FIG WORKING WEEK 2019
22–26 April, Hanoi, Vietnam
"Geospatial Information for a Smarter Life and Environmental Resilience"

Multi-Layer Optimisation Technique (M-LOT) for Shallow Water Hydrographic Survey Mapping Using Satellite-derived Bathymetry Application

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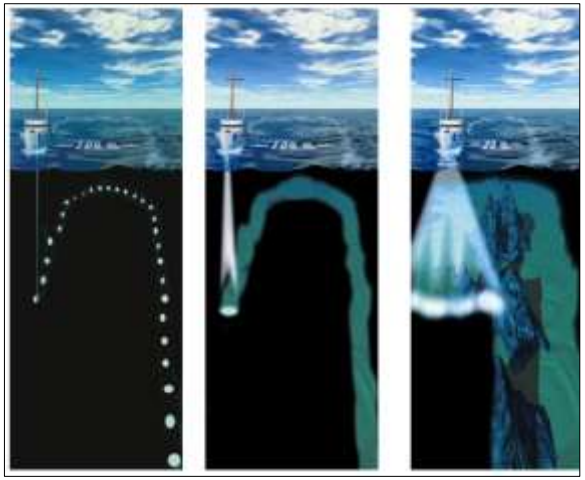
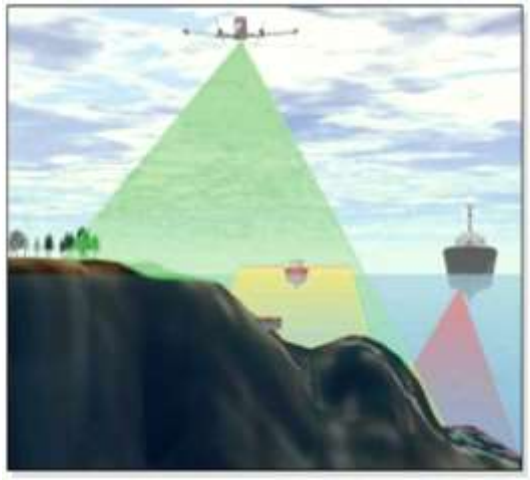
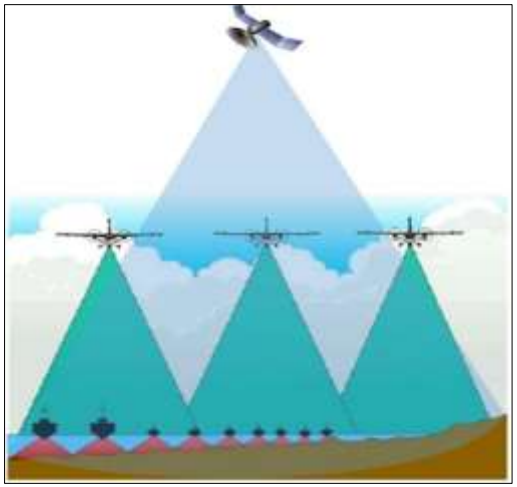
Kuala Lumpur, Malaysia

Background

- Acquisition technique of bathymetric data has evolve from shipborne platform to airborne and even by means of space-borne acquisition







shipborne → airborne → space-borne

Images retrieved from the NOAA Office of Coast Survey website: https://www.nauticalcharts.noaa.gov.

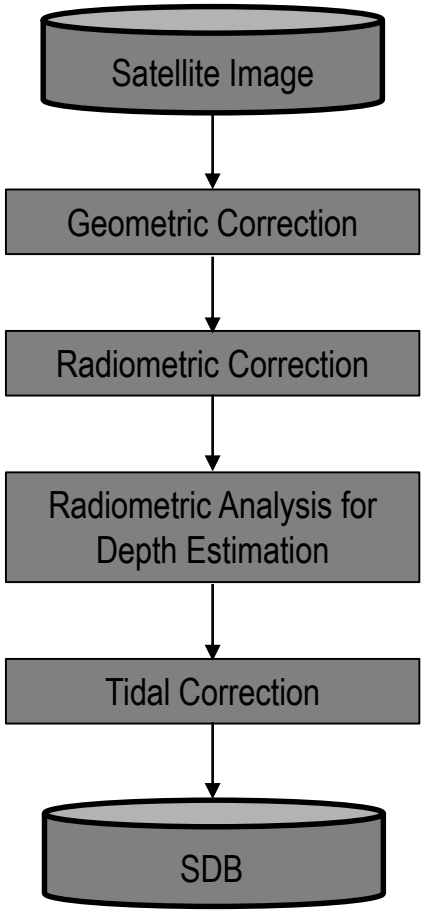
Background

- SDB is an acquisition method related to a systematic analysis modelling of the recorded light penetration intensity through the water column at different spectral bands (multi/hyperspectral)
- Various factors affected
  - height and direction of the sun
  - clouds and shadow
  - wind and sea surface condition
  - nature of seabed/sea bottom albedo
  - absorption and diffusion of light by the water column (turbidity, algae etc)
  - atmospheric condition
  - type of spectral bands

Background

Algorithms used for depth estimation/derivation from satellite images

- Banny and Dawson
  - Basic method.
  - Uses one band only.
- Lyzenga's
  - Uses multiple visible bands
  - Applicable to variable seafloor reflectivity
- Stumpf and Holderied
  - Adapting blue and green bands
- Lee's
  - Inversion method
  - Requires multiple bands (>5) and high resolution



SDB General Process Flow

- Geometric Correction
  - Correcting distortions of image
  - Improving horizontal accuracy
- Radiometric Correction
  - Calibration of recorded variance value reflected
  - Conversion to ToA radiance, *ToA reflectance*, sun-glint correction and atmospheric correction
- Radiometric Analysis for Depth Estimation
  - Ground truthing (radiative transfer model)
- Tidal Correction

Study Motivation

- Recognised as a cost and time effective solution - remote sensing environments
- Majority of the research conducted in Europe and American continents
- Few studies were carried out in Oceania and African coastal - outside of tropical climate environment
- Minimum sample of multispectral satellite images with limited study area
- Timely to have a detailed research in Malaysia - tropical environment
- No further analysis with survey standard - SP-44

The Study - Questions

How reliable this SDB technology in producing a consistent level of accuracy in the field of hydrographic surveying, especially for the shallow water area?

Which class of survey standard (IHO) that this technology capable of achieving?

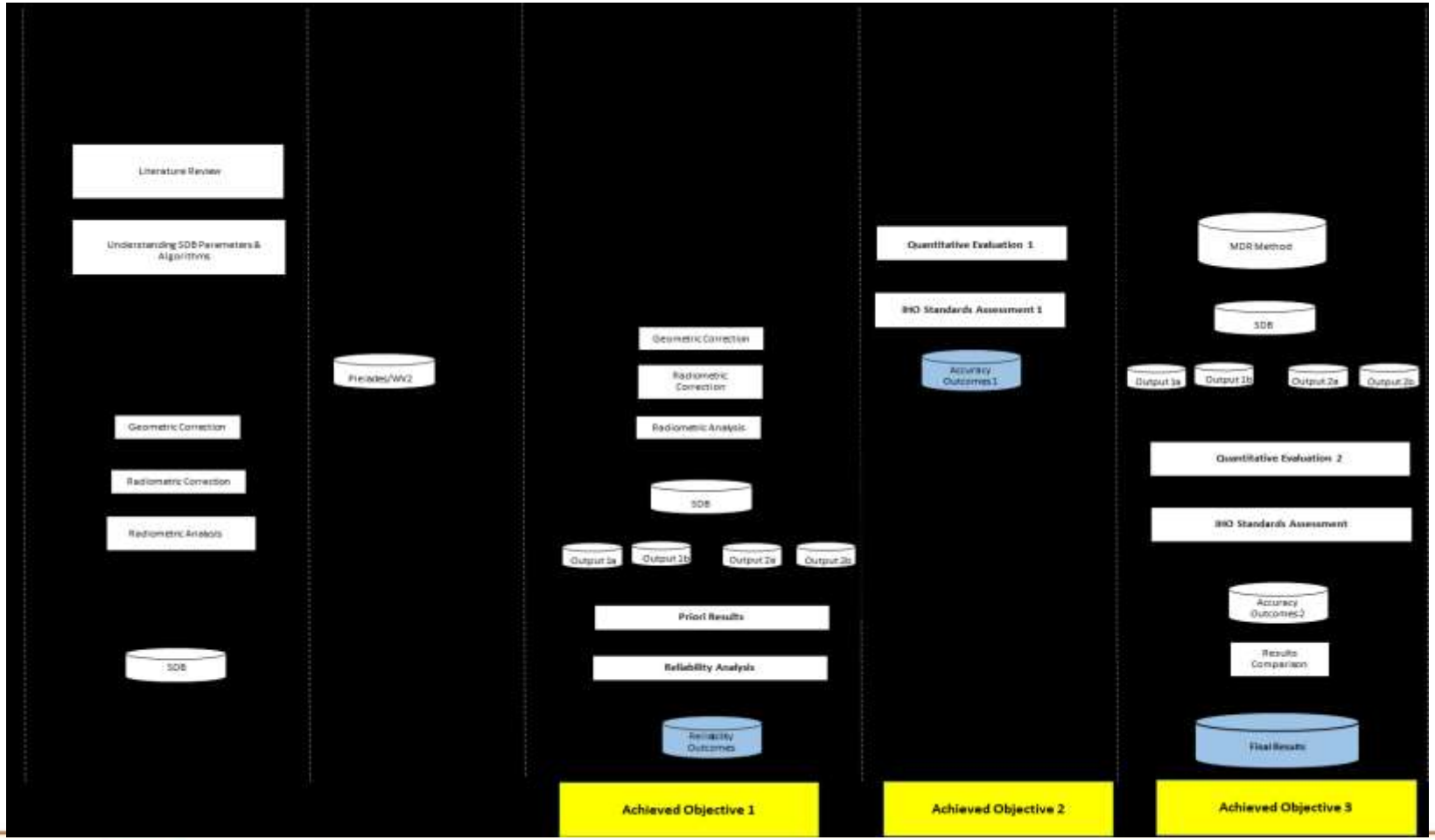
What improvement can be developed to simplify the current processing procedure which can adopt into hydrographic surveying application?

