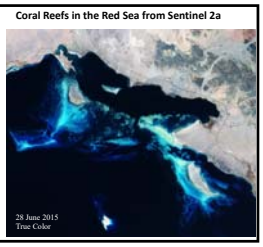
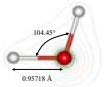
Coral Reefs in the Red Sea from Sentinel 2a

Session 2 (1 hr): Prof. Susan L. Ustin

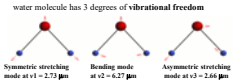
Title: Principles of remote sensing of water in the solar spectral region



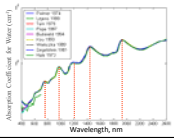
Absorption of energy by water



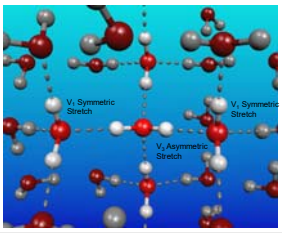
water molecule has 3 degrees of **vibrational freedom**

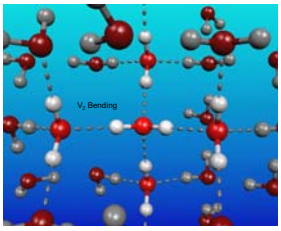


Combination	Liquid state
$v1 + v3$	0.739 μm
$2v1 + v3$	0.970 μm
$v1 + v2 + v3$	1.200 μm
$v1 + v3$	1.450 μm
$v2 + v3$	1.940 μm

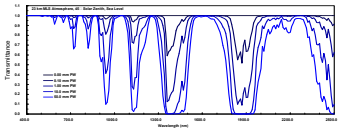


http://omlc.ogi.edu/spectra/water/



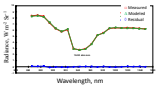


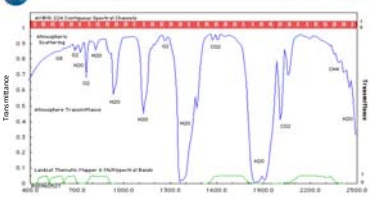
Influence of Water Vapor on the Solar Reflected Spectrum



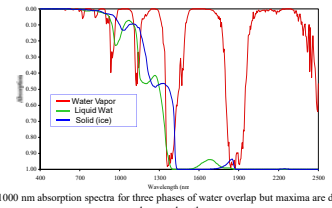
1. As water vapor becomes more concentrated, the band depth is deeper and broader and peak wavelength shifts.

2. Water Vapor can be Estimated by Spectral Fitting





Absorption by Water Vapor, Liquid and Solid Phases in the Solar Reflected Spectrum



Near 1000 nm absorption spectra for three phases of water overlap but maxima are displaced by wavelength

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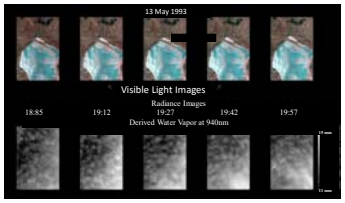
Water Vapor Measured at Rogers Dry Lake, CA



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Santa Monica Mountains, CA Measured with AVIRIS

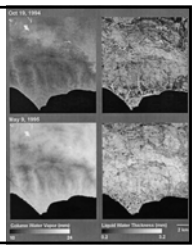
Differences in atmospheric water vapor and liquid water in the vegetation canopy

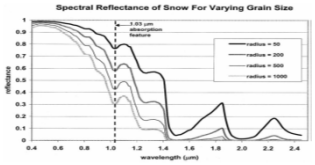
During Autumn and Spring over Santa Monica Mts., California

Image left: water vapor
Image right: liquid water

Darker areas have less water vapor between land surface and airborne detector.

To a first approximation the patterns represent topographic features.





• Reflectance *increases* as grain size *decreases*

Nolan and Dozier, 2000, Remote Sens. Environ. 74:207–216.

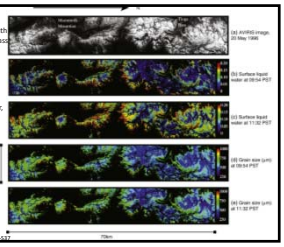
(a) AVIRIS image of Sierra Nevada from south of Mammoth Mountain to north of Tioga Pass acquired on 20 May 1996.

(b) Derived surface liquid water (0 to 0.20 volume fraction) at 09:54 PST (17:54 UTC).

