Fusing LiDAR with RTK GPS Using Random Forest Regression Shows Promise for DEMs of Mangrove and Sawgrass Soil Heights in Florida's Coastal Everglades

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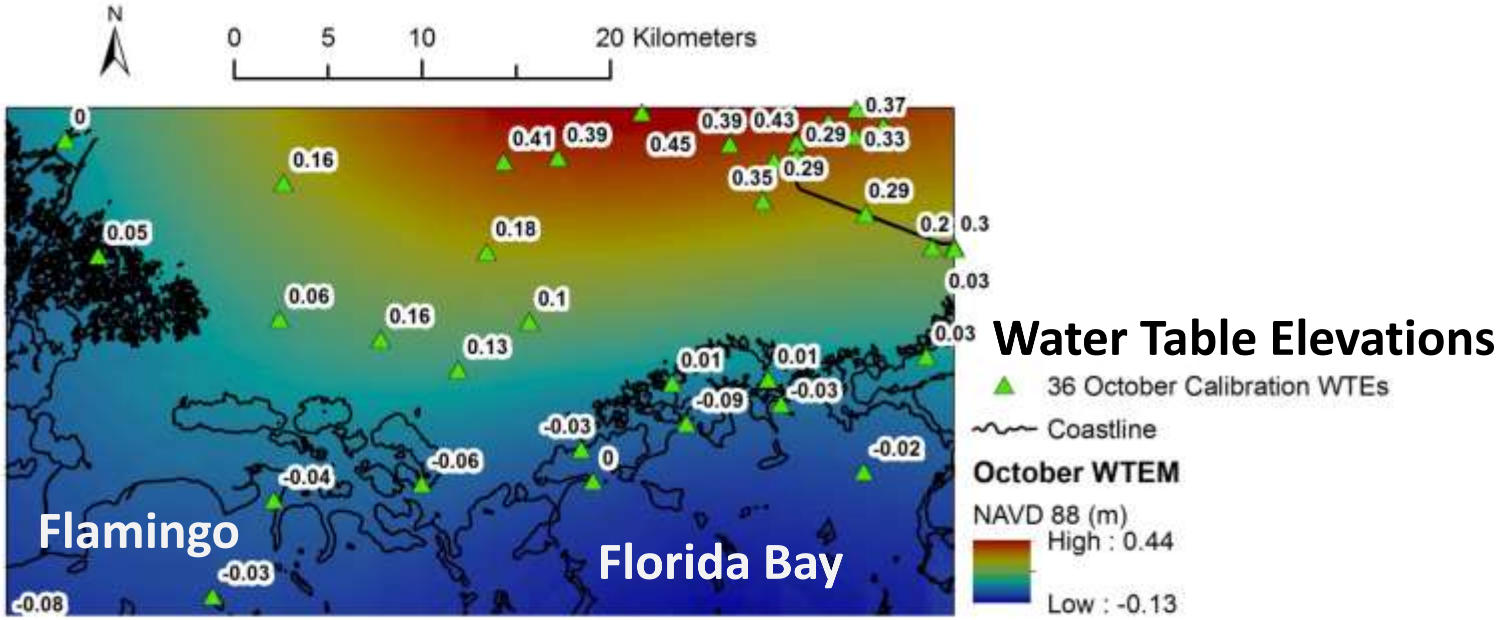
Significance of Digital Elevation Models (DEMs) in the Everglades

- Restoration requires accurate DEMs to monitor & simulate water levels, water depths & hydroperiods (e.g. Jones et al., 2012).
- Accurate & fine horizontal resolution DEMs are necessary for regional sea-level rise assessments (e.g. Zhang, 2011).



Available Elevation Data for the coastal Everglades

The Everglades hydrologic community agreed upon vertical elevation error threshold of **±15 cm** (Desmond, 2003; Jones et al., 2012).

- High Accuracy Elevation Data (HAED) collected by USGS 1995-2007
  - **Pros: Meets the strict error requirements**
  - **Cons: Coarse horizontal resolution (400 m)**

- Light Detection and Ranging (LiDAR)
  - **Pros: Fine horizontal resolution (e.g. 2 m)**
  - **Cons: Does not meet the strict error requirements**

Past efforts for correcting LiDAR

LiDAR is known to overestimate coastal marsh elevation, so previous studies make improvements by:

- Minimum Bin (MB) technique (e.g. Schmid et al., 2011)
  - **Assigns minimum LiDAR ground return value within a grid cell to that grid cell**
- Bias correction technique (e.g. Montane and Torres, 2006)
  - **Calculates correction factors based on GPS & LiDAR DEM for each vegetation community**

