Different remote sensing instruments record different segments, or bands, of the electromagnetic spectrum.

**Satellite Sensors**

- **NOAA** - AVHRR
- **LANDSAT** - MSS
- **LANDSAT** - TM
- **SPOT** - HRV (multispectral)
- **SPOT** - HRV (panchromatic)
- **NIMBUS-7** - CZCS
- **GOES** - VISSR
- **TERRA** - ASTER
- **TERRA** - CERES
- **TERRA** - MISR
- **TERRA** - MODIS
- **TERRA** - MOPITT

**Best bands per Category**

**LANDSAT Bands**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Bands</th>
<th>Wavelengths (μm)</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSS</td>
<td>1-6</td>
<td>0.55-1.75 (green)</td>
<td>20-25</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>0.45-0.51 (near)</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>10-11</td>
<td>0.76-0.91 (near)</td>
<td>50</td>
</tr>
<tr>
<td>TM</td>
<td>1-4</td>
<td>0.55-1.75 (green)</td>
<td>20-25</td>
</tr>
<tr>
<td></td>
<td>5-7</td>
<td>0.76-1.30 (near)</td>
<td>20-25</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.55-1.75 (thermal)</td>
<td>20-25</td>
</tr>
</tbody>
</table>

*Table 5.1: Wavelength Bands Used in LANDSAT 1 to 5 (Adapted From Lillesand and Kiefer 1987)*

**Electro-Optical Scanners**

- **LANDSAT** – Earth Resources Technology Satellite (ERTS)
- **SPOT** - Systeme Pour l’Observation de la Terre
- **CZCS** - Coastal Zone Color Scanner
- **NOAA** - Advanced Very High Resolution Radiometer (AVHRR)
- **GOES** - Geostationary Operational Env Satellites
**LANDSAT 1,2&3**

Multispectral Scanner System (MSS) instrument

**LANDSAT 4 & 5**

- Multispectral Scanner System (MSS)
- Thematic Mapper (TM)

**LANDSAT 7**

- Launch Date: April 15, 1999
- Status: operational despite Scan Line Corrector (SLC) failure May 31, 2003
- Sensors: ETM+
- Orbit: polar, sun-synchronous
- Equatorial Crossing Time: nominally 10 AM (+/- 15 min.) local time (descending node)
- Period of Revolution: 99 minutes; ~14.5 orbits/day
- Repeat Coverage: 16 days

**Sun-synchronous Orbits**

- Orbit that passes over the earth at the same local sun time.
- Return period every 18 days for LANDSAT 1,2&3 at 900km orbit.
- Return period every 16 days for LANDSAT 4&5 at 700km orbit.
- Return period every 16 days for LANDSAT 7 at 705km orbit.

**Sun-synchronous Orbit**

- This orbit is a special case of the polar orbit. Like a polar orbit, the satellite travels from the north to the south poles as the Earth turns below it.
- In a sun-synchronous orbit, though, the satellite passes over the same part of the Earth at roughly the same local time each day.

**Space Satellites that help Firefighters Monitor Raging Wildfires**

- NASA’s Total Ozone Mapping Spectrometer (TOMS)
- Sea-viewing Wide Field-of-view Sensor (SeaWIFS)
- National Oceanographic and Atmospheric Administration’s (NOAA) Geostationary Operational Environmental Satellite 8 (GOES 8)
- Terra - MODIS, and MOPITT
TOMS

Distribution of smoke over the west and mid-west U.S.

August 8, 2000. Smoke is seen as dark gray wisps; clouds are white and puffy.

SeaWiFS

A blanket of smoke (yellow) from the large fires burning in Idaho and western Montana extends across Montana and the Dakotas of western Minnesota.

SPOT Satellite

Satellite Pour l’Observation de la Terre

- High-resolution, optical imaging Earth observation satellite system.
- SPOT 5 launched May 4, 2002 with 2.5 m, 5 m and 10 m capability.

TOMS Measuring Ozone...
The stereo pairs are acquired in panchromatic (black and white) mode with a spatial resolution of 10 metres (along-track sampling of 5 metres) and a telescope viewing angle of ± 20°.

