THE NATURE OF REMOTE SENSING

Reading: Chapter 1

THE NATURE OF REMOTE SENSING

• Introduction
• Remote Sensing Systems
• Remote Sensing Physics
• Sensor Parameters
• Display and Data Systems
Definitions

- Remote Sensing = “Measurement at a Distance”
- This course is about Earth remote sensing
  - Airborne or satellite platforms
  - Optical region of the spectrum
    - visible (400-700nm) to thermal (long-wave) infrared wavelengths (8 to 12mm)

Definitions (cont.)

- Remote sensing requires
  - Active or passive source
  - Target
  - Medium (typically lossy)
  - Sensor (optics, detector)
- Source radiation modeled as a traveling wave
  - Time-harmonic
  - $c = \lambda \nu$
    - $c = 2.998 \times 10^8$ m/s
    - $\lambda$ is the wavelength
    - $\nu$ is the frequency
  - Also, wavenumber $1/\lambda$, cm$^{-1}$
- EM spectrum is infinite and continuous
- Energy interacts with matter
  - Reflection (Scattering)
  - Transmission
  - Absorption (Re-emitted)
- Sensor characteristics
  - Spatial (Ground Sample Interval)
  - Spectral (Range and width)
  - Temporal (Revisit time)
  - Radiometric (Precision)
Applications

- Environmental assessment and monitoring
- Global change detection
- Agriculture
- Nonrenewable resources
- Renewable resources
- Meteorology
- Mapping
- Military surveillance and reconnaissance
- News media

Types of Sensors and Sensing

- Multiangle Imaging SpectroRadiometer (MISR) sensor on NASA Terra satellite (http://www-misr.jpl.nasa.gov/)
**Broadband Sensors**

- Single, broad spectral band, typically 400nm wide in the visible spectrum
- Often called “panchromatic”
- Large number of photons collected, which allows smaller detectors, i.e. greater spatial resolution

*Corona* was the first global satellite reconnaissance mission
- High resolution camera
- Photographic film returned to Earth in re-entry capsule

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**Heat Capacity Mapping Mission (HCMM)**

- One-of-a-kind NASA sensor
  - First Applications
    - Explorer Mission AEM-1
  - April 26, 1978 - September 30, 1980
- Demonstrated relatively high resolution (600m) thermal remote sensing from satellites
- **Heat capacity** refers to retention and release of thermal energy by geologic materials during the diurnal cycle
**Multispectral Sensors**

- **Co-registered images in several relatively narrow spectral bands**
  - Typically 50-100nm wide in the visible spectrum, wider at longer wavelengths

- **Landsat Series (1-7)**
  - 1972 - date
  - Landsat 6 failed to achieve orbit, 5 and 7 still operating
  - Various multispectral sensors
    - Multispectral Scanner System (MSS): 4 bands, VNIR 80m
    - Thematic Mapper (TM): 7 bands, VNIR/SWIR 30m, TIR 120m
    - Enhanced Thematic Mapper (ETM+): 8 bands, PAN 15m, VNIR/SWIR 30m and TIR 60m

**Multispectral Display**

- **Visualize spectral content with 3-band color composites**

- **Example: color infrared (CIR)**
  - Red channel assigned to near IR sensor band
  - Green channel assigned to red sensor band
  - Blue channel assigned to green sensor band

- Vegetation appears red, soil appears yellow - grey, water appears blue - black
Airborne Sensors

Positive Systems, ADAR System 5500, single frame
Color infrared (CIR) composite of Tanque Verde Wash, Tucson

Hyperspectral Sensors

- Multispectral sensor with relatively high spectral resolution (typically 5 - 10 nm) and large number (typically 200) of nearly-contiguous bands
  - high spectral resolution potentially allows high discrimination of surface features
- Typically acquired with an imaging spectrometer over the wavelength range 400 to 2400nm
  - mostly airborne systems
  - Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (http://makalu.jpl.nasa.gov/aviris.html): 224 bands, 5-20m
  - Hyperion is first satellite hyperspectral sensor, on NASA EO-1 satellite (http://eo1.gsfc.nasa.gov/Technology/Hyperion.html): 220 bands, 30m

AVIRIS hyperspectral image cube of Los Alamos, NM (courtesy Chris Borel, LANL)
**Spectral Signatures**

AVIRIS CIR composite image of Palo Alto, CA

**Multitemporal Image Series**

Landsat Multispectral Scanner System (MSS) 13-year image series of copper mine expansion near Tucson, AZ
**Global Composites**

- Images from a single sensor, acquired over a long period of time (e.g., days or weeks)
- "Cloud-free" pixel composite
- Mosaiced
- Projected in a single map projection for the whole earth

