GEOGG141/ GEOG3051
Principles & Practice of Remote Sensing (PPRS)
Spatial & spectral resolution, sampling

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http://www2.geog.ucl.ac.uk/~mdisney/teaching/GEOGG141/
GEOGG141.html
http://www2.geog.ucl.ac.uk/~mdisney/teaching/3051/GEOG3051.html
Lecture outline

• Introduction to RS instrument design
  – radiometric and mechanical considerations
  – resolution concepts
    • spatial, spectral
    • IFOV, PSF
  – Tradeoffs in sensor design
Aims

• Build on understanding of EMR and surface, atmosphere interactions in previous lectures

• Considerations of resolution
  – all types and tradeoffs required

• Mission considerations
  – types of sensor design, orbit choices etc.

• Relationship of measured data to real-world physical properties
Resolution

• What do we mean by “resolution” in RS context
  – OED: the effect of an optical instrument in making the separate parts of an object distinguishable by the eye. Now more widely, the act, process, or capability of rendering distinguishable the component parts of an object or closely adjacent optical or photographic images, or of separating measurements of similar magnitude of any quantity in space or time; also, the smallest quantity which is measurable by such a process.
Resolution

• Even more broadly
• Not just spatial....
  – Ability to separate other properties pertinent to RS
• Spectral resolution
  – location, width and sensitivity of chosen λ bands
• Temporal resolution
  – time between observations
• Radiometric resolution
  – precision of observations (NOT accuracy!)
Spatial resolution

- Ability to separate objects in $x, y$
Spatial resolution v pixel size

- Pixel size does NOT necessarily equate to resolution

10 m resolution, 10 m pixel size

30 m resolution, 10 m pixel size

80 m resolution, 10 m pixel size

10m pixel size, 160x160 pixels

10m pixel size, 80x80 pixels

10m pixel size, 40x40 pixels

10m pixel size, 20x20 pixels

From http://www.crisp.nus.edu.sg/~research/tutorial/image.htm
Spatial resolution

- **Spatial resolution**
  - formal definition: a measure of smallest angular or linear separation between two objects that can be resolved by sensor

- **Determined in large part by Instantaneous Field of View (IFOV)**
  - IFOV is angular cone of visibility of the sensor (A)
  - determines area seen from a given altitude at a given time (B)
  - Area viewed is IFOV * altitude (C)
  - Known as ground resolution cell (GRC) or element (GRE)
Spatial resolution

• Problem with this concept is:
  – Unless height is known IFOV will change
    • e.g. Aircraft, balloon, ground-based sensors
    • so may need to specify (and measure) flying height to determine resolution
  – Generally ok for spaceborne instruments, typically in stable orbits (known h)
  – Known IFOV and GRE
Spatial resolution

Figure 1. Illustration of the geometrical instantaneous field-of-view reconstructed by projection from a pixel in the image plane.
IFOV and ground resolution element (GRE)

GRE = IFOV \times H

where IFOV is measured in radians
Total field of view

Image width = $2 \times \tan\left(\frac{TFOV}{2}\right) \times H$

where TFOV is measured in degrees
IFOV and ground resolution

- Image pixels often idealised as rectangular array with no overlap
- In practice (e.g. MODIS)
  - IFOV not rectangular
  - function of swath width, detector design and scanning mechanism
  - see later....

MODIS home page: http://modis.gsfc.nasa.gov/
Angular resolution

- Ultimately limited by instrument optics
  - diffraction effects
    - bending/spreading of waves when passing through aperture
  - diffraction limit given by Rayleigh criterion
    - \( \sin \theta = 1.22 \frac{\lambda}{D} \), where \( \theta \) is angular resolution; \( \lambda \) is wavelength; \( D \) diameter of lens
  - e.g. MODIS \( D = 0.1778 \text{m}, f = 0.381 \) in SWIR (\( \lambda \approx 900 \times 10^{-9}\text{m} \)) so \( \theta \approx 3.54 \times 10^{-4} \text{°} \). So at orbital altitude, \( h \), of 705km, spatial res \( \approx \theta h \approx 250 \text{m} \)
Aside: digital v Analogue

- **Digital image is a discrete, 2D array recording of target radiometric response**
  - x,y collection of picture elements (pixels) indexed by column (sample) and row (line)
  - pixel value is **digital number** (DN)
  - NOT physical value when recorded - simply response of detector electronics
  - Single value (per band) per pixel, no matter the surface!

