Satellite Data Assimilation for Naval Undersea Capability

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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
Modular Ocean Data Assimilation System (MODAS)

- 100 Separate programs
- Dynamic Climatology
- Relocatable Princeton Ocean Model
- SSH and SST from satellite altimeters
- 1/8 Degree Resolution
U.S. Navy’s MODAS System for Satellite Data Assimilation
MODAS

200 m temperature Climatology

MODAS including MCSST does not significantly alter climatology

SSH reveals concealed ocean environment

Points: AXBT Line Mesoscale Eddy
MODAS

Climatological Temp

AXBT Temp

SSH + SST + Clim

MODAS results

Cold core eddy

MODAS Temperature
at 200m
Working Hypothesis

• MODAS with all satellite data assimilated provides more realistic ocean environment.

• Difference in weapon acoustic preset between using MODAS with Satellite and MODAS without satellite indicates the value-added of satellite data
Procedures

• Compared 2 MODAS fields (with and without satellite data assimilation)

• Used a different metric for quantifying the effect on weapon presets
Environmental Fields

• 2 MODAS data fields
  – one with assimilated data from 3 altimeters (TOPEX/Poseidon, GFO, and ERS-2)
  – one without altimeter data assimilated

• 2 dates
  – June 30, 2001
  – October 10, 2001

• 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

• Resulting data set
  – 4,379 water column profiles
Areas of Investigation
Comparison of Sea Surface Temperature on Jun 30, 2001

MODAS Temperature WITH Altimeters

MODAS Temperature WITHOUT Altimeters
Comparison of Temperature at 100 m on Jun 30, 2001

MODAS Temperature WITH Altimeters

MODAS Temperature WITHOUT Altimeters
Comparison of Temperature at 400 m on Jun 30, 2001
Temperature Statistics for Japan/East Sea (JES)
June 30, 2001

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

Histogram
Temperature Difference
Mean = -0.271
SD = 1.15
Number of Occurrences

Bias
Temperature Bias (°C)

Root Mean Square Error (RMSE)
Temperature RMSE (°C)

Bias vs. Depth (m)
Root Mean Square Error (RMSE) vs. Depth (m)
Temperature Statistics for ECS
Jun 30, 2001

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

Histogram
Number of Occurrences vs. Temperature Difference
Mean = -0.628
SD = 0.929

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

Root Mean Square Error (RMSE)
Depth (m) vs. Temperature RMSE (C)
Temperature Statistics for KCA
Jun 30, 2001

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

Histogram
Number of Occurrences vs. Temperature Difference
Mean = 0.254
SD = 1.56

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

Root Mean Square Error (RMSE)
Depth (m) vs. Temperature RMSE (C)
Sound Speed Statistics for JES
Jun 30, 2001

Scatter Plot
MODAS Sound Speed (m/s) with Altimeters
MODAS Sound Speed (m/s) without Altimeters

Histogram
Number of Occurrences
Sound Speed Difference (m/s)
Mean = -0.283
SD = 1.11

Bias
Depth (m)
Sound Speed Bias (m/s)

Root Mean Square Error (RMSE)
Depth (m)
Sound Speed RMSE (m/s)
Sound Speed Statistics for ECS
Jun 30, 2001

Scatter Plot
MODAS Sound Speed (m/s) with Altimeters vs. MODAS Sound Speed (m/s) without Altimeters

Histogram
Mean = -0.643
SD = 0.922

Bias
Depth (m)

Root Mean Square Error (RMSE)
Depth (m)
Sound Speed Statistics for KCA
Jun 30, 2001

Scatter Plot
MODAS Sound Speed (m/s) with Altimeters
MODAS Sound Speed (m/s) without Altimeters

Histogram
Mean = 0.24
SD = 1.6

Bias
Sound Speed Bias (m/s)

Root Mean Square Error (RMSE)
Sound Speed RMSE (m/s)
Processing

• Naval Undersea Warfare Center Division Newport

• Weapon Acoustic Preset Program (WAPP)
  – Mk48 Acoustic Preset Calculation
  – Output: Percentage Area Coverage
Development Efforts Background