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**Non-Optical Sensors**

- Acquired in non-optical spectral regions, e.g. microwave
- Synthetic Aperture Radar (SAR)
- Measure different surface properties than optical images
- E.g. microwave can sense soil moisture and surface roughness

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Shuttle Imaging Radar (SIR-C) image of volcano in Galapagos Islands

Rough lava

Smooth lava
The Nature of Remote Sensing

- Introduction
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- Remote Sensing Physics
- Sensor Parameters
- Display and Data Systems

Sensor Parameter Space

- number of spectral bands
- GIFOV (m at nadir)

Systems:
- HYDICE
- AVIRIS
- HSI
- V, S
- GIFOV (m at nadir)
- 3.2 km altitude
- 6.1 km altitude
- visible/near infrared
- thermal infrared
- panchromatic
- shortwave infrared
- MODIS
- V, S
- TM
- AVHRR/1
- V, S, T
- AVHRR/2
- V, S, T
- MODIS
- V, S, T
- MISR
- V
- IRS-1C
- LISS-III
- SPOT
- TM
- ETM
- LISS-III
- ASTER
- TM
- ETM
- ASTER
Case Study: MODIS

- **Limit-of-the-art multispectral whiskbroom system**
- 36 spectral bands from visible to thermal on 4 focal planes
- 3 spatial resolutions: 250m, 500m, 1000m
- Diverse applications: land, oceans, atmosphere

MODerate resolution Imaging Spectrometer (MODIS)

<table>
<thead>
<tr>
<th>Geophysical variables</th>
<th>Band</th>
<th>Spectral range (nm)</th>
<th>GIFOV (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land/cloud boundaries</td>
<td>1, 2</td>
<td>620 - 670, 841 - 876</td>
<td>250</td>
</tr>
<tr>
<td>Land/cloud properties</td>
<td>3, 4, 5</td>
<td>459 - 479, 545 - 565, 1230 - 1250</td>
<td>500</td>
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<tr>
<td>Ocean color</td>
<td>8, 9, 10, 11</td>
<td>405 - 420, 438 - 448, 483 - 493, 526 - 536</td>
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<tr>
<td>Specific</td>
<td></td>
<td></td>
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<tr>
<td>vegetation chlorophyll cloud and vegetation</td>
<td></td>
<td></td>
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<tr>
<td>soil, vegetation differences</td>
<td>12</td>
<td>546 - 556</td>
<td>1000</td>
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<tr>
<td>green vegetation leaf/canopy properties</td>
<td>13</td>
<td>662 - 672</td>
<td>1000</td>
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<tr>
<td>snow/cloud differences</td>
<td>14</td>
<td>673 - 683</td>
<td>1000</td>
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<tr>
<td>land and cloud properties</td>
<td>15</td>
<td>743 - 753</td>
<td>1000</td>
</tr>
<tr>
<td>chlorophyll flourescence</td>
<td>16</td>
<td>862 - 877</td>
<td>1000</td>
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<tr>
<td>aerosol properties</td>
<td>17, 18, 19</td>
<td>890 - 920, 931 - 941, 915 - 965</td>
<td>1000</td>
</tr>
<tr>
<td>aerosol/atmosphere properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cloud/atmosphere properties</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

 NASA EOS MODerate resolution Imaging Spectrometer (MODIS)
### Case Study: MODIS (cont.)

<table>
<thead>
<tr>
<th>Geophysical variables</th>
<th>Band</th>
<th>Spectral range (µm)</th>
<th>GIFOV (m)</th>
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<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
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<tr>
<td>sea surface temperatures</td>
<td>20</td>
<td>3.66 - 3.84</td>
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<td>forest fires/volcanoes</td>
<td>21</td>
<td>3.929 - 3.989</td>
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<tr>
<td>cloud/surface temperature</td>
<td>22</td>
<td>3.929 - 3.989</td>
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<tr>
<td>cloud/ surface temperature</td>
<td>23</td>
<td>4.02 - 4.08</td>
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<td>troposphere temp/cloud fraction</td>
<td>24</td>
<td>4.433 - 4.498</td>
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<tr>
<td>troposphere temp/cloud fraction</td>
<td>25</td>
<td>4.482 - 4.549</td>
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<tr>
<td><strong>Atmosphere /clouds</strong></td>
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<tr>
<td>cirrus clouds</td>
<td>26</td>
<td>1.36 - 1.39</td>
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<tr>
<td><strong>Thermal</strong></td>
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<tr>
<td>mid-troposphere humidity</td>
<td>27</td>
<td>6.535 - 6.895</td>
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<tr>
<td>upper-troposphere humidity</td>
<td>28</td>
<td>7.175 - 7.475</td>
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<tr>
<td>surface temperature</td>
<td>29</td>
<td>8.4 - 8.7</td>
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<tr>
<td>total ozone</td>
<td>30</td>
<td>9.58 - 9.88</td>
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<tr>
<td>cloud/surface temperature</td>
<td>31</td>
<td>10.78 - 11.28</td>
<td></td>
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<tr>
<td>cloud/surface temperature</td>
<td>32</td>
<td>11.77 - 12.27</td>
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<tr>
<td>cloud height and fraction</td>
<td>33</td>
<td>13.185 - 13.485</td>
<td></td>
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<tr>
<td>cloud height and fraction</td>
<td>34</td>
<td>13.485 - 13.785</td>
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</tr>
<tr>
<td>cloud height and fraction</td>
<td>35</td>
<td>13.785 - 14.085</td>
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<tr>
<td>cloud height and fraction</td>
<td>36</td>
<td>14.085 - 14.385</td>
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</table>

