Solar Radiation Transfer through Vegetation, Part 2

- Scattering Theory
  - leaf optical properties
- Two-Stream Models for Radiative Transfer through Vegetation
- Modeling Albedo
- Remote Sensing
  - Satellites, Sensors
  - Vegetation Indices

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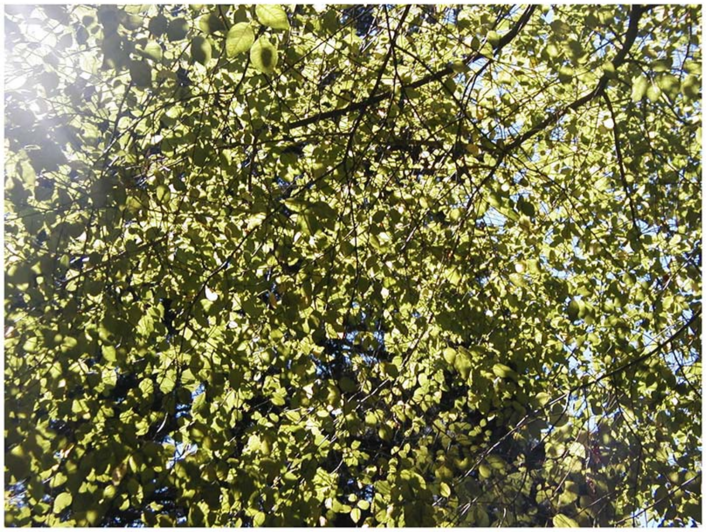
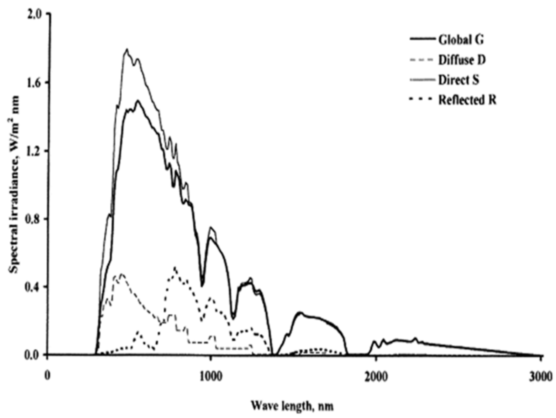
Last lecture we spoke of how one aspect of light in canopies is complimentary radiation, due to transmission and reflectance. We cover this aspect here. This topic is especially important for interpreting remote sensing from sensors on satellites or aircraft. The interpret reflectance signals from vegetation to interpret information about its structure, photosynthetic capacity, temperature, evaporation, health etc.

Absorption + Transmission + Reflectance = 1



Composition of Sunlight in a Canopy



From Ross, 1981

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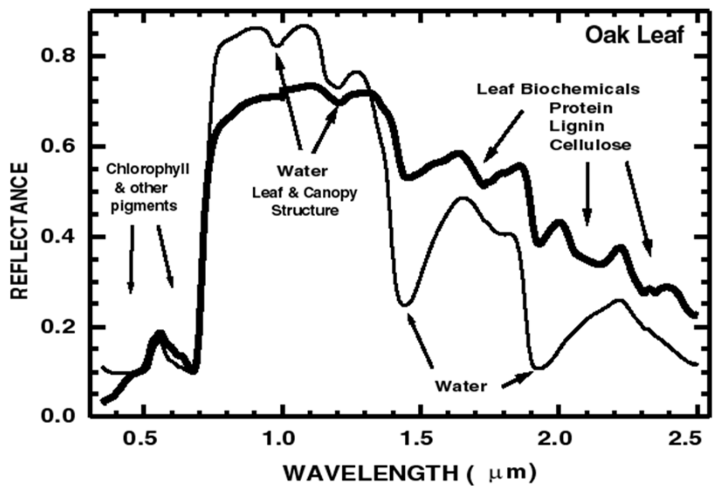
Interactions with foliage filters the amount and quality of sunlight in a canopy

Ross, J. 1980. The Radiation Regime and Architecture of Plant Stands. Dr. W Junk, The Hague.

