Role of optical remote sensing in many modeling studies

Mostly the NASA EOS Era

NPP = PARi * fAPAR * LUE
LUE = f(plant functional types, water/temp stress, nutrient stress)

Solar NDVI; EVI; BRDF modeling

Biomass = f(fractional cover, height)

NPV Production (mortality) = fNPV cover * carbon density
= f(plant functional types, stress, disturbance)
Many have now used this approach to estimate plant and plankton growth at regional and global scales. This has been instrumental in quantifying global ecological responses to climate variability.
Current role of optical remote sensing in carbon cycle studies

Mostly the NASA EOS Era

NPP = PAR\textsuperscript{i} \cdot fAPAR \cdot LUE

LUE = f(plant functional types, water/temp stress, nutrient stress)

Biomass = f(canopy fractional cover, height)

NPV Production (mortality) = fNPV cover \cdot carbon density

= f(plant functional types, stress, disturbance)

Solar \quad NDVI

Now & Tomorrow
Chemical and physiological change is central to understanding ecosystems, diversity, and the carbon cycle.

- Canopy stress, recovery
- Diffuse ecosystem change
- Invasive species
- Insect damage
Optical systems for regional and global ecological research
Bar thickness denotes relative differences in instrument performance (e.g., fidelity, signal-to-noise)

Landsat MSS
Landsat TM
Landsat ETM+
AVHRR
MODIS
MISR

Land Cover

fAPAR, fire
fAPAR-LAI, fCover, phenology, fire
fAPAR, LAI, phenology

fCover, Nitrogen correlates
fCover, fSpecies, fGroups, LUE, Water, LAI, Nutrients, Pigments
fCover, fSpecies, fGroups, LUE, Water, LAI, Nutrients
fCover, fSpecies, LUE, Water, LAI, Nutrients

1970s 1980s 1990s 2000s 2010s

Multispectral Sensors

High Spectral Resolution Sensors

Optical systems for regional and global ecological research
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Fractional cover, physiology, and functional groups from imaging spectroscopy (a.k.a. hyperspectral imaging)

Photosynthesis

Chl.

\[ 6H_2O + 6CO_2 + photon \rightarrow C_6O_6H_{12} + 6O_2 \]
Leaves ≠ Canopies

![Graphs showing differences in reflectance between leaves and canopies across different wavelengths.](image-url)
Leaf, Canopy, and Landscape Studies

- upper epidermis
- palisade layer
- spongy tissue
- lower epidermis
Spectral Modeling Studies (putting it all together)

Model Inputs
- Tissue Chemistry & Optics
- Tissue Volume
- Canopy Architecture
- Soil Constituents
- Observing & Atmospheric Constituents

Processing
Coupled Atmosphere and Vegetation-soil Photon Transport Model

Output: Simulated Radiance

Carefully constrained by extensive spatial field measurements
Spectral Modeling Studies – Signature Prediction

Closed-canopy Tropical Forest Example

![Graph showing spectral data with labels for Canopy gaps and shade, Leaf Reflectance/Chemistry, Leaf Angle Orientation, and Leaf Transmittance/Chemistry]
Conceptual model for ecosystem analysis via spectral remote sensing

- **Ecosystem Disturbance, Composition, Productivity**
- **Fire Fuels & Fuel Moisture**
- **Canopy Water Content**
- **Disturbance & Responses**
- **Fractional Cover of Biological Materials**
- **Plant Functional Types**
- **Light-use Efficiency & Pigments**

**Observations**

**Modeling**

**Analysis**

**Measurements**
Spectroscopic techniques isolate fractional cover of materials

Photosynthetic Vegetation

Non-Photosynthetic Vegetation

Bare Substrate

Water

Cellulose/Lignin

OH⁻
Cross-ecosystem Studies of Fractional Material Cover

Asner et al. 2005
Automated Tied-SWIR2 unmixing across ecosystems

Bioclimatic Zone

Accuracy Assessment

Fractional Cover (%)

PV
NPV
Bare

Asner et al. 2005
More detailed analysis of fraction cover + functional type

- Functional groups differ in processing of water, nutrients, and carbon.
- Functional groups differ in carbon residence times and turnover.
- Functional types differ in sensitivity to climatic stress and land use.

Dar Roberts et al.
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- **Analysis**
- **Measurements**
Spectroscopy Provides Routine Analysis of Atmospheric Water Vapor and Canopy Water Content

Rob Green et al., JPL
Canopy water as a gateway into high-LAI environments (forests)

Both NDVI and EWT appear non-linear

EWT reaches an asymptote at much higher LAI

NDVI, ~ 4

EWT, ~ 9
Leaf Pigments, Light-use Efficiency, and Photosynthetic Capacity

The diagram illustrates the absorption coefficients of various leaf pigments across different wavelengths (in nanometers). The pigments include chlorophyll a (chl a), chlorophyll b (chl b), beta-carotene, lutein, neoxanthin, violaxanthin, and zeaxanthin. The x-axis represents wavelength (nm), while the y-axis represents the absorption coefficient. Each pigment shows a distinctive peak across the wavelength spectrum.
**Xanthophyll cycle**

- violaxanthin
- low irradiance
- zeaxanthin
- excess irradiance

Absorption difference:

**Wavelength (nm)**

400 450 500 550 600 650

**Absorption coefficient**
PRI = \frac{\rho(531\text{nm}) - \rho(570\text{nm})}{\rho(531\text{nm}) + \rho(570\text{nm})}

deep of the year 2002

J. Moreno, Univ Valencia

SIFLEX data
Sodankyla, Finland
Observing leaf nitrogen to constrain photosynthetic capacity, and thus NPP.

Scott Ollinger et al.
Yet another approach: Fluorescence Explorer (FLEX) Mission

An absorption spectrum (a) shows a vibrational structure characteristic of the upper state.

A fluorescence spectrum (b) shows a structure characteristic of the lower state, displaced to lower energies (mirror image of the absorption).

Chlorophyll fluorescence spectral emission

J. Moreno, Univ Valencia
Canopy structural data are essential to separate the multiple components temperatures

J. Moreno, Univ Valencia
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Ecosystem Disturbance, Composition, Productivity

Fire Fuels & Fuel Moisture

Disturbance & Responses

Plant Functional Types

Canopy Water Content

Light-use Efficiency & Pigments

Fractional Cover of Biological Materials
Canopy chemistry → functional types → invasive species

Clouds & Development

Ohia (*Metrosideros*) Forest

Kilauea Iki Crater

Lava Flows

Kilauea Caldera

Hawaiian Archipelago
Combining Spectral Analysis Products
Canopy chemistry $\rightarrow$ functional types $\rightarrow$ invasive species

- Myrica invasion front (high leaf nitrogen)
- Myrica infestations (high leaf nitrogen and high canopy water)
- Hedychium in forest understory (high canopy water)
Species & Functional Type Mapping with Imaging Spectroscopy

Forest

- Conifers
  - Hard Pine
  - White Pine
  - Hemlock

- Broadleaf Deciduous Hardwoods
  - Red Oaks
    - 86.5%
  - White Oak
    - 71.0%
  - Mixed Conifer / Oaks
    - 76.9%
  - Successional
    - 84.6%

Overall

- 96.5%
- 79.8%
- 59.3%
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High Spectral Resolution Sensors

HF AVIRIS

AIS

R&D

fCover, fSpecies, fGroups,
LUE, Water, LAI, Nutrients, Pigments

fCover, fSpecies, fGroups,
LUE, Water, LAI, Nutrients

fCover, fSpecies, fGroups,
LUE, Water, LAI, Nutrients, Pigments

HF Spaceborne Spectroscopy