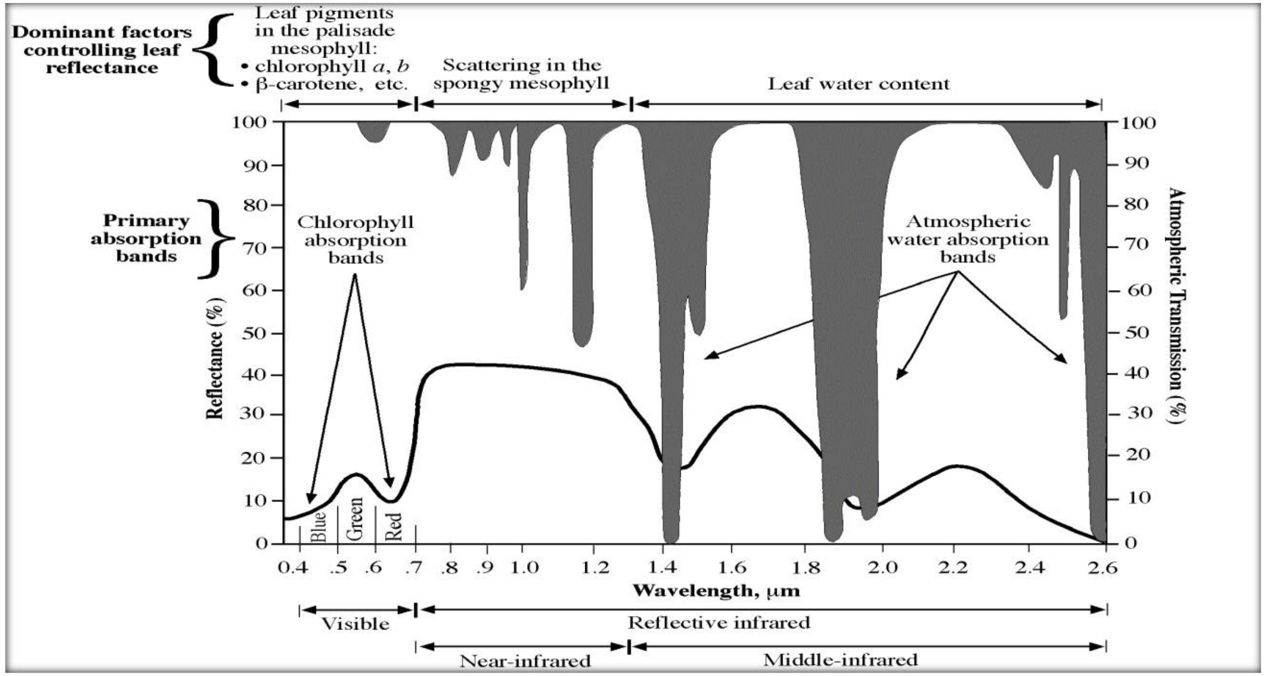
Remote Sensing for Agricultural Applications: Principles and Techniques (2023-2024)
Instructor: Prof. Tao Cheng (tcheng@njau.edu.cn). Nanjing Agricultural University

Lecture 5: Remote Sensing of Vegetation

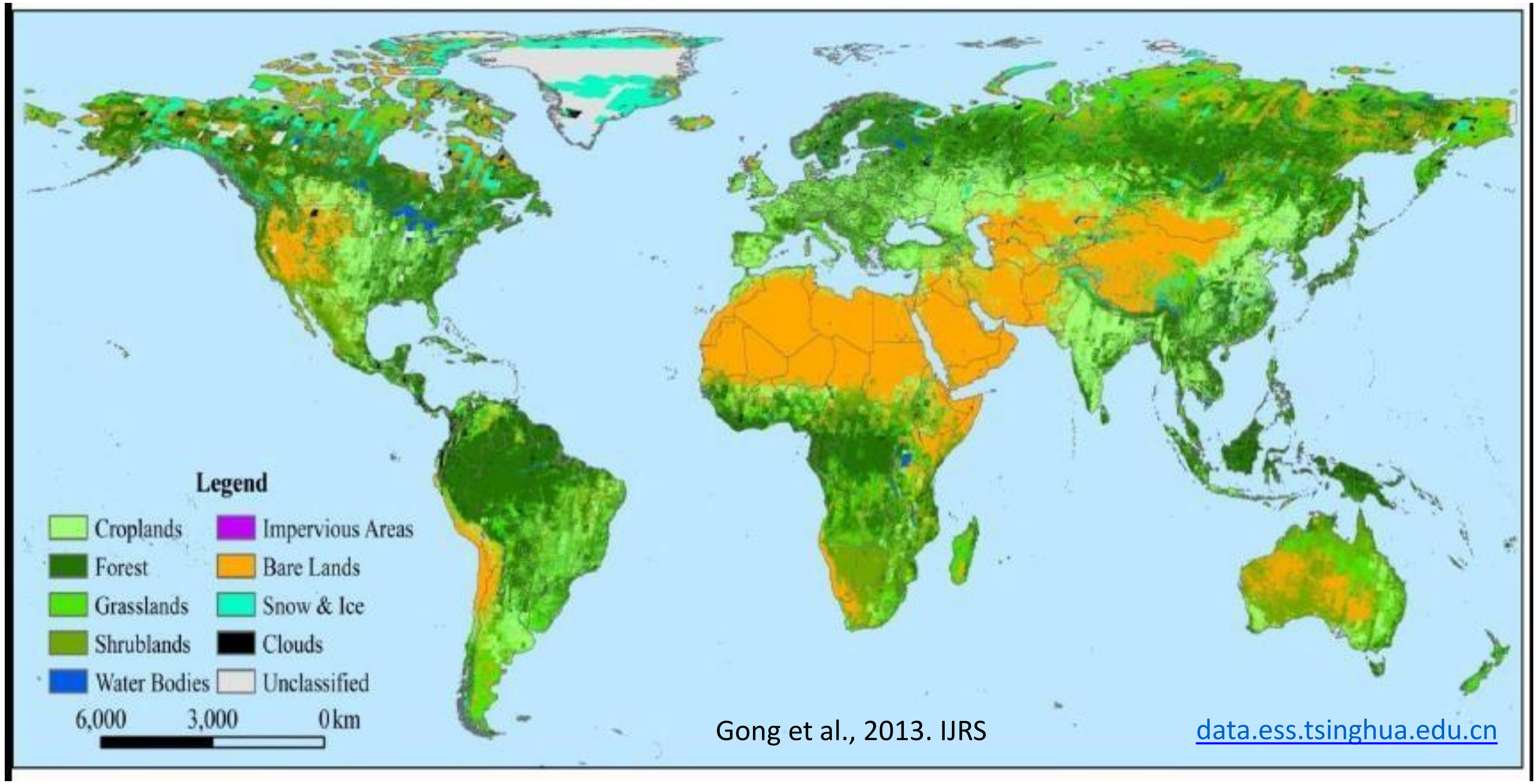


November 8, 2023

Outline

- **Leaf optical properties**
- **Dominant controlling factors of leaf and canopy reflectance**
- **PROSPECT and PROSAIL models**
- **Quantication of vegetation parameters**
- **Bidirectional reflectance distribution function (BRDF) and bidirectional reflectance factor (BRF)**
- **Vegetation Indices**

Vegetation on the Earth

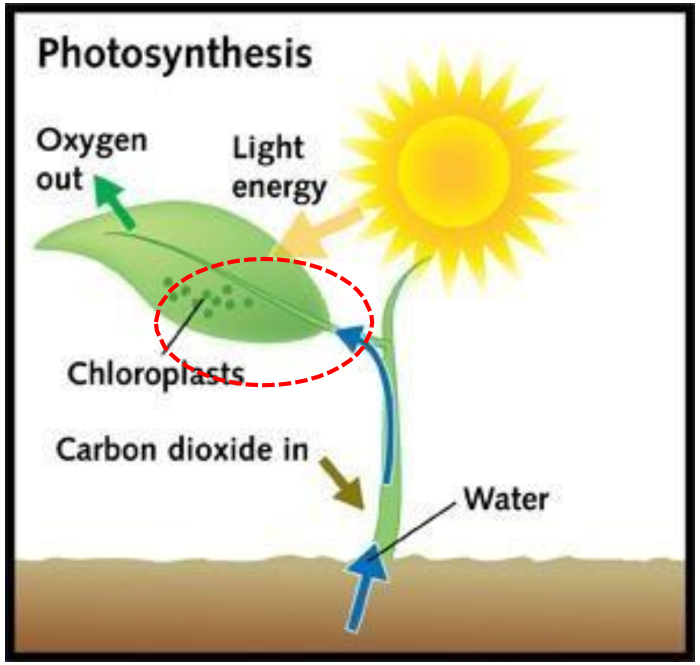


Many of remote sensing techniques developed for vegetation applications are generic in nature. We can use some techniques across a variety of fields:

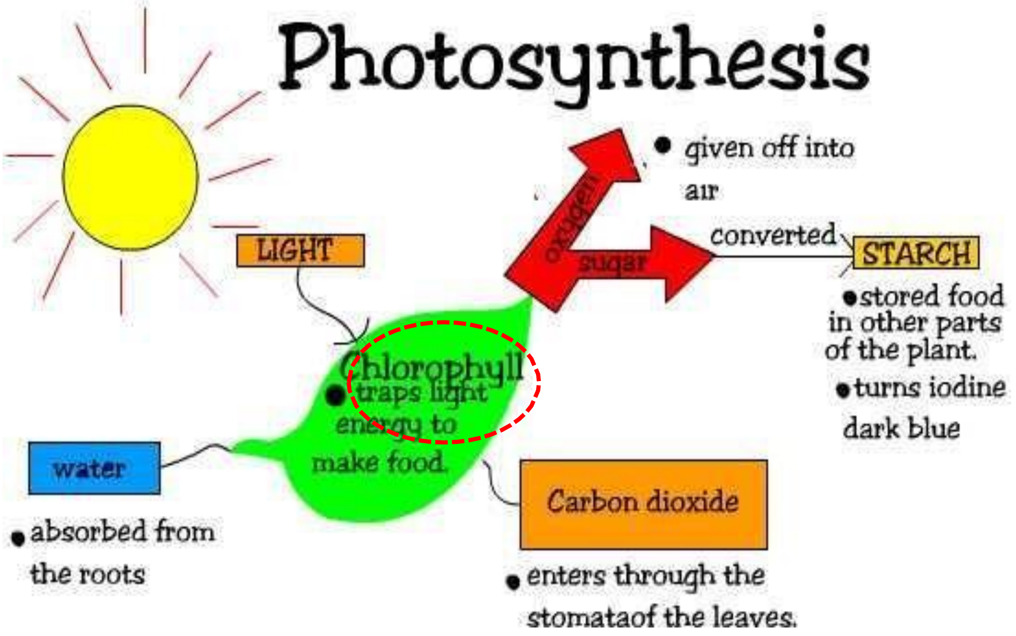
- Cropland
- Forest
- Rangeland
- Wetland

What makes vegetation unique?

- **The most important biological process: photosynthesis**



http://science.jrank.org



http://wikispaces.com

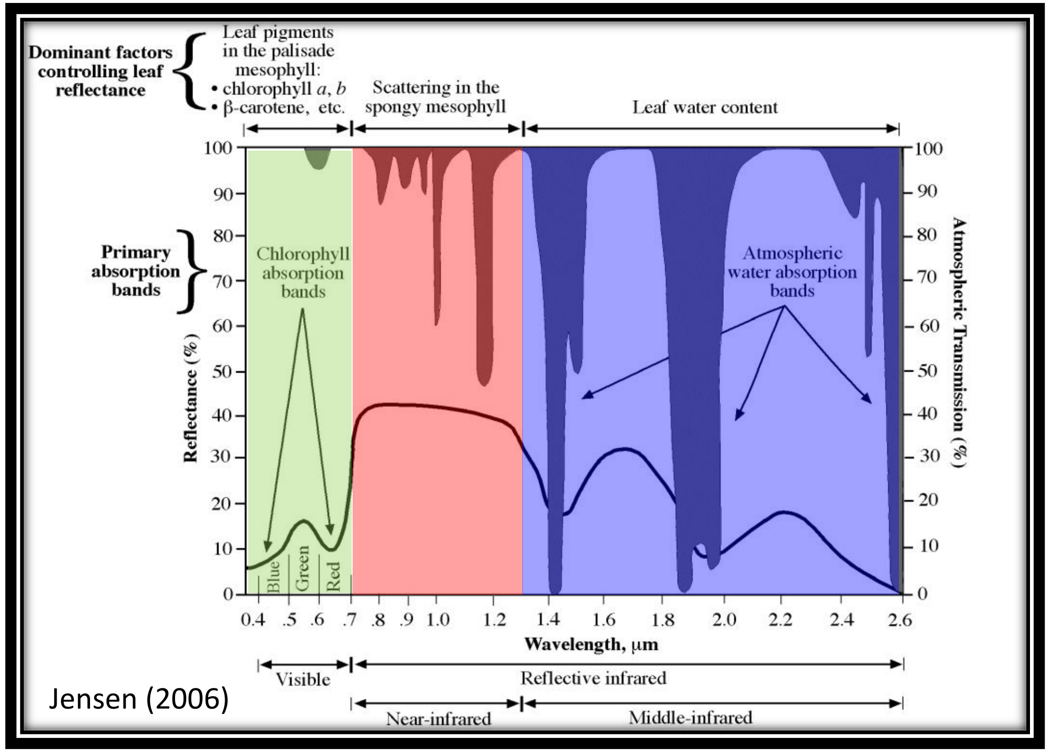
$$CO_2 + H_2O \xrightarrow[\text{叶绿体}]{\text{光能}} (CH_2O) + O_2$$

- **Our focus is on the interaction between vegetation and light energy.**
- **Plants absorb carbon dioxide and water to synthesize photosynthesis production.**

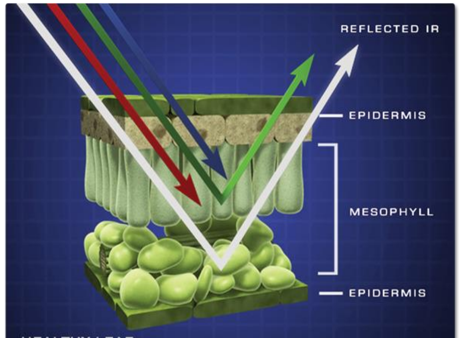
What controls leaf reflectance in the range of 400-2500 nm?

Main constituents in a healthy leaf:

- Pigments
- Water
- Cellulose, lignin, protein, starch, …



Jensen (2006)



http://www.nasa.gov

This is the fundamental for remote sensing of vegetation.

Controlling factor: *pigments*

- Two major classes of photosynthetic pigments:
  - Chlorophylls
  - Carotenoids

- Chl *a* and *b*:
  - responsible for the green color of leaves.

- *β-carotene*:
  - responsible for the orange color of an orange peel.

