Satellite Optical Remote Sensing of Ecosystem Function and Productivity

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Introduction

Global products have to be produced to meet the SBG science goals

from Table 8.1 of the 2017 Decadal Survey:

E-1 STRUCTURE, FUNCTION, AND BIODIVERSITY: What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? (Function is the physiology and underpinning of biophysical and biogeochemical properties of terrestrial vegetation and shallow aquatic vegetation.)

E-3 FLUXES: What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing?

Light Use Efficiency (LUE, ε) is a key descriptor of ecosystem function and helps determine ecosystem carbon fluxes

LUE can be derived from flux tower data as:

$$\varepsilon = GEP/(f_{APAR}\ PAR_{in})$$

Where:

GEP is the gross ecosystem production (calculated from tower data)

PAR_{in} is the incident Photosynthetically Active Radiation (measured at tower)

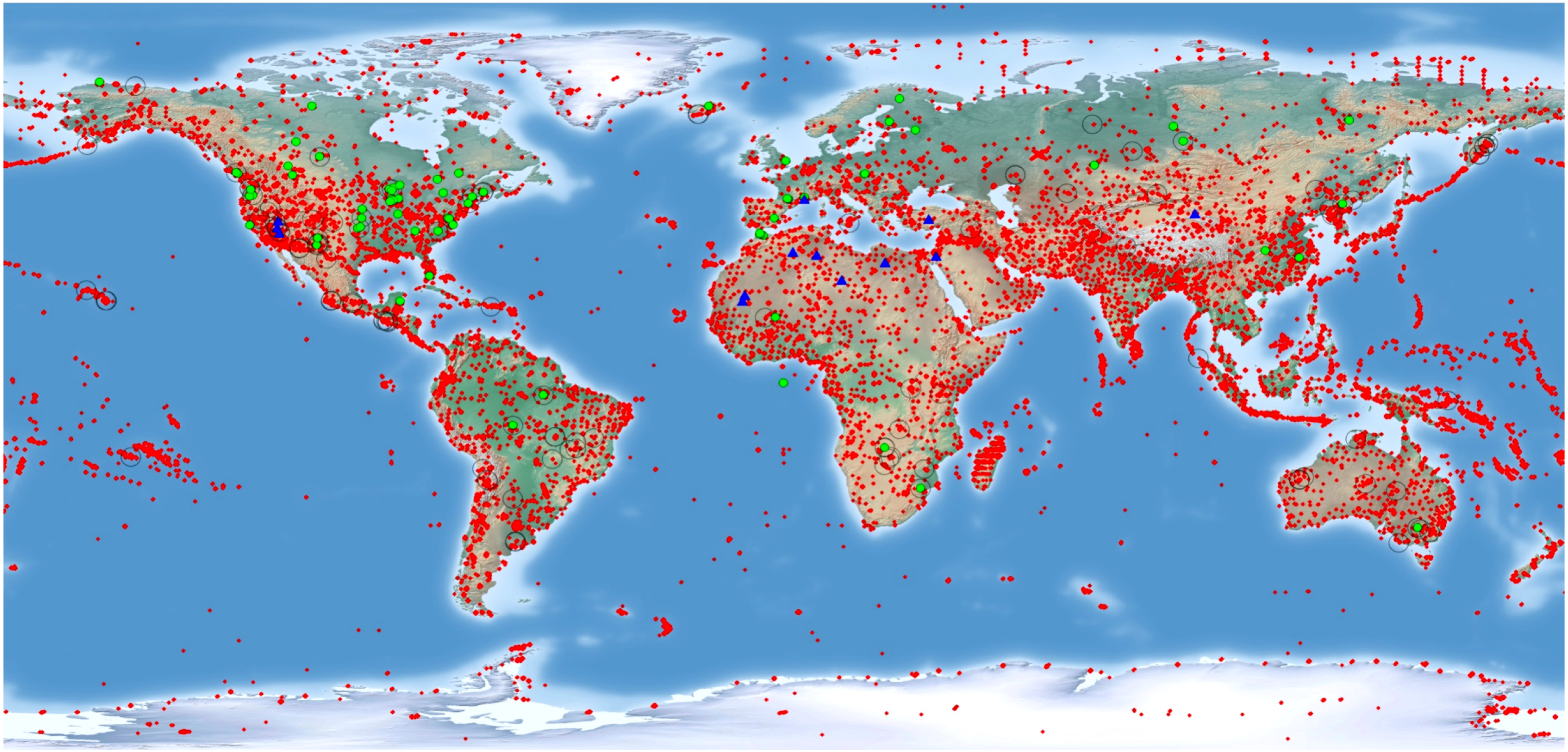
f_{APAR} is the fraction of PAR absorbed by vegetation

Hyperion Image Library

We can take advantage of existing datasets to explore issues in the development of global products

Hyperion produced a unique dataset of globally sampled spectral imagery

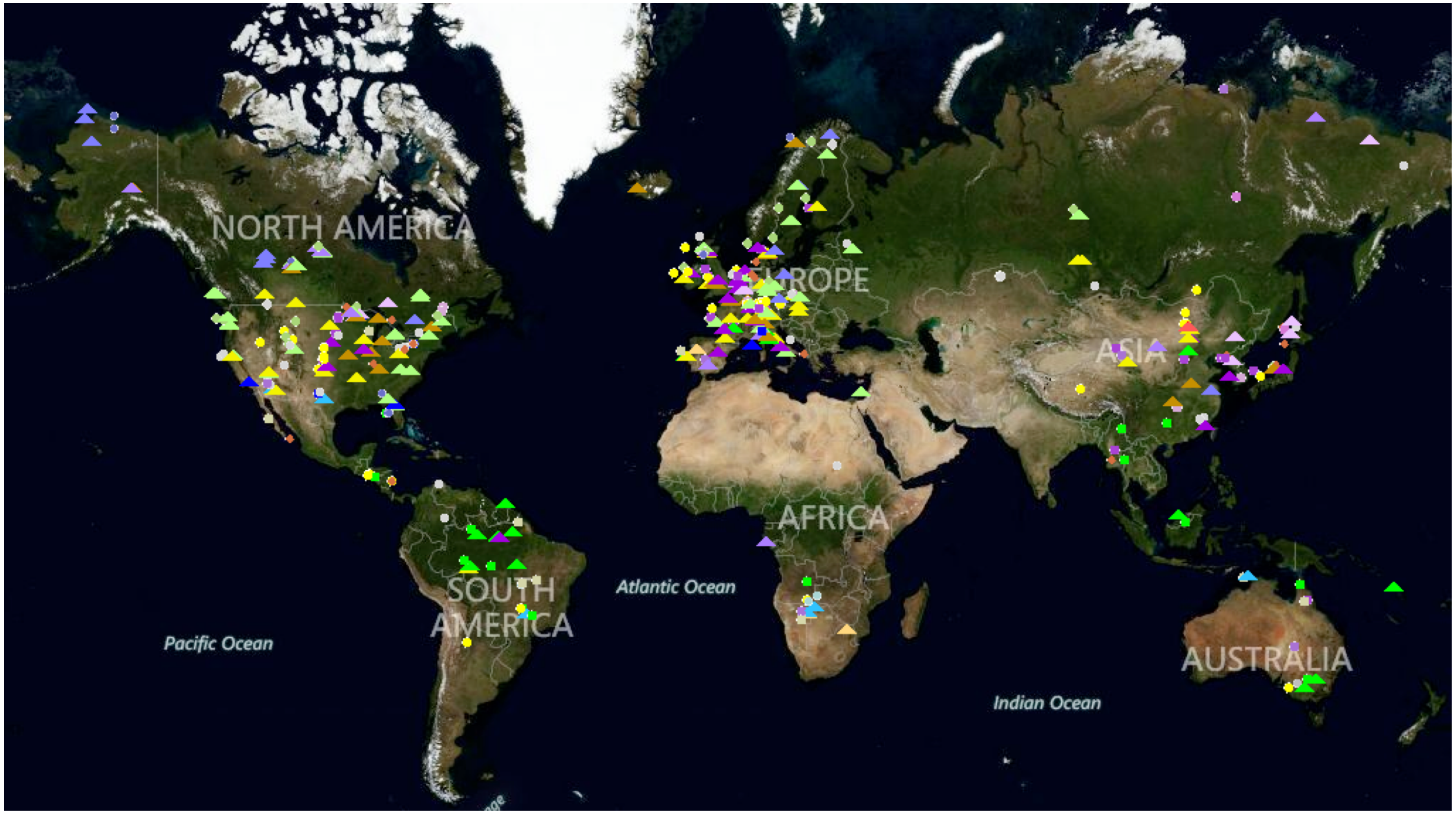
- Collecting >90,000 scenes over 16+ years



