Remote Estimation of Pigment Content and Composition in Terrestrial Vegetation: Challenges and Solutions

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Goal: To develop techniques for estimating contents and composition of pigments in terrestrial vegetation

- Total chlorophyll content, chlorophyll-*a* and -*b*
- Total carotenoids content
- Total anthocyanins content

Chlorophylls

Chlorophylls relate to both the physiological status and the photosynthetic capacity of vegetation.

Chlorophylls absorb solar radiation and provide mechanisms for its utilization in photosynthetic reactions.

Total canopy chlorophyll content is objective quantitative measure of vegetation greenness.

Carotenoids and Anthocyanins

- Carotenoids contribute to light-harvesting and also play a photo-protective role, preventing damage to the photosynthetic apparatus in leaves.
- The induction of anthocyanins biosynthesis occurs as a result of <u>deficiencies</u> in nitrogen and phosphorus, wounding, pathogen infection, desiccation, low temperature, UV-irradiation etc. Anthocyanins fulfill important physiological functions by being involved in the <u>adaptation to numerous stresses</u> and environmental strain reduction.

Three-band model for pigment content estimation based on Kubelka-Munk remission function

$$f(\rho_\infty) = (1 - \rho_\infty^{2})/2\rho_\infty = (a + b_b)/b_b \cong \rho_o^{-1}$$

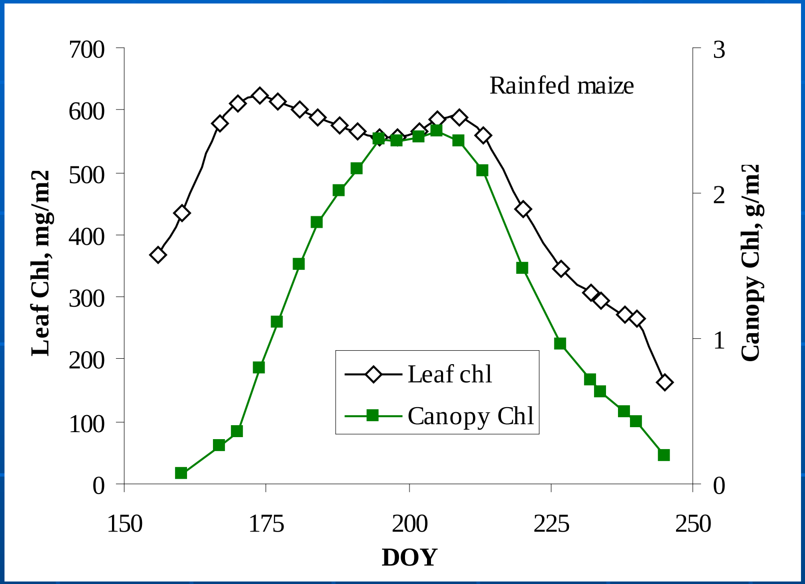
ρ_∞ is reflectance of an ideal layer, in which a further increase in thickness results in no noticeable difference, ρ_o is reflectance measured against black background

$$\rho^{-1}(\lambda) \propto [a_{pigm}(\lambda) + a_0(\lambda) + b_b]/b_b$$

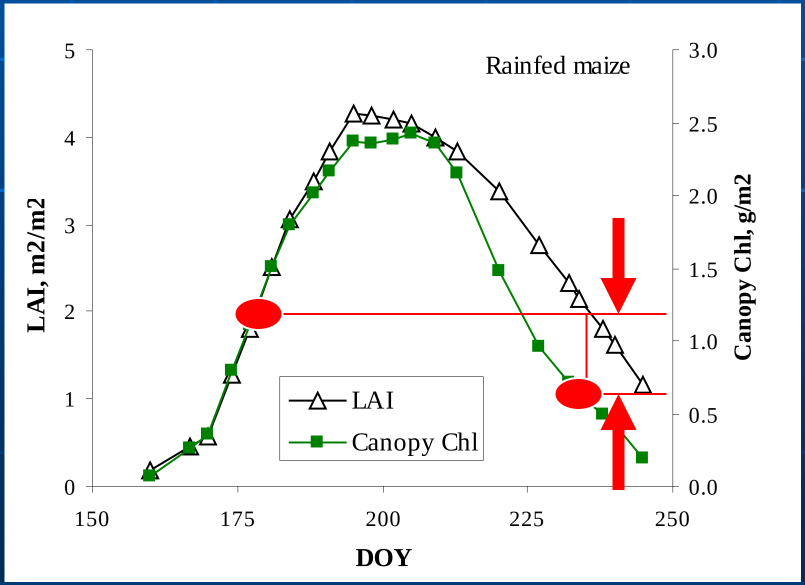
$$\text{Pigment Content} \propto [\rho^{-1}(\lambda_1) - \rho^{-1}(\lambda_2)]\ \rho(\lambda_3)$$

Gitelson et al., GRL, 2003, 2006

Total canopy chlorophyll content



Total canopy Chl = total LAI Chl_{leaf}



Chlorophyll content estimation

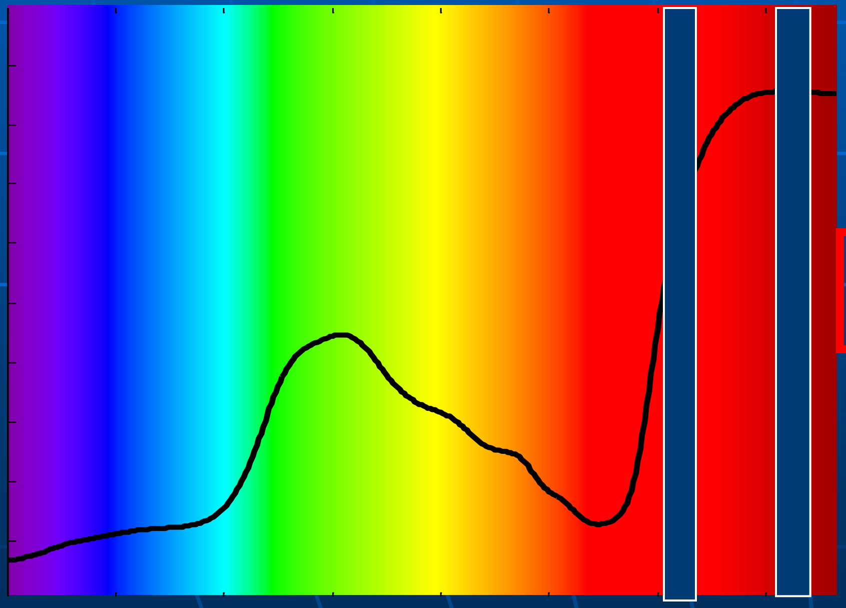
Only HyspIRI is able to uniquely provide it

$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Chlorophyll Index

$$CI \propto \underbrace{[\rho^{-1}(\lambda_1)}\ - \underbrace{\rho^{-1}(\lambda_2)]}\ \underbrace{\rho(\lambda_3)}$$

Gitelson et al., GRL, 2003, 2006



$$\boxed{\text{Total Chl} \propto CI = (\rho_{NIR}/\rho_{red\ edge}) - 1}$$

Gitelson et al., GRL, 2003

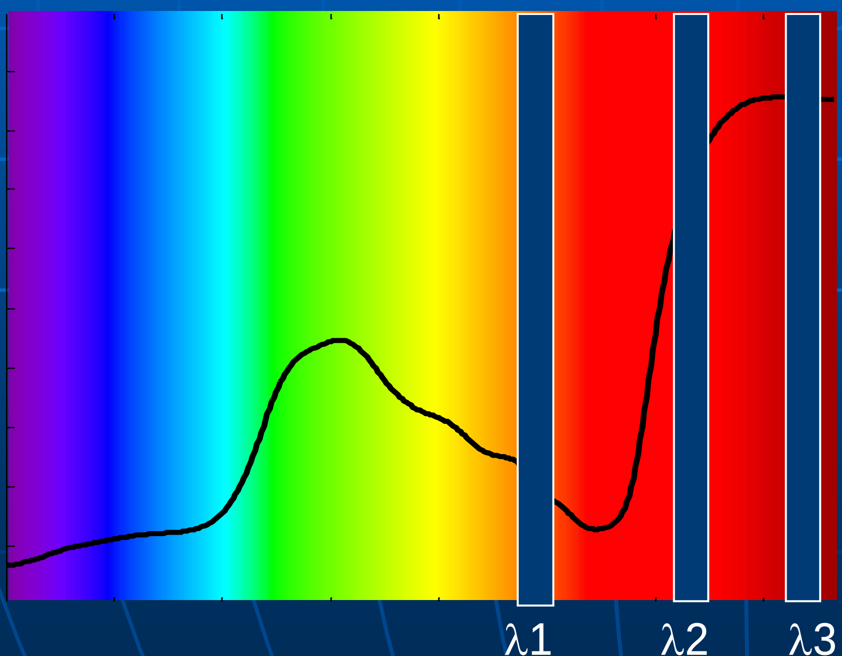
Only HyspIRI is able to <u>uniquely</u> provide it

