Crop Modeling Using the Arable Mark

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Crop Modeling Practice

Phenology
Photosynthesis and Water Use
Growth and Carbon Allocation
Measurement and Parameter Estimation

Modeling History

Crop models - breeding and management
Phenology models - plant protection
Carbon and water models - climate & weather
Data-driven models - SIB, CASA, LDAS

History of Modeling Efforts

History

Crop models: Breeding and management

<u>Wageningen Group</u>
Driven by management optimization
and international development
Basic building blocks in 1970's
Crop Diversification in 1980's

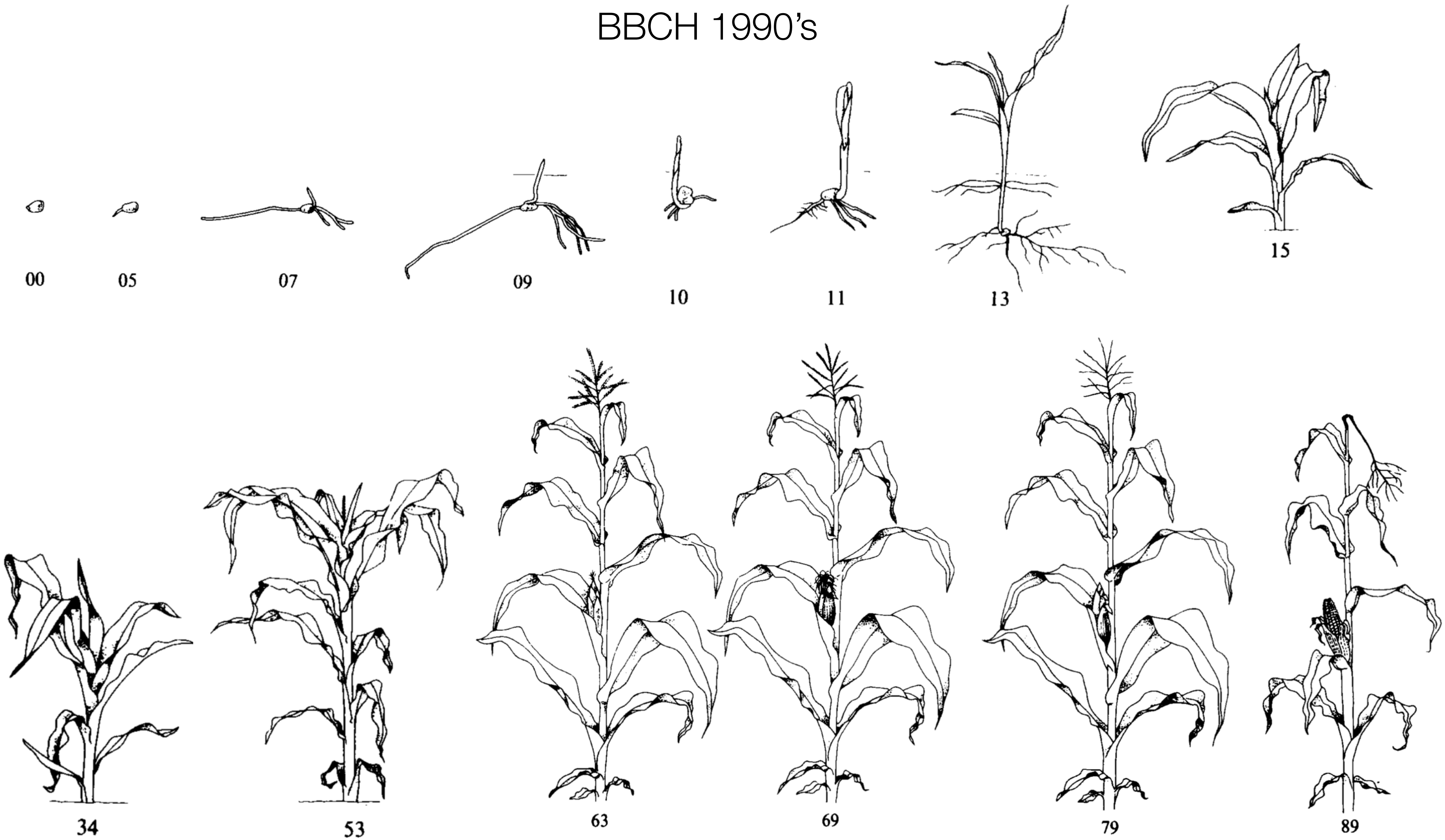
<u>CERES Group</u>
Driven to explore genetics and
defining phenotypic traits for breeding
Basic building blocks in 1970's
Crop Diversification in 1980's

<u>APSIM, DSSAT, EPIC</u>
Driven by operationalization
Most code is devoted to management

History

Phenology models - plant protection

BBCH 1990's



History

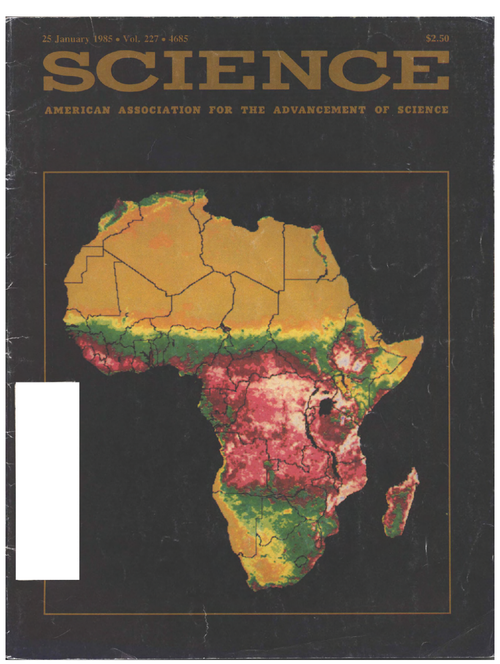
Carbon and water models - Climate and weather

1960's	1970's	1980's
John Monteith John Norman	John Farquhar Joe Berry	Steve Running Parton, Ojima, Paustian
Energy balance & Radiative transfer	Adding realism to plant biochemistry & behavior	Allocating carbon Nutrient balance

History

Data-driven models - SIB, CASA, NLDAS

1980's	**1990's**	**2000's**	**2010's**
FIFE 1987	BOREAS 1995	LBA 2005	ABOVE 2015
Land Classification Qualitative	Land Fluxes Quantitative	Land Atmos Interaction	Exotic Biogeochemistry



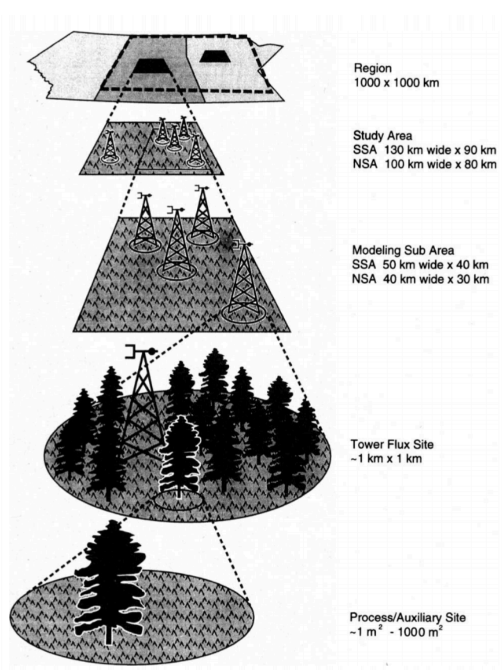
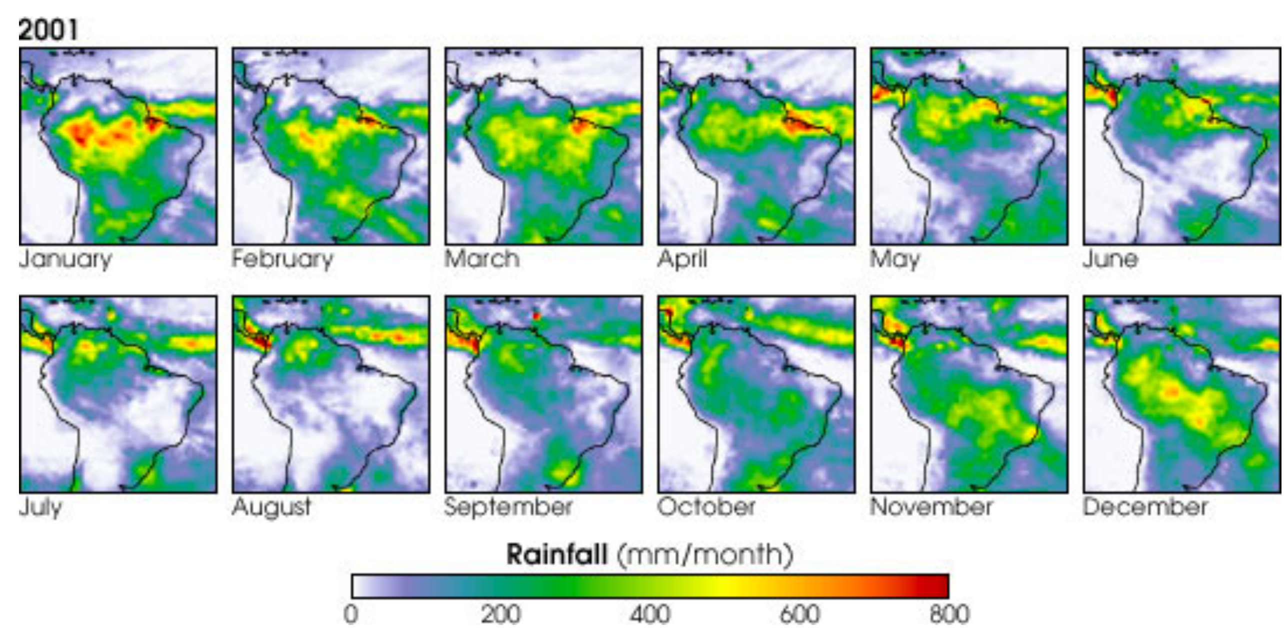


FIG. 2. Multiscale measurement strategy in BOREAS, see text in section 3.



Crop Modeling Practice

Practice

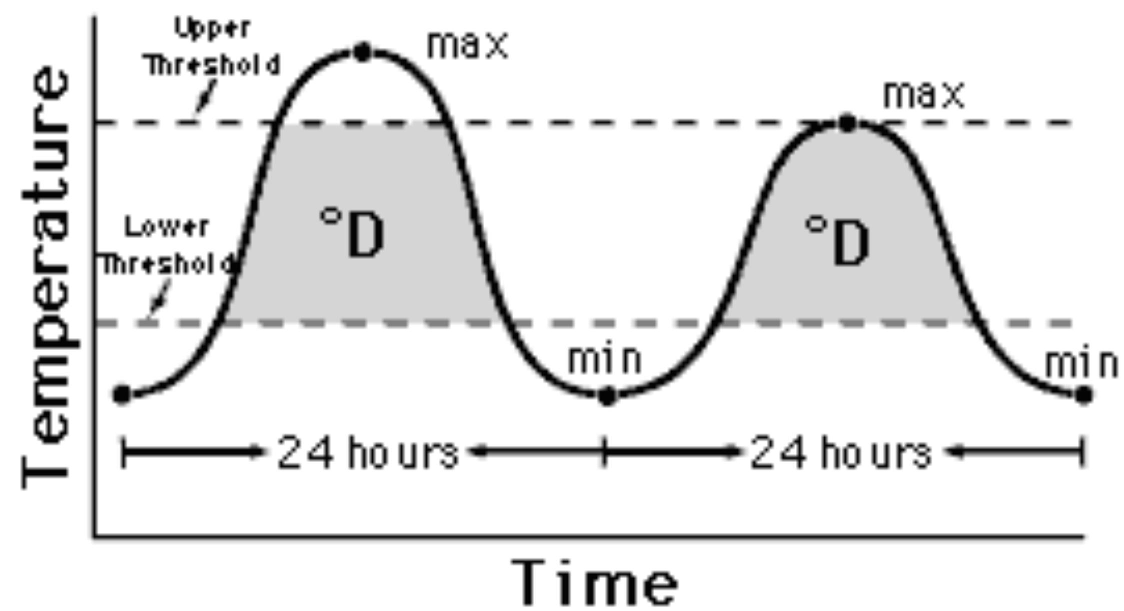
Phenology

Generally defined by *thermal* time

$$a = \min(T, Tupper)$$

$$b = \max(a, Tlower)$$

$$GDD = \int_0^{\tau} b\, dt$$



Units: °C-Day
Tlower: 8° or 10°C, Tupper 34°C

Chilling or *vernalization* requirements framed identically, but Tupper ≤ 0°C

Some crops (coffee, cocoa) have *dry season* requirements to induce flowering

Photoperiod sensitivity is present in some crops to induce flowering

$$f = \frac{1}{4 + c\left(\frac{daylength}{12.5}\right)}$$

In maize, the duration of flowering is shaped by genetic parameters for photoperiod sensitivity

Practice

Phenology

Phenological growth stages and BBCH-identification keys of maize
(*Zea mays* L.)

