Evaluation of Active and Passive Aerial Surveying Techniques for Submerged Structure Mapping in Shallow Coastal Water

Michael J. Starek, Behrokh Nazeri

School of Engineering and Computing Sciences
Texas A&M University-Corpus Christi

17th Annual JALBTCX Workshop 2016, Silver Springs MD

CONRAD BLUCHER INSTITUTE
FOR SURVEYING AND SCIENCE

Recognition

Behrohk Nazeri – analysis

Jake Berryhill – field work

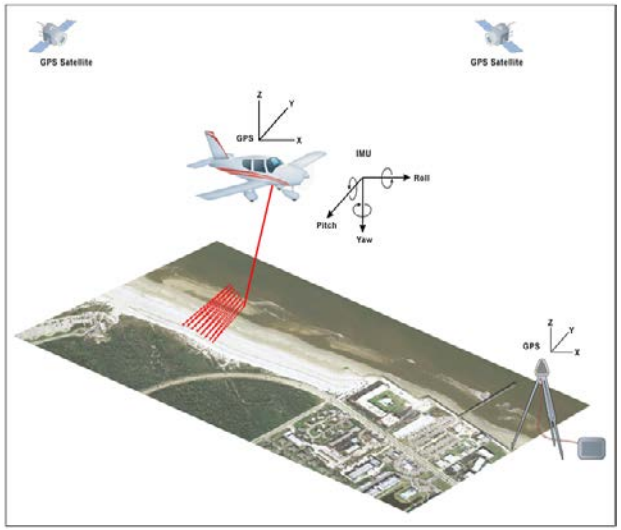
Introduction

- Submerged oil and gas pipelines pose navigation hazards
- Texas General Land Office (TGLO) effort to remove them

→ evaluate aerial surveying methods to map them

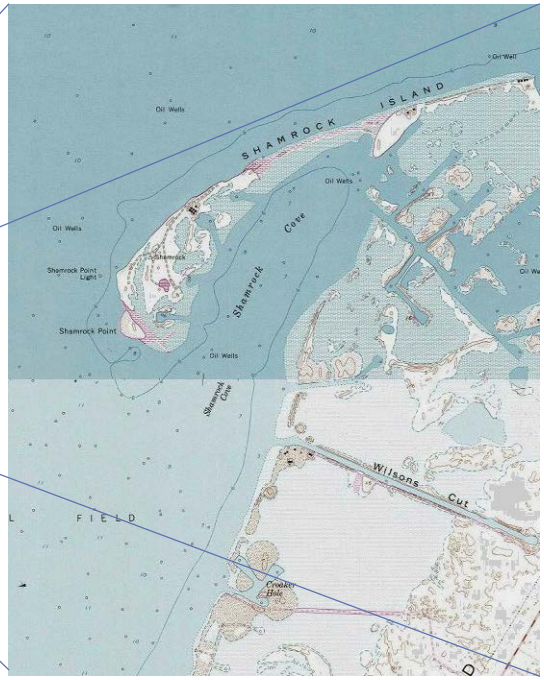
Aerial Techniques

- **Bathymetric Lidar**
  - DEM-based delineation
- **Aerial Imagery**
  - Sunglint correction
  - Edge detection
- **UAS Structure-from-Motion (SfM)**
  - Test image pre-conditioning on results
  - Glint correction, single vs. multiband



Study Area

- Shamrock Island in Corpus Christi Bay, TX
  - Sandy bottom mixed with seagrass
  - Depth <= 3 m (~2 m average), micro-tidal



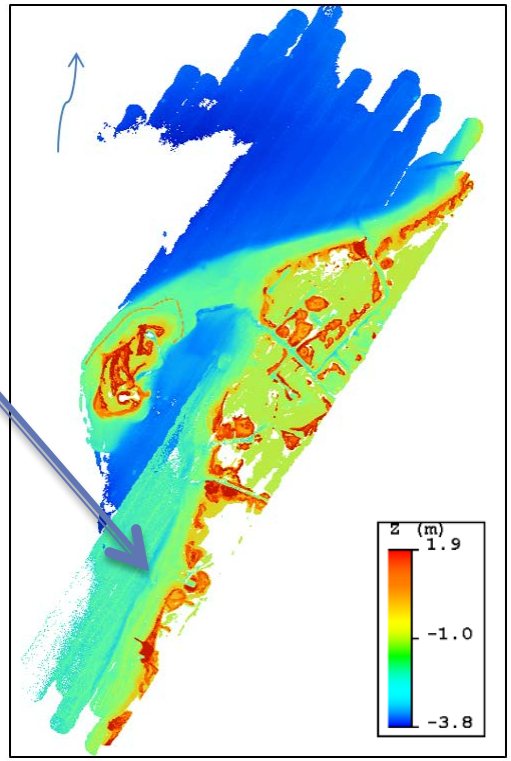
~16 sq. km area

Many residual oil and gas pipelines in area, heavy boating activity

Bathymetric LiDAR Survey

- UT BEG Chiroptera Lidar
  - ***Bathy*:** 515 nm, 36 kHz pulse, ~2.5 ns width
  - ***Topo*:** 1000 nm, up to 400kHz
- Survey characteristics
  - January 2015
  - Flying Height: 400 m
  - Swath Overlap: min of 30%
  - Mean Point Density
    - *Land:* 7 points per square meter
    - *Bathymetry*: 3 points per square meter

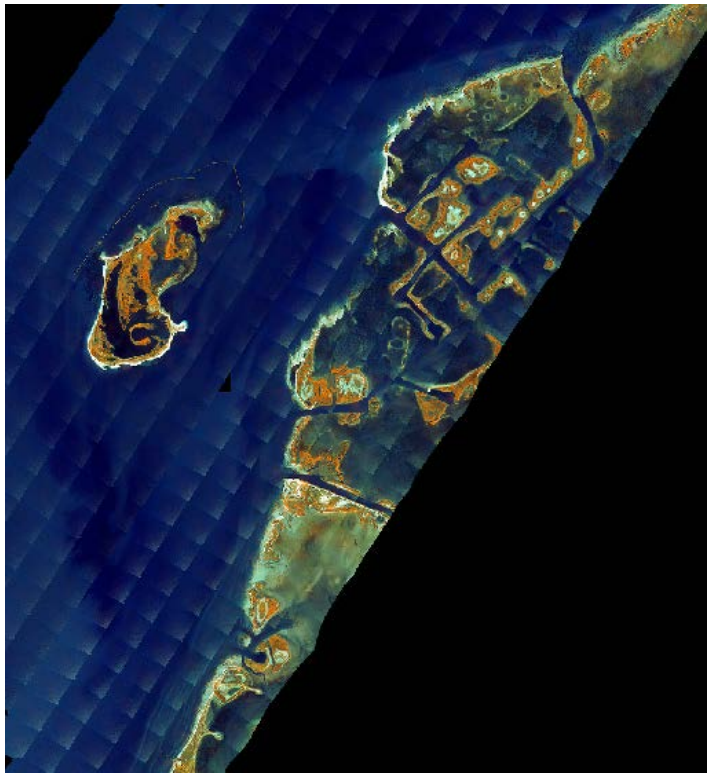
Data Gap



NAVD88 from Geoid 12a

Aerial Imagery

- DigiCAM 50 megapixel
  - Simultaneous acquisition
  - 8176 x 6132 pixels
  - GSD: 0.10 meter
  - Bands: NIR, Red, Green

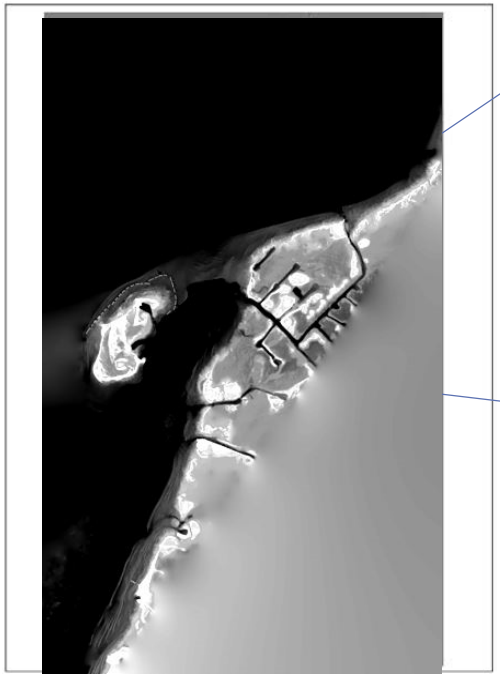


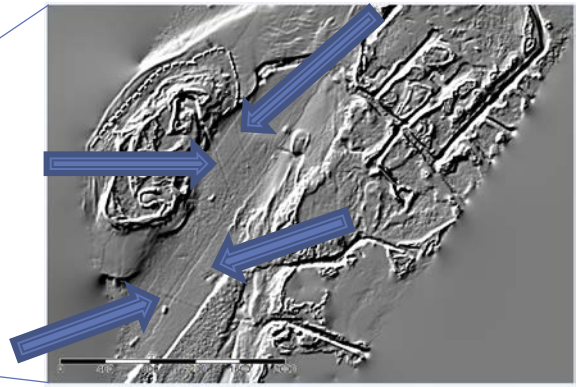
Bathymetric Lidar

- **Filter**
  - bottom and non-bottom using LASTools
- **DEM Generation**
  - 3 cell sizes (0.5 m, 1 m, 2 m)
  - Shaded reliefs at 3 sun angles (30, 45, 60)
- **Interpolation Methods**
  - *Delaunay Triangulated Irregular Network (TIN)*
  - *Inverse Distance Weighted average (IDW)*
    - Cannot estimate outside of the minimum and maximum range
  - *Multilevel B-spline*
    - Can model ridges and valleys not in the sample

