

TAKING THE PULSE OF THE PLANET

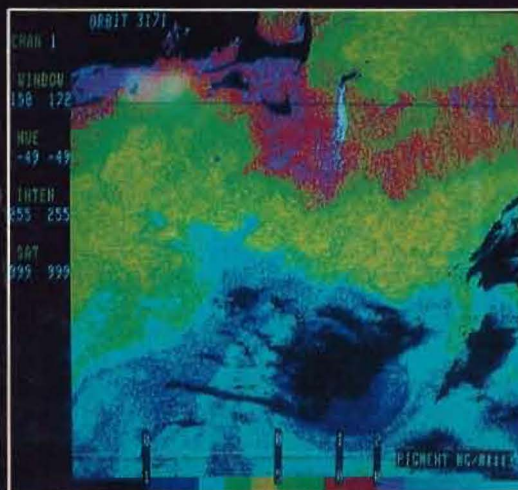
SATELLITES

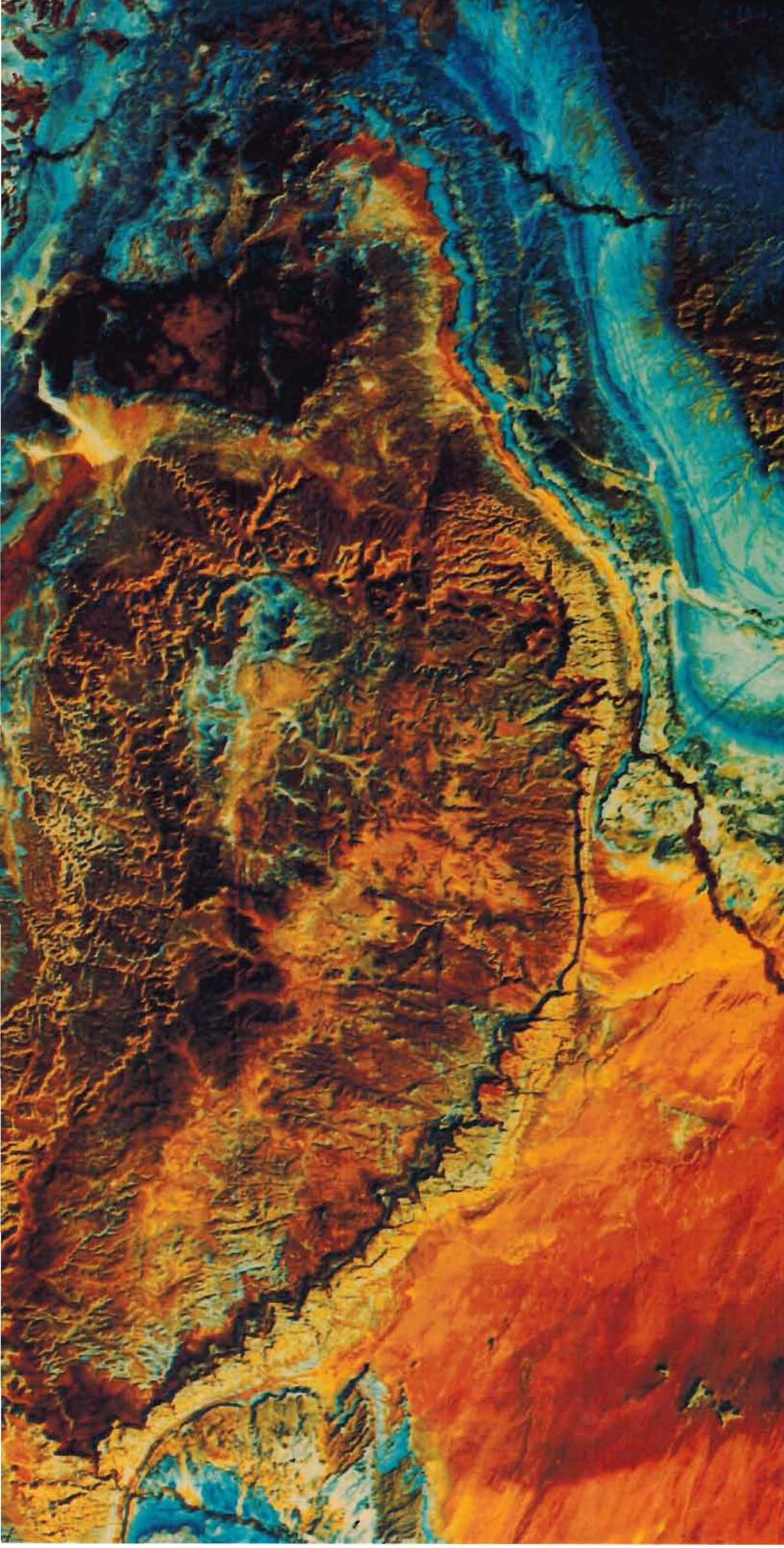
WATCH OVER THE WORLD

BY MARCIA BARTUSIAK

At TV sets across the nation, transfixed Americans watched the second mission of the space shuttle *Columbia*. From its orbit, 137 miles above Earth's surface, *Columbia* returned the scrutiny. The ship's cargo bay contained new surveillance instruments that inspected the planet's landscape, sniffed out carbon monoxide in its atmosphere and even surveyed the growth of ocean algae. The largest instrument aboard, a special imaging radar built by Caltech's Jet Propulsion Laboratory (JPL), provided the most dramatic discovery: a pass over the Sahara Desert showed a varied ancient terrain of terraces, fault lines, alluvial fan features and dry river valleys buried just below the now barren desert surface, remnants of a wetter past thousands of years ago. James Welch, deputy director of NASA's Earth and Planetary Division, has called the radar's unexpected "X-ray" capability "an outstanding revelation." The penetrating vision of the imaging radar caps a two-decade effort to monitor the Earth from afar. Today, satellites' keen eyes help geologists spot potential mineral deposits, agronomists monitor the spread of crop disease, and hydrologists measure mountain snowpacks to assess the supply of water that will arrive in the springtime thaw. In a sense, science is using its perch in outer space to take inventory of the world. Television viewers are most familiar with the