- Torpedo Acoustic & Ballistic Preset Development Efforts Performed by NUWC DIVNPT, Combat Systems Department, Weapon Guidance and Control Branch (Code 2213)
- Additional Tactical Decision Aid and Modeling Development Efforts for Harpoon, Tomahawk, SLMM, ISLMM
- Points of Contact:
  - Gene Bessacini: bessaciniea@npt.nuwc.navy.mil
  - David Cwalina: cwalinads@npt.nuwc.navy.mil
Weapon Acoustic Preset Program (WAPP) Objectives

• To Provide the Fleet with an On-Board Automated Interactive Means for Generating Mk 48 & Mk 48 ADCAP Acoustic Presets and Visualizing Torpedo Performance
• Base Computations on In Situ Environmental, Tactical, Target, and Weapon Parameters
• Track the Evolution of Weapon, Tactical, Target, and Environmental Models
• Provide Interfaces to
• Support Fleet Exercises, Training, and Program Deliveries
Acoustic Preset Program

• Mk 48 Acoustic Preset Program (M48APP)—Mk 48 Mod 3/4
• Mk 48 ADCAP Acoustic Preset Program (MAAPP)—ADCAP Baseline, Shallow, TPU
• Weapon’s Acoustic Preset Program (WAPP)—Integrated Mk 48 and Mk 48 ADCAP Capability
• Programs Provide a Presetting Capability Based Upon:
  • A Common Graphics User Interface for the Entry of Environmental, Tactical, Target, and Weapon Data
  • A Common Computational Engine for the Generation of Accurate Acoustic Performance Predictions
  • Common Output in the Form of a Ranked Listset of Search Depth/Pitch Angle/LD/Effectiveness Values Along With an Acoustic Ray Trace and Signal Excess Map
  • Mk 48 Mod Specific Presets/Vehicle Dynamics/Acoustics & Signal Processing
Program Evolution

• Initial Development of Mk 48 ADCAP Acoustic Preset Program to Support ADCAP Block I
• Incorporation of Shallow Water and Under Ice Capability
• Development of Mk 48 Mod 3/4 Presetting Capability
• Development of ADCAP Block II/Block IIA Capability
• Merge of
• High Frequency Environmental and Acoustic Sub-Model Update
Support Status

• Royal Australian Navy—Mk 48 Acoustic Preset Program Part of Collins Class Augmentation System (CCAS)
  – HP TAC-3/4 Host under Unix
  – Configuration Managed Under Product Version Control (PVC)
  – Application Embedded in Overall Architecture
  – Documentation and Training Provided
  – Provides Environmental Data Entry for CCAS
  – Interfaces to Other Tactical Systems Specified
• Royal Canadian Navy—Mk 48 Acoustic Preset Program Rearchitected for Java
  – PC version under development
Environmental Data Entry (EDE) Module

- Graphic Interface for Entry & Examination of Sound Speed Profile (Depth, Temperature, Sound Speed, Volume Scattering, Salinity) and Entry of Sea Surface/Sea Bottom Conditions
- Module Provides Manual Entry of Environmental Data for Op Area
  - US Systems Have Interface to Environmental Databases to Import System or Projected Environment
  - RAN Tactical Support System has Specification for Interface to Tactical Environment Sub-System (TESS) in Place
- Environmental Data is Associated to Preset Lists for Direct Recall of Computations
EDE Sea Surface Conditions

- Wind Speed/Wave Height/Sea State Coupled for Entry of Any Value
- Coupled By World Meteorological (WMO) or Beaufort Scale Convention
- Supports Sea States (0-9 WMO, 0-12 Beaufort) & Ice Cover
WAPP
Environmental Data Entry (EDE) Module

- Sea Bottom Conditions
- Bottom Depth (Any Depth Shallower Than Last Point in Sound Speed Profile (SSP))
- Bottom Type
  - Mud/Sand (Lossy Bottoms)
  - Clay
  - Gravel
  - Rock
EDE

Water Column Characteristics

- Water Column Characteristics
- Sound Speed Profile
  - Depth (ft/m)
  - Temperature (°F/°C)
  - Sound Speed (ft/sec, m/sec)
  - Volume Scattering Strength (VSS) (dB)
  - Salinity (ppt)
- Entry of Temperature or Sound Speed Supported With Computation of Unknown Quantity
EDE

