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ABSTRACT

This publication identifies some of the general concepts of remote sensing and explains the image collection process and computer-generated reconstruction of the data. Monitoring the ecological collapse in coral reefs, weather phenomena like El Nino/La Nina, and U.S. Space Shuttle-based sensing projects are some of the areas for which remote sensing currently is being used. Remote sensing is also very effective at monitoring human actions from an environmental standpoint. (YDS)

Remote Sensing: The View from Above

Know Your Environment

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THE ACADEMY OF NATURAL SCIENCES

Know *Your* Environment

A Publication of the Environmental Associates

Remote Sensing: The View From Above

Technology gives scientists a new way to look at the world-- and the world a new way to look at itself.

> *"In a highway service station over the month of June, was a photograph of the Earth taken coming back from the moon..."*
> Joni Mitchell, Refuge of the Road.

I. Introduction

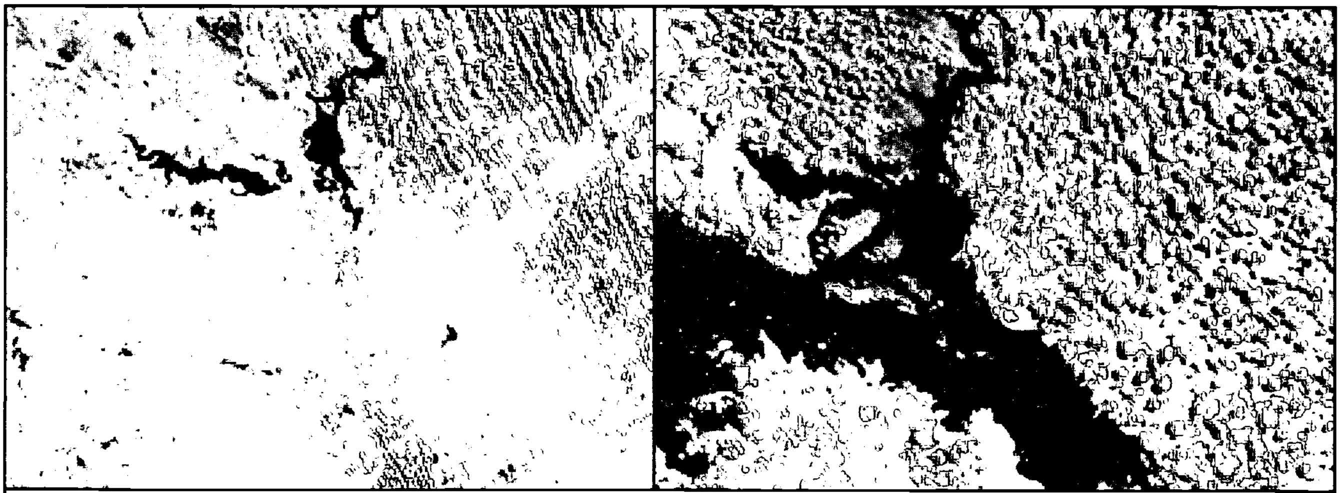
In the midst of the political and social turmoil of 1968, people all around the world paused to marvel at a photo sent back from the Apollo 8 spacecraft. The now-famous image--the blue Earth suspended alone in a black sky- seemed to show, for the first time, both the isolation and the majesty of our planet in space.

Few realized, however, that this dramatic picture only hinted at a revolution that was under way in how we would view the Earth. For over forty years, space travel has been giving humanity new opportunities, not only to peer into the depths of the cosmos, but also to look at the length and breadth of our own world. More than just a source of pleasing pictures, these sophisticated techniques now allow scientists to understand the Earth in ways we never before dreamed.

Since the beginning of spaceflight, an ever growing body of information is being gathered using space-based *remote sensing*. Agriculture, meteorology, oceanography, ecology, and cartography are just a few of the disciplines which have been transformed by this technology. Whether its ozone depletion, climate change or deforestation, some of the most important environmental issues of our time are only becoming understood because of vast networks of remote sensing devices and data analysis systems.

