GOES-R Near Surface UAS Feasibility Demonstration Study

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NOAA/NESDIS
GOES-R Program

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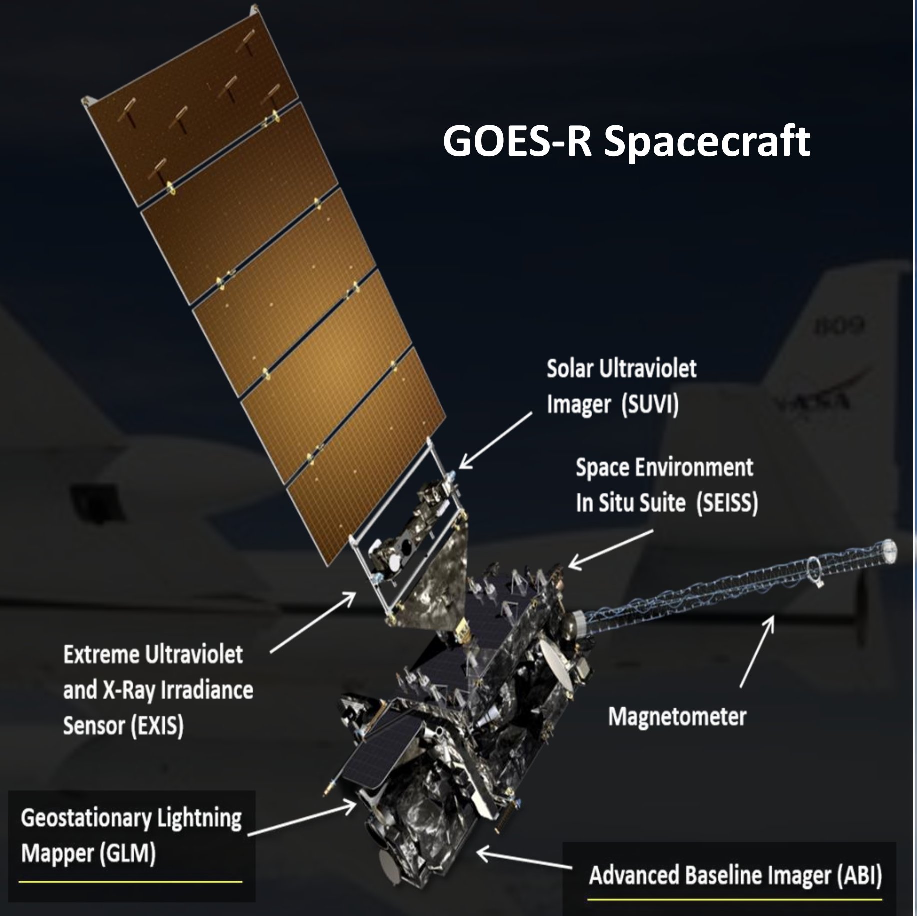
GOES-R Field Campaign Overview

The purpose of the GOES-R field campaign is to support post-launch validation of L1b & L2+ products:

- **Advanced Baseline Imager (ABI) & Geostationary Lighting Mapper (GLM):**
  - Planning ~6 week field campaign (~100 flight hours) with the high-altitude NASA ER-2 platform coordinated with ground based and near surface observations over several Earth targets
  - Time-Frame :
    - April – June 2017
  - An open access data portal will provide all validation datasets acquired during the campaign



[Padula et al. SPIE 2016]

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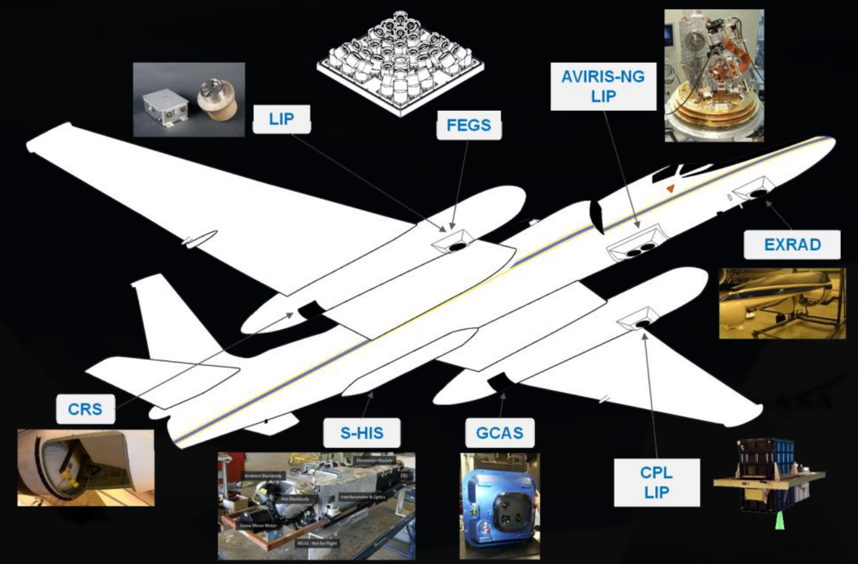
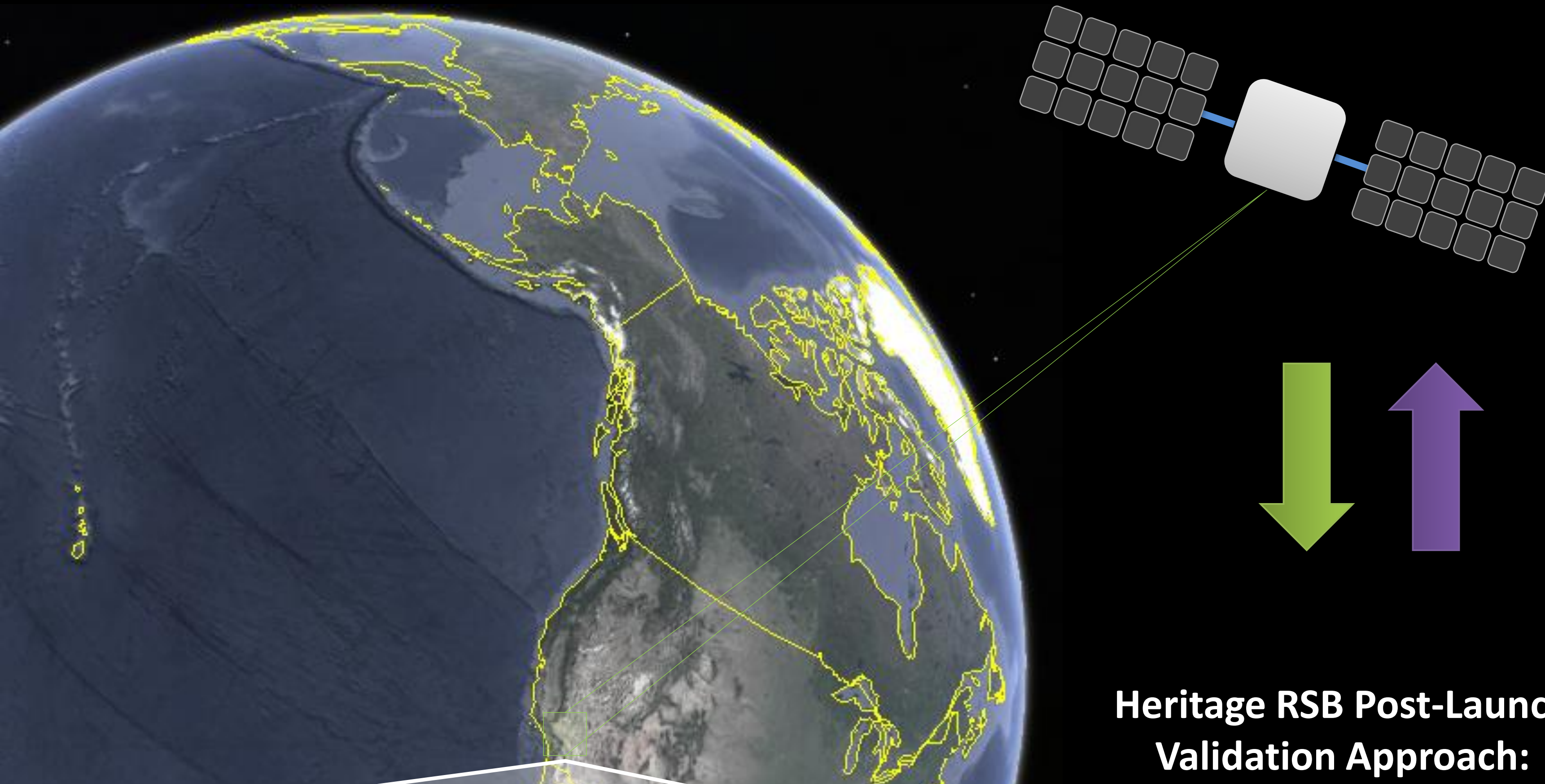
GOES-R Field Campaign ER-2 Based Instruments



[Padula et al. SPIE 2016]

High to Moderate Resolution Satellite Sensors Leverage Small Uniform Earth Targets for Post-Launch Validation

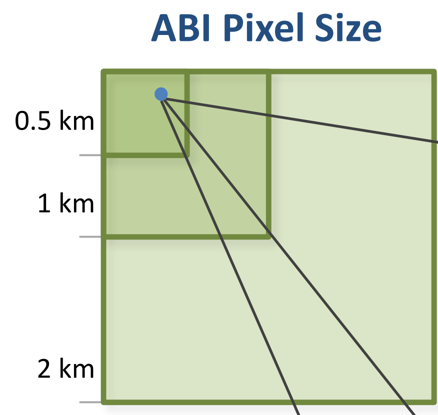


Heritage RSB Post-Launch Validation Approach:

Collect high quality surface reference data that is directly compared to satellite observations

Post-Launch Validation Challenges & Gaps for Low Resolution Environmental Satellite Sensors

- **Challenging to provide high quality data that can be directly compared to satellite observations without gross assumptions (i.e. uniformity):**
  - Ground validation measurements are typically point-based measurements
  - Often need to disturb the collection environment to make the measurements
  - Labor intensive
  - Costly (typically involves a large team)
  - Repeatability can be challenging
  - Limited collection geometry



- **Currently no operational capability to measure goniometric observations over regions comparable to environmental satellite observations**
- **Difficult to collect observations of extended regions**

Development of Advanced Post-Launch Validation Capabilities: Near Surface UAS Measurements

GOES-R Funded: “GOES-R Near Surface UAS Feasibility Demonstration Study” - NOAA Cooperative Institute Partnership with the University of Maryland (UMD) in collaboration with the NOAA UAS Program

Scope: Develop prototype UAS & assess the feasibility of near surface validation reference measurement capabilities in support of GOES-R Field Campaign validation efforts (L1b/L2+)

Phase 1: Procurement/Development & Integration of Prototype Systems:

Rotary UAS

Phoenix ACE XL Specifications
Endurance: 30 minutes
Fully autonomous system
Take-off weight: 10 lbs.

Customized electronic enclosure and autonomous 2 axis gimbal

Fixed-Wing UAS

Talon120 Specifications
Length: 6′ Wingspan: 12.5′ MGTOW: 20 lbs.
Payload capacity: 2.5 lbs.
Range: 8 miles LOS
Endurance: 2.0 – 2.5 hours
Fully autonomous system
Typical operating alt.: 50-500 ft. AGL; MSL up to 10,000 ft

Customized nose cone for high resolution georeferenced imagery

Collection Reference Data:

1) **Rotary UAS -** Goniometric observations & area collection

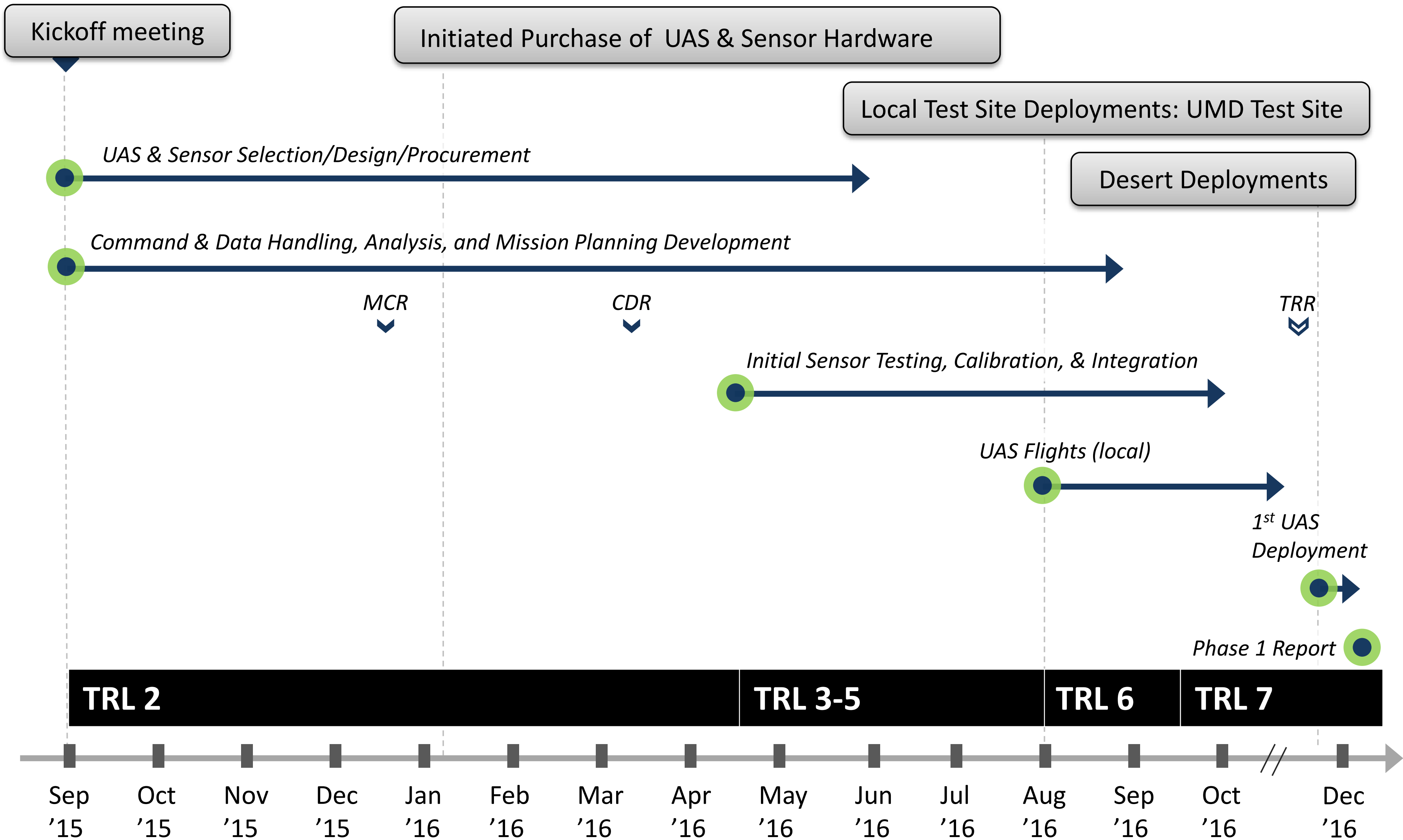
2) **Fixed-Wing UAS** – area collection

Phase 2: Capability & CONOPS Optimization

Phase 3: Intensive Field Campaign Deployment

GOES-R UAS Feasibility Demonstration Study Milestones & Schedule

Drafted & Submitted an initial set of near surface UAS science requirements to the NOAA Unmanned Aircraft Systems Program in January of 2015



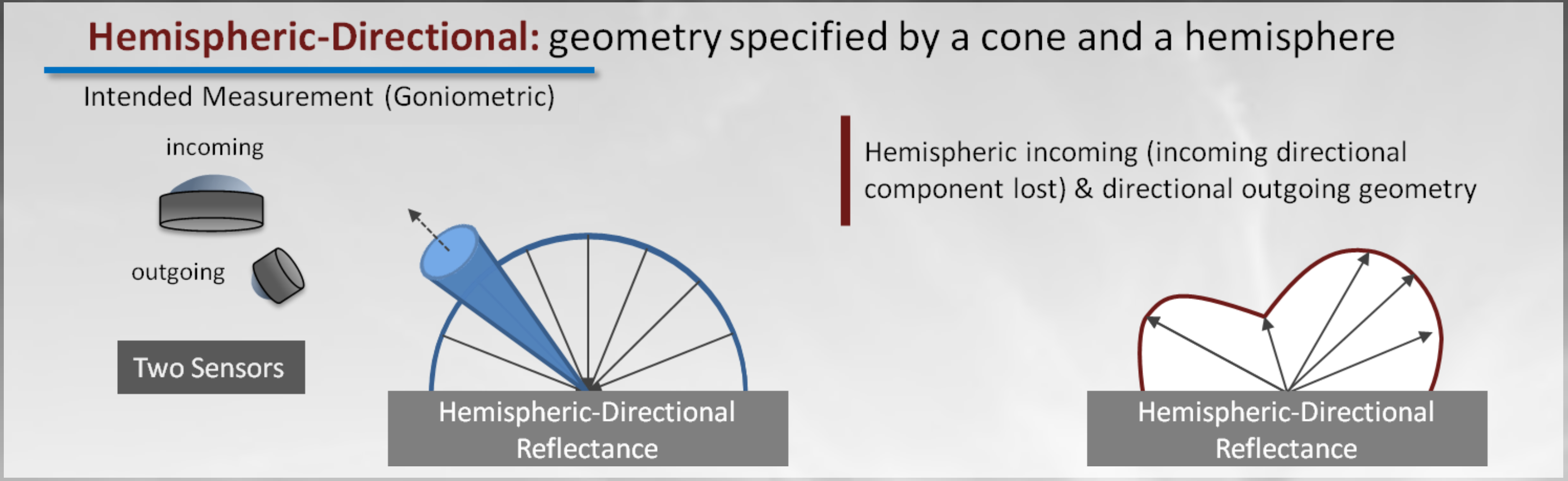
GOES-R Near Surface UAS Capability Priorities

1) Hyperspectral (0.35 – 2.5 µm) Reflective Solar Band (RSB) measurements are of highest priority

- **Upward Observation (total sky)**
- **Downward Observation (surface)**

  Ability to autonomously control the view geometry of the sensor payload(s) for oblique angle data collection of a fixed earth target: Range: 0° (nadir) to 90° (horizon) with a step size of 1° or less

  » Near surface ~10 m above ground level (i.e. assume atmosphere is negligible)



2) Broadband IR (8 – 14 µm) measurements

- **Directional Surface Observations (ideally filtered to match ABI spectral bands, primary focus ABI Bands 14-15)**

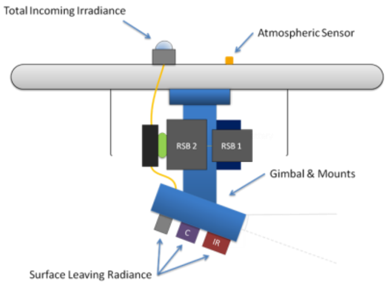
3) High resolution georeferenced imagery (NADIR & Oblique)

- **Context imagery of calibration/validation targets & Digital Elevation Model (DEM) generation**

Common Requirements for Both Systems

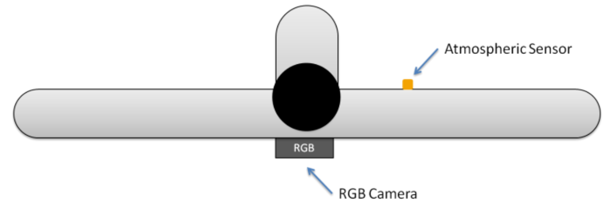
- All sensor measurements have documented SI traceable paths
- All sensor measurement uncertainties are documented and reviewed
- System design shall be flexible to integrate on multiple UAS
- UAS capable of autonomous flight through pre-programmed flight planning
- Meta data to be collected & stored (image acquisition times, sensor look angles, GPS data)

Baseline: Near Surface UAS Systems & Products



Baseline Capabilities:
- Observations over extended regions matching satellite view geometry
- Goniometric observations over a given target (directional hemispheric)

RSB 1 = Compact Hyperspectral (VNIR) Spectrometer
RSB 2 = Compact Hyperspectral (SWIR) Spectrometer
IR = LWIR Radiometer(s)
C = RGB HD Video (Context Imager)

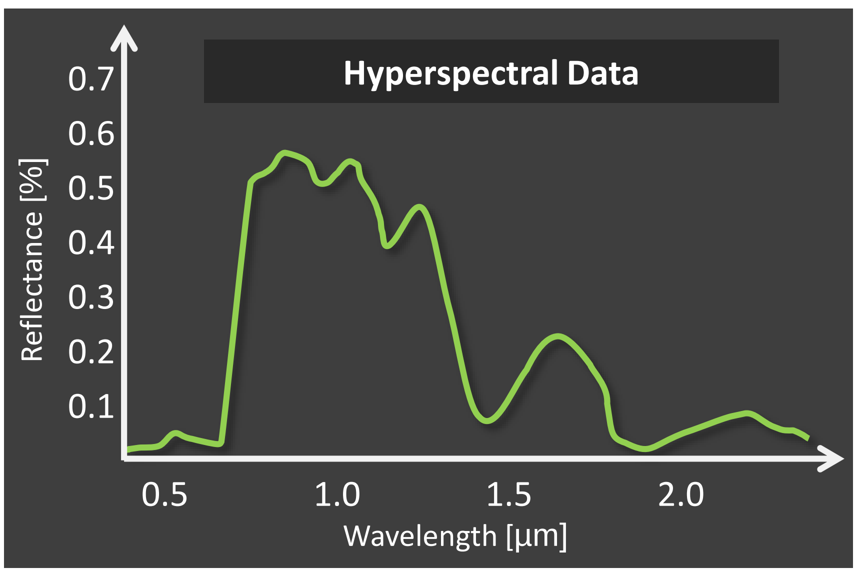


Primary Payload: RSB Hyperspectral (0.35 to 2.5 µm)
- non-imaging

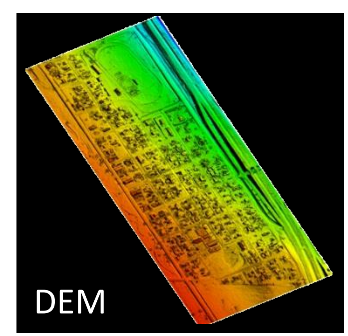
Filtered IR radiometers
Atmospheric profile (near surface)

Primary System

- 2D high resolution georeferenced and orthorectified mosaics
- Digital Elevation Model (± 1-5 m)
- Atmospheric profiles to maximum collection alt. (~400 ft or 121.9 m)

