The University of Arizona
Tucson Arizona

The Nature of Remote Sensing

Reading: Chapter 1

The Nature of Remote Sensing

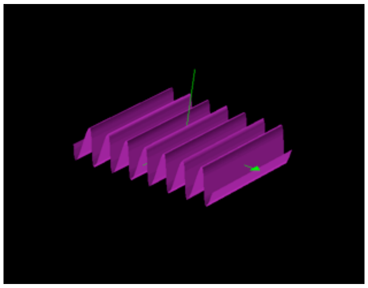
- *Introduction*
- *Remote Sensing Systems*
- *Remote Sensing Physics*
- *Sensor Parameters*
- *Display and Data Systems*

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)

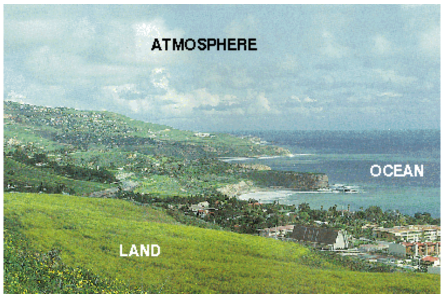
Definitions (cont.)

- 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
    - λ is the wavelength
    - ν is the frequency
  - Also, wavenumber $1/\lambda$ cm^{-1}
- EM spectrum is infinite and continuous
- Energy interacts with matter
  - Reflection (Scattering)
  - Transmission
  - Absorption (Re-emmitted)
- Sensor characteristics
  - Spatial (Ground Sample Interval)
  - Spectral (Range and width)
  - Temporal (Revisit time)
  - Radiometric (Precision)



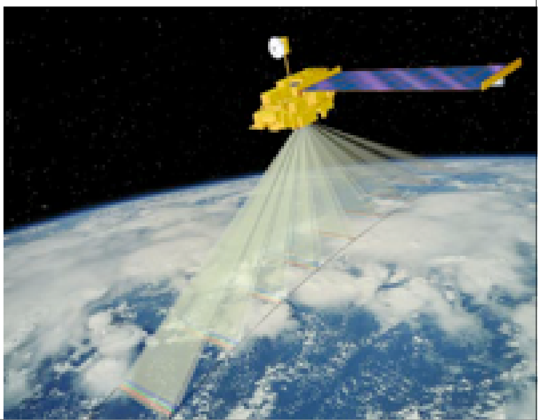
Applications

- *Environmental assessment and monitoring*
- *Global change detection*
- *Agriculture*
- *Nonrenewable resources*
- *Renewable resources*
- *Meteorology*
- *Mapping*
- *Military surveillance and reconnaissance*
- *News media*
- *Further reading: Remote sensing tutorial http://rst.gsfc.nasa.gov*



Types of Sensors and Sensing

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



Broadband Sensors

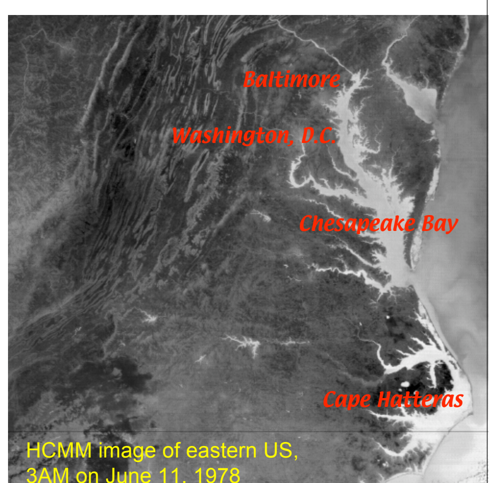
- *Single, broad spectral band, typically 400nm wide in the visible spectrum*
- *Often called "panchromatic"*
- *Large number of photons collected, which allows smaller detectors, i.e. greater spatial resolution*
- *Corona was the first global satellite reconnaissance mission*
  - *high resolution camera*
  - *photographic film returned to Earth in re-entry capsule*

Corona photograph of Dolon airfield, USSR, August 20, 1966

(http://www.nro.gov/corona/imagery.htm)

Heat Capacity Mapping Mission (HCMM)

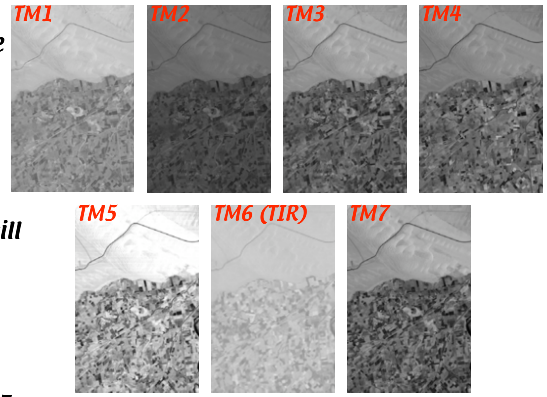
- *One-of-a-kind NASA sensor*
  - *First Applications Explorer Mission AEM-1*
  - *April 26, 1978 - September 30, 1980*
- *Demonstrated relatively high resolution (600m) thermal remote sensing from satellites*
- *Heat capacity refers to retention and release of thermal energy by geologic materials during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



