REMOTE SENSING
OF THE EARTH SYSTEM
Earth from Space

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OBSERVING THE EARTH FROM THE DISTANCE
WHAT IS REMOTE SENSING?
TABLE 1.1. Remote Sensing: Some Definitions

Remote sensing has been variously defined but basically it is the art or science of telling something about an object without touching it. (Fischer et al., 1976, p. 34)

Remote sensing is the acquisition of physical data of an object without touch or contact. (Lintz and Simonett, 1976, p. 1)

... Imagery is acquired with a sensor other than (or in addition to) a conventional camera through which a scene is recorded, such as by electronic scanning, using radiations outside the normal visual range of the film and camera—microwave, radar, thermal, infrared, ultraviolet, as well as multispectral, special techniques are applied to process and interpret remote sensing imagery for the purpose of producing conventional maps, thematic maps, resources surveys, etc., in the fields of agriculture, archaeology, forestry, geography, geology, and others. (American Society of Photogrammetry)

Remote sensing is the observation of a target by a device separated from it by some distance. (Barrett and Curtis, 1976, p. 3)

The term “remote sensing” in its broadest sense merely means “reconnaissance at a distance.” (Colwell, 1966, p. 71)

Remote sensing, though not precisely defined, includes all methods of obtaining pictures or other forms of electromagnetic records of the Earth’s surface from a distance, and the treatment and processing of the picture data. ... Remote sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area; it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself. (White, 1977, pp. 1–2)

“Remote sensing” is the term currently used by a number of scientists for the study of remote objects (earth, lunar, and planetary surfaces and atmospheres, stellar and galactic phenomena, etc.) from great distances. Broadly defined ... , remote sensing denotes the joint effects of employing modern sensors, data-processing equipment, information theory and processing methodology, communications theory and devices, space and airborne vehicles, and large-systems theory and practice for the purposes of carrying out aerial or space surveys of the earth’s surface. (National Academy of Sciences, 1970, p. 1)

Remote sensing is the science of deriving information about an object from measurements made at a distance from the object, i.e., without actually coming in contact with it. The quantity most frequently measured in present-day remote sensing systems is the electromagnetic energy emanating from objects of interest, and although there are other possibilities (e.g., seismic waves, sonic waves, and gravitational force), our attention ... is focused upon systems which measure electromagnetic energy. (D. A. Landgrebe, in Swain and Davis, 1978, p. 1)
REMOTE SENSING

"It is the science of deriving information about an object without actually coming in contact with it."
MILESTONE IN THE HISTORY OF REMOTE SENSING

Balloons → Pigeons → Airplanes → Satellites
1859 - Gaspard Felix Tournachon (Nadar) used balloons as platforms to take the firsts aerial photographs.

1880 - M. A. Batut took aerial photos in France using kites.
1903 – Bavarian Pigeons are used with the first light camera. This camera took photos every 30 seconds during the bird flight. They were faster than balloons and much smaller.

1908 - Wilbur Wright was a very important pilot for remote sensing. The first photograph from an airplane was taken by L. P. Bonvillain in France during a demo flight.
WORLD WARS
1910’s – 1950’s

• The planes replaced the balloons and pigeons in observing the enemy lines.

• Aerial photography was strongly developed.

• Photos were used by world nations for aerial reconnaissance.

• At the end of the wars this new technology was very much appreciated.
In fall 1962, reports indicated that the soviets were installing nuclear missiles in Cuba.

Satellite and U-2 images proved the existence of such missiles.

Both nations depended on images processing and interpretation (remote sensing) for evaluation and making decisions.
Remote sensing techniques helped to take pictures of the moon surface in order to make lunar maps.

Apollo 8 took the first photos of the Earth from space.
First multispectral photos were taken in 1968 on board Apollo 9 mission.

Four Hasselblad cameras were installed in the same platform and looking toward the same direction in order to take pictures at the same time for the same object.

These multispectral pictures were digitized and used to develop image processing techniques that later were used with Landsat data.
In July 1972 NASA launched the first “Earth Resources Technology Satellite” (ERTS-1).

These multispectral data provided a better understanding of our planet, including land used and land cover, urban development, and Earth global processes.

The name was later changed to LANDSAT and it has been a very successful long-term mission.
In the 70’s other sensors were developed to acquire images in other regions of the electromagnetic spectrum besides the visible, like the mid infrared and the thermal infrared.

- They had large field of view (in hundreds of kilometers).
- Such large scale cover was valuable for meteorology.
DEGRADATION OF THE OZONE LAYER

1980’s

• The Ozone Hole over the Antarctica, discovered by British scientists, was confirmed by the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) launched in 1978.

