

Some Musings On Current Evolutionary Trends In The Space Business

CubeSat Workshop
April 20, 2007

Tom Chrien
tchrien@raytheon.com



Some Formidable Lizards

- **Space-Based InfraRed Systems- High (SBIRS-High)**
- **National Polar-orbiting Operational Environmental Satellite System (NPOESS)**
- **Geostationary Operational Environmental Satellite (GOES)**
- **Transformational Communications Satellite (TSAT)**
- **Global Positioning System (GPS)**

...and their environmental niches

Missile Warning
SIGINT
Space Control
Meteorology
Communication
Planetary Science
Environmental Monitoring

IMINT
MASINT
Mapping
Navigation
TV/Radio
Earth Science
Astronomy

Punctuated Equilibria

Large, stable, central populations exert a strong homogenizing influence. New and favorable mutations are diluted by the sheer bulk of the populations through which they must spread. They build slowly in frequency, but changing environments usually cancel their selective value long before they reach fixation. Thus, phyletic transformations in large populations should be very rare...

But small, peripherally isolated groups are cut off from their parental stock. They live as tiny populations in the geographic corners of the ancestral range. Selective pressures are usually intense because peripheries mark the edge of ecological tolerance for ancestral forms. Favorable variations spread quickly. Small peripheral isolates are a laboratory for evolutionary change.

Operationally Responsive Space



.... space technology context is changing, making possible a movement to an additional business model and an expanded business base for space. Cost per kilogram on orbit is still a problem. But, capability per kilogram is soaring due to advances in information technology. This makes the alternative feasible. The door for small, micro and nanosatellites is open, allowing us to redefine cost and mission criticality curves, increase transaction and learning rates and the ability to assume risk.

Adm. Arthur K Cebrowski

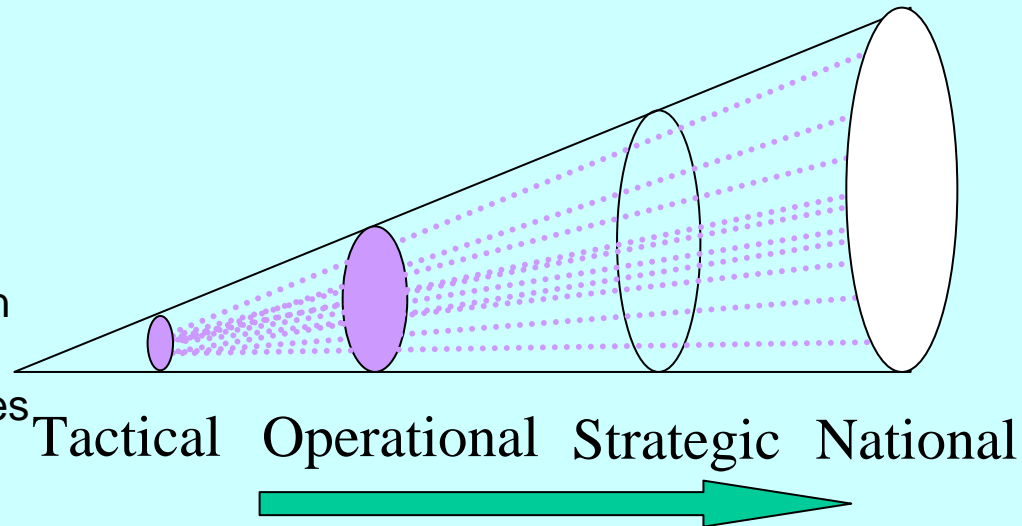
March 2004 US Senate Testimony

Evolving Meaning of *Operational*

Original Context From Cebrowski

Operational

Demand Driven
Military Capability
Autonomous
Integrated
Decentralized Control
Reduced Classification
Broadened User Base
Decreased Cycle Times
Risk Tolerant



Evolving Context: So important that it cannot fail

Some Advice I Received Early In My Career

...Pick a entirely new field of study and figure it
out
before long, you will be a world expert
(i.e. find your own niche)



H. G. Wells, The Outline of History, 1922

“The telescope has released the human imagination as no other implement has ever done. If there is any other apparatus worthy to be compared to its enlarging influence, it is the spectroscope, which was developed after the discoveries of Fraunhofer, the glass-worker, in 1814. Since man has lived on earth he has seen rainbows, but who could have told him that those bands of colour held in them a promise that one day he should be able to analyze the stars? But the spectroscope receives the rays from any luminous source, passes them through prisms and breaks them up into rainbow-like bands. These bands reveal under examination transverse lines of brightness and darkness which vary with the heat and the chemical composition of the source of light and of any intervening vapour. So that men can now sit in observatories and learn the composition and take the temperature of stars incalculable billions of miles away.”

Spectroscopic View Of Planet Earth

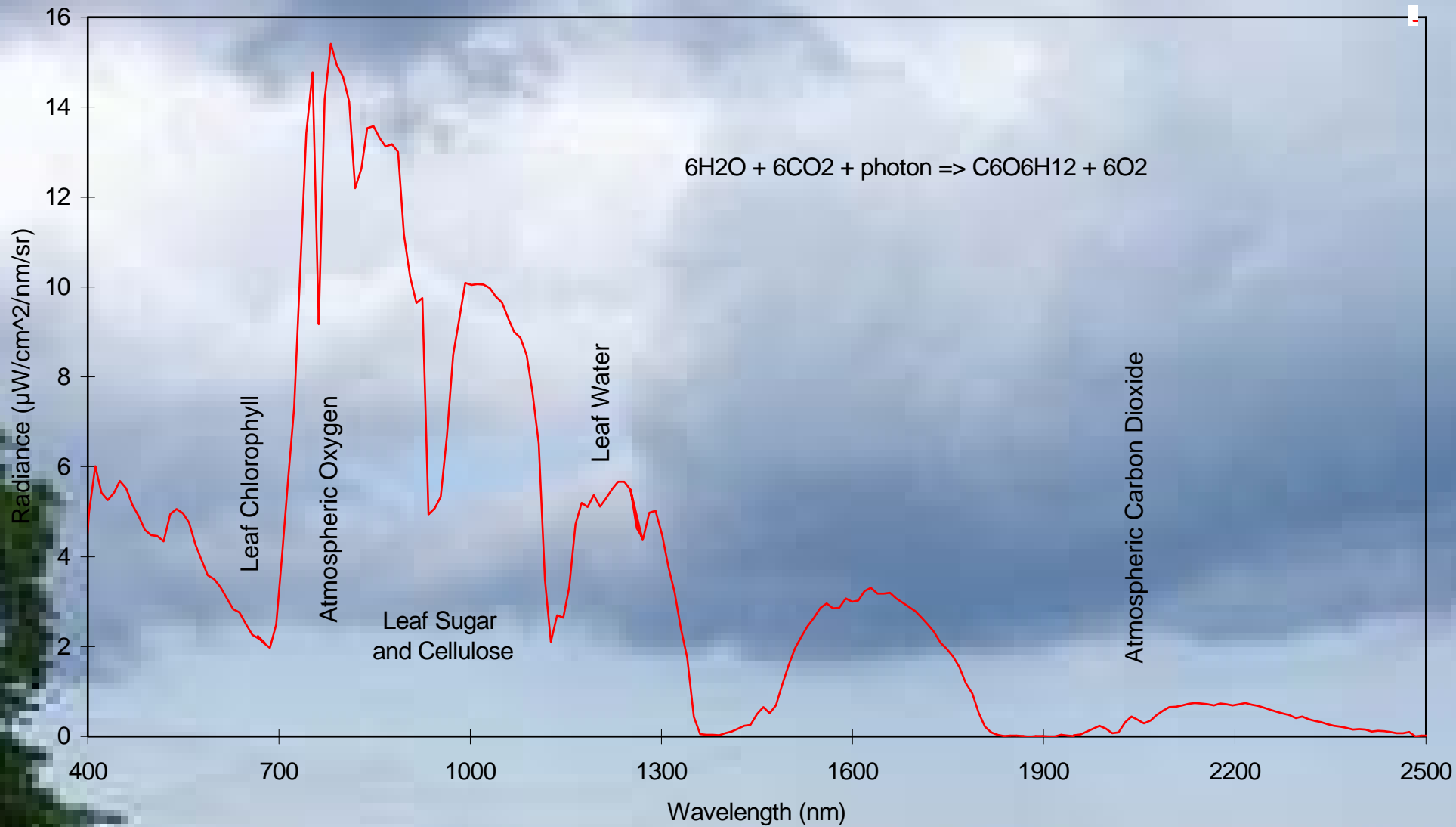
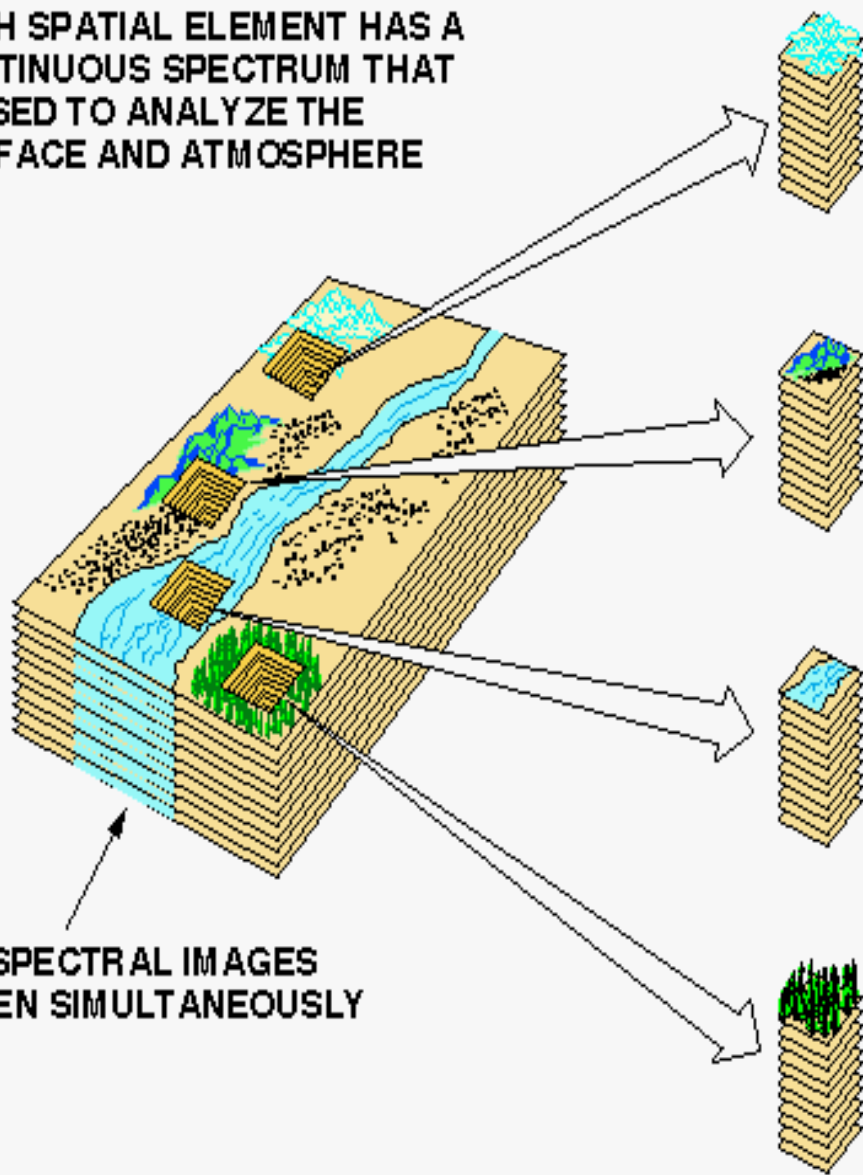
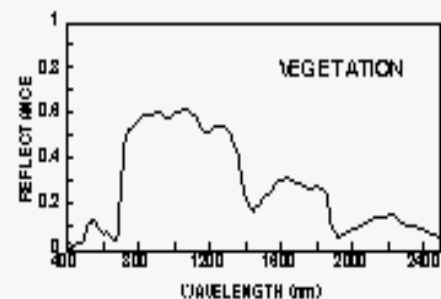
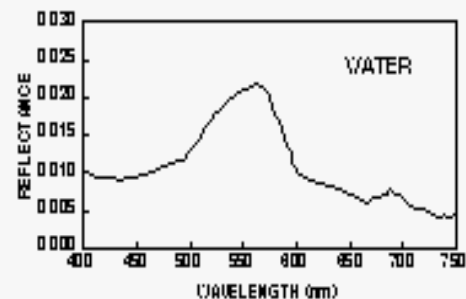
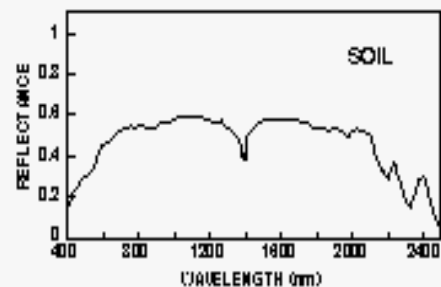
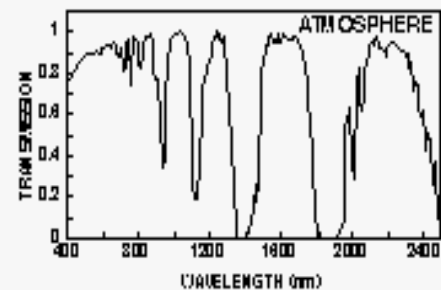


