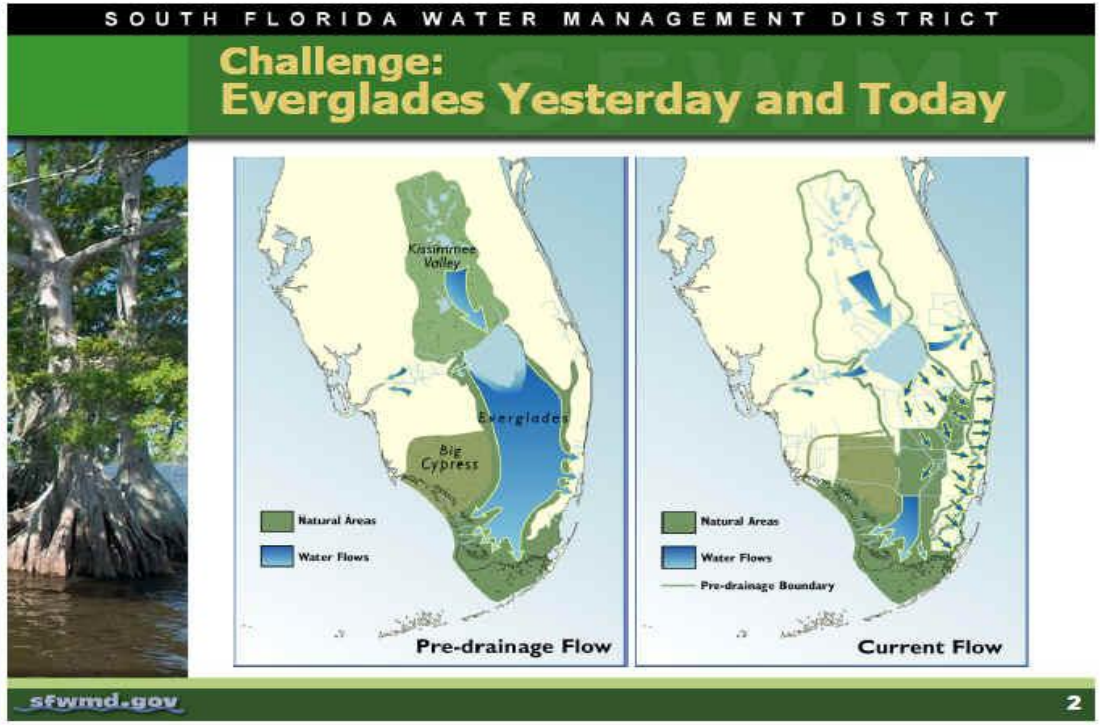
4th National Conference on Ecosystem Restoration

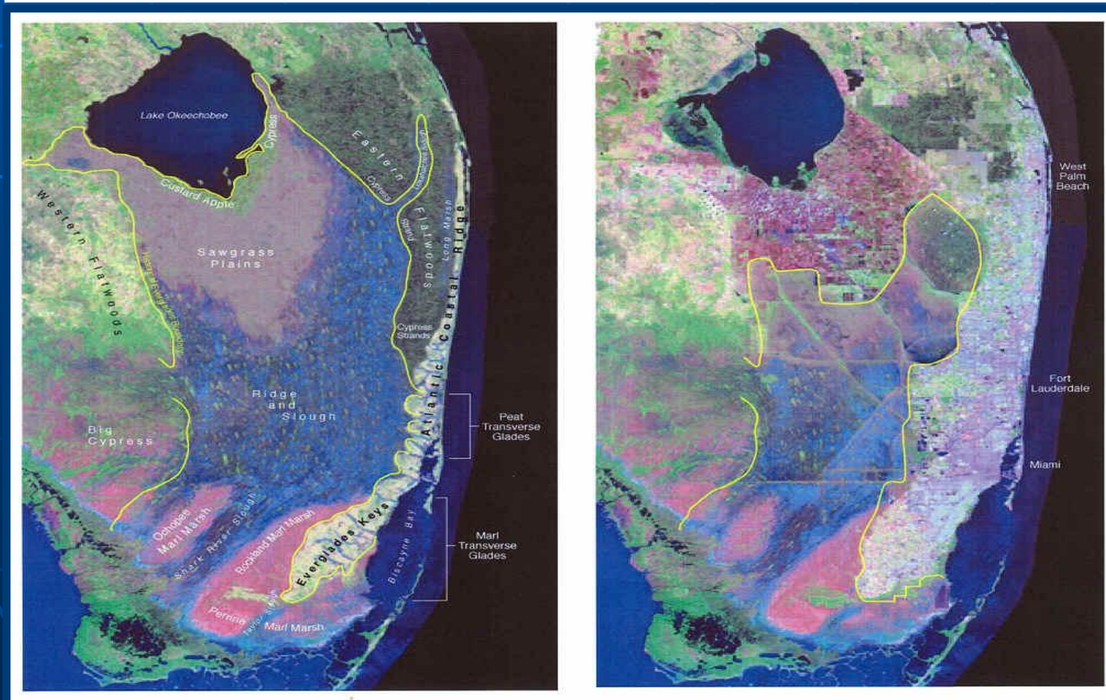
Hyperspectral/LIDAR/RADAR Imagery for Water Quality Monitoring and Environmental Impact Assessment In Ecosystem Restoration

Raul Mercado, PE, CFM

ATKINS

August 3, 2011


SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Challenge:
Everglades Yesterday and Today
Kissimmee Valley
Everglades
Big Cypress
Natural Areas
Water Flows
Pre-drainage Flow
Natural Areas
Water Flows
Pre-drainage Boundary
Current Flow
sfwmd.gov
2


Lake Okeechobee
Cypress
Custard Apple
Eastern
Cypress
Western Flatwoods
Sawgrass Plains
Flatwoods
Cypress Strands
Coastal Ridge
Ridge and Slough
Atlantic
Big Cypress
Peat Transverse Glades
Ochopee Marl Marsh
Shark River Slough
Rockland Marl Marsh
Everglades Keys
Biscayne Bay
Marl Transverse Glades
Marl Marsh
West Palm Beach
Fort Lauderdale
Miami

Nutrient (Phosphorus) Enrichment
Cattail Expansion

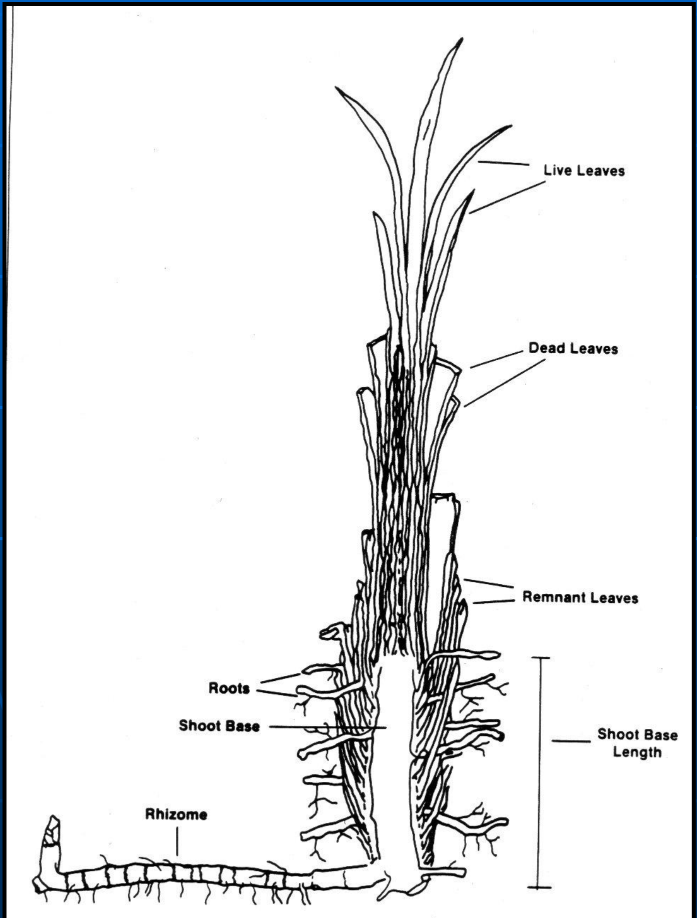
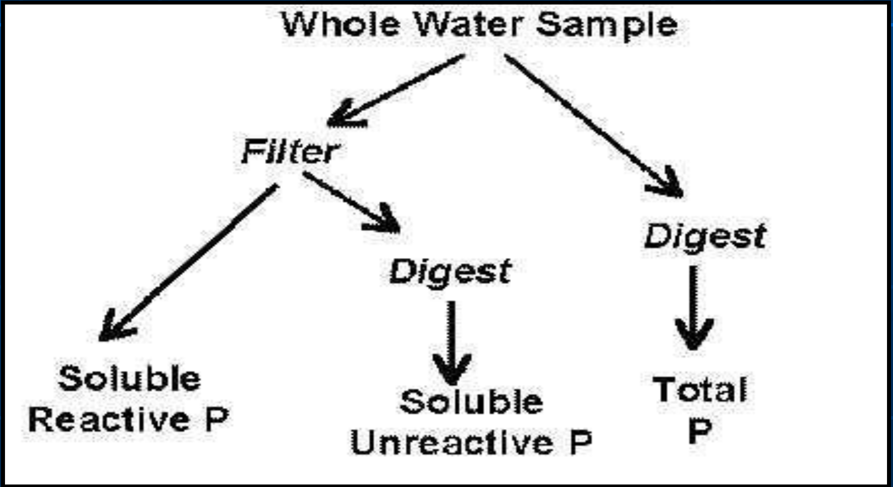


FIGURE 2 Schematic of Cattail Plant.



Nutrient (Phosphorus) Enrichment Cattail Expansion

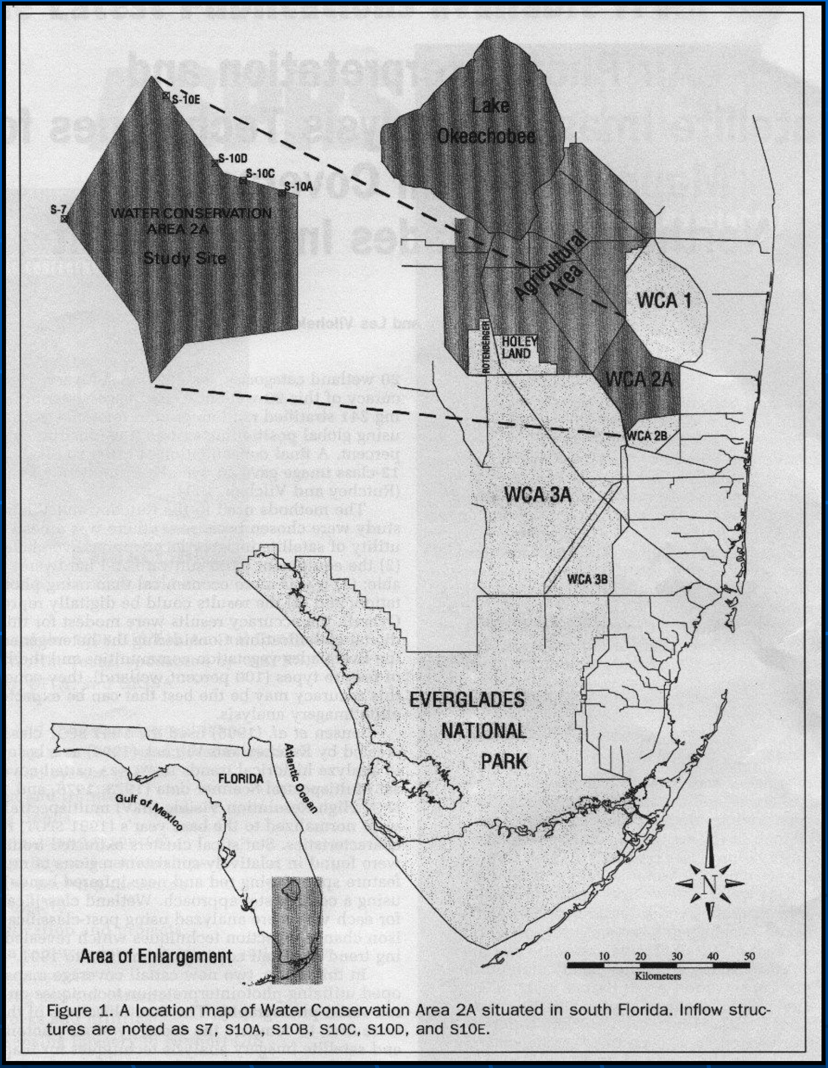
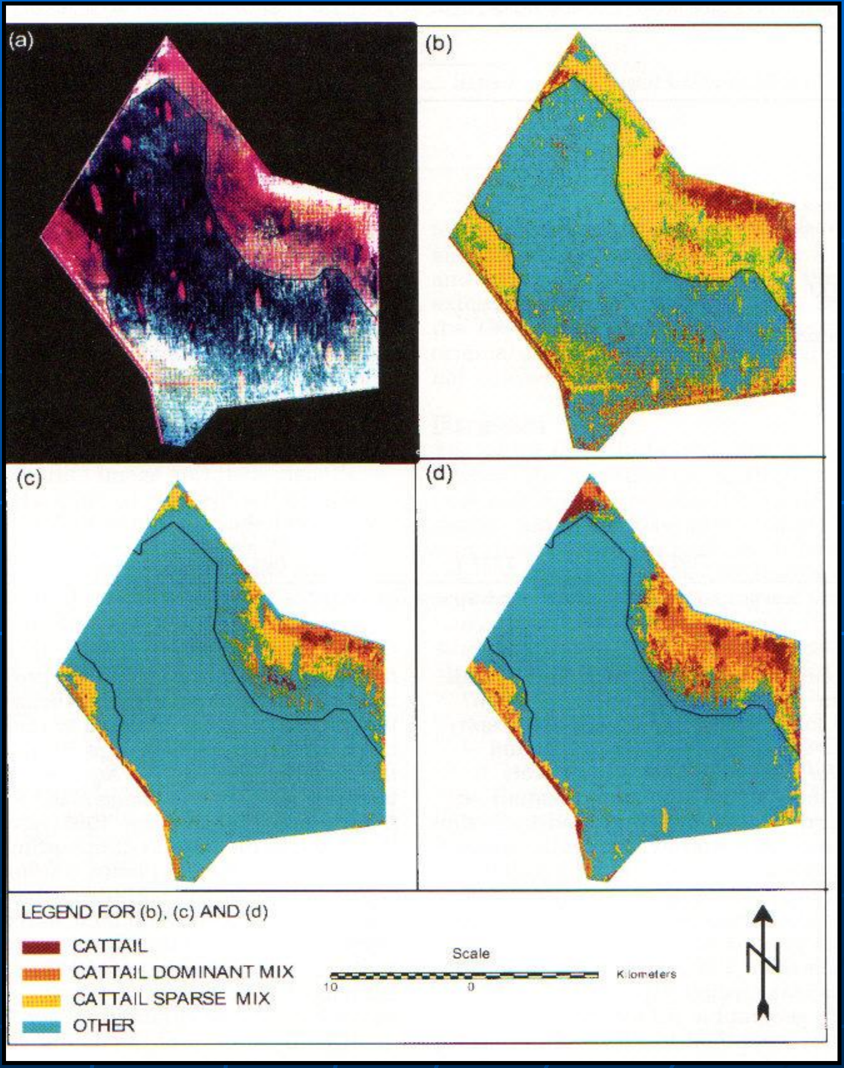


Figure 1. A location map of Water Conservation Area 2A situated in south Florida. Inflow structures are noted as S7, S10A, S10B, S10C, S10D, and S10E.