Spectrum of a Leaf



data from : speclab.cr.usgs.gov/national.parks/ Yellowstone/jplfig2.gif

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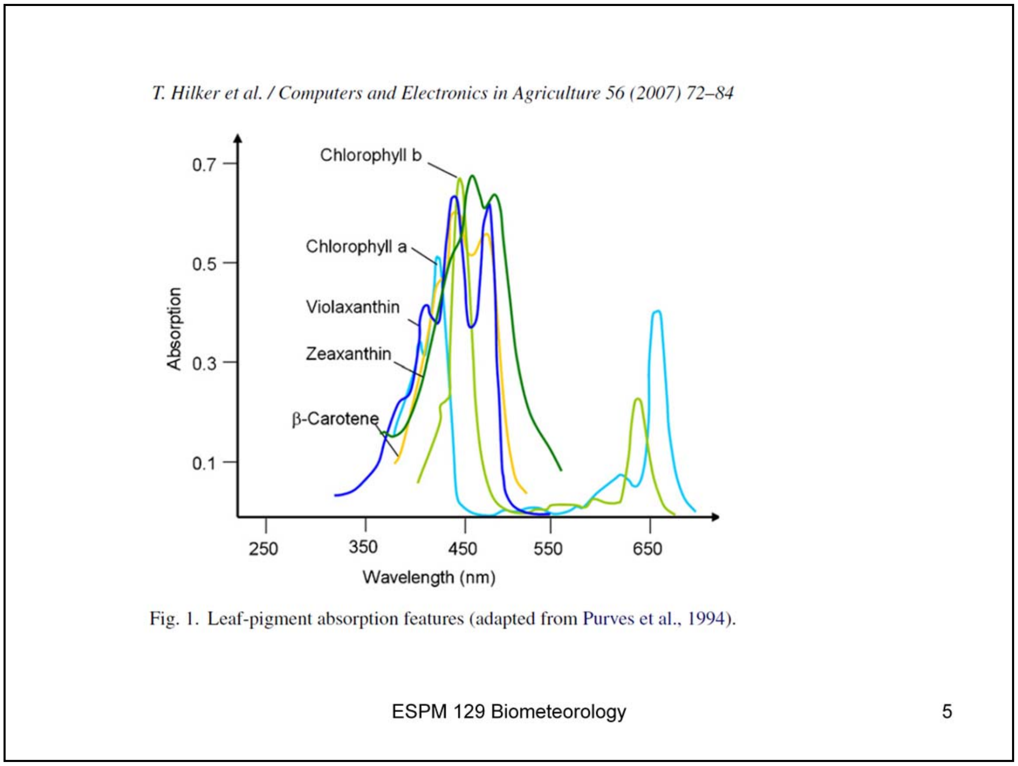
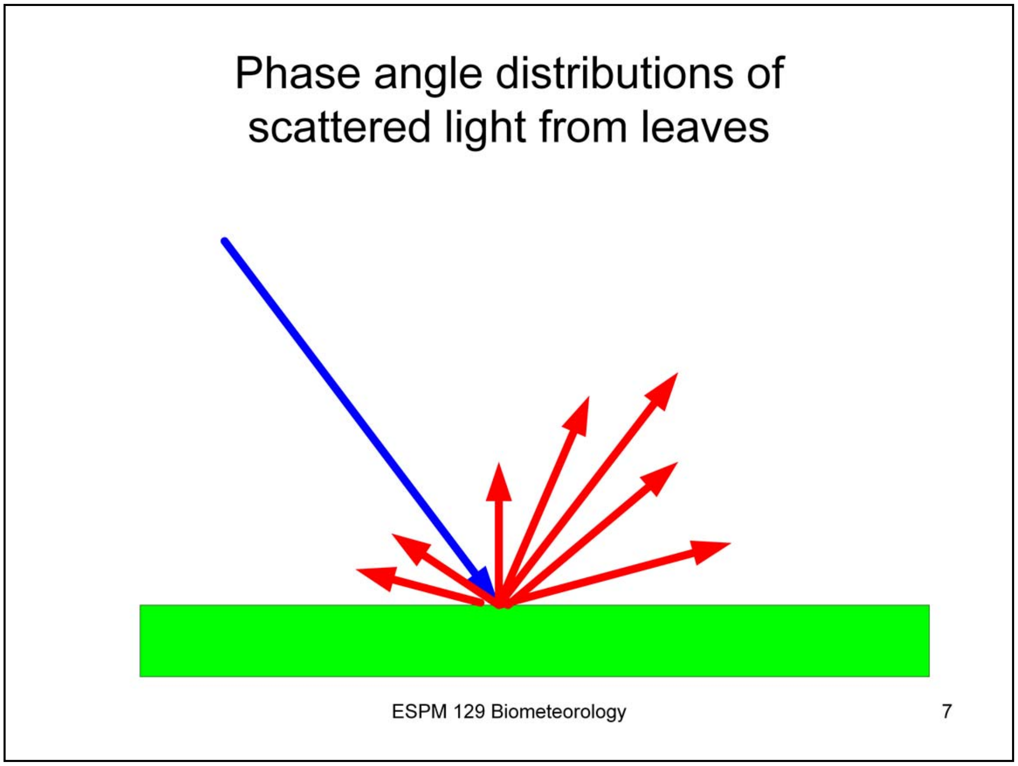
Here is the full short wave radiation spectrum of leaf reflectance. Note absorption by chlorophyll and pigments. Reflectance by water, by proteins, lignin and cellulose