Flux Tower Data

The global network of flux towers provides ground data of ecosystem carbon, energy and water fluxes

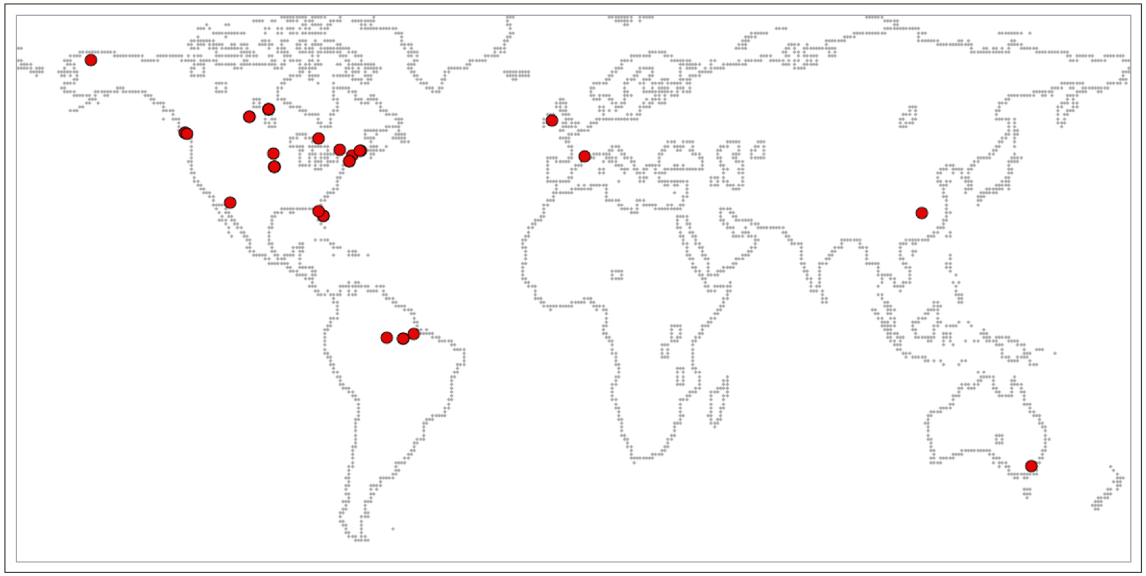
- Flux community has standardized flux calculations and gap filling in the development of synthesis datasets from 100s of towers

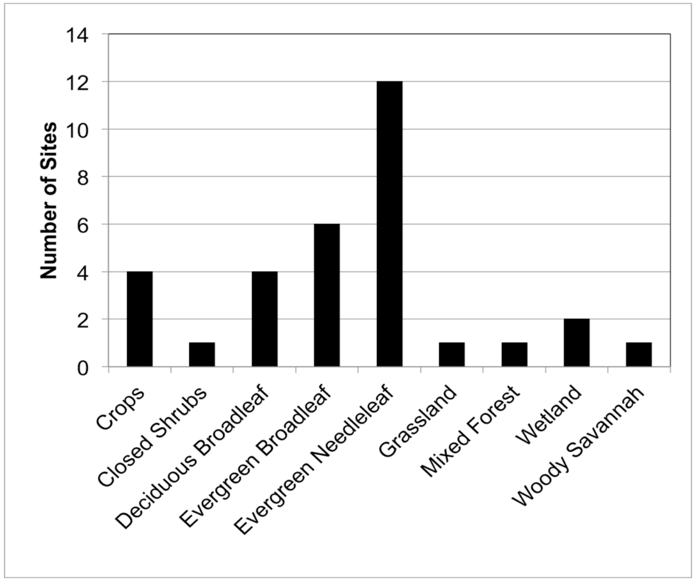


Remote Sensing of Fluxes: Hyperion and Fluxnet

Matched flux data from LaThuile Fluxnet Synthesis dataset with Hyperion imagery

- 79 observations of 33 different flux tower sites with a variety of different vegetation types
- Observed during mid-growing season to focus on spatial variability
- Averaged uniform regions around flux tower to improve SNR





Basic Algorithm Requirements

An index or algorithm used for retrieving a product should:

1) be sensitive to variations in the variable of interest
2) be insensitive to other factors
3) be linear to provide consistent results and for scaling