HCMM image of eastern US, 3AM on June 11, 1978

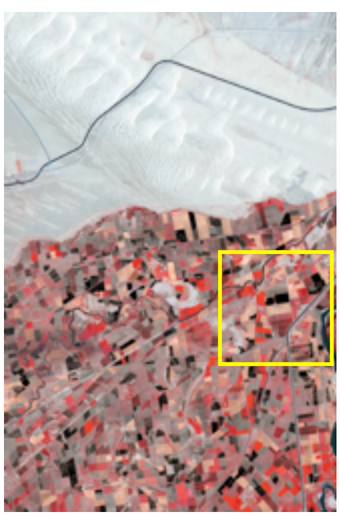
Multispectral Sensors

- *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*



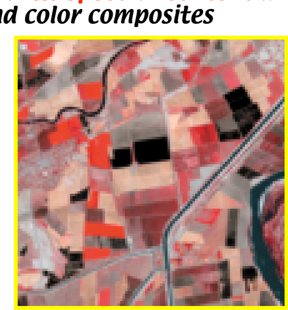
TM multispectral image of desert and agriculture near Yuma, Arizona

Multispectral Display



TM color infrared (CIR) composite of Imperial Valley, California

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



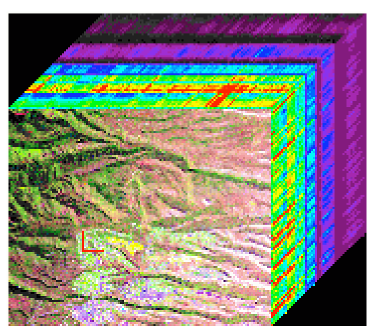
- *Example: color infrared (CIR)*
  - *red channel assigned to near IR sensor band*
  - *green channel assigned to red sensor band*
  - *blue channel assigned to green sensor band*
- *vegetation appears red, soil appears yellow - grey, water appears blue - black*

Airborne Sensors

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

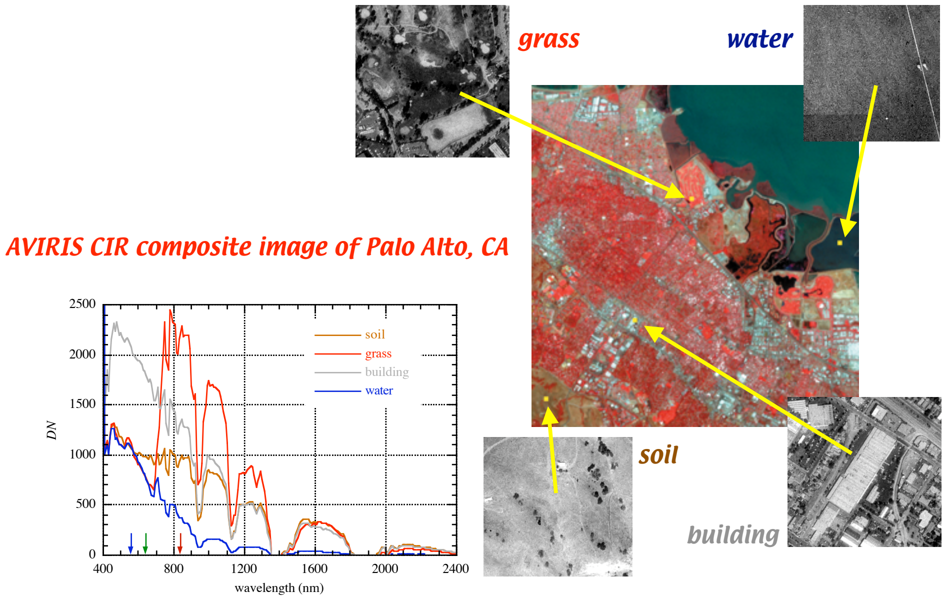
Hyperspectral Sensors

- *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*



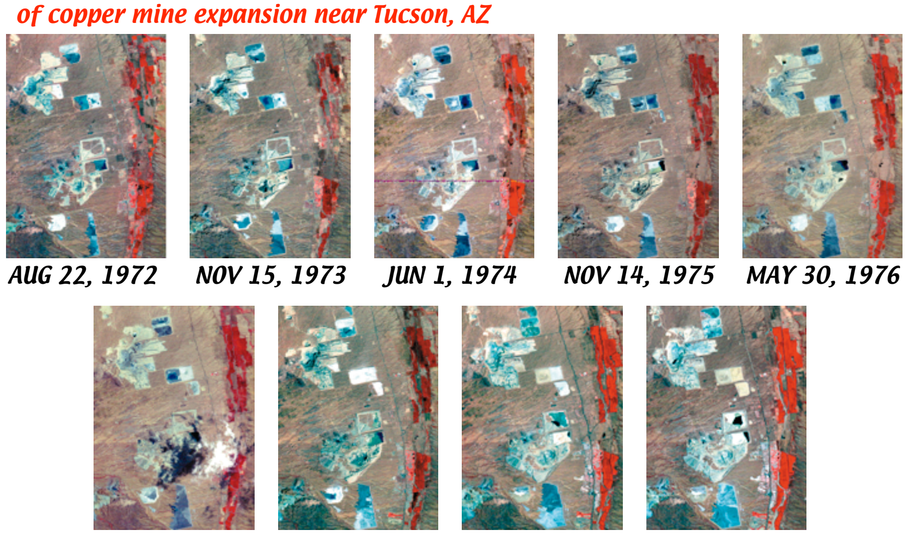
AVIRIS hyperspectral image cube of Los Alamos, NM (courtesy Chris Borel, LANL)