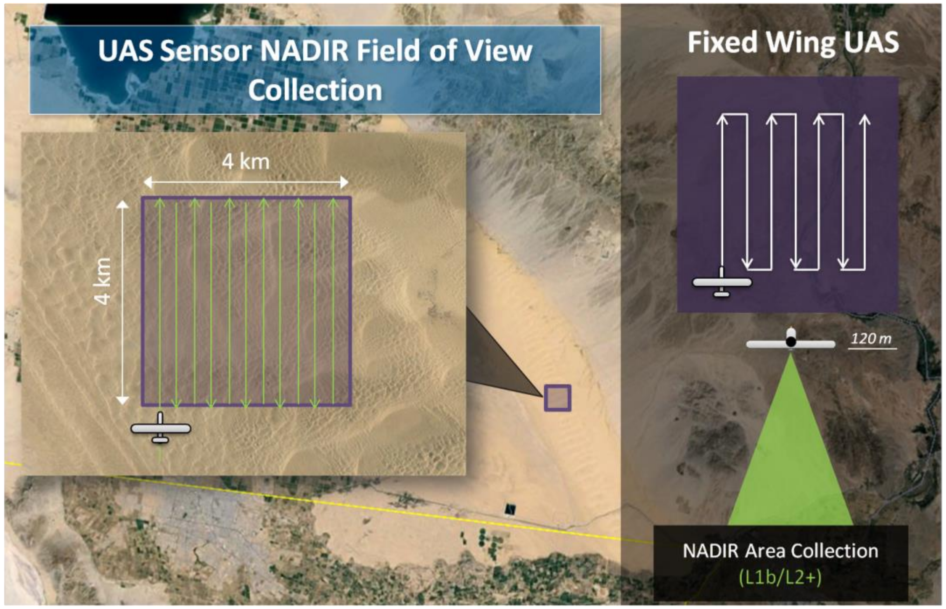


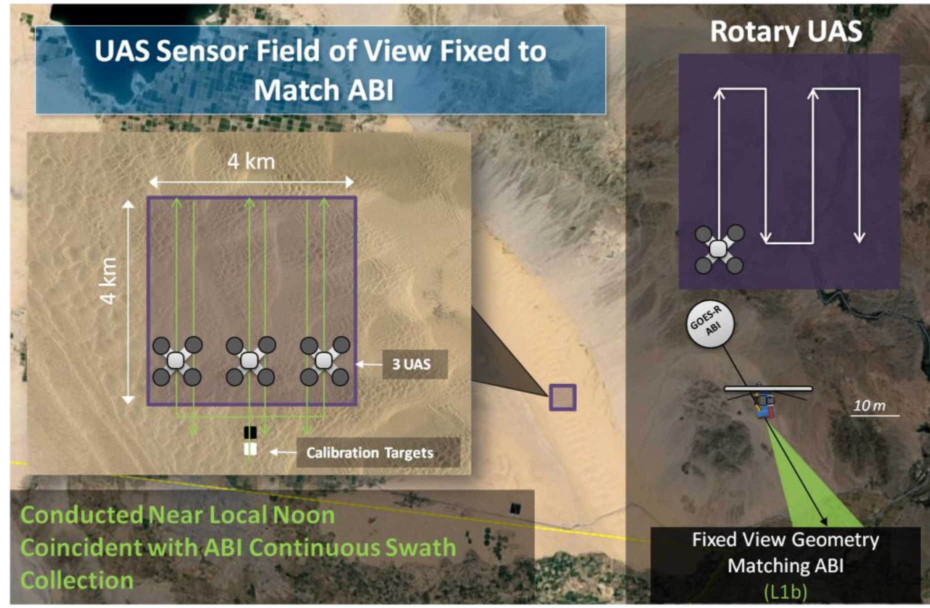
Pix4D Software

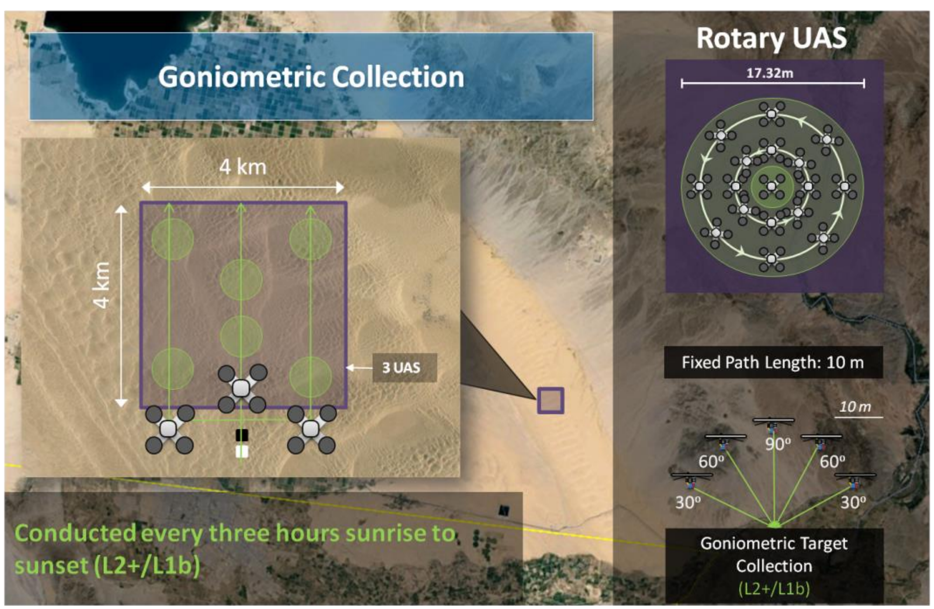


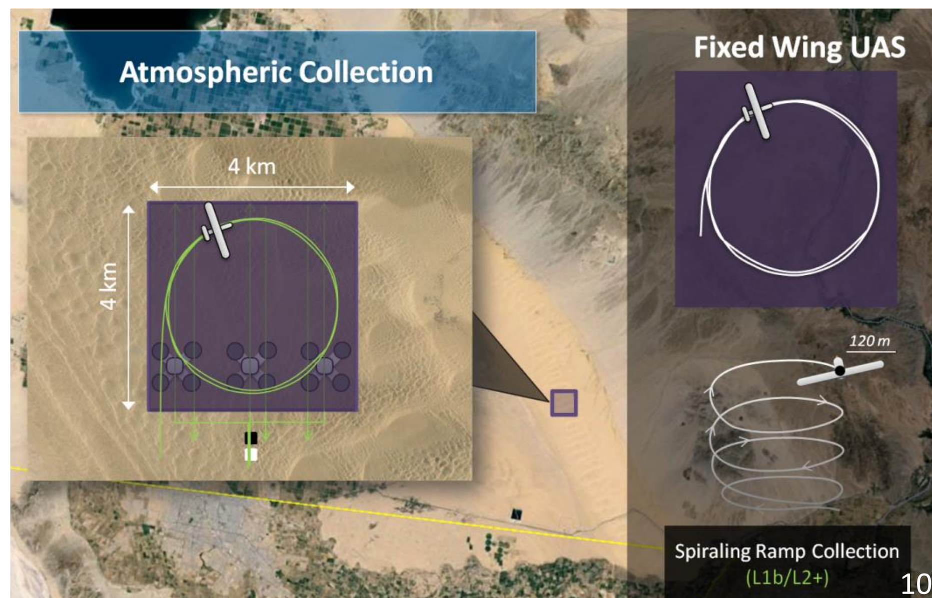
Images Courtesy: www.falconunmanned.com/falcon-uav-news/

Near Surface UAS Initial CONOP for Post-Launch Validation:
Validation of L1b Data & Support of L2+ Product Uncertainty

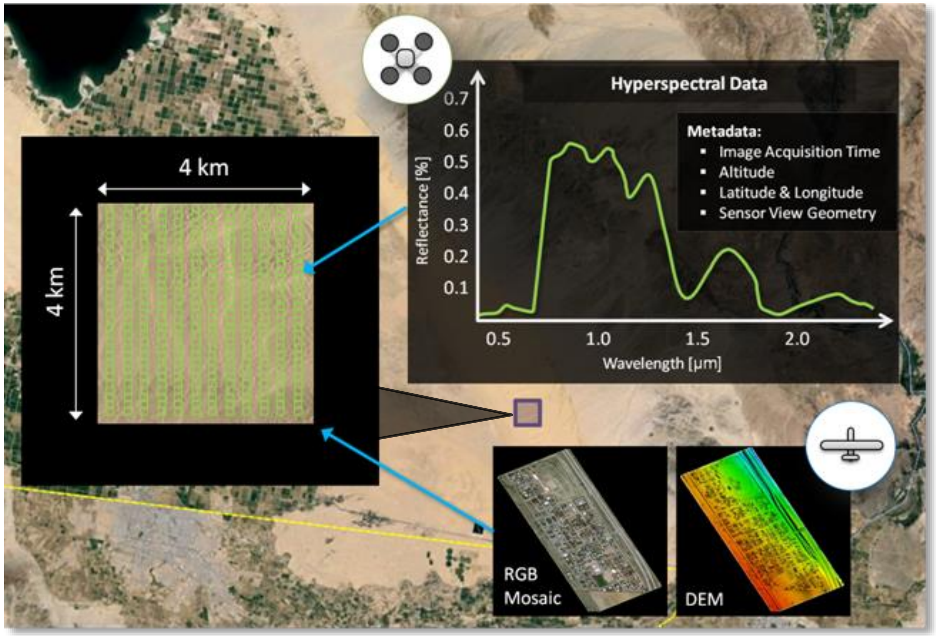








Near Surface UAS Measurements Provide Improved Validation Capabilities:
Validation of Satellite Data



UAS Capability Can Enhance GOES-R ABI Post-launch Validation Capabilities:

- Provides a pathway to validate radiometric performance post-launch (Reflective Solar Bands & Thermal Emissive Bands surface channels) and product performance uncertainties
- UAS deployments can support long-term monitoring of satellite sensor performance
- Enduring capability for Cal/Val scientist:
  - Near surface UAS campaigns can be replicated numerous times throughout the year at significantly reduced costs in comparison to heritage approaches
  - UAS deployments can support characterization of the degree of uniformity within the given satellite footprint (Ideally, for all reference Cal/Val sites (i.e. fixed ground instruments) in different seasons
- Goniometric surface measurements can be used to check components of model values used in retrieval algorithms

UNIVERSITY OF MARYLAND

UAS TEST SITE

A. JAMES CLARK SCHOOL *of* ENGINEERING

35+ UAS (fixed & rotor wing, 3 lbs to 160 lbs)

- 1 x UAVS Talon 240G
- 3 x UAVS Talon 120LE
- 3 x AV Wasp
- 3 x AV Raven
- 3 x AV Dragon Eye
- 1 x "Dragon Pi"
- 3 x Apprentice S15e
- 1 x FireFLY 6 hybrid
- 1 x DJI S-1000
- 2 x DJI S-900
- 1 x UAVS Phoenix 60
- 1 x UAVS Phoenix ACE LE
- 1 x UAVS Phoenix ACE XL
- 6 x 3DR Iris
- 1 x 3DR Solo
- 5 x DJI Phantom 3
- 1 x DJI Inspire

Payloads/Sensors specific to mission requirements

- Established Aug 2014 as one of six FAA UAS Test Sites
  - Partnered with Virginia & New Jersey
  - Located in Southern MD near Patuxent River NAS (Navy UAS test & eval)
- Govt/Academia/Industry research customers – focus on integrating UAS into National Airspace System & civil/commercial applications of UAS
- Robust airworthiness process; reachback to expertise at College Park
- Flight ops under public COAs, FAA Part 107, or foreign/international rules; airspace access nationwide including segregated airspace
- Major Research Projects
  - FAA, DHS: Airspace Intrusion Detection (1st *legal* UAS flight in Class C)
  - 1st civil UAS cargo flight across Chesapeake Bay (simulated medical supplies)
  - NOAA: GOES-R satellite cal/val & NERR mapping
  - GWU, USNA: Ship Air Wake Analysis (flown from YP boat in Chesapeake Bay)
  - US Navy: Open source autopilot (analysis of alternatives)
  - NASA: UAS Traffic Management (air traffic control for UAS)
  - Public Safety Agencies: life preserver drop, missing person search, comms relay, accident scene reconstruction, emergency vehicle support, radiation detection
  - Agriculture/Aquaculture/Anthropology/Geology: Aerial Surveys & 3D Mapping
  - AQWUA: A Quad with Underwater Abilities (fly/swim)
  - BVLOS/BLOS Ops (current requirement is visual LOS only)
  - Collaborative Control (UAS swarming)

Prototype Rotary System: UAS + Payloads

1. Reflective Solar Band (RSB) Sensor Suite:

- Hyperspectral coverage from 0.35 to 2.5 μm
  - Downward (directional)
  - Upward (total hemispheric)

2. IR Radiometer:

- Broadband IR – 8-14 μm/potentially filtered to match the ABI channels

3. Context Imager:

- RGB HD video - context imager

4. Atmospheric Sensor:

- T, RH, and Px profiles

Baseline Capabilities:

- Observations over extended regions matching ABI view geometry
- Goniometric observations over a given target (directional hemispheric)

Primary System – In Development

Rotary UAS

Phoenix ACE XL Specifications

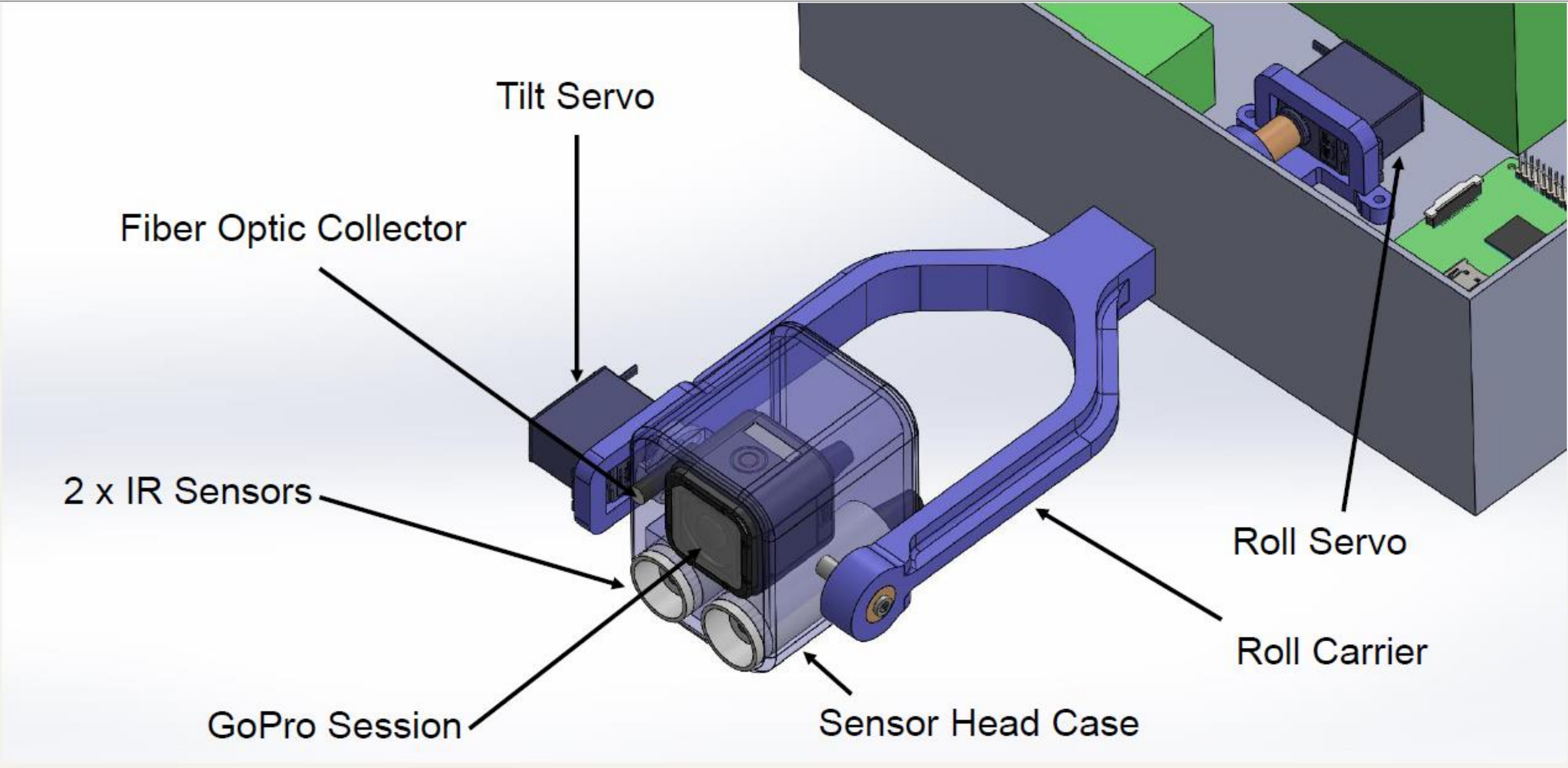
Endurance: 30 minutes of collection

Fully autonomous system

Payload Capacity: 10-12 lbs

Customized electronic enclosure and autonomous 2 axis gimbal

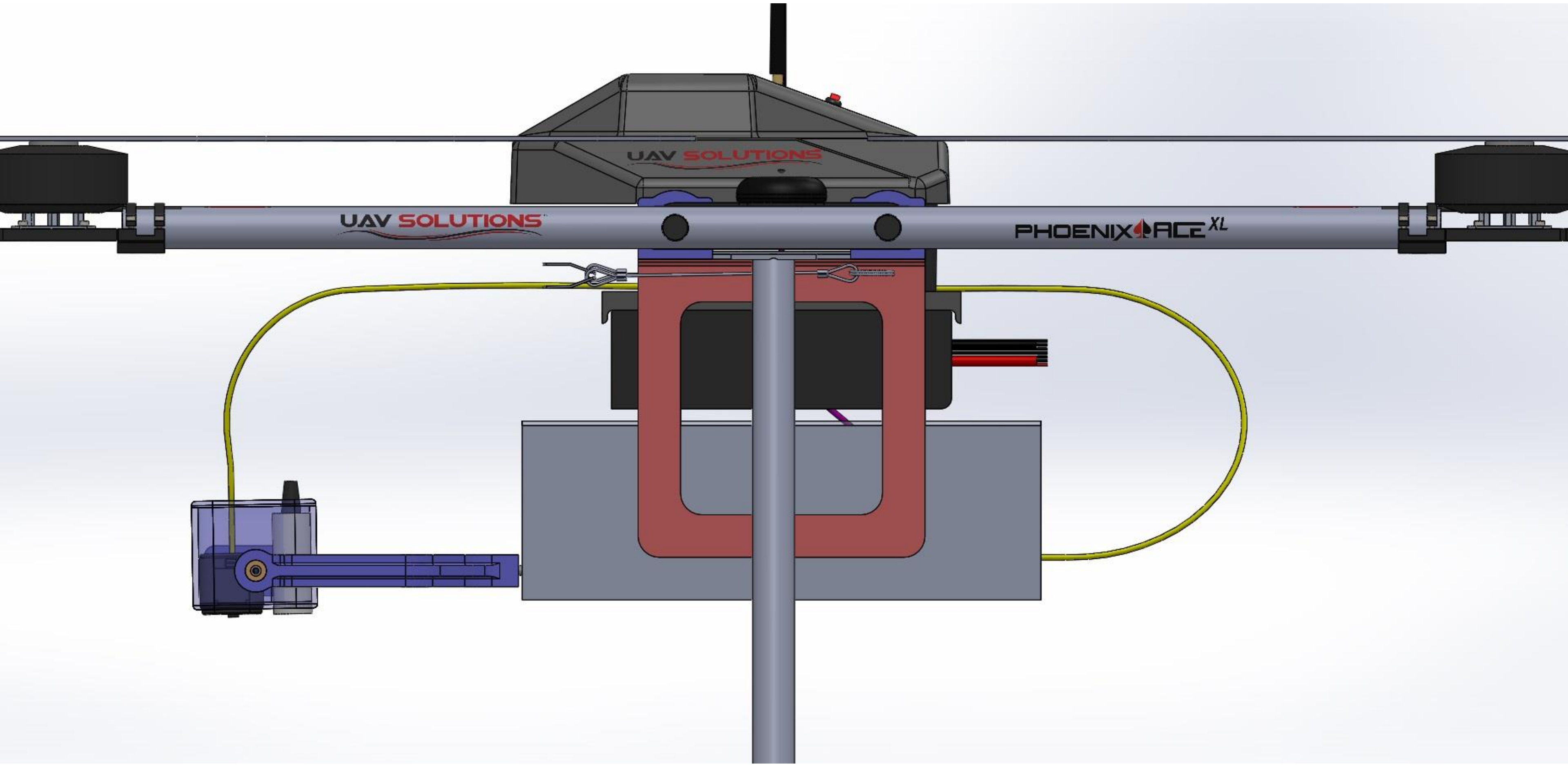
GOES-R Prototype Rotary UAS: Downward Observations



GOES-R Prototype Rotary UAS:

Gimbal & Fiber Motion

0º NADIR Viewing

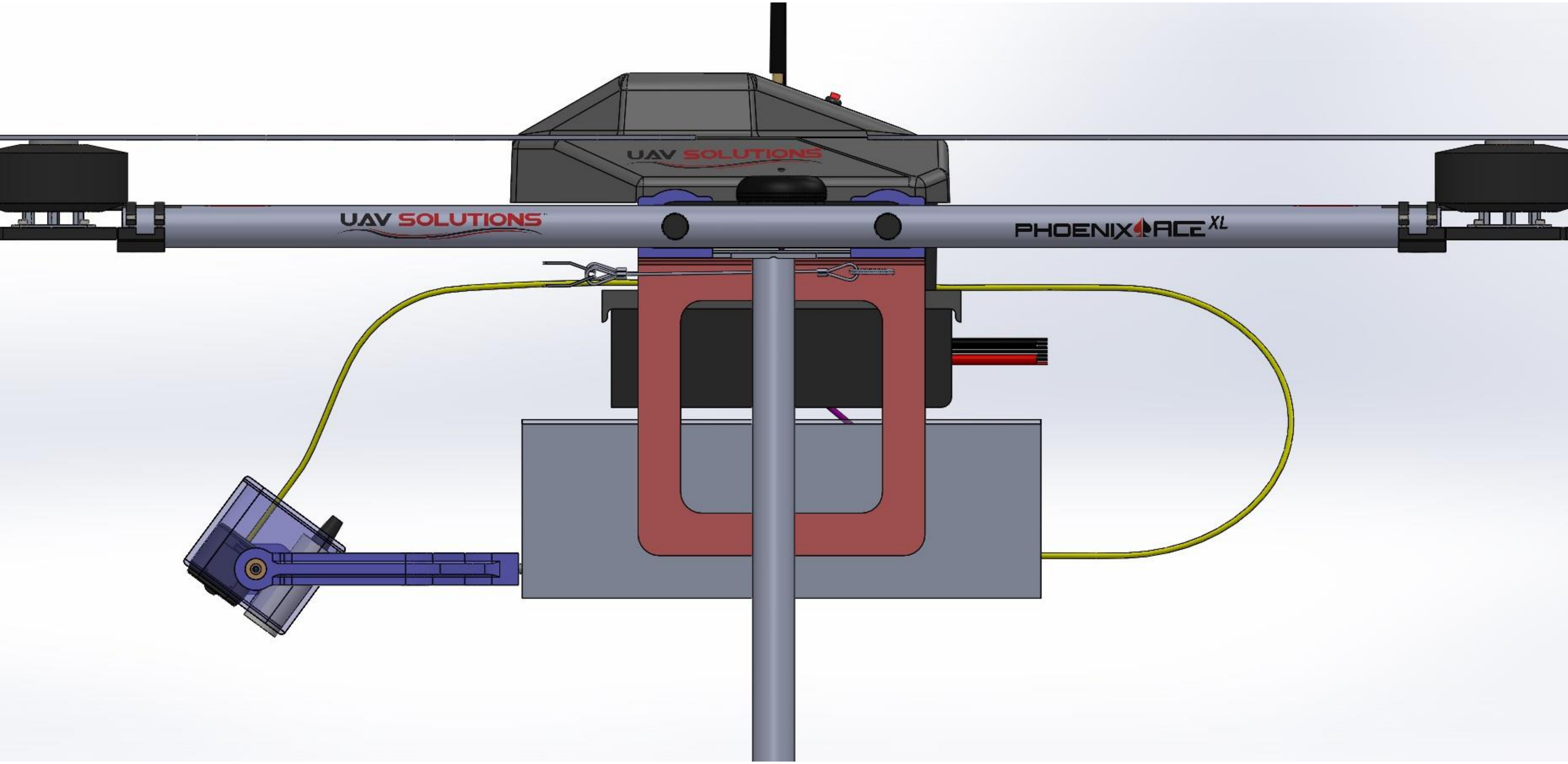


UAV SOLUTIONS

GOES-R Prototype Rotary UAS:

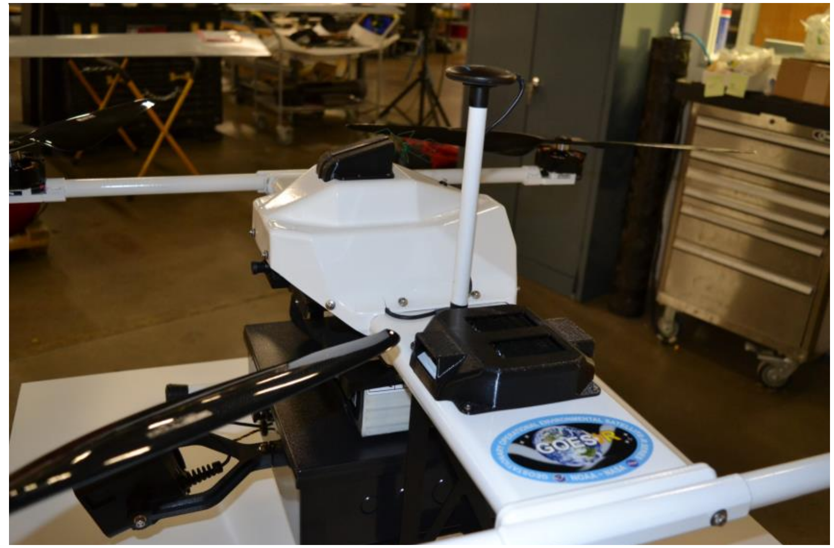
Gimbal & Fiber Motion

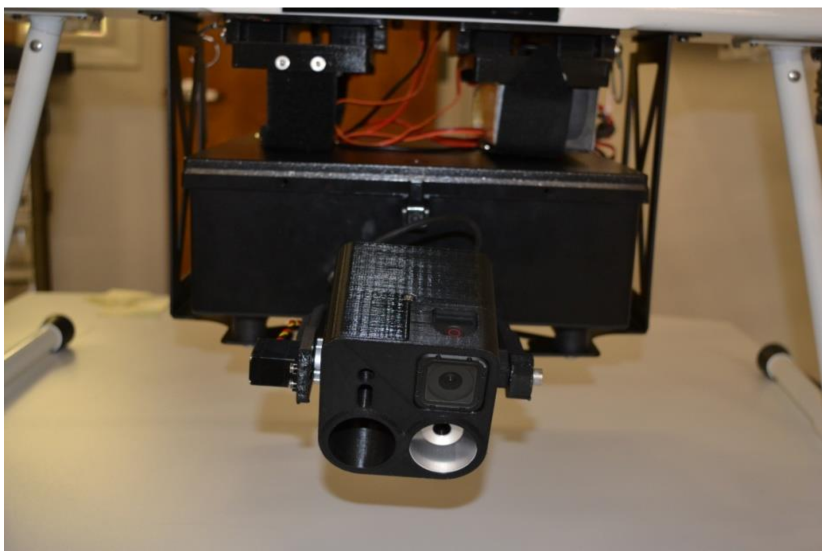
45° NADIR Viewing



Prototype Rotary UAS Developed:

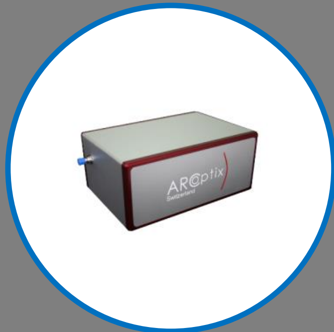
Flight Testing Without Payloads





Rotary UAS Payloads

Total Weight: 8.4 lbs



RSB Sensor Suite

IR Radiometer

Context Imager

Atmospheric Sensor

VNIR Spectrometer
(0.35 – 1.1 µm)

Non-Imaging

Ocean Optics
TRL 9

SWIR Spectrometer
(0.9 – 2.6 µm)

Non-Imaging

ARCoptix
TRL 4

Broadband IR
(8.0 – 14 µm)

Non-Imaging

Apogee Instruments
TRL 9

Context HD Video
(RGB)

Imaging

GoPro
TRL 9

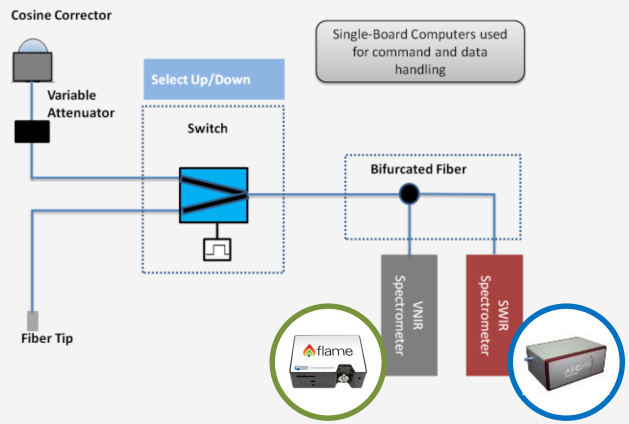
Atmospheric Sensor
(T, Px, RH)

Non-Imaging

InterMet Systems
TRL 7

Radiometric/Geometric Calibration & Characterization

NOAA Calibration Center laboratory developed for UAS payload calibration & characterization to ensure data quality



Reflective Solar Band Sensor Suite

Polarization Sensitivity

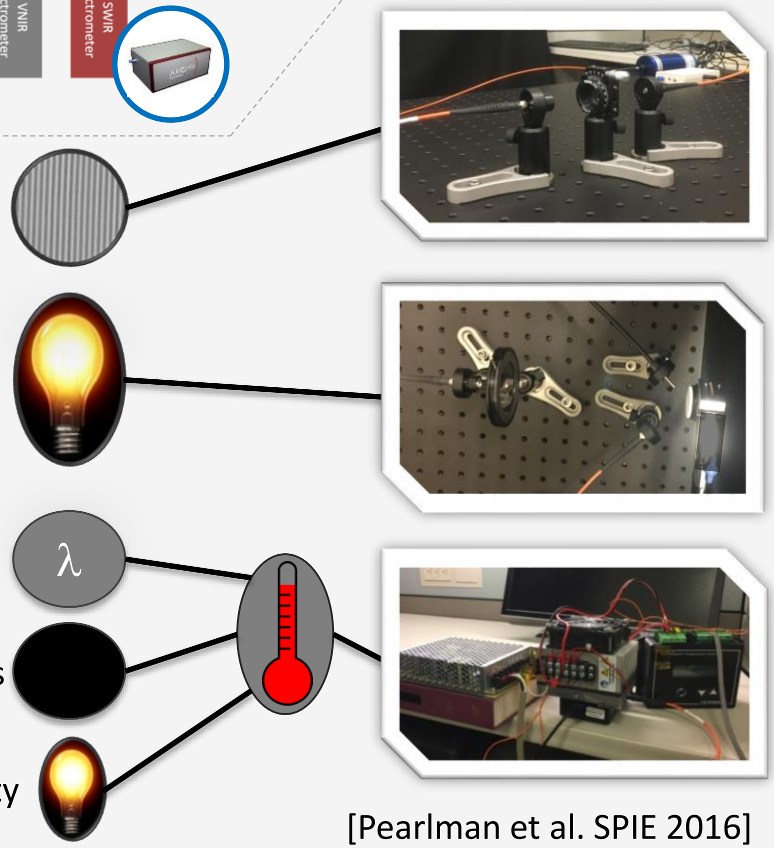
Calibration

Temperature Effects

Wavelength

Dark counts

Responsivity



[Pearlman et al. SPIE 2016]

Camera Calibration

To enable overlaying of sensor footprints in context imagery

Distorted

Corrected

[www.OpenCV.org]

Prototype Fixed-Wing System: UAS + Payloads

1. **High Resolution Camera:**
   - High resolution RGB camera
2. **Atmospheric Sensor:**
   - T, RH, & Px profiles

Baseline Capabilities:

- 2D high resolution georeferenced and orthorectified mosaics (NADIR & Oblique)
- Digital Surface Model (± 1-5 m)
- Atmospheric profiles to maximum collection alt. (~400 ft or 121.9 m)

Secondary System

Fixed-Wing UAS

Talon120 Specifications

Length: 6’ Wingspan: 12.5’
Endurance: 2.0 -2.5 hours
Range: 8 mile LOS
Fully autonomous system
Payload Capacity: 2.5 lbs

Fixed-Wing UAS Payloads

baseline

Cannon S100
(RGB)

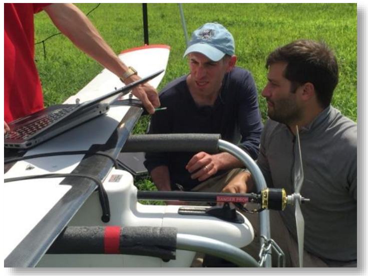
Imaging

Cannon
TRL 9

Atmospheric Sensor
(T, Px, RH)

Non-Imaging

InterMet Systems
TRL 7



GOES-R UAS Feasibility Demonstration Study:

Successful Fixed-Wing UAS functional & operational performance demonstrations

Completed successful test flights at the:

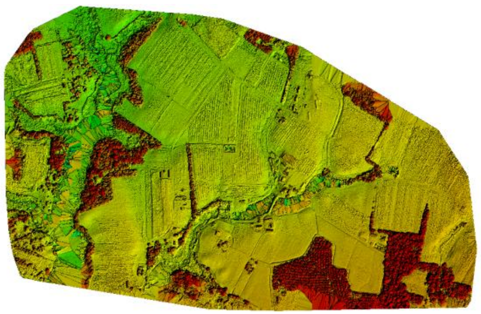
- University of Maryland (UMD) UAS test site in Bushwood, MD on August 3, 2016
- NOAA National Estuary Research Reserve (NERR) in Jug Bay, MD on August 8, 2016 – UAS test data provided to NOAA NERR as operational data
- Resulting products: 2D & 3D geo-referenced maps

NADIR Imagery

Oblique Imagery

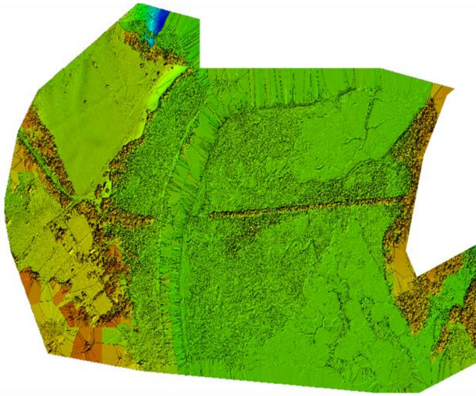
2D Geo-Referenced Orthomosaic

3D Digital Surface Model



2D Geo-Referenced Orthomosaic

3D Digital Surface



UMD UAS Test Site – Bushwood, MD

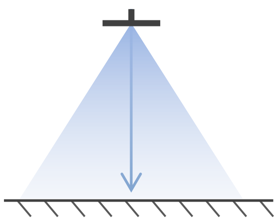
NOAA NERR – Jug Bay, MD

Fixed-Wing UAS Sample data

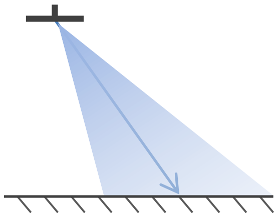
2D Georeferenced Imagery Mosaic - Flight Altitude of 700 ft

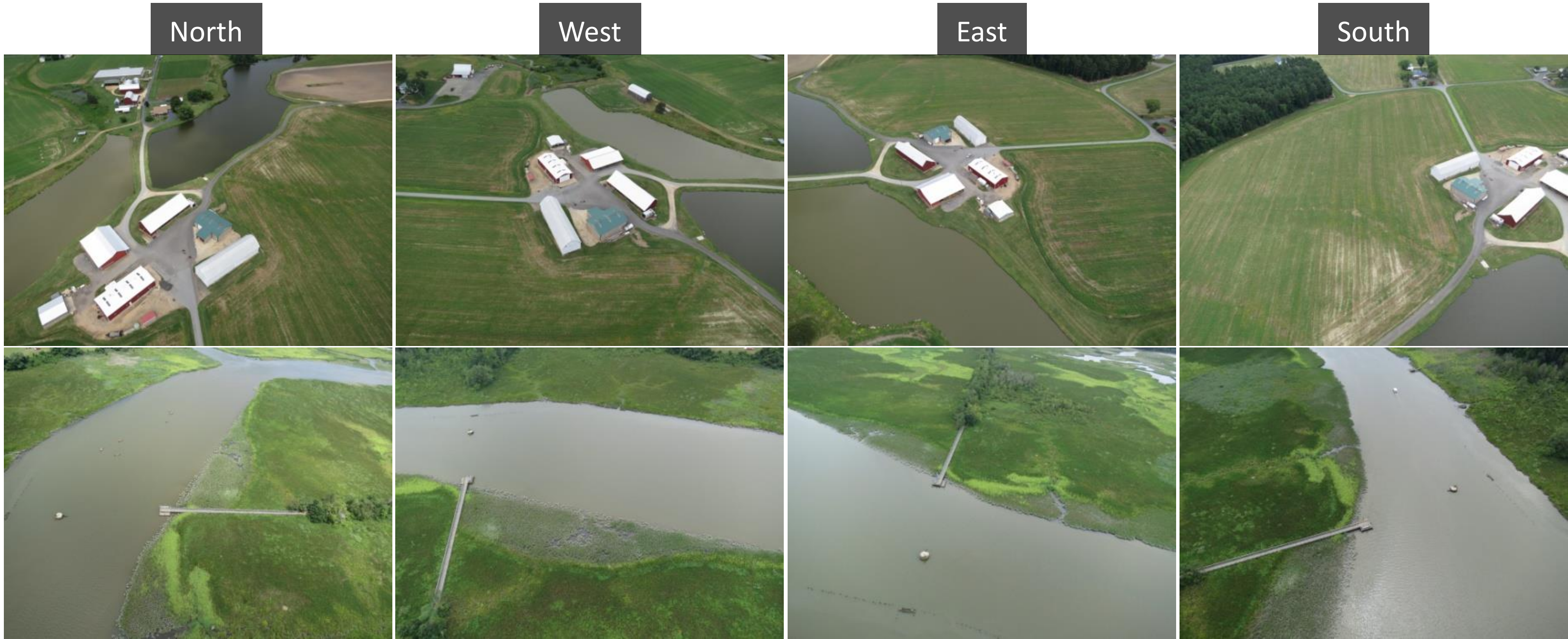
Fixed-Wing UAS Collection (NADIR to 45º)

NADIR Collection:



Oblique Collection (~45º)





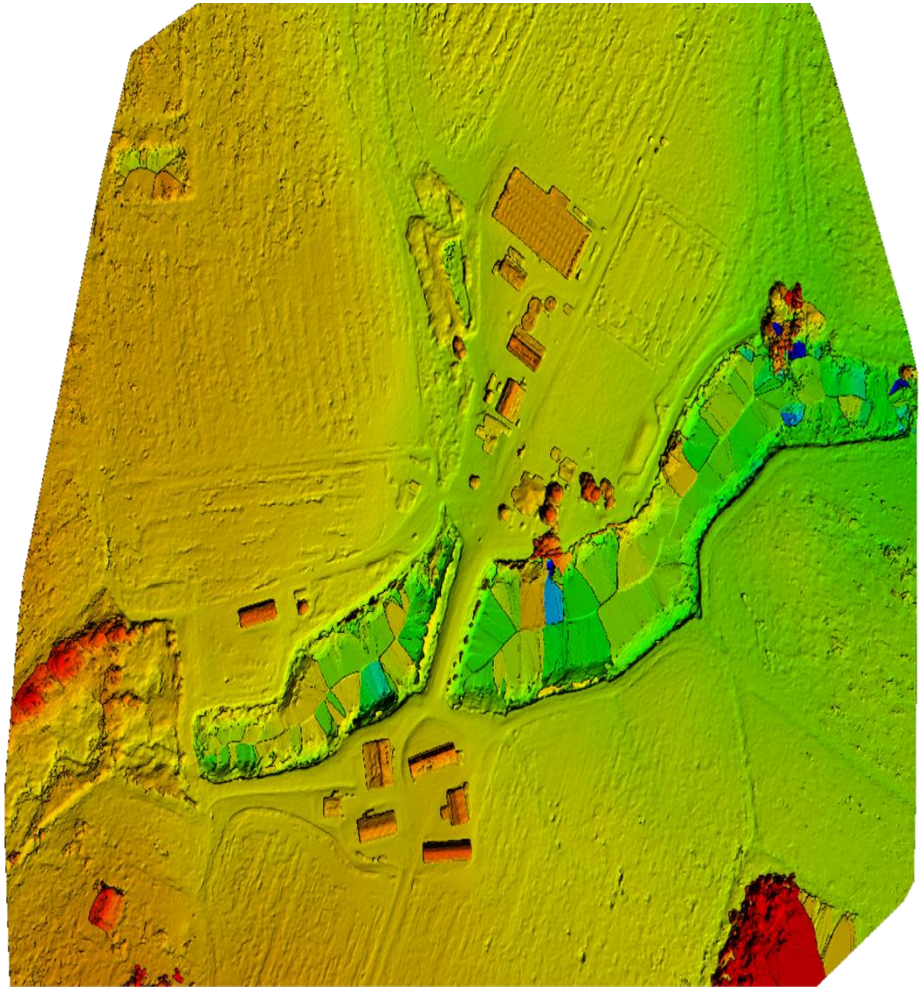
2D Georeferenced Orthomosaics Products NADIR + Oblique Imagery vs Nadir Only Imagery

NADIR + Oblique

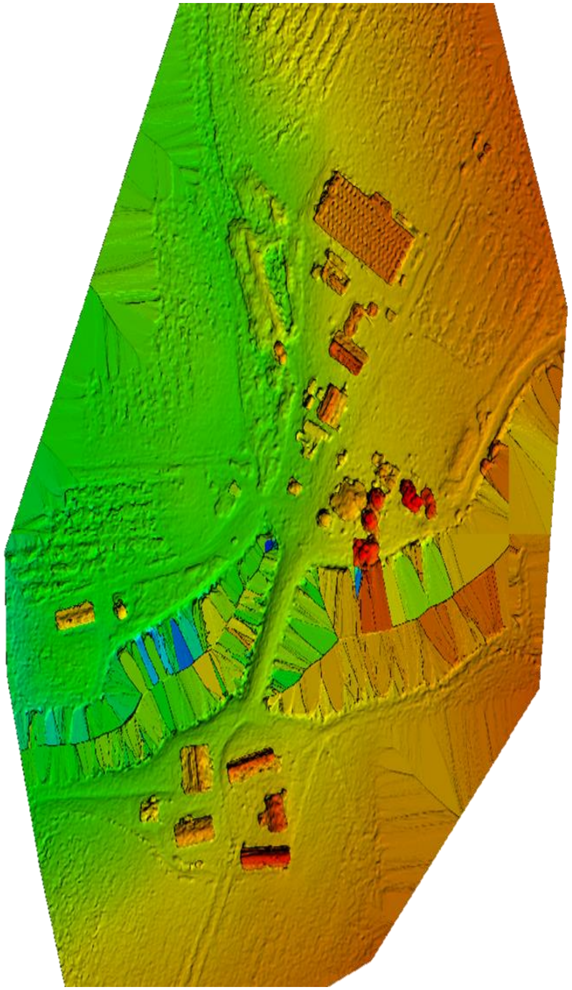
NADIR Only

3D Georeferenced Digital Surface Model (DSM) Products NADIR + Oblique Imagery & Nadir Only Imagery