Comprehensive Everglades Restoration plan (CERP)

- Everglades Forever Act of 1994 requires phosphorus delivery rate concentrations of 10 ppb in next 5-10 years.
- Comprehensive Everglades Restoration plan (CERP).
- Restoration Coordination And Verification (RECOVER)
  - Links science and the tools of science for system-wide planning evaluation and assessment.
  - Provides the scientific basis for meeting the overall objectives of the CERP
  - Provides the scientific basis for plan performance , and refinement during implementation.
  - Requires the development and implementation of system-wide spatially-based GIS/Remote Sensing ecosystem assessment tool

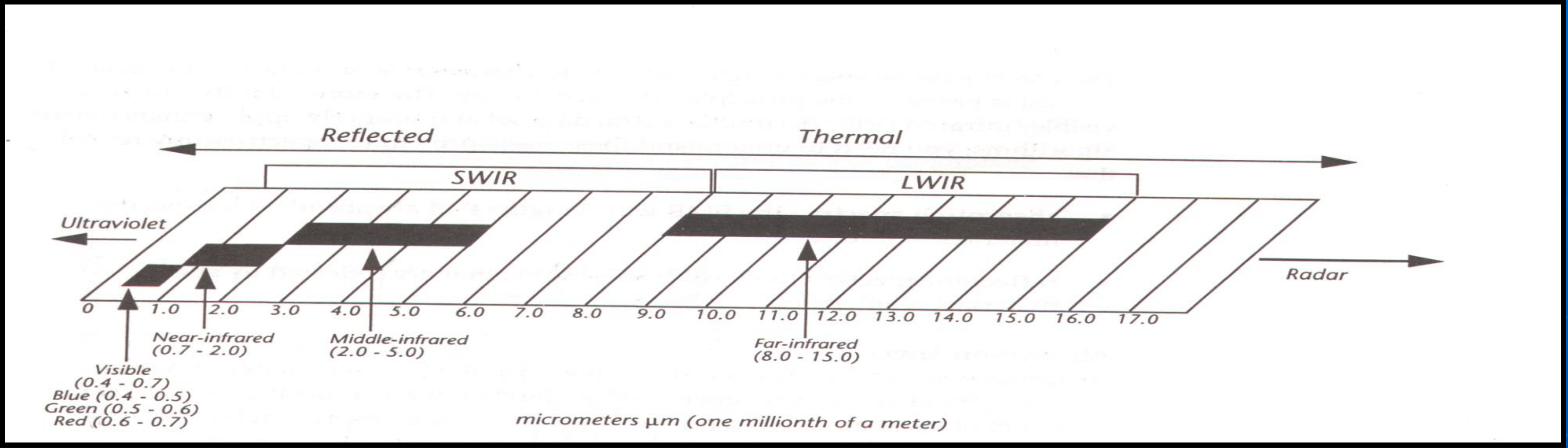
Regional Adaptive Assessment Tools For the Florida Everglades

- Everglades Landscape Model (ELM)

  Integrates hydrology, biology, and nutrient cycling in a spatially explicit simulation

- Across Trophic level System Simulation (ATLSS)
  - Integrated system of simulation models representing the biotic community of the Everglades region
  - Spatially explicit (500 m x 500m)
  - Satellite and airborne (LiDAR, IR, HIS, RADAR) data used
  - Use in combination with monitoring data at subregional level

Electromagnetic Spectrum



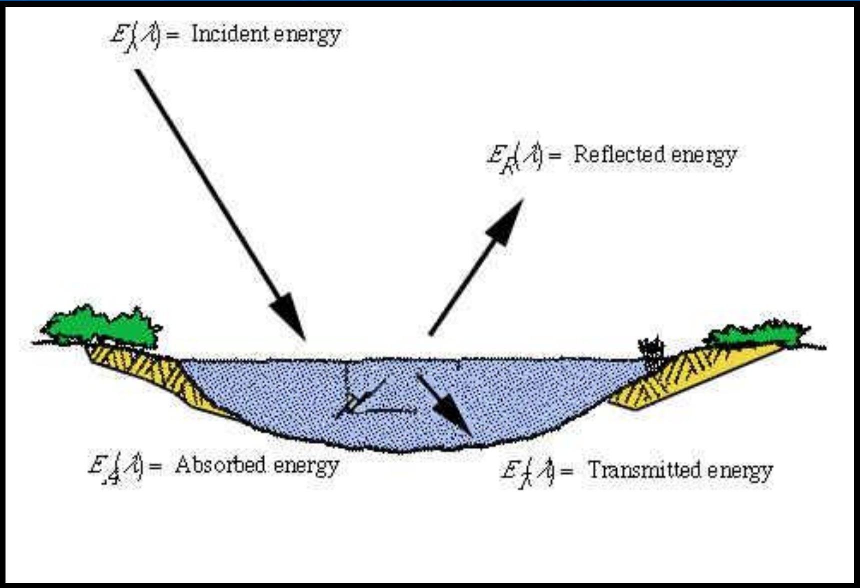
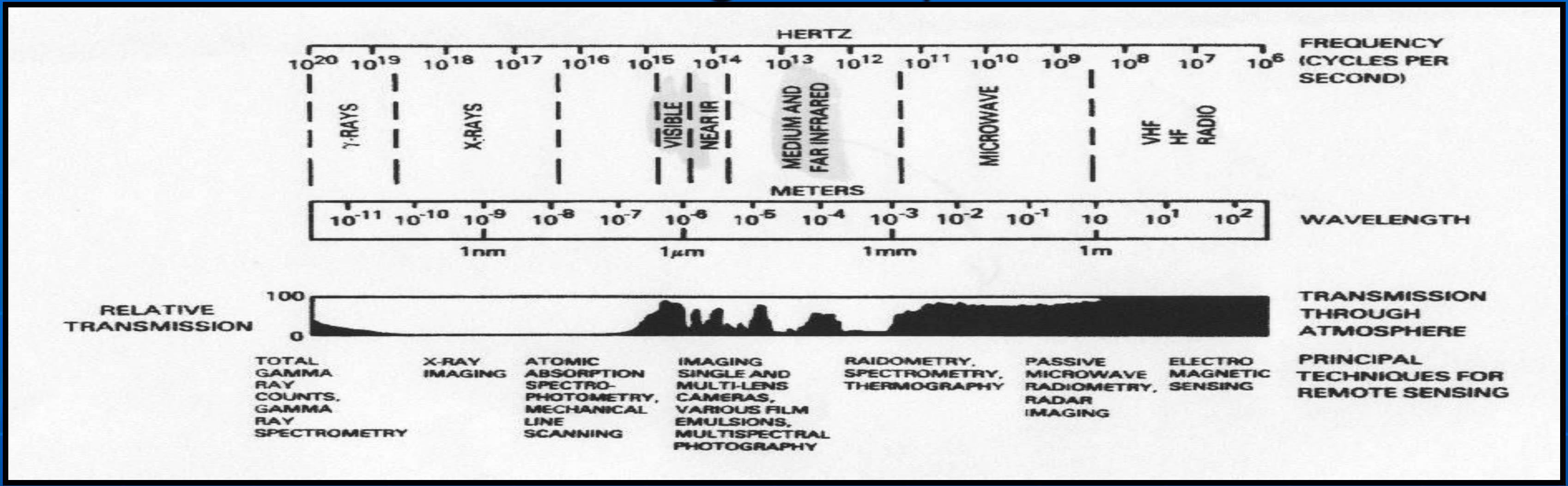
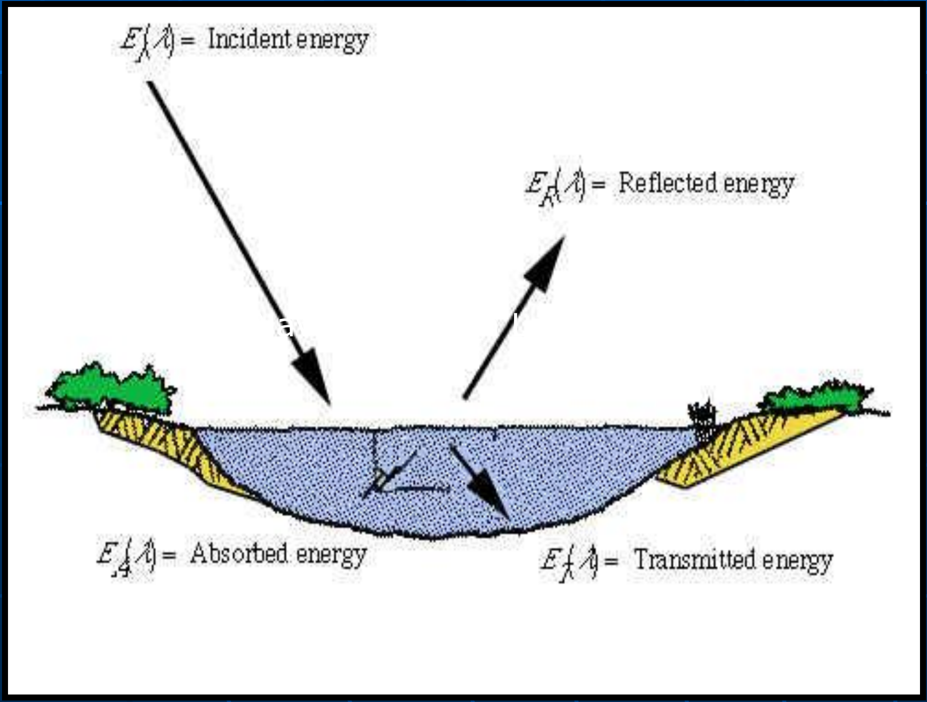


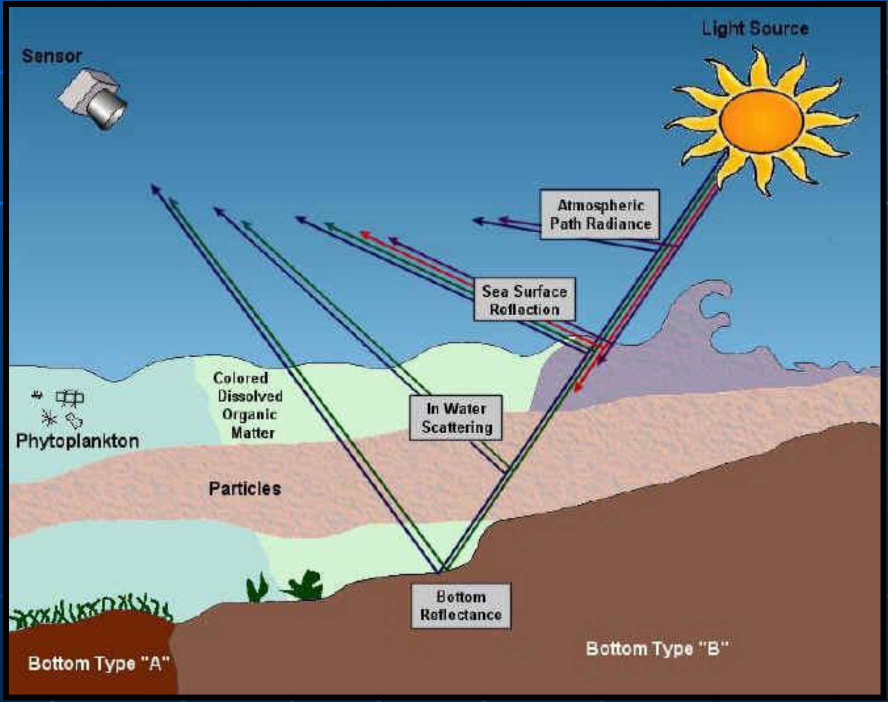
Table 1. Regions within the Visible and Infrared Spectrum

Visible		Infrared	
0.40-0.45 um	Violet	0.7 - 3.0 um	Near-Infrared
0.45-0.50 um	Blue	3.0 - 14 um	Thermal-Infrared
0.50-0.55 um	Green	14.0 - 1000 um	Far-Infrared
0.55-0.60 um	Yellow		
0.60-0.65 um	Orange		
0.65-0.70 um	Red		

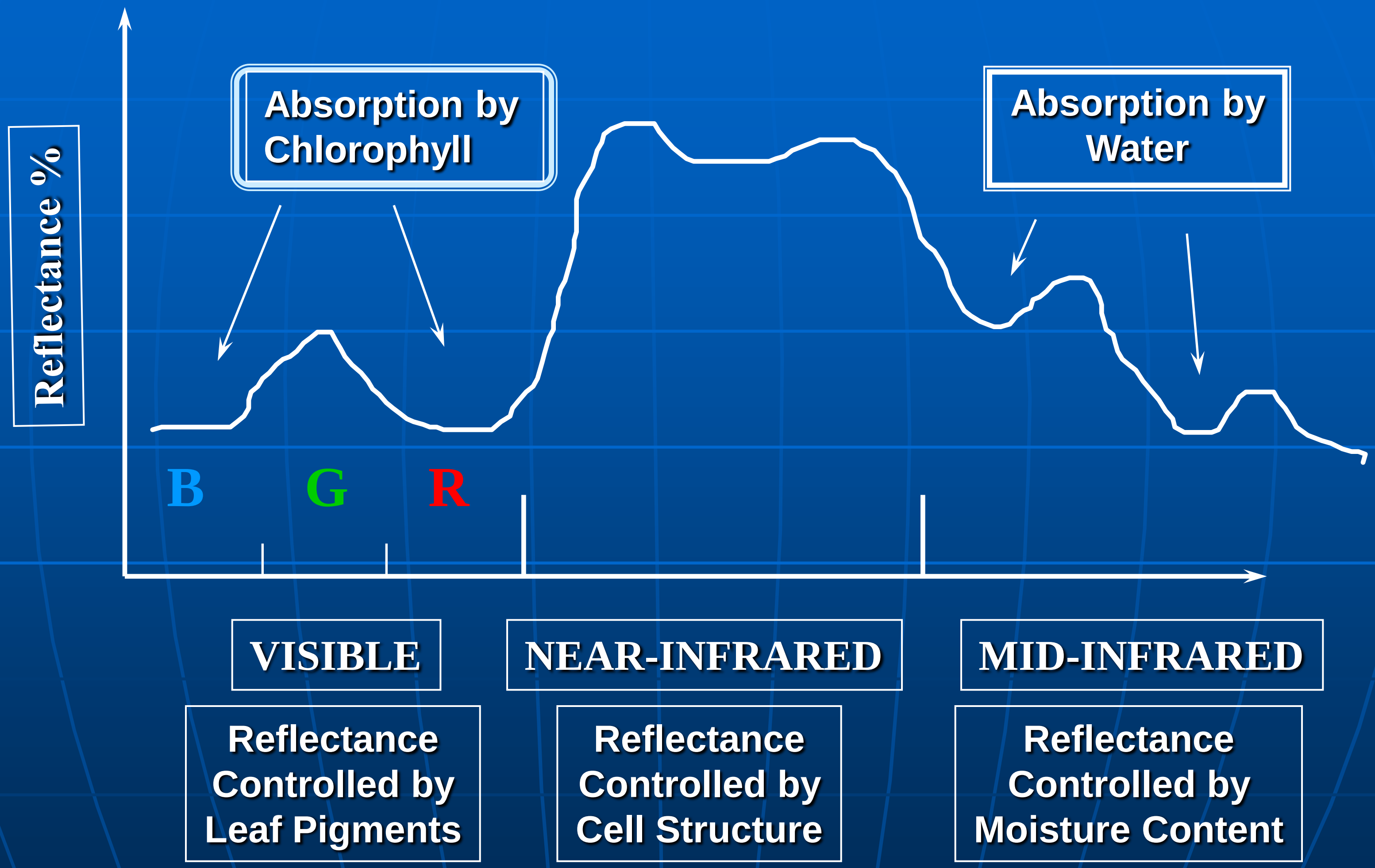
Absorbed And Transmitted Energy in the Electromagnetic Spectrum







Light Reflected From Vegetation Canopy



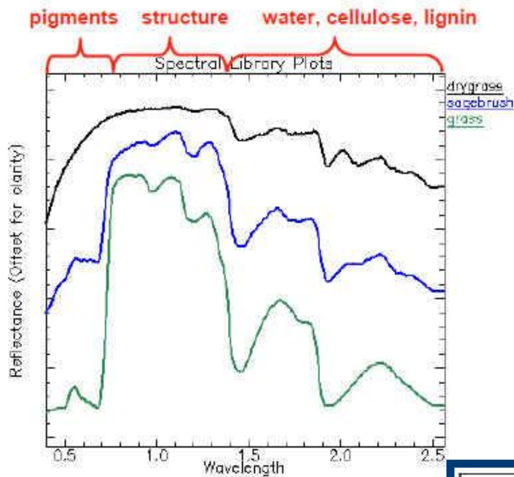
SPOT Image Corporation

Spectral Analysis

Vegetation Stress Indicators

Vegetation and Remote Sensing

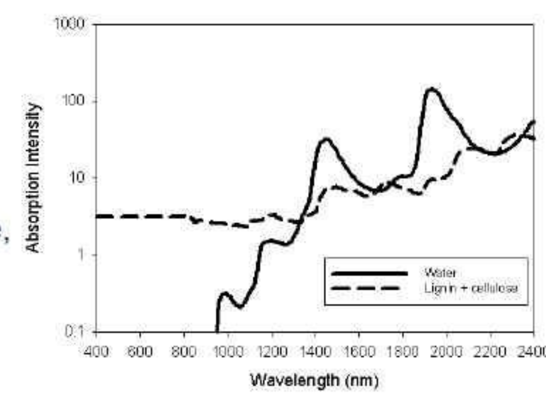
- Analysis for vegetation applications depends on reflectance properties
- Reflectance properties in general are due to:
  - Chemical composition (e.g., pigments)
  - Structure (e.g., leaf structure)



ITT Visual Information Solutions

Vegetation and Remote Sensing – SWIR

- Water – absorptions in NIR and SWIR
  - 1.9, 1.4, 1.19, .97 micrometers
  - Necessary in photosynthesis, reduces burn likelihood
- Woody parts – cellulose, lignin



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Spectral Analysis – Vegetation Stress Indicators