Spectral Signatures



Multitemporal Image Series

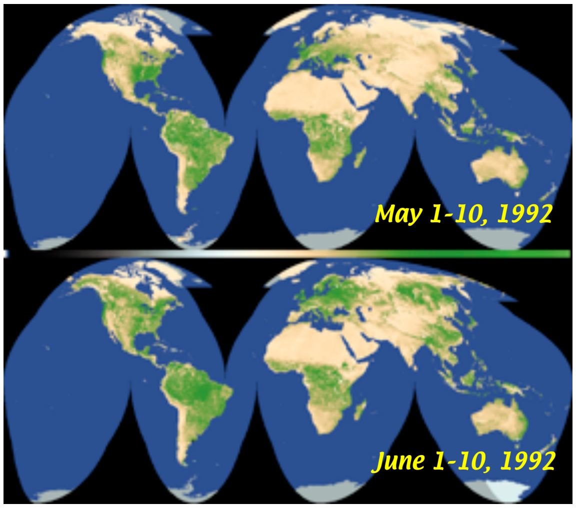
Landsat Multispectral Scanner System (MSS) 13-year image series of copper mine expansion near Tucson, AZ



AUG 22, 1972 NOV 15, 1973 JUN 1, 1974 NOV 14, 1975 MAY 30, 1976

JUN 30, 1977 OCT 11, 1978 JUL 13, 1983 JUN 14, 1985

Global Composites

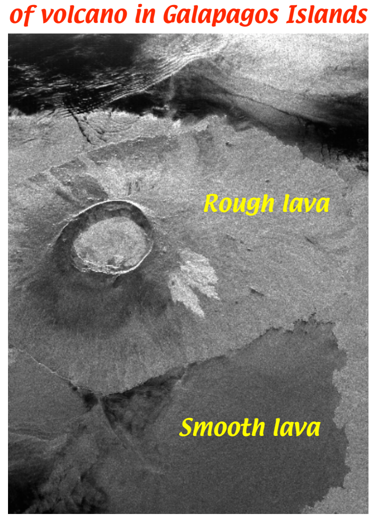


- *Images from a single sensor, acquired over a long period of time (e.g., days or weeks)*
- *“Cloud-free” pixel composite*
- *Mosaiced*
- *Projected in a single map projection for the whole earth*

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*

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



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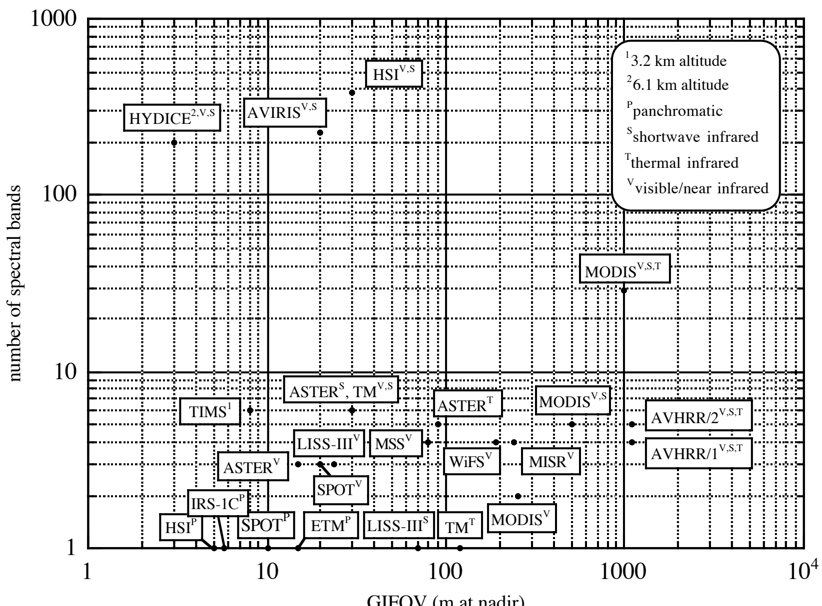
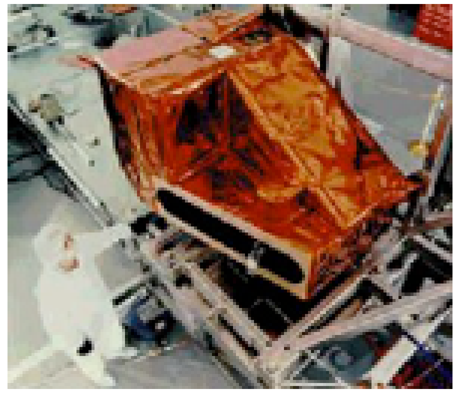
Sensor Parameter Space



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



NASA EOS MODerate resolution Imaging Spectrometer (MODIS)

Case Study: MODIS (cont.)