NADIR + Oblique

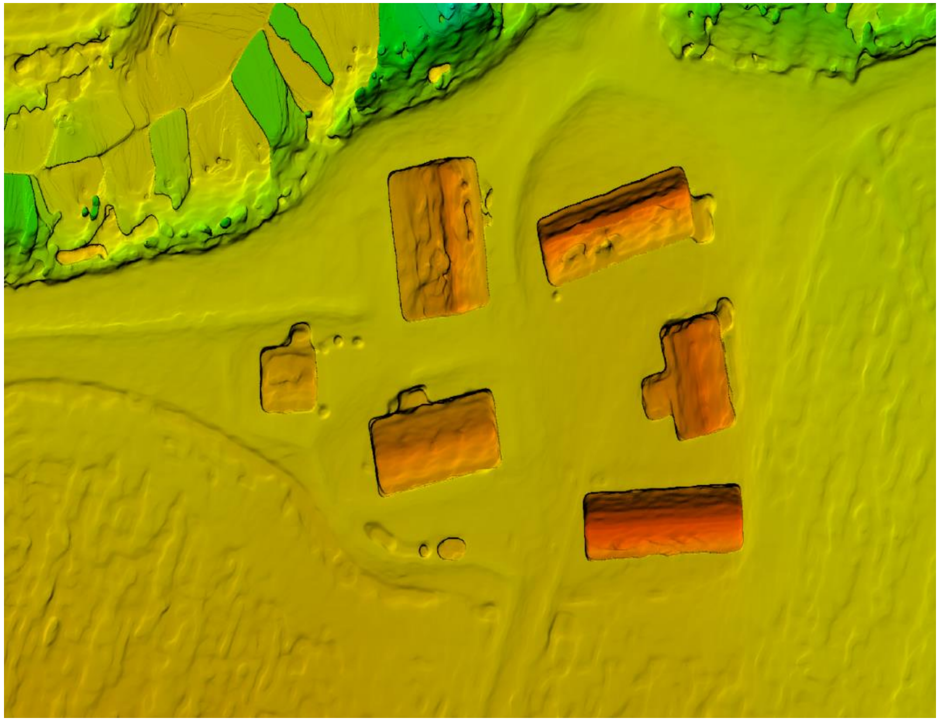


NADIR Only

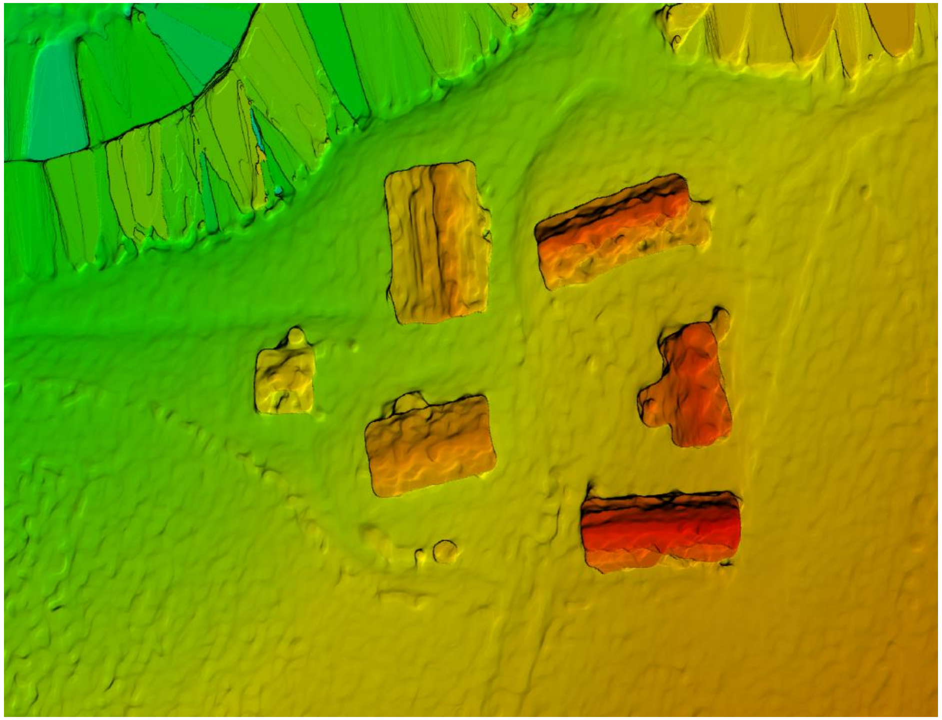


3D Georeferenced Digital Surface Model (DSM) Products NADIR + Oblique Imagery & Nadir Only Imagery -- Zoom In --

NADIR + Oblique



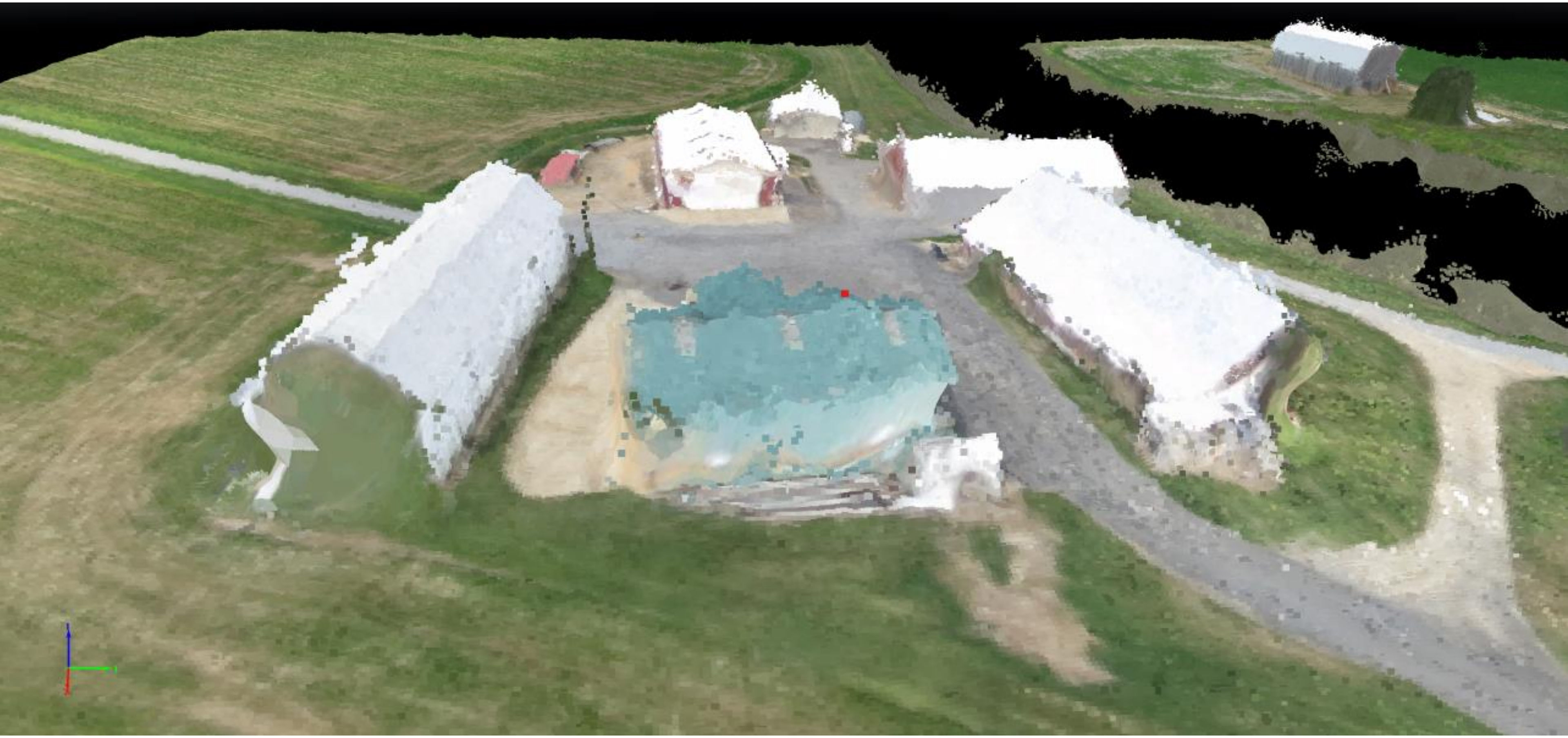
NADIR Only



- NADIR + Oblique imagery dataset produced an enhanced DSM (better defined structure) vs the NADIR only dataset

3D Georeferenced Digital Surface Model (DSM) Products NADIR + Oblique Imagery & Nadir Only Imagery
-- Zoom In --

NADIR Only

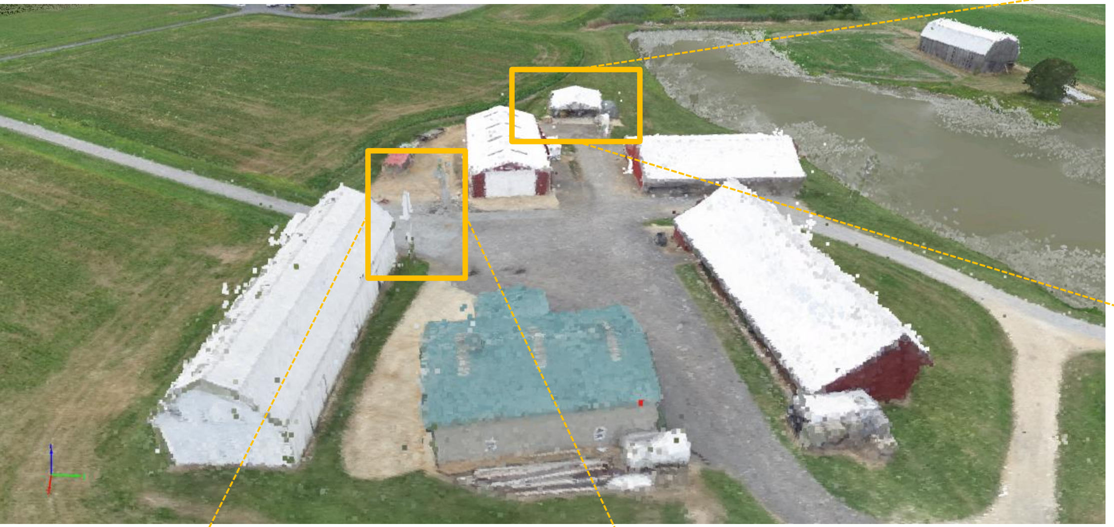


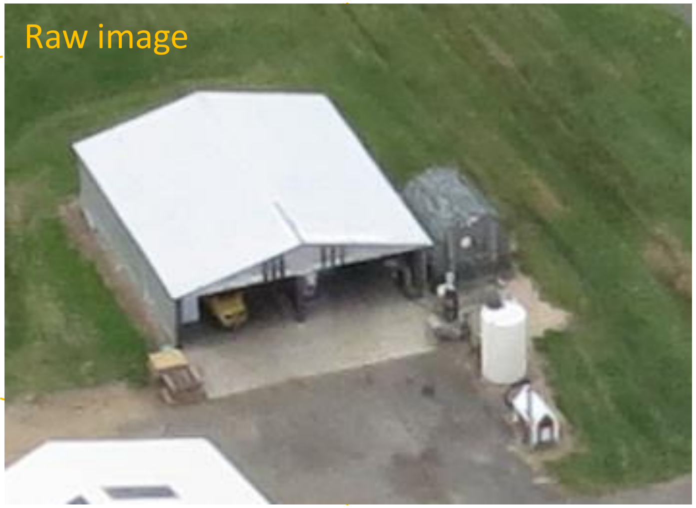
3D Georeferenced Digital Surface Model (DSM) Products NADIR + Oblique Imagery & Nadir Only Imagery
-- Zoom In --

NADIR + Oblique

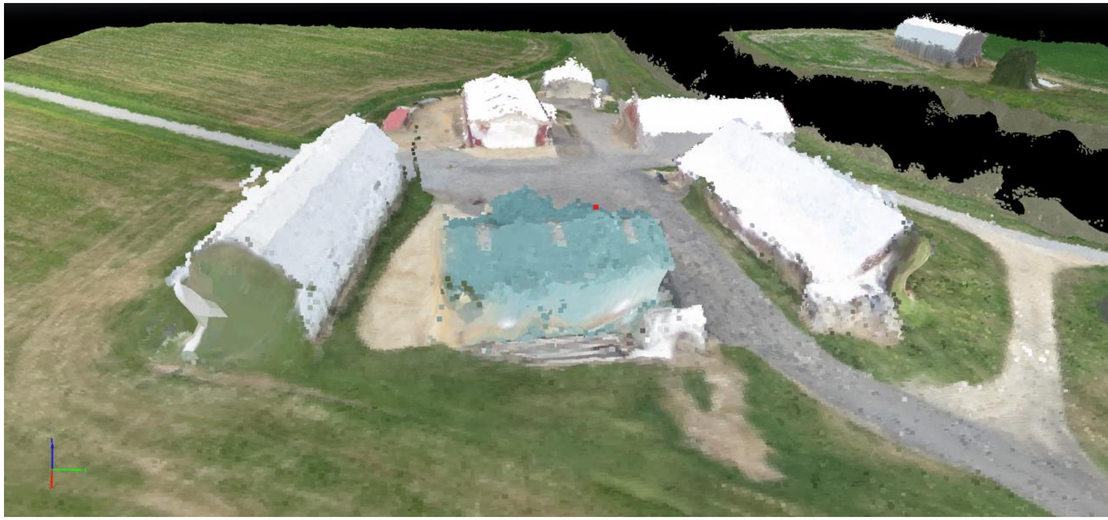
3D Georeferenced Digital Surface Model (DSM) Products NADIR + Oblique Imagery & Nadir Only Imagery
-- Zoom In --

NADIR + Oblique



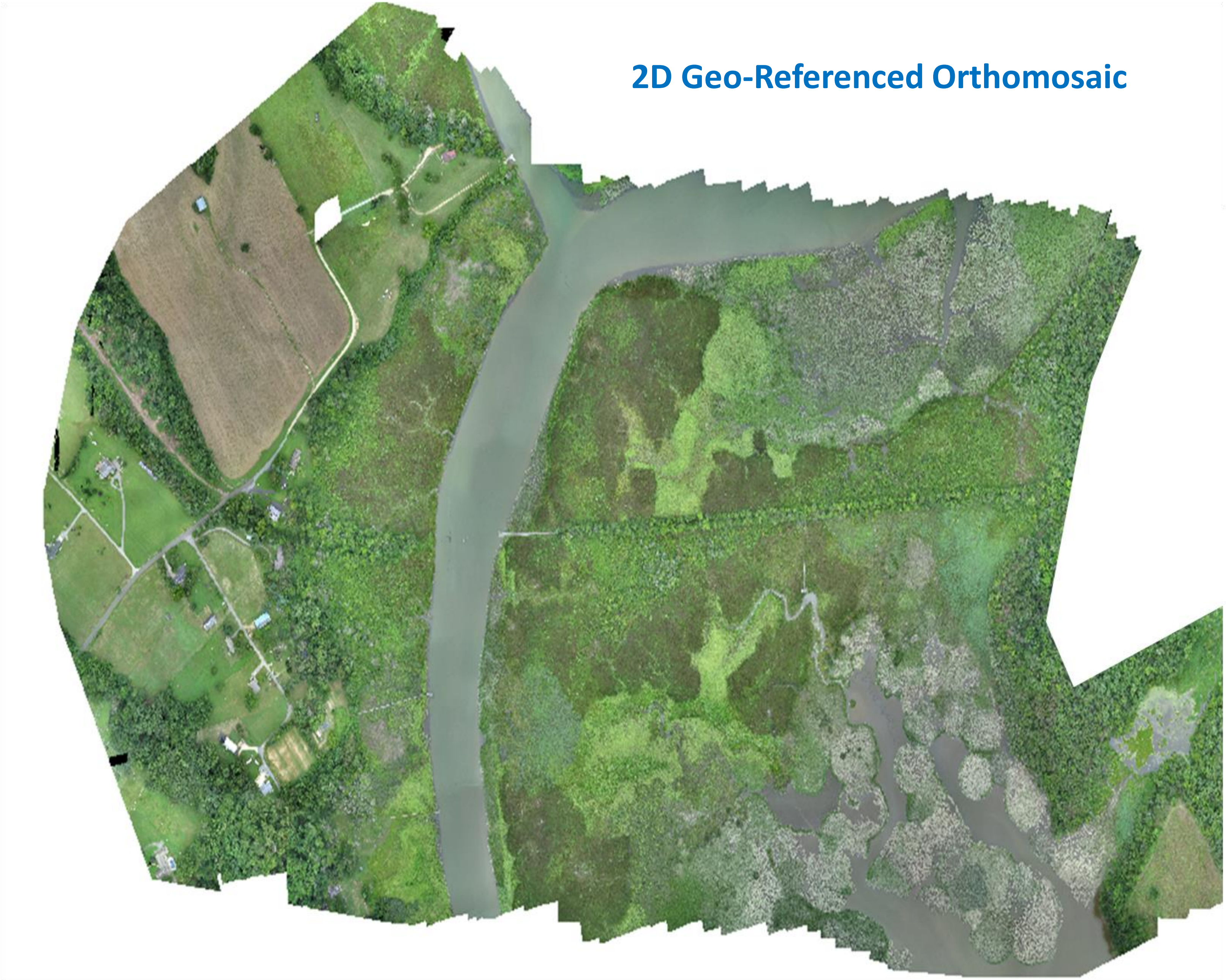


NADIR Only



NOAA National Estuary Research Reserve (NERR) Jug Bay, MD – August 8, 2016

2D Geo-Referenced Orthomosaic



NOAA National Estuary Research Reserve (NERR) Jug Bay, MD – August 8, 2016

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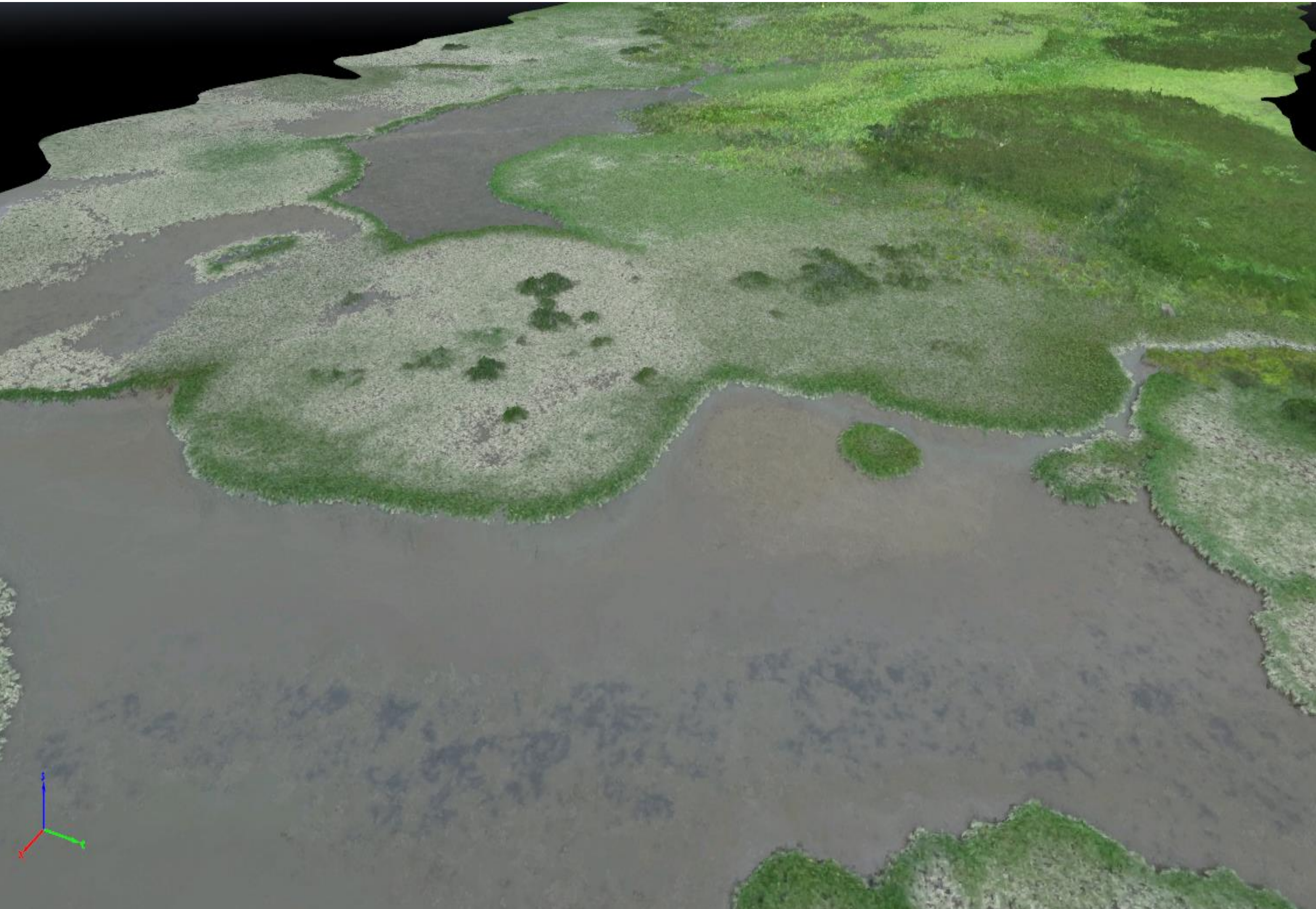
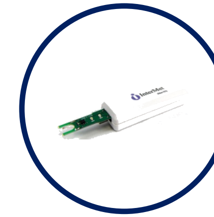
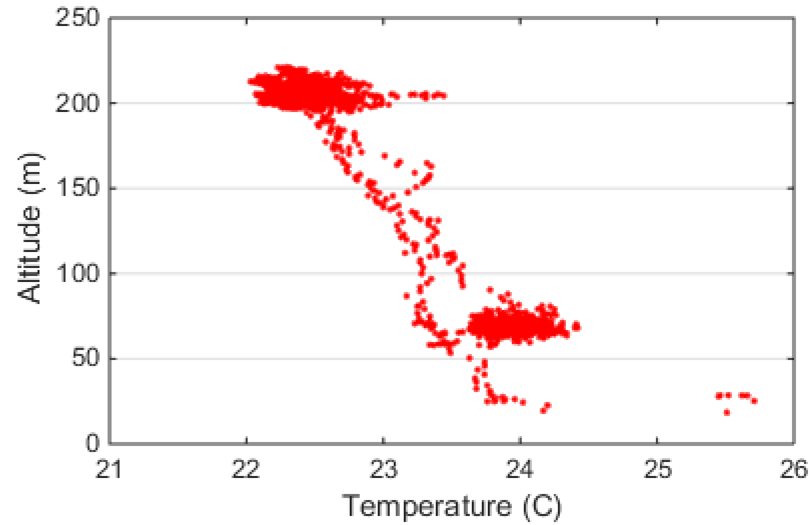
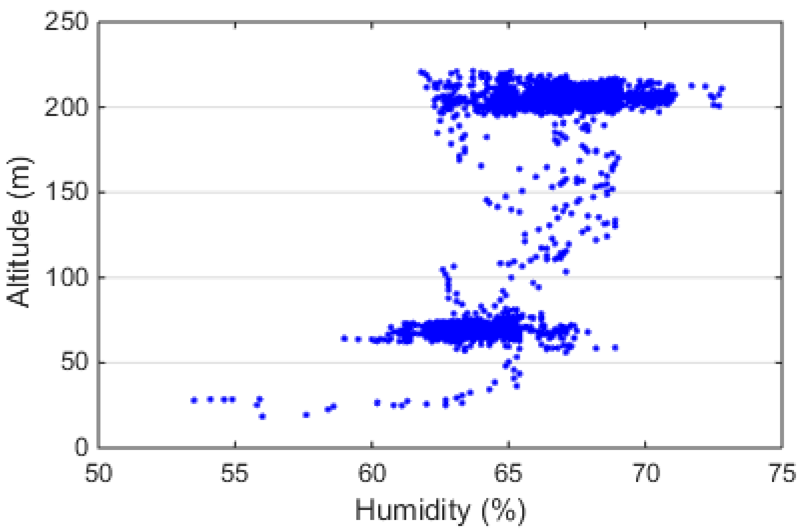


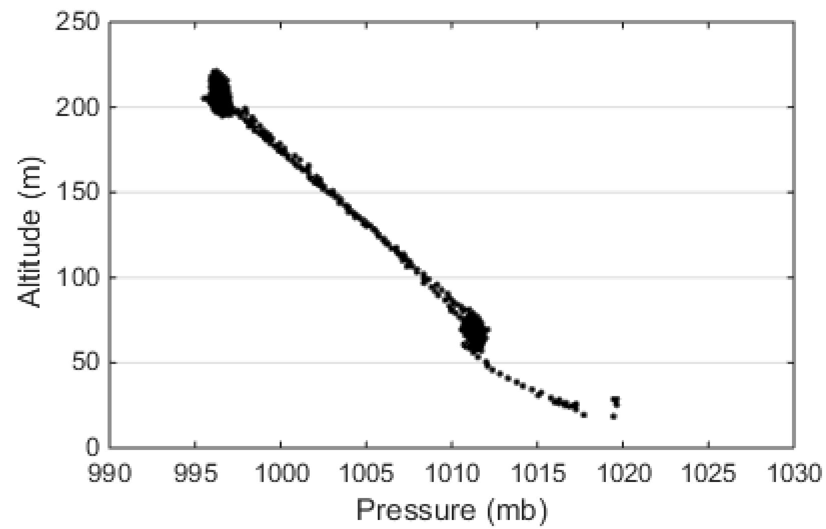
Atmospheric Sensor: Functional Performance Testing