### Commercial Systems

<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>WWW address</th>
<th>Sensor</th>
<th>GSI (m) pan/multi</th>
<th>GIFOV (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Space Imaging</td>
<td><a href="http://www.spaceimaging.com">http://www.spaceimaging.com</a></td>
<td>IKONOS</td>
<td>1/4</td>
<td>13 x 13, 11 x 1000</td>
</tr>
<tr>
<td></td>
<td>DigitalGlobe</td>
<td><a href="http://www.digitalglobe.com">http://www.digitalglobe.com</a></td>
<td>QuickBird</td>
<td>0.6/2.4</td>
<td>22 x 22, 22 x 200</td>
</tr>
<tr>
<td></td>
<td>Orbital Imaging</td>
<td><a href="http://www.orbimage.com">http://www.orbimage.com</a></td>
<td>OrbView-3</td>
<td>1/4</td>
<td>8 x 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EROS-B</td>
<td>0.82</td>
<td>16</td>
</tr>
<tr>
<td>South Korea</td>
<td>-</td>
<td><a href="http://spaceflightnow.com/taurus/kompasat/kompasat.html">http://spaceflightnow.com/taurus/kompasat/kompasat.html</a></td>
<td>KOMPASAT-1</td>
<td>6.6</td>
<td>15</td>
</tr>
<tr>
<td>France</td>
<td>SPOTImage</td>
<td><a href="http://www.spot.com/home">http://www.spot.com/home</a></td>
<td>SPOT 1-4</td>
<td>10/20</td>
<td>60/60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SPOT 5</td>
<td>2.5,5/10,20</td>
<td></td>
</tr>
</tbody>
</table>
**Then and Now**

Ronald Reagan Washington National Airport (courtesy Space Imaging Inc.)

IKONOS-P (1m)  
SPOT-P (10-m) simulated  
ETM-P (15-m) simulated

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**The Nature of Remote Sensing**

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Spectral Regions

- **Determined by:**
  - "windows" where atmospheric transmittance is relatively high
  - wavelength regions where detector sensitivity is relatively high

<table>
<thead>
<tr>
<th>Name</th>
<th>Wavelength Range (µm)</th>
<th>Radiation Source</th>
<th>Surface Properties of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible (V)</td>
<td>0.4-0.7</td>
<td>solar</td>
<td>reflectance</td>
</tr>
<tr>
<td>Near Infrared (NIR)</td>
<td>0.7-1.1</td>
<td>solar</td>
<td>reflectance</td>
</tr>
<tr>
<td>Short-Wave Infrared (SWIR)</td>
<td>1.1-1.35, 1.4-1.8, 2-2.5</td>
<td>solar</td>
<td>reflectance</td>
</tr>
<tr>
<td>Mid-Wave Infrared (MWIR)</td>
<td>3-4, 4.5-5</td>
<td>solar, thermal</td>
<td>reflectance, temperature</td>
</tr>
<tr>
<td>Thermal Infrared (TIR)</td>
<td>8-9.5, 10-14</td>
<td>thermal</td>
<td>temperature</td>
</tr>
<tr>
<td>Microwave, Radar</td>
<td>1mm-1m</td>
<td>thermal (passive) artificial (active)</td>
<td>Temperature (passive) roughness (active)</td>
</tr>
</tbody>
</table>

Atmospheric Transmittance

- **Atmospheric “windows” result from energy absorption by air molecules**
  - Water vapor (H₂O)
  - Carbon dioxide (CO₂)
  - Ozone (O₃)
  - Others to a lesser extent

