Remote Sensing 1 – Principles of visible and radar remote sensing & sensors

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Remote sensing glaciologist collecting data
Remote sensing

‘The art and science of gathering information about an object without being in contact with it’
David J. Schneider (Michigan Technological University)

The use of instruments or sensors to ‘capture’ the spectral and spatial relations of objects and materials observable from a distance – typically from above them
Remote sensing – a brief history

1858
- Balloon
- Pigeon camera

1900
- Plane
- Sputnik

1950
- Meteorological Satellites

1970
- Landsat-1

1990
- Landsat-4
- ERS-1

2010
- Space Shuttle
- Commercial Satellites
- Space Station

Chuvieco & Huete, *Fundamentals of Satellite Remote Sensing*
Primary components

A. Energy Source
B. Radiation and Atmosphere
C. Interaction with target
D. Energy recorded by sensor
E. Transmission, reception, processing
F. Interpretation and analysis
G. Application of information
Electromagnetic radiation

- energy derived from oscillating magnetic and electrostatic fields

- Properties include wavelength ($\lambda$) and frequency ($\nu$), related by

$$c = \lambda \nu$$

where $c =$ speed of light (299,893 km s\(^{-1}\)), $\lambda =$ wavelength ($\mu$m), and $\nu =$ frequency (hertz)
Electromagnetic spectrum

(a) Energy sources

(b) Atmospheric transmittance

Human eye
Photography
Thermal scanners
Multispectral scanners
Radar and passive microwave
Electromagnetic spectrum

- Each interval makes up a **band** or **channel** by a colour (if in the visible), a descriptive label (e.g. infrared), or a specified range of wavelengths.
- Subdivisions along the spectrum established for convenience.
- Wavelength measured in m, or some factor (cm, um, nm)
Regions used in RS

- EM spectrum divided into five wavelength bands.

- Most RS operate between wavelengths of 0.1 micrometer to 1 m.

This is the only portion of the spectrum that we can see as colors.
Energy source: sun or object emissions

- reflected solar radiation — PASSIVE (photography, VIR)
- radiation emitted by objects — PASSIVE (thermal IR, passive micro)
- provide own source of energy — ACTIVE (flash photo, radar, lidar)

NIR, SWIR, TIR of Ngozumpa glacier, Nepal (NASA, ASTER)

Oblique view of Russell glacier catchment, West Greenland, from airborne lidar
Surface interactions

radiation is
- absorbed into the target
- passes through the target
- reflects or bounces off the target, and is redirected

reflection depends on texture in comparison to wavelength.

- Specular – smooth surfaces, energy reflected in 1 direction.
- Diffuse – rough surfaces, energy reflected in all directions.
Spectral reflectance signatures

- how much energy is reflected in different areas of the spectrum by the material

Pelikka & Rees, 2010
Types of sensors: whiskbroom (e.g. Landsat)

Across-track scanning (whiskbroom)

Instantaneous field of view (IFOV) = \( \beta \)

\[ D = H \beta \]

(D = diameter of the circular ground area, 
H = flying height)

Lillesand & Kieffer (1999)
Types of sensors: pushbroom (e.g. ASTER, SPOT)
Displacement due to viewing geometry

\[ x' = \frac{fx}{H - z} \]

*H*: distance lens to ground

Displacement of point \( P \) with height \( z \) at distance \( x \) from nadir will be displaced by

\[ \frac{fxz}{H(H - z)} \]

against a point of height 0

Equivalent in ground plane, assuming \( z \ll H \)

\[ d \approx \frac{xz}{H} \]

Rees (2006)
Sensor pointing

Pointing capability

Advantage:
- Higher repeat frequency
- Stereo view capability

Disadvantage:
- Distortions
- Resolution decrease, when pointing

Lillesand & Kieffer (1999)
Orbits and platforms

Polar orbiting
Sun synchronous
Ascending – descending

Every satellite has its distinct orbit / repeat schedule
Satellites do not necessarily acquire all imagery possible

Lillesand & Kieffer (1999)
Orbits and platforms

Lillesand & Kieffer (1999)
Orbits and platforms
Resolution

ability to discriminate information, includes several aspects:

- **SPATIAL**: minimum separation at which objects appear independent and isolated
- **SPECTRAL**: number of sensor bands & associated spectral bandwidths
- **RADIOMETRIC**: how finely system can represent or distinguish differences in intensity (sensitivity, or range of values coded)
- **TEMPORAL**: Observation frequency
Spatial resolution

- Geostationary satellites (~5 km²)
- Polar orbiting meteorological (~1 km²)
- Regional-scale natural resources (~0.1 km²)
- Local-scale natural resources (~100 m²)
- Commercial satellites (~1 m²)

Timeline:
- 1960
- 1970
- 1980
- 1990
- 2000
Spectral resolution

Reflectance(%) vs. Wavelength (μm)