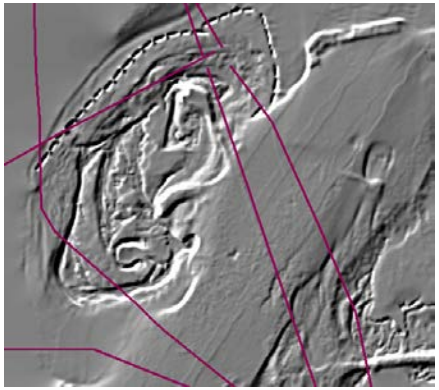
Pipeline Detection

- Multilevel B-spline interpolation (4 pipes: 4,6,12 in.)





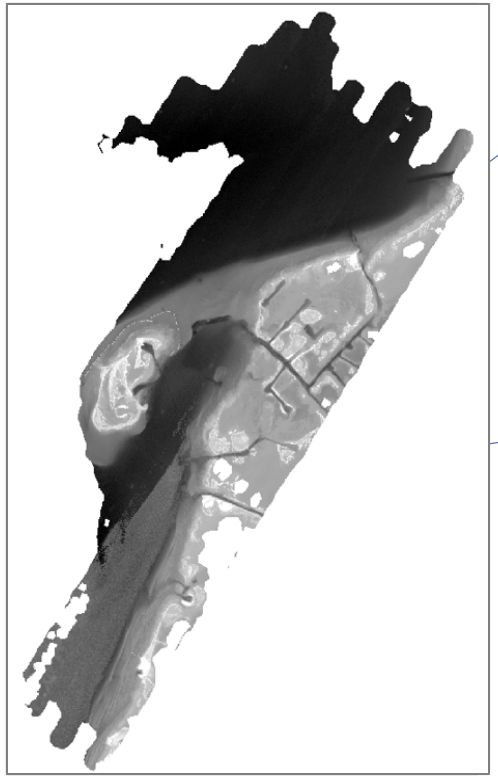
Visual Inspection

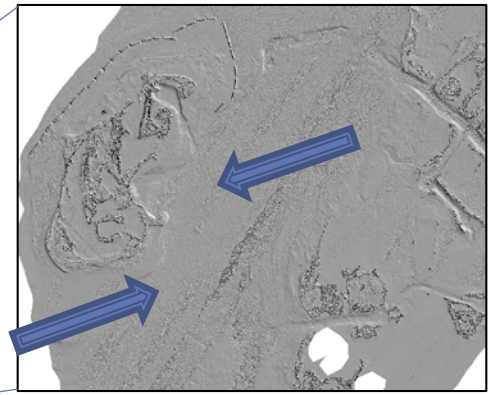


GLO ground truth layer

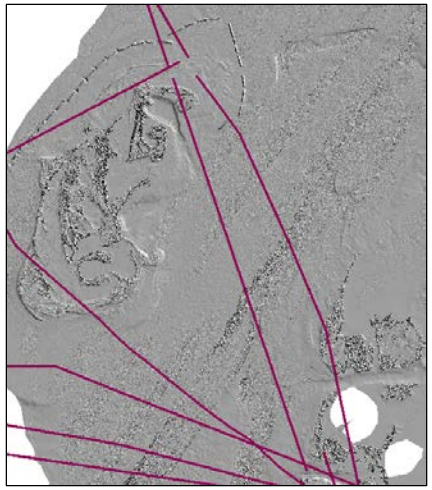
Pipeline Detection

- TIN (2 pipes, 6 and 12 in.)





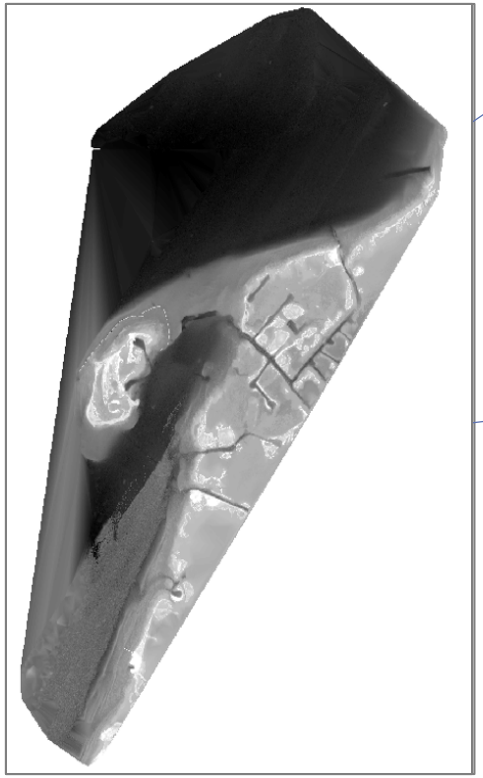
Visual Inspection

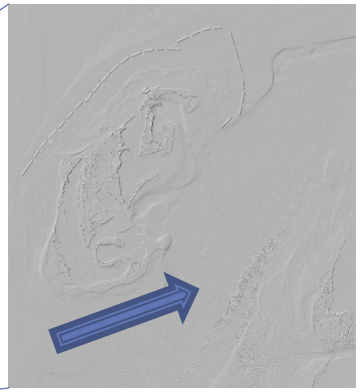


GLO ground truth layer

Pipeline Detection

- IDW (1 pipe – 12 inches)



