FLuorescence Airborne Research Experiment

FLARE in the Tropics using the Next Generation G-LiHT with FIREFLY

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Today's Talk

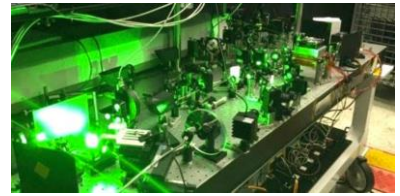
1) Next Generation G-LiHT v2.0 with FIREFLY (Cook/PI)
   - **G-LiHT** = **G**oddard's **Li**dar, **H**yperspectral and **T**hermal airborne imager
   - **FIREFLY** = **F**luorescence **I**maging of **RE**d and **F**ar-red **L**ight **Y**ield

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
   - Motivation and Objectives
   - Study Sites and Preliminary Results
     - Tropical Forests (Puerto Rico; March 2017)
     - Temperate Forests (SERC, MD; July/Aug 2017)
   - Current and future NASA-ESA collaborations

G-LiHT v2.0

FIREFLY



GLAMR

Puerto Rico Field Crew (March 2017)

1) Next Generation G-LiHT v2.0

with FIREFLY

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

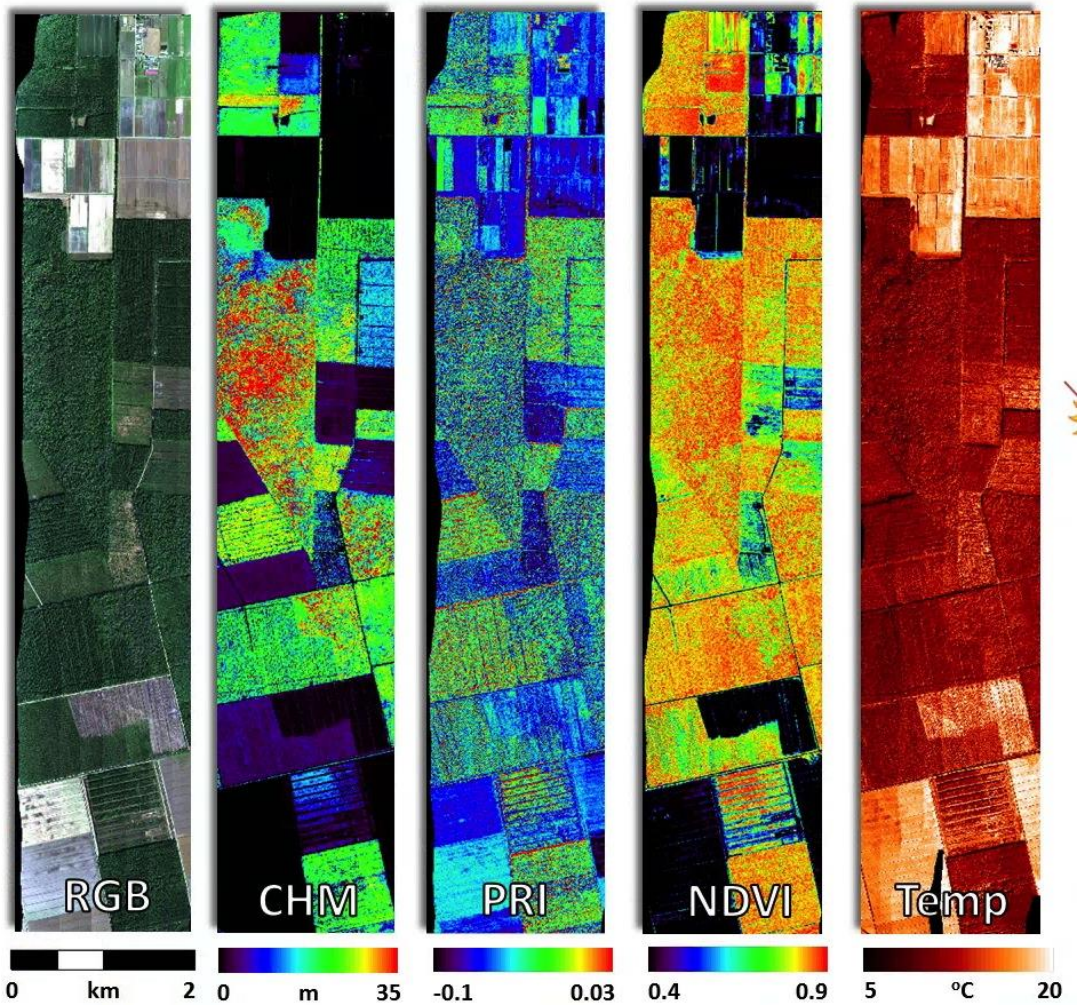
https://gliht.gsfc.nasa.gov/

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

1) ***lidar*** to provide 3D information about the spatial distribution of canopy elements;

2) ***imaging spectroscopy*** to discern species composition and variations in biophysical variables (e.g., photosynthetic pigments); and

3) ***thermal data*** to quantify surface temperatures and detect heat and moisture stress.



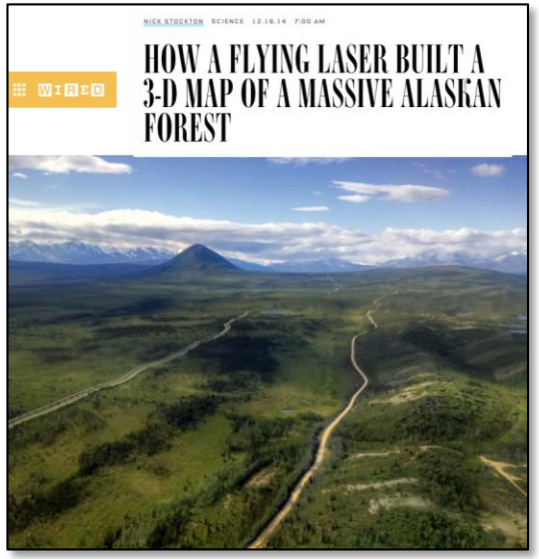
Loblolly pine plantation in lower coastal plan near Plymouth, NC

G-LiHT v2.0 with FIREFLY

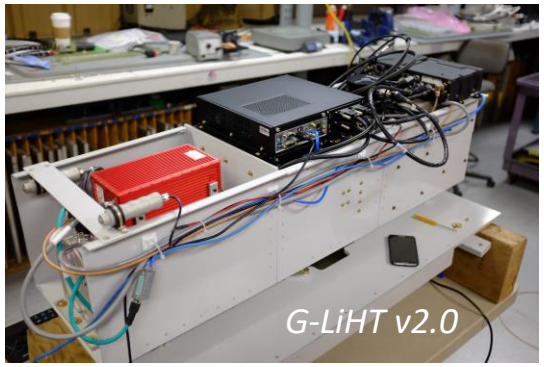
- *USFS contributed $250k to the upgrade of G-LiHT* in support of a 10-year commitment to inventory forests of interior AK.