Code	Description
Principal growth stage 0: Germination	
00	Dry seed (caryopsis)
01	Beginning of seed imbibition
03	Seed imbibition complete
05	Radicle emerged from caryopsis
06	Radicle elongated, root hairs and/or side roots visible
07	Coleptile emerged from caryopsis
09	Emergence: coleoptile penetrates soil surface (cracking stage)

GDD

Code	Description
Principal growth stage 1: Leaf development[1,2]	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
13	3 leaves unfolded
1 .	Stages continuous till . . .
19	9 or more leaves unfolded

GDD
100-400

Code	Description
Principal growth stage 3: Stem elongation	
30	Beginning of stem elongation
31	First node detectable
32	2 nodes detectable
33	3 nodes detectable
3 .	Stages continuous till . . .
39	9 or more nodes detectable[3]

GDD

Code	Description
Principal growth stage 5: Inflorescence emergence, heading	
51	Beginning of tassel emergence: tassel detectable at top of stem
53	Tip of tassel visible
55	Middle of tassel emergence: middle of tassel begins to separate
59	End of tassel emergence: tassel fully emerged and separated

GDD, *Vernalization*

Phenological growth stages and BBCH-identification keys of maize

Code	Description
Principal growth stage 6: Flowering, anthesis	
61	Male: stamens in middle of tassel visible Female: tip of ear emerging from leaf sheath
63	Male: beginning of pollen shedding Female: tips of stigmata visible
65	Male: upper and lower parts of tassel in flower Female: stigmata fully emerged
67	Male: flowering completed Female: stigmata drying
69	End of flowering: stigmata completely dry

GDD,
photoperiod

Code	Description
Principal growth stage 7: Development of fruit	
71	Beginning of grain development: kernels at blister stage, about 16% dry matter
73	Early milk
75	Kernels in middle of cob yellowish-white (variety-dependent), content milky, about 40% dry matter
79	Nearly all kernels have reached final size

GDD
600-1000

Code	Description
Principal growth stage 8: Ripening	
83	Early dough: kernel content soft, about 45% dry matter
85	Dough stage: kernels yellowish to yellow (variety dependent), about 55% dry matter
87	Physiological maturity: black dot/layer visible at base of kernels, about 60% dry matter
89	Fully ripe: kernels hard and shiny, about 65% dry matter

GDD

Code	Description
Principal growth stage 9: Senescence	
97	Plant dead and collapsing
99	Harvested product

Practice

Photosynthesis and Water Use

Plants dissipate radiative energy by warming up & transpiring

$$Rn = SW\downarrow + SW\uparrow + LW\downarrow + LW\uparrow = H + LE$$

$$Rn = H + LE$$

$$H = \frac{\rho}{r_H} c_p \left(T_{surface} - T_{air}\right)$$

$$LE = \frac{\rho}{r_S + r_H} \frac{c_p}{\gamma} \left(e_{sat}\left(T_{surface}\right) - e_{air}\right)$$

Stomatal conductance is a "plant behavior"

$$g_c = \left[\frac{Rn}{c_p} - g_H \cdot dT\right] \frac{\gamma}{VPD}$$

It determines dT and VPD

$$A = PAR \cdot fAPAR \cdot \varepsilon \cdot \beta(1 \ldots n)$$

$$fAPAR \cong 1 - e^{-kLAI}$$

PAR is incident light
fAPAR is the fraction that is absorbed (leaf area)
ε is photosynthetic capacity (chlorophyll content)
β are stress factors (including water stress: low gc)

Practice

Growth and Carbon Allocation

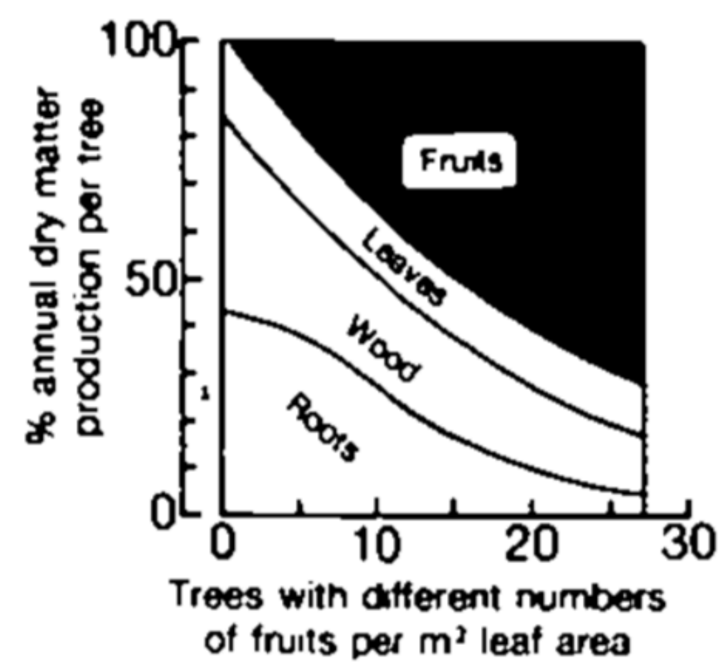
Photons
↓
Leaves

Tissue	Leaves	Fruit & Seeds	Stem + Coarse Roots	Fine Roots	Non-Structural Carbohydrates
Lifetime	Months	Months	Years	Months	Months

Allocation embodies economic or optimizing behavior
Leaves satisfy carbon demand of plant
Fine roots satisfy water and nutrient demand of plant
Wood is for height competition for light (and thus carbon)
NSC’s enable early emergence, and cover times of low A