9.2.2 What field spectra at canopy level reveal

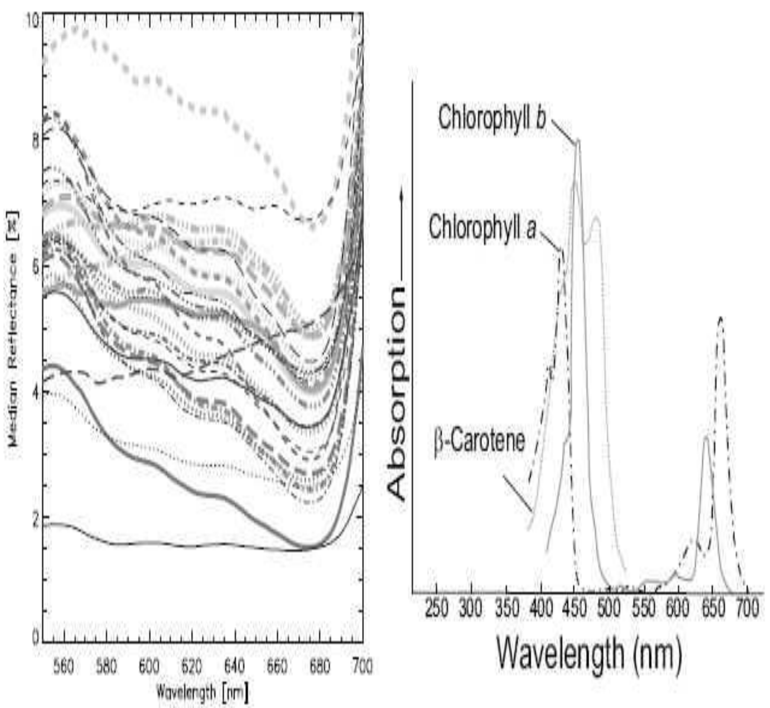
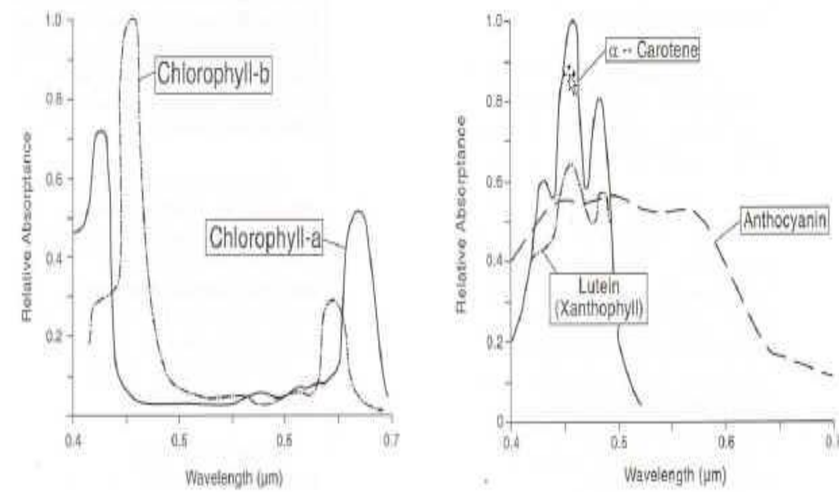


Figure 9.2: Median reflectance curves of 27 slatmarsh vegetation types in the visible part of the spectrum from 550 nm to 700 nm (a), and the absorption curves of plant pigments (b) (source: Purves et al. (1998)).

Vegetation and Remote Sensing - Visible

- Pigments biggest effect
  - Chorophyll most important



Images from Earth Observation Center Universiti Kebangsaan Malaysia

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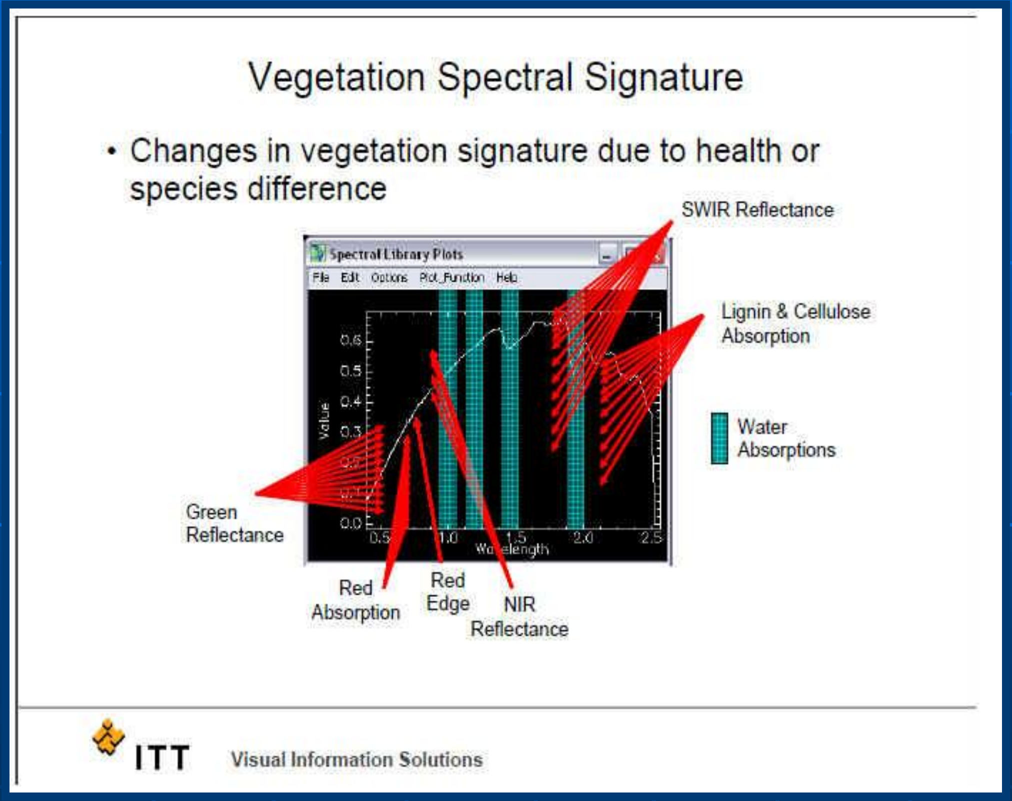
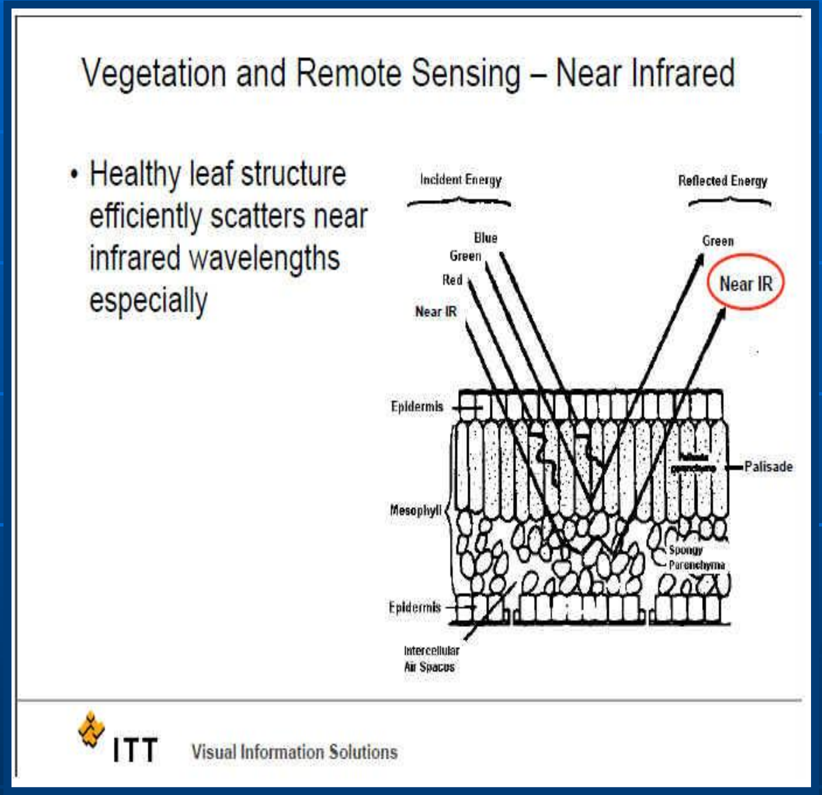
Spectral Analysis
Vegetation Stress Indicators

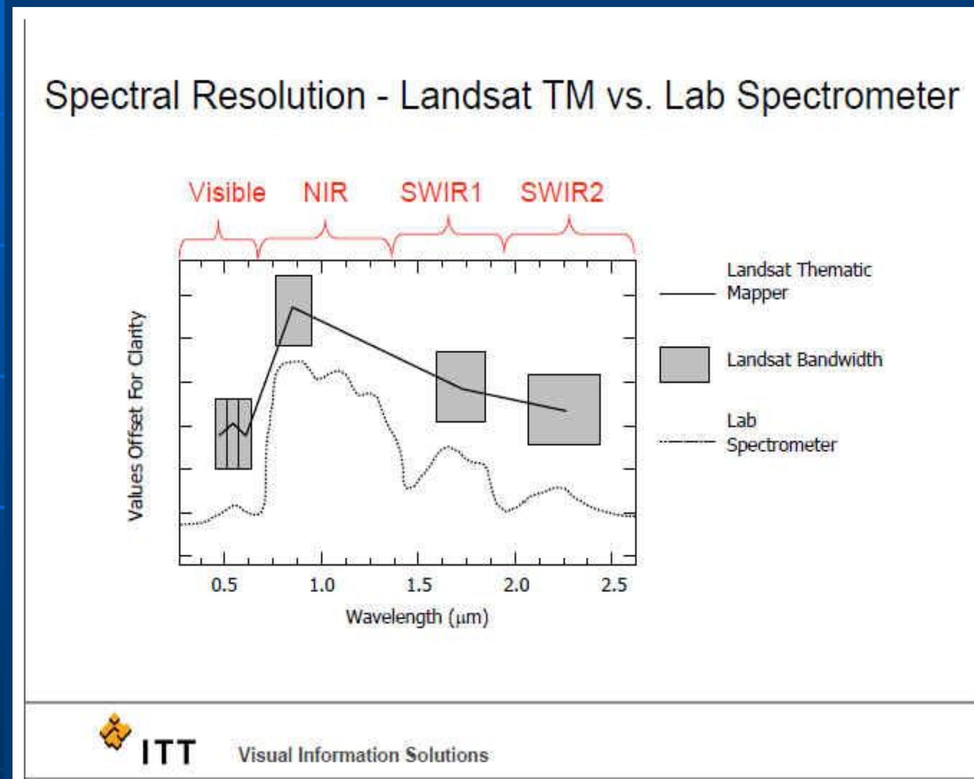




Transect Field Acquisition for Biomass Spectral Signature Library Development

Figure 1. Non-destructive, field collection of vegetation biomass along transects for remote sensing algorithm development and evaluation.

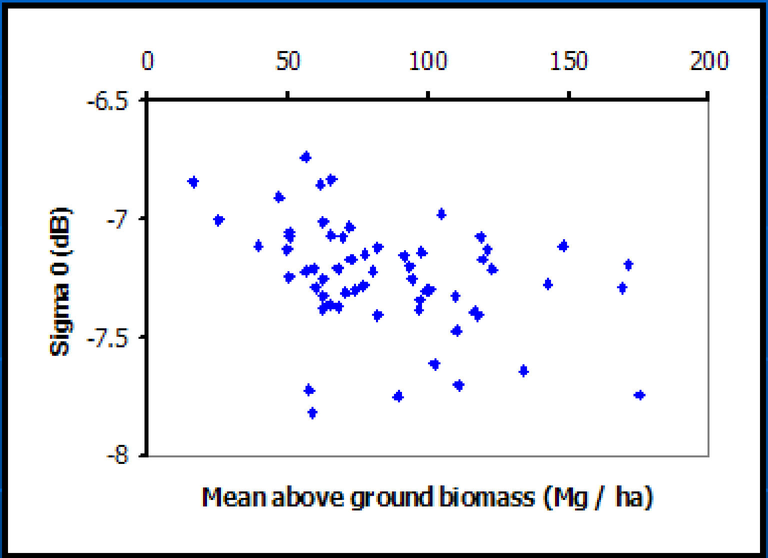
Figure 3. A library of South Florida land cover spectra is being built using handheld and laboratory spectroscopy.

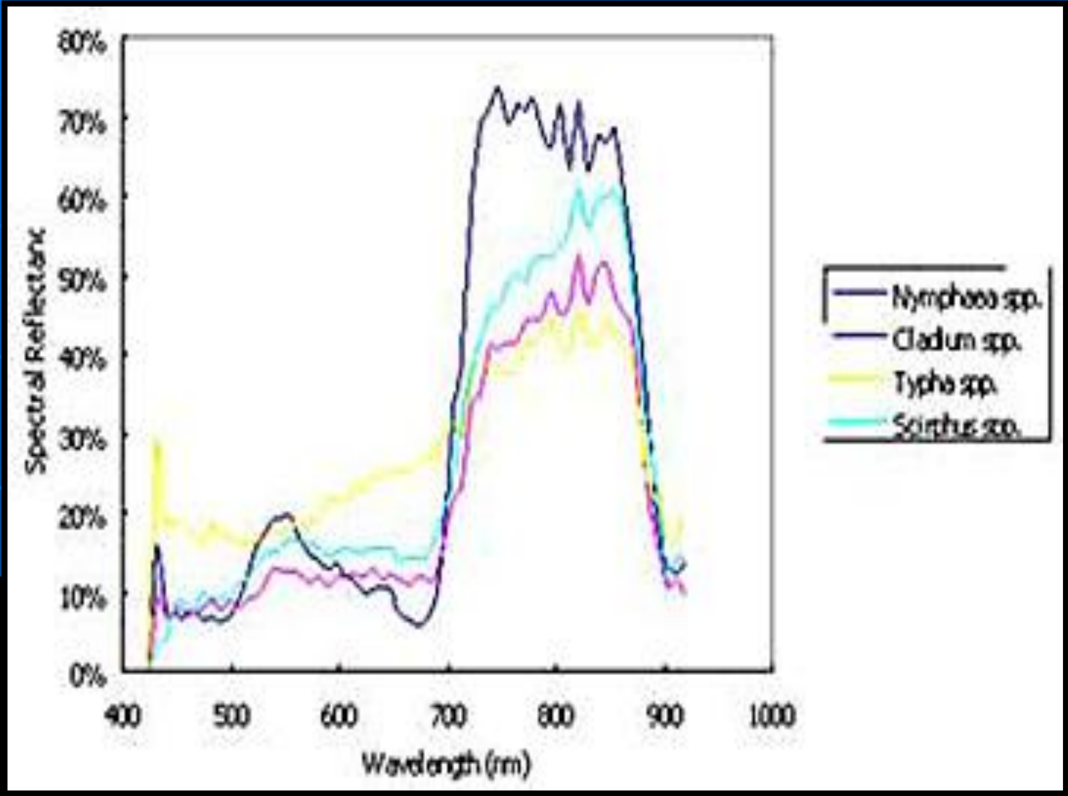


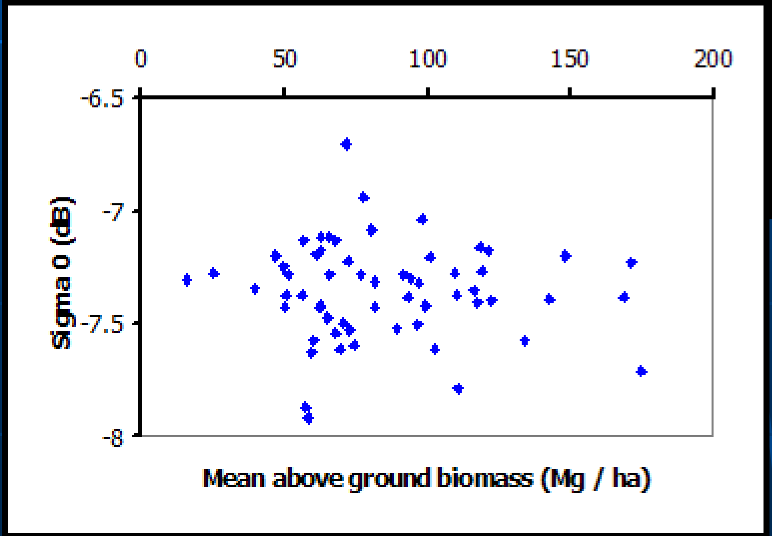
Spectral Biomass Analysis

Dry

Typha (Cattail)

