Focused Acoustic Forecasting-05 (FAF05): Real-Time Physical-Acoustical Modeling, Predictions and Adaptive Sampling

Pierre F.J. Lermusiaux, Ding Wang (MIT)
P.J. Haley, Jr., W.G. Leslie, H. Schmidt et al.

NURC: E. Coelho, E. Nacini and A. Cavanna
Cro. Met. Service: M. Tudor
HU: A. Robinson

http://www.deas.harvard.edu/~leslie/FAF05/

1. Collaborative Goals and Objectives
2. Results and Accomplishments
3. Methodology and Conclusions

MIT, FAF-05 Hot-Wash-up, Sept 12, 2005
FAF-05: Collaborative Goals and Objectives

Emphasis on methodology development and engineering tests

- Develop new algorithms and software for initiating the coupling of Harvard and MIT methodologies/software
  - HU real-time ocean environmental modeling, uncertainty prediction and adaptive sampling methodologies
  - MIT adaptive rapid environmental assessment and acoustic predictions
- Test and improve these algorithms and software in real-time
- Issue physical-acoustical adaptive sampling recommendations every day, aiming to
  - Capture the vertical variability of the thermocline (due to fronts, eddies, internal waves, etc)
  - Minimize the corresponding uncertainties.
Adaptive sampling plans are computed based on 1-to-2 days environmental forecasts of fields and uncertainties.
Adaptive Sampling in Vertical Cross-Sections

AUV-Track Base Lines - For - Specific Sound-speed Features

Base Lines

Composite Base Lines

Thermocline

Eddy

Internal Wave
FAF-05: Major Harvard-MIT Accomplishments

• **Initiated coupling of Harvard and MIT methodologies/software**
  - Ocean environmental fields and uncertainties predicted daily by HOPS’ ocean model and ESSE approach
  - Ensemble (various scenarios) of 0.5-2 days predictions of sound-speed sections computed and transferred to Ding Wang
  - Corresponding ensemble of acoustic TLs computed using RAM
  - Sound-speed sections and TL curves were input to Ding’s optimization algorithm, to estimate ideal parameters for the AUV’s yoyo sampling of the next 1-2 day(s)

• **Issued physical-acoustical adaptive sampling recommendations every day**, aiming to
  - Capture the vertical variability of the thermocline, due to: daily cycle, atmospheric-driven vertical mixing and mesoscale features (eddies, etc)
  - Minimize the corresponding uncertainties.
Data sources indicated are:

- GEBCO isobaths
- coastlines
- soundings ("spot depths")
- DBDBV 1 minute bathymetry
- GLOBE 30 second elevation
Historical and Synoptic Ocean Data, Atmospheric Forcing

Historical Data
• MREA03/BP03: Real-Time Mini-HOPS modeling in the Ligurian Sea/Elba. May-June 2003

Synoptic Data (FAF05)
• R/V Leonardo-AUVs: Sound-speed profiles east of Pianosa
• R/V Alliance: CTD profiles, Meteo Data
• NURC: Satellite Sea surface Temperature (SST)

Atmospheric Forcing (Ocean-Atmos. Fluxes)
• Cro. Met. Service: Aladin forecasts and analyses (~ 8 km resolution)
• FNMOC: Coarse resolution forecasts and analyses
• NURC: COAMPS forecasts and analyses
Satellite Sea Surface Temperature (SST):

- 24 July - 0443
- 25 July - 0418
- 25 July - 2108

Day-by-day variability

Day-light warming & skin effects

http://people.deas.harvard.edu/~leslie/FAF05/AVHRR/index.html
HOPS’ Ocean Dynamics Model: Primitive-Equations

Fundamental equations are Navier-Stokes in rotating frame of reference.