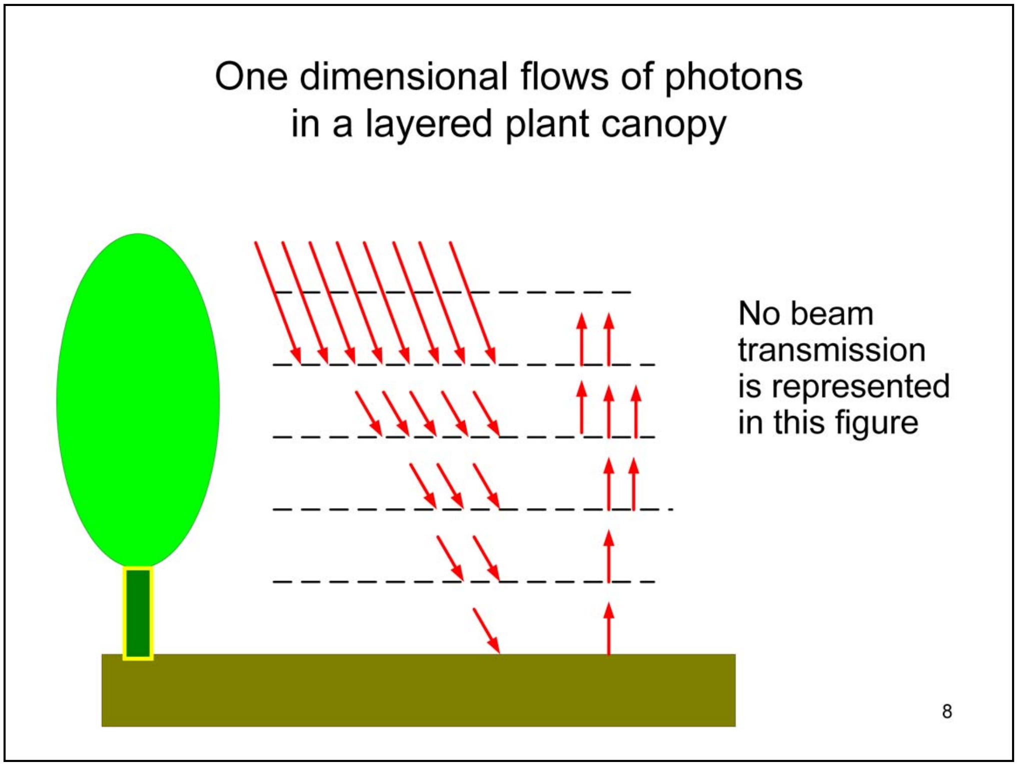
Absorption by Chlorophyll is strong near 450 nm and 650 nm

Typical optical properties for green leaves

	PAR, Visible	NIR	Solar shortwave
reflectance	0.09	0.51	
transmittance	0.06	0.34	
scattering	0.15	0.85	
absorptance	0.85	0.15	

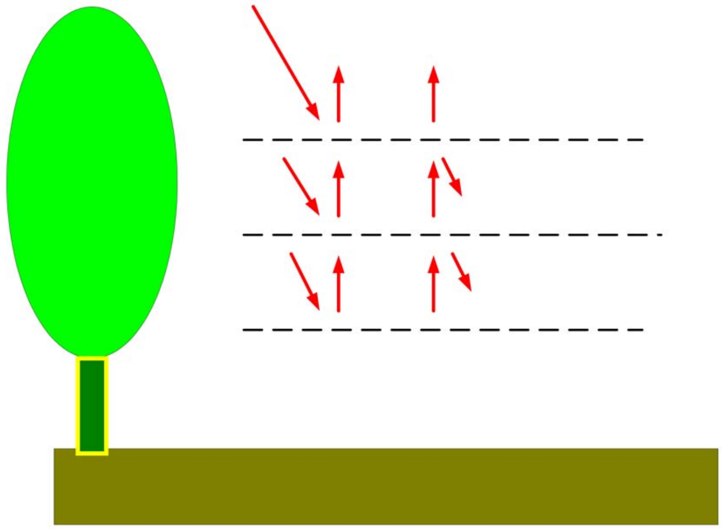


Scattering of light has a phase angle distribution



Simple one dimensional transfer of diffuse light

Flows of photons across adjacent layers



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Kubelka-Munk Eq, Suits (1972) version

The change in downward directed sunlight is **diminished** by the amount of diffuse radiation that is attenuated by a layer of leaves and it is **augmented** by the amount of upward directed diffuse radiation and beam radiation that is scattered downward.

The scattering factors are for layers not leaves.

$$\frac{dI\downarrow(\tau)}{d\tau} = aI\downarrow(\tau) - bI\uparrow(\tau) - c\,I_{beam}(\tau)$$

$$\frac{dI_{beam}}{d\tau} = -K \cdot I_{beam}$$

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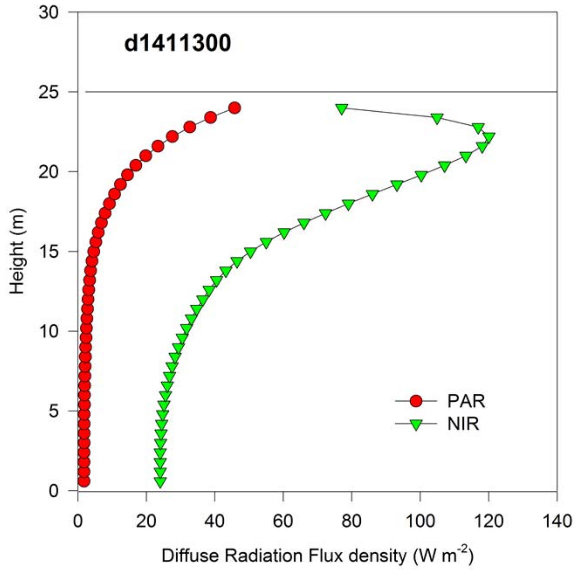
Kublelka Munk equation is a simple but salient model to define the main streams of photons in a turbid medium