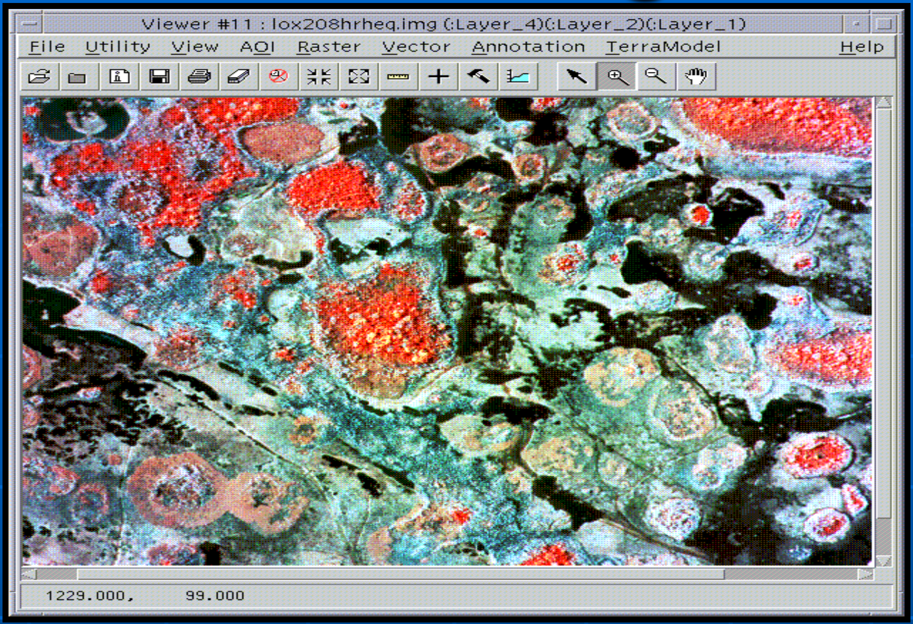






Wet

Everglades Biomass



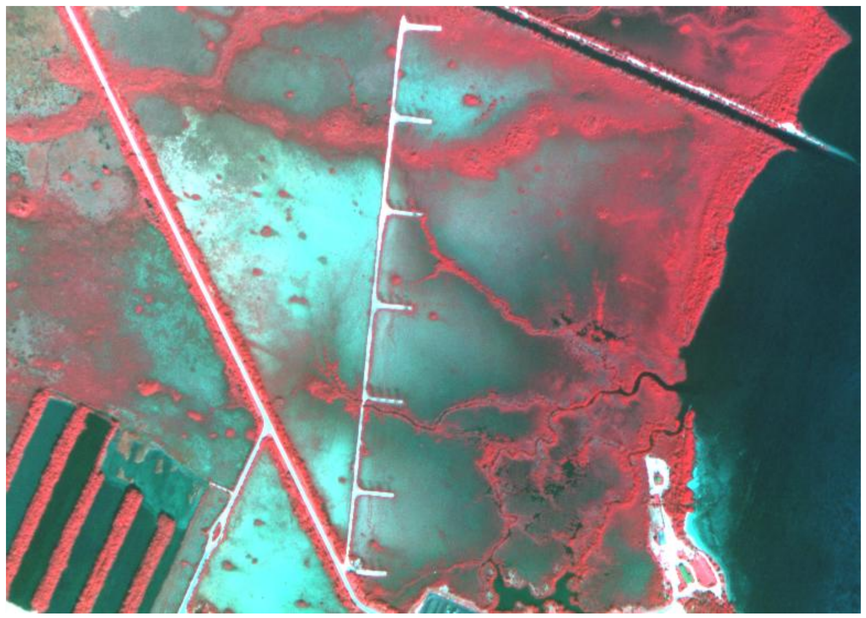
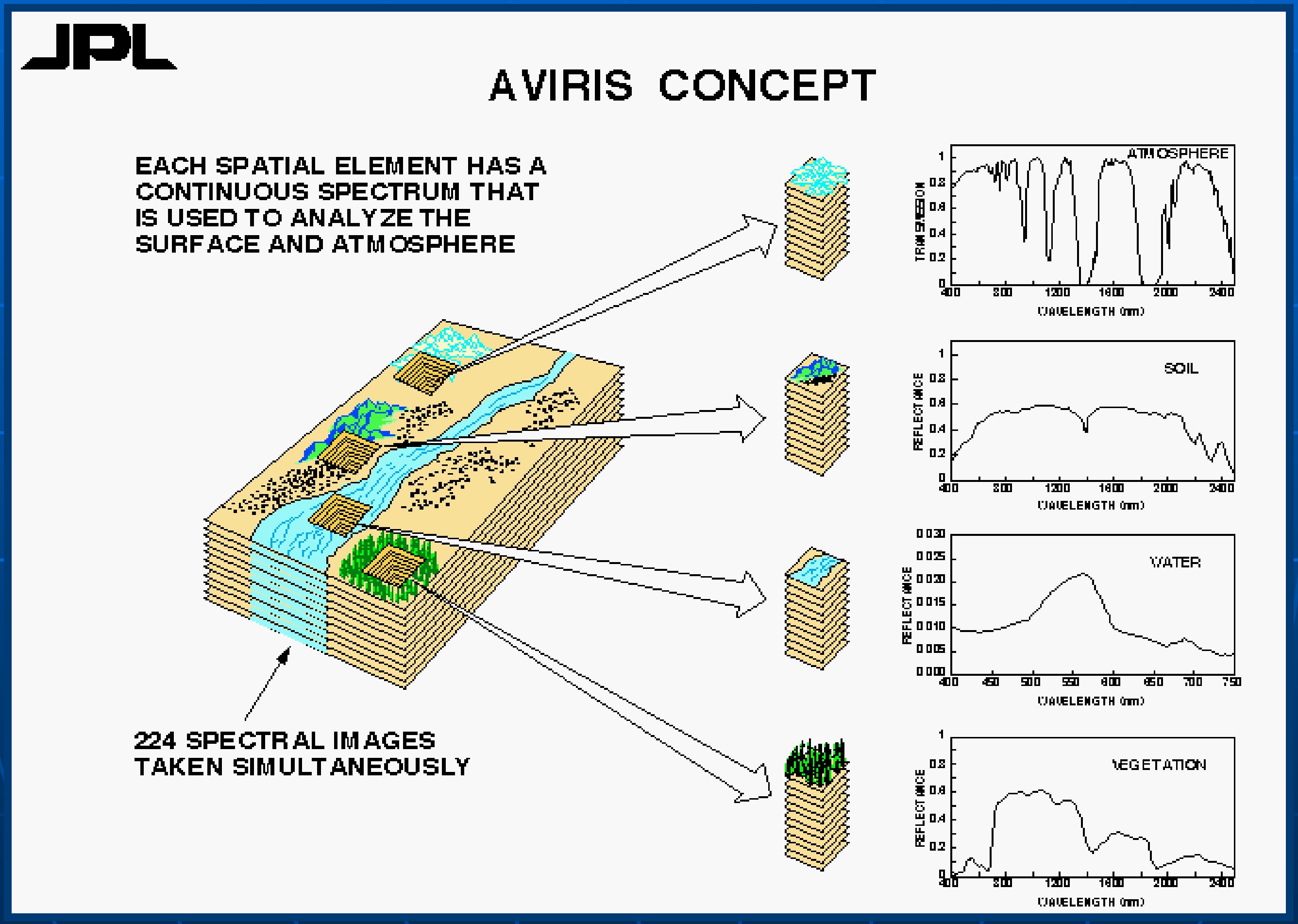


Table 2. Examples of vegetation indices.

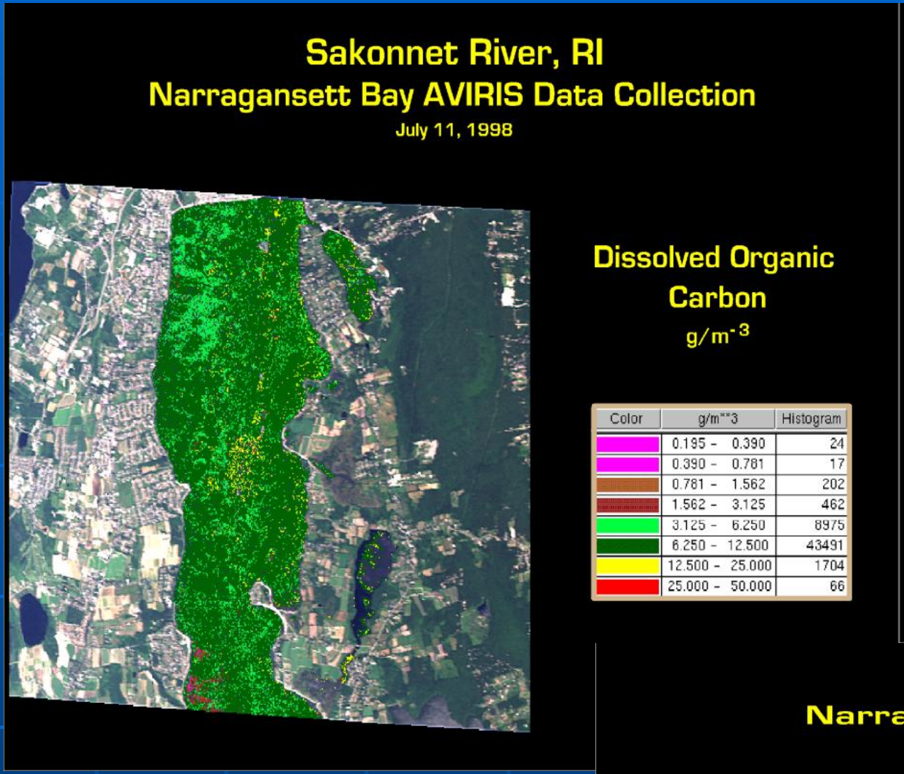
Index	Acronym	Formula	Correlation
Ratio Vegetation Index	RVI	NIR/RED	Biomass
Normalized Difference Vegetation Index	NDVI	(NIR - RED)/(NIR + RED)	Plat height, biomass, yield
Nitrogen Reflectance Index	NRI	(NIR/GREEN) /(NIR/GREEN)ref	Nitrogen status of corn