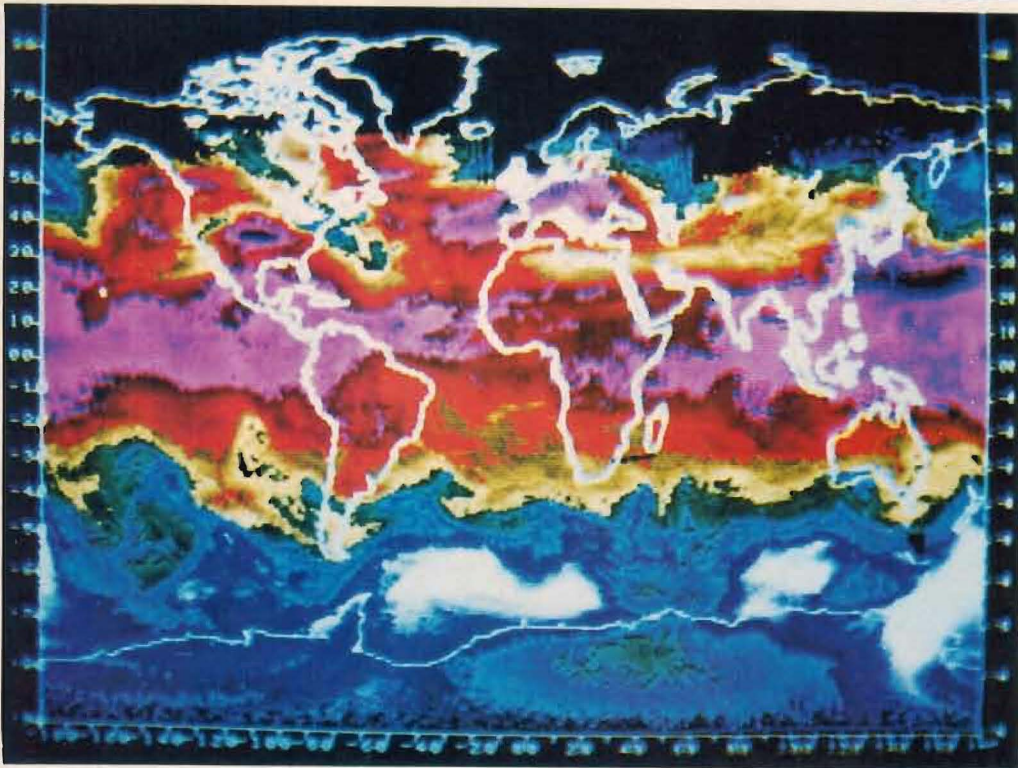
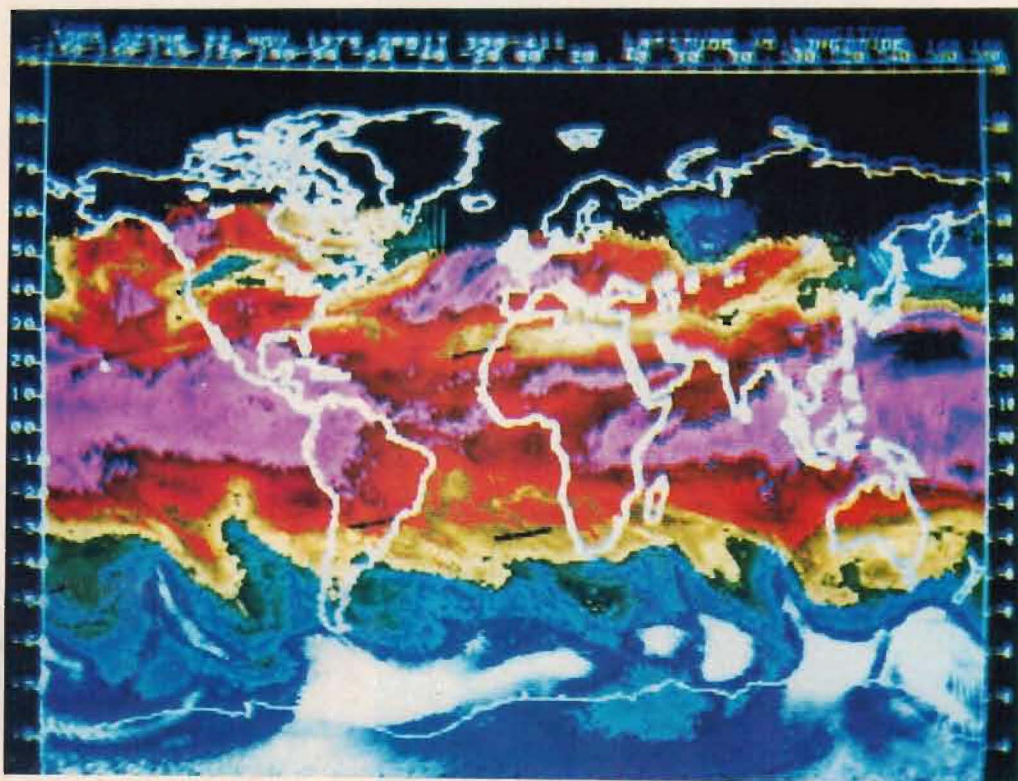
These images, taken by the Coastal Zone Color Scanner, indicate the amount of algae living in the ocean. Areas of dense algae are shown by colors at the right of each color scale. These views show (left) the East Coast from the Chesapeake to New Hampshire and (right) the shallow waters that lie south of Cape Cod.





More than a million Landsat images have spewed out of the computers. Scientists just started to dip into this reserve.

By combining a Landsat multispectral image with a Seasat radar image of the same scene, scientists can trace bands of rock. In this overview of the San Rafael Swell, an uplift area in eastern Utah, the browns and copper tones are sand dunes and sandstone; the blues are shale. The San Rafael River winds to the right of the swell.



One of the varied capabilities of Nimbus 7 is measuring changes in the amount of ozone in the Earth's atmosphere. In these global maps, reds, pinks and yellows are low-level ozone areas, and blues and whites indicate high ozone. These images, taken two days apart, show little change in low ozone areas, although there is great variability in higher ozone areas.