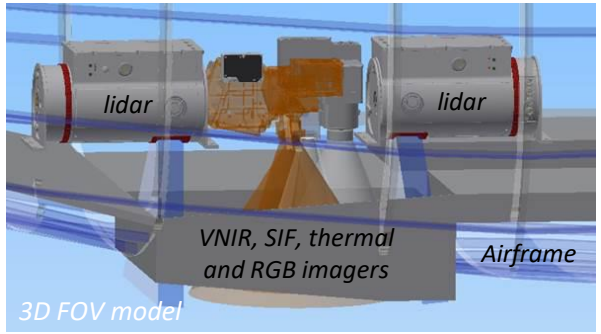
- *GSFC Code 610 contributed $80k to the design of FIREFLY*, an new imaging spectrometer for retrieving Solar-Induced Fluorescence (SIF).

- G-LiHT v2.0 provides *improved image data* and *redundancy* for large campaigns:
  - *LiDAR* – longer ranging, higher PRF and sampling density
  - *VNIR Imaging spectrometer* – 10x SNR, temp-controlled focal plane
  - *VNIR Irradiance spectrometer* – thermally stabilized detector
  - *Thermal camera* – 2x greater spatial resolution, 2x greater frame rate
  - *Fine-resolution RGB camera* – stereo images at ~4 cm GSD
  - *FIREFLY imaging spectrometer* (Headwall Photonics) and *fine-resolution irradiance spectrometer* (Ocean Optics QE Pro) for SIF retrievals