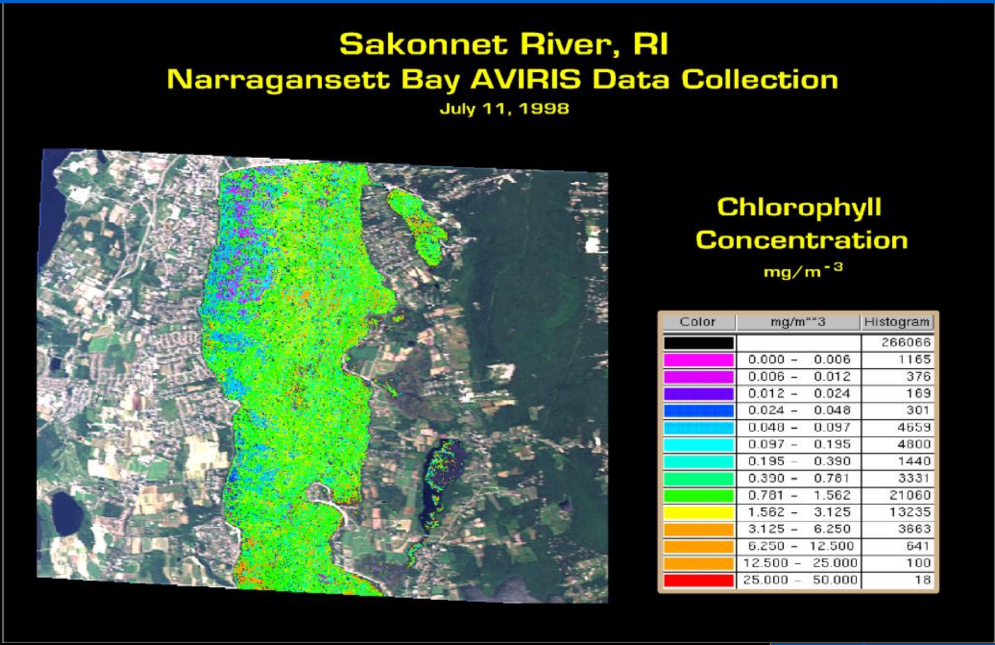
- HYPERSPECTRAL

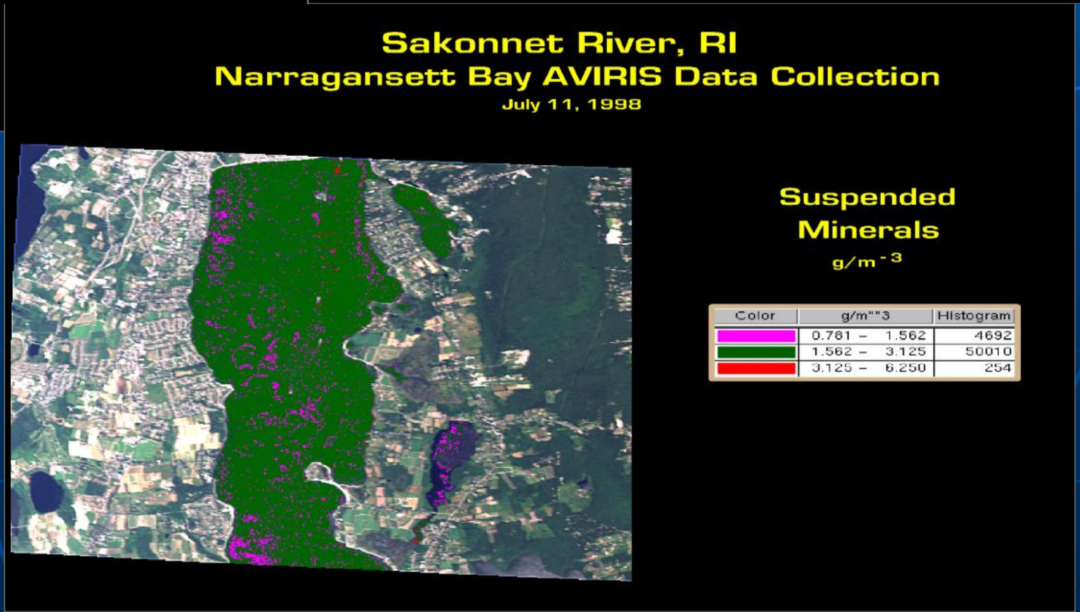
AVIRIS
Airborne HyperSpectral Sensor



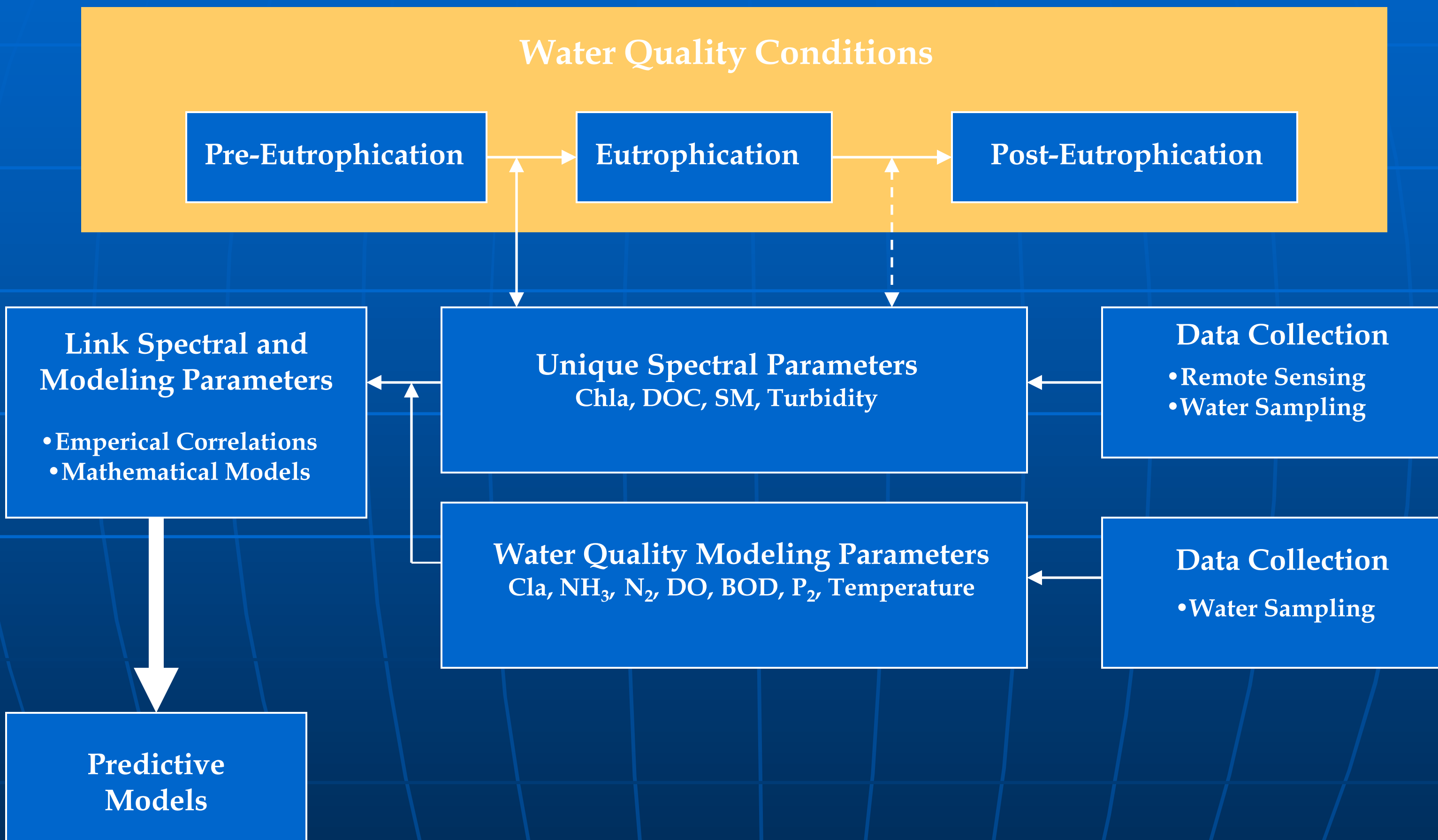
Hyper Spectral Water Quality Analysis



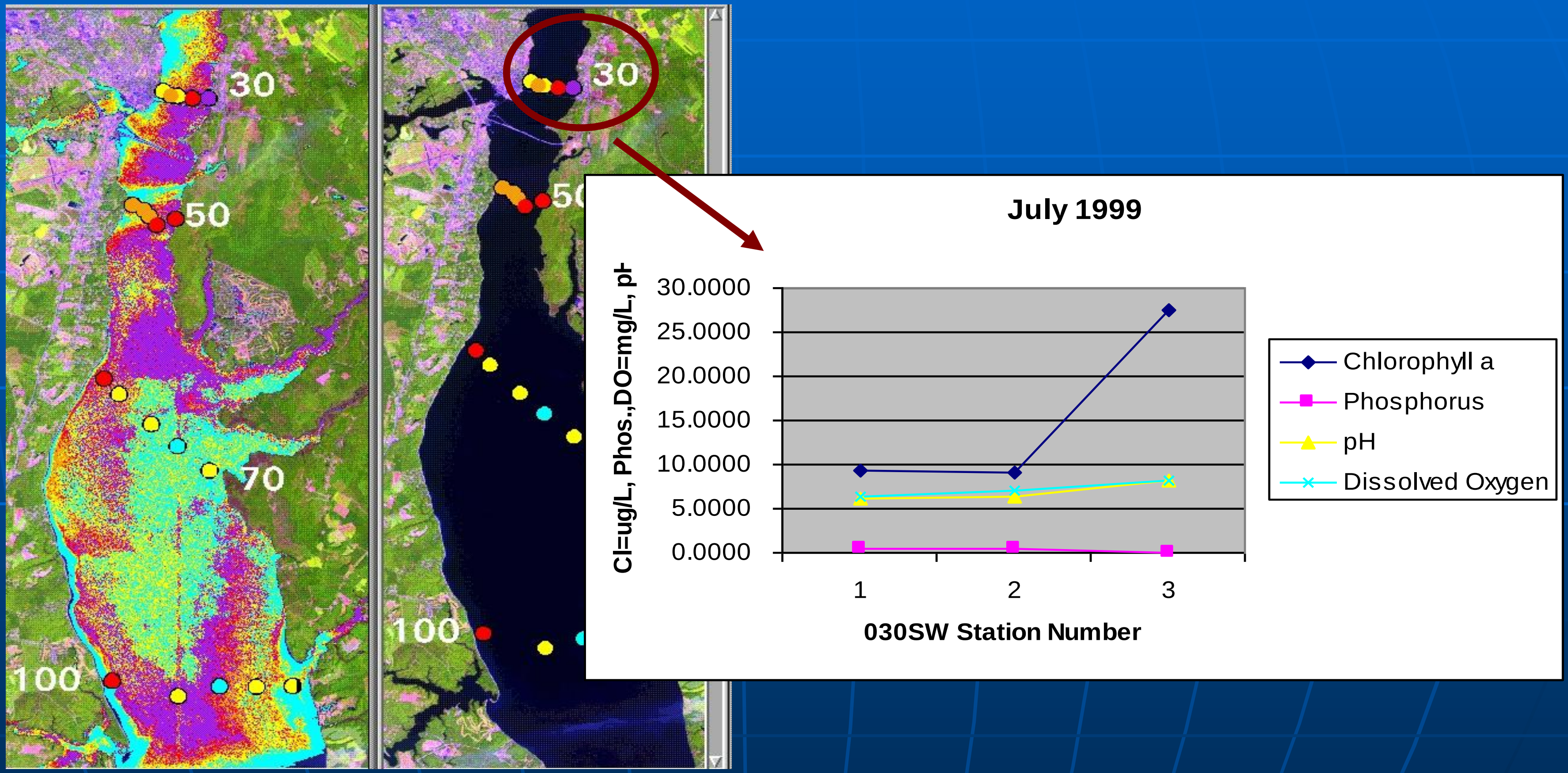




LINKAGE MODEL
(Water Quality, Geochemistry, Remote Sensing)



Neuse River Hyperspectral Water Quality Analysis



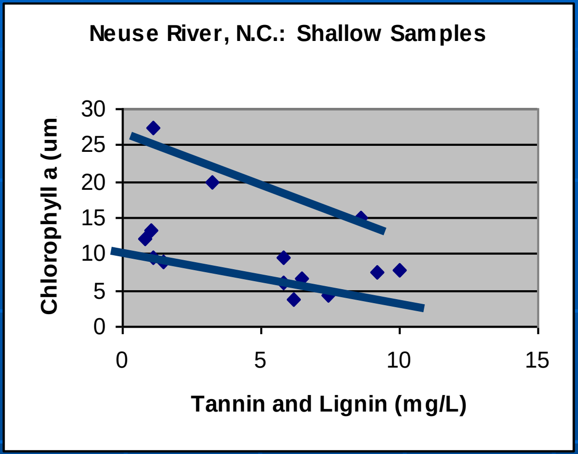
Source: NASA- EOCAP

Correlation of Field Chemistry and Hyperspectral Imagery

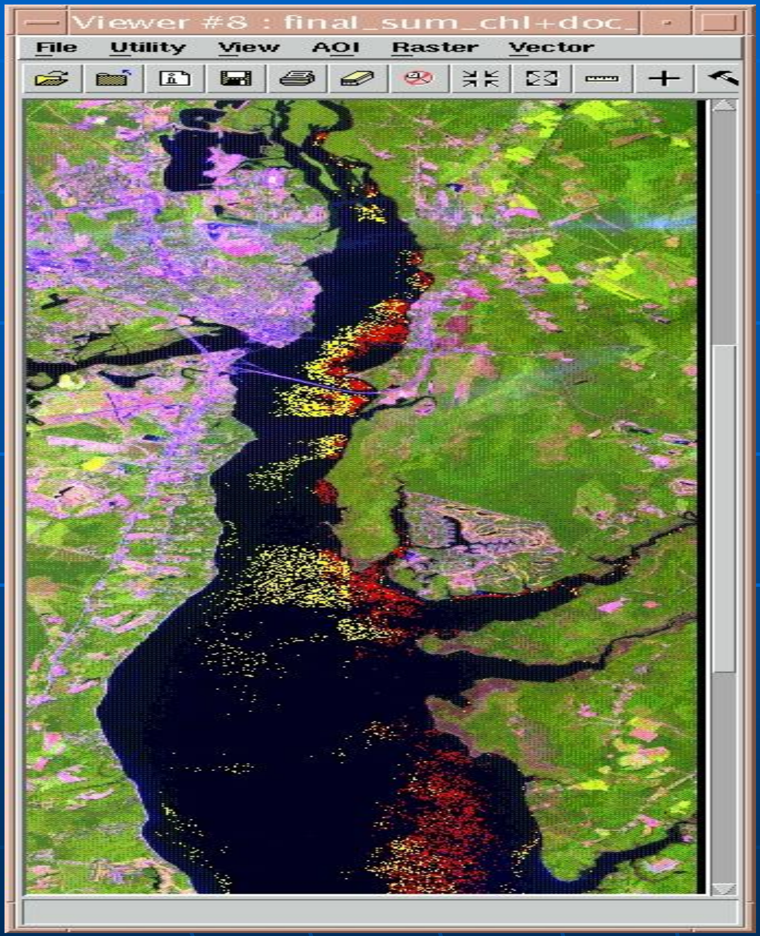
Field Chemistry	Hyperspectral Measurement
Tannin + Lignan (T+L)	DOC
TSS	Suspended Minerals + Chl + DOC
Chlorophyll a	Chl
TSS –Chl-(T+L)	Suspended Minerals
TSS (Attenuated)	Turbidity (HSSR)
Secchi Depth	Depth (if < VSSR)

Nutrient (Phosphorus) Enrichment Cattail Geochemistry Spectral Process

- Absorption is entered around 0.65 µm (visible red) and controlled by pigment in green-leaf chloroplast residing in outer leaf (Carotene and xanthophyll pigments absorb blue light and reflect green and red light).
- Strong reflectance between 0.7 and 1.0 µm (near IR) in the spongy mesophyll cells located in the interior or back of leaf.
- In HIS AVIRIS CHl analysis CHl peaks shift from 696 nm at 20 mg/l o 710 nm at 200mg/l in channels 36, 37, and 38.
- Stable isotopes O, N-NO3, H, C



NASA EOCAP RESEARCH PROJECT
Hyperspectral Image - Algae Potential Production Index (APPI) Map from Chla Measurements



The Neuse River, North Carolina

July 1999

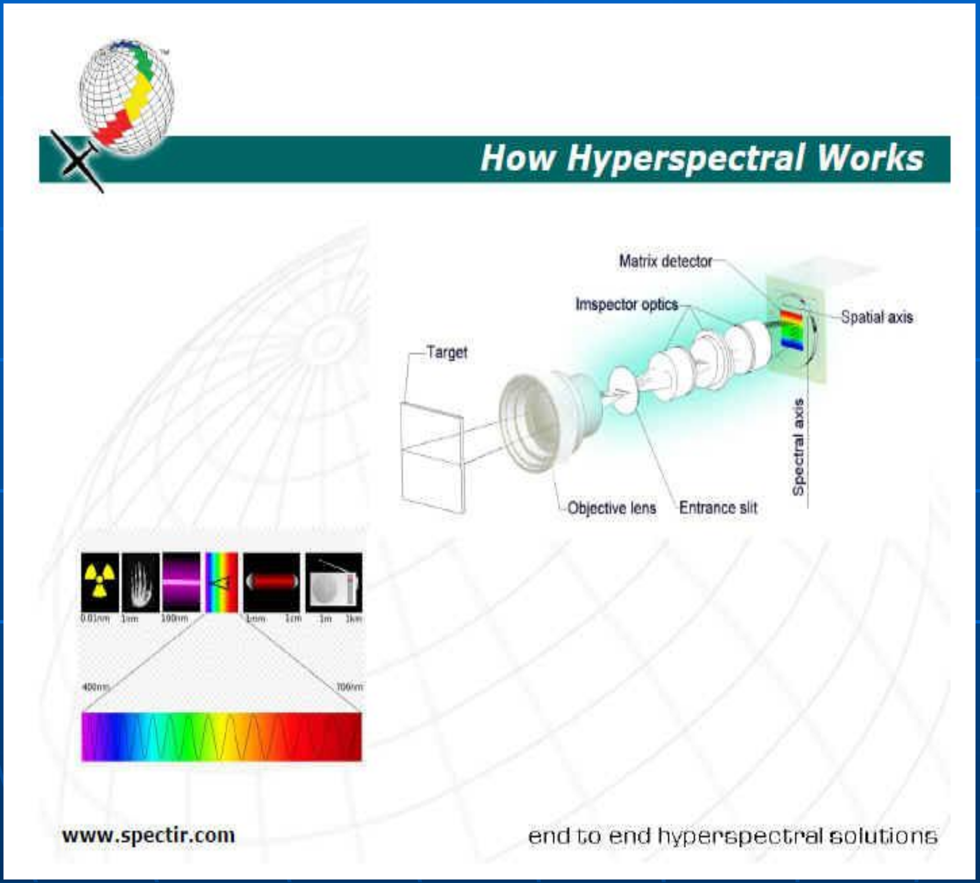
Red areas: high algae potential

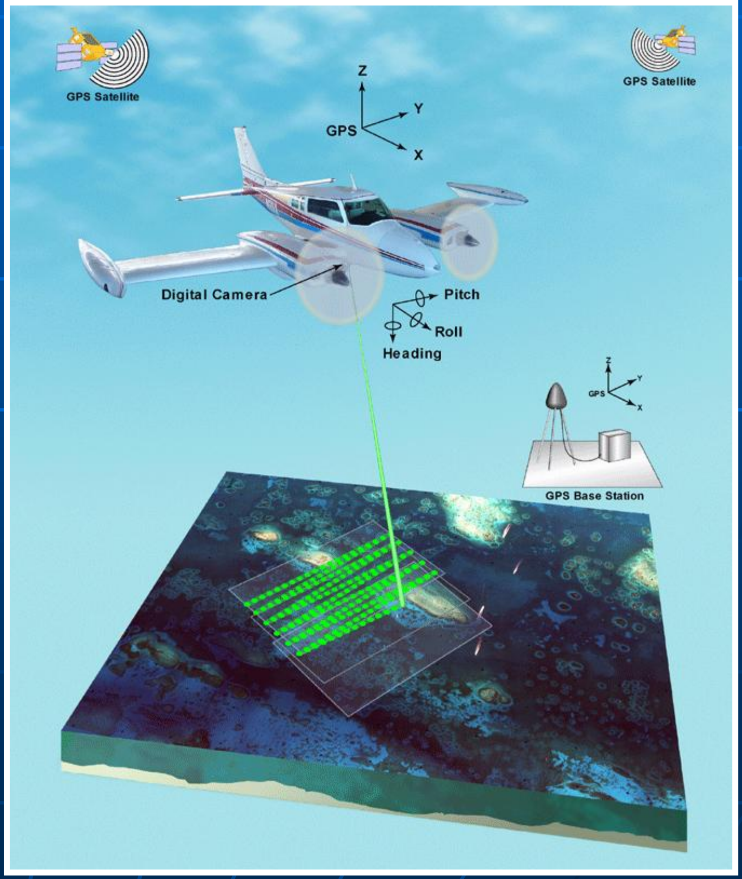
Yellow areas:moderate algae potential

Black areas : low algae potential

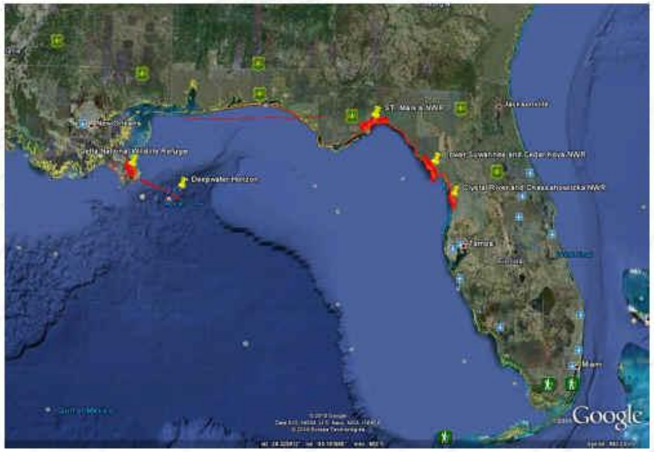
Source: NASA EOCAP, 1999

Hyperspectral Imagery Airborne Acquisition





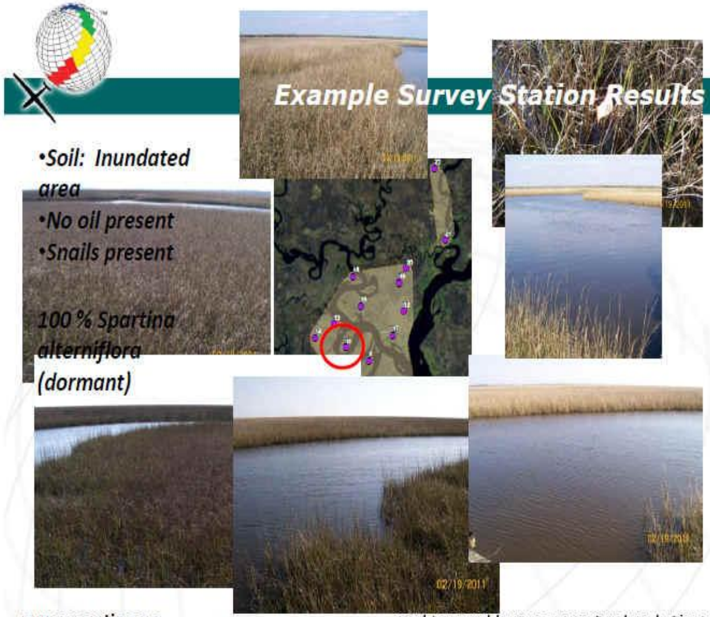
Areas of Coverage



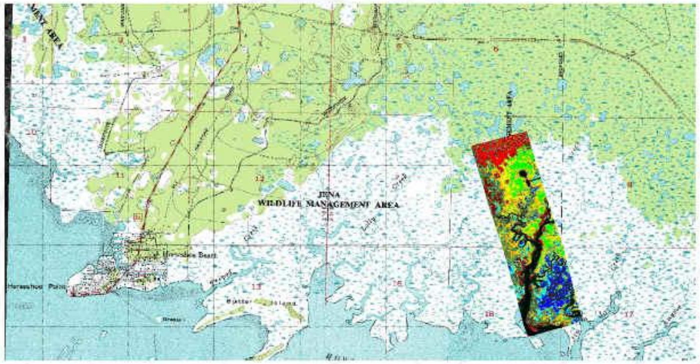
Example Survey Station Results

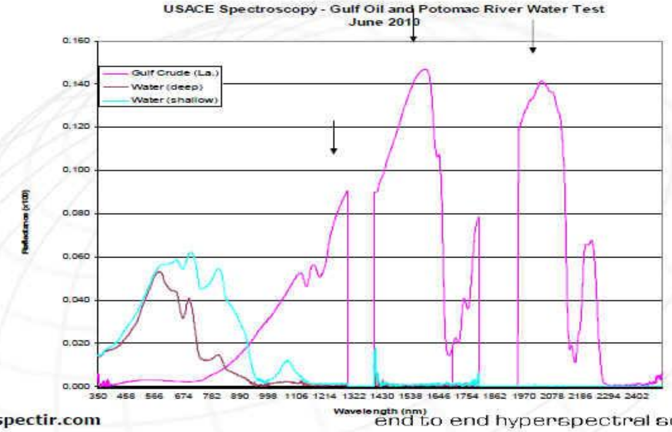
- Soil: Inundated area
- No oil present
- Snails present

