Sensitivity of Satellite Altimetry Data Assimilation on a Naval Anti-Submarine Warfare Weapon System

Steven Mancini LCDR, USN
Advisor: Prof. Peter Chu
Second Readers: Dr. Charlie Barron
Eric Gottshall, CDR USN
Past Thesis: Michael Perry ENS, USNR
Collaborator: David Cwalina
Contents

• Purpose and Objective
• Past and Present Thesis Summaries
• MODAS Introduction & Field Comparison
• WAPP Introduction & Processing
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Purpose

• To define Navy altimeter requirements as a minimum number of satellite altimeters necessary to ensure maximum weapon effectiveness
• To determine the point at which additional altimeter input no longer increases weapon effectiveness
• Collaboration elements
Objective

• Identify the sensitivity of satellite altimetry data assimilation on weapon presets
  – To determine if further work should be done to assess the value of the altimetry data
Past Thesis

- Michael Perry, June 2003
- GDEM vs MODAS with 3 altimeters
  - March 15, 2001
  - 117 vs 1633 profiles
  - 35.0-40.0N
  - 70.0-75.0W
- Area coverage is an effective metric for comparing weapon presets
Future Projects Recommended by Past Thesis

• More Extensive Data Set
  – Observe changes over time and for different locations
  – Examine areas of strong thermal or salinity contrast

• Altimeter Investigation
  – Vary the number of altimeters and observe the effect on area coverage
  – Determine optimal number of altimeters required
Current Thesis

• Compared WAPP output using 2 MODAS fields
• Looked at 3 geographic areas at 2 different times of year
• Used relative difference in area coverage for quantifying the effect on weapon presets
Process Flowchart

- Satellite SST & SSH
- Satellite SST only
- MODAS
- WAPP
- Presets
- Relative Difference
Modular Ocean Data Assimilation System (MODAS)

• Analysis tool only, predictive capability using NCOM
• Dynamic climatology uses optimum interpolation to ingest
  – SSH and SST from satellites
  – In situ measurements (XBTs, CTDs)
• Produces
  – 3-D Temp grid up to 1/8 degree resolution using surface-subsurface regressions
  – 3-D Sal grid using T-S regressions
  – Derives density, sound speed, mixed layer depth, etc.
MODAS Flowchart

- Remote SST & SSH Obs
- First Guess Fields
- In Situ Temp Obs
- 2-D Gridded SST & SSH
- Surf-Sub Regression
- 3-D Temp Profiles
- OI
- Temp Analysis
- Temp-Sal Regression
- 3-D Sal Profiles
- In Situ Salinity Obs
- OI
- Salinity Analysis
MODAS results

Climatological Temp

AXBT Temp

SSH + SST + Clim

6-Aug-1995

Cold core eddy

MODAS Temperature at 200m
MODAS Fields

• 2 daily global MODAS fields
  – June 30, 2001
  – October 10, 2001

• 2 versions
  – one with assimilated data from 3 altimeters (TOPEX, GFO, and ERS-2)
  – one without altimeter data assimilated
Areas of Investigation

• 3 geographic areas (5 X 5 degree boxes)
  – Sea of Japan (SOJ)
    35-40N, 130-135E
  – East China Sea (ECS)
    30-35N, 125-130E
  – Kuroshio Current Area (KCA)
    30-35N, 135-140E

• 6 cases (2 days X 3 areas)

• Resulting input data set
  – 4,379 pairs of water column profiles for each day
Comparison of MODAS Fields

- Compared fields at each horizontal grid point and depth ($\Delta X_i$)
- Computed volumetric
  - Mean $\Delta X_i$ (bias)
  - $\Delta X_i$ standard deviation

- RMSD =

- Created scatter plots, histograms and horizontally averaged bias and RMSD vertical profiles
Weapon Acoustic Preset Program (WAPP)

• Naval Undersea Warfare Center, Division Newport
• Generates Mk 48 torpedo acoustic presets
• Visualize predicted torpedo performance
WAPP Composition