Thermal Infrared Imagery

<table>
<thead>
<tr>
<th>Channel</th>
<th>NOAA 4, 5, 10 (µm)</th>
<th>NOAA 7, 9 (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.63-0.66 (red)</td>
<td>0.58-0.66 (red)</td>
</tr>
<tr>
<td>2</td>
<td>0.72-0.79 (green)</td>
<td>0.72-0.79 (green)</td>
</tr>
<tr>
<td>3</td>
<td>1.55-1.65 (nir)</td>
<td>1.55-1.65 (nir)</td>
</tr>
<tr>
<td>4</td>
<td>3.7-3.9 (thermal)</td>
<td>3.7-3.9 (thermal)</td>
</tr>
<tr>
<td>5</td>
<td>(Channel 4 repeated)</td>
<td>11.5-12.5 (thermal)</td>
</tr>
</tbody>
</table>
**GOES**
Geo-stationary Operational Environmental Satellite

- Weather forecasting
- Geo-stationary at 36,000 km

**Active Scanners**

Microwave - RADAR
RFoio Detection And Ranging

- SLAR - Side Looking Airborne Radar
- SAR - Synthetic Aperture Radar

- Cameras capture reflected visible wavelengths.
- Radar captures emitted microwave wavelengths that are bounced back to the antenna.

**Microwave Bands**

<table>
<thead>
<tr>
<th>Band Designation</th>
<th>Wavelength in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ka</td>
<td>0.75 – 1.18</td>
</tr>
<tr>
<td>K</td>
<td>1.10 – 1.67</td>
</tr>
<tr>
<td>Ku</td>
<td>1.67 – 2.40</td>
</tr>
<tr>
<td>X</td>
<td>2.65 – 3.17</td>
</tr>
<tr>
<td>C</td>
<td>3.75 – 7.00</td>
</tr>
<tr>
<td>S</td>
<td>7.50 – 15.00</td>
</tr>
<tr>
<td>L</td>
<td>15.00 – 30.00</td>
</tr>
<tr>
<td>P</td>
<td>30.00 – 100.00</td>
</tr>
</tbody>
</table>

**Radar**

- Radar resolution has two components: the "range" resolution and the "azimuth" resolution. These are determined by, among other factors, the width of the synthesized antenna (which is dictated by the pulse interval) and the wavelength.

**Radar – Shuttle Radar Topography Mission (SRTM)**

National Elevation Dataset (NED)
Hyperspectral Imaging

- Now coming into its own as a powerful and versatile means for continuous sampling of broad intervals of the spectrum, is hyperspectral imaging.

Interval narrows to 10 nanometers

- In hyperspectral data, that interval narrows to 10 nanometers (1 micrometer [μm] contains 1000 nanometers [1 nm = 10^-9 m]).
- Thus, we can subdivide the interval between 0.38 and 2.55 μm into 217 intervals, each approximately 10 nanometers in width.

Hyperspectral Sensors

- The Jet Propulsion Lab (JPL) has produced two hyperspectral sensors, one known as AIS (Airborne Imaging Spectrometer), first flown in 1982, and the other known as AVIRIS (Airborne Visible/InfraRed Imaging Spectrometer), which continues to operate since 1987.
- AVIRIS consists of four spectrometers with a total of 224 individual CCD detectors (channels), each with a spectral resolution of 10 nanometers and a spatial resolution of 20 meters.

AVIRIS Platform

- From a high altitude aircraft platform such as NASA’s ER-2 (a modified U-2), a typical swath width is 11 km.

AVIRIS data

- Below is a hyperspectral image of some circular fields in the San Juan Valley of Colorado.
- The colored fields are identified as to vegetation or crop type as determined from ground data and from the spectral curves plotted beneath the image for the crops indicated (these curves were not obtained with a field spectrometer but from the AVIRIS data directly).

Radar and Thermal Systems

- Canadian Radarsat, ERS-1 and ERS-2 managed by the European Space Agency, and JERS-1 and JERS-2 under the aegis of the National Space Development Agency of Japan, NASDA.
- Image acquired by Radarsat, showing part of Cape Breton in Nova Scotia, and the surrounding waters.
European Space Agency - Radar

- The European Space Agency, ESA, also has flown radar on its ERS-1 and ERS-2 satellites.
- Here is an image in black and white showing the San Francisco metropolitan area and the peninsula to its south, as well as Oakland, California, the East Bay, and beyond.

TIMS (Thermal IR Multispectral Scanner)

- Thermal data, especially from the 8-14 μm region become more valuable in singling out (classifying) different materials when this spectral interval is subdivided into bands, giving multispectral capability.
- NASA’s JPL has developed an airborne multiband instrument called TIMS (Thermal IR Multispectral Scanner) that is a prototype for a system eventually to be placed in space.