Yet for much of the public, satellite images and the information they convey seem vague, and far beyond the understanding of lay persons. The subject is, to use a cliche, "rocket science." Popular media may publish spectacular satellite pictures or announce findings made with remote sensing techniques, but few people have a clear sense of how crucial the knowledge is, how it is obtained, or how widespread and robust the sciences are which interpret it.

In the decades to come, remote sensing will be a key tool for making critical decisions affecting the Earth and its resources. It is important that informed citizens have a basic understanding of these technologies and how they are used.



Landsat 7 images of the Mozambique coast before and after last year's flooding. Such information allows scientists and policy makers to understand the scope of natural disasters and gives valuable clues in lessening the damaging effects.

Photos: Courtesy of NASA

II. The electromagnetic spectrum

Remote sensing, as we will see, is really just a way of enhancing and multiplying the capabilities of our natural senses. One of the most important of these human senses is vision, the ability of our eyes to detect light. Remote sensing increases the power of vision both by expanding our perspective and by allowing us to detect forms of energy that are invisible to human sight.

Light is only one class of a group of related energies known as electromagnetic radiation (EMR) that are present in our environment. Because the emission and reflection of many different types of EMR (including light) can be detected by instruments, they can also be used for remote sensing. Thus, to understand remote sensing, it is important to first understand the basics of EMR.

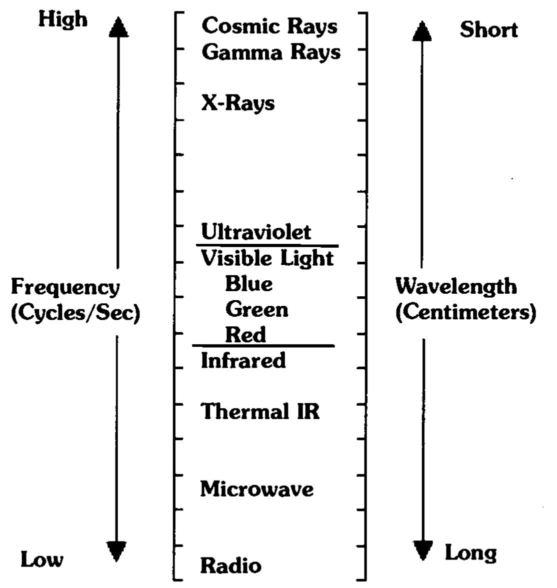
Electromagnetic radiation is one of the fundamental forms of energy in the universe. It can be thought of as moving in waves. The EMR spectrum includes such familiar phenomena as radio and x-rays as well as more exotic energies such as cosmic and gamma rays. The class (or *band*) of the radiated energy depends on the wavelength of the emission (or its frequency, as these two values are linked. See Figure 1).

Because of the way human vision has evolved, we tend to think of visible light as a special type of energy all to itself, a "natural" energy, as opposed to radio or microwaves which seem "artificial." Actually, all the forms of EMR are naturally present throughout the universe. In fact, at any given moment our sun is bombarding the earth with a variety of wavelengths of EMR, including visible light, infrared, radio and microwaves. (We are all familiar with another invisible radiation--ultraviolet--which our skin "detects" as sunburn).

Wavelength is also the factor that determines the color of visible light, ranging from longer wavelength (and hence lower frequency) red, through yellow and green, to the shorter waved, higher frequencies in the blue/violet end of the spectrum. A rainbow or a prism allows us to see the visible light broken down into it's color components. Frequencies that are lower than red (i.e. infrared) and higher than blue (ultraviolet) can be detected by special instruments.

Because the sunlight we see with our eyes is actually composed of a combination of visible light and invisible frequencies, it provides the principle natural source of EMR for remote sensing. Physical objects at the earth's surface can absorb, transmit, or reflect this energy, depending on the properties of the object. By measuring the intensity of absorption, transmission and reflection from features of the Earth's surface, scientists draw conclusions about the properties of the area being scanned.