Geophysical variables		Band	Spectral range (nm)	GIFOV (m)
General	Specific			
Land/cloud boundaries	vegetation chlorophyll cloud and vegetation	1 2	620 - 670 841 - 876	250
Land/cloud properties	soil, vegetation differences green vegetation leaf/canopy properties snow/cloud differences land and cloud properties	3 4 5 6 7	459 - 479 545 - 565 1230 - 1250 1628 - 1652 2105 - 2155	500
Ocean color	chlorophyll observations	8 9 10 11	405 - 420 438 - 448 483 - 493 526 - 536	1000
	sediments	12	546 - 556	
	sediments, atmosphere	13	662 - 672	
	cholorophyll flourescence	14	673 - 683	
	aerosol properties	15	743 - 753	
	aerosol/atmosphere properties	16	862 - 877	
Atmosphere/clouds	cloud/atmosphere properties	17 18 19	890 - 920 931 - 941 915 - 965	

Case Study: MODIS (cont.)

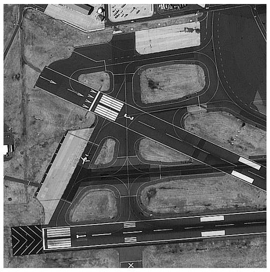
Geophysical variables		Band	Spectral range (μm)	GIFOV (m)
General	Specific			
Thermal	sea surface temperatures forest fires/volcanoes cloud/surface temperature cloud/ surface temperature	20 21 22 23	3.66 - 3.84 3.929 - 3.989 3.929 - 3.989 4.02 - 4.08	1000
	troposphere temp/cloud fraction troposphere temp/cloud fraction	24 25	4.433 - 4.498 4.482 - 4.549	
Atmosphere /clouds	cirrus clouds	26	1.36 - 1.39	
Thermal	mid-troposphere humidity upper-troposphere humidity surface temperature	27 28 29	6.535 - 6.895 7.175 - 7.475 8.4 - 8.7	
	total ozone	30	9.58 - 9.88	
	cloud/surface temperature cloud/surface temperature	31 32	10.78 - 11.28 11.77 - 12.27	
	cloud height and fraction cloud height and fraction cloud height and fraction cloud height and fraction	33 34 35 36	13.185 - 13.485 13.485 - 13.785 13.785 - 14.085 14.085 - 14.385	

Commercial Systems

Country	Company	WWW address	Sensor	GSI (m) pan/multi	GFOV (km)
USA	Space Imaging	http://www.spaceimaging.com	IKONOS	1/4	13 x 13, 11 x 1000
	DigitalGlobe	http://www.digitalglobe.com	QuickBird	0.6/2.4	22 x 22, 22 x 200
	Orbital Imaging	http://www.orbimage.com	OrbView-3	1/4	8 x 8
Israel	ImageSat	http://www.imagesatintl.com	EROS-A EROS-B	1.8 0.82	12.5 16
South Korea	-	http://spaceflightnow.com/taurus/kompsat/991220kompsat.html	KOMPSAT-1	6.6	15
France	SPOTImage	http://www.spot.com/home	SPOT 1-4 SPOT 5	10/20 2.5,5/10,20	60/60

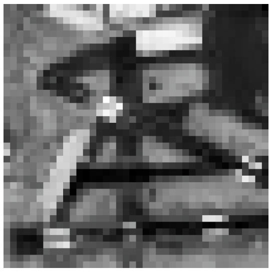
Then and Now

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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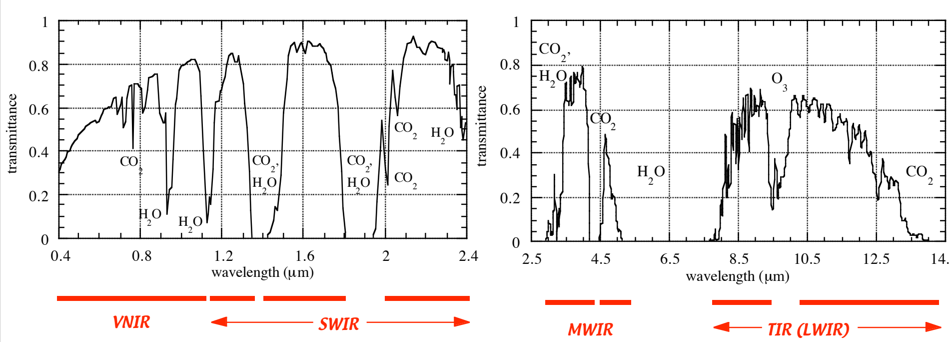
Spectral Regions

