Measuring the Earth System in a Time of Global Environmental Change with Imaging Spectroscopy

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Overview

- Objective and Available Signal
- Sensing versus Measurement
- Spectroscopic Approach to Measurement
- Imaging Spectroscopy
- Research and Applications
- Summary and Future
Objective
Components of the Earth System that are Changing

- Atmosphere
  - Clouds
  - Water Vapor
  - Carbon Dioxide
  - etc.

- Surface
  - Land Cover
  - Vegetation
  - Coastal and Inland Water
  - Wild Fires
  - Snow and Ice
  - etc.

Remote Sensing or Remote Measurement

- Remote Sensing: To get an ideas or sense of what is present.
  - A 20th century approach.

- Remote Measurement: To quantitatively determine properties of the Earth's surface and atmosphere through the physics, chemistry and biology of the interaction of electromagnetic energy with matter.
  - Imaging Spectroscopy a 21st century approach
Spectroscopy of the Earth

Spectroscopy: A Reflectance Spectrum Example

- Three materials are detected
- Three minerals are identified based on molecular absorption characteristics
- The expressed concentration of the three minerals may be derived
Multi Spectral 20th Century Approach
The 6 Solar LandSat TM Bands

Multi-spectral Observation
20th Century Approach

- Three materials are NOT detected
- Three minerals are NOT identified based on molecular absorption characteristics
- The expressed concentration of the three minerals may NOT be derived
Spectroscopy
21st Century Remote Measurement Approach

- Three materials are detected
- Three minerals are identified based on molecular absorption characteristics
- The expressed concentration of the three minerals may be derived

Plant Physiology and Carbon-Water-Nutrients are Directly Expressed in the Reflected Solar Spectrum

Photosynthesis

\[ 6\text{H}_2\text{O} + 6\text{CO}_2 + \text{photon} = \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]
Determining the composition and inferring processes on the Earth surface by counting photons at the top of the atmosphere is a challenging objective.

Spectroscopy provides a framework based in physics to achieve this remote measurement (more than sensing) objective in the context of the interaction of photons with matter.

The physics, chemistry and biology of spectroscopy have been validated through more than 100 years of laboratory and astronomical research and applications. (Fraunhofer 1814)
AVIRIS Instrument

AVIRIS is designed with 200 μm detectors and F/1 optics. It is hard to imagine larger detectors or faster optics. The AVIRIS design is in the advanced technology zone of the physics of spectroscopic measurements.

AVIRIS: PEARL HARBOR, HAWAII

Spectral
- Range: 370 to 2500
- Sampling: 9.8 nm
- Accuracy: 0.5 nm

Radiometric
- Range: 0 to Max Lambertian
- Sampling: 12 bits
- Accuracy: 96 percent

Spatial (ER-2 / Twin Otter aircraft)
- Swath: 11/2.2 km ER-2/TO
- Sampling: 20/4 m ER-2/TO
- Accuracy: 20/4 m ER-2/TO

Full INU/GPS geo rectification
ER-2 Platform 20 km Altitude

Twin Otter Platform, 4 km Altitude
New Capability, 5 to 8 km Altitude
AVIRIS On Board Proteus 040610

New Capability
AVIRIS On Board Proteus 040611
AVIRIS Throughput Increase in 2004

AVIRIS 2004 Performance Improvement
Following Completion of Foreoptics Refurbishment

Land Surface Measurement
Geology Example
Geology Example: Imaging Spectroscopy Remote Measurement

Imaging spectrometer data det over area of Interest

Cuprite, Nevada
AVIRIS 1995 data

Imagery is a combination of TM bands:
- TM 3 (0.67 µm)
- TM 2 (0.55 µm)
- TM 1 (0.45 µm)

Roger N. Clark
US Geological Survey
1995
Mineral Spectra

- Muscovite 32.4% [KAl_4O_8(OH)_2]•2H_2O
- Albite NaAlSi_3O_8, 9.4%
- Opaline CaSiO_2
- Jettite NaAlSi_3O_8(OH)_2•H_2O
- Dolomite CaMg(CO_3)_2