The flux density of upward directed radiation is *diminished* by the amount of diffuse and beam radiation that is scattered and is **augmented** by the amount of upward directed diffuse radiation
that is transmitted through the layer.

$$\frac{dI\uparrow(\tau)}{d\tau} = -a\,I\uparrow(\tau) + b\,I\downarrow(\tau) + c\,I_{beam}(\tau)$$

Profiles of diffuse radiation in the NIR and PAR wavebands



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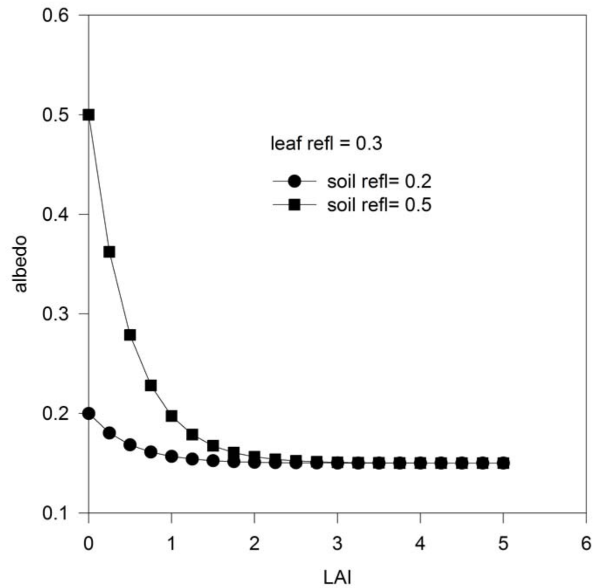
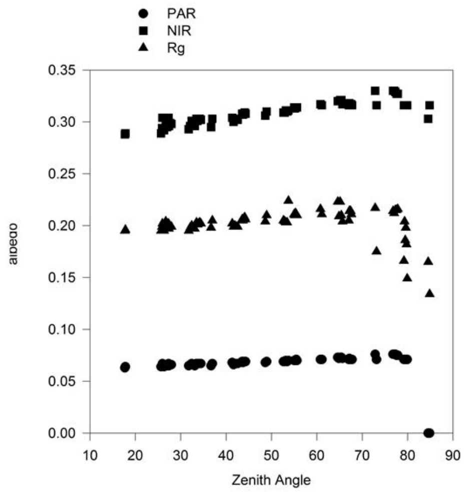
You can see visually the development of complimentary NIR radiation in the upper reaches of the canopy.

Albedo calculations as a function of leaf area index, using a simple big leaf model

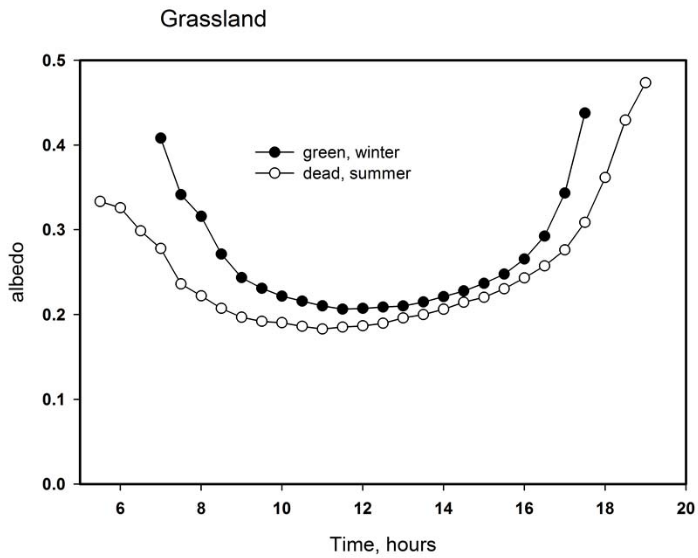


Canopy reflectivity as a function of waveband and solar angle



These calculations were based on a slab layer model.
What is wrong with them?

Diurnal pattern of albedo for two periods during the year over a California annual grassland