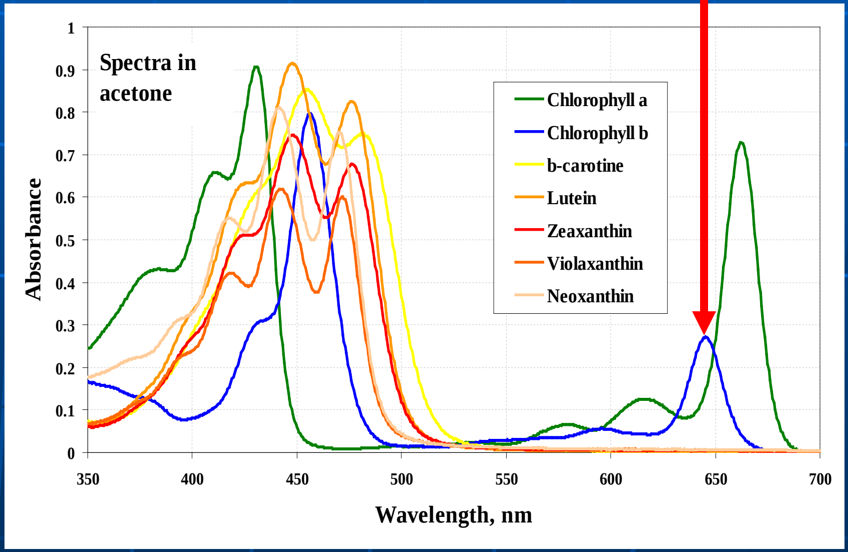
$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Chlorophyll-*b* Index

$$CI_{chl\text{-}b} \propto \underbrace{[\rho^{-1}(\lambda_1)}_{a_{chl\text{-}a} + a_{chl\text{-}b}} - \underbrace{\rho^{-1}(\lambda_2)]}_{a_{chl\text{-}a}} \underbrace{\rho(\lambda_3)}_{b_b}$$

Chl-*b*





$$\boxed{\text{Chl-}b \propto CI_{chl\text{-}b} = (\rho^{-1}_{650} - \rho^{-1}_{\text{red edge}})\ \rho_{NIR}}$$

Performance of different methods to assess chlorophyll

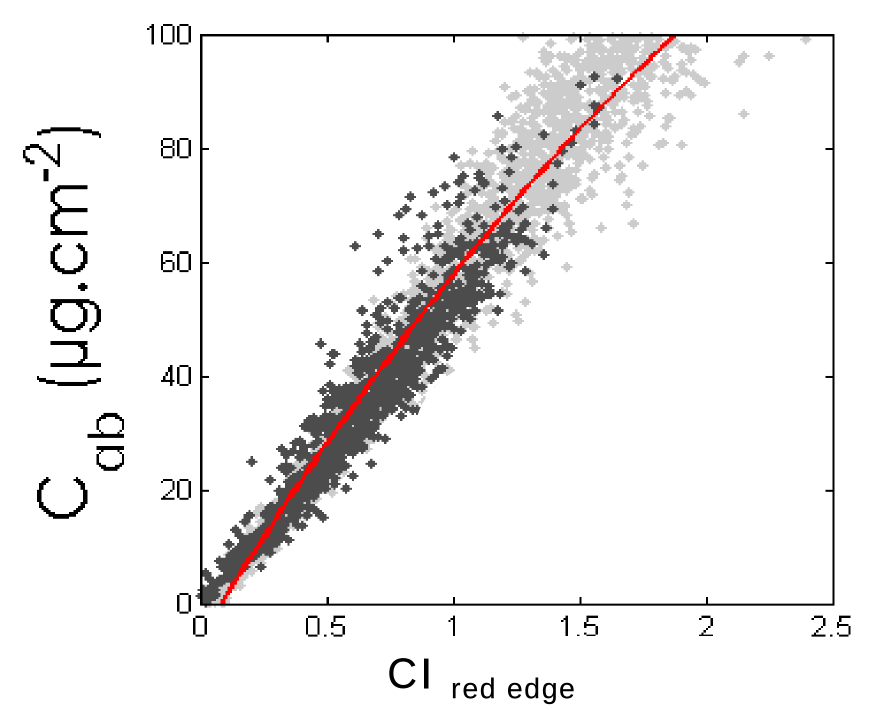
Method	λ_1	λ_2	λ_3	Wavelength selection database	Relationship adjustment database	RMSE synthetic database ($\mu g.cm^{-2}$) N=2000	RMSE reduced database ($\mu g.cm^{-2}$) N=660	RMSE extended database ($\mu g.cm^{-2}$) N=1097
mSR	**405**	720	910	Synthetic	Experimental	12.80	5.64	*NA*
3BM	**700-730**	**755-800**	**765-800**	**Synthetic**	**Experimental**	**5.34**	**5.72**	**6.19**
SR	**713**	779		Synthetic	Experimental	10.88	5.74	6.15
ND	**711**	776		Synthetic	Experimental	10.41	5.81	6.39
3BM	**700-730**	755-800	765-800	Synthetic	Synthetic	6.27	6.07	6.53
$CI_{red\ edge}$	**690-720**	760-800		(1)	Experimental	5.33	6.11	6.87
mND	**410**	715	830	Synthetic	Experimental	12.28	6.26	*NA*
DDn	**711**	229		Synthetic	Experimental	12.48	6.29	*NA*
$NDVI_{red\ edge}$	**710**	**750**		**(3)**	**Experimental**	**12.20**	**6.34**	**7.42**
SR	**713**	779		Synthetic	Synthetic	9.20	6.44	6.75
RII	**705**	750		(3)	Experimental	47.42	6.47	7.66
$ND_{705,935}$	**705**	935		(2)	Experimental	12.35	6.70	*NA*
$ND_{705,935}$	**705**	935		(2)	(2)	13.60	6.71	*NA*
ND	**711**	776		Synthetic	Synthetic	9.54	6.78	7.27
mSR	**405**	720	910	Synthetic	Synthetic	11.04	6.85	*NA*
$SR_{710,970}$	**710**	970		(2)	Experimental	10.98	7.23	*NA*

Feret et al., 2010 submitted

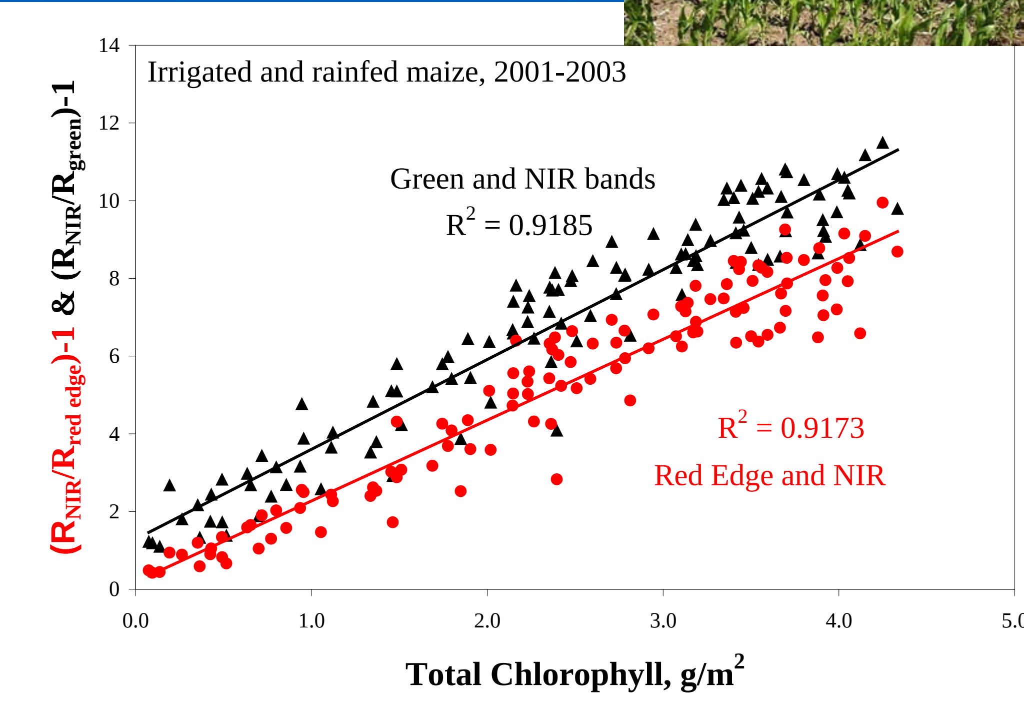
Only HyspIRI is able to uniquely provide it

$$CI_{red\ edge} \propto [(\rho_{red\ edge})^{-1}-(\rho_{NIR})^{-1}]\ \ \rho_{NIR}$$