Image Cube Concept

EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE

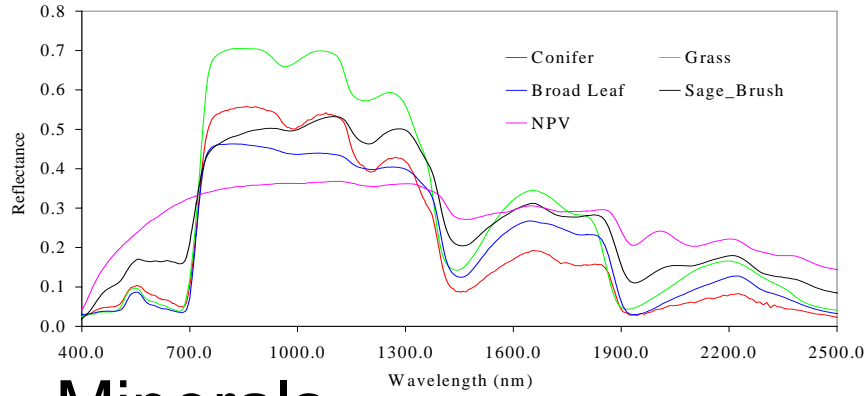


224 SPECTRAL IMAGES TAKEN SIMULTANEOUSLY

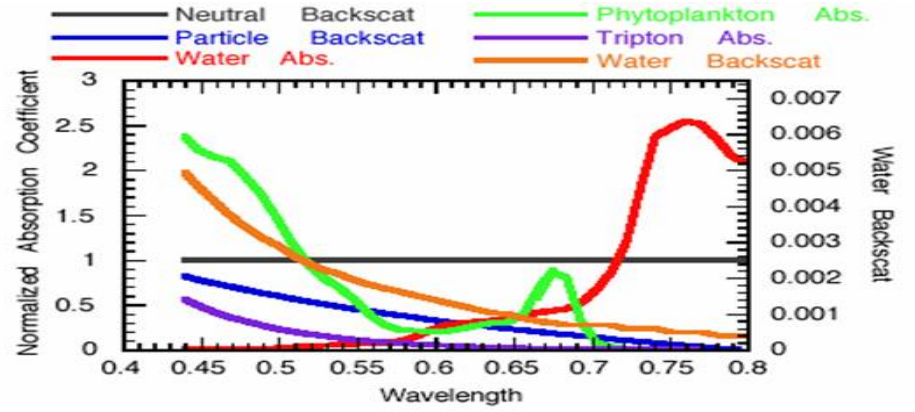


Earth Spectra

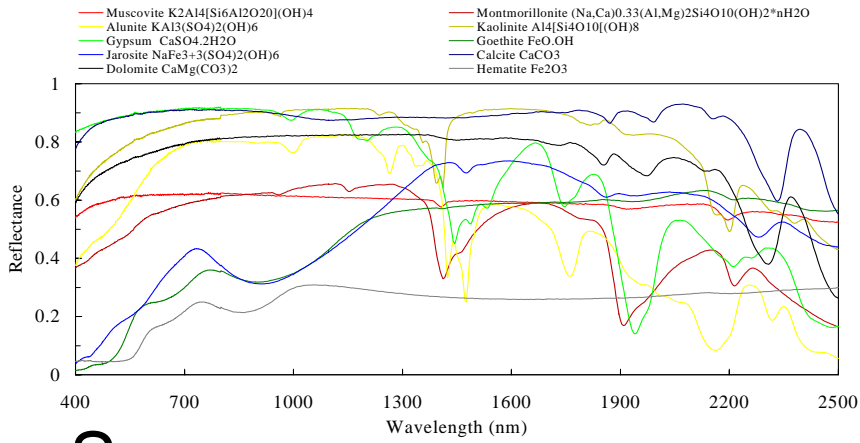
Vegetation



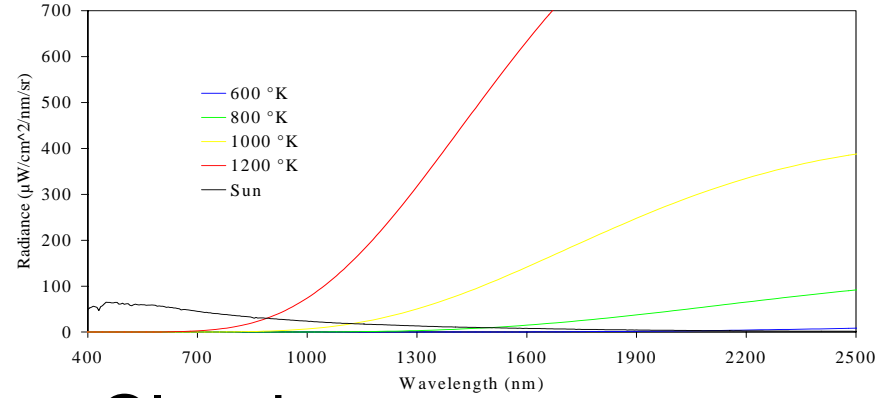
Water



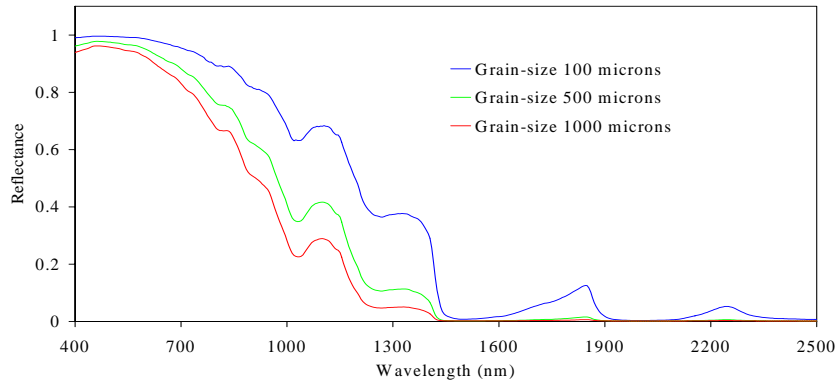
Minerals



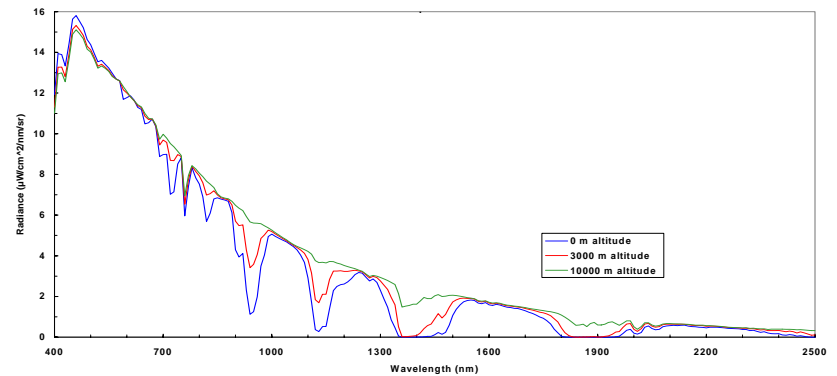
Fire



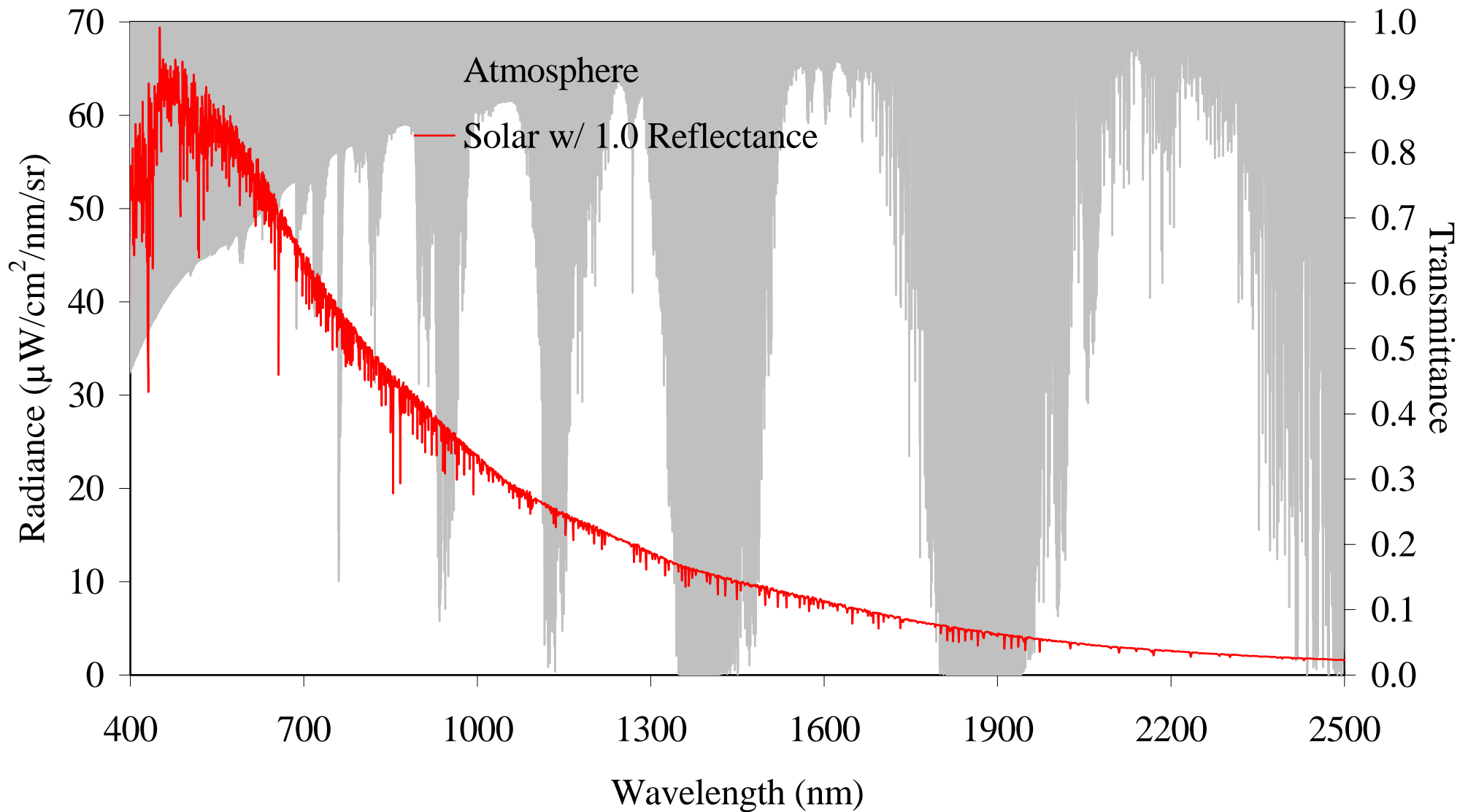
