G-LiHT v2.0 with FIRE

NASA's Airborne Multi-Sensor System
3D Radiative Transfer Modeling

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NASA Goddard Space Flight Center, Biospheric Science Laboratory

Today's Talk

1) Next Generation G-LiHT v2.0 with FIREFLY (Cook/PI)
   - **G-LiHT** = **G**oddard's **Li**dar, **H**yperspectral and **T**hermal airborne imager
   - **FIREFLY** = **F**luorescence **I**maging of **RE**d and **F**ar-red **L**ight **Y**ield

2) FIREFLY Characterization with GLAMR (McCorkel/PI)
   - **GLAMR** = **G**oddard's **L**aser for **A**bsolute **M**easurement of **R**adiance

3) FLARE Field Campaign (Cook/PI; 2017-18)
   - **FLARE** = **FL**uorescence **A**irborne **R**esearch **E**xperiment
   - Motivation and Objectives
   - Study Sites and Preliminary Results
     - **Tropical Forests** (Puerto Rico; March 2017)
     - **Temperate Forests & Crops** (MD & VA; July/Aug 2017)
     - **High Latitude Forests** (AK; July/Aug 2018)
   - Current and future NASA-ESA collaborations

Puerto Rico Field Cr

1) Next Generation G-LiHT v2.0

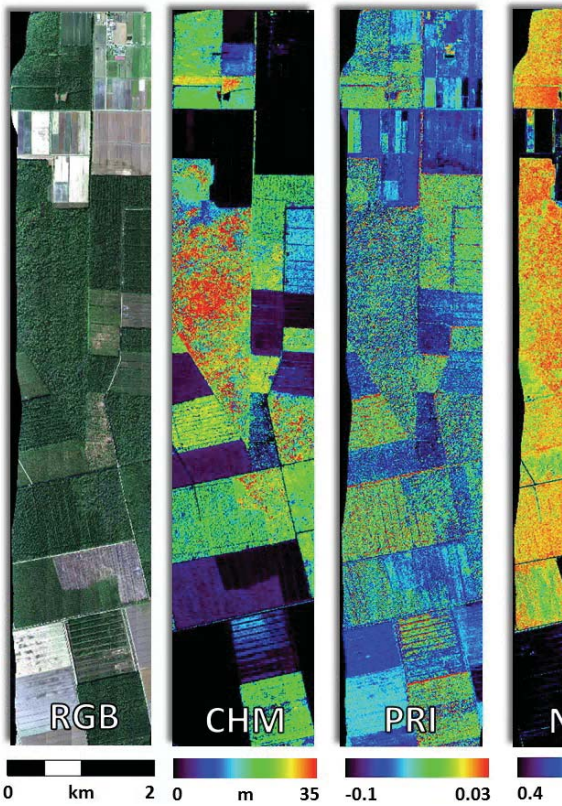
with FIREFLY

G-LiHT: Goddard's Lidar, Hyperspectral, and Thermal air

https://gliht.gsfc.nasa.gov/

G-LiHT is a portable, airborne imaging system that simultaneously ***maps the composition, structure, and function of terrestrial ecosystems*** using:

- ***lidar*** to provide 3D information about the spatial distribution of canopy elements;
- ***VNIR Imaging spectroscopy*** to discern species composition and variations in biophysical variables (e.g., photosynthetic pigments);
- ***thermal measurements*** to delineate wetlands and detect heat and moisture stress in vegetation;
- NEW ***stereo RGB photographs*** to identify fine-scale (~3 cm) canopy features; and
- NEW ***Solar-Induced Fluorescence*** (SIF) as a measure actual photosynthetic activity and indicator of vegetation stress.



Loblolly pine plantation in lower coastal pl

Next Generation G-LiHT v2.0

New/Upgraded Commercial Off-the-Shelf Instruments

- Two Riegl VQ 480i scanning lidars
- Headwall Micro-Hyperspec VNIR imaging spectrometer
- Headwall fine-resolution SIF imaging spectrometer
- Ocean Optics downwelling Irradiance spectrometers
- Phase One 100 MP Aerial Photographs
- Xenics thermal infrared camera
- Applanix POS AV V6 Precision GPS/INS

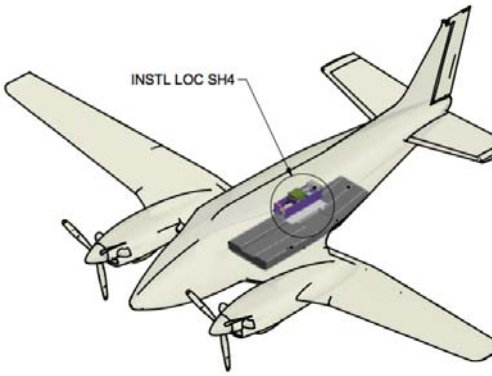
Acquisitions During 2017

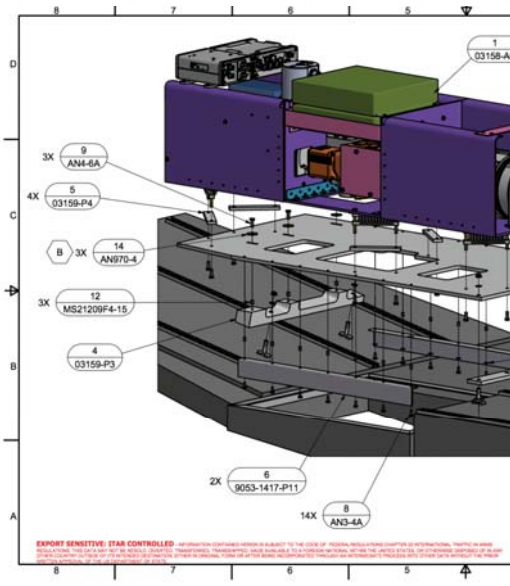
- Commissioning: ***February 2017***
- Science flights: ***250 hours (50 days)***
- Locations: 11 states from ***Puerto Rico to Maine***
- Raw data volume: ***40 TB***

G-LiHT–Aircraft I&T

- G-LiHT specifications
  - **Size:** 37 x 120 x 40 cm (W x L x H)
  - **Weight:** 100 kg (incl. interface plate)
  - **Power:** 360 W
  - **Data acquisition:** 2 @ PCs, 4 @ removable SSDs
  - **Material cost:** ~$1.2M

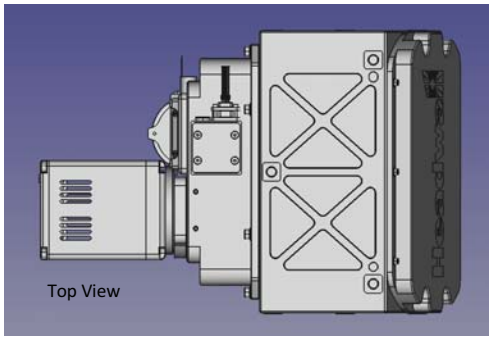
- Aircraft specifications
  - **CAS:** Dynamic Aviation (Bridgewater, VA)
  - **Make:** Beechcraft King Air A90 (military U-21A)
  - **Cabin:** Unpressurized, heat/AC
  - **Endurance/Range:** ~5 hours, 1000 nm
  - **Speed:** 120 to 200 knots
  - **Camera port:** 58 x 66 cm (W x L)
  - **Flight hour cost:** ~$2k per hour

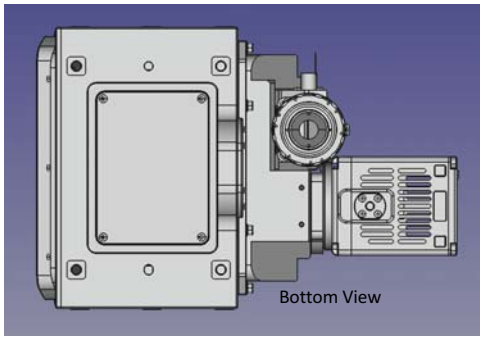


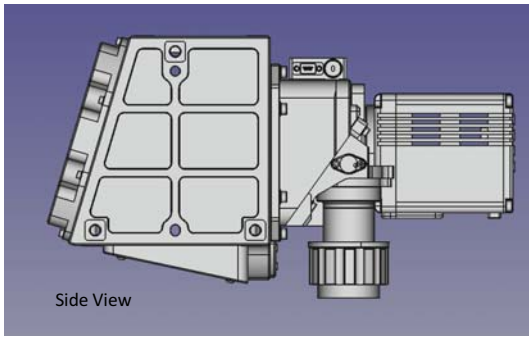


FIREFLY: **F**luorescence **I**maging of **RE**d and **F**ar-re

- Design: Aberration Corrected F2.5 Compact Dyson
- Spectral Range: 670 nm – 780 nm
- Spectral Channels : 2,160 w/o binning
- Spectral Resolution (FWHM) ≤ 0.17 nm
- Spatial FOV 23.5 deg with 1,600 samples
- Signal-to-Noise - 680:1
- Dimensions (mm): 300 L x 200 W x 200 H
- Shutter: Electro-mechanical
- Focal Plane: 16 bit TE Cooled sCMOS
- Power ≤ 30 W
- Weight: 6.3 kg