Item 2 is particularly important in the development of global products

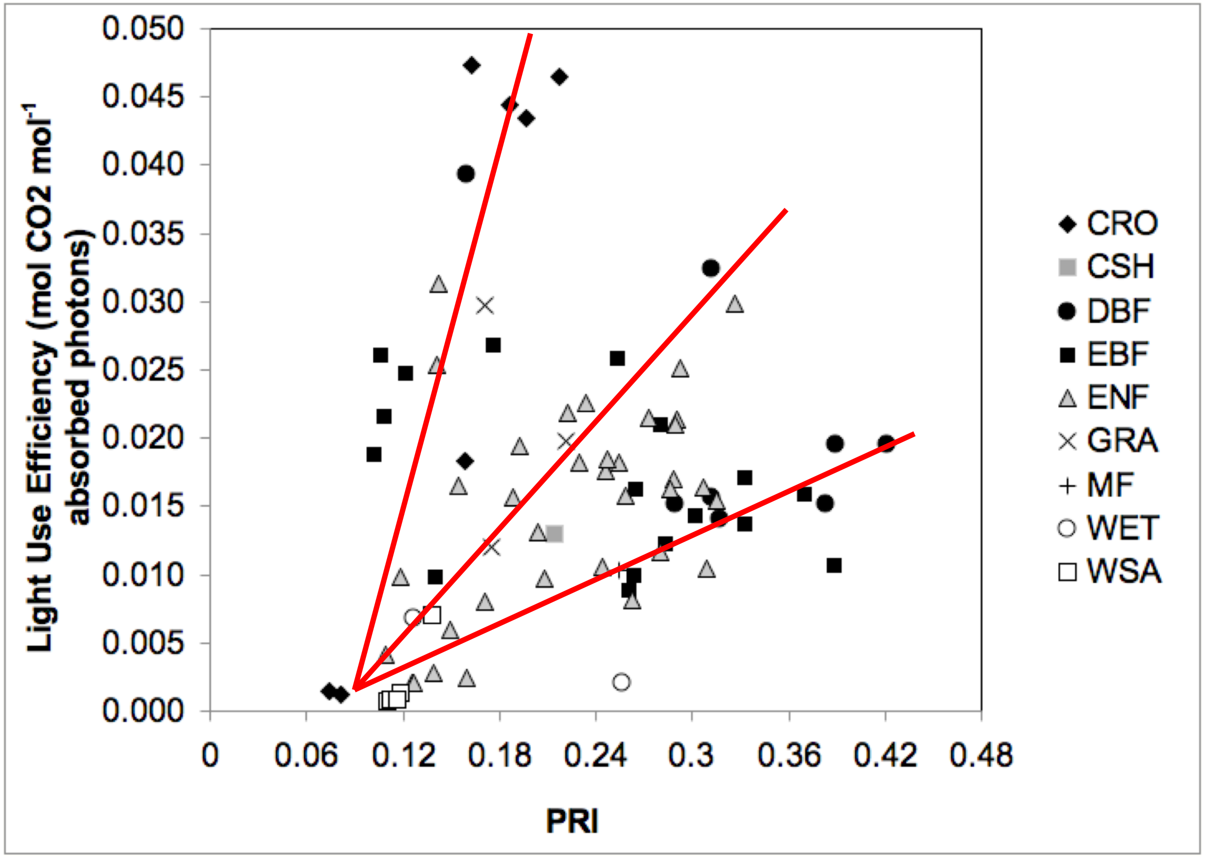
Indices/algorithms may be affected by factors such as differing canopy structures or background reflectances

Photochemical Reflectance Index (PRI)

Numerous studies have found relationships between PRI and LUE

However, PRI performs poorly in this analysis, with a range of possible responses

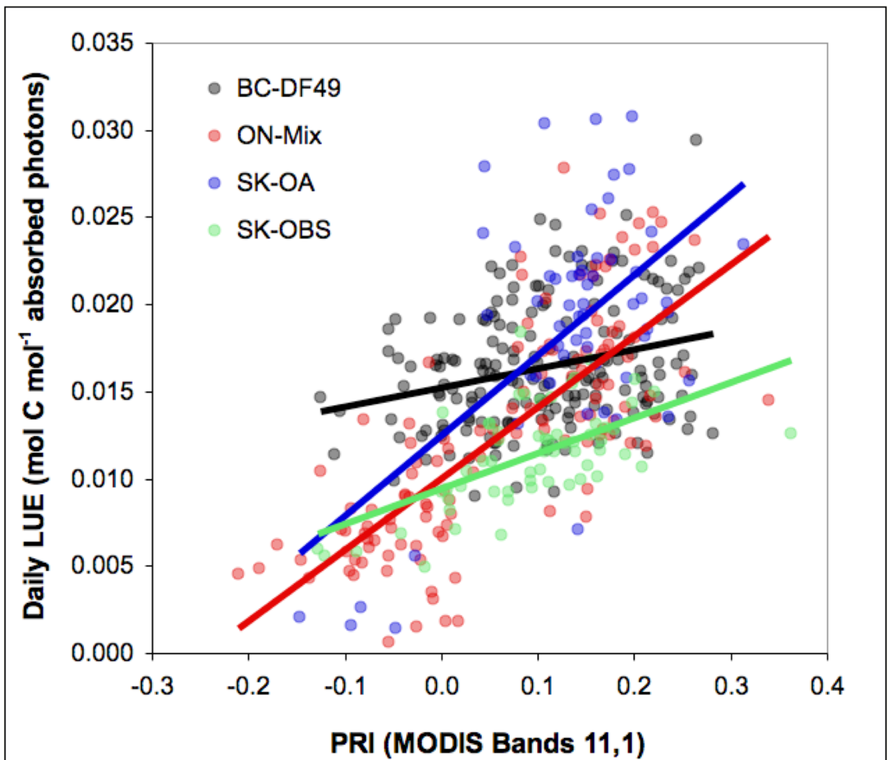
- Different sites/vegetation types show different response functions

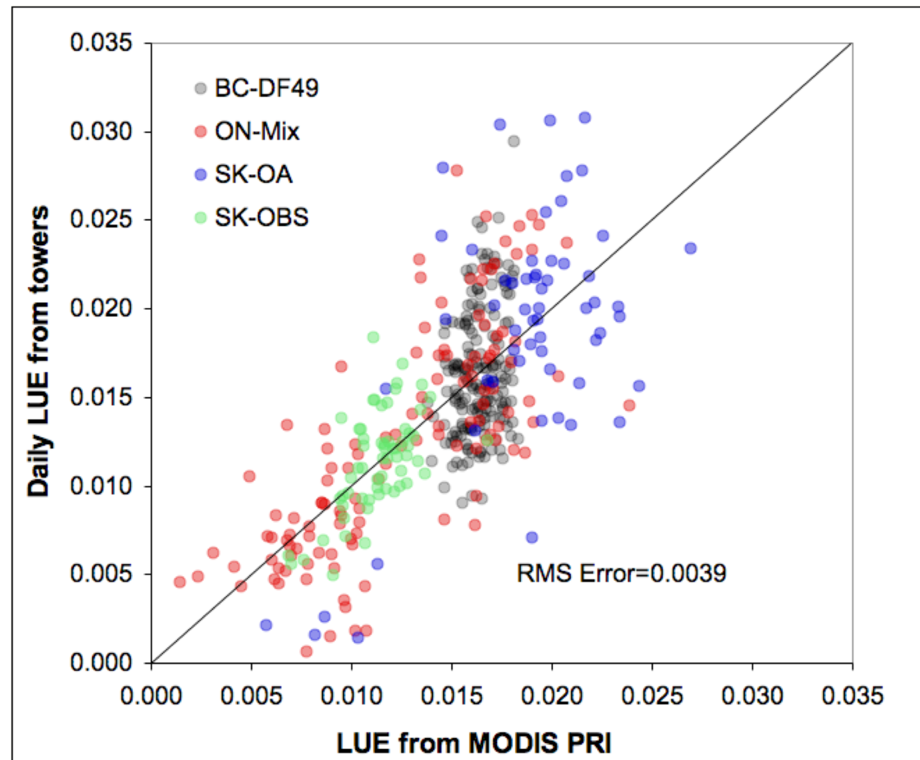


Photochemical Reflectance Index (PRI)