- **Analogue image is continuous**
  - e.g. photograph has representation down to scale of individual particles in film emulsion
Point spread function: PSF

- PSF: response of detector to nominal point source
- Idealised case, pixel response is uniform
- In practice, each pixel responds imperfectly to signal
  - point becomes smeared out somewhat

Figure 4. Idealised response function (point spread function).
Point spread function: PSF

- Example PSF of AVHRR (Advanced Very High (!) Resolution Radiometer)
AVHRR IFOV

• Scan of AVHRR instrument
  – elliptical IFOV, increasing eccentricity with scan angle

Figure 5. Sketch of pixel geometry for the AVHRR for adjacent scan lines to illustrate autocorrelation (Breaker 1990).
What’s in a pixel?

- Interesting discussion in Cracknell paper
  - mixed pixel (mixel) problem in discrete representation

If we want to use RS data for anything other than qualitative analysis (pretty pictures) need to know

- sensor spatial characteristics
- sensor response (spectral, geometric)
Examples

- High (10s m to < m)
- Moderate (10s - 100s)
- Low (km and beyond)

Jensen, table 1-3, p13.

<table>
<thead>
<tr>
<th>Suborbital Sensors</th>
<th>Spectral</th>
<th>Spatial (meters)</th>
<th>Temporal (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panchromatic film (b&amp;w)</td>
<td>Blue</td>
<td>0.5</td>
<td>Variable</td>
</tr>
<tr>
<td>Color film</td>
<td>Green</td>
<td>0.4</td>
<td>Variable</td>
</tr>
<tr>
<td>Color-infrared film</td>
<td>Red</td>
<td>0.5</td>
<td>Variable</td>
</tr>
<tr>
<td>NASA Airborne Terrestrial Applications Sensor (ATLAS)</td>
<td>Near-IR</td>
<td>8 bands</td>
<td>2.5 to 25</td>
</tr>
<tr>
<td>NASA Airborne Visible IR Imaging Spectrometer (AVIRIS)</td>
<td>Mid-IR</td>
<td>224 bands</td>
<td>2.5 or 20</td>
</tr>
<tr>
<td>Intermap Star-3i X-band radar</td>
<td>Thermal</td>
<td>2.5</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>Microwave</td>
<td>2.5</td>
<td>Variable</td>
</tr>
<tr>
<td>Satellite Sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-9 AVHRR LAC</td>
<td>—</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>NOAA- K, L, M (proposed)</td>
<td>—</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Landsat Multispectral Scanner (MSS)</td>
<td>—</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Landsat 4-5 Thematic Mapper (TM)</td>
<td>—</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Landsat 7 Enhanced TM (ETM) — Multispectral</td>
<td>—</td>
<td>0.52</td>
<td>0.9 μm</td>
</tr>
<tr>
<td>— Panchromatic</td>
<td>—</td>
<td>0.35</td>
<td>0.73 μm</td>
</tr>
<tr>
<td>SPOT HRV — Multispectral</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>— Panchromatic</td>
<td>—</td>
<td>0.51</td>
<td>0.37 μm</td>
</tr>
<tr>
<td>GOES Series (East and West)</td>
<td>—</td>
<td>0.52</td>
<td>0.72 μm</td>
</tr>
<tr>
<td>European Remote Sensing Satellite (ERS-1,2)</td>
<td>VV polarization C-band (5.3 GHz)</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Canadian RADARSAT (several modes)</td>
<td>HH polarization C-band (5.3 GHz)</td>
<td>1</td>
<td>—</td>
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<tr>
<td>Shuttle Imaging Radar (SIR-C)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)</td>
<td>—</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Terra Moderate Resolution Imaging Spectrometer (MODIS)</td>
<td>—</td>
<td>0.405</td>
<td>36 bands</td>
</tr>
<tr>
<td>Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)</td>
<td>—</td>
<td>0.52</td>
<td>3 bands</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.6 – 6 bands</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.12 – 5 bands</td>
</tr>
<tr>
<td>Terra Multiangle Imaging Spectroradiometer (MISR)</td>
<td>Nine CCD cameras in four bands (440, 550, 670, 860 nm)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>NASA Topex/Poseidon — TOPEX radar altimeter</td>
<td>(18, 21, 37 GHz)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>— POSEIDON single-frequency radiometer</td>
<td>(13.65 GHz)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Space Imaging IKONOS — Multispectral</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>— Panchromatic</td>
<td>—</td>
<td>0.45</td>
<td>0.9 μm</td>
</tr>
<tr>
<td>ORBIMAGE Orbview 3 — Multispectral</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>— Panchromatic</td>
<td>—</td>
<td>0.45</td>
<td>0.9 μm</td>
</tr>
</tbody>
</table>
Low v high spatial resolution?