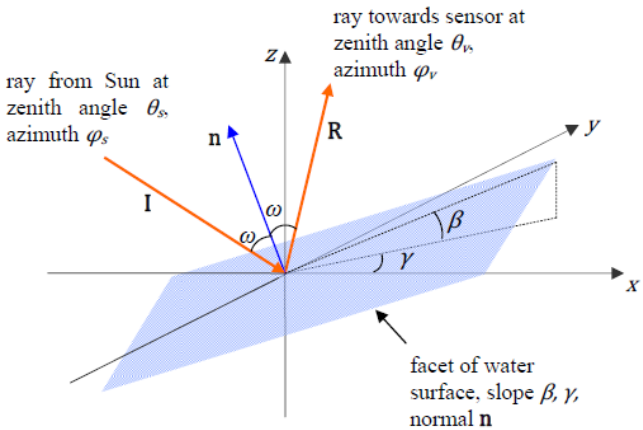


Visual Inspection

GLO ground truth layer

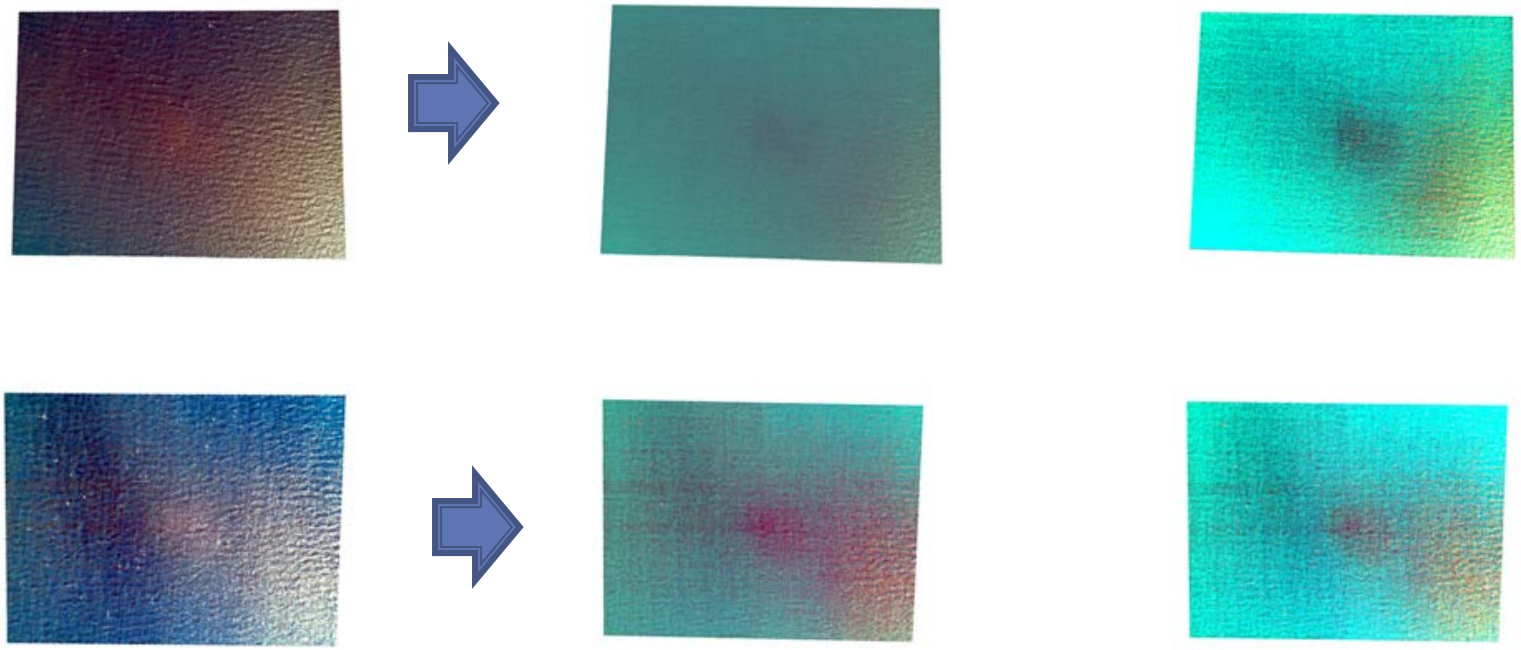
Aerial Imagery

- Sunglint
  - Sun radiation is directly reflected to the sensor over water
- Glint Correction
  - ***Hedley et al. 2005***
    - Min of NIR band in the image
    - Regression (NIR and Visible bands)
  - ***Lyzenga et al. 2006***
    - Mean of NIR band in the image
    - Covariance/Variance (NIR and Visible bands)



From (Kay et al 2009)

Glint Removal



a. Original Image b. Hedley Algorithm c. Lyzenga Algorithm

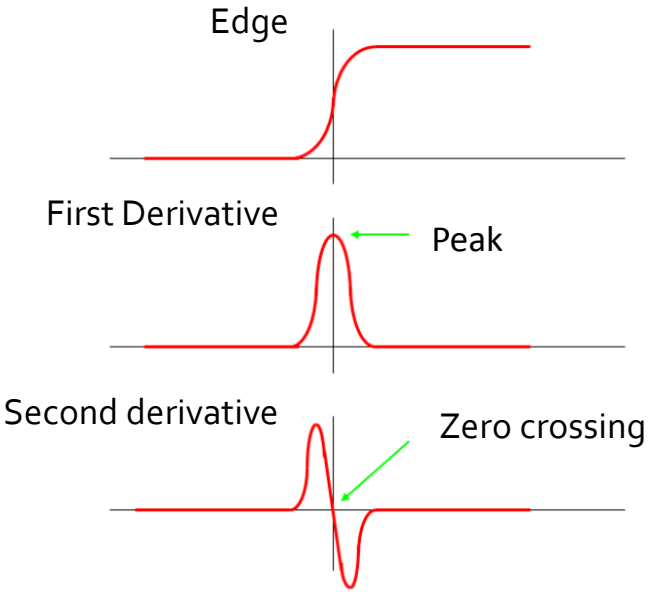
glint removal did not significantly improve manual delineation

Image size 355 x 267 meters

Edge Detection

- Most basic feature of the image
  - texture edges : boundaries of texture regions
  - Intensity edges : sharp change in intensity

- Main types of operators
  - Gradient: seek max and min 1st derivative
    - ***Sobel***
    - ***Prewitt***
  - Laplacian: zero crossings of 2nd derivative
    - Can be noisy
  - Gaussian:
    - ***Canny Edge Detector*** (gradient based)

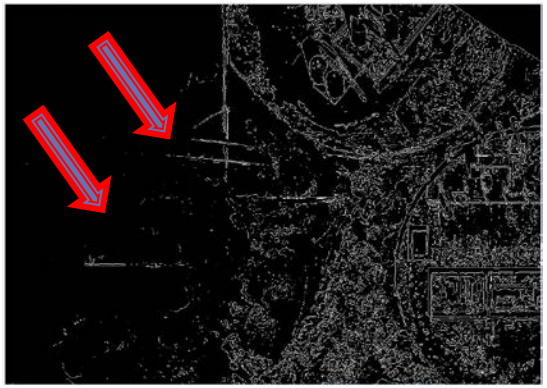


Edge Detection-cont'd

- **Sobel**
  - A pair of 3 x 3 convolution masks

Kernel1= Gx			Kernel 2 = Gy		
-1	0	1	-1	-2	-1
-2	0	2	0	0	0
-1	0	1	1	2	1

Figure 19. Sobel convolution



Sobel edge detection method

Edge Detection-cont'd

- **Prewitt**
  - A pair of 3 x 3 convolution masks

$S_x =$

-1	0	1
-1	0	1
-1	0	1

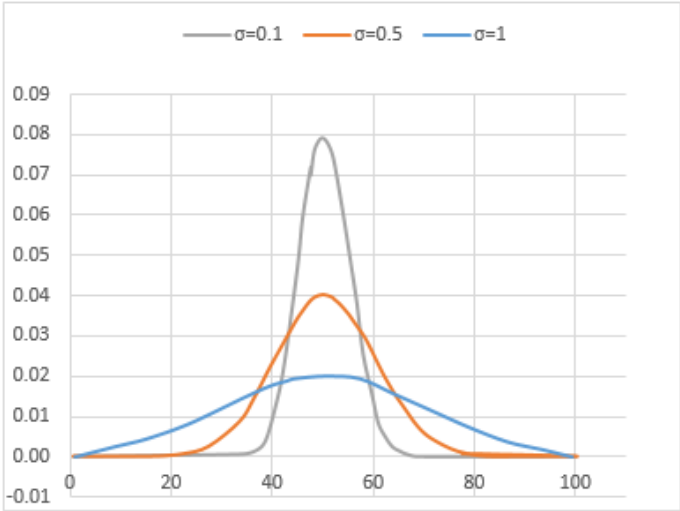
$S_y =$

1	1	1
0	0	0
-1	-1	-1

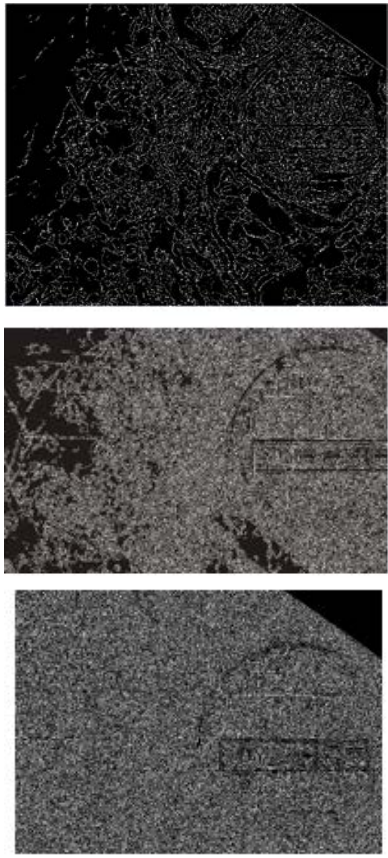
Figure 21. Prewitt convolution

Edge Detection-cont'd

- **Canny**
  - Gaussian kernel
  - Parameters
    - *Sigma*: smoothing
    - *Gradient Threshold*
      - Low = not edge
      - High = edge



$$G_\sigma(x,y) = \frac{1}{2\pi\sigma} e^{-(x^2+y^2)/(2\sigma^2)}$$



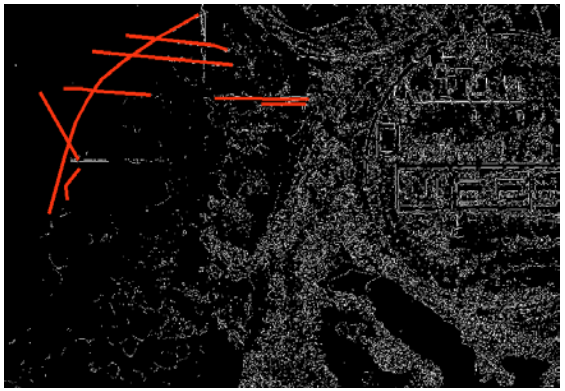
Increasing σ

No	Operator	Sigma	Low Threshold	High Threshold
1	Canny	1	.5	1
2	**Canny**	**1**	**5**	**15**
3	Canny	1	1	3
4	Canny	0.1	1	3
5	Canny	0.5	1	3
6	Canny	2	1	3