Leaf



Canopy



Feret et al., RSE, 2009

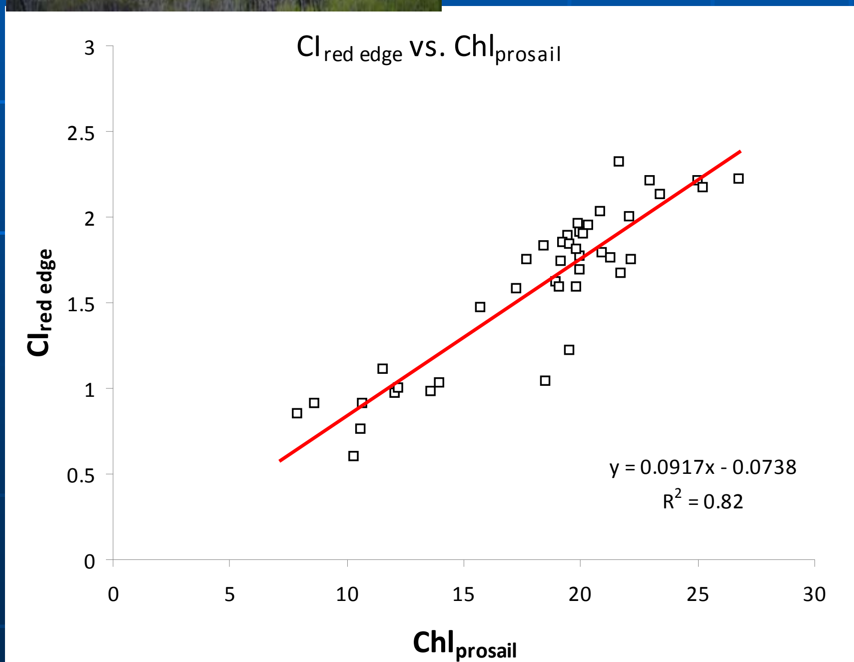
Gitelson et al., GRL, 2005

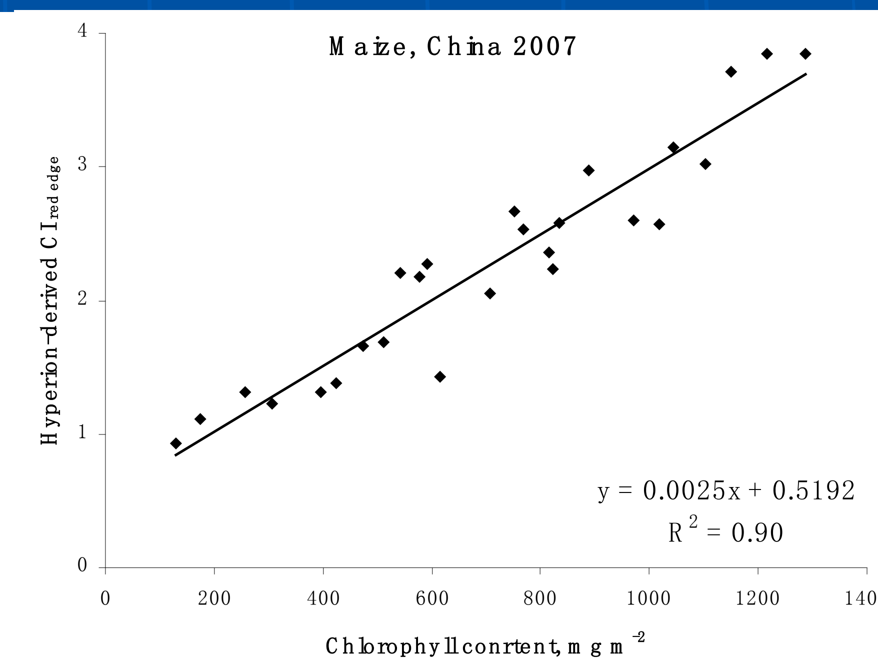
Only HyspIRI is able to uniquely provide it

$$CI_{red\ edge} \propto [(\rho_{red\ edge})^{-1}-(\rho_{NIR})^{-1}]\ \rho_{NIR}$$

Southern Old Aspen, the southern ecotone of the western boreal forests, Canada

Hyperion
Maize in China





Hilker et al., 2010, submitted

Wu et al., IJRS, 2010

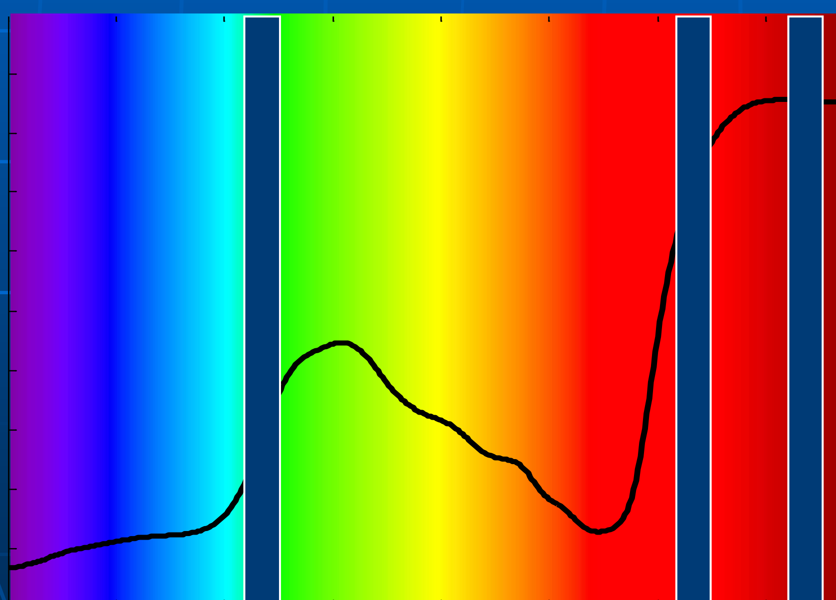
Carotenoids content estimation

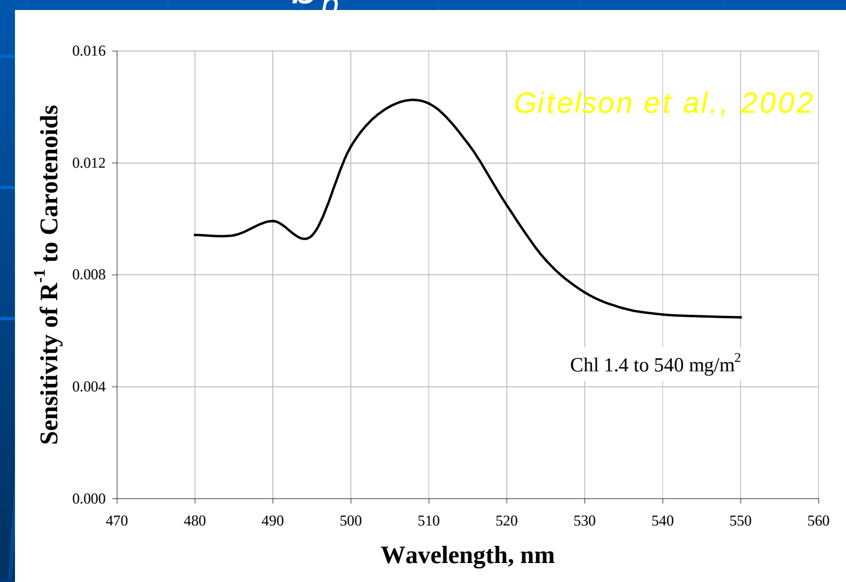
Only HyspIRI is able to uniquely provide it

$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Carotenoids Reflectance Index

$$CRI \propto \underbrace{[\rho^{-1}(\lambda_1)}_{a_{car} + a_{chl}} - \underbrace{\rho^{-1}(\lambda_2)]}_{a_{chl}} \; \underbrace{\rho(\lambda_3)}_{b_b}$$



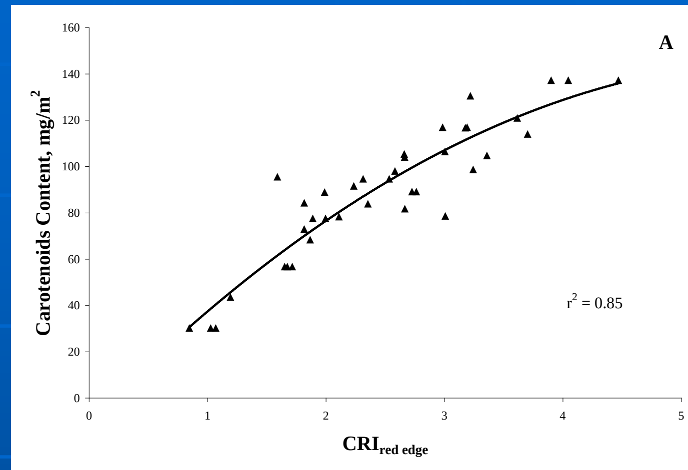


Gitelson et al., 2002

$$\boxed{Car \propto CRI = (\rho^{-1}_{515} - \rho^{-1}_{\text{red edge}})\ \rho_{NIR}}$$

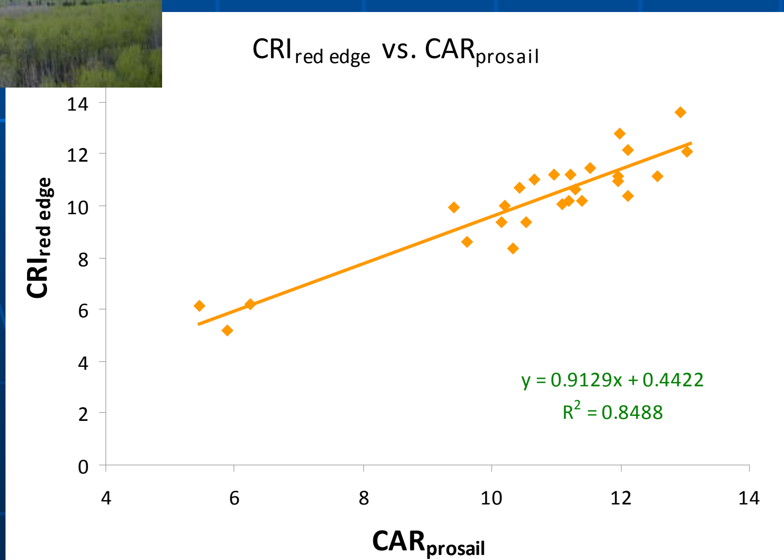
Only HyspIRI is able to uniquely provide it