Additional Fields

- Profile Name: Character String
- Table Group Identifier Associated with Profile
- Default Volume Scattering Strength (dB)
- Default Salinity (ppt)
- Lat/Long

Profile: default
DTG:

Table Group Identifier
Surfaced Target 3
Submerged Target 3

Default Conditions
VSS Background (dB): -75.00
Salinity: 35.00
Latitude: 45:00:00N
Longitude: 000:00:00E
# Acoustic Preset Module Display

![Acoustic Preset Module Display](image)

<table>
<thead>
<tr>
<th>Settings</th>
<th>Selected</th>
<th>Computed</th>
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<tr>
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<tr>
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<td>SD</td>
<td></td>
</tr>
<tr>
<td>Pitch Angle (deg)</td>
<td>PA</td>
<td></td>
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<tr>
<td>Ceiling (m)</td>
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<tr>
<td>Floor (m)</td>
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<td>Doppler Enable</td>
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<tr>
<td>Acoustic Search</td>
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</tr>
<tr>
<td>Trajectory Mode</td>
<td>Direct</td>
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<tr>
<td>Speed Combo</td>
<td>Hi/Mod</td>
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<tr>
<td>Ping interval</td>
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<tr>
<td>Search Mode</td>
<td>Snake</td>
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<td>Ast</td>
<td>In</td>
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<tr>
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<tr>
<td>NTS / NZE (dB)</td>
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<td>Laminar Dist (m)</td>
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<tr>
<td>Effectiveness</td>
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</table>

## Table Group Identifier

<table>
<thead>
<tr>
<th>SD</th>
<th>PA</th>
<th>LD</th>
<th>EFF</th>
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<tbody>
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<td>PA1</td>
<td>LD1</td>
<td>EFF1</td>
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<tr>
<td>SD5</td>
<td>PA5</td>
<td>LD5</td>
<td>EFF5</td>
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</tbody>
</table>

## Messages

- Must Compute Acquisition First
- Select Compute Presets
Acoustic Preset Module

Preset Computation

• Compute Presets Selection Sets
  Weapon Default Presets Based Upon
  Tactical Guidance, Determines Valid
  Search Depth/Search Angle
  Selections, Ranks and Recommends
  Settings

• Rerank Allows for Deviation from
  Default Presets in the Computation of
  Presets

• Acquisition Allows User to Evaluate
  Any Allowable Preset Combination
  Via Ray Trace/Signal Excess Map
Acoustic Preset Module

Tactical Presets

• Entry of Tactical Preset Values via Pull-Down Menus Configured for Mod 3/4

• Sub-Set of Total Tactical Presets Used in Acoustic Preset Computations

• Remaining Tactical Presets Entered to Complete Tactic List for Transfer to Combat Control System

<table>
<thead>
<tr>
<th>Target Mode</th>
<th>Sub</th>
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<tbody>
<tr>
<td>Search Depth (m)</td>
<td>SD</td>
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<tr>
<td>Pitch Angle (deg)</td>
<td>PA</td>
</tr>
<tr>
<td>Ceiling (m)</td>
<td>10</td>
</tr>
<tr>
<td>Floor (m)</td>
<td>200</td>
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<td>Doppler Enable</td>
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<td>Acoustic Search</td>
<td>Active</td>
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<td>Speed Combo</td>
<td>Hi/Med</td>
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<td>Ping Interval</td>
<td>Long</td>
</tr>
<tr>
<td>Search Mode</td>
<td>Snake</td>
</tr>
<tr>
<td>Ash</td>
<td>In</td>
</tr>
</tbody>
</table>
Acoustic Preset Module
Target Data

- Target Maximum Operating Depth Based on Target Classification
  - Limits Vertical Area Used in Acoustic Preset Computations
- Depth Zone of Interest (DZOI) Allows for Further Restriction of Target Region Based on Target Operating Characteristics
- Acoustic Target Strength (NTS dB)/Radiated Noise (NZE dBs)
- Anticipated Target Doppler (DIW, Low, High)
Acoustic Preset Module
Ranked Listset