This example shows PRI from MODIS applied to four different forest types
Each site has a different relationship between PRI and LUE
This problem can be addressed by using a classification to determine type of relationship to use

Classification approach used in MODIS *f*PAR/LAI products





Site corrections applied to data

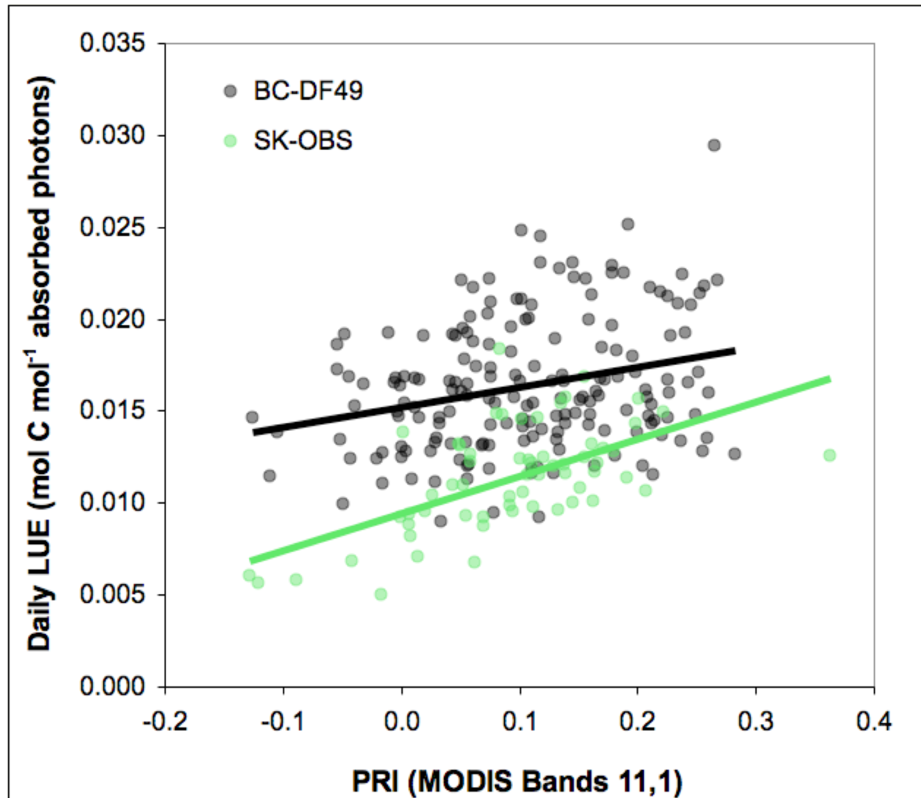
Middleton et al. RSE 2016

Photochemical Reflectance Index (PRI)

There are problems with using classifications to adjust for vegetation type differences

- Classification accuracy for MODIS landcover is around 80%
- Mis-classified pixels using the wrong relationship can result in significant errors
- We may not even know what classes to use

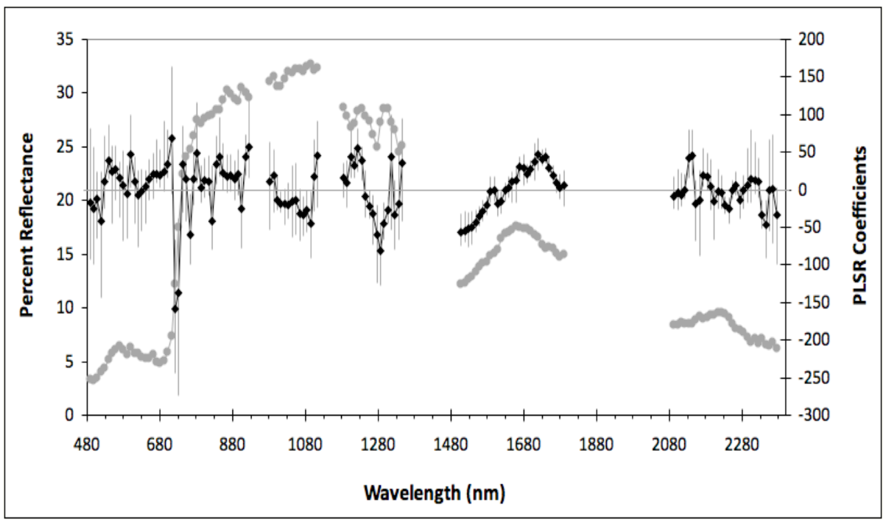
For example, in this MODIS PRI study Black spruce and Douglas fir had different relationships with LUE, even though both are Evergreen Needleleaf Forests



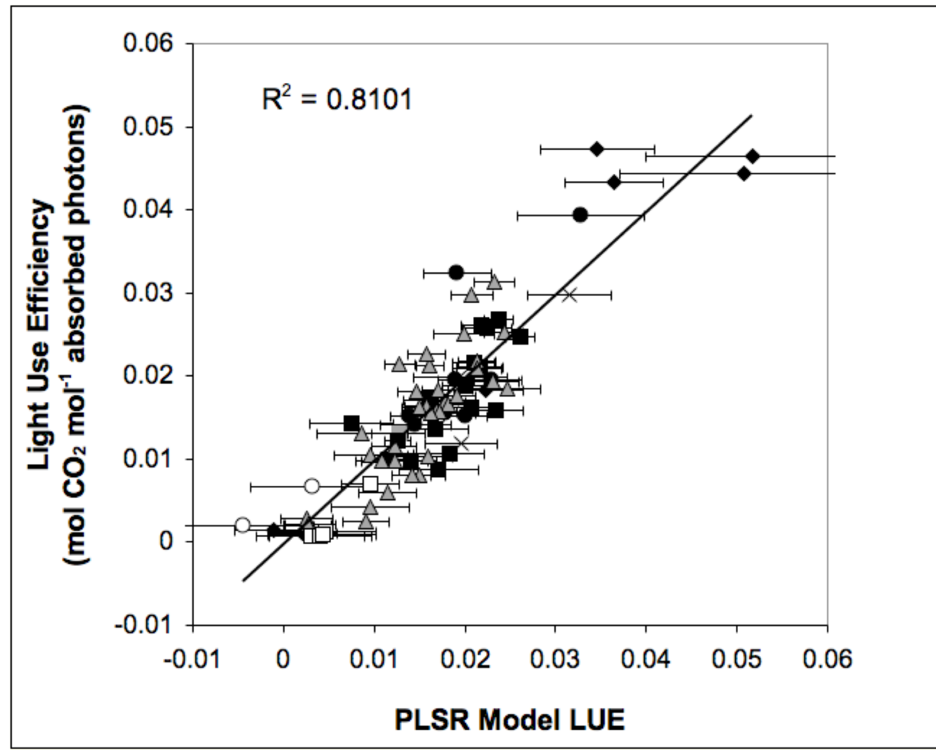
Middleton et al. RSE 2016

Partial Least Squares Regression

PSLR using all of the spectral information provides a good estimate of LUE for the entire population



