Satellite Derived Bathymetry - Measuring depths from the sky

By
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Motivation of the Study

The knowledge of the sea bottom is essential for activities such as shipping, fishing, dredging, offshore construction, defense and pipeline laying etc.

Eco-sounding vs. Remote Sensing (RS)

- Traditional methods include eco-sounding techniques like SONAR on ships borne surveys
  - Extremely time-consuming and expensive
  - Limited in case of shallow water observations especially waters shallower than 2–3 m deep because of sound saturation or/and inaccessibility of survey vessels.

- LiDAR - Light Detection And Ranging systems
  - Dependent on the clarity of water
  - Expensive

Advantage of RS over conventional echo sounding methods and LiDAR are temporal data availability, synoptic surface coverage, high spatial resolution and cost effectiveness
To derive an efficient methodology to utilize satellite remote sensing as an alternative to repeated in-situ measurements of coastal depths.

- To develop a suitable approach for nearshore bathymetry estimation using the machine learning technique (ML) on optical remote sensing based satellite datasets.

- To demonstrate the applicability of Satellite derived bathymetry for multi-temporal geomorphological studies.

- To assess the applicability of SAR datasets for bathymetry estimation.

- To combine optical and microwave remote sensing datasets and concepts to derive depths up to 50m.
Bathymetry estimation using ML with Optical Remote Sensing datasets

➢ **Case Study 1 and 2**

- Assessing the potential of Support Vector machine (SVM) as an improvement to the widely used Stumpf et al. (2003) model. The results are also compared with the widely used Linear transform model proposed by Lyzenga (1978, 1981, and 1985)
- Comparison of the relative performance of Sentinel MSI 10 m imagery with Landsat 8 OLI imagery 30 m imagery

➢ **Case Study 3**

- Coastal Monitoring using SDBS
Case Study 1 - Study Area

Study Area (a) Location of Dutch Sint Maarten Island (b) Near-shore bathymetry using echo-sounding measurements

Study Area (a) Rectangular box showing location of Ameland Inlet (b) Near-shore bathymetry using echo-sounding measurements
Data Used

- **In-situ Measurements**

  Eco-sounding Measurements are provided by UNESCO- IHE and Deltares, The Netherlands

  - Procured between January 2011 and 8th February 2011 for Sint Maarten Island
  - Procured on 20 May 2014 and 4 June 2014 for Ameland Inlet

  The datum level used - *NAP (Nieuw Amsterdams Peil)*- tide adjusted

- **Satellite datasets**

  - Landsat 7 ETM imagery (14th Jan 2011), WGS 84 UTM Zone 20
  - Landsat 8 imagery (9th March 2014), WGS 84 UTM Zone 31
General Methodology

Pre-Processing of Landsat 7 ETM and Landsat 8 OLI data
(Radiometric calibration and atmospheric correction using FLAASH)

Spatial Sub-setting - Land/ Water Separation
Dryland and most of the clouds are removed (Use NIR band depending on availability)

Applying Bathymetric Algorithm (Empirical, Machine Learning)
(Lyzenga (1978, 1981, 1985); Stumpf et al., (2003); Vojinovic et al. (2013))

Statistical Analysis between Satellite Derived Bathymetry and in-situ measurement data for validation
Bathymetry Retrieval


The proposed model is (Lyzenga, 1985)

\[ Z = a_0 + a_i X_i + a_j X_j \]

Where,

\[ X_i = \ln (R_{wi} - R_{dpi}) \text{ modified to } \ln (R_{aci}) \], \( R \) is DN/Radiance/Reflectance

\[ X_j = \ln (R_{wj} - R_{dpi}) \text{ modified to } \ln (R_{acj}) \]

\( a_0, a_i, a_j = \) coefficients determined through multiple regression using known depths and the corresponding reflectances.

Finally for \( n \) band, Lyzenga et al. (2006) proposed

\[ Z = a_0 + \sum_{i=1}^{N} a_i X_i \]

Where, \( X_i \) is same as above
Bathymetry Retrieval

Ratio Transform Model (Stumpf et al. 2003)

The algorithm is given by:

\[
Z = m_1 \frac{\ln(nR_W(\lambda_i))}{\ln(nR_W(\lambda_j))} m_0
\]

where, \(Z\) is depth, \(m_1\) is a tunable constant to scale the ratio to depth, \(n\) is a constant to ensure the ratio remains positive under all values, \(R_W\) is observed reflectance, and \(m_0\) is the offset.

