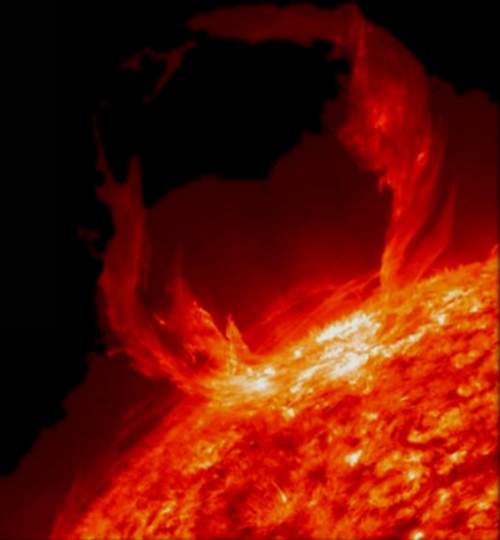
USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

# Combining observations in the reflective solar and thermal infrared domains to improve carbon, water and energy flux estimation

***Rasmus Houborg and Martha Anderson***



HyspIRI Science Symposium on Ecosystem Data Products (NASA GSFC May 4, 2010)

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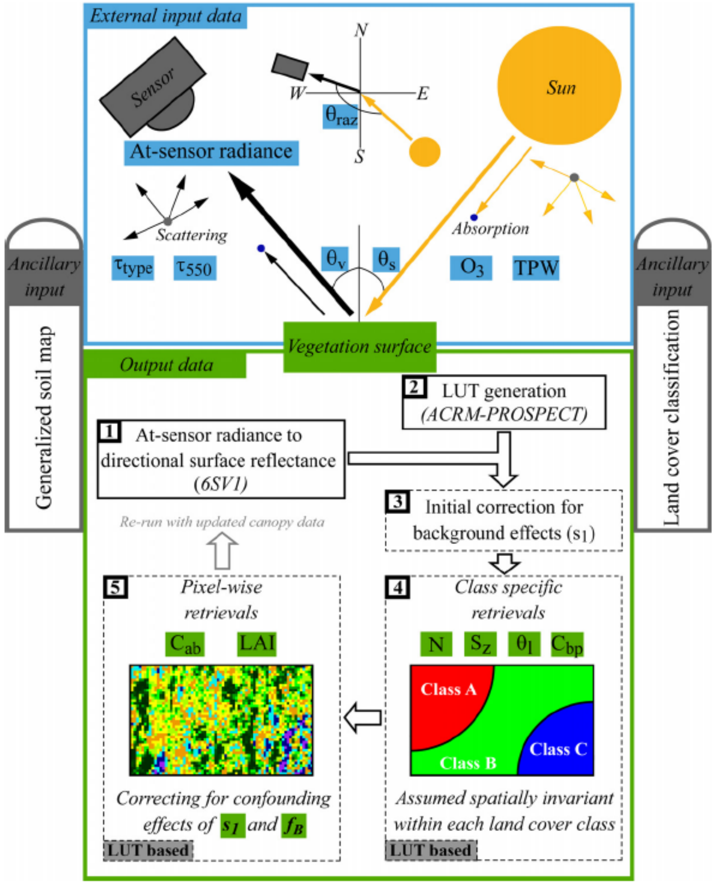
# Product description

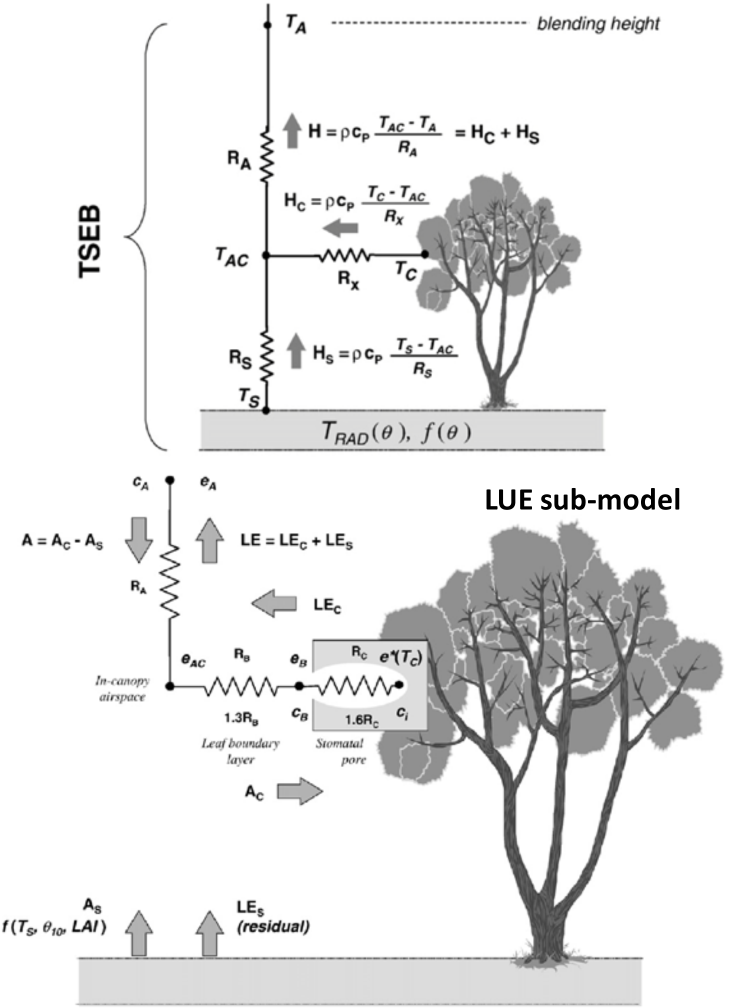
## REGFLEC (VNIR)



**LAI, $C_{ab}$, $f_B$**

$LUE_n$=f($C_{ab}$)

## TSEB-LUE (TIR)



# Why do we need HyspIRI?

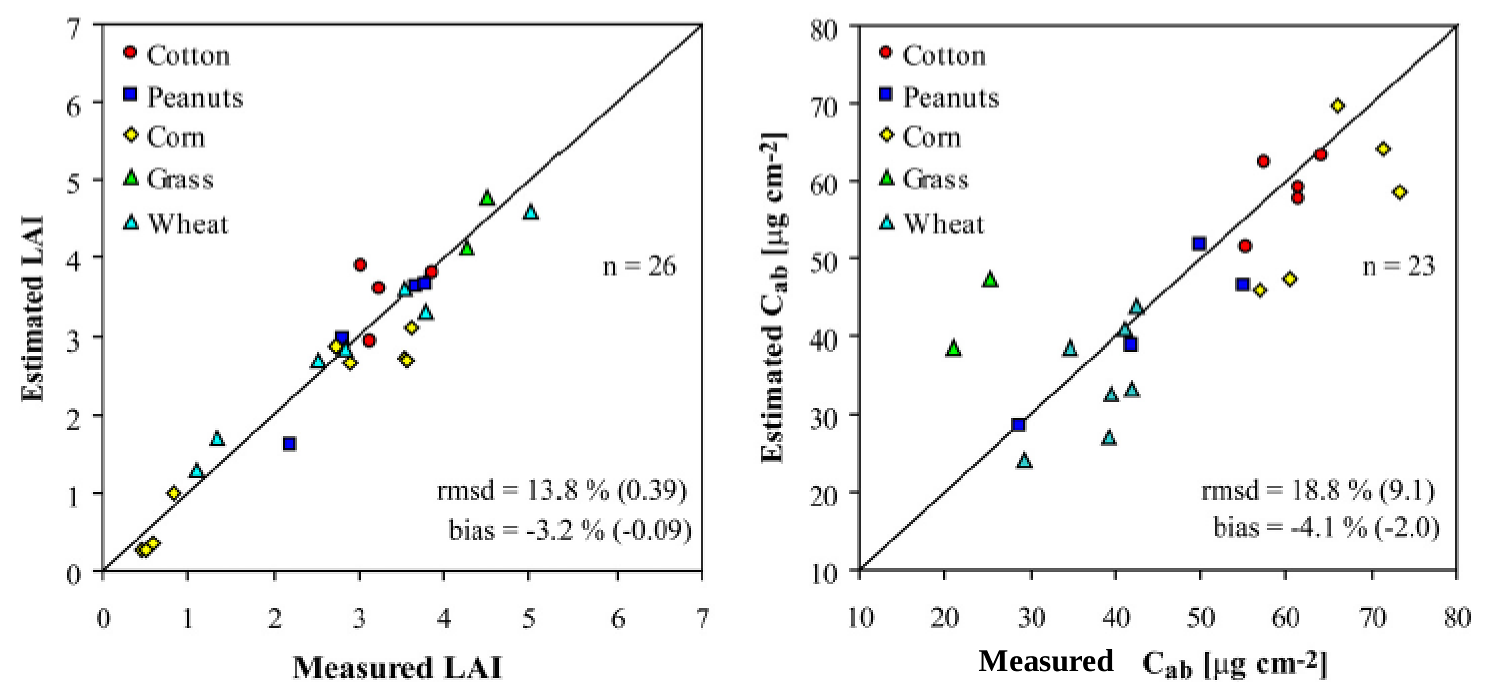
- ❖ Only HyspIRI will have the capability to simultaneously acquire observations in the reflective solar and thermal regions of the spectrum required as input to REGFLEC – TSEB-LUE
- ❖ HyspIRI will allow us to efficiently exploit the synergy between TIR and shortwave reflective wavebands for producing valuable remote sensing data for monitoring of carbon and water fluxes
- ❖ The integration of hyperspectral reflective measurements is likely to expand the utility of REGFLEC for high fidelity LAI and Cab retrievals, as the HyspIRI data will allow identification of shortwave bands and indices with optimized sensitivity to changes in leaf chlorophyll (e.g. PRI)

