Acoustic Energy Propagation in the Ocean Along Areas of Strong 4-Dimensional Sound Speed Variability

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The ocean is subject to complex dynamics that can produce time variant sound speed gradients with horizontal scales with potential to impact medium to high frequency acoustic propagation. Some of these features can critical grazing angles that may result in horizontal sound refraction, producing areas of stronger and weaker energy, time delays in the acoustic arrivals and changes on multi-path characteristics. The operational ocean forecast systems have skills to resolve some of these processes, but the acoustic propagation modeling solutions need to be able to handle these complex sound speed fields in order to reproduce the resulting sharp loss/gain changes along levels and directions (3D effects). These features can impact the accuracy of algorithms estimating source localization or doing ocean tomography and data assimilation.

US East Coast Example (US Navy NCOM ocean simulations)

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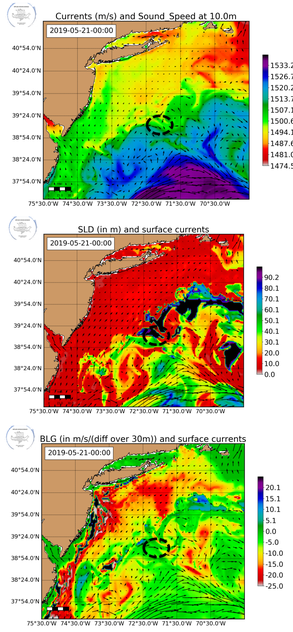

9 hours snapshot intervals of commonly used variables to create acoustic impacts awareness (Sound Speed, Sonic Layer Depth and Gradient Below the surface Layer)

This area is well known to be strongly impacted by tides and internal tides. Over the tidal cycles sharp small-scale changes are to be expected in the ocean state, These effects are not easily seen in these variables.

Over this 9 hours period sharp changes can be seen in acoustic propagation prediction at a reference location, as seen in the top right plots. The diagnose of these impacts requires also using the 3D diagnostics in the middle panels

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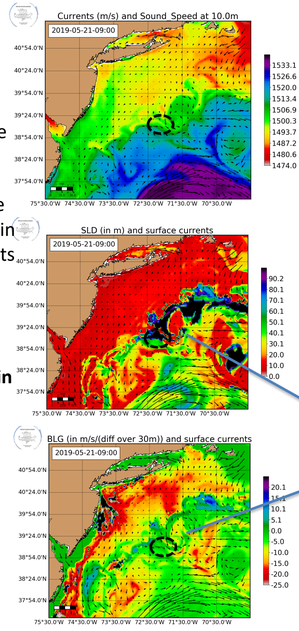

Framework to create awareness for the relevant processes impacting acoustic propagation:

1. **access real-time ocean data and ocean model forecasts;**
2. **build diagnostic variables for generic conditions and possible local small- scale dynamics, along the forecast ranges to predict relevant changes;**
3. **run local reference acoustic propagation simulations to predict possible acoustic impacts and identify thresholds along relevant ocean variables**
4. **Create Risk-Opportunity Acoustic Awareness Maps for Tactical use**

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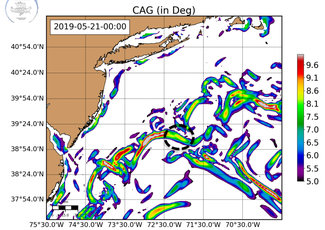
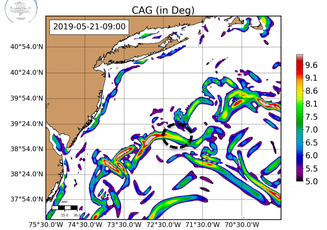
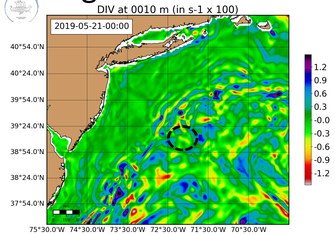
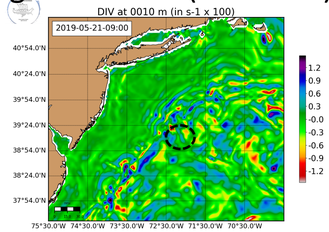
Change in 3D propagation conditions (AZM 220)



