UNIVERSITY of FLORIDA

E·S·S·I·E Engineering School of Sustainable Infrastructure & Environment

Estimating the spatial distribution of vegetation height, density, and ground elevation in a mesotidal salt marsh from a UAV LiDAR derived point cloud

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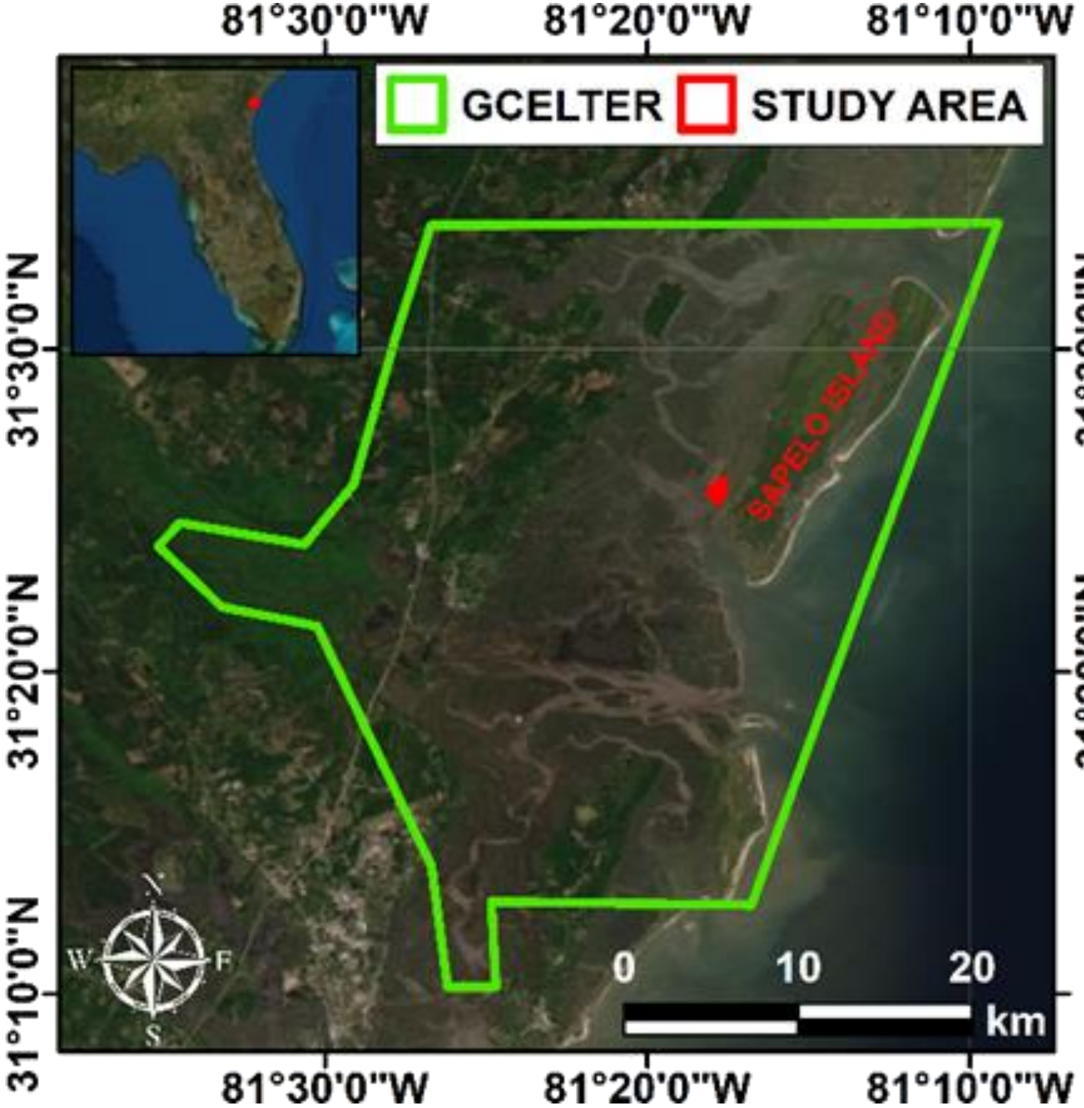
OBJECTIVE