- Graphical user interface (GUI)
  - Entering of environmental, tactical, target, and weapon data
- Computational engine
  - Generating acoustic performance predictions
- Output
  - A ranked listset
  - Acoustic ray traces
  - Signal excess maps
Environmental Data Entry (EDE) Window

- Water column parameters
  - T, S, Sound Spd, VSS
- Surface conditions
  - WS, WH, Sea State
- Bottom conditions
  - Depth, type
Presetting Process

- **SA selection algorithm**
  - Identifies optimal pitch angle for each search depth
- **Ray trace**
  - Range-independent ray propagation model accounts for spreading, refraction, volume absorption, boundary interactions
  - Fan of rays bound torpedo beam pattern
- **Signal excess map**
  - Uses monostatic, active sonar equation (reverb limited):
    \[ \text{SL} - 2\text{TL} + \text{TS} - \text{RL} - \text{DT} = \text{SE} \]
WAPP Ranked Listset

- Listset of search depth/pitch angle/laminar distance/effectiveness
- Listset ranked based on acoustic effectiveness (area coverage) and recommendation made accounting for cavitation and depth separation
Ray Trace Display
Signal Excess Map
Generated Output

• NUWC routine fed MODAS T,S fields into WAPP
  – grid point by grid point (bypassing EDE)
• 5 tactical scenarios run for each case:
  – ASW with low Doppler, deep target
  – ASW with high Doppler, deep target
  – ASW with low Doppler, shallow target
  – ASUW with low Doppler target
  – ASUW with high Doppler target
• 30 scenarios (6 cases X 5 tactics)
• Presetting process repeated for each grid point in each scenario → over 43,000 listset pairs!
Analysis of Output

• Used a statistical software package to compare listsets
  – Used relative difference (RD) in area coverage
  – Area coverage (AC)
    • Fraction of the search region with signal excess greater 0 dB (i.e., better than a 50% p(D))
    – \( \text{RD} = \frac{|AC_1 - AC_2|}{AC_1} \)
  – Only considered different SD/SA combinations chosen by WAPP

• Generated a histogram for each scenario
  – Shows the number of combinations that fall into set RD ranges
  – Calculated mean RDs, Prob(RD>0.1) and Prob(RD>0.2)
WAPP Output General Stats

Largest ASW values

Largest ASUW values

RD Probabilities

Mean RDs

Prob (RD > 0.1) - Prob (RD > 0.2)
ASW Histograms for KCA Jun

Histogram for KCA on June 30 (LD Deep ASW)
- Prob (RD > 0.1) = 37.5%
- Prob (RD > 0.2) = 6.44%
- Prob (RD > 0.5) = 0%
- Mean RD = 0.0925
- RD SD = 0.0628

Histogram for KCA on June 30 (HD Deep ASW)
- Prob (RD > 0.1) = 39.3%
- Prob (RD > 0.2) = 6.63%
- Prob (RD > 0.5) = 0%
- Mean RD = 0.0924
- RD SD = 0.0656

Histogram for KCA on June 30 (LD Shallow ASW)
- Prob (RD > 0.1) = 46.8%
- Prob (RD > 0.2) = 8.46%
- Prob (RD > 0.5) = 0%
- Mean RD = 0.102
- RD SD = 0.0665
Temperature Statistics for KCA
Jun 30

Scatter Plot

Histogram

Bias

Root Mean Square Difference (RMSD)

Mean = 0.254
SD = 1.56
RMSD = 1.58

Temperature Bias (C)

Depth (m)

Temperature RMSD (C)

Depth (m)
Comparison of Temperature at 400 m on Jun 30, 2001

MODAS Temperature WITH Altimeters

MODAS Temperature WITHOUT Altimeters
Sound Speed Statistics for KCA
Jun 30

Scatter Plot

MODAS Sound Speed (m/s) without Altimeters

MODAS Sound Speed (m/s) with Altimeters

Histogram

Mean = 0.24
SD = 1.6
RMSD = 1.62

Bias

Depth (m)