The Study - Objectives

Examine & Identify the level of reliability produced from the algorithms focusing on the shallow water area which reflects on the hydrographic mapping applications

Analyse the degree of accuracy and standards of bathymetric data derived from SDB technology in meeting the standard and specifications laid by IHO

Improve the SDB empirical method results with optimisation technique focusing on the tropical environmental parameter


Literature Review
Understanding SDB Parameters & Algorithms
Geometric Correction
Radiometric Correction
Radiometric Analysis
SDB
Pleiades/WV2
Geometric Correction
Radiometric Correction
Radiometric Analysis
SDB
Output 1a
Output 1b
Output 2a
Output 2b
Prior Results
Reliability Analysis
Reliability Outcomes
Achieved Objective 1
Quantitative Evaluation 1
IHO Standards Assessment 1
Accuracy Outcomes 1
Achieved Objective 2
MDR Method
SDB
Output 1a
Output 1b
Output 2a
Output 2b
Quantitative Evaluation 2
IHO Standards Assessment
Accuracy Outcomes 2
Results Comparison
Final Results
Achieved Objective 3

Research Area

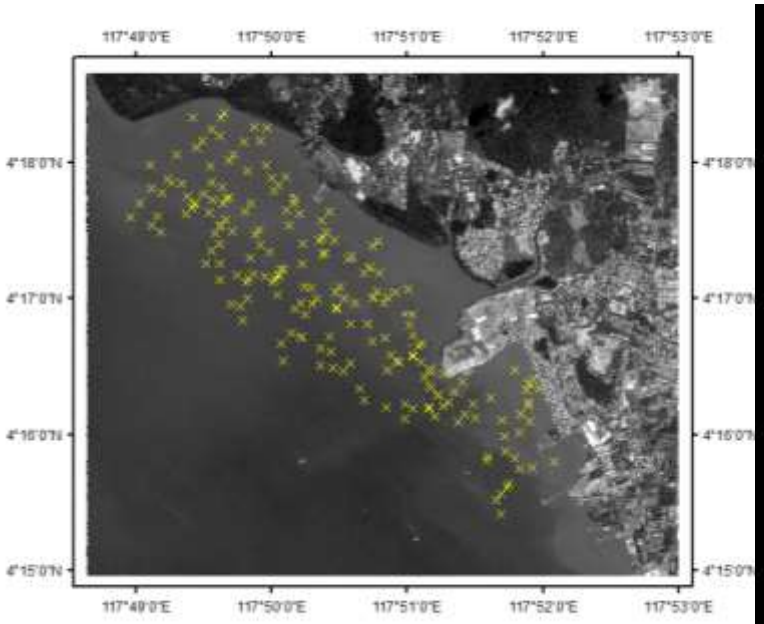
Data

Satellite Data/ Category	Spatial Resolution	Collection/ Owner	Area/Date Captured	Metadata
Sentinel-2A (High-Resolution)	10 m	Free download from ESA Website	Tawau (29 Nov 2016) Labuan (28 June 2017)	MSI_20161129T134807 MSI_20170628T094035
Pleiades (Very High-Resolution)	2 m	Supplied by Malaysian Remote Sensing Agency under cooperation with the National Hydrographic Centre	Tawau (12 July 2016)	DS_PHR1A_201607120241209
WorldView2 (Very High-Resolution)	0.5 m	Supplied by Universiti Malaysia Terengganu under joint research Marine Ecosystem Mapping for Taman Laut Labuan Project under Department of Marine Park Malaysia	Labuan (26 June 2015)	15JUN26025812-P2AS-056663834010

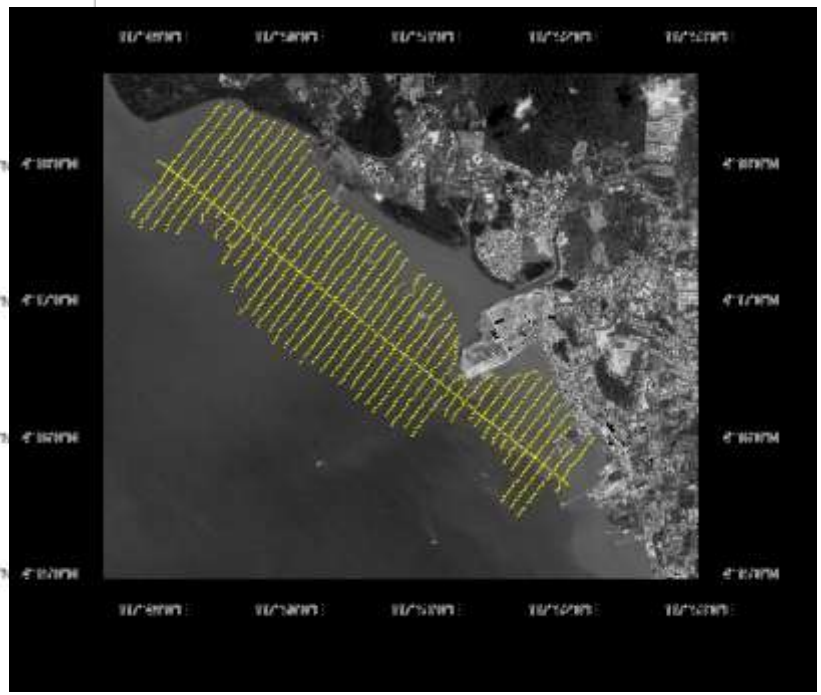
Data

Bathymetry Data	Depth Sensor	Positioning System	Spatial Resolution/Survey Order	Survey Area
SBES (30 Nov to 2 Dec 2016)	Odom Mk III	Veripos LD4	0.5 m Special Order	Tawau Port
MBES (6 to 27 April 2017)	Kongsberg EM 2040C	C-Nav 3050	0.5 m Special Order	Pulau Kuraman
SBES (6 to 27 April 2017)	Odom Mk III	C-Nav 3050	0.5 m Special Order	Pulau Kuraman

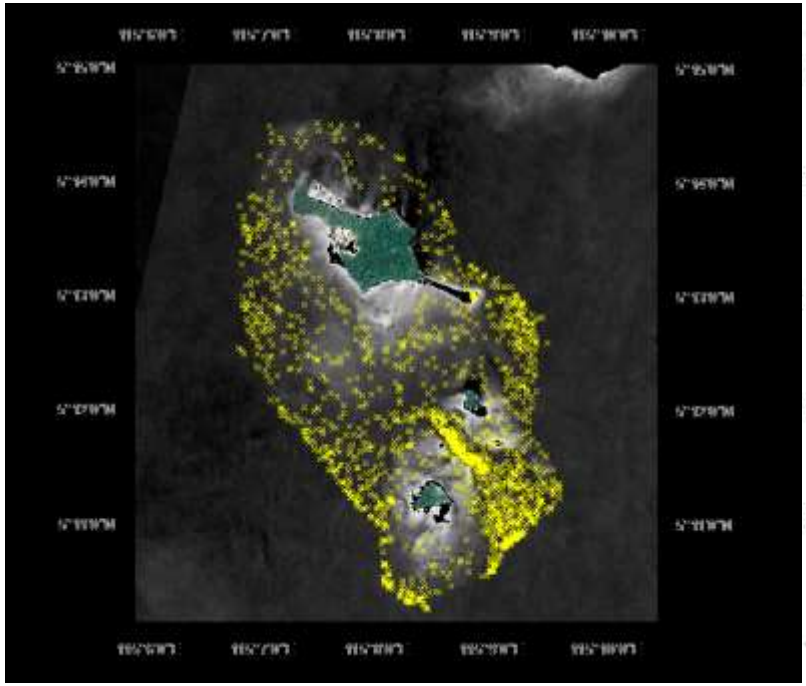
The Study- Processing (Tawau)



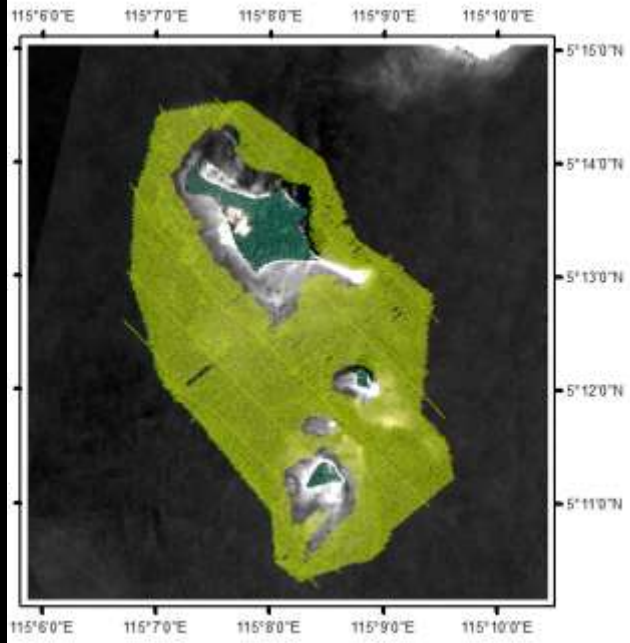
Training Dataset



Processing (Pulau Kuraman)