Snow



Clouds

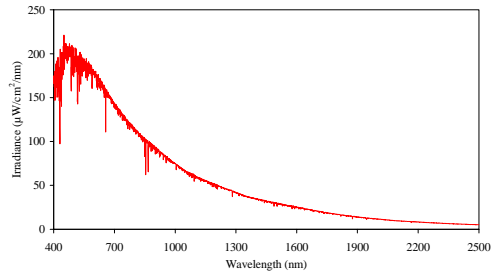


Solar Signal and Transmittance of the Atmosphere

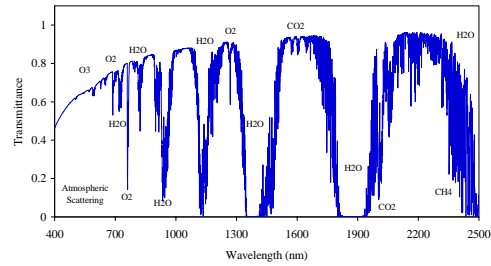


Imaging Spectroscopy Overview

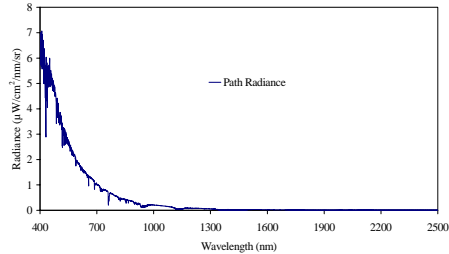
Solar Irradiance



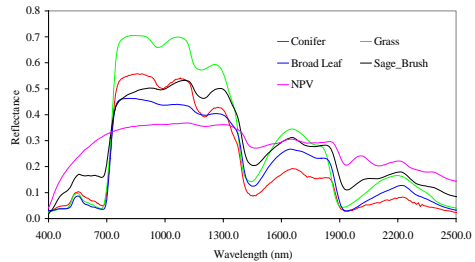
Atm. Transmittance



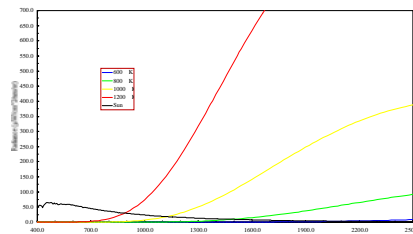
Path Radiance



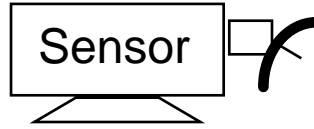
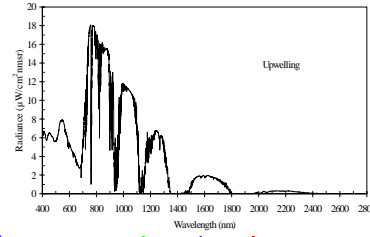
Surf. Reflectance