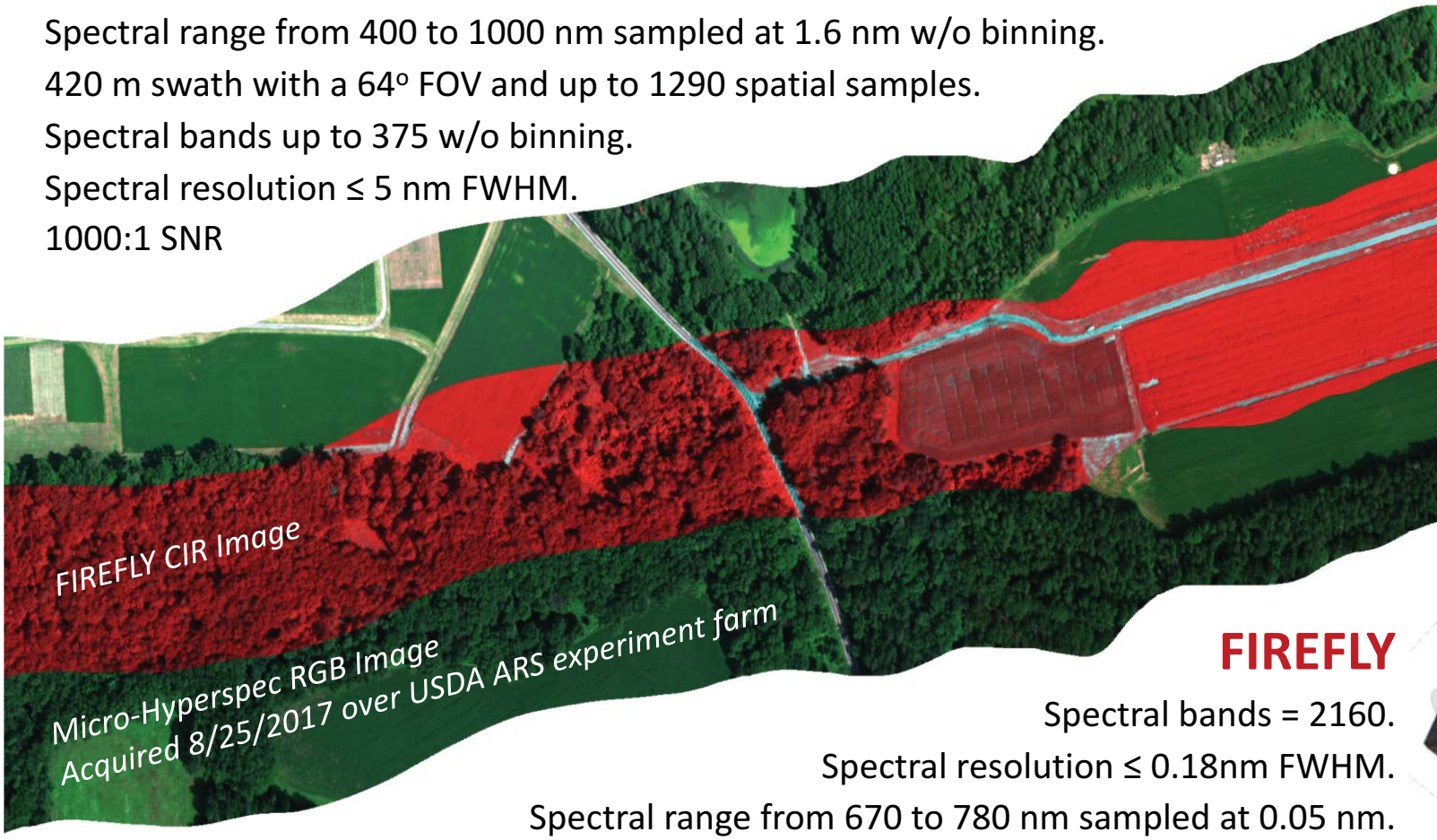






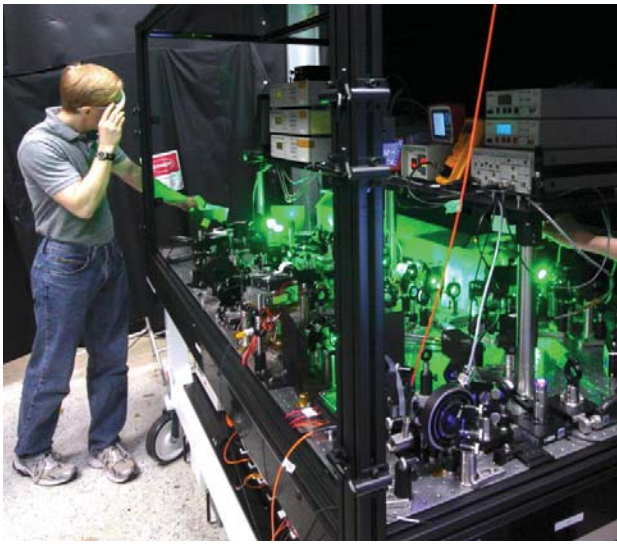
G-LiHT v2.0 – Micro-Hyperspec E-Series VNIR Imaging Spec

Spectral range from 400 to 1000 nm sampled at 1.6 nm w/o binning.
420 m swath with a 64° FOV and up to 1290 spatial samples.
Spectral bands up to 375 w/o binning.
Spectral resolution ≤ 5 nm FWHM.
1000:1 SNR



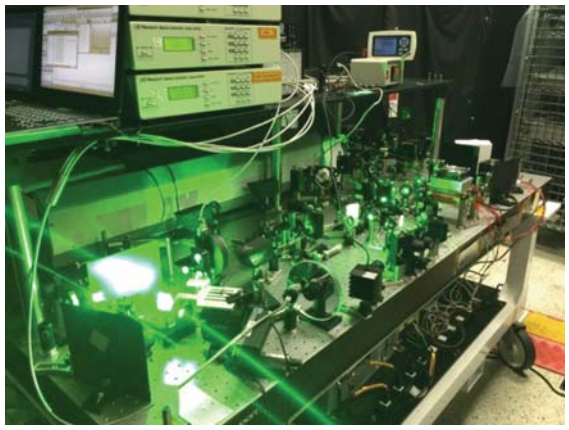
FIREFLY

Spectral bands = 2160.
Spectral resolution ≤ 0.18nm FWHM.
Spectral range from 670 to 780 nm sampled at 0.05 nm.
Telecentric 25mm lens with a 23.5° FOV and up to 1600 cross track spatial samples.



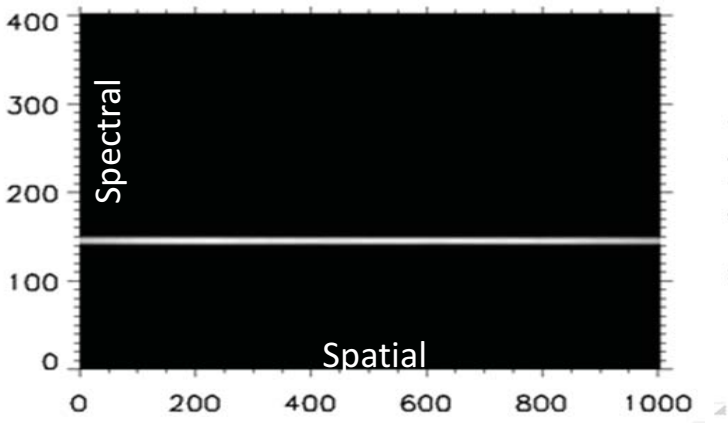
2) FIREFLY Characterization and Calibration

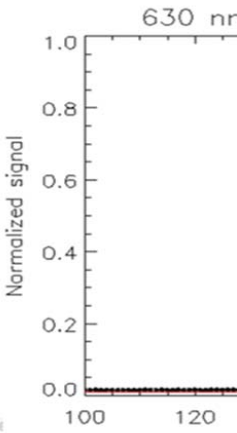
GLAMR: Goddard Laser for Absolute Measuremen



Instrument Model Parameterization for:

- Absolute Radiometric Response Functions.
- Spatial / Spectral Uniformity.
- Detector Linearity.
- Stray Light & Cross Talk.