Advantages over Linear Transform Model:
- It does not require subtraction of dark water pixels (atmospheric correction)
- It compensates for the different bottom types
- The ratio transform method has fewer empirical coefficients required for the solution, which makes the method easier to use and more stable over broad geographic area.
Regression style of learning is used to derive a relationship between the ratio of blue band to green band and water depth.

For regression, SVM can be expressed using the following notation:

\[
E = \sum_{i=1}^{p} L_{si} + \lambda \|Pf\|^2 = \sum_{i=1}^{p} L_{si} + \Omega(h, l)
\]

Where,

\(L_{si}\) represents the Vapnik’s \(\varepsilon\)-insensitivity loss function (Vapnik, 1998).

The training functions are further mapped into higher dimensional space by a non-linear kernel function. The radial basis function (RBF) kernel function is used which is expressed by the following notation.

\[
K(x_i, x_j) = \exp \left( -\varphi \|x_i-x_j\|^2 \right), \varphi > 0
\]

Where, \(\varphi\) is the Gaussian Function.

Other parameters –

The ‘shape’, i.e. smoothing parameter in the kernel function (i.e. variance of the Gaussian RBF kernel), \(C\) i.e. is the penalty parameter that determines the trade-off between the training error and the Vapnik-Chervonenkis dimension of the model.
Results and Discussion - The Dutch Sint Maarten Island

Comparison of bathymetry maps of Sint Maarten Island (1.00-15.00m) obtained using the various algorithms (a) in-situ measurements (b) Linear transform algorithm (c) Ratio transform algorithm (d) SVM

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Bias (m)</th>
<th>Dif Median (m)</th>
<th>r</th>
<th>RMSE (m)</th>
<th>Mean Absolute Error (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Transform Algorithm</td>
<td>0.02</td>
<td>-0.03</td>
<td>0.99</td>
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<tr>
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<td>0.99</td>
<td>0.69</td>
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</tbody>
</table>

Cost Parameter C = 100
ε loss function = 3.5

Misra et al. (2018)
### Results and Discussion – The Ameland Inlet

Comparison of bathymetry maps of Ameland Inlet (1.00-3.50m) obtained using the various algorithms (a) in-situ measurements (b) Linear transform algorithm (c) Ratio transform algorithm (d) SVM

Cost Parameter $C = 100$ 
$\varepsilon$ loss function = 0.50

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Bias (m)</th>
<th>Dif Median (m)</th>
<th>$r$</th>
<th>RMS E (m)</th>
<th>Mean Absolute Error (m)</th>
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<tr>
<td>Linear Transform Algorithm</td>
<td>-0.08</td>
<td>-0.43</td>
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<td>0.27</td>
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<tr>
<td>Ratio Transform Algorithm</td>
<td>-0.08</td>
<td>-0.44</td>
<td>0.87</td>
<td>0.35</td>
<td>0.28</td>
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<tr>
<td>Support Vector Machine</td>
<td>-0.09</td>
<td>-0.51</td>
<td>0.89</td>
<td>0.34</td>
<td>0.27</td>
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</table>
Case Study- 2

- Satellite Imagery
  - Sentinel 2 MSI data (10m): 12th March 2016, 15 February 2017
  - Landsat 8 OLI (30m) 27th February 2016; 4 April 2017
- Echo-sounder measurements: February 2016 and 2017

<table>
<thead>
<tr>
<th>Location</th>
<th>Sensor</th>
<th>$R^2$</th>
<th>RMSE (m)</th>
<th>MAE (m)</th>
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<tbody>
<tr>
<td>Ameland Inlet 2016</td>
<td>Sentinel 2 MSI</td>
<td>0.91</td>
<td>0.28</td>
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<td>Ameland Inlet 2017</td>
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<td>0.38</td>
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<td>Landsat 8 OLI</td>
<td>0.94</td>
<td>0.27</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Misra et al. (2019)

(a) Location of Study area; Bathymetry map of Ameland Inlet obtained from (b) in-situ measurements of 2016 (c) Sentinel 2 MSI Imagery of 2016 (d) Landsat 8 OLI Imagery of 2016

(a) In-situ measurements of 2017 (b) Sentinel 2 MSI Imagery of 2017 (c) Landsat 8 OLI Imagery of 2017
Objective-
Assess and report the geomorphological impact of beach restoration project with the help of rigorously calibrated and validated SDBs obtained from freely available medium resolution images (30 m).

