Imaging the Earth (I): The Troubled First Decade of Landsat

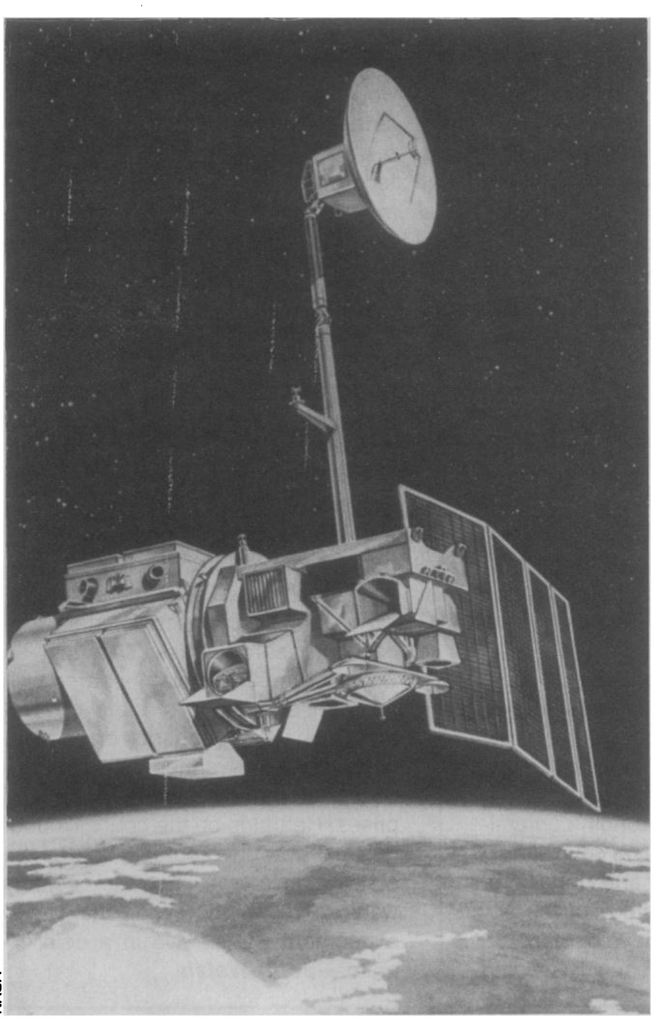
Landsat-D is about to be launched; if all goes well, problems with the program may be alleviated

This coming July, almost 10 years to the day after the launch of Landsat-1, the National Aeronautics and Space Administration (NASA) will orbit Landsat-D, the first of its second-generation remote sensing satellites. The timing is coincidental but fitting. The spacecraft caps a decade of brilliant technical success by NASA. But frustration among users of Landsat data has marred the achievement.

The conflict between NASA and the users is as old as Landsat itself. The idea for Landsat emerged in the 1960's, in the U.S. Geological Survey under its late director William T. Pecora. The early weather satellites and pictures taken by the Gemini astronauts had shown survey scientists something of orbital photography's power. A single image could encompass large-scale geological features that might take days or weeks to cover with aerial mapping. Better still, such photographs could show features so extensive that they had never been noticed from the ground and that were lost in the patchwork of aerial mosaics.

This is the first of two articles on the history of the Landsat program. Next: the search for a home.

Others were thinking along the same lines. In the Department of Agriculture, for example, Archibald Park and his colleagues were interested in large-scale surveys of crops and forest. Embryonic ideas for an Earth Resources Observation Satellite (EROS) took form as early as 1966, and by 1968 the Interior Department was asking the Office of Management and Budget for money to build it. The answer was "no": space belonged to NASA.



NASA

Landsat-D in orbit, an artist's conception.

NASA, meanwhile, was still preoccupied with getting Apollo to the moon. Under pressure from its fellow agencies it did agree to develop and launch an EROS satellite. But NASA did not want to get involved in cranking out survey data on a day-to-day basis. Quite aside from the demands of Apollo, NASA's charter (the National Aeronautics and Space Act of 1958) specifically stated that it was to be a research and development agency, not a vendor of services. At a minimum, Interior or perhaps Agriculture, as the prime users, would have to take responsibility for archiving and distributing the data EROS would collect.