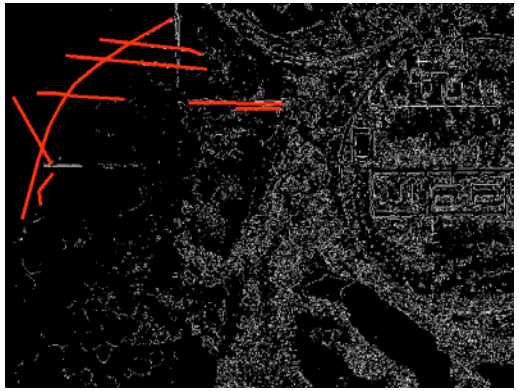
parameter tuning

Results Evaluation

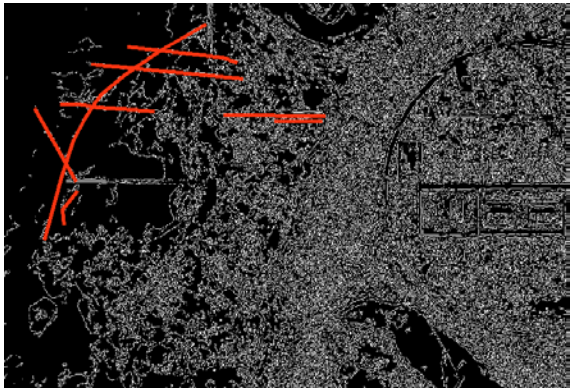
- Ground truth
  - Manually delineation and GLO data base
- Detected edges
  - Noise
  - Displacement from center (localization)
  - Edge continuity



Sobel



Prewitt



Canny (1,1,3)

Edge Detection Results

Evaluation of three methods

No	Approach	Edge Detection	Noise	Displacement	Edge Continuity
1	**Canny(1,[1,3])**	**74 out of 125**	Moderate	0.20 m	High
2	Sobel	50 out of 125	Low	0.35 m	Low
3	Prewitt	50 out of 125	Low	0.35 m	Low

Glint vs. No Glint

No	Approach	Detected edges (Hedley 2005)	Detected edges (Lyzenga 2006)
1	**Canny(1,[1,3])**	**85 out of 125**	**85 out of 125**
2	Sobel	51 out of 125	50 out of 125
3	Prewitt	50 out of 125	50 out of 125

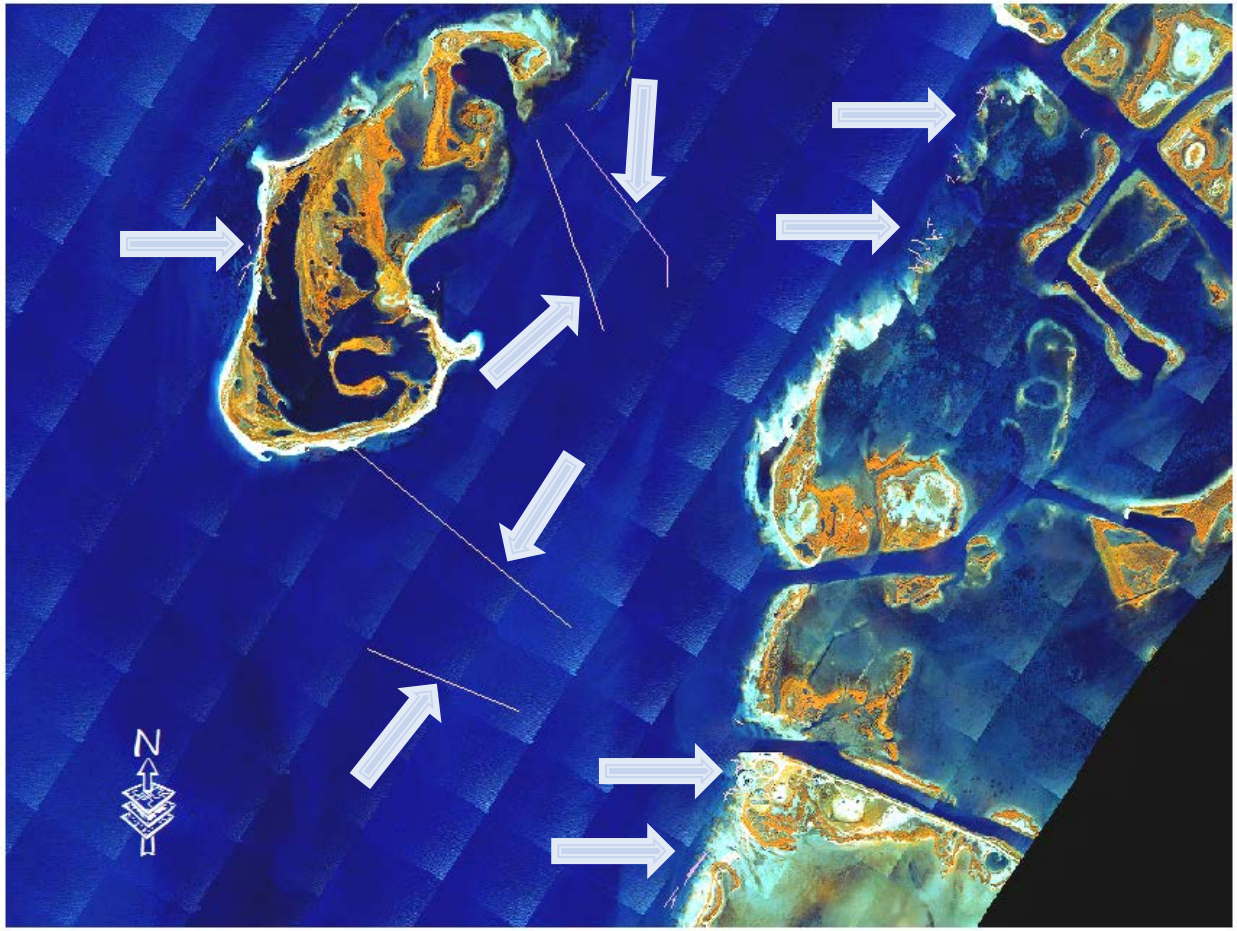
Conclusions: Lidar vs Imagery

- Bathymetric Lidar
  - Enabled deeper water (larger) pipe detection
  - multilevel B-spline worked best on this data
  - Unable to resolve pipes in shallow water
    - Need higher pt density (> 10 pts/m^2), shorter pulse width
- Aerial Imagery
  - Limited pipeline detection in deeper water (> 1 m)
  - Enabled shallow water pipe detection (<= 1 m)
  - Canny edge detection performed best
    - Glint correction helps, need noise filter to automate

Best solution → Fusion of Lidar + Imagery

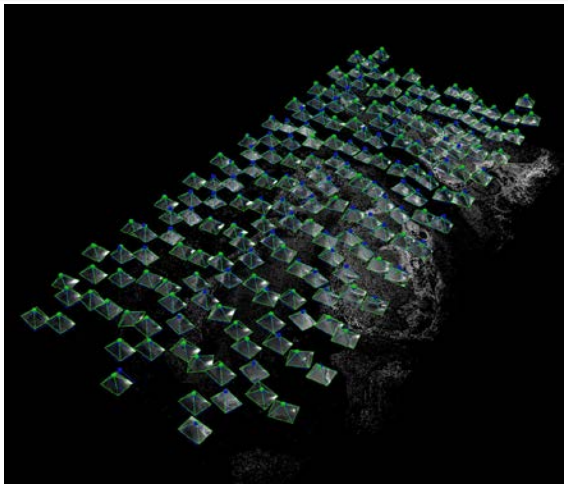
Map Product

Submerged Pipelines Shamrock Cove
Corpus Christi, TX 2016



UAS-SfM for Bathymetry

- Structure from Motion (SfM)
  - Simultaneous camera pose & scene geometry
  - Match features in multiple overlapping images



Feature detection "SIFT"