Root Mean Square Difference (RMSD)

Depth (m)

Sound Speed Bias (m/s)

Sound Speed RMSD (m/s)
Sound Speed Profiles for KCA

Jun 30

Position: 33.75N, 135E

Position: 33.75N, 137.5E

Position: 33.75N, 140E

Position: 32N, 135E

Position: 32N, 137.5E

Position: 32N, 140E

Position: 30N, 135E

Position: 30N, 137.5E

Position: 30N, 140E

Sound Speed (m/s)

Depth (m)

WITH altimeters

WITHOUT altimeters
ASUW Histograms for SOJ Oct 10

**Histogram for SOJ on October 10 (HD ASUW)**

- Prob (RD > 0.1) = 91.5%
- Prob (RD > 0.2) = 84.1%
- Prob (RD > 0.5) = 1.82%
- Mean RD = 0.303
- RD SD = 0.12

**Histogram for SOJ on October 10 (LD ASUW)**

- Prob (RD > 0.1) = 81.8%
- Prob (RD > 0.2) = 62.3%
- Prob (RD > 0.5) = 1.01%
- Mean RD = 0.241
- RD SD = 0.131
Temperature Statistics for SOJ
Oct 10

Scatter Plot
MODAS Temperature (C) without Altimeters vs. MODAS Temperature (C) with Altimeters

Histogram
Number of Occurrences vs. Temperature Difference (C)
Mean = 0.867
SD = 1.53
RMSD = 1.76

Bias
Depth (m) vs. Temperature Bias (C)

Root Mean Square Difference (RMSD)
Depth (m) vs. Temperature RMSD (C)
Comparison of Temperature at 100 m on Oct 10, 2001

MODAS Temperature WITH Altimeters

MODAS Temperature WITHOUT Altimeters
Sound Speed Statistics for SOJ
Oct 10

Scatter Plot

Histogram

Mean = 0.813
SD = 1.46
RMSD = 1.67

Bias

Root Mean Square Difference (RMSD)
Sound Speed Profiles for SOJ

Oct 10

Position: 40N, 130E

Position: 40N, 132.5E

Position: 40N, 135E

Position: 38N, 130E

Position: 38N, 132.5E

Position: 38N, 135E

Position: 36N, 130E

Position: 36N, 132.5E

Position: 36N, 135E

Sound Speed (m/s)

Depth (m)

WITH altimeters

WITHOUT altimeters
## Sensitivity Table

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Prob(RD&gt;0.1)</th>
<th>Prob(RD&gt;0.2)</th>
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<tr>
<td>ECS Jun HD Deep ASW</td>
<td>17.5</td>
<td>2.6</td>
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<tr>
<td>ECS Jun LD Deep ASW</td>
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<td>KCA Jun LD Deep ASW</td>
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Conclusions

• WAPP output is sensitive to satellite altimetry data assimilation
  – Especially when MODAS fields differ significantly in the depth zone of interest (due to better depiction of mesoscale features by the field with altimetry)

• Satellite altimeter data contributed as much as an 80-90% chance of having a different engagement outcome
  – Assuming RD of 0.1-0.2 in AC is enough
Recommendations

• Proceed with the next step
  – Value is related to positive affect on outcome (hit versus miss)

• Perform a study that compares WAPP output using MODAS fields and in situ measurements
  – Ultimate MODAS verification
  – To correlate satellite data value to predicted real world performance

• Perform hardware-in-the-loop simulations
  – To compare hit-miss ratios using presets generated in above experiment for MODAS fields and “reality”

• Vary the number of altimeters assimilated
  – To answer the “how many are required” question
Recommended Future Work

**PART 1**
- Satellite SST & SSH
- MODAS
- WAPP
- In situ obs
- Presets

**PART 2**
- Hardware-in-the-loop simulations
- Hit-miss ratio
- Hit-miss ratio
- Hit-miss ratio
- Presets
Questions?