Unmanned Aerial System-Based Lidar and Imagery in National Estuarine Research Reserve Marshes: Post Mission Review

Kirk Waters et al

Outline

- Project Overview
- Requirements and CONOPS
- Operations
- Results
- Technology Readiness

Project Objectives

Evaluate the efficacy of unmanned aerial system imagery and lidar

- Primarily interested in diverse marsh systems
- Use National Estuarine Research Reserves

Compare to manned data

Evaluate value of private sector contracting for an operational program

General Questions to Address

Vegetation mapping

- Need to monitor habitat and vegetation changes
- Can this imagery provide a better product than manned?
- If so, at what price?

Elevation

- Lidar has trouble in marsh areas. Smaller footprint help?
- Transect versus 3D on beaches
- Canopy by combining imagery structure-from motion (SfM) and lidar data?

Technical Plan – Products

- Multi-spectral (at least four-band) imagery three-centimeter resolution or better
- Lidar flown on the same platform to produce elevation data
- Lidar data will be classified for ground, water, and unclassified and have a non-vegetated vertical accuracy of 10 centimeters or better
- A digital elevation model from Structure from Motion (SfM)

Technical Project Plan – Contract

Contracted imagery and lidar surveys through the Coastal Geospatial Services Contract to Quantum Spatial and PrecisionHawk

Expected PrecisionHawk Lancaster platform, five-band multi-spectral imager, a Velodyne PUCK lidar

Flights at altitudes of 250 to 300’

Exact specifications determined by the contractor to meet the data requirements

Recap of Pre-Mission Issues

Certificate of Authorization

- May takes longer than you'd think
- Might not fit your window

Land Ownership

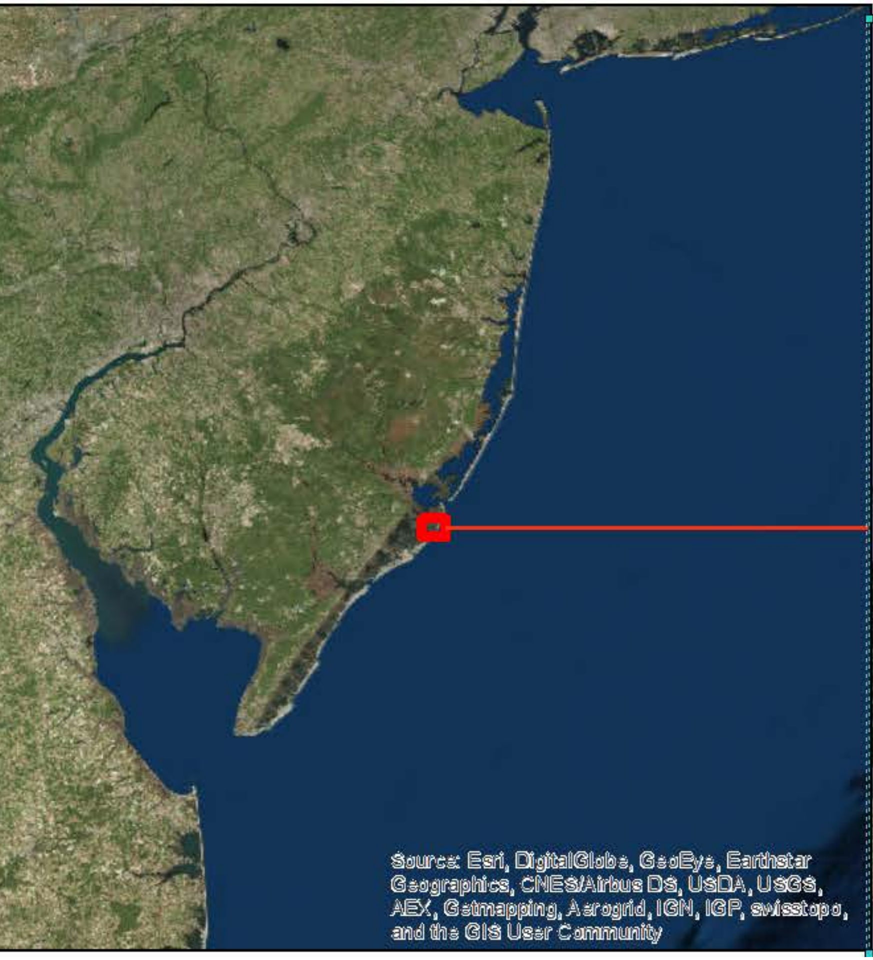
- Permission can take time
- You may be denied

Contracting

- Long process
- Rapid response a challenge

Overview of Areas for Flight

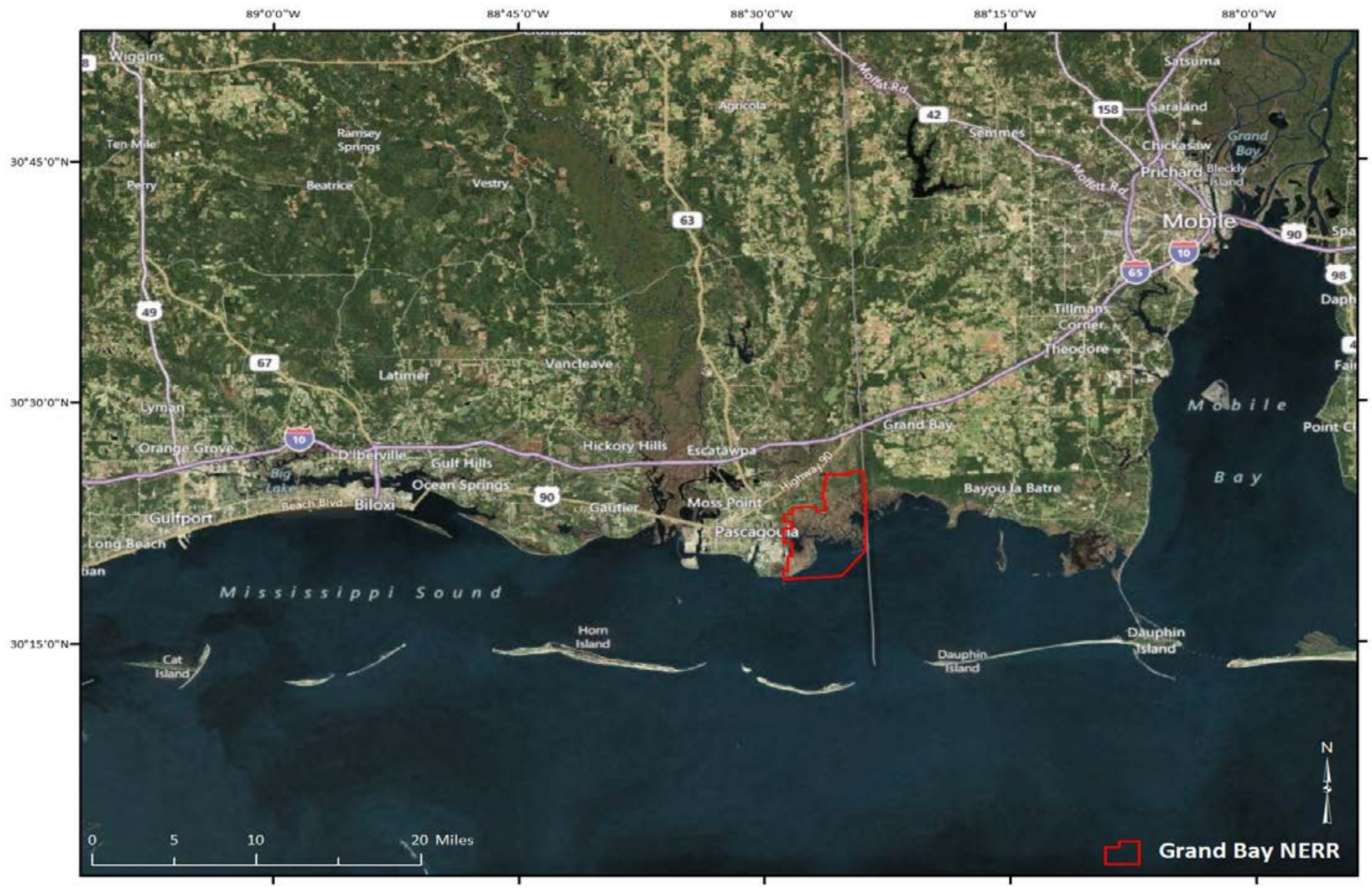
Jacques Cousteau NERR
Flown March 2017



Views of JCNERR

Office for Coastal Management

Project Areas – Grand Bay Reserve Flown May 2017



Pine savanna, *pinus elliottii/palustris*

Black Needlerush*, Juncus roemerianus*

Smooth Cordgrass, *Spartina alterniflora*

Sentinel Site

Elevation and sediment dynamics

- Surface elevation tables
- Marker horizons
- Digital elevation models

Vegetation surveys

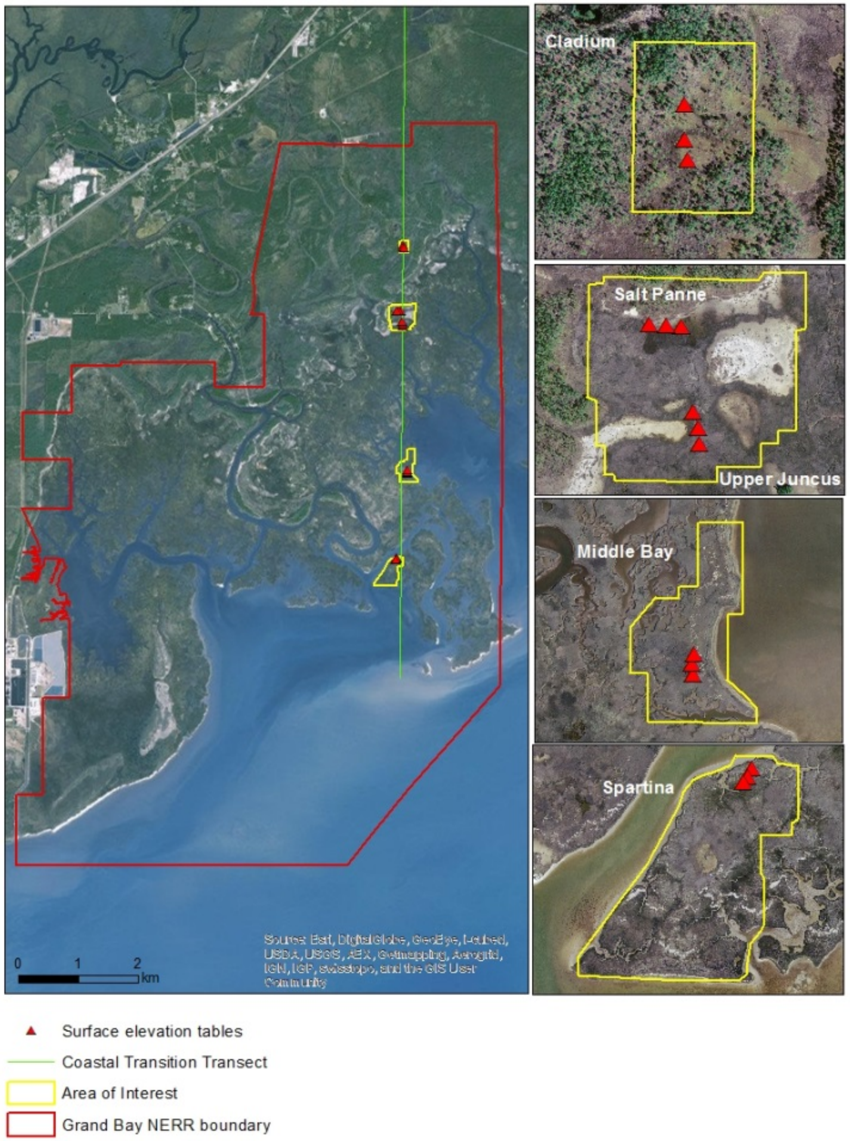
- Emergent marsh plots
- Balloon mapping and unmanned aerial vehicles
- Marsh grass elevation ranges