# Relevance

- Accurate means for mapping surface fluxes at fine spatial scales (<100m) are critically important to local water resource and agricultural management
- Carbon fluxes are particularly valuable for monitoring vegetation productivity and for studying carbon cycle functioning in response to changes in environmental and physiological controls and a changing climate
- Leaf chlorophyll is being increasingly recognized as a key for quantifying photosynthetic efficiency and gross primary production of terrestrial vegetation
- Thermal-based LSMs are well suited for mapping instantaneous fluxes down to 1 m resolution, as TIR data provide valuable information about the sub-surface moisture status, obviating the need for precipitation input and prognostic modeling of soil transport processes.

# Mapping vegetation parameters

| Sensor | Vegetation | N | | LAI | | Cab | |
|---|---|---|---|---|---|---|---|
| | | LAI | Cab | RMSD | Bias | RMSD | Bias |
| SPOT 20m *(OK, U.S.)* | Cotton/peanuts/corn/grass/wheat | 26 | 23 | 14% (0.39) | -3.2% (-0.09) | 19% (9.1) | -4.1% (-2.0) |
| SPOT 10m *(MD, US)* | Soybean/grass/corn/alfalfa | 47 | 41 | 13% (0.40) | -0.9% (-0.03) | 11% (4.9) | -0.1% (-0.02) |
| Aircraft 1m *(MD, US)* | Corn | 31 | 31 | 10% (0.25) | 0.5% (0.01) | 10% (4.4) | -2.2% (-0.9) |
| SPOT 20m *(Denmark)* | Maize/barley/wheat | 19 | 26 | 19% (0.74) | -9.0% (-0.40) | 10% (5.3) | -0.2% (-0.08) |
| MODIS 250m *(DK)* | Barley/wheat | 48 | - | 20% (0.54) | 9.0% (0.24) | - | - |
| | Forest | 19 | - | 18% (0.63) | -15% (-0.52) | - | - |



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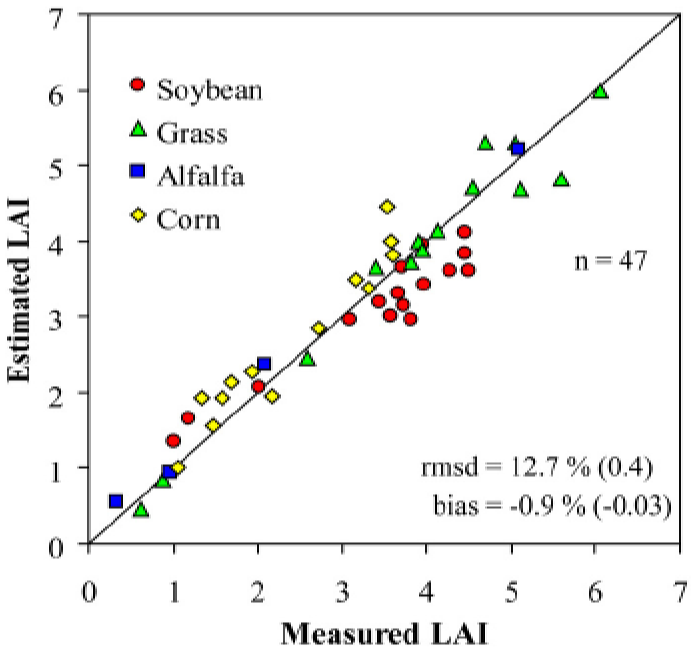

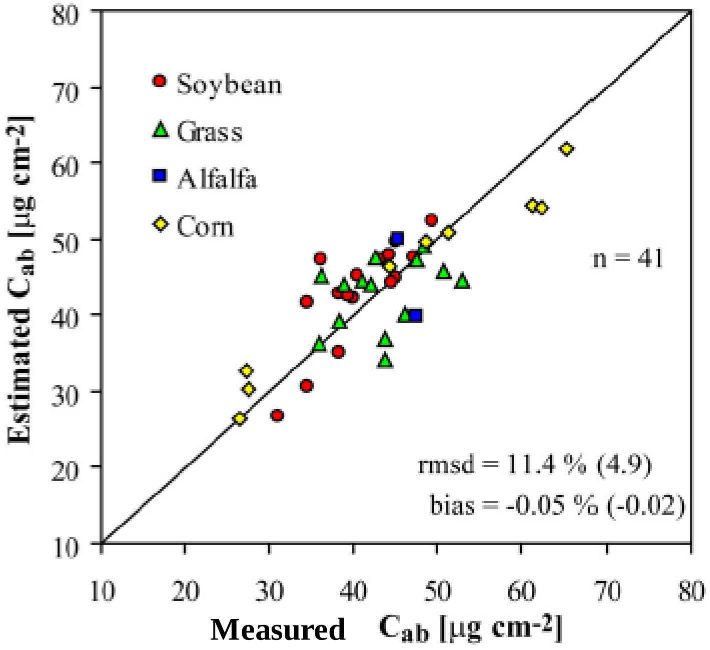

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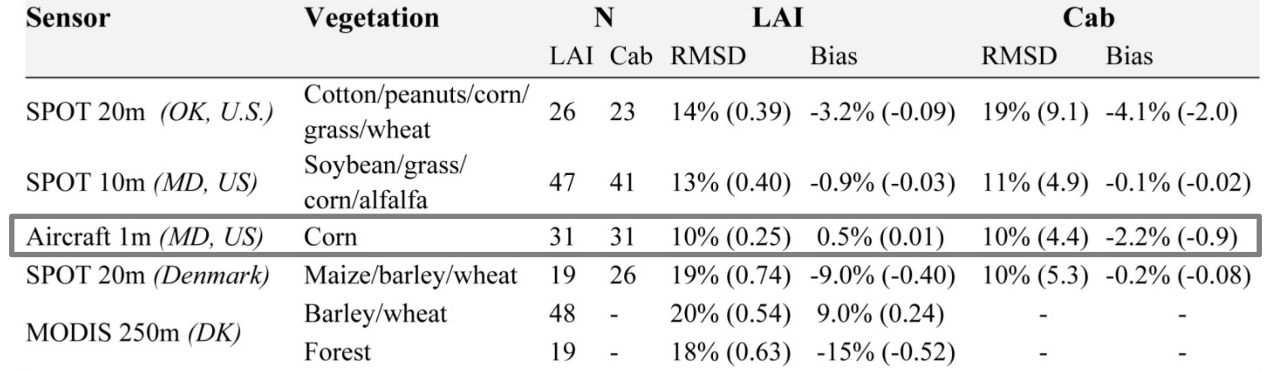