Feature correspondence

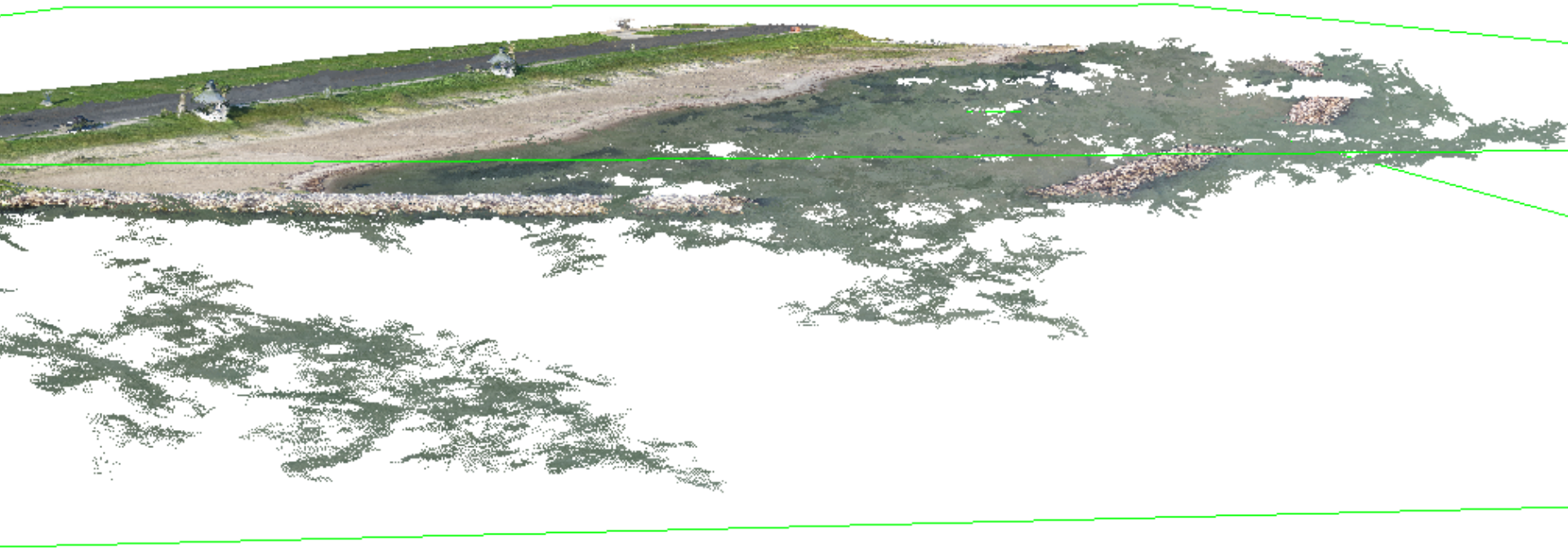
Pose Reconstruction

Sparse 3D Reconstruction

Dense 3D matching

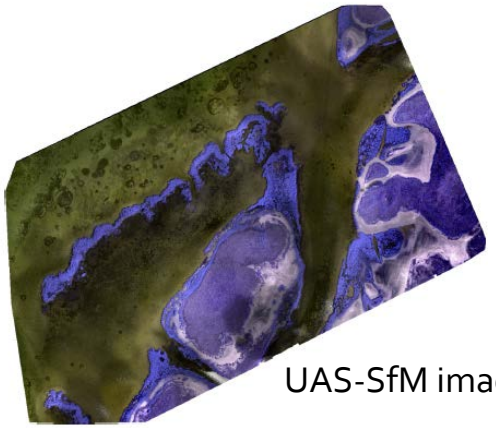
Pix4D, Agisoft,…→point cloud, DSM, ortho.

Can image preconditioning improve noisy SfM bathy point clouds?



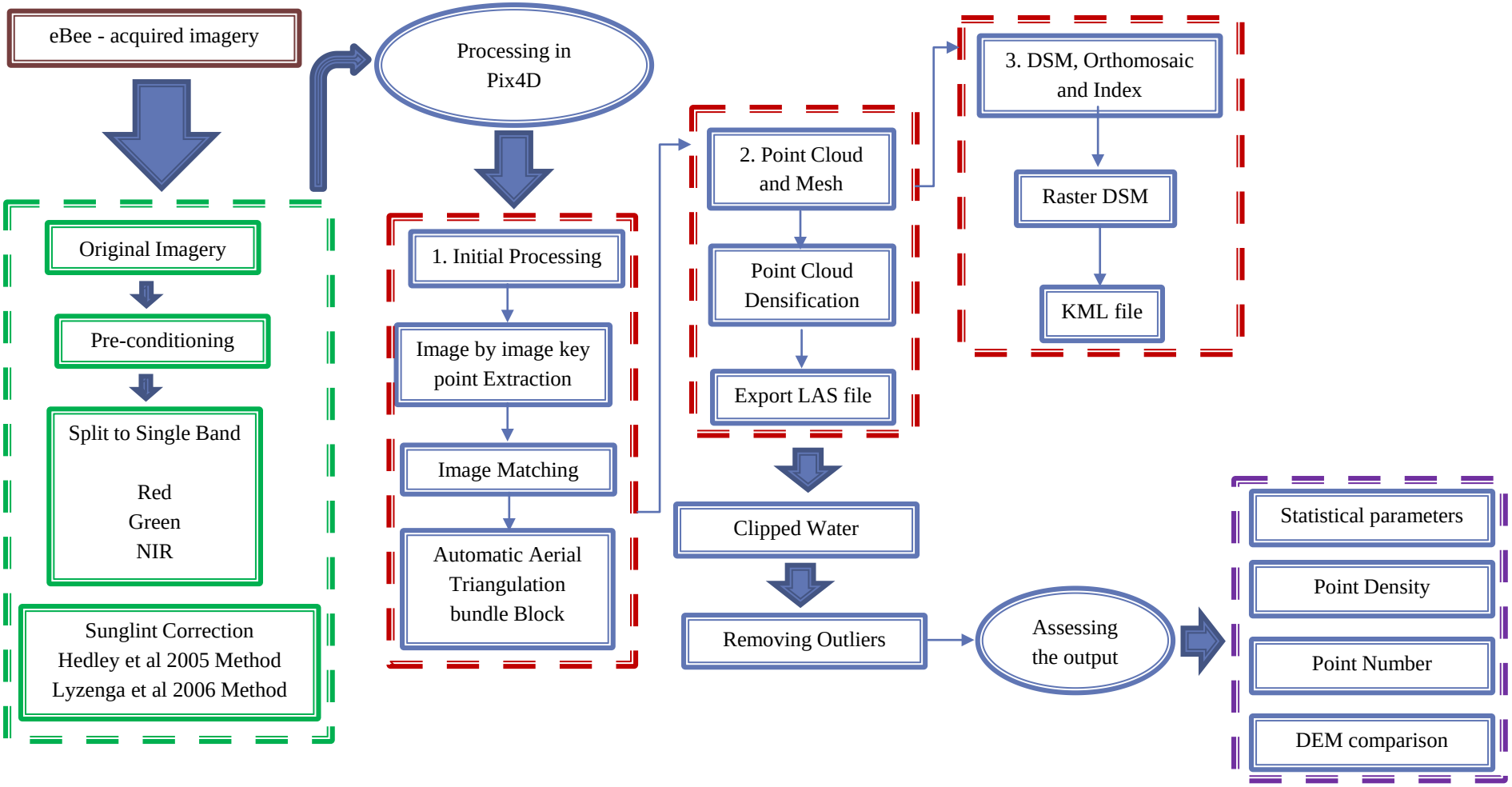
UAS- Survey

- **Platform**: eBee
- **Camera**: Canon S110
  - 3-bands: NIR-R-G
  - 12 megapixels
- **Flight planning**
  - Overlap and side lap 80%, ~50 acres
  - Altitude 310 ft, (~3cm GSD)
  - WGS 84 (ellipsoid heights)