Emitted Radiance

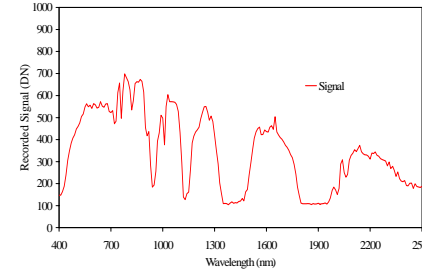


At Sensor

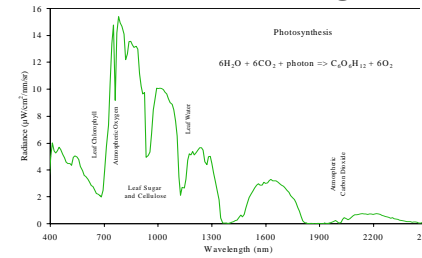


Data downlink

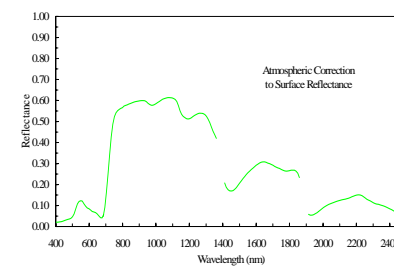
Measured signal



Calibrated Signal



Reflectance

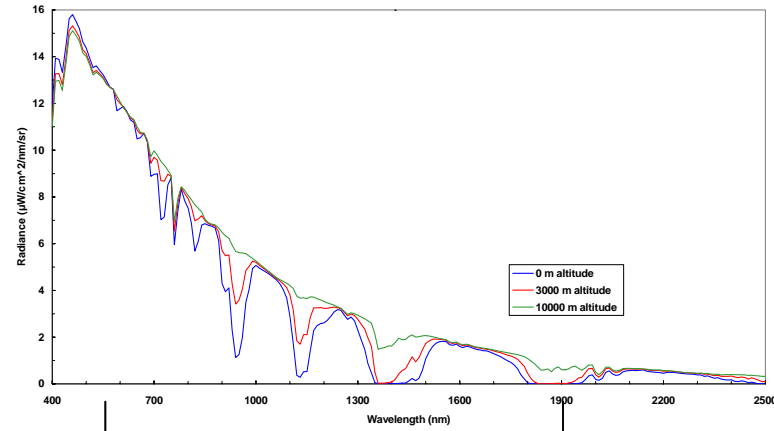


Calibration Parameters

Atmospheric Correction

Data Exploitation

Cirrus Cloud Detection Over Mojave Desert



Visible Image

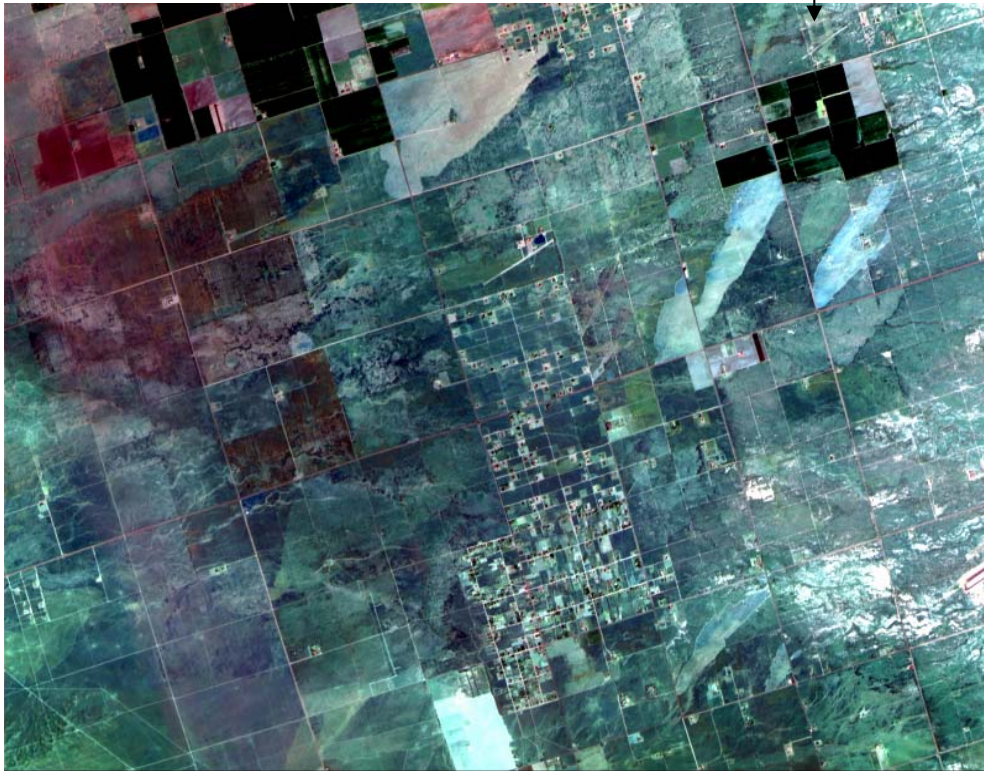
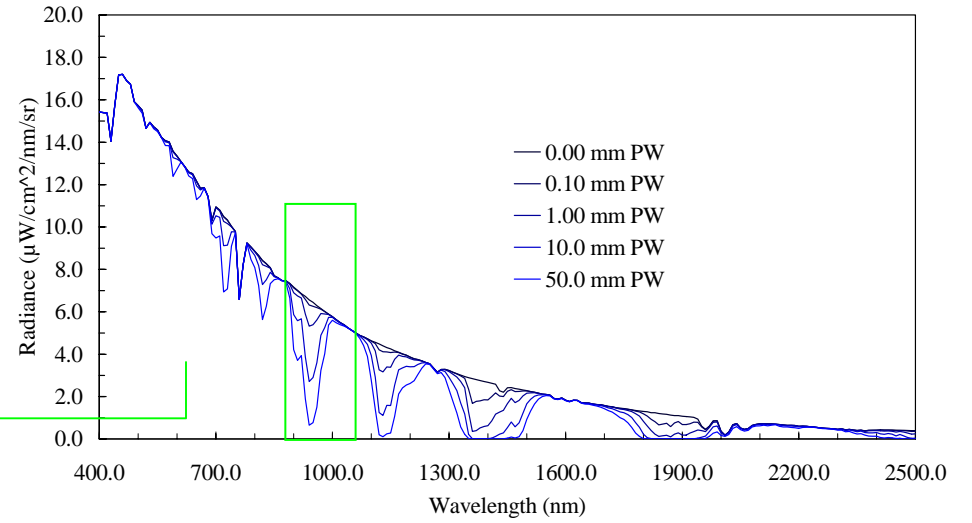


Image from 1380 nm

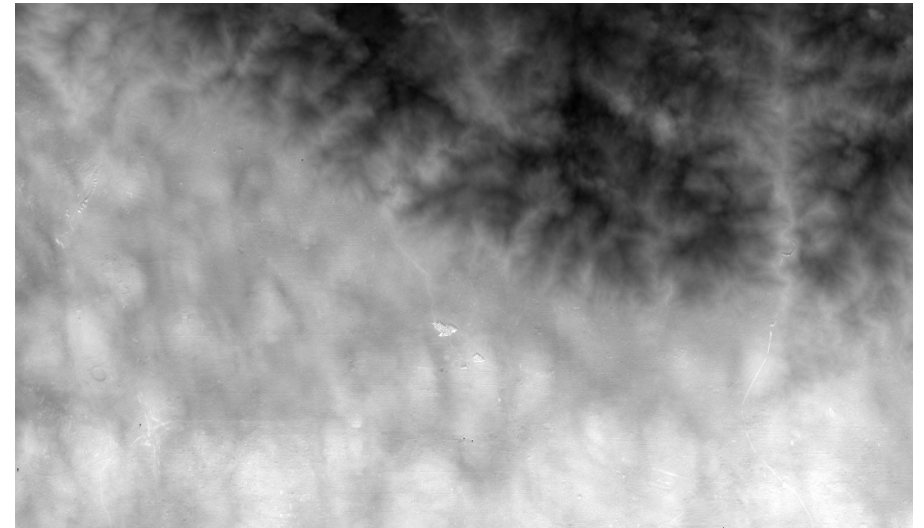
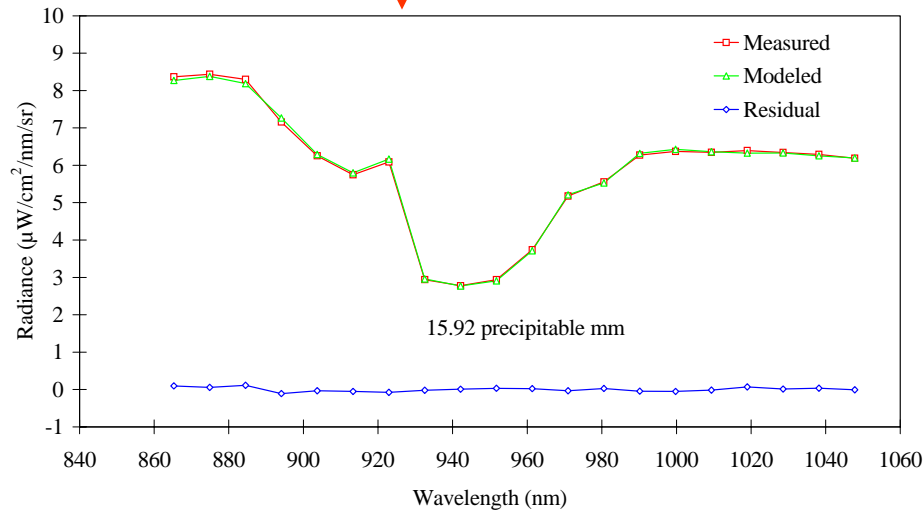


Accounting For Water Vapor



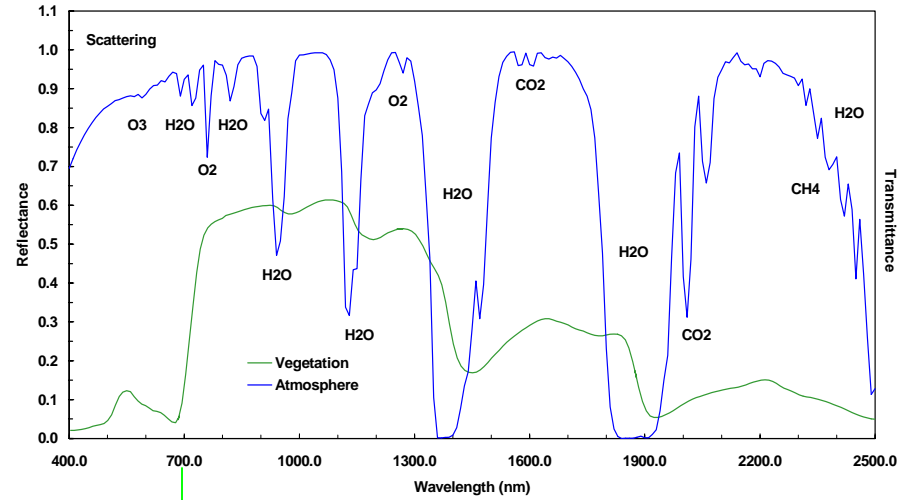
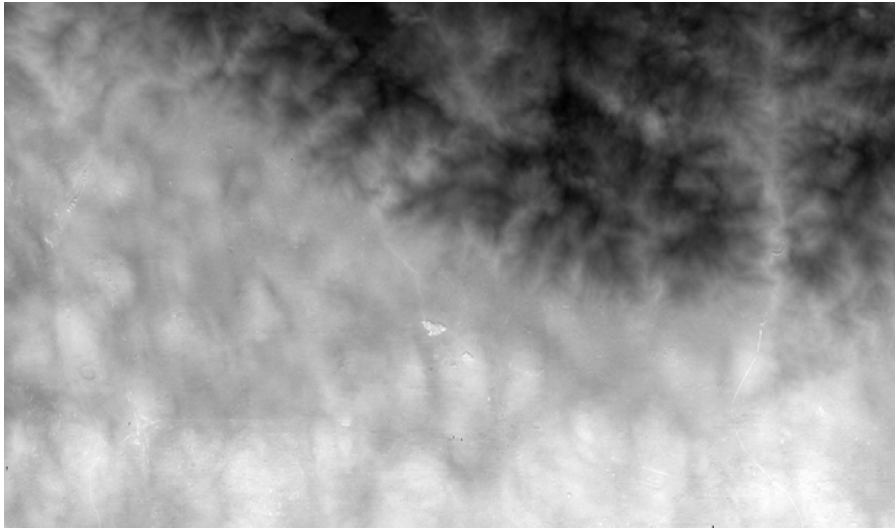
Measured