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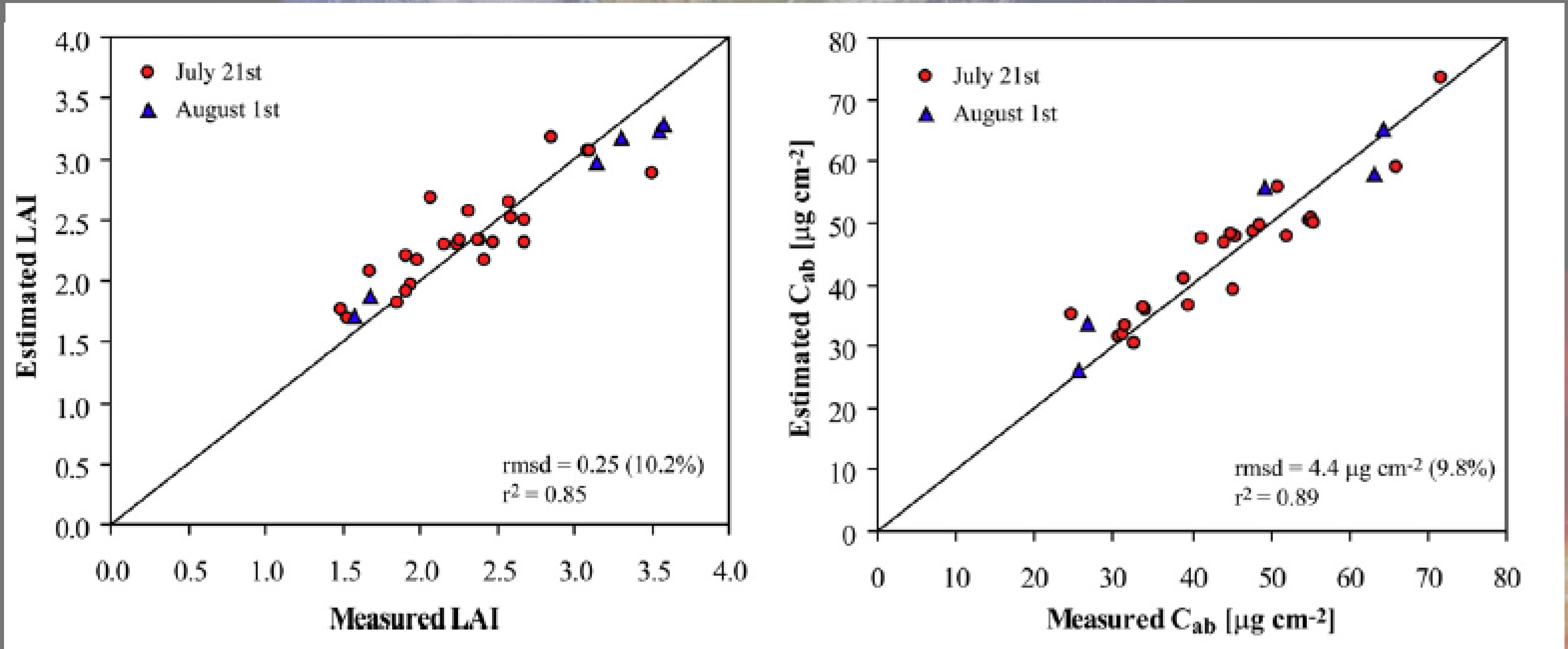

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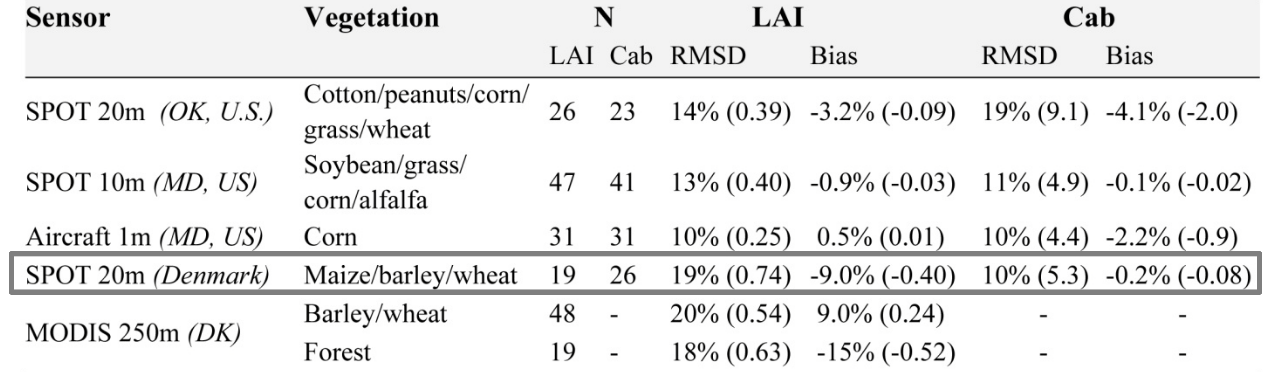

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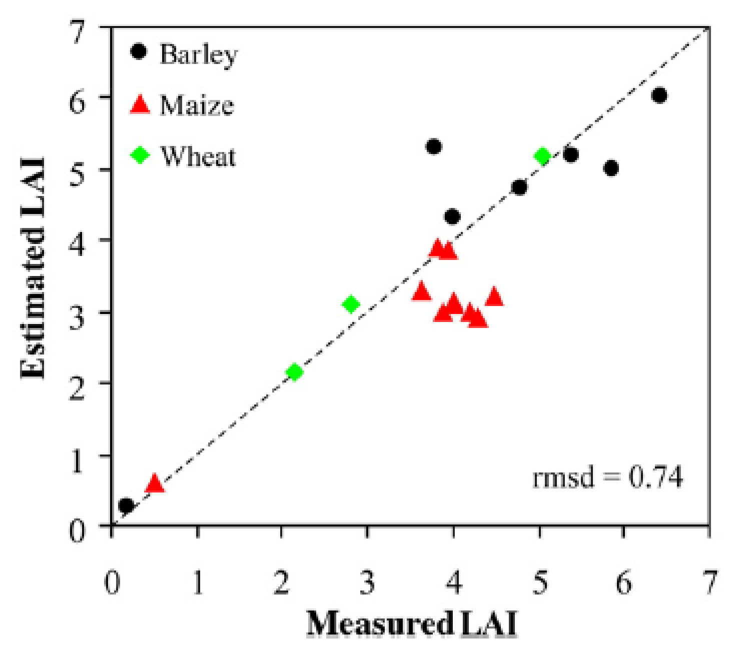

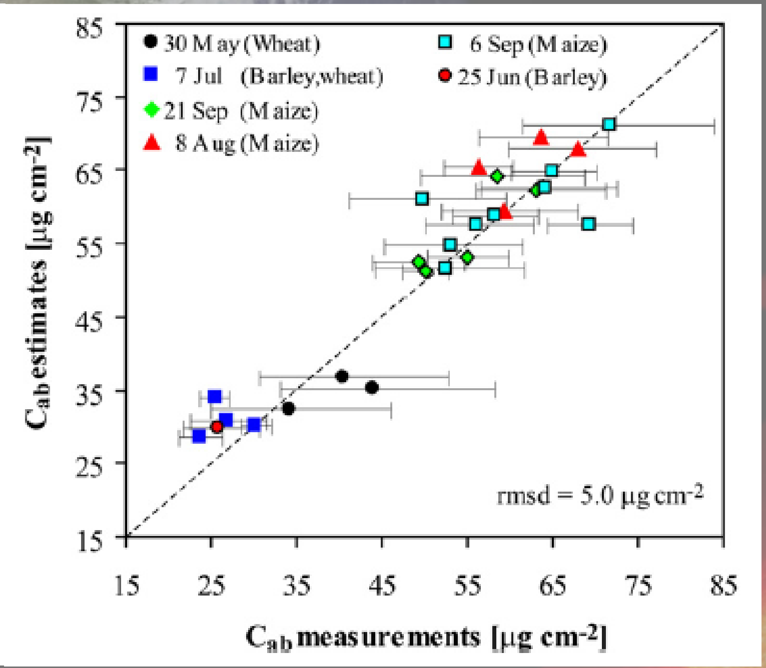

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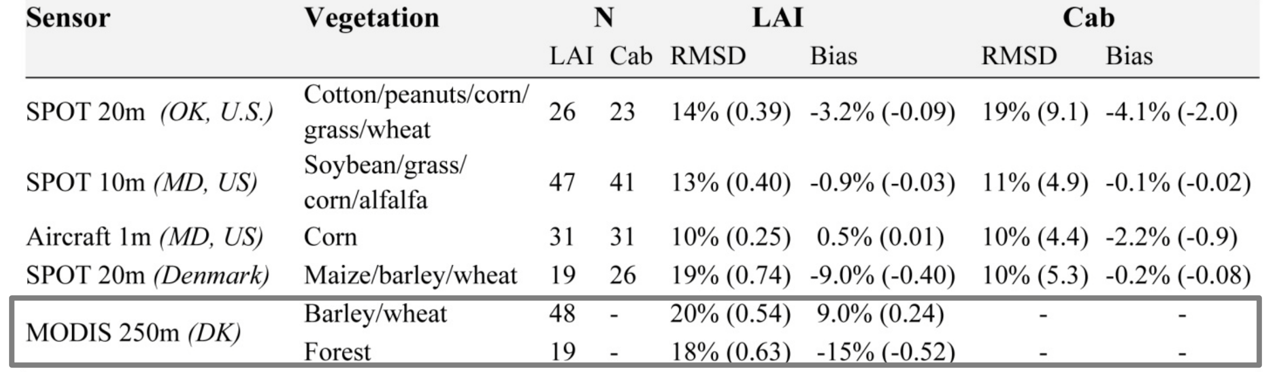