The people at Interior had always felt that EROS should have been their satellite anyway, so it was a deal. The system set up then is still in effect today: NASA collects the satellite data at Goddard Space Flight Center in Greenbelt, Maryland, and Interior sells it through the Geological Survey's EROS Data Center in Sioux Falls, South Dakota.

After the pact was made, NASA's once modest efforts in remote sensing research hardware escalated into full-fledged program development. And therein lay the problem. "The minute that NASA stepped in," says one observer, "the program took on a definitive characteristic. NASA is very good at building *things* and managing big programs. Then once it has built those things, having put 10 times the money into developing the instruments as into learning how to analyze the data, NASA just says, 'Here it is community, *use* it.' A prime example today is Landsat-D. They're spending $500 million on the system and you could carry around the money for analysis in a thick wallet."

In fairness, NASA originally presumed that the users of the data would pay for the analysis themselves—a hope not always realized. More recently, the agency has had trouble getting the money for data analysis. (Landsat-D project scientist Vincent Salomonson finds this is a very sore point. The actual figure for anlaysis over the next several years is about $5 million, he says, and most of that money is for checking the integrity and quality of the data, not for applications per se.)

In NASA's hands, EROS became ERTS, the Earth Resources Technology Satellites. ERTS-1 was launched on 23 July 1972. Built into the same spacecraft frame designed for the Nimbus weather satellites, ERTS-1 resembled a stocky ocean buoy, with a pair of rectangular, photovoltaic wings open to the sun. It flew based-down, 900 kilometers above the surface. The polar orbit took the satellite over any given spot on the earth once every 18 days, between 9 and 10 a.m.

The main instrument on ERTS-1, a triplet of television cameras (return beam vidicons) for photographing the earth in color, failed shortly after launch. But disappointment was soon forgotten as the mission controllers at Goddard became entranced with the data coming from the spacecraft's other instrument, an experimental device called the multispectral scanner (MSS).

The MSS had been tested on high-altitude aircraft, but no one was really sure what to expect from it in orbit. A "scanner" mirror rocked from side to side some 13 times per second. By deflecting light from the ground into the detectors, the mirror scanned the scene below in a series of parallel swaths—rather like someone walking along a path while sweeping it with a broom. Its "multispectral" sensors took the spectrum between green light and the near infrared, divided it into four wavelength bands, and measured the brightness of each band separately. The idea was to compare the reflectance of a scene in the various bands and thus identify crops, forests, landforms, cities, and patterns of land use by their "color."

The MSS worked beautifully, recalls Salomonson. "The resolution and the image quality were much better than anyone had expected. It became the primary instrument."