Water level monitoring

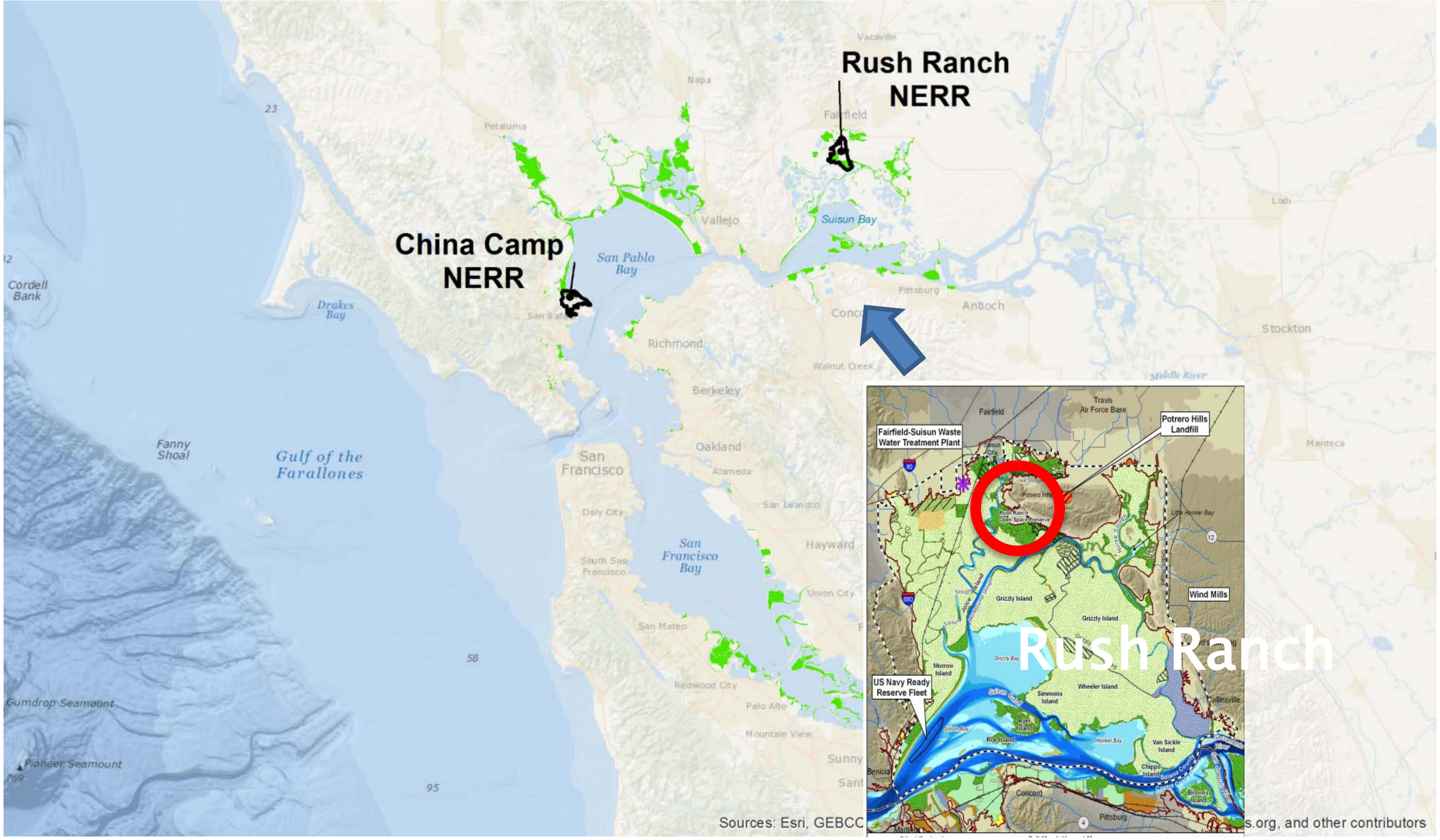
- Stormwater management program stations
- Site-specific depth loggers
- Ground water wells

Vertical control

- NOAA tide station
- Digital leveling
- GPS occupations

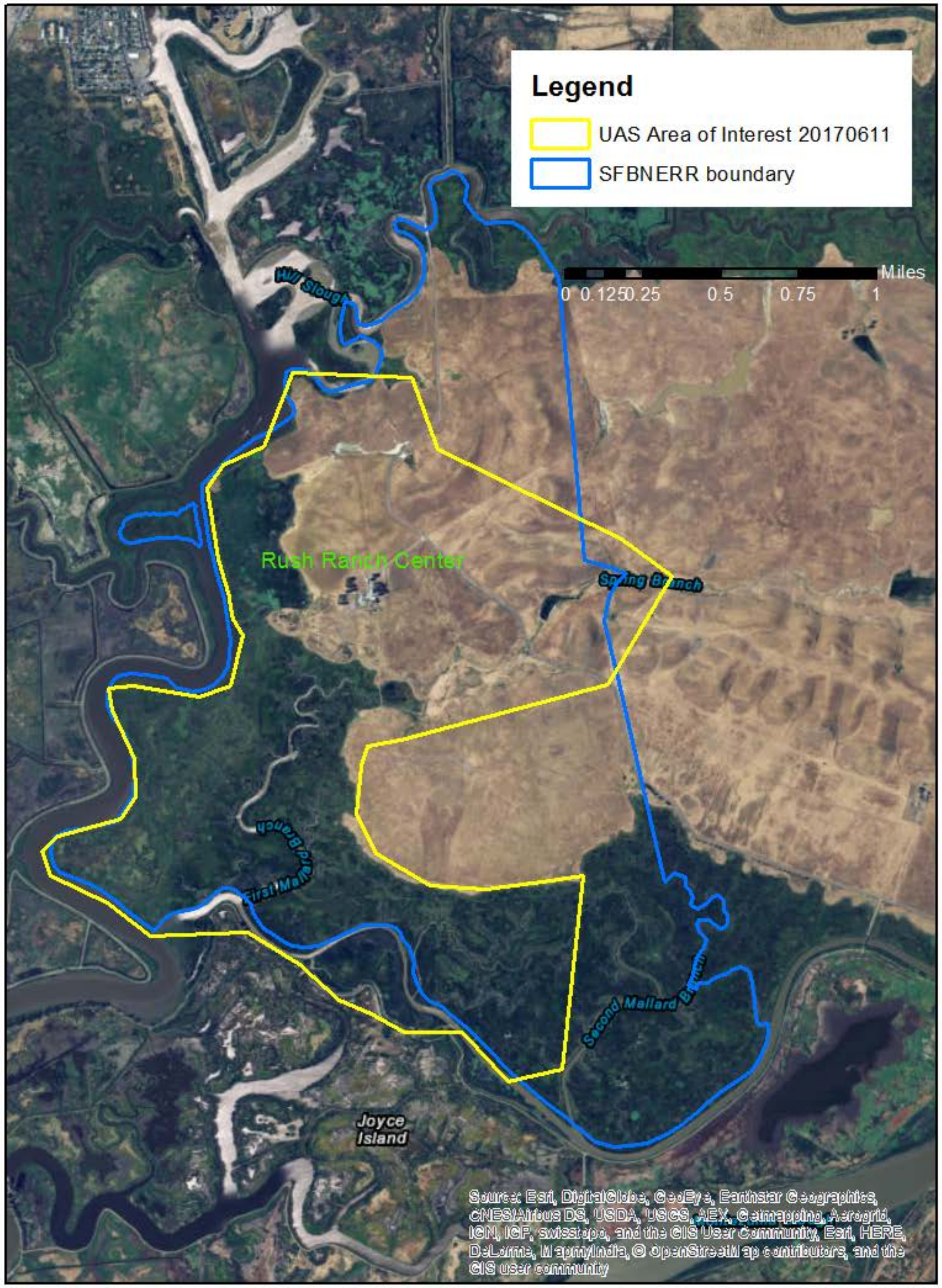


Project Areas – San Francisco Bay Reserve Flown September 2017



Final AOI for Rush Ranch

- Many iterations
- COA issues
- Bird nesting issues



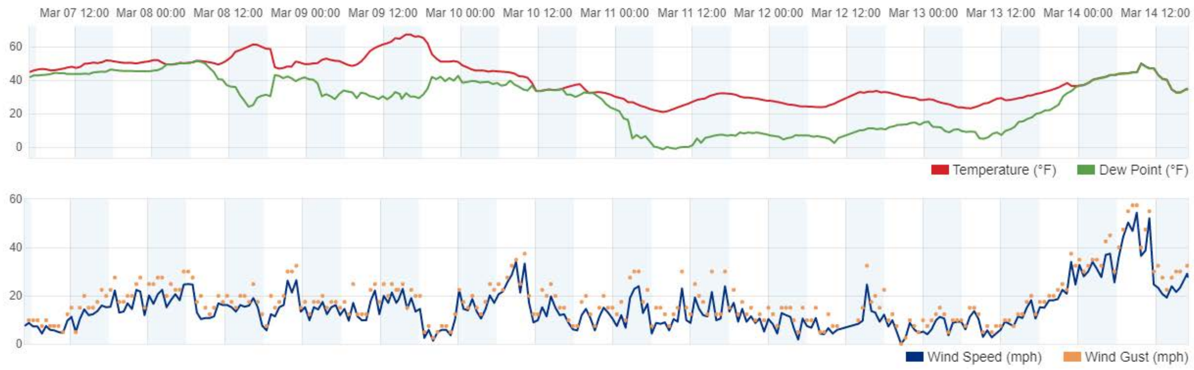
Flight Operations

Platforms Used

- **Lancaster 5**
  - Fixed wing
  - JCNERR: Lidar and Imagery
  - GBNERR: Lidar
- **Matrice 100**
  - Quadcopter
  - GBNERR: Imagery
- **Matrice 600**
  - Hexacopter
  - SFBNERR: Lidar and Imagery

JCNERR Operations

- March 6-12, 2017
- 11 or 12" targets
- Windy – too windy
- Lidar, then imagery
- Fixed wing system
- 5-band MicaSense RedEdge
- Velodyne puck lidar
- Bird closure March 15.

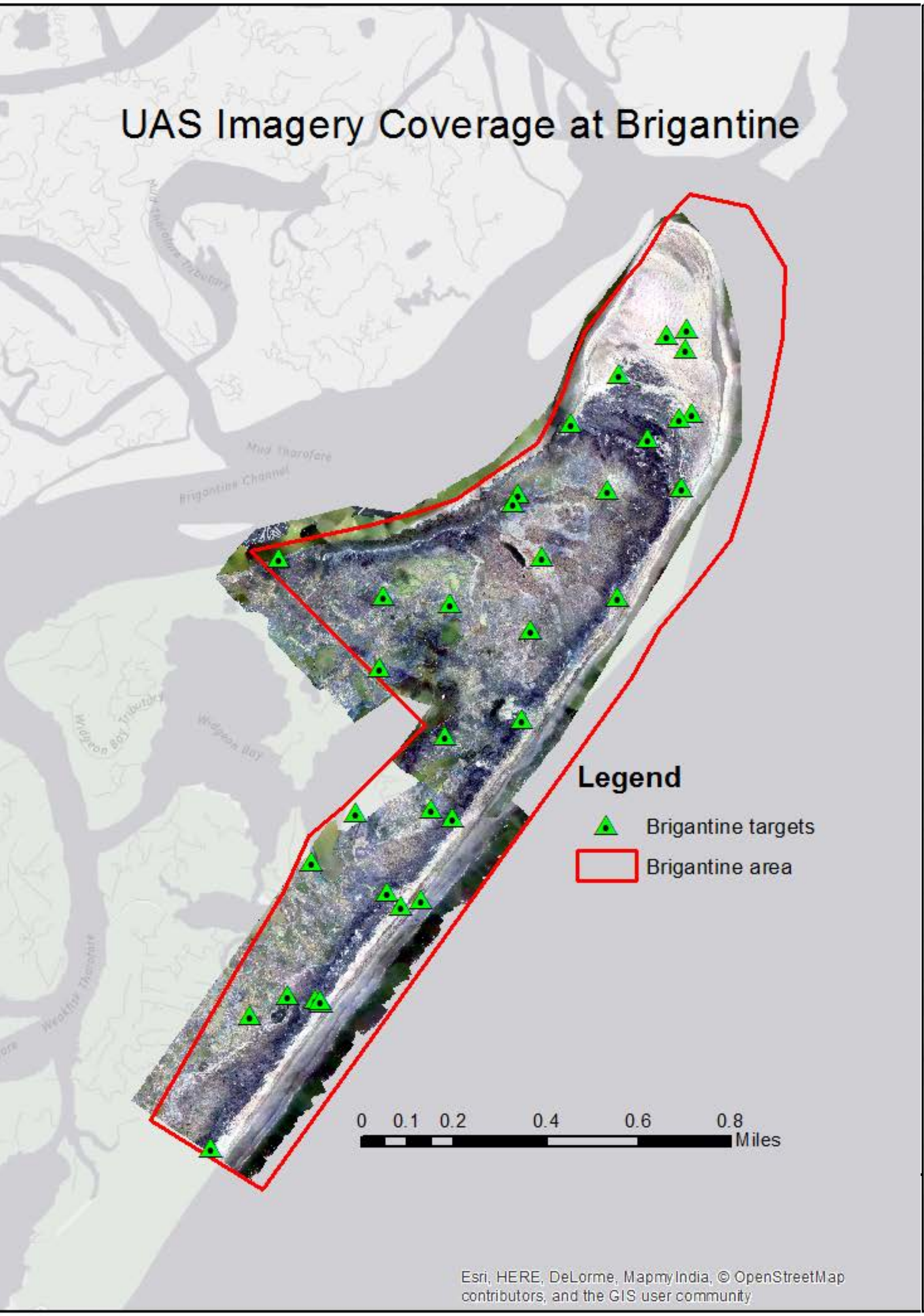


Sensor Specs at JCNERR

LiDAR Survey Settings & Specifications	
Acquisition Dates	03/07/17, 03/08/17, 03/10/17
Aircraft Used	Precision Hawk Lancaster Rev 5 Dual-Frequency GPS
Sensor	Velodyne Puck VLP-16
Maximum Returns	2 (Strongest/Last Return)
Nominal Pulse Density	30 pulses/m^2
Nominal Pulse Spacing	18 cm
Survey Altitude (AGL)	50 m
Target Speed	27 kts
Field of View	110^o
Scan Frequency	5 – 20 Hz
Pulse Rate	300 kHz
Pulse Duration	6 ns
Pulse Width	15 cm
Wavelength	903 nm
Pulse Mode	Single Pulse in Air (SPiA)
Beam Divergence	3 mrads
Swath Width	143 m
Overlap	50%