http://www.wired.com/2014/12/alaska-laser-survey-3d-map/

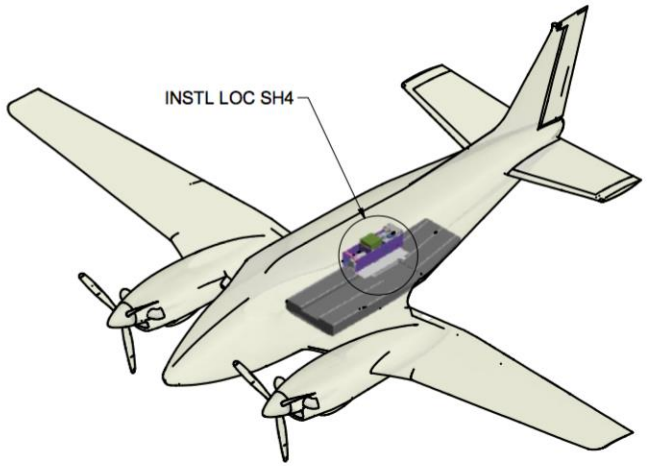




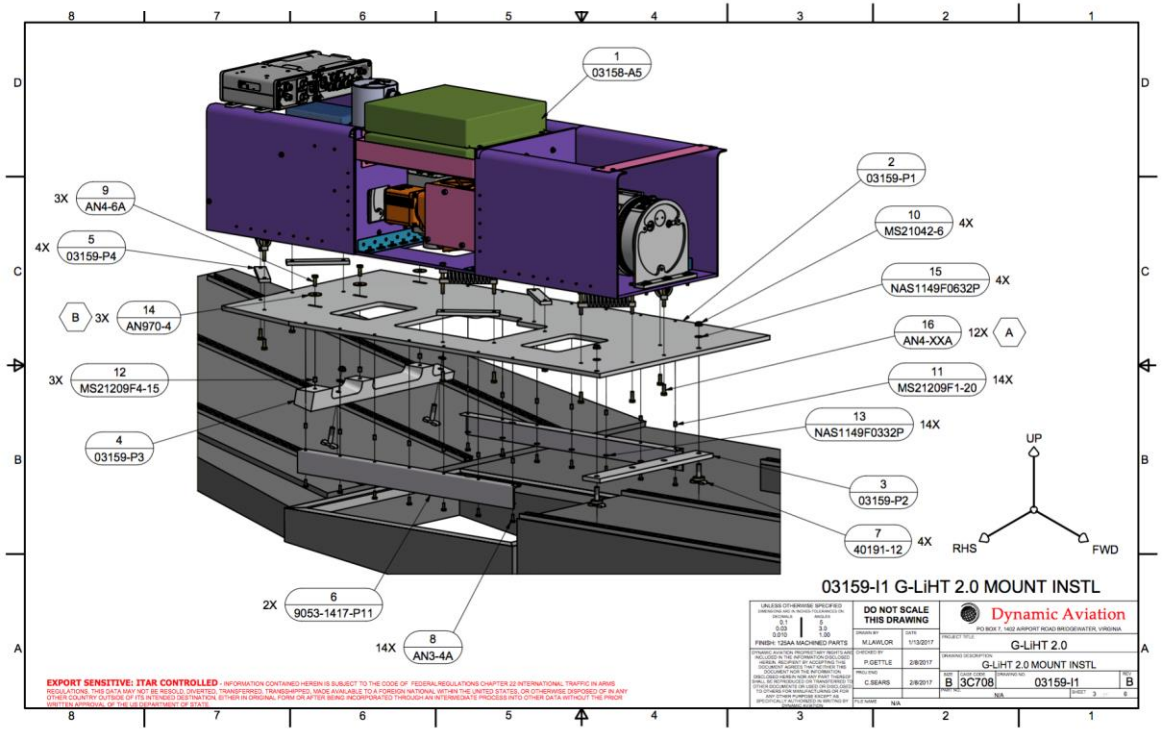
G-LiHT–Aircraft I&T

- 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

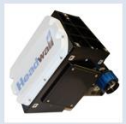



G-LiHT v2.0 w/new instrument housing installed on King Air



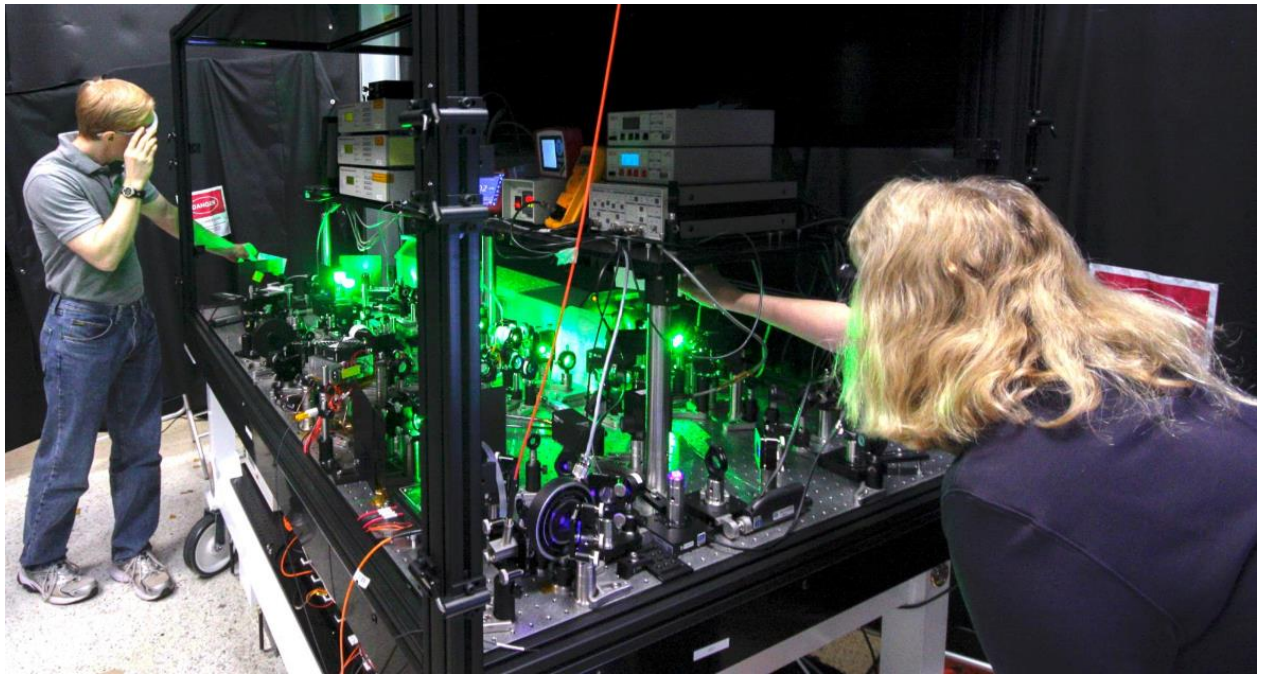
FIREFLY: Fluorescence Imaging of REd and Far-red Light Yield

- FIREFLY is a compact, fine-resolution, imaging spectrometer (1 m GSD, ≤0.2 nm FWHM) for retrieving SIF in the red and far-red spectral range (670 to 780 nm)
- Designed in partnership with Headwall Photonics (Fitchburg, MA); commercially available in 2017
- Other commercial/research airborne SIF imaging spectrometers in use:

	AisaIBIS (aka HyPlant) *Jülich, Germany*	**FIREFLY** *NASA GSFC*	**CFIS** *NASA JPL*
Manufacturer	 Specim, Finland	 Headwall Photonics, USA*	 NASA JPL
Measurement specs: • *Spectral range* • *Bandwidth (FWHM)*	*670 to 780 nm* *0.2 to 0.3 nm*	*670 to 780 nm* *≤0.2 nm*	738 to 772 ~0.1 nm
Purpose	*ESA FLEX studies* • red & far-red bands • 1 m spatial resolution	*FLEX* and *CC&E studies* • red & far-red bands • 1 m spatial resolution	*NASA OCO-2 validation* • far-red band only • coarser spatial res.
Maiden flight	2012	2017	2015
Co-Manifested instruments	• AISA-FENIX *VSWIR*	NASA G-LiHT: • *Lidar* • *VNIR* • *Thermal*	---
Calibration & Characterization	*GLAMR* (GSFC facility)* (tunable lasers, NIST traceable, ~0.5% accuracy)		Traditional lamp-based (~3% accuracy)

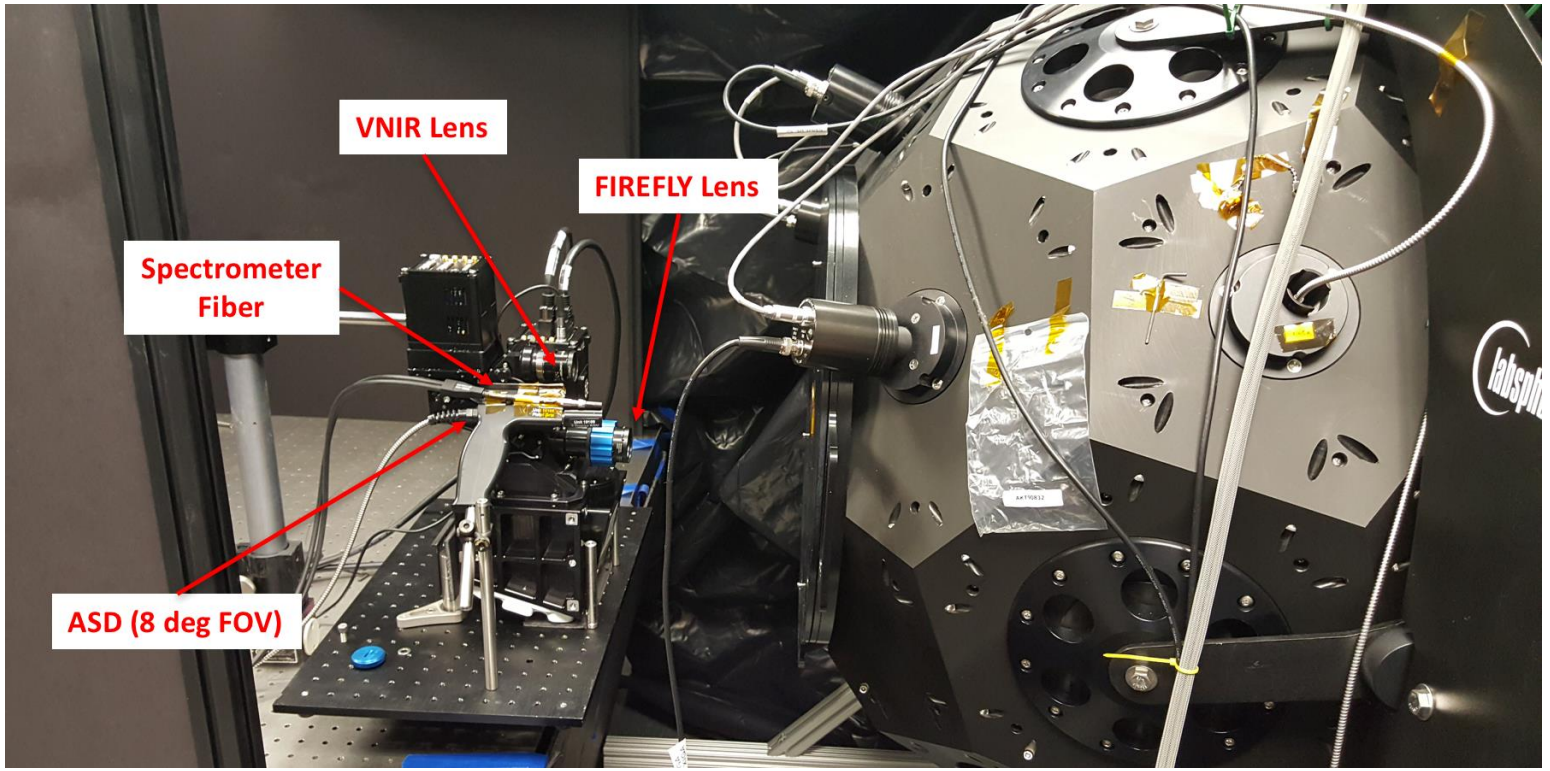
G-LiHT's multi-sensor approach is critical to interpreting SIF (e.g., canopy reabsorption, non-photosynthetic quenching)