Photos from www.photographyheat.com

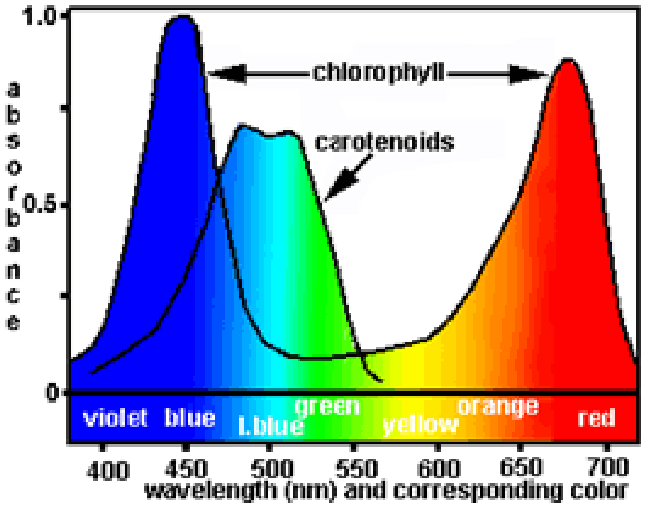


Image courtesy of D.W.Reed, TAMU

Absorption spectra of pigments

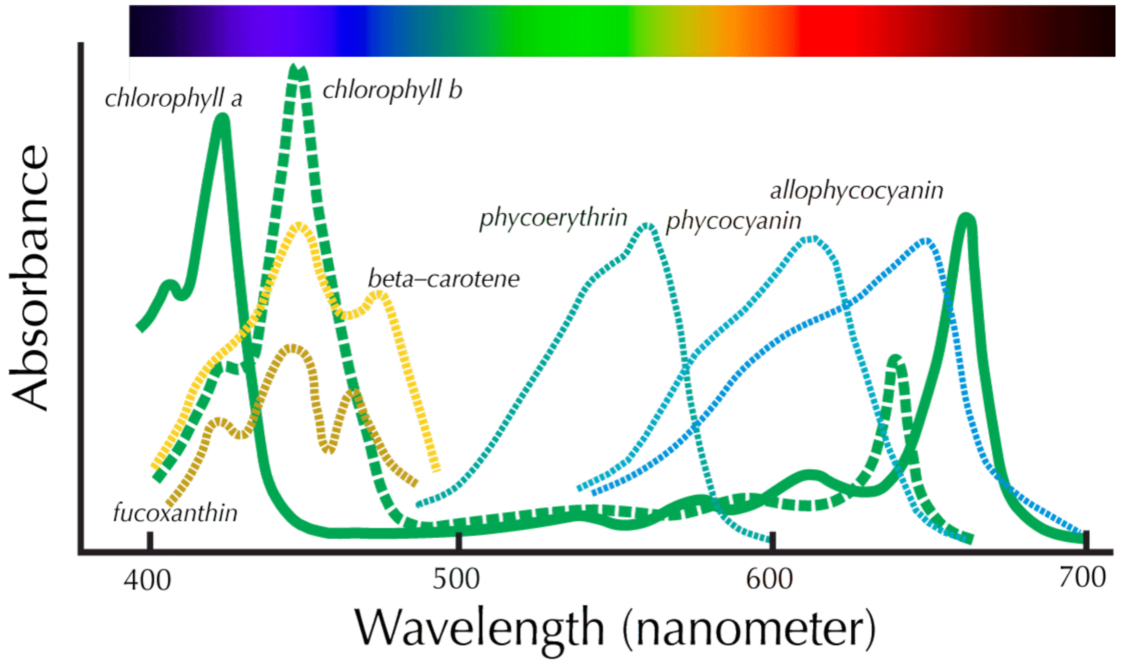
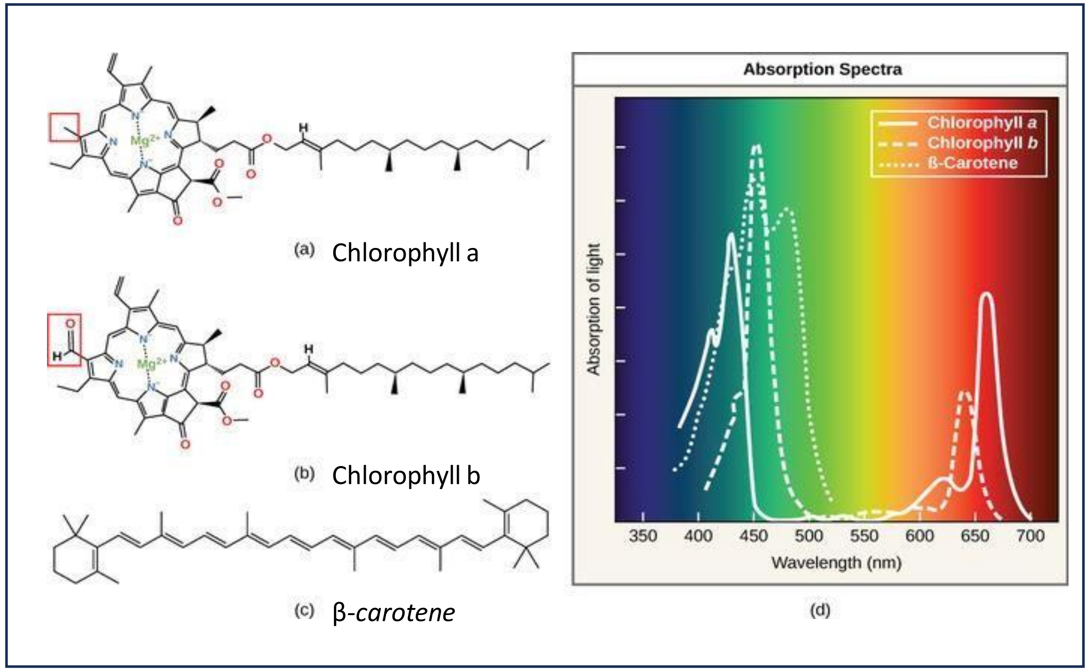


Figure from http://www.yorku.ca/planters/photosynthesis

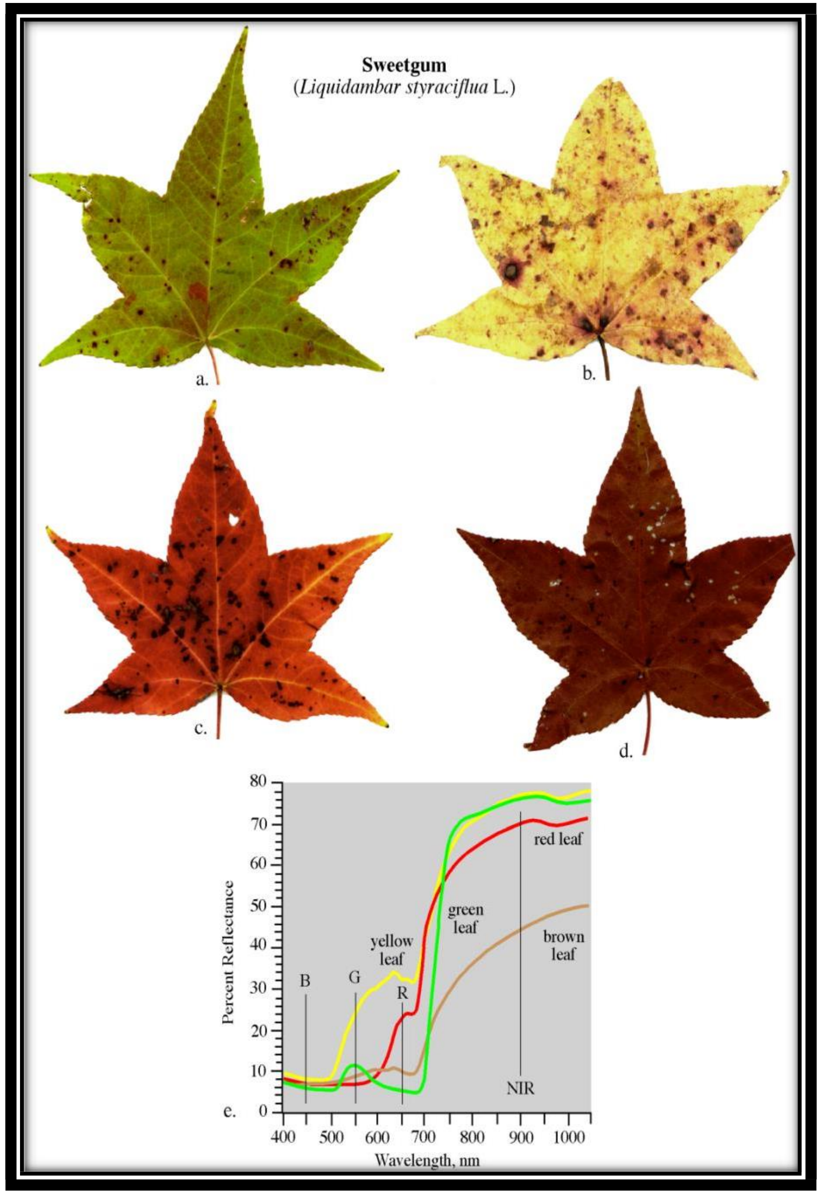
- Chl *a* absorption peaks at 430 and 660 nm.
- Chl *b* absorption peaks at 450 and 650 nm.

Q1: what is the difference between pigment absorbance spectra and leaf reflectance spectra?



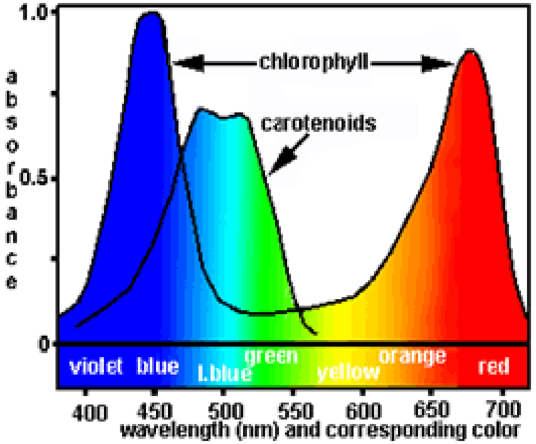
http://www.boundless.com

Spectral reflectance properties of Sweetgum leaves under different stages



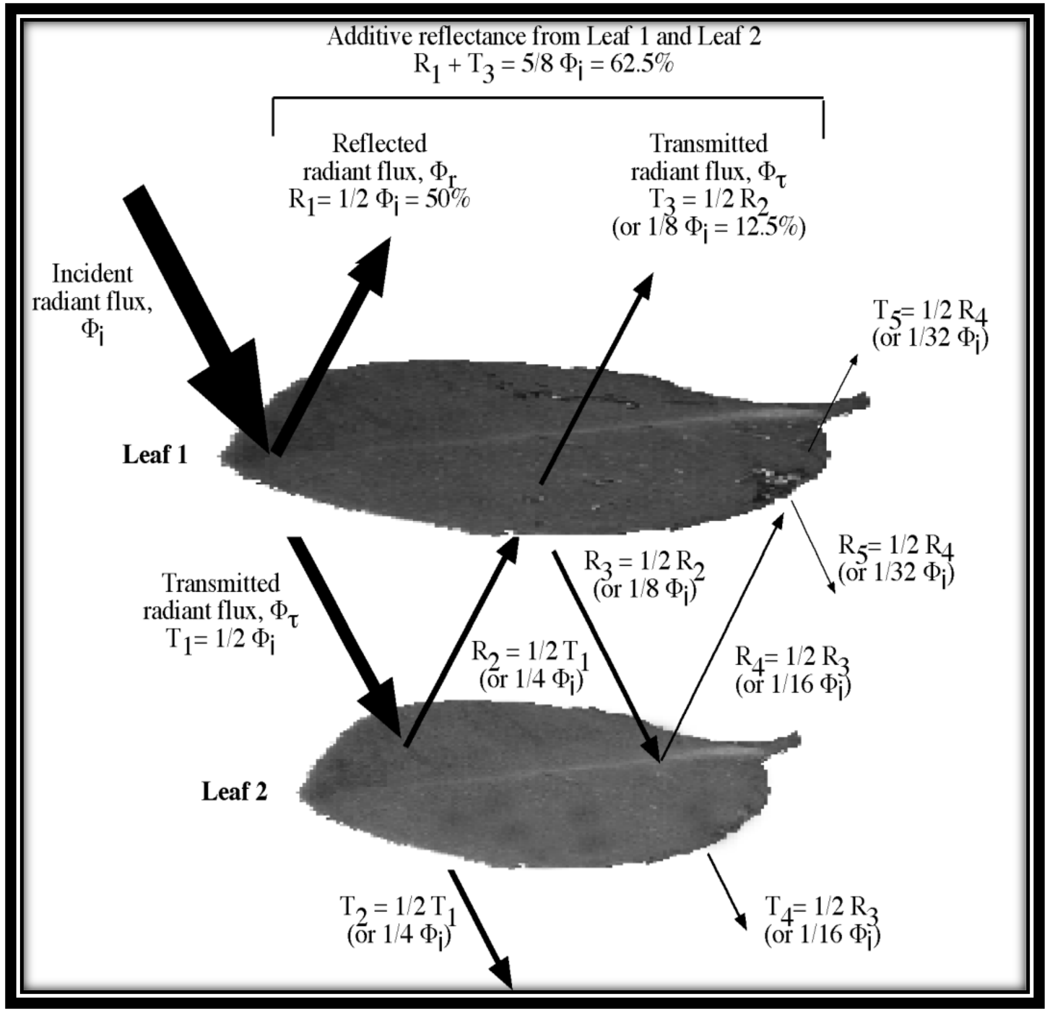
Jensen (2006)

- Four different leaves obtained from a single healthy Sweetgum tree:
    a. Green: photosynthesizing
    b. Yellow: senescing (chls degrade)
    c. Red: senescing (cars synthesized)
    d. Brown: senesced (on the ground)
- Chl *a+b* dominate during the green-up period, while carotenoids and other pigments dominate during senescence.

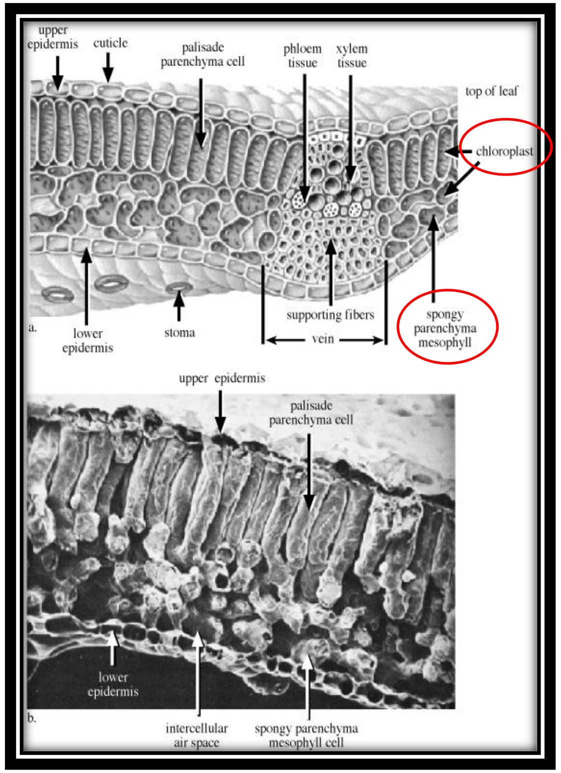


Controlling factor: *leaf structure*

- Internal scattering of NIR energy within and between leaves
- More leaf layers in a healthy, mature canopy may lead to increased NIR reflectance.