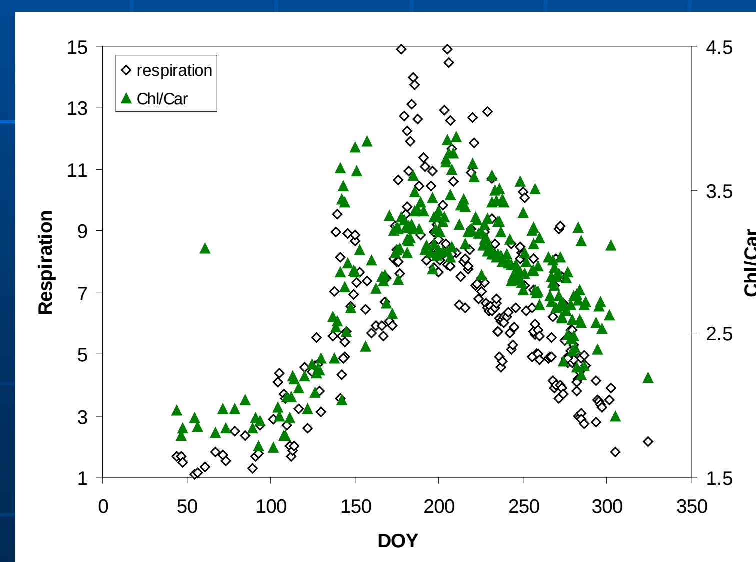
Carotenoids content estimation



Gitelson et al., 2002

The Douglas-fir stand, Canada





Hilker et al., 2010, submitted

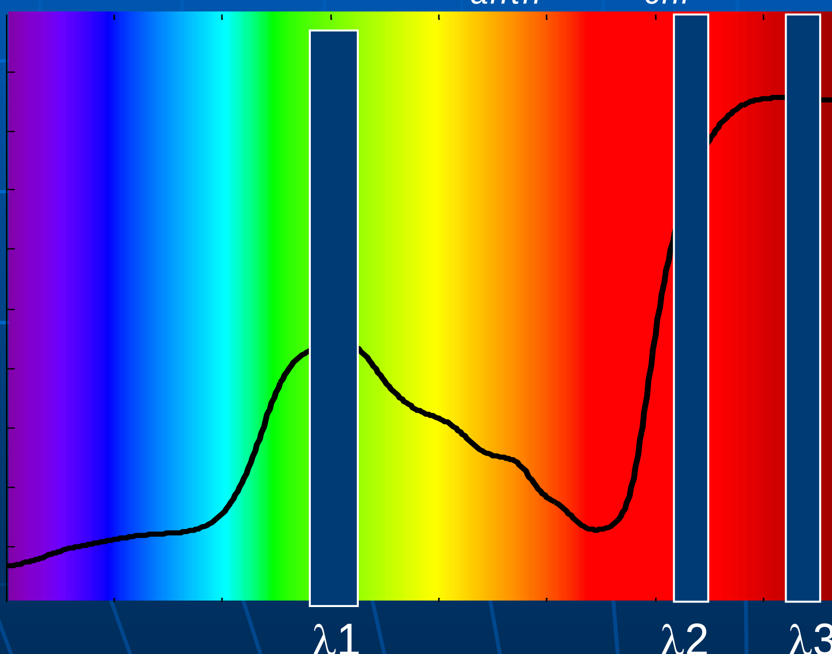
Anthocyanins content estimation

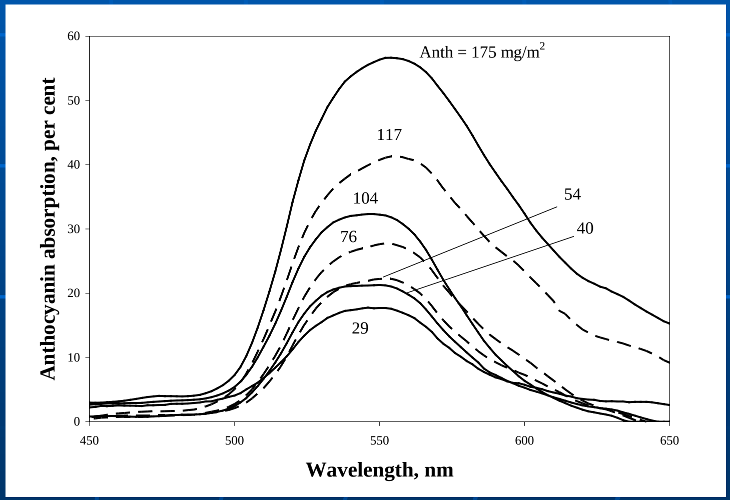
Only HyspIRI is able to uniquely provide it

$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Anthocyanin Reflectance Index

$$ARI_{red\ edge} \propto \underbrace{[\rho^{-1}(\lambda_1)}_{a_{anth}\ +\ a_{chl}} - \underbrace{\rho^{-1}(\lambda_2)]}_{a_{chl}}\ \underbrace{\rho(\lambda_3)}_{b_b}$$



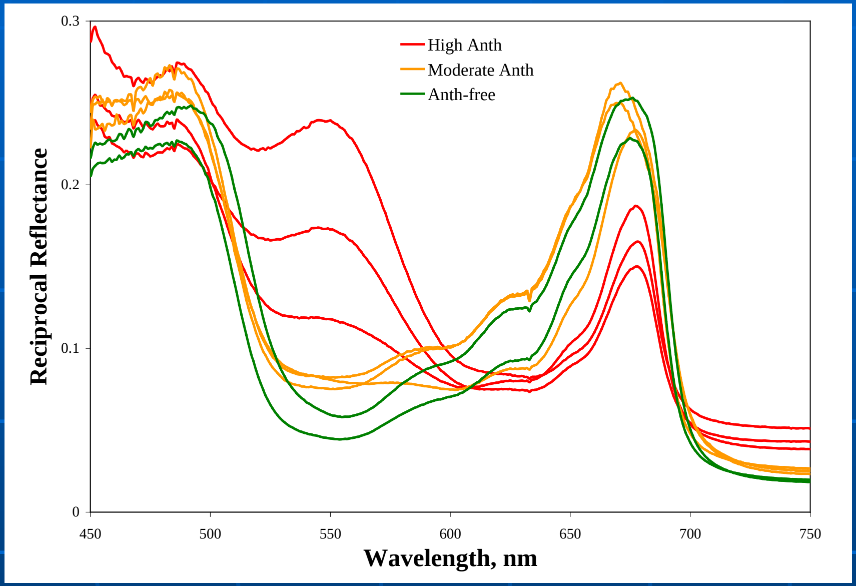


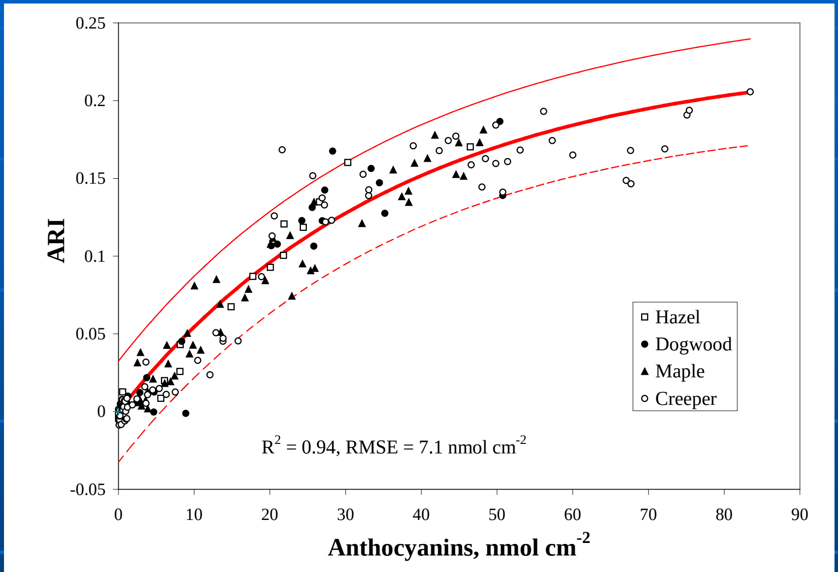
Gitelson et al., 2009

$$\boxed{Anth \propto ARI = (\rho^{-1}_{550} - \rho^{-1}_{red\ edge})\ \rho_{NIR}}$$