Few efforts were made to apply contemporary modeling to correct LiDAR for DEM improvement

Research Objective

Develop models to correct LiDAR for an improved DEM product that meets Everglades' vertical error by:

1) Using RTK GPS and Random Forest Regression (RFR)
2) Comparing RFR with Minimum Bin (MB) and biased-correction techniques for best results

Study area

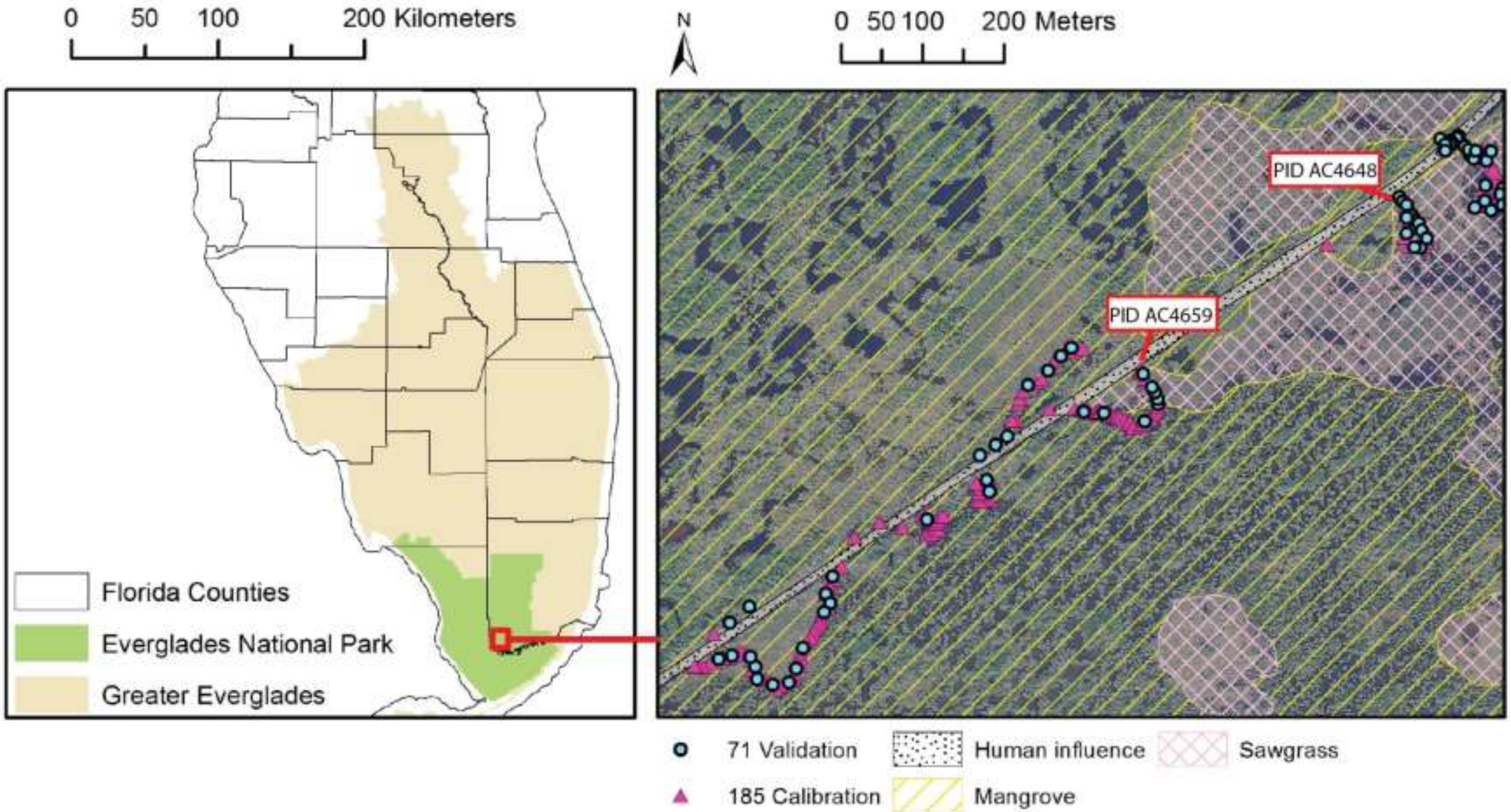


Figure 1 Map of study area located just south of Nine Mile Pond.