* *Supported in part by GSFC Internal R&D funds*



2) FIREFLY Characterization with GLAMR

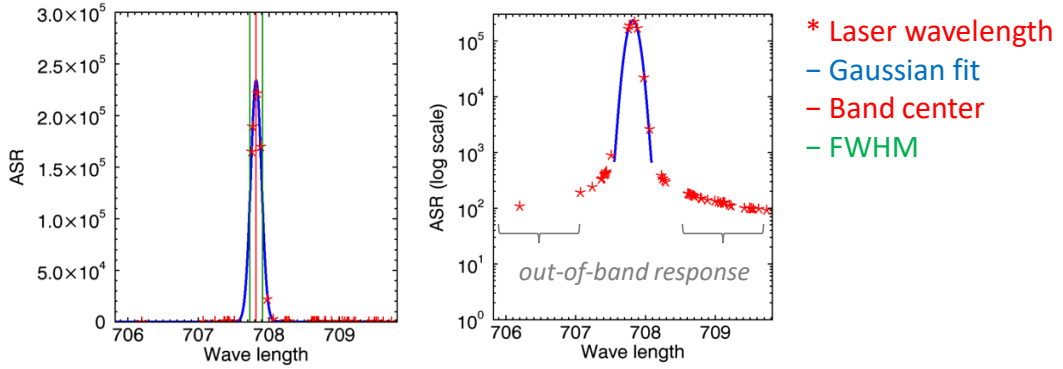
GLAMR Setup and Narrowband Scans



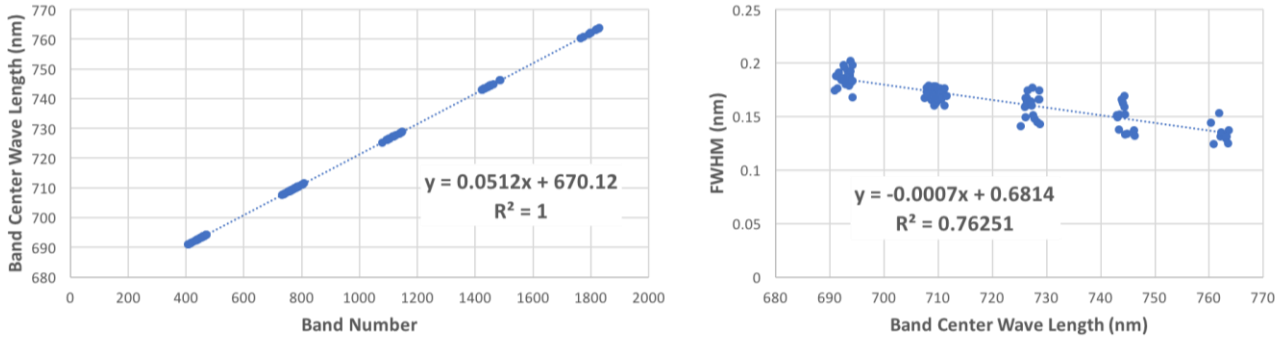
- Ti: Sapphire laser
- NIST transfer radiometer
- Acquired data in five regions:
  - 690-694.5 nm
  - 707-711.5
  - 725-729.5
  - 742-746.5
  - 760-764.5
- 0.05 to 0.15 nm step sizes
- Alternating 10 s light, 10 s dark

GLAMR Results

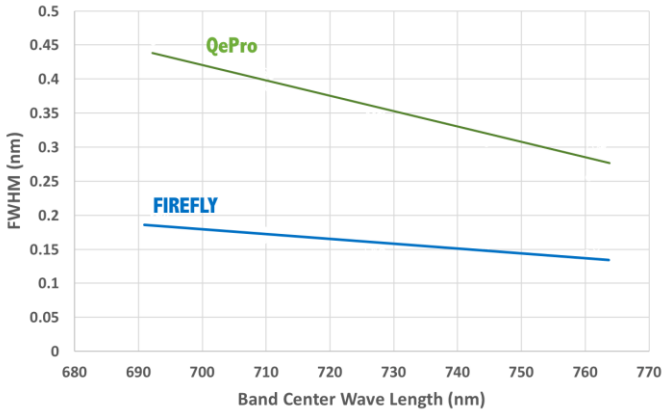
- E.g., Absolute Spectral Response (ASR) for single pixel:



- FIREFLY calibration results:



- FIREFLY vs. Ocean Optics QE Pro:



QE Pro is a common field spectrometer for measuring SIF, but compared to FIREFLY:

- spectral resolution was twice as coarse
- dark noise was greater (not shown here)

3) FLARE Field Campaign

Puerto Rico

FLARE is a NASA-ESA Collaboration on FLEX

MOTIVATION

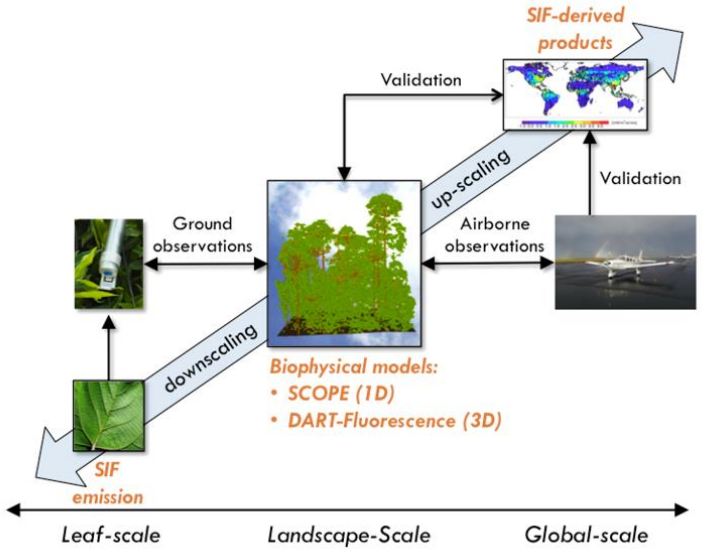
Fluorescence Explorer (FLEX)