PLSR coefficients and sample reflectance spectra

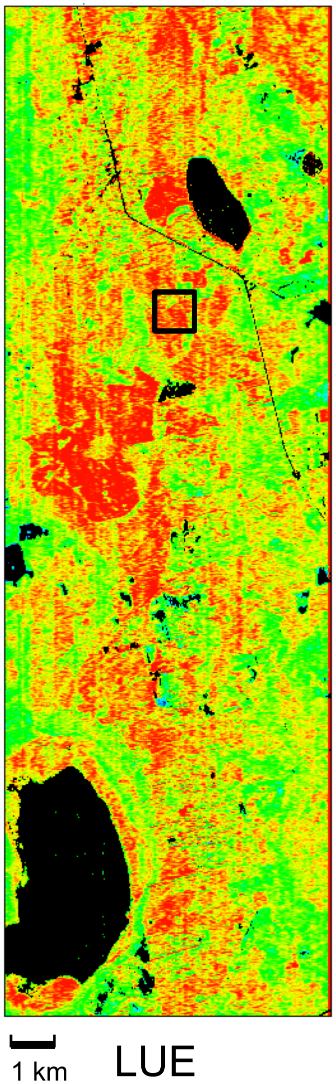


LUE estimate from reflectances vs. observed LUE from flux towers

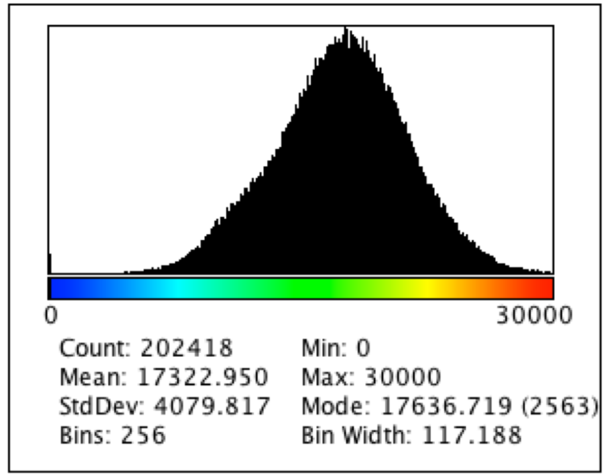
Partial Least Squares – LUE

Spectral imagery can describe spatial variability in LUE over landscapes

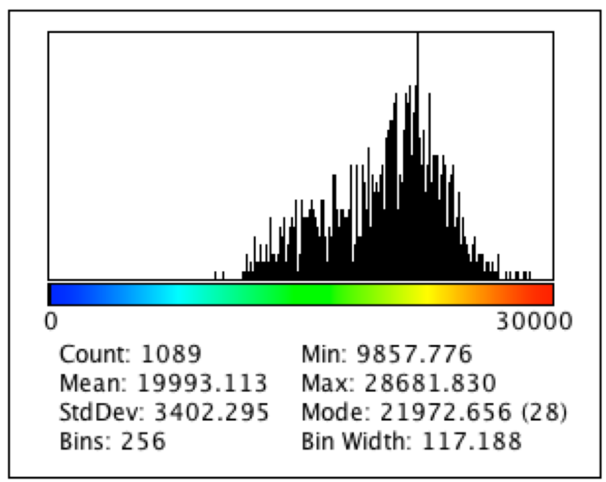
Florida Slashpine site (29.755° N -82.163° W)