Misra and Balaji, (2020)
Sentinel based depths for Puducherry

Satellite Imagery
- Sentinel 2 MSI data (10m): 31 January 2017
- Landsat 8 OLI (30m) 5th February 2017
- Echo-sounder measurements: February 2017

<table>
<thead>
<tr>
<th>Location</th>
<th>Sensor</th>
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<th>MAE</th>
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<tr>
<td>Puducherry Coast</td>
<td>Sentinel 2 MSI</td>
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<td>0.27</td>
<td>0.19</td>
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<td>Landsat 8 OLI</td>
<td>0.98</td>
<td>0.30</td>
<td>0.21</td>
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</tbody>
</table>

Lack of availability of time series data in case of sentinel 2 MSI dataset

(a) Spatial extent considered; Bathymetry map of Puducherry coast obtained from (b) in-situ measurements (c) Sentinel 2 MSI Imagery (d) Landsat 8 OLI Imagery

Misra and Balaji, (2020)
Data and Methodology

(a) Data
In-situ measurements procured from National Institute of Ocean Technology (NIOT), Chennai, India.

(b) Methodology

<table>
<thead>
<tr>
<th>In situ measurements</th>
<th>Satellite Imagery</th>
<th>Used For</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td><strong>Approx. Extent (Km²)</strong></td>
<td><strong>Depth Range (m)</strong></td>
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<tr>
<td>February 2015</td>
<td>10</td>
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</tr>
<tr>
<td>March 2016</td>
<td>1.7</td>
<td>0-7.8</td>
</tr>
<tr>
<td>February 2017</td>
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<td>0-9.5</td>
</tr>
<tr>
<td>July 2017</td>
<td>2</td>
<td>0-10.0</td>
</tr>
<tr>
<td>October 2017</td>
<td>2</td>
<td>0-9.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bathymetry Retrieval

➢ **Optimal Input Parameter Selection**

❑ Possible Parameters

• Coastal blue, Blue, Green, Red Bands Selected
• Band ratios

❑ Selection Method

• Correlation
• Stepwise Regression

<table>
<thead>
<tr>
<th>Satellite bands and ratios</th>
<th>Coefficient of determination (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal blue (cb)</td>
<td>0.79</td>
</tr>
<tr>
<td>Blue (b)</td>
<td>0.83</td>
</tr>
<tr>
<td>Green (g)</td>
<td>0.95</td>
</tr>
<tr>
<td>Red (r)</td>
<td>0.95</td>
</tr>
<tr>
<td>Coastal Blue/Blue</td>
<td>0.94</td>
</tr>
<tr>
<td>Coastal Blue/Green</td>
<td>0.98</td>
</tr>
<tr>
<td>Coastal Blue/Red</td>
<td>0.96</td>
</tr>
<tr>
<td>Blue/Green</td>
<td>0.99</td>
</tr>
<tr>
<td>Blue/Red</td>
<td>0.96</td>
</tr>
<tr>
<td>Green/Red</td>
<td>0.53</td>
</tr>
</tbody>
</table>

➢ **Depth Retrieval using Support Vector Machine**

➢ **Multi-temporal Geomorphological Change Analysis**
Results and Discussion

Bathymetry Retrieval using Optical Remote sensing

- **Calibration data**: in-situ data of February 2015, March 2016 and February 2017 are combined, divided in 80-20 Ratio in training and testing phases.