PARKE, STAVERT AND HUSSEY (1982)

AN EYE ON ARMS

A sophisticated network of reconnaissance satellites may be the key to arms-control verification. America's military satellites can see, hear or feel nuclear weapons being tested, deployed or launched and even tell whether production plants are operating.

Altogether, we may have as many as 50 operational spy satellites in orbit at a time. The CIA's two big KH-11 satellites transmit images directly to Earth, providing immediate, or "real time," data. Lower-flying satellites, such as the Air Force's Big Bird and close-looks, which take conventional photographs, have finer resolution (the close-looks can distinguish objects as small as six inches across) but shorter lifetimes and may be replaced in 1984 by a single large satellite. These satellites can see missile pads being built and missiles and material being transported; they can reveal launchers, missile-carrying bombers, ships and subs, and observe flight tests, test sites and production plants.

Infrared sensors on the Defense Support Program's early-warning satellites can detect heat plumes given off by rockets and announce a missile launch. Nuclear explosions in space or the atmosphere can be detected by the ultraviolet and X-ray sensors of the Global Positioning System satellites, which are also used for military navigation. Listener satellites intercept the telemetry, or information on performance, that Soviet missiles send back during testing.

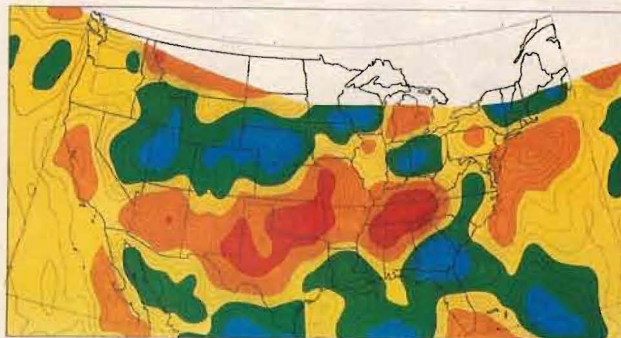
According to Thomas Longstreth, research analyst with the Arms Control Association, satellites are "a significant means of verifying arms-control agreements."

—Signe Hammer

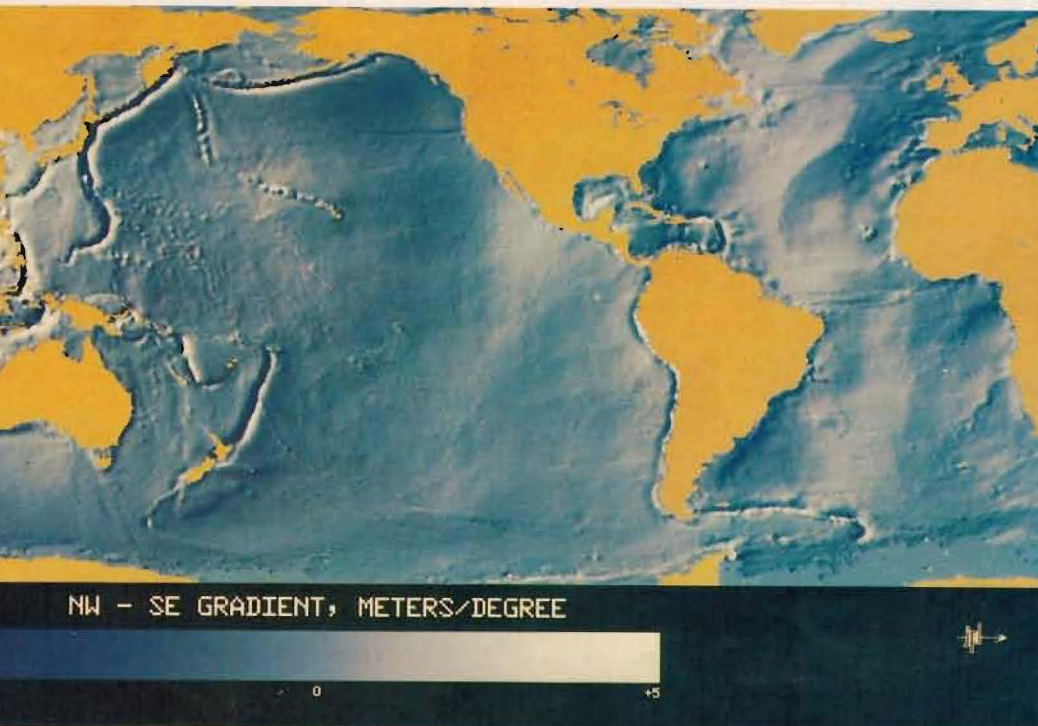
and infrared wavelengths. That's the key to Landsat's power: every bit of terrestrial real estate—soil, rocks, plants and man-made edifices—sends out a spectral signature, a sort of fingerprint in light. The newest Landsat can also sense thermal radiation emitted by warm objects on the ground.