Gitelson et al., 2001

Anthocyanins content estimation





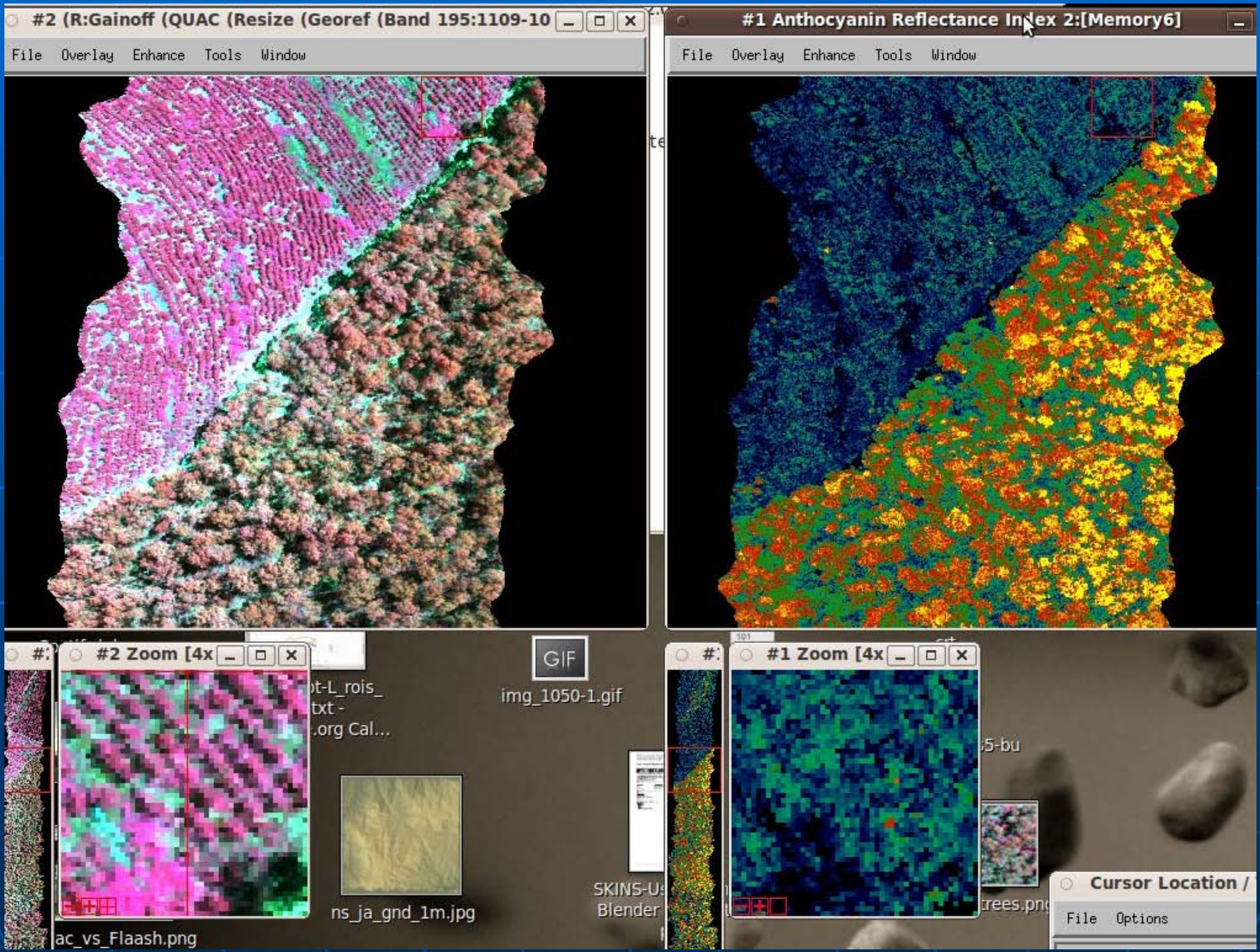
Gitelson et al., 2009

The induction of anthocyanins biosynthesis occurs as a result of deficiencies in nitrogen and phosphorus and other stresses

Anthocyanin levels (ARI) indicate physiological and biochemical changes from water stress (Asner, PNAS, 2004)

"…ARI showed high values for eucalypt as compared with other species. The differences were so amazing that I even used that as a classification algorithm and for tree delineation."

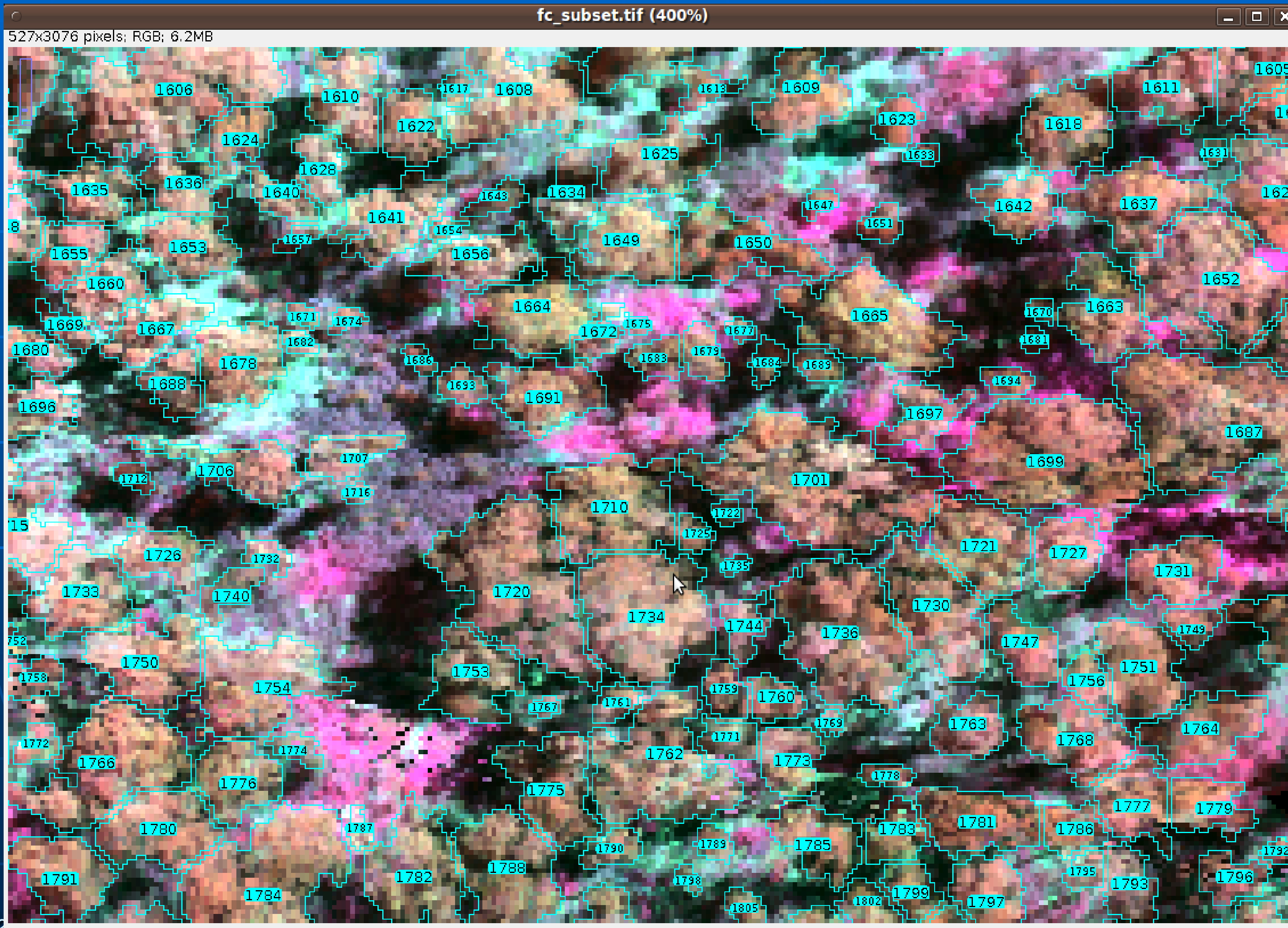
Jose A. Jimenez Berni, CSIRO



Vegetation Index Map: ARI = $(\rho^{-1}_{550} - \rho^{-1}_{710}) \times \rho_{800}$

Only HyspIRI is able to <u>uniquely</u> provide it

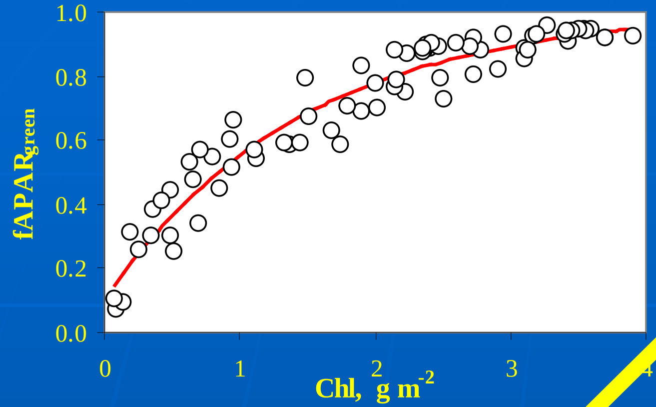
Tree delineation based on Anthocyanin Reflectance Index

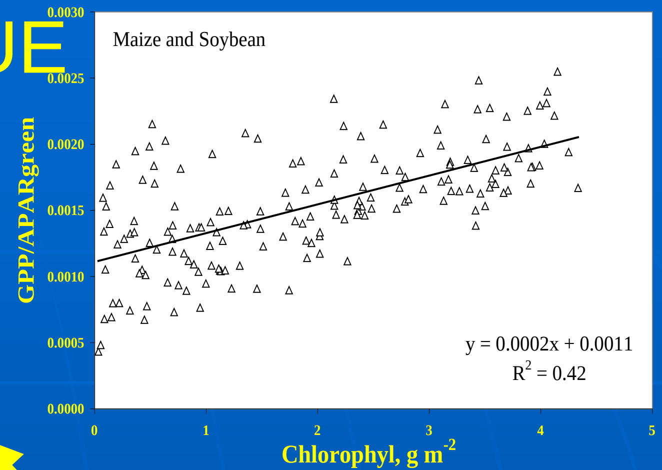


Courtesy: Jose A. Jimenez Berni, CSIRO

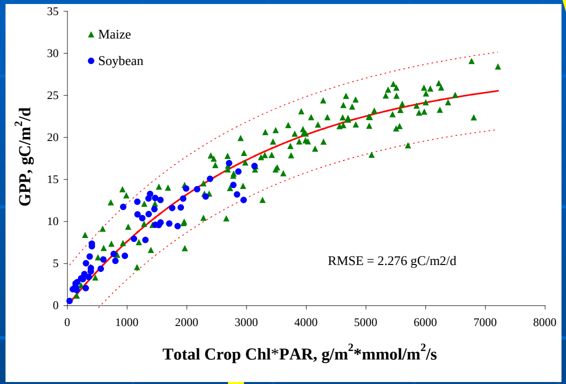
Relevance to carbon cycle science and climate science