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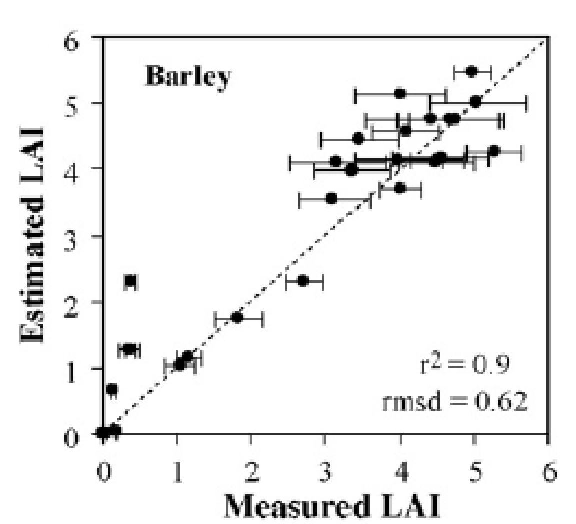
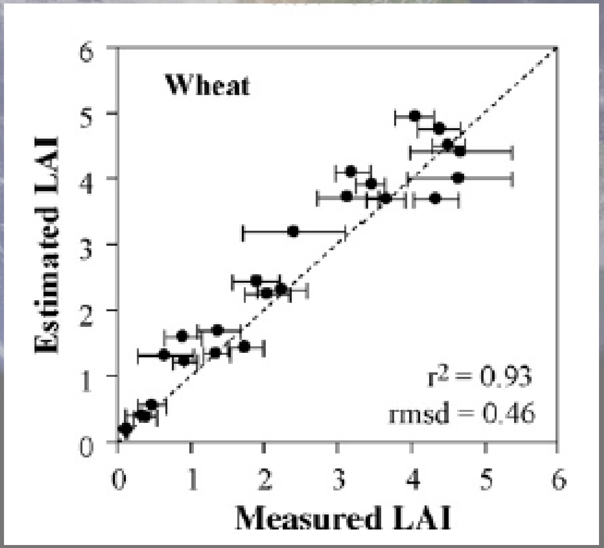
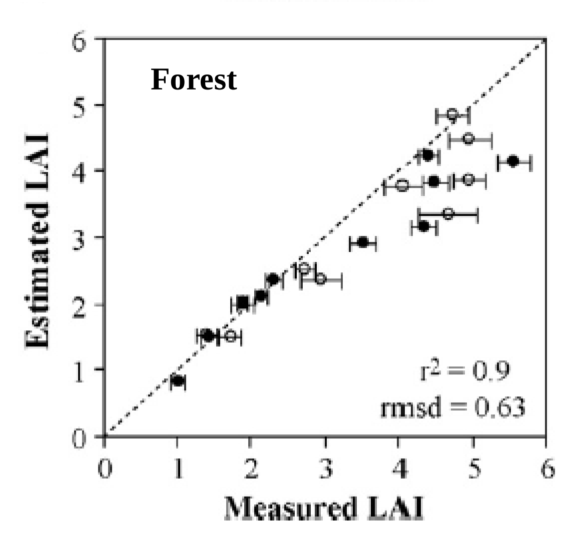
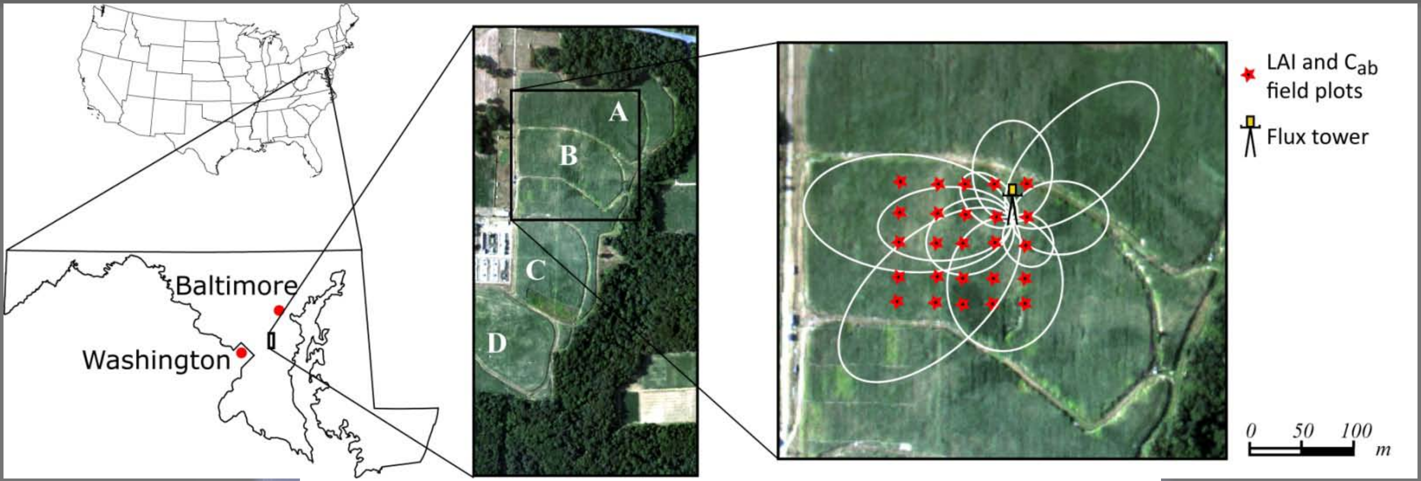
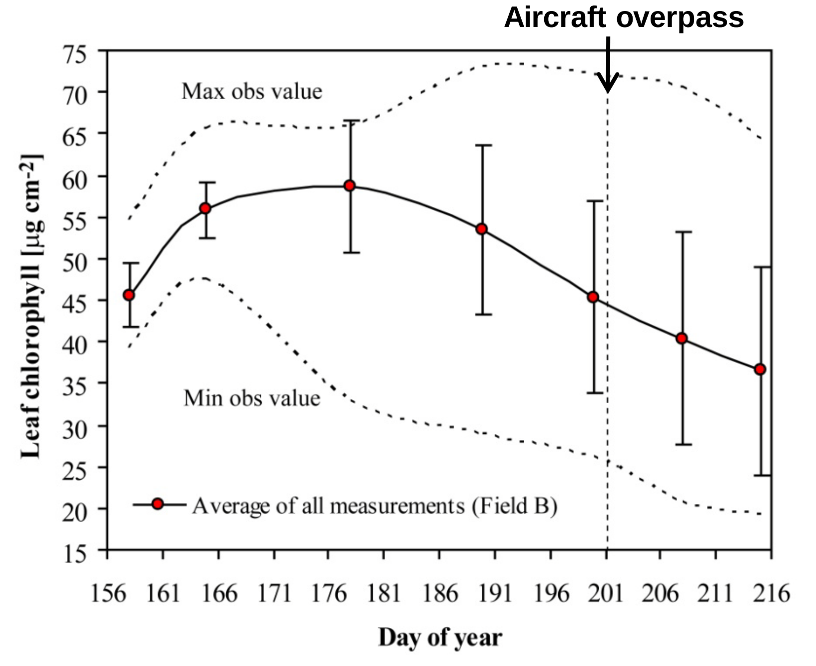