Principles
Root-shoot competition
Leaf-fruit competition

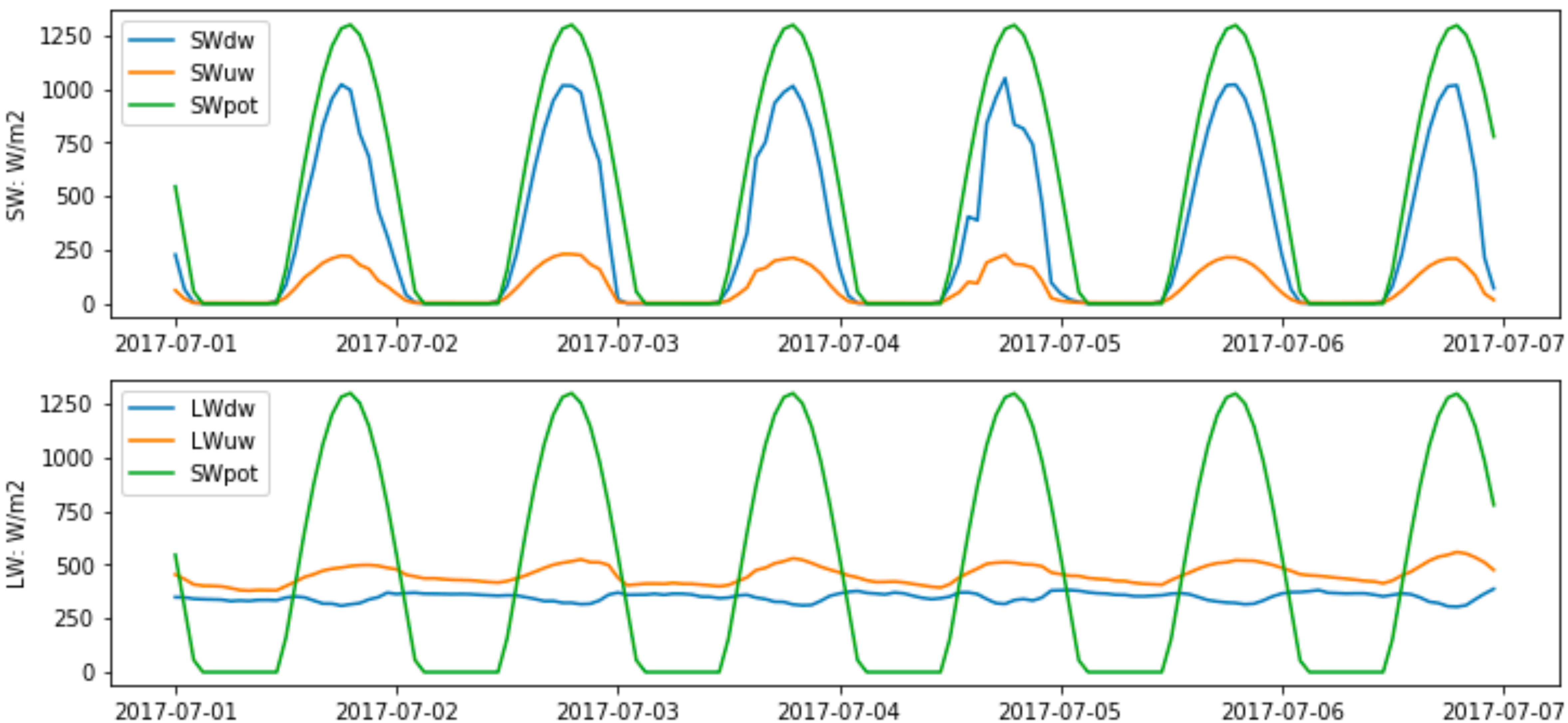
A. Apple



Practice

Measurement and Parameter Estimation

$$Rn = SW\downarrow + SW\uparrow + LW\downarrow + LW\uparrow$$

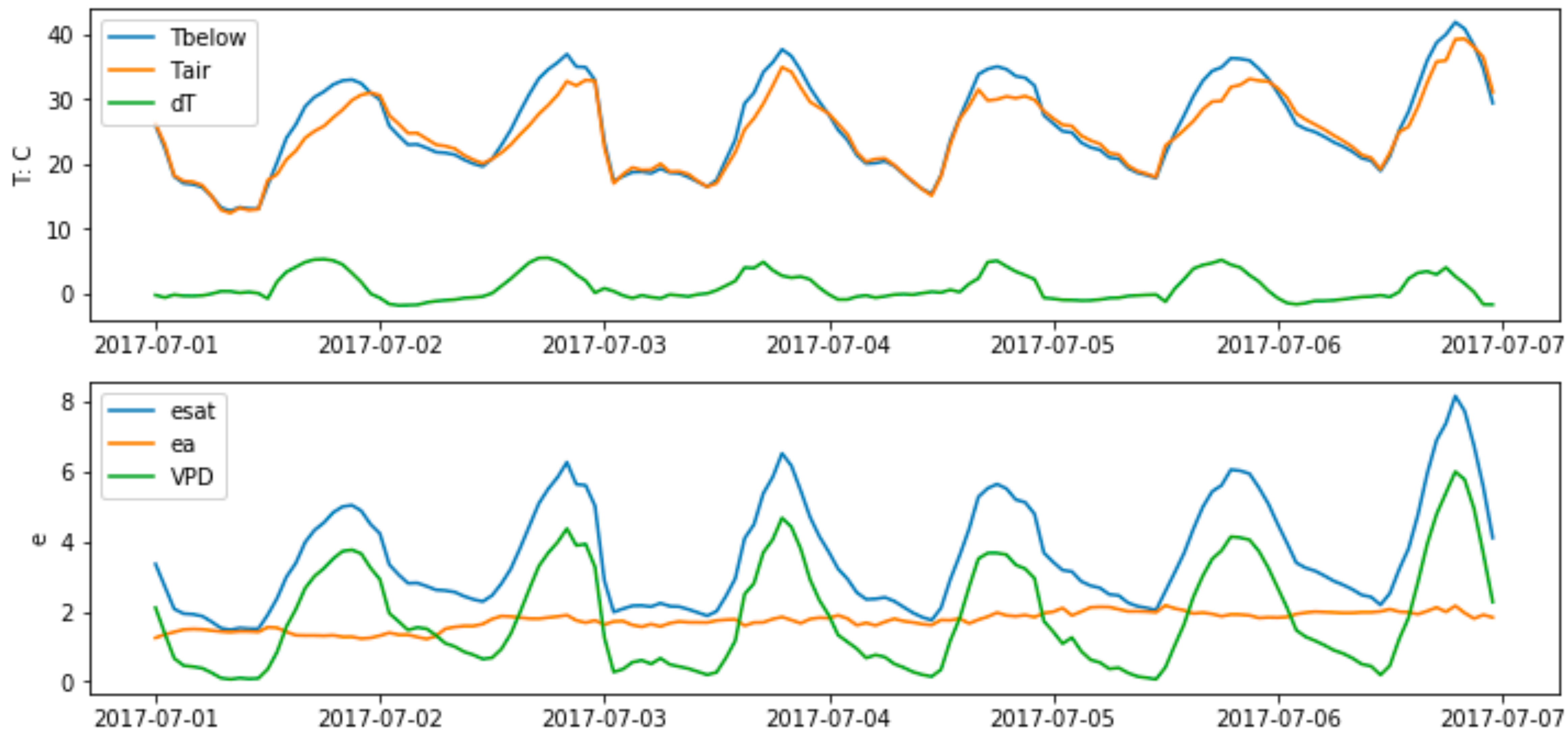


Practice

Measurement and Parameter Estimation

$$H = \frac{\rho}{r_H} c_p \left(T_{surface} - T_{air}\right)$$

$$LE = \frac{\rho}{r_S + r_H} \frac{c_p}{\gamma} \left(e_{sat}\left(T_{surface}\right) - e_{air}\right)$$

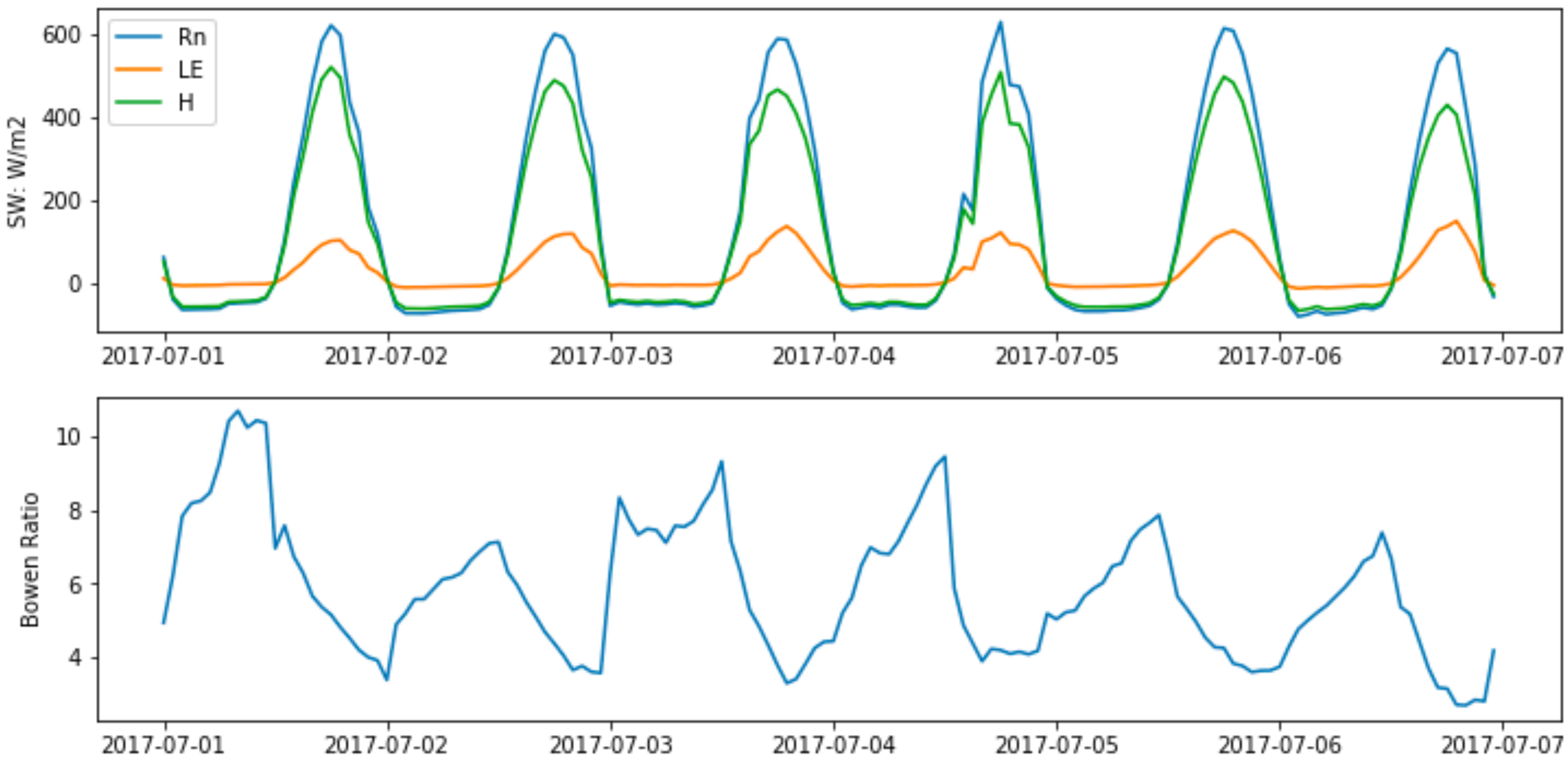


Practice

Measurement and Parameter Estimation

$$H = \frac{\rho}{r_H} c_p \left(T_{surface} - T_{air}\right)$$

$$LE = \frac{\rho}{r_S + r_H} \frac{c_p}{\gamma} \left(e_{sat}\left(T_{surface}\right) - e_{air}\right)$$