- **What is advantage of low resolution?**
  - Can cover wider area
  - High res. gives more detail BUT may be too much data
    - Earth’s surface ~ $500 \times 10^6 \text{ km}^2$ ~ $500 \times 10^6 \text{ km}^2$
    - At 10m resolution $5 \times 10^{12}$ pixels (> $5 \times 10^6 \text{ MB per band, min.}$)
    - At 1km, 500MB per band per scene minimum - manageable (ish)
  - OTOH if interested in specific region
    - urban planning or crop yields per field,
    - 1km pixels no good, need few m, but only small area
- **Tradeoff** of coverage v detail (and data volume)

From http://modis.gsfc.nasa.gov/about/specs.html
Spectral resolution

• **Measure of wavelength discrimination**
  – Measure of smallest spectral separation we can measure
  – Determined by sensor design
    • detectors: CCD semi-conductor arrays
    • Different materials different response at different $\lambda$
    • e.g. AVHRR has 4 different CCD arrays for 4 bands
  – In turn determined by sensor application
    • visible, SWIR, IR, thermal??
Remember atmospheric “windows”?
Spectral resolution

• Characterised by full width at half-maximum (FWHM) response
  – bandwidth > 100nm
  – but use FWHM to characterise:
  – 100nm in this case

Multispectral concept

- Measure in several (many) parts of spectrum
  - Exploit physical properties of spectral reflectance (vis, IR)
  - Emissivity (thermal) to discriminate cover types

Spectral information: vegetation

- Leaf pigments
- Cell structure
- Water content

Dominant factor controlling leaf reflectance

Primary absorption bands

Chlorophyll absorption

Water absorption

Reflectance [%]

Wavelength (µm)

Visible
Near-Infrared
Shortwave Infrared

Blue
Green
Red
Broadband & narrowband

• AVHRR 4 channels, 2 vis/NIR, 2 thermal
  – broad bands hence less spectral detail

From http://modis.gsfc.nasa.gov/about/specs.html
Broadband & narrowband

- **SPOT-HRVIR**
  - another broad-band instrument

From http://spot4.cnes.fr/spot4_gb/hrvir.htm
Broadband & narrowband

• **CHRIS-PROBA**
  - Compact Hyperspectral Imaging Spectrometer
  - Project for Onboard Autonomy
  - Many more, narrower bands
  - Can select bandsets we require

From http://www.chris-proba.org.uk
Broadband & narrowband

- **CHRIS-PROBA**
  - different choice
  - for water applications
  - coastal zone colour studies
  - phytoplankton blooms

From http://www.chris-proba.org.uk
Aside: signal to noise ratio (SNR)