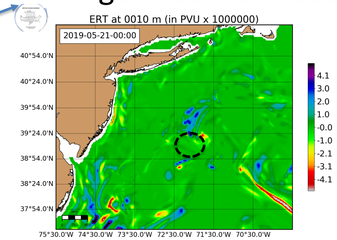


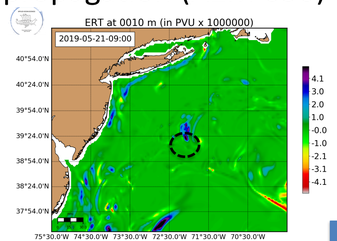
Change in Surface Ducting conditions (AZM 180)





Change in Sub-Surface propagation (AZM 050)





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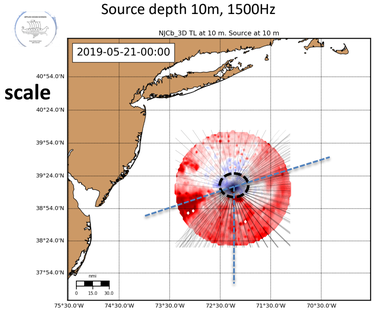
Source depth 10m, 1500Hz



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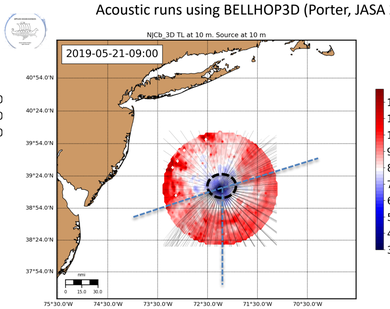
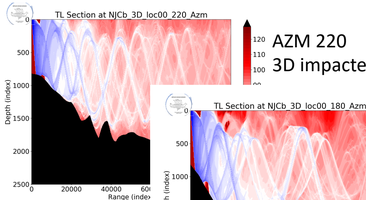
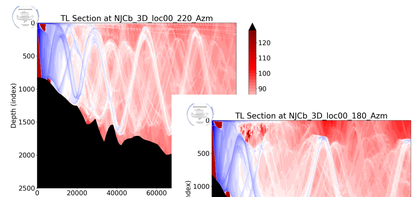
Acoustic runs using BELLHOP3D (Porter, JASA 2019)

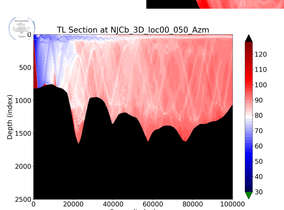




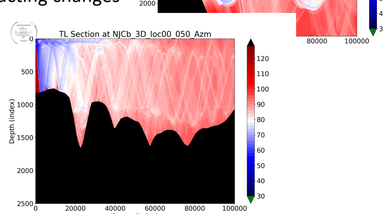
AZM 220
3D impacted propagation



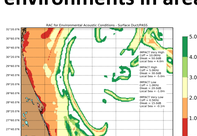
AZM 180
surface ducting changes



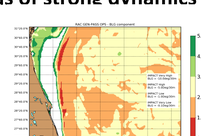
AZM 050
Sub-surface ducting



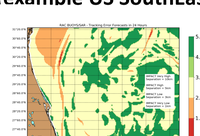
This approach enables to create Environmental Awareness maps showing Risk/Opportunities and to select numerical solutions and/or sampling strategies to characterize the ocean-acoustic environments in areas of strong dynamics (example US SouthEast Coast).



Ducting opportunities



Ducting conditions



Sonobuoy conditions

From variables pdf's

From operators

Risk Management RAC Codes	Probability			
	A>0.75	0.75>B>0.5	0.5>C>0.25	0.25>D>0.1
Level I – Very High	1	1	2	3
Level II – High	1	2	3	4
Level III - Medium	2	3	4	5
Level IV - Minimal	3	4	5	5

Severity

1 – Critical 2 – Serious 3 – Moderate 4 – Minor 5 – Negligible