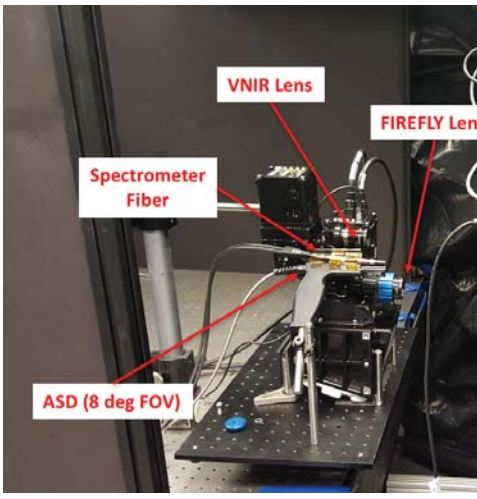




Following a NIST traceable heritage from SIRCUS
Spectral Irradiance and Radiance responsivity Calibrations us

GLAMR Setup for Narrow Band Scans to Characterize FIREFLY & Downwelling Irradiance Spectrometers

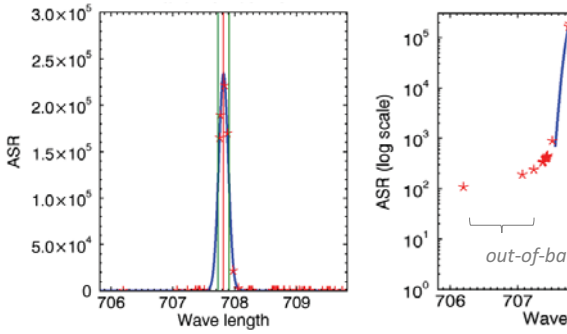
- Ti: Sapphire laser
- NIST transfer radiometer
- Acquired data in five regions:
  - 690-694.5 nm
  - 707-711.5
  - 725-729.5
  - 742-746.5
  - 760-764.5
- 0.05 to 0.15 nm step sizes
- Alternating 10 s light, 10 s dark



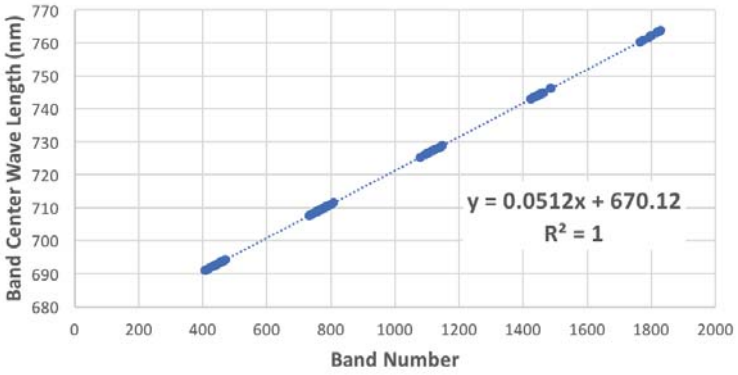
NASA Goddard SPACE FLIGHT CENTER

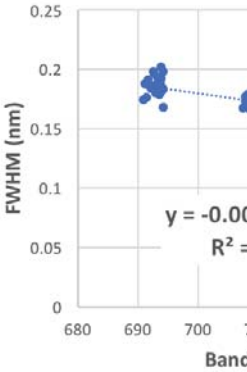
GLAMR Results

- Absolute Spectral Response (ASR) for single pixel:

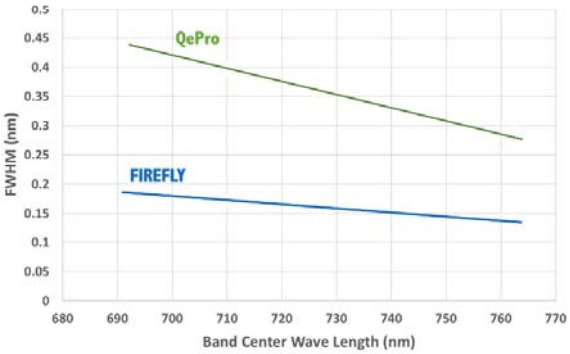


- FIREFLY calibration:





- FIREFLY vs. Ocean Optics QE Pro:



QE Pro is a comm
measuring SIF, but

- spectral resolution
- dark noise is much

G-LiHT v2.0: Linearity and Stability Checks

HELIOS D-Series High Dynamic Range Uniform Light Source

- **Wide Angle Spatial Uniformity Characterization.**
- **High Dynamic Range for Linearity Characterization.**
- **Periodic Assessment of Radiometric Stability.**
- **Portable NIST Traceable Radiometry**

Cross Calibration & Stability Assessment for all G-LiHT Optical Sens

FIREFLY & Micro-Hyperspec Imaging Spectrometers

Downwelling Irradiance Spectrometers

Intercalibration of EOS with G-LiHT

http://earthobservatory.nasa.gov (16 April 2013)

Journal of Applied Remote Sensing

Overview of the 2015 Algodones Sand Dunes field campaign to support sensor intercalibration

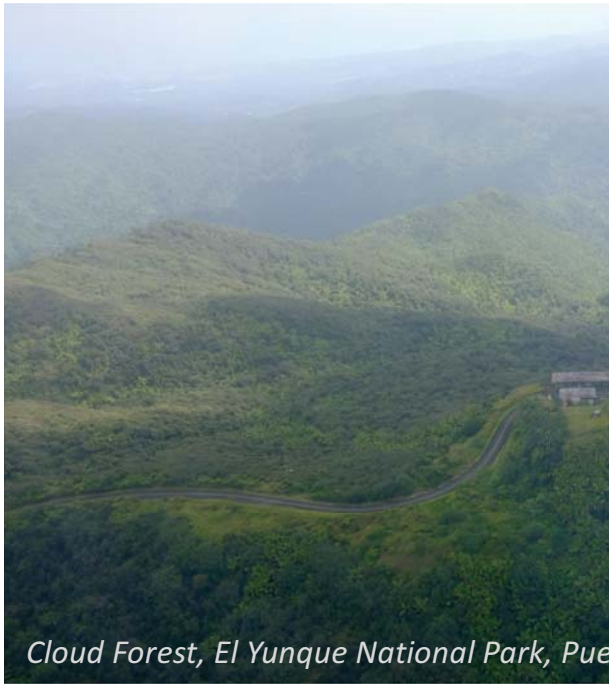
Joel McCorkel
Charles M. Bachmann
Craig Coburn
Aaron Gerace
Larry Leigh
Jeff Czapla-Myers
Dennis Helder
Bruce Cook

SPIE.

FLARE

FLuorescence Airborne Research Experiment

3) FLARE Field Campaign



Cloud Forest, El Yunque National Park, Pue

FLARE is a NASA-ESA Collaboration on FL

MOTIVATION

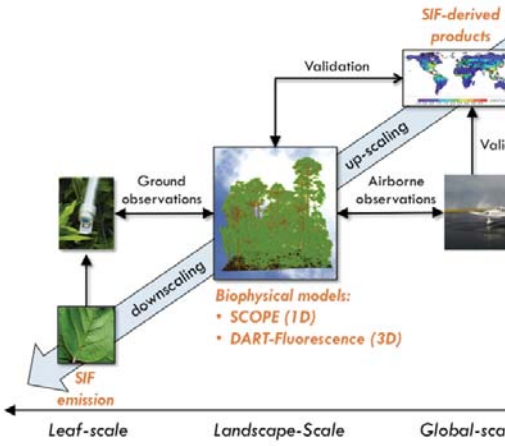
Fluorescence Explorer (FLEX)

- Selected as ESA's 8th Earth Explorer mission.
- Measures *actual photosynthetic activity* (Solar Induced Fluorescence, SIF) and indicators of *vegetation stress.*

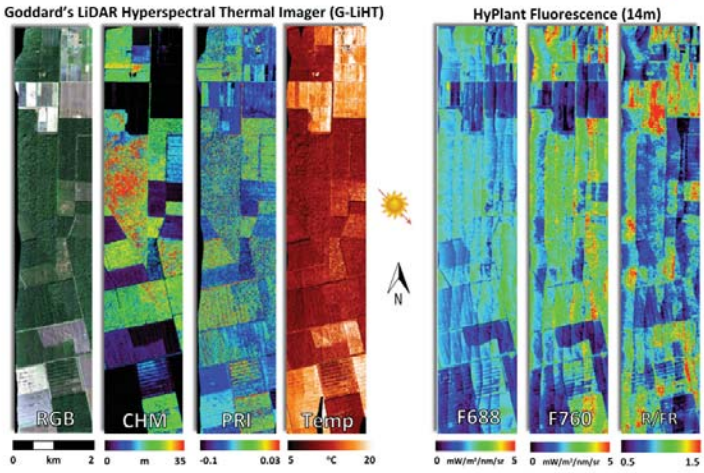
Coordinated NASA & ESA field campaigns will:

- support ongoing *collaboration* between NASA & ESA;
- advance *instrument and measurement techniques*;
- provide data for *development of retrieval algorithms*;
- provide cal/val *observations for different biomes*; and
- advance the *science basis* for interpreting FLEX data.

Field data is needed for scaling and interpre



SIF & G-LiHT data from 2013 FLEX-US Pilot Study



FIELD CAMPAIGNS

Tropical Forest (March 2017):

- Puerto Rico (coincides with DOE NGEE-Tropics
- NSF LTER & CZO site; NGEE-Tropics and FIA
- Complex canopy; environmental and nutrient

Mid-Latitude Broadleaf Deciduous Forests (Au

- Smithsonian Environmental Research Center, M
- 46 ha stem map; NEON site; close to NASA G

Airborne & Ground Measurements:

- AM/Noon/PM on 3 different days with *G-LiH*
- Continuous leaf-level SIF, optical properties, p

Puerto Rico Science Objectives

Primary r
Secondar

1) Validate FIREFLY radiometry and SIF retrievals (tarps, gra
2) Obtain enough measurements to parameterize DART-Flu and SCOPE models to simulate SIF emissions in tropical f optical properties, vegetation structure).
3) Compare diurnal SIF emissions from different plant funct (G-LiHT w/FIREFLY; Fluo-Wat); and
4) Compare SIF emissions for different stand ages and envir conditions (soils, climate) (G-LiHT w/FIREFLY).