- Describes sensitivity of sensor response
  - ratio of magnitude of useful information (signal) to magnitude of background noise S:N
  - All observations contain inherent instrument noise (stray photons) as well as unwanted signal arising from atmos. scattering say)
  - 5:1 and below is LOW SNR. Can be 100s or 1000s:1
  - SNR often expressed as log dB scale due to wide dynamic range
    - e.g. $20 \log_{10}(\text{signal}_\text{power}/\text{noise}_\text{power})$ dB
Aside: signal to noise ratio

- Vegetation spectra measured using 2 different instruments
  - LHS: Si detector only, note noise in NIR
  - RHS: combination of Si, InGaAs and CdHgTe
  - Note discontinuities where detectors change (~1000 and 1800nm)
Multispectral concept

• MODIS: 36 bands, but not contiguous
  – Spatial Resolution: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36)
  – Why the difference across bands??
    • bbody curves for reflected (vis/NIR) & emitted (thermal)

From http://modis.gsfc.nasa.gov/about/specs.html
MODIS (vis/NIR)

<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth</th>
<th>Spectral Radiance</th>
<th>Required SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land/Cloud/Aerosols Boundaries</strong></td>
<td>1</td>
<td>620 - 670</td>
<td>21.8</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>841 - 876</td>
<td>24.7</td>
<td>201</td>
</tr>
<tr>
<td><strong>Land/Cloud/Aerosols Properties</strong></td>
<td>3</td>
<td>459 - 479</td>
<td>35.3</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>545 - 565</td>
<td>29.0</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1230 - 1250</td>
<td>5.4</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1628 - 1652</td>
<td>7.3</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2105 - 2155</td>
<td>1.0</td>
<td>110</td>
</tr>
<tr>
<td><strong>Ocean Color/Phytoplankton/Biogeochemistry</strong></td>
<td>8</td>
<td>405 - 420</td>
<td>44.9</td>
<td>880</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>438 - 448</td>
<td>41.9</td>
<td>838</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>483 - 493</td>
<td>32.1</td>
<td>802</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>526 - 536</td>
<td>27.9</td>
<td>754</td>
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<tr>
<td></td>
<td>12</td>
<td>546 - 556</td>
<td>21.0</td>
<td>750</td>
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<tr>
<td></td>
<td>13</td>
<td>662 - 672</td>
<td>9.5</td>
<td>910</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>673 - 683</td>
<td>8.7</td>
<td>1087</td>
</tr>
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<td></td>
<td>15</td>
<td>743 - 753</td>
<td>10.2</td>
<td>586</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>862 - 877</td>
<td>6.2</td>
<td>516</td>
</tr>
<tr>
<td><strong>Atmospheric Water Vapor</strong></td>
<td>17</td>
<td>890 - 920</td>
<td>10.0</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>931 - 941</td>
<td>3.6</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>915 - 965</td>
<td>15.0</td>
<td>250</td>
</tr>
</tbody>
</table>

From http://modis.gsfc.nasa.gov/about/specs.html
# MODIS (thermal)