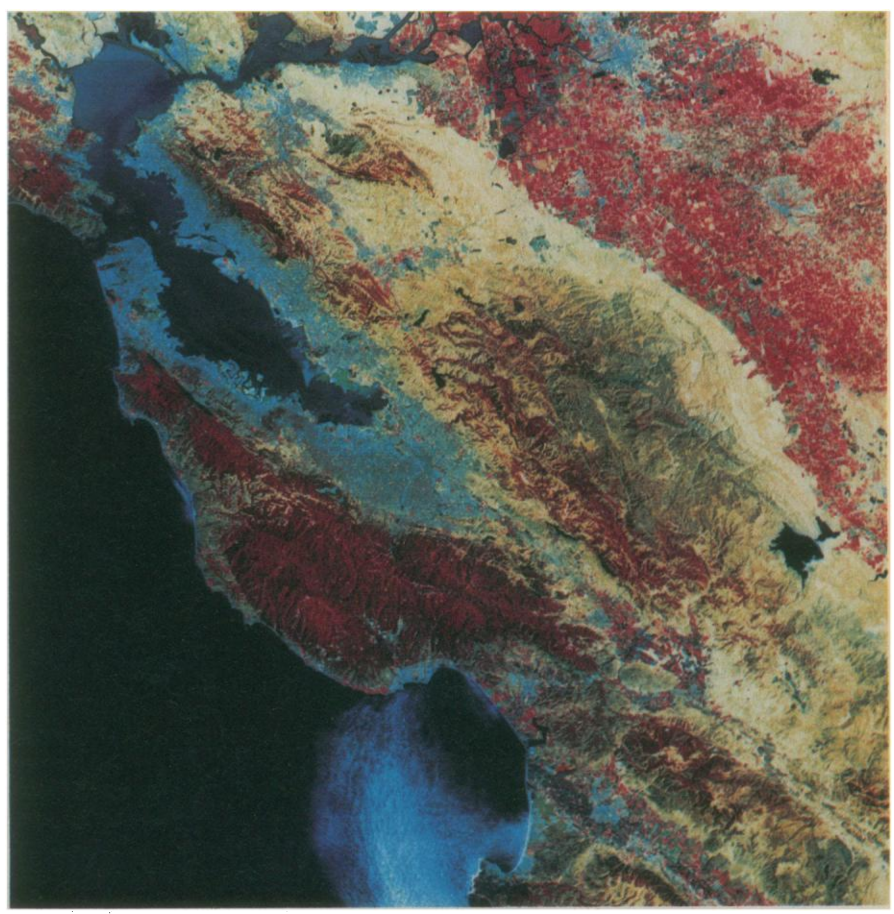
The imagery from MSS, printed in false color in order to include the invisible infrared band, had an eerie and unexpected beauty. There were scarlet forests, red patchwork farms, blue city grids, brown crinkled mountains, and a delicate web of highways. The information content was enormous. Using ERTS-1 images of California, it took just 40 man-hours to inventory 25 separate crops in 8865 separate fields. Agronomists were able to detect and monitor such plant diseases as corn leaf blight. Geologists could take in whole fault zones at a glance. Hydrologists could monitor the Sierra snowpack and could easily inventory surface water in rivers, lakes, and streams. Land use planners could see urban sprawl and strip-mine damage made painfully obvious.

By the mid-1970's, it was not just the original federal agencies who were involved but state and local governments as well. Mining and oil companies were taking notice. Private firms were springing up to analyze the data for paying clients. The demand for satellite remote sensing edged inexorably upward, and NASA, like it or not, began to be drawn into a quasi-operational program.

ERTS-B, the backup for the first spacecraft, was launched on 22 January 1975. To emphasize its utility for remote sensing of the land (as opposed to the oceans or the atmosphere), agency officials renamed the whole program "Landsat." The original ERTS, naturally, became Landsat-1. Landsat-3 followed in March 1978 and is the only one of the trio still in operation today.

Planning for a second-generation scanner had begun as early as 1970. The thematic mapper, as it is now called, advances the 80-meter resolution of the MSS to 30 meters, and senses not just four spectral bands but seven. In agriculture, the mapper will be able to resolve much smaller fields and make more accurate and reliable distinctions between, for example, corn and soybeans. In other realms it will make finer distinctions between different types of land use or different varieties of rock.

To this end, NASA engineers exploited their experience with Landsat-1, -2, and -3 to optimize the choice of bands. Various combinations would then yield information about the depth of rivers and lakes, indicate the growth stage and vigor of crops, measure the absorption of light by chlorophyll, measure total biomass and stress on a crop, differentiate between snow and clouds, and detect hydrothermally altered rocks and clays. A final band lying in the thermal infrared would measure temperature. Changes between day and night could then be converted into estimates of the heat capacity of a given region and thus into



NASA

Landsat-3 photographs San Francisco Bay

Urban areas around the bay appear as a blue gridwork. Just below, the redwood forests of the Santa Cruz Mountains show up scarlet. In the upper right, the fields of California's central valley are a red-and-pink plaid.

information on subsurface structure.