![Graph showing atmospheric transmittance](image)
Radiation Sources

- Approximately equal at the top-of-the-atmosphere (TOA) in the Mid-Wave IR (MWIR)

Human Vision

- Sensitive over very small range of total solar spectrum

solar spectrum and human visual sensitivity
**Spectral Signatures**

- **Vegetation** spectral reflectance has several distinguishing features
  - "red edge" at 720 - 780nm caused by cellular structure
  - Low reflectance in the blue and red caused by chlorophyll absorption; slightly higher reflectance in the green
  - Water absorption features at 1400nm and 1900nm

**Spectral Signatures (cont.)**

- Soil and geologic minerals show relatively smooth spectral reflectance
  - Water absorption features in soils at 1400nm and 1900nm
  - Narrow molecular absorption features caused by characteristic molecules
**Myth of Spectral Signatures**

- Idealized characteristic of surface materials is never achieved in practice
  - natural variability
  - atmospheric variability
  - “mixing” of materials
  - shadows
  - bidirectional reflectance distribution function (BRDF)
  - sensor noise
- Nevertheless, spectral signatures are a useful concept

![Graph showing spectra of pixel samples from 3 materials](image.png)
Multitemporal Parameters

- **Meteorology** requires frequent revisits (at least hourly)
- **Agriculture** requires less frequent revisits (weekly)
- **Geology** requires infrequent revisits (every few million years)
  - “events” such as volcanos and landslides are exceptions

<table>
<thead>
<tr>
<th>System</th>
<th>Revisit Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 1-3</td>
<td>18 days</td>
</tr>
<tr>
<td>Landsat 4-7</td>
<td>16 days</td>
</tr>
<tr>
<td>AVHRR</td>
<td>1 day or 7 hrs</td>
</tr>
<tr>
<td>SPOT</td>
<td>26 days at nadir</td>
</tr>
<tr>
<td></td>
<td>1, or 4-5 days pointing</td>
</tr>
<tr>
<td>IRS-1A, B</td>
<td>22 days</td>
</tr>
<tr>
<td>MODIS</td>
<td>2 days</td>
</tr>
<tr>
<td>GOES</td>
<td>30 min</td>
</tr>
</tbody>
</table>

Scan Parameters

- **Field-Of-View (FOV, radians):** used by system designers
- **Ground-projected FOV (GFOV, km):** used by data users
Scanner Types

In-track pushbroom  Pointing pushbroom

Continuous coverage whiskbroom scanner (MODIS)

Pixel Parameters

- **Instantaneous Field-Of-View (IFOV, mrad)**
- **Ground-projected IFOV (GIFOV, m)**
- **Ground Sample Interval (GSI, m)**
  - Also called Ground Sample Distance (GSD)
- **GIFOV and GSI determine geometric “spatial resolution”**
  - Defined at-nadir, “pixel growth” occurs off-nadir
  - Instrument response also affects spatial resolution
Sensor Comparison

- **Whiskbroom**: Landsat Enhanced Thematic Mapper ETM+
- **Pushbroom**: Earth Observer - 1 Advanced Land Imager ALI

Signal-to-Noise Ratio (SNR) - Alaska low-light image, both 30m GIFOV

- Landsat ETM+ (November 2000)
- EO-1 ALI (December 2000)

Sensor Comparison (cont.)

Local geometry - Maricopa, AZ, July 27, 2001

- Landsat-7 ETM+ Level 16 band 1
- EO-1 ALI Level 1R band 2
The Instrument Response

- Any measuring instrument is limited in the degree of detail it can capture
- This limit is referred to as the instrument’s “resolution”
  - widely used, but often misused, term
- Two aspects for remote sensors
  - spatial response
  - spectral response

Spatial Response

- The total system response to a spatial “impulse” signal
- Larger than geometric GIFOV
  - time integration smear (cross-track for whiskbrooms, in-track for pushbrooms)
  - optics blur
  - electronic filters (cross-track for whiskbrooms; not common for pushbrooms)
  - detector electron diffusion, charge transfer inefficiency (pushbrooms)
- The net spatial response is the convolution of all these factors, converted to a common spatial coordinate system
**Imaging Simulation**

- Example: simulation of Landsat TM imaging
  - Model TM spatial response components (at a common scale)

**Imaging Simulation (cont.)**

*TM spatial response components*
Imaging Simulation (cont.)

High resolution aerial photography

- Scanned aerial photograph, GSI = 2m
  - Rotated to align with TM orbit and scan direction

Imaging Simulation (cont.)

- Apply each component of the spatial response and downsample to 30m
  - Optics
  - Optics and GIFOV
  - Optics, GIFOV and electronics
  - Downsample 2m → 30m GSI
Imaging Simulation (cont.)