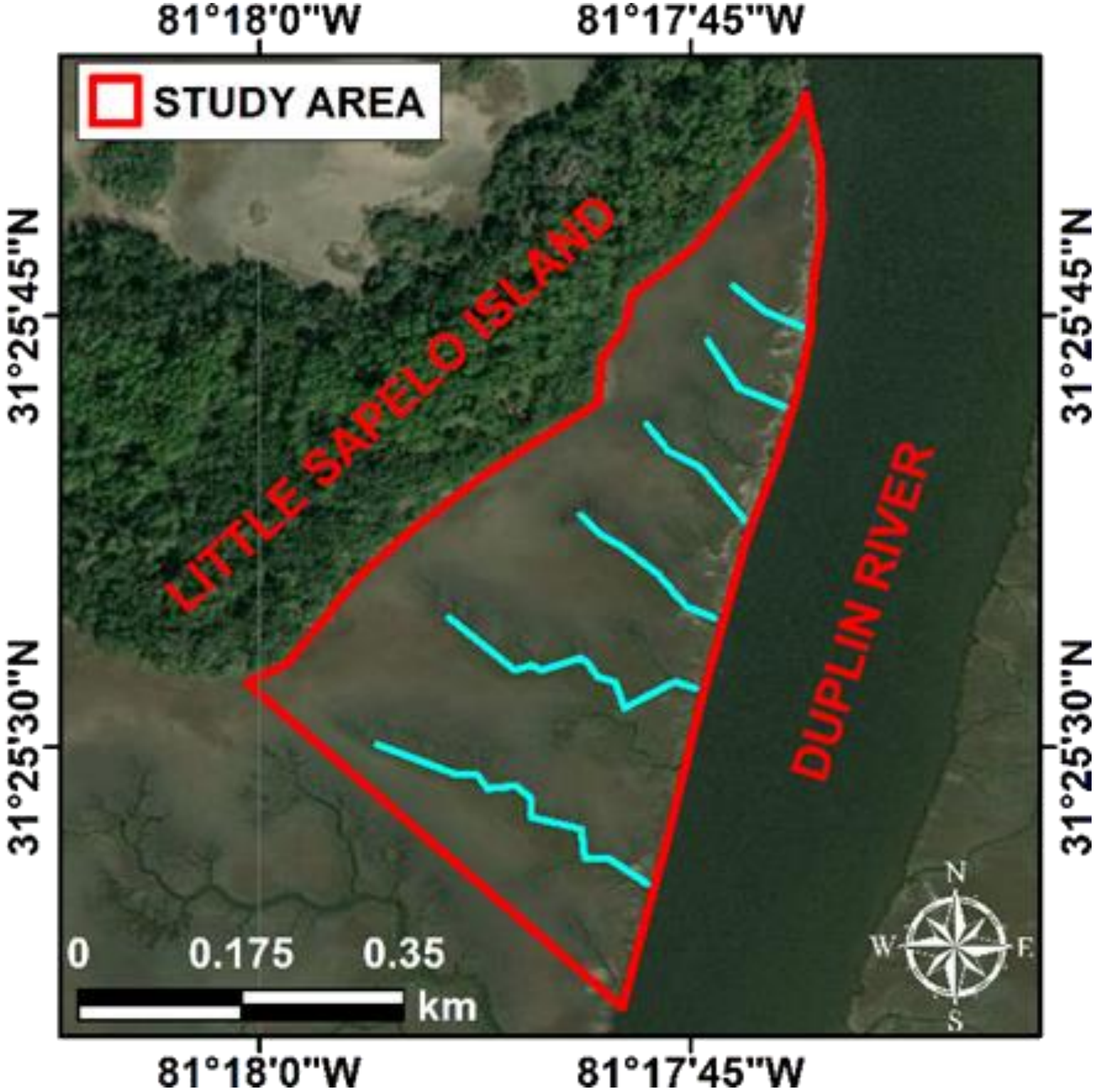
CONVERT UAV-BASED LIDAR POINTS INTO GROUND ELEVATION, VEGETATION HEIGHT AND VEGETATION DENSITY, WITHOUT THE SUPPORT OF ADDITIONAL DATASETS

METHOD

1. DEVELOP AN ALGORITHM THAT ESTIMATES THE LOCAL SHAPE OF THE GROUND BY USING A REGRESSION SURFACE FITTING THE MINIMUM GROUND ELEVATIONS
2. TRANSFORM THE POINT CLOUD USING THE REGRESSION SURFACE, TO REMOVE THE INFLUENCE OF THE GROUND SLOPE IN NON-FLAT AREAS → GROUND ELEVATION
3. TRAIN AND TEST A GENETIC ALGORITHM USING LIDAR-, RGB-, AND COUPLED LIDAR-RGB- BASED PREDICTORS → VEGETATION HEIGHT AND DENSITY

STUDY AREA



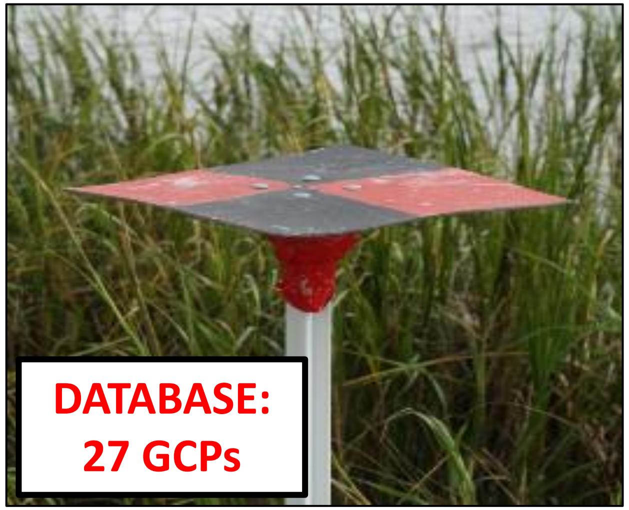


*Georgia Coastal Ecosystem Long Term Ecological Research

REMOTE SENSING DATASETS

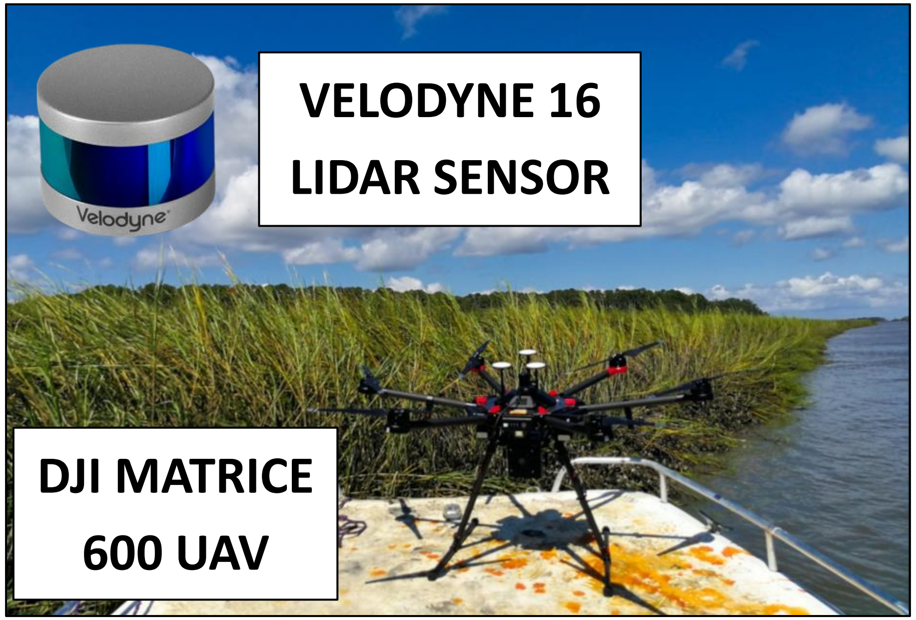
GROUND CONTROL POINTS

- Wooden 30×30 cm^2 square target
- Placed on a 2-m-tall t-post
- Painted with red and black paint