Figure 1: The Electromagnetic Spectrum

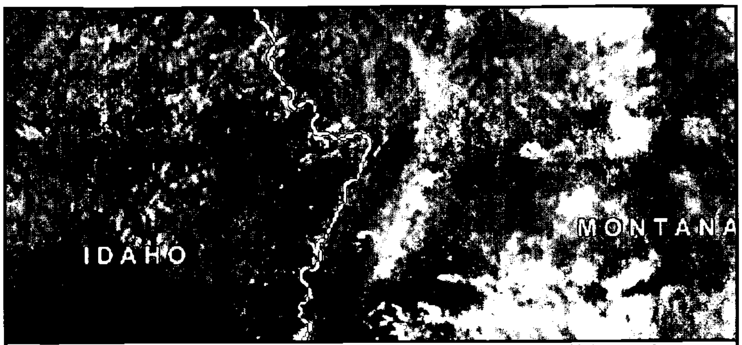


Many of the basic forms of energy in the universe are related as part of the electromagnetic spectrum. Note that as the wavelengths of energy decrease, the frequency increases. Image: R.Wall, ANS

For example, when a beam of light reaches the Earth from the sun, part of it is absorbed by our atmosphere and part of it is reflected. The remainder is transmitted to the earth's surface. Striking the side of a building, some of it may be absorbed and re-emitted, but much of the energy is reflected. (The energy re-emitted is often done so at other wavelengths, such as infrared. Though infrared is invisible, we can sense it as heat. This is the reason sunlit pavement is warm to the touch.)

If the reflected energy from a building strikes our eye, we interpret it as the shape and color of the structure, but in reality we are seeing the visible portion of the sunlight as it has been altered by the physical object it is striking. The invisible wavelengths of energy are also being absorbed and/or reflected, depending on how they interact with the material of the building. Using lenses and other techniques, ***remote sensing devices can be focused on the reflection and absorption of particular bands of EM.***

Though light is an important source of data for satellites, (providing images much like what we would see if we were actually looking down from the spacecraft), other types of EMR can reveal features that might not be apparent in visible light. This is particularly useful, because different classes of objects and materials vary in how they reflect or absorb different frequencies of EMR.



Where there's smoke... A plume of smoke from wildfires in Idaho, clearly visible in NOAA satellite images as it drifts across Montana. Photo: Courtesy NOAA Satellite Active Archive

Although there are actually other types of forces and characteristics which may be studied by remote sensing, electromagnetic radiation (EMR) is certainly the most important medium. Some writers even define remote sensing simply as using satellite based sensors to record electromagnetic radiation from the Earth, though, as we'll see a broader definition may be more accurate.

III. As Old As Humanity, As New as the Space Age

Remote sensing has been described as "a dominant component of human activity."[1] Though the term relatively new, in many ways the practice is as old as humanity. Our earliest ancestors almost certainly climbed trees or stood on high ground to get a view of their surroundings. Decisions were made--eg. where to hunt, where to roam--based on this information. In a rudimentary form, they were in fact remotely sensing electromagnetic radiation and processing geographic data.

We have an instinctive understanding that by viewing things from a distance--gaining a broader perspective--we are able to gain additional information about the things we are observing. With the advent of aviation, perspective widened considerably and remote sensing was able to became an organized study in it's own right. Early uses of aerial observation and photography like mapmaking and military intelligence were common practices by the mid-twentieth century. The specialized study of *photogrammetry*--analyzing pictures by making measurements of their features--was the precursor of modern remote sensing techniques.

In order to maximize the advantages of larger perspective, however, additional instruments were needed to augment human vision. While the human eye has a remarkable capacity to gather information, there are several factors which limit its use as a detection device. Besides only seeing visible light, our perspective is limited by our location, and we do not form a lasting record just by looking at something. In other words, any given phenomena has a host of attributes that can be sensed, beyond what human eyes alone can see and what the human mind alone can remember and analyze.