LUE



LUE Histogram for full scene

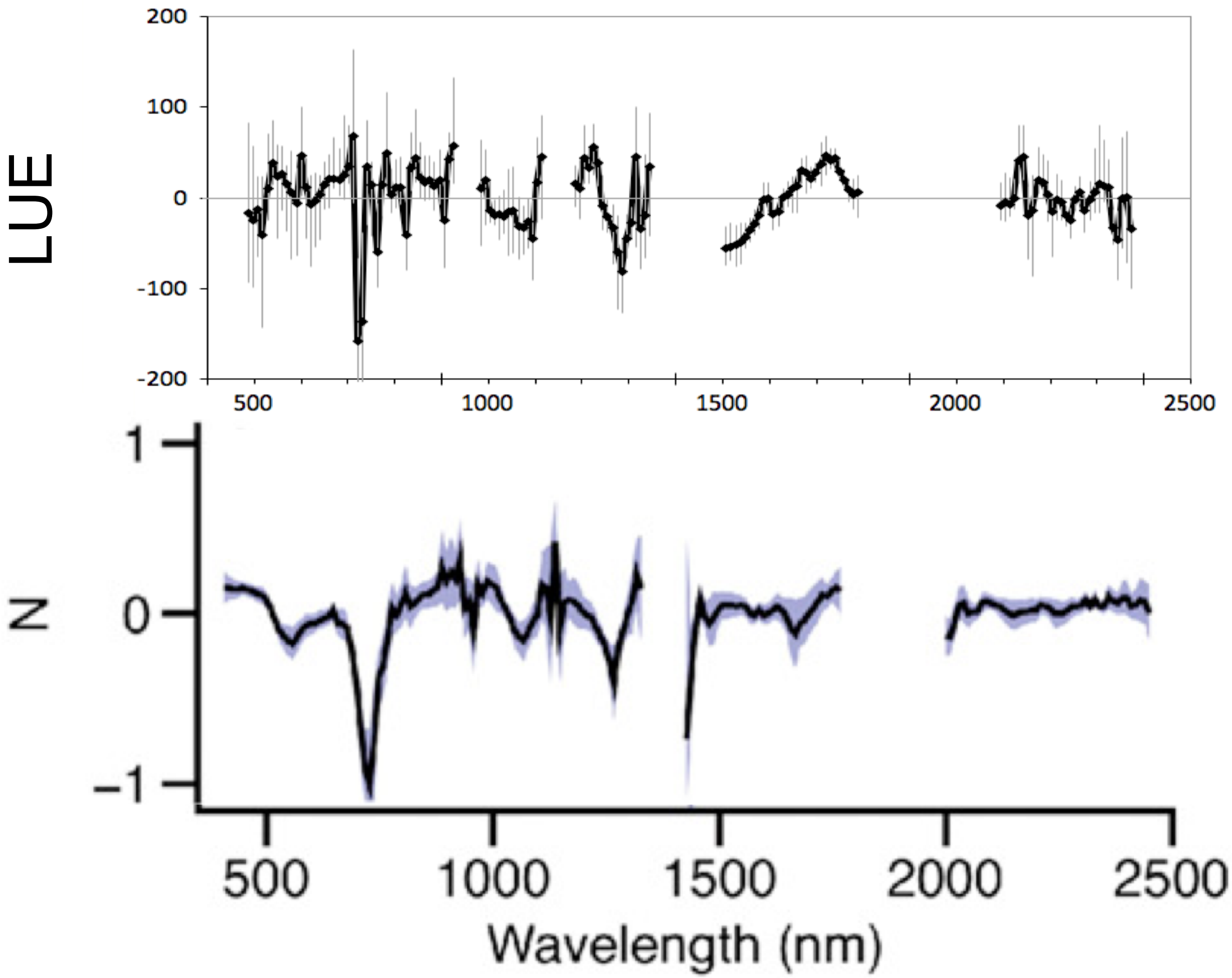


LUE Histogram for sq km around tower

Partial Least Squares – LUE

Similarity in PLSR coefficients suggests that variability in LUE is related to leaf N

- A link between function and foliar traits



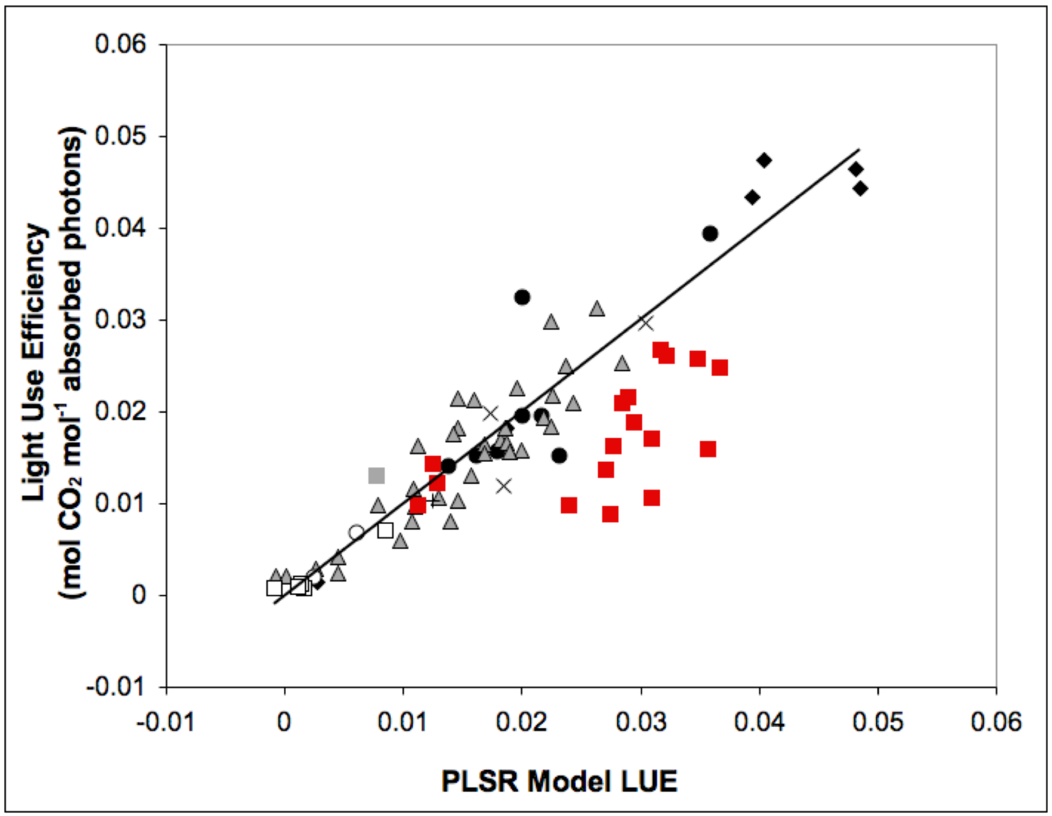
Huemmrich et al. *in review*

Asner et al. RSE 2015

Partial Least Squares – LUE

Statistical models are only as good as their training data

- Tests where specific vegetation types were removed from training datasets often performed poorly when applied to the test data
- Points to the need to develop diverse training datasets



Black/gray points – training data

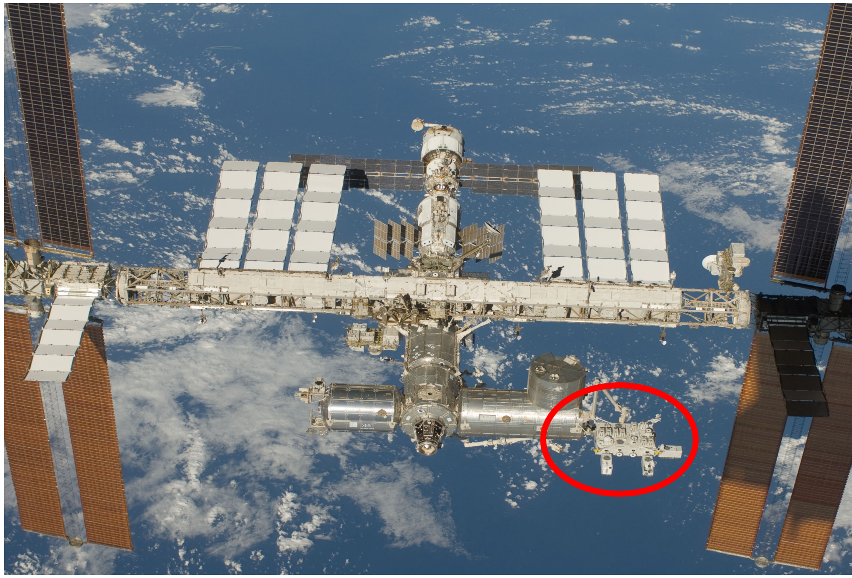
Red points – Evergreen Broadleaf Forests