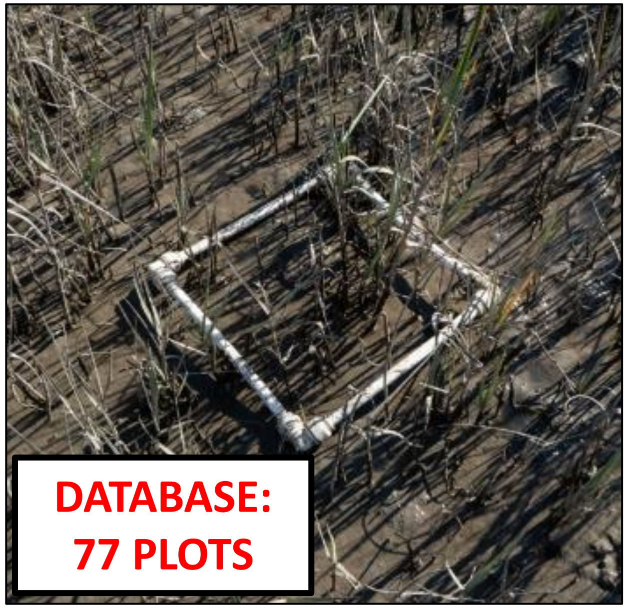
UAV BASED LIDAR POINT CLOUD

Flight altitude: ~50 m



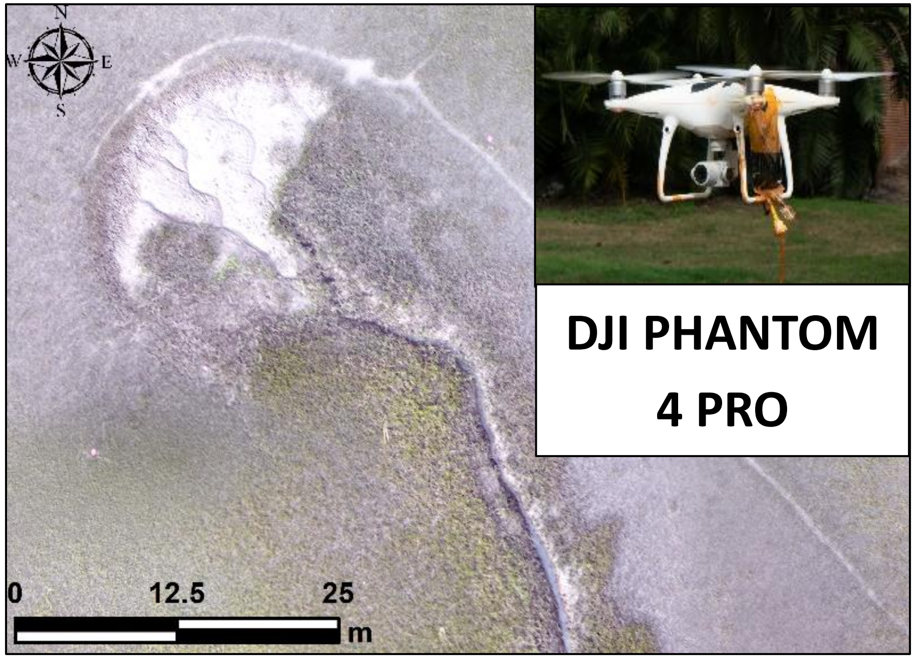
VEGETATION SURVEY

- 40×40 cm^2 square plots
- Uniformly distributed
- Vegetation height, vegetation density, ground elevation



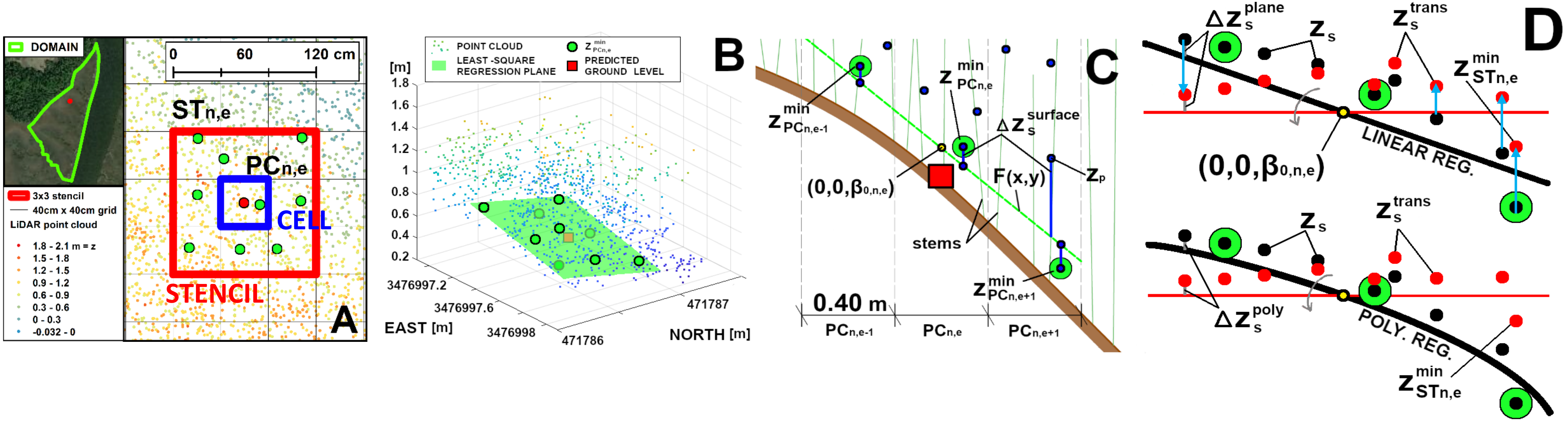
RGB IMAGES

- Flight altitude: 105 m above ground
- Image footprint: 175 x 115 m^2
- 80% overlap