- **Validation data**: July and October 2017

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Predictor Variable</th>
<th>No. of Data Points</th>
<th>Minimum Depth (m)</th>
<th>Maximum Depth (m)</th>
<th>Mean Depth (m)</th>
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</thead>
<tbody>
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<td>Testing Phase</td>
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<td>208</td>
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<td>10.36</td>
<td>5.29</td>
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</table>

<table>
<thead>
<tr>
<th>Scenario</th>
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<th>R²</th>
<th>RMSE (m)</th>
<th>MAE (m)</th>
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<tr>
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<td>0.13</td>
<td>0.09</td>
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<tr>
<td>Scenario (2)</td>
<td>b+g+r+(b/g)+(b/r)+(g/r)</td>
<td>0.98</td>
<td>0.32</td>
<td>0.14</td>
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<tr>
<td>Scenario (3)</td>
<td>Cb+b+g+r+(cb/b)+(cb/g)+(cb/r)+(b/g)+(b/r)+(g/r)</td>
<td>0.98</td>
<td>0.39</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Misra and Balaji, (2020)
Results and Discussion

- Validation of SVR based depth retrieval and multi-temporal bathymetry maps

  - The b/g model is selected for depths along the coast of Puducherry
  - 32.85% of this training dataset is selected as support vectors
  - C and $\varepsilon$ values chosen are 1000 and 0.1 respectively,
  - Training error of 3.22%, Testing Error-2.55%
  - Comparison of the testing dataset with the in-situ measurements yields a correlation of 0.99.

<table>
<thead>
<tr>
<th>Statistical Parameters</th>
<th>Feb-15</th>
<th>Mar-16</th>
<th>Feb-17</th>
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<tr>
<td>Number of data points</td>
<td>96840</td>
<td>5341</td>
<td>16019</td>
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<tr>
<td>Min (m)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Max (m)</td>
<td>10.41</td>
<td>12.07</td>
<td>9.57</td>
</tr>
<tr>
<td>Mean (m)</td>
<td>6.68</td>
<td>6.98</td>
<td>5.64</td>
</tr>
<tr>
<td>Median (m)</td>
<td>7.15</td>
<td>7.58</td>
<td>6.03</td>
</tr>
<tr>
<td>Standard Deviation (m)</td>
<td>2.28</td>
<td>2.64</td>
<td>1.95</td>
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<tr>
<td>Bias (m)</td>
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<td>0.17</td>
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<tr>
<td>Diff(Median) (m)</td>
<td>-0.43</td>
<td>-0.11</td>
<td>0.59</td>
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<tr>
<td>$R^2$</td>
<td>0.85</td>
<td>0.96</td>
<td>0.85</td>
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<td>RMSE (m)</td>
<td>1.07</td>
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<td>0.79</td>
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<tr>
<td>MAE (m)</td>
<td>0.85</td>
<td>0.31</td>
<td>0.59</td>
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</table>

Misra and Balaji, (2020)
## Validation Dataset (a) May 2017 (b) October 2017

<table>
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<tr>
<th></th>
<th>0-2</th>
<th>2-4</th>
<th>4-6</th>
<th>6-8</th>
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<td>Min (m)</td>
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<tr>
<td>Max (m)</td>
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<td>Median (m)</td>
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<td>Standard Deviation (m)</td>
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<td>0.75</td>
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<td>0.77</td>
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<td>Bias (m)</td>
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<td>0.12</td>
<td>-0.29</td>
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<td>0.48</td>
<td>0.48</td>
<td>0.39</td>
<td>0.48</td>
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<table>
<thead>
<tr>
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<th>0-2</th>
<th>2-4</th>
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<td>Z_{\text{sat}}</td>
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<td>8.00</td>
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<td>Max (m)</td>
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<td>4.73</td>
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<td>7.99</td>
<td>9.50</td>
<td>9.50</td>
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<tr>
<td>Mean (m)</td>
<td>1.33</td>
<td>1.85</td>
<td>4.10</td>
<td>4.99</td>
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<td>8.35</td>
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<tr>
<td>Median (m)</td>
<td>1.37</td>
<td>1.80</td>
<td>3.05</td>
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<td>Dif(Median) (m)</td>
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<tr>
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<td>0.69</td>
<td>0.42</td>
<td>0.98</td>
<td>0.89</td>
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<tr>
<td>MAE (m)</td>
<td>0.97</td>
<td>1.20</td>
<td>0.59</td>
<td>0.34</td>
<td>0.95</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Misra and Balaji, (2020)
Comparison of bathymetry map obtained using (a) In-situ measurement (b) Landsat OLI imagery of May 2017