Additional practical assumptions limit the range of modeled scales in time and space:
1. Boussinesq fluid (small variations of density about a state of reference)
2. Turbulent flow reduced to scale window of interest, here:
   - Sub-mesoscale, mesoscale to large-scale ocean processes
   - Processes outside this window are averaged and their effects parameterized (turbulent closures)
3. Thinness approximation (H/L << 1)

Result: the so-called Primitive-Equations of Ocean Dynamics
High-Resolution Nested Ocean Modeling Domains

<table>
<thead>
<tr>
<th></th>
<th><strong>Mini-HOPS</strong></th>
<th><strong>Elba</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resolution</strong></td>
<td><strong>100m</strong></td>
<td><strong>300m</strong></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>$nx \times ny \times nz$</td>
<td></td>
</tr>
<tr>
<td><strong>Extent</strong></td>
<td>$8.8 \times 11.3 \text{ km}$</td>
<td>$31.5 \times 37.5 \text{ km}$</td>
</tr>
<tr>
<td><strong>Domain center</strong></td>
<td>$42.59^\circ \text{N}, 10.14^\circ \text{E}$</td>
<td>$42.63^\circ \text{N}, 10.24^\circ \text{E}$</td>
</tr>
<tr>
<td><strong>Domain rotation</strong></td>
<td>$0^\circ$</td>
<td>$0^\circ$</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>$dt=50s$, 90 minutes/(model day)</td>
<td>$dt=300s$, 120 minutes/(model day)</td>
</tr>
<tr>
<td></td>
<td>$dt=300s$, 15 minutes/(model day)</td>
<td>$dt=300s$, 20 minutes/(model day)</td>
</tr>
</tbody>
</table>
Characteristic Acoustic Sections
Small Ensemble of Acoustic Sections, Created based on Different scenarios

Here, different atmospheric forcing and SST assimilation

**Scenario 1**
Realizations of section 1 (10.105,42.59 ; 10.122,42.6)

**Scenario 2**
Realizations of section 1 (10.105,42.59 ; 10.122,42.6)
Day-to-day Variability Significant in Sound-speed Sections

Due to: Atmospheric forcing, Mesoscale oceanography, Daily cycle, etc.

July 23:

Early Morning  
Afternoon

Here: due to the predicted stronger winds in 23-24 July, sound speeds reduced in the surface and the thermocline deepened.

July 24:

Early Morning  
Afternoon
Result Example:
Horizontal Maps of Fcst T and Currents (25 Jul)

Pianosa Domain
(100 m res.)

Corresponding FAF05 Sections

http://people.deas.harvard.edu/~leslie/HOPS/HOPS.html
Result Example:
Horizontal Maps of Fcst T and Currents (25 Jul)

Elba Domain (300 m res.)

SST: 25 July - 0418

Corresponding satellite SST

http://people.deas.harvard.edu/~leslie/HOPS/HOPS.html
Legend:
• Blue line is the forward path.
• Green line is the backward path.
• AUV avoids surface/bottom by turning 5 m before surface/bottom

Example of Results of Yoyo Control
Jul 20-21: showing AUV capture of "afternoon effects"
FAF-05: Methodology and Daily Protocols

- Ocean physics nested model (Mini-HOPS) used for 4d predictions, initialization and data assimilation via Optimal Interpolation
  - Assimilated satellite SST snapshots. Utilized synoptic sound speed profiles for tuning/evaluation.
  - Ocean model forced by high resolution atmospheric fluxes.

- Environmental uncertainties estimated based on various scenarios
  - Computed daily as a function of different initial condition estimates, assimilation procedures, modeling domains, numerical/physical model parameters, and time of day.

- Ensemble of acoustic predictions (RAM) computed for ensemble of sound speed predictions (in interpolated sections)

- Optimized AUV yoyo parameters to capture the vertical variability of the thermocline (due to fronts, eddies, internal waves, etc) and minimize the corresponding uncertainties

- Optimal sampling parameter estimates and corresponding environmental and acoustical predictions emailed daily to the FAF05-MIT team at-sea aboard the R/V Leonardo