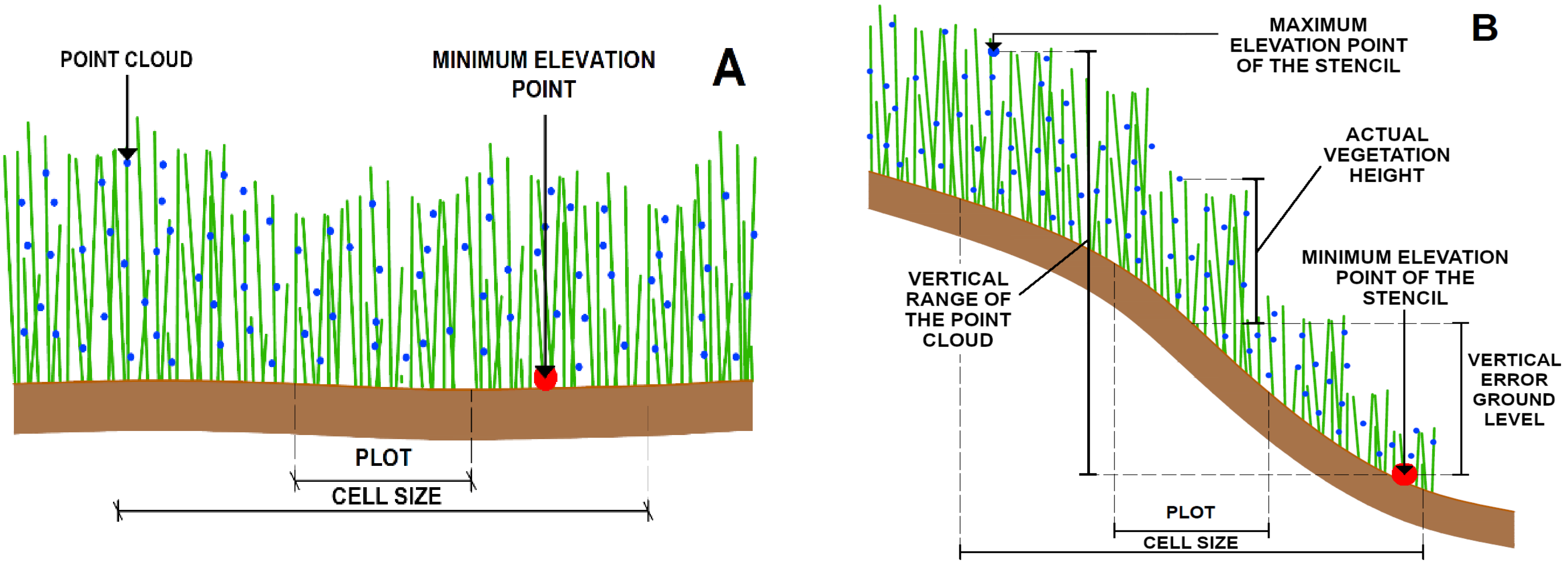


POINT CLOUD TRANSFORMATION

1. The point cloud is divided in *(n,e)* cells ($PC_{n,e}$) of dimensions 0.4 m × 0.4 m
2. The elevation of the lowest point of the cloud in each *(n,e)* cell is defined
3. A least-squares regression surface is determined using the minimum points in the cells composing a $ST_{n,e}$
4. The vertical distances between the LiDAR points and the regression surface are calculated
5. A transformed point cloud is obtained for each $ST_{n,e}$ stencil. The minimum of these distances ($z^{min}_{ST_{n,e}}$) is identified
6. The relative elevation of each point of the transformed point cloud in $ST_{n,e}$ with respect to $z^{min}_{ST_{n,e}}$ is calculated



WHY?


POINT CLOUD
MINIMUM ELEVATION POINT
A
PLOT
CELL SIZE
MAXIMUM ELEVATION POINT OF THE STENCIL
B
ACTUAL VEGETATION HEIGHT
VERTICAL RANGE OF THE POINT CLOUD
MINIMUM ELEVATION POINT OF THE STENCIL
VERTICAL ERROR GROUND LEVEL
PLOT
CELL SIZE

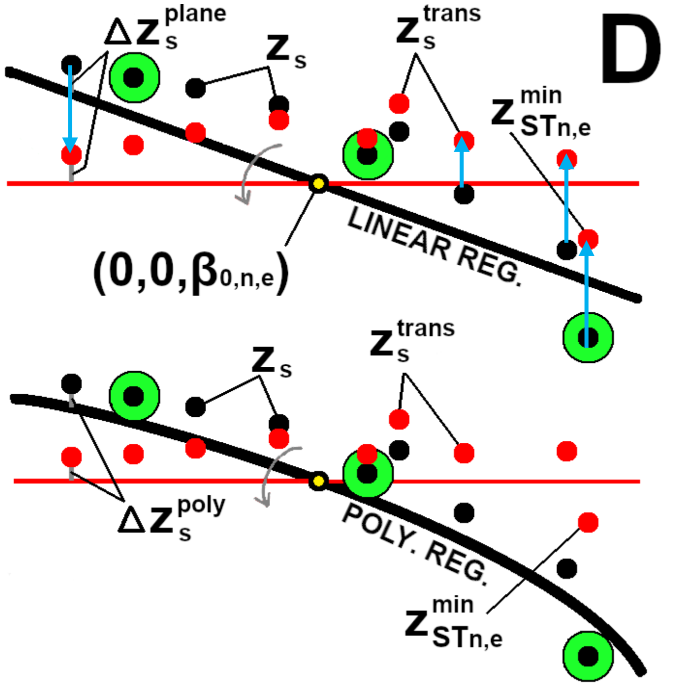
GROUND ELEVATION ESTIMATE

Linear regression is made between the measured and computed ground elevation

$$z = a + b \cdot z^{min}_{method_{n,e}}$$

$z^{min}_{method_{n,e}}$ is considered as:

1. The minimum elevation of the non-transformed point cloud in $ST_{n,e}$
2. The minimum elevation of the point cloud transformed by using a regression plane
3. The minimum elevation of the point cloud that is transformed by using a second-order polynomial regression instead of the planar regression



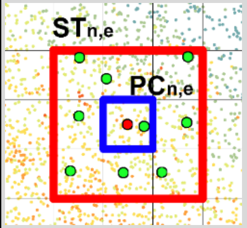
LIDAR POINT CLOUD. Evaluation metrics for the ground elevation.