Comparison of bathymetry map obtained using (a) In-situ measurement (b) Landsat OLI imagery of October 2017

Misra and Balaji, (2020)
(a) Nearshore Profiles of May 2017

- **T1**: 
  - Bias (m) = -0.05
  - Diff Median (m) = 0.17
  - RMSE = 0.58
  - MAE = 0.47

- **T2**: 
  - Bias (m) = 0.27
  - Diff Median (m) = -0.02
  - RMSE = 0.37
  - MAE = 0.31

- **T3**: 
  - Bias (m) = 0.07
  - Diff Median (m) = 0.38
  - RMSE = 0.97
  - MAE = 0.69

- **T4**: 
  - Bias (m) = 0.16
  - Diff Median (m) = 0.03
  - RMSE = 0.60
  - MAE = 0.41

- **T5**: 
  - Bias (m) = 0.24
  - Diff Median (m) = -0.12
  - RMSE = 0.24
  - MAE = 0.26

- **T6**: 
  - Bias (m) = 0.26
  - Diff Median (m) = -0.12
  - RMSE = 0.46
  - MAE = 0.35

- **T7**: 
  - Bias (m) = 0.36
  - Diff Median (m) = 0.38
  - RMSE = 0.71
  - MAE = 0.55

- **T8**: 
  - Bias (m) = 0.006
  - Diff Median (m) = 0.36
  - RMSE = 0.50
  - MAE = 0.44

- **T9**: 
  - Bias (m) = -0.03
  - Diff Median (m) = -0.77
  - RMSE = 0.53
  - MAE = 0.43

- **T10**: 
  - Bias (m) = -0.35
  - Diff Median (m) = -0.56
  - RMSE = 0.54
  - MAE = 0.49

- **T11**: 
  - Bias (m) = -0.37
  - Diff Median (m) = -0.80
  - RMSE = 0.51
  - MAE = 0.42

- **T12**: 
  - Bias (m) = -0.72
  - Diff Median (m) = -0.56
  - RMSE = 0.83
  - MAE = 0.72

---

Misra and Balaji, (2020)
(b) Nearshore Profiles of Oct 2017

- Insitu depths (m)
- SDB depths

Misra and Balaji, (2020)
Analysing geomorphological changes using satellite derived bathymetry

<table>
<thead>
<tr>
<th>S No.</th>
<th>Description of survey</th>
<th>Period of survey</th>
<th>Quantity (m³)</th>
<th>Discharge location</th>
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<tbody>
<tr>
<td>1</td>
<td>Pre Bathymetry Survey</td>
<td>6/1/17</td>
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<tr>
<td>2</td>
<td>1st Post Bathymetry Survey</td>
<td>23/2/17</td>
<td>34314</td>
<td>On Shore</td>
</tr>
<tr>
<td>3</td>
<td>2nd Post Bathymetry Survey</td>
<td>13/3/17</td>
<td>11718</td>
<td>In Sea near New pier</td>
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<tr>
<td>4</td>
<td>3rd Post Bathymetry Survey</td>
<td>22/5/17</td>
<td>29424</td>
<td>New pier</td>
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<tr>
<td>5</td>
<td>4th Post Bathymetry Survey</td>
<td>2/6/17</td>
<td>51447</td>
<td>In Sea near New pier</td>
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<tr>
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<td>2/7/17</td>
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<td>6th Post Bathymetry Survey</td>
<td>27/7/17</td>
<td>22255</td>
<td>New pier</td>
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<tr>
<td>8</td>
<td>7th Post Bathymetry Survey</td>
<td>18/8/17</td>
<td>93856</td>
<td>New pier</td>
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<td></td>
<td><strong>Grand Total</strong></td>
<td></td>
<td><strong>307033</strong></td>
<td></td>
</tr>
</tbody>
</table>

Phases of beach nourishment (NIOT) (Source: NIOT)  
Misra and Balaji, (2020)

SDBs for the months (a) February 2017 (b) May 2017 (c) October 2017 (d) January 2018
Change in depths (a) Feb 2017 - May 2017 (b) May 2017 - Oct 2017 (c) Oct 2017 – January 2018

Changes in sediment volume (a) February 2017 - May 2017 (b) May 2017-October 2017 (c) October 2017 – January 2018

Misra and Balaji, (2020)
DSAS based Shoreline Change Analysis – Extension ArcGIS 10.5

February 2017 - May 2017:
- Erosion: 83%
- Accretion: 17%
- Average NSM: -13.68m
- Average EPR: -3.42m/month

May 2017 and October 2017:
- Erosion: 47%
- Accretion: 53%
- Average NSM: 7.7m
- Average EPR: 1.2m/month.