Data

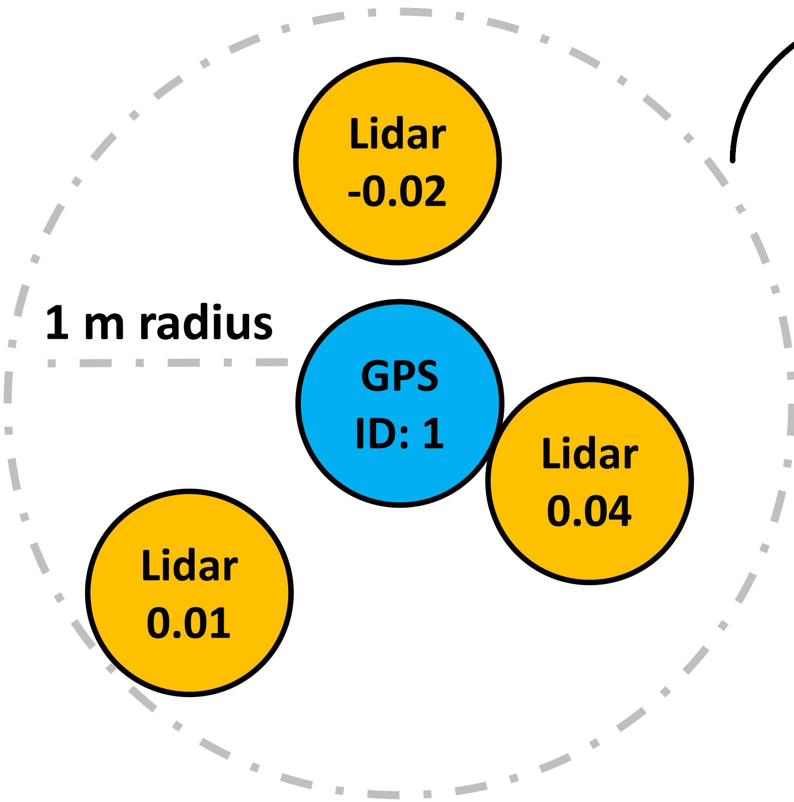
- **FDEM LiDAR ground returns**
  - Collected Feb 2008
  - Point density 2 pts/m^2
- **SFWMD Land cover data**
  - Photointerpreted from Feb-March 2004 imagery
- **Real Time Kinematic (RTK) GPS**
  - Collected for this study Feb 2016
  - Vertical positons <0.03 m (1 σ)
  - 256 total (162 mangrove, 72 sawgrass, 22 road)