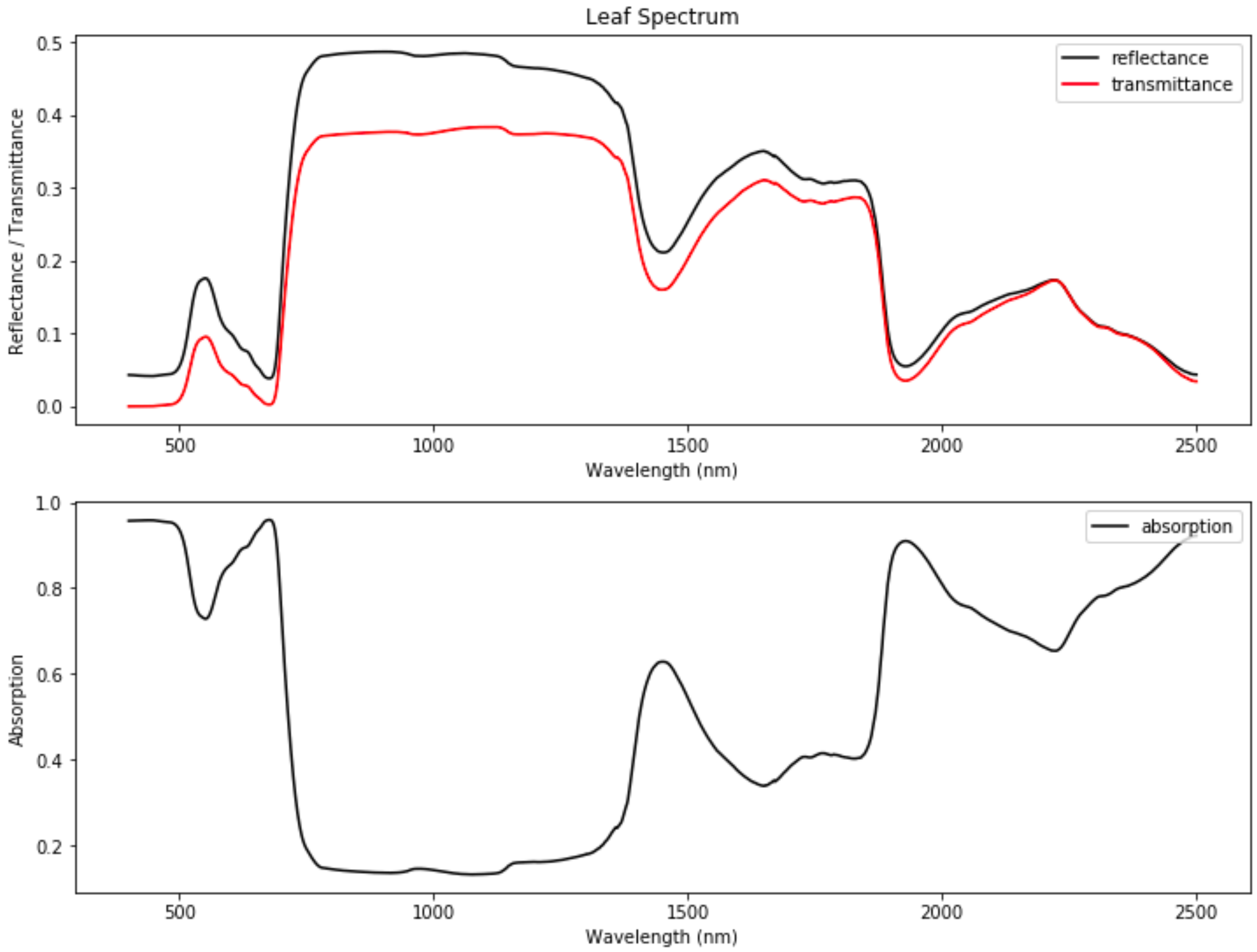


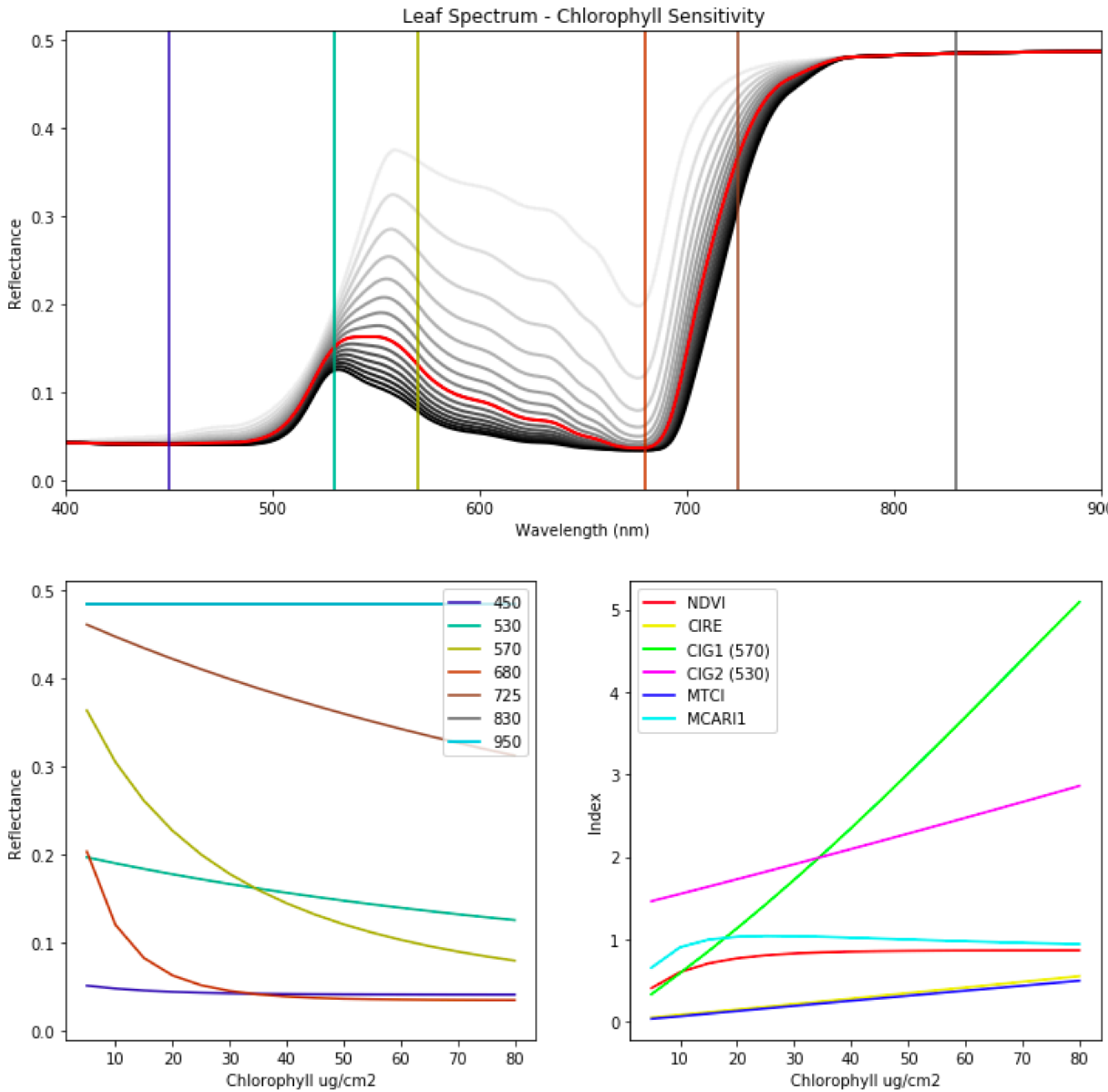
Practice

Deep Dive into Vegetation Spectroscopy

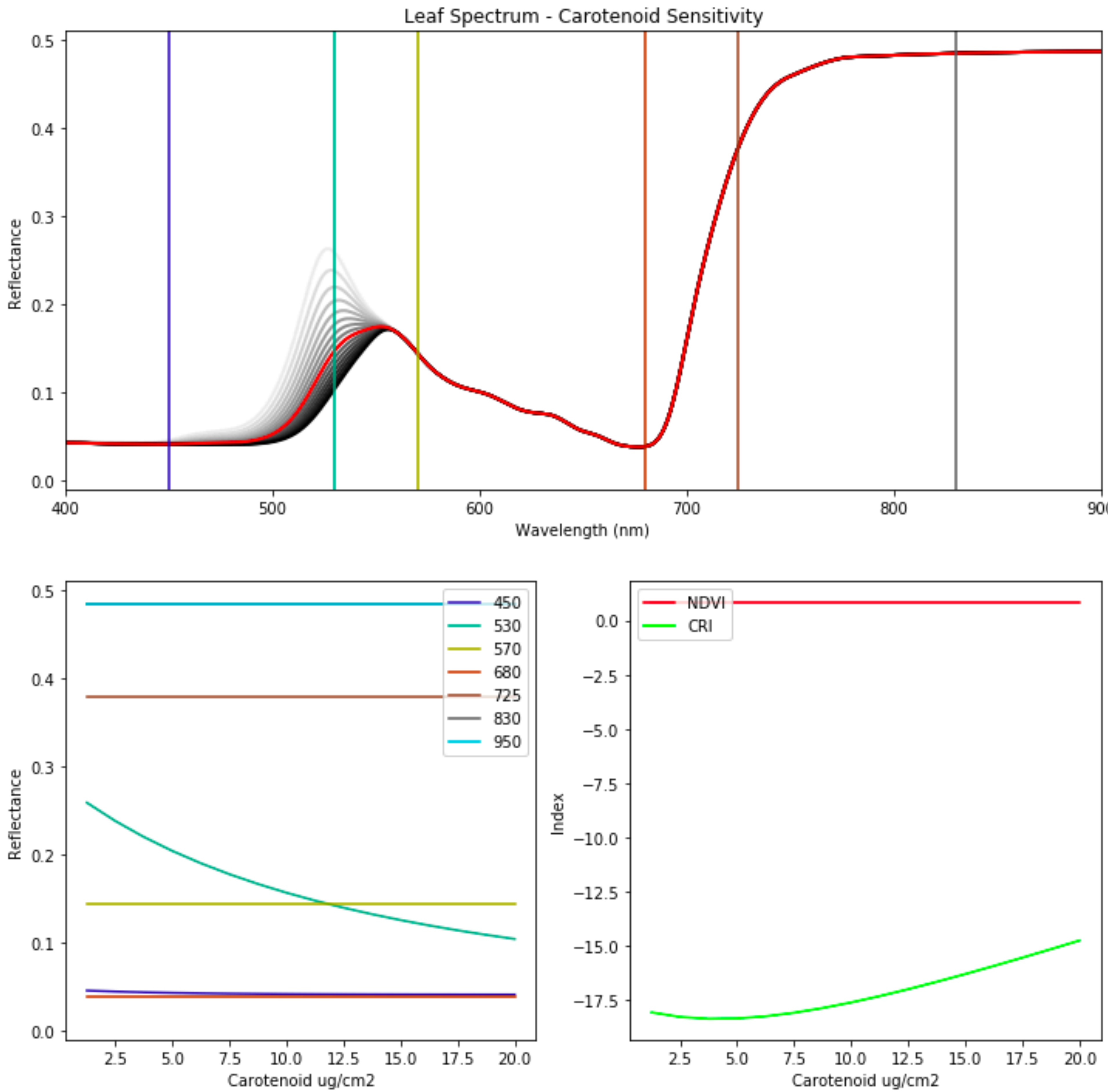
Leaf Pigments

This is what a typical leaf looks like



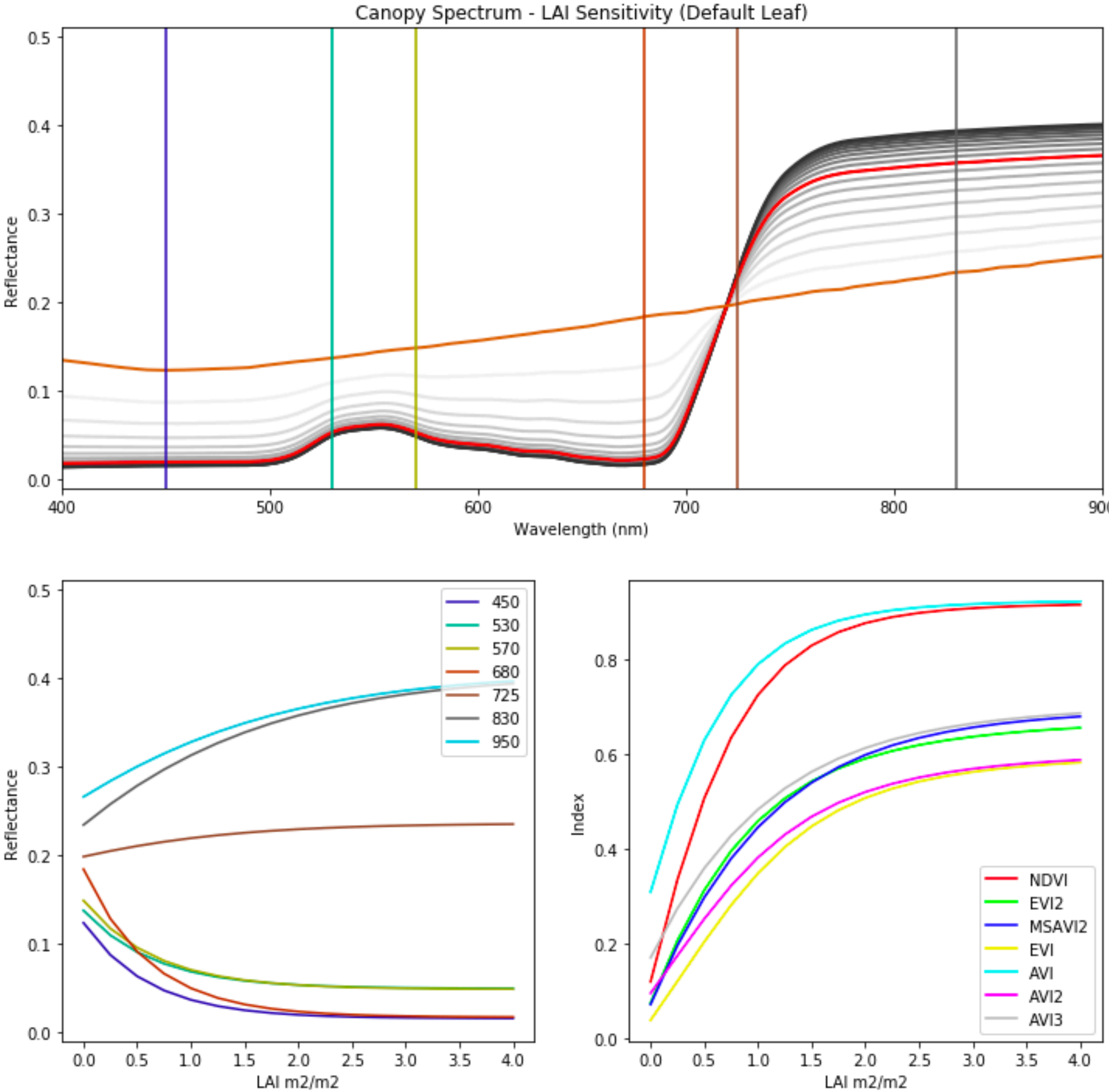


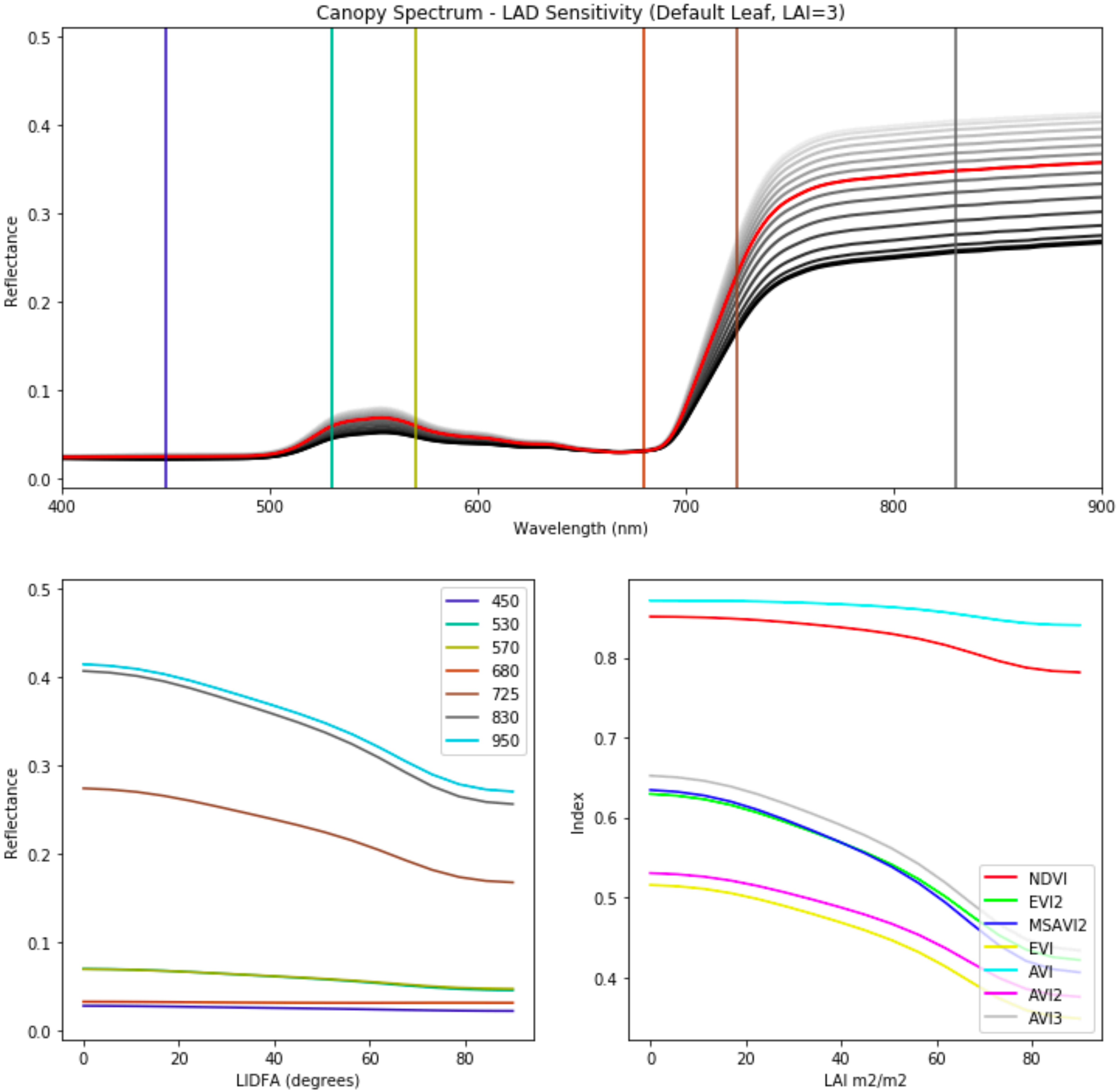
Leaf Spectrum - Chlorophyll Sensitivity
Reflectance
Wavelength (nm)
450
530
570
680
725
830
950
Reflectance
Chlorophyll ug/cm2
NDVI
CIRE
CIG1 (570)
CIG2 (530)
MTCI
MCARI1
Index
Chlorophyll ug/cm2