Modeled

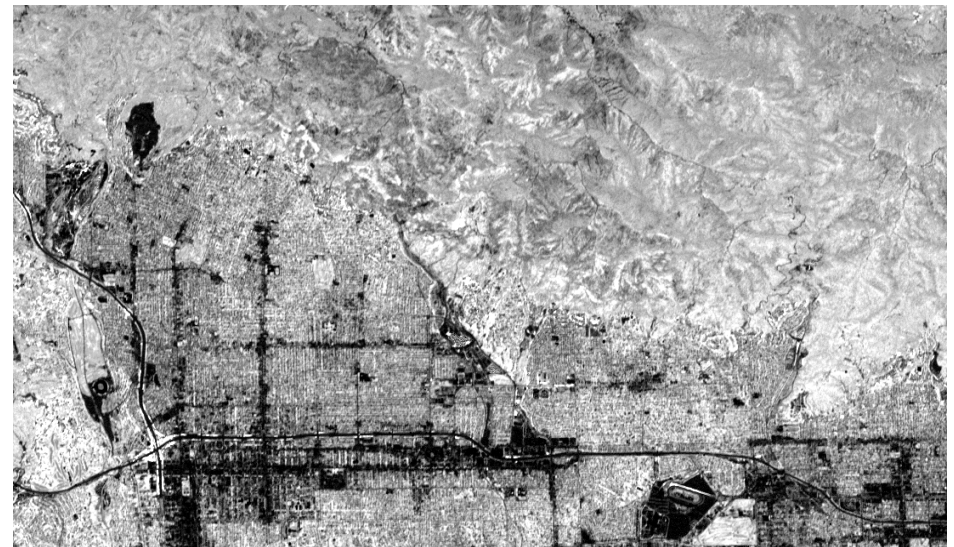
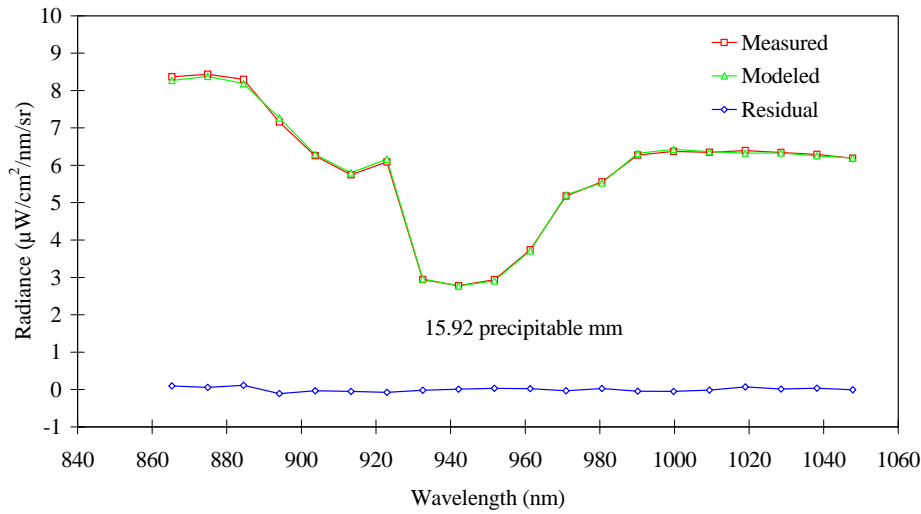


Water Vapor
Parameter map

Accounting For Liquid Water



Vapor and Liquid Modeled



Liquid Water
Parameter map

Radiance To Reflectance Inversion

$$L_t = \mu F_0 \rho_a / \pi + \mu F_0 T_d \rho_s T_u / \pi$$

L_t is the at sensor radiance

μ is the cosine of the solar zenith angle

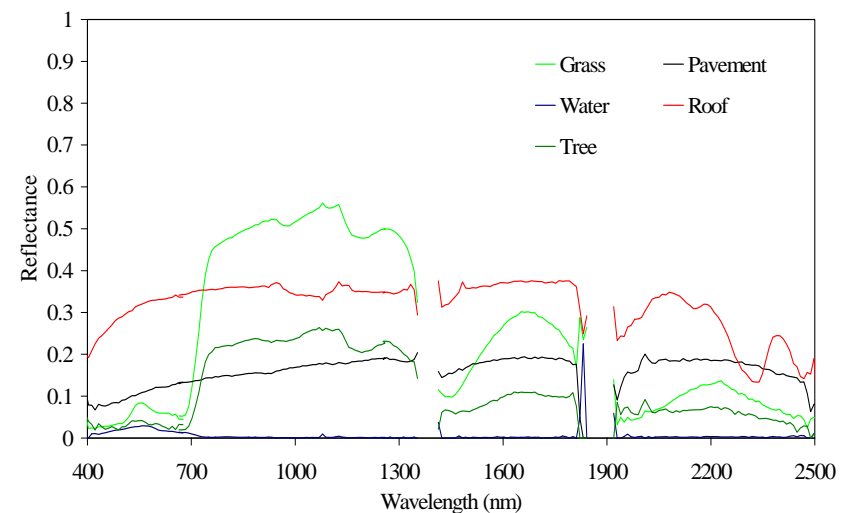
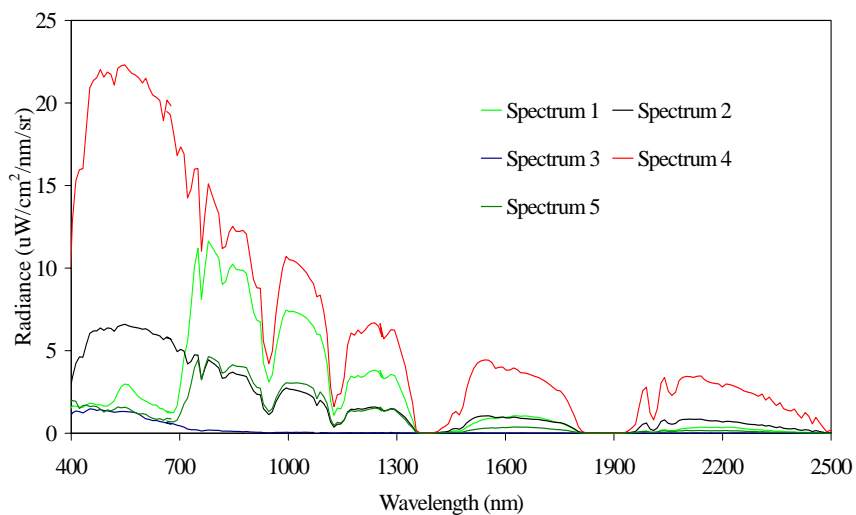
F_0 is the exo atmospheric irradiance

ρ_a is the upward reflectance of the atmosphere

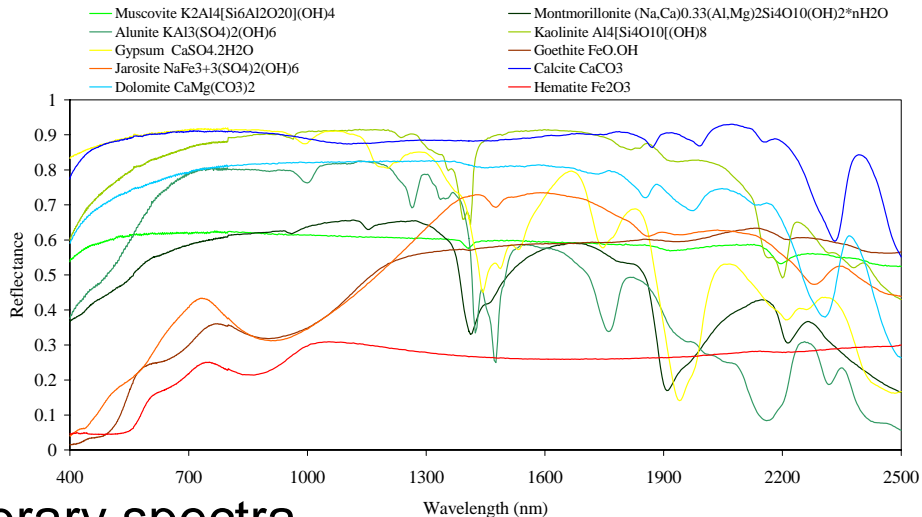
T_d is the downward transmittance

ρ_s is the reflectance of the surface

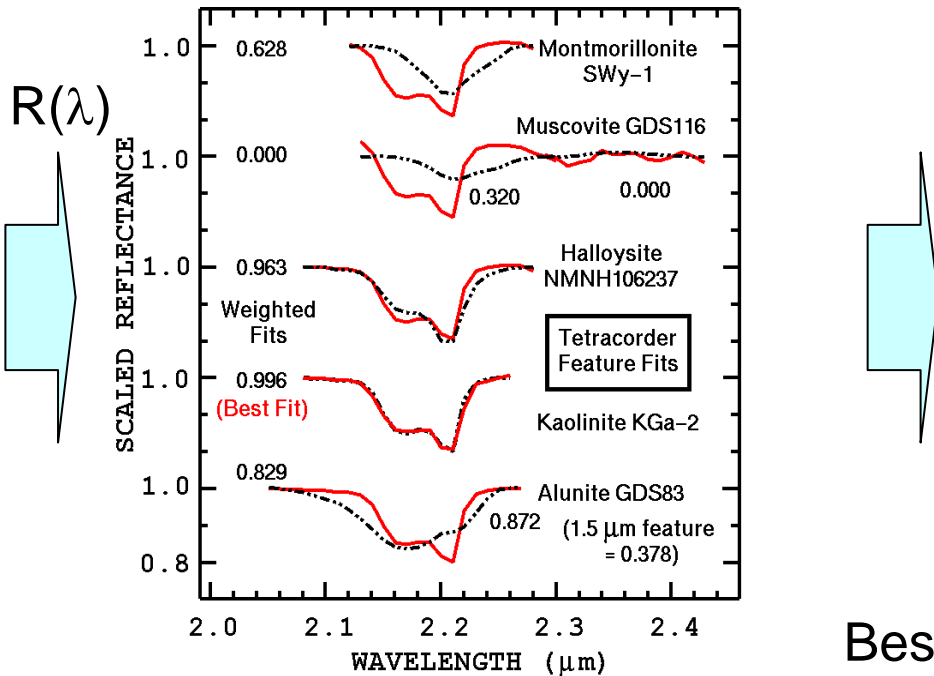
T_u is the upward transmittance of the atmosphere