University of Maryland (UMD) UAS test site in Bushwood, MD on August 3, 2016







Challenges Addressed

- **Open Source Flight Controller**
  - Enables access to the UAS metadata (Pixhawk)
- **Autonomously Controlled Payload Gimbal**
  - Customized 2-axis servo to ensure the UAS based sensors match the view geometry of the satellite sensor
  - Mission Planner & flight controller (Pixhawk)
- **Payload Command and Data Handling**
  - Developed a multiple sensor architecture using multiple single board computers (Raspberry PI) in parallel
- **Time Synchronization of the UAS System**
  - Ensures proper metadata tagging between sensor payloads and UAS flight controller
- **Near Surface Flight Operations: ~10 m**
  - Radiative transfer simulations validated the approach
- **Oblique Image Capability Added**
  - Enables enhanced image analysis & 3D geo-referenced imagery products via structure from motion techniques

Summary

- Developed a fixed-wing UAS mapping capability and conducted 4 successful flights that generated 2D & 3D geo-referenced products over a targeted area
- Developed and tested a multi-sensor payload suite for the rotary UAS:
  - Payload integrated local flight testing scheduled for November 10-11, 2016
  - Desert Validation Target (U.S. Southwest)
    - TBD Test Site: operational performance demonstration (rotary & fixed-wing UAS)
- Developing web-based data discovery and visualization tools to enhance data sharing and analysis
- Developing image quality and data product levels to optimize end products
- The GOES-R near surface UAS feasibility demonstration study supports advanced capability development for the GOES-R field campaign.
  - Final report to be completed late 2016

BACK-UP

GOES-R Advanced Baseline Imager

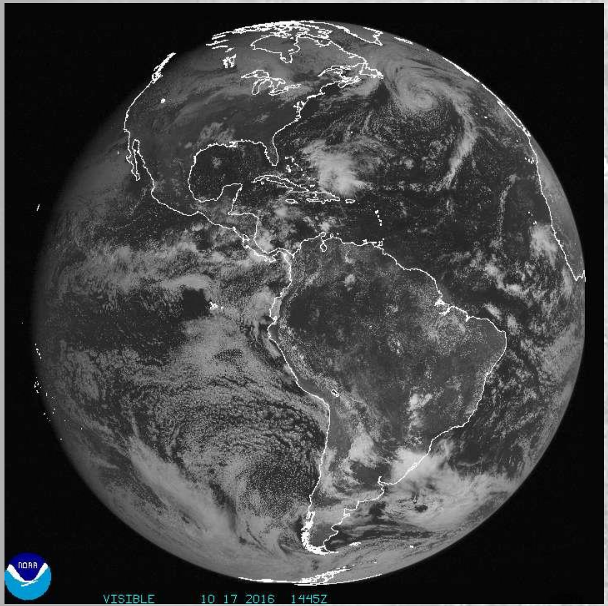
ABI MODES OF OPERATION

- **Full Disk:** Hemispheric Coverage of 83° local zenith angle, temporal resolution of 5-15 minutes, and spatial resolution of 0.5 to 2km
- **Mesoscale:** Provides coverage over a 1000x1000km box with a temporal resolution of 30 seconds, and spatial resolution of 0.5 to 2km.
- **Continental US:** The CONUS scan is performed every 5 minutes, providing coverage of the 5000km (E/W) and 3000km (N/S) rectangle over the United States. The spatial resolution is 0.5 to 2km.
- **Flex Mode:** The flex mode will provide a full disk scan every 15 minutes, a CONUS every 5 minutes, and two mesoscale every 60 seconds (or one sub-region every 30 seconds).

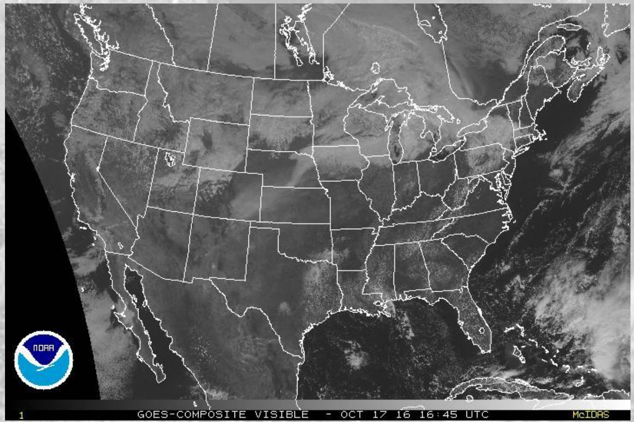
COMPARISON GOES-R SERIES ABI VS CURRENT GOES

ATTRIBUTE :	ABI	CURRENT GOES IMAGER
Spectral Coverage	16 bands	5 bands
Spatial Resolution		
0.64 µm Visible	0.5 km	~ 1 km
Other visible/near-IR	1.0 km	n/a
Bands (>2 µm)	2 km	~ 4 km
Spatial Coverage		
Full Disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	30 or 60 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

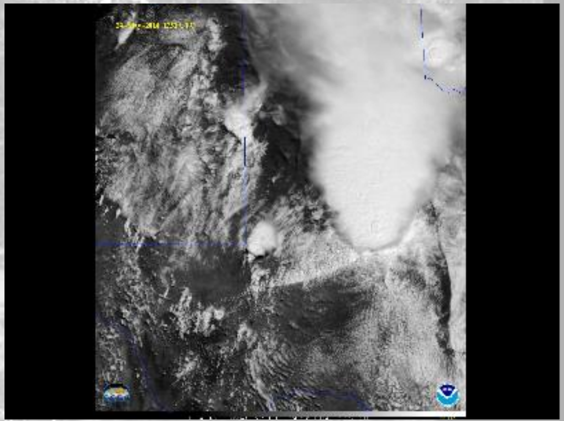
Full Disk



CONUS



Mesoscale



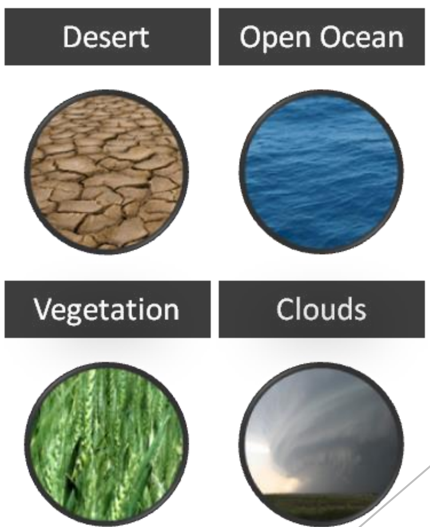
Information Courtesy: http://www.goes-r.gov/spacesegment/abi.html

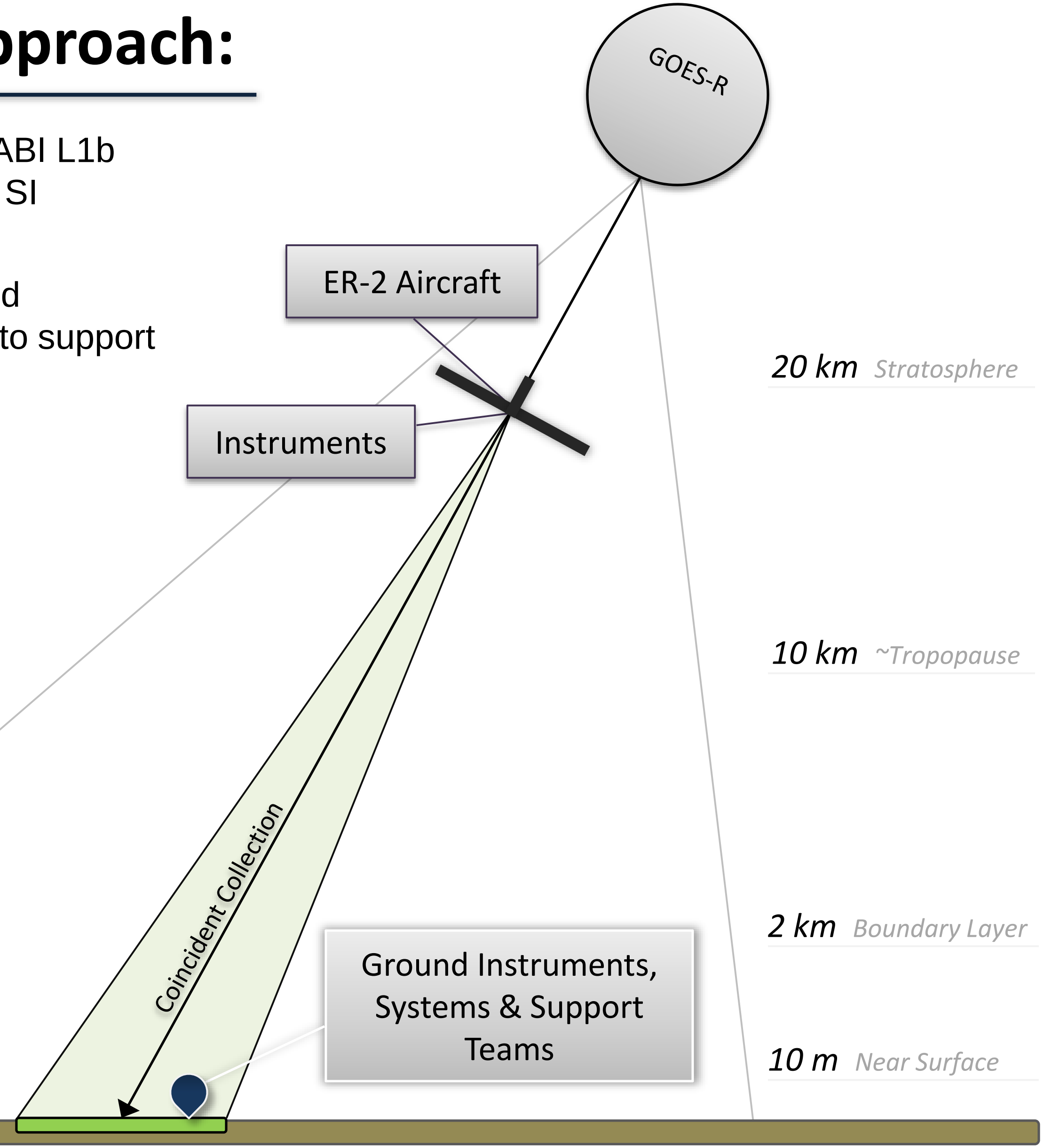
ABI Field Campaign Approach:

Primary Objective: provide validation of ABI L1b spectral radiance observations to validate SI traceability

Secondary objective: provide surface and atmospheric geo-physical measurements to support L1b & L2+ product validation

Targets of Interest:





GOES-R Field Campaign ER-2 Based Instruments

Candidate Instruments	
AVIRISng	Next-Generation Airborne Visible/Infrared Imaging Spectrometer
S-HIS	Scanning High-resolution Interferometer Sounder
FEGS	Fly's Eye GLM Simulator
LIP	Lightning Instrument Package
CPL	Cloud Physics Lidar
CRS	94-GHz (W-band) Cloud Radar System (CRS)
EXRAD	ER-2 X-band Doppler Radar
GCAS	GeoCAPE Airborne Simulator (GCAS)

Instrument	Type	Spectral Range	Spectral Res.	GSD	FOV	Swath Width
AVIRISng	HSI	380 – 2510 nm	5 nm	0.3 m to 20 m	34 deg	~11 km
S-HIS	Hyperspectral	3.3 - 18 µm	0.5 cm^{-1}	2 km	40 deg	40 km
FEGS	Passive EO	near-infrared (777.4 nm)	10 nm			~10 km
LIP	Passive Electrical					
CPL	Lidar	1064, 532, & 355 nm		30x200 m		
CRS	Doppler Radar	94 GHz (W-band; 3 mm wavelength)		na		
EXRAD	Doppler Radar	9.6 GHz X-band		1.2 km		25 km conical scan and fixed nadir
GCAS	Hyperspectral	300 – 490 nm; 480 -900 nm	0.6 nm; 2.8 nm	350 x 1000 m; 250 x 250 m	45 deg; 70 deg	

ABI & GLM combined campaign provides an opportunity for data collection with broad suite of instruments

Critical Set of Instruments

Add-on Capability

Two Main Paths to Validate SI Traceability

Direct Comparison of Observations from SI Traceable Reference Sensor(s)

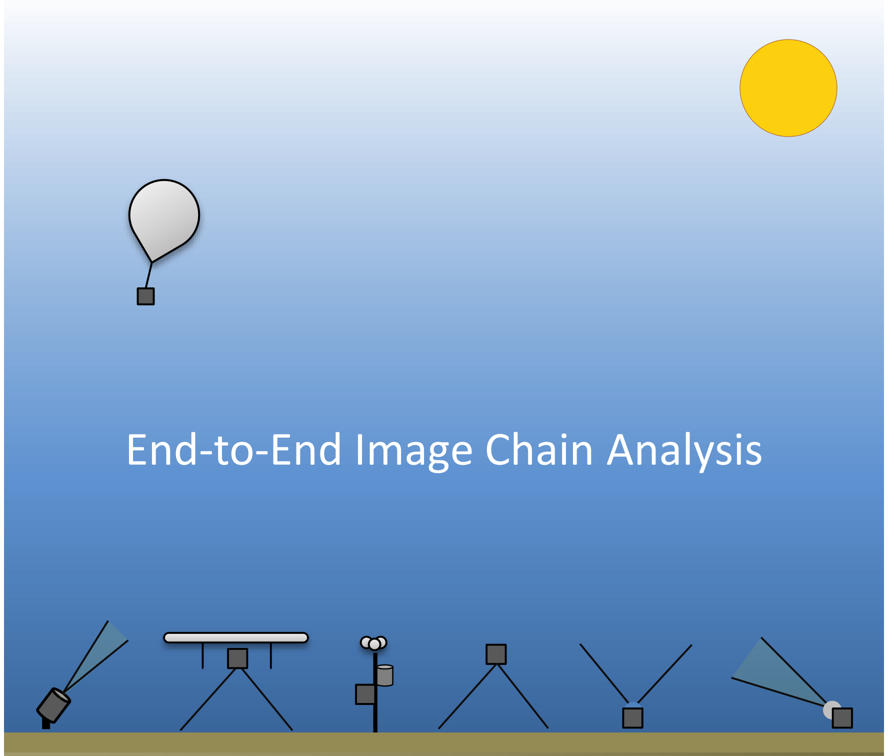
- Well calibrated reference sensor(s)
- Match the reference sensor and satellite sensor view geometry

High-Altitude Aircraft Approach

Radiance to Radiance Comparison (L1b)

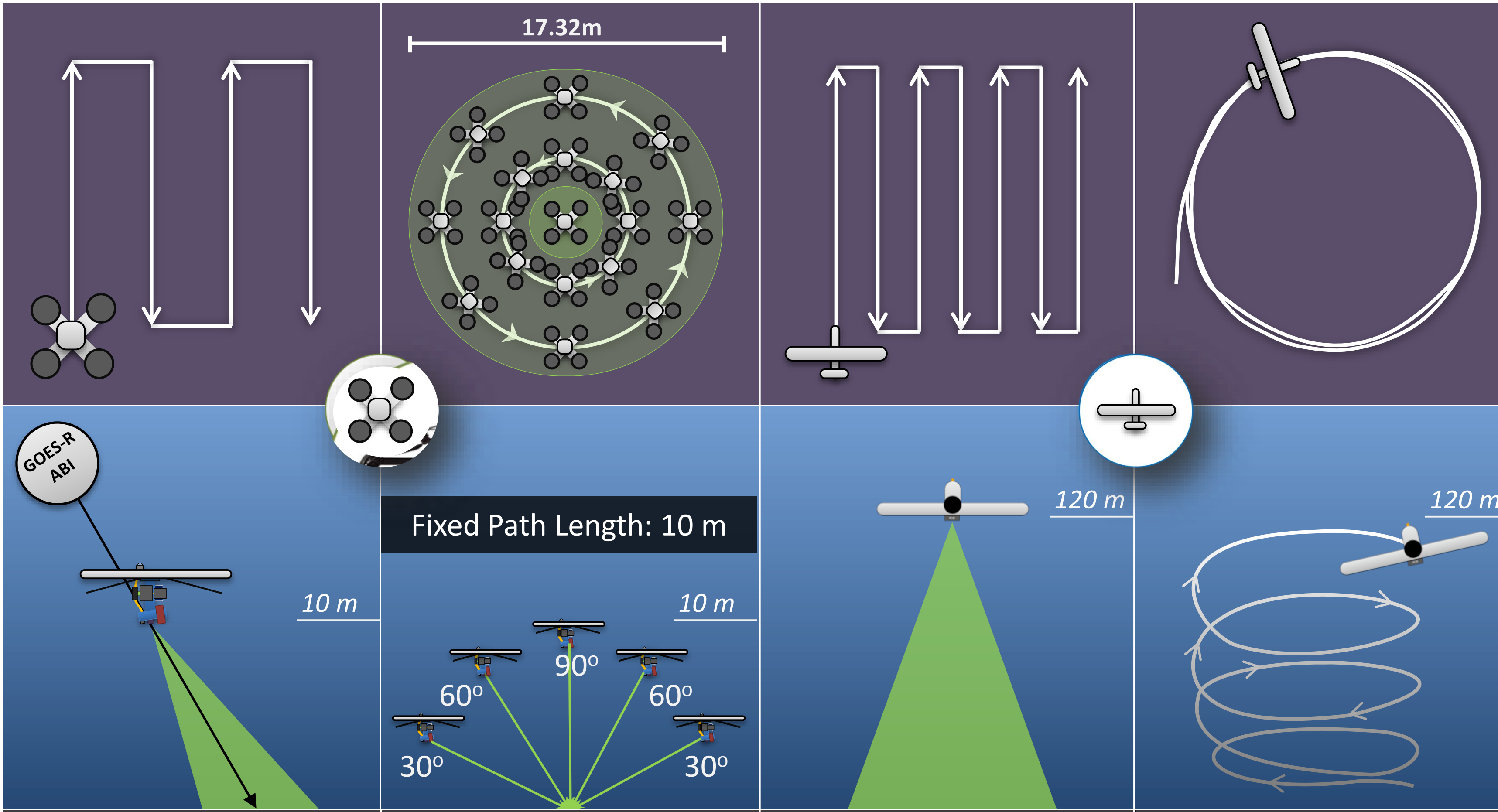
SI Traceability through Earth Surface Reference Observations

- Measurement of the primary physical state variables at the time of satellite image acquisition over a uniform target
- Radiative Transfer Modeling



Comparison conducted through modeling (L1b & L2+)

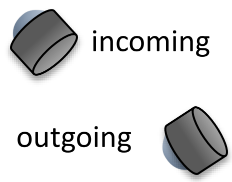
Four UAS Baseline Collection Types



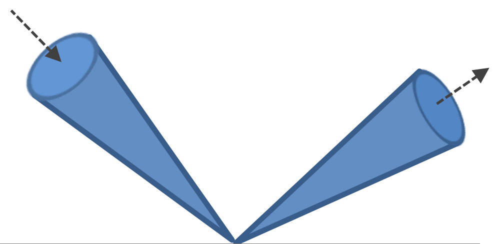
Fixed View Geometry Matching ABI (L1b)	Goniometric Target Collection (L2+/L1b)	NADIR & Oblique Area Collection (L1b/L2+)	Spiraling Ramp Collection (L1b/L2+)

Fundamental Surface Reflectance Measurement Challenges

Bi-Directional: geometry specified by two cones

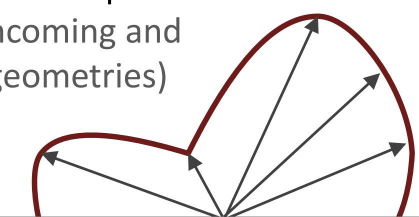


Two Sensors



Bidirectional Reflectance Distribution Function (BRDF)

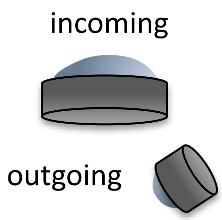
All combinations of incoming & outgoing geometry are required (Ex. BRDF for one incoming and multiple outgoing geometries)



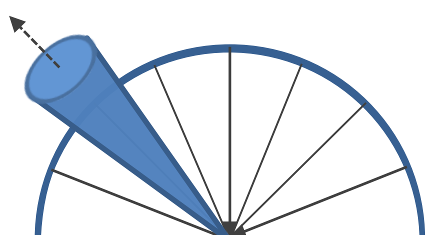
Bidirectional Reflectance Distribution Function (BRDF)

Hemispheric-Directional: geometry specified by a cone and a hemisphere

Intended Measurement (Goniometric)

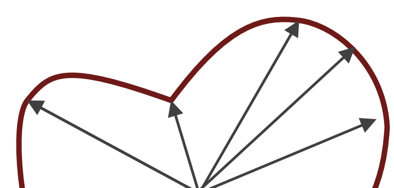


Two Sensors



Hemispheric-Directional Reflectance

Hemispheric incoming (incoming directional component lost) & directional outgoing geometry



Hemispheric-Directional Reflectance

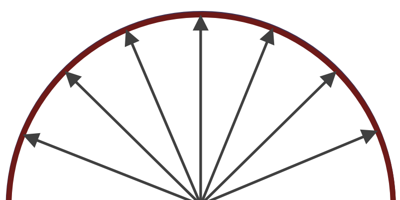
RSB Validation Using the Earth's Surface as a Reference:

Lambertian Surface Assumption

Property of Interest:

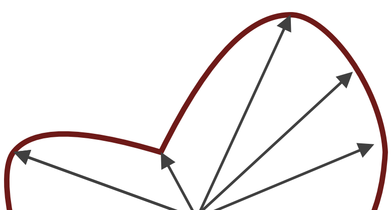
Surface Reflectance (r)

$$r(\lambda) = \frac{Outgoing}{Incoming}$$



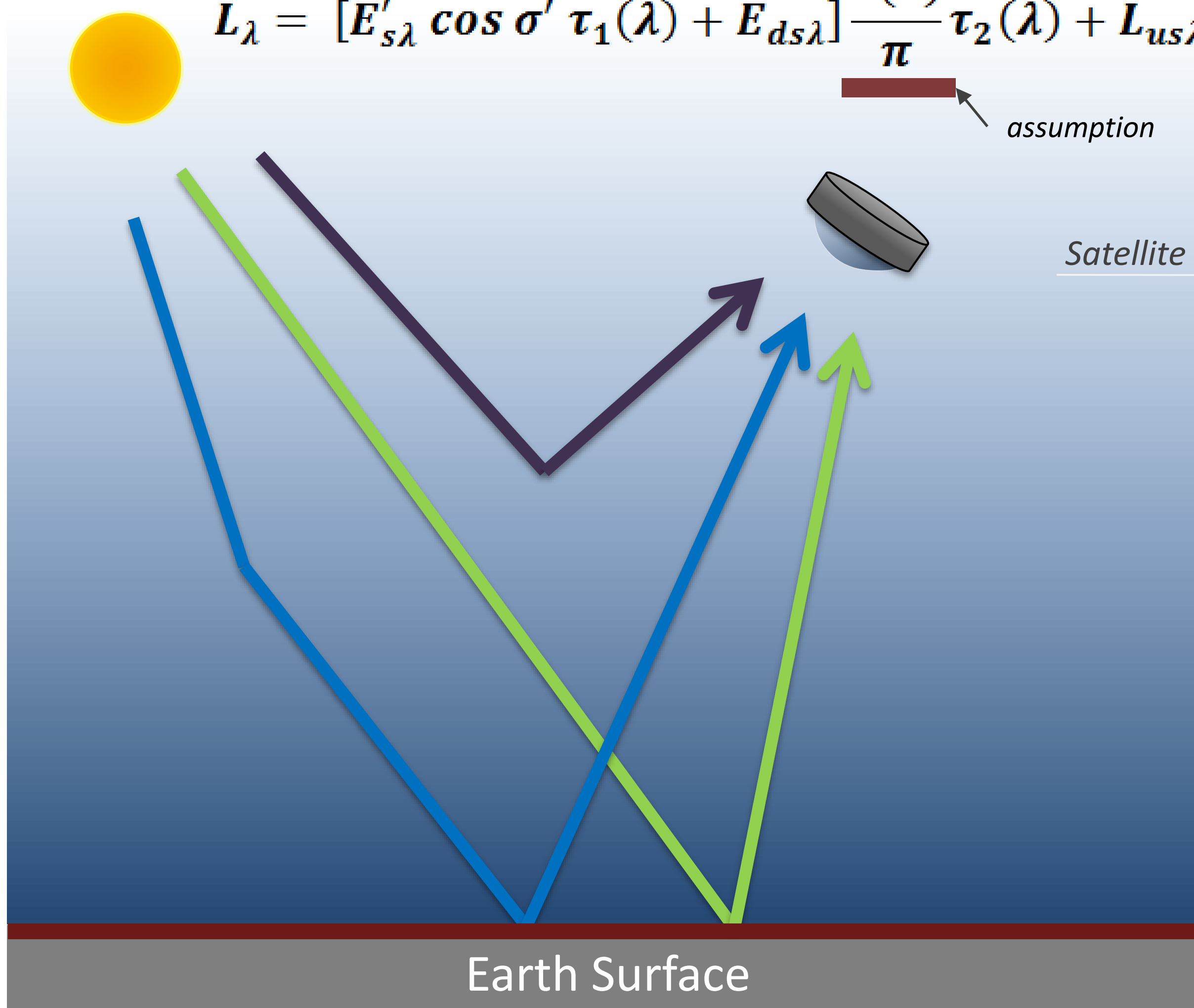
Lambertian Surface

*assumption



Bidirectional Reflectance Distribution Function (BRDF)

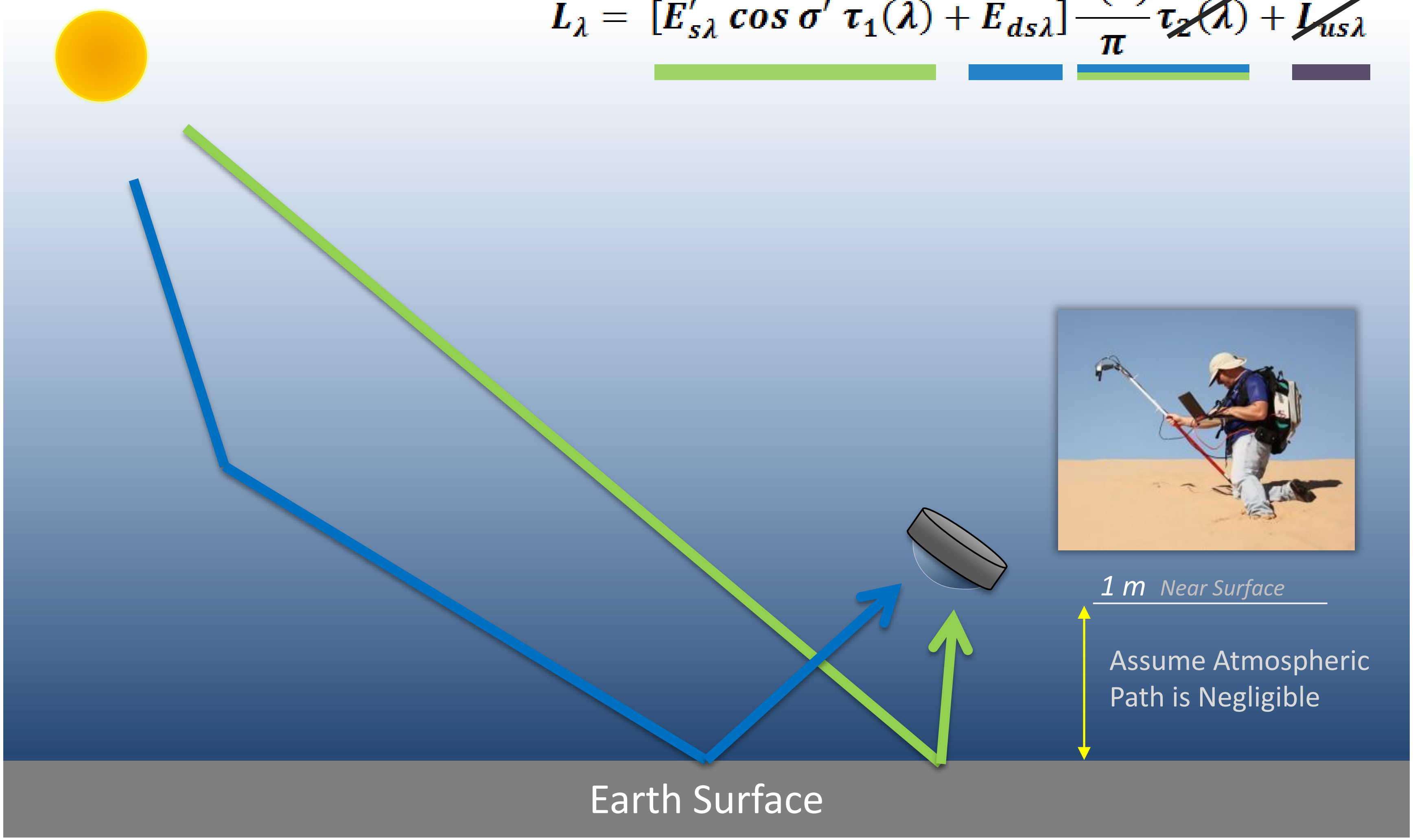
$$L_\lambda = [E'_{s\lambda} \cos\sigma' \, \tau_1(\lambda) + E_{ds\lambda}] \frac{r(\lambda)}{\pi} \tau_2(\lambda) + L_{us\lambda}$$



RSB: Field Surface Reflectance Measurements

Governing Equation:

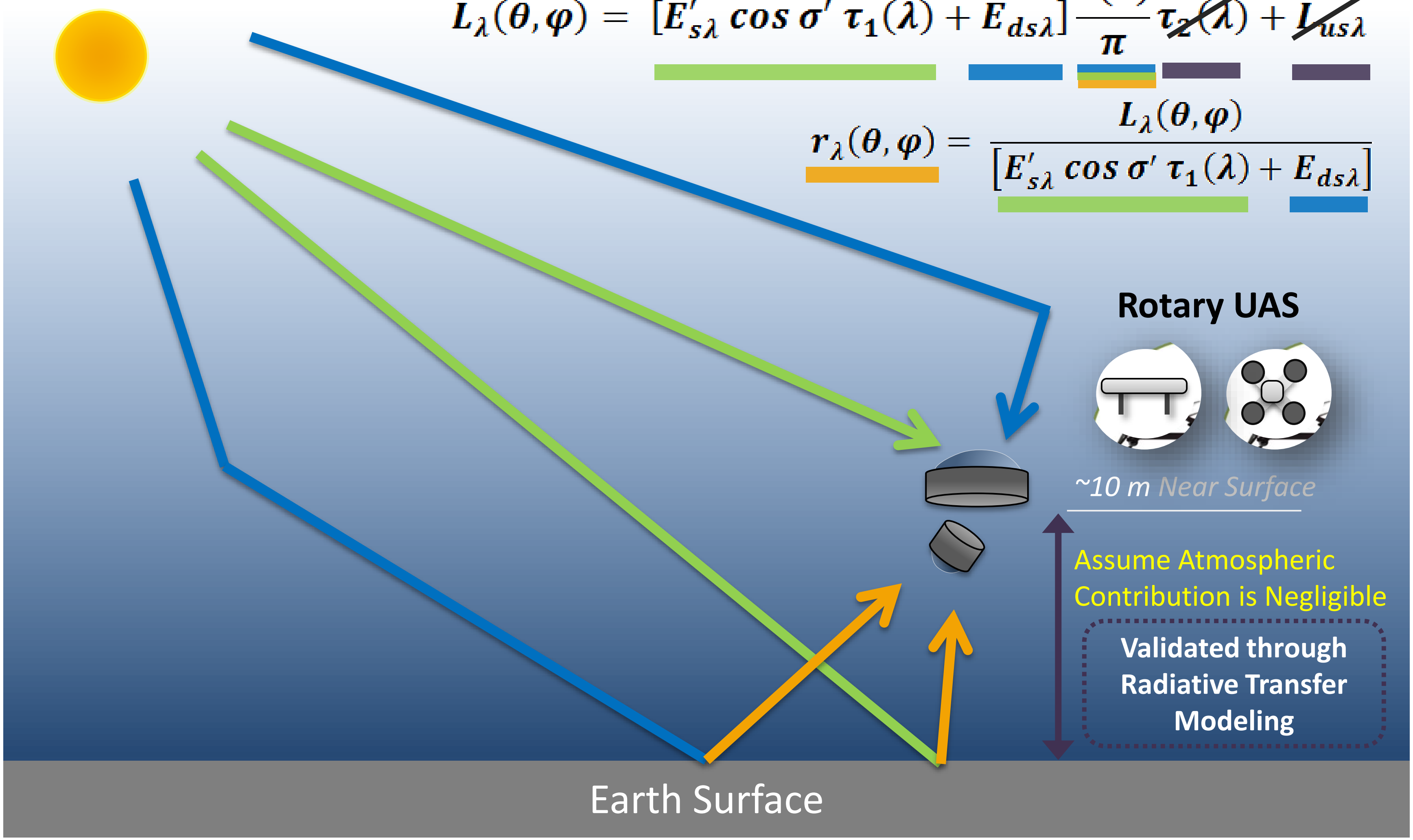
$$L_\lambda = [E'_{s\lambda} \cos\sigma' \, \tau_1(\lambda) + E_{ds\lambda}] \frac{r(\lambda)}{\pi} \cancel{\tau_2(\lambda)} + \cancel{L_{us\lambda}}$$



UAS RSB Fundamental Near Surface Measurement Approach:
Hemispheric Directional Reflectance

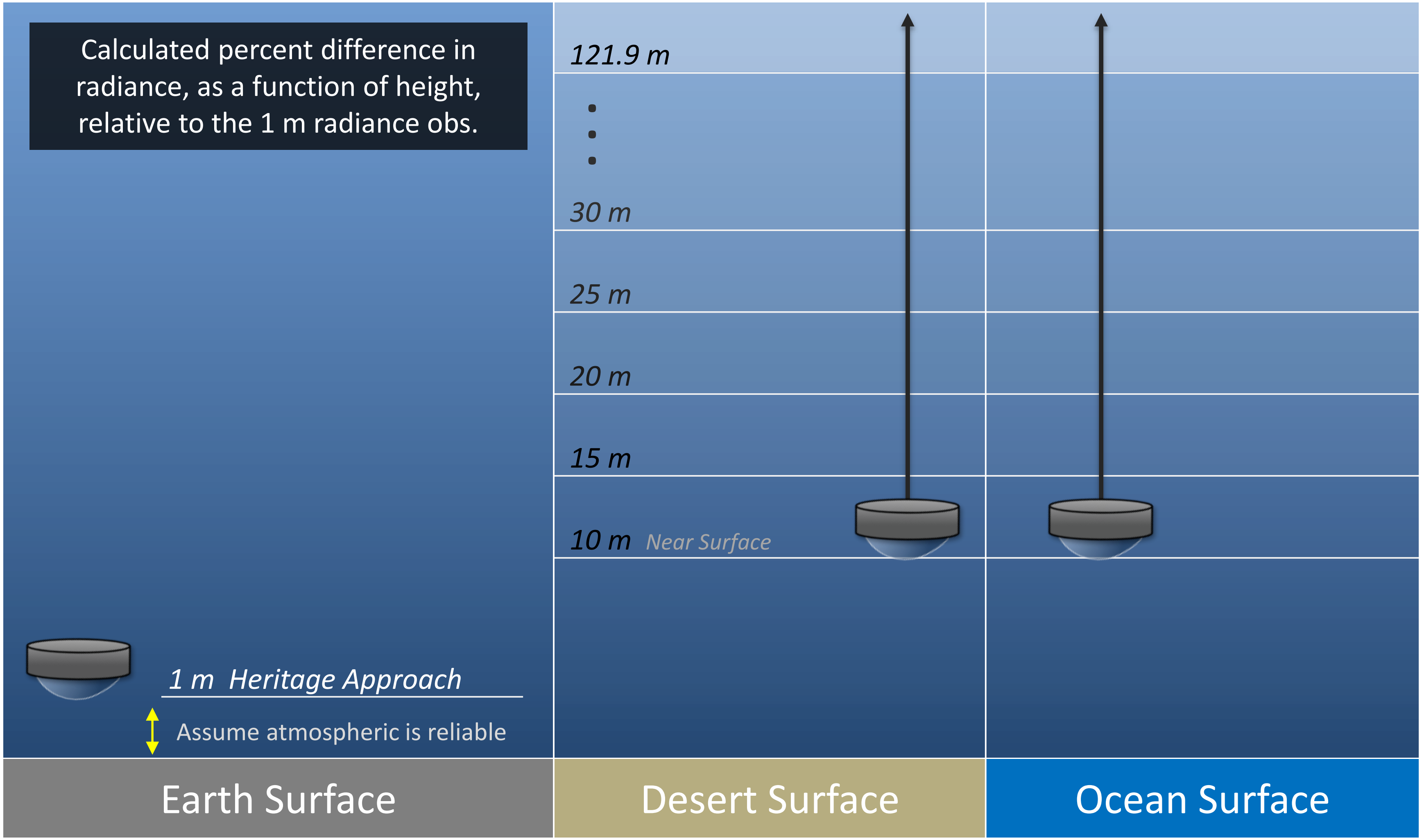
$$L_{\lambda}(\theta,\varphi) = [E'_{s\lambda}\cos\sigma'\,\tau_1(\lambda) + E_{ds\lambda}]\frac{r(\lambda)}{\pi}\cancel{\tau_2(\lambda)} + \cancel{L_{us\lambda}}$$

$$r_{\lambda}(\theta,\varphi) = \frac{L_{\lambda}(\theta,\varphi)}{[E'_{s\lambda}\cos\sigma'\,\tau_1(\lambda) + E_{ds\lambda}]}$$

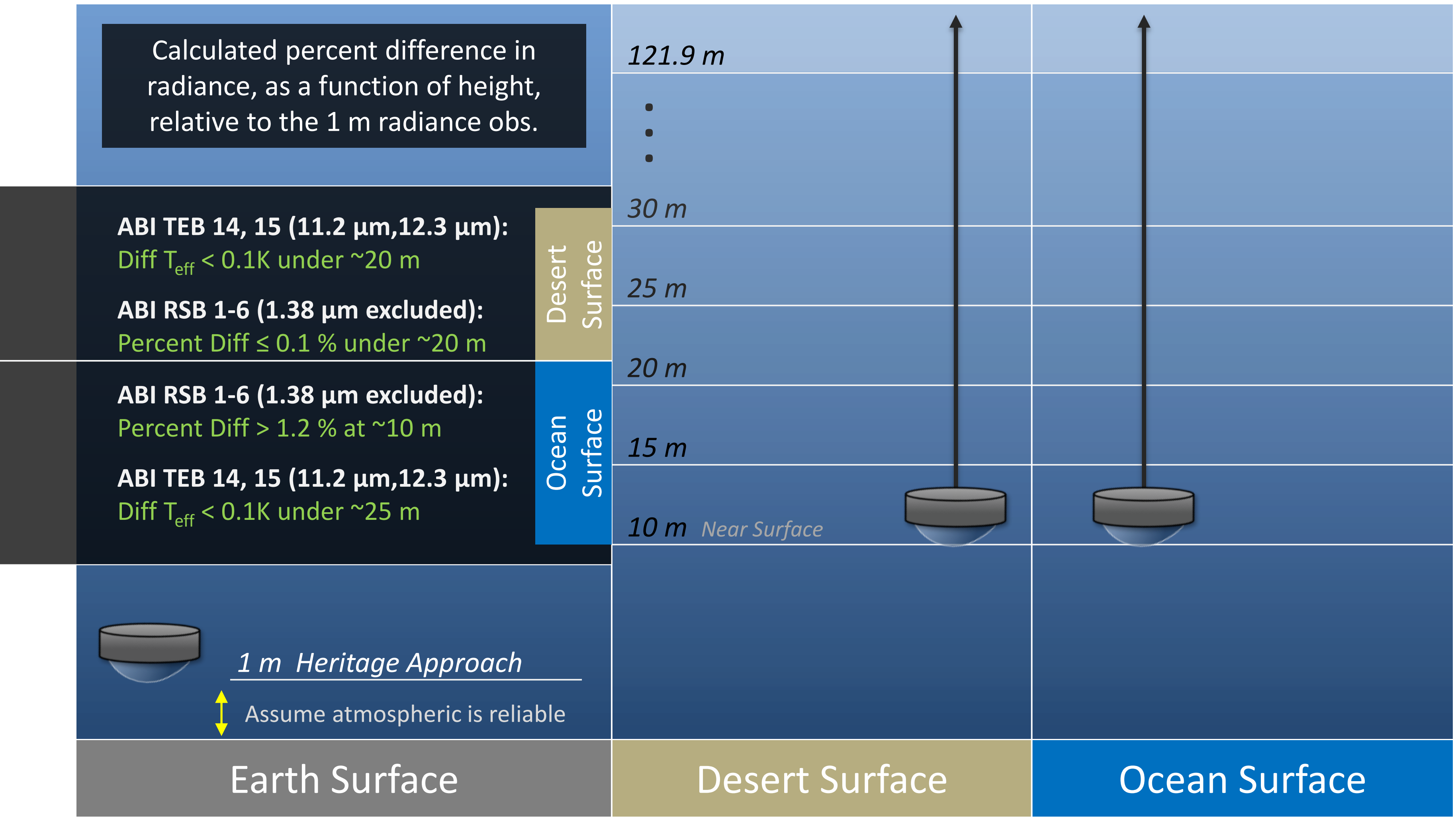


Padula et al. 2016 (SPIE) & Pearlman et al 2016 (SPIE)

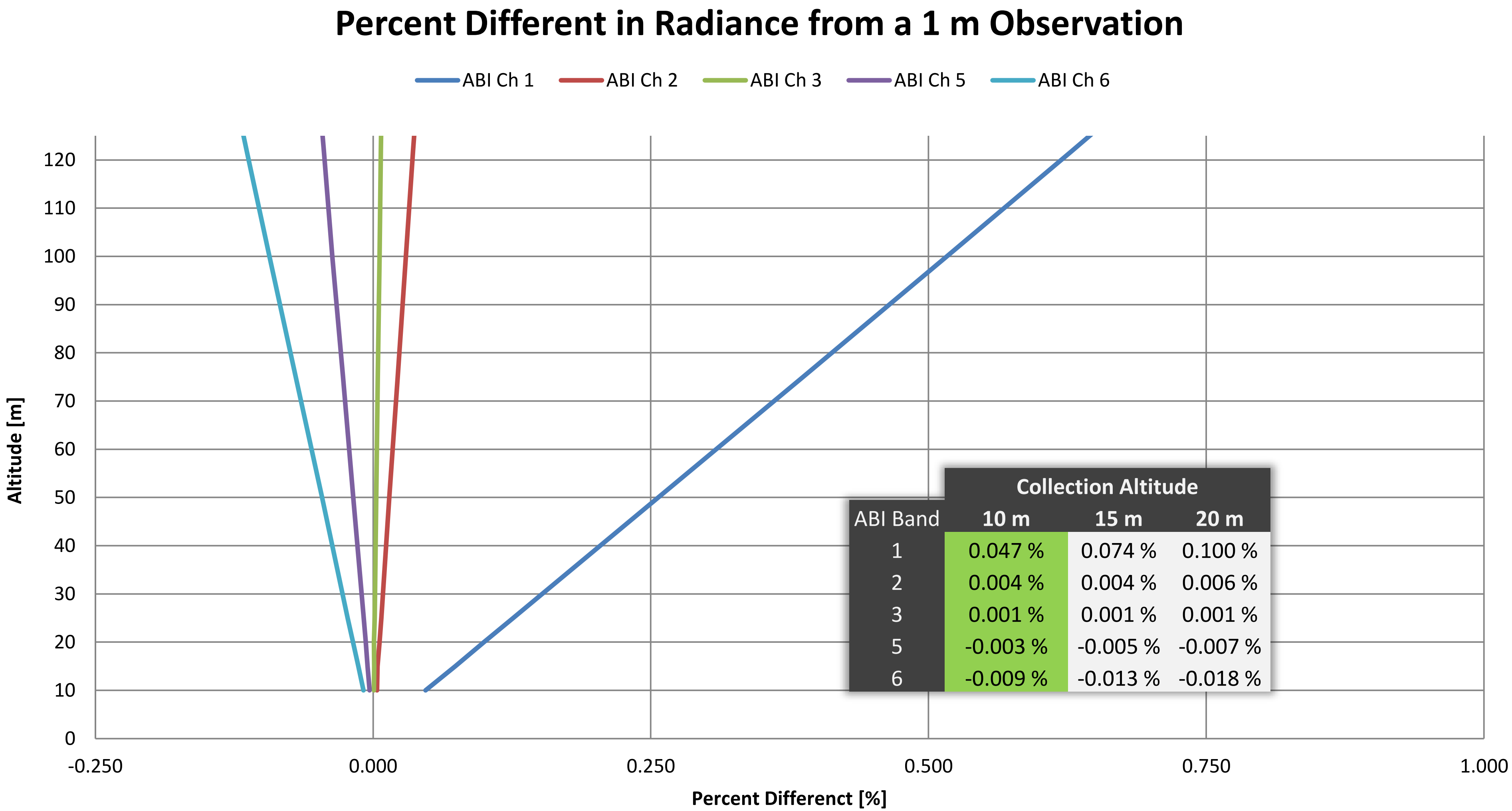
Initial UAS Collection Altitude Study



Initial UAS Collection Altitude Study



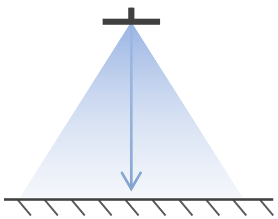
UAS Collection Altitude Study: RSB Desert