DATASETS	$ST_{n,e}$ minimum		Regression Plane		Regression Polynomial Curve	
	RMSE [cm]	MAE [cm]	RMSE [cm]	MAE [cm]	RMSE [cm]	MAE [cm]
Test Creeks+Marsh	7.8	4.7	5.9	4.2	9.7	7.1
Test Creeks	13.9	13.9	10.3	10.3	7.1	7.0
Test Marsh	7.2	5.2	5.8	4.2	9.6	7.0

BEST METHOD: PLANAR REGRESSION $z = -0.018 + z^{min}_{method_{n,e}}$

GENETIC ALGORITHM - MODEL PREDICTORS

GENETIC ALGORITHM. Model predictors for the genetic algorithm used to determine vegetation height and density.

Datasets	LiDAR		RGB	
Variables	$M_{n,e}$	Number of points	$R^{min}_{n,e}, R^{max}_{n,e}, R^{mean}_{n,e}$	Red minimum, maximum and mean intensity values
	$\sigma_{n,e}$	Elevation Std. Dev.		
	$G_{n,e}$	Elevation Skewness	$G^{min}_{n,e}, G^{max}_{n,e}, G^{mean}_{n,e}$	Green minimum, maximum and mean intensity values
	$K_{n,e}$	Elevation Kurtosis		
	$z^{max}_{n,e}$	Maximum elevation	$B^{min}_{n,e}, B^{max}_{n,e} B^{mean}_{n,e}$	Blue minimum, maximum and mean intensity values
	$z^{mean}_{n,e}$	Mean elevation		
	$z^{mode}_{n,e}$	Mode elevation	$GRAY^{min}_{n,e}, GRAY^{max}_{n,e}, GRAY^{mean}_{n,e}$	Grayscale minimum, maximum and mean intensity values
	$z^{median}_{n,e}$	Median elevation		

$$\hat{P} = \frac{P - \bar{P}}{SD_P}$$

STANDARDIZED MODEL PREDICTOR ($\hat{P}$)

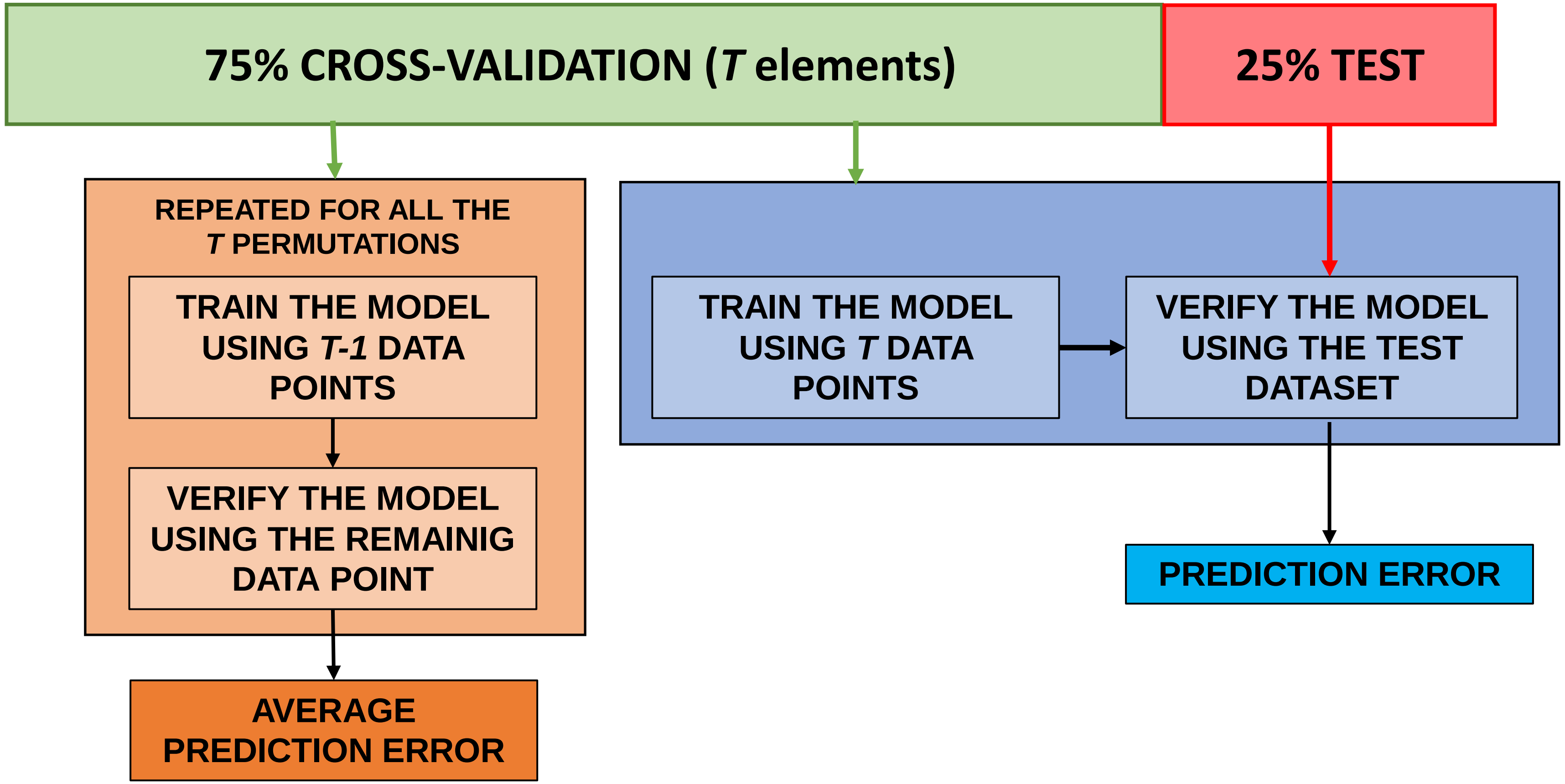
PREDICTOR ORIGINAL VALUE (P)

PREDICTOR'S MEAN ($\bar{P}$)

PREDICTOR'S STANDARD DEVIATION (SD_P)

TRAINING, VALIDATION AND TESTING

TRAINED AND VALIDATED USING A LOOCV



ERROR EVALUATION

$$MAE = \frac{\sum_{i=1}^{N}\left(y_o - y_{pr}\right)}{N}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(y_o - y_{pr}\right)^2}{N}}$$

VEGETATION PROPERTIES ESTIMATE

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VEGETATION HEIGHT. Evaluation metrics obtained from the training, validation, and testing procedure of the genetic algorithm.