- List Set of Search
  Depth/Pitch Angle/Laminar
  Distance/Effectiveness
  Values

- List Set Ranked Based on
  Acoustic Coverage
  Effectiveness and
  Recommendation Made
  Accounting for Cavitation and
  Depth Separation

- Laminar Distance Utilized in
  Weapon Order Generation
  for Gyro/RTE

<table>
<thead>
<tr>
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<th>LD</th>
<th>EFF</th>
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<tbody>
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<td>SD1</td>
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<td>SD2</td>
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<td>EFF2</td>
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<tr>
<td>SD3</td>
<td>PA3</td>
<td>LD3</td>
<td>EFF3</td>
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<td>PA4</td>
<td>LD4</td>
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<tr>
<td>SD5</td>
<td>PA5</td>
<td>LD5</td>
<td>EFF5</td>
</tr>
</tbody>
</table>
Acoustic Preset Module Tactic Lists

- Module Provides Capability to Store and Recall Tactical Preset Lists Along with Environmental Data, Scenario and Listset Data
- Data is Stored Local to Weapon’s Module
- Lists May Be Transferred Via Network to Combat Control System
  - RAN Implementation Has Specification for Transfer to Engagement Sub-System (ESS)
  - Additional Window for Parameterization of Scenario/Environment for Transfer to Engagement Sub-System (ESS)
Ray Trace Display
Acoustic Preset Module
Ray Trace Display

- Ray Trace Selectable from Pull-Down Menu
- Provide a Visual Interpretation of Mk 48 Acoustic Performance
- Impact of Boundary Interactions and Refraction Shown
- Variable Target Depth Bands (Near-Surface, Depth Zone of Interest, Target Max Depth)
- Effects of Reverberation Apparent for Low Doppler Targets
Signal Excess Display

Legend:
- Magenta: 0 dB < Sig Ex < 4 dB
- White: 4 dB < Sig Ex
- Orange: Time Delay

Display Scale (m): 610

Bottom Type: Sand
Sea State: 1
DZOI Eff
Effectiveness: 69.46
Laminar Distance: 2164
Acoustic Preset Module
Signal Excess Display

- Signal Excess Selectable from Pull-Down Menu
- Provide a Visual Interpretation of Mk 48 Acoustic Performance Over Depth Band of Target
- Effects of Ray Bending Apparent
- Effects of Reverberation Apparent for Low Doppler Targets
• **Coverage Area**
  – Percentage of the search region with signal excess greater than a chosen threshold

• **5 Tactics Were Explored:**
  – ASW with low Doppler, deep target
  – ASW with high Doppler, deep target
  – ASW with low Doppler, shallow target
  – ASUW with low Doppler, shallow target
  – ASUW with high Doppler, shallow target

• **Values Normalized Over Acoustic Modes**
Analysis of Output

• Used a statistical software package to determine relative error (RE) in coverage area produced by the 2 different input fields
  – Compared coverage areas with positive signal excess
  – Only considered cases where a different search depth/angle combination was chosen by the WAPP

• Generated histograms that show the number of these combinations that fall into set RE ranges
  – Done for each region, time, and tactic
East China Sea (June) HD ASUW

Histogram for East China Sea in June (HD ASUW)

- Prob (RE > 0.1) = 39.6%
- Prob (RE > 0.2) = 19.6%
- Prob (RE > 0.5) = 0.282%
- Mean RE = 0.111
- RE SD = 0.0989
Kuroshio Region (June) HD Deep ASW

Histogram for Kuroshio Current Area in June (HD Deep ASW)

- Prob (RE > 0.1) = 39.3%
- Prob (RE > 0.2) = 6.63%
- Prob (RE > 0.5) = 0%
- Mean RE = 0.0924
- RE SD = 0.0656
Kuroshio Region (June) LD Shallow ASW

Histogram for Kuroshio Current Area in June (LD Shallow ASW)

Number of Search Depth-Angle Combinations

Relative Error

Prob (RE > 0.1) = 46.8%
Prob (RE > 0.2) = 8.46%
Prob (RE > 0.5) = 0%
Mean RE = 0.102
RE SD = 0.0665
Histogram for Kuroshio Current Area in June (HD ASUW)