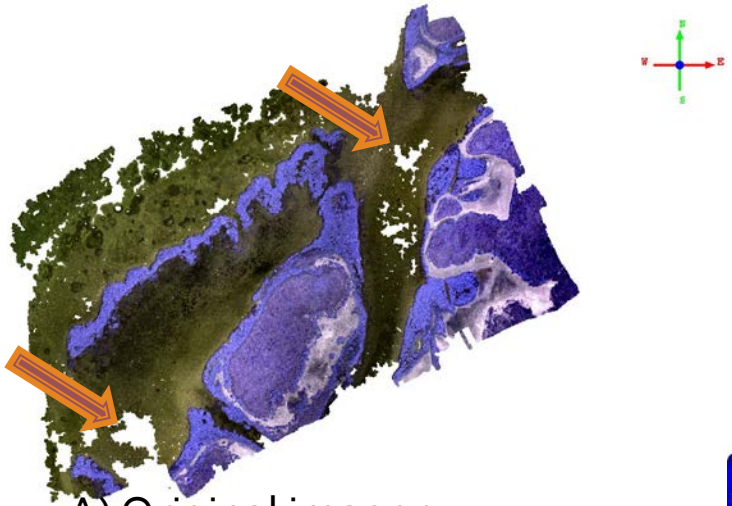
UAS-SfM imagery

SfM Processing Workflow

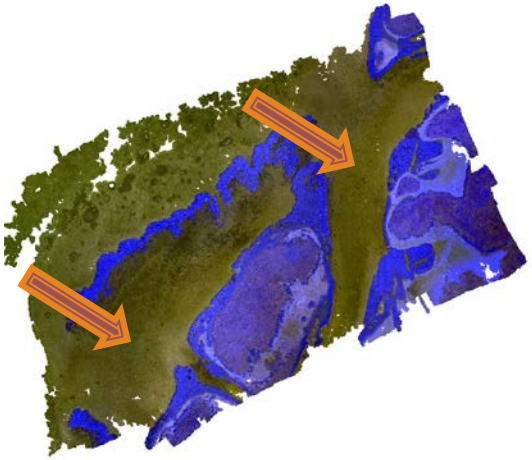


Methodology → Result

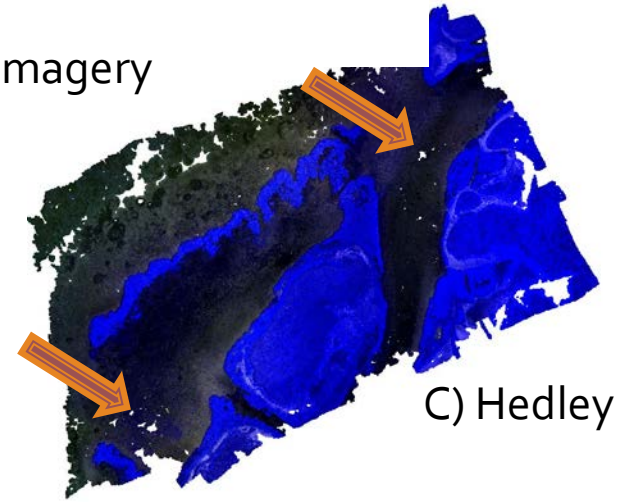
UAS-SfM: Glint vs Non-Glint



A) Original imagery



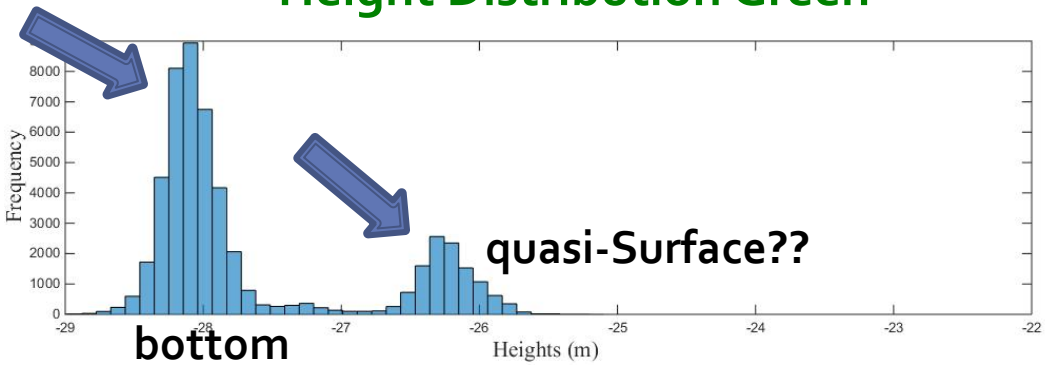
B) Lyzenga et al. 2006



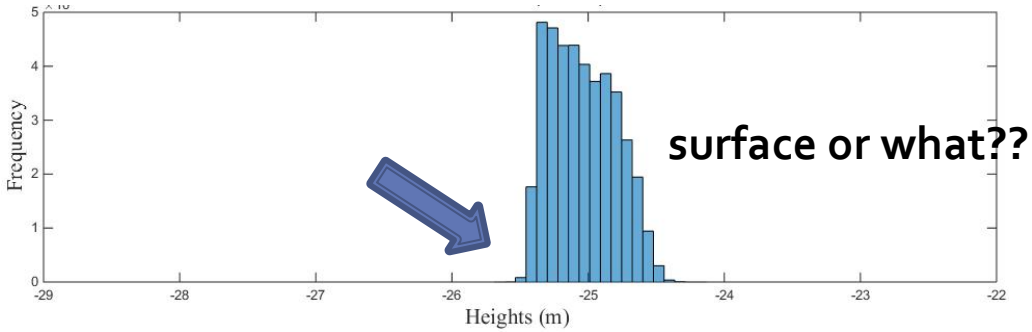
C) Hedley et al. 2005

UAS-SfM: Single Band

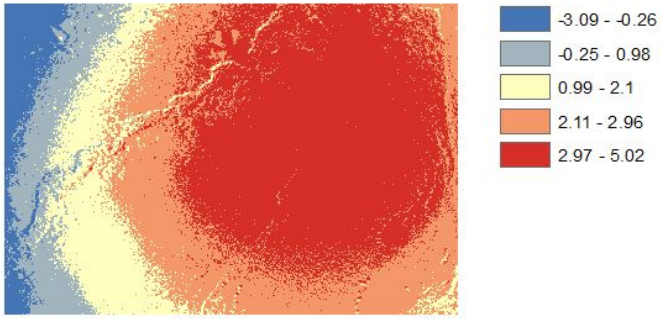
Height Distribution Green



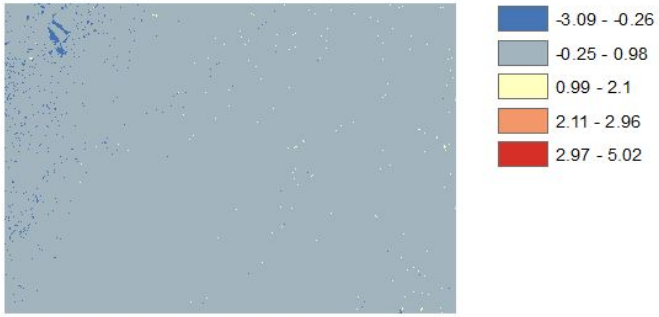
Height Distribution NIR (water)



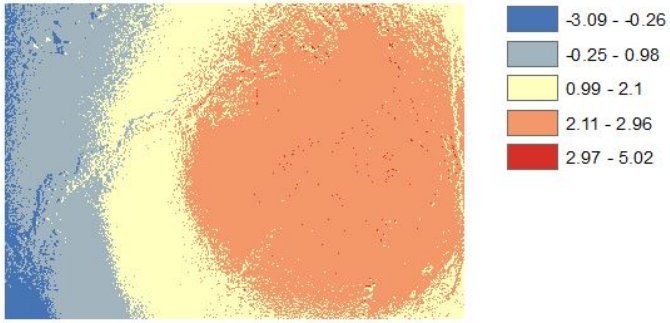
DEM Comparisons



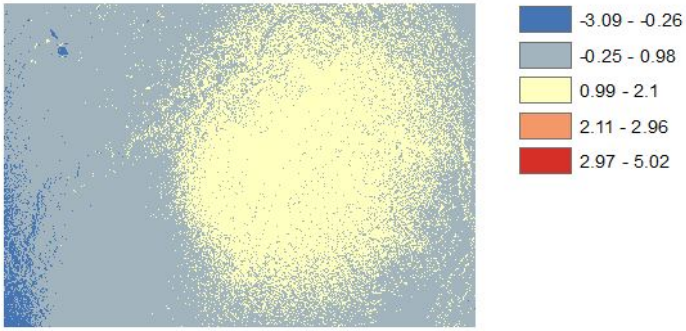
[NIR – Green] +Δz



[Hedley – Multiband] Δz~=0



[Red – Multiband] +Δz



[Lyzenga – Multiband] –Δz

380m x 260m area – units: meter

Point Cloud Statistics

Point Density

	Approach	Number of Points	Point density	Percentage
1	Original multiband	16,180,268	52.360 ppm²	0
2	Hedley et al. (2005)	16,256,463	52.438 ppm²	0.50 %
3	Lyzegna et al. 2006)	16,562,361	53.257 ppm²	2.36 %
4	Single band-NIR	12,892,046	44.443 ppm²	-20.32 %
5	Single band-red	18,647,020	57.129 ppm²	15.22 %
6	Single band-green	18,692,357	57.485 ppm²	15.52 %