By using a vantage point like outer space, adding specialized sensors and recording devices, and using computers to examine the results, whole new images and attributes materialize.

In general then, remote sensing can be thought of as having the following key features:

~The acquisition of information about an object or process;

~Acquiring the information from some point that is not in contact or close proximity to the object being observed;

~Recording the information in a form that can be further analyzed.

With near-Earth space travel now routine, an ever growing number of orbiting satellites and computer technologies have been able to gain perspectives that can now include whole continents or even the entire planet. Along with its sister discipline *geographic information systems, or GIS* (the use of computers to manipulate geospatial data), remote sensing has become a central analytical tool in understanding the environment.

But while the remainder of our discussion will focus on ways that technology has allowed us to gather information with a precision far beyond simple human observation, it is also important to realize that remote sensing involves a crucial human element. There remains a subjective role in both the presentation and interpretation of the data collected by remote sensing.

For example, we know that different types of plants have unique ways of absorbing and reflecting certain frequencies of electromagnetic radiation. The "spectral signature" of a deciduous forest will be different than that of a coniferous forest. That difference however is not a precise, "all-or-nothing" value; it ranges across variable measurements. It is up to the scientists using the data to compare numerous sites, develop schemes for classifying the observations, and ultimately to compare the information gathered with the satellites to known points on the Earth. This last process, known as "ground truthing" is the only sure way to lessen the levels of ambiguity that may exist in remotely sensed data.

IV. Collecting the image

Thus far we have looked at some of the general concepts of remote sensing: it represents a natural progression in enhancing observations by gaining broader perspectives; it involves the use of instrumentation to detect energies that are invisible to the human eye; electromagnetic radiation from the sun is the most important form of these energies and the way objects and features respond to electromagnetic energy can be interpreted to gain information about the object. Now let us turn to some of the specifics of how this process is undertaken.

One important characteristic of remote sensing is that information is not gathered in the same manner that we normally see objects or acquire photographs. To understand this, we have to think of images not simply as pictures, but as composites of information. By this, we don't simply mean the context (eg. "that's a picture of a tree") but that the composition of the image itself can be translated into a body of information.

To illustrate, look at some small part of a black and white photo--a person's eye in a class picture, for instance. That tiny dot can be thought of as conveying three pieces of information--where it is located horizontally (the *x-axis*), where it is located vertically (the *y-axis*) and how dark it is on some hypothetical scale from pitch black to totally white, also known as the *grayscale*.

Now think of the entire picture as being made up of thousands of such tiny dots, known as *picture elements*, or--in a term that has become more widely known in computer circles-- *pixels*. Each pixel is defined by its location and its brightness. If we had a compilation of this data for each pixel--x and y axes and grayscales--we would have all the information that we needed to re-create the picture . In remote sensing, the grayscale of a pixel is called its *Digital Number or DN*, often a figure between 0 and 255.

Although there are a variety of techniques for remote sensing, the most common technologies assemble images one pixel at a time. (The term *raster* is the general description of this process.) As a satellite passes over a given region, its scanner detects the electromagnetic energy from the ground in discrete units, each translated into a pixel and each pixel representing a given area of ground. Ultimately the pixels are combined to form the larger image.

The Digital Number for a given pixel of any given image will depend on the intensity of the energy reaching the detectors. ***This may vary depending on which wavelengths of energy are being observed***. In other words, if the detector is sensitive to light in the red band, the DN will be very high when the sensor scans objects that are red. In many satellites, there are multiple detectors, each one designed to be sensitive to a different set of energy wavelengths.