October 2017 and January 2018:
- Erosion: 24%
- Accretion: 76%
- Average NSM: 7.3m
- Average EPR: 1.8m/month.

Shoreline changes (a) February 2017 - May 2017 (b) May 2017 - October 2017 (c) October 2017 - January 2018

Misra and Balaji, (2020)
Microwave Remote Sensing based bathymetry estimation (Objective 3)

- Sea Surface Roughness in SAR images can be used to estimate bathymetry.

- Wave propagation models exist to predict wave refraction as a function of depth (Lui et al., 1985).

By estimating wave direction and wavelength throughout the image, water depths can be estimated by inverting these models, i.e. finding a depth that generates the correct wave direction and wavelength.

An intrinsic assumption - the same wave train exists throughout the image

SAR’s concept of Imaging Bathymetry (Marghany, 2010)
Wave refraction in SAR images can be used to estimate bathymetry.

- Shoaling and Refraction
- Linear dispersion equation

\[ h = \frac{1}{k} \tan^{-1} \left( \frac{\omega^2}{gk} \right) \]

Or, equivalently

\[ h = \frac{L}{2\pi} \tan^{-1} \left( \frac{2\pi L}{T^2 g} \right) \]

where,
- \( h \) is the water depth;
- \( k \) is the wave number of the gravity wave;
- \( \omega \) is the angular frequency of the gravity wave;
- \( L \) is the wavelength of the gravity wave and it is \( L = \frac{2\pi}{k} \);
- \( T \) is the period of the gravity wave and it is \( T = \frac{2\pi}{\omega} \);
- \( g \) is the gravity acceleration.
Study Area

- Study Area along Maharashtra's coast
- Study Area along Puducherry coast

Misra, Balaji and Muslim (2020)
Data Used

Depth Measurements

- Hydrographic Chart data
  Admiralty chart dataset is used for calibration and validation of the Wave based model for the case study 1 located in Maharashtra. The depth values are digitized in ArcGIS environment and the resultant .shp is generated for the analysis.

- GEBCO datasets
  The GEBCO_2019 Grid is the latest global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) - 15 arc-second grid.

SAR datasets

ALOS PALSAR Dual Pol HH polarized data of 12.5m resolution of 16th June 2007 and 26th January 2007 for Maharashtra and Puducherry region respectively.
Methodology

1. Import Raster product (.xml)
2. Multi-look Processing
3. Speckle Filtering
4. Terrain correction and Radiometric Calibration
5. Geotiff file
6. Pre-processing of satellite data
7. Spectral Analysis of SAR image
8. Smoothing
9. Application of linear dispersion equation
10. Obtaining depth maps

- Track Start point
- FFT Box (Fast Fourier Transform - Image Spectra)
  - Wave number: x,y component (u,v)
  - Obtain wavelength and wave directions

Next FFT box till it reaches shoreline

Misra, Balaji and Muslim (2020)
Raster Scanning Technique

- The original Maharashtra image with water pixels is of the dimension 5600*4700 pixels. The image is subset to the size 3495*3154 pixels.

- In case of Puducherry image, the dimensions of 2251*1747 pixels are reduced to 886*613. The data is basically resampled to 15m spatial resolution.

- A median filter with a kernel size 5×5 is applied on both the imageries.

- For both the case studies, a 128×128-pixels window box is utilized for FFT calculations. The FFT window is shifted by a uniform distance of 5 pixels (75m) starting from the first point until it approaches the coastline.
Results and Discussion – Maharashtra Region

The swell wavelength in the range of 130–250 m.

The peak period after track analysis and first guess has been found to be 13 s.