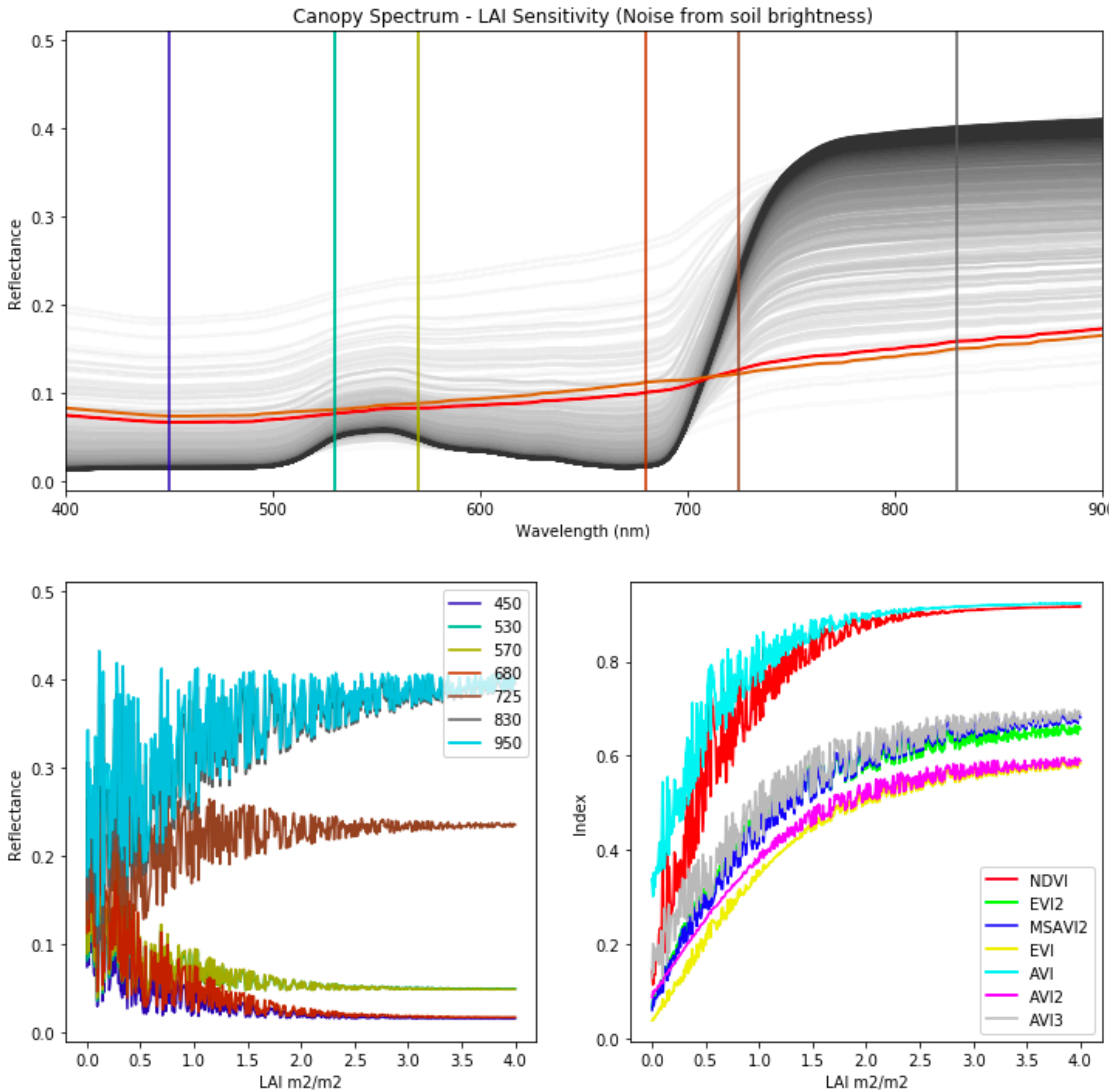
Leaf Spectrum - Carotenoid Sensitivity
Reflectance
Wavelength (nm)
0.0
0.1
0.2
0.3
0.4
0.5
400
500
600
700
800
900
Reflectance
Carotenoid ug/cm2
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
450
530
570
680
725
830
950
Index
Carotenoid ug/cm2
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
NDVI
CRI

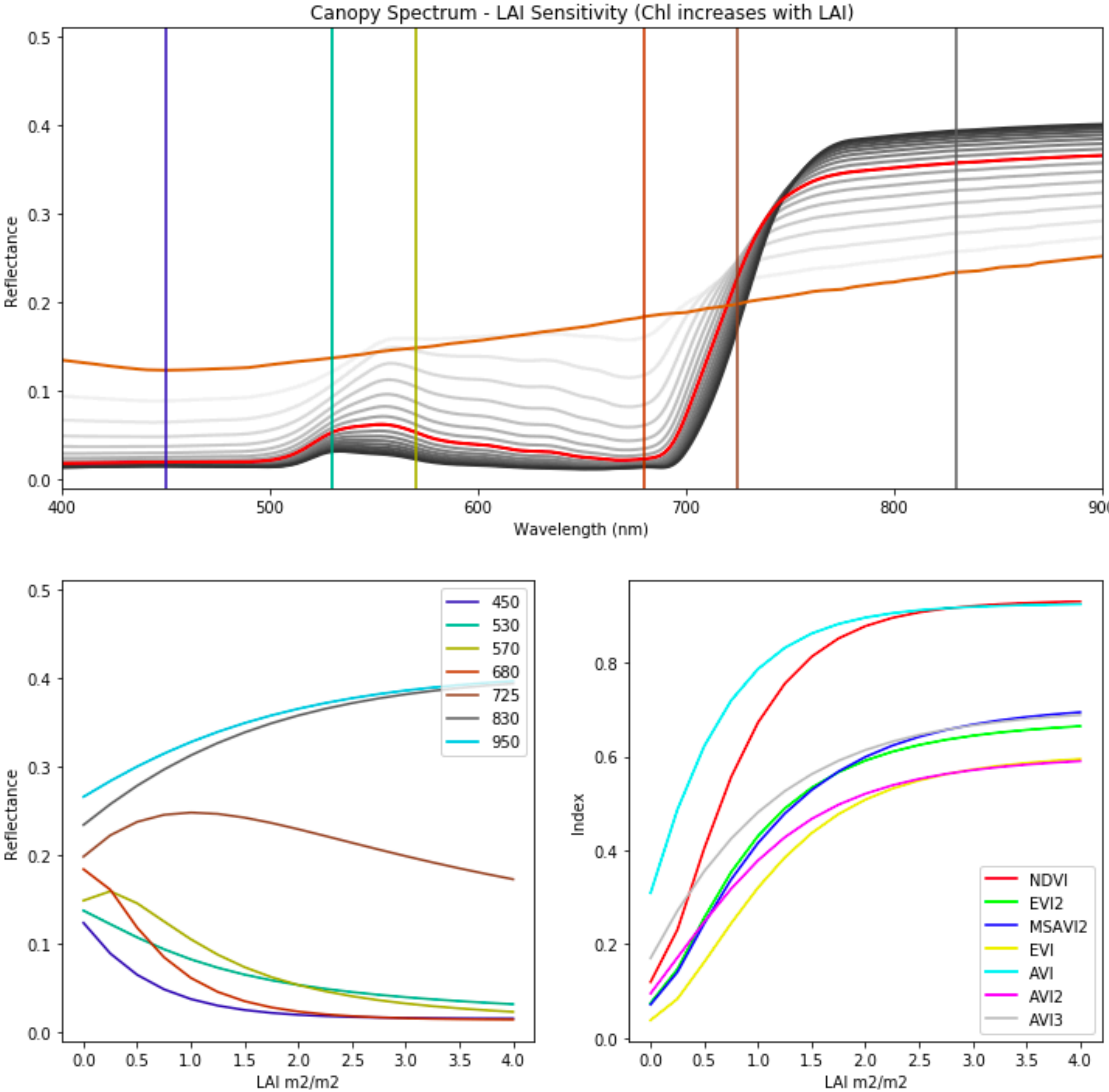
Canopy Properties - LAI


Canopy Spectrum - LAI Sensitivity (Default Leaf)
Reflectance
Wavelength (nm)
400
500
600
700
800
900
0.0
0.1
0.2
0.3
0.4
0.5
Reflectance
LAI m2/m2
450
530
570
680
725
830
950
Index
LAI m2/m2
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3

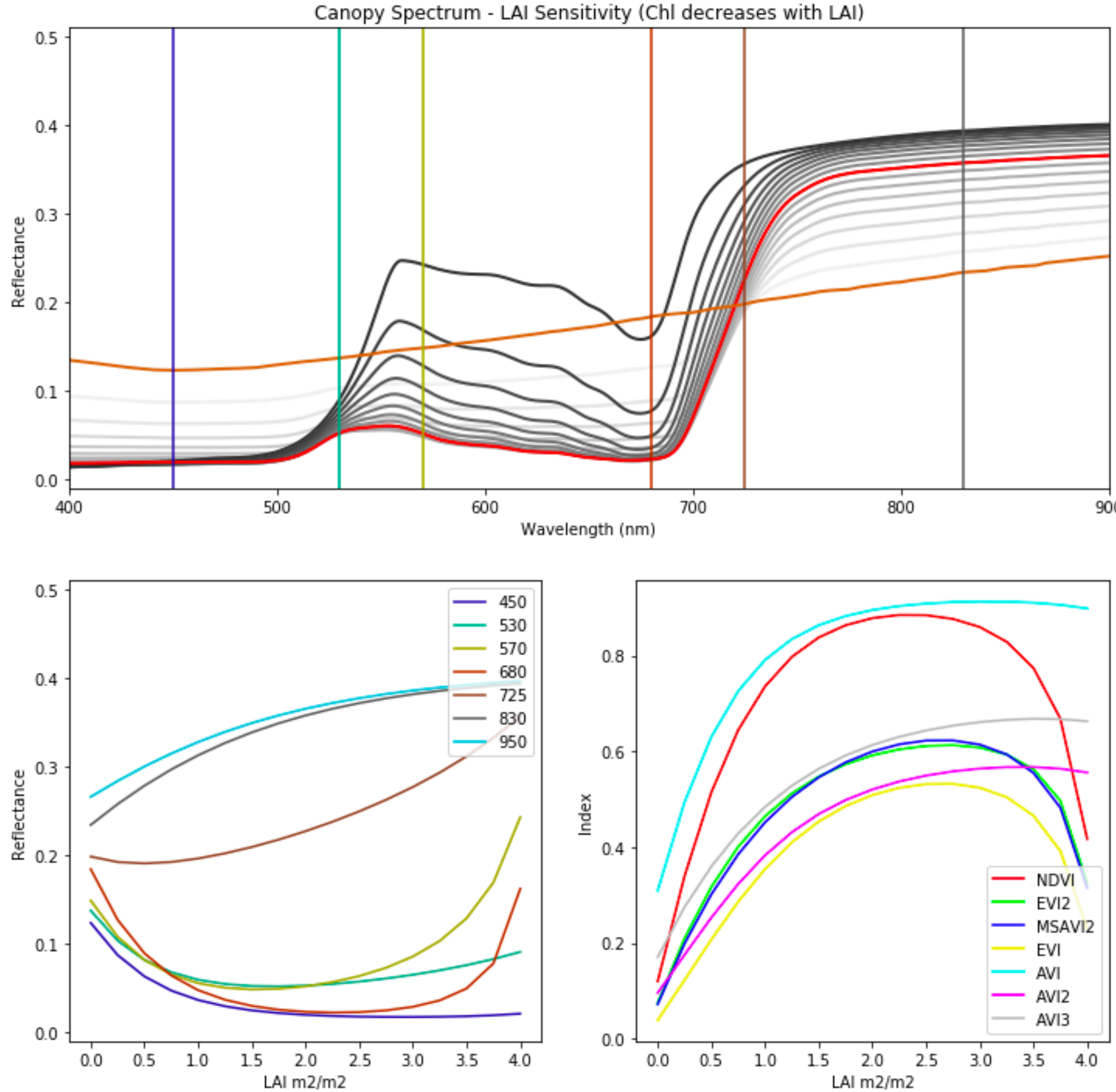


Canopy Spectrum - LAD Sensitivity (Default Leaf, LAI=3)
Reflectance
Wavelength (nm)
0.0
0.1
0.2
0.3
0.4
0.5
400
500
600
700
800
900
450
530
570
680
725
830
950
LIDFA (degrees)
0
20
40
60
80
Index
LAI m2/m2
0.4
0.5
0.6
0.7
0.8
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3

