NETSIM

A Realtime
Virtual Ocean
Hardware-in-the-loop
Acoustic Modem Network Simulator

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UComms 2018

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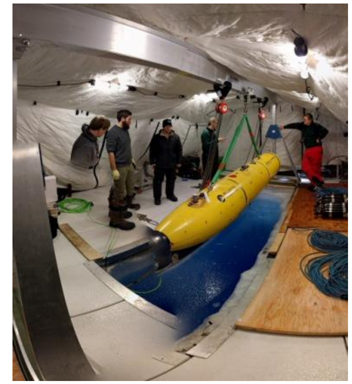
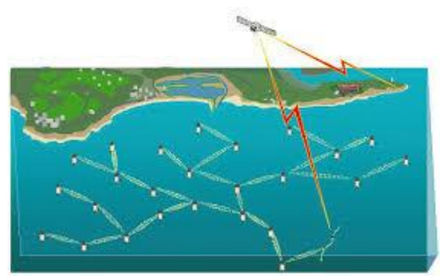
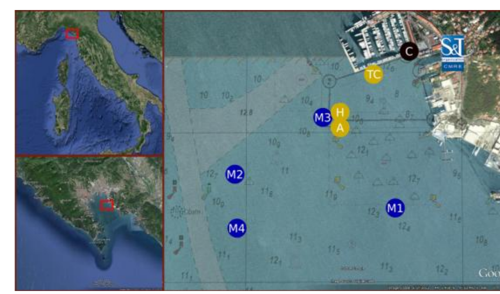
Existing Acomms Test-beds



- At-sea testing
  - Benefits:
    - Real environment, choice of location
  - Limitations:
    - High cost and logistics
    - Limited temporal variation
- Hardware Test-beds (e.g. Seaweb, LOON)
  - Benefits:
    - Real environment, remotely accessible
  - Limitations:
    - Spatially constrained
    - Limited mobile node support
    - No concurrent users
    - Significant cost



2005 Rice. *Seaweb Acoustic Com/Nav Networks*



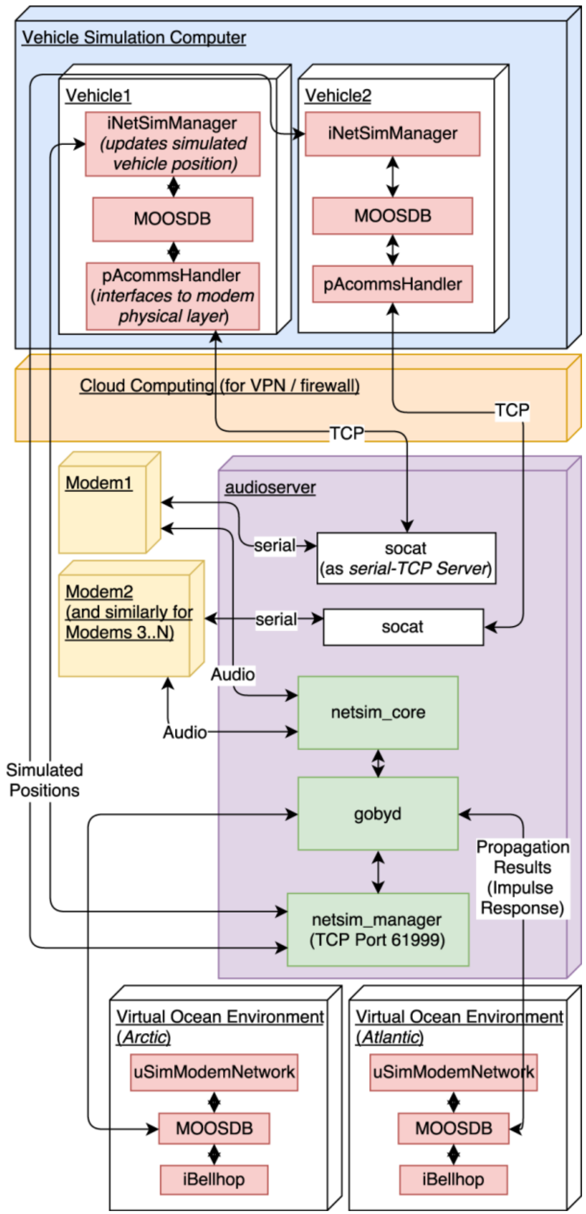
2014. Alves, et al. *The LOON in 2014*

NETSIM: Motivation

- Hardware-in-the-loop virtual testbed
  - Benefits:
    - Low cost
    - Always accessible, concurrent users
    - Variety of available environments
  - Limitations:
    - Performance is only as accurate as the Virtual Ocean and channel models.