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

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

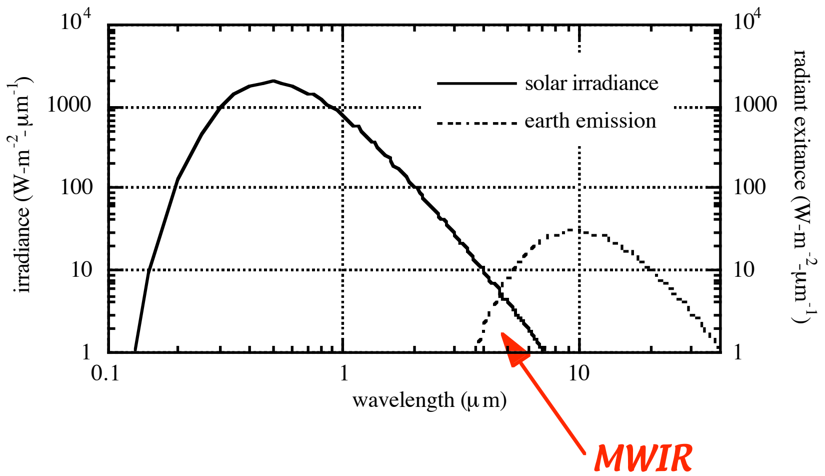
Atmospheric Transmittance

- ***Atmospheric "windows" result from energy absorption by air molecules***
  - *Water vapor (H_2O)*
  - *Carbon dioxide (CO_2)*
  - *Ozone (O_3)*
  - *Others to a lesser extent*



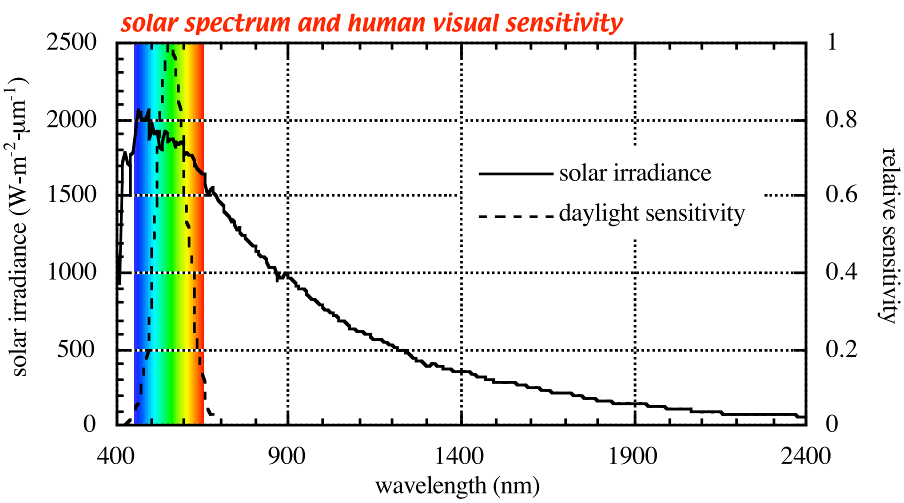
Radiation Sources

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



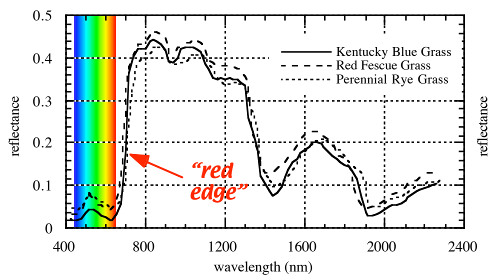
Human Vision

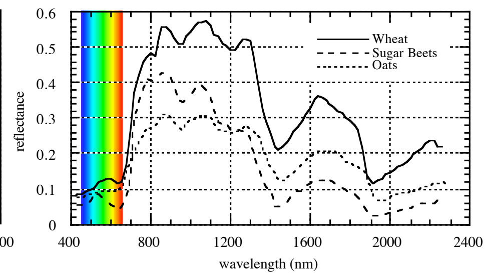
- ***Sensitive over very small range of total solar spectrum***



Spectral Signatures

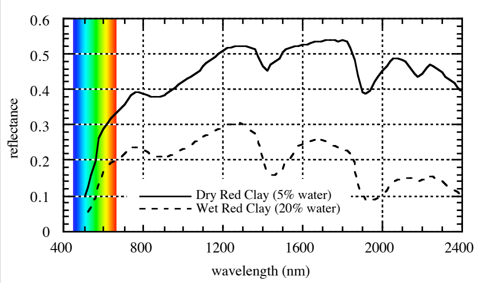
- ***Vegetation* spectral reflectance has several distinguishing features**
  - ***"red edge" at 720 - 780nm caused by cellular structure***
  - ***Low reflectance in the blue and red caused by chlorophyll absorption; slightly higher reflectance in the green***
  - ***Water absorption features at 1400nm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

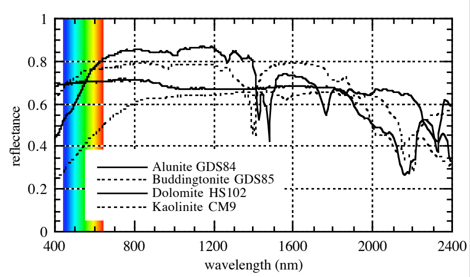




Spectral Signatures (cont.)