NASA's engineers still thought of Landsat as an exercise in technology development, however, and so they planned to put the thematic mapper on a simple, one-instrument spacecraft: Landsat-D. The project was announced as a new start in 1977, with a launch projected for 1981. The ever-growing Landsat user community promptly erupted in pent-up rage.

"There was this great hue and cry about 'continuity'," recalls Anthony J. Calio, deputy administrator of the National Oceanic and Atmospheric Administration and until recently a prime mover of the Landsat program as head of NASA's Office of Space and Terrestrial Applications. By this time the market for Landsat products was several million dollars per year. Many of the largest users—including several state governments and such politically potent federal departments as Interior, Agriculture, and Commerce—had begun to make heavy investments in computers, software, and trained personnel. Unfortunately, it was all specialized for the original MSS. None of the software and little of the training would suffice for the thematic mapper, which would have very different characteristics. People were perfectly willing for NASA to develop new technology. But to protect their investment they demanded a less abrupt transition. They wanted NASA to find room on Landsat-D for an old-style MSS.

"The general feeling at NASA was that the MSS wasn't needed," recalls Calio, echoing some of the agency's frustration at the time. "We thought that when people saw the thematic mapper data they wouldn't be interested in the scanner anymore."

But the users' grievances went far beyond continuity. "As we explored new uses for Landsat," says Calio, "it became a requirement by the customer community that they wanted both new data and retrospective data, and they wanted it rapidly. So we were subject to a lot of criticism because we didn't act like an operational agency. People wondered why, when they put a nickle in the slot, they didn't just get a map out. But they forget it wasn't structured for that. These were experimental spacecraft. The way the ground data system developed, the way the whole flow of products was established—it was not geared up to be a production operation cranking out hundreds of scenes per day. It broke down trying to keep up with the throughput."

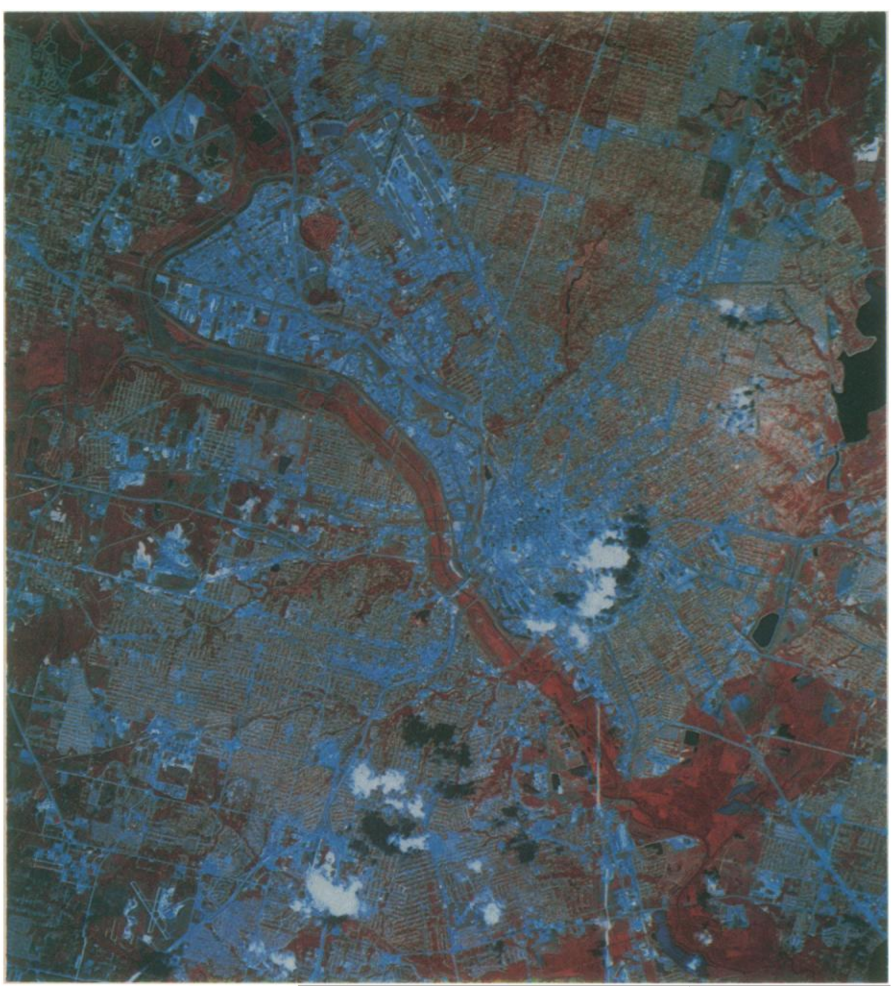
Out in the field, meanwhile, one heard words like "incompetent" and "insensitive to user needs." One still hears them. A single Landsat scene on computer tape currently costs about $300 from the EROS Data Center (EDC). This is a bargain, most users say, except that delivery of fresh images can take up to 6 months. This delay is intolerable in applications that require timely data, such as agriculture and pollution control. EDC, in turn, blames the delay on slow processing of the incoming data at Goddard.