Remote Sensing, Scientific Persian Rug

Provides Spatial information on the Mosaic

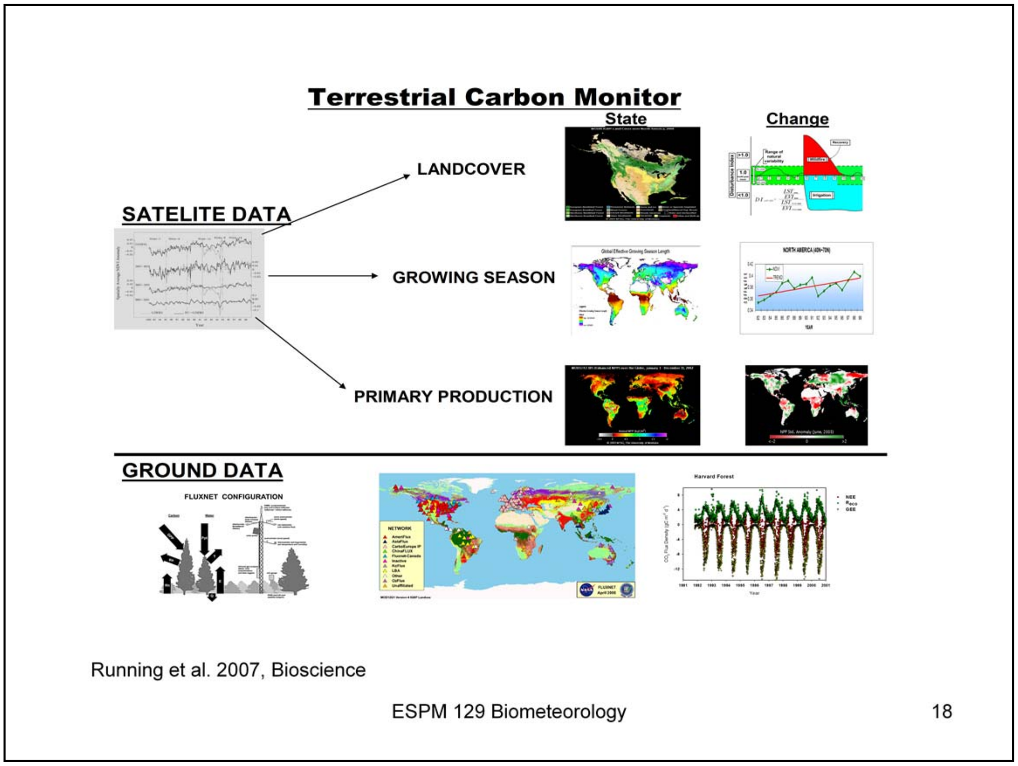
Requires Validation on How Bright or How Large the pixels may be

Challenge for Landscape to Global Upscaling

Converting Virtual ‘Cubism’ back to Virtual ‘Reality’

Realistic Spatialization of Flux Data
Requires the Merging Numerous Data Layers with varying:
Time Stamps (hourly, daily, weekly),
Spatial Resolution (1 km to 0.5 degree) and
Data Sources (Satellites, Flux Networks, Climate Stations) and Using these
Data to Force Mechanistic Biophysical Model

As noted we are dealing with a hierarchy of space scales. Different remote sensing sensors can view the ground at different spatial resolution, to build a spatial mosaic of the land surface.



Remote sensing can give us lots of different types of information that is of interest to ecosystem ecologist. GPP, leaf area index, evaporation, fire, disturbance, land use, change in land use, fraction of land cover, etc, etc

Satellites

- **Pros**
- Global, Regional and Local Coverage
- Can detect Seasonal trends, inter-annual Changes in Surface Properties
- Can Detect Change by Disturbance

- **Issues**
- Resolution of Spectral Bands
- Number of Bands
- Sampling Frequency
- Spatial Resolution
- Validate Algorithms with Direct Eddy Flux Measurements

- **Cons**
- Clouds, Clouds, Clouds
- Inferred estimates of NPP and LAI
- Relies on Empirical Algorithms
- Intermittent Coverage
- Can’t Assess NEP or ET directly

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Remote sensing has a bunch of attendant pros and cons. The most glaring con is clouds. Most passive sensors can’t see through clouds. Other issues are overpass times and view frequency.

AVHRR

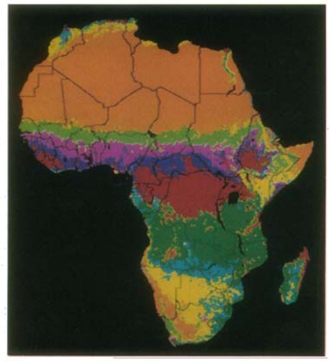
AVHRR	1 km pixel	4-5 broadbands (visible, NIR and thermal)	2399 km swath 14 times day, polar orbit	**1978 to present**

AVHRR Sensor characteristics

Swath width	2399km
Resolution at nadir	1.1km approx.
Altitude	833km
Quantisation	10 bit
Orbit type	Sun synchronous
No. of orbits per day	14.1 (approx.)

AVHRR Spectral characteristics

Channel No	Wavelength	Typical use
1	0.58 - 0.68	Daytime cloud, haze and surface mapping
2	0.725 - 1.00	Land-water boundaries
3	3.55 - 3.93	Night cloud mapping, sea surface temperature
3A	N/A	Snow and ice detection
3B	N/A	Night cloud mapping, sea surface temperature
4	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	11.50 - 12.50	Sea surface temperature



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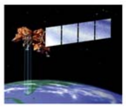
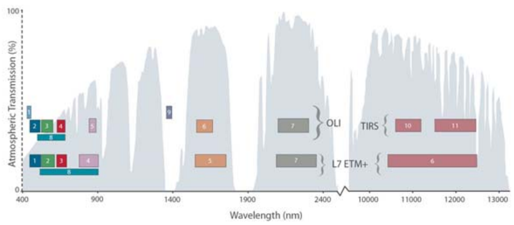
One of the longest sensor systems in orbit. It is important for detecting changes in land use over time. Few spectral bands and coarse spectral resolution. Fairly good spatial, pixel resolution, 1 km. Frequent overpasses, 14 times per day.