Misra, Balaji and Muslim (2020)
Results and Discussion – Maharashtra Region

➢ The water depth at the farthest point (almost 47 km away from shoreline) has been found to be 45m

Admiralty charts a $R^2$ value of 0.98, a RMSE of 1.1m and MAE of 0.97m. GEBCO data, $R^2$ of 0.97 with a RMSE error of 1.34m and MAE of 1.1m.
Results and Discussion – Puducherry Region

- The swell wavelength in the range of 120-250 m.
- The peak period after track analysis and first guess has been found to be 13s.

Misra, Balaji and Muslim (2020)
Results and Discussion – Puducherry Region

➢ The water depth at the farthest point (almost 11 km away from shoreline) has been found to be 30m.

Comparison with depths obtained from GEBCO- $R^2$ value of 0.97 is obtained with a RMSE of 0.83 m and MAE of 0.66m.

Misra, Balaji and Muslim (2020)
Combining SVR depths with WBA depths (Objective 4)

- Bathymetry Retrieval using Optical Remote sensing and SVM

- **Data**
  - In-situ measurements – Hydrographic Chart data for Maharashtra and field measurement data of Feb 2015
  - Satellite Imagery - Landsat 8 OLI imagery: Maharashtra - 12th November 2013; Puducherry - 16th Feb 2015

<table>
<thead>
<tr>
<th>Study region</th>
<th>Training Phase</th>
<th>Testing Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of data points</td>
<td>Min depth (m)</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>1115</td>
<td>1</td>
</tr>
<tr>
<td>Puducherry</td>
<td>834</td>
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Misra, Balaji and Muslim (2020)
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Misra, Balaji and Muslim (2020)
Bathymetry Retrieval using Optical Remote sensing and SVM

- Maharashtra

Depth ranges = 1-15m

- SVM model

Input: blue/green ratio
C = 100 and ε = 1 and
27 % of support vectors used for prediction
Training error = 13.70%
Testing error = 11.93%

- Comparison of the predicted depths with the hydrographic chart values

\[ R^2 = 0.95 \]
\[ \text{RMSE} = 0.95 \text{m} \]
\[ \text{MAE} = 0.69 \text{m}. \]
➢ **Puducherry**

Depth ranges = 1-10m

- SVM model

Input: blue/green ratio
C = 1000 and $\varepsilon = 0.2$ and
21.69 % of support vectors used for prediction
Training error = 3.89%
Testing error = 3.22%

- Comparison of the predicted depths with the hydrographic chart values

$R^2 = 0.99$
RMSE = 0.17m
MAE = 0.11m.
Combining Optical Remote sensing and Microwave Remote Sensing based bathymetry estimations

Bathymetry map obtained from the (left) combination of Optical and microwave remote sensing for Maharashtra region (right) GEBCO data

Bathymetry map obtained from the (left) combination of Optical and microwave remote sensing for Puducherry region (right) GEBCO data

Misra, Balaji and Muslim (2020)
Conclusions

• The ML approach is evidently an improvement to the ratio transform model by Stumpf et al. (2003). SVM that works with a single ratio input provides similar results when compared with Lyzenga model, which uses three input parameters.

• It is evident from the study that both Sentinel 2 MSI and Landsat 8 OLI datasets with medium resolution, can be used complimentarily, especially for temporal analysis.

• The method called Wave based approach is used to derive bathymetry by exploiting the wave transformation phenomena of refraction and shoaling. The uncertainty in the results are observed to be mainly influenced by the accuracy of wavelengths derived from the FFT analysis and not the peak wave period.

• Considering, optical remote sensing works for depths between 0-10m and SAR for 10-50m, both SVM and WBA approaches can be combined to generate depth maps of 75m resolution.
Limitations

• Require in-situ measurements for training and validation, which is essentially a major drawback of empirical algorithms.

• Reflectance based models perform well in the depth ranges of 3-20m, beyond which any algorithm fails to discern depths.

• SAR works on the assumption that the same train exists throughout the image, so that changes in wavelength are caused by changes in depth.

• Hugely depends on the availability of SAR data that clearly depicts waves in the imagery. The inconsistencies observed in the results are due to the lack or poor appearance of sea surface signature in the image.
Thank You
ankitamisra1987@gmail.com