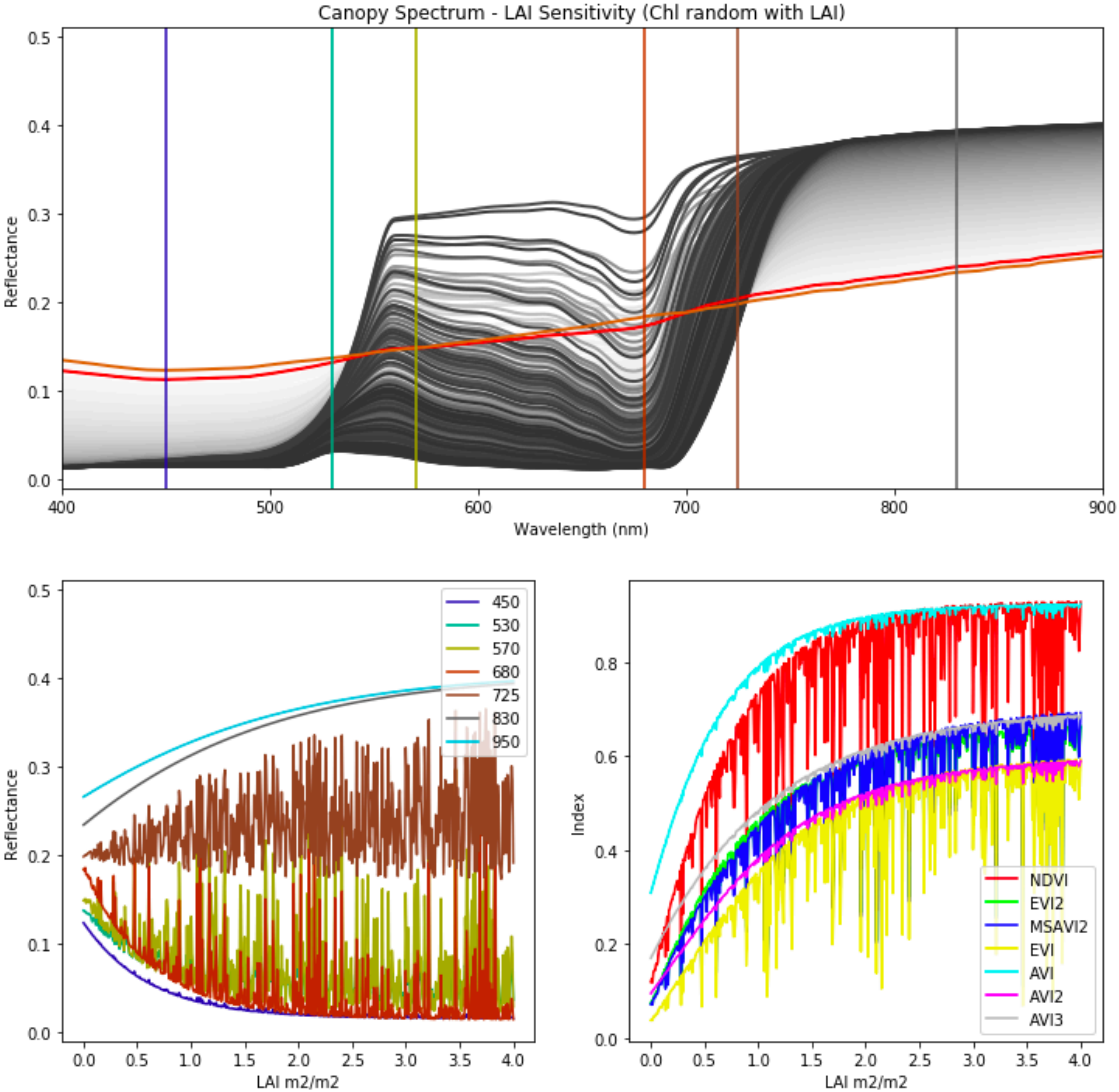

Canopy Spectrum - LAI Sensitivity (Noise from soil brightness)
Reflectance
Wavelength (nm)
0.0
0.1
0.2
0.3
0.4
0.5
400
500
600
700
800
900
450
530
570
680
725
830
950
LAI m2/m2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Index
0.2
0.4
0.6
0.8
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3



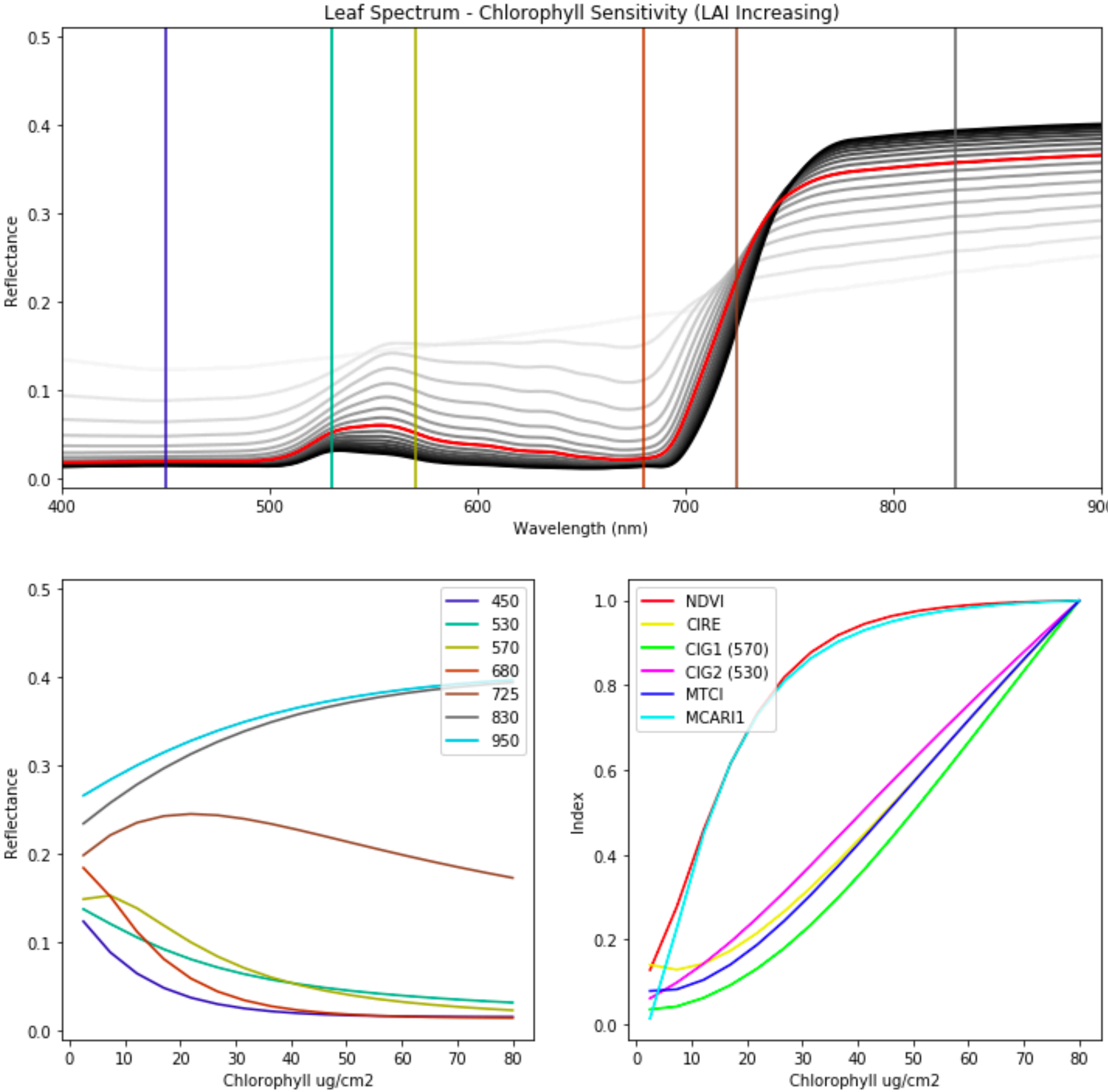
Canopy Spectrum - LAI Sensitivity (Chl increases with LAI)
Reflectance
Wavelength (nm)
450
530
570
680
725
830
950
LAI m2/m2
Index
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3



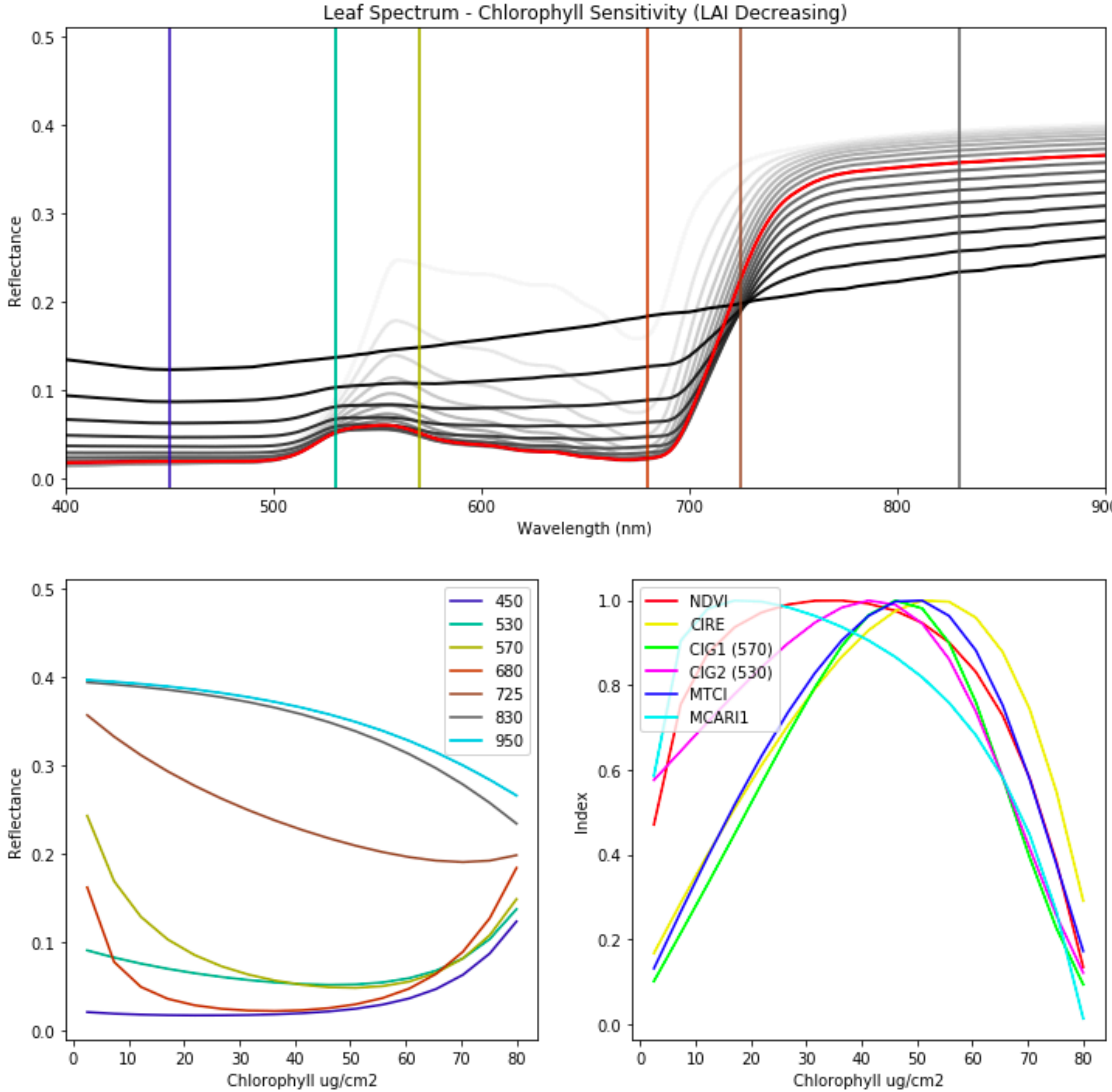
Canopy Spectrum - LAI Sensitivity (Chl decreases with LAI)
Reflectance
Wavelength (nm)
Reflectance
LAI m2/m2
450
530
570
680
725
830
950
Index
LAI m2/m2
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3