LANDSAT

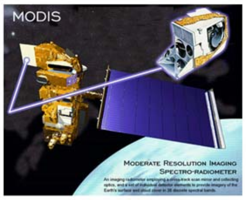


	spatial	bands	Frequency/ Domain	launch
Landsat TM	15m Panchromatic 30m PAR, NIR, SWIR 100m therma	11 bands Pan 520-900nm 5 Bands VNIR 2 Bands SWIR 1 Band TIR	16 days	LANDSAT1, 1972 LANDSAT 8, 2013

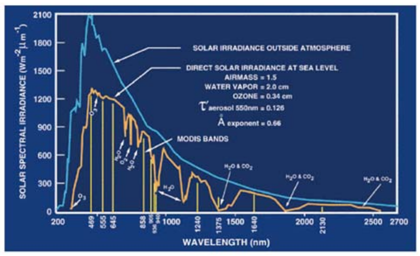


Fairly high resolution image of earth, at 30 m resolution. The series goes back to 1972 and recently LANDSAT 8 was launched. With high spatial resolution comes less frequent overpasses, every 16 days. Has a fair number of bands in visible, near infrared and thermal bands.

MODIS



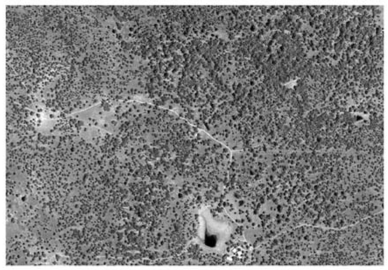
	resolution		repeat	duration
MODIS	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)	36 bands	1030 hrs Terra 1330 hrs Aqua (8 day composites are produced)	**1999 Terra; 2002 Aqua**



MODIS has become a workhorse for many land-atmosphere studies over the last decade. Daily overpass, 36 bands and moderate spatial resolution, 1 km.

IKONOS, SPOT, Quick Bird

IKONOS	1m PAN 4m multispectral (MS)	MS 4 bands (450-520, 520-600, 630-690, 760-900nm) Pan (525.8-928.5nm)	Revisit 1-3 days	1999
Quickbird	60 cm PAN 3 m MS		18 x 18 km	2001



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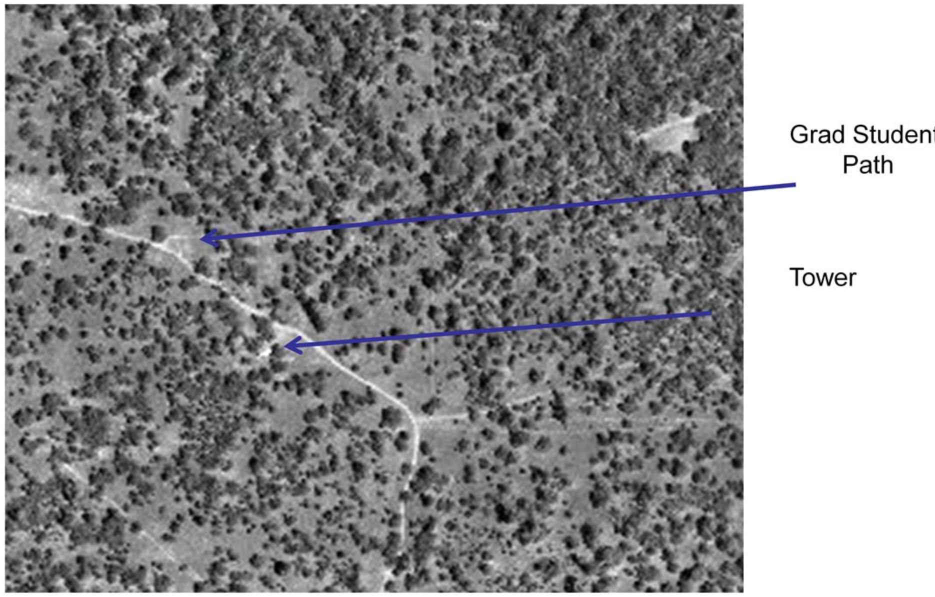
Sensors like IKONOS, SPOT and Quick Bird are commercial and tasked. Yet they can give you super high spatial resolution, down to 1 m.

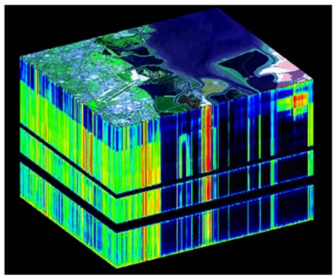

Grad Student Path
Tower

Spatial Resolution

Maggie Kelly

AVIRIS

AVIRIS	20 m pixel, 11 km swath	224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers, 10 nm.	Airborne on U2	On request



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AVIRIS is flown on U2 for scheduled tasks. It provides a hypercube of data with 224 contiguous spectral changes. The areal domain is limited. Here is an image over our Delta field sites this summer

Twitchell Island

My House

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GOOGLE EARTH

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Hard to Beat Google Earth in terms of details and high resolution images of a scene or landscape. But the images are not refreshed often, so hard to do science with them.