GPP ∝ fAPAR×PAR×LUE





Chlorophyll



$fAPAR_{green}$

depends on amount of *chlorophyll*

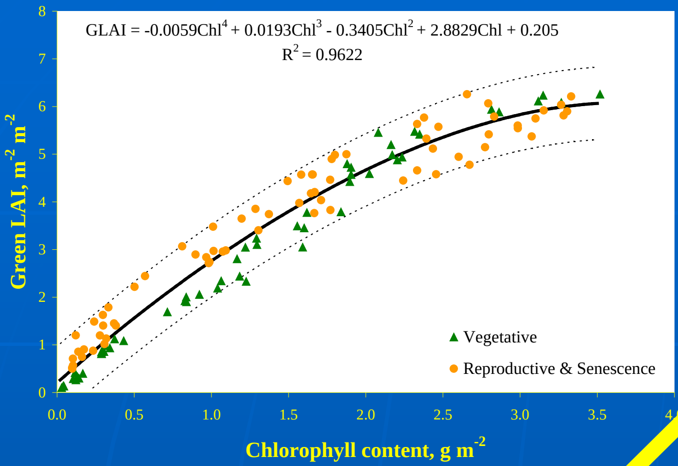
LUE

chlorophyll is an indicator of efficiency of using fAPAR for photosynthesis

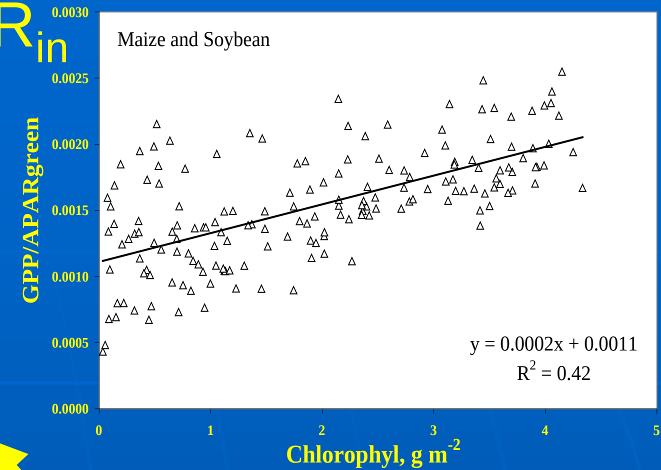
GPP = Chl×LUE×PAR

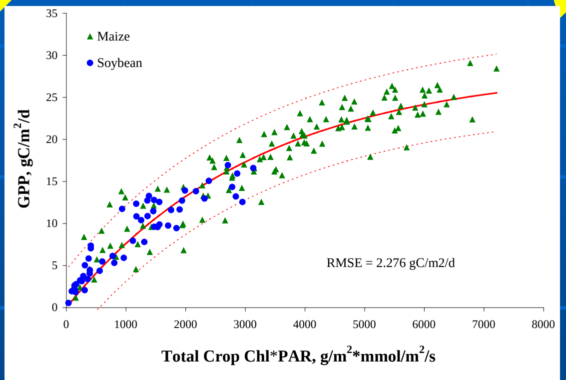
1. Production Efficiency Models

$GPP \propto LAI \times LUE \times PAR_{in}$



Chlorophyll





Green LAI

LUE

chlorophyll is an indicator of efficiency of using fAPAR for photosynthesis

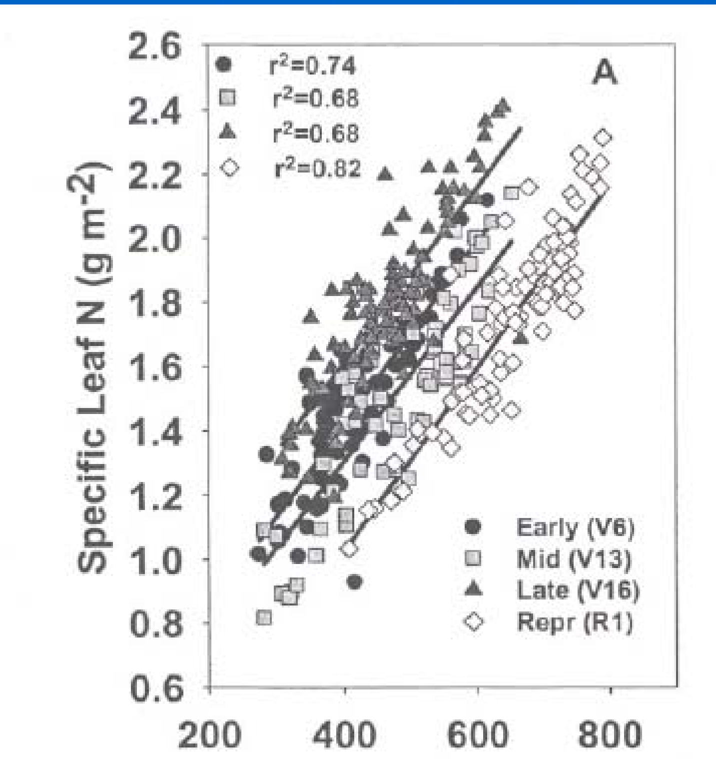
Relates closely to *chlorophyll*

Chlorophyll is objective characteristic of plant greenness

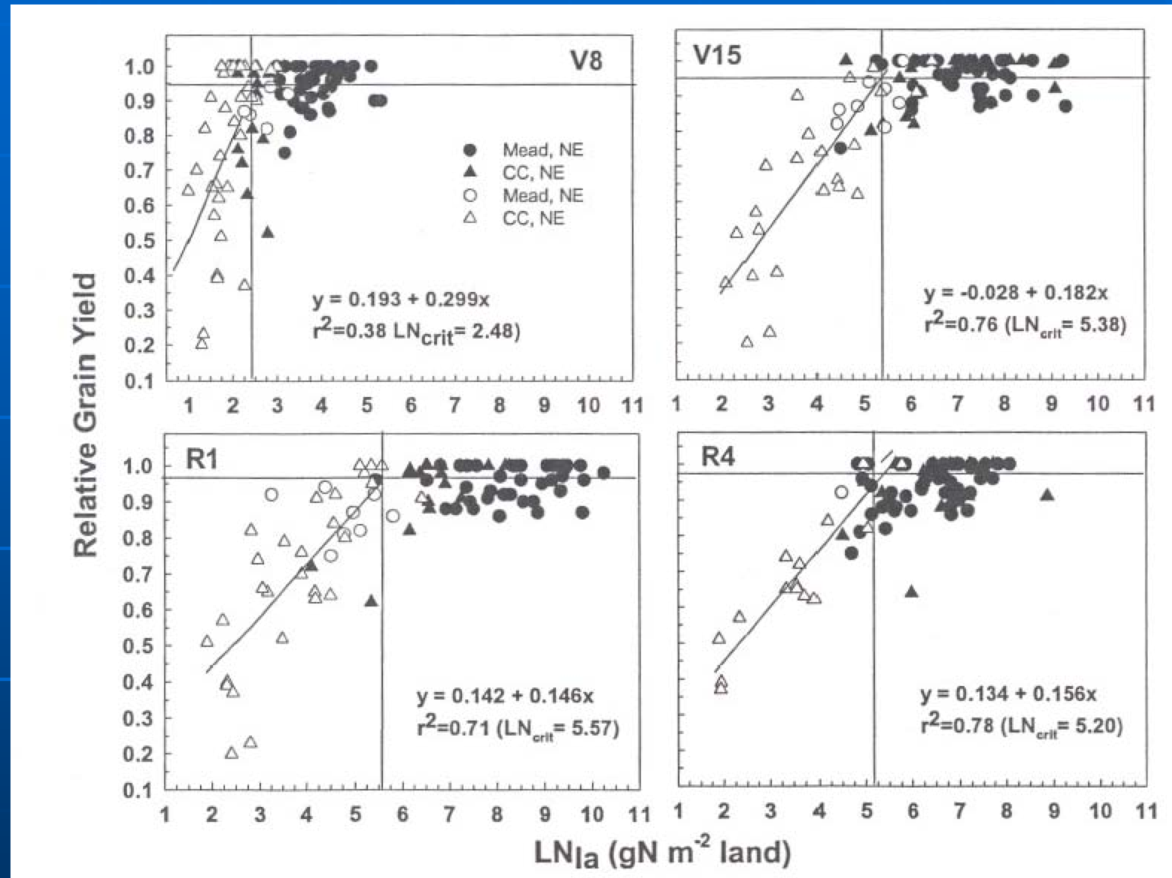
$GPP = Chl \times LUE \times PAR$

2. Canopy Photosynthesis Models

Diagnosis of Maize N Status



Leaf Chlorophyll Content (mmol m^{-2})



Specific leaf nitrogen (g N m^{-2} leaf) is closely related to leaf chlorophyll content