In the color scheme adopted for Landsat, strong sources of infrared radiation, such as vegetation, are shown in red. Forests, jungles and croplands blaze across the pictures like spreading fires. Experts study these hues to identify major crops, measure acreage and diagnose the health of plants. Wheat acreage in Kansas was once assessed with an accuracy of 97 percent. In Maine, paper companies use seasonal Landsat images to conduct quick forest surveys. Evergreens retain their reddish Landsat tones throughout the year; hardwoods change from pink to red to brown during the growing season.

Man's sprawling urban developments show up as dabs of grayish-blue, due to the intense visible light reflected off concrete highways, airports and buildings. Open land can show up as white, green or brown, depending on the condition of the soil. Clear water looks dark, because it is a poor reflector in all the bands of light collected by Landsat. "When we see patches of color in rivers, lakes and coastal estuaries, it's an indication of sediments in the water," points out Freden. "In this way, we can



(Above) This map of the United States, put together with data collected by Magsat, shows the magnetic fields arising from sources in the Earth's crust. (Left) Seasat gathered the data for this relief map of the world's oceans. The Mid-Atlantic Ridge and the trenches along the western margins of the Pacific Plate are clearly visible.



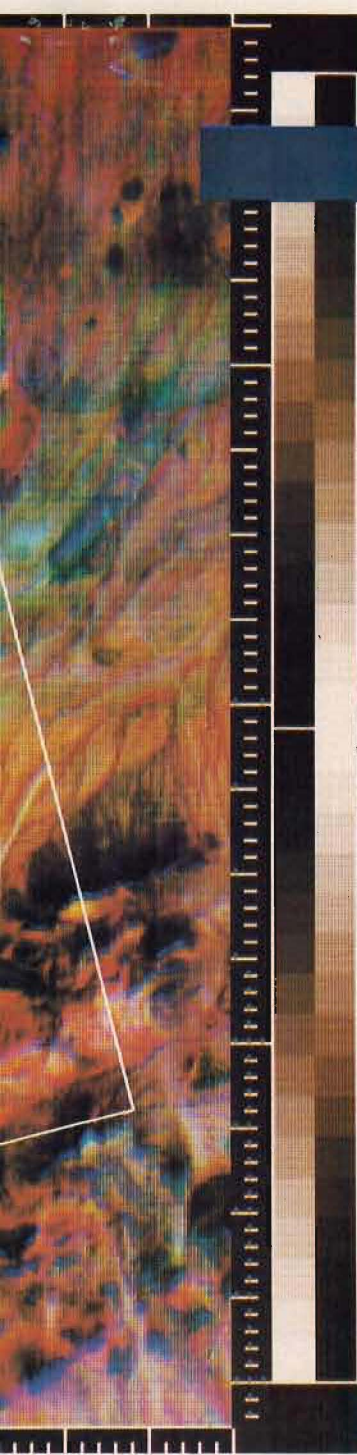


study current flows and tidal actions and pinpoint any dumping of pollutants.”

From the sales records, oil- and mineral-exploration companies are the biggest users of Landsat data. And for good reason. From their 500-mile altitude, Landsat satellites have been able to discover thousands of extensive geological features that went unseen in ground and aerial surveys and provide an opportunity to hunt out new domes and fault lines, where oil may be found.