100 % Spartina alterniflora (dormant)



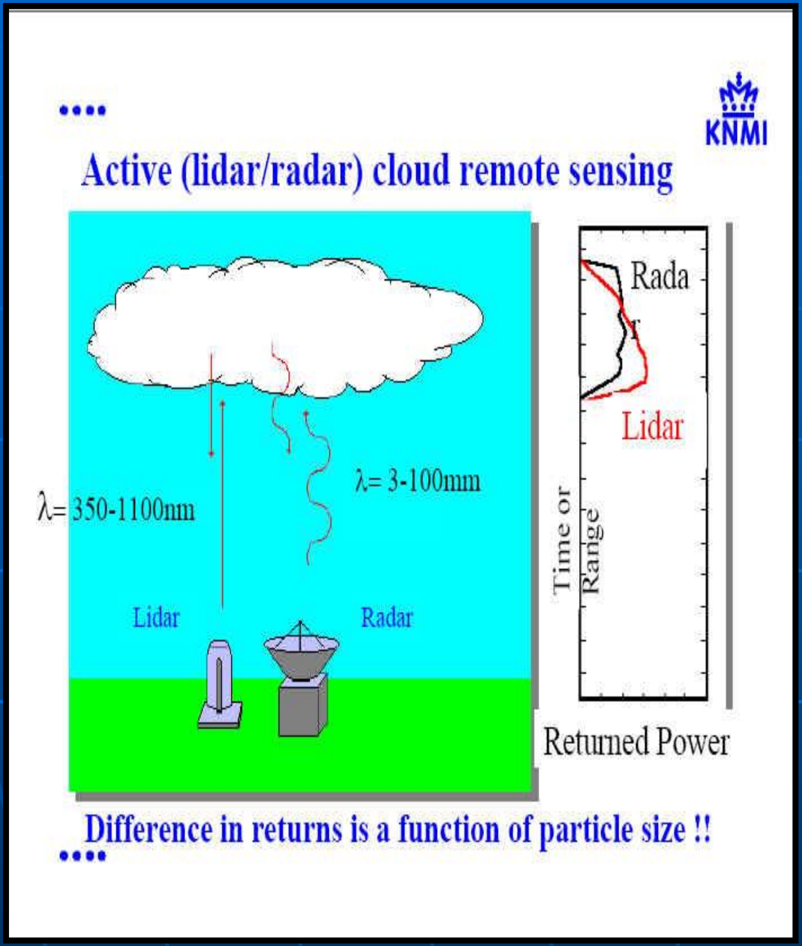
Index File

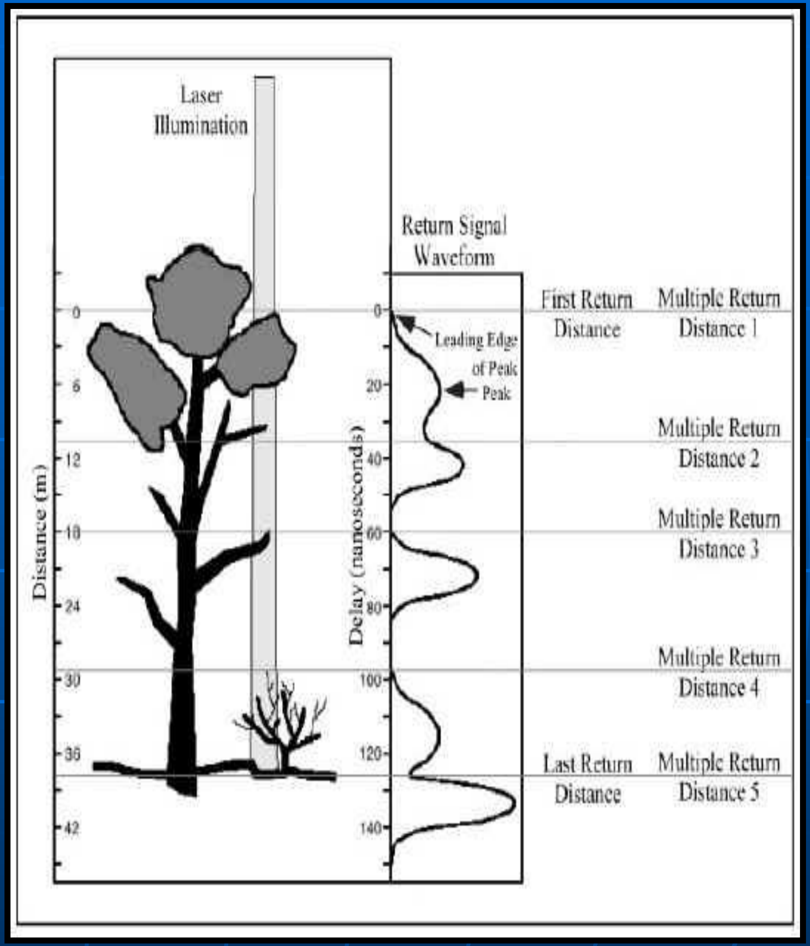




- LiDAR

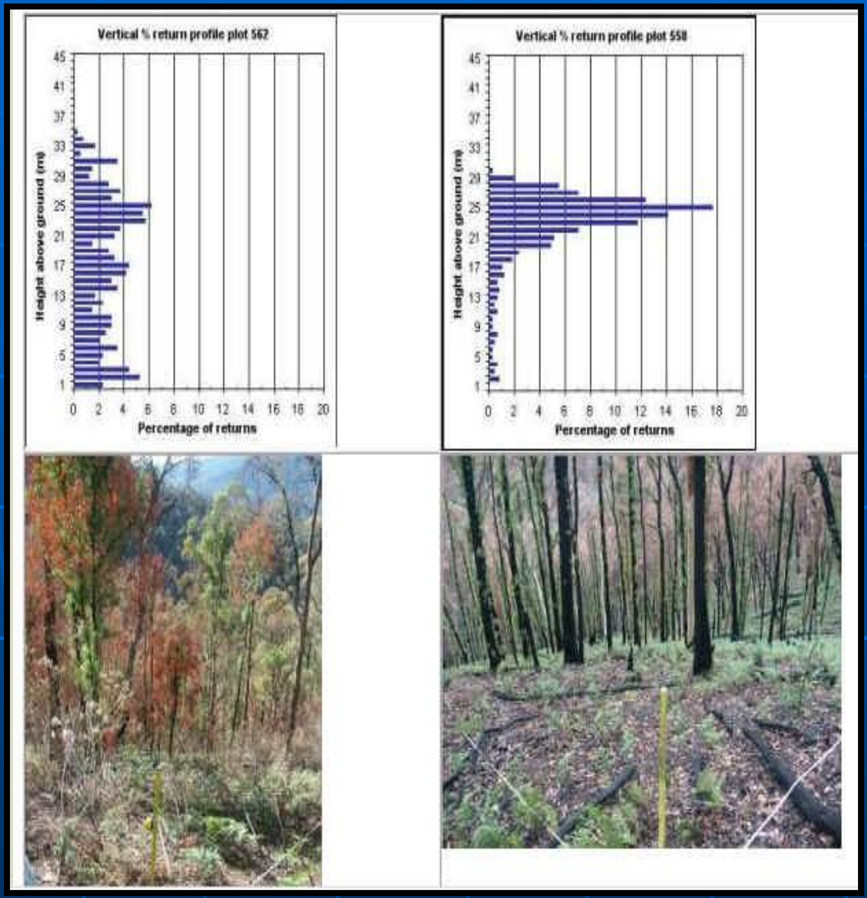
LiDAR Return Signal

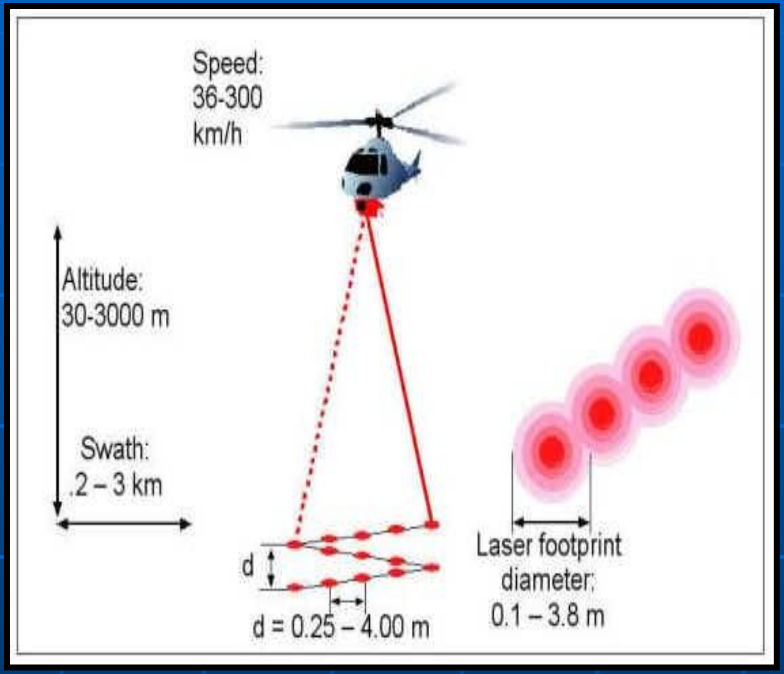




Think LASER as a small footprint beam of high return intensity.

LiDAR Biomass Mapping





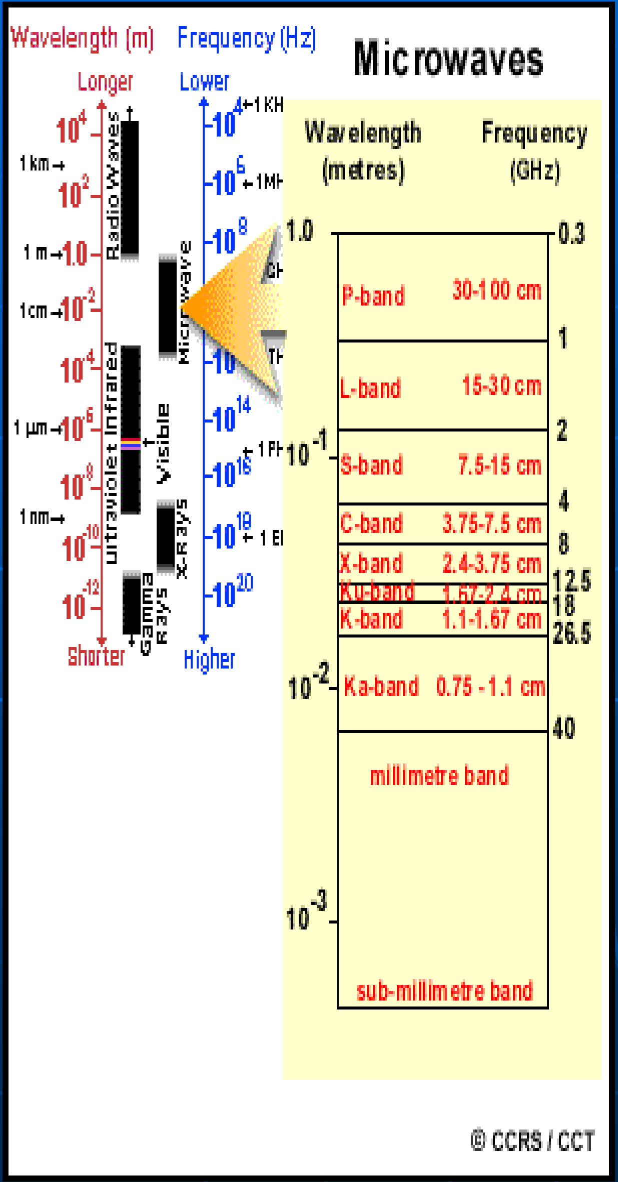
Source: The InJune Landscape Study

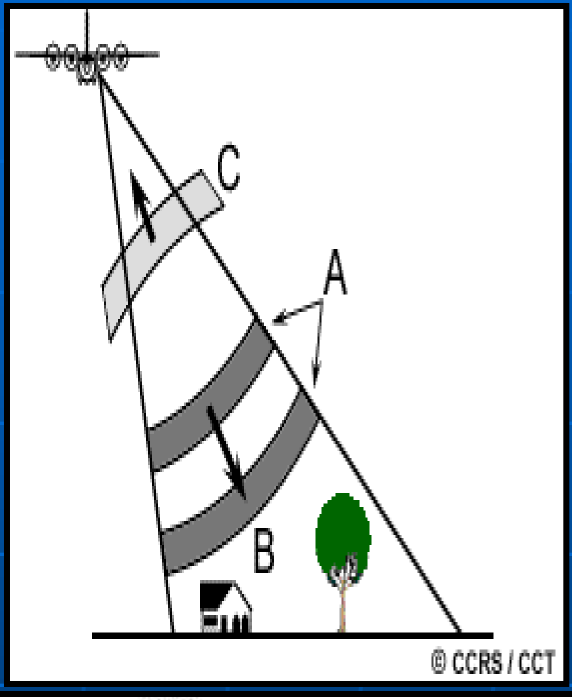
- RADAR

RADAR BANDS

- P Band – Wavelengtht of 30-100 cm frequency of 0.3 GHz
  Longest RADAR wavelength, strongest correlation to vegetation biomass.
- L Band – Wavelenght of 15-30 cm frequency of 1-2 GHz
  Use onboard SEASAT, JERS-1 and NASA systems.
- S Band – Wavelenght of 8-15 cm frequency of 2-4 GHz
  Requires a large antenna. Not easily attenuated.
- C Band – Wavelenght of 4-8 cm frequency of 4-8 GHz
  Weakest correlation to vegetation biomass.
- X Band – Wavelenght of 2.5-4 cm frequency of 8-12 GHz
  The lowest dynamic range to vegetative biomass.
- KBand – Wavelenght of 0.75-1.2 cm frequency of 1.7-2.5 GHz
  Use in early radar applications but uncommon today.