Earth Observing System (EOS) satellite Terra

- Physically, the Terra spacecraft is roughly the size of a small school bus.
- It carries a payload of five state-of-the-art sensors that will study the interactions among the Earth’s atmosphere, lands, oceans, life, and radiant energy (heat and light).
- Each sensor has unique design features that will enable Earth Observing System (EOS) scientists to meet a wide range of science objectives.

TERRA Instruments

- **ASTER**
- **CERES**
- **MISR**
- **MODIS**
- **MOPITT**

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)

- ASTER consists of three different subsystems; the Visible and Near Infrared (VNIR), the Shortwave Infrared (SWIR), and the Thermal Infrared (TIR). To find out more about each module click on the item of interest.

ASTER GDEM

- Distribution started on June 29, 2009
- **ASTER GDEM Derived Watershed**
- Makadi, Egypt
- The Ministry of Economy, Trade and Industry of Japan (METI) and the National Aeronautics and Space Administration (NASA) are collaborating on a project to develop ASTER Global Digital Elevation Model (ASTER GDEM), a DEM data which is acquired by a satellite-borne sensor “ASTER” to cover all the land on earth.
CERES - Clouds and the Earth's Radiant Energy System

CERES instruments aboard Terra measure the Earth's total radiation budget and provide cloud property estimates that enable scientists to assess clouds' roles in radiative fluxes from the surface to the top of the atmosphere.

Animation: http://terra.nasa.gov/About/CERES/ceres_swath.html

MISR - Multi-angle Imaging Spectro-Radiometer

MISR views the Earth with cameras pointed at nine different angles. One camera points toward nadir, and the others provide forward and aftward view angles, at the Earth's surface, of 26.1°, 45.6°, 60.0°, and 70.5°. As the instrument flies overhead, each region of the Earth's surface is successively imaged by all nine cameras in each of four wavelengths (blue, green, red, and near-infrared). MISR is uniquely capable of observing cloud and aerosol plume structures in the atmosphere three-dimensionally, as well as measuring the relative heights and types of clouds. Its stereoscopic measurement abilities enable MISR to observe the amount of sunlight that is reflected at various angles. MISR will also help scientists trace smoke and aerosol plumes back to their sources.

Animation: http://terra.nasa.gov/About/MISR/misr_sci.html

MODIS - Moderate-resolution Imaging Spectroradiometer

With its sweeping 2,330-km-wide viewing swath, MODIS sees every point on our world every 1-2 days in 36 discrete spectral bands. Consequently, MODIS greatly improves upon the heritage of the NOAA Advanced Very High Resolution Radiometer (AVHRR) and tracks a wider array of the earth's vital signs than any other Terra sensor.

MODIS sees changes in the Pacific phytoplankton populations that may signal the onset of the famous Niño Neta climatic siblings well ahead of their arrival. In turn, by coupling its sea surface temperature and ocean color measurements,

Animation: http://terra.nasa.gov/About/MODIS/modis_sci.html

Ocean temperature from MODIS

Ocean color from MODIS

MOPITT - Measurements of Pollution in the Troposphere

MOPITT is an instrument flying on NASA's EOS Terra spacecraft, measuring the global distributions of carbon monoxide (CO) and methane (CH₄) in the troposphere.

Fires in California

The combined smoke from the Fades and Power Fires in northern California southwest of Lake Tahoe was filling in the northern end of the Sacramento Valley on October 14, 2004. This image was captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite in the afternoon, when smoke had become so thick the actively burning areas of the fire that MODIS on the Terra satellite detected during its morning overpass could no longer be picked up.

Detectors and Aerosols from Space

LITE stands for Lidar Technology Experiment.

LITE flew on shuttle mission STS-64 in September, 1994.
**Lidar - Light Detection And Ranging (laser radar)**

- A lidar also transmits and receives electromagnetic radiation, but at a high frequency. Lidars operate in the ultraviolet, visible, and infrared region of the electromagnetic spectrum.

**RADARSAT**

- The mosaic of Africa consists of approximately 1,600 scenes of Wide 2 images (south of the 10° S parallel) and ScanSAR Wide images (north of the 10° S parallel), which were acquired between 1997 and 2002.