- ***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***

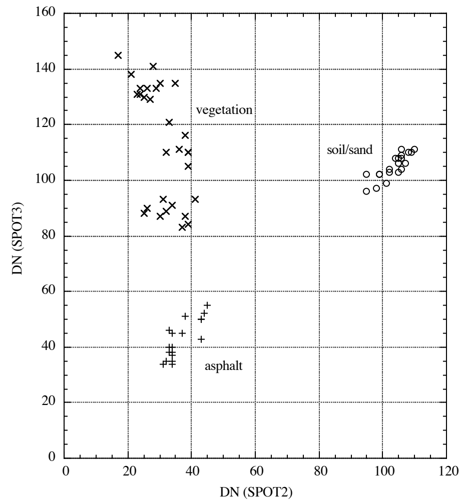




Myth of Spectral Signatures

- ***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***

spectra of pixel samples from 3 materials



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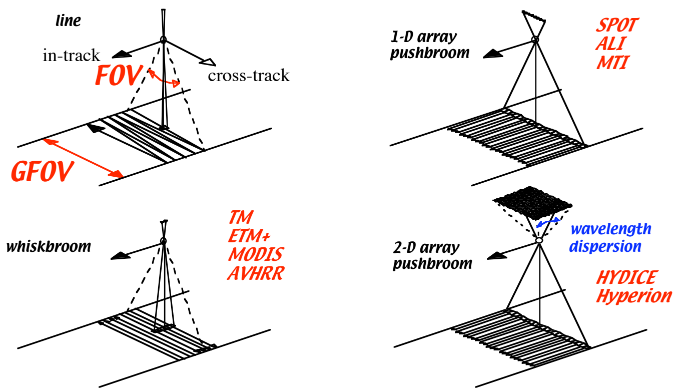
Multitemporal Parameters

- *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

System	Revisit Interval
Landsat 1-3	18 days
Landsat 4-7	16 days
AVHRR	1 day or 7 hrs
SPOT	26 days at nadir 1, or 4-5 days pointing
IRS-1A, B	22 days
MODIS	2 days
GOES	30 min

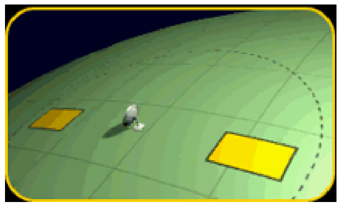
Scan Parameters

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

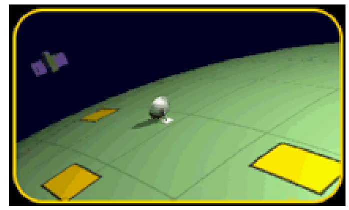


Scanner Types

In-track pushbroom



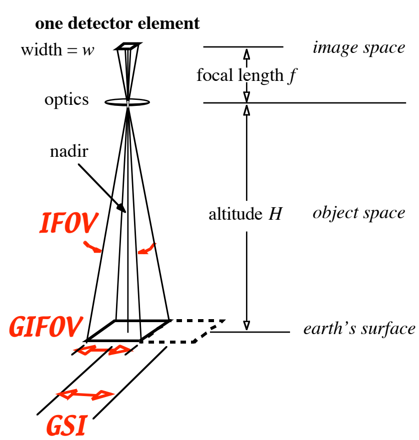
Pointing pushbroom



Continuous coverage whiskbroom scanner (MODIS)

Pixel Parameters

- ***Instantaneous Field-Of-View (IFOV, mrads)***
- ***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***



Instantaneous pixel geometry

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)

E0-1 ALI (December 2000)

Sensor Comparison (cont.)

Local geometry - Maricopa, AZ, July 27, 2001

Landsat-7 ETM+ Level 1G band 1

E0-1 ALI Level 1R band 2

The Instrument Response

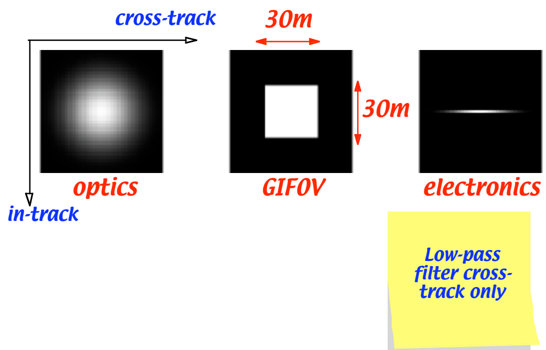
- *Any measuring instrument is limited in the degree of detail it can capture*
- *This limit is referred to as the instrument's "resolution"*
  - *widely used, but often misused, term*
- *Two aspects for remote sensors*
  - *spatial response*
  - *spectral response*

