Remote Sensing Platforms

1. Optical Platforms

- LANDSAT
- SPOT

LANDSAT
- Designed by NASA to provide regular near global earth coverage
- Orbits are near polar, sun synchronous
- Repeat cycles: 14 orbits each day; revisits every 16 to 18 days
- Whiskbroom sensor

LANDSAT 1, 2, 3 - Payload
- RBV (Return Beam Vidicon):
  - Blue/green, red, IR bands (Bands 1, 2, 3)
  - 80 m resolution
  - Single instantaneous picture
  - High cartographic accuracy
- MSS (Multispectral Sensor):
  - First global digital multispectral images
  - Blue/green (0.5-0.6), red (0.6-0.7), and near IR (0.7-0.8)
  - 6 bit data
LANDSAT 4, 5

- Designed to travel 8 days out of phase so that coverage is available at least every 8 days
- Payload
  - MSS scanner (as for Landsat 1, 2, 3)
  - TM (thematic mapper): improvement over MSS; scanning mirror, 8 bit data; captures data in both directions of oscillating mirror

LANDSAT 6, 7

- LANDSAT 6 – launched October, 1993
  - Did not achieve orbit
- LANDSAT 7
  - Payload: Enhanced Thematic Mapper Plus (ETM+)
  - ETM+: 8 channels in total

ETM+ Channels (μm)

1) 0.45 - 0.52, 30m
2) 0.52 - 0.60, 30m
3) 0.63 - 0.69, 30m
4) 0.76 - 0.90, 30m
5) 1.55 - 1.75, 30m
6) 10.4 - 12.5, 60m
7) 2.08 - 2.35, 30m
8) 0.50 - 0.90, 15m

Araona Crater

- Suspected crater impact; Amazon forest region
- 8 km wide; 3 m deep
- Occurred ~20,000 years ago
**SPOT (Satellite Pour l’Observation de la Terre)**

- Joint venture between France, Sweden, and Germany
- First commercial remote sensing satellite
- Carried pair of sensors to view either side
- Used pushbroom technology (a satellite first!)
- Repeat pattern of 26 days; pointable optics allow same area to be viewed every 4 or 5 days (different angles)
- Near polar, sun synchronous
- Altitude: 832 km; Period: 101 minutes

**SPOT Satellites Launched**

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launch Date</th>
<th>Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPOT 1</td>
<td>Feb/86</td>
<td>Decommissioned: 12/31/90</td>
</tr>
<tr>
<td>SPOT 2</td>
<td>Jan/90</td>
<td>Still Operational (mostly!)</td>
</tr>
<tr>
<td>SPOT 3</td>
<td>Sept/93</td>
<td>Stopped Functioning 1996</td>
</tr>
<tr>
<td>SPOT 4</td>
<td>Mar/98</td>
<td>Still Operational</td>
</tr>
<tr>
<td>SPOT 5</td>
<td>May/2002</td>
<td>Still Operational</td>
</tr>
</tbody>
</table>

**SPOT Payload**

- Both multispectral (20x20 m) and panchromatic (10x10 m) modes
- Dynamic range of 8 bits
- Swath of 60 km
- Unable to sense in upper-mid and thermal IR ranges (CCD limitation)

**SPOT Example**

- 10 metre panchromatic SPOT image
- Agricultural fields in a gridded format
  - A. Crop in mid-harvest
  - B. Bowtie: combine patterns
  - C. Surface salt (use of ground water irrigation)

**2. Meteorological (Weather) Satellites**

- Operate in VIR
- Primary purpose: weather prediction and monitoring
- Difference from earth resource satellites? Resolution on order of kms as opposed to 10 or 100s of metres
- Consider two here: AVHRR and GEOS

**AVHRR**

- AVHRR – Advanced Very High Resolution Radiometer
- Resolution of 1.1 km (at best)
- Can download in real-time, or store onboard and transmit at a later time
- Also used to monitor ocean temperatures, snow cover, flood monitoring, regional soil moisture, wildfire mapping, fire detection, volcanic eruptions, etc.
AVHRR – Temporal Coverage