# LUE – Leaf chlorophyll inter-correlation





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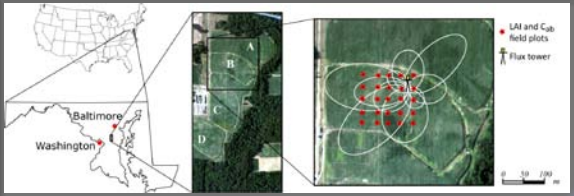

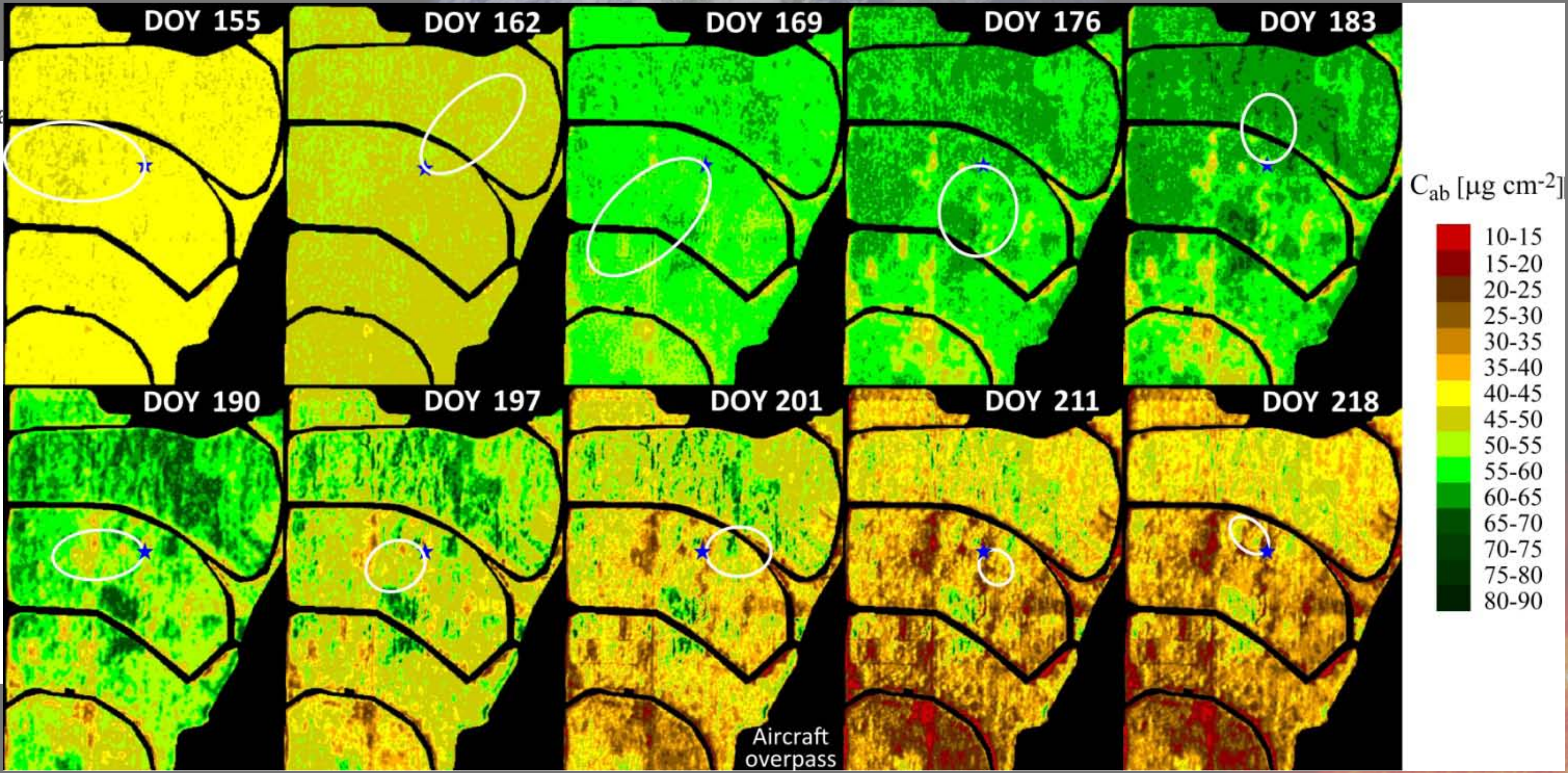

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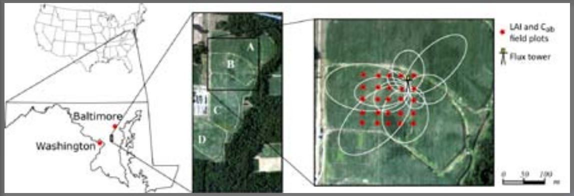


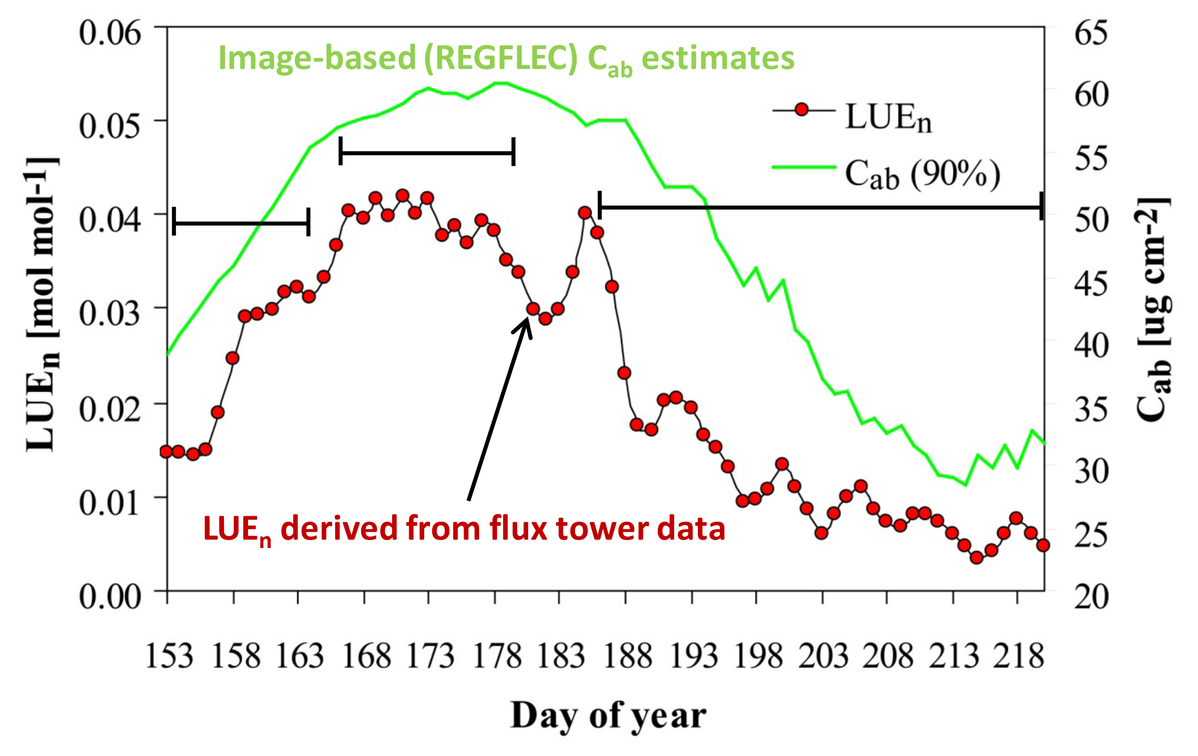
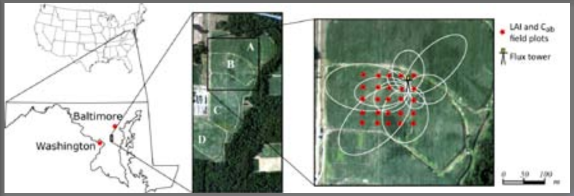
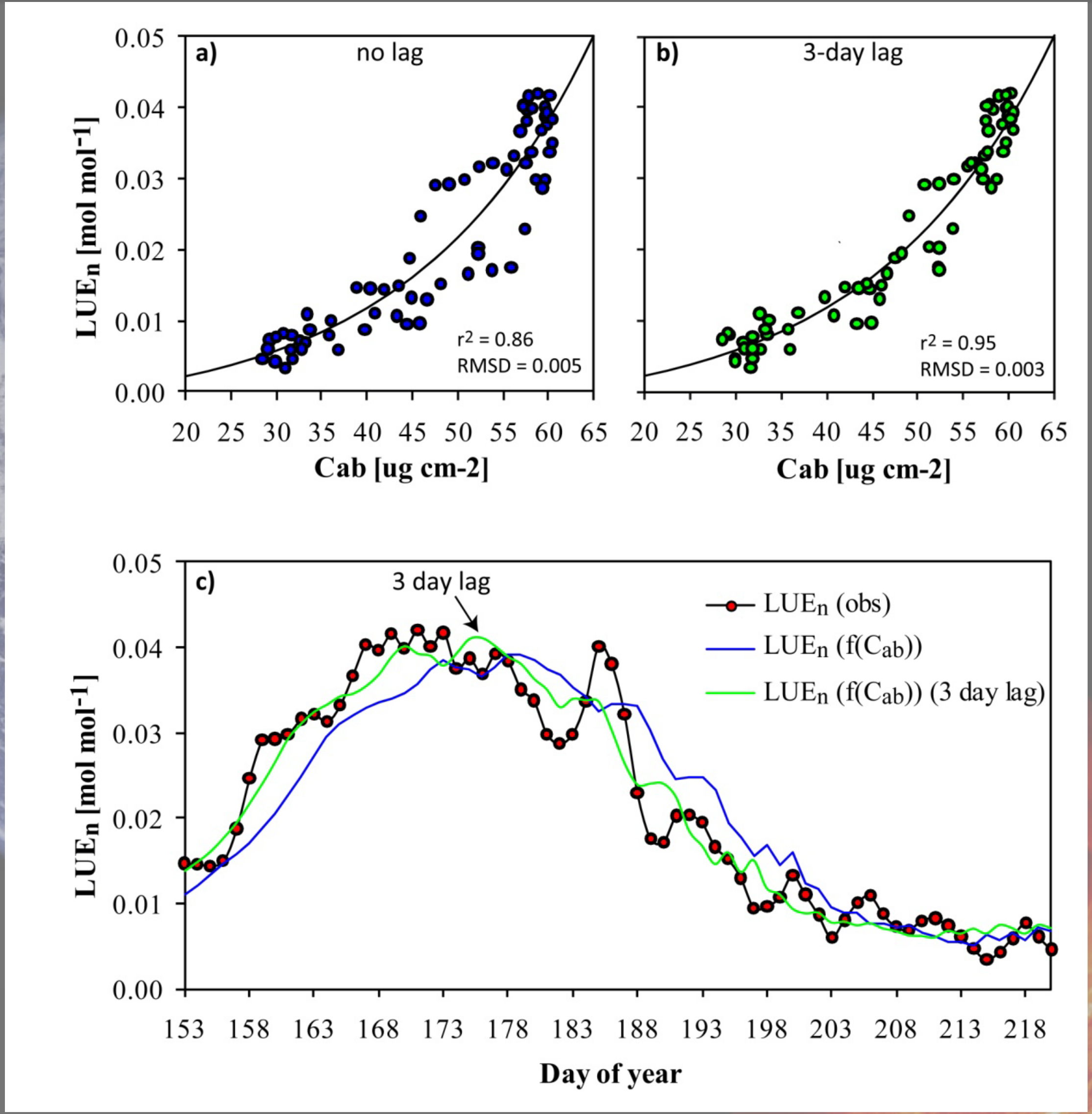


