Council, to upgrade the operational system and put it in better working order. Research ef-

forts to make better use of the Landsat data, including image enhancement techniques and automatic digital processing of the data, have also been stepped up. The new director of INPE, Nelson de Jesus Parada, says that orders for data are now filled within 20 days of their receipt and that the station is operating reliably. Orders from other countries, Bolivia in particular, are growing rapidly.

Most Brazilian users of Landsat data rely on visual interpretation of photographs produced from each of the four spectral bands in which the satellite's sensors operate. The data are initially recorded in digital form, however, and lend themselves to image enhancement techniques and to computerized analysis. The research effort at INPE is moving in this direction. About 50 researchers are developing methods for producing soil maps, making crop forecasts, and exploiting other sources of remote sensing data. The intent, according to Parada, is to perfect methods and pass them on to others, although the agency is doing some routine data interpretation now for groups of users that are not yet capable of doing their own. The researchers have at their disposal a budget of about $250,000 per year and a sophisticated computerized facility for digital image analysis bought from General Electric; the system, one of a dozen or so in the world, comes with computer programs that make it easy to enhance the contrast of a particular image, to assign false colors, to classify portions of the image according to spectral characteristics—all in an interactive manner that allows the researcher to try one approach after another.

An agronomy group, for example, is concentrating on soil maps and is estimating crop yields in trial plots on an experimental basis. Crop forecasting would be a major contribution to Brazil, which does not have any alternative system for collecting agricultural data. This lack was pointed up by the frost that hit coffee-growing areas on 16 July 1975, and led to newspaper reports that 80 percent of the trees had been destroyed and to a strong reaction in the coffee markets; in fact, an INPE map based on a Landsat photo taken after the frost showed the damage was even more extensive, approaching 100 percent in the region studied. INPE investigators are pleased with their preliminary results in crop forecasting and hope to extend their experiments to an entire state in the near future.

The geological group is mapping four 100,000-square-kilometer regions in great detail as a way of feeling out the potential of the technique. In the process they have found a number of previously unknown structures and in one region are proposing a major revision in the accepted tectonic interpretation. Working with known areas of bauxite, iron, and tin mineralization, they are working out the identifying radiometric signatures of the ore bodies in preparation for automatic analysis of larger areas of the country that may also yield ore deposits. One study has focused on peculiar circular volcanic structures as large as 30 kilometers across. Some of these structures are known to contain uranium and thorium deposits. The INPE investigators have been able to show that most of the known deposits occur around the edges of smaller, circular formations within the larger structures, and they suggest that the pattern may be a useful guide to further exploration.

An oceanography remote sensing group at INPE is mapping coastal navigational hazards with Landsat. They are also combining Landsat images and sea-surface temperature data from the U.S. NOAA-IV satellite's infrared sensors in an attempt to provide daily charts of upwelling areas off Brazil's coast that are prime fishing areas. Because of a complex pattern of currents, the upwelling areas are small and tend to shift location rapidly, to the distress of Brazil's small fishing industry.

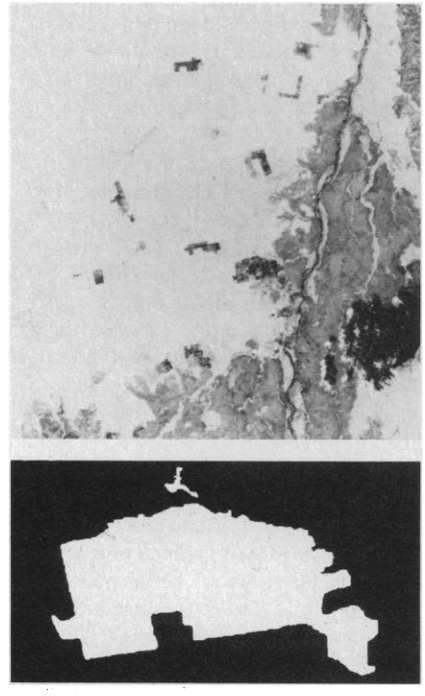

Fig. 1. (Top) Landsat image (band 5) of a portion of the Amazon Basin showing a number of cleared areas. The image here is reversed, with cleared portions appearing as dark areas. (Bottom) INPE computer analysis of the portion of the image containing the largest fazenda or plantation; the amount of deforested land, 164,877 square kilometers, is calculated automatically. [Source: Instituto de Pesquisas Espaciais, Brazil]

Very few of the results of the Brazilian Landsat effort have been published in the international literature. The major users of the data, such as the national oil company, Petrobras, or the principal mining agency, are secretive about what they are doing. But there are several indications that Landsat data are already having a substantial impact on Brazil. The national geographic institute is revising the official map of the country with Landsat data, a nontrivial task that will also have greater impact than it would in the United States, where accurate maps already exist. "For Brazil, it would be a major benefit," Mendonça says, "if Landsat produces nothing more than good maps."

Even more important, however, may be the uses of Landsat as a monitoring tool. The government agency charged with overseeing development of Brazil's huge Amazon wilderness, known by its initials SUDAM, is now using Landsat data to make a yearly check on the extent of deforestation in a region where many private landholders are clearing land for cattle ranches. Brazilian law restricts clearing to 50 percent of the area in a fazenda, as they are known, but in the past there was simply no effective way of enforcing the limit—a circumstance that many landowners were suspected of taking advantage of. But the Landsat photos show cleared areas unambiguously (Fig. 1) and SUDAM last year used them to resolve a number of alleged abuses.

With Landsat data now widely available for most of South America, with active programs in most of the countries, and with a second Landsat ground station in the planning stage (in Argentina), remote sensing is well on the way to becoming a major development tool in this part of the world. One Brazilian observer, reflecting on this course of events and what he sees as evident benefits to his country, told *Science* that he thinks "the best forms of foreign aid are no longer efforts in the style of the AID [Agency for International Development] but transference of technology in the style of NASA," which, he says, "has done a good job." In any case, it is noteworthy that in the backlash here over the Carter Administration's human rights policy—a backlash that has led to a cancellation of military assistance pacts and other agreements—no one has even suggested canceling Landsat programs. Remote sensing, apparently, is too important for politics.—ALLEN L. HAMMOND