Though sophisticated electronic sensors are often used now to detect specific EM bands, for many years this was accomplished with the use of filters and multiple ras. When the EMR radiation from the Earth's surface passes through a filter, only those portions of the spectrum in the filter's particular EMR band are allowed to reach the detector. The intensity of that portion of the spectrum--that is, how much energy the object is reflecting or emitting in particular bands--will determine how much energy reaches the detector.

If, for example, the area being scanned was a section of a housing development in which all the roofs were red, the red filter would pass a strong signal to the detector. Such an area would have very little blue or green light. The signal strength for the pixel or pixels corresponding to that area would be very high for the red band and very low for the other two. If the next block was a football field covered with astro-turf, the image would have a very high signal in the green band and low in the red.

The Landsat satellite program, the workhorse of America's remote sensing efforts, uses just this technique. Seven Landsat satellites have been launched and Landsats 5 and 7 are still returning data, orbiting the Earth from pole to pole, at a height of about 900 kilometers, covering the entire Earth every ten days.. The Landsats used devices known as Multi-Spectral Scanners (MSS) and, on later flights, Thematic Mappers (TM) to scan the Earth's surface.

The operation of the MSS and the TM have been compared to sweeping back and forth with a broom. As the satellite moves over a predetermined length of travel, the scanner on board the spacecraft swings across a proportional distance from side to side. On each swing, the detector will make about 3000 separate exposures, each representing a pixel. The light passes through filters which are sensitive to a particular wavelength of energy before reaching the detector. In the case of the MSS,the energy captured is divided between 4 bandwidth filters--red, green and two filters in the infrared band. Each sweep therefore actually produces 4 separate sets of images

By synchronizing the sweeps with the forward motion of the satellite (passing over different areas of the Earth with each orbit) the MSS captures a series of images (or "scenes), each 185 kilometers square. Each scene consists of over seven million separate exposures, or pixels, with each pixel representing the DN for an area of land that is 57 by 79 meters in size.

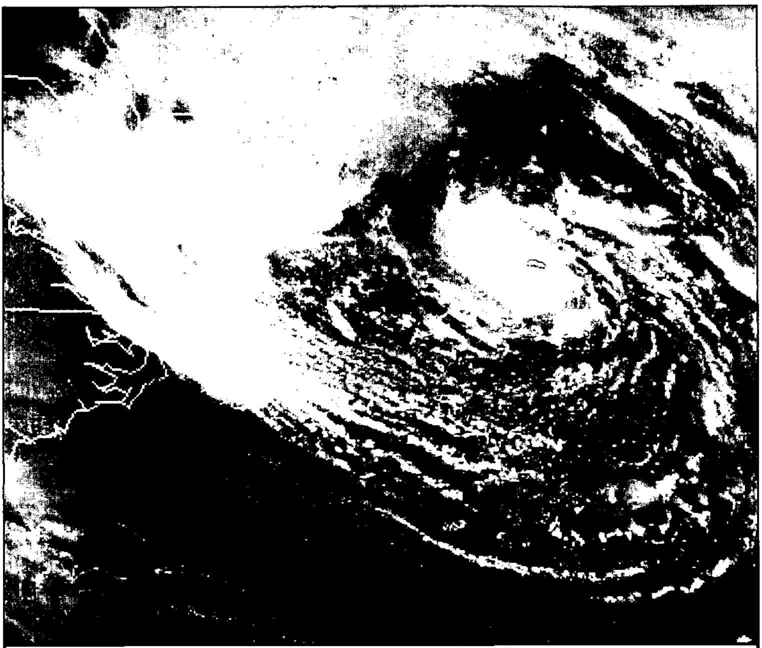
For this reason, the MSS is said to have a 79 meter resolution, because the smallest feature it can capture is 79 meters in size. Since most areas have smaller features, the DN for each pixel is actually equal to an average of the energy in that area. The MSS would not distinguish, for example, an individual house or other small features. It would give the average intensity of the emission for the house, its yard and other features in a 57 x 70 meter area. A large grassy field would have a DN that indicates the average emission of the vegetation making up the field.