Puerto Rico Airborne-Ground Field Campaign (P

NASA's Fluorescence Airborne Research Experiment (FLAR

US-DOE Next Generation Ecosystem Experiments - Tropic

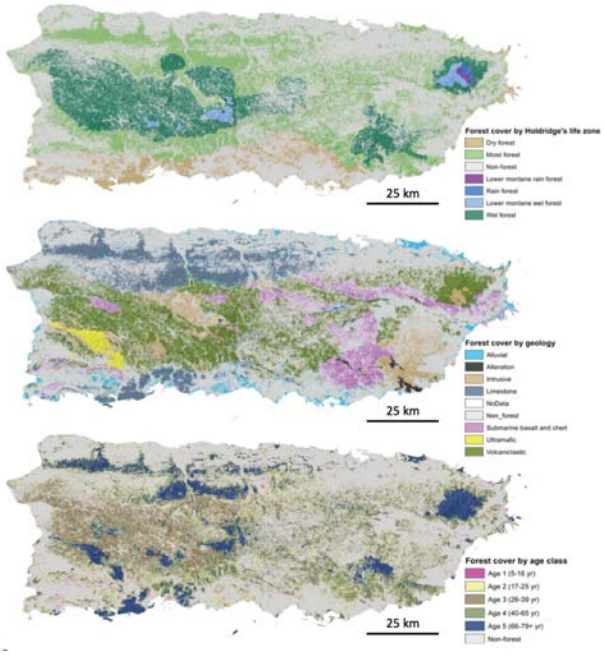
Next Generation Ecosystems (NGEE) - Tro

Michael Keller (PI), Douglas Morton, Bruce Cook, Sebastian Martinuzzi

Holdridge Life Zones

Geology

Age class

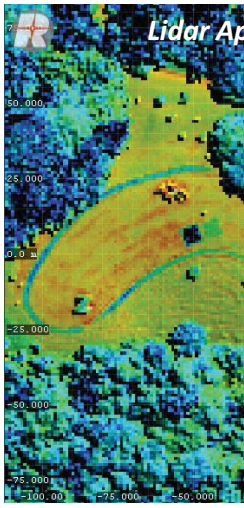


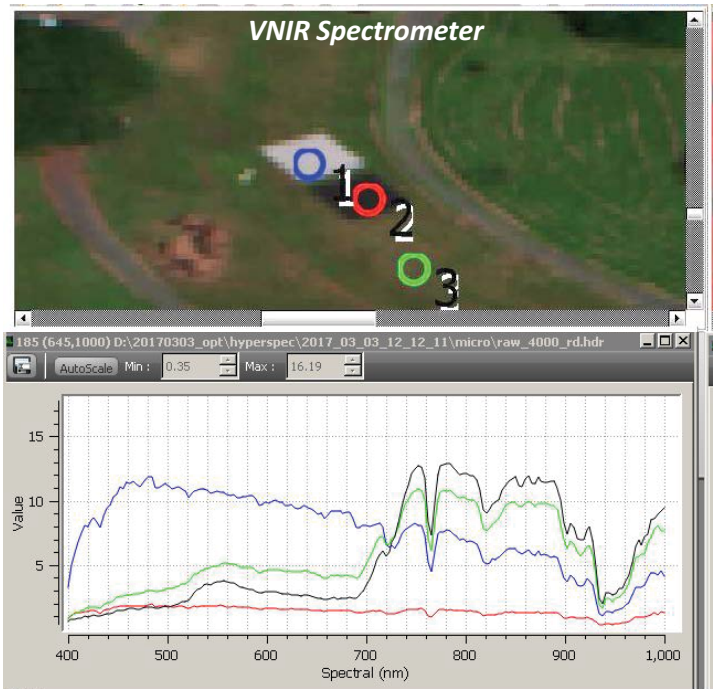

El Yunque National Forest

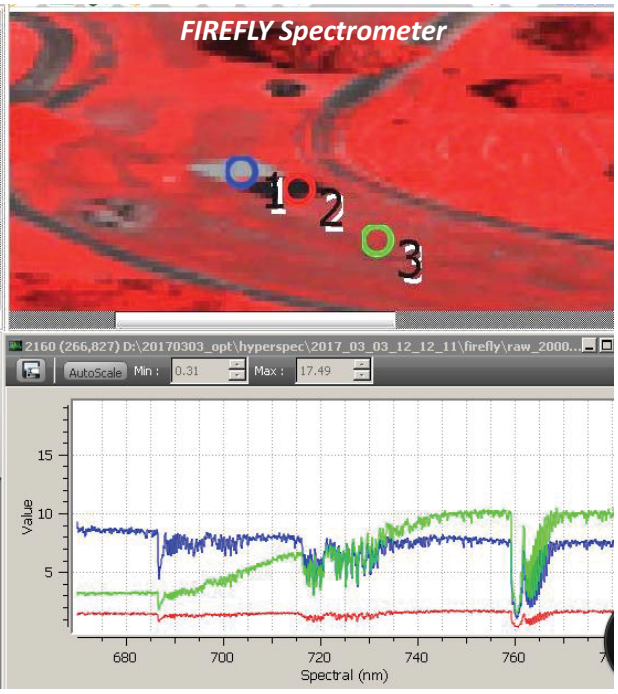
- NGEE-Tropics is a $25M US-DOE project designed to determine if tropical forests will act as net carbon sinks through the 21st Century
- G-LiHT data collected during 2017 will be used to predict growth rates of secondary tropical forests as a function of soils, climate, and land use history.

G-LiHT Airborne Observations

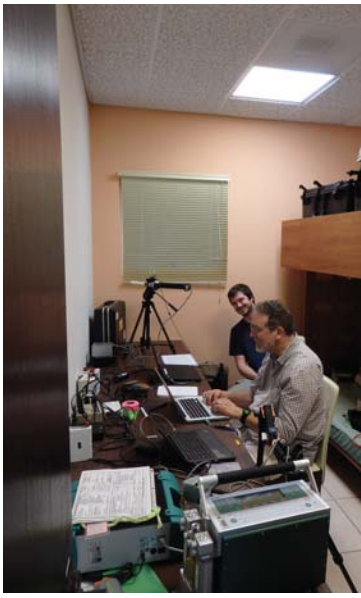
1) ***Calibration tarps***, NFI plots at USFS Intl. Institute of Tropical Forestry (IITF)
2) ***Native and exotic tropical tree species***
    - Botanical Garden of the University of Puerto Rico (UPR)
    - Arboretum Parque Doña Inés
3) USFS, NSF (LTER, CZO), Smithsonian and university ***research plots (island-wide)***