- NETSIM can be a test bed for:
  - Modem designs
  - Networking protocols
  - Real-time channel simulators
  - Vehicle autonomy for improved acomms

NETSIM: Design



Three decoupled major components:

- Audioserver (netsim_core/netsim_manager)
  - real-time audio processing (to/from modems)
  - virtual vehicle position
  - serves connections to modem link layer interface (serial)
- Virtual Ocean Environment simulator and channel model
- Vehicle Simulation (provides positions in virtual env). Can be located anywhere on the internet.

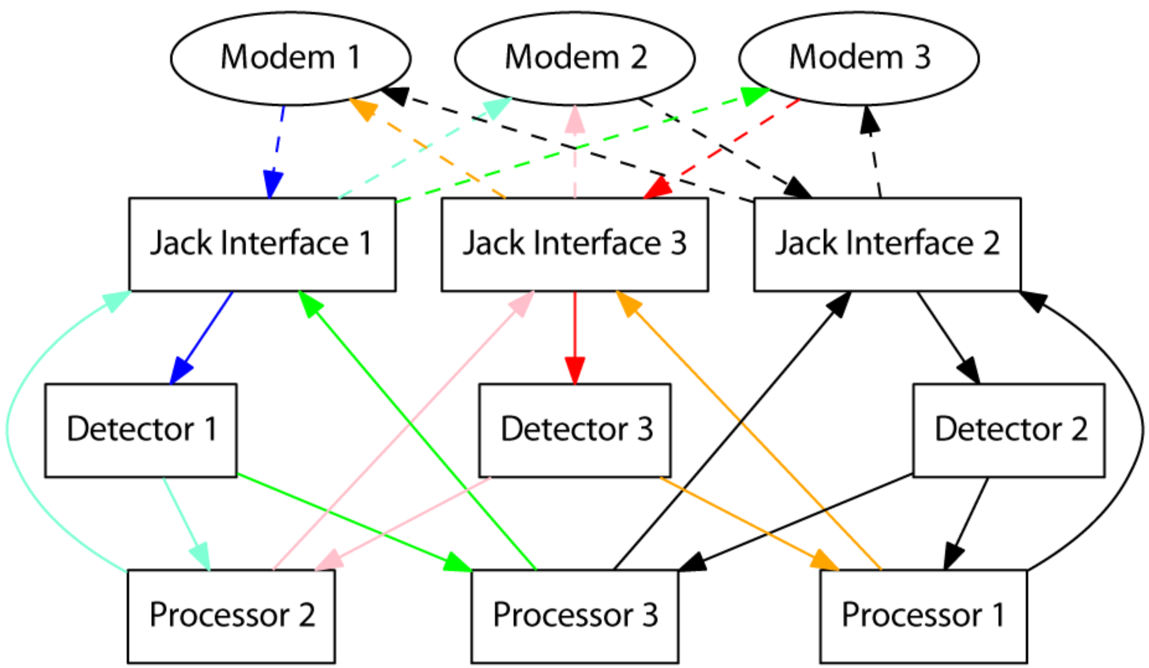
Audioserver: netsim_core

- Audio processing
  - real-time audio record/playback using Jack Linux audio
  - based on Goby3 publish/subscribe middleware
  - multithreaded and scalable
- Current setup (Hardware)
  - M-Audio Fast Track Ultra 8R (8-in, 8-out, 96kHz, 24-bit)

  - Intel Xeon X5450 (4 cores @ 3.0 GHz): probably excessive.