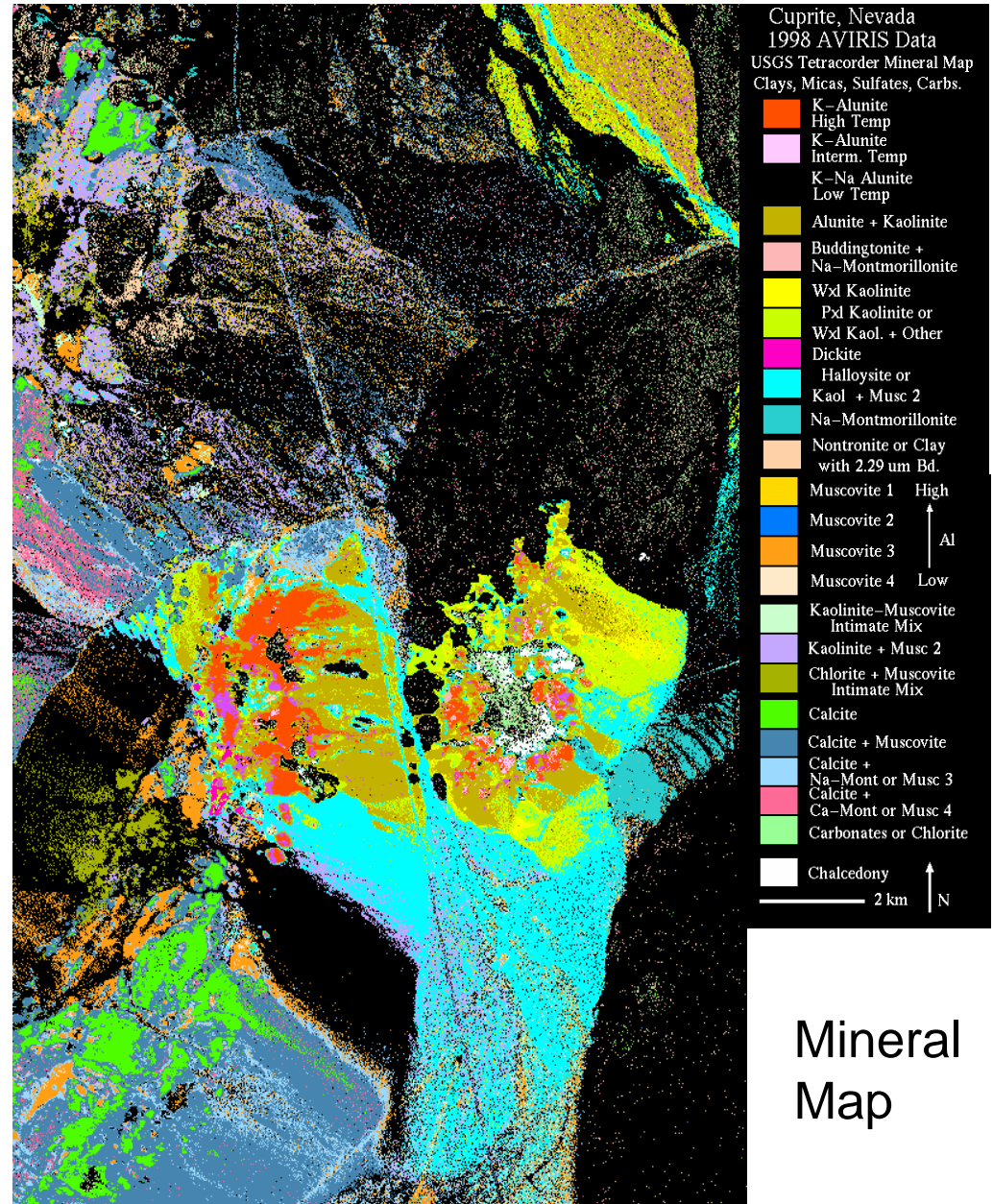
Mineral Mapping With USGS's Tetracorder



Library spectra



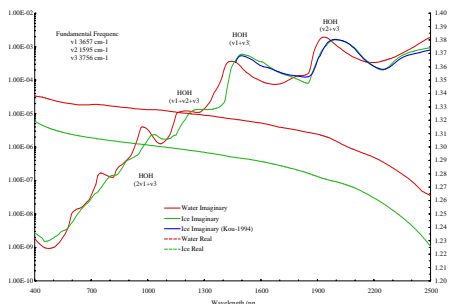
Best Match



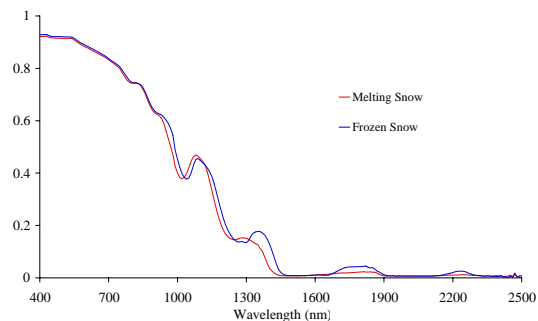
Mineral Map

Snow and Ice Model Matching

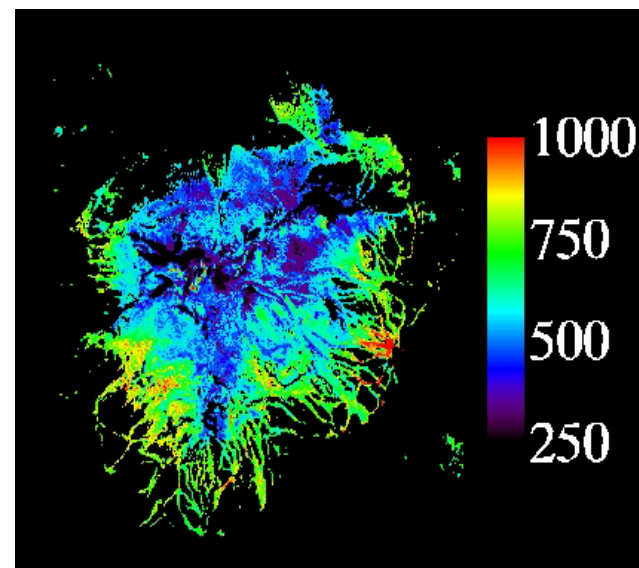
Complex refractive
Index of water and ice



Physical model of
Snow spectral reflectance

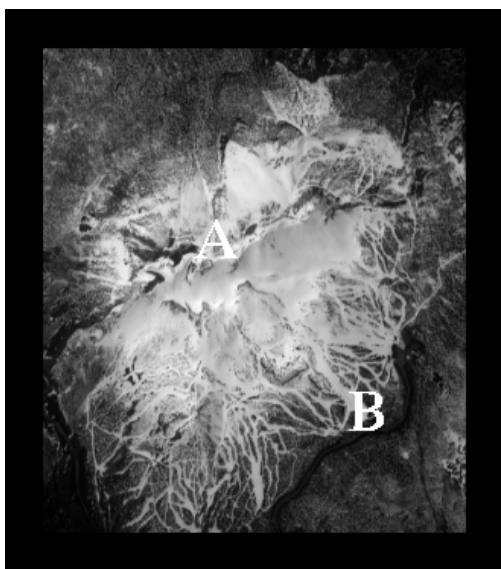
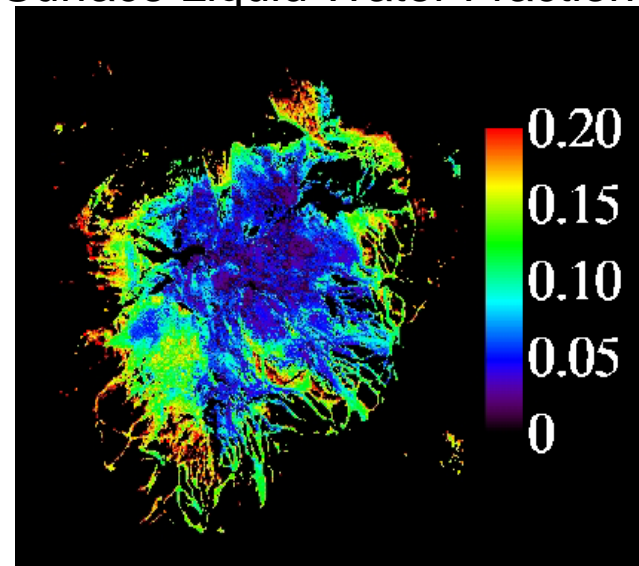