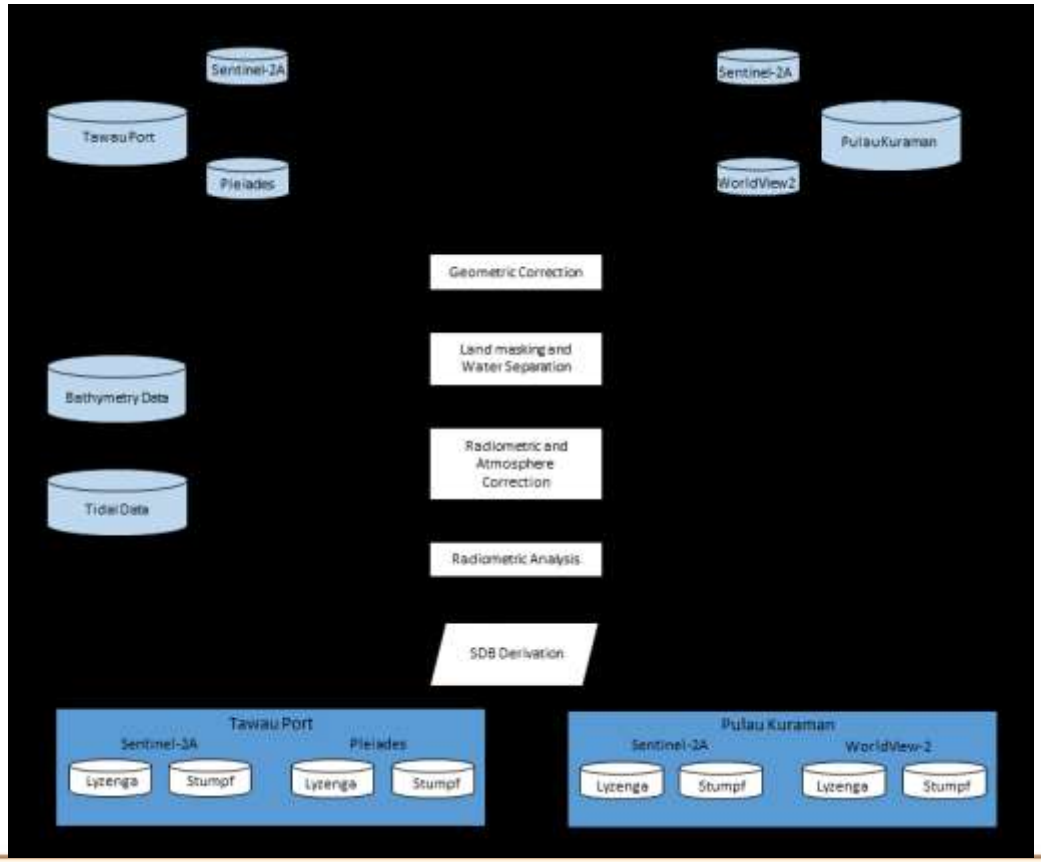


Training Dataset

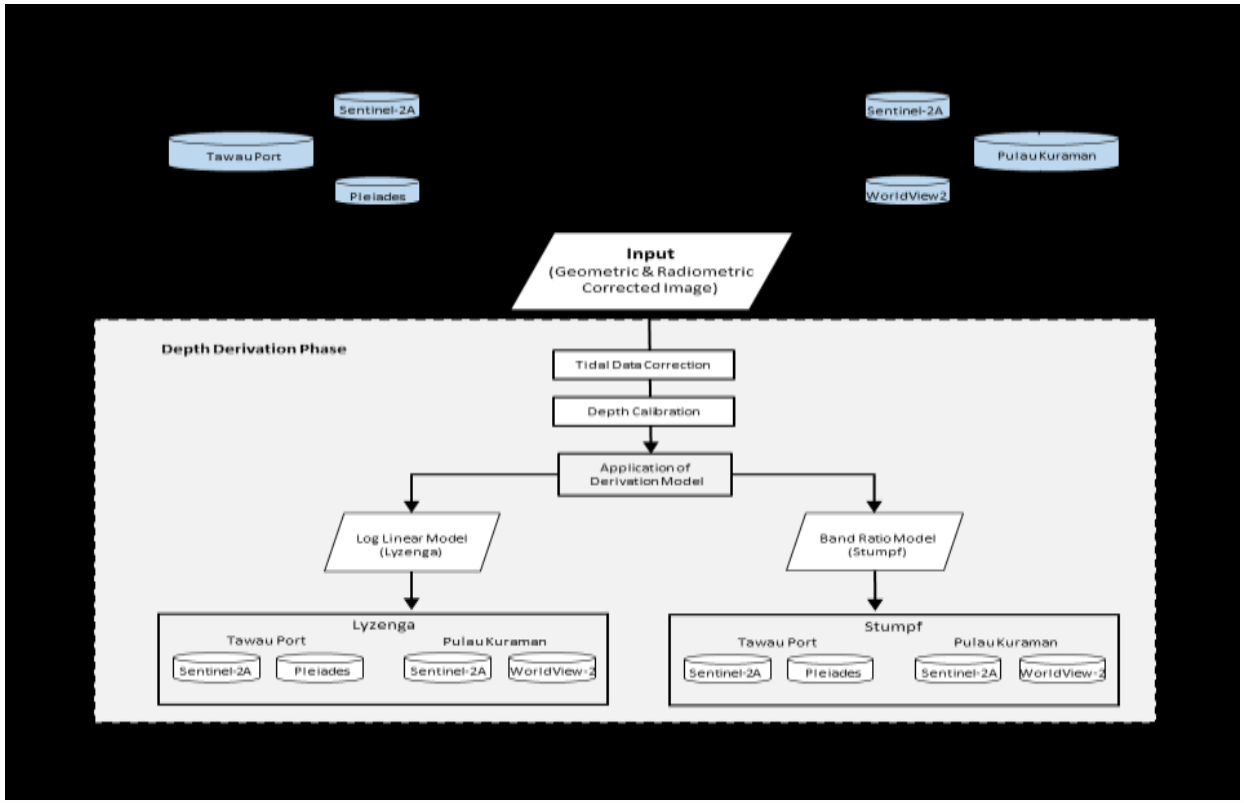


Full Dataset

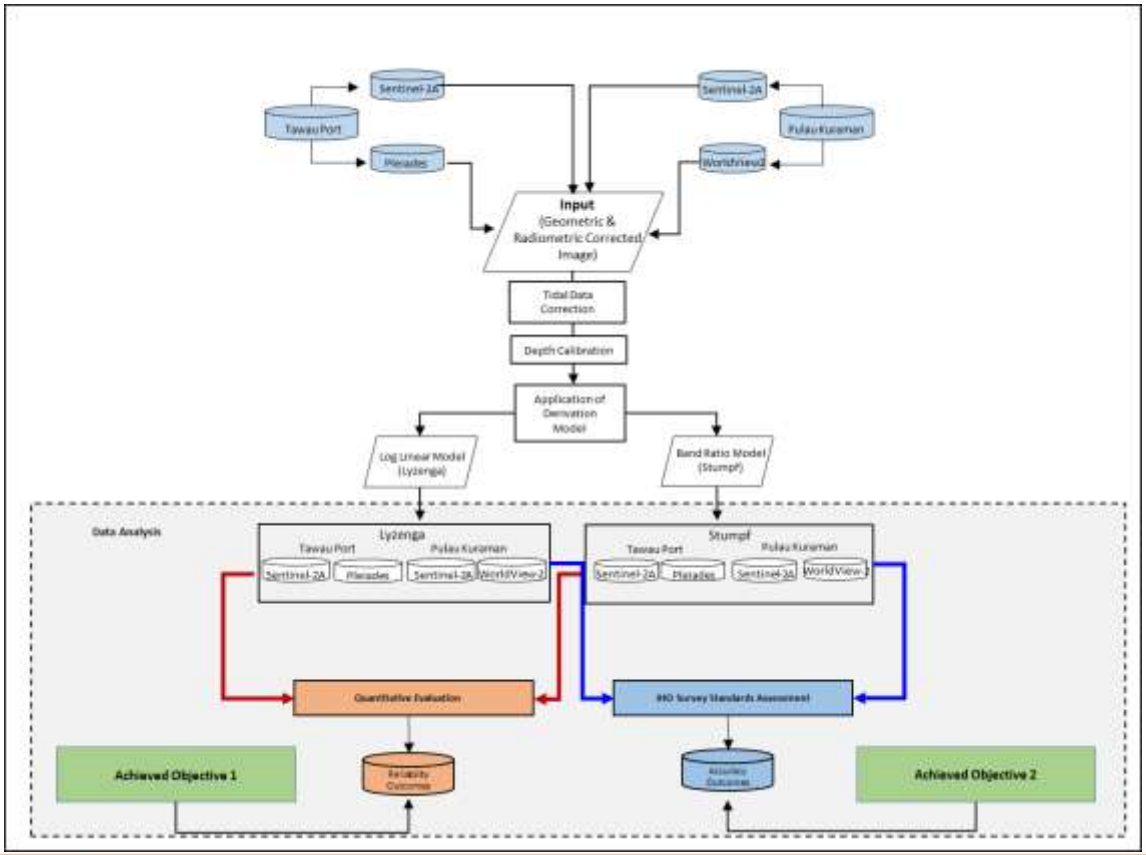
Data Processing



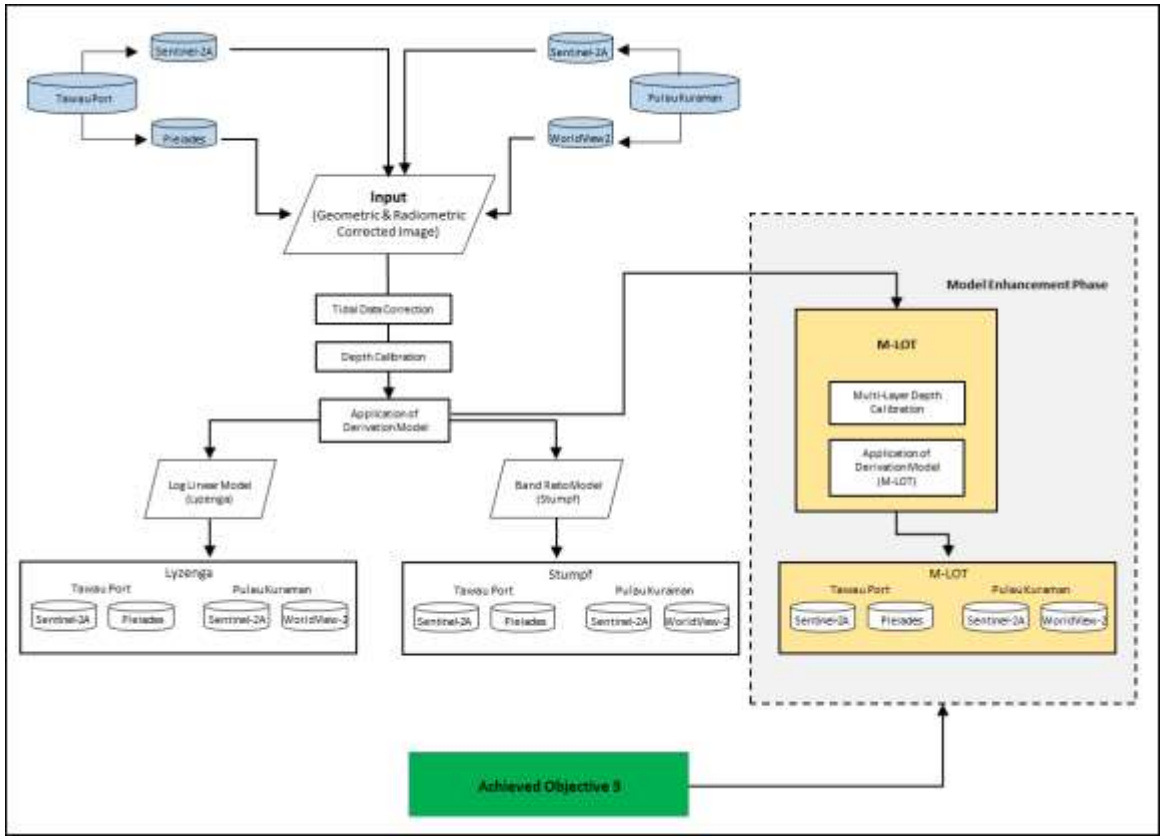
Depth Derivation



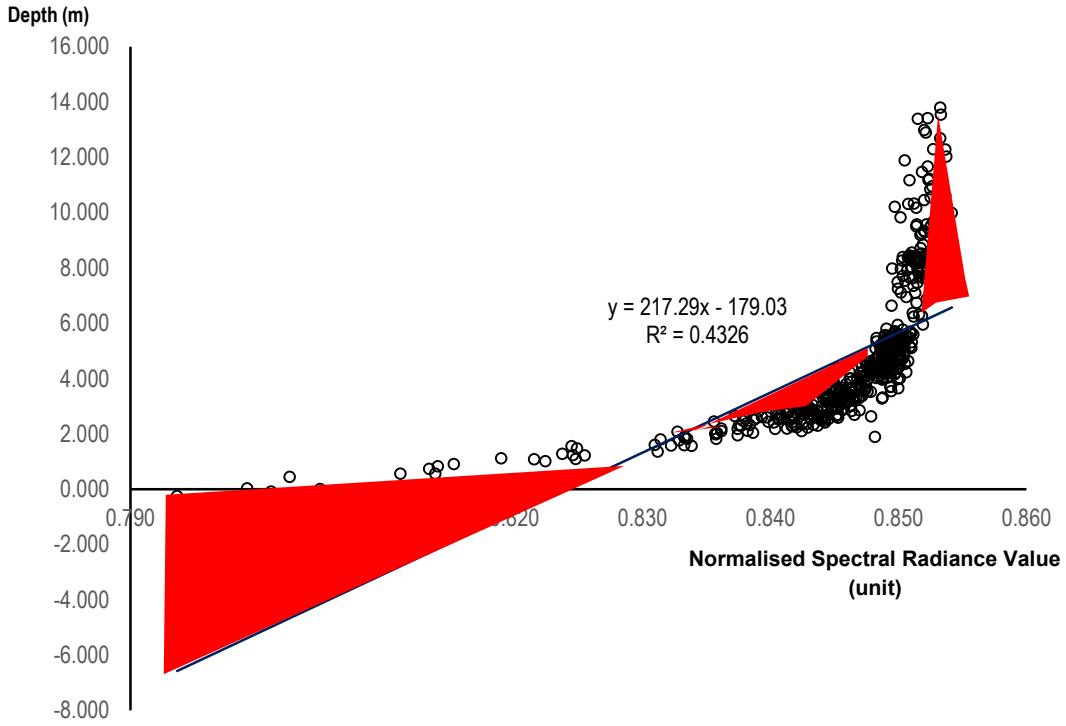
Data Analysis



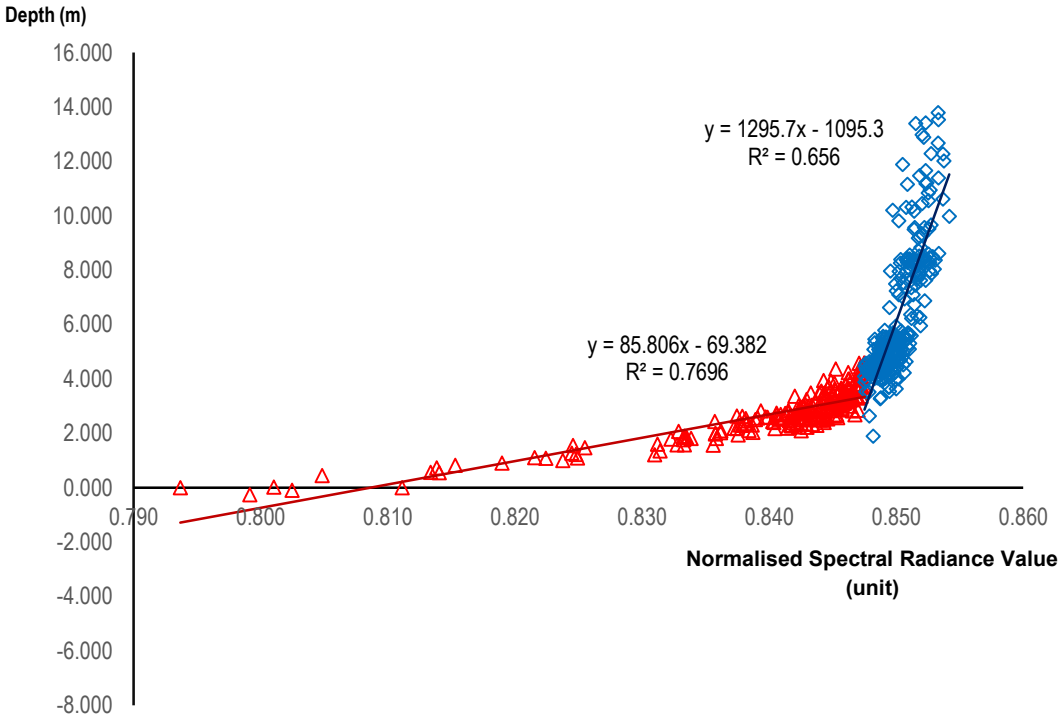