• Since then, TOMS makes daily maps of global ozone concentration.

• TOMS data were used as scientific evidence in the First Protocol of Montreal, were 40 nations agreed to reduce the use of CFC’s in 50% for year 1999.
EARTH OBSERVING SYSTEM
1990’S

CZCS
Pigments

TOMS-Ozone Layer

SeaWiFS
Chl-a

MODIS
Chl-a

AVHRR-SST
TOWARD A HIGHER RESOLUTION
2000’s

IKONOS
1 METER

HYPERION
220 BANDS
OVERVIEW OF REMOTE SENSING PROCESS

PHYSICAL OBJECTS

SENSOR DATA

EXTRACTED INFORMATION

APPLICATIONS

- LAND USE
- HYDROLOGY
- GEOLOGY
- SOILS
- VEGETATION
The quantity most frequently measured by current remote sensors is the electromagnetic energy emanating from the object of interest.
ELECTROMAGNETIC SPECTRUM

Wavelength (nm)

Gamma Ray  X-Ray  UV Visible  Infrared  Microwave (Radar)  Radio

0.03  300  400  700  $10^6$ (1 mm)  $3 \times 10^8$ (30 cm)

400  500  600  700

Blue  Green  Red
6 to 7 millions cones:
- 64% red
- 32% green
- 2% blue

120 millions rods:
more sensitive, but do not detect colors.
DETECTING THE REMOTE SIGNAL
SPECTRAL DIFFERENTIATION
Image formation

U.V.  Visible  Infrared

![Image of wavelength spectrum and bands]

Bands
LANDSAT TM

1  2  3  4  5  6  7

Display channels
Colour composite

B, G, R 1, 2, 3
Natural colours

B, G, R 2, 3, 4
Conventional false-colour

B, G, R 1, 4, 7
Optimised false-colour

μm

0.4  0.45  0.5  0.55  0.6  0.65  0.7

near  mid  thermal
Mayaguez Bay with Different Bands

TM Image
Mayaguez Bay with Different Bands

True Color  False Color

TM Image
SPATIAL DIFFERENTIATION

DIGITAL IMAGING
PIXEL

IMAGE ROWS
A B C D E

IMAGE COLUMNS
1 2 3 4 5 6 7 8
EVERYTHING IS ABOUT SCALES

PUERTO RICO FROM THE SHUTTLE
CHANGING OUR PERSPECTIVE
LA PARGUERA FROM A PLANE
LA PARGUERA FROM SPACE

Thematic Mapper
LA PARGUERA FROM SPACE
SAME SCENE–DIFFERENT PIXEL SIZE

Satellite
Pour l'Observation
de la Terre

SPOT – 20 m

Compact
Airborne
Spectrographic
Imager

CASI – 5 m
SAME SCENE—DIFFERENT PIXEL SIZE

CASII – 5 m
Compact Airborne Spectrographic Imager

IKONOS
1 m
REMOTE SENSING AS A SYSTEM

Element of an image

Direction of motion
Satellite

Transmission to ground-station

Sensor

Scanning
Scene

Resolution cell

Where?

Pixel coordinates

What?
Grey shades or colour

How much?
Sensitivity
ROLE OF THE ATMOSPHERE

Spectral Windows

Solar Radiation

\[ \lambda \mu m \]

O_2

O_3

H_2O

CO_2

H_2O

Trasparency

0%

50%

100%

**Platforms**: Where the sensors are mounted.

**Sensors**: Instruments on the platforms.

- **ETM+**
- **AVIRIS**
- **GER 1500**

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Satellite data

High altitude data

Low altitude data

Ground Observation
REMOTE SENSORS

Passive Sensors
- Aerial Cameras
- Visible or Thermal

Active Sensors
- Microwave (Radar)
- Acoustic Sensors
The sensor detects solar radiation that has been reflected from features at the earth’s surface.
REMOTE SENSING OF REFLECTED RADIATION

Sample Radiation ($\lambda$)

Reference Radiation ($\lambda$)

$$R(\lambda) = \frac{\text{Sample Radiation (} \lambda \text{)}}{\text{Reference Radiation (} \lambda \text{)}}$$

Reflectance spectra of rocks and vegetation:

- Vegetation
- Sandstone
- Limestone
- Shale
REMOTE SENSING OF EMITTED RADIATION

The sensor detects solar radiation that has been absorbed by the earth, then reemitted as thermal infrared radiation.
INFRARED (THERMAL) SENSORS