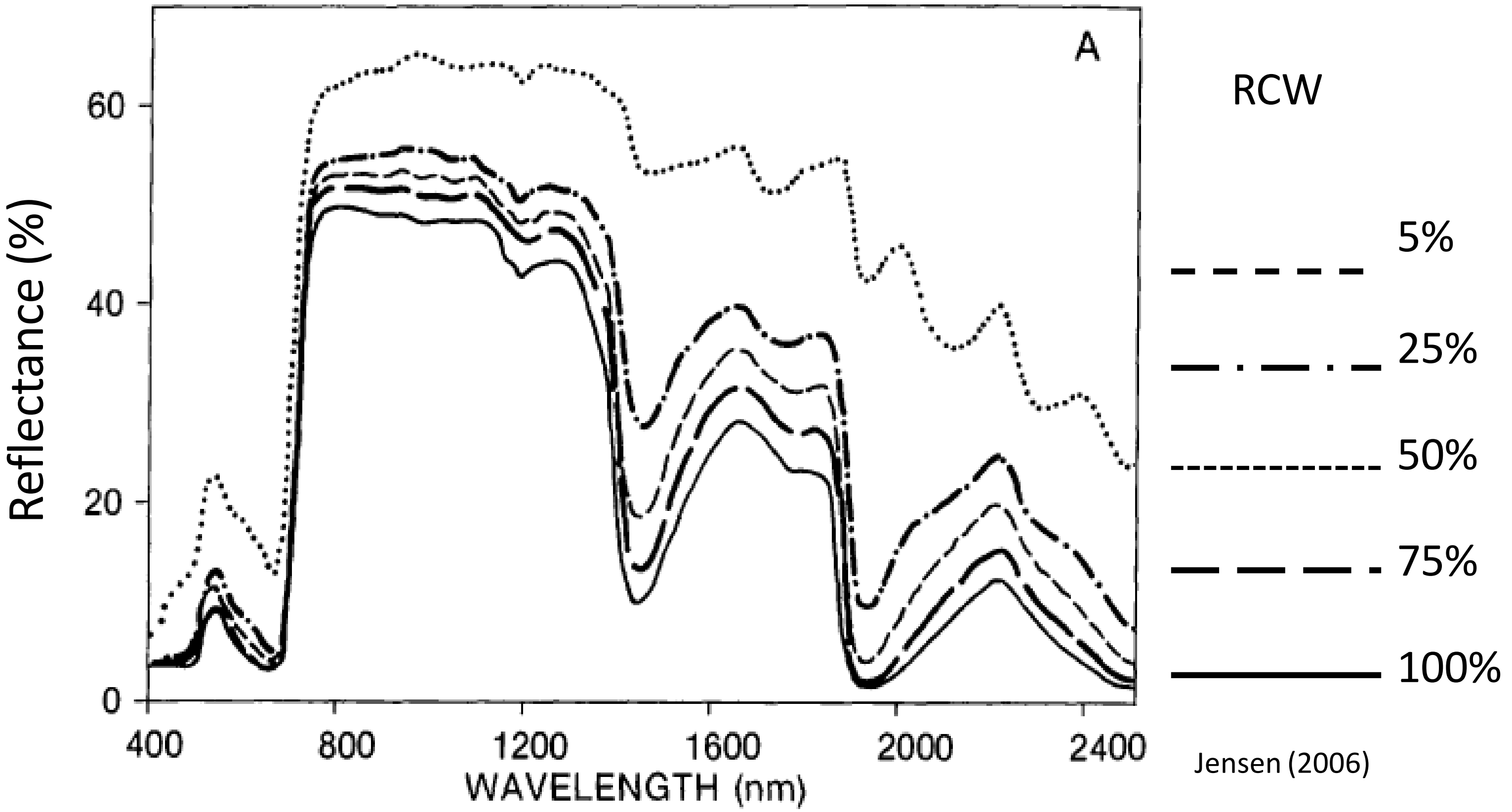
Hypothetical additive NIR reflectance from a canopy of two leaf layers



Leaf internal structure

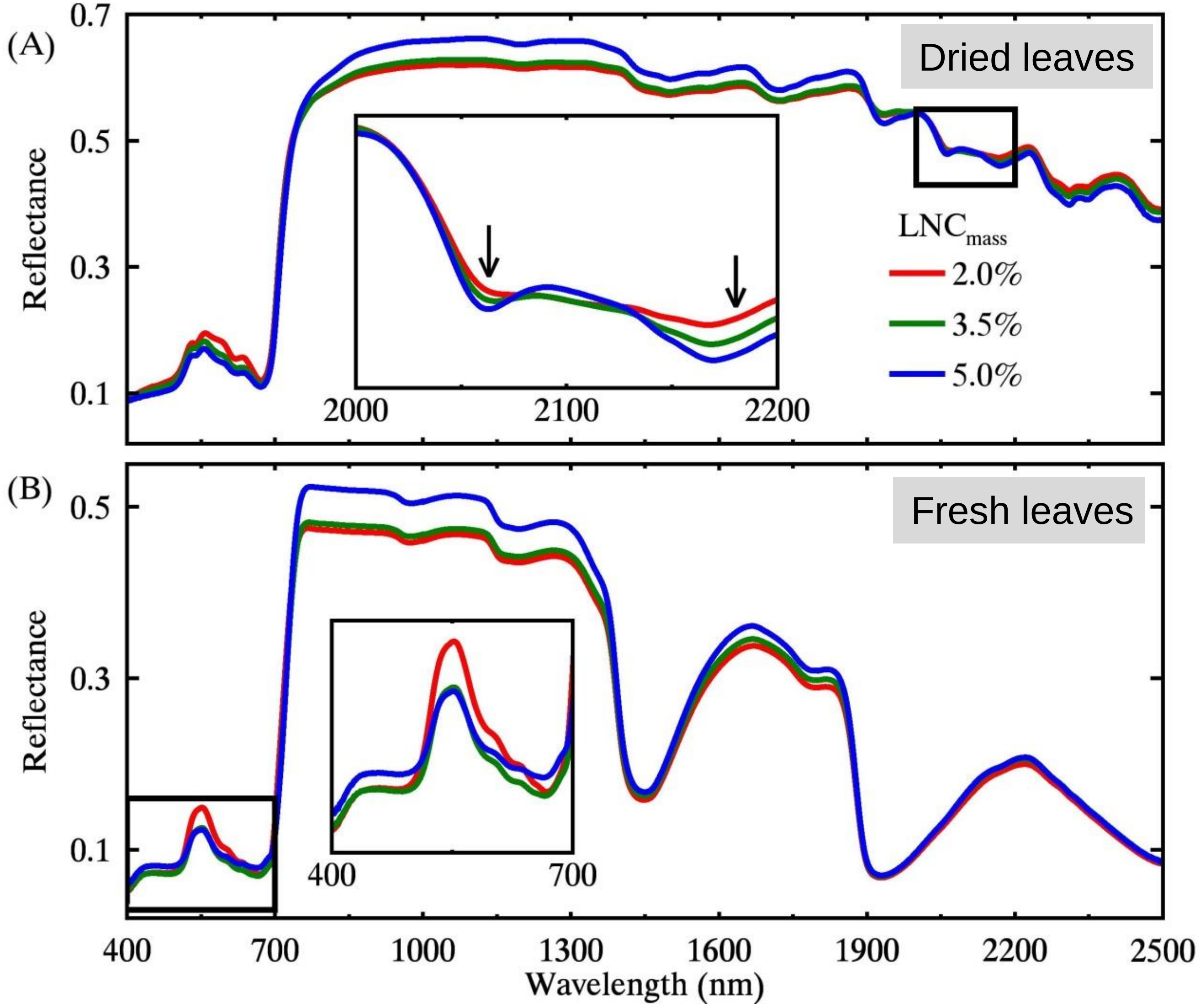
Jensen (2006)

Controlling factor: *leaf water content*



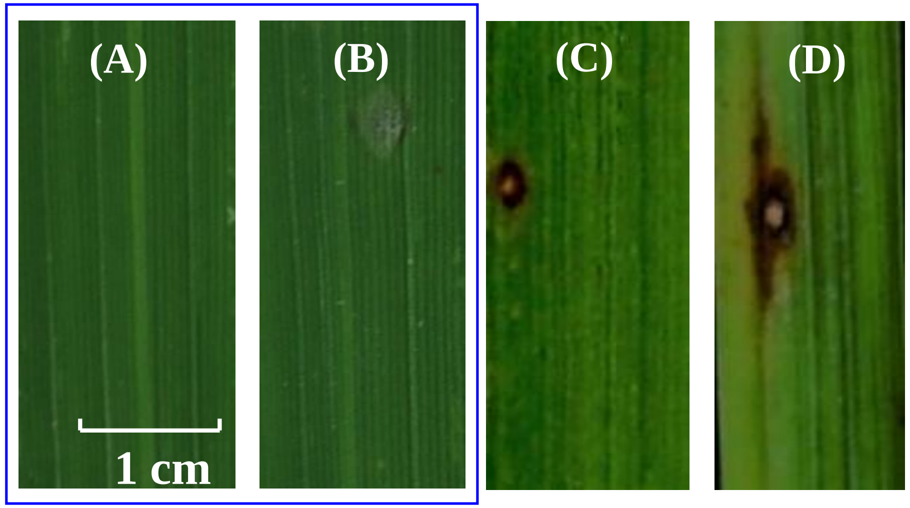
- Leaf reflectance changes in response of decreasing relative water content

Controlling factor: *leaf water content*



- For dried leaves, the absorption features of dry matter (e.g., protein, cellulose, lignin) are apparent in the shortwave infrared (SWIR) region.
- For fresh leaves, the weak absorption features of dry matter are mostly gone. They are masked by strong water absorption features.

Leaf spectral responses to rice blast damage



(A) Asymptomatic (B) Early infection (C) Mild infection (D) Severe infection

Remote Sensing of Environment 257 (2021) 112350

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Spectroscopic detection of rice leaf blast infection from asymptomatic to mild stages with integrated machine learning and feature selection

Long Tian, Bowen Xue, Ziyi Wang, Dong Li, Xia Yao, Qiang Cao, Yan Zhu, Weixing Cao, Tao Cheng*

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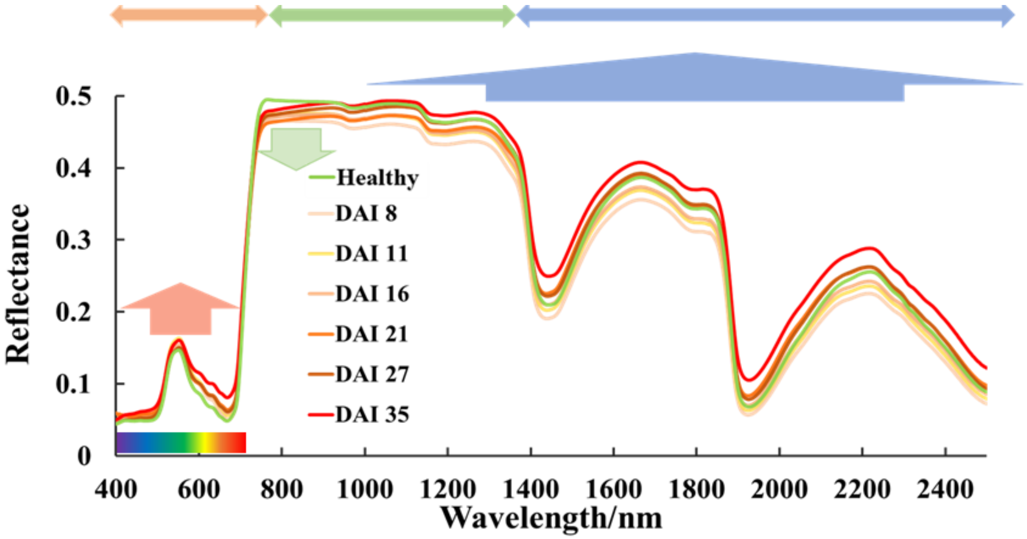
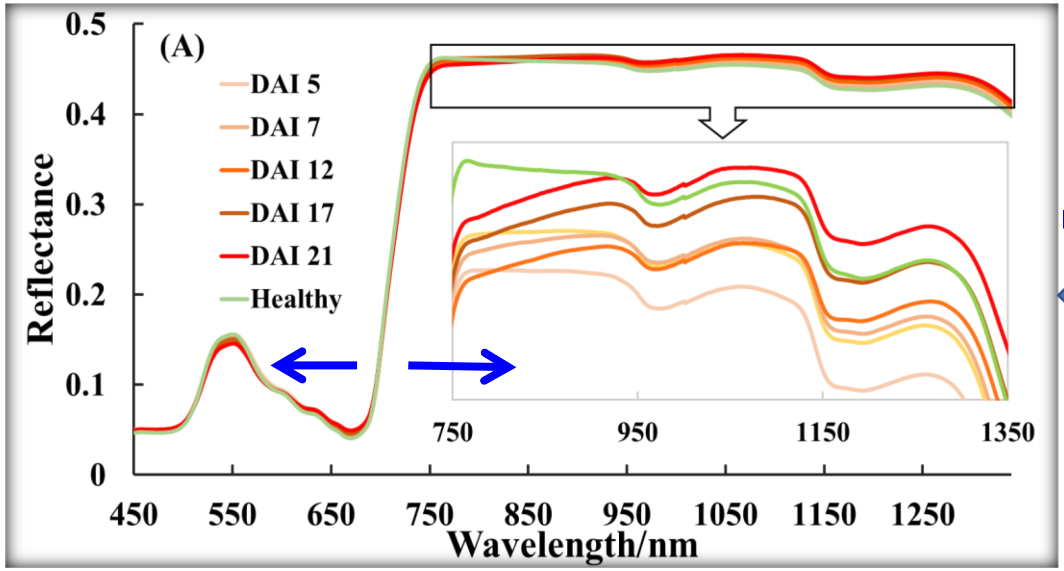
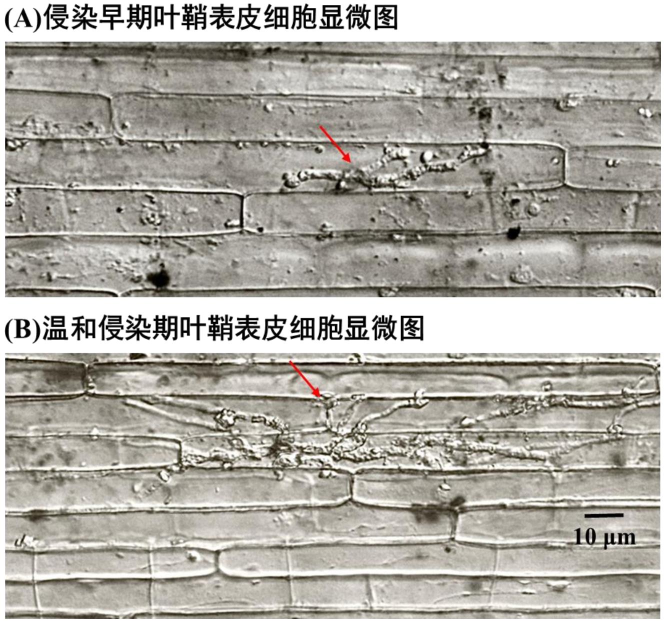


Q2: how did leaf reflectance respond to the rice leaf blast damage?

Leaf spectral responses to rice blast damage



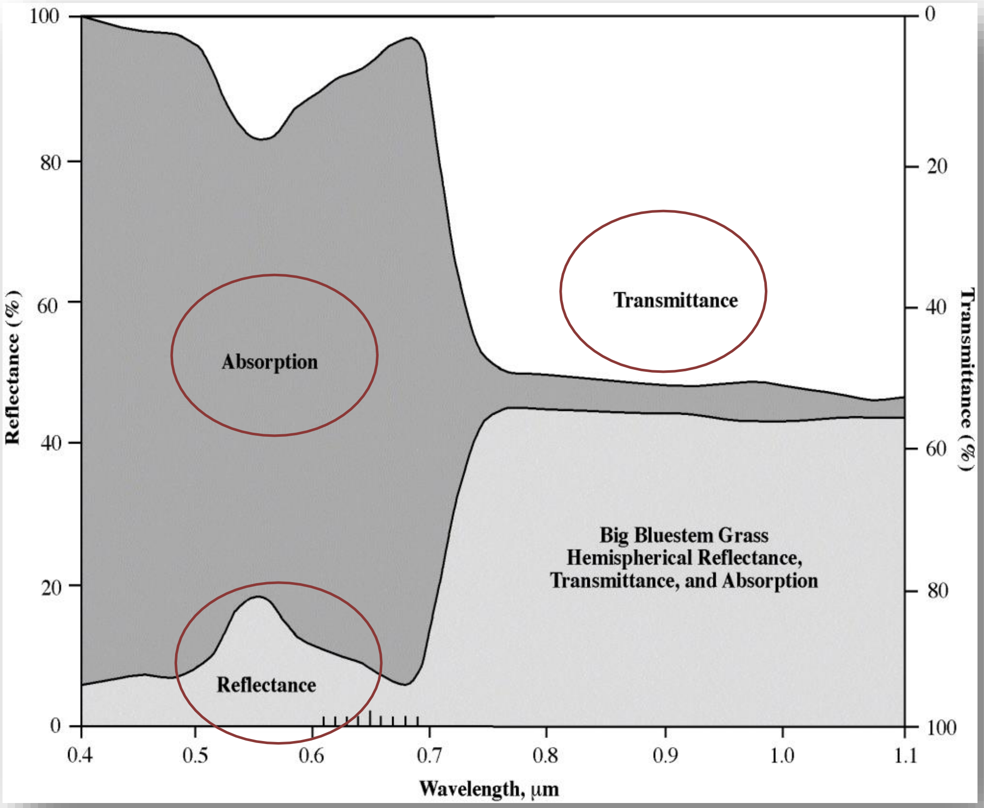
Interpretation



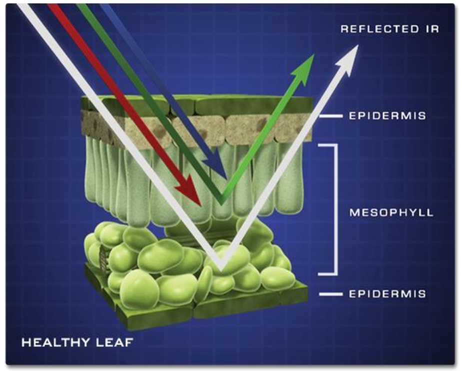
Micrograph of RB mycelia (denoted by red arrows) interacting with rice cells at the early (A) and mild (B) infection stages, respectively.