Digital Orthophotography Specifications	
Equipment	MicaSense RedEdge
Spectral Bands	Red, Green, Blue, Near-Infrared, Red Edge
Ground Sample Distance	8cm per pixel at 120m
HFOV	47.2°
Frame Rate	1 frame/sec
Final Project Resolution	6.5cm pixel size
Image	12-bit GeoTiff

Launching Lancaster at JCNERR



UAS Imagery Coverage at Brigantine
Legend
Brigantine targets
Brigantine area
0 0.1 0.2 0.4 0.6 0.8
Miles
Mud Thorofare
Brigantine Channel
Widgeon Bay
Widgeon Bay Tributary
Weakfish Thorofare
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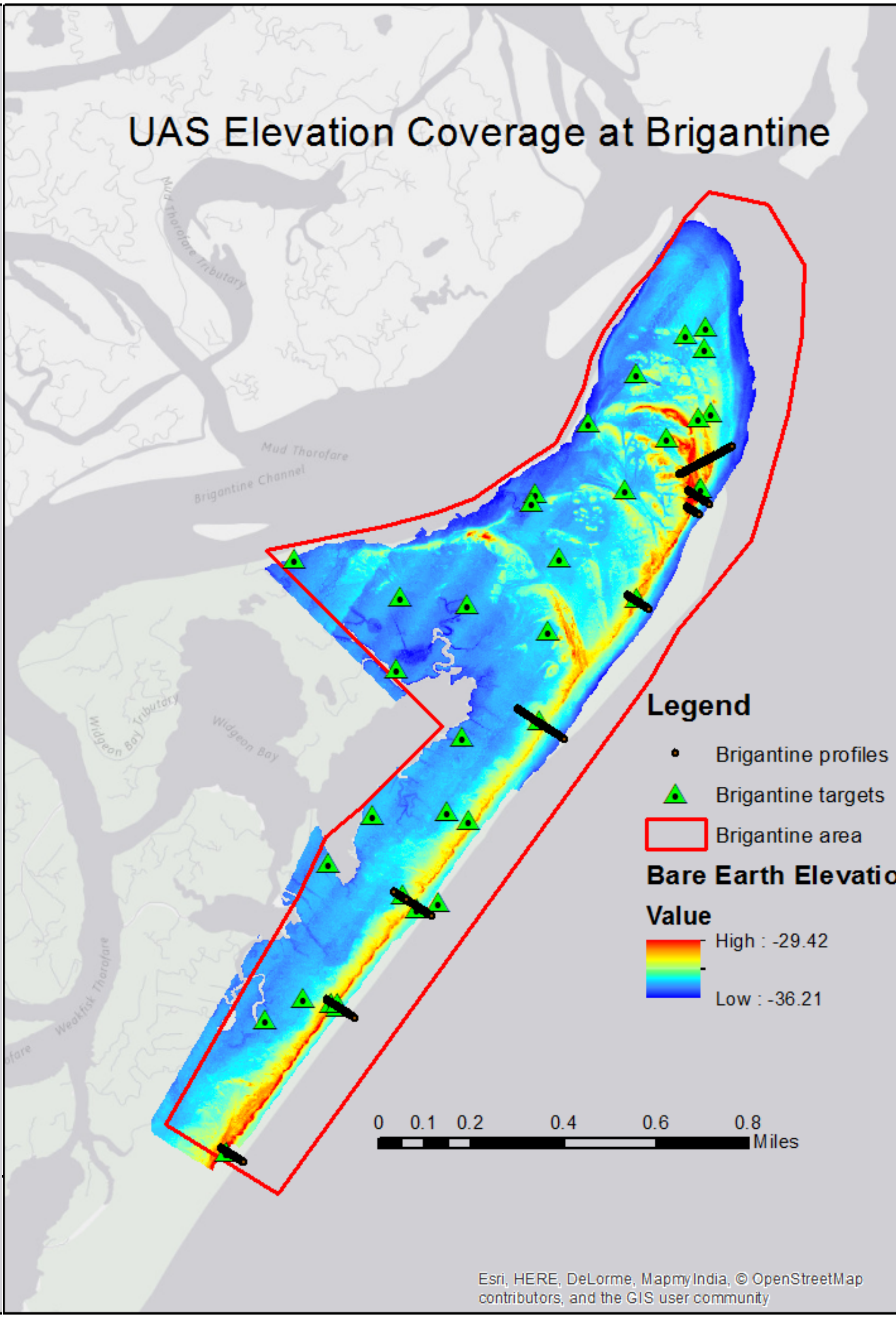


UAS Elevation Coverage at Brigantine
Legend
Brigantine profiles
Brigantine targets
Brigantine area
Bare Earth Elevatio
Value
High : -29.42
Low : -36.21
0 0.1 0.2 0.4 0.6 0.8
Miles
Mud Thorofare
Brigantine Channel
Widgeon Bay
Widgeon Bay Tributary
Weakfish Thorofare
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

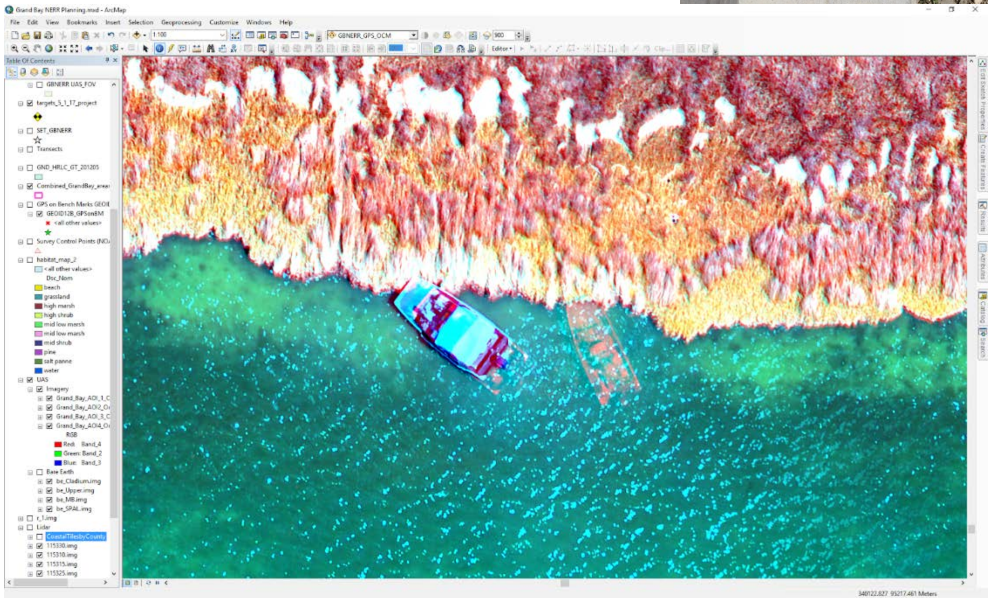
Jacques Cousteau NERR

Data Quality Explanation and Reprocessing

- Data Quality
  - Lack of Ground Control
    - Contract miscommunication
    - Led to Imagery and LiDAR Issues
  - Imagery
    - Data Voids
      - Lack of gimble on Micasense camera
      - Insufficient Overlap with Micasense
    - Color Balancing
      - Inexperience with radiometric calibration on Micasense data.
  - LiDAR
    - Flight line shifts
      - Combination of poor processing procedures and flight lines perpendicular to the wind.
    - Intensity Data
      - Standalone Velodyne Puck was used
      - Inexperience working with Intensity data and converting from 8-bit to 16-bit
- Reprocessing
  - LiDAR
  - Rebuilding trajectory data with single coordinate
    - Processing using Terrasolid suite
  - Imagery
    - Lack of ground control, radiometric targets and sufficient overlap makes this data not fixable

Grand Bay NERR Operations

- May 8-11, 2017
- Two platforms
  - Lidar = Lancaster
  - Imagery = Matrice
- Access by boat
- Firmware problems
- Good weather
- Ground control
- Imagery with Zenmuse X5

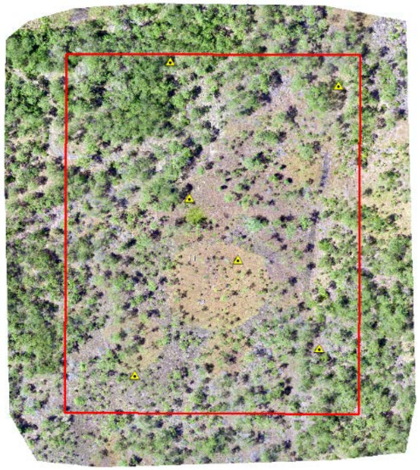


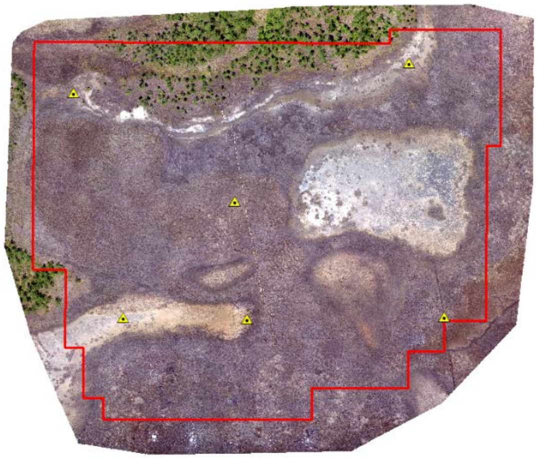
Sensor Specs at GBNERR

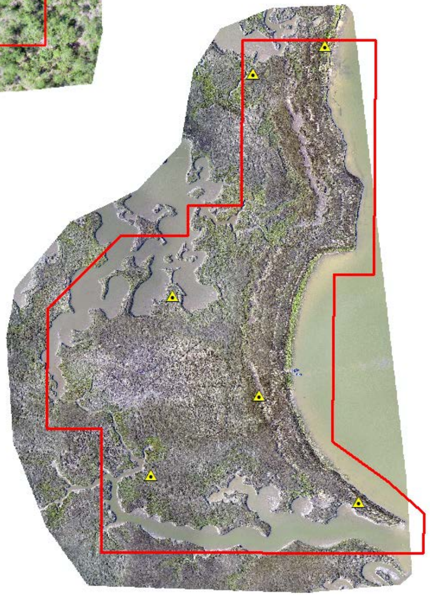
Grand Bay LiDAR Survey Settings & Specifications	
Acquisition Dates	05/09/17, 05/10/17, 05/11/17
Aircraft Used	Precision Hawk Lancaster Rev 5 Dual-Frequency GPS
Sensor	Velodyne Puck VLP-16
Maximum Returns	2 (Strongest/Last Return)
Nominal Pulse Density	30 pulses/m^2
Nominal Pulse Spacing	18 cm
Survey Altitude (AGL)	50 m
Target Speed	27.2 kts
Field of View	110^0
Scan Frequency	5 – 20 Hz
Pulse Rate	300 kHz
Pulse Duration	6 ns
Pulse Width	15 cm
Wavelength	903 nm
Pulse Mode	Single Pulse in Air (SPiA)
Beam Divergence	3 mrads
Swath Width	143 m
Overlap	50%

Digital Orthophotography Specifications	
Equipment	DJI Zenmuse X5
Spectral Bands	Red, Green, Blue, Near-Infrared
Ground Sample Distance	3cm per pixel at 50m
Megapixels	16.0 MP
Frame Rate	Max 7 frame/sec
Final Project Resolution	3cm pixel size
Image	8-bit GeoTiff