Canopy Spectrum - LAI Sensitivity (Chl random with LAI)
Reflectance
Wavelength (nm)
450
530
570
680
725
830
950
Reflectance
LAI m2/m2
Index
LAI m2/m2
NDVI
EVI2
MSAVI2
EVI
AVI
AVI2
AVI3

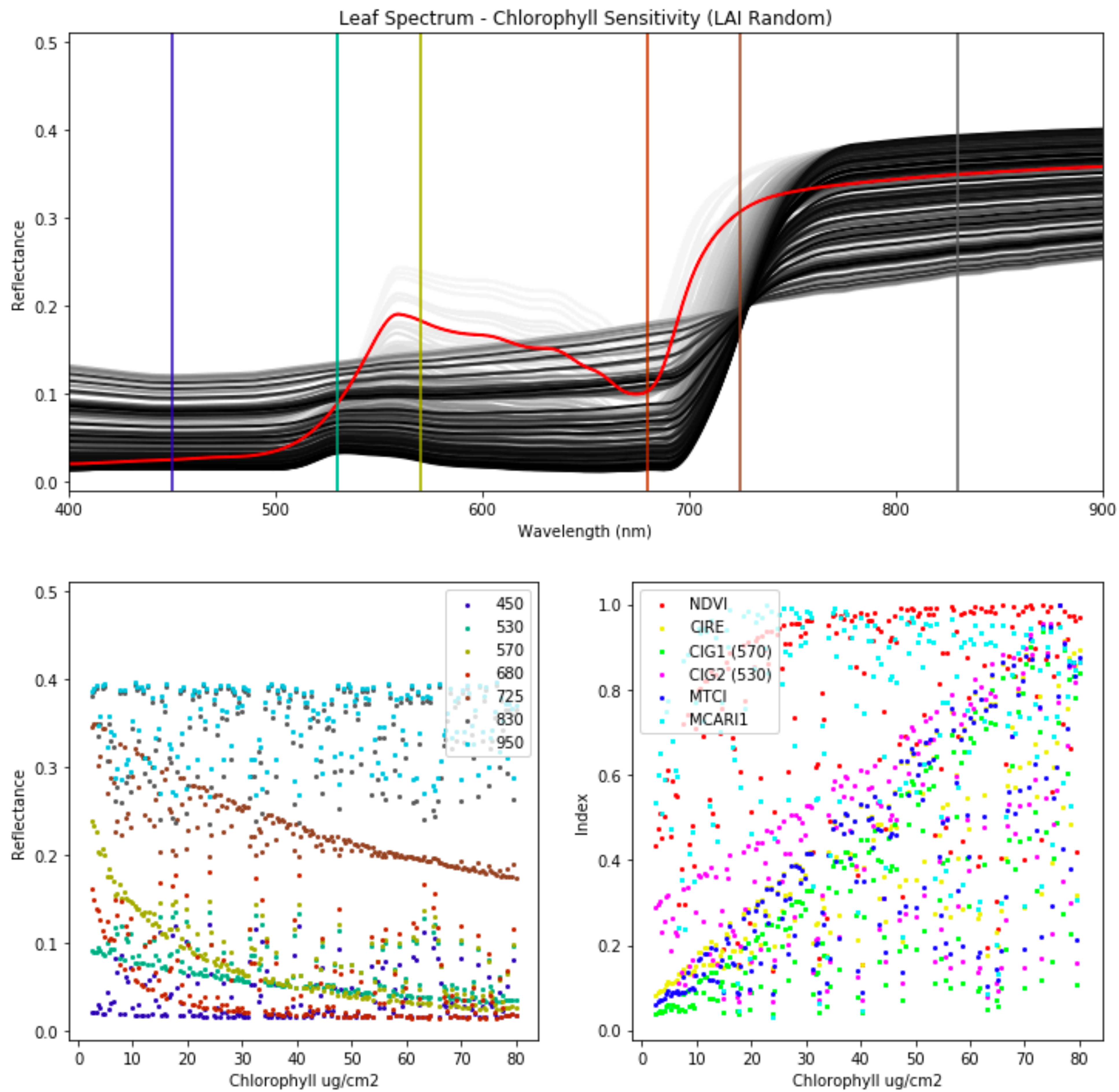
Canopy Properties - Chlorophyll



Leaf Spectrum - Chlorophyll Sensitivity (LAI Increasing)
Reflectance
Wavelength (nm)
400
500
600
700
800
900
0.0
0.1
0.2
0.3
0.4
0.5
450
530
570
680
725
830
950
Reflectance
Chlorophyll ug/cm2
NDVI
CIRE
CIG1 (570)
CIG2 (530)
MTCI
MCARI1
Index
Chlorophyll ug/cm2
0
10
20
30
40
50
60
70
80
0.0
0.2
0.4
0.6
0.8
1.0



Leaf Spectrum - Chlorophyll Sensitivity (LAI Decreasing)
Reflectance
Wavelength (nm)
450
530
570
680
725
830
950
Chlorophyll ug/cm2
NDVI
CIRE
CIG1 (570)
CIG2 (530)
MTCI
MCARI1
Index

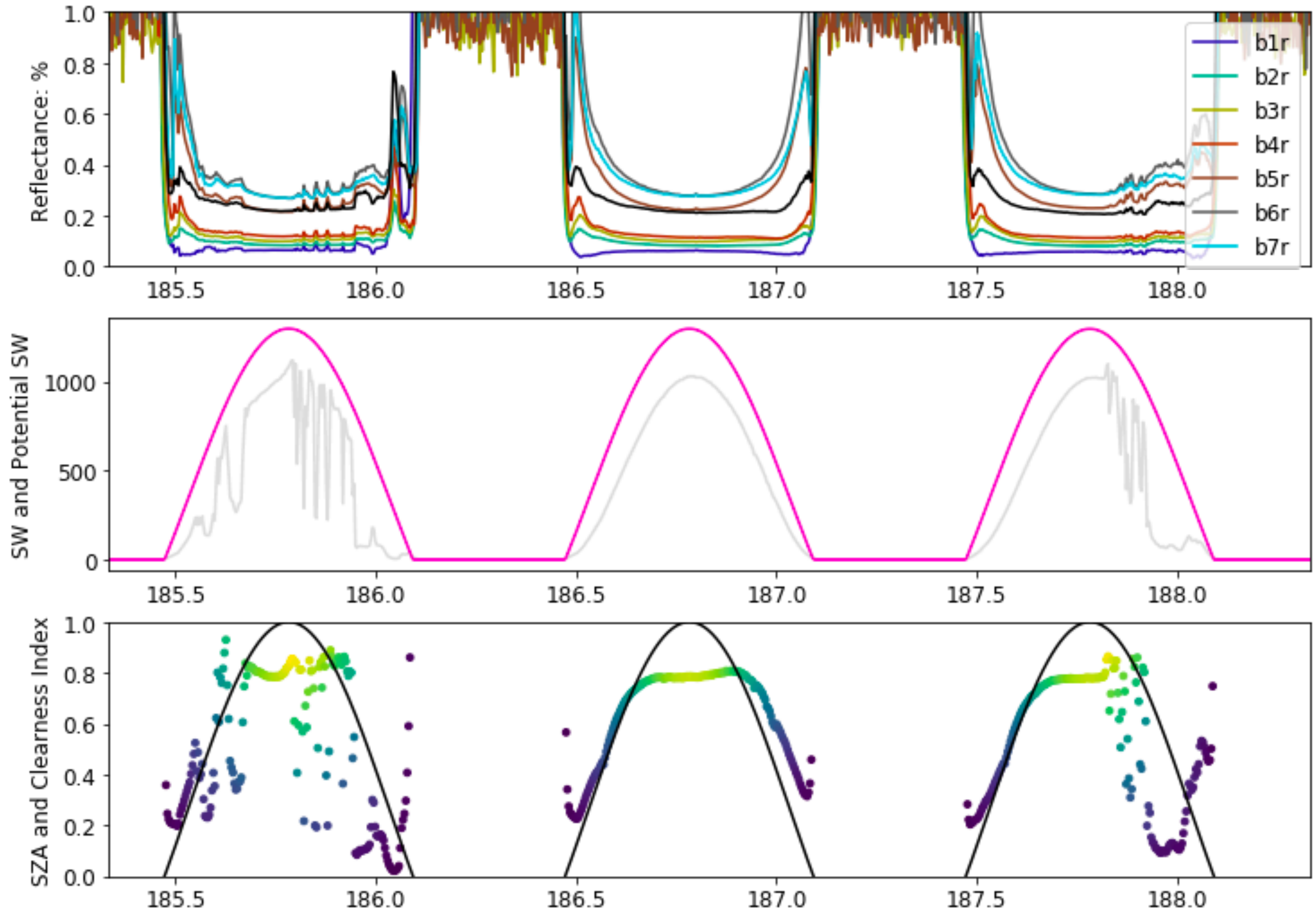


Leaf Spectrum - Chlorophyll Sensitivity (LAI Random)
Reflectance
Wavelength (nm)
450
530
570
680
725
830
950
Reflectance
Chlorophyll ug/cm2
NDVI
CIRE
CIG1 (570)
CIG2 (530)
MTCI
MCARI1
Index
Chlorophyll ug/cm2