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

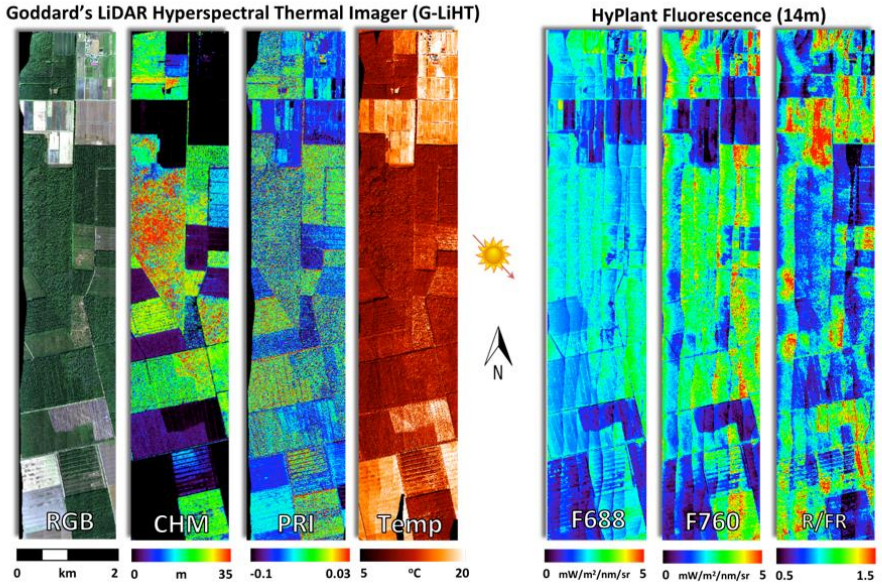
Coordinated NASA & ESA field campaigns will:

- 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 interpretation of SIF



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



FIELD CAMPAIGNS

Tropical Forest (March 2017):

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

Mid-Latitude Broadleaf Deciduous Forest (July 2017)

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

Airborne & Ground Measurements:

- AM/Noon/PM on 3 different days with *G-LiHT* & *FIREFLY*
- Continuous leaf-level SIF, optical properties, photosynthesis

Puerto Rico Science Objectives

Primary measurement
Secondary measurement

1) Validate FIREFLY radiometry and SIF retrievals (tarps, grass);

2) Obtain enough measurements to parameterize DART-Fluorescence and SCOPE models to simulate SIF emissions in tropical forests (leaf optical properties, vegetation structure).

3) Compare diurnal SIF emissions from different plant functional types (G-LiHT w/FIREFLY; Fluo-Wat); and

4) Compare SIF emissions for different stand ages and environmental conditions (soils, climate) (G-LiHT w/FIREFLY).

Puerto Rico Airborne-Ground Field Campaign (March 2017)

FLARE
FLuorescence Airborne Research Experiment

NASA's Fluorescence Airborne Research Experiment (FLARE)

NGEE – TROPICS
NEXT GENERATION ECOSYSTEM EXPERIMENTS - TROPICS

US-DOE Next Generation Ecosystem Experiments - Tropics

50 Science flight hours
20 TB raw data

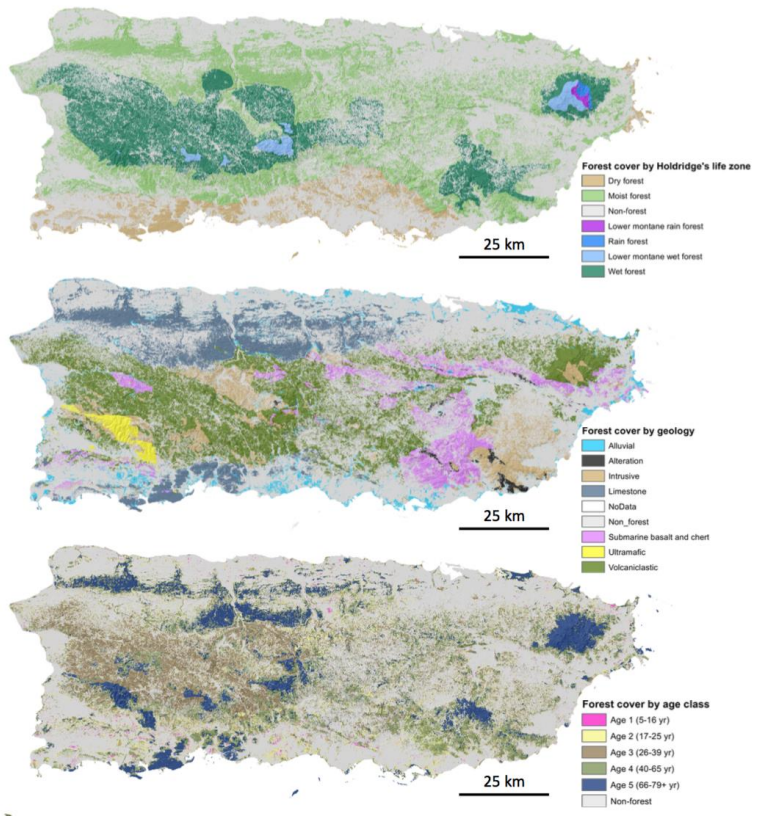
Next Generation Ecosystems (NGEE) - Tropics

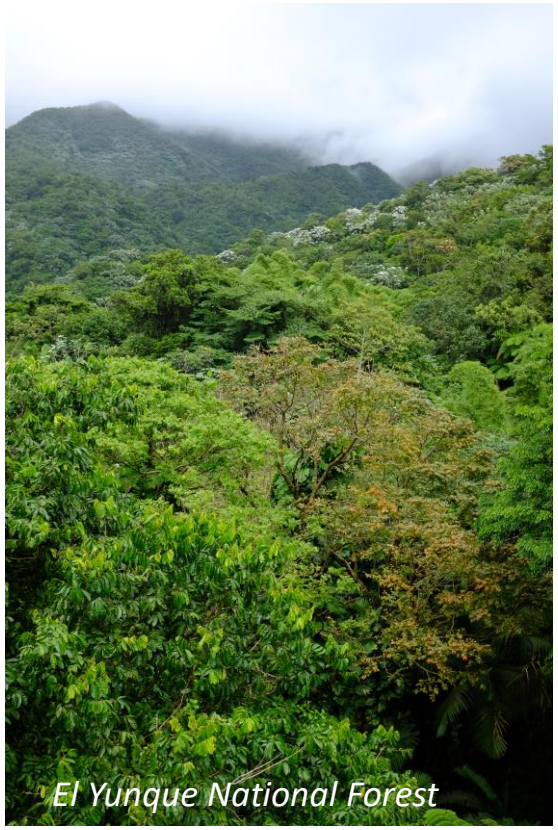
Michael Keller (PI), Douglas Morton, Bruce Cook, Sebastian Martinuzzi