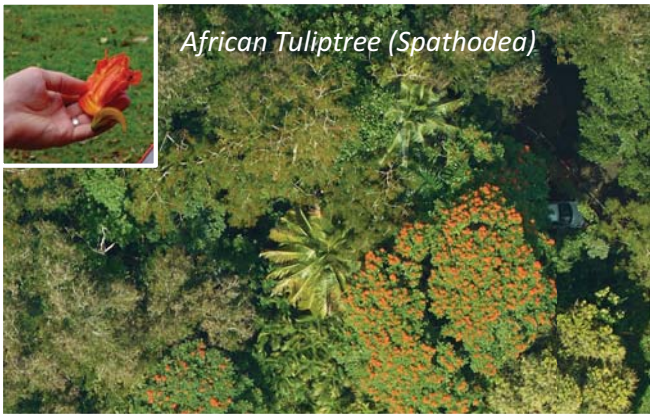


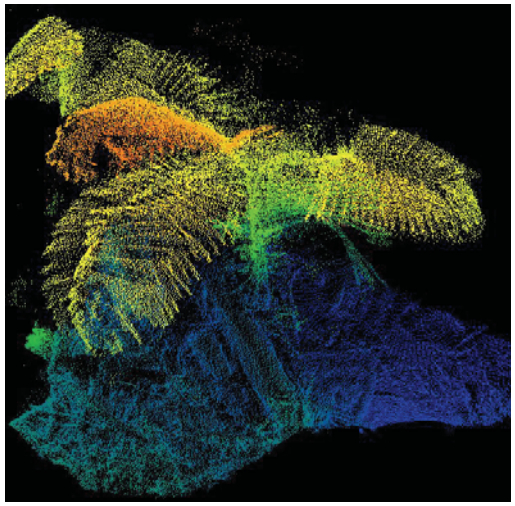


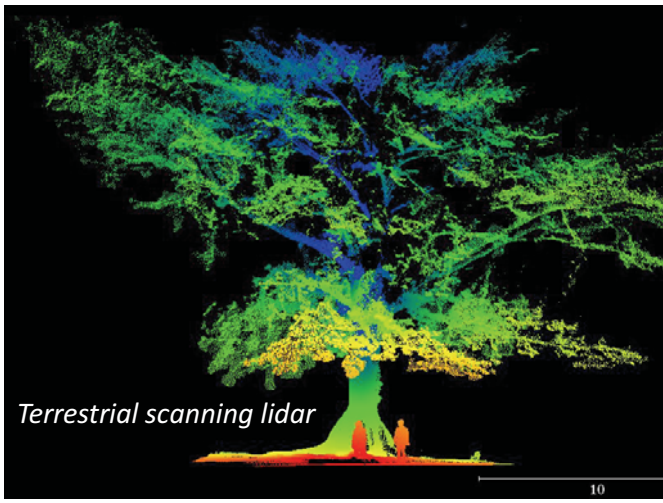





Vegetation Structure in Complex Car

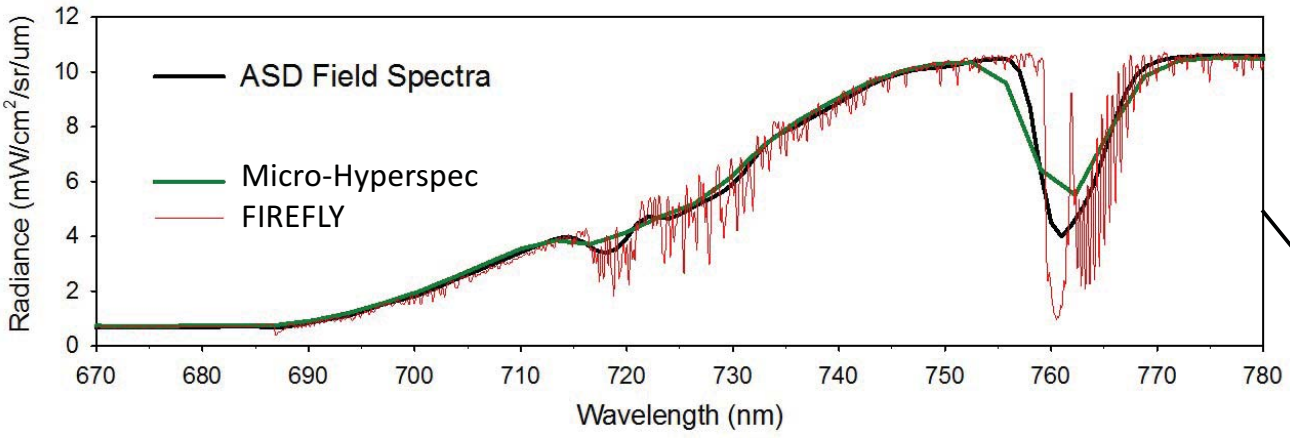


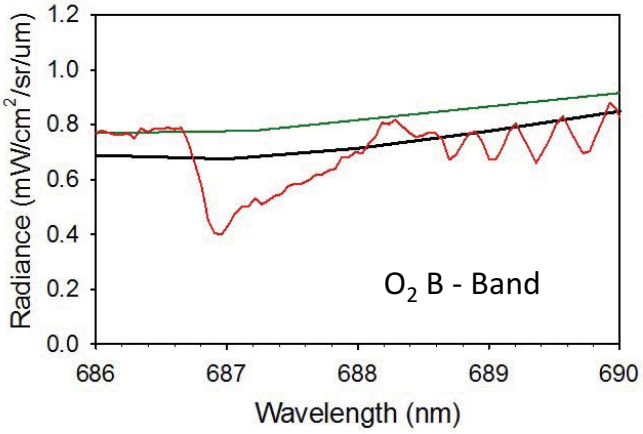


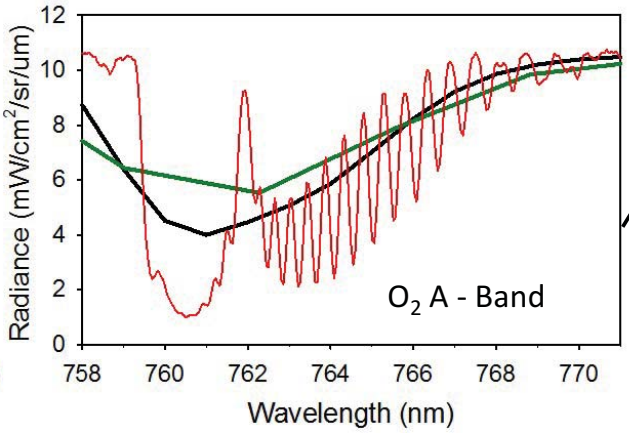


FLARE: Airborne & Ground Observations

Verification of at-sensor FIREFLY signal using calibration tarps.