Walters, 2003

Walters, 2003

Leaf Nitrogen Per Unit Land Area is closely related to relative grain yield

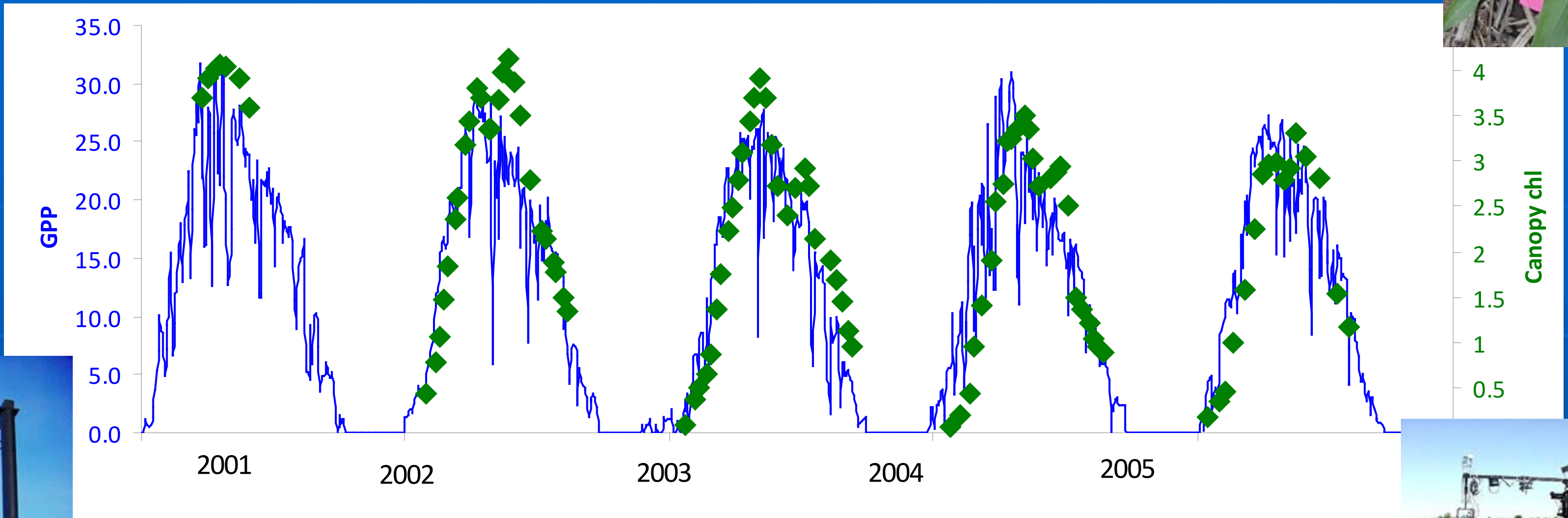
Chlorophyll Content

GPP

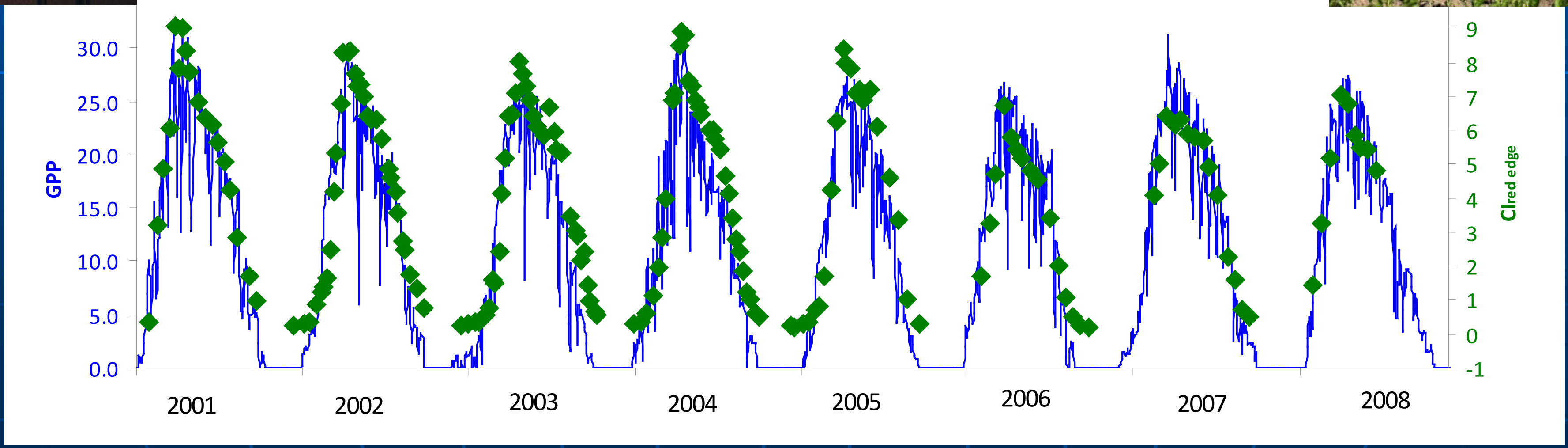
N content

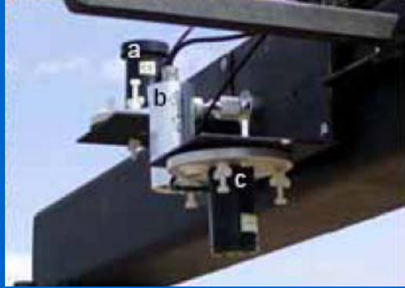
To estimate remotely *GPP*, one should find the way to accurately retrieve *chlorophyll content* from remotely sensed data

GPP and Canopy Chlorophyll



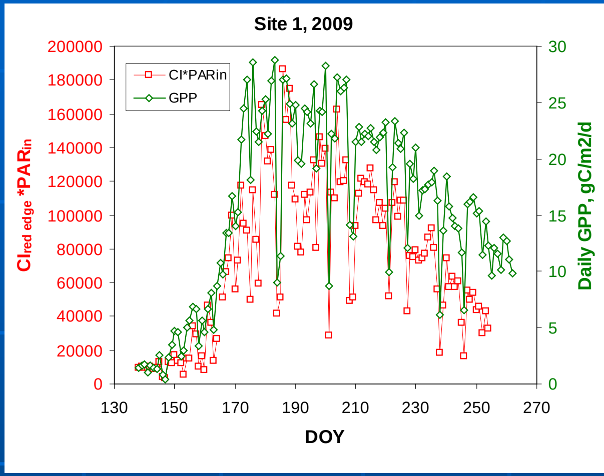
Proximal Sensing: GPP and Red edge Chlorophyll Index