(c) Derived surface liquid water 98 min later, at 11:32 PST (19:32 UTC).

(d) Derived grain size (radius of effective sphere, 250 to 1000 µm) at 09:54 PST.

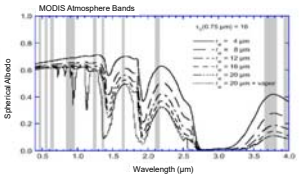
(e) Derived grain size at 11:32 PST.



Dozier et al. 2009, Remote Sens. Environment 113:325-337

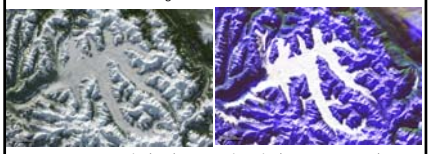
Reflectance of Clouds

Increases as droplet size decreases



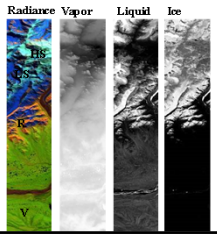
The smaller the droplet, the larger the surface area to volume is.
More surface area increases reflectance.

How to Distinguish Clouds and Snow?



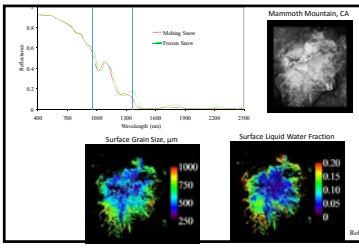
True Color (RGB) False Color (SWIR2, SWIR1, NIR)

OLI Data (from Landsat 8) of glacier in Vancouver, Canada 8 Jan. 2016

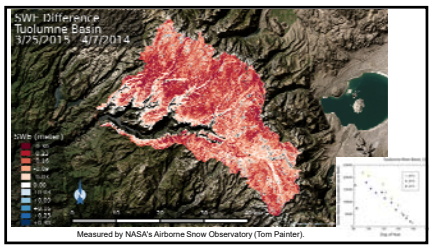


- **Water vapor** ranges from 0.51 to 12.7mm precipitable water per pixel
- **Liquid water** ranges from 0 to 7.4 mm equivalent path transmittance
- **Ice** ranges from 0 to 27.9 mm equivalent path transmittance

Robert O. Green

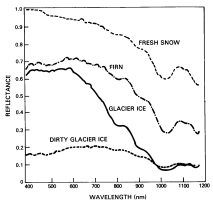


Robert O. Green



Measured by NASA's Airborne Snow Observatory (Tom Painter).

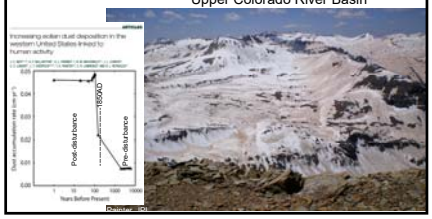
Weathering and Aging of Ice and Snow



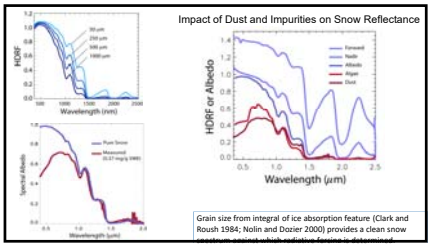
Why do we care?

Tom Painter, JPL

Upper Colorado River Basin



Impact of Dust and Impurities on Snow Reflectance



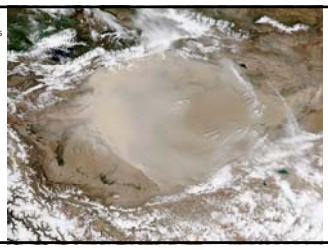
Grain size from integral of ice absorption feature (Clark and Roush 1984; Nolin and Dozier 2000) provides a clean snow spectrum against which radiative forcing is determined

Glacial Retreat on Ellesmere Island, Canada

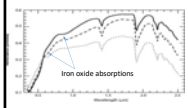
Taklimakan Desert acquired May 1, 2016

Visible bands,

Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi NPP satellite



Measuring Dust Composition from Spectroscopy

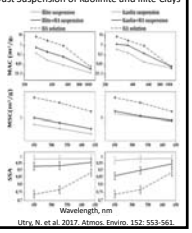


Spectra of CH08. Spectra of dust samples from a 2:1 mixture of high magnetization goethite and hematite from the Bodélé Depression, Chad.