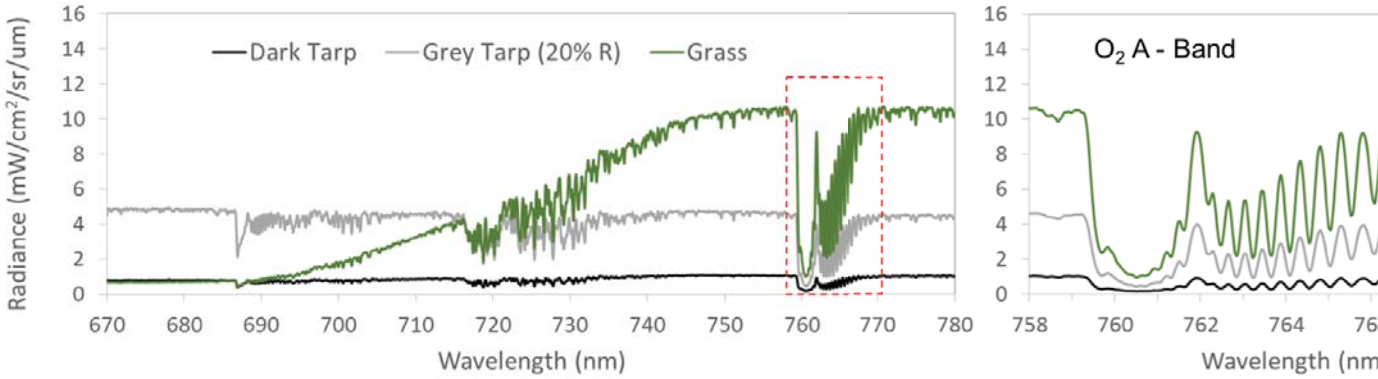




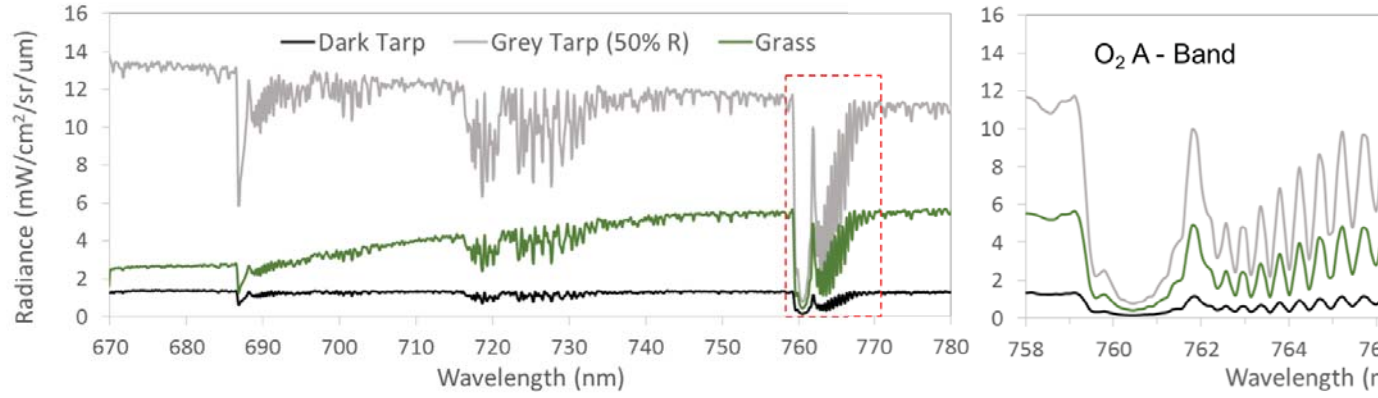


FIREFLY & HyPlant Spectra of Tarps

FIREFLY – FLARE 2017 Campaign



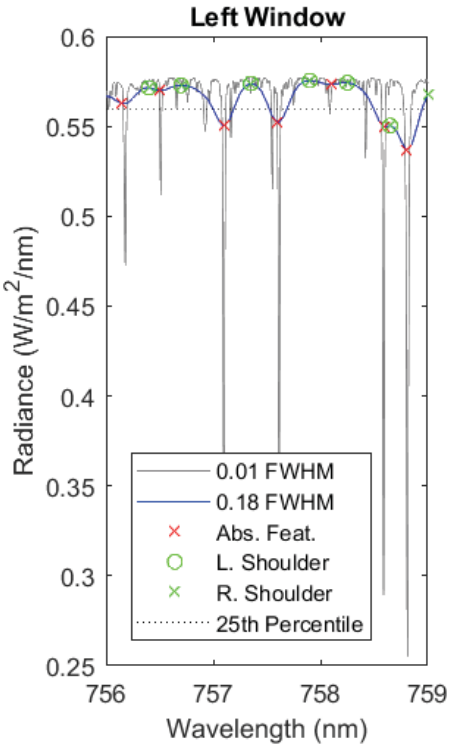
HyPlant – FLEX-US 2013 Campaign

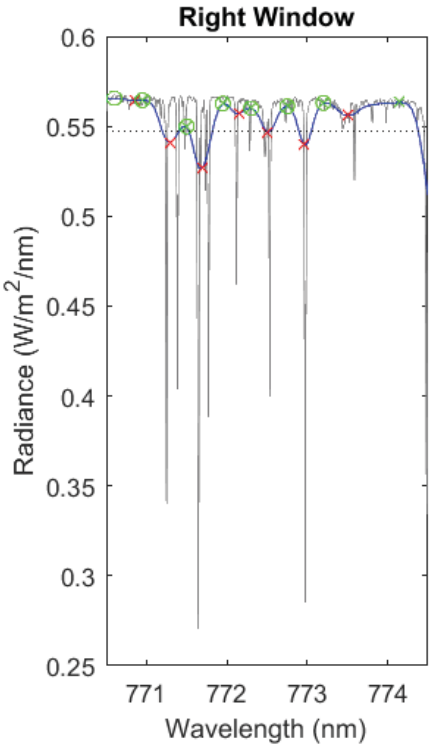


Solar Features Used for Airborne SIF Re

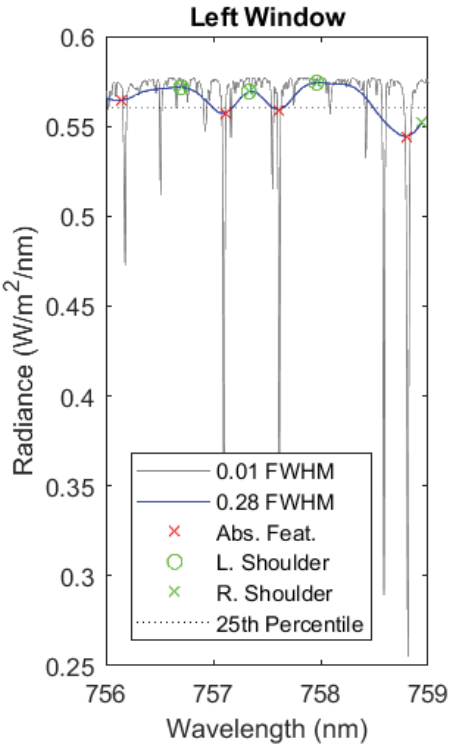
- Solar features simulated from fine-resolution (0.01 FWHM) solar spectrum ***outside the O_2 A***
- Candidate shoulders (green) and absorption features (red) for FIREFLY and QE Pro.

FIREFLY-like (0.18 FWHM)



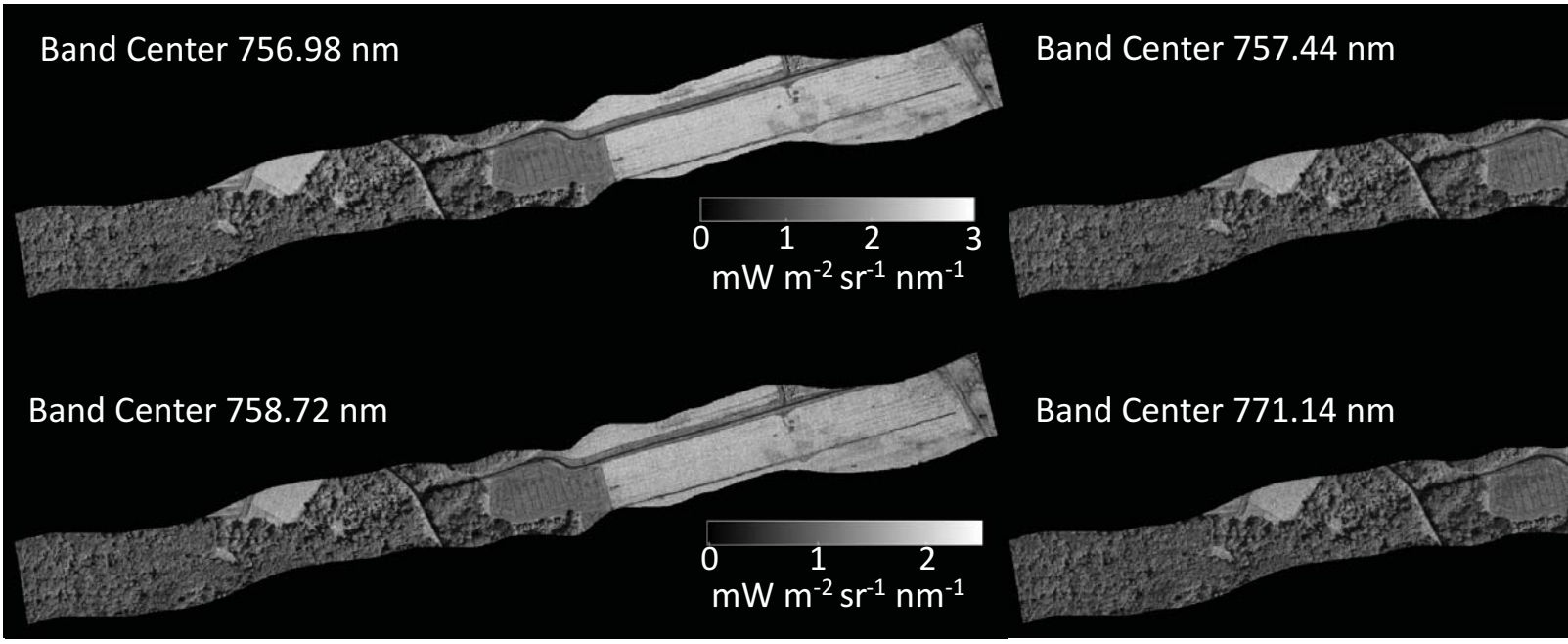


QE Pro-like (0.28



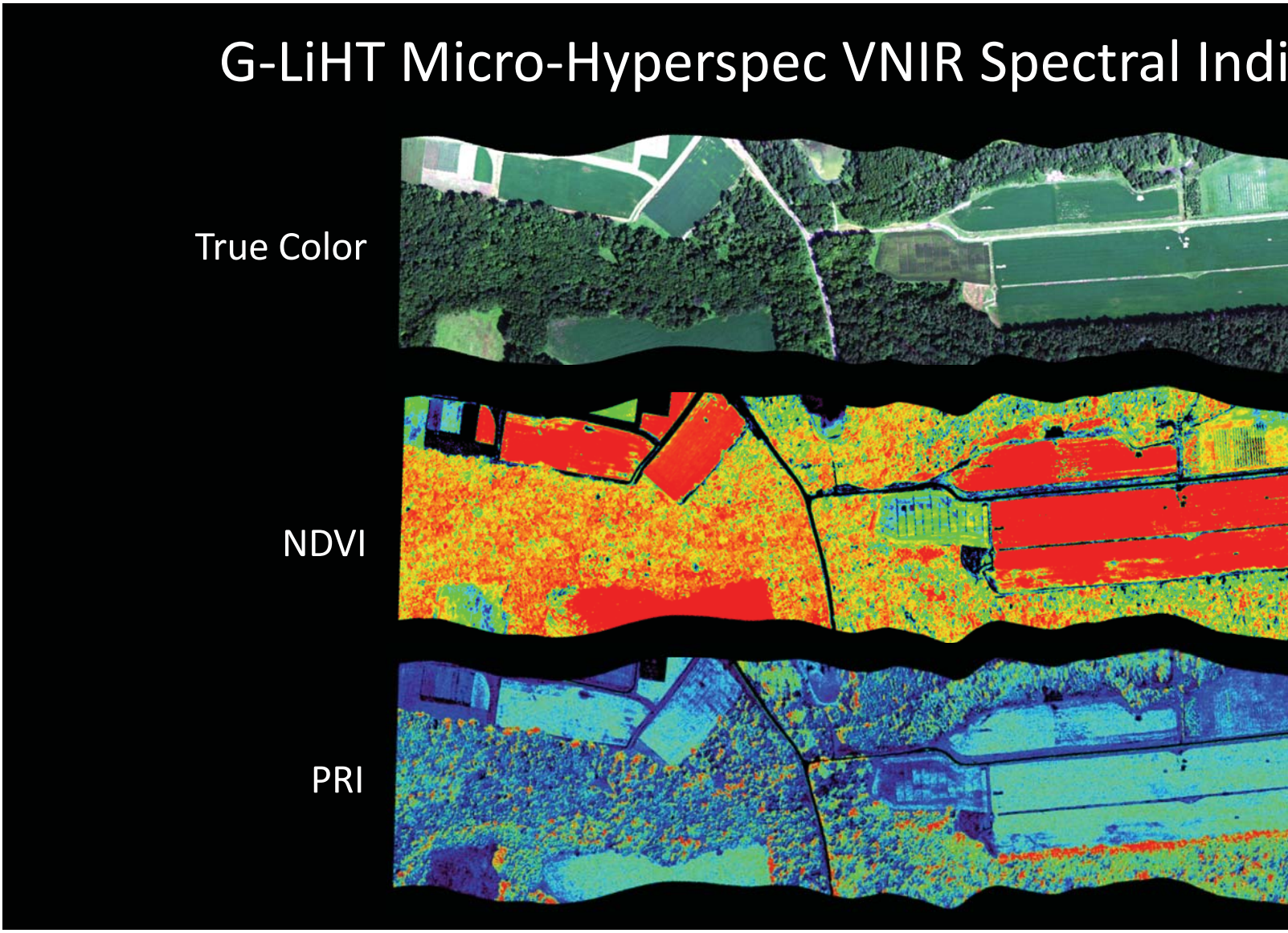
FLARE: Far-Red SIF Retrieval in Forests &

- ***Fraunhofer Line Depth (FLD)*** method using ***solar features outside the O_2 A-band***, avoiding complications due to T, P, O_2, H_2O and cloud and aerosol particulates.
- Maps created with ***four different solar features*** show similar spatial trends with h