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*

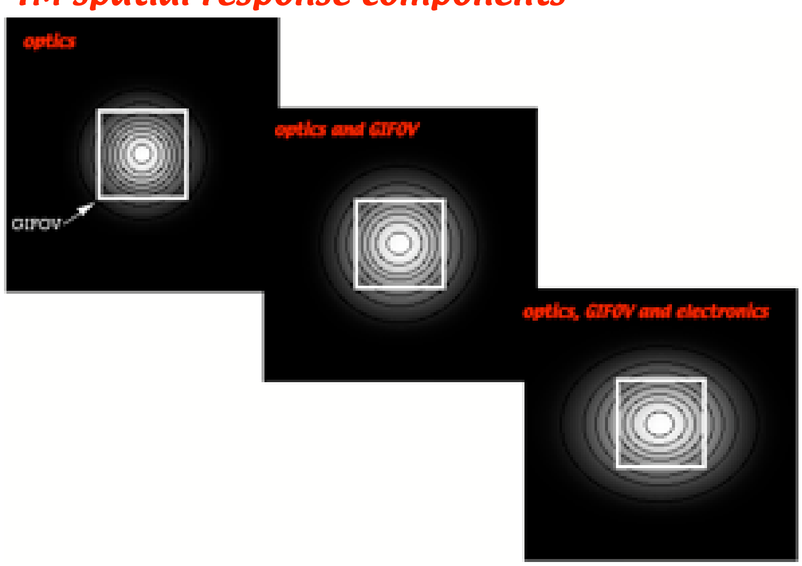
Imaging Simulation

- ***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

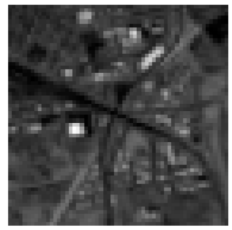
optics, GIFOV and electronics

downsample
2m –> 30m GSI

Imaging Simulation (cont.)

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

simulated TM



real TM

real TM (contrast-adjusted)

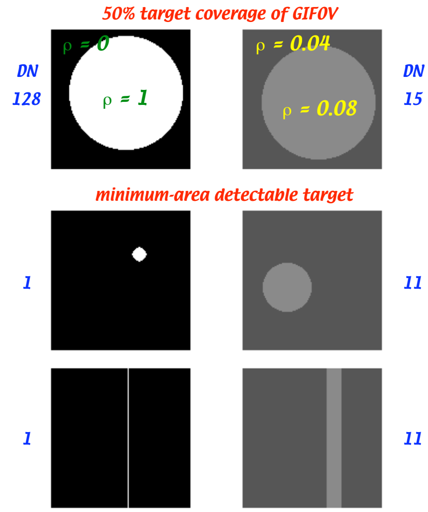
Spatial Resolution

- *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*

Berkeley Pier: 7m wide, concrete and wood

Detectability

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

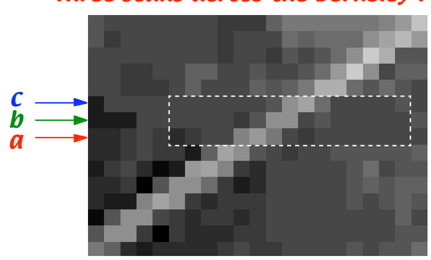


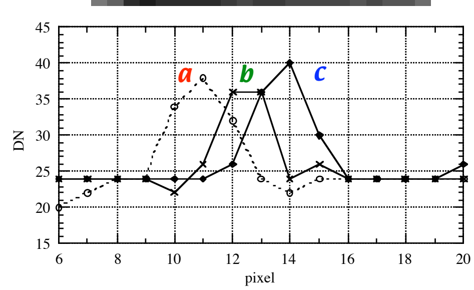
Dependence of detectability on object size and contrast

Sampling

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

Three scans across the Berkeley Pier

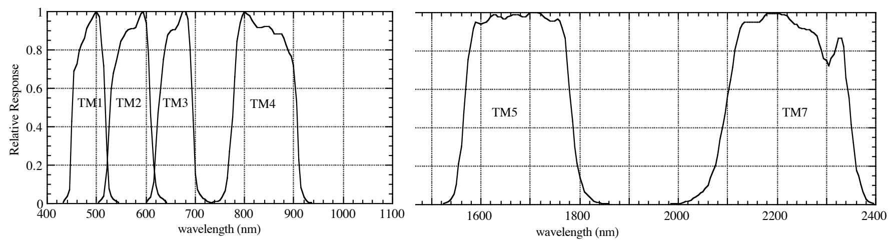




Spectral Response

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

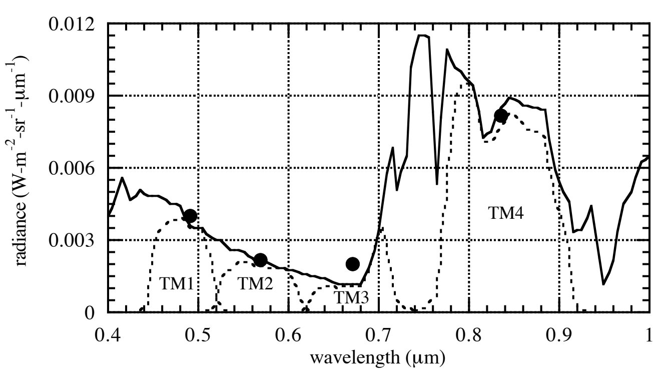
Example spectral response curves - Landsat Thematic Mapper (TM)



Spectral Resolution

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

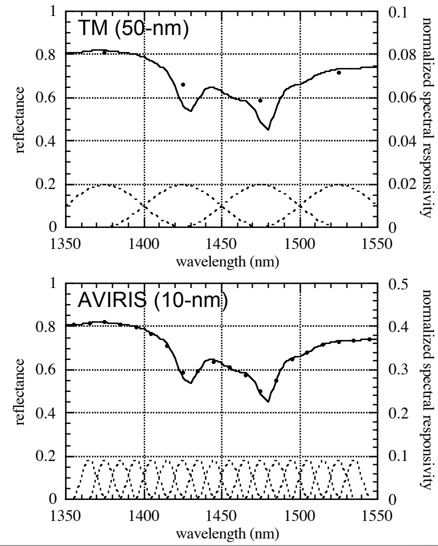
Simulation of TM band measurements of a vegetation spectral signal



Spectral Resolution (cont.)