Model Enhancement



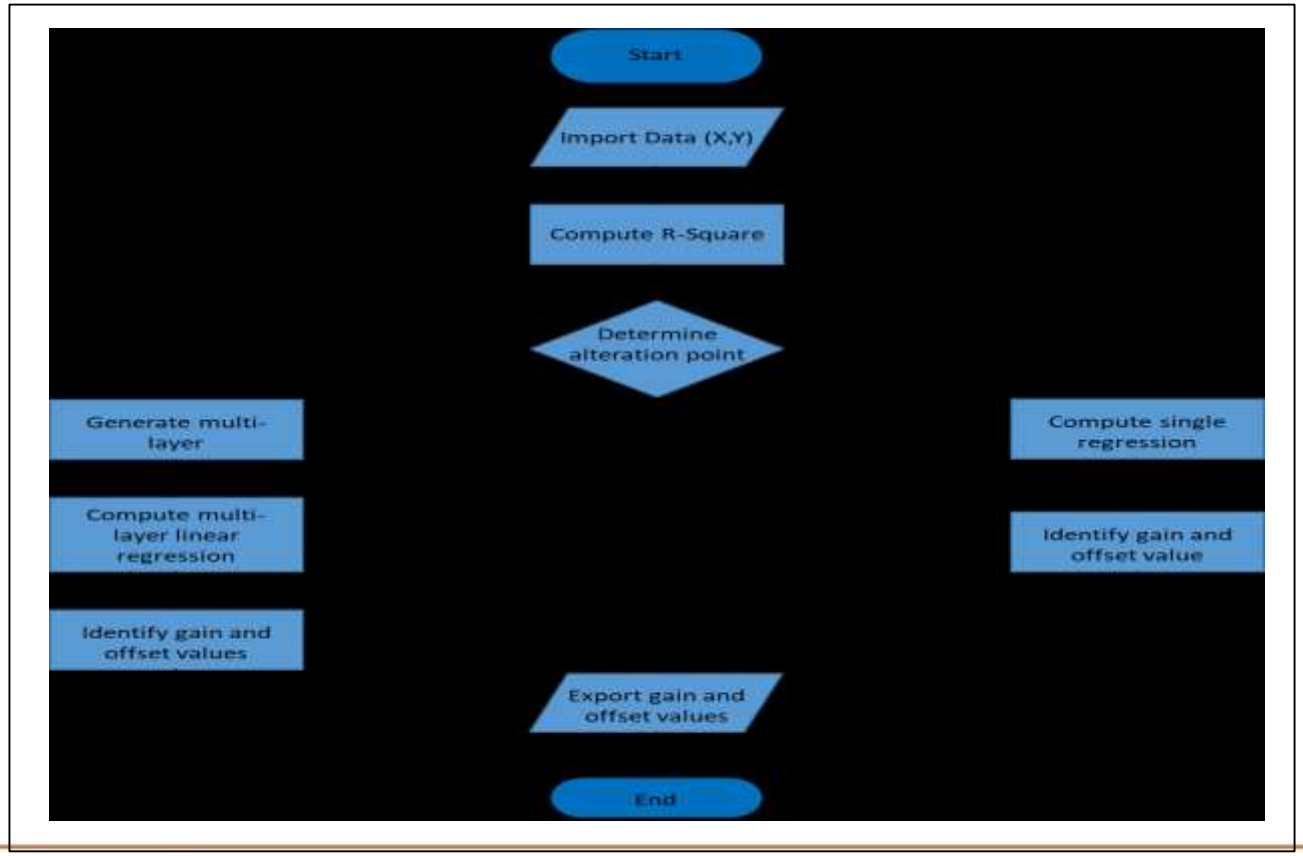
Model Enhancement



Model Enhancement



The Study- Model Enhancement



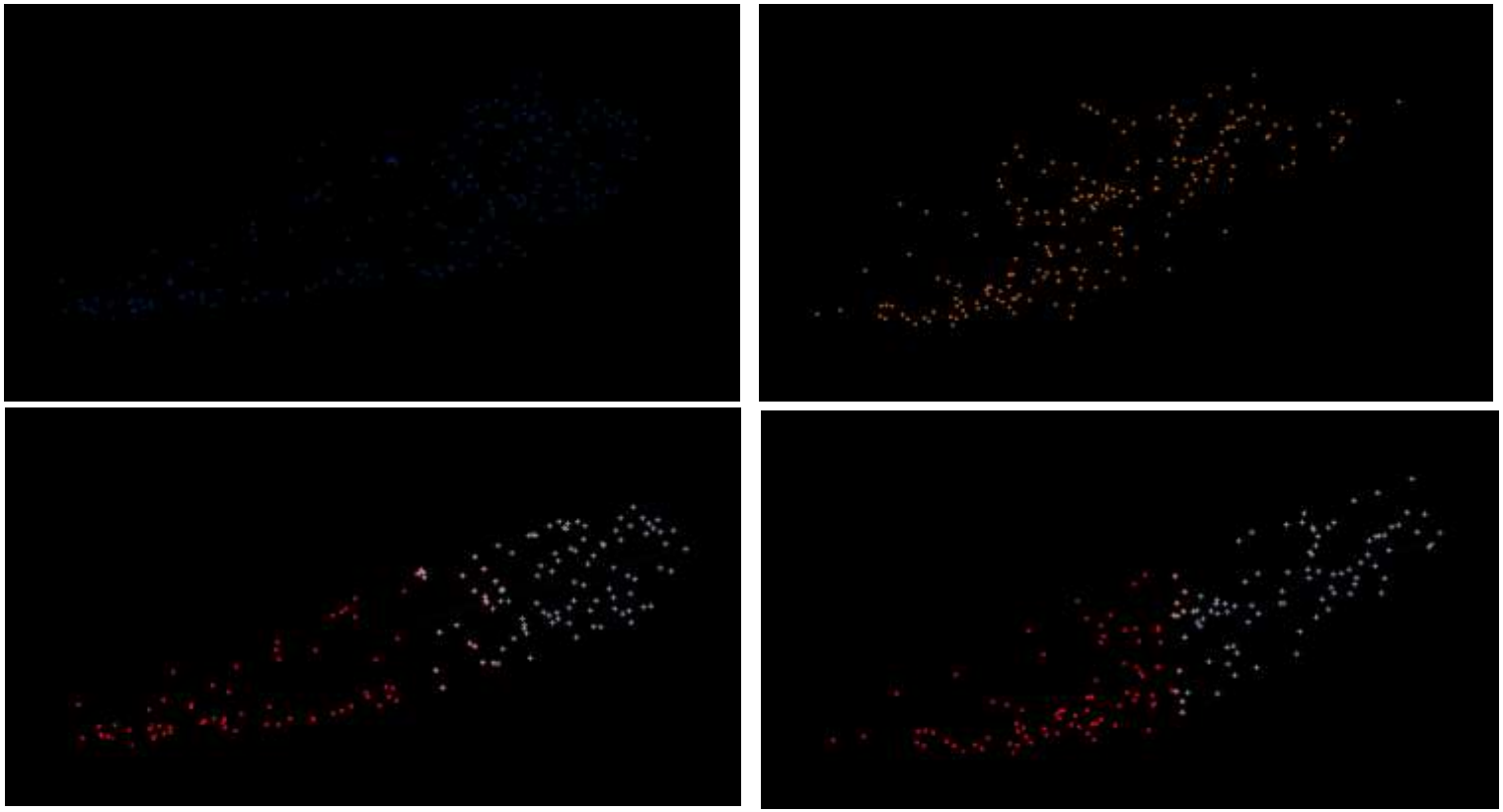
Model Enhancement

- Apply simple filtering algorithm using least square adjustment method for linear regression and the coefficient of determination value formula