- Compare to real TM of same area, acquired 4 months later

\[ \text{simulated TM} \quad \text{real TM} \]

Spatial Resolution

- A "subpixel" object smaller than the GIFOV can be detected, but not resolved
- Detectability of a subpixel object depends on:
  - object size relative to the sensor GIFOV
  - object radiance contrast to the surrounding background
  - scene noise ("clutter")
  - sensor noise
**Detectability**

- Low-contrast subpixel targets must be bigger than high-contrast targets for detection

**Sampling**

- The measured radiance of a subpixel object depends on the location of the object relative to the pixel samples
**Spectral Response**

- Individual band spectral response determined by
  - detector responsivity
  - filter transmission (discrete spectral band sensors)
  - spectrometer slit width (hyperspectral sensors)

*Example spectral response curves - Landsat Thematic Mapper (TM)*

**Spectral Resolution**

- As in the spatial case, the width of the instrument spectral response determines its ability to record detail in the spectral signal

*Simulation of TM band measurements of a vegetation spectral signal*
**Spectral Resolution (cont.)**

- Hyperspectral systems with narrow spectral responses (typically about 10nm) are useful for detecting fine spectral detail

![Simulation of spectral doublet measurement with two different spectral resolutions](image)

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**Image Formats**

- **BIS (BIP): Band Interleaved-by-Sample (-Pixel)**
  - lines 1-8
  - bands 1-7
  - samples 1-8

- **BIL: Band Interleaved-by-Line**
  - lines 1-8
  - bands 1-7

- **BSQ: Band Sequential**
  - lines 1-8
  - bands 1-7

**File Formats**

- **raw**
  - no header

- **geoTIFF**
  - variant of TIFF that includes geolocation information in header ([http://remotesensing.org/geotiff/geotiff.html](http://remotesensing.org/geotiff/geotiff.html))

- **HDF**
  - Hierarchical Data Format ([http://hdf.ncsa.uiuc.edu/](http://hdf.ncsa.uiuc.edu/))
  - self-documenting, with all metadata required to read an image file contained within the image file
  - variable length subfiles
  - NASA specific version: EOS-HDF ([http://hdf.ncsa.uiuc.edu/hdfeos.html](http://hdf.ncsa.uiuc.edu/hdfeos.html))

- **NITF**
  - Department of Defense
Display Systems

- **Digital Numbers (DNs)** are image data
- **Grey Levels (GLs)** are numerical display values
- **Look-Up Tables (LUTs)** map DNs → GLs and change image brightness, contrast and colors
  - Actual displayed colors depend on the color response characteristics of the display system

![Display System Architecture](image)

Color Composites

- Composite any three sensor bands into RGB
- **Color IR (CIR) mode** approximates CIR film spectral response
  - Interpretation key:
    - red = vegetation
    - grey, yellow = soils
    - blue, black = water

### Generic Composites

<table>
<thead>
<tr>
<th>Display Color</th>
<th>Color Mode</th>
<th>TrueColor (TC)</th>
<th>Color IR (CIR)</th>
<th>False Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red (R)</td>
<td>Red</td>
<td>Red</td>
<td>NIR</td>
<td>Any</td>
</tr>
<tr>
<td>Green (G)</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
<td>Any</td>
</tr>
<tr>
<td>Blue (B)</td>
<td>Blue</td>
<td>Green</td>
<td>Green</td>
<td>Any</td>
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</table>

### Sensor-Specific Composites

<table>
<thead>
<tr>
<th>Composite</th>
<th>MSS</th>
<th>TM</th>
<th>SPOT</th>
<th>AVIRIS</th>
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</thead>
<tbody>
<tr>
<td>TC</td>
<td>NA</td>
<td>3,2,1</td>
<td>NA</td>
<td>27,17,7</td>
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<tr>
<td>CIR</td>
<td>4,2,1</td>
<td>4,3,2</td>
<td>3,2,1</td>
<td>51,27,17</td>
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</tbody>
</table>
**Color Composite Example**

- **TM2**
- **TM3**
- **TM4**
- **Color IR (CIR)**
- **TM1**
- **TM2**
- **TM3**
- **True Color (TC)**

**Data Processing Systems**

- **“Standard” types of preprocessing**
  - radiometric calibration
  - geometric calibration
  - noise removal
  - formatting

- **Generic description**
  - Level 0: raw, unprocessed sensor data
  - Level 1: radiometric (1R or 1B) or geometric processing (1G)
  - Level 2: derived product, e.g. vegetation index

*Generally, higher levels of processing cost more!*