Audioserver: netsim_core

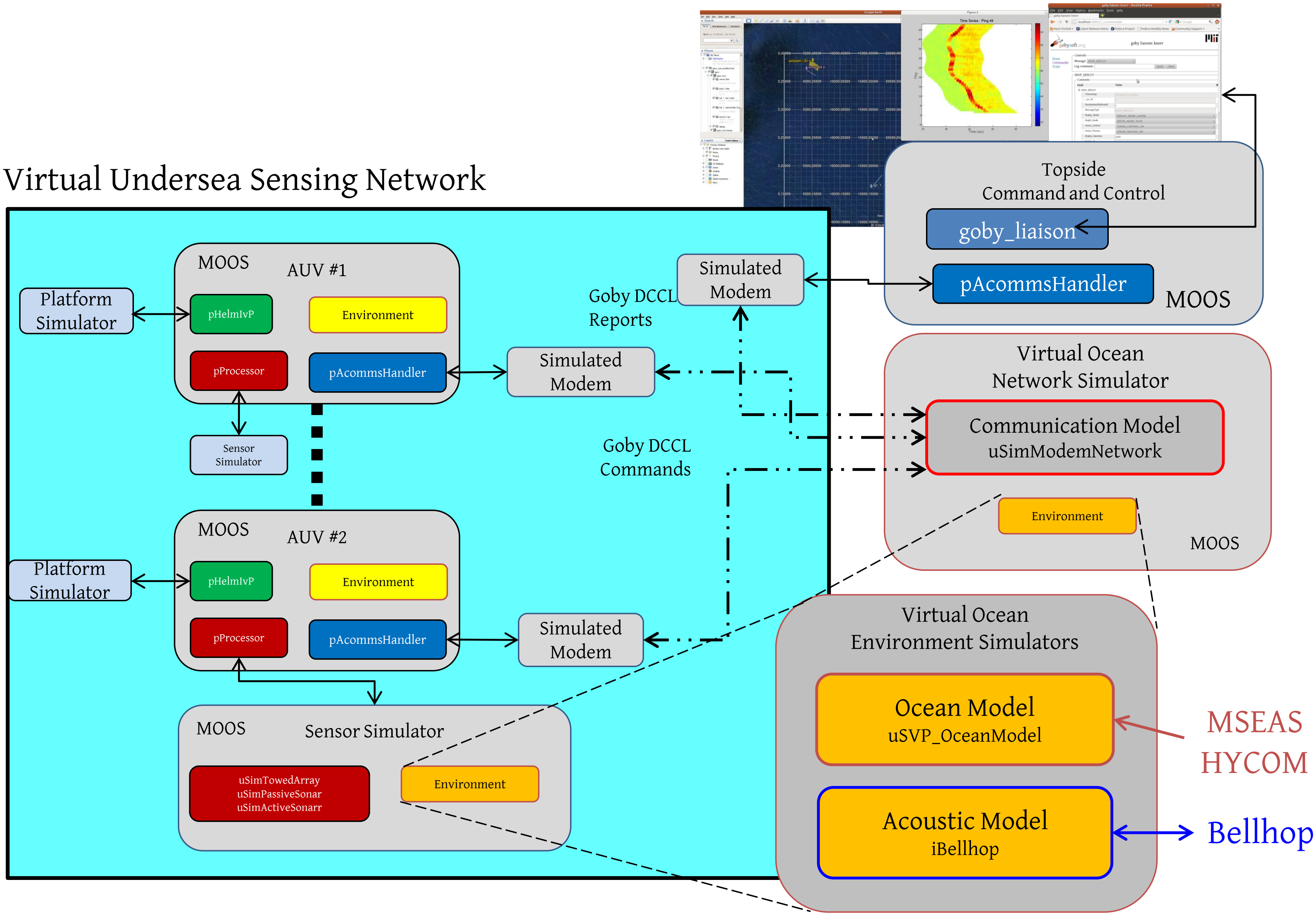
- 3 modem example:
  - Modems 1 (blue) & 3 (red) transmit
  - Depending on spatial and temporal separation, packet collision could occur at modem 1
  - Each Rx/Tx pair "sees" a different channel