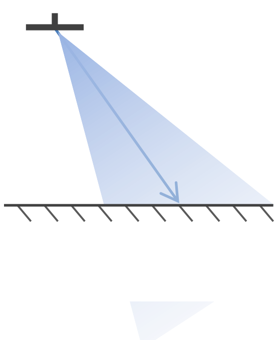
	Collection Altitude		
ABI Band	10 m	15 m	20 m
1	0.047 %	0.074 %	0.100 %
2	0.004 %	0.004 %	0.006 %
3	0.001 %	0.001 %	0.001 %
5	-0.003 %	-0.005 %	-0.007 %
6	-0.009 %	-0.013 %	-0.018 %

Fixed-Wing UAS Collection (NADIR to 45º)

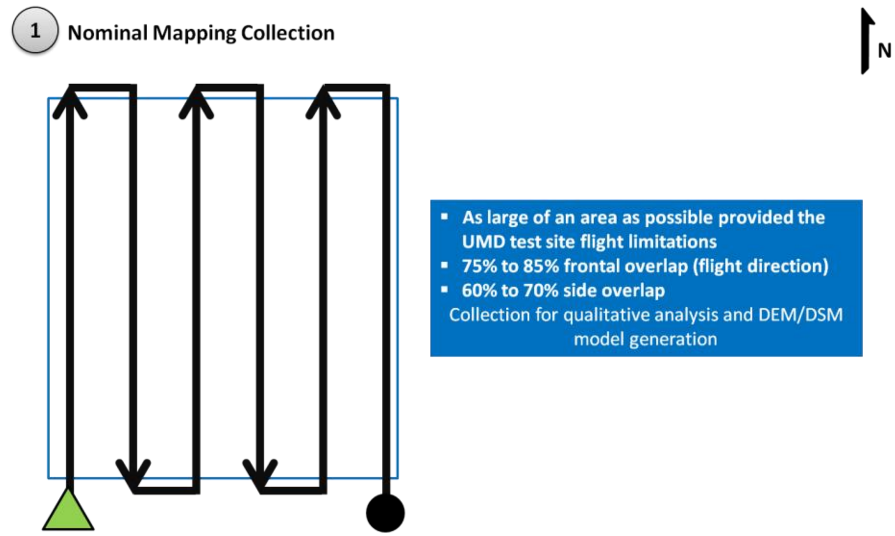
NADIR Collection:



Oblique Collection (~45º)



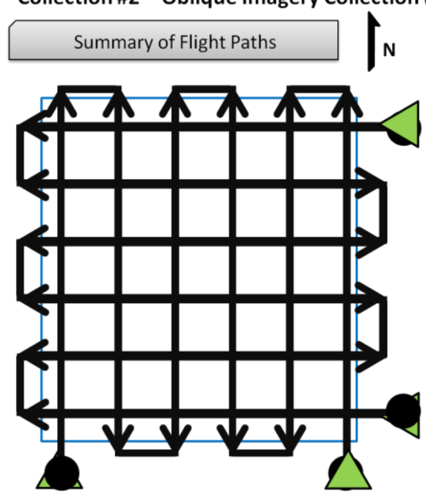
Collection #1 – Large Area Imagery Collection (NADIR)



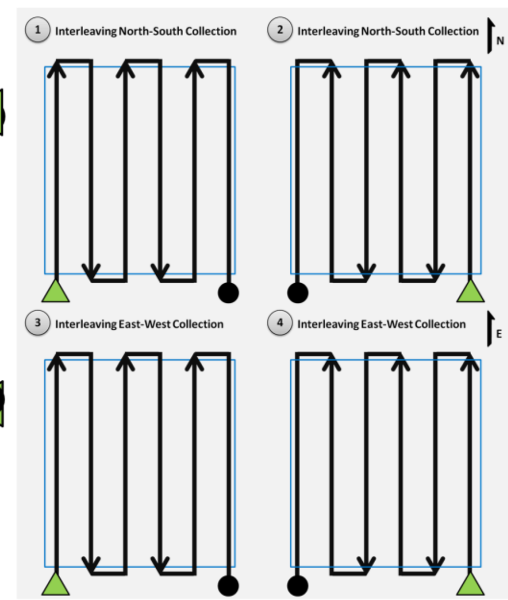
- As large of an area as possible provided the UMD test site flight limitations
- 75% to 85% frontal overlap (flight direction)
- 60% to 70% side overlap

Collection for qualitative analysis and DEM/DSM model generation

Collection #2 – Oblique Imagery Collection (45 degrees)



Focused area collection optimized for qualitative analysis and DEM/DSM model generation



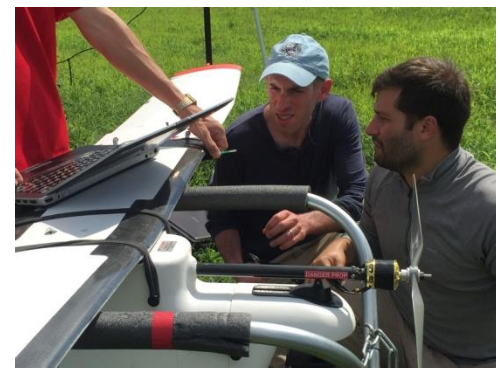
Fixed-Wing UAS Functional Performance Demonstration Collection Summary

Collection Set #1:

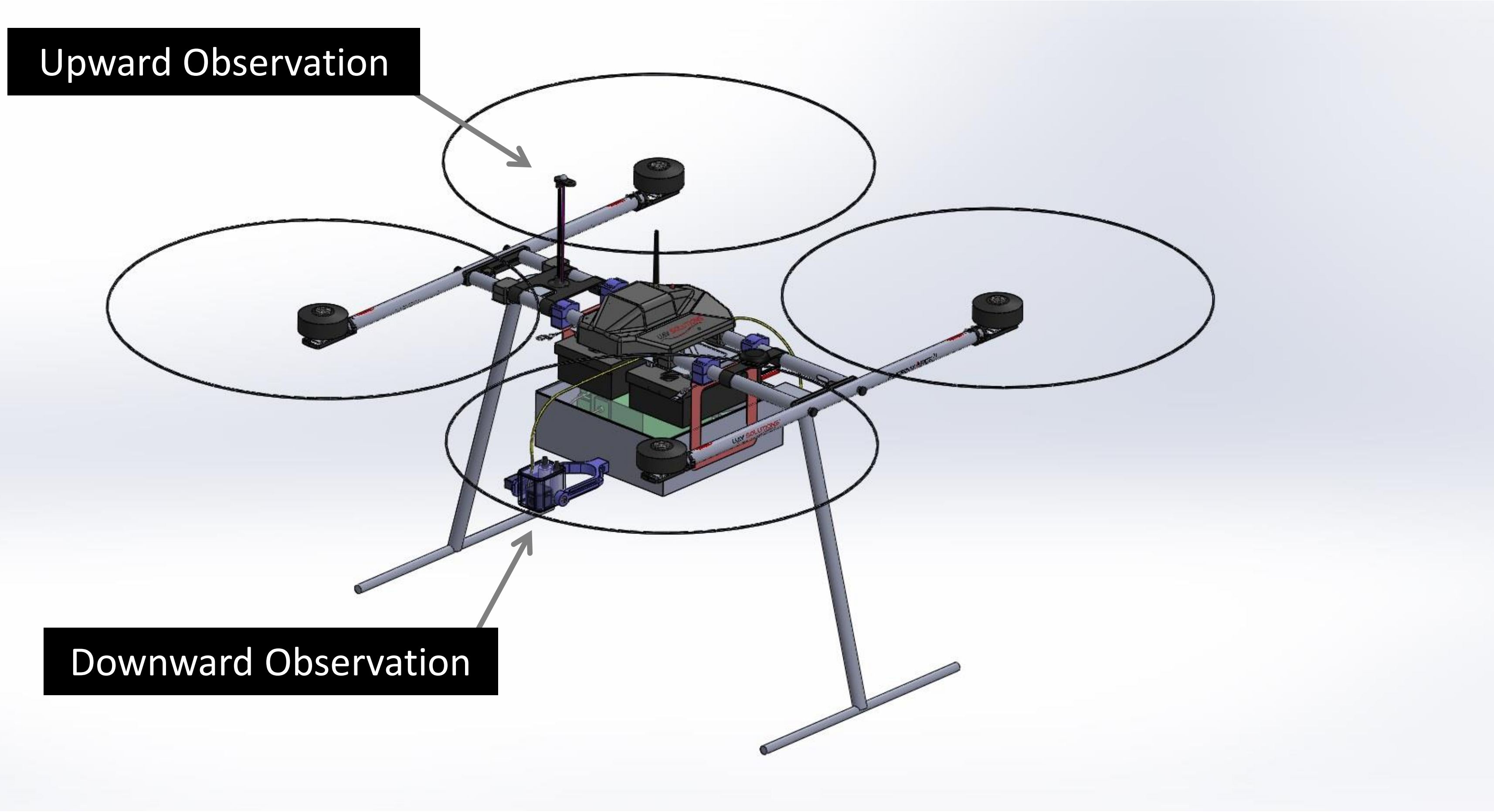
- Nadir imagery collection
- Duration: 1.25 hrs
- Collection Altitude: 700 ft
- Ground Spot Distance (GSD): 3”
- Area Mapped: ~470 acres (~2 km^2)

Collection Set #2:

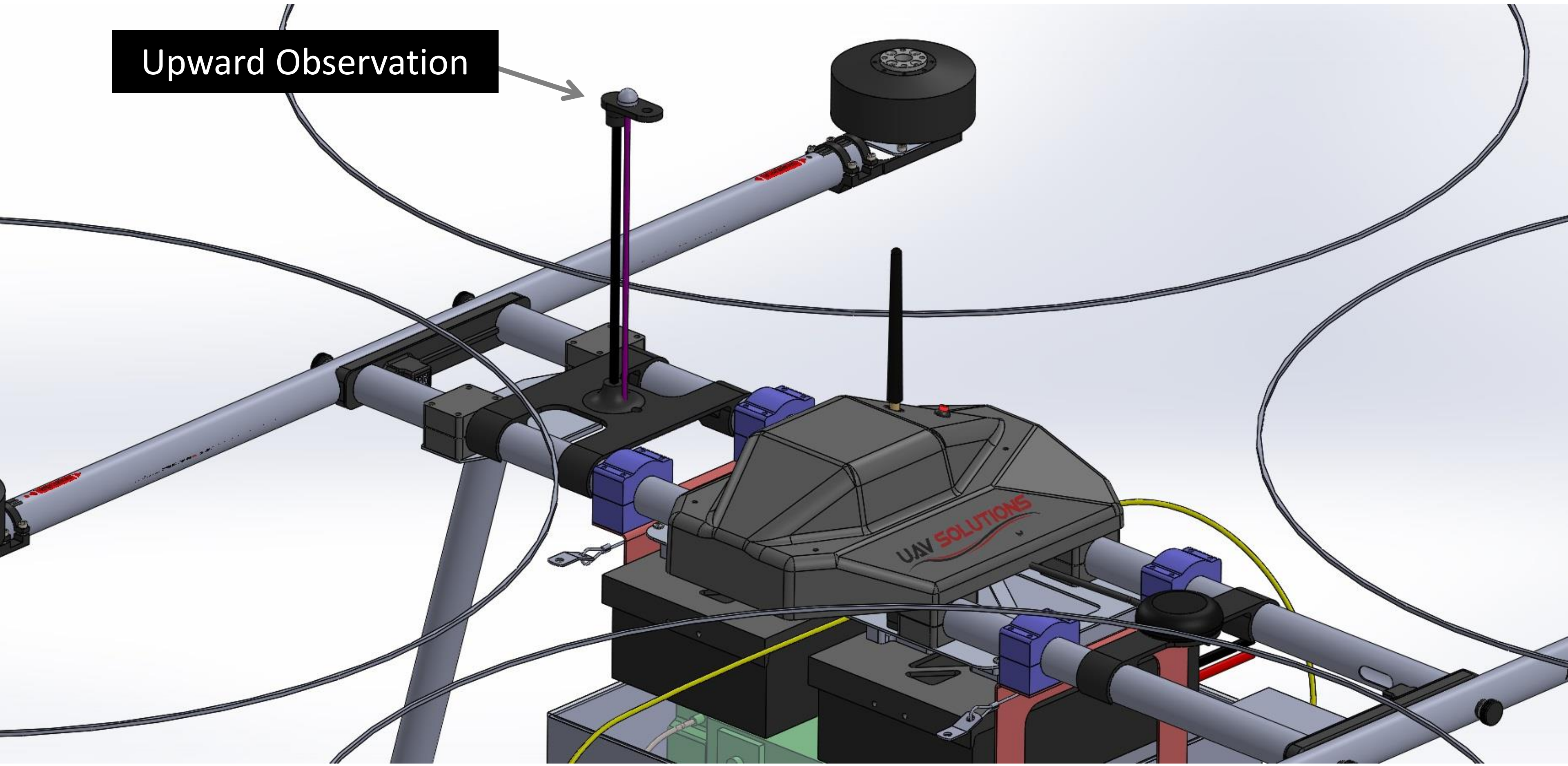
- Oblique imagery collection (45 deg)
- Duration: 1 hr
- Collection Altitude: 400 ft
- Ground Spot Distance (GSD): 2-8”
- Area Mapped: ~100 acres



GOES-R Prototype Rotary UAS

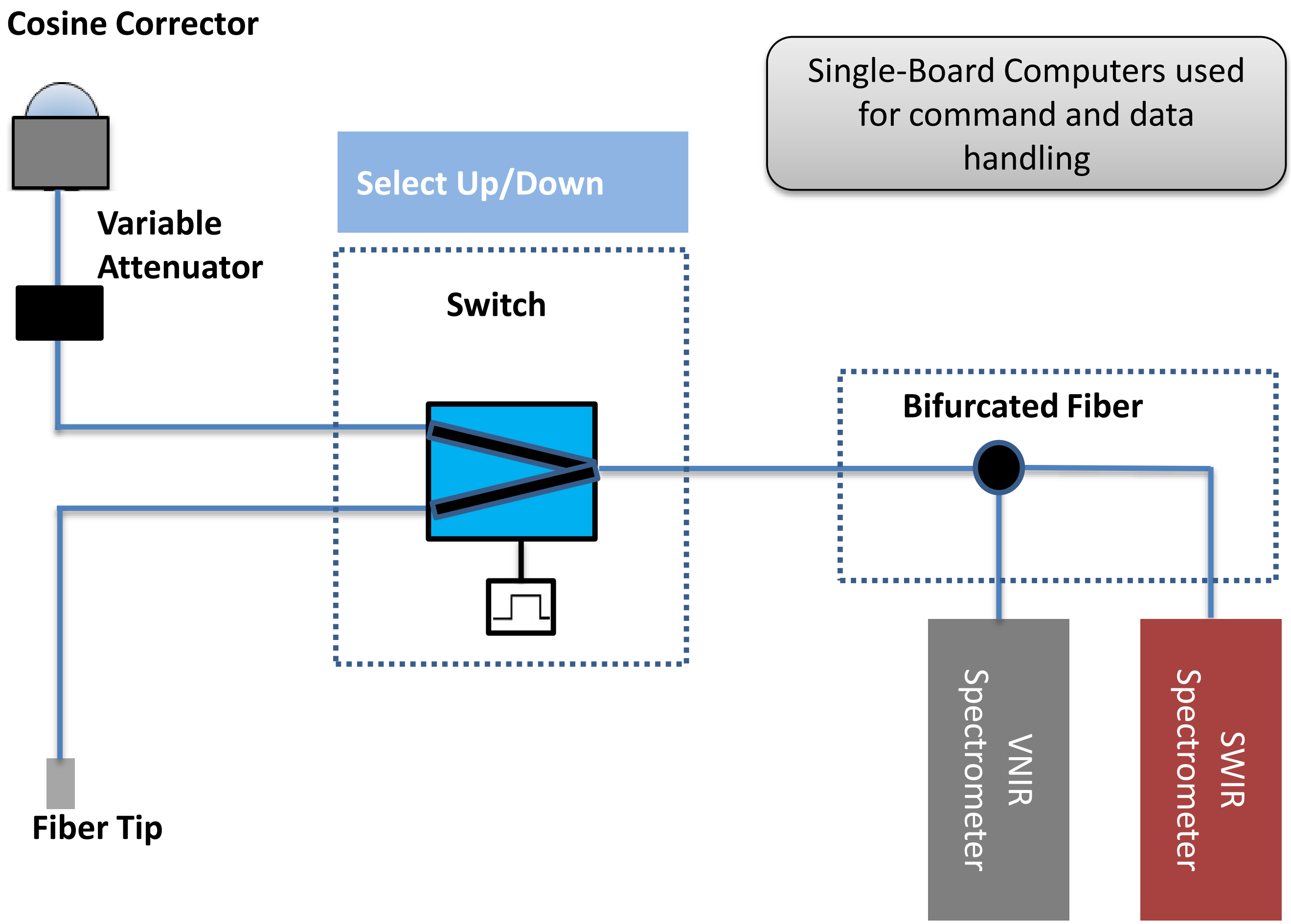


GOES-R Prototype Rotary UAS: Upward Observations



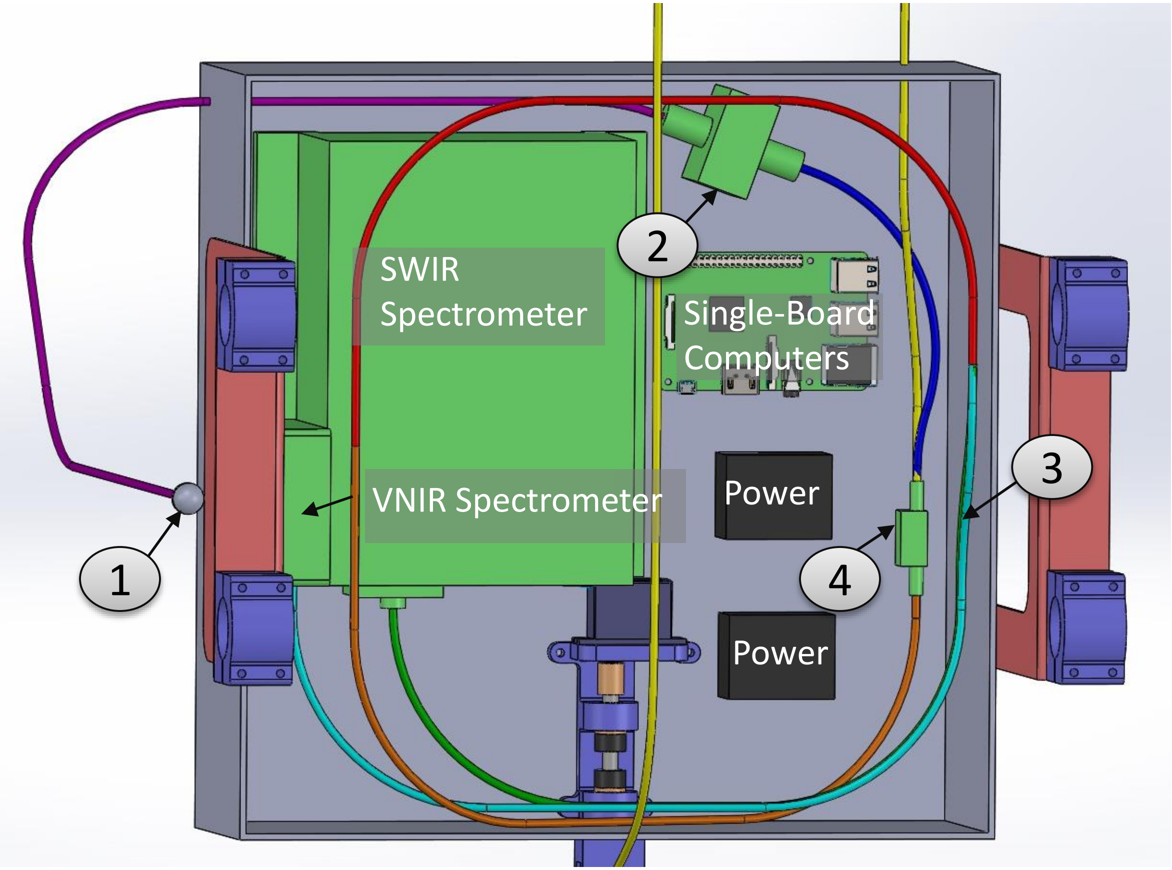
Basic Design Concept of the Updated Design: UAS Reflective Solar Band Sensor Suite

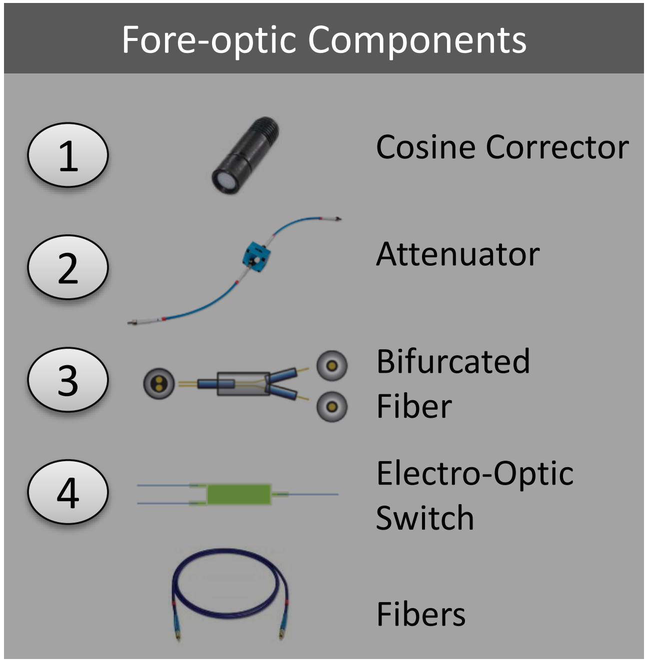
- Provides simple, light (~8 lbs) with the required functionality:
  - Can make hyperspectral radiance and irradiance measurements in the visible to SWIR
  - Can readily switch between upward & downward-viewing collection
- Features:
  - Two compact spectrometers covering wavelengths 350 nm-2600 nm
  - Ability to remove a spectrometer



5% (*k*=1) Radiometric Uncertainty Requirement driven by ABI radiometric uncertainty

Rotary UAS Enclosure for UAS sensor suite Design





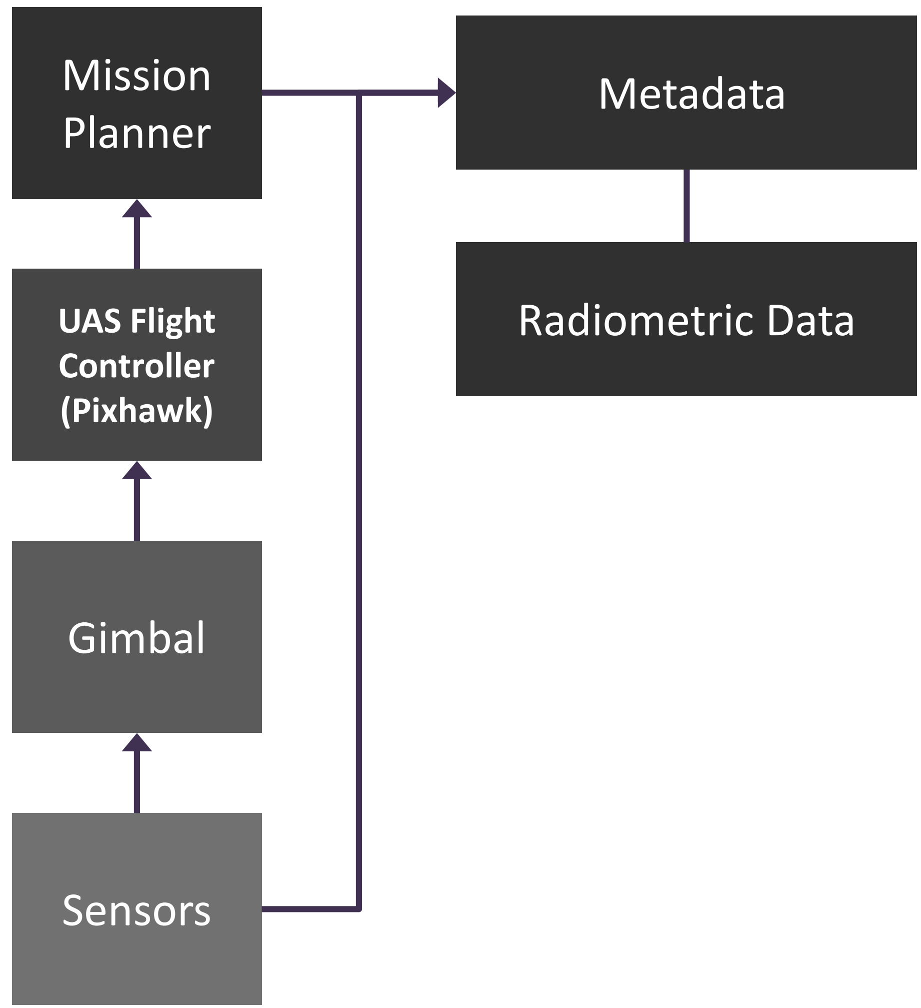
- Custom enclosure, fiber lengths, and configuration designed to meet fiber bending requirements
- Alternative configuration established in case of electro-optic switch delivery delay:
  - » The system can be configured to allow for downward only measurements

Image courtesy of UAV Solutions, Inc.