The Thematic Mapper (TM), which replaced the MSS on later Landsats, operates in a similar fashion. The TM, however, acquires seven bands of EMR radiation--blue-green light, green light, red, 3 bands in the near and mid-infrared spectrum, and a longer wave value known as the thermal infrared. This last band represents the infrared emitted from a body as a result of its temperature. . The TM is also considered an improvement because it has a resolution of 30 meters.

V. Where do the pictures come from?

It is important to remember that the Landsat's users are not receiving a color picture of the image; they are receiving a dataset that describes each pixel in terms of its location and a numerical value of intensity for the signal in the corresponding band of the EMR spectrum. The images that we think of as satellite "photos" are usually computer generated reconstructions of this data.

To create a picture of the area being scanned, the pixels must be reassembled into an electronic or printed image. Since the data for each pixel is simply the brightness of the reflection in a particular band, a direct translation of the data would look like a black and white photo, that is, a set of grayscales for each bandwidth that the detector records.



The Perfect Storm: Though it was never assigned a name, the confluence of weather patterns that struck the East Coast in October of 1991would become the subject of a best-selling book and a popular movie. Here, a satellite image overlaying a map of the U.S. gives a dramatic view of the storm's scope and power. **Photo: Courtesy NOAA Satellite Active Archive**

Because the human eye is much more sensitive to colors than to shades of gray, it is useful to assign colors to enhance the amount of information conveyed by the image. Pictures representing the visible radiations can be created by assigning each pixel intensities of red, green, and blue in proportion to the pixel's DN in that band. This might be thought of as a sort of digital "paint by numbers." The final image will have the colors in proportion to those captured by the detectors, also known as a *true color* image, again similar to what we would see if we were actually looking down from the spacecraft.

The intensity of radiation in the invisible wavelengths, however, have no direct correlation to visible colors. To create images of invisible energy the pixels are assigned a *false color* designation. An image captured in the infrared band, for instance, can have each pixel assigned the color red, in an intensity relative to the strength of its infrared reflection. Thus even though infrared has no visible color, it will be possible to assess the level of infrared reflection visually.

The design of color schemes is up to the scientist and depends on the type of information they are trying to capture. Although there are standardized systems, there is also a bit of artistry, depending on the image one wishes to convey.

From the multi-spectral data, a variety of images can be generated using computer techniques to interpret the meaning of the DN's. In this sense, the captured image is only the beginning, with the location and DN's of the pixels being the raw material for a range of analysis.

For example, healthy plants have been found to give very high reflections in the infrared bands. This fact has been a key in using remote sensing to study vegetation and land use. While green grass and the astroturf field mentioned above might have similar DN's in the green band, the real grass would have much higher reflectance in the infrared.

Similarly, observation in the thermal infrared band can reveal internal characteristics of a phenomena that may be invisible to reflected light. An electrical generating plant, for instance, may be releasing heated water into a river. This would not necessarily change the optical qualities of the water but would show up as a "plume" in the thermal infrared.

Because this information is conveyed as a numerical dataset, it also lends itself to all sorts of combinations and mathematical manipulation. These mathematical tools can be used both to increase the precision of the interpretation as we as enhance the visual image. Computer technologies make this extremely complex process practical.

A simple example of image processing and analysis is the Normalized Difference Vegetation Index (NDVI). This is a calculated quantity which allows researchers to construct images that indicate the health of the vegetation in a particular landscape.

Healthy green plants tend to absorb light from the red and blue portions of the spectrum, while reflecting infrared. A mathematical ratio can be calculated between the DN's of the pixels in the infrared band and the DN's of the pixels in the red band.

"The objective of vegetation analysis, from spectral measurements," one writer notes "is to reduce the spectral data to a single number that is related to physical characteristics of vegetation ..."[2]

An image can be constructed, using the value of the ratio in place of the DN to color-code each pixel, essentially forming a picture of the area's vegetation in terms of its relative health.