Surface Grain Size [μm]



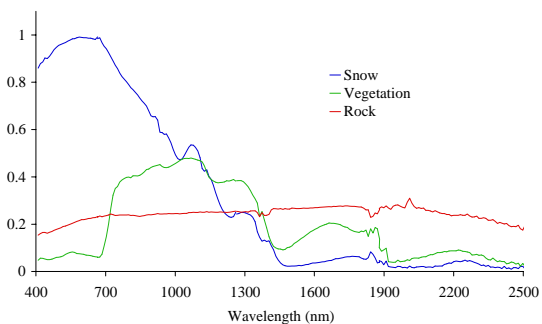
Nonlinear least square
Model matching

Surface Liquid Water Fraction



Calibrated Radiance

Atmospheric
Correction



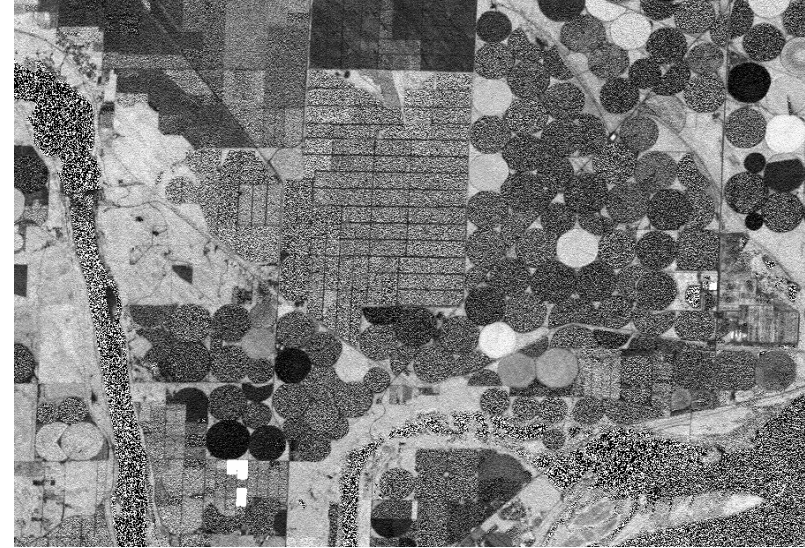
Reflectance Spectra

Vegetation Parameter Over Wallula, WA

False Color



Cellulose



Liquid Water

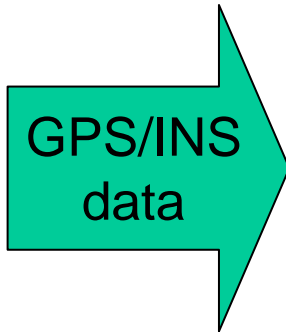
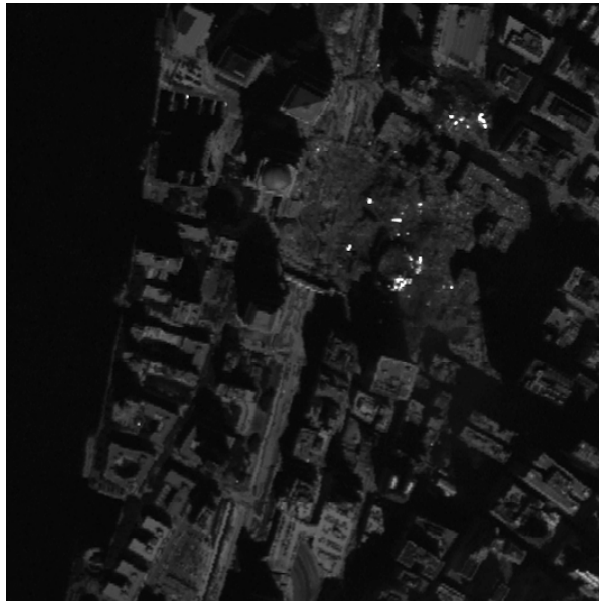


Chlorophyll

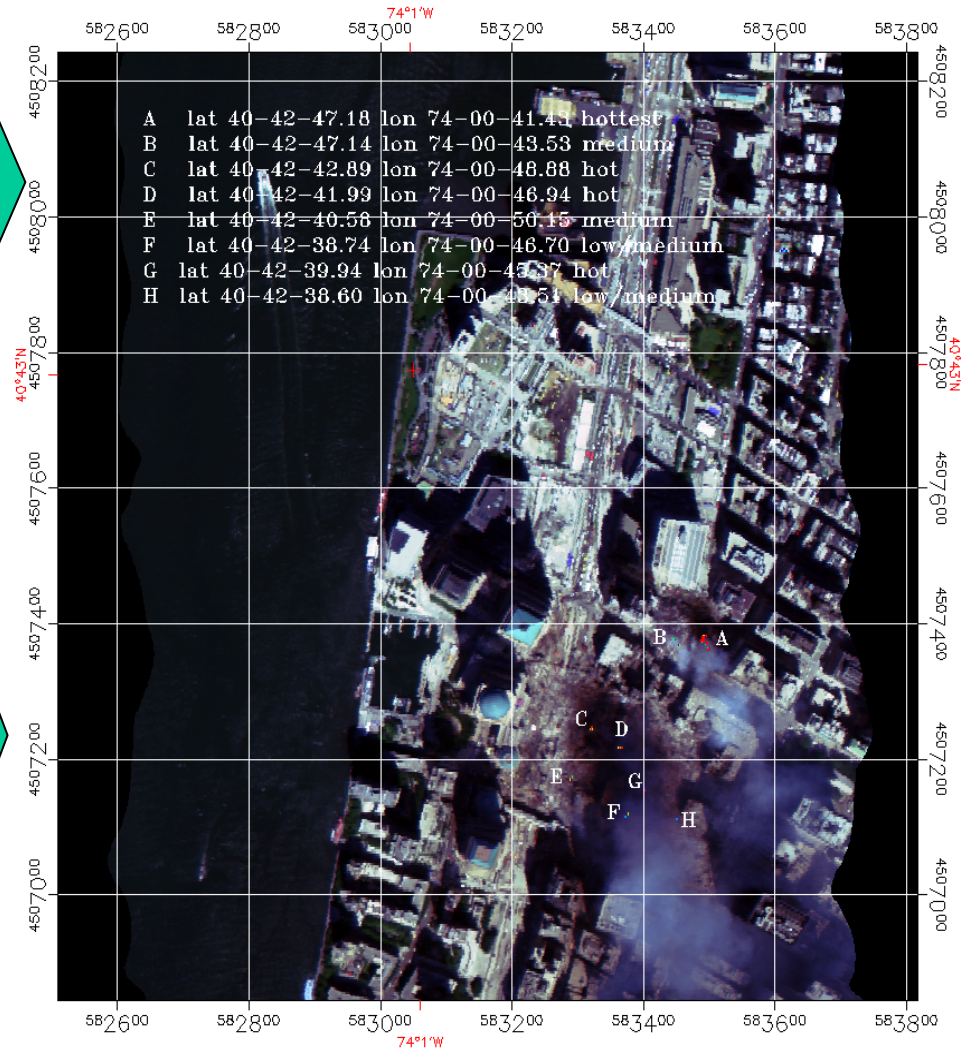
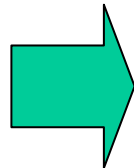
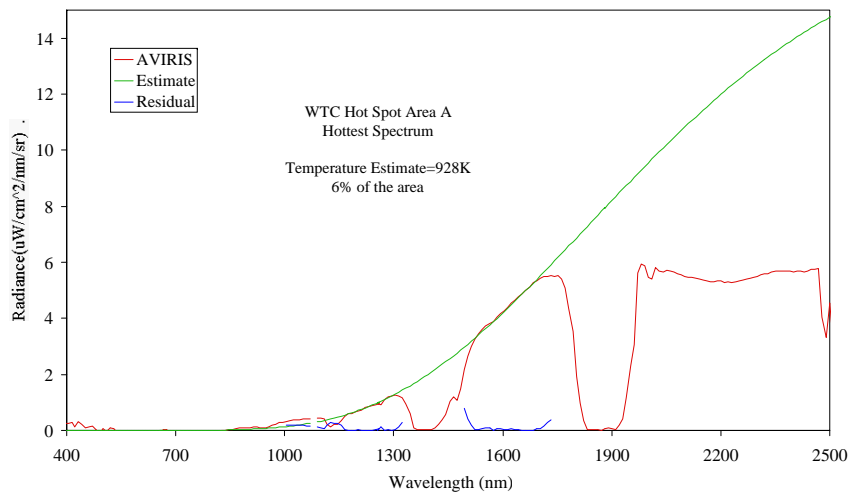


World Trade Center Hot Spot Mapping

Radiance Image Cube (SWIR)