Temperature and radiation of bodies

- Wavelength of maximum emission of radiation
- Human body
- Flame
- Infrared
- Visible
- Sun

Temperature (Kelvin)

λ (μm)

0.5

310 600 6000
Sea Surface Temperature
The sensor illuminates the terrain with its own energy, then records the reflected energy as it has been altered by the earth’s surface.
SIDE-LOOKING AIRBORNE RADAR
SLAR
MULTI-SPECTRAL SENSORS

HYPER-SPECTRAL SENSORS
The earth's surface. This is a composite of numerous satellite images, each selected to be cloud-free. It is unrealistic because, at any moment, half of the Earth is in nighttime darkness and much of it is cloud-covered. But this beautiful image lets us view the entire surface at once. It shows densely vegetated regions in green, dry deserts in yellow or brown, and ice-covered regions in white.
THE EARTH SYSTEM SCIENCE

It is the science that studies the whole Earth as a system of many interacting parts and focuses on the changes within and between those parts.
**Atmosphere**: The mixture of gases that surrounds the Earth (Ex. N, O, Ar, CO₂, and water vapor).

**Hydrosphere**: The totality of the Earth’s water, except the water vapor in the atmosphere.

**Biosphere**: All of the Earth’s organisms.

**Geosphere**: The solid Earth, composed principally of rock and regolith.
EARTH'S CLIMATE SYSTEM

- Atmospheric Composition: Gases, particles
- Incoming solar radiation
- Reflected solar radiation
- H₂O, N₂, O₂, CO₂, O₃, SO₂, dust
- Weathering and erosion
- Active volcanoes
- Snow and glacier ice
- Sea ice
- Heat exchange
- Evaporation
- Precipitation
- Wind stress
- Terrestrial radiation
- BIOSPHERE
- LITHOSPHERE
- Tectonic uplift
- Motion of lithospheric plates
- Rising magma
- Ocean Basins: Shape, volume, deep circulation, salinity, sea level

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MOVEMENT OF WORLD PLATES
ACCORDING TO GPS STUDIES

5 cm/yr
Heflin et al., 2004.2

GPS Velocities for Caribbean sites relative to North America

Mann, et. al., 2002
Shuttle Radar Topography Mission (SRTM) was an international project maintained by the National Imagery and Mapping Agency and NASA. The mission objective is to obtain the most complete high-resolution digital topographic database of the Earth. This SRTM radar consists of a main antenna onboard the space shuttle and an outboard antenna located at the end of a 60 meter mast. This separation measurement remains constant, and therefore when the reflected radar signals reach the individual sensors, representing a single point where the radar reflected from the surface, accurate elevation of the earth’s surface can be calculated.
SAN FRANCISCO AREA
AN EARTHQUAKE PRODUCING A TSUNAMI ACROSS THE INDIAN OCEAN DECEMBER 26, 2004
Land Cover Time Sequence of Mount St. Helens, Washington, as seen from Landsat MSS
Cleveland Volcano at Aleutian Arc, Alaska

ISS- Digital Camera
Total Ozone Mapping Spectrometer
Code 916: Atmospheric Chemistry and Dynamics Branch

TOMS

Nimbus 7 Observatory
These false-color images are from the June 16, 1991 eruption of Mt. Pinatubo, Philippines. The gas and ash clouds were tracked by TOMS for several weeks as they encircled the Earth. These satellite observations demonstrate the enormous amounts of gas and ash emitted, as well as details such as differences in peak concentrations and geographic extent. TOMS also detects many smaller volcanic clouds.
SOUFRIERE HILLS
MONTSERRAT

-Began erupting on July 18, 1995
-Dome collapse on June 25, 1997
-An ash cloud erupted from the Volcano on October 27, 1999
HYDROSPHERE
RIVER PLUMES DETECTED
WITH OCEAN COLOR SENSORS

Orinoco River

SeaWiFS Sensor
August 2004

Amazon River
CRYOSPHERE

It is the part of the Earth's surface that remains perennially frozen. It includes glaciers (10% of Earth’s land surface), sea ice and vast areas of frozen ground (20% of Earth’s land surface) that lie beyond the limits of glaciers. Thus, nearly a third of the Earth’s land area belongs to the cryosphere.
Himalayas from ASTER
MELTING OF THE CRYOSPHERE DUE TO CLIMATE CHANGE
Satellite view of Antarctica. The East Antarctic Ice Sheet overlies the continent, while the much smaller West Antarctic Ice Sheet covers a volcanic island arc and surrounding seafloor. Major ice shelves occupy large coastal embayments. The ice-covered regions of Antarctica nearly equal the combined areas of Canada and the conterminous United States.
CONDITION OF THE OZONE LAYER
AND TEMPERATURE TRENDS