- The changes in leaf internal structure induced reflectance decreases in the NIR region (750-950 nm).
- The changes in leaf chlorophyll content caused a shifting of red edge to shorter wavelengths.

Leaf optical properties



Jensen (2006)



http://www.nasa.gov

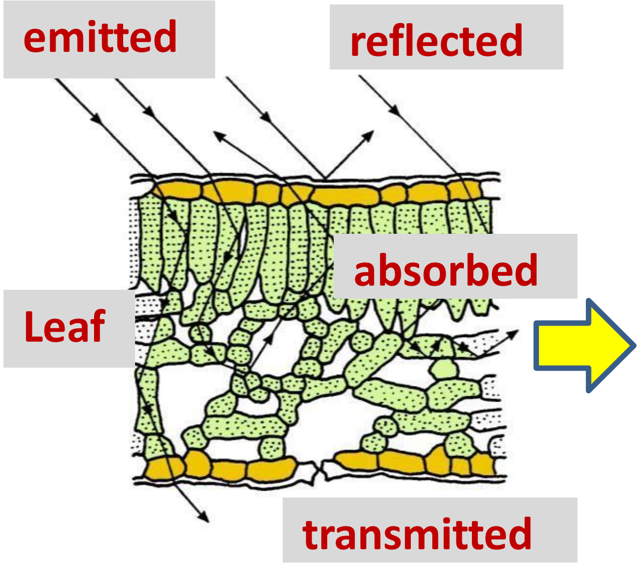
$$1 = \rho_\lambda + \tau_\lambda + \alpha_\lambda$$

→ *Hemispherical absorbtance*

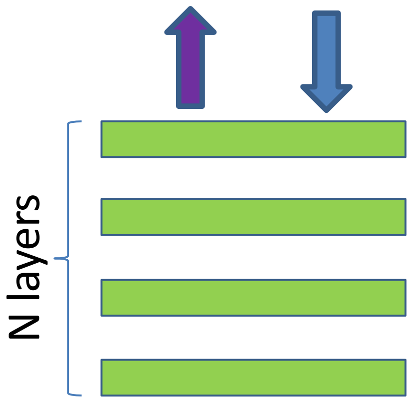
→ *Hemispherical transmittance*

→ *Hemispherical reflectance*

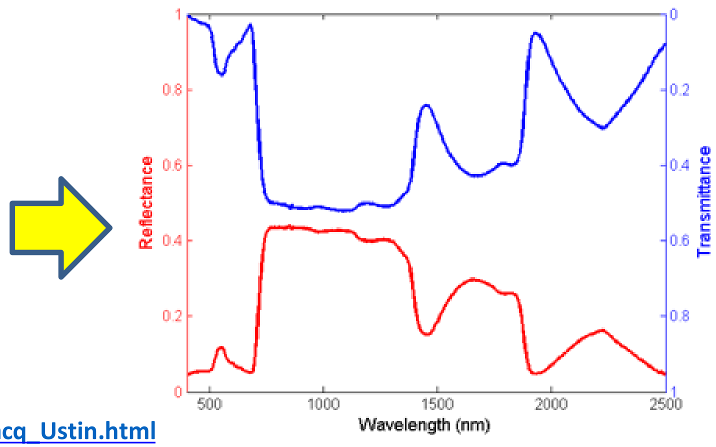
PROSPECT: the leaf optical properties model



Seen by PROSPECT



Leaf **reflectance**
transmittance spectra



http://www.photobiology.info/Jacq_Ustin.html

Jacquemoud & Ustin, 2008

REMOTE SENS. ENVIRON. 34:75–91 (1990)

PROSPECT: A Model of Leaf Optical Properties Spectra

S. Jacquemoud and F. Baret
INRA, Station de Bioclimatologie, Montfavet, France

PROSPECT is a radiative transfer model based on Allen's generalized "plate model" that represents the optical properties of plant leaves from 400 nm to 2500 nm. Scattering is described by a spec-

spectral information obtained on plant canopies from remote sensing techniques is limited by the need of detailed information on leaf optical properties.

Remote Sensing of Environment 113 (2009) S56–S66

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

PROSPECT + SAIL models: A review of use for vegetation characterization

Stéphane Jacquemoud [a,*], Wout Verhoef [b], Frédéric Baret [c], Cédric Bacour [d], Pablo J. Zarco-Tejada [e], Gregory P. Asner [f], Christophe François [g], Susan L. Ustin [h]

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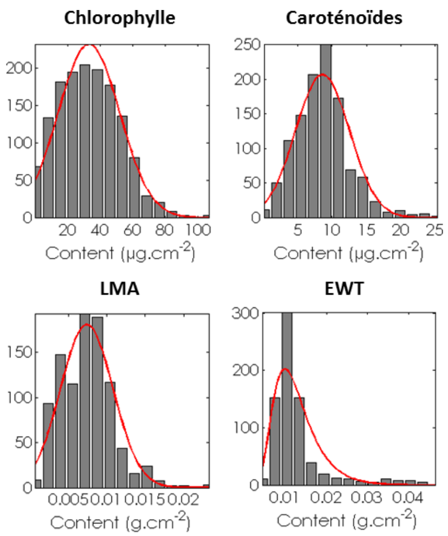
A R T I C L E I N F O

Article history:
Received 27 October 2007
Received in revised form 18 January 2008
Accepted 26 January 2008

A B S T R A C T

The combined PROSPECT leaf optical properties model and SAIL canopy bidirectional reflectance model, also referred to as PROSAIL, has been used for about sixteen years to study plant canopy spectral and directional reflectance in the solar domain. PROSAIL has also been used to develop new methods for retrieval of vegetation biophysical properties. It links the spectral variation of canopy reflectance, which is mainly related

PROSPECT: the leaf optical properties model



Feret et al., 2011

PROSPECT-4
① N
② Chl
③ Cw
④ Cm

Uses:

① Optimization of spectral indices
② Understanding of leaf optical properties
③ Coupling with canopy radiative transfer models (e.g., SAIL)

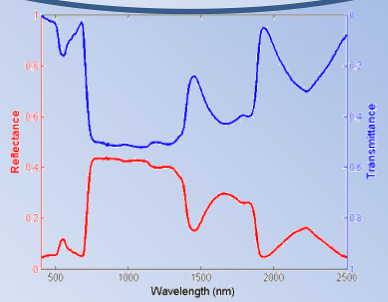
PROSPECT-5

① Leaf structure (N)
② Chlorophyll content (Chl)
③ Carotenoid content (Car)
④ Water content (Cw)
⑤ Dry matter content (Cm)

Input variables

Forward mode →

← Backward mode



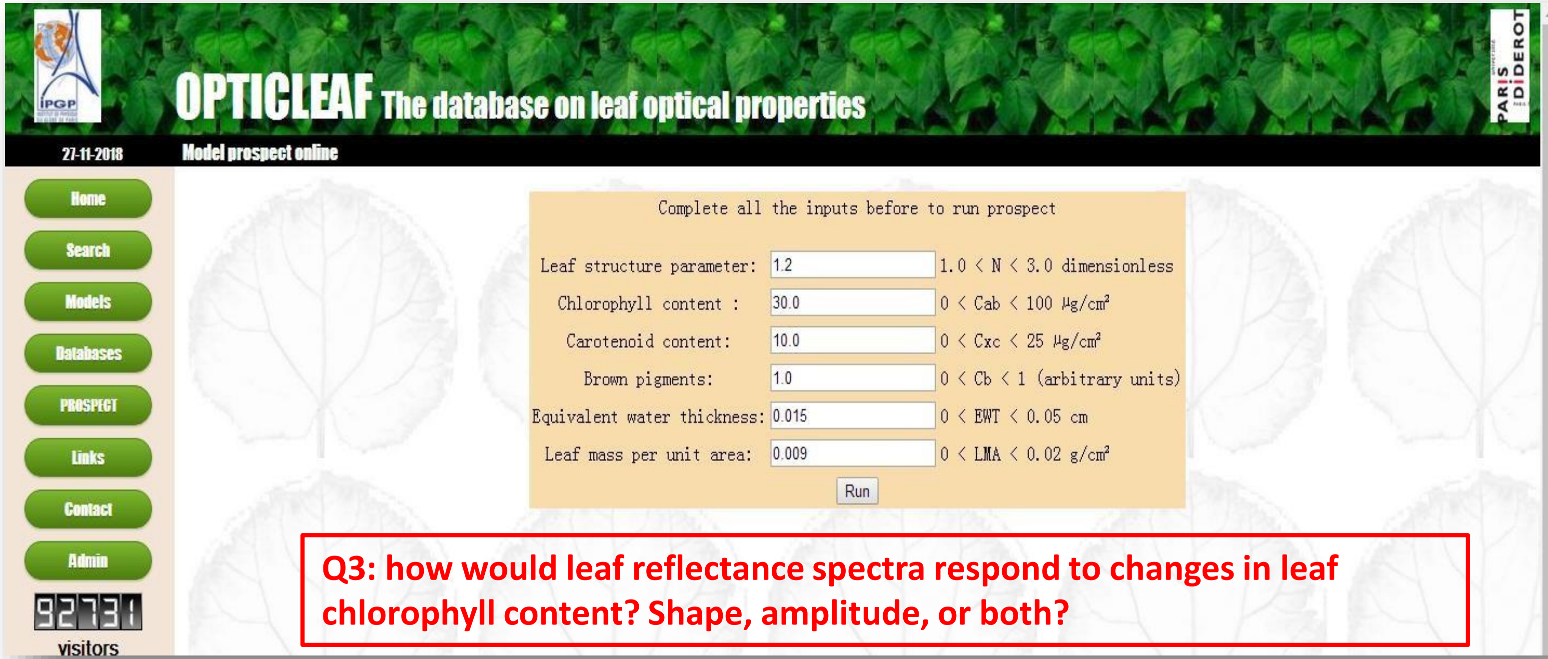
Spectral database

Output

Download PROSPECT at http://teledetection.ipgp.jussieu.fr/prosail/

Parameter	Name	Unit	Range
① N	Leaf structure parameter	dimensionless	1.0 ~ 3.0
② Chl	Chlorophyll content	$\mu g/cm^2$	0 ~ 100
③ Car	Carotenoids content	$\mu g/cm^2$	0 ~ 25
④ Cb	Brown pigment content	(arbitrary units)	0 ~ 1
⑤ Cw	Water content	cm	0 ~ 0.05
⑥ Cm	Dry matter content	g/cm^2	0 ~ 0.02

http://opticleaf.ipgp.fr/index.php?page=database accessed in November 2022



Q3: how would leaf reflectance spectra respond to changes in leaf chlorophyll content? Shape, amplitude, or both?

4SAIL

① Leaf reflectance and transmittance

① Leaf area index (LAI)

② Leaf inclination distribution function(LIDF)

③ Hot spot parameter(S_L)

④ Ratio of diffuse to total incident radiation(SKYL)

⑤ Soil reflectance (ρ_s)

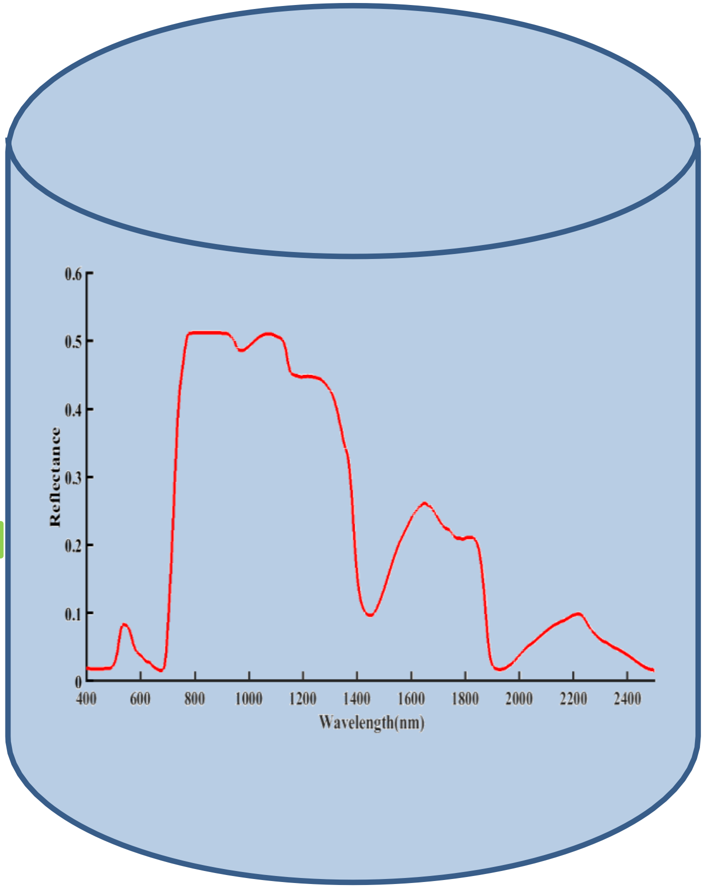
⑥ Solar zenith angle (θ_s)

⑦ Viewing zenith angle (θ_v)

⑧ Relative azimuth angle(φ_{sv})

Forward

Backward



Input variables

Output spectrum

- **Do not be scared by the complexity of physical models! They just represent an efficient way to generate simulations and perform physical inversions of vegetation parameters.**

How can we get PROSAIL codes?