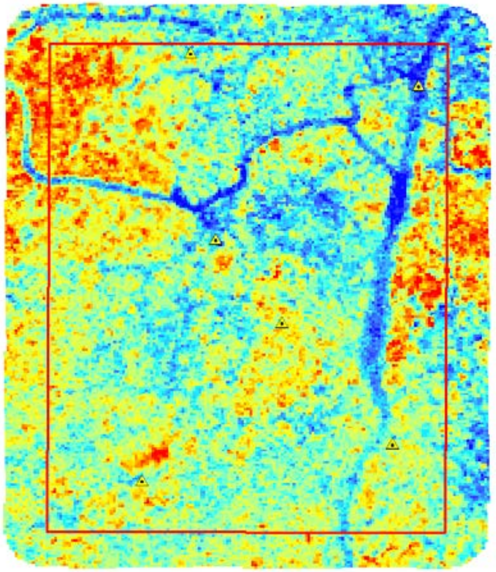
Imagery Coverage at GBNERR

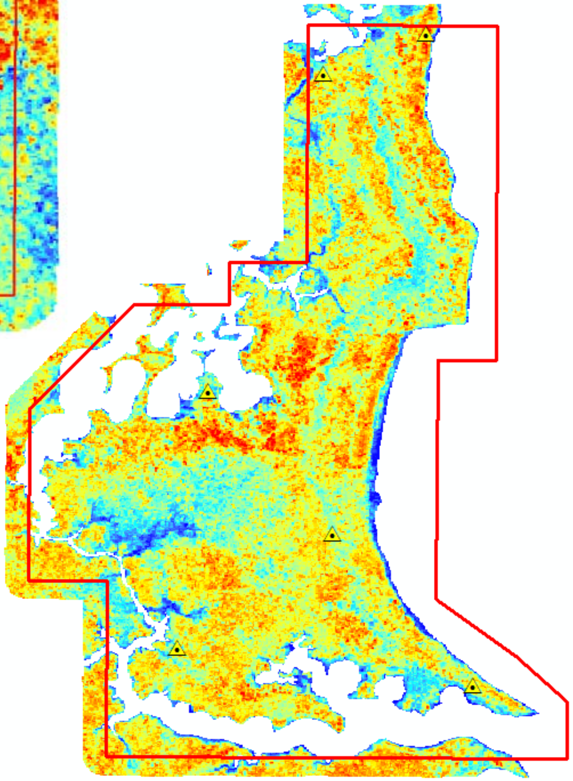


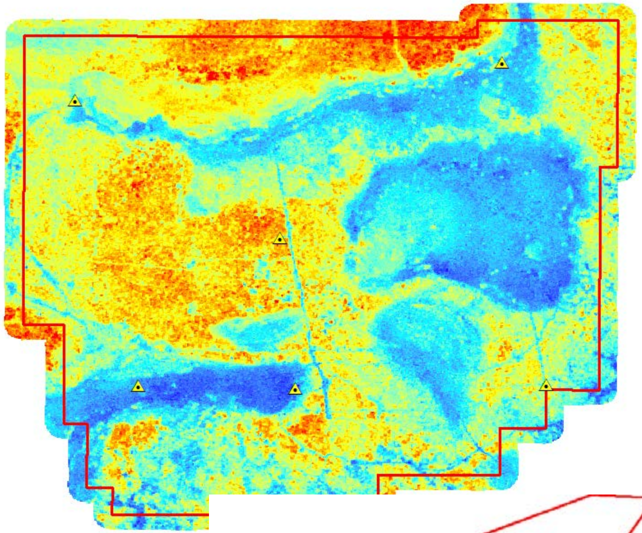


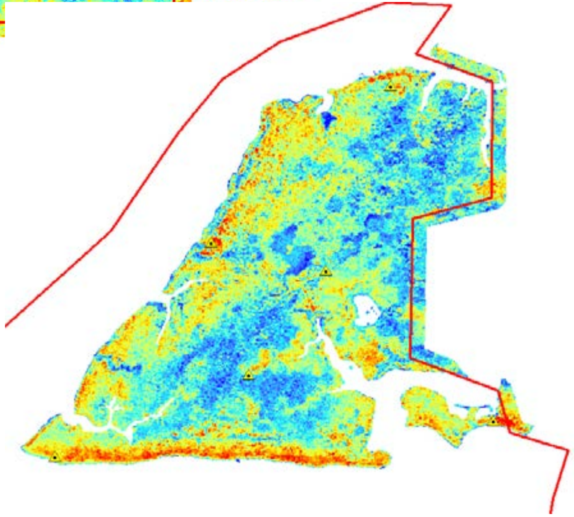


Lidar Coverage in GBNERR





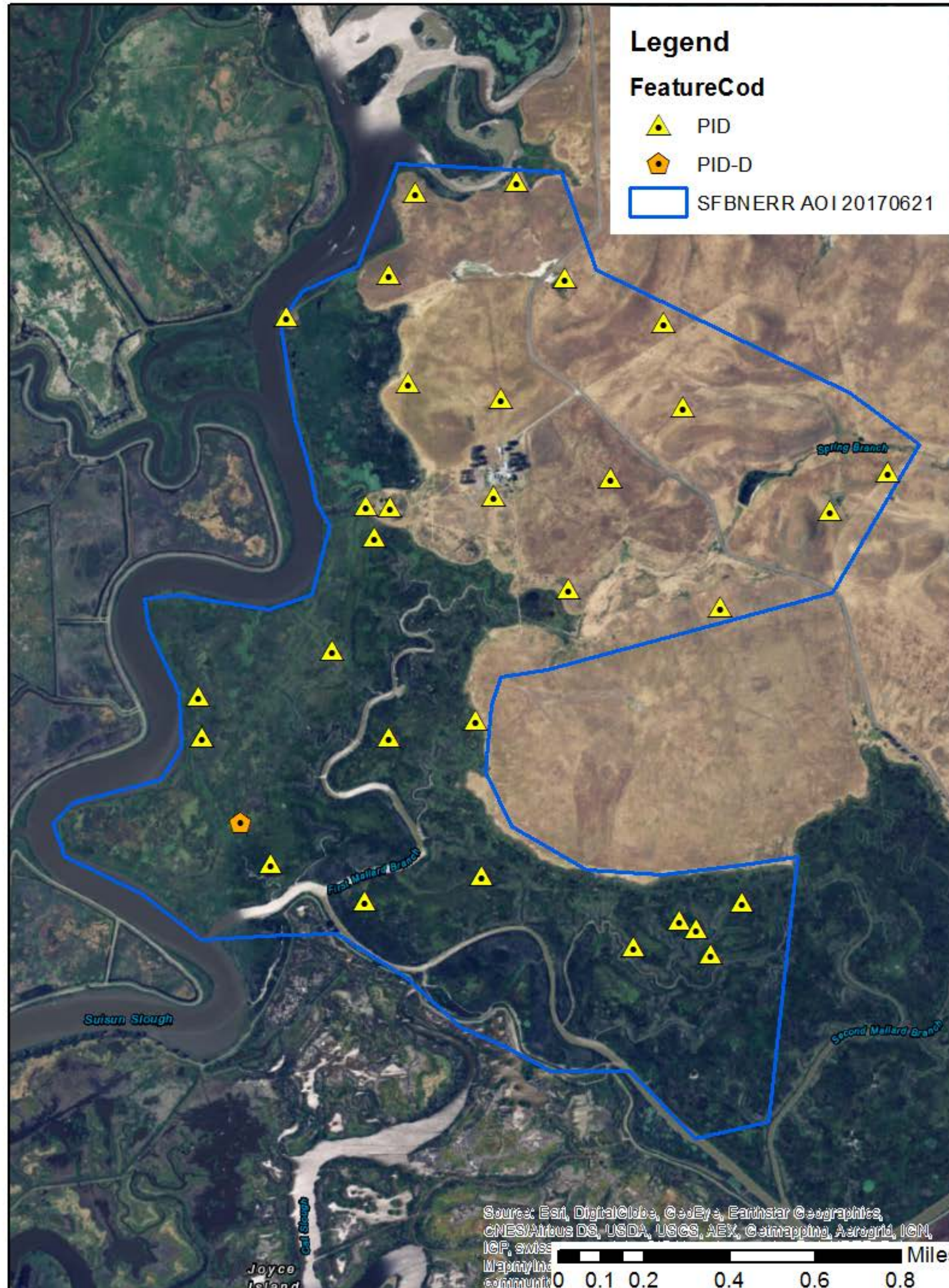


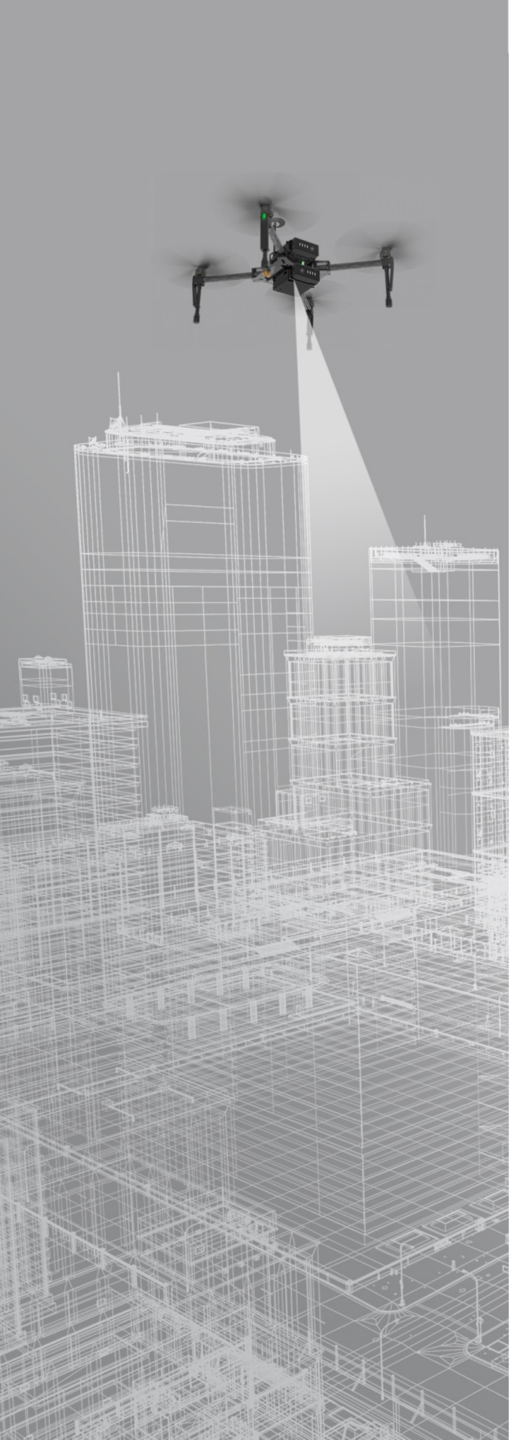


SFBNERR Operations

- Flights Sept 5-10, 2017
- Hot! Fire hazards
- Matrice 600 hexacopters
- 5-band MicaSense RedEdge
- Yellowscan lidar
- Simultaneous collect
- 200 ft COA ceiling
- Bigger targets

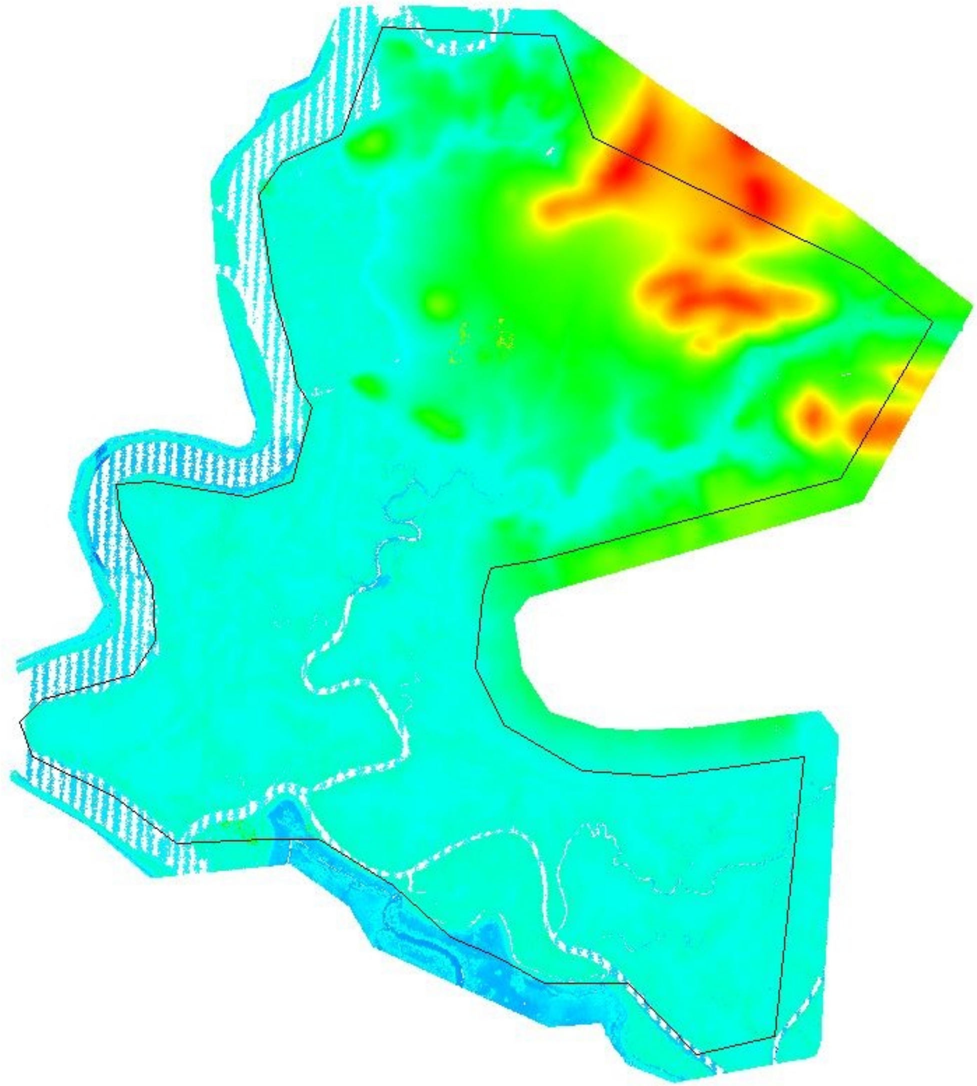
- **Awaiting data**
- **380K+ images to mosaic**
- **Lidar can exceed 500 pts/m^2**
- **Operations were from outside the marsh**
- **Benchmarks moving**