A variety of similar techniques can be used to enhance the quality of the image or to interpret new features of it from existing data.

VI. Remote Sensing in Action

Direct electromagnetic radiation is only one of several properties of the Earth which can be sensed from space. "Force fields" such as gravity can also be detected, as can acoustic, or sound waves, such as used to sense undersea features. Remote sensing can also generate its own EMR and measure the response of the areas towards which it is targeted. Reflected radio waves (radar), is an example of this, as is the use of laser measurements. And while some remote sensing may be a simple as a hand held camera on the Space Shuttle, most--like our brief description of EMR sensing--tend to be highly technical and specialized pursuits.

Yet the results of remote sensing and GIS studies are very practical and quite literally "down to Earth." A few examples will make clear the important applications of this technology.

A. Landsat for Coral Reef Monitoring

"Reefs around the world are in ecological collapse, especially in the Florida Keys," says Phil Dustan of the College of Charleston. "We need to use remote sensing to help fight for their conservation."[3]

Answering this need, NASA's Landsat 7 satellite has spent the past year gathering images of coral reefs in 900 locations around the world. Over 5000 separate views of reefs, some taken several times over the year, have given scientists a first look at how wind, waves and seasonal changes affect these vital ecosystems. As on land, scientists are relying on measuring infrared reflection to determine the health of the reefs. According to NASA"The near infrared band best gathers the electromagnetic signature of a thriving ecosystem."[4]

The Landsat observations will provide a valuable tool for scientists to survey and track, in "near real-time", widespread condition of coral reefs. According to reef ecologist Bruce Hatcher of Dalhousie University. "We no longer are limited to the observations we can collect by wandering around in small boats and sampling individual reefs to infer large-scale processes from a few samples."[5]

To verify that the Landsat data was accurate, (the "ground truthing"mentioned above) a team of scientists compared the results of the satellite survey with detailed ground studies of Carysfort Reef in the Florida Keys. . Both the Landsat survey and the ground studies were in agreement that the live coral had declined from 50% to 5% of the reefs surface.

Like wetlands and rainforests, coral reefs have many critical roles in the planets ecosystems, particularly in the environmental health of marine systems. With the detailed archive of Landsat data, scientists will be able to better understand the normal functioning of the reefs as well as the types of stresses to which they are exposed.

B. El Nino/La Nina - A Troubling Duo

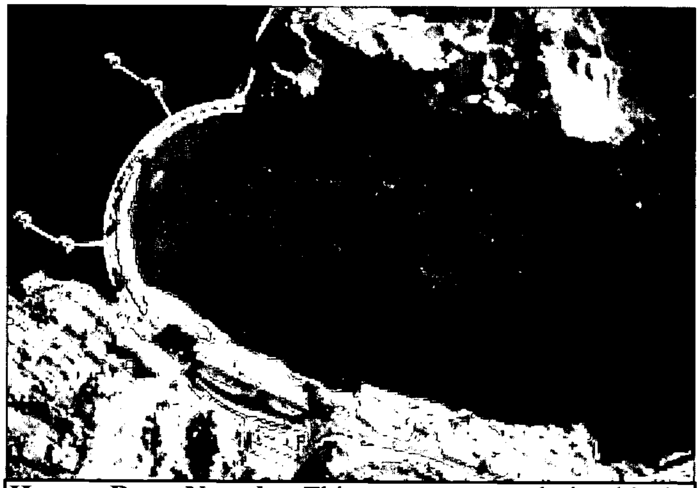
Few weather phenomena have become as famous as the periodic changes in the circulation and temperature of the Pacific known as El Nino and La Nina. Since their discovery in the late 1980's, the two interrelated weather patterns have given meterologists an entirely new perspective on global weather.

In order to better understand the dimensions of the El Nino/La Nina activity, scientists require a large body of data about the characteristics of the Pacific Ocean. The TOPEX/Poseiden satellite, a joint project of the U.S. and France, is one of many used to evaluate ocean conditions, in this case, changes in sea level.