PROSPECT + SAIL = PROSAIL

	Matlab	Fortran	IDL	Python	R	Web interface	GUI
PROSPECT-4	PROSPECT4_Matlab.rar	PROSPECT4_Fortran.rar					
PROSPECT-5	PROSPECT5_Matlab.rar	PROSPECT5_Fortran.rar				PROSPECT5	
PROSPECT-D	PROSPECT-D_Matlab.rar	PROSPECT-D_Fortran.rar					
PROCOSINE	Toolbox_Cosine.rar						
PROSAIL	PROSAIL_5B_Matlab.rar	PROSAIL_5B_Fortran.rar	PROSAIL_5B_IDL.zip	PyProSAIL	HSDAR		ARTMO
PROSPECT-D + SAIL	PROSAIL_D_Matlab.rar	PROSAIL_D_Fortran.zip		PROSAIL-2.0.0alpha			
DART							DART
6S		Msixs (Ver 8.0)		Py6S		Web Sixs	

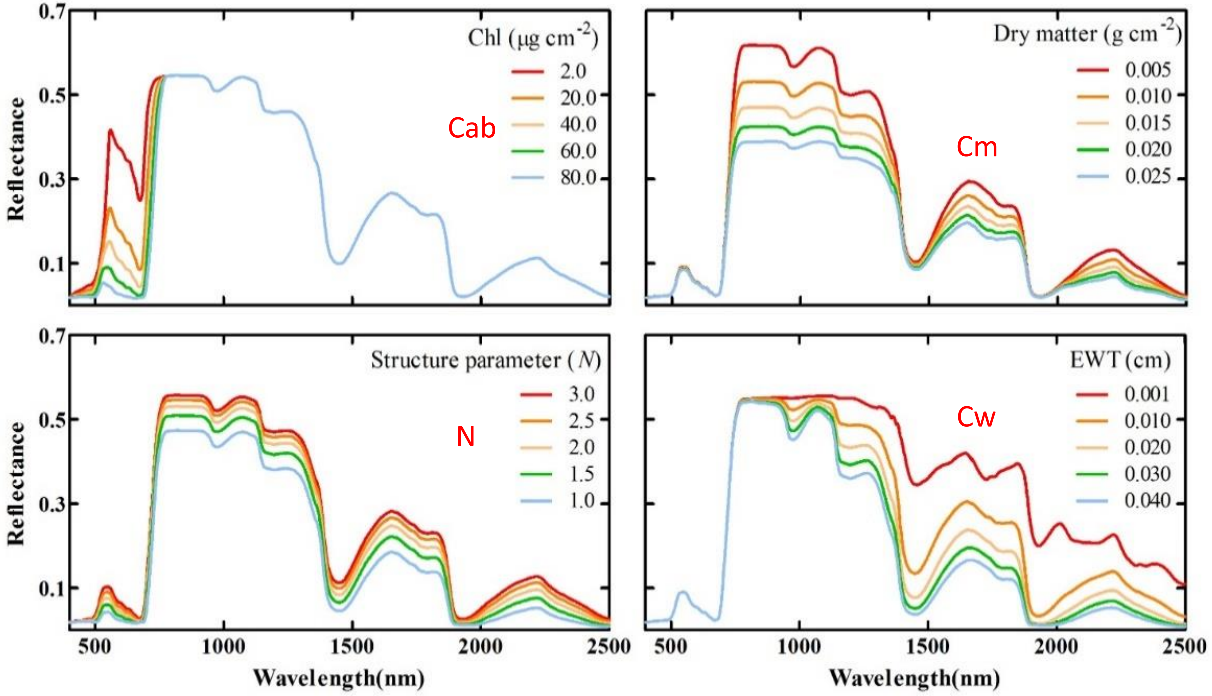
http://teledetection.ipgp.jussieu.fr/prosail/

PROSPECT

- **The combined PROSPECT leaf optical properties model and SAIL canopy bidirectional reflectance model, also referred to as PROSAIL, have been used for about thirty years to study plant canopy spectral and directional reflectance in the solar domain.**
- **PROSAIL has also been used to develop new methods for retrieval of vegetation biophysical properties. It links the spectral variation of canopy reflectance, which is mainly related to leaf biochemical contents, with its directional variation, which is primarily related to canopy architecture and soil/vegetation contrast.**
- **PROSAIL has become one of the most popular radiative transfer tools due to its ease of use, general robustness, and consistent validation by lab/field/space experiments over the years.**

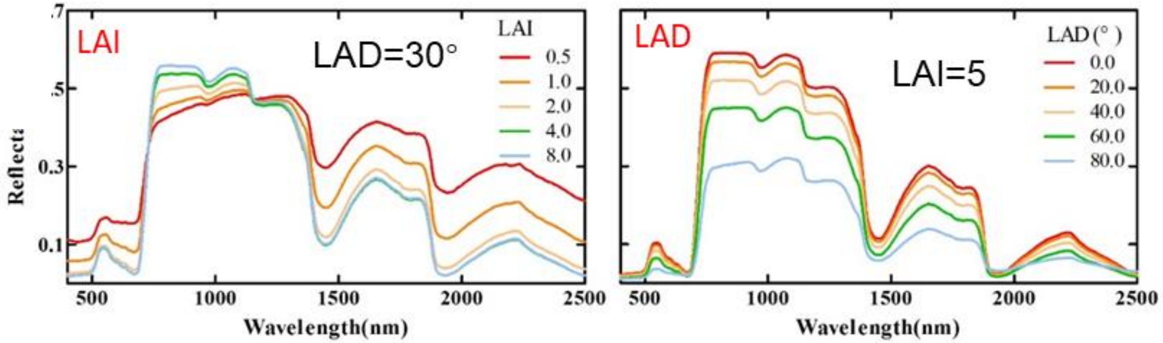
Variability in leaf and canopy reflectance

Effect of various factors on leaf reflectance



Q4: what is the main affecting spectral range for each factor?

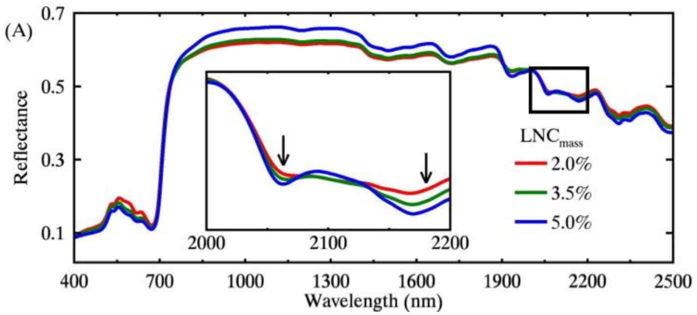
Effect of various factors on canopy reflectance

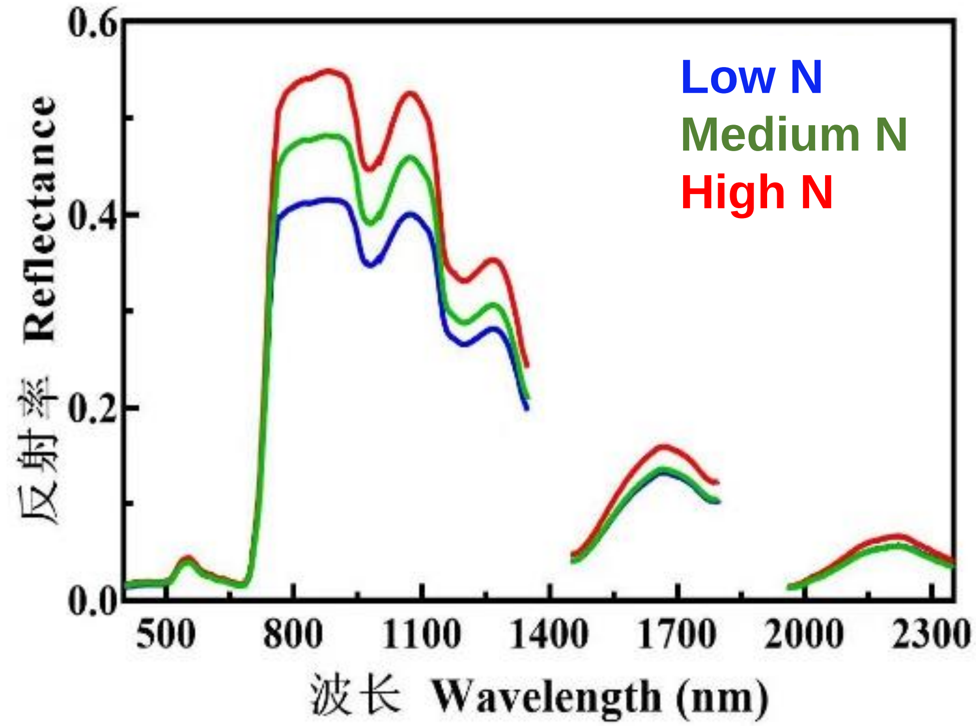


LAD=0°, horizontal
LAD=90°, vertical

PROSAIL-5B simulations by Dr. LI Dong,2022/04/27

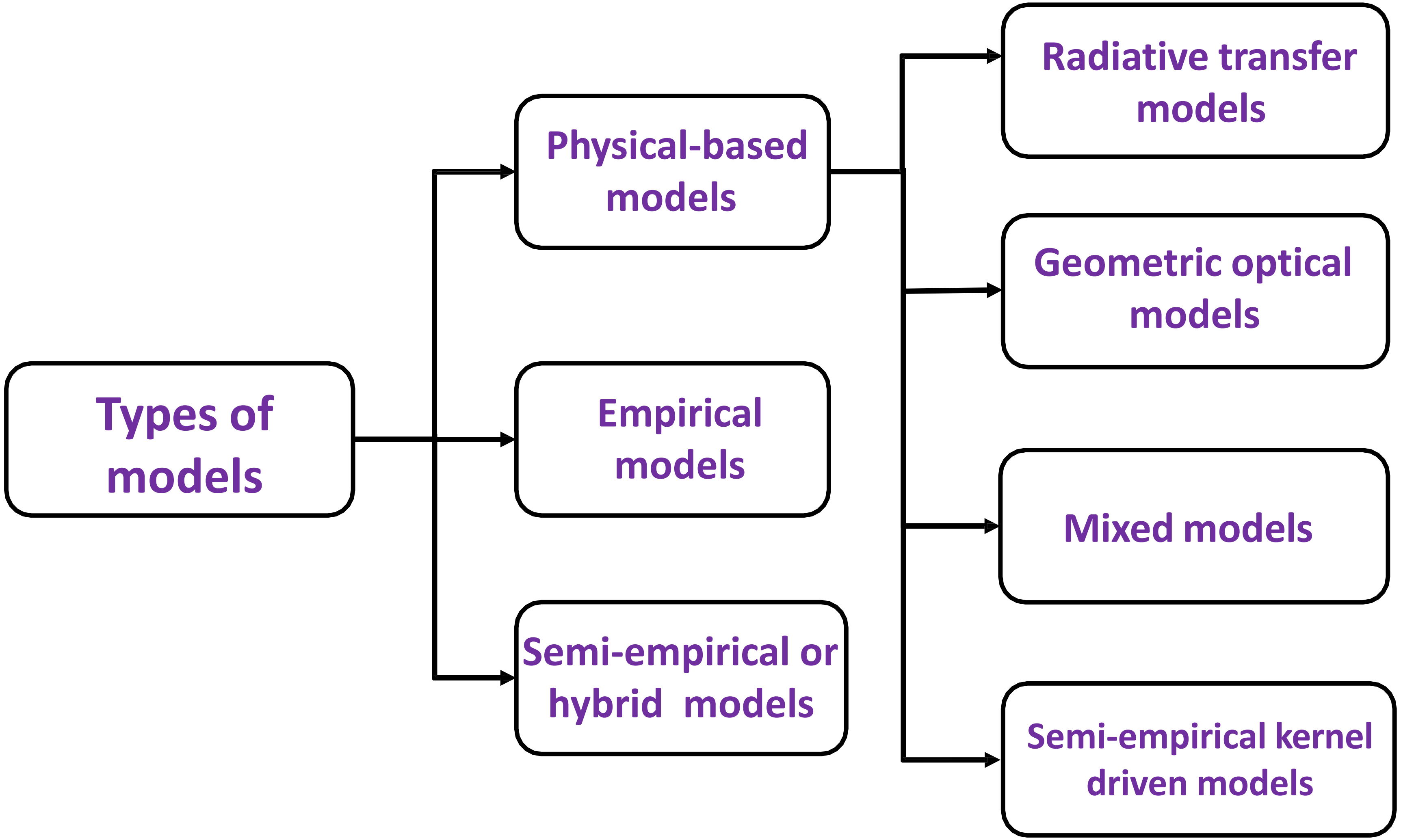
Masking effect of foliar water on other absorption features in canopy reflectance





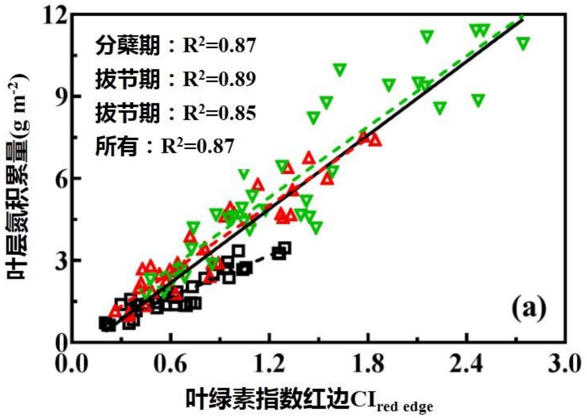
- N absorption features are mainly located in the shortwave infrared (SWIR) region.
- They are apparent in the reflectance spectra of dry leaves (e.g., 2030 & 2180 nm), but not in those of crop canopies.

Models for quantification of vegetation parameters

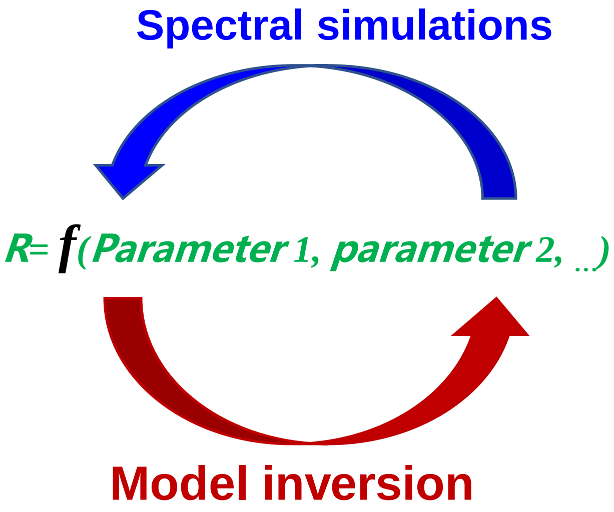


Principles of quantitative methods

- **Empirical modeling or data driven**
  - $y = ax + b$ (x is a VI, y is the parameter to be quantified)
  - Practical and easy-to-use
  - High accuracy with local models but probably difficult for generalization



- **Physical modeling**
  - Based on PROSPECT or PROSAIL models
  - More complicated to use
  - Mechanistic and high interpretability



- **Hybrid or semi-empirical modeling**
  - Combination of empirical and physical models

Our recent publications

Remote Sensing of Environment 206 (2018) 1–14

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

PROCWT: Coupling PROSPECT with continuous wavelet transform to improve the retrieval of foliar chemistry from leaf bidirectional reflectance spectra

Dong Li, Tao Cheng*, Min Jia, Kai Zhou, Ning Lu, Xia Yao, Yongchao Tian, Yan Zhu, Weixing Cao

National Engineering and Technology Center for Information Agriculture (NETCIA), Key Laboratory of Crop System Analysis and Decision Making, Ministry of Agriculture, Jiangsu Key Laboratory for Information Agriculture, Nanjing Agricultural University, One Weigang, Nanjing, Jiangsu 210095, China

1. Physical modeling

2. Empirical modeling

Remote Sensing of Environment 231 (2019) 111240

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Assessment of unified models for estimating leaf chlorophyll content across directional-hemispherical reflectance and bidirectional reflectance spectra

Dong Li, Long Tian, Zefu Wan, Min Jia, Xia Yao, Yongchao Tian, Yan Zhu, Weixing Cao*, Tao Cheng*

National Engineering and Technology Center for Information Agriculture (NETCIA), MARA Key Laboratory of Crop System Analysis and Decision Making, Jiangsu Key Laboratory for Information Agriculture, Nanjing Agricultural University, One Weigang, Nanjing, Jiangsu 210095, China

3. Semi-empirical modeling

Remote Sensing of Environment 282 (2022) 113284

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Assessing a soil-removed semi-empirical model for estimating leaf chlorophyll content

Dong Li [a], Jing M. Chen [b], Weiguo Yu [a], Hengbiao Zheng [a], Xia Yao [a], Weixing Cao [a], Dandan Wei [c], Chenchao Xiao [c], Yan Zhu [a,*], Tao Cheng [a,*]