<table>
<thead>
<tr>
<th>Number</th>
<th>Date</th>
<th>Node</th>
<th>Node</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIROS-N</td>
<td>10/13/78</td>
<td>1500</td>
<td>0300</td>
<td>01/30/80</td>
</tr>
<tr>
<td>NOAA-6</td>
<td>06/27/79</td>
<td>1930</td>
<td>0730</td>
<td>11/16/86</td>
</tr>
<tr>
<td>NOAA-7</td>
<td>06/23/81</td>
<td>1430</td>
<td>0230</td>
<td>06/07/86</td>
</tr>
<tr>
<td>NOAA-8</td>
<td>03/28/83</td>
<td>1930</td>
<td>0730</td>
<td>10/21/85</td>
</tr>
<tr>
<td>NOAA-9</td>
<td>12/12/84</td>
<td>1420</td>
<td>0220</td>
<td>05/11/94</td>
</tr>
<tr>
<td>NOAA-10</td>
<td>09/17/86</td>
<td>1930</td>
<td>0730</td>
<td>Present</td>
</tr>
<tr>
<td>NOAA-11</td>
<td>09/24/88</td>
<td>1340</td>
<td>0140</td>
<td>09/13/94</td>
</tr>
<tr>
<td>NOAA-12</td>
<td>05/14/91</td>
<td>1930</td>
<td>0730</td>
<td>12/10/94</td>
</tr>
<tr>
<td>NOAA-13</td>
<td>05/13/92</td>
<td>1340</td>
<td>0140</td>
<td>Present</td>
</tr>
<tr>
<td>NOAA-14</td>
<td>05/15/93</td>
<td>1930</td>
<td>0730</td>
<td>Present</td>
</tr>
<tr>
<td>NOAA-15</td>
<td>05/15/94</td>
<td>1930</td>
<td>0730</td>
<td>Present</td>
</tr>
<tr>
<td>NOAA-16</td>
<td>05/14/95</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-17</td>
<td>06/24/96</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA-18</td>
<td>05/20/97</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


AVHRR – Spectral Range

<table>
<thead>
<tr>
<th>Band</th>
<th>Satellites:</th>
<th>Satellites:</th>
<th>IFOV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOAA-6,8,10</td>
<td>NOAA-7,9,11,12,14,15</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.58 - 0.68</td>
<td>0.58 - 0.68</td>
<td>1.39</td>
</tr>
<tr>
<td>2</td>
<td>0.725 - 1.10</td>
<td>0.725 - 1.10</td>
<td>1.41</td>
</tr>
<tr>
<td>3</td>
<td>3.55 - 3.93</td>
<td>3.55 - 3.93</td>
<td>1.51</td>
</tr>
<tr>
<td>4</td>
<td>10.50 - 11.50</td>
<td>10.3 - 11.3</td>
<td>1.41</td>
</tr>
<tr>
<td>5</td>
<td>band 4 repeated</td>
<td>11.5 - 12.5</td>
<td>1.30</td>
</tr>
</tbody>
</table>

(μmeters) (μmeters) (milliradians)

GOES – Geostationary Operational Environmental Satellite

- Satellites launched by NOAA / NASA work in concert with similar satellites launched by USSR, ESA and Japan
- Provide geostationary coverage ie. Orbiting around ~36,000 km
- Resolution varies as a function of wavelength

GOES Imager Characteristics

<table>
<thead>
<tr>
<th>Band (μm)</th>
<th>Spatial Resolution at Nadir (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55 – 0.75</td>
<td>1</td>
</tr>
<tr>
<td>3.80 – 4.00</td>
<td>4</td>
</tr>
<tr>
<td>6.50 – 7.00</td>
<td>8</td>
</tr>
<tr>
<td>10.20 – 11.20</td>
<td>4</td>
</tr>
<tr>
<td>11.50 – 12.50</td>
<td>4</td>
</tr>
</tbody>
</table>
3. Passive Microwave Radiometers

- SSM/I
- TMI (Tropical Rainfall Measuring Mission) (N/A)
- AMSR (Advanced Microwave Scanning Radiometer) (N/A)