Input source	Steps LOOCV	RMSE [cm]	MAE [cm]
LiDAR	Test	17.5	12.6
Photogrammetry	Test	38.1	31.1
LiDAR + RGB	Test	14.0	10.0

$$\widehat{V^H_{n,e}} = 0.92\,\widehat{\sigma_{n,e,LiDAR}}$$

VEGETATION DENSITY. Evaluation metrics obtained from the validation and testing procedure for the genetic algorithm.

$$B_{n,e} = \Delta z_{n,e} \times V^D_{n,e}$$

Input source	Steps LOOCV	RMSE [stems/m²]	MAE [stems/m²]
LiDAR	Test	9.4	6.9
Photogrammetry	Test	16.6	12.7
LiDAR + RGB	Test	9.4	6.9

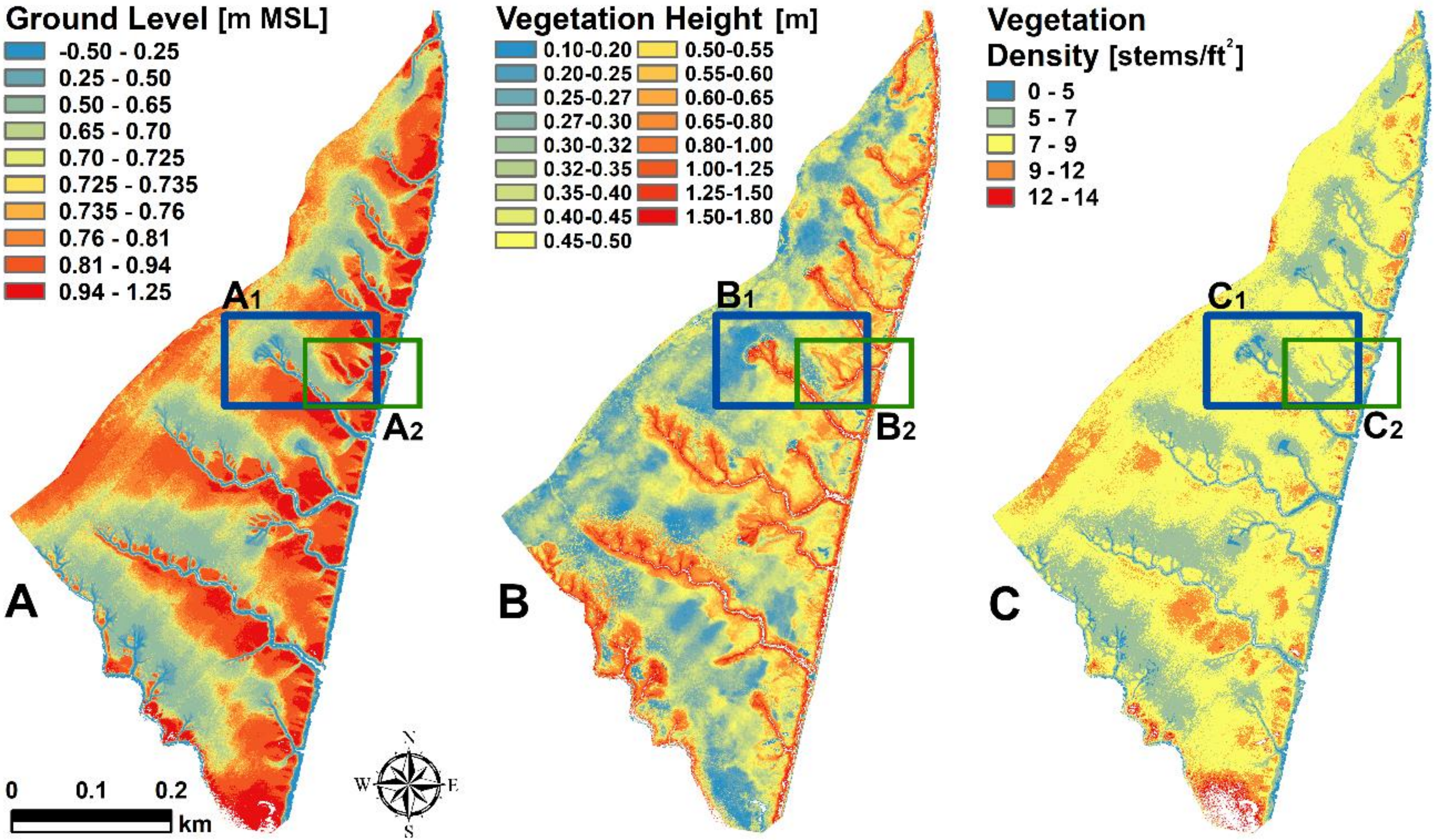
$$\widehat{B_{n,e}} = 0.39\left(\widehat{\sigma_{n,e,LiDAR}} + \widehat{z^{median}_{n,e,LiDAR}}\right)$$

HIGH RESOLUTION MAPS

$$z = -0.018 + z^{min}_{method_{n,e}}$$

$$\widehat{V^{H}_{n,e}} = 0.92\,\widehat{\sigma_{n,e}}$$

$$\widehat{B_{2,n,e}} = \widehat{V^{D}_{n,e} \times \Delta z_{n,e}} = 0.39\left(\widehat{\sigma_{n,e}} + \widehat{z^{median}_{n,e}}\right)$$



OBSERVATIONS

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Ground Level
- -0.50 - 0.25
- 0.25 - 0.50
- 0.50 - 0.65
- 0.65 - 0.70
- 0.70 - 0.725
- 0.725 - 0.735
- 0.735 - 0.76
- 0.76 - 0.81
- 0.81 - 0.94
- 0.94 - 1.25