Holdridge Life Zones

Geology

Age class

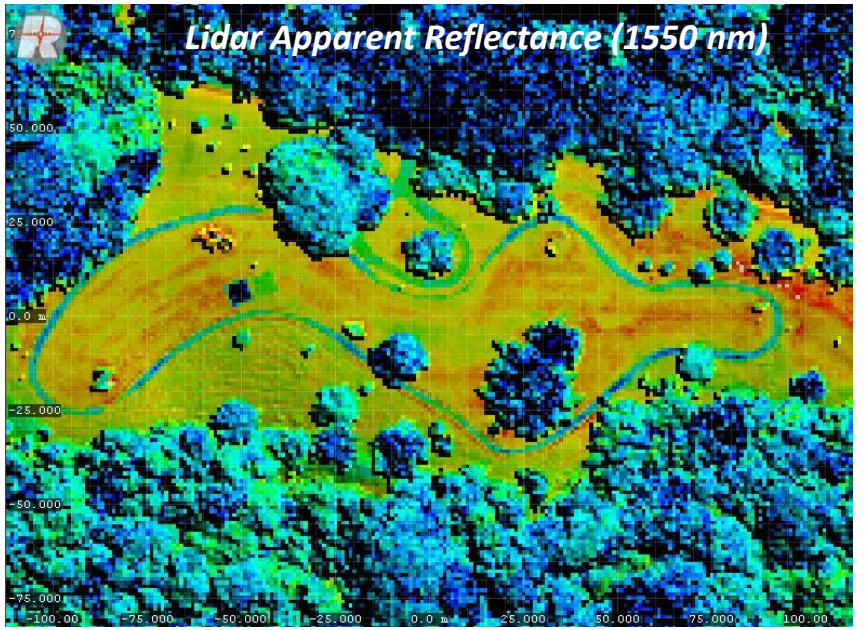


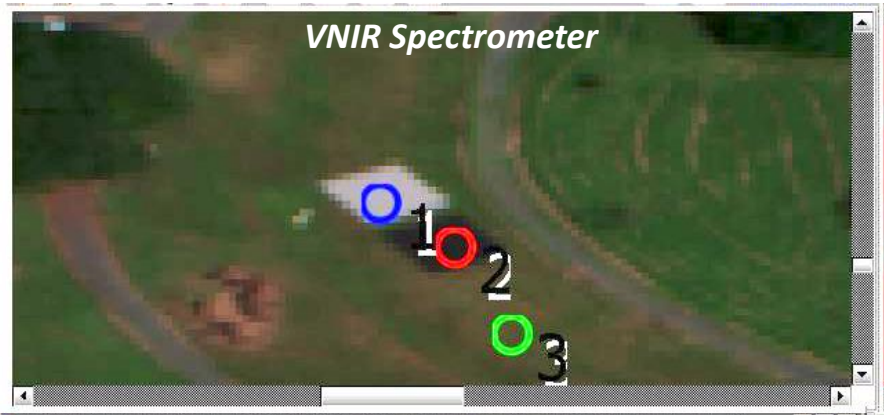


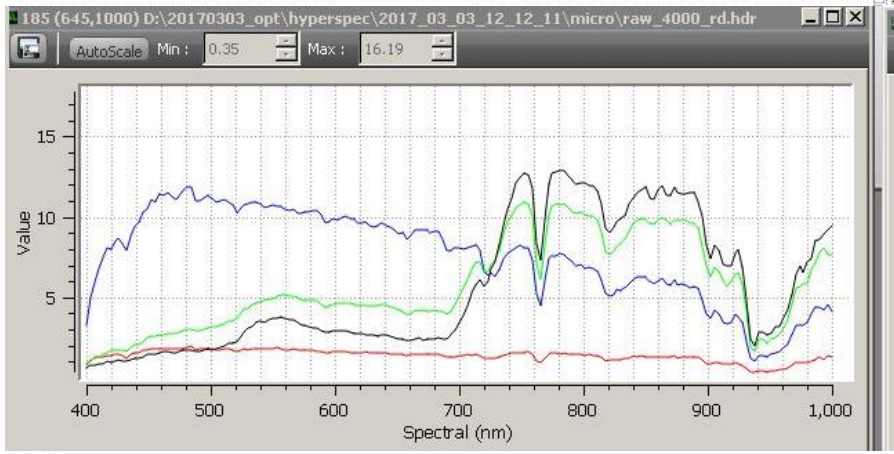
- NGEE-Tropics is a $25M US-DOE project designed to determine if tropical forests will act as net carbon sinks through the 21st Century
- G-LiHT data collected during 2017 will be used to predict growth rates of secondary tropical forests as a function of soils, climate, and land use history.

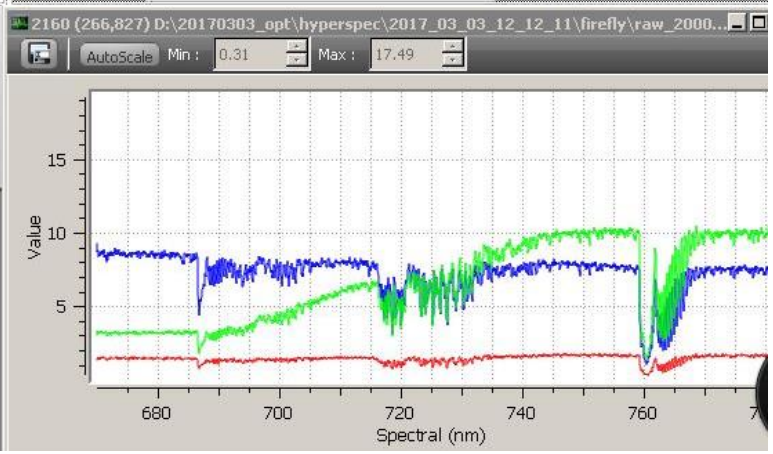
G-LiHT Airborne Observations

1) Calibration tarps, vegetation 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, Smithsonian and university ground plots (island-wide)