SSM/I (Special Sensor Microwave / Imager)

- Measures emissivity (passive sensor)
- Polarized receptions (V or H)
- Conical scan
- Swath: 1400km

SSM/I Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency (GHz)</th>
<th>Resolution (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19V</td>
<td>19.35</td>
<td>70x45</td>
</tr>
<tr>
<td>19H</td>
<td>19.35</td>
<td>70x45</td>
</tr>
<tr>
<td>22V</td>
<td>22.235</td>
<td>60x40</td>
</tr>
<tr>
<td>37V</td>
<td>37.0</td>
<td>38x30</td>
</tr>
<tr>
<td>37H</td>
<td>37.0</td>
<td>38x30</td>
</tr>
<tr>
<td>85V</td>
<td>85.5</td>
<td>16x14</td>
</tr>
<tr>
<td>85H</td>
<td>85.5</td>
<td>16x14</td>
</tr>
</tbody>
</table>

SSM/I Data Products

- Raw data converted into sensor data records (SDRs) and environmental data records (EDRs)
- SDRs: calibrated, ground referenced, antenna pattern corrected brightness temperatures
- SDRs used to compute EDRs
- EDRs: quantitative parameters eg. Cloud water, rain rate, surface wind, soil moisture, sea ice information, water vapour content, precipitation amount
SSM/I SDR Example

- Based on “brightness temperature” i.e. emissivity
- Siberia in December
- Land should be “colder” than open ocean, but not in the 19GHz range i.e. Land has higher emissivity

SSM/I EDR Example

- Derived wind velocities using multiple SSM/I bands
- Experimentally derived equation to generate wind speeds

SSM/I Antarctica Temporal Sea Ice Concentrations

- Jan/96 to Dec/96 progressive changes in sea ice concentrations
- Red/Blue: highest/lowest ice concentrations

4. Active Radar Platforms

- SEASAT
- ERS-1, ERS-2
- RADARSAT

Seasat

- First satellite carrying SAR sensor
- Launched 1978; failed 99 days later
- Also carried a radar altimeter, scatterometer, microwave radiometer, and VIR radiometer
- SAR operated at 1.275 GHz (L-band, 23.5 cm) to generate a 100km swath at 25m resolution
- Nominal incidence angle of 20 degrees

SEASAT - Satellite Platform
**Variation of SAR Incidence Angle**
- Large look angles, such as SIR-A’s 47° degrees, reduce the effect of topography and enhance the sensitivity to surface roughness (top).
- SAR imaging radars with small look angles, such as SEASAT, enhance the topography at the expense of surface roughness (bottom).

**SEASAT - Coregistration**
- LANDSAT alone in dark red in top right
- SEASAT and LANDSAT coregistered elsewhere
- Note enhanced relief in coregistered region

**SEASAT: L-band penetration**
- Sediment deposits at mouth of Kuskokwim River (southwest Alaska) captured by penetration of L-band signal into the water

**ERS-1, ERS-2**
- ERS-1 launched in 1991; ERS-2 launched 1995
- Each carried the following major instruments:
  - Active Microwave Instrument (AMI) (includes a SAR)
  - Radar Altimeter (RA)
  - Along-Track Scanning Radiometer (ATSR)
  - Global Ozone Monitoring Experiment (GOME – ERS-2 only)
ERS-1, ERS-2 SAR

- C-band sensor, VV mode
- Steep, fixed angle of incidence (23 degrees)
- Resolution: 30 m
- Swath: 80 – 100 m
- Sun synchronous, near polar, near circular orbit

ERS-1 Versus RADARSAT

RADARSAT-1

- Canadian owned and operated SAR satellite
- Operates in C-band (5.6 cm; 5.3 GHz), HH
- Launched in 1995; expected lifespan of 5 years
- Designed to support timely data delivery
- Scenes commercially available for $3,000 U.S.