<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth</th>
<th>Spectral Radiance</th>
<th>Required NE[delta]T(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface/Cloud Temperature</td>
<td>20</td>
<td>3.660 - 3.840</td>
<td>0.45(300K)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>3.929 - 3.989</td>
<td>2.38(335K)</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>3.929 - 3.989</td>
<td>0.67(300K)</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>4.020 - 4.080</td>
<td>0.79(300K)</td>
<td>0.07</td>
</tr>
<tr>
<td>Atmospheric Temperature</td>
<td>24</td>
<td>4.433 - 4.498</td>
<td>0.17(250K)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>4.482 - 4.549</td>
<td>0.59(275K)</td>
<td>0.25</td>
</tr>
<tr>
<td>Cirrus Clouds Water Vapor</td>
<td>26</td>
<td>1.360 - 1.390</td>
<td>6.00</td>
<td>150(SNR)</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>6.535 - 6.895</td>
<td>1.16(240K)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>7.175 - 7.475</td>
<td>2.18(250K)</td>
<td>0.25</td>
</tr>
<tr>
<td>Cloud Properties</td>
<td>29</td>
<td>8.400 - 8.700</td>
<td>9.50(300K)</td>
<td>0.05</td>
</tr>
<tr>
<td>Ozone</td>
<td>30</td>
<td>9.580 - 9.880</td>
<td>3.69(250K)</td>
<td>0.25</td>
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<tr>
<td>Surface/Cloud Temperature</td>
<td>31</td>
<td>10.780 - 11.280</td>
<td>9.55(300K)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>11.770 - 12.270</td>
<td>8.94(300K)</td>
<td>0.05</td>
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<tr>
<td>Cloud Top Altitude</td>
<td>33</td>
<td>13.185 - 13.485</td>
<td>4.52(260K)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>13.485 - 13.785</td>
<td>3.76(250K)</td>
<td>0.25</td>
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<tr>
<td></td>
<td>35</td>
<td>13.785 - 14.085</td>
<td>3.11(240K)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>14.085 - 14.385</td>
<td>2.06(220K)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

1 Bands 1 to 19 are in nm; Bands 20 to 36 are in μm
2 Spectral Radiance values are (W/m² -μm-sr)
3 SNR = Signal-to-noise ratio
4 NE(delta)T = Noise-equivalent temperature difference

**Note:** Performance goal is 30-40% better than required

From [http://modis.gsfc.nasa.gov/about/specs.html](http://modis.gsfc.nasa.gov/about/specs.html)
MODIS: fires over Sumatra, Feb

- Use thermal bands to pick fire hotspots
  - brightness temperature much higher than surrounding

From http://visibleearth.nasa.gov/cgi-bin/viewrecord?12163
ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
- on Terra platform, 90m pixels, both night-time images

From http://visibleearth.nasa.gov/cgi-bin/viewrecord?8160
Thermal imaging (~10-12\(\mu\)m)

From http://www.ir55.com/infrared_IR_camera.html
Multi/hyperspectral

- **Multispectral**: more than one band
- **Hyperspectral**: usually > 16 contiguous bands
  - $x, y$ for pixel location, “$z$” is $\lambda$
  - e.g. AVIRIS “data cube” of 224 bands
  - AVIRIS (Airborne Visible and IR Imaging Spectroradiometer)

Multi/hyperspectral

- AVIRIS
Multi/hyperspectral

- AVIRIS

Measured spectra from AVIRIS data

From http://www.fas.org/irp/imint/docs/rst/Intro/Part2_24.html
## Multi/hyperspectral

<table>
<thead>
<tr>
<th>Satellite Sensors</th>
<th>Manufacturer</th>
<th>Number of Bands</th>
<th>Spectral Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTHSI on MightySat II</td>
<td>Air Force Research Lab</td>
<td>256</td>
<td>0.35 to 1.05 μm</td>
</tr>
<tr>
<td>Hyperion on EO-1</td>
<td>NASA Goddard Space Flight Center</td>
<td>220</td>
<td>0.4 to 2.5 μm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airborne Sensors</th>
<th>Manufacturer</th>
<th>Number of Bands</th>
<th>Spectral Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVIRIS (Airborne Visible Infrared Imaging Spectrometer)</td>
<td>NASA Jet Propulsion Lab</td>
<td>224</td>
<td>0.4 to 2.5 μm</td>
</tr>
<tr>
<td>HYDICE (Hyperspectral Digital Imagery)</td>
<td>Naval Research Lab</td>
<td>210</td>
<td>0.4 to 2.5 μm</td>
</tr>
</tbody>
</table>
## Multi/hyperspectral