Another complaint: in the early days at Goddard, before anyone realized that those first images might later be important for looking at long-term changes, the data were stored on tape in analog form instead of digitally. Some of those tapes have seriously deteriorated. "You can't get the data off the tapes," laments one user.

Given the general discontent at the time of the Landsat-D announcement, the federal user agencies were ready to force the continuity issue. In early 1978 an ad hoc council was put together under presidential science adviser Frank Press, and before the year was out the Office of Management and Budget (OMB) had passed the council's recommendation on to NASA in the form of an order: for the sake of continuity, Landsat-D would carry a multispectral scanner.

"OMB did pass the hat among the user agencies to get the money to pay for the scanner," says Calio, "but when the hat came back, it was empty. So that first year, at least, NASA had to eat it all—$6 million or $7 million."

About the same time, stung by criticism of "insensitivity to the users," the agency moved to heal the split. It inaugurated a nationwide program of applications research and technology transfer, which has been quite successful in introducing new users to the system and is still in operation today. And in mid-1979, in an effort to avoid a repeat of the data distribution debacle, the agency restructured its plans for the Landsat-D ground systems. In particular, the MSS is now to function in a high-throughput, operational mode from the beginning. "It's going to crank out up to 200 scenes per day," vows Calio.

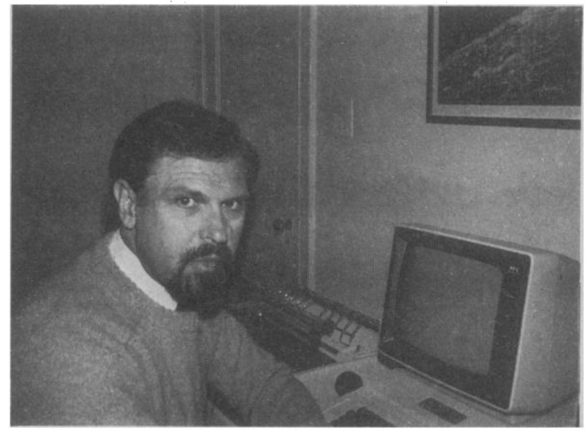


NASA

Dallas in Infrared

This multispectral image was taken from an aircraft at 65,000 feet.

The thematic mapper, however, will stay under the engineers' control until January 1985. First they will have to learn to correct its pictures for such things as the motion of the spacecraft, the interaction of the reflected light with the atmosphere, and the jitter of the spacecraft as the scanner and mapper mirrors go banging back and forth. Only then will they study how to boost the data processing to production levels. "A very large segment of this activity is number crunching," explains Calio. "The way you write the software for experimental diagnostics is not the same as for high throughput."



Charles Sheffield

"The technological lead has passed out of the hands of this country."