Image-based (REGFLEC) $C_{ab}$ estimates

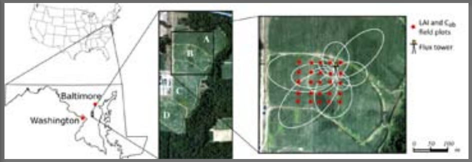
$LUE_n$ derived from flux tower data

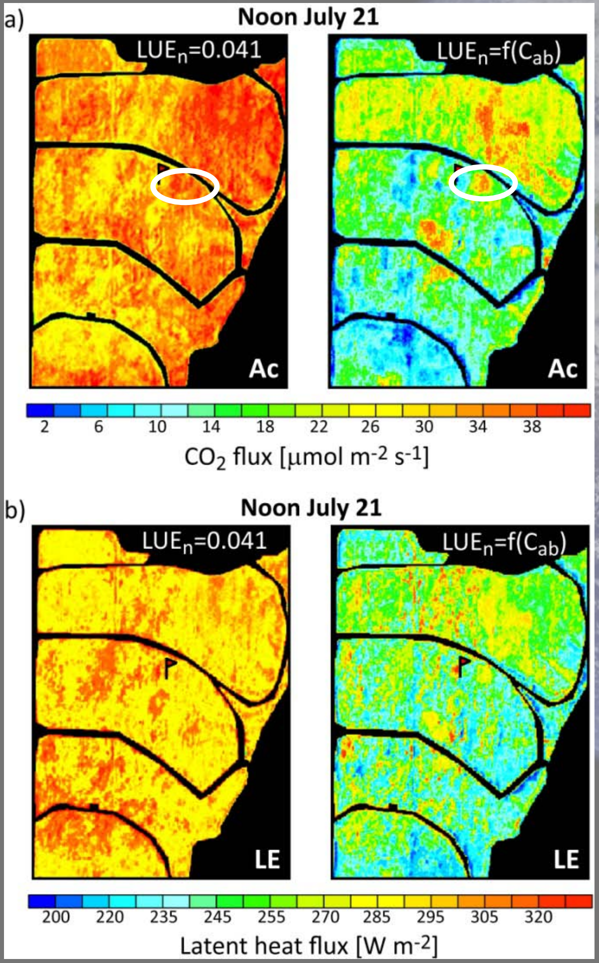
# LUE – Leaf chlorophyll inter-correlation