<table>
<thead>
<tr>
<th>Collection</th>
<th>Sensor</th>
<th>Number of bands</th>
<th>Wavelength range</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBE-I</td>
<td>Earth Search Sciences Inc.</td>
<td>128</td>
<td>0.4 to 2.5 μm</td>
</tr>
<tr>
<td>CASI</td>
<td>ITRES Research Limited</td>
<td>up to 228</td>
<td>0.4 to 1.0 μm</td>
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<td>HyMap</td>
<td>Integrated Spectronics</td>
<td>100 to 200</td>
<td>Visible to thermal infrared</td>
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<td>EPS-H</td>
<td>GER Corporation</td>
<td>VIS/NIR (76), SWIR1 (32), SWIR2 (32), TIR (12)</td>
<td>VIS/NIR (0.4 to 0.5 μm), SWIR1 (1.5 to 2.5 μm), SWIR2 (2.0 to 2.5 μm), TIR (8.7 to 12.5 μm)</td>
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<tr>
<td>DAIS 7915</td>
<td>GER Corporation</td>
<td>VIS/NIR (32), SWIR1 (8), SWIR2 (32), MIR (1), TIR (6)</td>
<td>VIS/NIR (0.4 to 0.5 μm), SWIR1 (1.5 to 2.5 μm), SWIR2 (2.0 to 2.5 μm), MIR (3.9 to 5.9 μm), and TIR (8.7 to 12.5 μm)</td>
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<td>DAIS 21115</td>
<td>GER Corporation</td>
<td>VIS/NIR (76), SWIR1 (64), SWIR2 (64), MIR (1), TIR (6)</td>
<td>VIS/NIR (0.4 to 1.0 μm), SWIR1 (1.5 to 1.8 μm), SWIR2 (2.0 to 2.5 μm), MIR (3.9 to 5.9 μm), and TIR (8.7 to 12.5 μm)</td>
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<tr>
<td>AISA</td>
<td>Spectral Imaging Ltd</td>
<td>up to 288</td>
<td>0.42 to 1.0 μm</td>
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<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Sponsoring Agencies</th>
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<td>ARIES-I</td>
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<td>Auspace Ltd, ACRES, Earth Resource Mapping Pty. Ltd., Geomage Pty. Ltd., CSIRO</td>
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<td>CHRIS</td>
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<td>NEMO</td>
<td>COIS</td>
<td>Space Technology Development Corporation, Naval Research Laboratory</td>
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<td>PRISM</td>
<td></td>
<td>European Space Agency</td>
</tr>
</tbody>
</table>
Examples

- Some panchromatic (single broad bands)
- Many multispectral
- A few hyperspectral

Jensen, table 1-3, p13.
Broadband v narrowband?

• **What is advantage of broadband?**
  – Collecting radiation across broader range of $\lambda$ per band, so more photons, so more energy
  – Narrow bands give more spectral detail BUT less energy, so lower signal (lower SNR)
  – More bands = more information to store, transmit and process
  – BUT more bands enables discrimination of more spectral detail

• **Trade-off again**
The Sentinel Era: 2014-

• Part of Copernicus programme (GMES as was)
  – “…accurate, timely, easily accessible information to improve management of the environment, understand/mitigate climate change and ensure civil society”

• Sentinel missions will service these requirements
  • MULTIPLE missions to improve temporal sampling and reliability
  • S1A, B (6/2014, 2015) C-band RADAR mapping
  • S5: 2020 Atmospheric, S5-P (2016) to provide continuity with Envisat instruments

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4
Sentinel 1: Orbits, swaths, payload

ESA'S RADAR OBSERVATORY MISSION FOR COPERNICUS OPERATIONAL SERVICES

SATELLITE PAYLOAD

**C-Band SAR**
- Centre frequency: 5.405 GHz
- Polarisation: VV+VH,HH+HV
- Incidence angle: 20° - 45°
- Radiometric accuracy: 1 dB (3σ)
- NESZ: -22 dB
- DTAR: -22 dB
- PTAR: -25 dB

