Multi-angle and Thermal Remote Sensing

25 April 2003
Outline

• Multi-angle remote sensing
  – MISR
  – ATSR
  – POLDER

• Thermal remote sensing
  – Review of thermal emittance
  – Thermal inertia
  – ASTER
Principles of Multi-angular Remote Sensing

- Bidirectional reflectance
- Depends on viewing and illumination geometries
MISR characteristics

9 view angles at Earth surface: nadir to 70.5° forward and backward

4 bands at each angle: 446, 558, 672, 866 nm

Continuous pole-to-pole coverage on orbit dayside

400-km swath
9 day coverage at equator
2 day coverage at poles

275 m - 1.1 km sampling

7 minutes to observe each scene at all 9 angles

14-bit quantization

On-board radiometric calibration
Automated co-registration of MISR imagery

- Physical MISR instrument
  - 9 angles x 4 bands
  - 36 non-registered images

- Virtual MISR instrument
  - 9 angles x 4 bands
  - 36 co-registered images

Image grid

WGS84 ellipsoid

SOM grid
Changes in scene brightness with angle

Oblique view looking at forward scatter
Changes in scene brightness with angle

Less oblique view looking at backscatter
Visualizing surface textures with MISR

Hudson and James Bays
24 February 2000

multi-spectral compositing

nadir view blue band
nadir view green band
nadir view red band

380 km
Visualizing surface textures

- Forward scatter red band
- Nadir red band
- Backscatter red band

Multi-angular compositing

Hudson and James Bays
24 February 2000

- Stratocumulus cloud
- Pack ice (rough)
- Fast ice (smooth)
Cloud and ice bidirectional reflectances

[Graph showing the normalized 672 nm BRF for different types of surfaces.
- Cloud
- Pack (rough) ice
- Fast (smooth) ice

The graph plots the view zenith angle (degrees) against the normalized 672 nm BRF. The data is categorized as backward and forward scattering for James Bay.]
Other multi-angle sensors

- Along Track Scanning Radiometer (ATSR)
  - dual view
  - NIR and thermal bands (ATSR-2 also has 3 visible bands)
  - European Space Agency (ESA)

- Polarization and Directionality of the Earth’s Reflectances (POLDER)
  - 15 spectral bands in visible and near-infrared
  - polarization information
  - French-Japanese partnership
Thermal Remote Sensing
Sources of surface temperature gain and loss

- Absorbed shortwave energy (emitted from Sun) (heat gain)
- Longwave emitted energy from earth (heat loss)
- Anthropogenic heating
  - urban areas
  - power plants
- Geothermal
  - volcanoes
  - hot springs
Thermal basics, revisited

- Recall that radiant temperature is not equal to kinetic temperature (except for a blackbody)
- Emissivity is the ratio of radiant emittance relative to that of a blackbody
- Emissivity is a spectral quantity (it varies with wavelength)
Thermal Basics, revisited

• Planck’s Blackbody Equation:
  – describes the spectral distribution of emitted energy as a function of temperature
• Stefan-Boltzmann Law:
  – shows that emitted radiation increases as a function of the 4th power of the temperature
• Wien’s Law:
  – there is a maximum wavelength at which a blackbody radiates and this is determined by temperature
Planck’s Radiation Law

\[ M_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\kappa T} - 1} \]

- \( M_\lambda \) = spectral radiant exitance (emittance), units are \( \text{W m}^{-2} \mu\text{m}^{-1} \)
- \( \lambda \) = wavelength
- \( T \) = the blackbody’s temperature in Kelvin (K)
- \( h = 6.625 \times 10^{-20} \text{ Js}^{-1} \)
- \( c = 3 \times 10^8 \text{ ms}^{-1} \)
- \( k = 1.38 \times 10^{-11} \text{ JK}^{-1} \)

Emitted solar energy

\[ M_{\lambda,\text{sun}} = \frac{3.74151 \times 10^8}{\lambda^5 e^{4387.9/\kappa 6000} - 1} \]
Irradiance at the earth’s surface

\[ E_{earth} = \frac{M_{sun}}{\square} \times \square \times A \]

For the Sun-Earth geometry:

\[ \frac{\square \times A}{\square} = 2.16 \times 10^5 \]
Sunlight reflected by the earth, converted to radiance:

\[ L_{refl} = \frac{E_{earth} * \Box}{\Box} \]
Energy emitted by earth

\[ L_{\text{earth}} = \frac{M_{\text{earth}}}{\square} \ast \square \]
Thermal Properties

• Heat capacity
  – ability of a material to absorb heat energy
• Thermal conductivity
  – rate of heat transfer through a substance
• Thermal inertia
  – thermal response of a material to a change in temperature

Can be used to map surface types
Diurnal changes in radiant temperature for different materials

Change in surface temperature as a function of surface energy balance
Kirchhoff’s Law

\[ 1 = \bar{R} + \bar{E} \]

\(\bar{R}\) = reflectance

\(\bar{E}\) = emittance

thus,

\(\bar{E} = 1 - \bar{R}\)
Measuring Radiant Temperature

- Stefan-Boltzmann Law

\[ M_{BB} = \square T^4 \]

- The radiant temperature measured by a sensor is a combination of an emitted component and a reflected component

\[ M = \square T^4_{\text{kin}} + \square T^4_{\text{sky}} \]
\[ T_{rad}^4 = T_{kin}^4 + T_{sky}^4 \]

\[ T_{rad} = 4\sqrt{T_{kin}^4 + T_{sky}^4} \]
Thermal Inertia

- A measurement of the thermal response of a material to temperature changes
- Thermal inertia of a material may be calculated as the square root of the product of density, thermal conductivity, and specific heat of the material
- These material properties must be measured *in situ* so, thermal inertial cannot be determined from remote sensing measurements
Apparent Thermal Inertia Example: Northern Death Valley

- **albedo image**
  - SPOT panchromatic image

- **radiant temp: day**
  - TIMS daytime image

- **radiant temp: night**
  - TIMS predawn image

\[
ATI = \frac{1}{T} \frac{A}{A}
\]
Computing Apparent Thermal Inertia

1. Use visible image to estimate albedo
2. Use calibrated thermal imager to estimate radiant temperatures from day and night images
3. Compute apparent thermal inertia (ATI)

\[ ATI = \frac{1 - A}{\Delta T} \]

where, A is the albedo of the material and \( \Delta T \) is the change in temperature between day and night observations
Spaceborne Thermal Imagery

- Landsat -- has one thermal channel
- AVHRR -- has two thermal channels
- ATSR -- has three thermal channels
- MODIS -- has several thermal channels
- ASTER -- has several thermal channels

Detectors in the thermal region need to be cooled.
Changes in detector temperature are a source of noise.
Deep space can be used as a calibration target.
Atmospheric Windows for Thermal Remote Sensing:

- 3-4 μm
- 8-9 μm
- 10.5-12.5 μm
Emittance spectra of various minerals

Emittance spectra can be used in ways similar to reflectance spectra to map and characterize surface materials.
ASTER Image of Saline Valley, CA

RGB composite image using VNIR bands (3, 2, 1)

(vegetation is red)
ASTER Image of Saline Valley, CA

RGB composite image using SWIR bands (4, 6, 8)

(show reflectance differences of clays, carbonate and sulfate minerals)
ASTER Image of Saline Valley, CA

RGB composite image using TIR bands (13, 12, 10)

(quartz is red, carbonates are green, mafic volcanic rocks are purple)