$$\hat{X} = (A^T P A)^{-1}(A^T P F)$$

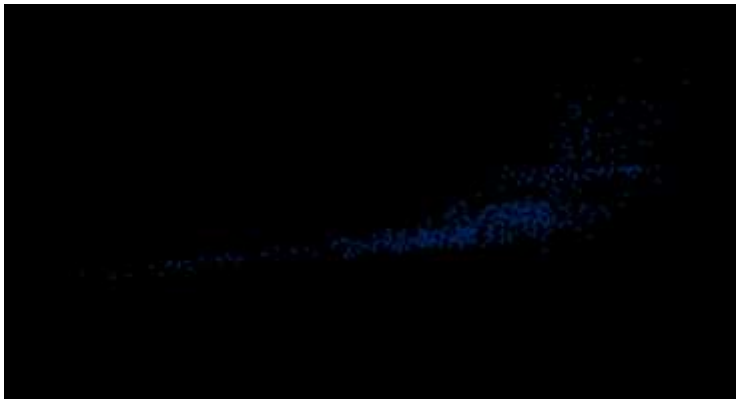
$$F = Ax$$

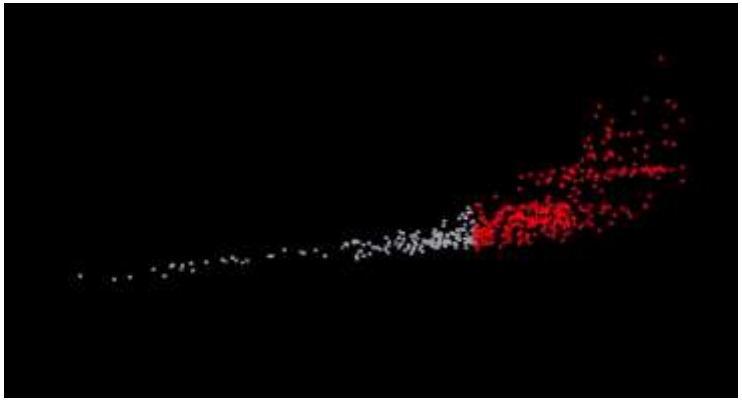
$$R^2 = \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2}$$



Regression Summary (Stumpf Tawau Port)		
	Sentinel-2A	Pleiades
R Square	0.5948	0.6214
Slope (Gain)	321.32	427.52
Y-Axis Intercept (Offset)	- 326.85	- 383.49
Observations	196	199

Regressions Summary (M-LOT Tawau Port)						
	Sentinel-2A			Pleiades		
	Single Linear	Lower Layer	Upper Layer	Single Linear	Lower Layer	Upper Layer
R Square	0.7276	0.6035	0.1943	0.7424	0.3663	0.4761
Slope (Gain)	321.55	314.31	282.0	460.33	385.28	373.08
Y-Axis Intercept (Offset)	-327.11	-319.72	-285.64	-413.61	-345.93	-333.08
Observations	166	84	86	183	88	95

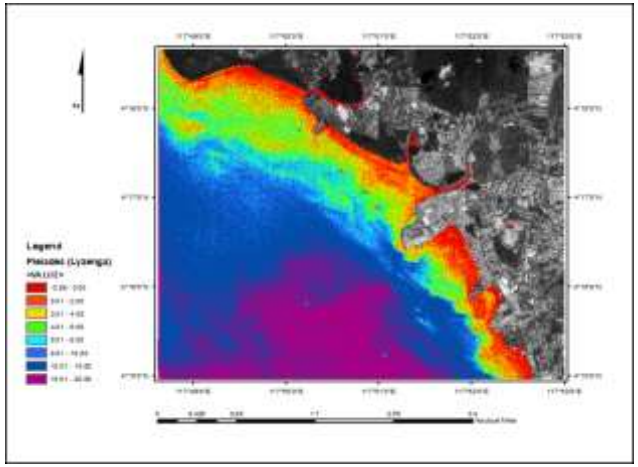




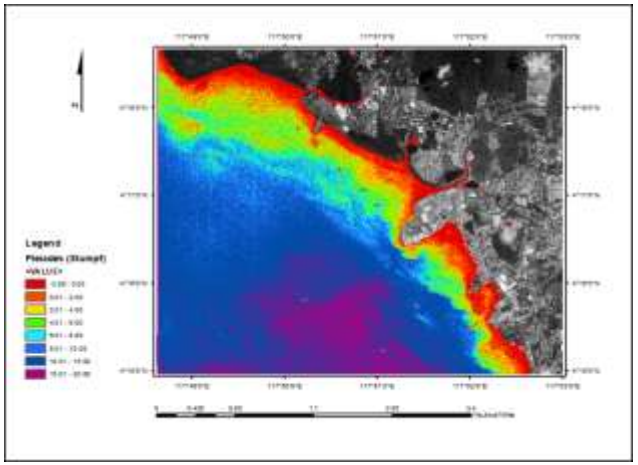

Regression Summary (Stumpf Pulau Kuraman)		
	Sentinel-2A	WorldView-2
R Square	0.5665	0.4326
Slope (Gain)	211.4	217.29
Y-Axis Intercept (Offset)	-212.69	-179.03
Observations	492	496

Regressions Summary (M-LOT Pulau Kuraman)						
	Sentinel-2A			WorldView-2		
	Single Linear	Lower Layer	Upper Layer	Single Linear	Lower Layer	Upper Layer
R Square	0.5968	0.6798	0.5626	0.4326	0.7544	0.6055
Slope (Gain)	206.17	68.716	305.65	217.29	84.056	1295.7
Y-Axis Intercept (Offset)	-207.34	-67.634	310	-179.03	-67.894	-1095.3
Observations	488	165	328	492	225	272

