DEVELOPMENT OF NEW RETRACKING METHODS FOR MAPPING SEA LEVELS OVER THE SHELF AREAS FROM SATELLITE ALTIMETRY DATA

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DECLARATION

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The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University’s Digital Repository**, subject to the provisions of the Copyright Act 1968.

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I hereby certify that the work embodied in this thesis contains a published paper/s/scholarly work of which I am a joint author. I have included as part of the thesis a written statement, endorsed by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.

‘I, Dr. Xiaoli Deng, attest that the Research Higher Degree Candidate, Nurul Hazrina Idris contributed as a joint author to the papers as listed in the list of publications’.

__________________________  _______________________
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September, 2014                  September, 2014
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ABSTRACT

Through research carried out in the last few years, sea level anomalies (SLAs) from altimeter range measurements have been improved in the near coastal zone between 50-100 km from the coastline using waveform retracking techniques. However, closer than about 10 km from the coastline, the improvement of altimetry data accuracy is still challenging due to the complex nature of the coastal topography and rougher coastal sea states. Although there is a healthy diversity of waveform retracking algorithms that have been beneficial to the coastal community, there is a lack of clear recommendations and guidelines on which retracker should be used under the various conditions. This dissertation presents a waveform retracking system that improves the accuracy of coastal altimetry data through the optimal selection and seamless switching of retrackers.

The principles of the system are twofold. The first is to reprocess altimeter waveforms using the optimal retracker, which is sought, based on the analysis from a fuzzy expert system. The second is to minimise the relative offset in the retrieved SLAs caused by switching from one retracker to another, using a neural network. With the retracking system, the risk of assigning the waveform to an inappropriate retracker is minimised by including information about the waveform shapes and statistical features of the retracking results in the fuzzy expert system. The system also reduces inconsistency in the retracked SLAs when switching retrackers by employing the neural network to handle the nonlinear relationship between the retracker and the scattering surface, thus providing seamless transition from the open ocean to coast, or vice versa.

The retracking system has been demonstrated to 20 Hz waveforms of Jason-1 and Jason-2/OSTM missions from 2009 to 2011. It has been applied to areas of the Great Barrier Reef in Australia and the Prince William Sound in Alaska. The regional investigations have demonstrated that the retracking system can effectively improve the quality of the altimeter derived SLAs in coastal regions. It reduces the standard deviation of the unretracked sea levels by up to 500 cm for Jason-1 and 300 cm for Jason-2. It extends the SLA profiles further (1-7 km) to the coastline and recovers up to 70% more data than the existing retrackers from the Sensor Geophysical Data Records.
Comparison with the SLAs from the tide gauges indicates that the SLAs from the retracking system are more reliable than those of from the SGDR products, in the sense that it has a higher (>0.8) temporal correlation and smaller (<17 cm) RMS errors. The retracked SLAs from the retracking system also produce reliable geostrophic velocities as they are consistent with those of the high frequency radar velocities in the Great Barrier Reef region. Comparison with the Regional Ocean Modelling System (ROMS) at Prince William Sound shows good agreement between the SLA patterns from the retracking system and the ROMS.

The results obtained in this dissertation, therefore, present a significant improvement in the accuracy and precision of the estimated SLAs and efficiently reduce the altimetry no-data gap in coastal regions. In addition, it also addresses the systematic validation protocol for validating the altimetry retracked SLAs using the HF radar in the region of the Great Barrier Reef, and using the ROMS in the region of Prince William Sound.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>AVISO</td>
<td>Archiving, Validation, and Interpretation of Satellite Oceanographic</td>
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<tr>
<td>AMSR-E</td>
<td>Advanced Microwave Scanning Radiometer Earth Observing System</td>
</tr>
<tr>
<td>COG</td>
<td>Gate Position of Centre Area</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
</tr>
<tr>
<td>EGM2008</td>
<td>Earth Gravitational Model</td>
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<tr>
<td>FES</td>
<td>Finite Element Solution</td>
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<td>FSSR</td>
<td>Flat Sea Surface Response</td>
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<td>GDR</td>
<td>Geophysical Data Record</td>
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<td>GIM</td>
<td>General Ionospheric Model</td>
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<tr>
<td>GOES</td>
<td>Geostationary Operational Environmental Satellite</td>
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<td>GOT</td>
<td>Global Ocean Tide Model</td>
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<tr>
<td>HF</td>
<td>High Frequency</td>
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<tr>
<td>IMOS</td>
<td>Integrated Marine Observing System</td>
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<td>IMP</td>
<td>Improvement of Percentage</td>
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<td>LEP</td>
<td>Leading Edge Position</td>
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<td>MLE</td>
<td>Maximum Likelihood Estimator</td>
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<td>MLF</td>
<td>Multi-layer Feed Forward</td>
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<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
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<td>MOG2D</td>
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<td>Acronym</td>
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<td>MSS</td>
<td>Mean Sea Surface</td>
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<td>OceanMAPS</td>
<td>Ocean Model Analysis and Prediction System</td>
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<td>OCOG</td>
<td>Offset Centre of Gravity</td>
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<td>OI</td>
<td>Optimal Interpolation</td>
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<td>PDF</td>
<td>Probability Density Function</td>
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<td>PTR</td>
<td>Radar Point Target Response</td>
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<td>PWS</td>
<td>Prince William Sound</td>
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<td>ROMS</td>
<td>Regional Ocean Modelling System</td>
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<td>RMS</td>
<td>Root Mean Square</td>
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<td>SGDR</td>
<td>Sensor Geophysical Data Record</td>
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<td>Significant Wave Height</td>
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<td>WRF</td>
<td>Weather Research and Forecasting</td>
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LIST OF SYMBOLS