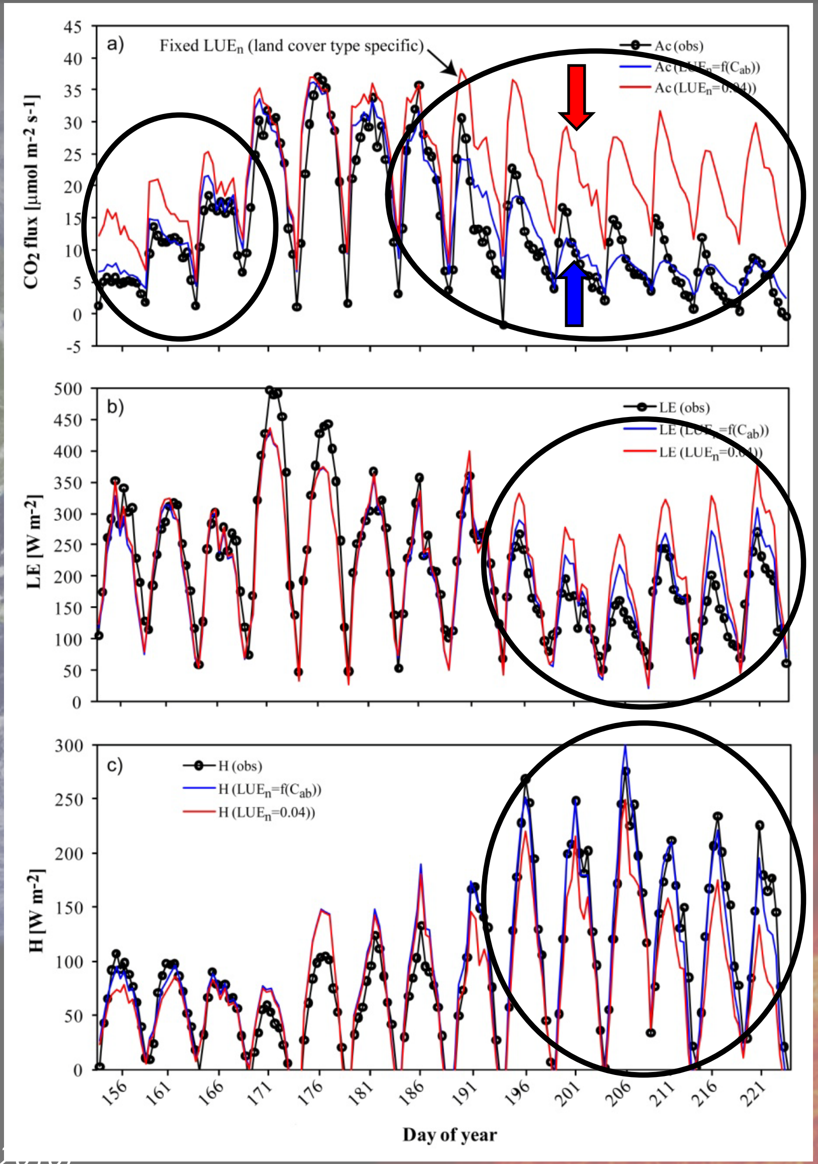




# Thermal-based flux mapping







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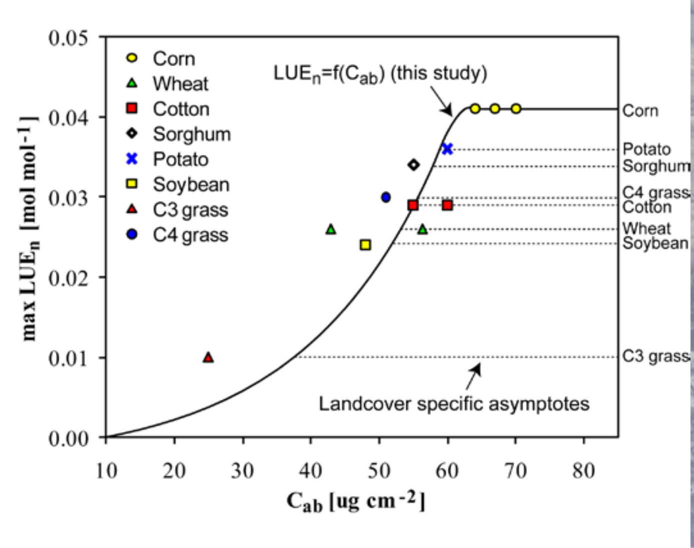
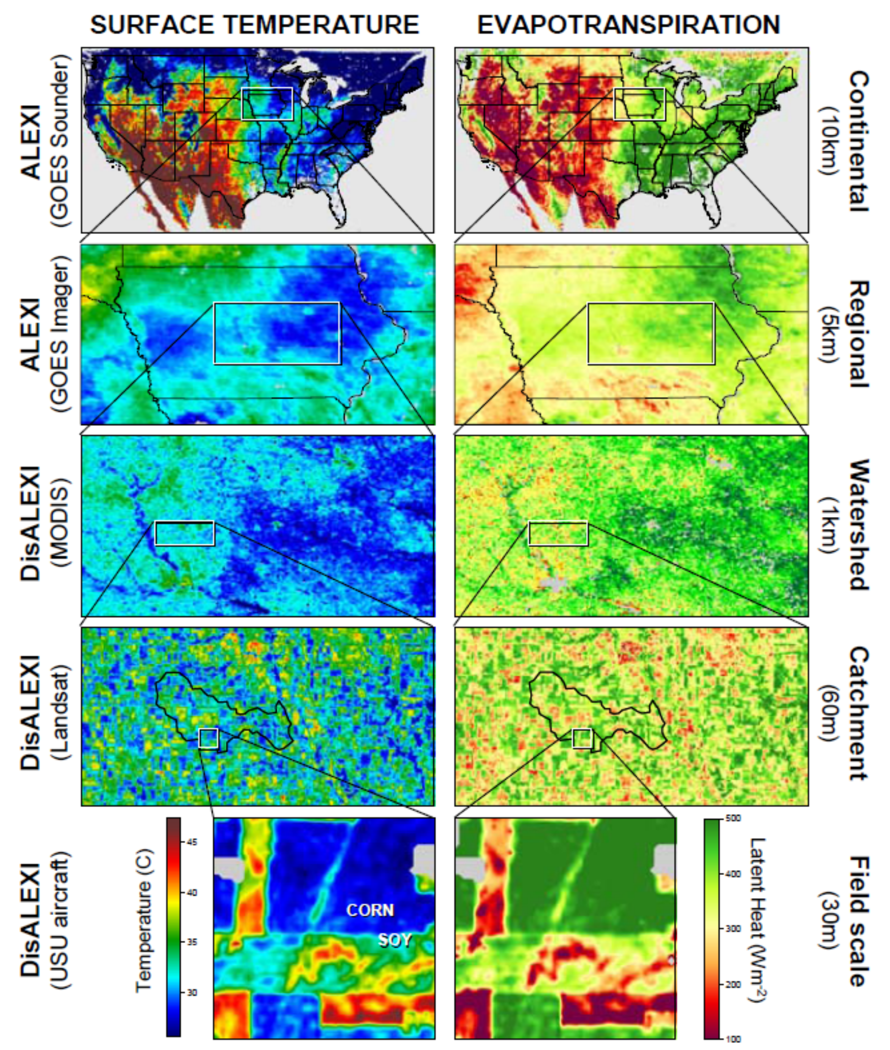
# Thermal-based flux mapping

## Application to other regions





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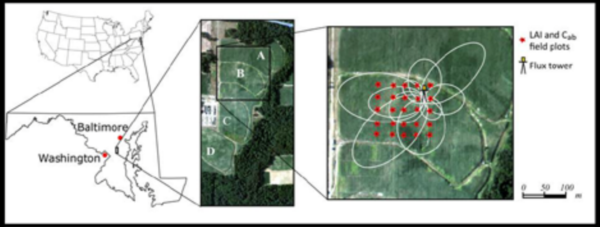
# Combining observations in the reflective solar and thermal domains for improved carbon and energy flux estimation

Rasmus Houborg[1,3], Martha Anderson[2], W. P. Kustas[2]

[1] Earth System Science Interdisciplinary Center, University of Maryland, College Park
[2] USDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD
[3] Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, MD (contact: rasmus.houborg@nasa.gov)

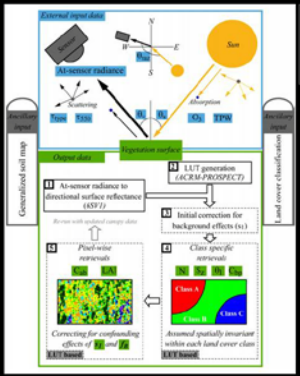
Chlorophylls absorb photosynthetically active radiation and thus function as vital pigments for photosynthesis, which makes leaf chlorophyll content ($C_{ab}$) useful for monitoring vegetation productivity and an important indicator of the overall plant physiological condition. This study investigates the utility of integrating remotely sensed estimates of $C_{ab}$ into a thermal-based Two-Source Energy Balance (TSEB) model that estimates land-surface CO2 and energy fluxes using an analytical, light-use-efficiency (LUE) based model of canopy resistance. The LUE model component incorporates LUE modifications from a nominal (species-dependent) value ($LUE_n$) in response to short-term variations in environmental conditions. However $LUE_n$ may need adjustment on a daily timescale to accommodate changes in physiological condition and nutrient status. Day to day variations in $LUE_n$ were assessed for a heterogeneous corn crop field in Maryland, U.S.A. through model calibration with eddy covariance $CO_2$ flux tower observations. The optimized daily $LUE_n$ values were then compared to estimates of $C_{ab}$ integrated from gridded maps of chlorophyll content weighted over the tower flux source area. The time-continuous maps of daily $C_{ab}$ over the study field were generated by fusing in-situ measurements with retrievals generated with an integrated radiative transfer modeling tool (accurate to within ±10%) using at-sensor radiances in green, red and near-infrared wavelengths acquired with an aircraft imaging system. The resultant daily changes in $C_{ab}$ within the tower flux source area generally correlated well with corresponding changes in daily calibrated $LUE_n$ values derived from the tower flux data, and hourly water, energy and carbon flux estimation accuracies from TSEB were significantly improved when using $C_{ab}$ for delineating spatio-temporal variations in $LUE_n$. The results demonstrate the synergy between thermal infrared and shortwave reflective wavebands in producing valuable remote sensing data for operational monitoring of carbon and water fluxes.

## STUDY SITE

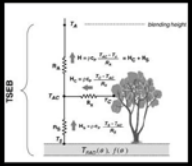


Natural color aircraft imagery mosaic (1 m resolution) of the OPE3 corn field (labeled B) study site in Maryland with a blowup of the area in immediate vicinity of the flux tower. Locations of LAI and leaf chlorophyll ($C_{ab}$) sampling sites are indicated by the red stars. 90% source areas of the flux tower CO2 fluxes at the time of midday are depicted for a collection of days.