[a] *National Engineering and Technology Center for Information Agriculture (NETCIA), MARA Key Laboratory of Crop System Analysis and Decision Making, MOE Engineering Research Center of Smart Agriculture, Jiangsu Key Laboratory for Information Agriculture, Institute of Smart Agriculture, Nanjing Agricultural University, One Weigang, Nanjing, Jiangsu 210095, China*

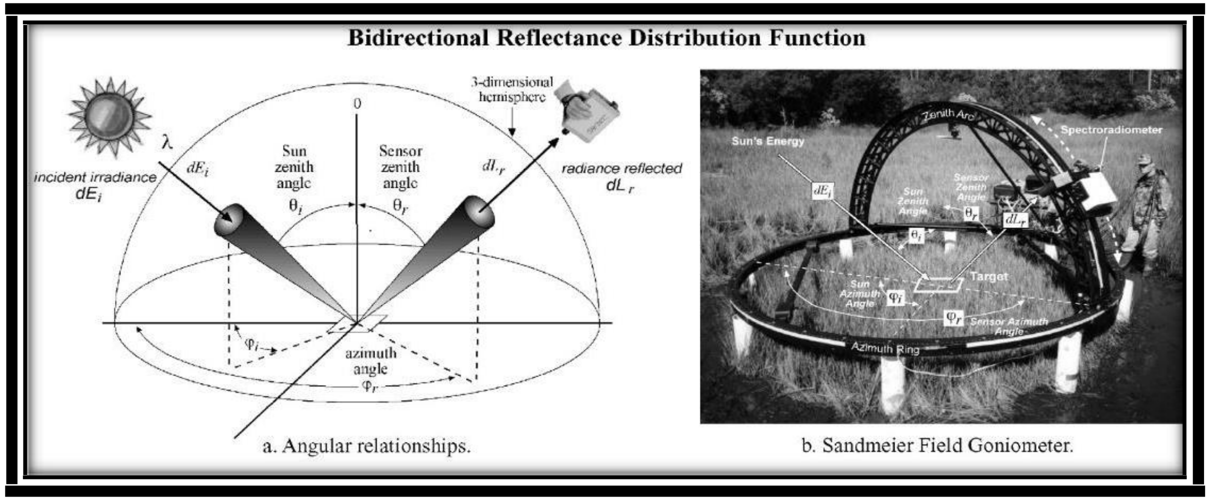
[b] *Department of Geography and Planning, University of Toronto, Toronto, Ontario, Canada*

[c] *Land Satellite Remote Sensing Application Center, Ministry of Natural Resource of the People's Republic of China, Beijing 100048, China*

Q5: why did we study all these three types of models?

Bidirectional Reflectance Distribution Function (BRDF)

- **Canopy reflectance is dependent on sensor-target-sun geometry.**



a. Angular relationships. b. Sandmeier Field Goniometer.

Goniometer, designed by S.Sandmeier

Jensen (2006)

Sensor position

$$BRDF(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda) = \frac{dL_r(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)}{dE_i(\theta_i, \varphi_i; \lambda)}$$

Solar position

- ◆ **solar zenith angle, solar azimuth angle**
- ◆ **sensor zenith angle, sensor azimuth angle**
- ◆ **wavelength**

Bi-directional Reflectance Factor (BRF)

- **BRF is the measured radiance reflected from a surface in a specific direction divided by the radiance reflected from a Lambertian reference panel measured under the same illumination geometry.**

$$BRF(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda) = \frac{dL_r(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)}{dL_{ref}(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)} \times R_{ref}(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)$$

- **BRF is also a function of sensor position, solar position, and wavelength.**

Q6: what is the difference between BRDF and BRF?

Anisotropy factor (ANIF)

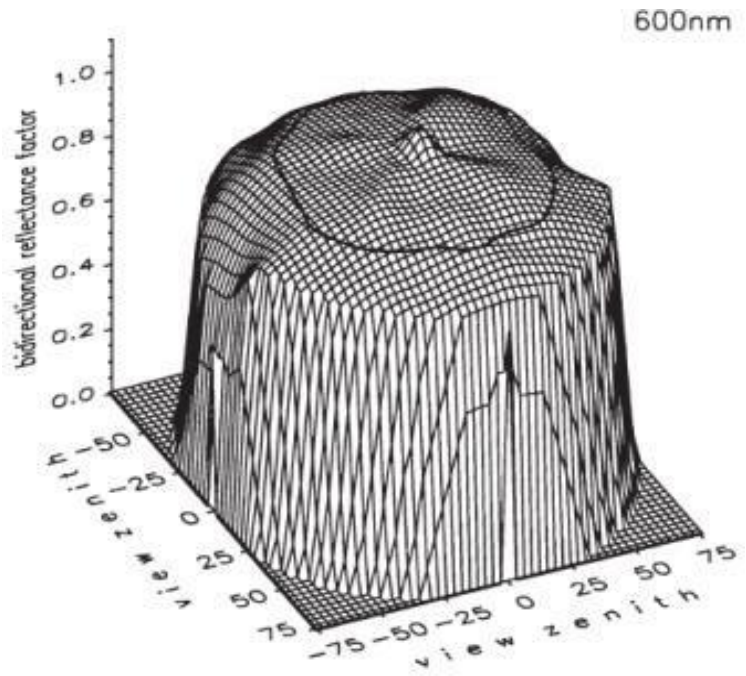
- It is possible to develop an anisotropy factor (ANIF), which is used to analyze the spectral variability in BRDF data.

- ANIF means we can normalize the reflectance at different angles relative to the reflectance at the nadir position.

$$ANIF(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)$$

$$= \frac{R(\theta_i, \varphi_i; \theta_r, \varphi_r; \lambda)}{R_0(\theta_i, \varphi_i; \lambda)}$$

Nadir-normalized BRDF data.



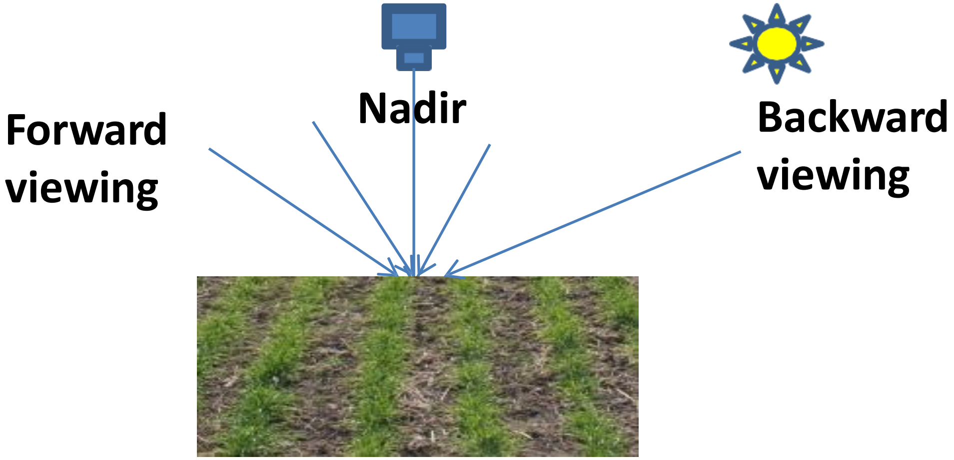
BRDF shape

ANIF of a Spectralon panel

Sandmeier et al. (1998b)

Viewing geometry

- **Vegetation canopies are not Lambertian surfaces.**

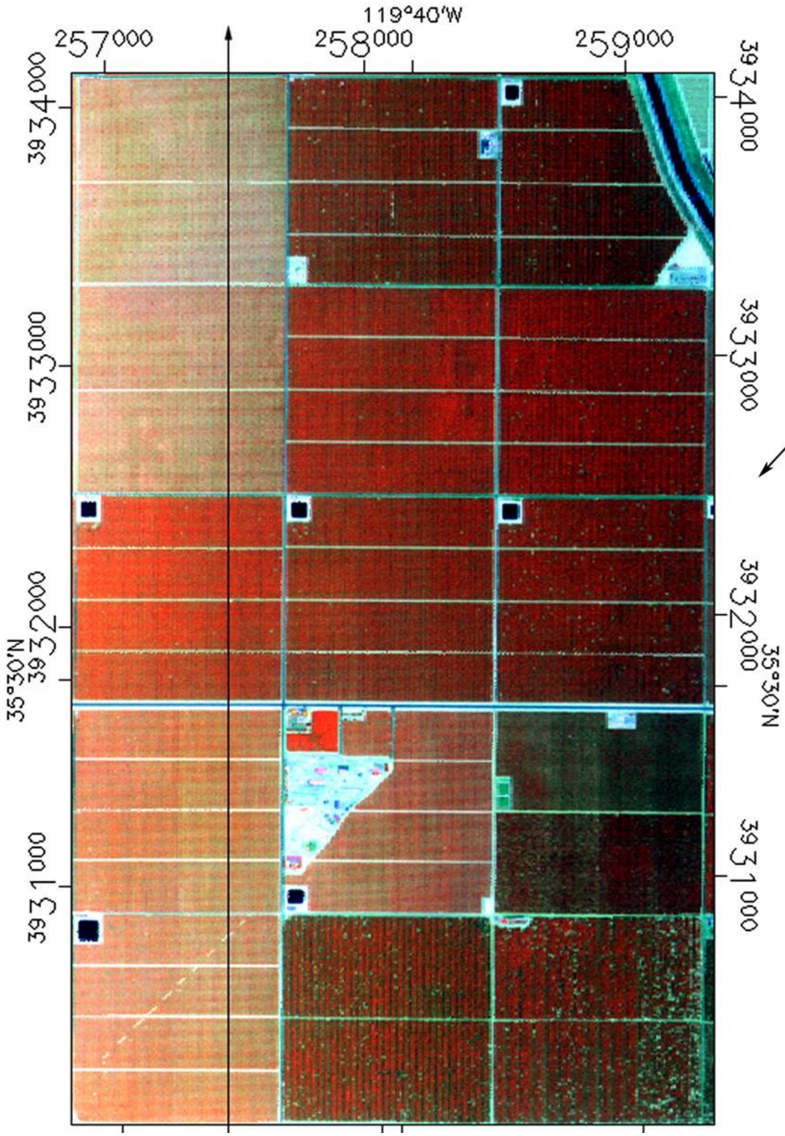


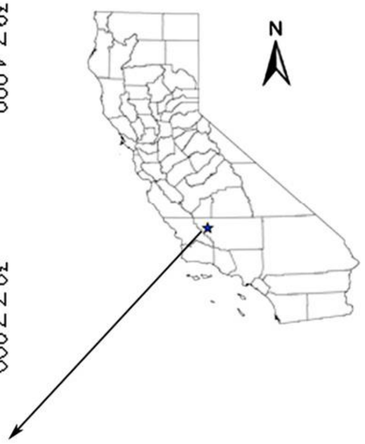
- **Most satellite instruments acquire nadir observations to reduce the BRDF effect.**

Top view

Oblique view

An example of the BRDF effect

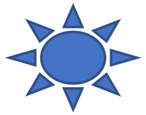




Flight path (S-N)

Cheng et al. (2013)

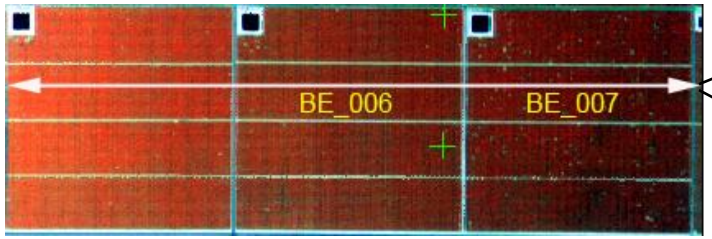
- A MASTER image acquired in the morning (11am local) looks brighter in the backward direction.



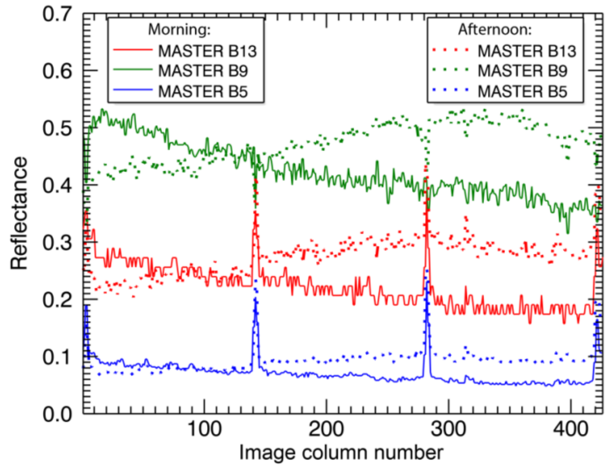
Q7: The image looks brighter in the right side than in the left side. Why?

The effect of view angle on canopy reflectance

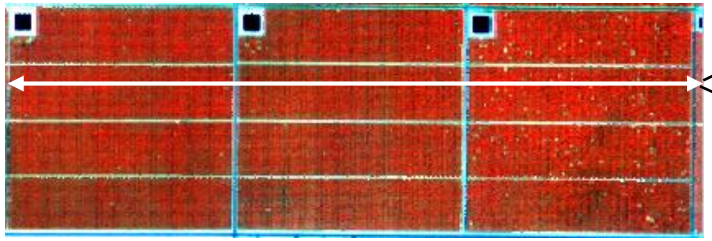
Before correction (morning image)

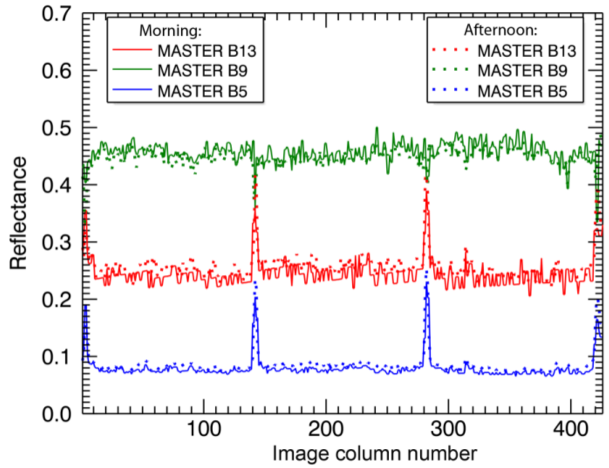


-9° 0° View zenith angle 24°



After correction (morning image)





- **Empirical correction:**
  - **Modeling reflectance as a function of view zenith angle**
  - **Correct for the cross-track brightness gradient**

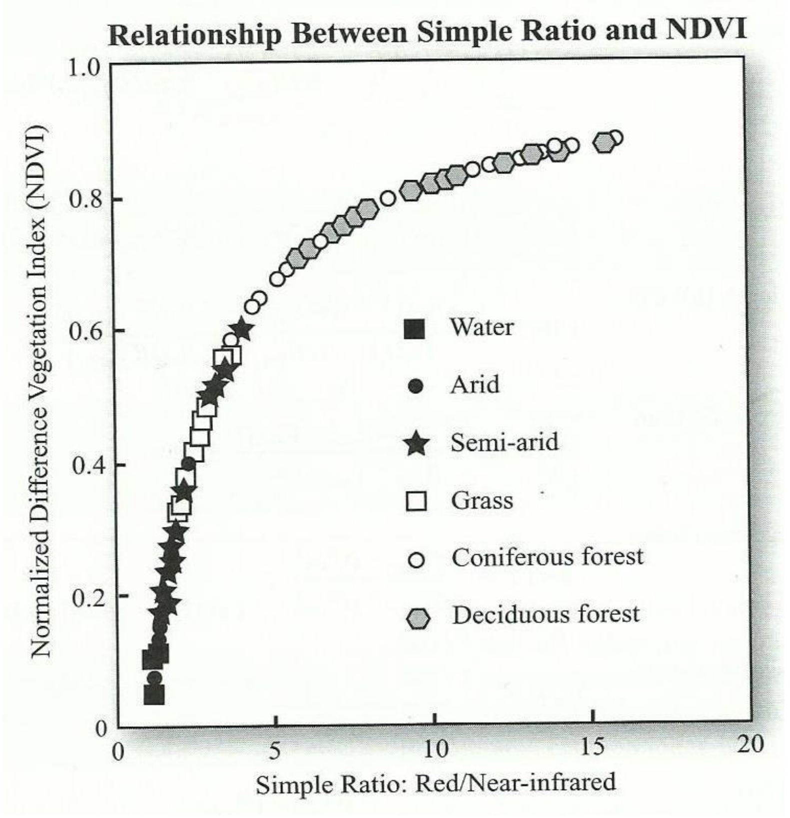
Cheng et al. (2013)

Vegetation indices

- **Simple Ratio - SR**
  - $$SR = \frac{\rho_{red}}{\rho_{nir}}$$ **(Cohen, 1991)**

- **Normalized Difference Vegetation Index – NDVI**
  - $$NDVI = \frac{\rho_{red} - \rho_{nir}}{\rho_{red} + \rho_{nir}}$$ **(Rouse, 1974)**

- **SR and NDVI are one-to-one.**
- **Many others have been developed in the past few decades.**



Note the sensitivities of NDVI in high-biomass and low-biomass zones.