Vegetation Height
- 0.10-0.20
- 0.20-0.25
- 0.25-0.27
- 0.27-0.30
- 0.30-0.32
- 0.32-0.35
- 0.35-0.40
- 0.40-0.45
- 0.45-0.50
- 0.50-0.55
- 0.55-0.60
- 0.60-0.65
- 0.65-0.80
- 0.80-1.00
- 1.00-1.25
- 1.25-1.50
- 1.50-1.80

Vegetation Density [stems/ft^2]
- 0 - 5
- 5 - 7
- 7 - 9
- 9 - 12
- 12 - 14

GROUND ELEVATION

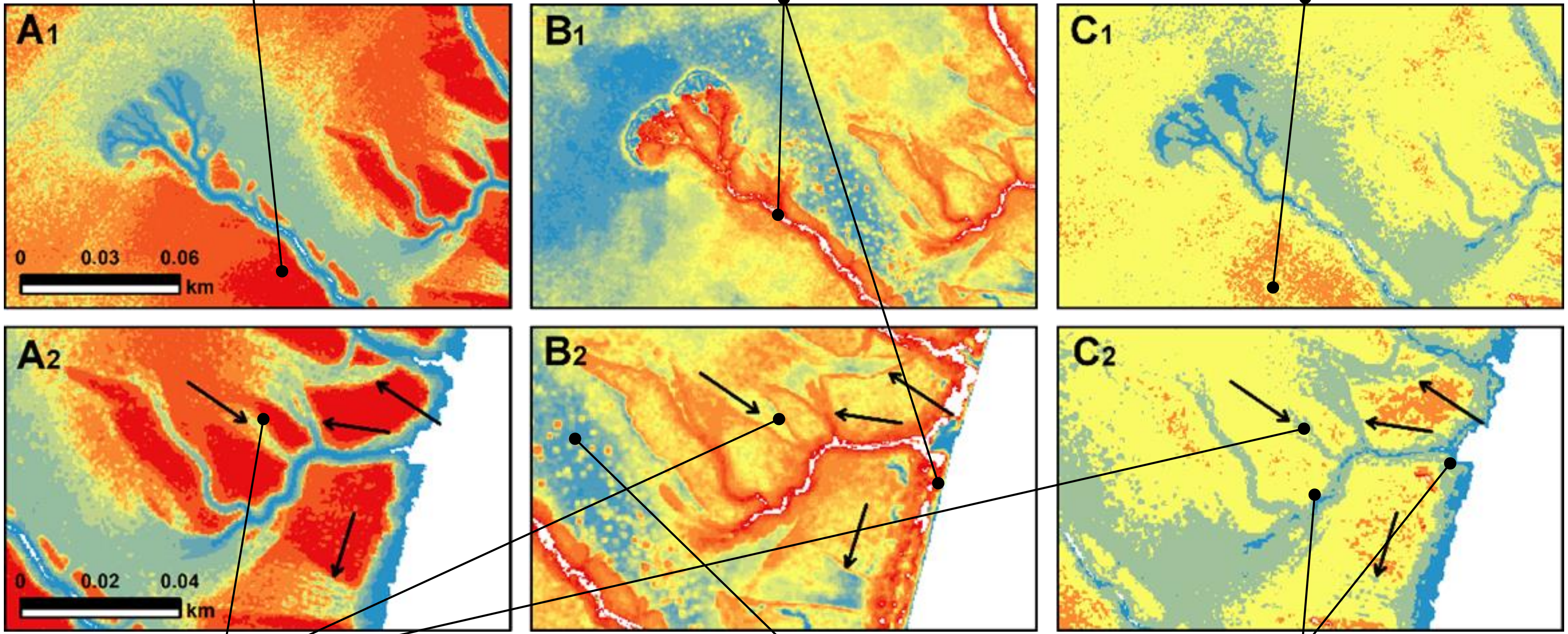
THERE IS A PREFERENTIAL SEDIMENTATION PROCESS ON THE SW SIDE OF THE CHANNELS

VEGETATION HEIGHT

SPARTINA ALTERNIFLORA GROWS HIGH CLOSE TO THE CREEKS AND THE DUPLIN RIVER, IN CONJUNCTION WITH HIGH GROUND ELEVATION

VEGETATION DENSITY

HIGH VEGETATION DENSITY WAS CALCULATED IN CONJUNCTION WITH SHORT AND MEDIUM CANOPY HEIGHT



FUNNEL-SHAPED AND LOW-VEGETATED CORRIDORS

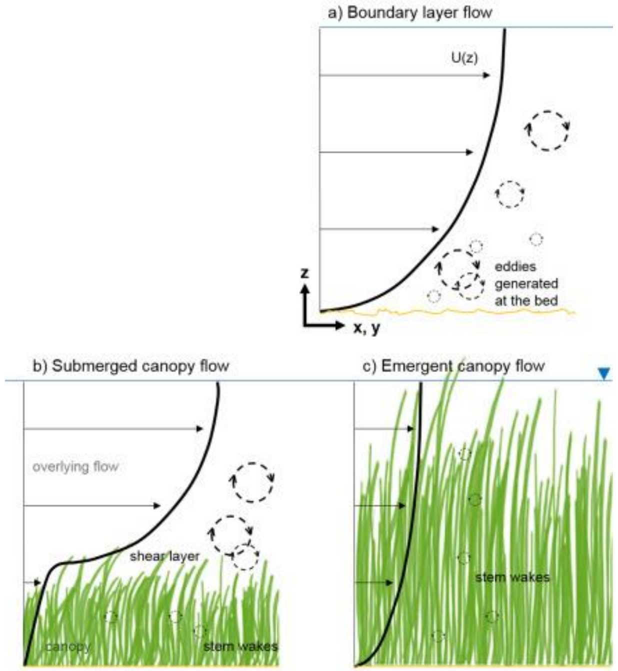
VEGETATION HEIGHT PROGRESSIVELY DECREASE REACHING THE INNER PART OF THE MARSH

LOW VEGETATION DENSITY WAS CALCULATED ON THE CREEKS LEVEES AND HEADS, IN CONJUNCTION WITH HIGH VEGETATION

ADVANTGES AND APPLICATIONS

- Understand the seasonal variation in vegetation features and distribution
- Quantify the effects of droughts on the vegetation
- Evaluate marsh vertical accretion due to organic and inorganic deposition
- Quantify the impact of extreme events such as hurricanes and storms on both vegetation and ground elevation