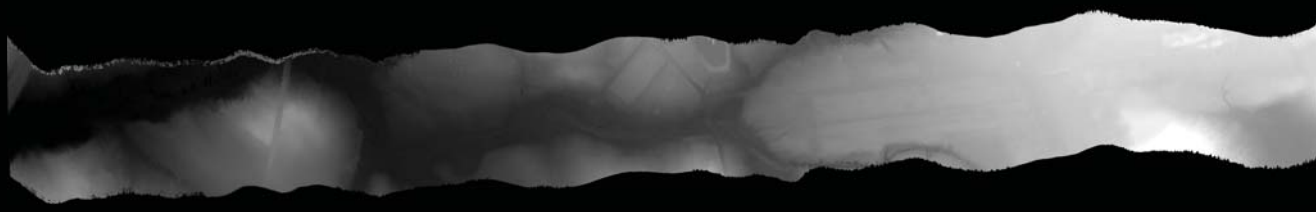
USDA Beltsville Agricultural Research Center (BARC), Maryland
Optimizing Production inputs for Economic and Environmental Enhancement (OPE^3)

G-LiHT Micro-Hyperspec VNIR Spectral Indi

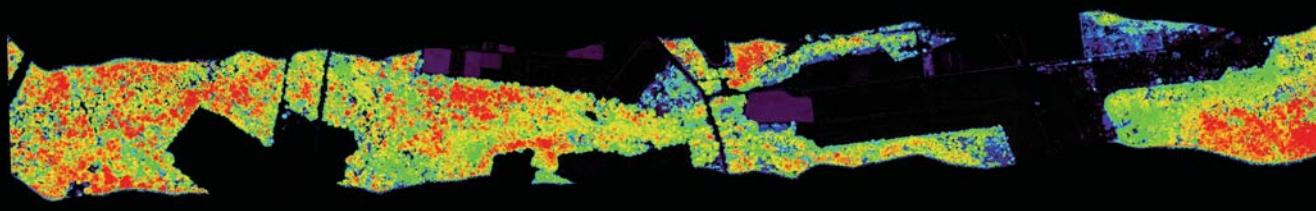


LiDAR Products

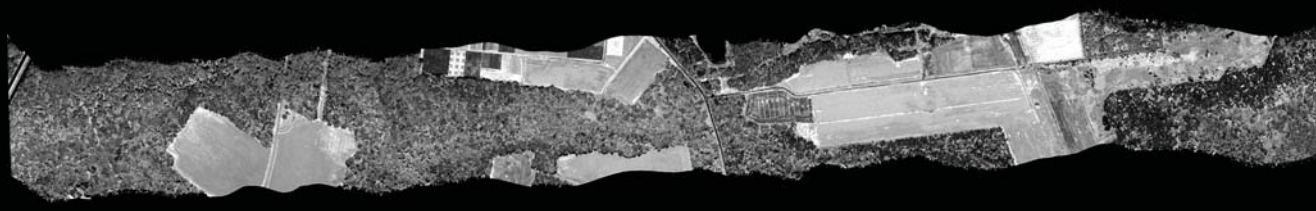
Elevation



Canopy height



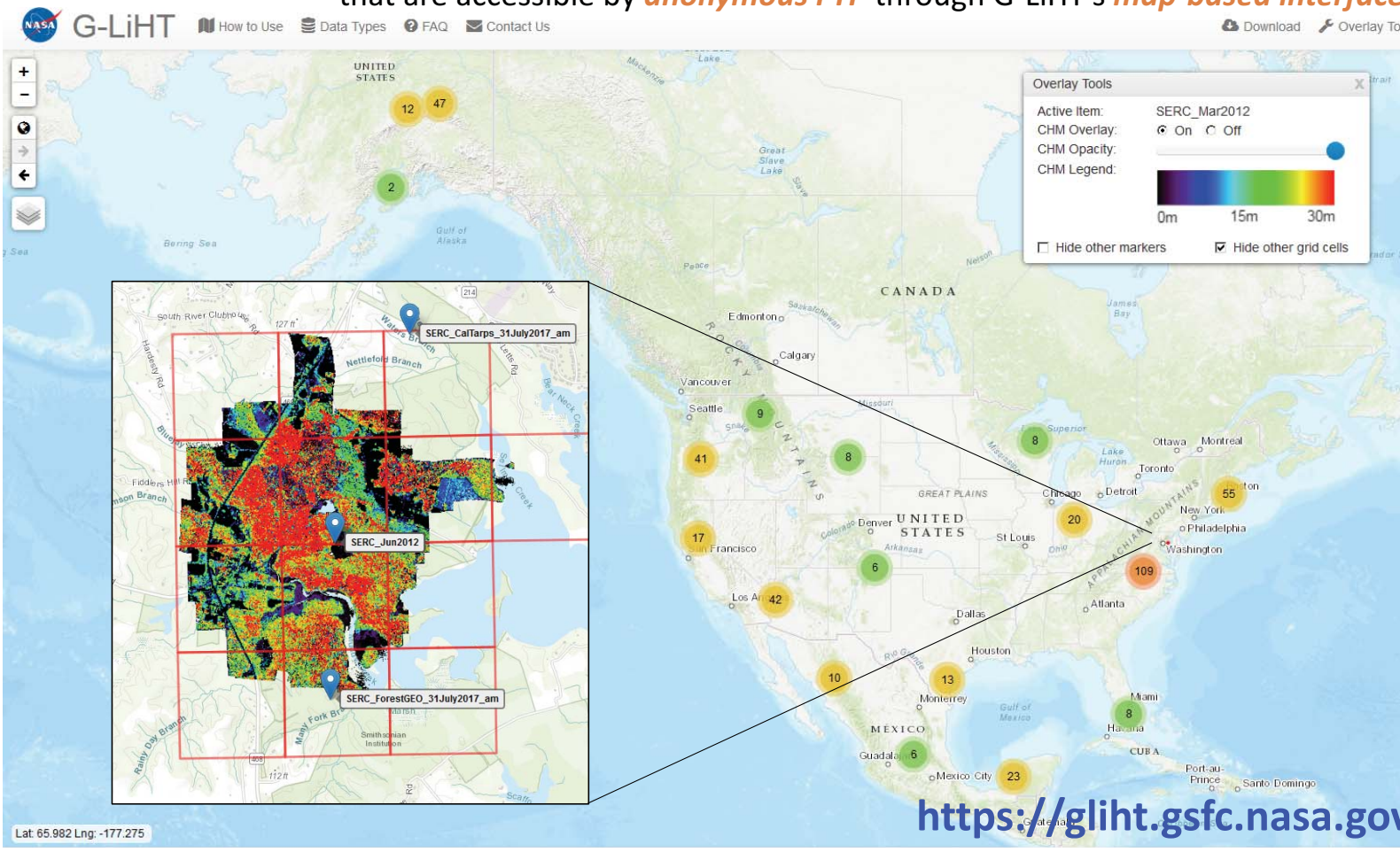
Apparent reflectance (1550 nm)



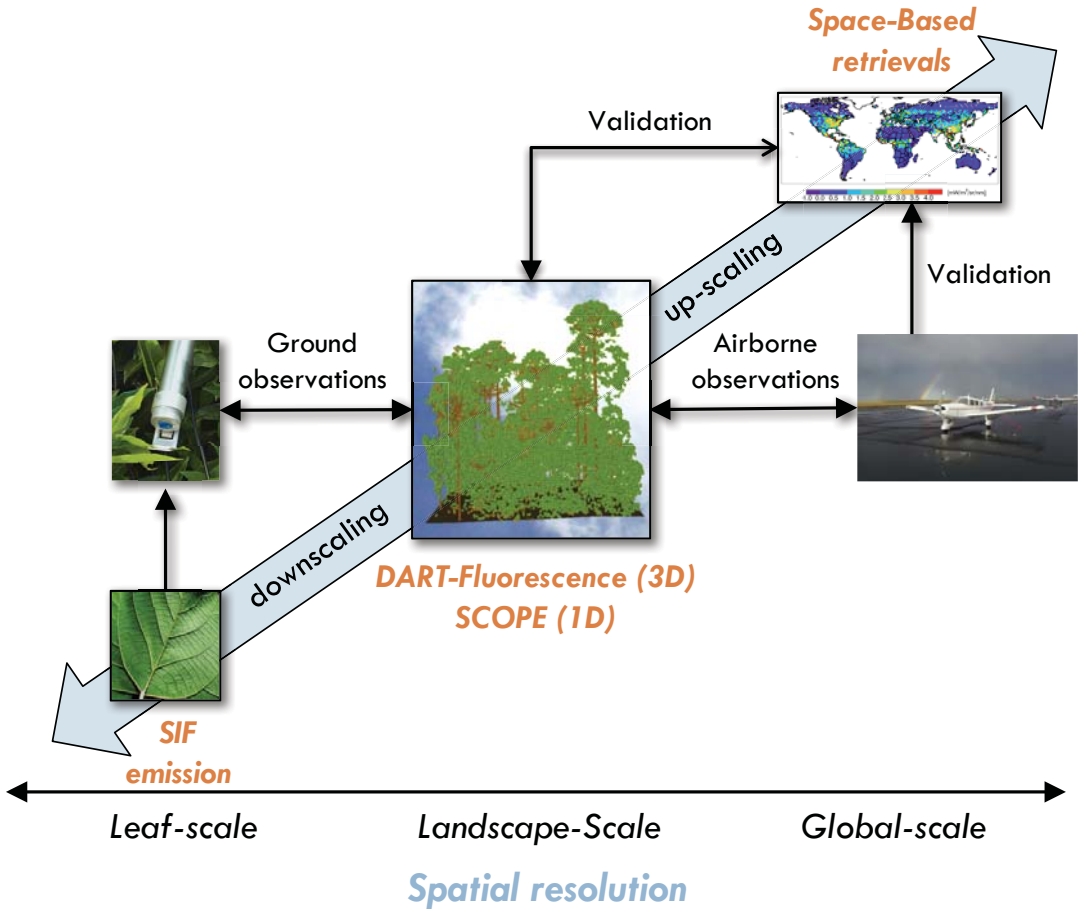
G-LiHT Open Access Data Server

L1 through L3 data products shared with the science community in ***user friendly fo***