- Montmorillonite (Na,Si,Ca)_{22}Al_{10}Si_{2}O_{52}(OH)_{4}•2H_2O
- Elvanite Al_{10}Si_{10}O_{26}•4H_2O
- Geothite Fe_{3}SiO_4
- Calcite CaCO_3
- Bassinite Fe_2SiO_3

Wavelength (nm)

Reflectance

0.2 0.4 0.6 0.8 1.0 1.2

400 700 1000 1300 1600 1900 2200 2500

Mineral Spectra

- Montmorillonite SWy-1
- Muscovite GDS116
- Halloysite NMNH106237
- Weighted Fits
- Kaolinite KGa-2
- Alunite GDS83

Scaled Reflectance

0.628 0.963 0.996 0.829

0.000 0.320 0.000 0.872

2.0 2.1 2.2 2.3 2.4

Wavelength (μm)
Cuprite, NV
Measured minerals in the 400 to 1500 nm spectral region with imaging spectroscopy

Cuprite, NV
Measured minerals in the 1000 to 2500 nm spectral region with imaging spectroscopy
Atmosphere Measurement
Water Vapor
Cirrus Clouds

Measuring Atmospheric Water Vapor
Derived Water Vapor at Low Elevation

Derived Water Vapor at High Elevation
Water Vapor at All Spectra

AVIRIS Water Vapor at Rogers Dry Lake, CA

Radiance Images
18.85 19.12 19.27 19.42 19.57
Derived Water Vapor
Image of the Mojave Desert, CA

Measuring Cirrus Clouds
Image of the Mojave Desert, CA at 1380 nm

Vegetation Measurement
  Vegetation type
  Vegetation Carbon
Remote Measurement of Vegetation with Imaging Spectroscopy

Multi Spectral Remote Sensing of Vegetation the 20th Century Approach

The spectral signatures are missing.
Imaging Spectroscopy is Required for Vegetation Type, Water, Carbon, Cover, Light use, Chemistry, etc.
MESMA Vegetation Mapping
Santa Barbara Front Range

Accuracy: 87%

MESMA Vegetation Species Map
Generated from Oct. 23, 1996 AVIRIS
Plant Functional Types from Spectral Unmixing

Desertification in Central Argentina
Carbon Impacts Called for by UNEP

AVIRIS 4.5m

Unprotected/Graded

Protected/Not Graded
High-Precision Surface Cover Analysis Using VNIR red-edge and SWIR (2000-2400 nm) Spectra
*Only SWIR Field Data Shown Here*

**Tied Field Spectra Showing Full Arid/Semi-arid Site Variability**

*Tied at 2080 nm*

**Tied SWIR Spectra**

Desertification in Central Argentina
VNIR-SWIR Spectral Deconvolution

Accuracy Assessment Using the Same Physical Model But with ETM+, Hyperion and AVIRIS Data

Measurements for Terrestrial Vegetation for Carbon from Imaging Spectroscopy

- **Fractional Vegetation Cover**
  - Green vegetation (GV)
  - Non-photosynthetic vegetation (NPV)
  - Soil, Water, Snow/ice

- **Plant Functional Types**
  - Grass/forb/shrub/tree
  - Thick/thin leaves
  - Broad/needle leaves
  - Deciduous/evergreen

- **Disturbance and Response of Vegetation Cover**
  - Recovery/change in fractional cover
  - Recovery/change in ecosystem function
  - Spectral signatures of vegetation stress and damage

- **Canopy Physiology and Function**
  - Light use efficiency
  - Canopy liquid water
  - Canopy chemistry
**Four Mainstream Land Carbon Models**

*Where are the satellite constraints?*

<table>
<thead>
<tr>
<th>Major Model Inputs</th>
<th>CENTURY</th>
<th>CASA</th>
<th>SIB3</th>
<th>Ecosystem Demography</th>
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Currently there is large uncertainty in terrestrial vegetation Carbon storage and change. Not helped with current satellite measurements.

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**Four Mainstream Land Carbon Models**

*With proposed Flora Spaceborne imaging spectrometer measurements*

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Flora will reduce the current large uncertainty in Carbon storage and change in terrestrial vegetation.
Remote Measurement of Agricultural Vegetation Stress with RVSI

RVSI uses the spectroscopy and is superior in measuring stress.

