Environmental Science from Satellites (emphasizing snow)

Jeff Dozier, UCSB
Radiation principles, for passive remote sensing

- Sun (5800K)
- Earth (288K)
- Scaled for Earth-Sun Distance

Radiance, $Wm^{-2} \mu m^{-1} sr^{-1}$ vs Wavelength, $\mu m$
Atmospheric absorption of solar and infrared radiation

NASA Goddard Institute for Space Studies
http://www.giss.nasa.gov
Gulf Stream temperatures from MODIS, May 2, 2001
Measurement scale constrained by physics and technology (and money)

- **Spatial** resolution (IFOV/GSD) and coverage (field-of-view/regard)
  - Optical diffraction sets minimum aperture size
- **Spectral** resolution ($\Delta\lambda$) and coverage ($\lambda_{\text{min}}$ to $\lambda_{\text{max}}$)
  - Narrow bands need bigger aperture, more detectors, longer integration time
- **Radiometric** resolution (S/N, NE$\Delta\rho$, NE$\Delta$T) and coverage (dynamic range)
  - Aperture size, detector size, number of detectors, integration time
- **Temporal** resolution (revisit) and coverage (repeat)
  - Pointing agility, period for full coverage
SeaWiFS image—global chlorophyll July 1997 - Sept 1998

Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE
Effect of dynamic range
Landsat true color, 24 Apr 1986

Blue band showing variability in Mono Lake

Saturated pixels in blue band
Spatial, spectral characteristics of some multispectral sensors
Data rate

\[
\frac{(\text{swath width}) \times (\text{velocity}) \times (# \text{ bands}) \times \left(\frac{\text{bits}}{\text{band}}\right)}{(\text{spatial resolution})^2} = \text{data rate}
\]

\[
\frac{[\text{km}] \times \left[\frac{\text{km}}{\text{sec}}\right] \times [\text{bands}] \times \left[\frac{\text{bits}}{\text{band}}\right]}{[\text{m}]^2} = \left[\frac{\text{Mbits}}{\text{sec}}\right]
\]

e.g., Landsat 5

\[
\frac{[185 \text{ km}] \times \left[\frac{7.4 \text{ km}}{\text{sec}}\right] \times [7 \text{ bands}] \times \left[8 \frac{\text{bits}}{\text{band}}\right]}{[30 \text{ m}]^2} \approx 85 \left[\frac{\text{Mbits}}{\text{sec}}\right]
\]
Data rates of some sensors

- **Landsat (15m,30m)**
  - Peak: 127.5 Mbit/sec
  - Average: 10.5 Mbit/sec

- **MODIS (250m,500m,1000m)**
  - Peak: 21.2 Mbit/sec
  - Average: 12.2 Mbit/sec

- **AVHRR (1.1km)**
  - Peak: 6.0 Mbit/sec
  - Average: 4.8 Mbit/sec
Hyperspectral data
Absorption of water vapor, liquid water, and ice
Snow reflectance and its variation with grain size (radius)
Reflectance of dry and wet snow

- Reflectance of dry snow
- Reflectance of wet snow

Wavelength (nm) vs Reflectance chart:
- Melting Snow (red line)
- Frozen Snow (blue line)
Surface wetness with AVIRIS, Mt. Rainier, 14 June 1996

AVIRIS image, 409, 1324, 2269 nm
precipitable water, 1-8 mm
liquid water, 0-5 mm path absorption
vapor, liquid, ice (BGR)
Example: Multi-resolution snow products for the hydrologic sciences (http://www.snow.ucsb.edu)
Fractional snow cover, Sierra Nevada, March 7 2004
Daily MODIS acquisition, processing for Sierra Nevada snow cover and albedo

Ingest from NASA DAACs

Sierra Nevada = 128 MB/day
Snow-covered land = 8 GB/day

reproject, mosaic, subset, format

MODIS snow cover & albedo algorithm

Sierra Nevada = 20 MB/day
Snow-covered land = 1.25 GB/day

Database

MODster

Terra Server

Alexandria
Nonlinear set of equations for each pixel

\[
\begin{pmatrix}
R_1 \\
R_2 \\
\vdots \\
R_N
\end{pmatrix}
= 
\begin{pmatrix}
\rho_{\text{snow}}(r, c, \lambda_1, a_1) & \rho_{12} & \cdots & \rho_{1M} \\
\rho_{\text{snow}}(r, c, \lambda_2, a_2) & \rho_{22} & \cdots & \rho_{2M} \\
\vdots & \vdots & \ddots & \vdots \\
\rho_{\text{snow}}(r, c, \lambda_N, a_N) & \rho_{N2} & \cdots & \rho_{NM}
\end{pmatrix}
\begin{pmatrix}
F_1 \\
F_2 \\
\vdots \\
F_M
\end{pmatrix}
\]

where \(0 \leq F_i \leq 1\) and \(\sum F = 1\)

Solve for \(r, c\) and \(F\) (least squares)

consider better topographic correction for illumination angle,
viewing angle, and subpixel topography
MODIS and topography

Vegetation causes differences in view angle
Model structure for MODIS snow-covered area and albedo

- MODIS cloud mask (48 bits)
- MODIS 7 land bands (112 bits)
- MODIS quality flags
- Topography

- Watershed info
- MODIS view angles
- MODIS snow cover and albedo
- Solar zenith, azimuth

- Snow fraction
- Snow albedo
- Basin mask

- Processing Legacy

- RMS error
- Veg fraction
- Soil fraction

- Quality flag
- Shade fraction
- Open water fraction
Earth System Science Workbench: conceptual model

• Experiment
  – Network of models
    » … ingest / synthesize data
    » … generate products

• Notebook
  – Persistent storage that can be queried
  – Keeps track of all experiments

• Laboratory
  – Experiment execution environment
<table>
<thead>
<tr>
<th>Date</th>
<th>SCA (%)</th>
<th>CCA (%)</th>
<th>Sensor zenith (degrees)</th>
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<tr>
<td>March 3</td>
<td>73</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>March 4</td>
<td>74</td>
<td>18</td>
<td>48</td>
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<tr>
<td>March 5</td>
<td>78</td>
<td>27</td>
<td>36</td>
</tr>
<tr>
<td>March 7</td>
<td>69</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>March 8</td>
<td>55</td>
<td>31</td>
<td>62</td>
</tr>
</tbody>
</table>

2004, March 3 vs March 4
2004, March 4 vs March 5
2004, March 5 vs March 7
2004, March 7 vs March 8

% change in SCA
-100--75
-75--50
-50--25
-25--10
0
10--25
25--50
50--75
75--100
Applications: snowmelt modeling, Marble Fork of the Kaweah River

(Molotch et al., GRL, 2004)

\[
\text{Melt Flux} = \left( R_{\text{net}} m_q + T_d a_r \right) \times SCA
\]

where:

\( m_q = \) Energy to water depth conversion, 0.026 cm W\(^{-1}\) m\(^2\) day\(^{-1}\)

\( a_r = (\text{convection parameter, based on wind speed, humidity, and roughness}) \)
Magnitude of snowmelt: Modeled – Observed snow water equivalence

Tokopah basin, Sierra Nevada

SWE difference, cm

-250 - -140
-140 - -105
-105 - -70
-70 - -35
-35 - 35
35 - 70
70 - 105
105 - 140
140 - 288

Assumed w/ update

Assumed albedo

AVIRIS albedo
Finis

(“Finis, the author of all books”
—James Joyce, *Finnegan’s Wake*)