RADAR Spectral Signal





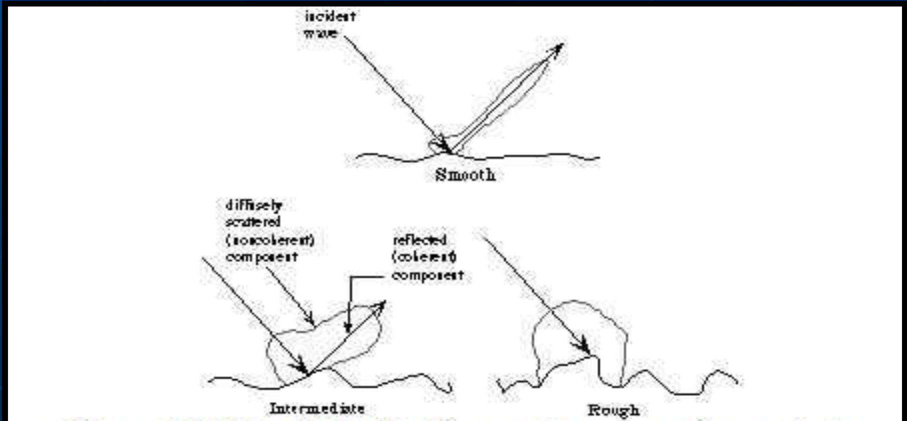
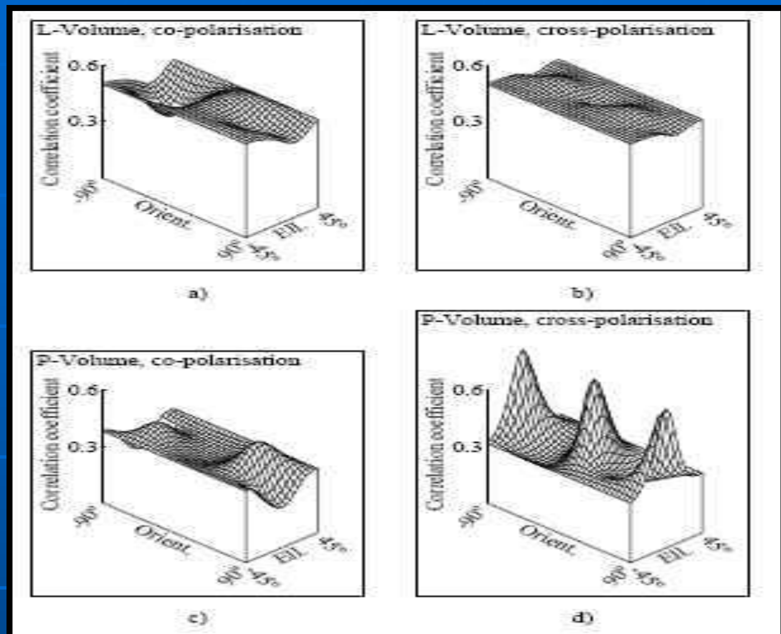
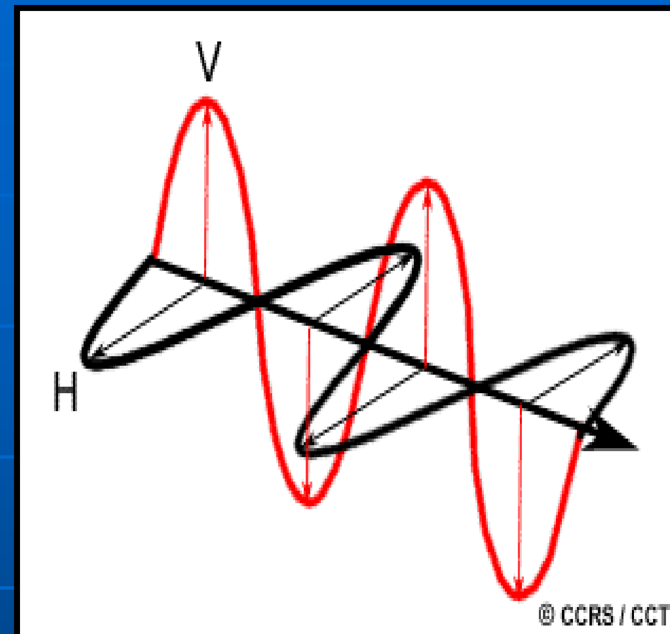


Figure 2.10 The effects of surface roughness on surface scattering

Source: Canada Centre For remote sensing

RADAR Signal Return



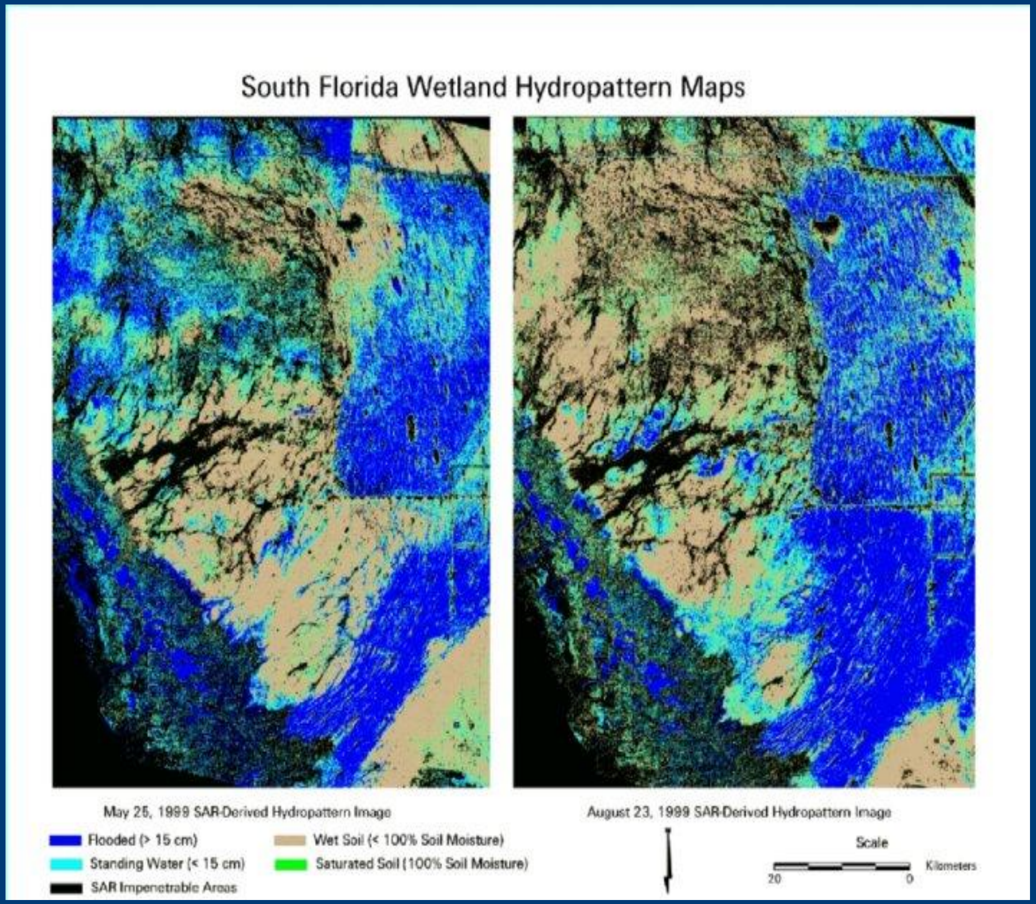


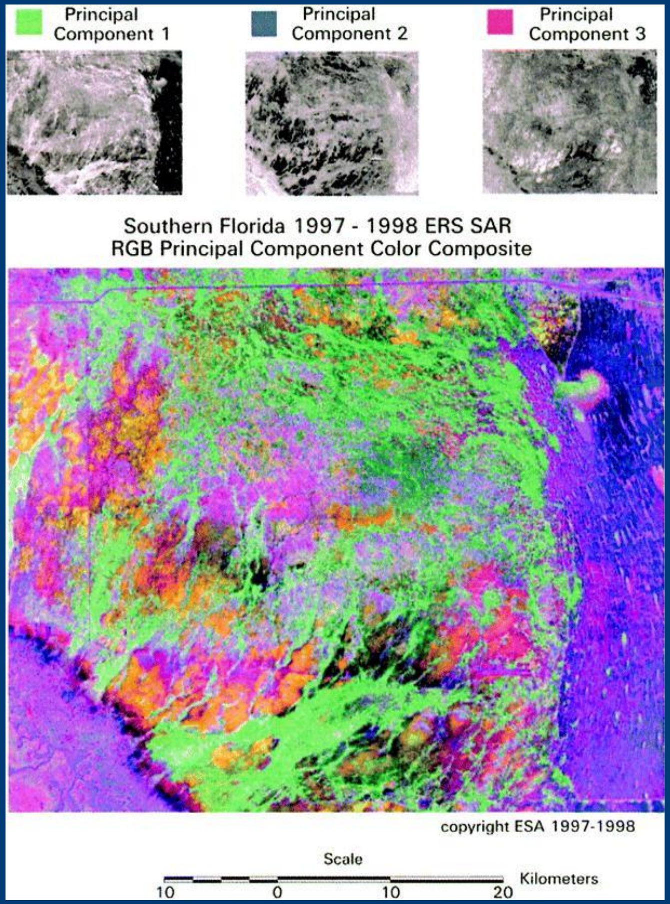
Source: Canada Centre For remote sensing

The Synthetic Aperture Radar (SAR) backscatter coefficient (*sigma-0*) is a complex function of local characteristics including topography, geological composition, soil moisture and salinity, and vegetation density and structure.

Think RADAR image as dependent on wavelength, frequency, and polarization (Orientation of electric field)

Wetland Hydroperiod Patterns Using SAR





Depth of Water Spectral Analysis

- Water penetration with LiDAR, HIS and RADAR

Light penetration in an aqueous environment is limited to the visible and near infrared wavelength range that extends from approximately 400-850 nm for standard spectral analysis.

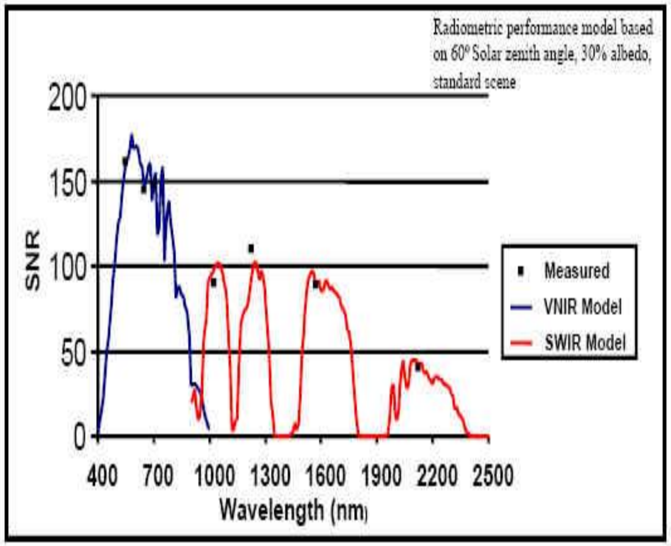
With LiDAR, HIS and RADAR (SWIR, LWIR, Microwave)

- Emergents can be detected at depths of 1 to 1.8 meters
- Sub-emergents can be detected at depths of 0.6 to 2.4 meters
- Some macrophytes can be detected below depths of 3 to 4 meters

- Above and below ground biomass can be detected and qualified by type of geochemical impact.

Hyperspectral Spectral Analysis Water Depth Penetration

Hyperion SNR



Hyperion Measured SNR						
550 nm	650 nm	700 nm	1025 nm	1225 nm	1575 nm	2125 nm
161	144	147	90	110	89	40

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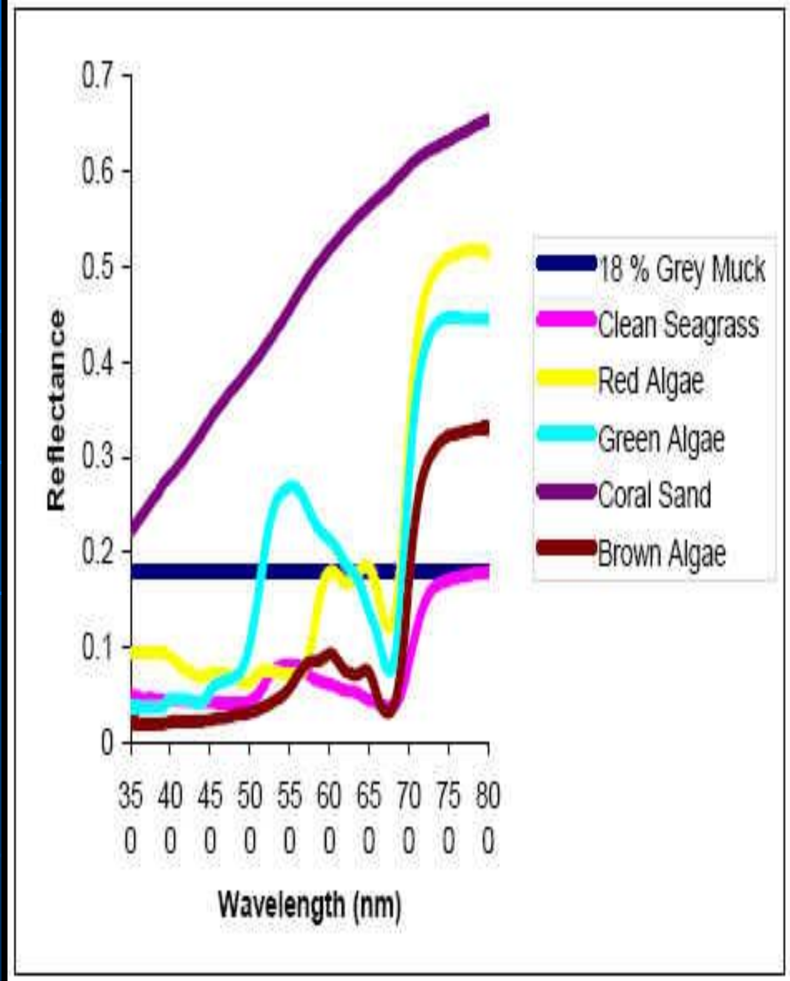

New Remote Sensing Technology Paradign for Water Quality Monitoring and Ecosystem Assessment and Restoration

- CLOUD COMPUTING
- NANO TECHNOLOGY
- SENSOR FUSION

Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers and storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider (Wikepedia)

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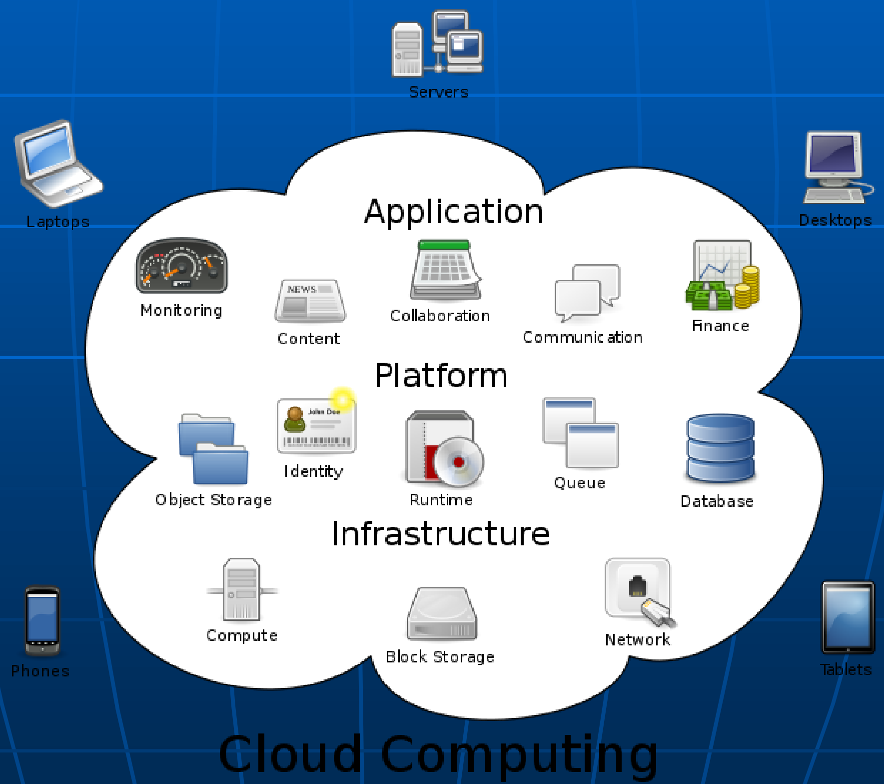
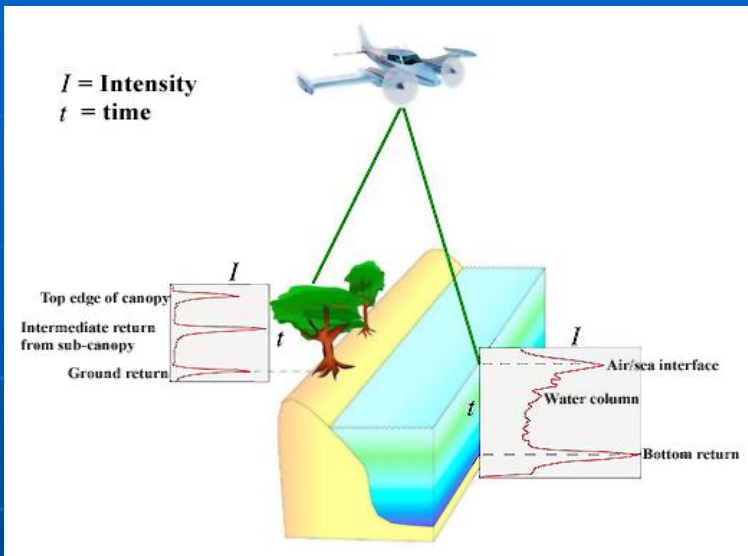
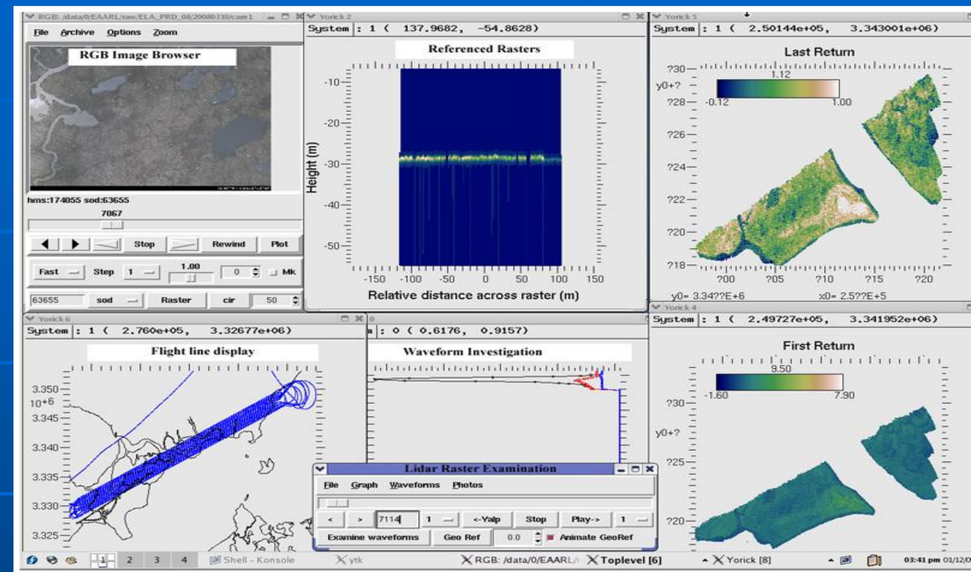