- Agricultural applications
- Describe ground elevation and vegetation characteristics in other coastal features, such as dunes
- Obtain the vegetation parameters to use in the numerical models, favoring their calibration



CONCLUSIONS

- OUR APPROACH REDUCES THE ERROR INTRODUCED BY NON-FLAT GROUND IN THE COMPUTATION OF VEGETATION CHARACTERISTICS AND GROUND LEVEL, THUS CAPTURING THEIR LARGE GRADIENTS IN THE PROXIMITY OF TIDAL CREEKS
- VEGETATION PATTERNS AND EVOLUTION CAN BE ANALYZED USING OUR METHOD
- LIDAR-DERIVED PREDICTORS HAVE LARGER PREDICTIVE ABILITIES THAN RGB-BASED PREDICTORS IN DESCRIBING VEGETATION HEIGHT AND DENSITY
- USING A COUPLED LIDAR-RGB DATASET PROVIDES LITTLE OR NO IMPROVEMENT IN COMPARISON WITH USING ONLY THE LIDAR DATASET

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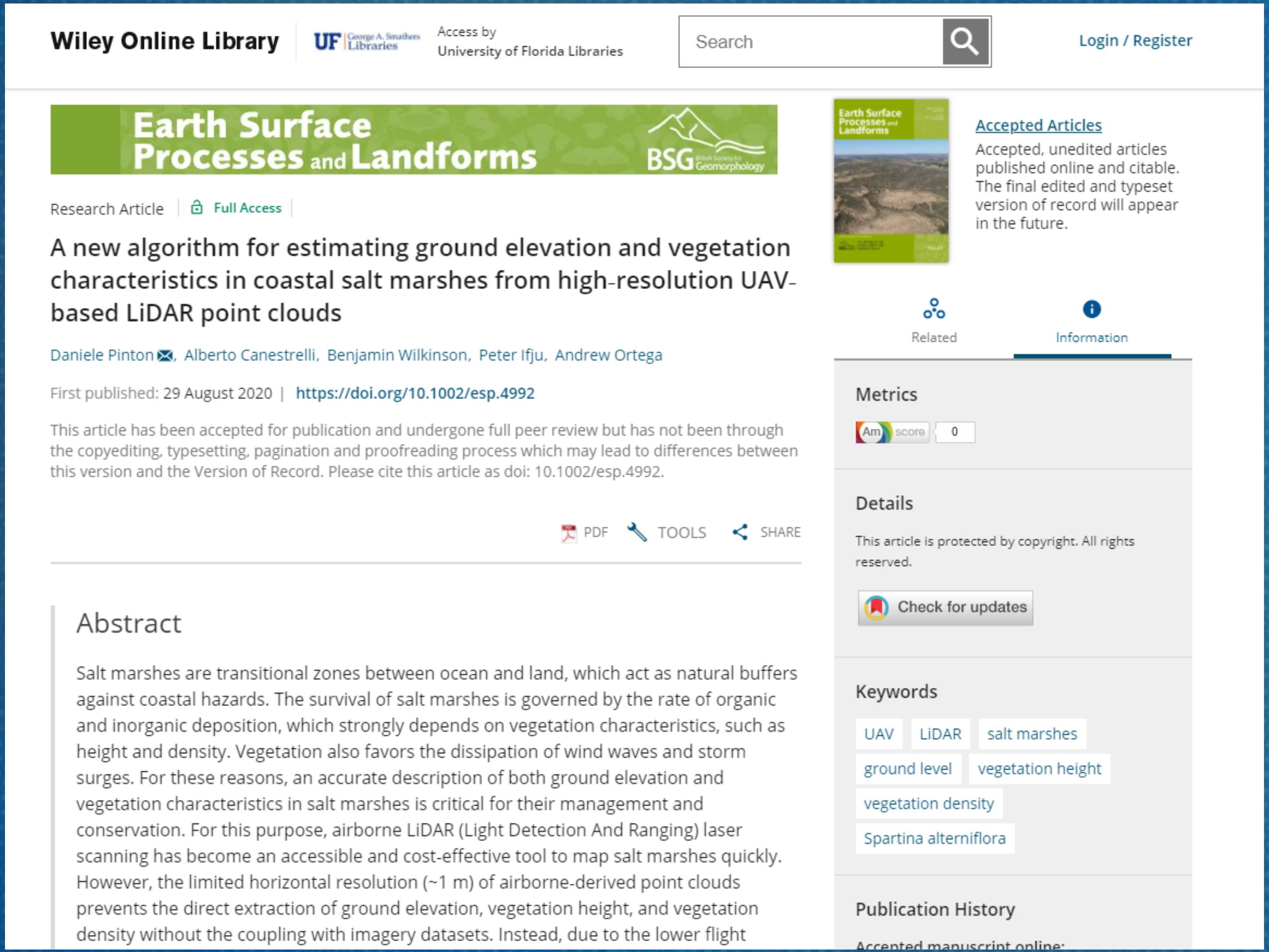
THANK YOU!



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A new algorithm for estimating ground elevation and vegetation characteristics in coastal salt marshes from high-resolution UAV-based LiDAR point clouds

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Abstract

Salt marshes are transitional zones between ocean and land, which act as natural buffers against coastal hazards. The survival of salt marshes is governed by the rate of organic and inorganic deposition, which strongly depends on vegetation characteristics, such as height and density. Vegetation also favors the dissipation of wind waves and storm surges. For these reasons, an accurate description of both ground elevation and vegetation characteristics in salt marshes is critical for their management and conservation. For this purpose, airborne LiDAR (Light Detection And Ranging) laser scanning has become an accessible and cost-effective tool to map salt marshes quickly. However, the limited horizontal resolution (~1 m) of airborne-derived point clouds prevents the direct extraction of ground elevation, vegetation height, and vegetation density without the coupling with imagery datasets. Instead, due to the lower flight

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