Sawgrass

Mangrove

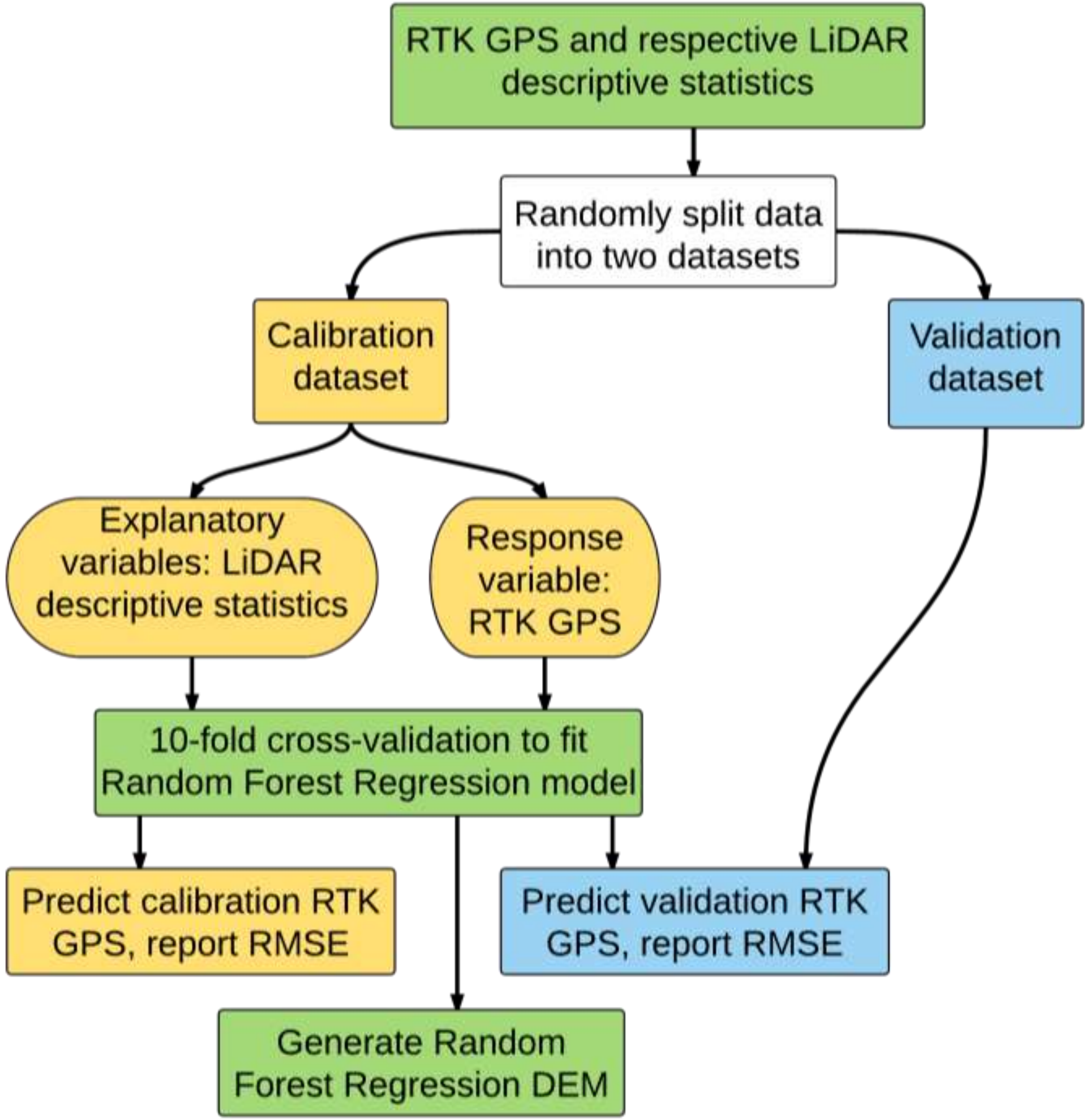
Methods: Proximity Analysis

To assess **accuracy of LiDAR ground returns** and **test RFR model**, the relationship between RTK GPS and LiDAR is determined **by proximity and statistical analysis**:



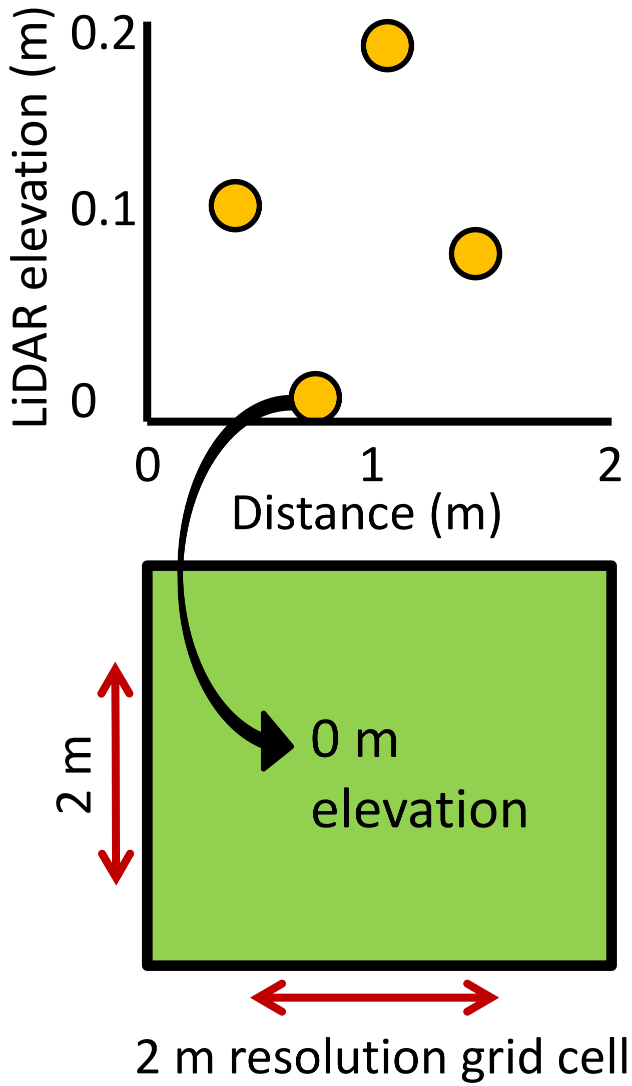
GPS ID	LiDAR min	LiDAR max	LiDAR µ	n
1	-0.02	0.04	0.01	3
…	…	…	…	…
256	0.01	0.01	0.01	1

Methods: RFR


RTK GPS and respective LiDAR descriptive statistics
Randomly split data into two datasets
Calibration dataset
Validation dataset
Explanatory variables: LiDAR descriptive statistics
Response variable: RTK GPS
10-fold cross-validation to fit Random Forest Regression model
Predict calibration RTK GPS, report RMSE
Predict validation RTK GPS, report RMSE
Generate Random Forest Regression DEM