Measured for three particle size fractions: fine (PM63, solid line), medium (63–125 μm, dashed-line), and coarse (125–2000 μm, dotted-line).

Moskowitz, B.M. 2016. Aeolian Research 22: 93-106.

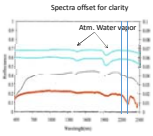
Dust Suspension of Kaolinite and Illite Clays



Utry, N. et al. 2017. Atmos. Enviro. 152: 553-561.

NaCl Laboratory spectrum
KCl Laboratory spectrum
Average Spectrum (n=1029),
Gypsum Laboratory spectrum ($CaSO_4$ 2 H_2O)

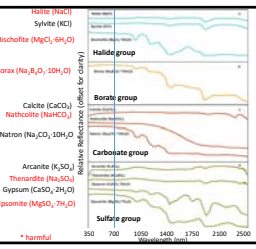
Spectra offset for clarity



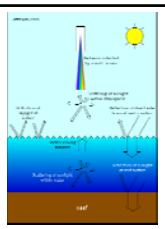
Lake Maharlu in the Mountains of Southwest Iran

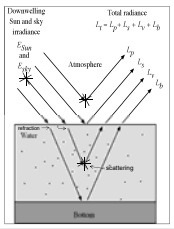
the Salar de Arizaro, Argentina

Spectra of common salts are found on dry lakebeds, that might become wind-blown



Sources of light contributing to the remotely sensed signal of water bodies





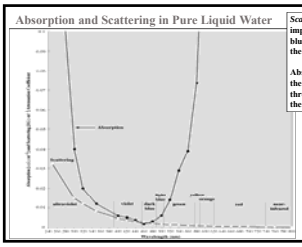
Absorption & Scattering from Water

Total radiance, (L_t) recorded by a remote sensing system over water is a function of the electromagnetic energy received from:

L_p = atmospheric path radiance
L_s = free-surface layer reflectance
L_v = subsurface volumetric reflectance
L_b = bottom reflectance

Jensen, 2000

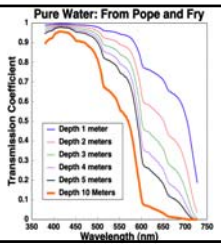
Absorption and Scattering in Pure Liquid Water



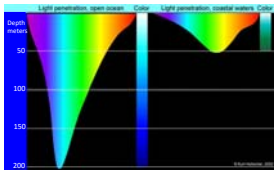
***Scattering* in the water column is important in the violet, dark blue, and light blue portions of the spectrum (400 - 500 nm).**

Absorption data is truncated in the ultraviolet and in the yellow through NIR regions because the attenuation is so large.

Jensen, 2000

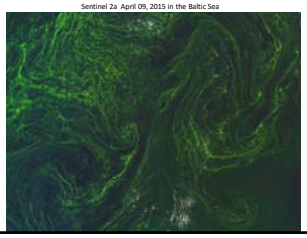


Light Penetration in Water

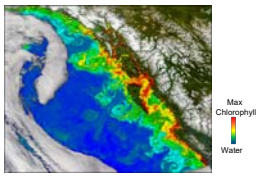


What λ order are these displayed in?

Sentinel 2a April 09, 2015 in the Baltic Sea



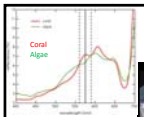
Chlorophyll Density in Coastal Waters



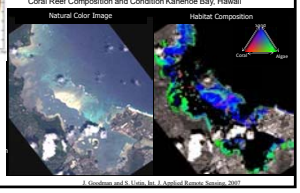
Colors indicate chlorophyll concentrations in this SeaWiFS image of the coast of British Columbia, Canada (NASA)

SeaWiFS (Sea-viewing Wide Field of View Sensor)

Monitoring Health of Coral Reefs and their Composition

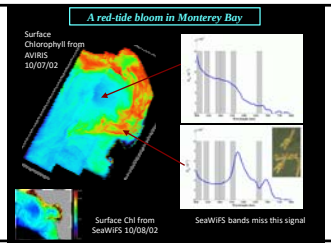


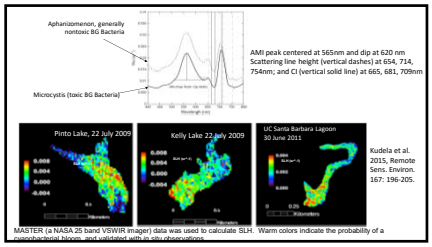
Coral Reef Composition and Condition Kanehoe Bay, Hawaii