NASA and its prime contractor, General Electric, wrestled with the ground system all through 1979 and 1980. Meanwhile, Hughes Aircraft was having problems with the mapper. Hughes also built the multispectral scanners in the first three Landsats, but the spectral bands of the mapper were narrower and there were more of them, which meant more detectors had to be crowded into the instrument's focal plane. At each point of each image the mapper was supposed to distinguish between 256 levels of brightness instead of the scanner's 64. Its signal-to-noise ratio was supposed to be higher. It was supposed to return data to earth at 85 million bits per second instead of the scanner's 15 million bits per second. Inexorably, Hughes' original estimate of $40 million for the mapper began to escalate toward $120 million. NASA, faced even then with shrinking budgets and under the gun to get a new MSS flying as soon as possible, began to contemplate the ultimate irony: flying Landsat-D without its thematic mapper.

"Half a dozen times at least, we were on the brink of leaving the thematic mapper off," says Salomonson. "At one time the thrust was to dump the whole thing and build a solid-state device instead."

There are those who think they should have. The device Salomonson refers to is the multilinear array (MLA). If the mapper scans the countryside like a whisk broom, the multilinear array would do it like a push broom. Thousands of tiny silicon detectors (charge-coupled devices) would be lined up perpendicular to the spacecraft's direction of motion; each would scan a continuous line, and together these lines would build up a two-dimensional image with very high resolution. MLA's are available commercially for aerial work. The French National Space Program, for instance, will use an American-built MLA aboard its SPOT satellite, a commercial remote sensing spacecraft that it plans to launch in 1984. This makes some people frantic.

"The technological lead has passed out of the hands of this country," declares Charles Sheffield of Earthsat Corporation, a Maryland firm specializing in the analysis of Landsat data. "The thematic mapper reaches 30-meter resolution, but you can't push the scanner technology much further. If we ever do transfer Landsat to the private sector, they will be taking over obsolete technology. The multiple linear array is the logical next step. But the U.S. isn't developing it—at least not for civilian use."

True enough, there is no plan (and no money) to fly an MLA on a satellite, say NASA planners. Under the Reagan Administration that will be left to private industry. "But unequivocally, our MLA development program is one of the finest and most advanced in the world," says James C. Welch, technical director of NASA's Earth and Planetary Exploration Division. The problem with flying it on Landsat-D, he maintains, was that the silicon detectors in the MLA need a lot of work before they can operate in the far infrared, the region the thematic mapper will explore. "We could have done what the French are doing," he says, "but there would have been no advantage over Landsats 1, 2, and 3. The thematic mapper is miles ahead."

Anthony J. Calio

"These were experimental spacecraft."

Thus, NASA stayed with the thematic mapper. Fortunately, Hughes was able finally to get its problems under control. The projected launch date was slipped to 1982, and by late 1980 the thematic mapper was solidly back on board.

Landsat-D is currently undergoing final checkout at the General Electric Space Divison plant in Pennsylvania. A Delta 3920 launch vehicle awaits the satellite at Vandenberg Air Force Base in California. In July, if all goes well, the boxy, awkward-looking satellite will take its station in polar orbit some 700 kilometers above the surface and in smooth, efficient streams the data will begin to flow out to the users. With its MSS and eventually its thematic mapper set up for high-volume production, Landsat-D could go a long way toward ending a decade of tension and recrimination.

Unfortunately, the deeper controversy will not end there. Rhetoric aside, the problems of the last decade were not really NASA's fault. Congress created NASA to be a research and development agency, and with Landsat it fulfilled that role very well. NASA is not supposed to be an operational agency, so not surprisingly it did not act like one.

More important, however, the National Aeronautics and Space Act of 1958 has a fundamental omission: it does not tell NASA what to do when a given space technology becomes mature. Arguably, the Landsat system could have been made operational years ago. But then who would run it? The decision was not NASA's to make; it was, and is, the responsibility of Congress and the White House.—M. MITCHELL WALDROP