Four nominal operational modes designed for inter-operability with other systems:
- Strip Map Mode with 80 km swath and 5x5 m (range x azimuth) spatial resolution
- Interferometric Wide-Swath Mode with 250 km swath, 5x20 m (range x azimuth) spatial resolution and burst synchronisation for interferometry
- Extra-Wide-Swath Mode with 400 km swath and 20x40 m (range x azimuth) spatial resolution
- Wave Mode with 5x5 m (range x azimuth) spatial resolution leap-frog sampled images of 20x20 km at 100 km along the orbit, with alternating 23° and 36.5° incidence angles.
Sentinel 2: Orbits, swaths, payload

THE OPERATIONAL COPERNICUS OPTICAL HIGH RESOLUTION LAND MISSION

MISSION OBJECTIVES

European wide-swath high-resolution twin satellites super-spectral imaging mission designed for data continuity & enhancement of Landsat and SPOT-type missions, > land cover, usage and change-detection-maps
> geophysical variable maps (leaf chlorophyll content, leaf water content, leaf area index, etc.)

SATELLITE PAYLOAD

MSI (Multi Spectral Instrument)
> Imaging principle: filter based push broom imager
> Telescope design: Three mirror anastigmatic telescope with Silicon Carbide mirrors and structure, and dichroic beam splitter to separate VNIR and SWIR spectral channels
> Focal plane arrays: Si CMOS VNIR detectors, HgCdTe SWIR detectors, passively cooled (190 K)
> Electronics: front end, video and compression electronics, including state-of-the-art wavelet-based data compression
> Combination of on-board absolute calibration with a solar diffuser covering the full FoV, dark calibration over ocean at night, and vicarious calibration over ground targets
> 13 spectral bands: 443 nm–2190 nm (including 3 bands for atmospheric corrections)
> Spectral resolution: 15 nm–180 nm
> Spatial resolution: 10 m, 20 m and 60 m
> Swath: 290 km
> Radiometric resolution/accuracy: 12 bit / < 5%
Sentinel 2: Orbits, swaths, payload

**MISSION OBJECTIVES**

European global land and ocean monitoring mission. It provides 2 day global coverage Earth observation data (with 2 satellites) for sea and land applications with real-time products delivery in less than 3 hours.

**SATELLITE PAYLOAD**

**OLCI** (Ocean and Land Colour Instrument)
- Swath width: 1270 km, with 5 tilted cameras
- Spatial sampling: 300 m @ SSP
- Spectrum: 21 bands [0.4-1.02] μm
- Radiometric accuracy: 2% abs, 0.1% rel

**SLSTR** (Sea and Land Surface Temperature Radiometer)
- Swath width: dual view scan, 1420 km (nadir) / 750 km (backwards)
- Spatial sampling: 500 m (VIS, SWIR), 1 km (MWIR, TIR)
- Spectrum: 9 bands [0.55-12] μm
- Noise equivalent dT: 50 mK (TIR) at 270K

**SRAL** (Sentinel-3 Ku/C Radar Altimeter)
- Radar measurement modes: LRM and SAR
- Tracking modes: closed and open-loop
- Pulse repetition frequency: 1.9 KHz (LRM), 17.8 KHz (SAR)
- Total range error: 3 cm

**MWR** (MicroWave Radiometer)
- dual 23.8/36.5 GHz
- Radiometric accuracy 3K absolute (0.6 K relative)

**POD** (Precise Orbit Determination)
- GPS, LRR and DORIS (3 cm final accuracy after processing)
Summary

- Angular, temporal, spectral resolution
  - Function of orbit, swaths etc.
  - Optimised for mission requirements
  - Sentinels exemplify approach of **MULTIPLE** platforms
  - Allows for higher spatial/temporal resolution and/or reliability
  - Provide continuity of older missions
    - eg OLCI & SLSTR on S2 for MERIS & AATSR, S5-P for SCIAMACHY
    - May need to compromise on spectral, spatial BUT continuity vital (see Essential Climate Variables ECVs)