More than a million Landsat images have spewed out of computers, yet to construct each image computers use just a fraction of the digitalized information gathered by the satellites. Scientists are only now starting to dip into that immense reservoir. Dividing the intensity of the infrared band by the intensity of the red band, for example, yields a useful vegetation index. The larger the ratio, the healthier the crop. Geologists such as Herbert Blodgett, of NASA's Goddard Space Flight Center, are applying the same kind of analysis to identify rock types, a valu-





A comparison of an aerial photograph (left) and a Thematic Mapper Simulator image (above), both taken of Silver Bell copper deposit in Arizona, demonstrate the Thematic Mapper's ability to discern characteristics of rock not visible to the naked eye. The yellow and orange areas indicate iron oxides and clays, both of which are associated with ore deposits (outlined).

able guide when searching for new mineral deposits. In one image of western Saudi Arabia, for example, Blodget was able to pinpoint pockets of granite amid beds of volcanic and sedimentary rock. Even some pyrite, or fool's gold, stood out.

While Landsat conducts its geological surveys, a host of other satellites are circling the globe to study other aspects of Earth's environment. The Solar Mesosphere Explorer, for example, has been monitoring the density of ozone in the upper atmosphere, a crucial measurement because the ozone layer protects us from the sun's harmful ultraviolet rays.

MAGNETIC ANOMALIES

Magsat (magnetic field satellite) went up for eight months in 1979 to take more than a billion readings of the strength and direction of Earth's magnetic field. By sieving the data, scientists have been able to map "magnetic anomalies," faint fields caused by unseen sources deep within the Earth's crust. Each feature—in effect, the magnetic signature of the rocks beneath the Earth's surface—promises to provide clues about the composition, temperature and structure of the Earth's crust all the way down to the mantle.

Some satellites, like NASA's Nimbus probes, are extremely versatile. Nimbus 7, launched four years ago, maps sea ice, monitors aerosol concentrations in the atmosphere and measures global distributions of carbon monoxide, methane and ammonia. It also carries the only sensor in orbit specifically designed to study living marine resources. By measuring the blue-to-green color shifts of ocean waters around the world with its Coastal Zone Color Scanner (CZCS), Nimbus 7 is indirectly counting the number of phytoplankton, or algae, in the water. "These are the tiny plants that form the bottom of the food chain that eventually leads to man," points out Warren Hovis, chairman of the CZCS team. "In order to determine the number of fish that we'll have available in our coastal waters, we first have to know how much food will be available to those fish."

Recently, the National Marine Fisheries Service used an oceanographic vessel to measure algae concentrations from Cape Hatteras, in North Carolina, to Cape Cod. The survey took a month. CZCS conducted the same survey in two minutes.

On the Pacific Coast, Ocean Data Services of Monterey, California, is radioing the latest figures from the color scanner to trawlers at sea to help fishermen locate the best fishing grounds. Tuna, for example, like to congregate in clear water right at the edge of algae-rich water.

Up to this point, sensors such as the CZCS and the Landsat multispectral scanner have been passive devices that simply record the electromagnetic waves being reflected off or emitted from the Earth. Advances in technology, however, are allowing satellite detectors to become more active. Imaging radar sends ultrahigh-frequency radio signals toward a target and then gleans information from the minuscule echo that is reflected back to the satellite. "The strength of this echo is usually less than the energy dissipated when a raindrop hits the Earth," points out Michael Kobrick, a scientist at JPL.

While Landsat looks at the chemical makeup of a surface, an imaging radar is concentrated on the physical textures. A rough surface will reflect a lot of radar energy back to the detector. Hence mountainous terrain, lava flows and forests will show up as very bright sources in a radar image. Smooth targets like desert floors and calm bodies of water will appear dark because they return practically no energy. "It's like looking at the Earth with alien eyes," notes Kobrick.

Unlike Landsat, imaging radar is not affected by the weather

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Radar satellites have a surprising ability: they can look two yards below the surface of the ground.