**5 minutes of LITE observations over the Sahara on September 15, 1994**

**RADARSAT-1**

- **Swath**: 50 km to 500 km
- **Revisit Time**: 3 - 5 days
- **Spatial Resolution**: (10 - 100) metres
- **Price**: US$2000-2500

**SAR Applications**

**Example of Applications**

- Prestige Oil Spill off Spain
Airborne Laser Scanning

ALS/LiDAR is an active remote sensing sensor that measures distance with reflected laser light.

- Two basic families of lidar systems exist: waveform and discrete-return used in for a number of applications.
- First developed in 1960 by Hughes Aircraft Inc.
- Modern computers and DGPS make it practical.
- Typically used in very accurate mapping of topography.
- New technologies and applications are currently being developed.
- Lidar points are used to create high resolution Digital Elevation Models (DEM).

LIDAR - GLAS

GLAS is Geoscience Laser Altimeter System on IceSAT launched Jan 12, 2003 for measuring:
- ice sheet elevations
- changes in elevation through time
- height profiles of clouds and aerosols
- land elevations
- vegetation cover
- approximate sea-ice thickness.

From: Alan Forghani, C188 lecture 2006

Contra Costa County – Lidar (4inch)

Contra Costa County – Remote Sensing

Ortho Photo
IR Photo
Lidar – First Pulse
Lidar – Last Pulse
Contours
Terrain Model
Popular Contemporary Platforms & Sensors

Quickbird Imaging Satellite (October 18, 2001)

Spatial and Spectral Resolution

<table>
<thead>
<tr>
<th>Spatial Characteristics</th>
<th>PAN (Resolution)</th>
<th>Multi-spectral (Resolution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>60'x60'</td>
<td>80'x80'</td>
</tr>
<tr>
<td>Green</td>
<td>60'x60'</td>
<td>80'x80'</td>
</tr>
<tr>
<td>Blue</td>
<td>60'x60'</td>
<td>80'x80'</td>
</tr>
</tbody>
</table>

IKONOS Imaging Satellite (September 24, 1999)

Resolution at Nadir (the point on the ground vertically beneath the sensor)
- 0.82 meters panchromatic;
- 3.2 meters multispectral

Landsat Data Continuity Mission (LDCM)

- The Landsat Data Continuity Mission (LDCM) is the future of Landsat satellites. It will continue to obtain valuable data and imagery to be used in agriculture, education, business, science, and government.
- The Landsat Program provides repetitive acquisition of high resolution multispectral data of the Earth’s surface on a global basis. The data from the Landsat spacecraft constitute the longest record of the Earth’s continental surfaces as seen from space. It is a record unmatched in quality, detail, coverage, and value.

New Satellite Sensors

GeoEye-1 (launched 9/6/08)

- The world’s highest resolution and most-accurate commercial Earth-imaging satellite and is able to collect imagery with a ground resolution of 0.41 meters (about 1.6 inches) in black and white mode and 1.64 meters in color.
- By combining the multispectral and panchromatic imagery is able to produce color images at an unprecedented 0.41 meter resolution.
- Due to US Government licensing, commercial customers can only receive color imagery at half-meter resolution.
NASA Plans Team of Mini-Satellites

- Weighing 44 pounds, and about the size of a solar-panel-clad birthday cake, they will be among the smallest -- and smartest -- satellites ever launched.
- The Constellation Trailblazer mission is preparing the way for this network of 22-pound (10 kilogram) satellites which is being planned for launch in 2010. These 100 small orbiters will be launched as a single payload, and then deployed like frisbees upon reaching orbit. NASA aims to build these satellites at a cost of $1 million each.

Unmanned Aerial Vehicles (UAVs)

"Unmanned Aerial Vehicles (UAVs) and Imaging Systems For Real-Time Disaster Data Gathering"

ALTUS II with AIRDAS sensor
Vince Ambrosia
CA. State University – Monterey Bay / NASA-Ames
Terrain Draping of Fire Data

Tactical Fire Imaging

"Tunnel Fire" Oakland Hills

Visible Channel Composite
Thermal / IR Channel Composite

Oakland Hills Fire October 1991

AIRDAS Data Collected Over Berkeley Hills, 15 May 2003

SMART DUST

From displaying ground based LiDAR ...

The New-New Maps:
Welcome – SONY PS3 PlayStation

- Cell Broadband Engine Architecture
- PS3 to reach the petaFLOPS mark (thousand trillion floating point operations per second)
- Realistic Real time Rendered Terrain model

Some other Web sites for Remote Sensing

- http://rst.gsfc.nasa.gov/Front/tofc.html