NANO TECHNOLOGY: The Experimental Advanced Airborne Research LiDAR (EAARL)





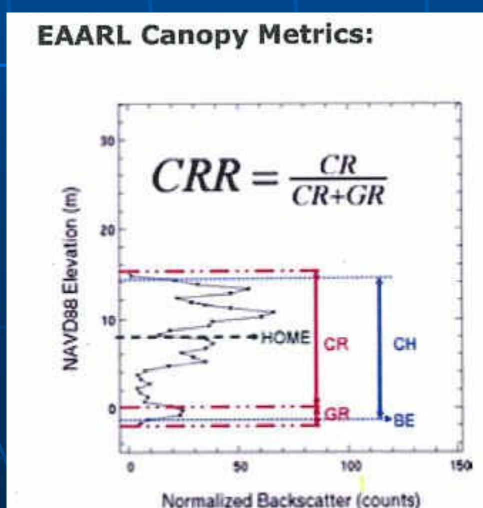


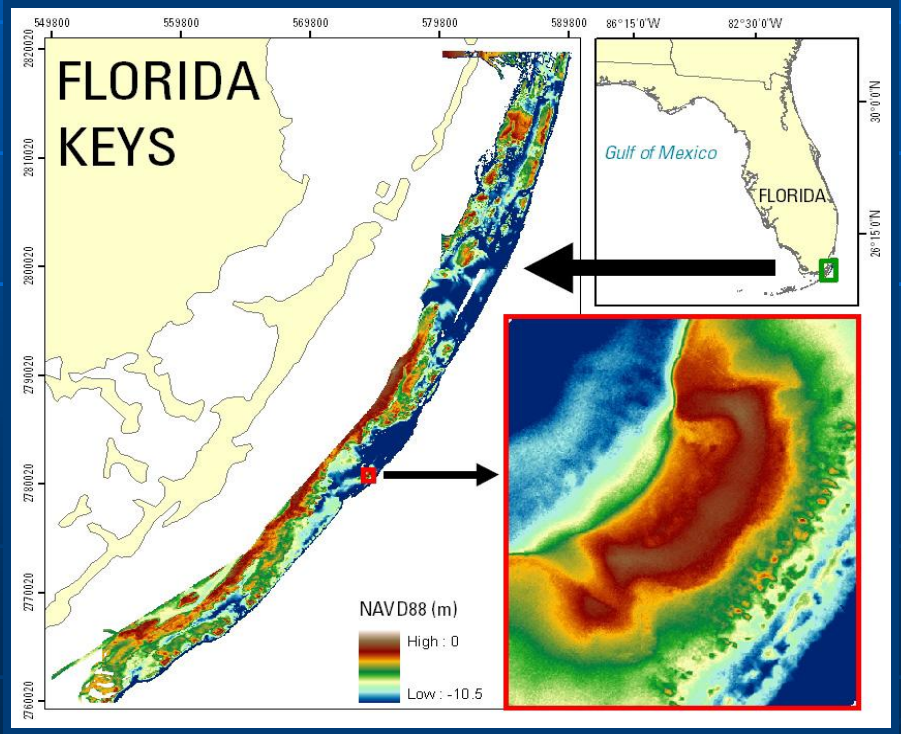
Figure 2. Normalized Backscatter

1. A relatively short 1.3 ns laser pulse
2. A radically narrowed receiver field-of-view (1.5-2 mrad)
3. Digitized signal temporal backscatter amplitude waveforms
4. Software as opposed to hardware implementation of real-time signal processing

NASA EAARL System Specifications	
Total system weight:	250 lbs.
Maximum power requirement:	28 VDC at 24 amps
Nominal surveying altitude:	300 m AGL
Raster scan rate:	97 knots (50 m/s)
Laser sample per raster:	25 rasters/second
Swath width at 300 m altitude:	240 m
Sample spacing:	Swath center = 2 x 2 m Swath edges = 2 x 4 m
Area surveyed per hour: (300 m altitude, 50 m/s)	43 km^2 per hour
Nominal power required:	400 Watts
Illuminated laser spot diameter on the surface:	20 cm
Nominal ranging accuracy:	3 - 5 cm
Nominal horizontal positioning accuracy:	< 1 m
Digitizer temporal resolution:	1 nanosecond (13.9 cm in air, 11.3 cm in water)
Minimum water depth:	30 cm
Maximum measurable water depth:	26 m

(EAARL) Specifications

(EAARL) Example in South Florida



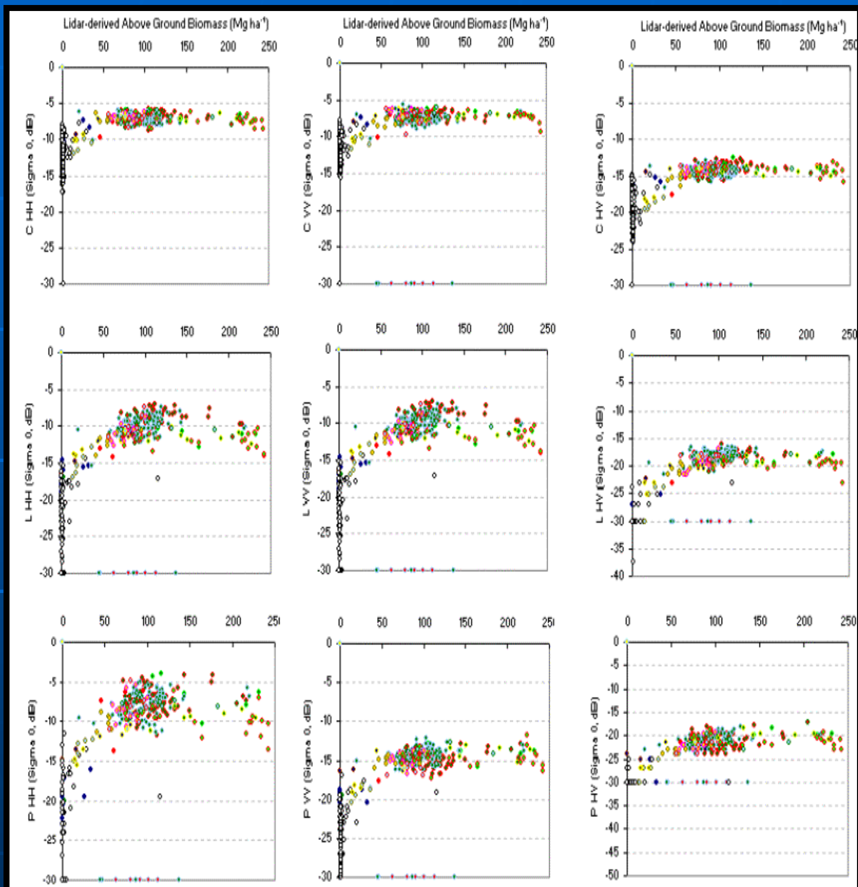
SENSOR FUSION: Nutrient (Phosphorus) Enrichment and Impacted Biomass Determination

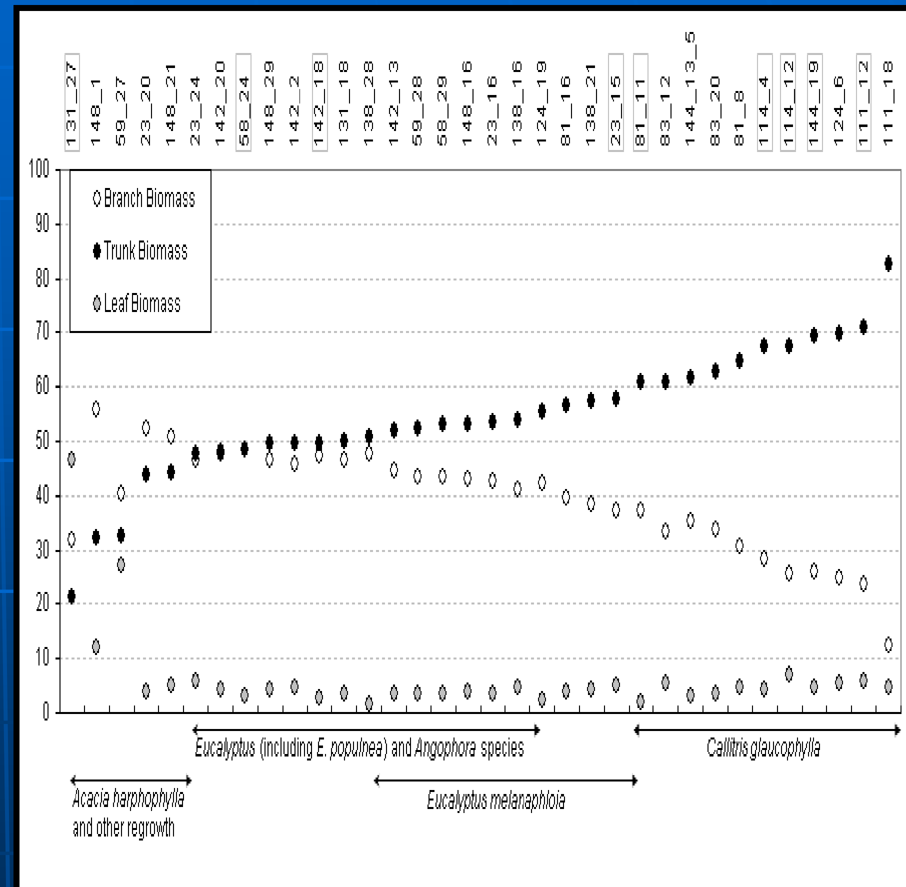
- LiDAR and RADAR provide complementary information about vegetation structure and biomass.
- LiDAR is sensitive to leaf biomass material and better suited for under story biomass determination.
- RADAR is sensitive to structural features and better suited for hardwood/woody species biomass determination.
- RADAR penetration into the vegetation canopy and the dry/wet medium is dependent on the wavelength, polarization, and incidence angle.
- The incidence angle determines the amount of vegetation illuminated, and the polarization determines the type of interaction with the vegetation and its medium (above or below the surface).

SENSOR FUSION: Nutrient (Phosphorus) Enrichment and Impacted Biomass Determination

- HyperSpectral and LiDAR imagery provide complementary information about pollutant geochemistry indicators of pigment in vegetation structure and biomass.
- Pollutant absorption through pigment in green-leaf chloroplast residing in outer leaf.
- Geochemical reactio of spongy mesophyll cells located in the interior or back of leaf.

Nutrient (Phosphorus) Enrichment LiDAR/RADAR Spectral Analysis

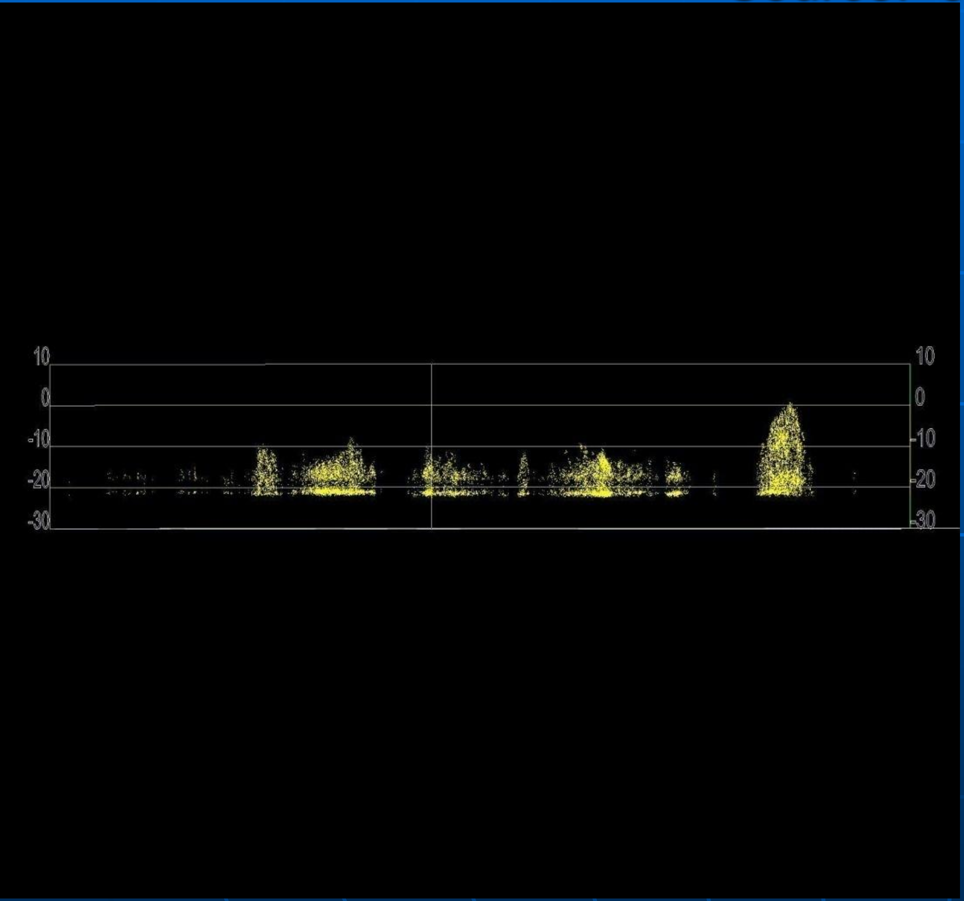


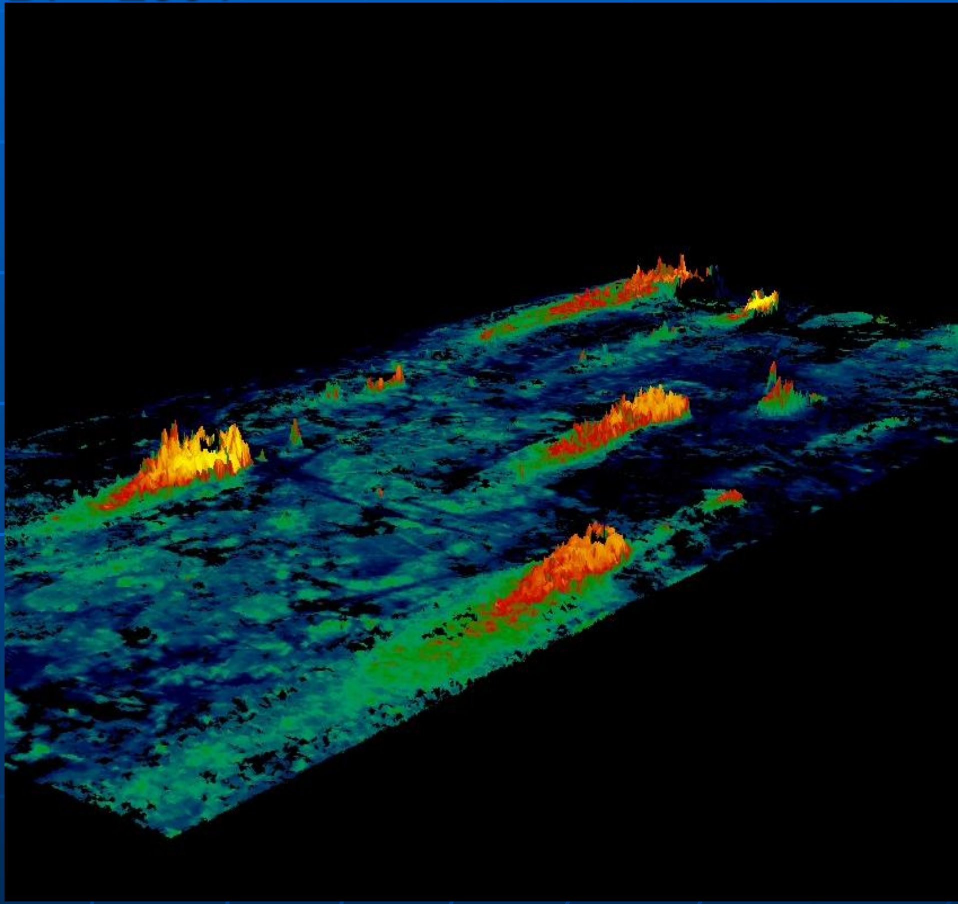


Source: The InJune Landscape Study

LiDAR and Hyperspectral Everglades Cypress Island Canopy Mapping

Source: 3DI – 2001





LiDAR Energy

Hyper Spectral Reflectance

LIDAR/RADAR Biomass Data