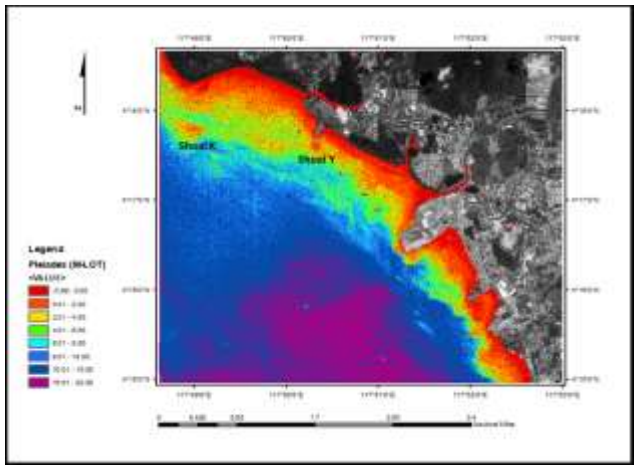
Results & Analysis



Lyzenga model

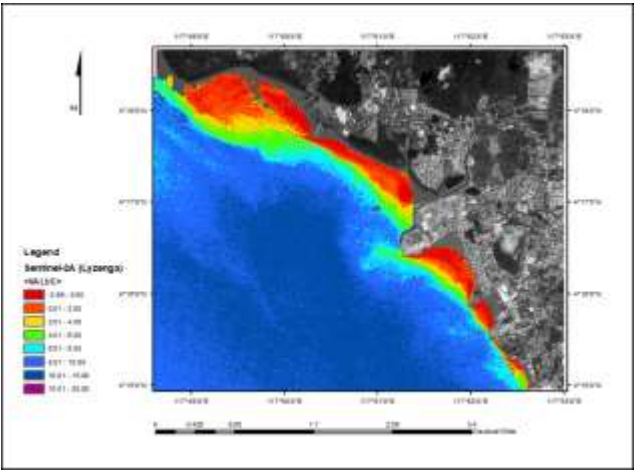


Stumpf model

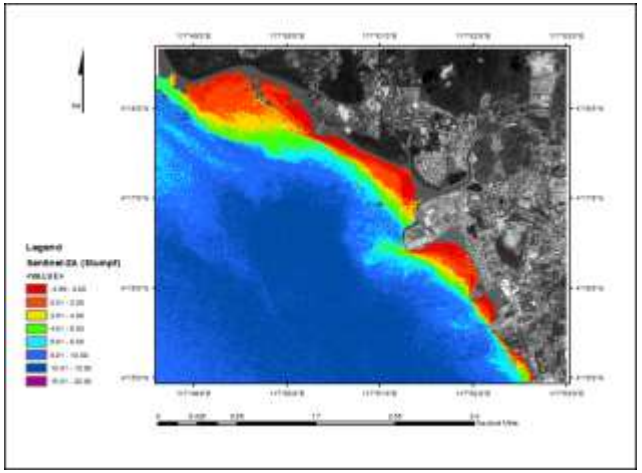


M-LOT model

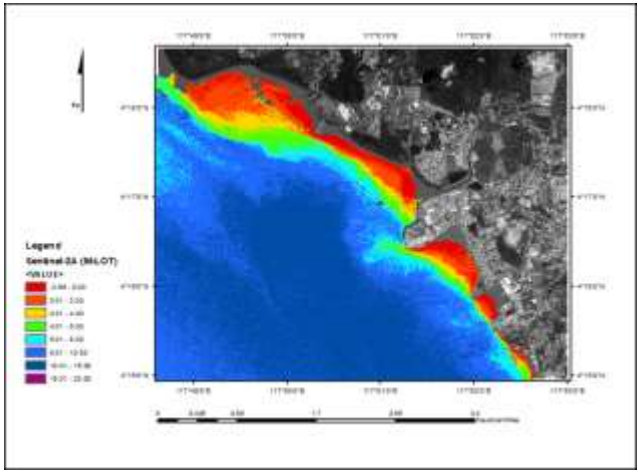
Results & Analysis



Lyzenga model

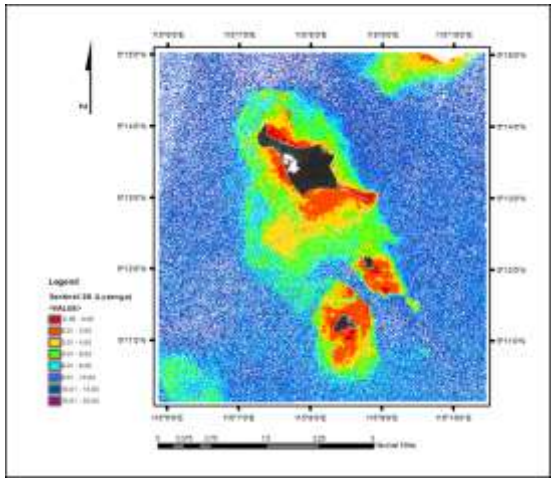


Stumpf model

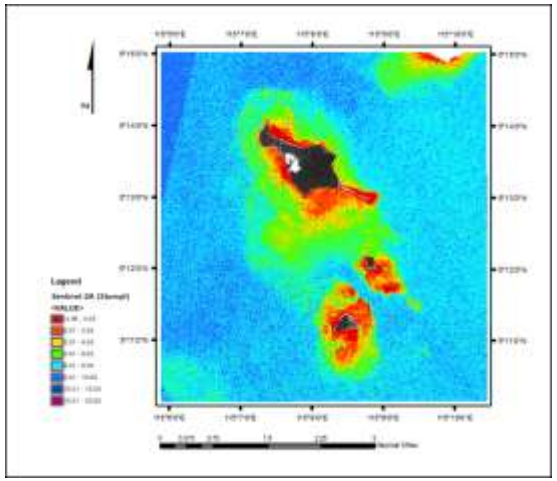


M-LOT model

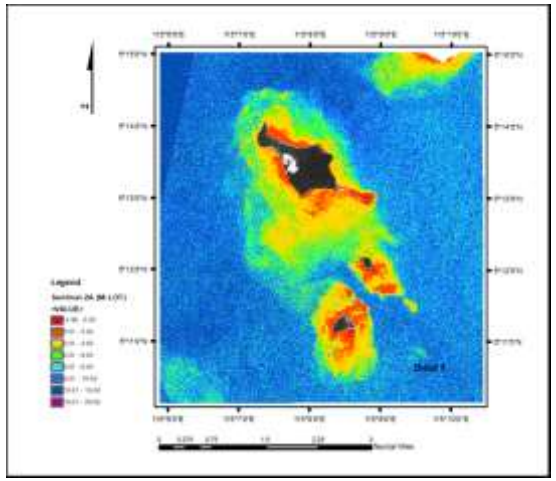
Results & Analysis



Lyzenga model

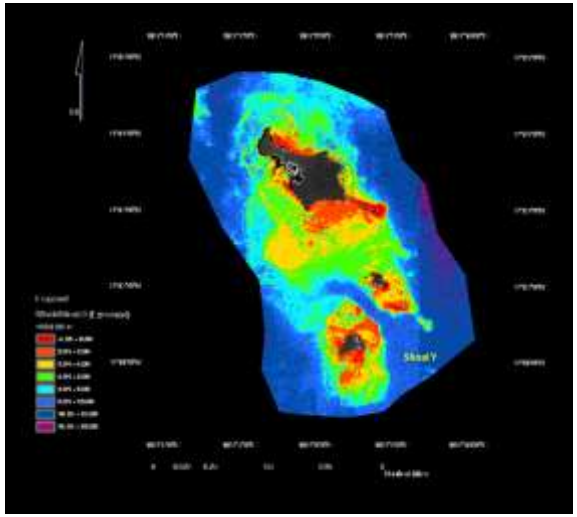


Stumpf model

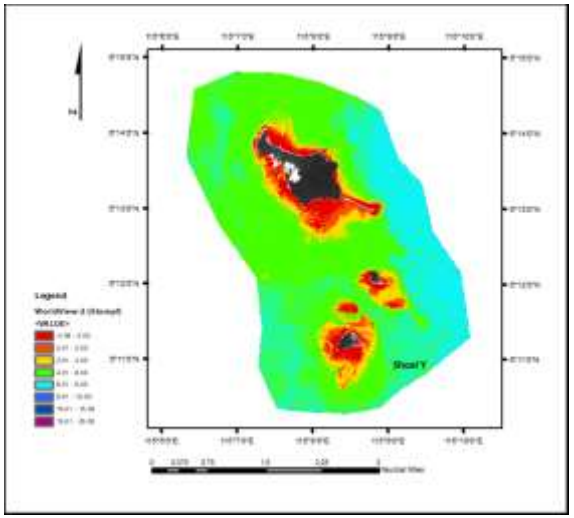


M-LOT model

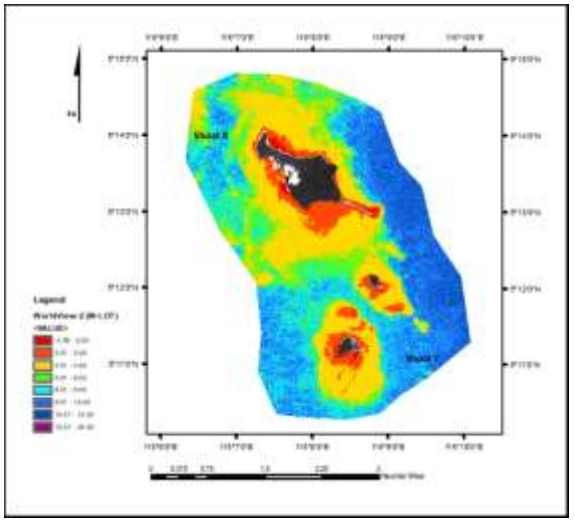
Results & Analysis



Lyzenga model



Stumpf model



M-LOT model

Results & Analysis

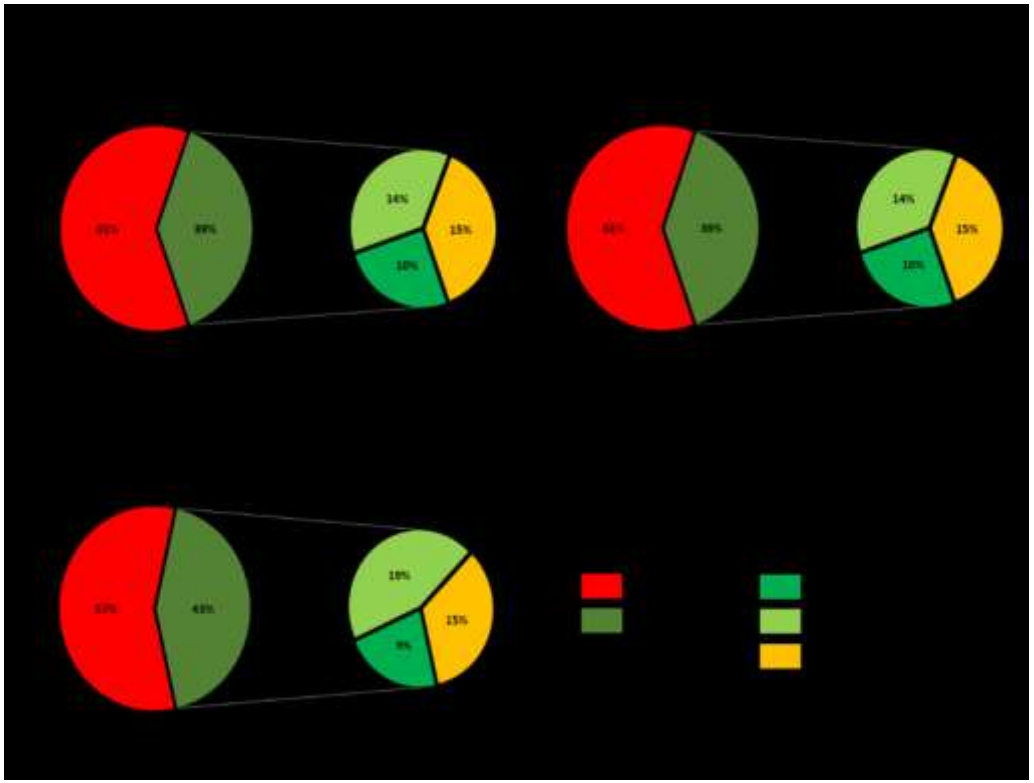
	Sentinel-2A (Tawau Port)			Pleaides (Tawau Port)		
	Lyzenga	Stumpf	M-LOT	Lyzenga	Stumpf	M-LOT
Sample Variance	5.159	5.124	4.713	3.992	3.963	3.240
RMSE	4.464	4.459	4.307	4.323	4.435	4.379
Standard Deviation	2.271	2.264	2.171	1.998	1.991	1.800
Sum	-2203.843	-2196.262	-1409.845	-1061.813	-917.150	-272.315
Sample Count	2113	2113	2113	2213	2213	2213

Results & Analysis

	Sentinel-2A (Pulau Kuraman)			WV2 (Pulau Kuraman)		
	Lyzenga	Stumpf	M-LOT	R-Lyzenga	Stumpf	M-LOT
Sample Variance	4.393	5.813	5.105	2.676	3.887	3.437
RMSE	2.118	2.411	2.263	1.841	2.975	1.958
Standard Deviation	2.096	2.411	2.259	1.634	1.972	1.854
Sum	-79793.673	9136.311	-32656.619	424317.754	1118489.646	316645.097
Sample Count	259013	259013	259013	502081	502081	502081

Results & Analysis

	Sentinel-2A (Tawau Port)		
	Lyzenga	Stumpf	M-LOT
Total Samples	2113	2113	2113
IHO Passed	822	826	906
IHO Failed	1291	1287	1207
	IHO Survey Order Distribution		
Special Order	209	207	198
Order 1A/1B	297	299	399
Order 2	316	320	309