Model Matching to Planck Blackbody



Fraction, temperature, and latitude, Longitude coordinates for each hot spot

World Trade Center Asbestos Mapping

Library Spectra

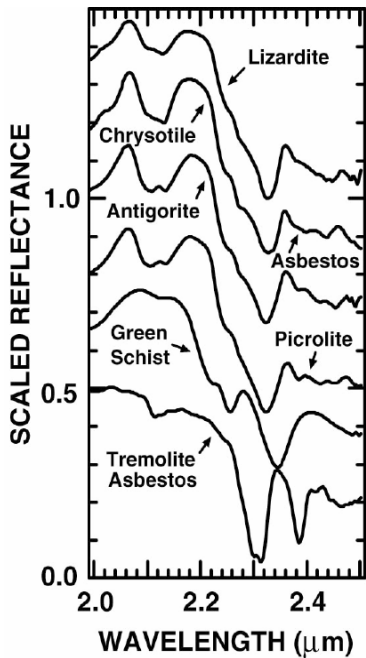
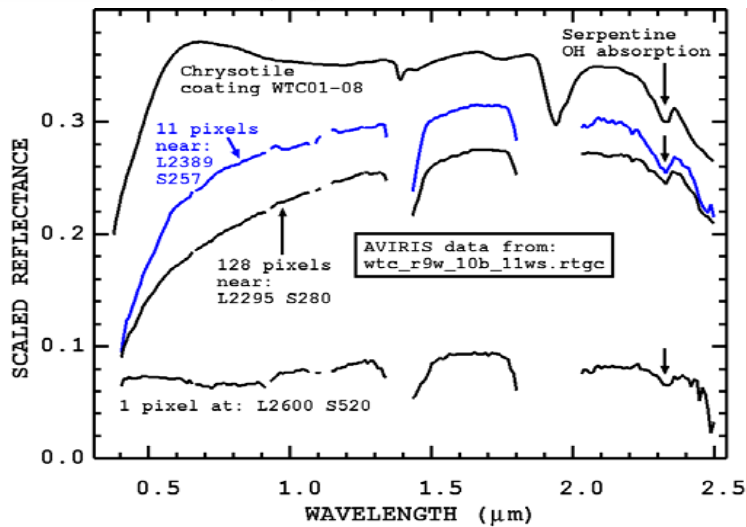


Image map
Of match to
Chrysotile

Match to
measured
spectra



World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0a8
product

Material Absorption
Feature map (minerals
with Mg-OH features
near 2.3-microns):

Possible
Serpentines
possible
chrysotile

Possible
Amphiboles or Clays

Possible
actinolite or
richterite
talc or
tremolite

saponite or
talc or
tremolite

Possible detection of
serpentines and
amphiboles on this map
does not distinguish
between asbestiform
and non-asbestiform
varieties.

Image sampling:
1.7 meters/pixel

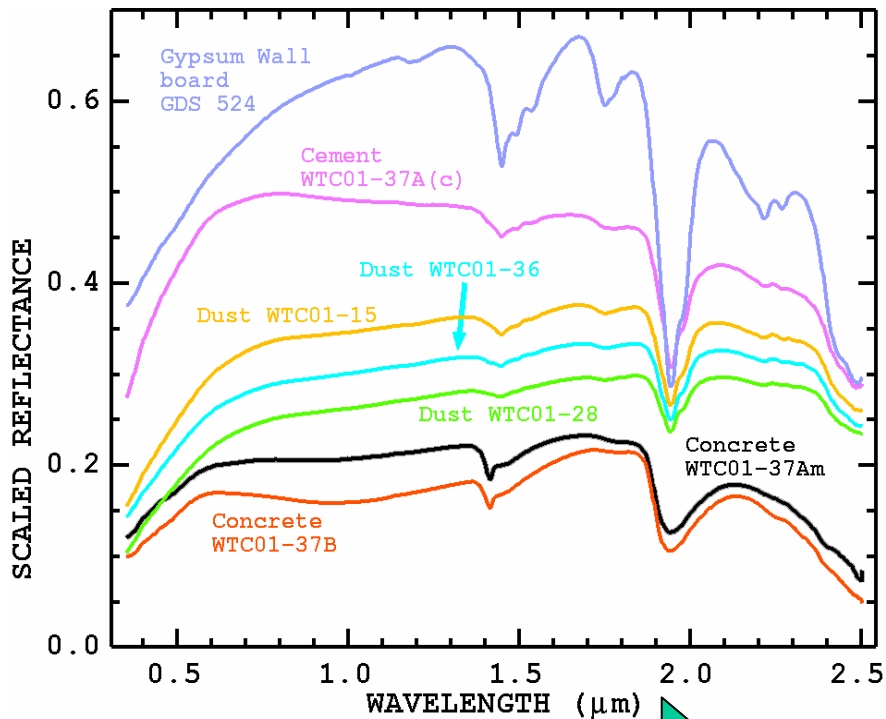
N
200
meters

Preliminary
Scientific
Data Product
subject to
revision



World Trade Center Debris Identification

Site-specific spectral library



Feature Matching to Reflectance spectra

World Trade Center area, New York

U.S. Geological Survey
Clark et al., 2001

NASA/JPL AVIRIS data
Sept 16, 2001 16:21 GMT

USGS
Imaging Spectroscopy
Tetracorder 4.0awtc2
product

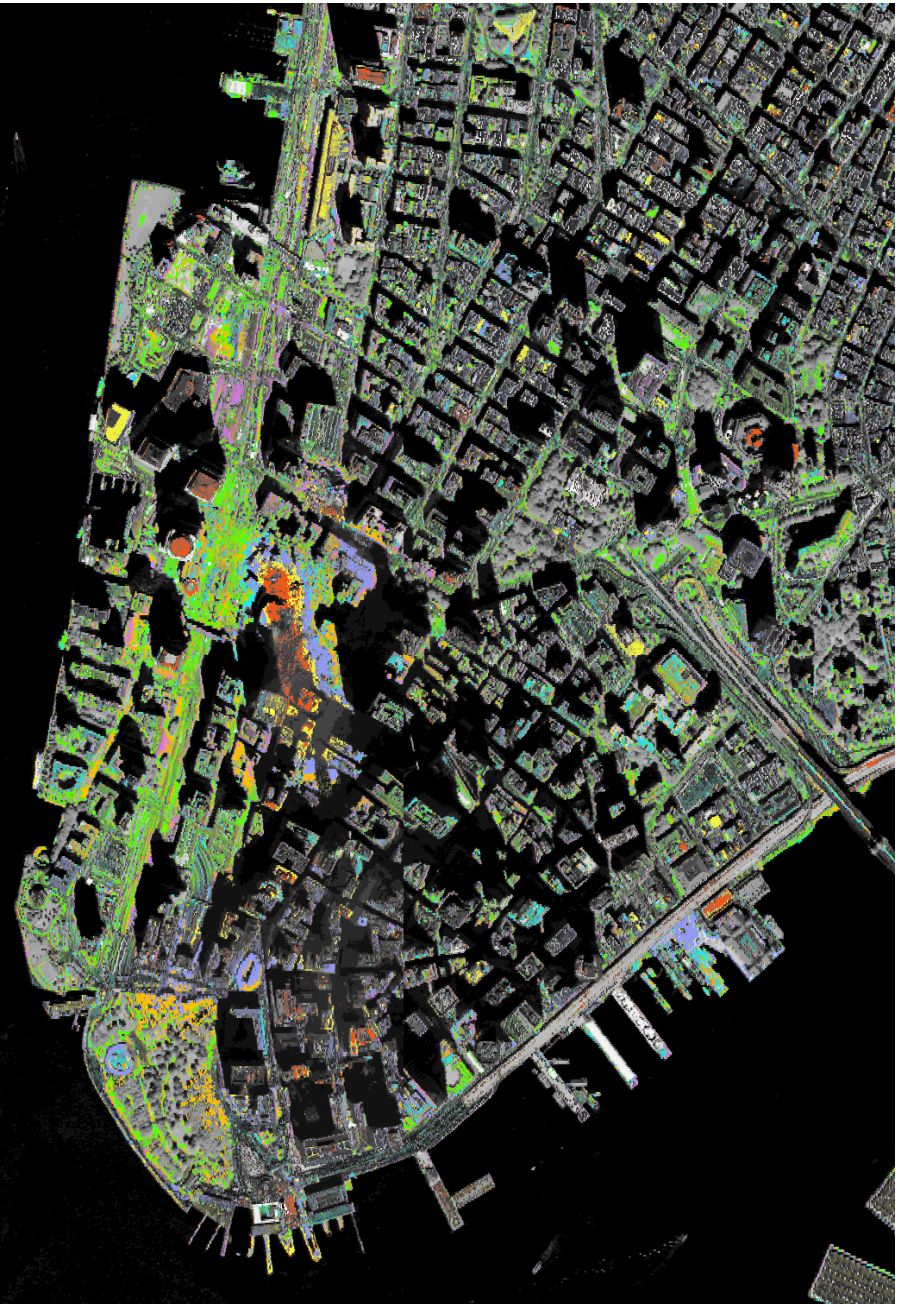
Spectral Shape Map

This map shows materials whose spectra are similar to the reference materials below. It is not a map of the identification of these materials. A similarity map is analogous to a map of materials with similar colors viewed with your eyes. The colors may indicate similar compositions.

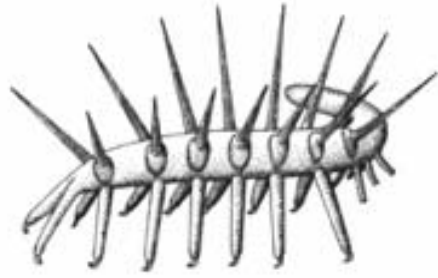
- concrete (WTC01-37B)
- concrete (WTC01-37Am)
- cement (WTC01-37A)
- dust (WTC01-15)
- dust (WTC01-28)
- dust (WTC01_36)
- gypsum wall board

Image sampling:
1.7 meters/pixel

N
↑
200
meters



Guess the Genetic Survivors of the Burgess Shale which one are we most closely related to?



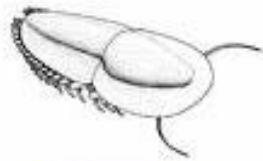
Hallucigenia



Opabinia



Marella



Naraoia



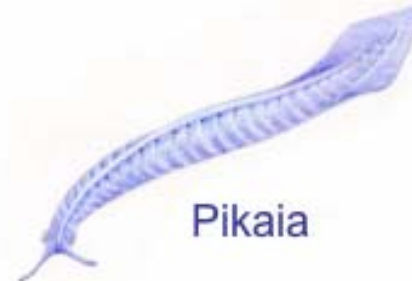
Aysheaia



Anomalocaris



Wiwaxia



Pikaia

Dominant Form of Life On Earth?