Jensen (2006)

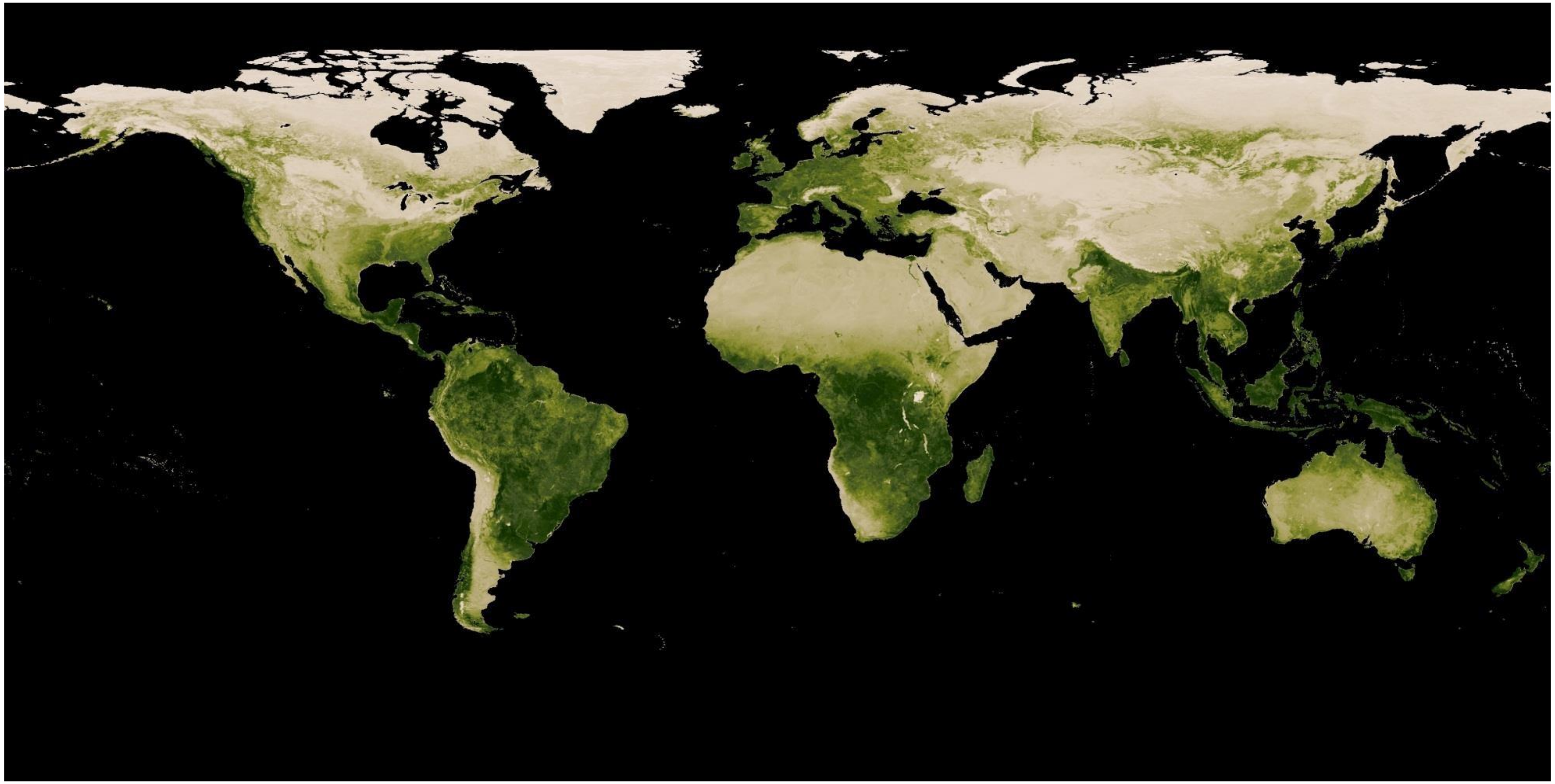
Advantanges and disadvantages of NDVI

- **Advantages:**
  - NDVI can be used to monitor vegetation changes in seasonal and inter-annual cycles.
  - NDVI helps reduces multiplicative noise (illumination differences, cloud shadows, etc)

- **Disadvantages:**
  - NDVI can be influenced by additive noise effects (path radiance)
  - NDVI is sensitive to LAI but tends to saturate when LAI is high (>3).
  - NDVI is sensitive to canopy background (e.g., soil) variations

NDVI is still widely used and long term records of NDVI are available.

Global NDVI map



NDVI is used as a measure of greenness or vegetation vigor.

Images by Reto Stockli, NASA's Earth Observatory Group, using data provided by the MODIS Land Science Team.

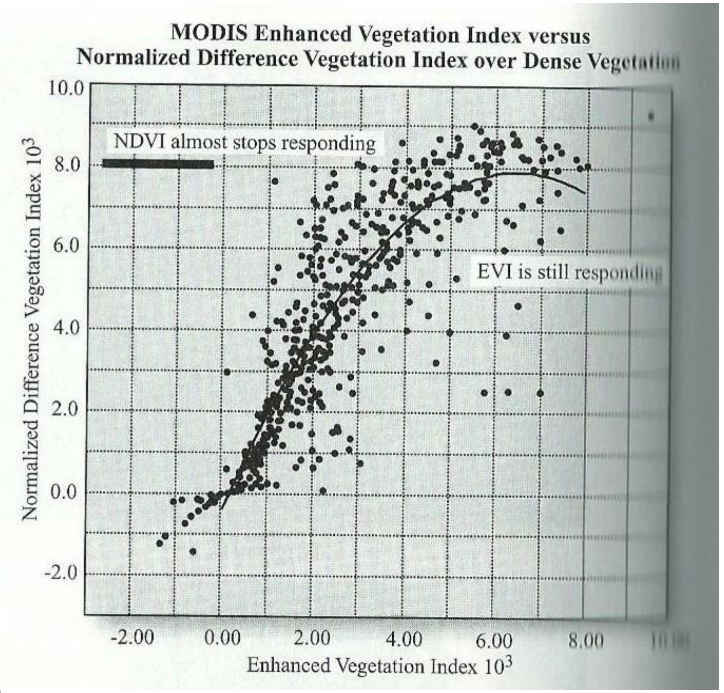
Figure from http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD13A2_M_NDVI

Enhanced vegetation index - EVI

- **Developed by a MODIS science team:**

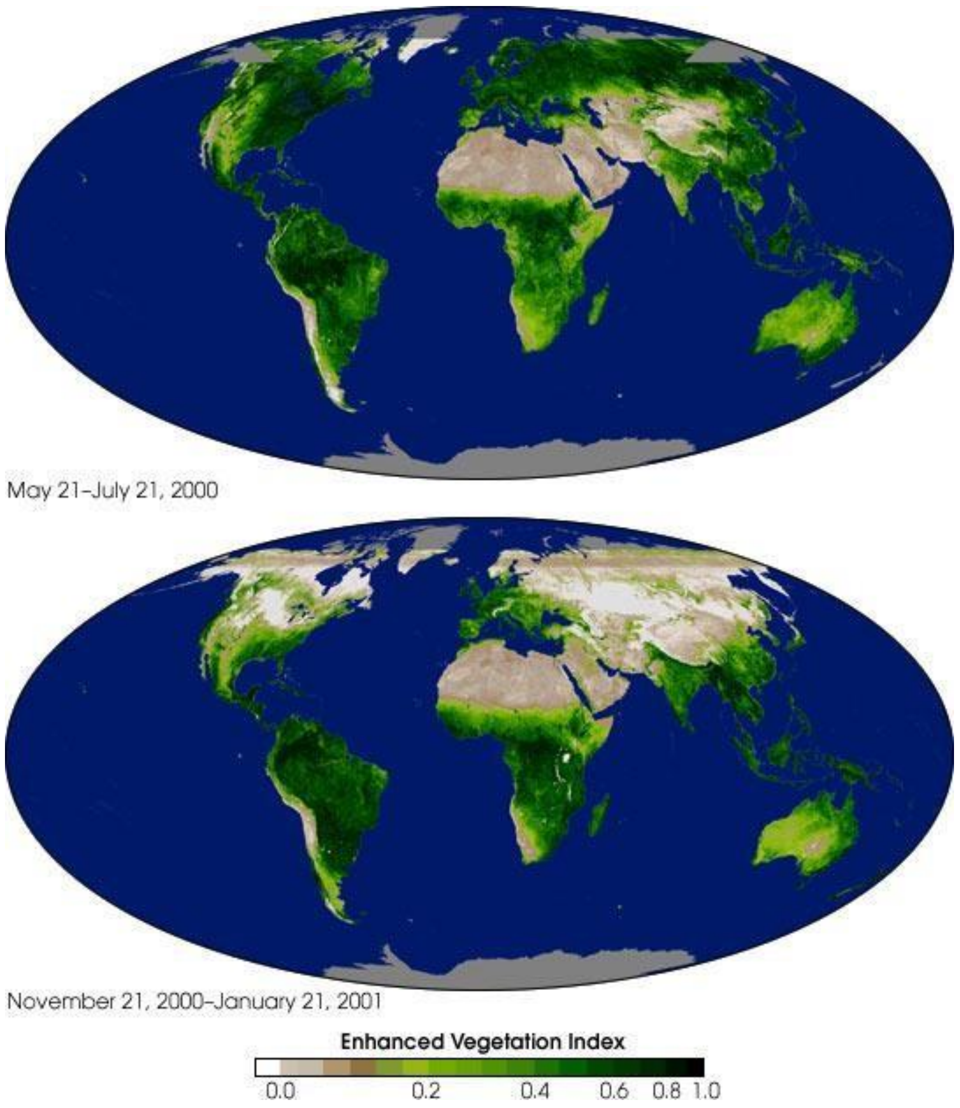
$$EVI = 2.5 \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + 6.0 \times \rho_{red} - 7.5 \times \rho_{blue} + 1}$$

- **has improved sensitivity to high-biomass regions**
- **is less sensitive to canopy background and atmospheric influences**



Jensen (2006)

Seasonal changes in EVI



MAY-JULY

NOV- JAN

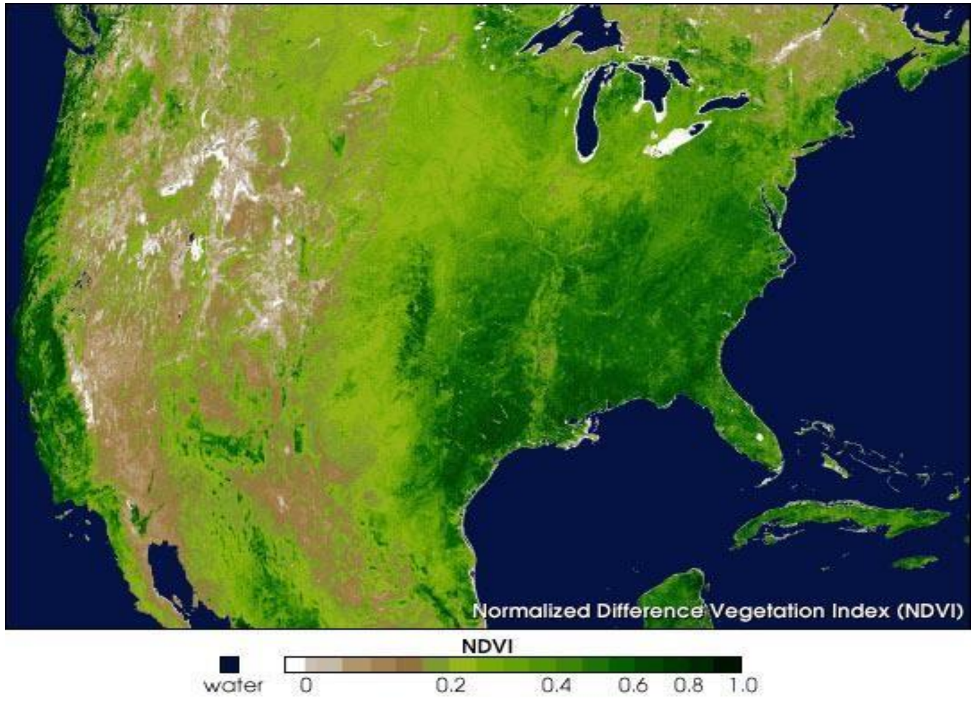
Averages of two months MODIS EVI data

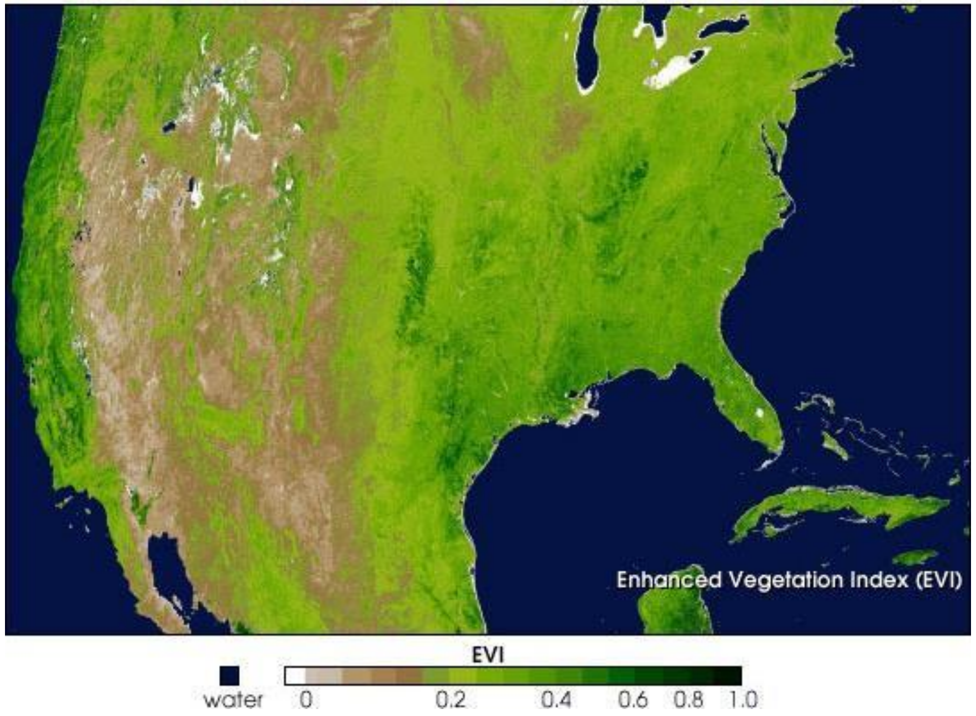
Figure from: http://earthobservatory.nasa.gov/IOTD/view.php?id=2033

MODIS NDVI vs EVI

March 5 through March 20, 2000

Image credit: University of Arizona





- **NDVI is sensitive to chlorophyll**
- **EVI has less aerosol contamination problems**
- **EVI is more sensitive to NIR reflectance and canopy structural variations (e.g., LAI, canopy architecture)**