Take Home Points

Trade-Offs between Duration and Longevity and Fewer Bands (AVHRR, LANDSAT)

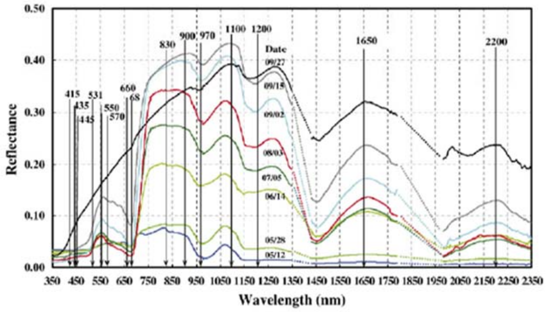
Higher Number of Channels (MODIS) and Regular Overpass

Lower Frequency of Overflights and Higher spatial resolution (IKONOS, QUICK BIRD, AVIRIS)

Vegetation Indices

Normalized difference vegetation index	NDVI	$$\frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d}$$
Enhanced vegetation index	EVI	$$EVI = Gain \frac{NIR - \mathrm{Re}\,d}{C_1 + \mathrm{Re}\,d + (C_2\,\mathrm{Re}\,d - C_3 Blue)}$$
Soil adjusted vegetation index	SAVI	$$\frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d + L}(1 - L)$$
Photochemical reflectance index	PRI	$$\frac{R_{531} - R_{570}}{R_{531} + R_{570}}$$
Simple ratio	SR	$$\frac{NIR}{\mathrm{Re}\,d}$$

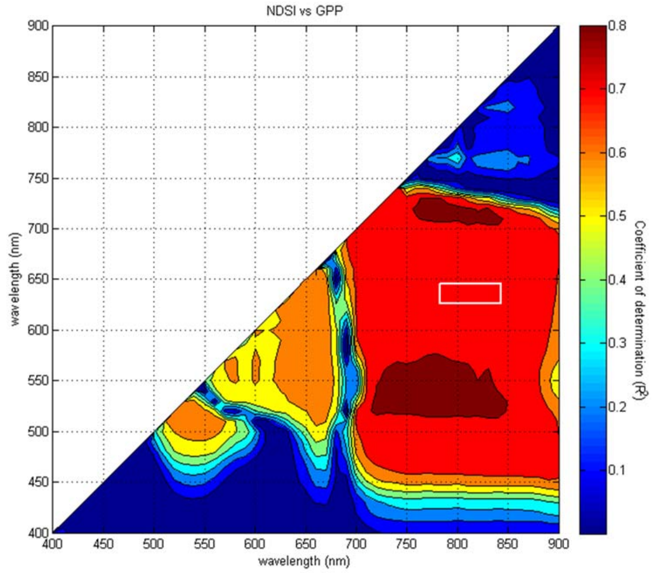
Alphabet Zoo of Vegetation Indices



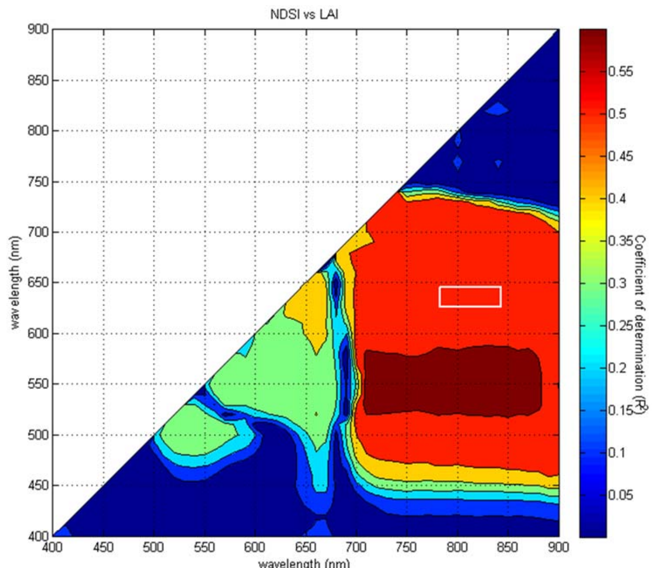
PRI: [R531−R570]/[R531+R570]
WI: R900/R970
SIPI: [R800−R445]/[R800−R680]
NPQI: [R415−R435]/[R415+R435]
GRI: R830/R550
SWWI: R1650/R850
NDVI: [R830−R660]/[R830+R660]
SAVI: 1.5[R830−R660]/[R830+R660+0.5]
RVI: R830/R660
WDVI: R830−1.06R660
MSAVI: (1+0.5)[R830−R660]/[R830+R660+0.5]
EVI: 2.0[R830−R660]/[1+R830+6R660−7.5R460]
GEMI: $\eta(1-0.25\eta)$−(R660−0.125)/(1−R660)
NDMI1: [R1650−R830]/[R1650−R850]
NDMI2: [R2200−R1100]/[R2200+R11100]
BI: 6 [R460/R660]