Height Statistics

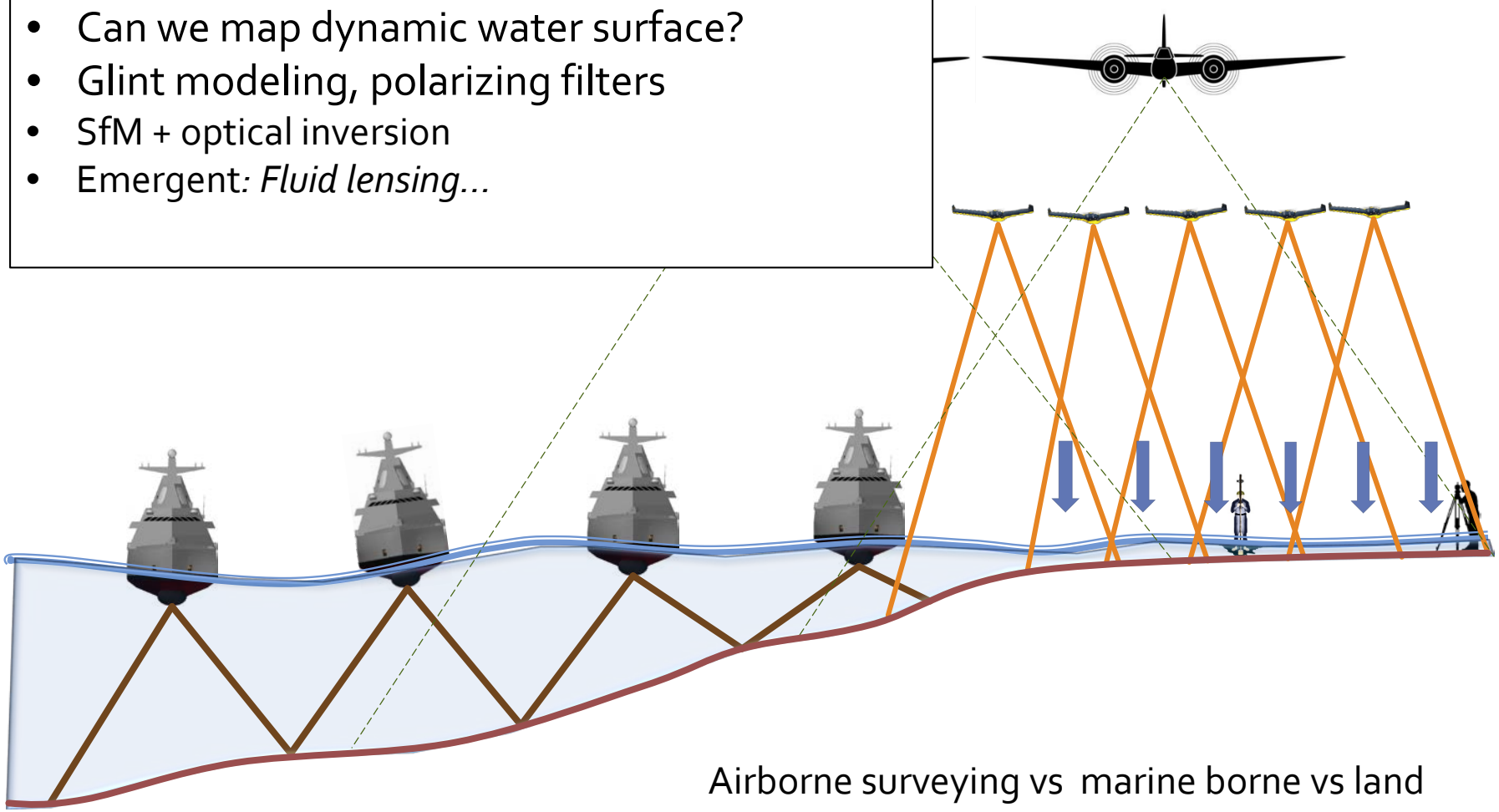
	Water						
		Multiband (Original)	Lyzenga 2006	Hedley 2005	Red	NIR	Green
1	**'Min Z'**	-28.489	-28.005	-28.024	-26.036	**-25.679**	-29.208
2	'Max Z'	-24.654	-24.399	-24.299	-24.285	-24.150	-25.123
3	**'Mean Z'**	-26.875	-26.175	-26.375	-25.110	**-25.038**	-27.655
6	'Std Z'	0.585	0.453	0.502	0.235	**0.236**	0.802

Pre-conditioning improves SfM bathy results!

Conclusions

UAS-SfM Challenges and Future Work

- Can we map dynamic water surface?
- Glint modeling, polarizing filters
- SfM + optical inversion
- Emergent*: Fluid lensing…*



Airborne surveying vs marine borne vs land surveying in shallow water (source: NTS)

Acknowledgement

National Oceanic and Atmospheric Administration (NOAA)
Texas General Land Office (TGLO) and Coastal Management Program (CMP);
TGLO Contract No. 15-050-000-8395.

Views expressed here are the authors' and do not necessarily reflect those of NOAA or TGLO.

Michael J. Starek
Michael.starek@tamucc.edu

Thank You JALBTCX!
Questions?

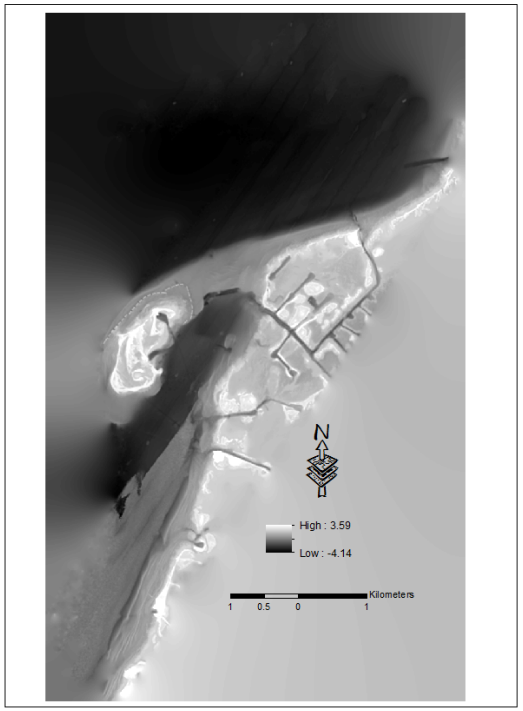
"Retired" Lights & Mirrors Award Champion Since 2010

