GOES-R Near Surface UAS Feasibility Demonstration Study

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NOAA/NESDIS
GOES-R Program

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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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[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.
  - Features:
    - Customized electronic enclosure and autonomous 2-axis gimbal

### Fixed-Wing UAS
- **Talon120LE**
  - 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
  - Features:
    - Swappable nose cone for flexible payload integration to achieve different mission sets
    - 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
Drafted & submitted an initial set of near surface UAS science requirements to the NOAA Unmanned Aircraft Systems Program in January of 2015

Initiated Purchase of UAS & Sensor Hardware

Local Test Site Deployments: UMD Test Site

Desert Deployments

UAS Flights (local)

Initial Sensor Testing, Calibration, & Integration

Command & Data Handling, Analysis, and Mission Planning Development

Initiated Purchase of UAS & Sensor Hardware

MCR

CDR

TRL 2

TRL 3-5

TRL 6

TRL 7

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

**Primary Payload:** RSB Hyperspectral (0.35 to 2.5 μm)
- non-imaging
- Filtered IR radiometers
- Atmospheric profile (near surface)

**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)

- 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)

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
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)

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
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)

Phoenix ACE XL Specifications
Endurance: 30 minutes of collection
Fully autonomous system
Payload Capacity: 10-12 lbs

Primary System – In Development
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
GOES-R Prototype Rotary UAS:
Gimbal & Fiber Motion

45° NADIR Viewing
Prototype Rotary UAS Developed:
Flight Testing Without Payloads

Images Courtesy: UAV Solutions, Inc.
Rotary UAS Payloads

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

Total Weight: 8.4 lbs
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)

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

- 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

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 45°)

NADIR Collection:

Oblique Collection (~45°)
2D Georeferenced Orthomosaics Products NADIR + Oblique Imagery vs Nadir Only Imagery
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 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 --
2D Geo-Referenced Orthomosaic
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 2 km.
- **Mesoscale**: Provides coverage over a 1000x1000 km box with a temporal resolution of 30 seconds, and spatial resolution of 0.5 to 2 km.
- **Continental US**: The CONUS scan is performed every 5 minutes, providing coverage of the 5000 km (E/W) and 3000 km (N/S) rectangle over the United States. The spatial resolution is 0.5 to 2 km.
- **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**

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

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:**
- Desert
- Open Ocean
- Vegetation
- Clouds

Diagram:
- GOES-R
- ER-2 Aircraft
- Instruments
- Ground Instruments, Systems & Support Teams
- Coincident Collection
- 20 km Stratosphere
- 10 km Tropopause
- 2 km Boundary Layer
- 10 m Near Surface
## GOES-R Field Campaign ER-2 Based Instruments

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

**Critical Set of Instruments**

Add-on Capability

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

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

End-to-End Image Chain Analysis

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+)

Fixed Path Length: 10 m

Width: 17.32 m

- 120 m
- 120 m
- 120 m
- 120 m
- 120 m
Fundamental Surface Reflectance Measurement Challenges

**Bi-Directional:** geometry specified by two cones

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

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

- Hemispheric incoming (incoming directional component lost) & directional outgoing geometry
RSB Validation Using the Earth’s Surface as a Reference: Lambertian Surface Assumption

Property of Interest: Surface Reflectance ($r$)

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

Lambertian Surface

Bidirectional Reflectance Distribution Function (BRDF)

Earth Surface

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

Satellite

*assumption
RSB: Field Surface Reflectance Measurements

**Governing Equation:**

\[ L_\lambda = \left[ E'_{s\lambda} \cos \sigma' \tau_1(\lambda) + E_{dsl\lambda} \right] \frac{r(\lambda)}{\pi} \tau_2(\lambda) + L'_{us\lambda} \]
UAS RSB Fundamental Near Surface Measurement Approach:
Hemispheric Directional Reflectance

\[ L_\lambda(\theta, \varphi) = \left[ E'_{s\lambda} \cos \sigma' \tau_1(\lambda) + E_{d\lambda} \right] \frac{r(\lambda)}{\pi} \tau_2(\lambda) + I_{us\lambda} \]

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

Rotary UAS

Initial UAS Collection Altitude Study

Calculated percent difference in radiance, as a function of height, relative to the 1 m radiance obs.

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Earth Surface</th>
<th>Desert Surface</th>
<th>Ocean Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>121.9 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 m Near Surface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Initial UAS Collection Altitude Study

**Calculated percent difference in radiance, as a function of height, relative to the 1 m radiance obs.**

<table>
<thead>
<tr>
<th></th>
<th>Desert Surface</th>
<th>Ocean Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABI TEB 14, 15</strong> (11.2 μm, 12.3 μm):</td>
<td>Diff $T_{eff} &lt; 0.1K$ under ~20 m</td>
<td>Diff $T_{eff} &lt; 0.1K$ under ~25 m</td>
</tr>
<tr>
<td><strong>ABI RSB 1-6</strong> (1.38 μm excluded):</td>
<td>Percent Diff $\leq 0.1%$ under ~20 m</td>
<td>Percent Diff $&gt; 1.2%$ at ~10 m</td>
</tr>
</tbody>
</table>

**Earth Surface**

- Assume atmospheric is reliable

1 m *Heritage Approach*

### Results:

- **121.9 m**
  - 
  - 
  - 
- **30 m**
- **25 m**
- **20 m**
- **15 m**
- **10 m** *Near Surface*
UAS Collection Altitude Study: RSB Desert

Percent Different in Radiance from a 1 m Observation

<table>
<thead>
<tr>
<th>Collection Altitude</th>
<th>ABI Band 10 m</th>
<th>ABI Band 15 m</th>
<th>ABI Band 20 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.047 %</td>
<td>0.074 %</td>
<td>0.100 %</td>
</tr>
<tr>
<td>2</td>
<td>0.004 %</td>
<td>0.004 %</td>
<td>0.006 %</td>
</tr>
<tr>
<td>3</td>
<td>0.001 %</td>
<td>0.001 %</td>
<td>0.001 %</td>
</tr>
<tr>
<td>5</td>
<td>-0.003 %</td>
<td>-0.005 %</td>
<td>-0.007 %</td>
</tr>
<tr>
<td>6</td>
<td>-0.009 %</td>
<td>-0.013 %</td>
<td>-0.018 %</td>
</tr>
</tbody>
</table>
Fixed-Wing UAS Collection (NADIR to 45°)

NADIR Collection:

Oblique Collection (~45°)
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 km²)

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

Upward Observation

Downward Observation
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
• 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.
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)
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)

1. Yuma, AZ (ideal)
2. White Sands Missile Range
3. Algodones Dunes, CA
3D Digital Surface Model
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)

Meta Data