Methods

Minimum Bin (MB) technique



Bias-correction technique

Calculate mean bias (Δ_μ) between RTK GPS **calibration dataset** and MB for each land cover

↓

Adjust MB by Δ_μ per respective land cover

↓

MB calibrated DEM where accuracy & error assessed by **validation dataset**

Results: Proximity Analysis

Table 1 Descriptive statistics for surveyed GPS (Z_{GPS}) and LiDAR ground returns (Z_{LiDAR}) within a 1 m radius of each GPS. Where $\mu_{\Delta_{min}}$ = mean difference between minimum LiDAR values and GPS, all in meters.

Land cover	**n**	Z_{GPS}				Z_{LiDAR}				$\mu_{\Delta_{min}}$	$\mu_{\Delta_{max}}$	$\mu_{\Delta_{\mu}}$
		min	**max**	**μ**	**σ**	**min**	**max**	**μ**	**σ**			
Consolidated	256	-0.55	1.1	-0.05	0.33	-0.37	1.21	0.17	0.34	0.17	0.26	0.22
Mangrove	162	-0.55	0.26	-0.14	0.11	-0.37	0.96	0.11	0.24	0.19	0.30	0.25
Sawgrass	72	-0.26	0.06	-0.16	0.06	-0.20	0.84	0.03	0.18	0.15	0.24	0.19
Road	22	0.51	1.10	0.98	0.13	0.60	1.21	1.06	0.12	0.04	0.12	0.08

For our study area:

- LiDAR continuously overestimates ground
- It is more difficult for LiDAR to penetrate surface water with dark peat soils below low-density mangroves compared to high density sawgrass

Results: RFR Model Performance

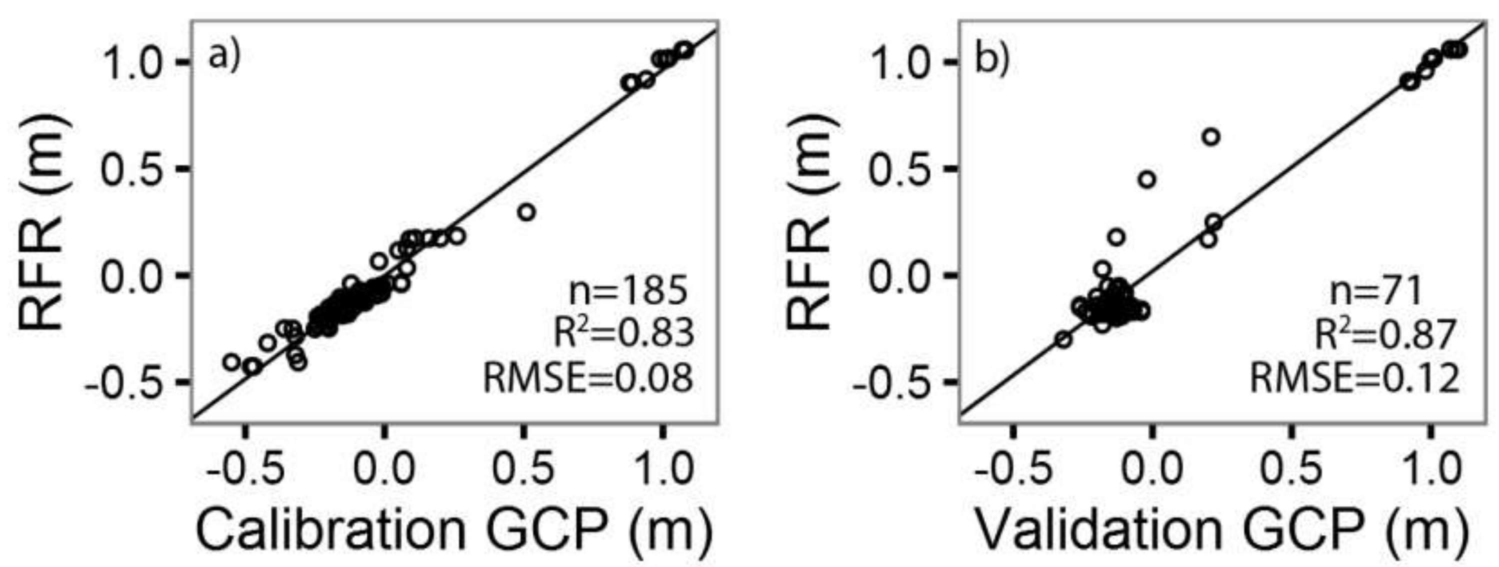


Figure 2 Relationships between actual and predicted elevation of all land covers for calibration and validation data.