Perry et al., 2002
Shelton NE
NASA EOCAP program

Water Vapor at All Spectra
AVIRIS Water Vapor at Rogers Dry Lake, CA

Image of the Mojave Desert, CA
Measuring Cirrus Clouds

Image of the Mojave Desert, CA
Image of the Mojave Desert, CA at 1380 nm

Wild Fire Measurement

Fire Properties
Vegetation Properties
Simi Fire f031027
AVIRIS Radiance on topography

Simi Fire f031027
AVIRIS Radiance, topography and post fire picture
Hot Spot Radiance Modeled with Planck Function

AVIRIS view
2003 California Fires
Simi Valley, California
Fire Through the Spectrum

AVIRIS Hot High Fraction Spectrum

[Graph showing AVIRIS estimate and residual for the Simi Valley Fire spectrum. Temperature estimate is 998K, suggesting an accurate match for the spectrum sample area.]
Hot Spot Radiance Modeled with Planck Function

AVIRIS from unburned to burning vegetation
AVIRIS Hot High Fraction Spectrum

AVIRIS Spectra

Temperature & Area Derivation

AVIRIS Derived Temperatures

Detailed Fire temperature for structure and research
AVIRIS Derived Temperatures

Temperatures 800 to 1450 K

Detailed structure of fire process

AVIRIS Derived Fire Fractional Areas

Fractional Areas ~ 1 to 13 % and higher

At 4 m spatial scale high fractions at the edges
Snow and Ice Measurement
Snow Grain Size
Snow Melting

Snow and ice distribution and properties are changing due to global warming.
AVIRIS and Snow Hydrology

Costal and Inland Water

- Properties to Measure with Imaging Spectroscopy
  - Chlorophyll and other constituent
  - Water depth
  - Aquatic vegetation
  - Coral
  - Pollution
Costal and Inland Waters
Spectral Signatures of Water Constituents
(from John Mustard)

**Model Based Inversion for Chlorophyll**

Five-week Acrobat towfish volume time-series from R/V Zephyr

September - October 2002
- Towed-undulating surveys
- Surface underway mapping
- bottle samples

Airborne Remote Sensing

Two overflights in October
2500 x spatial resolution of satellite
far greater spectral resolution and coverage
ground-truth optics
Research and Applications

- Atmosphere: water vapor, clouds properties, aerosols, absorbing gases...
- Ecology: chlorophyll, leaf water, lignin, cellulose, pigments, structure, nonphotosynthetic constituents...
- Geology and soils: mineralogy, soil type...
- Coastal and Inland waters: chlorophyll, plankton, dissolved organics, sediments, bottom composition, bathymetry...
- Snow and Ice Hydrology: snow cover fraction, grain size, impurities, melting...
- Biomass Burning: subpixel temperatures and extent, smoke, combustion products...
- Environmental hazards: contaminants directly and indirectly, geological substrate...
- Calibration: aircraft and satellite sensors, sensor simulation, standard validation..
- Modeling: radiative transfer model validation and constraint...
- Commercial: mineral exploration, agriculture and forest status...
- Algorithms: autonomous atmospheric correction, advance spectra derivation...
- Other: human infrastructure...
Summary

- Measuring the Earth system in a time of global environmental change
- Imaging Spectroscopy enables remote measurement
- Remote Measurement determination of the properties of the Earth's surface and atmosphere through the physics, chemistry and biology of the interaction of electromagnetic energy with matter.

- Imaging spectroscopy a 21st century approach

Future Vision

What is needed: High Fidelity Imaging Spectroscopy

- High Signal-to-noise ratio required for molecular spectroscopy
- Uniformity is required for spectroscopy in the image domain
- Excellent calibration for quantitative results (spectral, radiometric, spatial)
Future: Advanced high throughput and high uniformity designs

A possible design: 30 meter spatial resolution and 60 km swath
The Imaging Spectroscopy Vision for the future:

Thank You

- AVIRIS website: http://aviris.jpl.nasa.gov
- Email: rog@jpl.nasa.gov
- AVIRIS Workshop Proceedings: On-line at website
- AVIRIS Workshop: May 2005