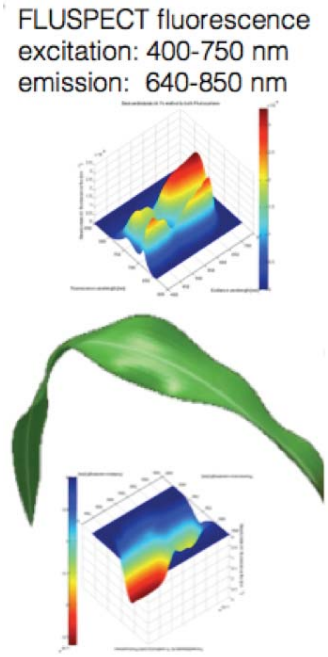
that are accessible by ***anonymous FTP*** through G-LiHT's ***map-based interface***

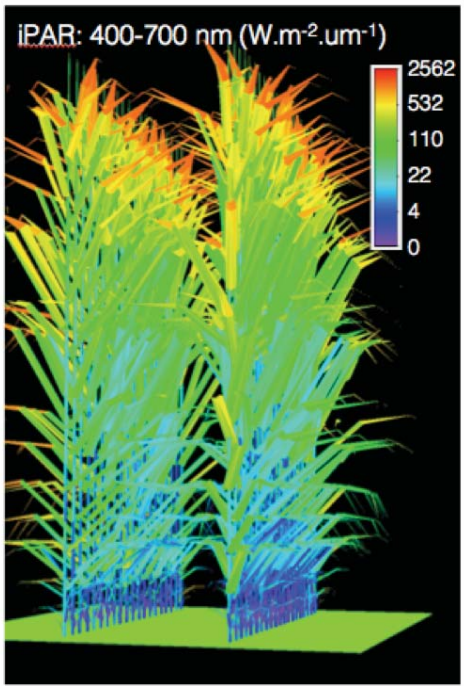


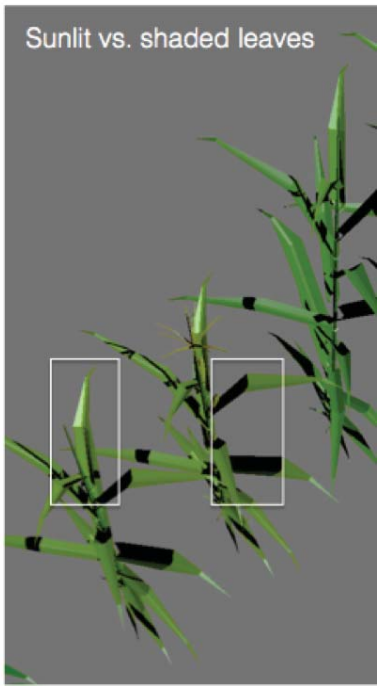
FLARE: Integrating Observations & Models t



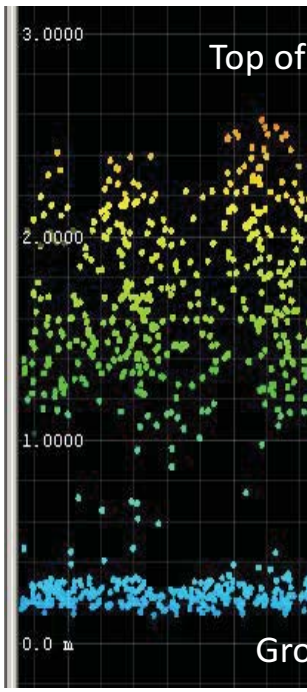
DART-Fluorescence







G-LiHT LiDAR Corn C



Z. Maler

- The DART-Fluorescence 3D radiative transfer model includes:
  - ✓ implementation of ***FLUSPECT*** leaf radiative transfer model;
  - ✓ spatially explicit distinction of ***sun and shade adapted leaves*** based on iPAR; and
  - ✓ adjustment of fluorescence efficiency and optical properties according to ***light a***

G-LiHT Multi-Sensor Inputs for SIF-GPP

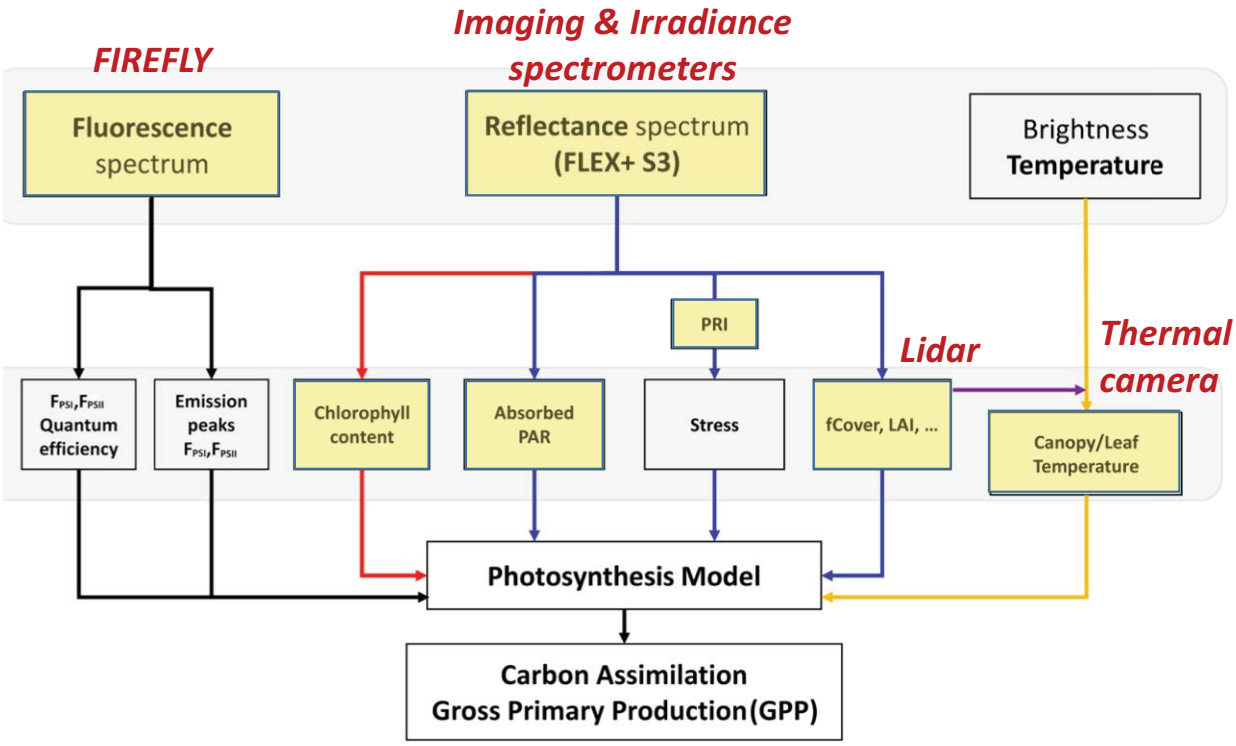


Figure 6.6. Advanced photosynthetic and carbon assimilation products that can be derived from the fluorescence spectra, the surface reflectance spectra and the brightness temperature Level-2 products. (University of Valencia)

Take-Home Message

1) ***G-LiHT v2.0*** is a ***complete airborne package for measuring and interpreting S*** allowing us to ***up/down-scale from leaf-to-canopy-to-space*** using 3D radiativ models, and ***account for multiple energy pathways in photosynthesis models***

2) FIREFLY's spectral resolution and out-of-band response has been characterize GLAMR calibration facility, and ongoing calibration is being used to evaluate ***n***

3) FLARE is a HQ-funded field campaign designed to ***support NASA-ESA collabor*** and advance the ***science basis for interpreting the SIF signal in different biom***

   a) G-LiHT measurements in Puerto Rico and Florida during March 2017 provide the ***fi*** ***resolution (1 to 2 m) airborne SIF measurements in tropical and subtropical fores***

   b) SIF Retrieval methods are being evaluated in ***temperate forests*** and ***agricultural re*** the Eastern US, and laboratory exchanges will allow us to compare methods & resu

   c) Planning is underway for a ***airborne campaign in high-altitude forests*** (AK) during an opportunity for a coordinated campaign with others.