SATELLITES

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or time of day. "Radar is important," stresses Kobrick, "because it can pass right through a cloud as if it weren't there. In fact, you can't tell from a radar picture whether it was raining or even nighttime." Large sections of Brazil were not mapped until an airborne radar was able to pierce the clouds that often hide its rain forest. In the future, NASA hopes to orbit an imaging radar around Venus to give man a clear look at the geology that lies beneath that planet's perpetually murky veil of sulfuric acid clouds.

MASSIVE SHORT CIRCUIT

NASA launched the first civilian imaging radar into Earth orbit five years ago aboard an oceanographic satellite named Seasat. A massive short circuit cut its working life to three months, but not before oceanographers gained the most sensitive images yet of that two-thirds of our planet covered by water. They saw the structure and dynamics of miles-long surface waves, polar ice sheets, currents, oil slicks and eddies to a resolution of 25 yards. In one startling picture of the sea off Nantucket Island, the ripplelike shapes on the surface could be seen to follow the shapes of sandbars on the shallow ocean bottom.

Although the satellite's imaging radar was not designed to look at land, its spectacular images of mountain chains, volcanoes and canyons introduced many Earth scientists to its power as a space sensor and encouraged NASA to carry an imaging-radar system aboard the second shuttle flight. During each second of operation, 1,500 pulses of radar energy were sent out by the shuttle instrument, each pulse a burst of power that would light a 1,000-watt lamp. The shuttle radar scanned 4 million square miles of land in this way, including those regions of Egypt and Sudan that were found by computer analysis to harbor ancient watercourses beneath the desert sand.

The radar's surprising ability to look at least two yards below ground may be of limited use on Earth. "For radar to actually penetrate the surface, the area must be dry, and the material on the ground has to be fine grained and homogeneous," explains Ronald Blom, a geologist with the radar science and applications group at JPL. "Nobody ever thought that there was a place on Earth that would fit both those criteria." The hyperaridity in that particular part of the Sahara may have done the trick; it rains there only once every 30 to 50 years. But conditions in other parts of the solar system may be more suitable. The arid conditions on Mars, for example, might make the Red Planet the ideal subject for subsurface imaging.

NASA announced last December that *Columbia* had struck gold during her No-

vember 1981 flight. An infrared radiometer aboard the shuttle identified deposits of iron oxide and kaolinite clay in a remote section of Baja California. "Areas containing these minerals are high-priority exploration sites for gold, silver, copper, lead and zinc deposits," according to Alexander Goetz of JPL and Lawrence Rowan of the U.S. Geological Survey.

The identification of the minerals was made by a team of U.S. and Mexican scientists who were lifted by helicopter to the mountainous area last October. The area, about three miles in diameter, is the first such site to be identified from space.

Recently, JPL scientists have come to appreciate the power of combining perspectives from different sensors. By mixing data from Seasat and Landsat, they can trace bands of rock that cannot be discerned in any one map. Landsat provides the chemical information (vegetation, composition of the rocks), while the radar image defines the structural relief (whether the terrain is rough or smooth). Blom used this technique to analyze the San Rafael Swell, a 1,100-square-mile uplift in eastern Utah. The whole, in this case, is definitely greater than the sum of

Survival, not economic gain, could be the most compelling motive for further research into remote sensing.

its parts. In his computer-generated colors, vivid blue bands of shale swirl around a middle core of reddish-brown sandstone. Such a geologic fingerprint is more than academic: the Swell contains economically significant deposits of uranium for nuclear reactors.

But survival rather than economic gain may be the most compelling motive for further research in monitoring by satellite. Bruce Murray, former director of JPL, put it this way in one of his last addresses to the laboratory's personnel: "The Earth's climate has been undergoing large and rapid natural changes throughout the glacial ages, a geological period that still continues. The critical atmospheric carbon dioxide balance that governs in the long run the melting of the ice caps and the rise in sea level is perilously close to responding to human activity. Thus, sometime in the future, perhaps even as early as 1990, global climate monitoring, detailed identification of the crucial environmental parameters and preliminary forecasting will become a U.S. national imperative." In all likelihood, remote sensing from space will be a key to meeting that challenge. ■

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