Results & Analysis

	Sentinel-2A (Tawau Port)		
	Lyzenga	Stumpf	M-LOT
Total Samples	2113	2113	2113
IHO Passed	822	826	906
IHO Failed	1291	1287	1207
	IHO Survey Order Distribution		
Special Order	209	207	198
Order 1A/1B	297	299	399
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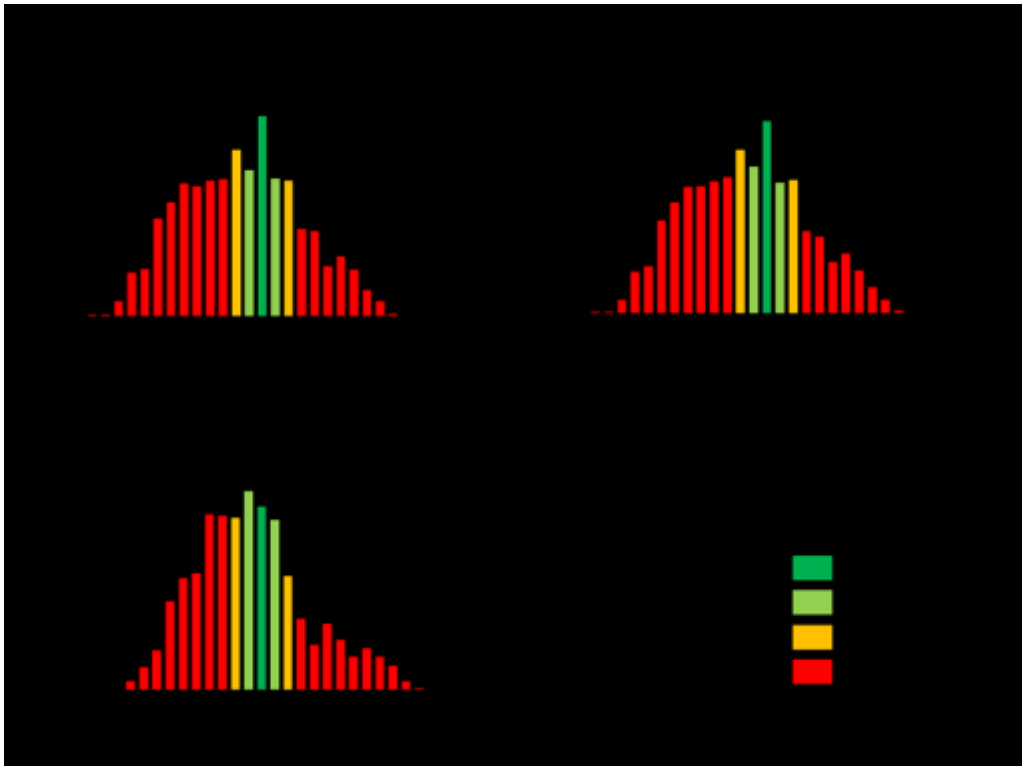
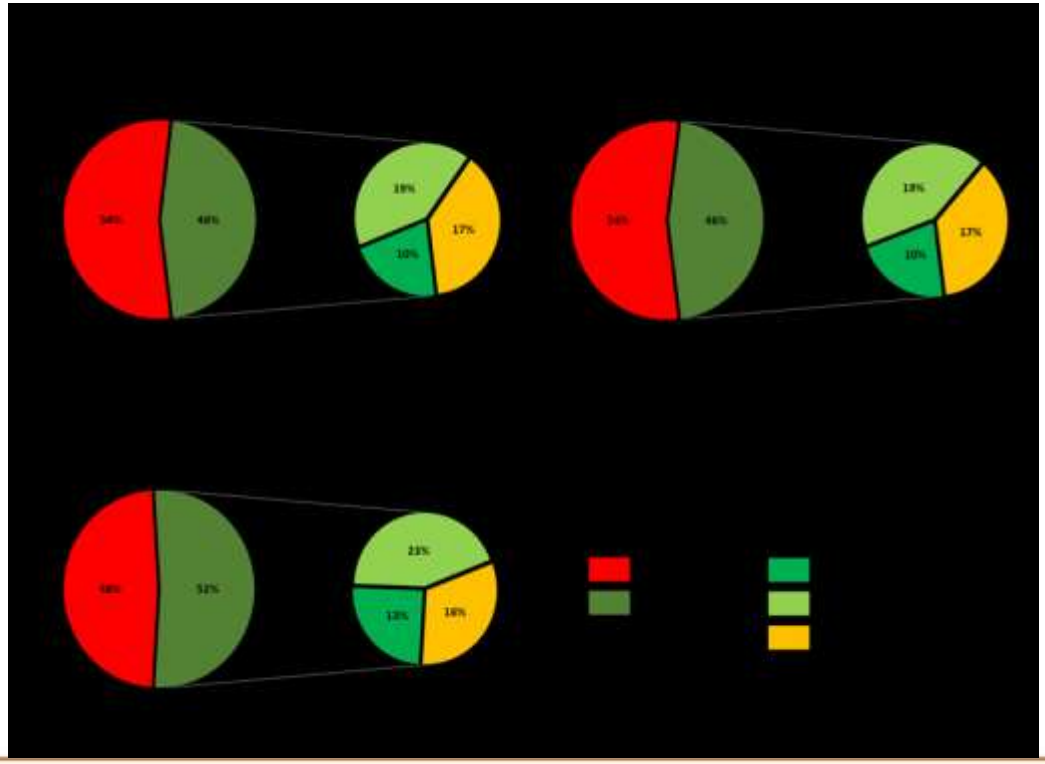


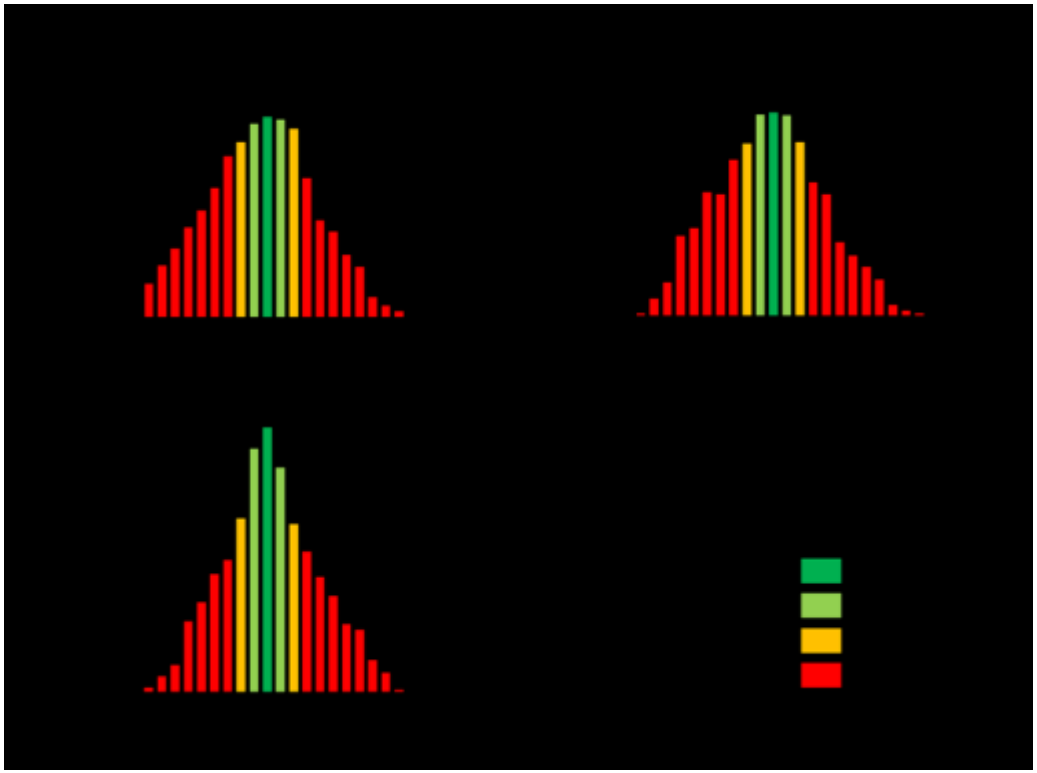
Results & Analysis

	Pleiades (Tawau Port)		
	Lyzenga	Stumpf	M-LOT
Total Samples	2213	2213	2213
IHO Passed	1019	1016	1149
IHO Failed	1194	1197	1064
	IHO Survey Order Distribution		
Special Order	214	217	283
Order 1A/1B	417	429	500
Order 2	388	370	366



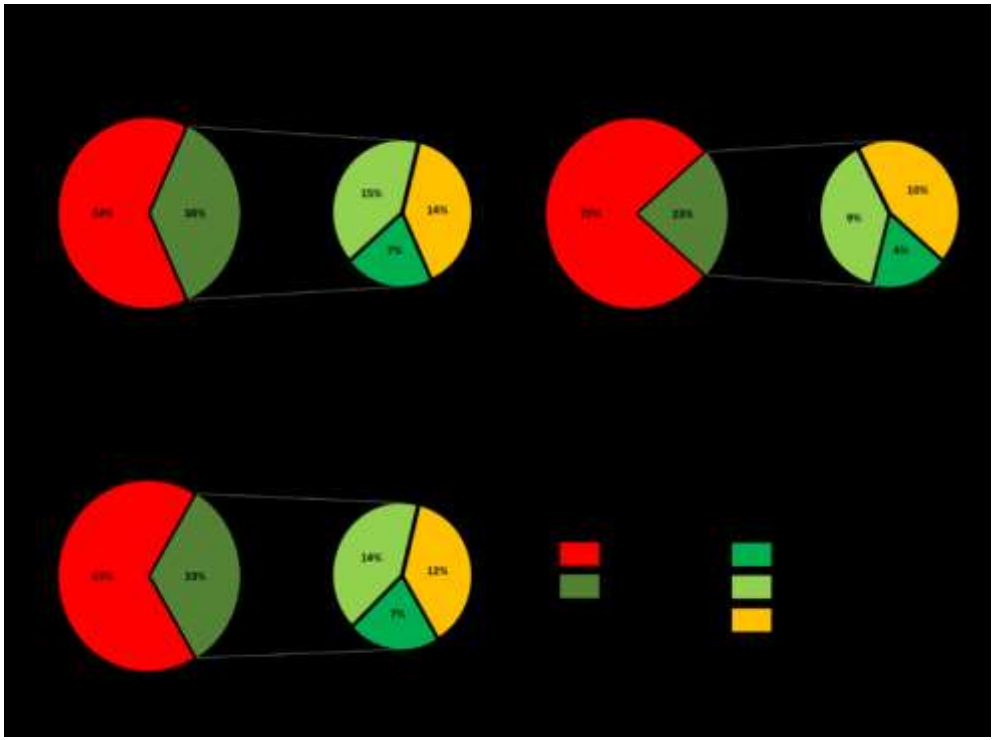
Results & Analysis

	Pleiades (Tawau Port)		
	Lyzenga	Stumpf	M-LOT
Total Samples	2213	2213	2213
IHO Passed	1019	1016	1149
IHO Failed	1194	1197	1064
	IHO Survey Order Distribution		
Special Order	214	217	283
Order 1A/1B	417	429	500
Order 2	388	370	366