- Prob (RE > 0.1) = 56%
- Prob (RE > 0.2) = 30.2%
- Prob (RE > 0.5) = 0.0544%
- Mean RE = 0.145
- RE SD = 0.109

Kuroshio (June) HD ASUW
Histogram for Kuroshio Current Area in June (LD ASUW)

Prob (RE > 0.1) = 43.6%
Prob (RE > 0.2) = 17.2%
Prob (RE > 0.5) = 0.0378%
Mean RE = 0.109
RE SD = 0.0817
JES (October) LD Deep ASW

Histogram for Sea of Japan in October (LD Deep ASW)

Prob (RE > 0.1) = 26.6%
Prob (RE > 0.2) = 4.41%
Prob (RE > 0.5) = 0%
Mean RE = 0.0777
RE SD = 0.0569
Histogram for Sea of Japan in October (LD Shallow ASW)

Prob (RE > 0.1) = 36.7%
Prob (RE > 0.2) = 8.79%
Prob (RE > 0.5) = 0%
Mean RE = 0.0921
RE SD = 0.0726
Histogram for Sea of Japan in October (HD ASUW)

Prob (RE > 0.1) = 91.5%
Prob (RE > 0.2) = 84.1%
Prob (RE > 0.5) = 1.82%
Mean RE = 0.303
RE SD = 0.12
Histogram for Sea of Japan in October (LD ASUW)

- Prob (RE > 0.1) = 81.8%
- Prob (RE > 0.2) = 62.3%
- Prob (RE > 0.5) = 1.01%
- Mean RE = 0.241
- RE SD = 0.131

Number of Search Depth-Angle Combinations

Relative Error
East China Sea (October) HD ASUW

Histogram for East China Sea in October (HD ASUW)

Prob (RE > 0.1) = 49.2%
Prob (RE > 0.2) = 14%
Prob (RE > 0.5) = 0%
Mean RE = 0.11
RE SD = 0.0751
East China Sea (October) LD ASUW

Prob (RE > 0.1) = 51.9%
Prob (RE > 0.2) = 25.4%
Prob (RE > 0.5) = 0.987%
Mean RE = 0.142
RE SD = 0.127
Kuroshio (October) HD Deep ASW

Histogram for Kuroshio Current Area in October (HD Deep ASW)

- Prob (RE > 0.1) = 35.7%
- Prob (RE > 0.2) = 4.53%
- Prob (RE > 0.5) = 0%
- Mean RE = 0.0861
- RE SD = 0.0588
Kuroshio (October) LD Deep ASW

Histogram for Kuroshio Current Area in October (LD Deep ASW)

Prob (RE > 0.1) = 33.5%
Prob (RE > 0.2) = 3.38%
Prob (RE > 0.5) = 0%
Mean RE = 0.0834
RE SD = 0.0568
Histogram for Kuroshio Current Area in October (LD Shallow ASW)

- Prob (RE > 0.1) = 50.7%
- Prob (RE > 0.2) = 8.34%
- Prob (RE > 0.5) = 0%
- Mean RE = 0.106
- RE SD = 0.0632
Kuroshio (October) HD ASUW

Histogram for Kuroshio Current Area in October (HD ASUW)

- Prob (RE > 0.1) = 43.6%
- Prob (RE > 0.2) = 8.51%
- Prob (RE > 0.5) = 0.0232%
- Mean RE = 0.0997
- RE SD = 0.0689
Histogram for Kuroshio Current Area in October (LD ASUW)

Prob (RE > 0.1) = 47.5%
Prob (RE > 0.2) = 6.93%
Prob (RE > 0.5) = 0.0682%
Mean RE = 0.103
RE SD = 0.0679
Conclusions

• Coverage area with positive signal excess is an effective metric for comparing weapon presets.
• Large difference was found in the weapon acoustic preset using MODAS with satellites and MODAS without satellite.
• This may imply the importance of satellite altimetry (such as GFO) for Naval operations.
Future Projects

• 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
Questions?