B : Bandwidth of altimeter

c : Speed of light

H : Altimeter height above referenced ellipsoid

τ : Waveform epoch

H₀ : Distance between the satellite and nadir point

v : Spacecraft speed

σₚ : Width of the radar point target response function

rₜ : Time resolution

ξ : Off-nadir pointing angle

σₛ : Standard deviation of sea surface elevation related to significant wave height

I₀ : Bessel function

A : Waveform amplitude

G₀ : Gain of radar antenna

Lₚ : Two-way propagation loss

λ : Radar carrier wavelength

h : Modified satellite altitude

Rₜ : Radius of the Earth

γ : Antenna beam width parameter
\( P_N \): Waveform thermal noise

\( t \): Time of altimeter measurement

\( t_0 \): Arrival time of the half power point of the radar return

\( \sigma \): Waveform rise time

\( g_0 \): Expected tracking gate

\( T \): Altimeter sampling time

\( P_1 \): Waveform power

\( N \): Total number of samples in the waveform

\( n_1 \): Number of bins affected by aliasing at the beginning of the waveform

\( n_2 \): Number of bins affected by aliasing at the end of the waveform

\( W \): Width of waveform

\( \sigma_0 \): Sea surface roughness

\( T_h \): Threshold level

\( q \): Threshold value

\( G_r \): Retracking location on the leading edge of the waveform

\( G_k \): Location of the first gate exceeding threshold level

\( r^2 \): Square of correlation coefficient

\( C_{xy}^2 \): Covariance of variables \( x \) and \( y \)

\( S_x \): Standard deviation of variable \( x \)

\( S_y \): Standard deviation of variable \( y \)
\( \sigma_{\text{raw}} \): Standard deviations of the difference between raw SSHs and geoid heights

\( \sigma_{\text{retracked}} \): Standard deviations of the difference between retracked SSHs and geoid heights

\( x_k \): Vector of current weights

\( g_k \): Current gradient

\( \alpha_k \): Learning rate

\( \bar{a} \): Mean of samples a

\( \bar{b} \): Mean of samples b

\( n_a \): Size of sample a

\( n_b \): Size of sample b

\( s_a^2 \): Variance of samples a

\( s_b^2 \): Variance of samples b

\( \phi \): Degree of freedom

\( \alpha \): Significance level

\( \sigma_x \): Standard deviations of the differences between retracked SSHs before the offset reduction and geoid heights

\( \sigma_y \): Standard deviations of the differences between retracked SSHs after the offset reduction and geoid heights

\( k \): Number of clusters

\( z_k \): Cluster centres

\( \sigma^2 \): Kernel parameter
$x_i$: Set of data vectors

$y_i$: Class of data vectors

$\alpha_i$: Lagrange multipliers

$f_t$: Compressed pulse shape by a Gaussian function

$\mu_A(x)$: Membership function of set A

$u_g$: Surface velocity in a direction $90^\circ$ clockwise from the orbital track

$G$: Gravitational acceleration

$f$: Coriolis parameter

$y$: Along-track distance

$C$: Covariance of the variable being estimated with the data

$e_i$: Measurement error

$e_u$: Noise error

$\frac{\psi}{2}$: Variance of $\psi$

$C_{uu}$: Covariance in across-shelf direction

$C_{vv}$: Covariance in along-shelf direction

$C_{uv}$: Covariance in uv direction

$r$: Spatial separation

$\tau_0$: Surface wind stress

$A_v$: Eddy viscosity

$u$: Velocity in east-west direction
\textbf{v} : Velocity in north-south direction

\textbf{D}_E : Ekman depth

\textbf{z} : Water depth
LIST OF PUBLICATIONS