- One band
- Three bands

Band 1
Band 2
Band 3
Band 4
Radiometric resolution

indicates the sensitivity of the sensor

- For digital images, the radiometric resolution refers to the range of values coded by the sensor (number of divisions of bit depth).
- Radiometric resolution has improved over time:
  - Early sensors: 128 values (7 bits)
  - Landsat: 256 values (8 bits)
  - AVHRR: 1024 values (10 bits)
  - IKONOS & Quickbird: 2048 (11 bits)
  - MODIS: 4096 (12 bits)
## Sensors and platforms (visible)

<table>
<thead>
<tr>
<th>Platform / Sensor</th>
<th>Launch</th>
<th>Spatial resolution</th>
<th>Temporal revisit</th>
<th>Spectral resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUICKBIRD-2</td>
<td>2001</td>
<td>0.6 m</td>
<td>1-3 days</td>
<td>PAN, 3 VIS+NIR</td>
</tr>
<tr>
<td>IKONOS</td>
<td>1999</td>
<td>1 m</td>
<td>3 days</td>
<td>PAN, 3 VIS+NIR</td>
</tr>
<tr>
<td>LANDSAT MSS</td>
<td>1972</td>
<td>79x56m</td>
<td>16 days</td>
<td>4 MS</td>
</tr>
<tr>
<td>LANDSAT TM-ETM+</td>
<td>1984-1999-(2003)</td>
<td>15, 30m, 60m</td>
<td></td>
<td>PAN, 6 MS, 1TIR</td>
</tr>
<tr>
<td>TERRAASTER</td>
<td>1999-</td>
<td>15, 30, 90m</td>
<td>16 days</td>
<td>3 VIS/NIR, 6 SWIR, 5 TIR</td>
</tr>
<tr>
<td>SPOT HRV</td>
<td>1984-</td>
<td>20m / 10m</td>
<td>3 days</td>
<td>3 VIS, 1 PAN</td>
</tr>
<tr>
<td>NOAA AVHRR</td>
<td>1982</td>
<td>1100 m</td>
<td>1-2 days</td>
<td>VIS + TIR</td>
</tr>
<tr>
<td>TERRA/AQUA MODIS</td>
<td>1999</td>
<td>250-1000m</td>
<td>1-2 days</td>
<td>VIS + TIR</td>
</tr>
<tr>
<td>ENVISAT MERIS</td>
<td>2002</td>
<td>300 m</td>
<td></td>
<td>16 VIS+SWIR</td>
</tr>
<tr>
<td>ENVISAT (A)ATSR</td>
<td>2002</td>
<td>1000 m</td>
<td>1-2 days</td>
<td>TIR</td>
</tr>
</tbody>
</table>
Common RS systems for observing the cryosphere

- Aerial photography
- Visible and near infra-red
- Thermal infra-red
- Laser ranging
- Radar altimetry
- Passive microwave
- Imaging radar / scatterometry
- Synthetic aperture radar (SAR)
1. Aerial photography

- V-NIR
  - traditionally photochemical (exposure of silver halide crystal ‘grains’ into metallic silver, chemical development = negative)
  - Film = detector
  - Film and filters = spectral response
  - very high geometric fidelity
  - increasingly digital now
2. Electro-optical V-NIR

- spectral range similar to air photos
- digital detection mechanism, calibrated photodiode arrays
- fully digital processing stream
- deployed from aircraft or satellites
- ground resolution limited by detector resolution
- most sensors multispectral, some hyperspectral
- majority image at nadir, some backward / stereo
- FOV from 10s to 1000s of km (typically 50-200 km. e.g. Landsat 7, 185 km.)
2. Electro-optical V-NIR: Landsat
2. Electro-optical V-NIR: SPOT
SPOT stereo capability
2. Electro-optical V-NIR

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
  - 14 bands, backward-looking NIR, 60 km swath, 15-90 m pixel
MODIS - Moderate-resolution Imaging Spectroradiometer
  - 36 bands, lower resolution, rapid response
3. Thermal IR

- thermal (~8 to 14 um) major part of black-body radiation emitted at terrestrial temperatures
- useful for detecting Earth (& sea) surface temperatures
- does not detect reflected sunlight
- does not penetrate clouds
- coarser spatial resolution at longer wavelengths
- ASTER and MODIS have TIR capability
- primary TIR imager Advanced Along-Track Scanning Radiometer (AATSR)
4. Laser ranging (altimetry)

- active ranging device, for measuring Earth surface topography
- NIR pulse emitted, clock started, pulse travels reflects returns, detected by photodiode
- pulse detection stops clock, with propagation speed TWTT means range to surface determined
- extremely high vertical resolution possible
- ICESat 2003-2010, ICESat-2 March 2016
5. Radar altimetry

- conceptually similar to LA (ranging)
- microwave radiation (~10 GHz frequency) – key difference: can observe through clouds
- TWTT and structure of returned pulse (waveform)
- waveform includes surface roughness / scattering information
- dry surface snow can absorb radar energy

- slope-induced error from nadir ($B$) to point of closest return ($A$).
- $0.5^\circ$ slope can give 8 km error in $x,y$ and 40 m in $z$ from space
6. Passive microwave