Audioserver: netsim_manager

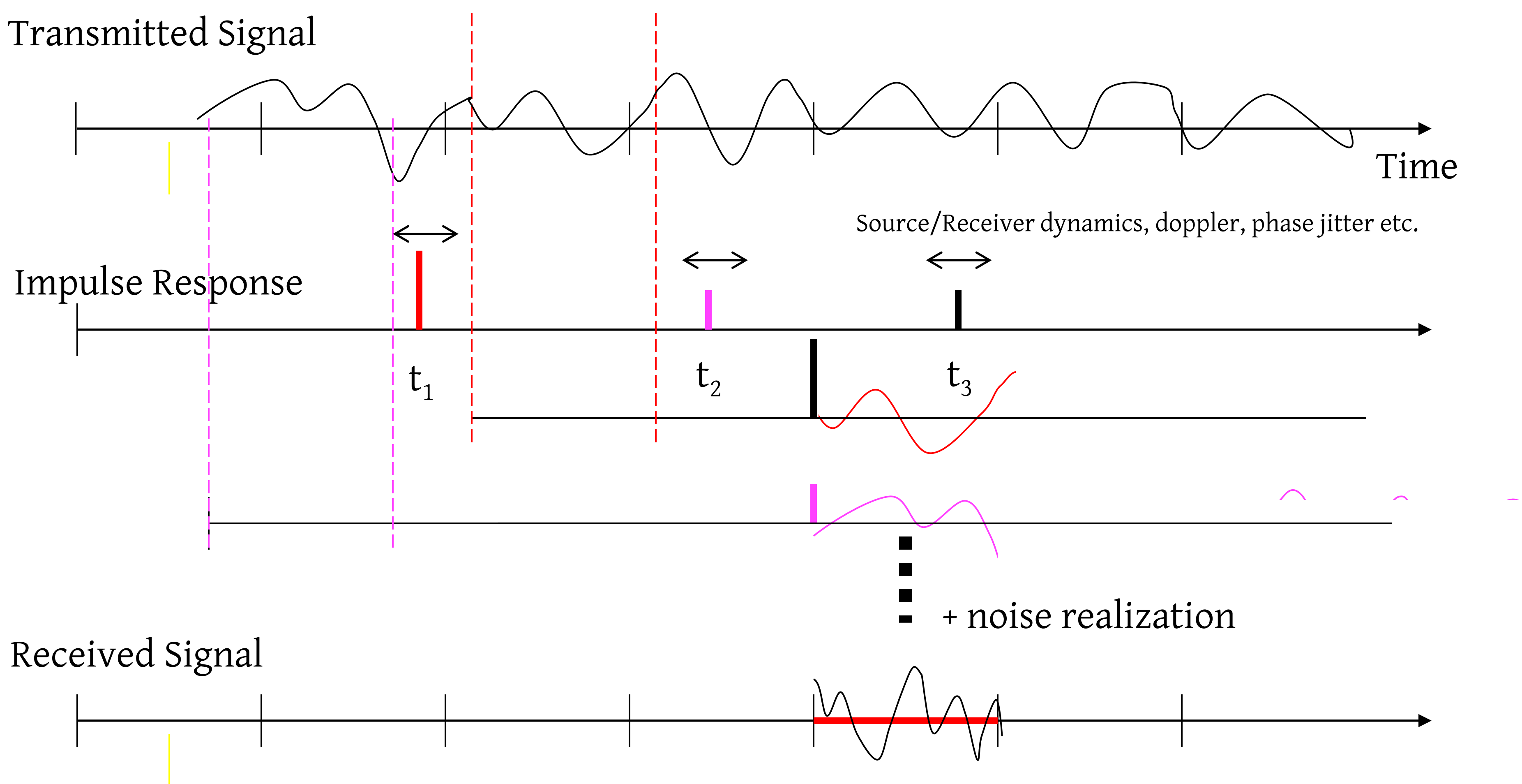
- Basic TCP-based protocol for interfacing to vehicle simulations:
  - Latitude, longitude, depth, time, speed heading
  - No constraint on choice of vehicle software (e.g. MOOS, ROS, Goby, etc.)
- Forwards a given simulated vehicle location to the correct virtual environment.
  - For example, vehicles can simultaneously run in the Atlantic and the Arctic on the same audioserver.