High Reflection of Light

WHITE SURFACE
FRACTURA EN LA ANTÁRTIDA 2008

Fuente: National Snow and Ice Data Center

Plataforma Wilkins
Lugar de la desintegración

ANTÁRTIDA

6 de marzo de 2008
28 de feb. de 2008
29 de feb. de 2008
8 de marzo de 2008

25 millas

Gráfica / El Nuevo Día
OCEANS OF THE WORLD

- Atlantic Ocean
- Caribbean Sea
- Gulf of Mexico
- Southern Ocean
- Indian Ocean
- Pacific Ocean
- Arctic Ocean
- Arabian Sea
- Mediterranean Sea
- Persian Gulf
- Gulf of Mexico
- Caribbean Sea
- Southern Ocean
- Southern Ocean

Courtesy Walter H. F. Smith and David T. Sandwell
Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

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Fitoplancton Chl-a
FITOPLANCTON

"Phytoplankton are the foundation of the marine food chain and they can influence Earth’s climate."

Color Del Oceano

Fotosintesis

Plankton bloom
ESTIMACION GLOBAL DE FITOPLANCTON USANDO SENSORES DE COLOR DEL OCEANO
Advanced Very High Resolution Radiometer (AVHRR)

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TEMPERATURA SUPERFICIAL DEL OCEANO
USANDO EL AVHRR
PATRONES DE CORRIENTES SEGÚN EL AVHRR

Gulf of Mexico Loop Current
March 22-23, 1995
AVHRR (SST) – NOAA 12
Moderate Resolution Imaging Spectroradiometer (MODIS)

- 36 bandas del visible al infrarrojo
- Resolución Espacial
  - 250 m (bandas 1-2)
  - 500 m (bandas 3-7)
  - 1000 m (bandas 8-36)
Temperatura Superficial Del Oceano

Clorofila-a De Fitoplancton
ATMOSPHERE
GOES OBSERVATIONS OF THE CARIBBEAN

http://www.goes.noaa.gov/browsh2.html
Madeline and Lester visit Mexico
17 October 1998
GOES project
GOES VISIBLE IMAGE
HURRICANE FRANCES
Major dust storms are most frequent in arid and semiarid regions that are concentrated in the subtropical high-pressure belts north and south of the equatorial zone. Arrows show the most common trajectories of dust transported during major storms.
EFFECT OF THE SAHARA DUST
EFFECT OF THE SAHARA DUST
EFFECT OF THE SAHARA DUST

A massive sandstorm blowing off the northwest African desert has blanketed thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand. The massive nature of this particular storm was first seen in this SeaWIFS image acquired on Saturday, 28 February 2003 when it reached over 1000 miles into the Atlantic. These storms and the rising warm air can lift dust 45,000 feet or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean where they often require the local weather to issue air pollution alerts as was recently the case in San Juan, Puerto Rico. Recent studies by the U.S. Geological Survey suggest that Saharan dust have linked the decline of the coral reefs in the Caribbean to an increasing frequency and intensity of Saharan Dust events. Additionally, other studies suggest that Saharan Dust may play a role in determining the frequency and intensity of hurricanes formed in the eastern Atlantic Ocean.
EFFECT OF THE SAHARA DUST
EFFECT OF THE SAHARA DUST
Photosynthesis

Carbon dioxide + water + energy \[\overset{\text{Photosynthesis by plants}}{\rightarrow}\] Carbohydrates + Oxygen

Light rays from the sun

Oxygen (O\(_2\)) given off to the atmosphere

Carbon dioxide (CO\(_2\)) from the atmosphere

Carbohydrates

Water (H\(_2\)O) from the soil
VEGETATION INDEX
EARTH'S PRODUCTIVITY
Global Distribution of Coral Reefs
THE GREAT BARRIER REEF
THE FUTURE
REMOTE SENSING AS A TOOL FOR MONITORING CLIMATE CHANGE
MAKING THE SYSTEMS WORK TOGETHER

Simultaneous Nadir Overpass (SNO)

Requires:
More efficient computers
Better algorithms
Direct Ties to User Applications
Better filtering of information
Increasing numbers of tailored products
Changing ideas of what products are

Approximate Increases in Sensor Data Volume *

NOTE: GOES, POES, and GOES-R estimates are for sensor data. NPOESS estimate includes data and products.
Observing Systems
Global Earth Observation System of Systems