Results: Corrected LiDAR DEMs

Table 2 Descriptive statistics for each experiment. Where RFR = Random Forest Regression, MB = Minimum Binning, $MB_{calibrated}$ = MB calibrated by the respective mean bias, Δ_{μ}= mean difference between experiment values and GPS, n = number of GPS.

Land cover	**Experiment**	**$RMSE_Z$**	**Δ_{μ}**	**Median**	**Skew**	**σ**	**n**
Consolidated	RFR	0.09	0.01	0.00	1.54	0.09	71
	$MB_{calibrated}$	0.20	0.05	0.00	1.22	0.19	71
	MB	0.26	0.17	0.10	1.23	0.20	185
Mangrove	RFR	0.11	0.01	0.00	1.55	0.11	30
	$MB_{calibrated}$	0.22	0.08	0.10	0.43	0.21	30
	MB	0.23	0.15	0.12	0.53	0.18	132
Sawgrass	RFR	0.09	0.01	0.01	0.87	0.09	30
	$MB_{calibrated}$	0.21	0.03	-0.03	1.64	0.21	30
	MB	0.15	0.12	0.10	1.11	0.09	42

Conclusions

Primary purpose of this study: develop models to correct LiDAR for improved DEM product that meets Everglades' elevation error requirements (±15 cm).

- **Our results demonstrate the RFR-based DEM exceeds these requirements:**
  - **Mangrove = σ and RMSE = 11 cm; Δ_μ = 1 cm**
  - **Sawgrass = σ and RMSE = 9 cm; Δ_μ = 1 cm**

This work has potential to better assist restoration projects with more <u>accurate, precise, and high resolution</u> DEMs.

Acknowledgements

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Many thanks to Everglades National Park staff!

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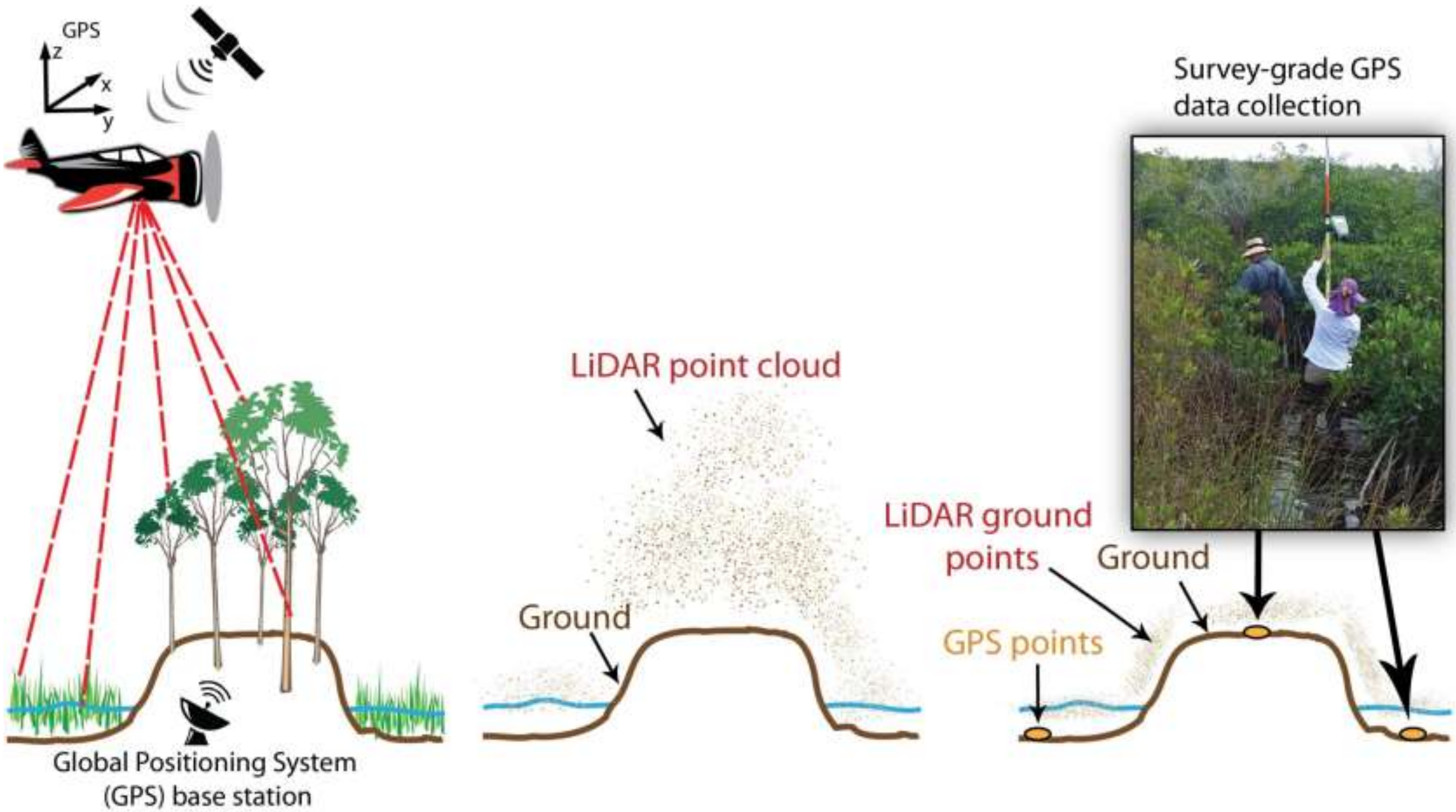
Thank you!