An example list of published vegetation indexes

TABLE 6.1

A Summary of Studies on the Determination of N Status for Cereal Crops with Hyperspectral Data

Reference	Crop Type	Coverage of Growth Stages	Best VI or Analytical Method	Level of Observation	Variable of N Status
Xue et al. (2004)	Rice	Tillering, jointing, heading, and filling	R_{810}/R_{560}	Canopy	LNC_{mass}
Nguyen and Lee (2006)	Rice	Panicle initiation and booting	PLSR	Canopy	LNC_{mass}
Tang et al. (2007)	Rice	Booting, heading, milking, and maturing	SMLR	Canopy	LNC_{mass}
Zhu et al. (2007b)	Rice	Jointing, booting, heading, and filling	$(R_{1220} - R_{710})/(R_{1220} + R_{710})$	Canopy	LNC_{mass}
Zhu et al. (2007a)	Rice	Heading and filling	$(R_{1220} - R_{610})/(R_{1220} + R_{610})$	Canopy	LNC_{mass}
Stroppiana et al. (2009)		Tillering, stem elongation, booting, flowering	$(R_{503} - R_{483})/(R_{503} + R_{483})$	Canopy	PNC
Inoue et al. (2012)	Rice	Panicle formation stage	D_{740}/D_{522}	Canopy; aircraft	PNA
Wang et al. (2012)	Rice	Jointing, booting, heading, and filling	$(R_{924} - R_{703} + 2 \times R_{423})/(R_{924} + R_{703} - 2 \times R_{423})$	Canopy	LNC_{mass}
Yu et al. (2013)	Rice	Tillering, jointing, booting, heading, flowering, and filling	VIs and SMLR	Canopy	LNC_{mass}, PNC, PNA
Tian et al. (2014)	Rice	Tillering, jointing, booting, heading, filling, and milking	R_{553}/R_{537}	Canopy	LNC_{mass}
Cheng et al. (2016)	Rice	Booting, heading	CWA	Canopy	LNC_{mass}
Moharana and Dutta (2016)	Rice	Booting, heading, and filling	$R_{705}/(R_{717} + R_{491})$	Satellite	LNC_{mass}
Qin et al. (2016)	Rice	Jointing, heading, milking, ripening	R_{738}/R_{522}	Canopy	LNC_{mass}
Hansen and Schjoerring (2003)	Wheat	Early stem elongation to heading (BBHC-scale growth stages 30–51)	$(R_{750} - R_{734})/(R_{750} + R_{734})$	Canopy	LNC_{mass}
Zhu et al. (2007a)	Wheat	Initial heading, full heading, initial filling, full filling	$(R_{1220} - R_{610})/(R_{1220} + R_{610})$ & R_{1220}/R_{610}	Canopy	LNC_{mass}
Feng et al. (2008)	Wheat	Jointing, booting, anthesis, initial-filling, midfilling, late-filling	$R(\lambda) = Rs - (Rs - R_0) * \exp(-(\lambda_0 - \lambda)^2/2\sigma^2)$	Canopy	LNC_{mass}
Li et al. (2010)	Wheat	Feekes 4–7, Feekes 8–10	$(R_{410} - R_{365})/(R_{410} + R_{365})$	Canopy	LNC_{mass}
Wang et al. (2012)	Wheat	Jointing, booting, heading, initial-filling, midfilling, late-filling	$(R_{924} - R_{703} + 2 \times R_{423})/(R_{924} + R_{703} - 2 \times R_{423})$	Canopy	LNC_{mass}

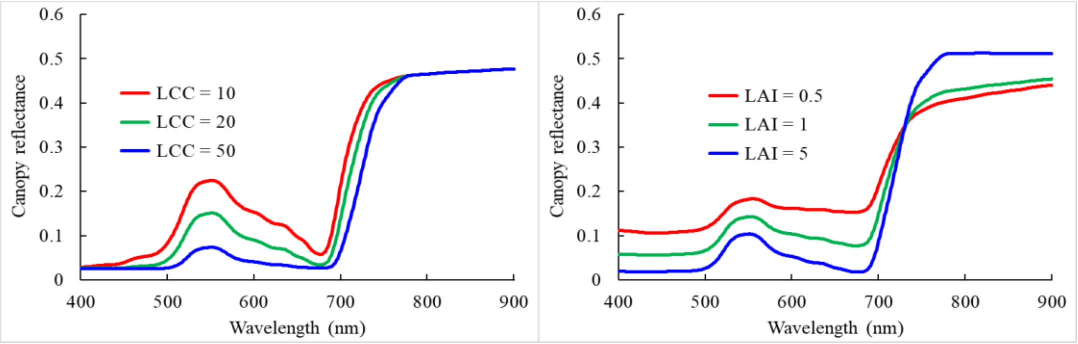
(Continued)

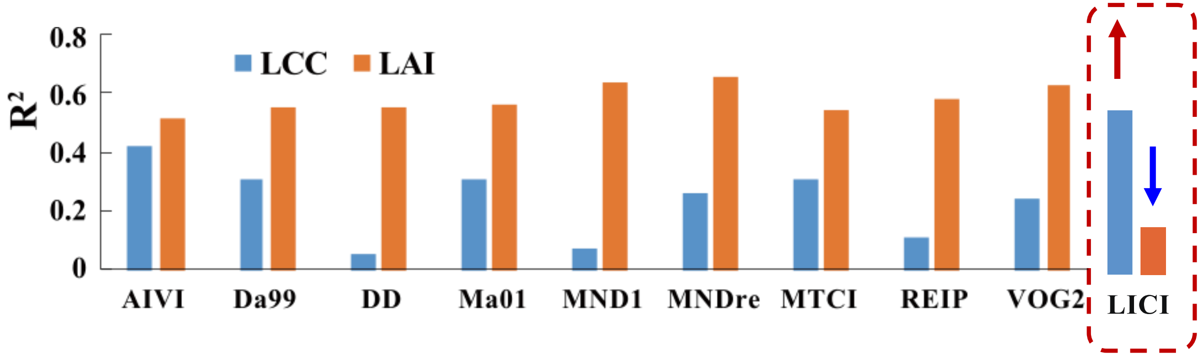
Q8: Why do people keep developing new indices?

Cheng et al., 2018

LICI: A new chlorophyll index for reducing the canopy structural effect

- Canopy reflectance in the red and red-edge regions is affected by both canopy sturcture (leaf area index, LAI) than leaf chlorophyll content (LCC)
- Traditional chlorophyll indices are even more senstitive to LAI than to LCC
- **LAI-insensitive chlorophyll index (LICI)** was proposed to correct for this effect and enhance its sensitivity to LCC





Remote Sensing of Environment (2020). 248, 111985

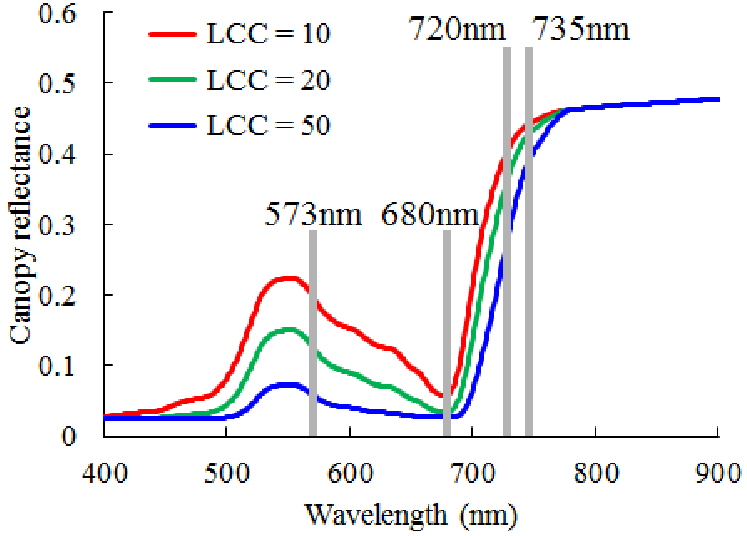
How does LICI work to reduce the canopy structural effect?

A traditional chlorophyll index

$$MTCI = \frac{R_{754} - R_{709}}{R_{709} - R_{681}}$$

LICI

$$LICI = \frac{R_{735}}{R_{720}} - \left(\frac{R_{573} - R_{680}}{R_{573} + R_{680}}\right)$$



VI	Correlation with LAI	Correlation with LCC
$VI_1 = RVI_{735,720}$	**Positive**	**Positive**
$VI_2 = NDVI_{573,680}$	**Positive**	**Negative**
$LICI = VI_1 - VI_2$	**Decreased**	**Increased**

- **LICI had the strongest correlation with LCC and weakest correlation with LAI.**

Narrowband spectral indices: good or bad?

- **Pros (upside):**
  - Multiple index choices become available for almost any growth parameter
  - Sensitive bands or regions (e.g., red edge) are determined for sensor development
  - Empirical models are built for converting canopy sensor measurements to physical values

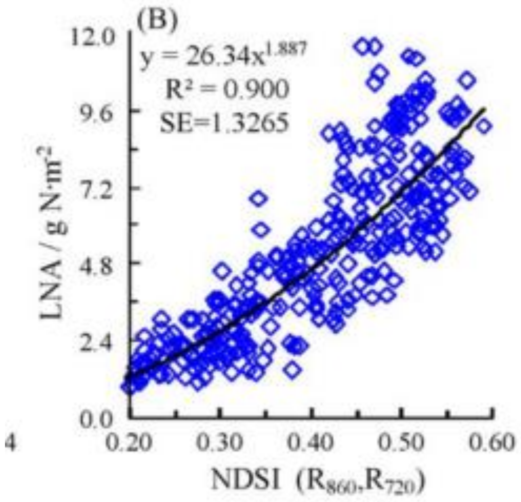


Table 2. Relationships between leaf nitrogen accumulation (LNA), leaf dry weight (LDW), and leaf nitrogen concentration (LNC) and different spectral indices (n = 192) and their prediction performance (n = 252).

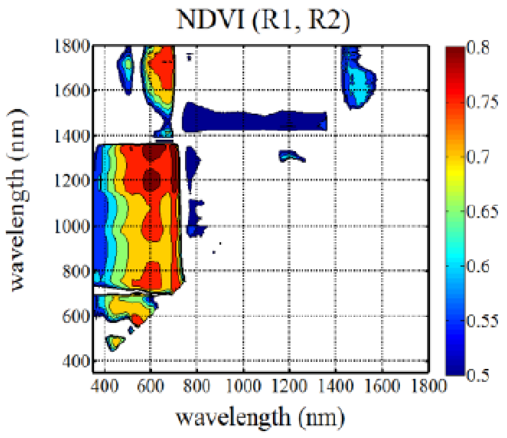
Spectral index	R^2_{cal}†			Performance of monitoring model			Reference
	LNA	LDW	LNC	R^2_{val}	RRMSE	RE	
				New indices			
$SR_2(R_{770}, R_{752})$	0.90	0.88	0.16	0.85	0.23	0.20	this study
$SR(R_{770}, R_{752})$	0.88	0.88	0.15	0.80	0.24	0.21	this study
				Existed indices			
ND(759, 730)	0.88	0.84	0.15	0.78	0.35	0.27	Hansen and Schjoerring, 2003
SDr/SDb	0.87	0.85	0.14	0.76	0.27	0.25	Feng et al., 2008
ND(860, 720)	0.85	0.83	0.12	0.78	0.35	0.28	Yao et al., 2010
SR(937,718)	0.82	0.82	0.13	0.80	0.25	0.20	Bajwa et al., 2010
FD_{742}	0.82	0.82	0.12	0.56	0.35	0.33	Feng et al., 2008
GVI‡	0.79	0.78	0.11	0.77	0.27	0.25	Bronson et al., 2003
SR(810, 560)	0.78	0.77	0.11	0.76	0.27	0.20	Xue et al., 2004
GNDVI	0.77	0.77	0.10	0.70	0.38	0.35	Bronson et al., 2003
SR(1100, 560)	0.74	0.72	0.11	0.78	0.27	0.26	Zhou et al., 2006
SR(950,660)	0.68	0.68	0.12	0.68	0.28	0.26	Zhu et al., 2007
$R_{Average(760, 810, 870, 950, 1100)}/R_{660}$	0.65	0.64	0.09	0.67	0.28	0.27	Zhu et al., 2006
SR(810, 660)	0.64	0.64	0.08	0.66	0.29	0.25	Zhu et al. 2008
				LNC sensitive indices			
NDVIg-b	0.24	0.23	0.66	0.02	0.49	0.40	Hansen and Schjoerring, 2003
$SR(R_{553}, R_{537})$	0.03	0.02	0.67	0.06	0.58	0.44	Tian et al. 2014
ND(1220, 710)	0.03	0.03	0.51	0.07	0.52	0.46	Zhu et al. 2007

Chu et al., (2014). AJ

CGMD 402 (NETCIA)

Narrowband spectral indices: good or bad?

- **Cons (downside):**
  - We may be **distracted** by too many band combinations (focus on common ones?)
  - Spectral information is not fully used (> 2~3 bands?)
  - **Underlying physical mechanisms** are not well understood for trait~VI correlations

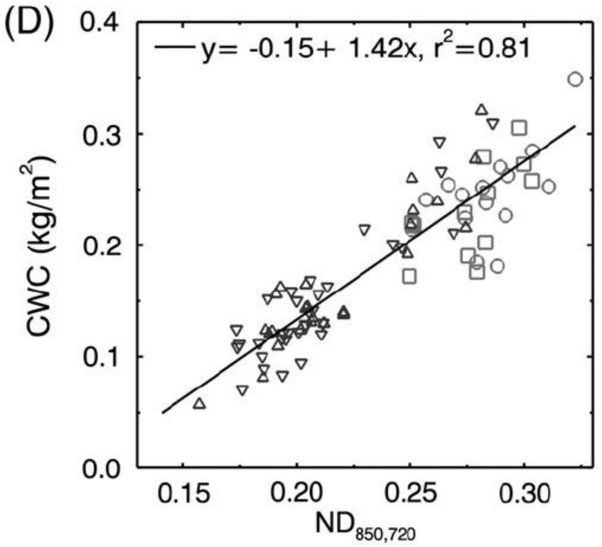


Yao et al., (2015). RS

106 K. Yu et al. / ISPRS Journal of Photogrammetry and Remote Sensing 78 (2013) 102–115

Table 3
Published vegetation indices used in this study.

Index	Equation	Reference
Simple ratio (SR)		
SR1	R_{800}/R_{675}	Jordan (1969)
SR2	R_{810}/R_{560}	Xue et al. (2004)
SR3	R_{750}/R_{710}	Zarco-Tejada et al. (2001)
SR4	R_{750}/R_{700}	Gitelson and Merzlyak (1996)
Normalized difference index		
NDVI	$(R_{800}-R_{680})/(R_{800}+R_{680})$	Blackburn (1998)
GNDVI	$(R_{801}-R_{550})/(R_{801}+R_{550})$	Daughtry et al. (2000)
ND705	$(R_{750}-R_{705})/(R_{750}+R_{705})$	Sims and Gamon (2002)
mSR705	$(R_{750}-R_{445})/(R_{705}-R_{445})$	Sims and Gamon (2002)
MTCI	$(R_{750}-R_{710})/(R_{710}-R_{680})$	Dash and Curran (2004)
NDVI [503, 483]	$(R_{503}-R_{483})/(R_{503}+R_{483})$	Stroppiana et al. (2009)
NDVI [565, 533]	$(R_{565}-R_{533})/(R_{565}+R_{533})$	Tian et al. (2011)
NDVI [1220, 710]	$(R_{1220}-R_{710})/(R_{1220}+R_{710})$	Zhu et al. (2007)



Cheng et al., (2014). RSE

Q9: How can we improve the comparability of results between VI related studies?

Further readings

- RSE Chapter 11