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 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 deficiencies in nitrogen and phosphorus, wounding, pathogen infection, desiccation, low temperature, UV-irradiation etc. Anthocyanins fulfill important physiological functions by being involved in the adaptation to numerous stresses and environmental strain reduction.
Three-band model for pigment content estimation based on Kubelka-Munk remission function

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

$\rho_\infty$ is reflectance of an ideal layer, in which a further increase in thickness results in no noticeable difference, $\rho_o$ is reflectance measured against black background.

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

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

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.

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

Chlorophyll Index

\[
\text{CI} \propto \left[ \rho^{-1}(\lambda_1) - \rho^{-1}(\lambda_2) \right] \rho(\lambda_3)
\]

Gitelson et al., GRL, 2003, 2006

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

Gitelson et al., GRL, 2003
Only HyspIRI is able to **uniquely** provide it

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

**Chlorophyll-b Index**

\[ CI_{chl-b} \propto [\rho^{-1}(\lambda_1) - \rho^{-1}(\lambda_2)] \rho(\lambda_3) \]

\[ a_{chl-a} + a_{chl-b} \]

\[ a_{chl-a} \]

\[ b_b \]

\[ \text{Chl-b} \]

26 August, 2010

HyspIRI

\[ \text{Chl-b} \propto CI_{chl-b} = (\rho^{-1}_{650} - \rho^{-1}_{\text{red edge}}) \rho_{\text{NIR}} \]
Performance of different methods to assess chlorophyll

<table>
<thead>
<tr>
<th>Method</th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
<th>$\lambda_3$</th>
<th>Wavelength selection database</th>
<th>Relationship adjustment database</th>
<th>RMSE synthetic database (µg.cm$^{-2}$) N=2000</th>
<th>RMSE reduced database (µg.cm$^{-2}$) N=660</th>
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*Feret et al., 2010 submitted*
Only HyspIRI is able to uniquely provide it

\[ C_{\text{red edge}} \propto \left[ \left( \rho_{\text{red edge}} \right)^{-1} - \left( \rho_{\text{NIR}} \right)^{-1} \right] \rho_{\text{NIR}} \]

Leaf

Canopy

\[ C_{\text{ab}} \ (\mu g.cm^{-2}) \]

\[ C_{\text{red edge}} \]

\[ \text{Total Chlorophyll, g/m}^2 \]

Irrigated and rainfed maize, 2001-2003

\[ (R_{\text{NIR}}/R_{\text{red edge}})^{-1} \& (R_{\text{NIR}}/R_{\text{green}})^{-1} \]

Green and NIR bands

\[ R^2 = 0.9185 \]

\[ R^2 = 0.9173 \]

Red Edge and NIR

Feret et al., RSE, 2009

Gitelson et al., GRL, 2005
Only HyspIRI is able to **uniquely** provide it

\[ C_{\text{red edge}} \propto \left[ \left( \rho_{\text{red edge}} \right)^{-1} - \left( \rho_{\text{NIR}} \right)^{-1} \right] \rho_{\text{NIR}} \]

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

\[ y = 0.0917x - 0.0738 \quad R^2 = 0.82 \]

\[ y = 0.0025x + 0.5192 \quad R^2 = 0.90 \]

Hyperion
Maize in China

Hilker et al., 2010, submitted
Wu et al., IJRS, 2010
Carotenoids content estimation
\[ \rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_{0}(\lambda) + b_{b}] / b_{b} \]

\[ \text{Carotenoids Reflectance Index} \]

\[ \text{CRI} \propto [\rho^{-1}(\lambda_{1}) - \rho^{-1}(\lambda_{2})] / \rho(\lambda_{3}) \]

Carotenoids Reflectance Index

\[ \text{Car} \propto \text{CRI} = \left( \rho^{-1}_{515} - \rho^{-1}_{\text{red edge}} \right) \rho_{\text{NIR}} \]

Gitelson et al., 2002
Carotenoids content estimation

Only HyspIRI is able to uniquely provide it

The Douglas-fir stand, Canada

Carotenoids Content, mg/m²

\[ y = 0.9129x + 0.4422 \]

\[ R^2 = 0.8488 \]

Gitelson et al., 2002

Hilker et al., 2010, submitted
Anthocyanins content estimation
\[ \rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b] / b_b \]

**Anthocyanin Reflectance Index**

\[ \text{ARI}_{\text{red edge}} \propto [\rho^{-1}(\lambda_1) - \rho^{-1}(\lambda_2)] \rho(\lambda_3) \]

\[ \text{Anth} \propto \text{ARI} = (\rho^{-1}_{550} - \rho^{-1}_{\text{red edge}}) \rho_{\text{NIR}} \]

*Only HyspIRI is able to uniquely provide it*

Map of reflectance at different wavelengths.

**Anthocyanin absorption, per cent**

*Gitelson et al., 2009*

*Gitelson et al., 2001*
Anthocyanins content estimation

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: $\text{ARI} = (\rho^{-1}_{550} - \rho^{-1}_{710}) \times \rho_{800}$
Tree delineation based on Anthocyanin Reflectance Index

Only HyspIRI is able to **uniquely** provide it

**Courtesy**: Jose A. Jimenez Berni, CSIRO
Relevance to carbon cycle science and climate science
GPP $\propto f\text{APAR}_\text{green} \times \text{PAR} \times \text{LUE}$

Chlorophyll

$f\text{APAR}_\text{green}$ depends on amount of chlorophyll

chlorophyll is an indicator of efficiency of using fAPAR for photosynthesis

GPP = Chl$\times$LUE$\times$PAR

1. Production Efficiency Models
Chlorophyll is an indicator of efficiency of using fAPAR for photosynthesis.

\[ \text{GPP} \propto \text{LAI} \times \text{LUE} \times \text{PAR} \]

Green LAI

Relates closely to \textit{chlorophyll}

\textit{Chlorophyll} is objective characteristic of plant greenness

\[ \text{GLAI} = -0.0059 \text{Chl}^4 + 0.0193 \text{Chl}^3 - 0.3405 \text{Chl}^2 + 2.8829 \text{Chl} + 0.205 \]

\[ R^2 = 0.9622 \]

LUE

\textit{chlorophyll} is an indicator of efficiency of using fAPAR for photosynthesis

\[ y = 0.0002x + 0.0011 \]

\[ R^2 = 0.42 \]
Diagnosis of Maize N Status

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

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

Walters, 2003
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

Site 1 2009

Site 2 2009

Site 3 far 2009

y = 97.726x^2 + 3927.7x + 1990.8
R^2 = 0.90

y = 84.431x^2 + 3584.3x + 5000.1
R^2 = 0.93

y = 56.877x^2 + 2990.8x + 12528
R^2 = 0.92
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

\[ y = 0.0772x + 0.7447 \]

\[ R^2 = 0.7639 \]

Hilker et al., 2010, submitted
Conclusions

- HyspIRI is unprecedented possibility to measure globally spectrally, spatially and even temporally 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\textsubscript{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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