Nature of LiDAR Elevation Data

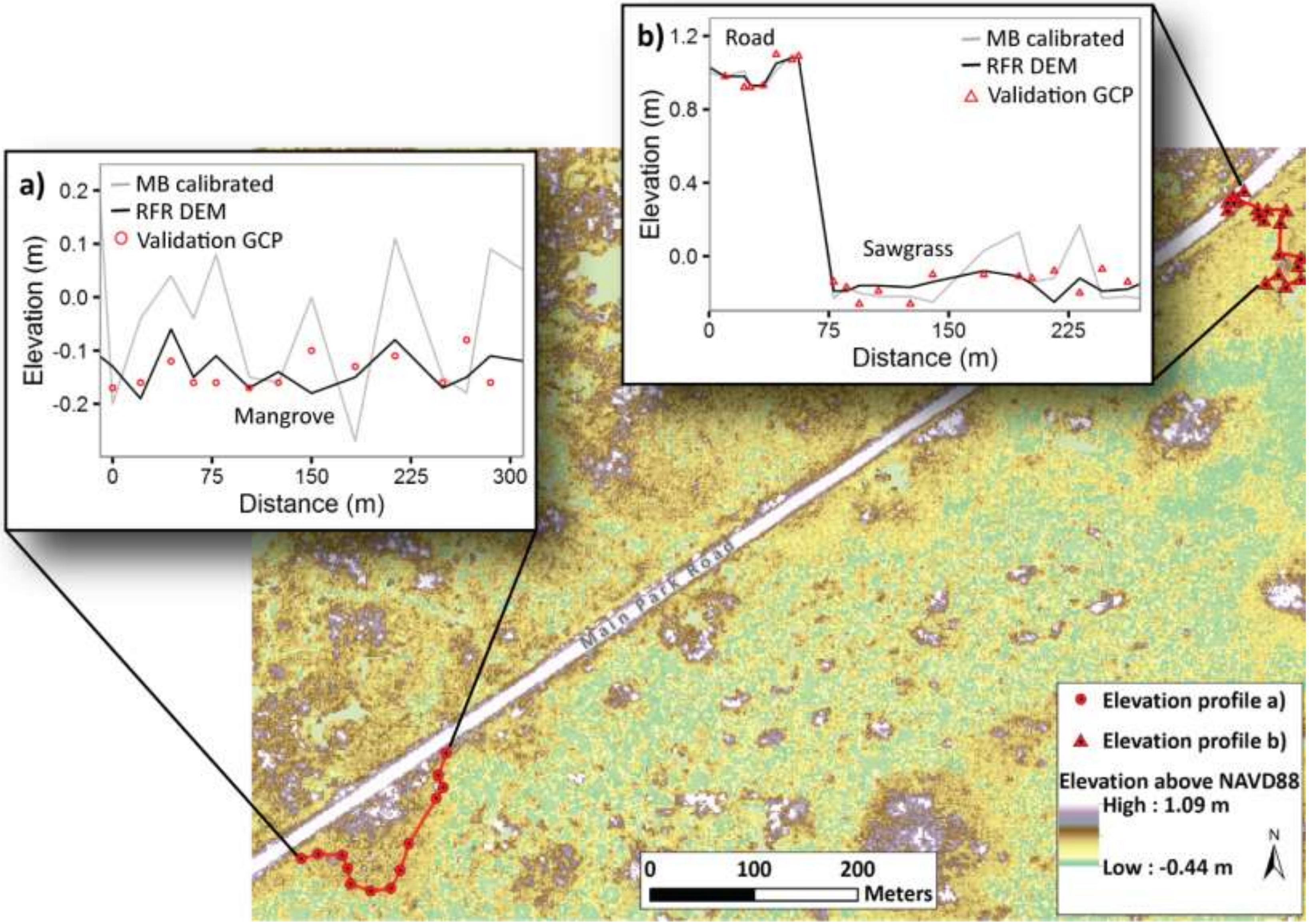


1. Light Detection and Ranging (LiDAR) elevation data collection

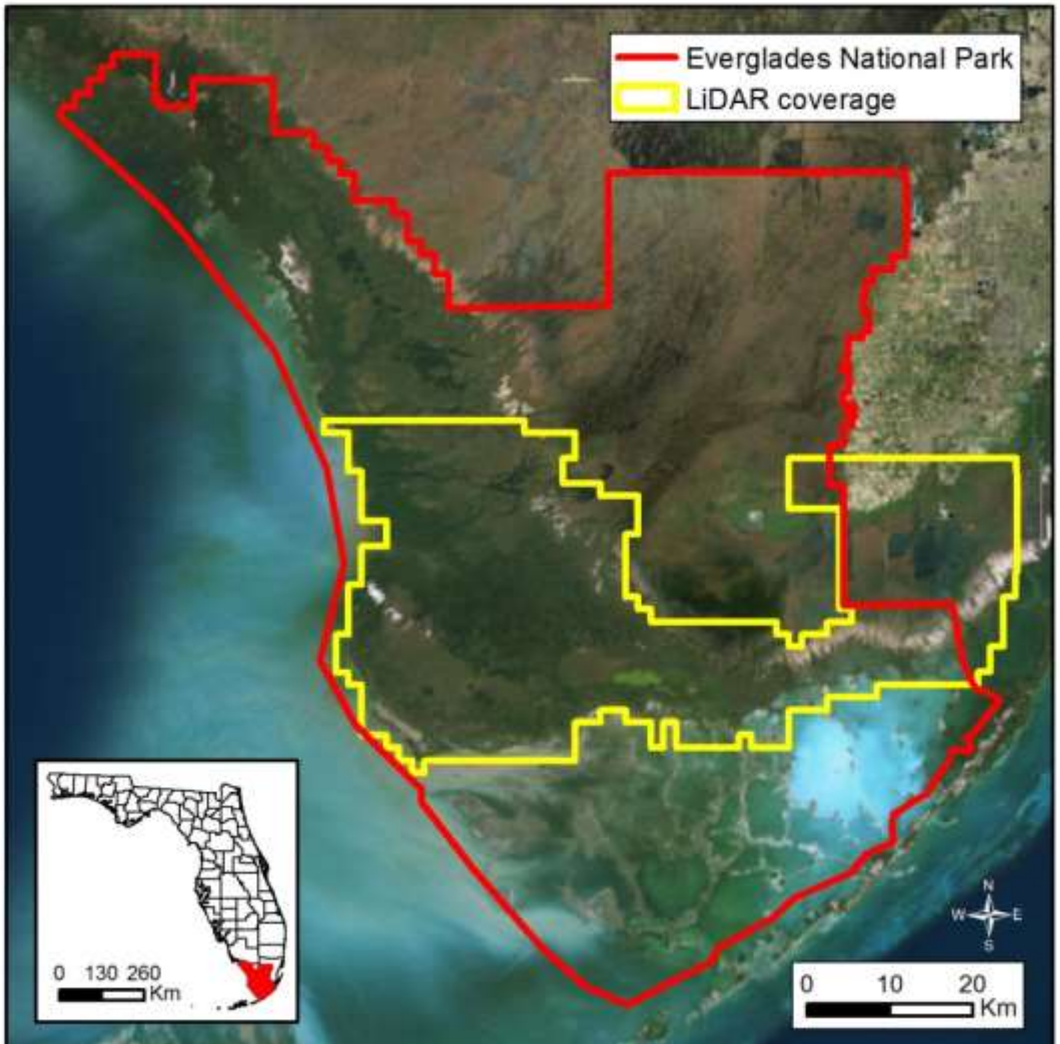
2. Process LiDAR where vegetation points are removed and 'ground' points remain

3. LiDAR 'ground' points never truly reach the ground, but survey-grade GPS will

Results: RFR DEM



Future Research



- Test this approach to predict e.g. HAED for other vegetation communities within the entire coastal Everglades.
- Incorporate accretion rates into DEMs for modeling water depth change due to regionally adjusted sea-level rise projections.