- detects radiation between wavelengths 3-6 mm (brightness temperature of surface emission)
- able to penetrate through clouds – very useful!
- longer wavelengths detected by beam-scanning antenna: results in coarser resolution data
  - 1 m antenna (wavelength 2 cm) = 14 km resolution.
- spectral resolution low, typical 15-35 GHz
- abrupt backscatter change resulting from phase change of water – snowmelt monitoring
6. Passive microwave sensors

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Satellite</th>
<th>Years</th>
<th>Spatial resolution (km)</th>
<th>Frequency (GHz)</th>
<th>Swath width (km)</th>
<th>Max. latitude (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMMR</td>
<td>Nimbus 7</td>
<td>1978-1988</td>
<td>136 x 89 87 x 57 54 x 35 47 x 30 28 x 18 70 x 45 60 x 40 38 x 30 16 x 14 74 x 43 51 x 30 27 x 16 31 x 18 14 x 8 6 x 4</td>
<td>6.6 10.7 18.0 21.0 37.0 19.35 22.24 37.0 85.5 6.93 10.65 18.7 23.8 36.5 89.0</td>
<td>780</td>
<td>84.2</td>
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<tr>
<td>SSM/I</td>
<td>DMSP</td>
<td>1987-</td>
<td></td>
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<tr>
<td>AMSR/E</td>
<td>Aqua</td>
<td>2002-</td>
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7. Imaging radar

- side-looking or multi-angled antennas to determine angular dependence of backscatter
- ‘real-aperture’ or ‘side-looking’ radar
- active, so independent of illumination, MW so independent of clouds (& atmosphere)
7. Imaging radar: scatterometry

- measures normalised radar cross-section ($\sigma^0$, how ‘detectable’ an object is)
- separate measurement of noise-only power
- subtracted from signal + noise measure to determine backscatter signal power
7. Synthetic Aperture Radar (SAR)

- also side-looking imaging radar
- forward motion of platform used to **synthesize** a very long antenna
- gives much higher ground resolution than imaging radar
- signal amplitude and phase recorded
Weird-looking SAR geometry..
7. Imaging radar: foreshortening

- strange geometry in range direction
- due to measure of signal travel time, not angle
- time delay between echoes determines relative distance in image
- point b relatively closer to antenna
7. Imaging radar: foreshortening

ERS-1

View direction

JERS-1

Look angle: 23°  39°
7. Imaging radar: shadowing
### 7. Imaging radar: SAR sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Wavelength</th>
<th>Spatial res.</th>
<th>Polarization</th>
<th>Repeat cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEASAT SAR</td>
<td>23.5 cm</td>
<td>25 m</td>
<td>HH</td>
<td>unknown</td>
</tr>
<tr>
<td>ERS-1 AMI SAR</td>
<td>5.6 cm</td>
<td>26 m</td>
<td>VV</td>
<td>35-days</td>
</tr>
<tr>
<td>JERS-1 SAR</td>
<td>23.5 cm</td>
<td>24 m</td>
<td>HH</td>
<td>44-days</td>
</tr>
<tr>
<td>RADARSAT-1</td>
<td>5.6 cm</td>
<td>8 – 100 m</td>
<td>HH</td>
<td>24-days</td>
</tr>
<tr>
<td>ERS-2 AMI SAR</td>
<td>5.6 cm</td>
<td>26 m</td>
<td>VV</td>
<td>35-days</td>
</tr>
<tr>
<td>ENVISAT ASAR</td>
<td>5.6 cm</td>
<td>12.5 m – 1 km</td>
<td>single, cross, dual</td>
<td>35-days</td>
</tr>
<tr>
<td>ALOS PALSAR</td>
<td>23.6 cm</td>
<td>7 m – 1 km</td>
<td>single, dual, full</td>
<td>44-days</td>
</tr>
<tr>
<td>RADARSAT-2</td>
<td>5.6 cm</td>
<td>3 – 100 m</td>
<td>single, cross, full</td>
<td>24-days</td>
</tr>
<tr>
<td>TerraSAR-X</td>
<td>3.1 cm</td>
<td>1 – 16 m</td>
<td>single, cross, dual</td>
<td>11-days</td>
</tr>
<tr>
<td>COSMO-Skymed</td>
<td>3.1 cm</td>
<td>1 – 100 m</td>
<td>single, cross</td>
<td>16-days</td>
</tr>
</tbody>
</table>

TanDEM-X (DLR / Infoterra) launched 2010
Cryosat-2 (ESA) launched 2010
Sentinel-1 (ESA) launched 2014
DESDynl (NASA) planning..
Summary

Introduction to remote sensing
- Definitions, brief history, system components
- Radiation and the electromagnetic spectrum
- Energy sources, surface interactions and reflectance signatures
- Common sensor types, geometry and orbits
- Resolution

Remote sensing of the cryosphere
- Introduction to aerial photography,
- electro-optical and thermal systems,
- laser and radar ranging (altimetry),
- passive microwaves,
- imaging radar / SAR