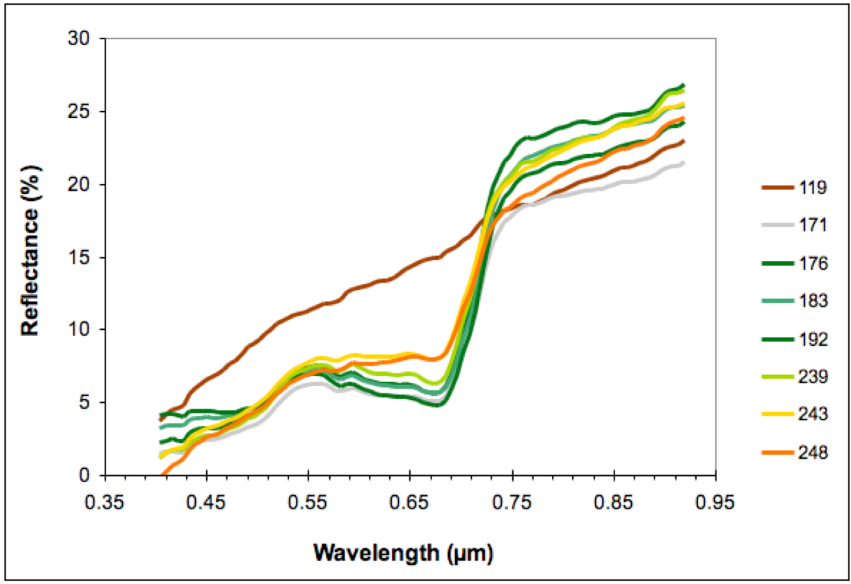
Algorithm Transfer to Different Instrument

If we develop an algorithm with one instrument can we transfer it to another?

HICO (Hyperspectral Imager for the Coastal Ocean)

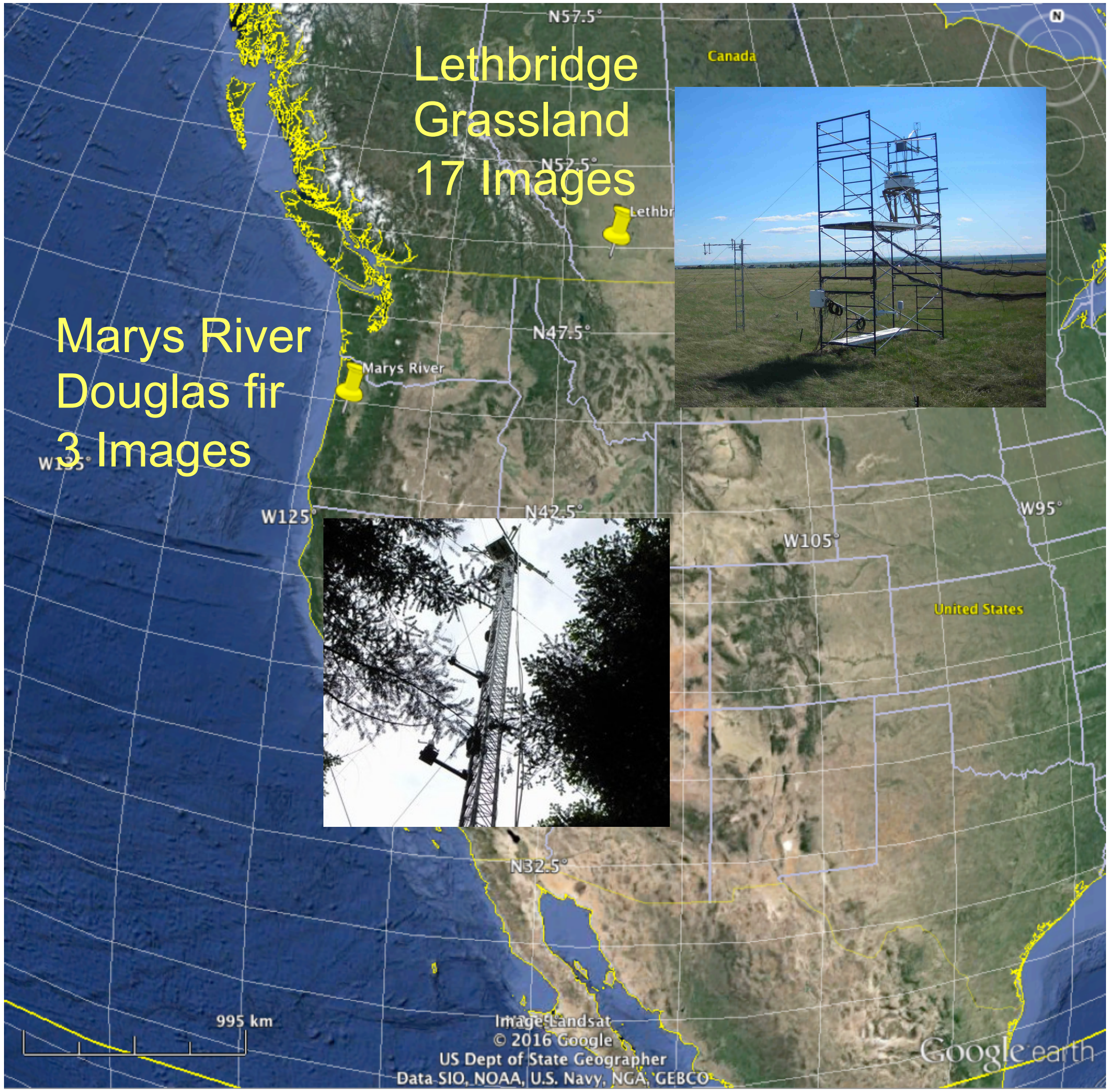
- HICO launched to ISS on September 10, 2009
  - operations ended in September 2014
- GSD: ~100 m
- Image size: 42 x 192 km
- Spectral range: 352 - 1080 nm
  - 398 - 920 nm were used
  - 5.7 nm bins
- Atmospherically corrected using ATREM