The TOPEX/Poseiden uses several methods including laser and radar based altimeters to determine the sea level with a very high degree of accuracy. Sea level heights can be determined to within 3 to 5 centimeters (about 2 inches) and then compared to seasonal averages for locations across the Pacific.

Scientists can follow the currents by looking at the "hills and valleys" or "bumps" in the level of the ocean surface relative to the center of the Earth. "If the scientists can map those 'bumps and valleys,' they can deduce the oceanic surface currents and study their behavior over time."

Because water expands as it heats and becomes less dense than colder water, the warmer water will float to the top of the water column, increasing the height of the sea level. Using mathematical techniques, it is possible to calculate ocean temperatures from this data. The values of temperatures, like the NDVI of a land area, can then be assigned as values to pixels and create maps that are color coded according to the ocean temperature. Because El Nino is caused by changes in water tempera-


Hoover Dam, Nevada This one-meter resolution black and white image highlights Hoover Dam. Space Imaging's IKONOS satellite captured the image December 25, 1999. **Photo: Courtesy Space Imaging**

ture, this gives an early warning that the process is under way.

In addition to the El Nino phenomena, the altimetry data from TOPEX/Posiedon (and it's recently launched successor, JASON) also provide important information that can be applied to such diverse areas as sport sailing, commercial fishing, offshore industries, tracking marine mammals, and predicting hurricanes.

C. The Shuttle Radar Topography Mission

Not all space based sensing is done from unmanned satellites. The U.S Space Shuttle provides a unique platform for remote sensing and has been used for that since its inception. By having scientists and engineers in space to physically operate the equipment, far more complex remote sensing tasks can be undertaken.

One of the most recent and comprehensive Shuttle based sensing projects was the Shuttle Radar Topography Mission (SRTM). Flown in February of this year, the SRTM used a technique called radar interferometry to obtain extremely precise measurements of the contours of the earth's surface.

Radar signals which the shuttle bounced off the Earth's surface were received by two antennas--one on the shuttle and one on a 200 foot mast deployed from the shuttle's cargo bay. The slight difference in the time it took the signal to reach the two antennas was then used to measure the differences in the earth's elevation.

Because the radar is not impaired by clouds, and the because the Shuttle flew over most of the Earth's surface, the images will be "the most precise 'picture' ever of Earth's land surface... enough data will be acquired to generate the most complete topographic map of Earth's land surface ever produced."

The products of this mission will include both finished maps and raw data "tailored to the needs of the civil, military, and scientific user communities."[6] Applications range from high level defense and disaster planning to better maps for backpackers.

VII. Conclusion - The Sky's the Limit

We have touched on only a handful of the ways that remote sensing is being used to monitor, understand and manage the Earth's environment. There are literally hundreds, if not thousands of other applications of earth sensing satellites alone. Many of these, such as weather forecasts of ever increasing accuracy, have become staples of our every day life. Others, like the ability of governments to confidently monitor compliance with international treaties, are part of an invisible global infrastructure. And still others--the privately marketed image of Hoover Dam shown on this page for example--represent new commercial products that may change many dimensions of business.

But perhaps most important from an environmental standpoint, remote sensing gives us the ability to monitor many of the significant impacts of human actions on the globe's ecosystems. Deforestation, desertification, temperature change, sea level, cloud cover, sediment production--these are just a few of the Earth's characteristics that can be monitored from space.

Because satellites are in place for extended periods of time, and because they pass repeatedly over the same locations, we are now able to evaluate what changes have occurred in a region and tease out those factors that are the result of human influence. With so many environmental controversies now rooted in disputes over questions of fact, we can't help but welcome any tool that brings greater objectivity to the debate. ●

Next Month: Know Your Environment begins its two part look at "Hunger and the Environment." Don't miss Part I: "The Ecological Dimensions of Food Production."

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