Application to a real field

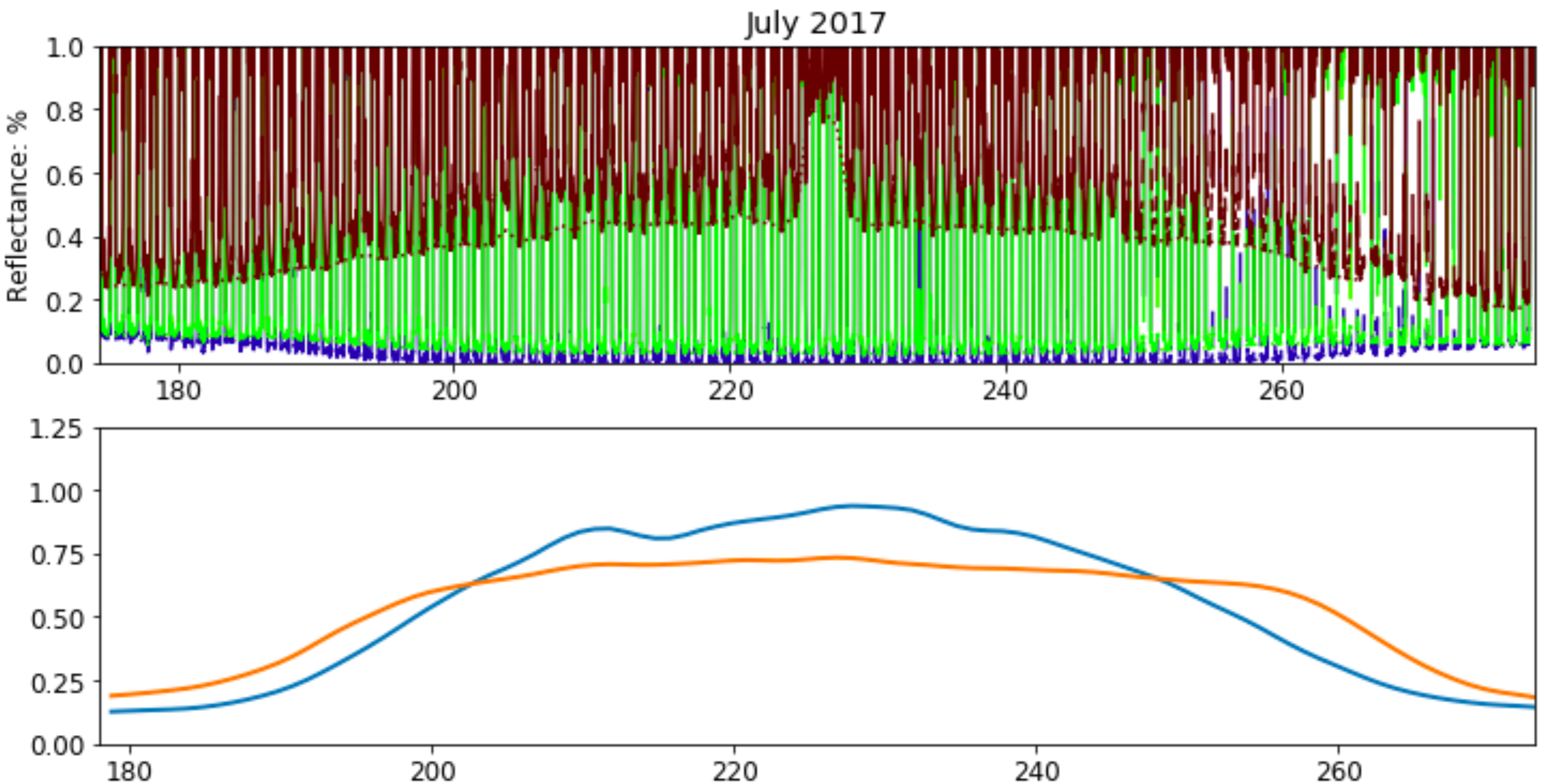
Extraction of daily bi-hemispheric reflectance from sub-daily directional-hemispheric reflectance

Basically, the path thru the canopy is longer at higher zenith angles



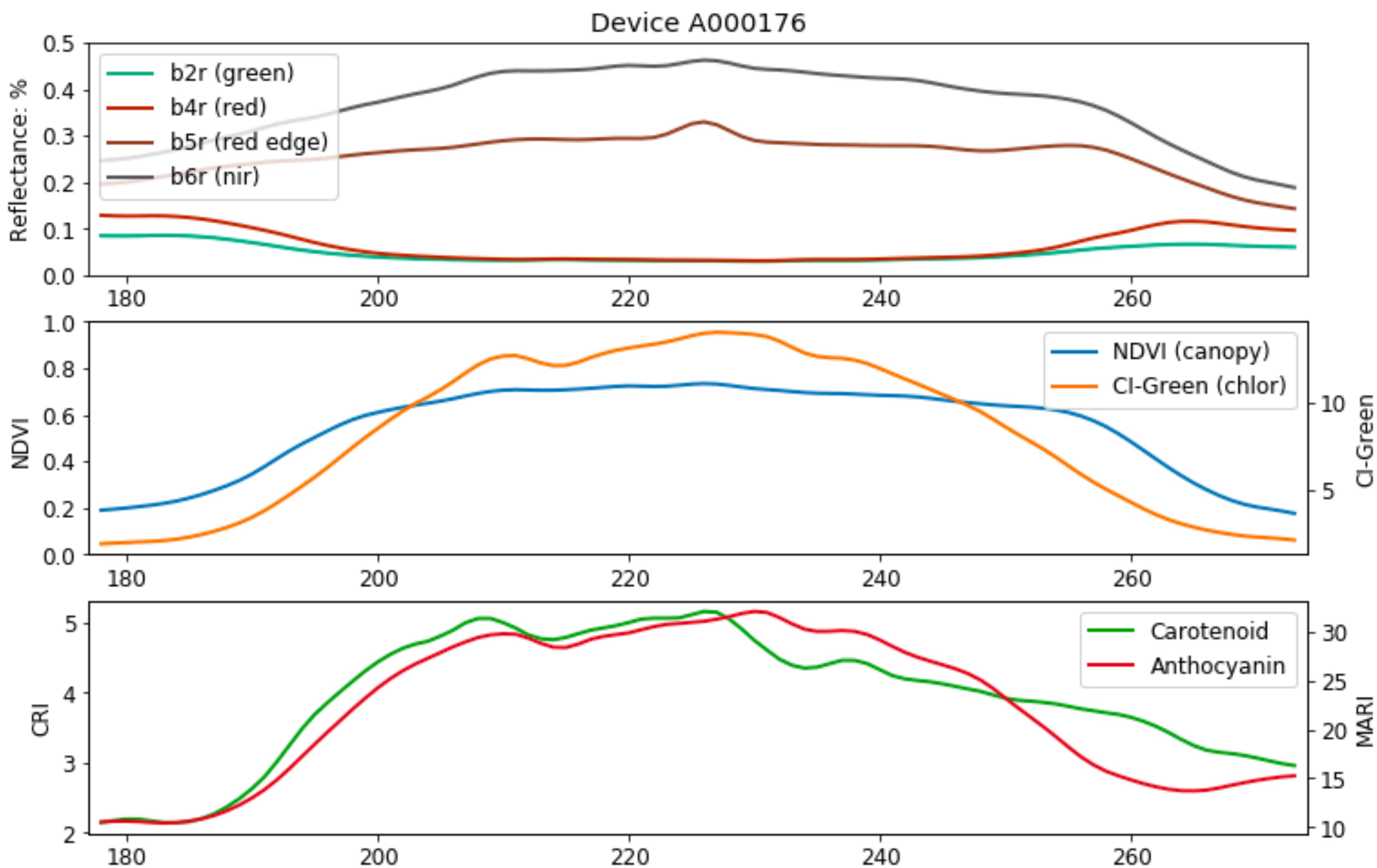
Extraction of daily bi-hemispheric reflectance from sub-daily directional-hemispheric reflectance

This is the fast-changing sub-daily part:



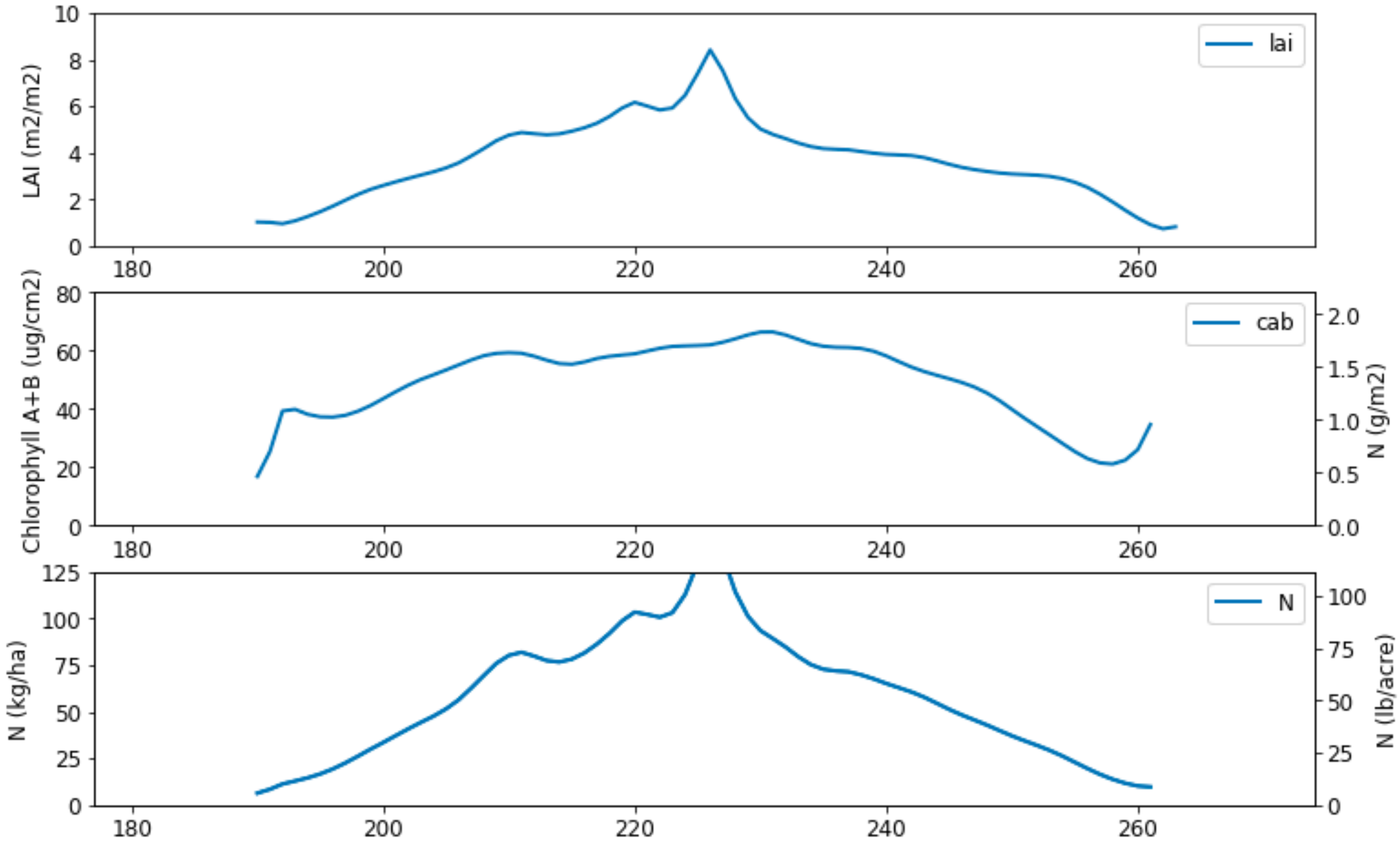
This is the slow-changing daily part

Tracking canopy attributes over time

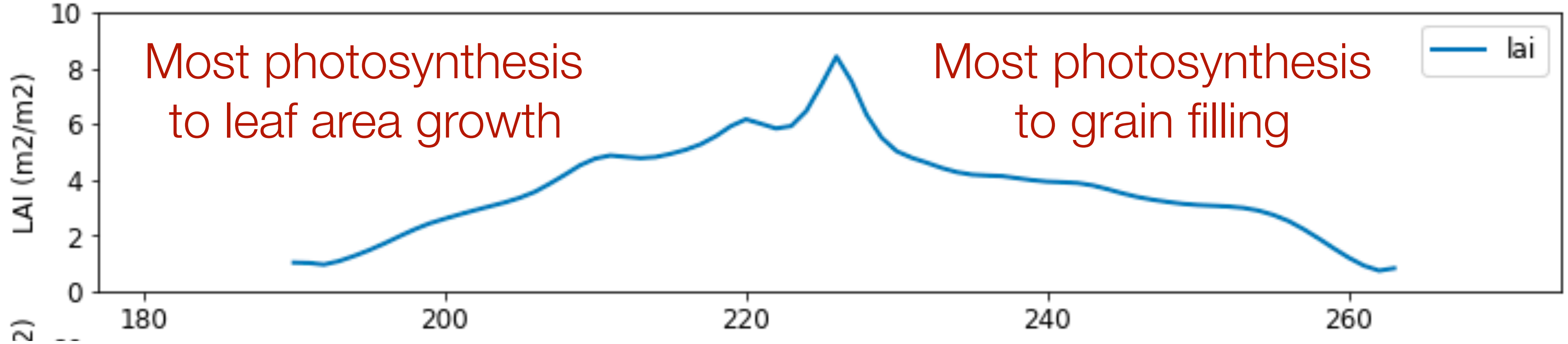


Inverting canopy attributes into physical units

LAI, leaf chlorophyll, canopy N



Inferring C partitioning from canopy cover



Inferring N partitioning from canopy N content