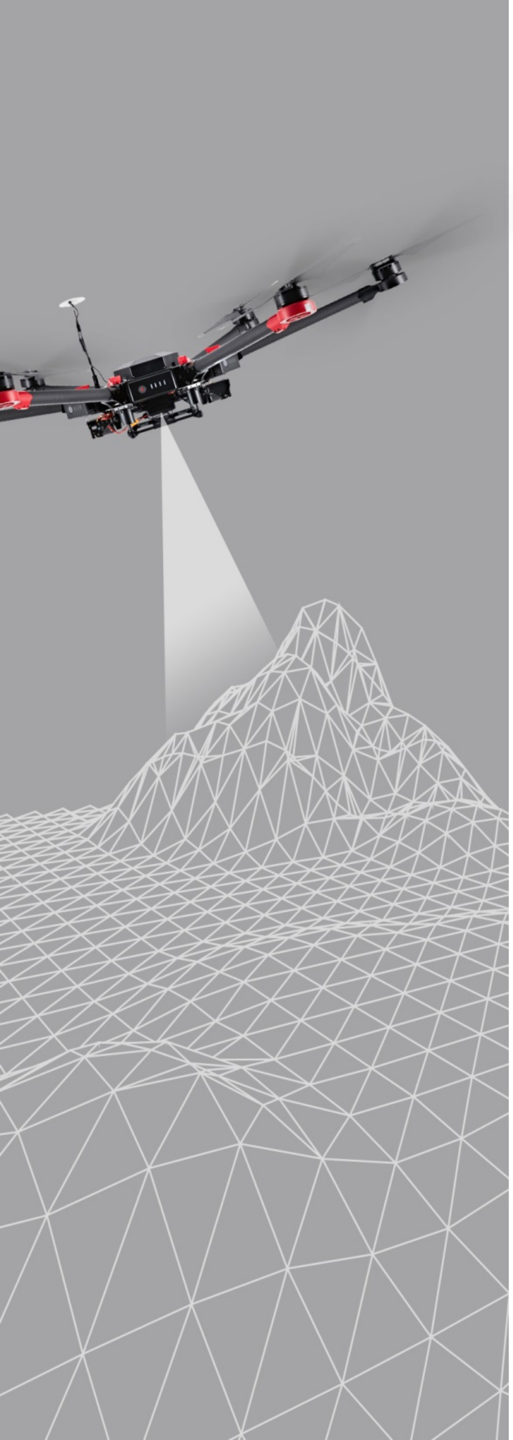




SFBNERR Results

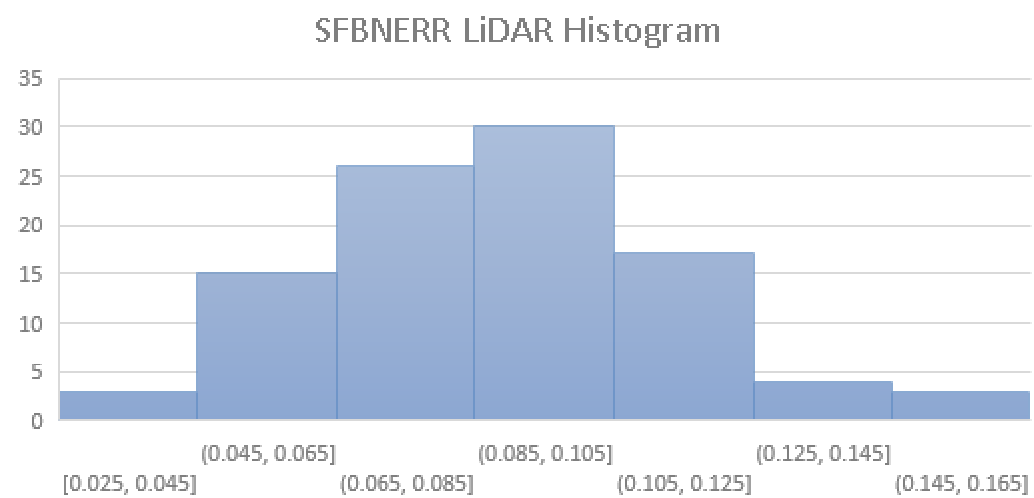
LiDAR AOI

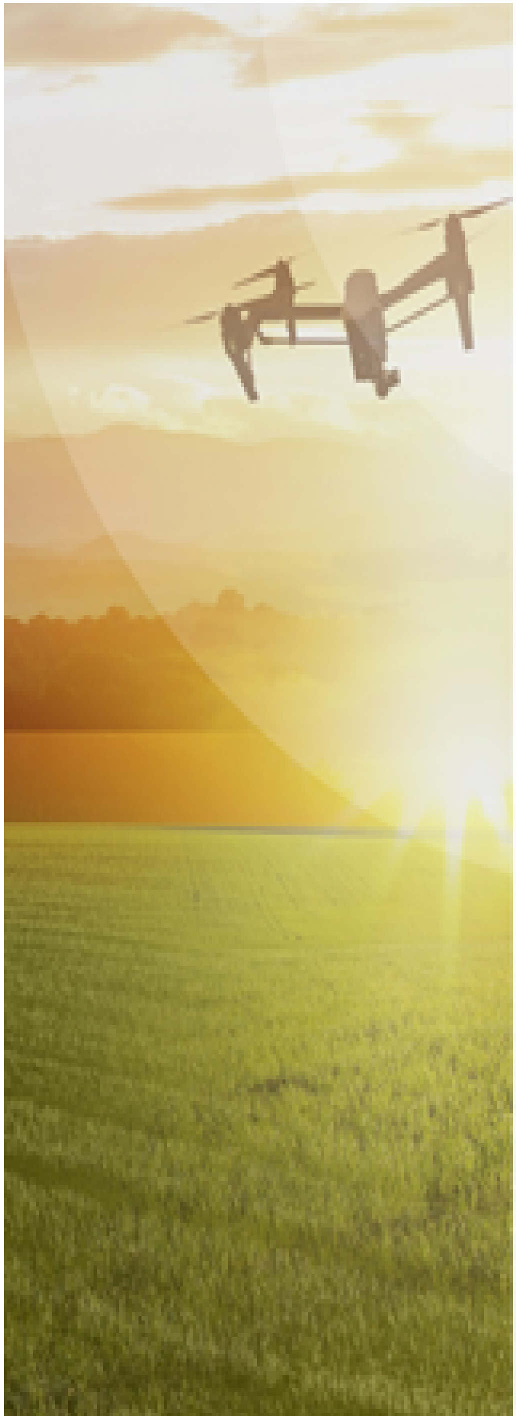




SFBNERR Results
LiDAR Accuracy

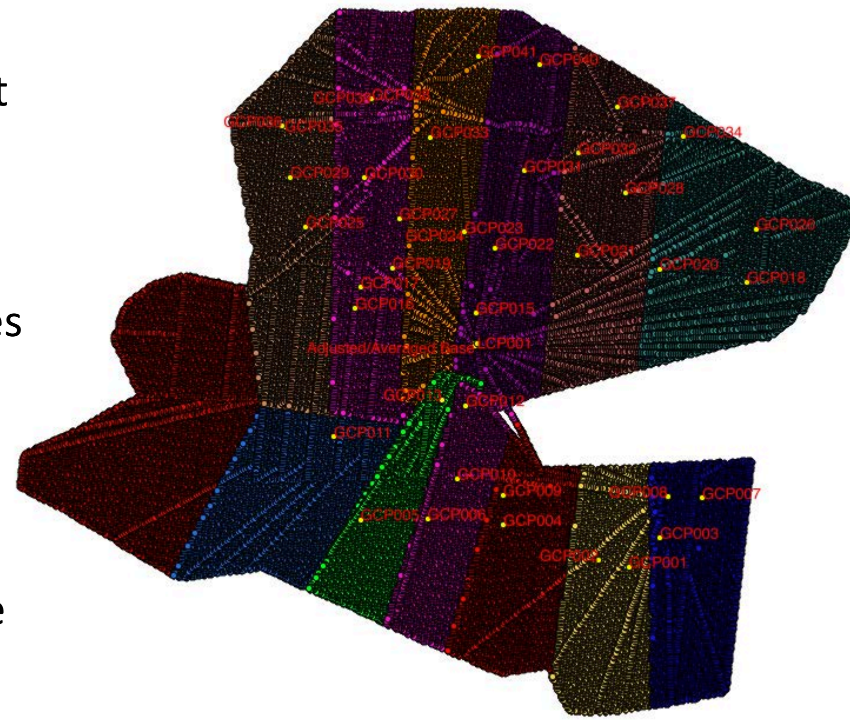
- Survey Information
  - 44 Visual Ground Control Points
  - 55 NVA Survey Points
- LiDAR Accuracy against all 94 points:
  - RMSE 9.14 cm
  - Highest Outlier
    - GCP006: 16.4 cm
  - Tightest Accuracy
    - LCP001: 2.5 cm





SFBNERR Results
Imagery Processing

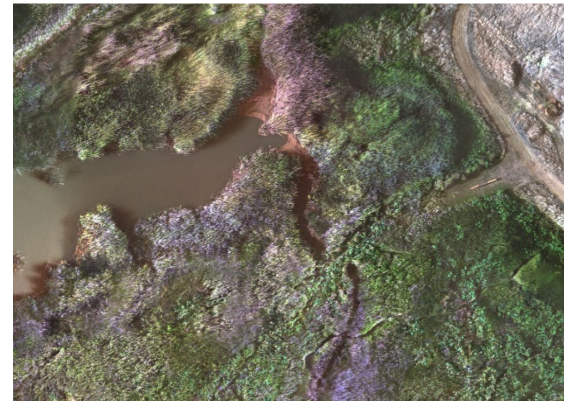
- **First Pass at Processing**
  - 8 Blocks
  - 3 P2 AWS Instances
  - All blocks finished Tie Point analysis. Stalled out in point cloud creation
- **Second Pass**
  - 13 Blocks
  - 3 G3 AWS Instances
  - Radiometric Calibration Issues.
  - Visible Seamlines and blurriness
    - Most likely due to cat tails and grass swaying during collection



SFBNERR Results
Imagery Processing

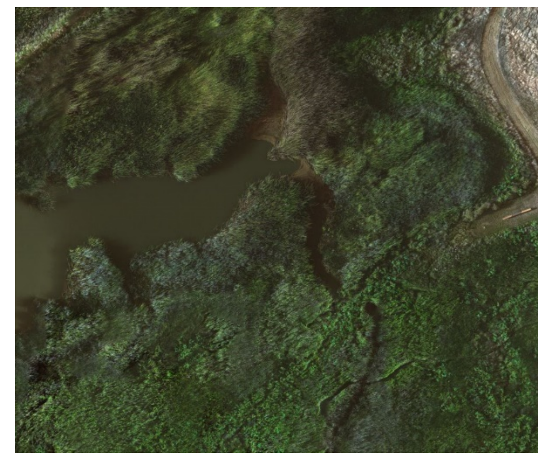
Final Approach

- 6 G3 AWS Instances.
- 13 Blocks
  - 12/13 have at least 3 GCPs
  - Blocks of ~40k images
- Preprocess by stacking bands and converting to radiance
  - Decreases number of images processed and corrects radiometric calibration
- Converting back to DN
  - Viewable in GIS