Requirement Compliance

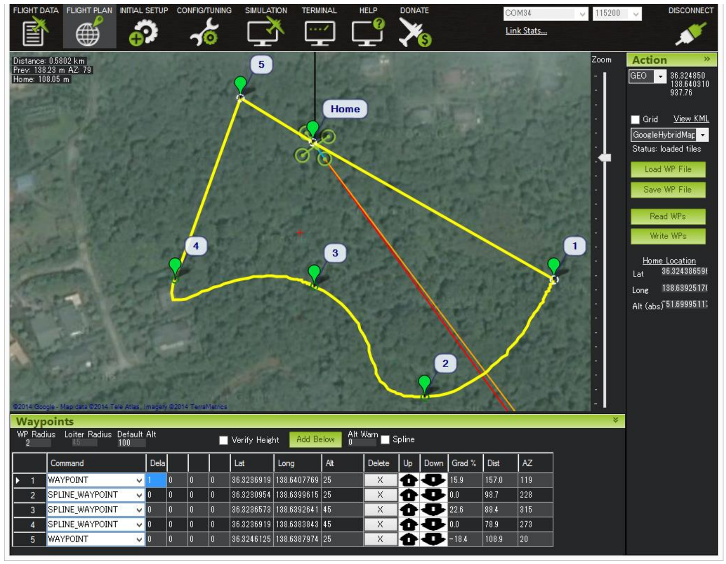
Requirement	Status
Command & Data Handling	●
Power	●
Cost	●
Mass	●
Radiometric Performance	●

Successfully completed Mission Concept Review and Critical Design Review – demonstrating compliance to requirements



Directional Measurements Achieved Through Autonomous Gimbal + UAS Mission Planning

Mission Planner



http://planner.ardupilot.com/

» Point-and-click waypoint entry, using Google Maps/Bing/Open street maps/Custom WMS

» Select mission commands from drop-down menus

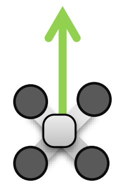
» Download mission log files and analyze them

» Configure APM settings for your airframe

» **Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator**

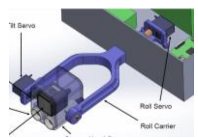
» **Autonomously control UAS, Gimbal, and Sensor(s)**

UAS heading



Heading Controlled by UAS Flight (Yaw)

- Defined pre-flight via mission planner waypoints
- UAS "front" is defined with the gimbal looking forward



Gimbal Controlled Autonomously by Flight Controller (Pitch & Roll)

- View geometry defined pre-flight via mission planner waypoints
- Range: 0° (nadir) to 90° (horizon) with a step size of 1° or less

Leveraging UAS in flight control, 2 axis (roll & pitch) gimbal, open source flight controller (Pixhawk), and autonomous mission planning (Mission Planner)

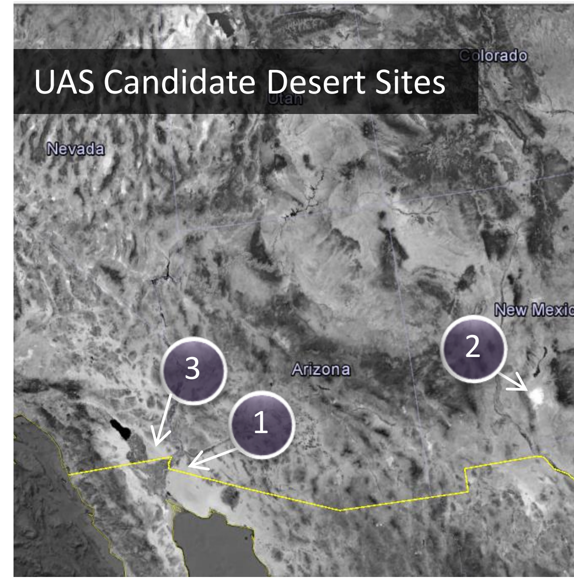
GOES-R Near Surface UAS Feasibility Demonstration Study: Operational Environment Testing

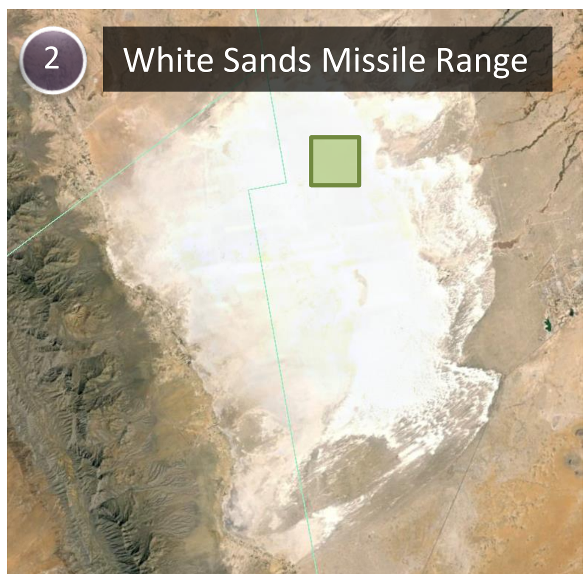
Desert Site Selection:

- Testing planned for late 2016
- Site characteristics include:
    - 4 km x 4 km region
    - All candidate sites will be identified using the same criteria used to select the ER-2 desert target ROIs
    - Accessible to fly for 1 week

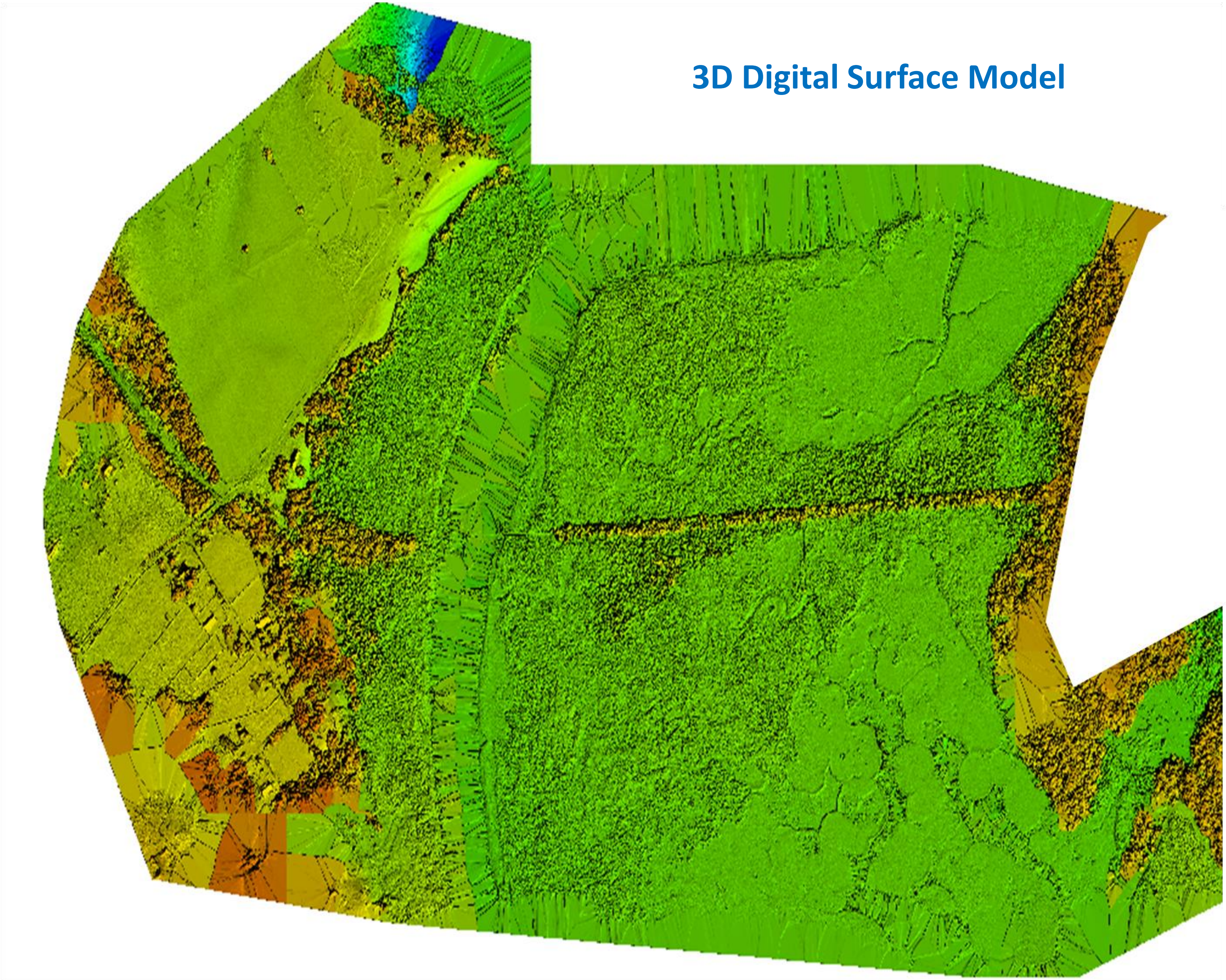
Planned Supplemental Observations for the GOES-R Field Campaign (NOT planned for test flights):

- Mobile SURFRAD station located at the target site:
    - L1b observations of interest – Sun Photometer, Surface Weather observations (T, Px, RH, & Wind Speed)
- Radiosonde Launches for each UAS collection (launched a few minutes before the start of each collection)

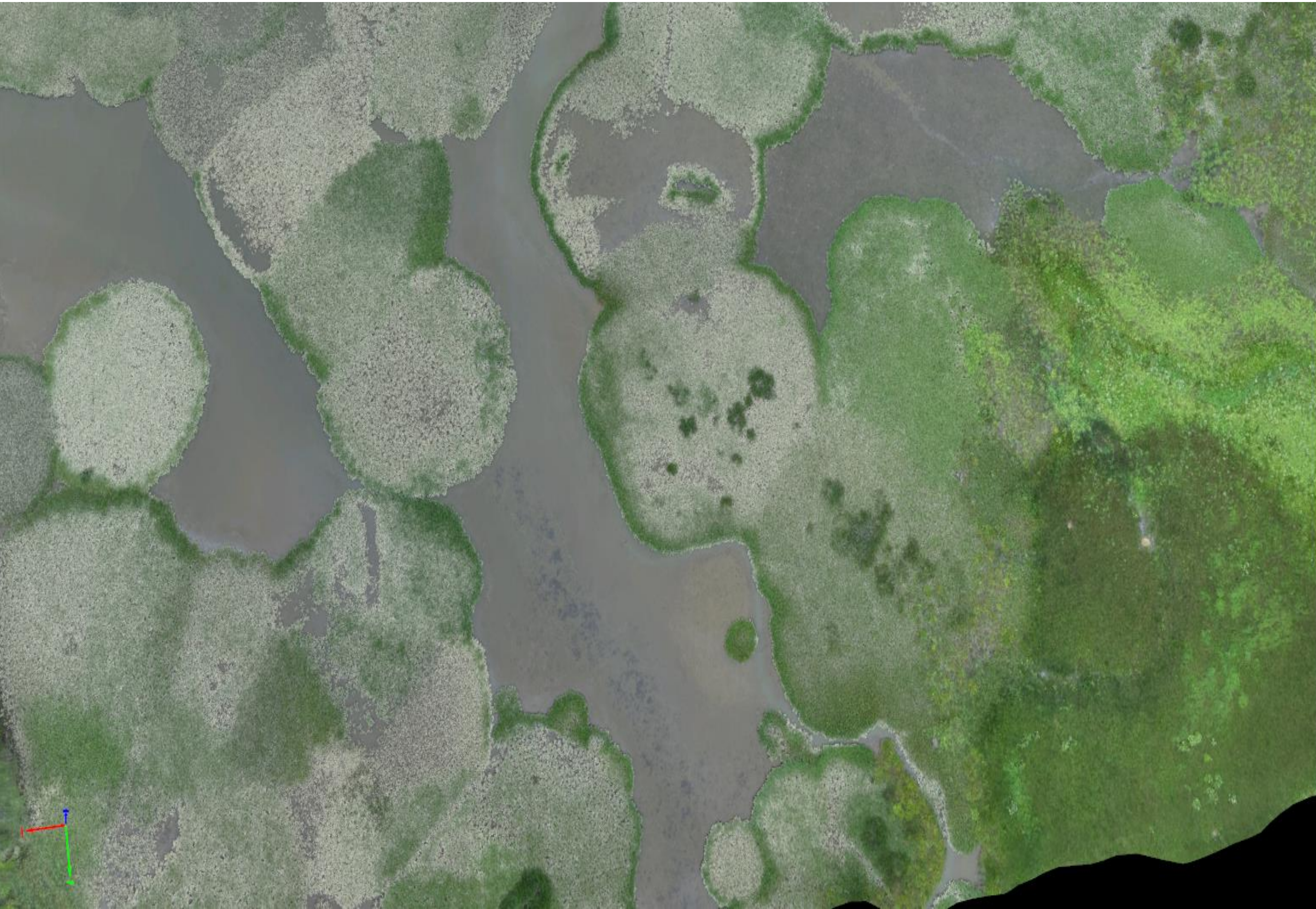




NOAA National Estuary Research Reserve (NERR) Jug Bay, MD – August 8, 2016

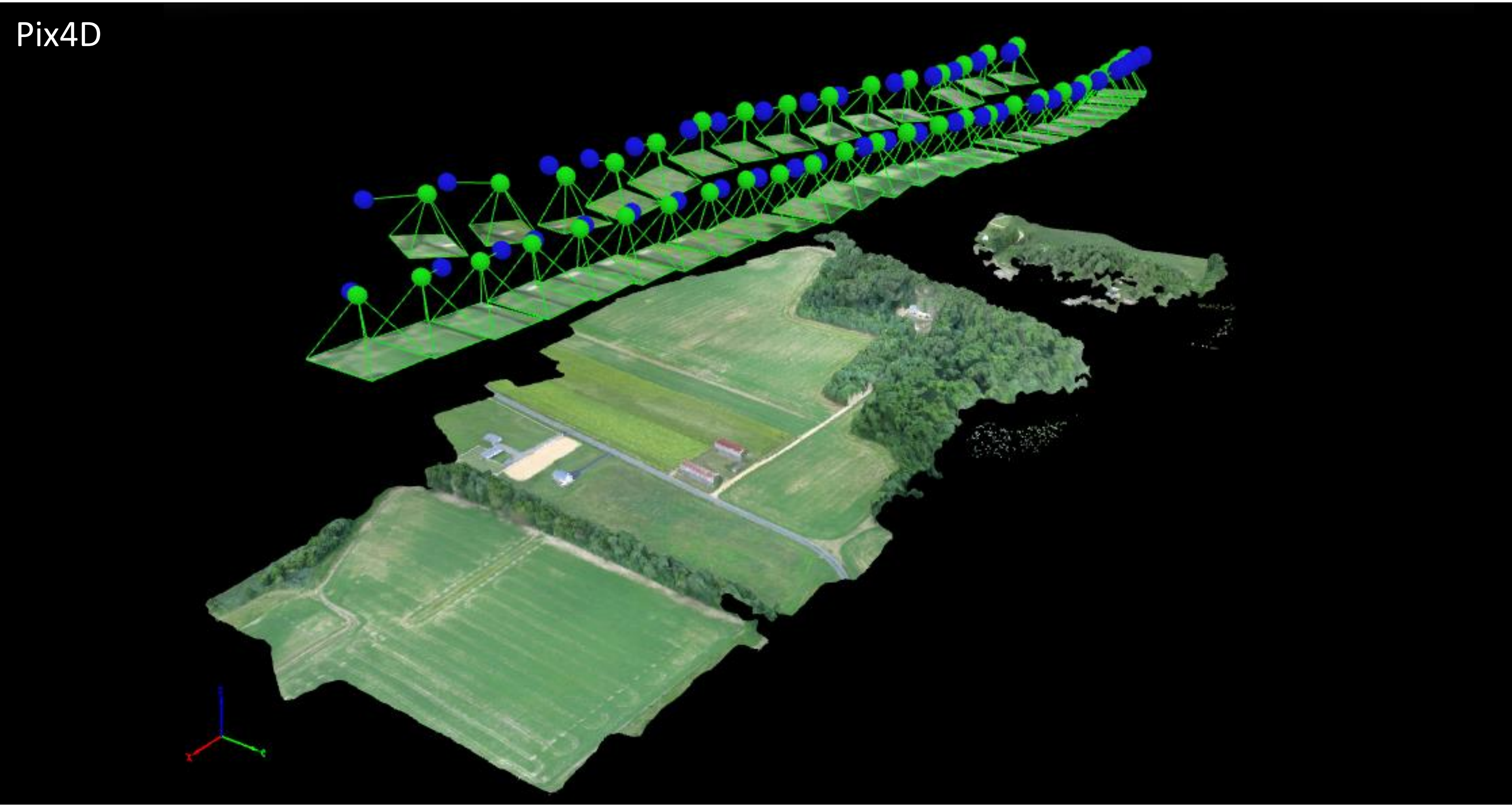


NOAA National Estuary Research Reserve (NERR) Jug Bay, MD – August 8, 2016



Fixed-Wing UAS Sample data

3D Digital Surface Model



Fixed-Wing UAS Sample data

3D Digital Surface Model

Fixed-Wing UAS Sample data

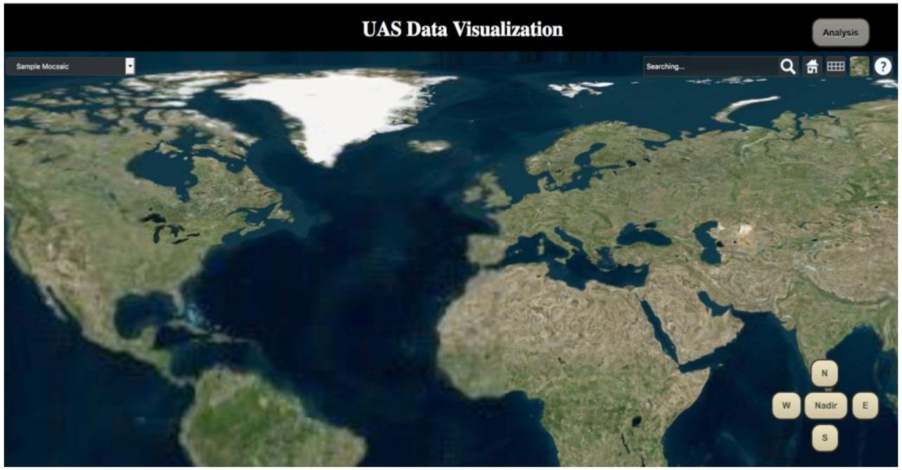
2D Georeferenced Imagery Mosaic

Fixed-Wing UAS Sample data

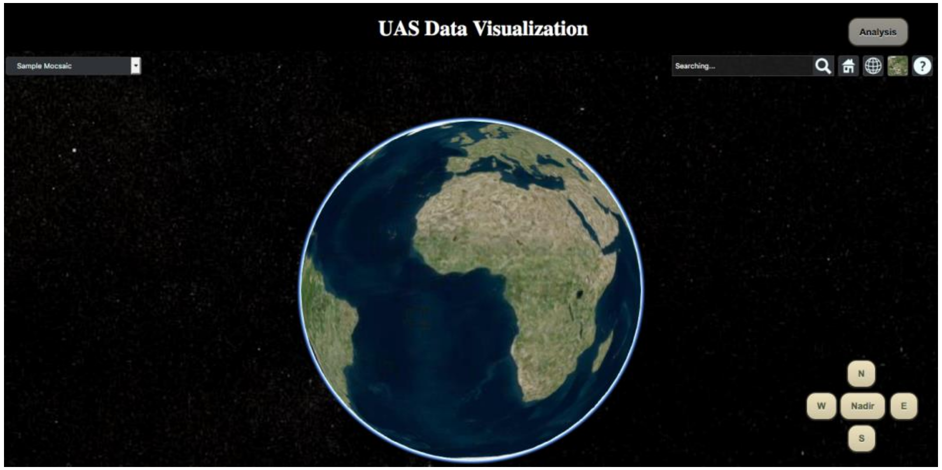
2D Georeferenced Imagery Mosaic

UAS Data Visualization

Web-based discovery and visualization prototypes in development



2D view (Flat Map)



3D view (Globe)