Michael J. Starek
Michael.starek@tamucc.edu

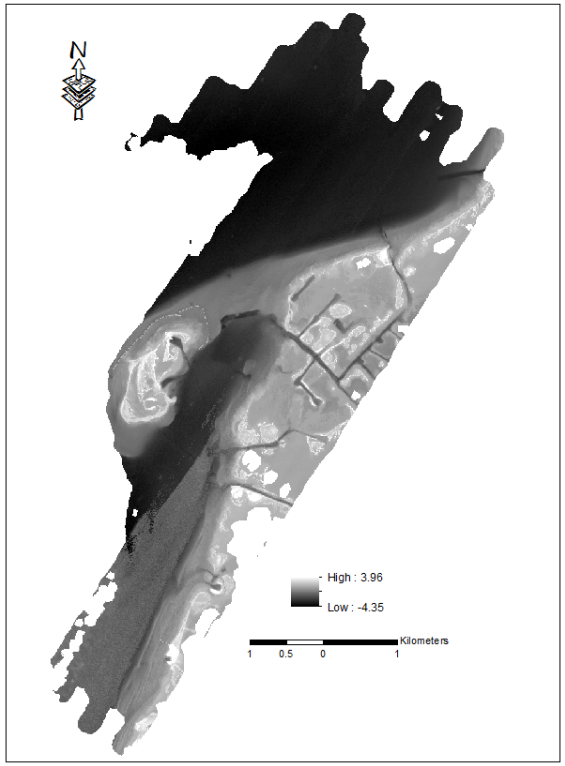
TEXAS A&M UNIVERSITY CORPUS CHRISTI

SfM 3D Fly Through North Padre Island, TX

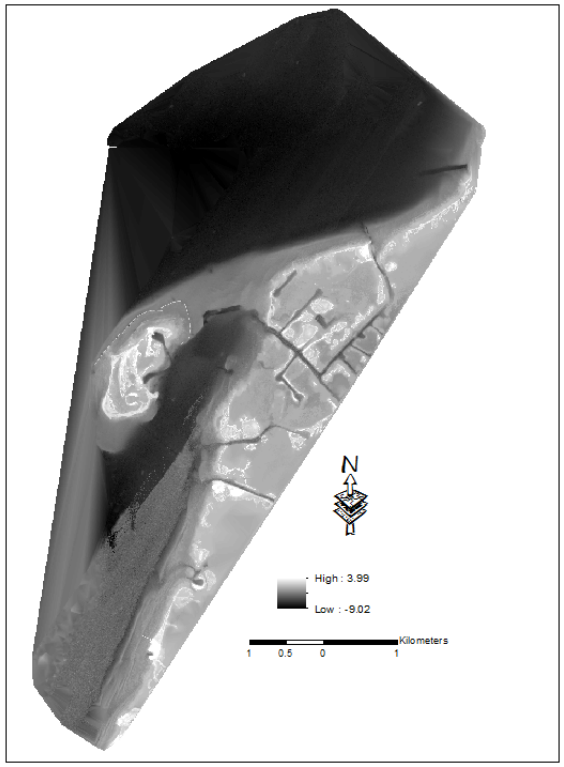
Topo-Bathymetric DEMs



Multilevel B-spline



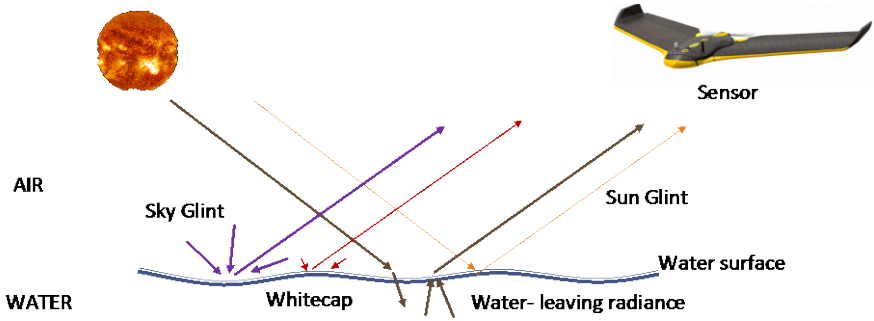
2D TIN

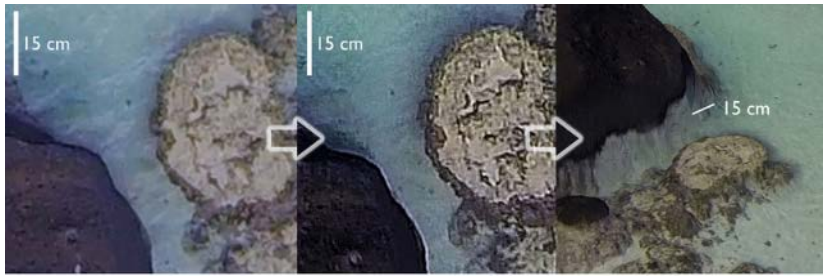


IDW

Challenges and Future Work

- Lidar
  - Need higher pt. density and shorter pulse width
  - Cloud segmentation, DEM edge detection
- Edge Detection
  - Noise reduction algorithms
- UAS-SfM
  - Can we detect water surface?
  - Glint modeling, polarizing filters
  - Emergent methods
    - SfM + optical inversion
    - Fluid lensing

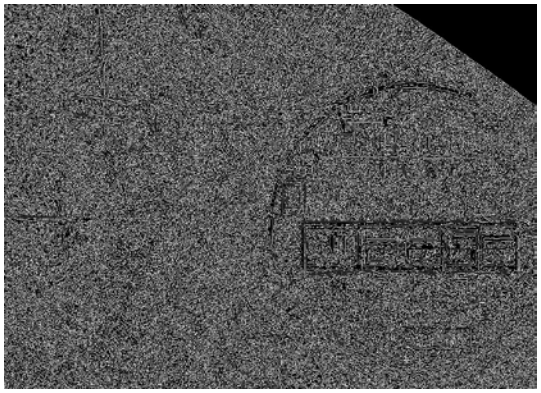




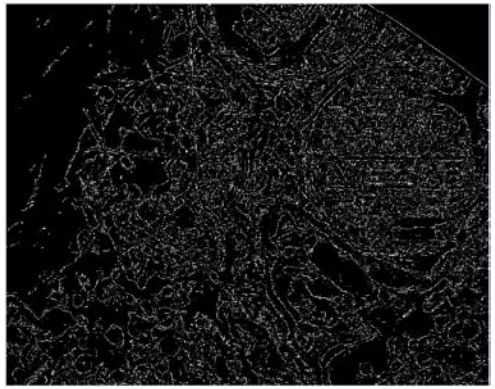
Fluid Lensing example from NASA

Canny Example

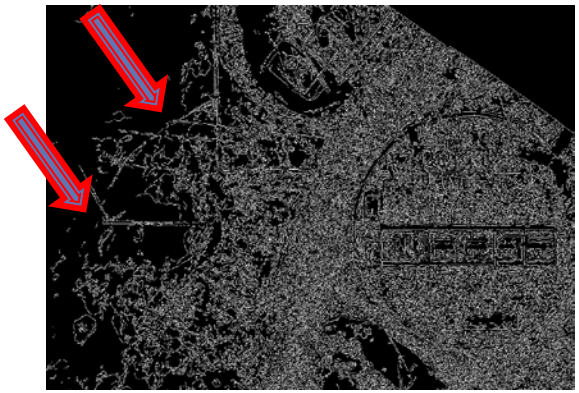
a) Original Image



b) Sigma = 0.1 , LT= 1 , HT= 3

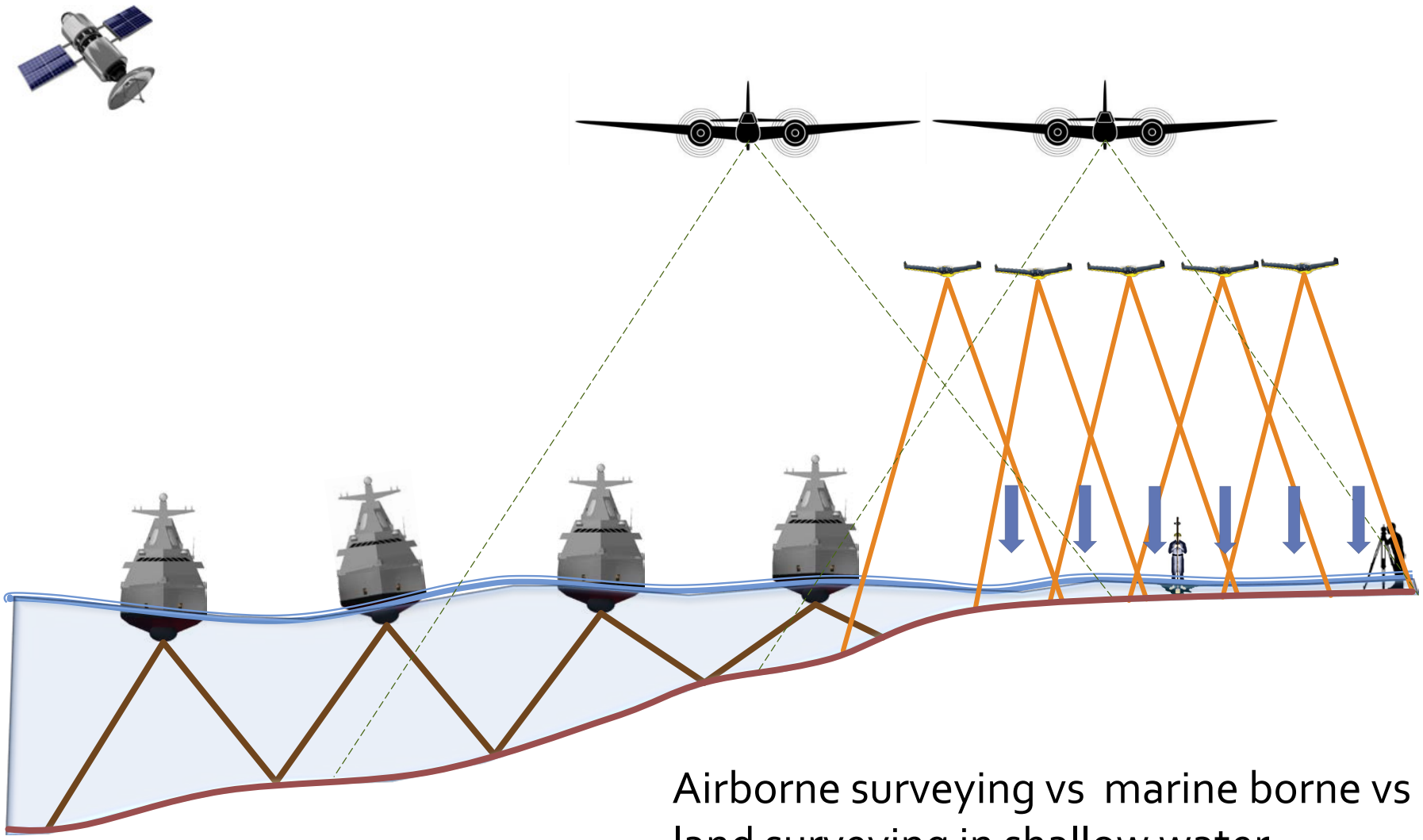


c) Sigma = 10 , LT= 1 , HT= 3



d) Sigma = 1 , LT= 1 , HT= 3

Conclusions



Airborne surveying vs marine borne vs land surveying in shallow water (source: NTS)