RADARSAT-1 Imaging Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Nominal Resolution (m)</th>
<th>No. of Positions/Beams</th>
<th>Swath Width (km)</th>
<th>Incidence Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>8</td>
<td>15</td>
<td>45</td>
<td>37 - 47</td>
</tr>
<tr>
<td>Standard</td>
<td>30</td>
<td>7</td>
<td>100</td>
<td>20 - 49</td>
</tr>
<tr>
<td>Wide</td>
<td>30</td>
<td>3</td>
<td>150</td>
<td>20 - 45</td>
</tr>
<tr>
<td>ScanSAR Narrow</td>
<td>50</td>
<td>2</td>
<td>300</td>
<td>20 - 49</td>
</tr>
<tr>
<td>ScanSAR Wide</td>
<td>100</td>
<td>2</td>
<td>500</td>
<td>20 – 49</td>
</tr>
<tr>
<td>Extended (H)</td>
<td>18 – 27</td>
<td>3</td>
<td>75</td>
<td>52 – 58</td>
</tr>
<tr>
<td>Extended (L)</td>
<td>30</td>
<td>1</td>
<td>170</td>
<td>10 - 22</td>
</tr>
</tbody>
</table>
**RADARSAT-1 – Glacier Ice Movement**
- Ice motion on Antarctica glacier
- Variations in velocities can be determined using repeat coverages of the same area

**RADARSAT-1 – Ship Detection**
- "Ocean Monitoring Workstation", produced at the CCRS, is an automated system that uses RADARSAT to locate ships

**RADARSAT-1 – Rice Crop Monitoring**
- False colour composite RADARSAT imagery
- Combined one standard and two fine mode images

**RADARSAT-1 Oil Spill Monitoring**
- Oil floats on water creating a smoother surface than surrounding water

**RADARSAT-1 – Flood Monitoring**
- Red River, MN
- Smooth, standing water appears dark (A)
- Brighter areas are not flooded
- Corner reflectors (trees and water) appear at (B)
- Town of Morris not flooded (E)
SAR Sea Ice Classification

- Why? Navigation and environmental monitoring
- "Holy Grail" of Remote Sensing/Computer Vision problems
- Many scientists have tried to find solutions
- Problems? Speckle, incidence angle, ice variations, insufficient resolution, need to account for tone, texture, and shape (just like the operator!)
**RADARSAT-2 Imaging Modes**

- More frequent revisits
- Faster response to emergency situations

**RADARSAT 2: Right and Left Looking**

**RADARSAT-2 HH vs HV**

**Satellite Gravimetry**

- GRACE: Gravity Recovery and Climate Experiment (launch 2002)
- Two identical satellites separated by ~220km along track
- Slides courtesy of Prof. Fotopoulos (U. of Toronto)

**GRACE - Payload**

- Accelerometers
- GPS receivers
- Laser corner-cube reflector assembly
- Two STAR Cameras
- Litton Gyro and actuators
- K-band microwave ranging

- Detect non-gravitational acceleration acting on SVs and remove from satellite-to-satellite distance
- 24 dual frequency channels
- Precise time tagging of the measurements for inter-SV range change
- Absolute positions of SV
- Enables tracking by ground based lasers
- 3-axis stabilized, nearly Earth-pointed orientation so that K-band antennas are pointed precisely at each other
- For inter-satellite tracking
Earth’s gravity field reflects the composition and structure of the planet.

Changes in the gravity field are caused by the redistribution of mass within the Earth and water mass or above its surface (atmosphere).

Observations of spatio-temporal variations in Earth’s gravity field place constraints on models of global mass variability and temporal exchange among the land, ocean and atmosphere.

Earth’s global gravity field described in terms of the shape of the geoid (equipotential surface roughly approximating MSL over oceans).

- GRACE travels over areas of snow & ice sheets
- change in mass/ground recorder
- combine with in-situ measurements & other data
- determine if areas are growing/shrinking
- input for climate change and sea level change

GRACE: Water, Ice and Snow

GRACE Measurements Show Mass Loss in Greenland
- Ice mass loss in Greenland observed from GRACE (2002-2005)
- contributes to 0.4mm/yr to global sea level rise

The End

Good luck on your final exams!