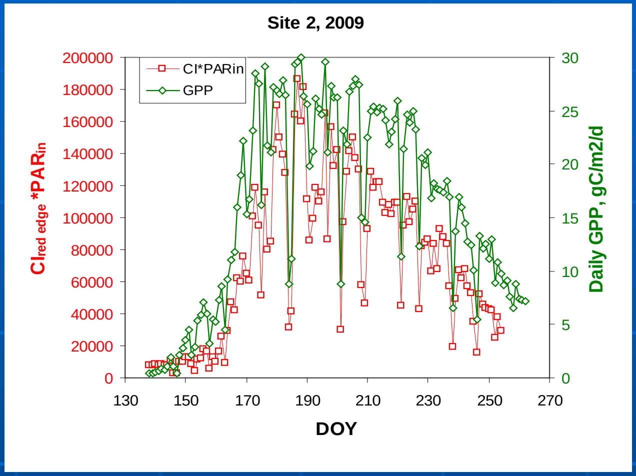


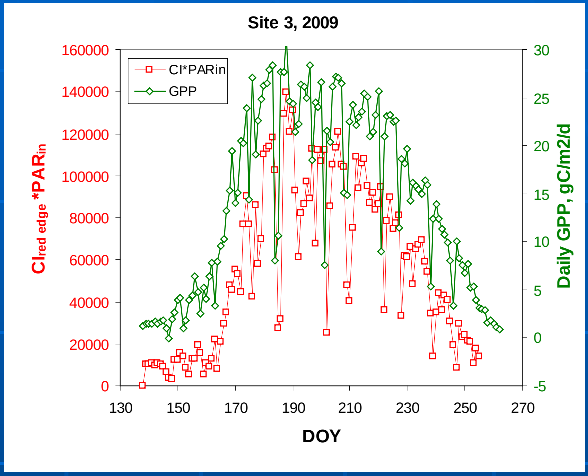


SKYE estimates of GPP

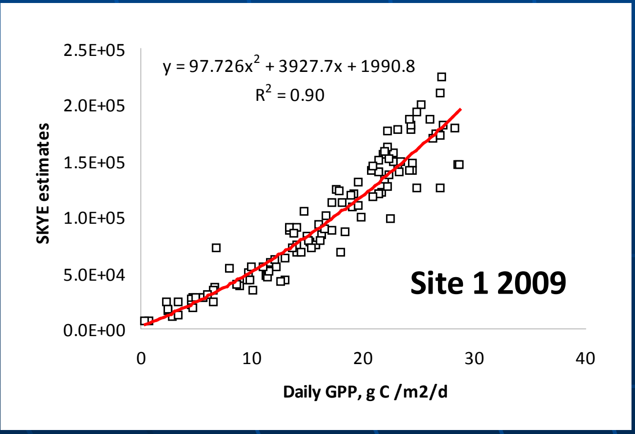
GPP & SKYE $CI_{red\ edge}$ vs. DOY

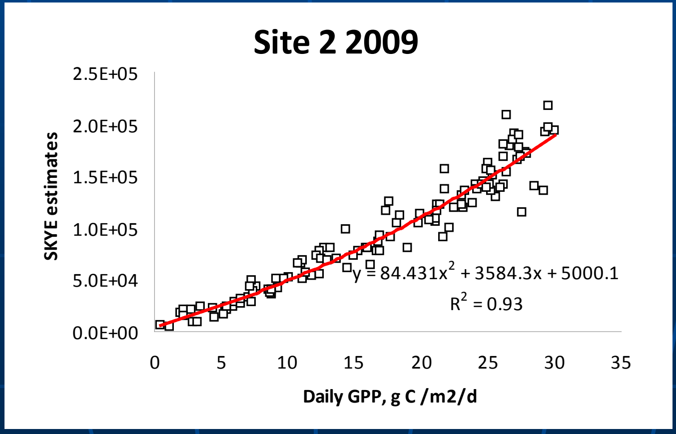


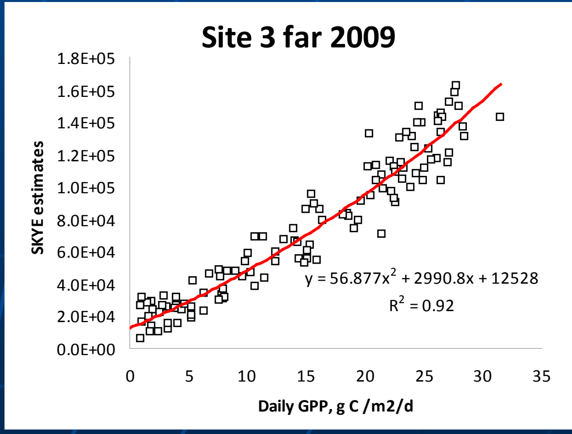




SKYE $CI_{red\ edge}$ vs. Maize GPP

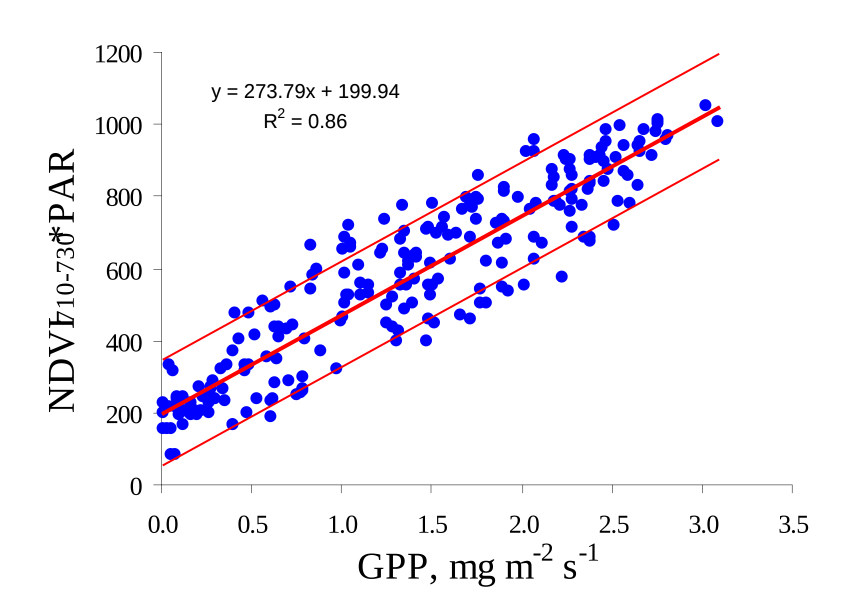


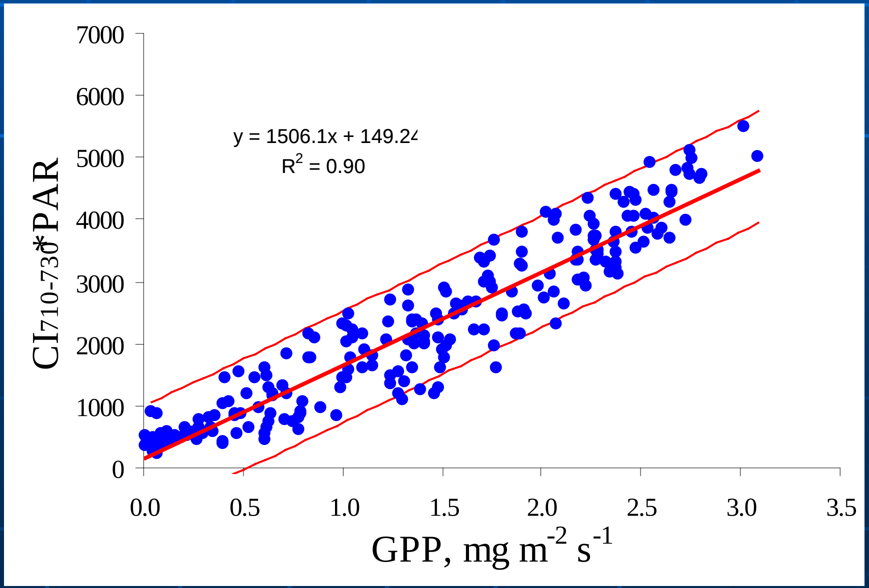




Species independent GPP estimation GPP vs. Red Edge NDVI and Chlorophyll Index

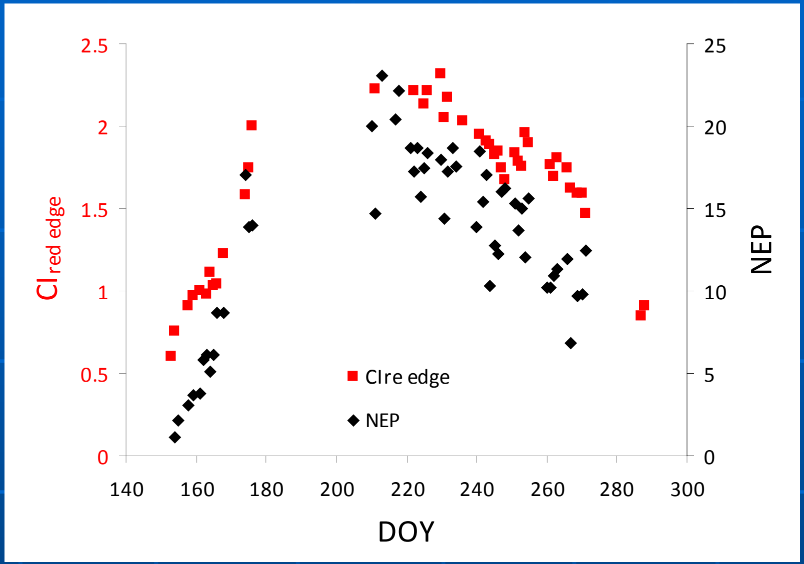
with red edge band 710-730 nm

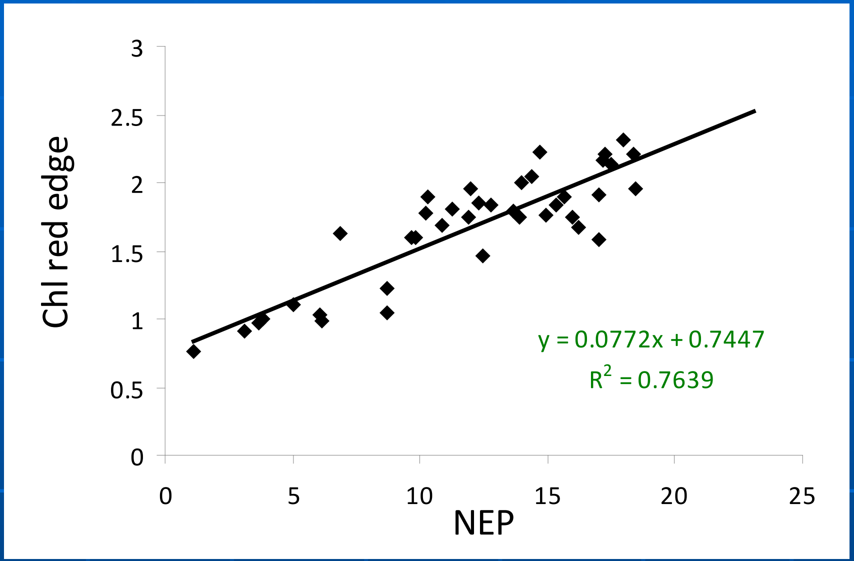


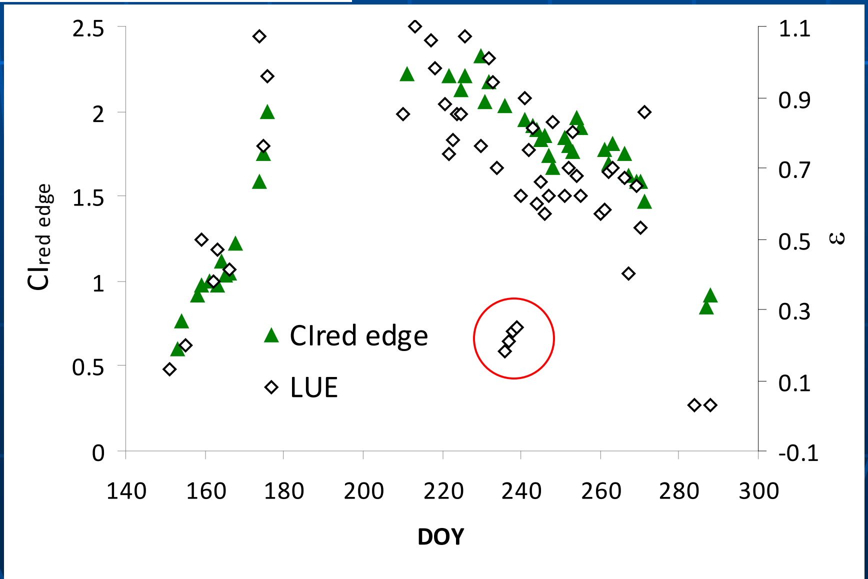


Chlorophyll vs. NEP and LUE

Southern Old Aspen, the southern ecotone of the western boreal forests, Canada







Hilker et al., 2010, submitted

Conclusions

- HyspIRI is unprecedented possibility to measure globally <u>spectrally, spatially and even temporally</u> pigment content and composition
    - in terrestrial vegetation
    - in inland and coastal waters (phytoplankton pigment concentrations)
- Pigment content and composition is a bridge between observations and models. It can be used for development of other HyspIRI products (e.g., LUE, GPP, LAI, $fAPAR_{green}$ among others)
- Main challenge is to calibrate and validate the products. To measure pigments analytically is labor intensive and time consuming. We developed reflectance-based techniques for pigment contents retrieval from radiometric data taken at leaf level and close range that can be used as ancillary data.

Thank you

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