Left: First/Second Approach

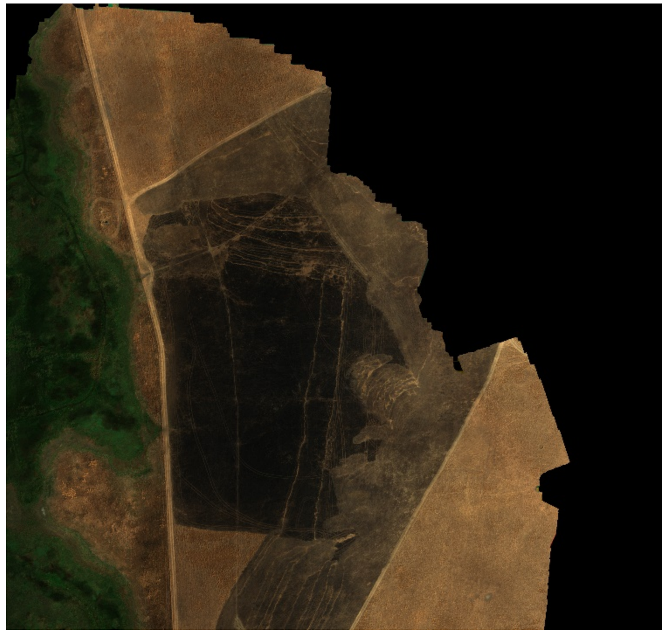
Below: Final Approach

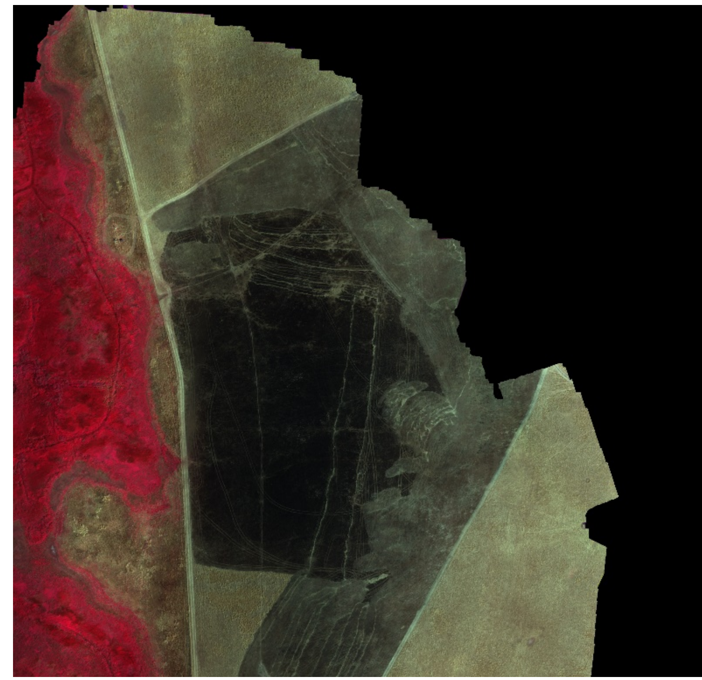


Current Status

- Blocks, 1,2,3,4,5,7 finished
- 157,701 of 363,152 images processed

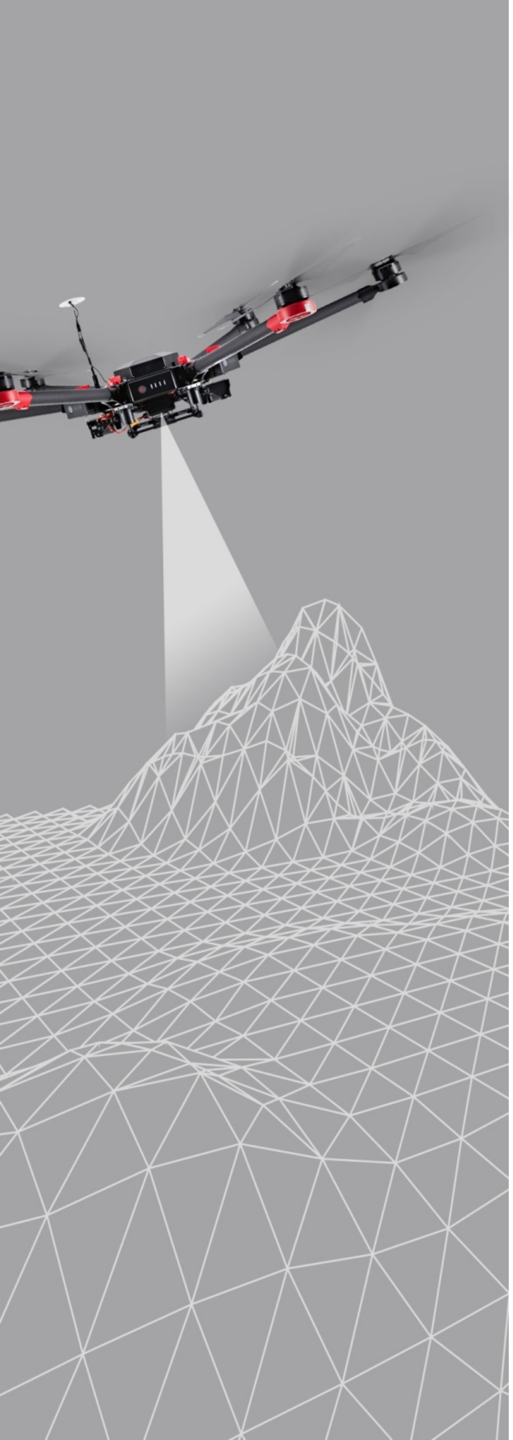
SFBNERR Results
Imagery Processing





UAS Summary Across NERRS

Location	Platform	Sensor	Altitude	Density/Res
JCNERR	Lancaster r5	Velodyne Puck VLP-16 lidar	50 m	68 points/m^2
GBNERR	Lancaster r5	Velodyne Puck VLP-16 lidar	50 m	106 points/m^2
SFBNERR	Matrice 600	Yellowscan lidar	40 m	~400 points/m^2
JCNERR	Lancaster r5	MicaSense 5-band	100 m	6.5 cm
GBNERR	Matrice 100	ZenMuse X5 3-band	120 m	3 cm
SFBNERR	Matrice 600	MicaSense 5-band	60 m	~4 cm



General PrecisionHawk Best Practices Moving Forward

- Robust LiDAR Processing Team
  - Brought in experts and equipped them with the best software
- LiDAR Sensors
  - Moving away from the Velodyne Puck towards a Riegl laser
    - Two sensors will be operational by end of Q1
- Survey
  - More attention to contracting to ensure proper survey is incorporated into the project
  - Hired individuals with survey background to design and manage field surveying.
- Imagery Processing
  - Brought in multispectral experts with experience performing radiometric calibration on multiband imagery.
  - Diversified processing software, so that different methods can be tried to achieve the best result.
  - Fundamental shift to “data delivery” vs. “data delivery with preferred processing methods.”
- Metadata
  - Staffed imagery and LiDAR teams with industry experts with understanding of standard metadata.

Data Evaluation and Results

Technical Project Plan – Evaluation

Vegetation Mapping Evaluation

- Evaluate spatial accuracy
- Automated supervised classification process
- Single species identification
- Evaluate combined imagery and elevation for mapping

Elevation Evaluation

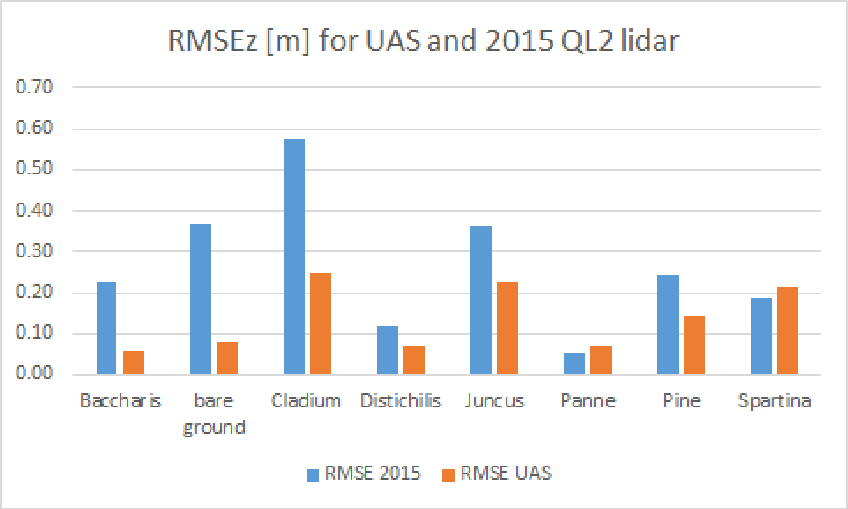
- Lidar and SfM accuracy assessment
- Marsh penetration
- Lidar + SfM?
- Jacques Cousteau Reserve – evaluate lidar beach volume
- Business case analysis

Spatial Accuracy Results

Site	Data Type	Sample Number	Accuracy (RMSE)
JCNERR	Imagery	22	0.60 m
GBNERR	Imagery	21	0.15 m
SFBNERR	Imagery	~33	?
JCNERR	Lidar – rapid static	19	1.46 m
JCNERR	Lidar – RTK profiles	472	1.35 m
GBNERR	Lidar	106	0.07 m
SFBNERR	Lidar	44	?

* JCNERR did not have ground control targets, leading to the failure to meet specifications. Some reprocessing is being done using validation points for control. RTK profiles have limited spatial extent and may have vegetation.
* SFBNERR data has not been received for evaluation yet.

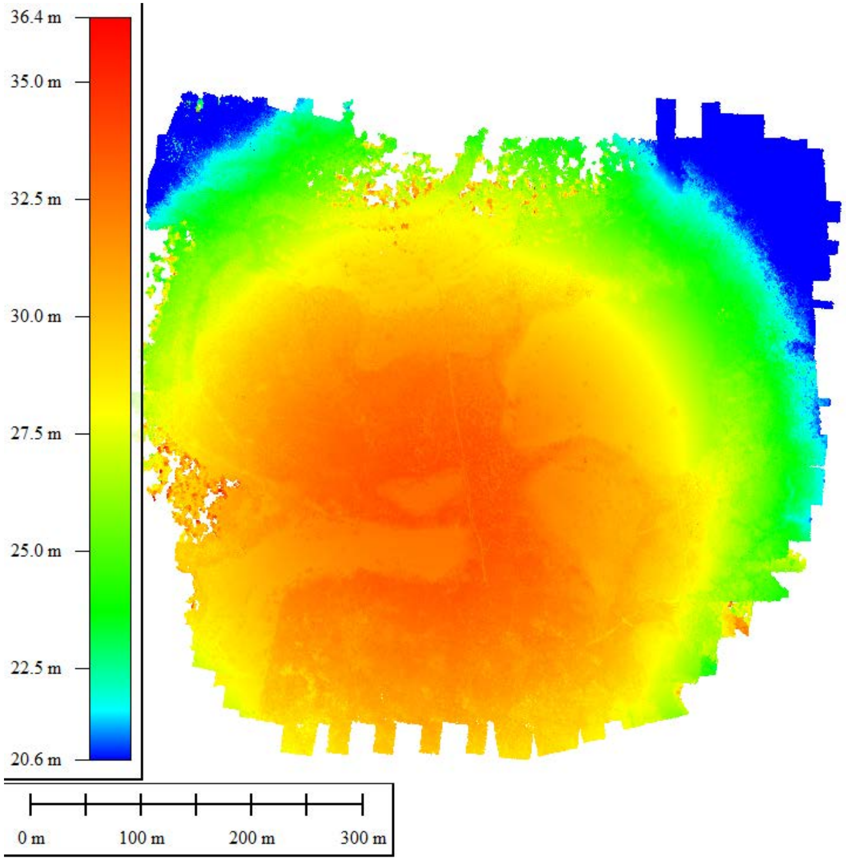
GBNERR Lidar Comparison with Manned in Vegetation



- **UAS error is generally smaller**
- **UAS has greater consistency**
- **UAS appears to be doing a better job penetrating marsh vegetation**
- **NB: Bare ground areas in 2017 were not all bare ground in 2015**

Structure from Motion (SfM) Results

- Generally not satisfactory
- Autocorrolation with homogeneous vegetation doesn’t work well
- Better in JCNERR than in GBNERR
- Elevation range in GBNERR often made no sense
- Not good enough to merge with lidar



GBNERR Image Classification Evaluation

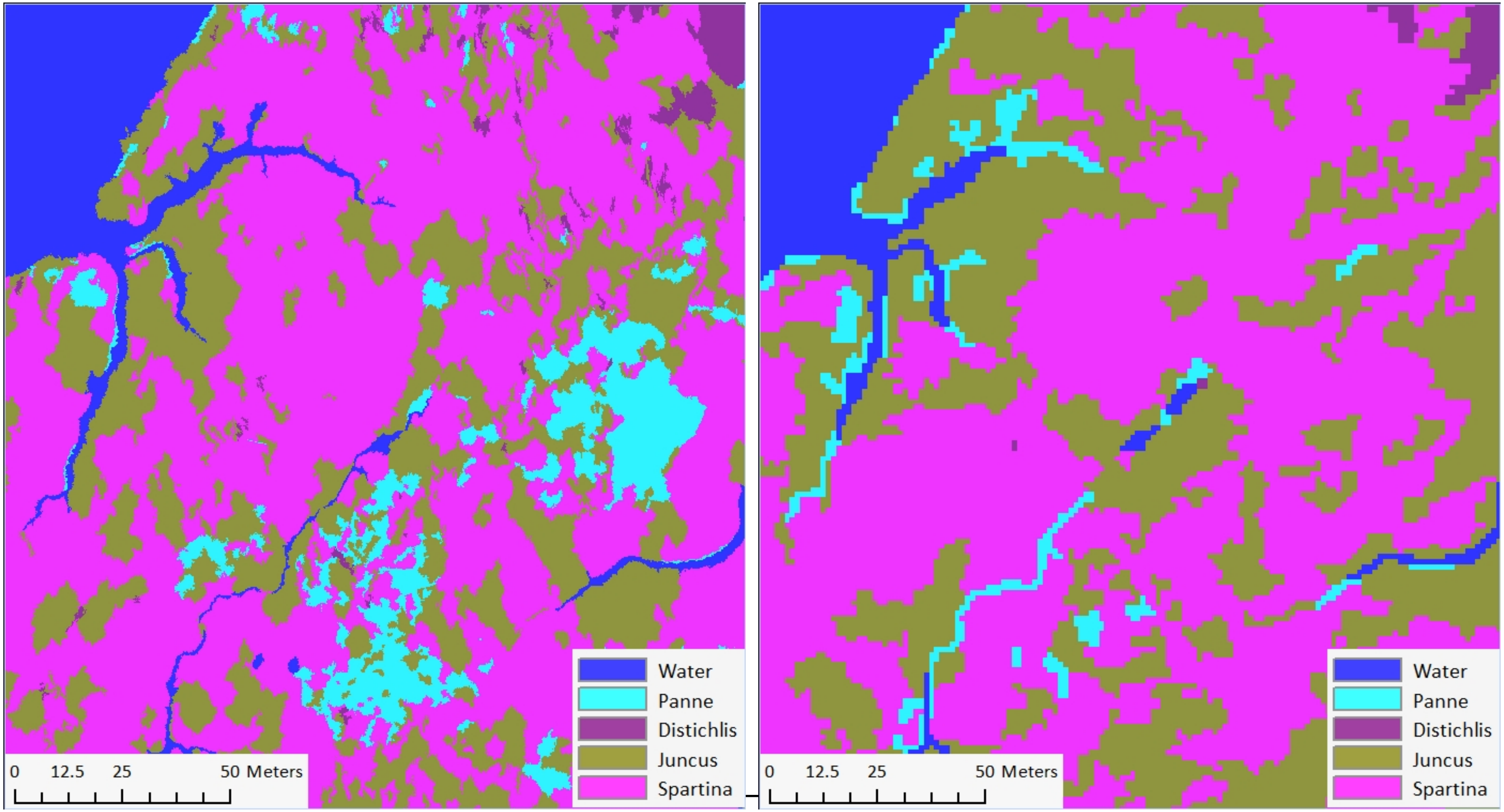
Protocol: NOAA standard operating procedures for high resolution habitat mapping; NERRS habitat classification standard