http://www.nasa.gov/mission_pages/station/science/experiments/HREP-HICO.html

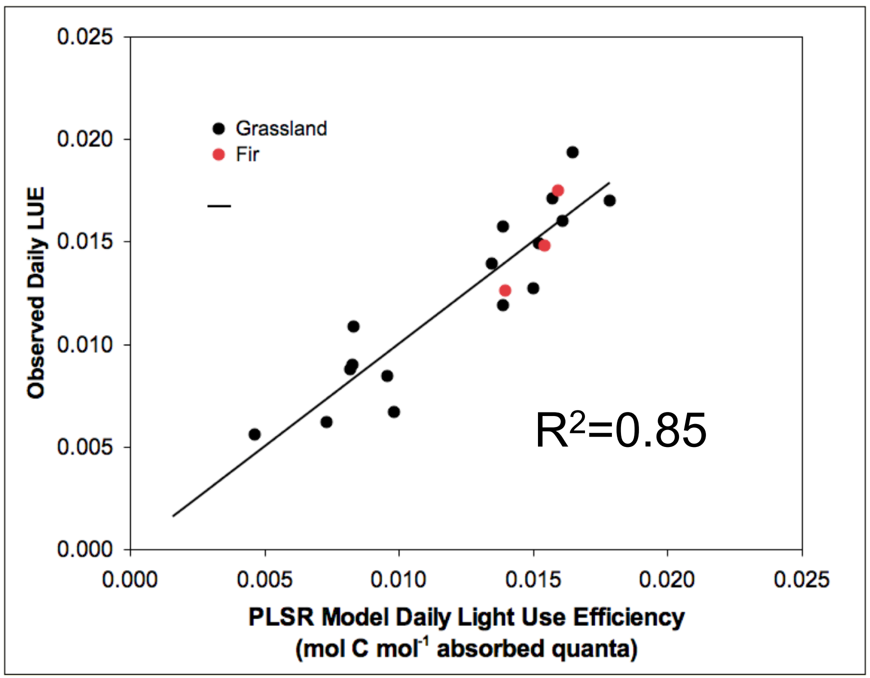
HICO Study Sites

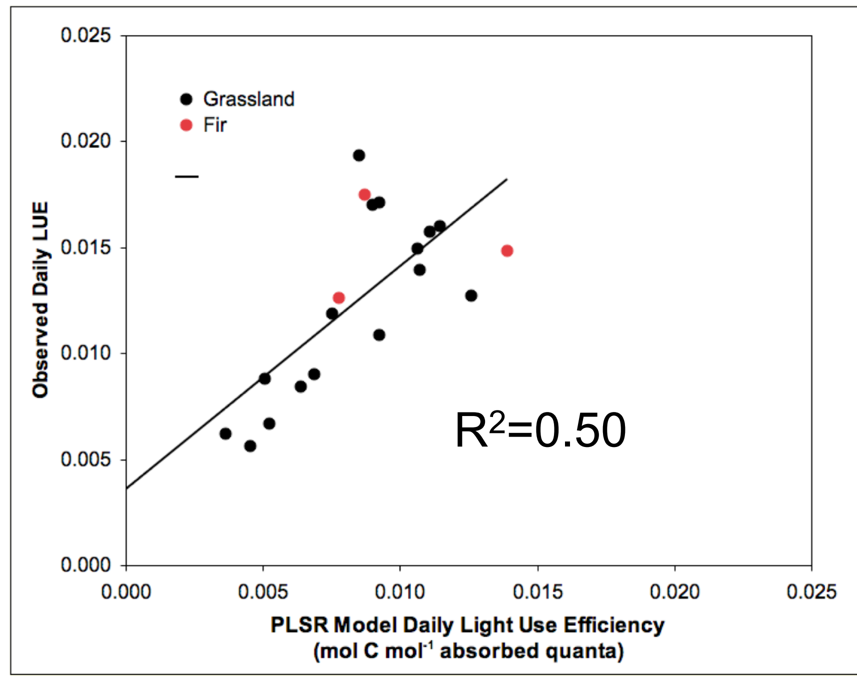


Algorithm Transfer to Different Instrument

Calculated PLSR from Hyperion dataset using only VNIR bands
- R^2=0.69 (down from R^2 of 0.81 using all bands)

Applied Hyperion coefficients to nearest HICO bands





PLSR trained using HICO data, applied to the HICO data

PLSR trained using Hyperion data, applied to the HICO data

Hyperion-Fluxnet 2015 Combination

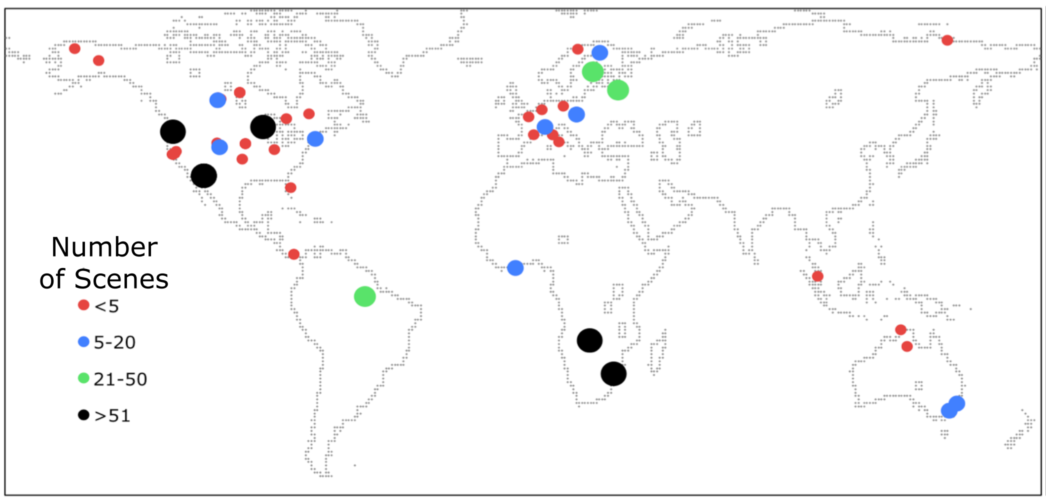
We can extend this type of global product study

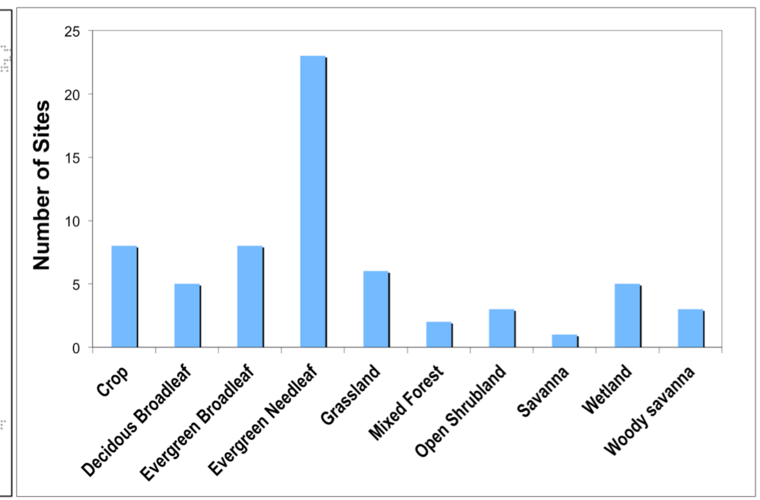
Fluxnet 2015 is the latest flux synthesis dataset

- Including data from over 200 tower sites

Hyperion has imaged many of these sites

- Combination provides rich dataset for global algorithm development and testing





Hyperion images of Fluxnet 2015 towers collected during years when towers were active and have cloud cover ≤40%

Point size and color on map indicate number of scenes for each site

Total of 64 sites and 914 images

Conclusions

- A common (global) spectral approach appears feasible.
- We must have training data that is representative of the variety of global vegetation types
  - Fluxnet is an example of a well developed network, in terms of instrumentation, protocols, data processing, and data archival
  - This may not be true for other products
  - For other products SBG will have to look at coordination or development of measurement networks for algorithm development and testing
  - These ground measurement networks should be in place before launch to account for lead times to getting quality data
- The Hyperion library can provide historic data for these studies
  - These data combined with data from other sensors (e.g. AVIRIS, DESIS, HISUI) can be used to develop and test algorithms for SBG
  - Results suggest algorithms developed using one sensor may be transferred to another