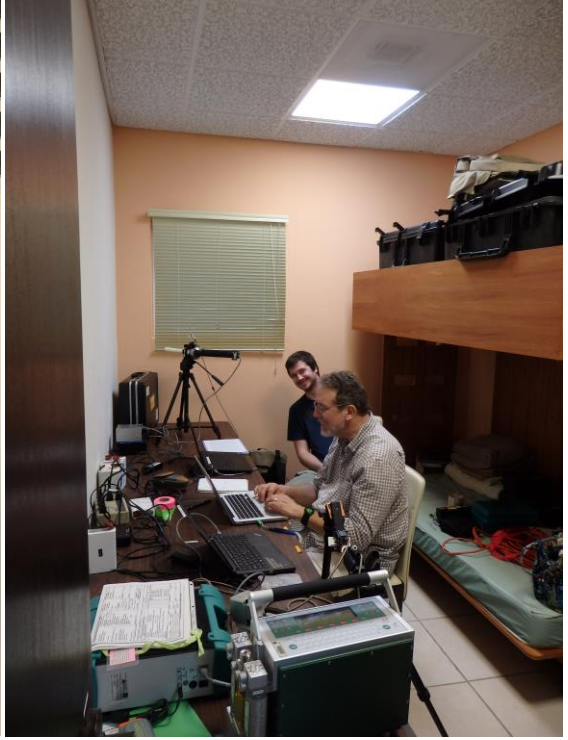






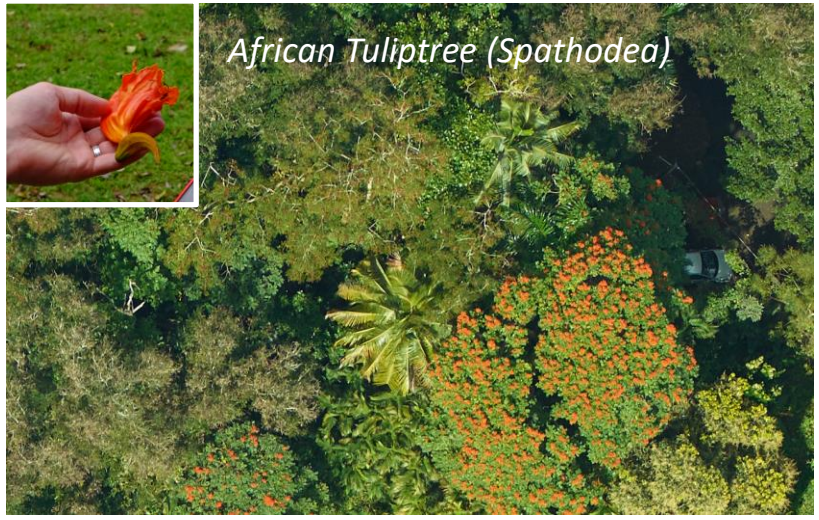


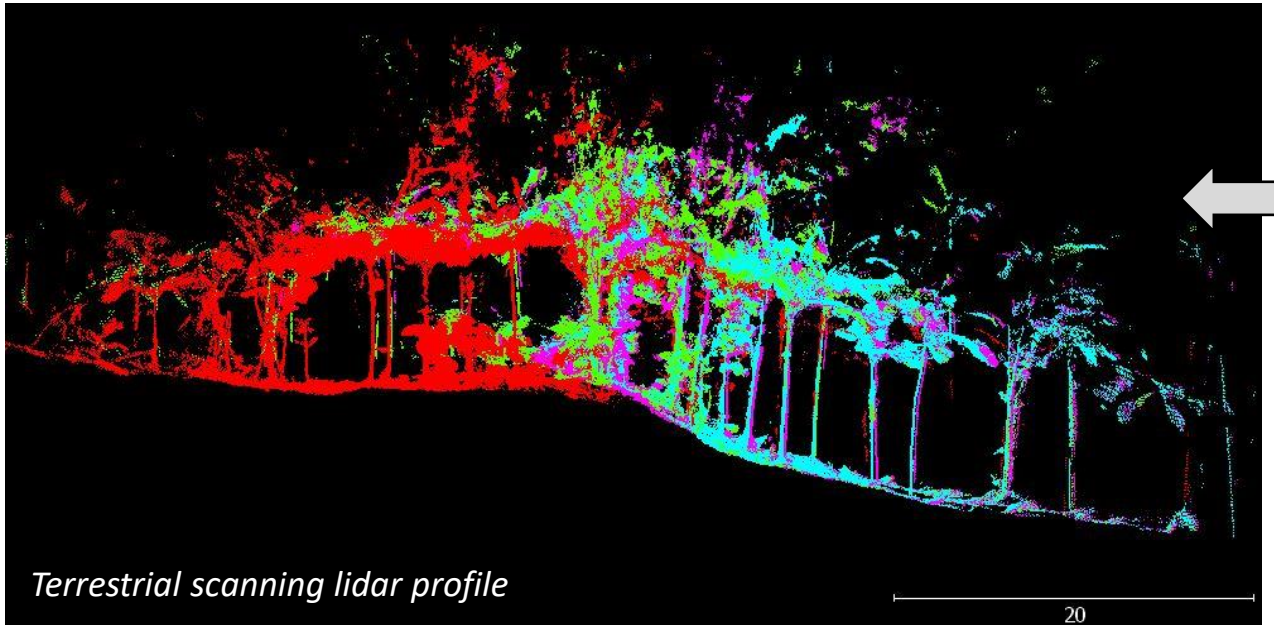




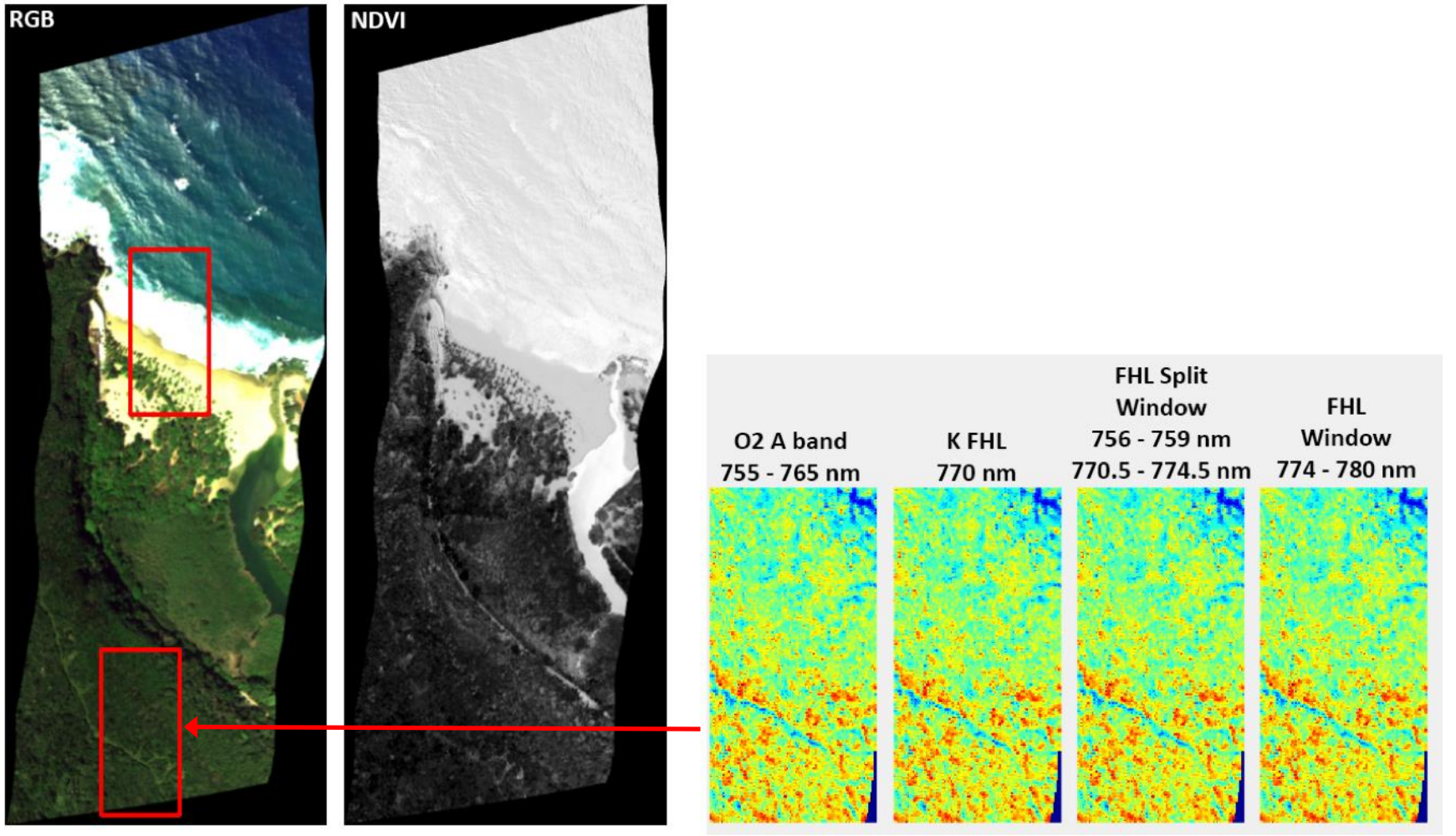


Vegetation Structure in Complex Canopies





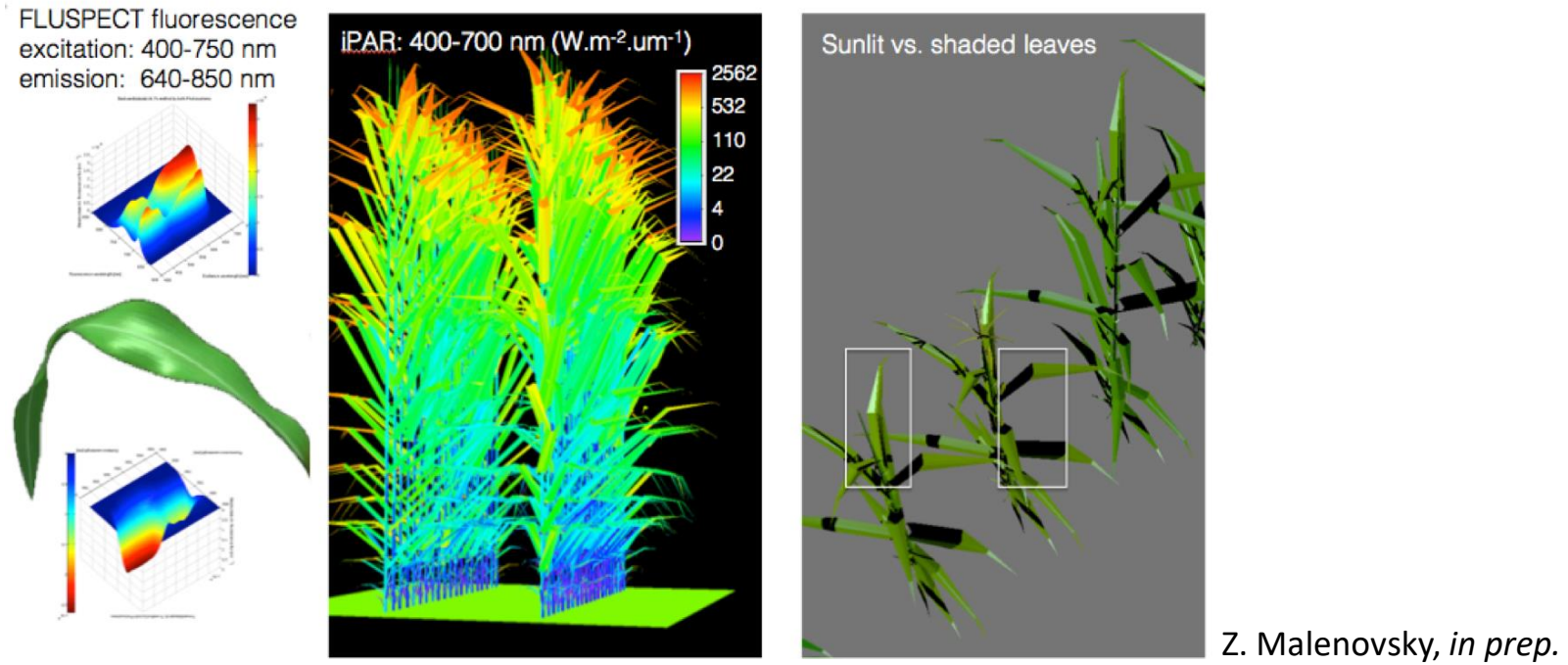
SIF Retrieval Example



Different retrieval methods show similar spatial patterns

Ian Paynter, 618/Biospheric Sciences (B33, A107)

DART-Fluorescence



Z. Malenovsky, *in prep.*

- 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 adaptation***.

Take-Home Message

1) G-LiHT v2.0 is currently the most complete airborne package for measuring and interpreting SIF emissions in complex forest canopies, allowing us to up/down-scale from leaf-to-canopy-to-space using sophisticated 3D radiative transfer models.

2) FIREFLY's spectral resolution and out-of-band response has been measured using NASA's GLAMR laser calibration facility, and will be used to determine SNR of SIF retrievals.

3) FLARE is a HQ-funded field campaign designed to support NASA-ESA collaboration on FLEX, and advance the science basis for interpreting the SIF signal in different forest biomes.

    1) G-LiHT measurements in Puerto Rico and Florida during March 2017 provide the first, fine-resolution (1 to 2 m) airborne SIF measurements in tropical and subtropical forests.

    2) G-LiHT measurements will be acquired in temperate forests of New England (USFS Forest Heath Survey; June 2017) and Smithsonian Environment Research Center (Edgewater, MD; July 2017).

4) Planning is underway for a coordinated NASA-ESA airborne campaign in high-altitude forests with G-LiHT, HyPlant and CFIS during 2018.