Collected training data, generated image objects, and performed supervised classification (eCognition)

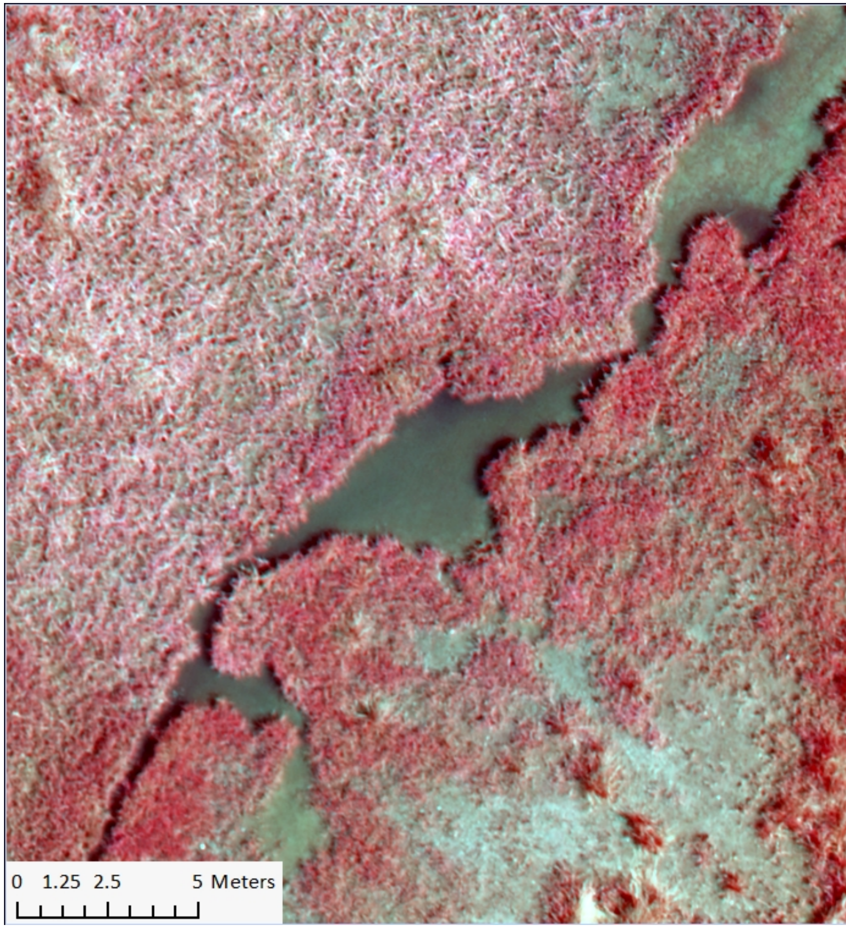
Ran process on both UAS imagery and WorldView 3 satellite imagery and compared results

	WorldView 3	UAS ZenMuse X5
Resolution	1.2 m	3 cm
Bands	8	4 (3+1)
Date acquired	May 2015	May 2017

GBNERR Image Classification Evaluation



GBNERR Image Classification Evaluation

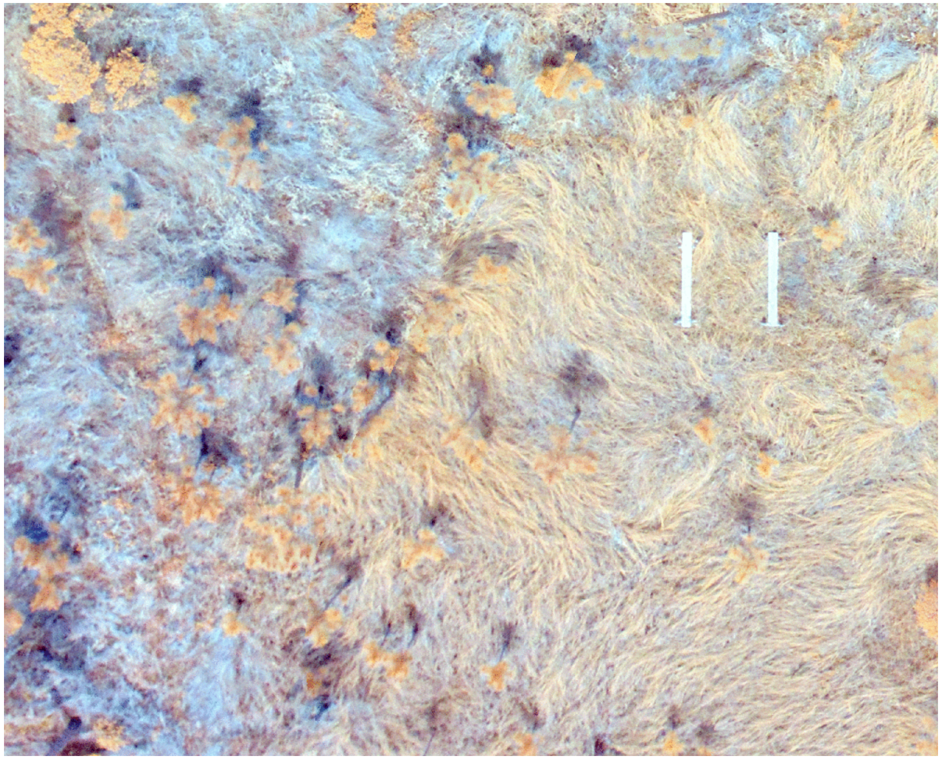


- **Overall accuracy about the same between the two**
- **UAS imagery capable of mapping detailed features**
- **UAS image mosaic had problems with spectral uniformity across scene**
- **UAS band-offset caused problems in forested areas**

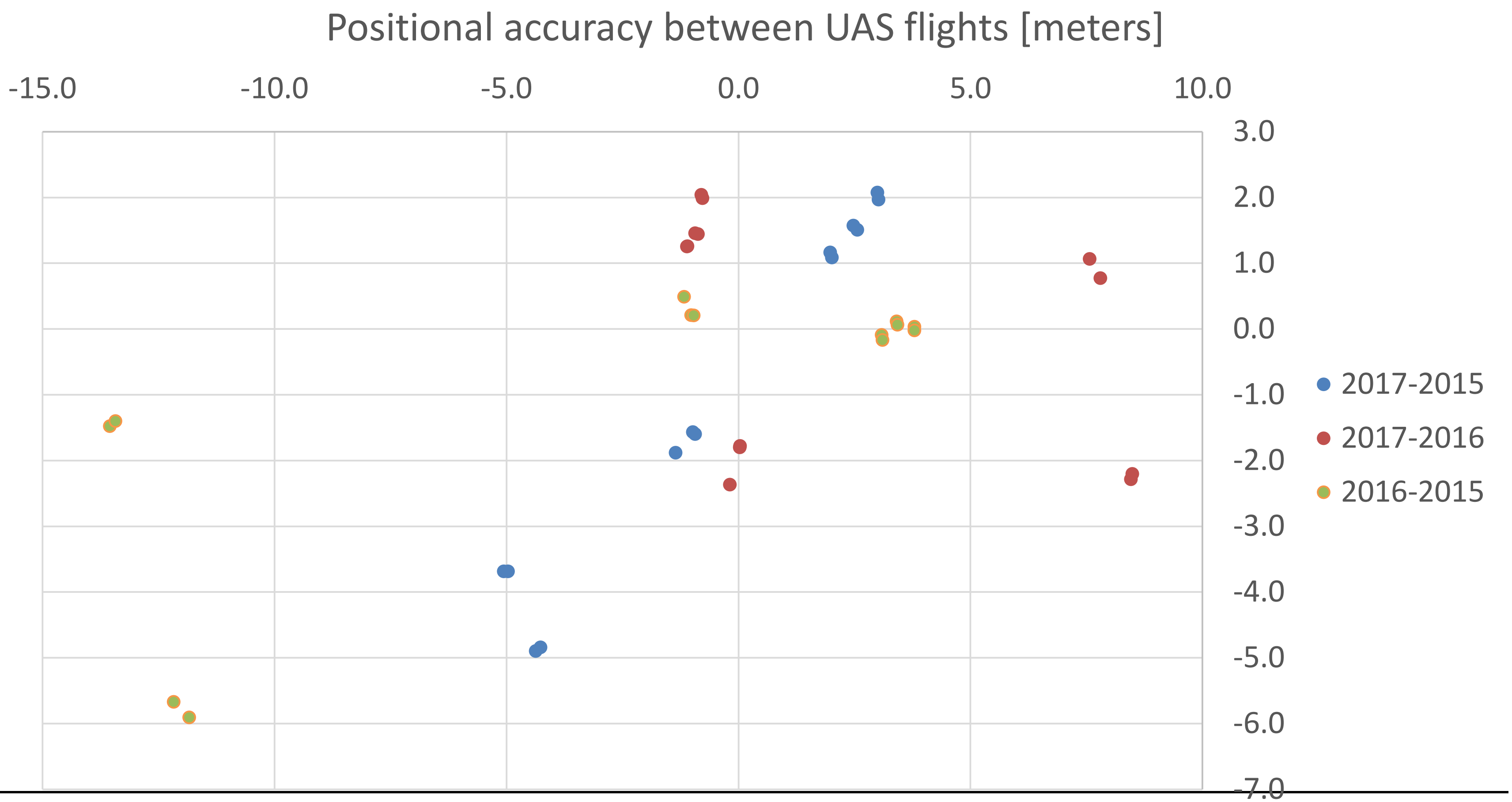
Comparison to Previous UAS Imagery

- **Previous GBNERR collections in 2015 and 2016**
- **Between 1 and 2 cm GSD**
- **Used the SET table infrastructure to compare**
- **See artifacts from image mismatch**

2015 -> 2016 -> 2017

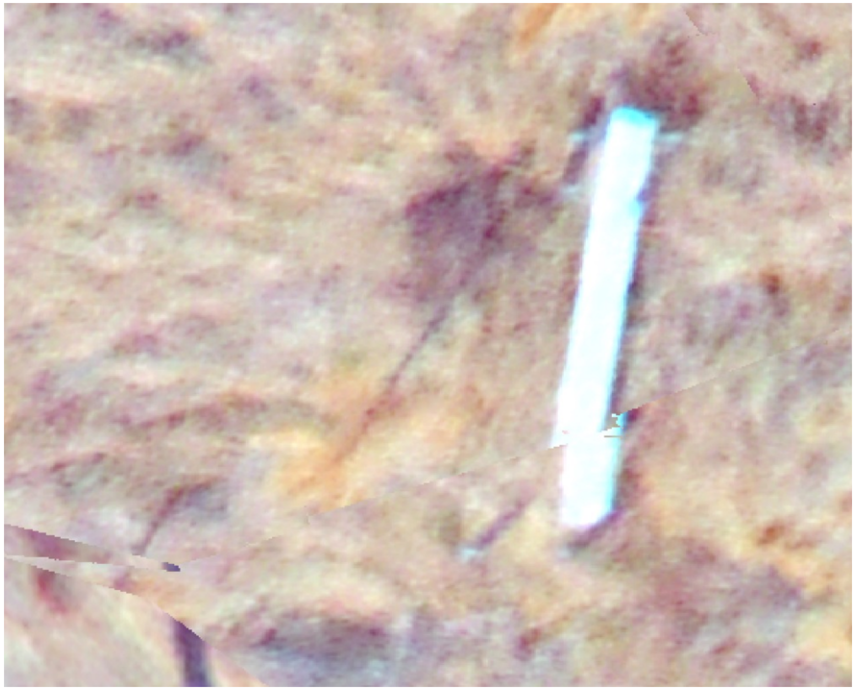


Comparison to Previous UAS Imagery SET Bench Locations - Quantitative



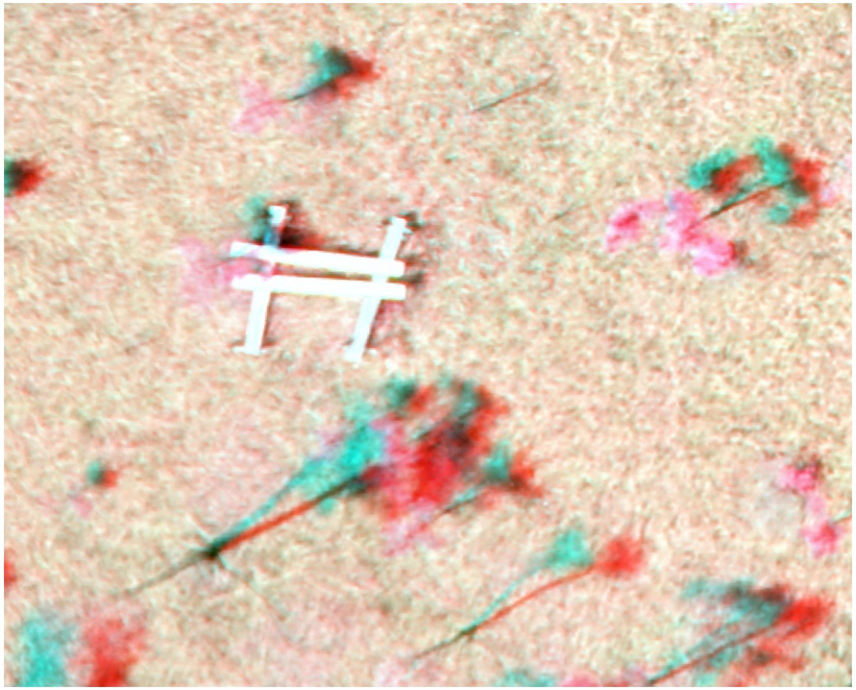
Qualitative Imagery Issues

2015



2016

2017 Imagery Had Issues Too



Using 2-passes of 3-band cameras to make 4-bands was a problem for things that moved, such as shadows