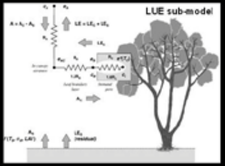
## MODELS



Schematic diagram of the coupled 6SV1 - ACRM - PROSPECT REGularized canopy reFLECtance (REGFLEC) modeling tool. REGFLEC is an automatic and image-based methodology that facilitates direct use of at-sensor radiance observations in green, red and near-infrared wavebands for the retrieval of vegetation parameters. Input requirements are sparse and the integrated modeling system requires no calibration and may be run for any locality with availability of standard atmospheric state data, a land cover classification and soil map

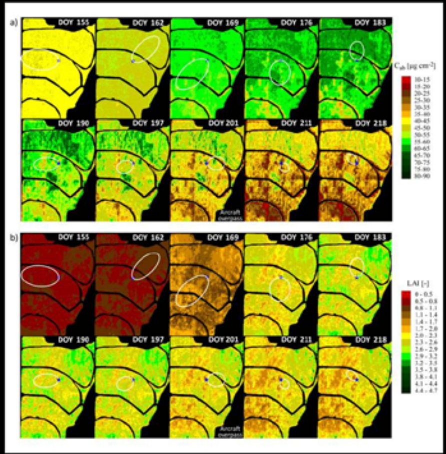


Thermal-based Two-Source Energy Balance (TSEB) modeling scheme. The thermal data ($T_{rad}$) provide valuable information about the sub-surface moisture status, obviating the need for precipitation input data and prognostic modeling of the soil water balance.

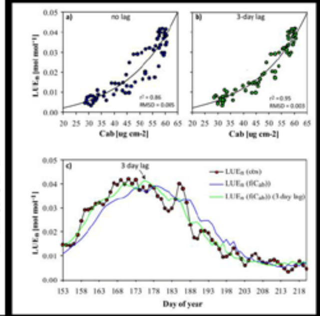


LUE-based canopy resistance method for computing coupled carbon and water fluxes within the TSEB framework. LUE is modified from a nominal value ($LUE_n$) in response to variations in humidity, $CO_2$ concentration, temperature, wind speed, and fraction of diffuse radiation.

## VEGETATION MAPS AND LUE-Cab INTERCORRELATION



Weekly maps of leaf chlorophyll ($C_{ab}$) (a) and LAI (b) generated by fusing in-situ measurements in vicinity of the flux tower with image-based (REGFLEC) retrievals derived using reflectances acquired from aircraft on doy 201. The fusion approach assumes that (1) the relative temporal evolution of LAI and $C_{ab}$ at any point within the field follows the temporal characteristic at one of the in-situ sampling sites, and (2) spatial pattern anomalies of LAI and $C_{ab}$ present during the aircraft acquisition are preserved. Daily averaged source areas (90%) of the flux tower $CO_2$ fluxes are overlain.

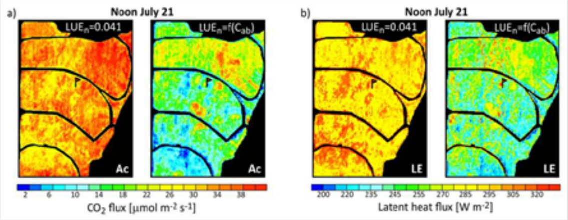


Scatter plots of model calibrated $LUE_n$ and footprint averaged leaf chlorophyll content and associated exponential fits with (a) and without (b) a 3-day lag applied to the leaf chlorophyll timeseries record. c) Timeseries intercomparison plot of model calibrated $LUE_n$ and $LUE_n$ estimated as exponential functions of $C_{ab}$. The improved agreement with the lagged $C_{ab}$ estimates suggest that short-term environmental stresses are not immediately manifested in the $C_{ab}$ record.

## CONCLUSIONS

- ➢ An integrated radiative transfer modeling tool (REGFLEC) facilitated accurate retrieval of leaf chlorophyll ($C_{ab}$) and LAI from remote spectral observations in the visible domain
- ➢ The spatio-temporal $C_{ab}$ record was highly correlated with variations in nominal light-use-efficiency, and thus proved useful for optimizing flux estimates by a thermal-based Two-Source Energy Balance (TSEB) model that implements a LUE-based model of canopy resistance
- ➢ The symphony of $LUE_n$ (that varied seasonally as a function of $C_{ab}$) and thermal input data provided accurate flux retrievals for a 'difficult' site characterized by highly variable degrees of plant stress
- ➢ The results demonstrate utility in combining observations in the reflective solar and thermal domains for estimating carbon, water and heat fluxes within a coupled framework

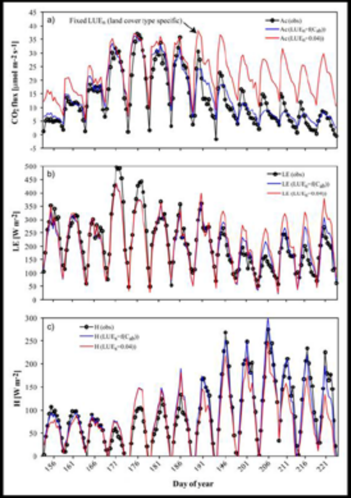
## FLUX MAPPING



Maps of $CO_2$ flux (a) and latent heat flux (b) at the time of the aircraft overpass comparing TSEB_LUE (Two-Source Energy Balance model implementing a Light-Use-Efficiency based model of canopy resistance) output from runs using nominal LUE parameterized as a function of remotely sensed leaf chlorophyll ($C_{ab}$) (right panels) and runs assuming a fixed value for the entire field (left panels). Evidently, the use of spatially variable values of $LUE_n$, retrieved from remote sensing estimates of $C_{ab}$, has a pronounced effect on simulated fluxes.

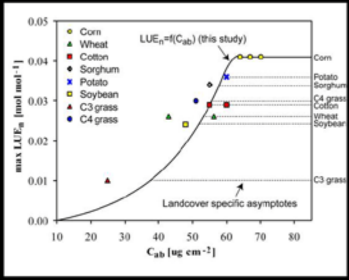
## FLUX VALIDATION

Comparison of hourly eddy covariance flux observations with model estimates of $CO_2$ (a), latent heat (b) and sensible heat (c) fluxes generated with the TSEB_LUE using a fixed $LUE_n$ and a $LUE_n$ that varied seasonally as a function of leaf chlorophyll. Each diurnal segment represents flux data averaged by hour over 5-day intervals. Consideration of temporal changes in $LUE_n$ (as dictated by variations in $C_{ab}$) improves the accuracy of simulations of carbon uptake by the corn field, particularly during leaf expansion and development (doy 156 - 171) and late stages of leaf maturity and leaf senescence (> doy 191), where observed fluxes otherwise would be vastly overestimated. While performance improvements are less pronounced for latent and sensible heat fluxes, the results do promote photosynthetic capacity (i.e. $LUE_n$) as a key control on also water and energy fluxes.



The coupled REGFLEC – TSEB_LUE modeling system described here demonstrates the synergy between TIR and shortwave reflective wavebands in producing valuable remote sensing data for operational monitoring of carbon and water fluxes. The ALEXI/DisALEXI modeling suite (based on TSEB) facilitates scalable flux mapping using thermal imagery from a combination of geostationary and polar orbiting satellites, zooming in from the national scale to sites of specific interest. We are currently working toward a full integration of the functional link between LUE and leaf chlorophyll within ALEXI/DisALEXI to improve thermal-based flux mapping activities at field to regional scales. New missions with high-resolution (sub-field scale, <100m) TIR and shortwave imaging capabilities, such as LDCM (Landsat Data Continuity Mission) and HyspIRI, will enable a continuation of these flux mapping activities at field to regional scales.

## APPLICATION TO OTHER REGIONS



In-situ measurements of maximum leaf chlorophyll ($C_{ab}$) from various land cover types plotted against land cover specific maximum nominal LUE ($LUE_n$) compiled from a survey of literature values. The exponential $LUE_n$ - $C_{ab}$ relationship for corn derived in this study is shown with an asymptotic behavior above the max $LUE_n$ (0.041). Points representative of other land cover types tend to fall in close proximity to this relationship that may be valid for these cover types also as long as the upper asymptote is adjusted to correspond to the maximum $LUE_n$ for the given land cover type (dashed lines).

## MULTI-SCALE FLUX MAPPING