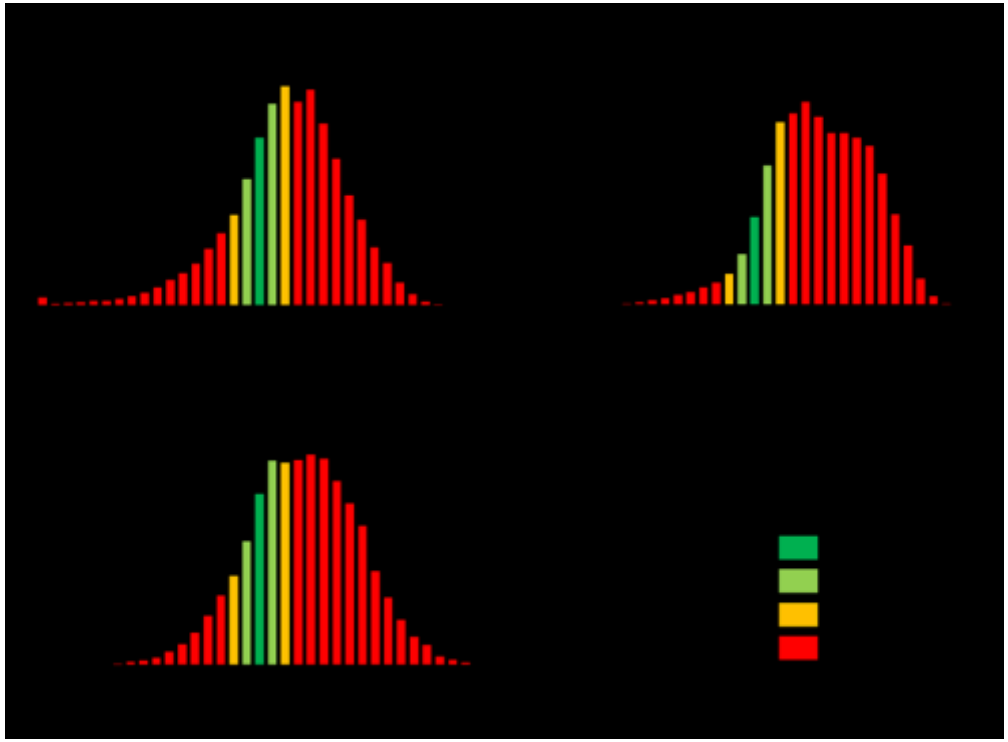
Results & Analysis

	Sentinel2A (Pulau Kuraman)		
	Lyzenga	Stumpf	M-LOT
Total Samples	460252	460252	460252
IHO Passed	166747	103418	151100
IHO Failed	293505	356834	309152
	IHO Survey Order Distribution		
Special Order	34245	18401	32311
Order 1A/1B	67143	39617	61991
Order 2	65359	45400	56798



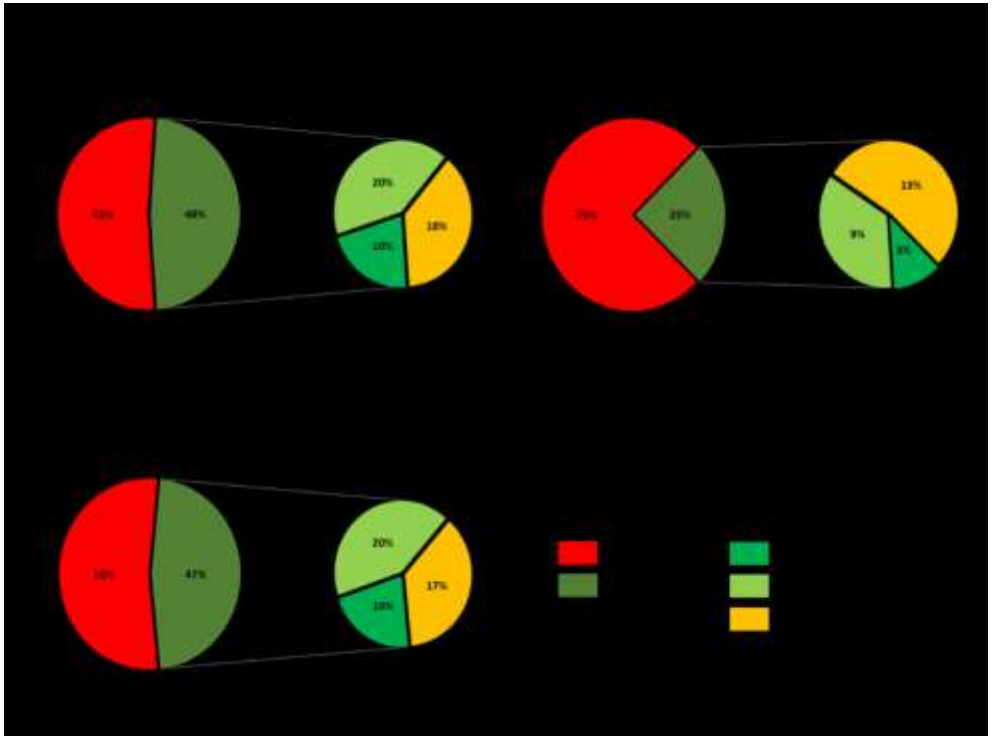
Results & Analysis

	Sentinel2A (Pulau Kuraman)		
	Lyzenga	Stumpf	M-LOT
Total Samples	460252	460252	460252
IHO Passed	166747	103418	151100
IHO Failed	293505	356834	309152
	IHO Survey Order Distribution		
Special Order	34245	18401	32311
Order 1A/1B	67143	39617	61991
Order 2	65359	45400	56798



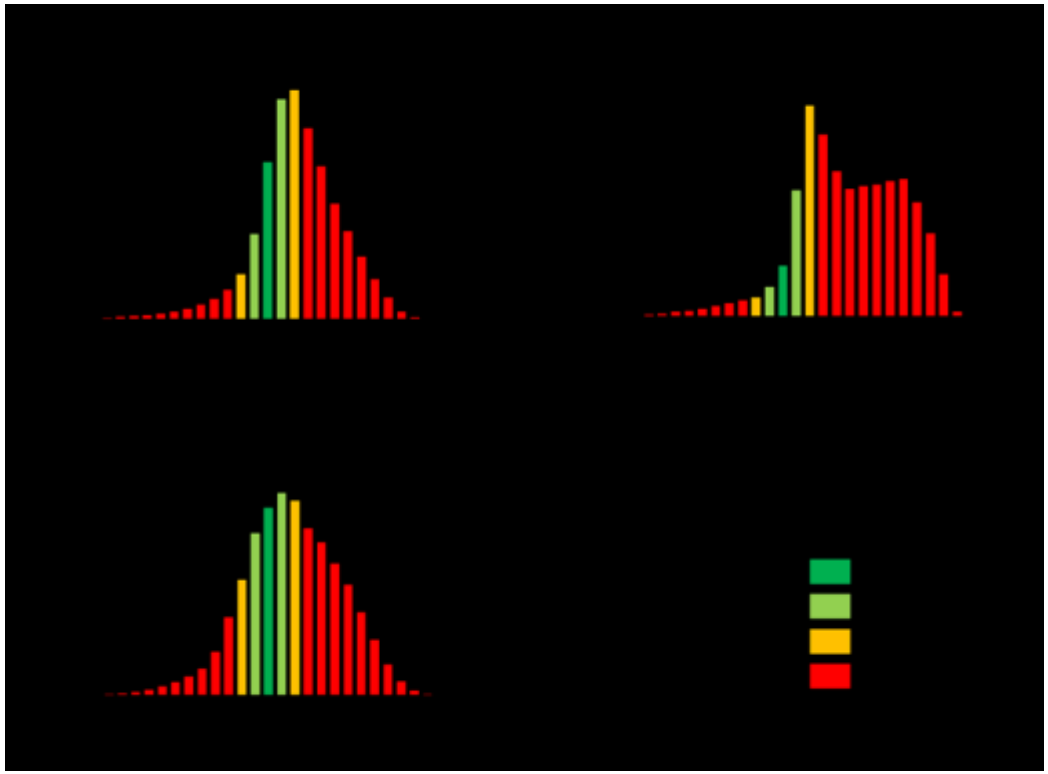
Results & Analysis

	Worldview-2 (Pulau Kuraman)		
	Lyzenga	Stumpf	M-LOT
Total Samples	502081	502081	502081
IHO Passed	239639	123147	235260
IHO Failed	262442	378934	266821
	IHO Survey Order Distribution		
Special Order	50692	14364	50167
Order 1A/1B	98634	43408	98235
Order 2	90313	65375	86858



Results & Analysis

	Worldview-2 (Pulau Kuraman)		
	Lyzenga	Stumpf	M-LOT
Total Samples	502081	502081	502081
IHO Passed	239639	123147	235260
IHO Failed	262442	378934	266821
	IHO Survey Order Distribution		
Special Order	50692	14364	50167
Order 1A/1B	98634	43408	98235
Order 2	90313	65375	86858



Challenges

Difficult to have good quality image

- Minimum change to have an ideal condition/'acceptable' quality

Complex processing

- SDB for hydrography application heavily required an experience hydrographic surveyor supervision
- Tedious calibration techniques

Rough replication of seabed

- Features not always detected and/or difficult to determine

Low depth (acceptable) penetration

- 10 m on average – depends on water clarity
- Unable to meet S-44 Special Order and Order 1a

Sea bottom albedo effect

- Radiance/luminance very depending on seabed types, alga etc
- Require detail analysis especially on the factor of bottom type/albedo

Conclusions

SDB is not a rhetorical application for shallow water area in tropical environment

- Further study still required to improve the consistency (very shallow area)

Urgent need - to establish the standards for SDB application

- Achievable as the new IHO SP-44 will have entirely new concept/objective oriented

About time to have a detail guideline for SDB application (shallow water area)

- Adopting this promising technology as an assessment tool

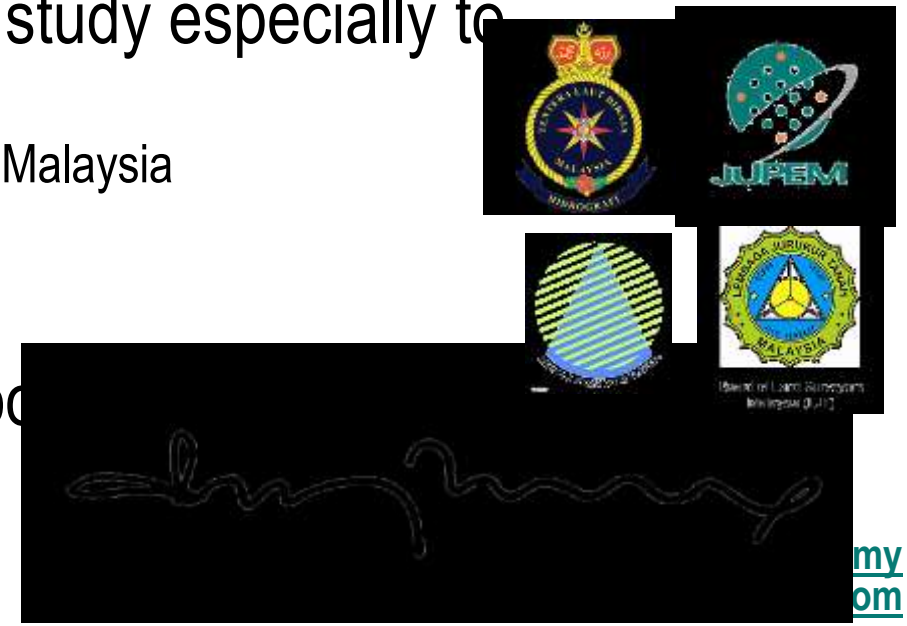
Positive progress and promising results

Will give significant contributions to HOs/relevant agencies

More area to analyse especially on the factor of bottom type/albedo

Dedication

- Special thanks to various organisations and agencies for the unconditional support to this study especially to
  - National Hydrographic Centre
  - Department of Survey and Mapping Malaysia
  - Malaysia Remote Sensing Agency
  - Board of Land Surveyors Malaysia
- Audience - thank you for choo



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Cảm ơn!

chúc một ngày
tốt lành