Inoue et al 2008. RSE

NSDI= R(λ_2)-R(λ_1)/R(λ_2)+R(λ_1)



NSDI= $R(\lambda_2)-R(\lambda_1)/R(\lambda_2)+R(\lambda_1)$



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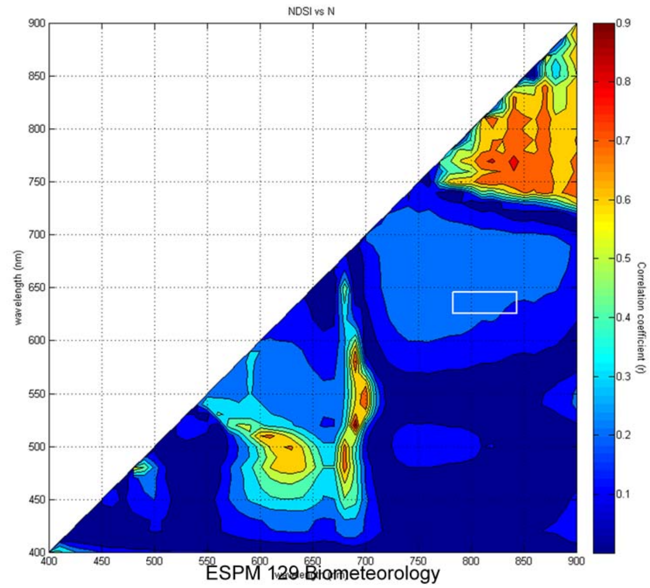
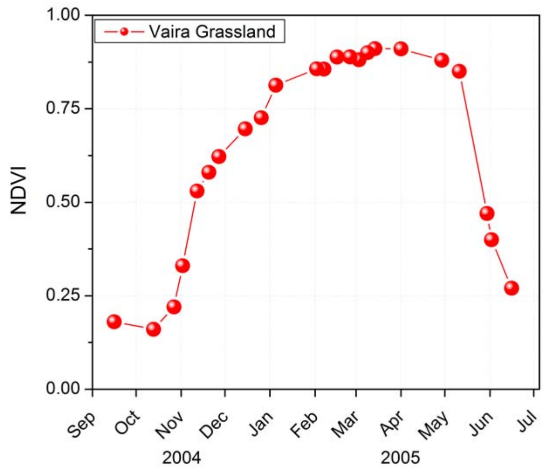
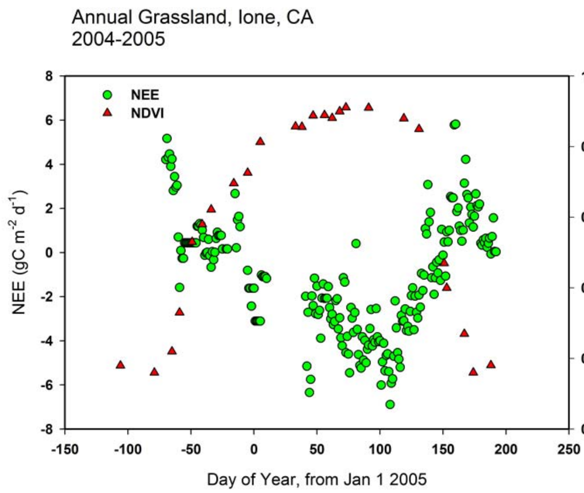


Seasonality of NDVI





Annual Grassland, Ione, CA
2004-2005
NEE
NDVI
NEE (gC m-2 d-1)
NDVI
Day of Year, from Jan 1 2005

Summary

- Leaves are dark in the visible and reflective in the NIR
- Radiative transfer models consider beam penetration and scattering of light by leaves
- Satellites provide indirect information on canopy structure and function via vegetation indices that record reflected sunlight in different EM bands
- Satellite spatial resolution tends to be inversely related to spectral resolution

	resolution		repeat	duration
MODIS	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)	36 bands	1030 hrs Terra 1330 hrs Aqua (8 day composites are produceds)	**1999 Terra; 2002 Aqua**
AVIRIS	20 m pixel, 11 km swath	224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers, 10 nm.	Airborne on U2	On request
IKONOS	1m Panchromatic 4m multispectral (MS)	MS 4 bands (450-520, 520-600, 630-690, 760-900nm) Pan (525.8-928.5nm)	1-3 days	
SPOT-5	2.5 & 5m Pan 10m MS 20m SWIR band	MS 4 bands (500-590, 610-680, 790-890, 1580-1750nm) Pan 510-730nm	3 to 26 days ±31° inclination	
AVHRR	1 km pixel	4-5 broadbands (visible, NIR and thermal)	2399 km swath 14 times day, polar orbit	**1978 to present**
Landsat TM	15m Pan 30m MS 60m TIR I	Pan 520-900nm 5 Bands VNIR 2 Bands SWIR 1 Band TIR	16 days	1999 landsat 7

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http://homepage.mac.com/alexandreleroux/arsist/

Some of the highlights on the Sensors