J. Goodman and S. Ustin, Int. J. Applied Remote Sensing, 2007

A red-tide bloom in Monterey Bay

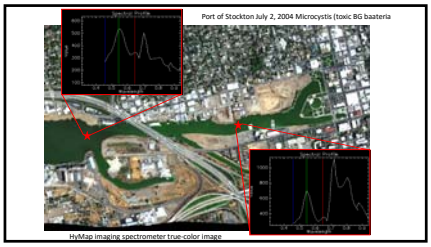




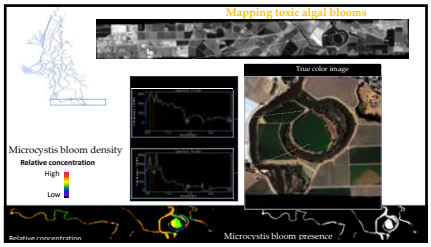
AMI peak centered at 565nm and dip at 620 nm Scattering line height (vertical dashes) at 654, 714, 754nm; and CI (vertical solid line) at 665, 681, 709nm

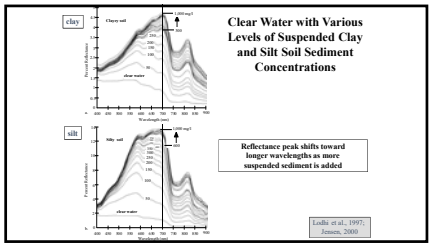
Kudela et al. 2015, Remote Sens. Environ. 167: 196-205.

MASTER (a NASA 25 band VSWIR imager) data was used to calculate SLH. Warm colors indicate the probability of a cyanobacterial bloom, and validated with in situ observations



HyMap imaging spectrometer true-color image



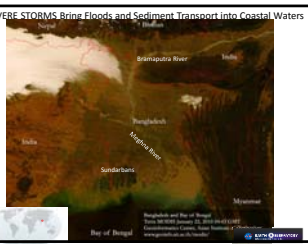


Clear Water with Various Levels of Suspended Clay and Silt Soil Sediment Concentrations

Reflectance peak shifts toward longer wavelengths as more suspended sediment is added

Ledhe et al., 1997; Jensen, 2000

SEVERE STORMS Bring Floods and Sediment Transport into Coastal Waters

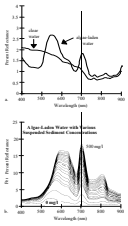


Deforestation in the mountains and loss of mangrove forest in the Betsiboka Estuary, on the northwest coast of Madagascar, has accelerated soil erosion after heavy rains. Sediments with iron oxides produce the color

Flooding in Southern Africa

Jan. 31, 2013

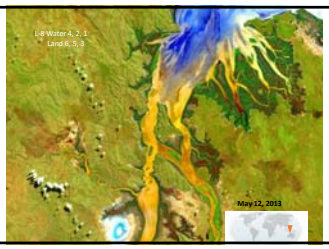
43



% reflectance of clear water and algae-laden water

% reflectance of algae-laden water at various suspended sediment concentrations ranging from 0 - 500 mg/l

Han, 1997; Jensen, 2000



Trellis Drainage: Formed by bands of hard and soft rock or in folded areas of mountains

Yarlung Tsangpo River, China (Credit: NASA/GSFC/LaRC/JPL, MISR Team)

Brahmaputra River (braided or meandering stream channel)

Located between the Tibetan Plateau to the north and the Himalaya Mountains to the south; about 35km south of Lhasa

15km length of river

A process when faster-moving water erodes the outer banks and widens its valley, and slower-moving water on the inner side of the bend is where sediments are deposited.

Space Shuttle Photograph

Teshekpuk Lake on Alaska's North Slope

Beaufort Sea

Tundra Thermokarst Development

Combination of Ice heaving and Wind direction

Lake colors:
Sediment differences
Depth differences
Sun angle differences?

ASTER 08/15/2000

Map Glacial Retreat and Rate of retreat

Helheim glacier (outlet from Greenland Ice Sheet)

June 2005 (top),
July 2003 (middle),
and May 2001 (bottom).