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

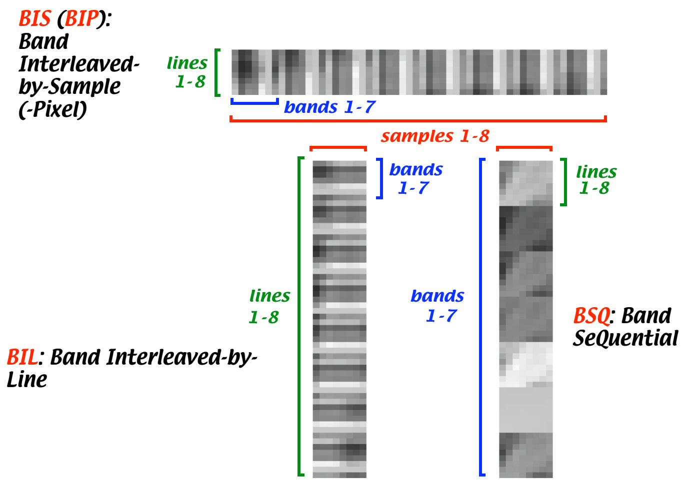
Simulation of spectral doublet measurement with two different spectral resolutions



The Nature of Remote Sensing

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

Image Formats



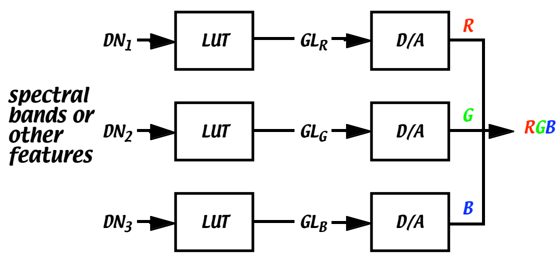
File Formats

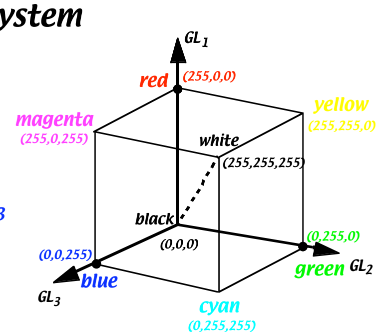
- *raw*
  - *no header*
- *geoTIFF*
  - *variant of TIFF that includes geolocation information in header (http://remotesensing.org/geotiff/geotiff.html)*
- *HDF*
  - *Hierarchical Data Format (http://hdf.ncsa.uiuc.edu/)*
  - *self-documenting, with all metadata required to read an image file contained within the image file*
  - *variable length subfiles*
  - *NASA specific version: EOS-HDF (http://hdf.ncsa.uiuc.edu/hdfeos.html)*
- *NITF*
  - *National Imagery Transmission Format (http://remotesensing.org/gdal/frmt_nitf.html)*
  - *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





RGB color cube

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*

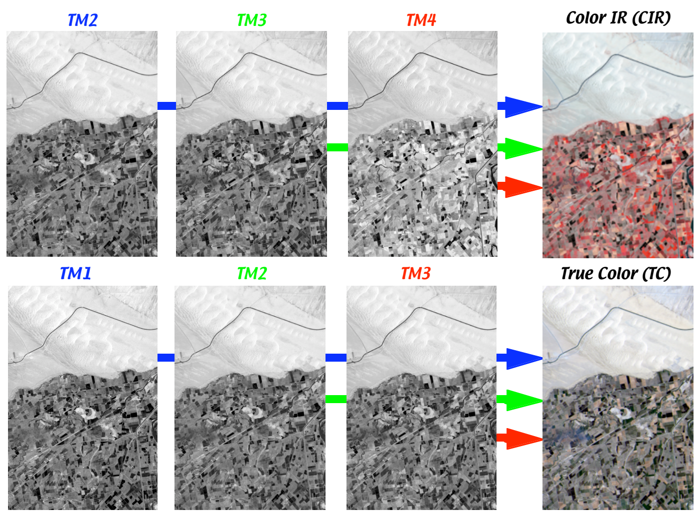
generic composites

Display Color	Color Mode		
	TrueColor (TC)	Color IR (CIR)	False Color
Red (R)	Red	NIR	Any
Green (G)	Green	Red	Any
Blue (B)	Blue	Green	Any

sensor-specific composites

composite	MSS	TM	SPOT	AVIRIS
TC	NA	3,2,1	NA	27,17,7
CIR	4,2,1	4,3,2	3,2,1	51,27,17

Color Composite Example



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!