Results Summary

- We believe the UAS data can meet similar accuracy requirements used for manned flights with proper care (e.g. ground control)
- SfM may not be a good choice in homogeneous marsh areas
- UAS lidar penetration in marshes appears to have an advantage over manned and much higher density
- UAS imagery advantages for habitat mapping are still being evaluated
- The private sector data is of higher quality than the previous UAS data in GBNERR we reviewed
- Can be cost effective, though right technology is situation dependent

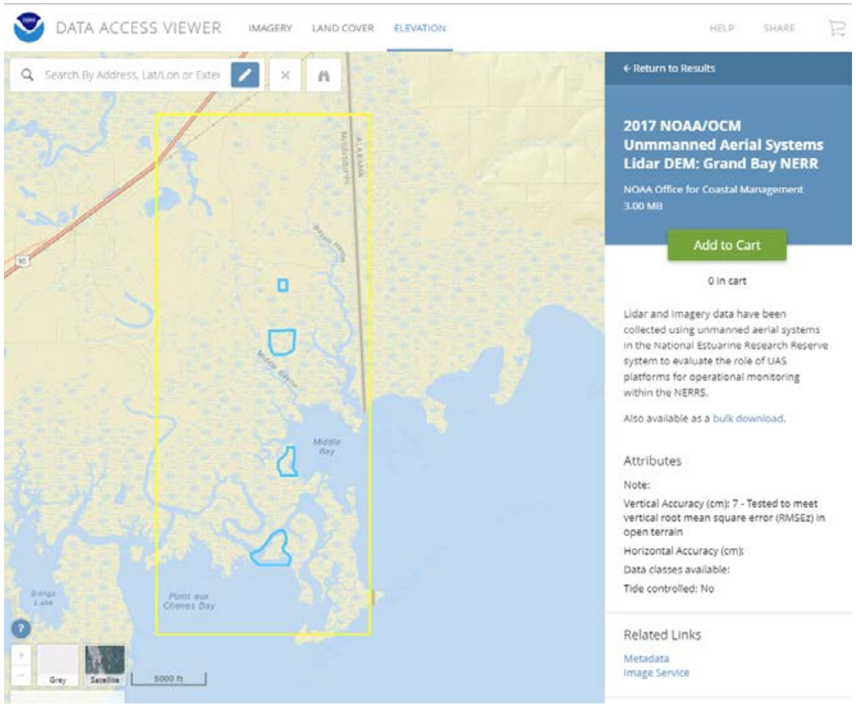
Data Distribution and Management

Distribute on Digital Coast

- Lidar and Imagery on Data Access Viewer

Archive at NCEI

- Lidar only; NCEI not responsive on imagery
- Lidar and imagery also in Azure cloud



Technical Readiness Level (TRL)

Start

- **Platforms: 8; flight proven but not in this environment**
- **Lidar: 5; concept for marsh grass penetration validated, but no prototype demonstration**
- **Imagery: 7; similar systems have been flown in the environment**

End

- **Platforms: 8; though platforms changing**
- **Lidar: 8; system was demonstrated in the operational environment**
- **Imagery: 8; system was demonstrated in the operational environment**

TRL Continued

- **TRL for mapping may be different than individual components**
- **Overall starting TRL seemed higher than it was.**
- **Private sector came a long way and put a lot of their own money into the project**
- **A lot like a manned project**

Cast of Characters

NOAA Office for Coastal Management
- Kirk Waters
- Nina Garfield
- Jamie Carter
- Nate Herold

Reserve System
- Jared Lewis
- Andrea Habeck
- Jonathan Pickford
- Sue Bickford

Quantum Spatial
- Adam Meyer
- Steve Raber

PrecisionHawk
- Blaine Horner
- Patrick Mills
- Pilots

Questions?

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Extra slides

Expected Significance

Improve quality of data used for habitat mapping and assessment to support improved understanding and management

- NOAA Next-Generation Strategic Plan goal – Healthy oceans and estuaries

Provide highly detailed rapid assessment with low mobilization costs and minimal environmental impact to understand changes, threats, and dynamics

- National Ocean Service Priorities Roadmap – Place-based conservation

Evaluate ability of UAS-derived coastal intelligence to meet NOAA needs

- National Ocean Service Priorities Roadmap priority – Coastal intelligence

Evaluate commercial UAS capabilities to make more informed operational decisions regarding employment of appropriate technology

- Reserve system operations improvement

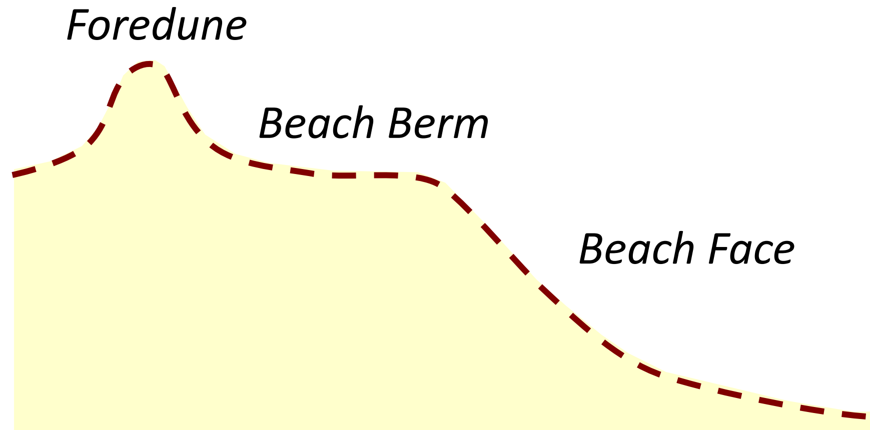
Project Scope

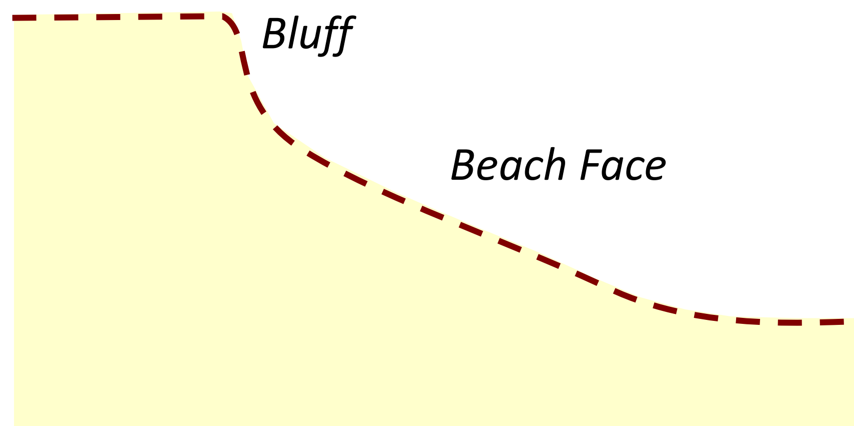
Acquire multi-spectral imagery and lidar in three different ecosystems

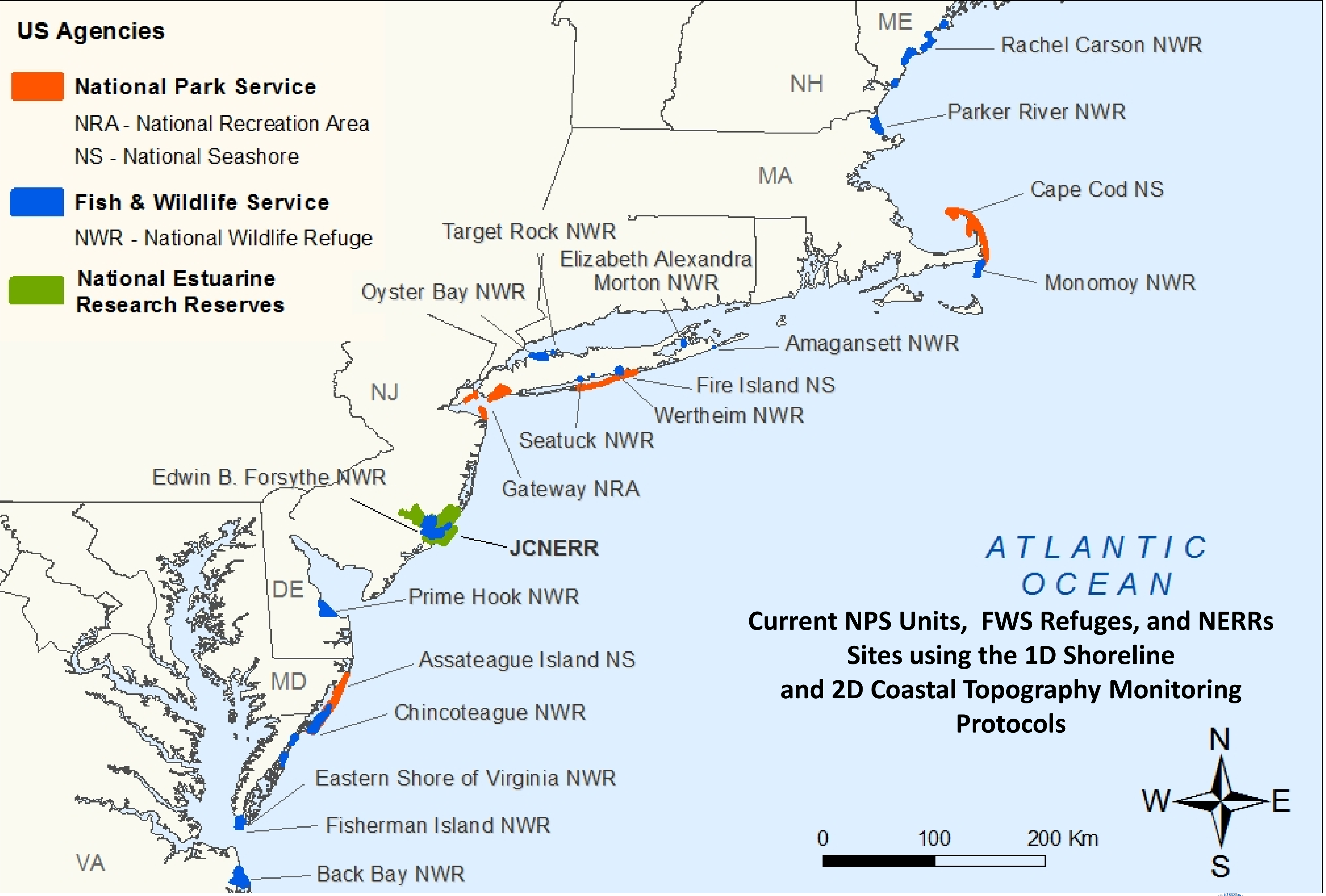
- Evaluate the horizontal and vertical accuracy of unmanned aerial system (UAS) georeferenced imagery and lidar
- Evaluate this lidar to measure ground elevations through marsh vegetation and compare to manned systems lidar
- Assess the trade-offs between UAS lidar and interpolated Real-Time Kinematic (RTK) transects
- Compare UAS imagery to manned systems imagery at the supervised classification step of vegetation mapping
- Evaluate the gains from additional data sources compared to imagery alone for vegetation mapping
- Evaluate the ability of the private sector to provide UAS-based data using a Brooks Act contract

Two surveys per site to provide multi-season imagery and elevation repeatability

2-D Beach Cross Sections







Current NPS Units, FWS Refuges, and NERRs Sites using the 1D Shoreline and 2D Coastal Topography Monitoring Protocols

Office for Coastal Management