MIT Virtual Ocean Autonomy Testbed



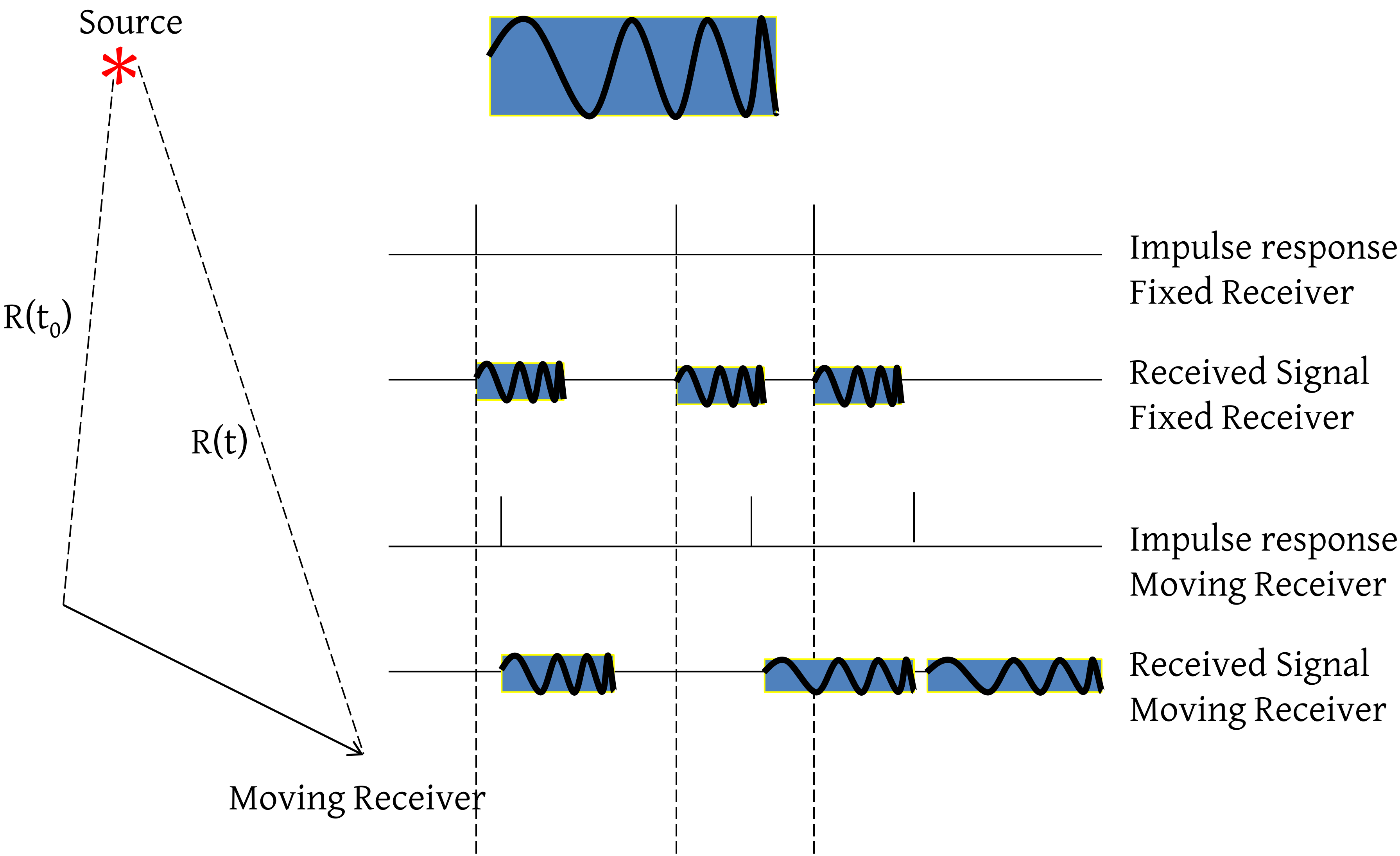
Real-Time Signal Construction

Passive Sonar: Target signal modeled as spectrally shaded pseudo-random noise. 50% overlap/add for received signal.
Active Sonar, Communication: Phase coherent transmit within slot. Time-varying impulse response.



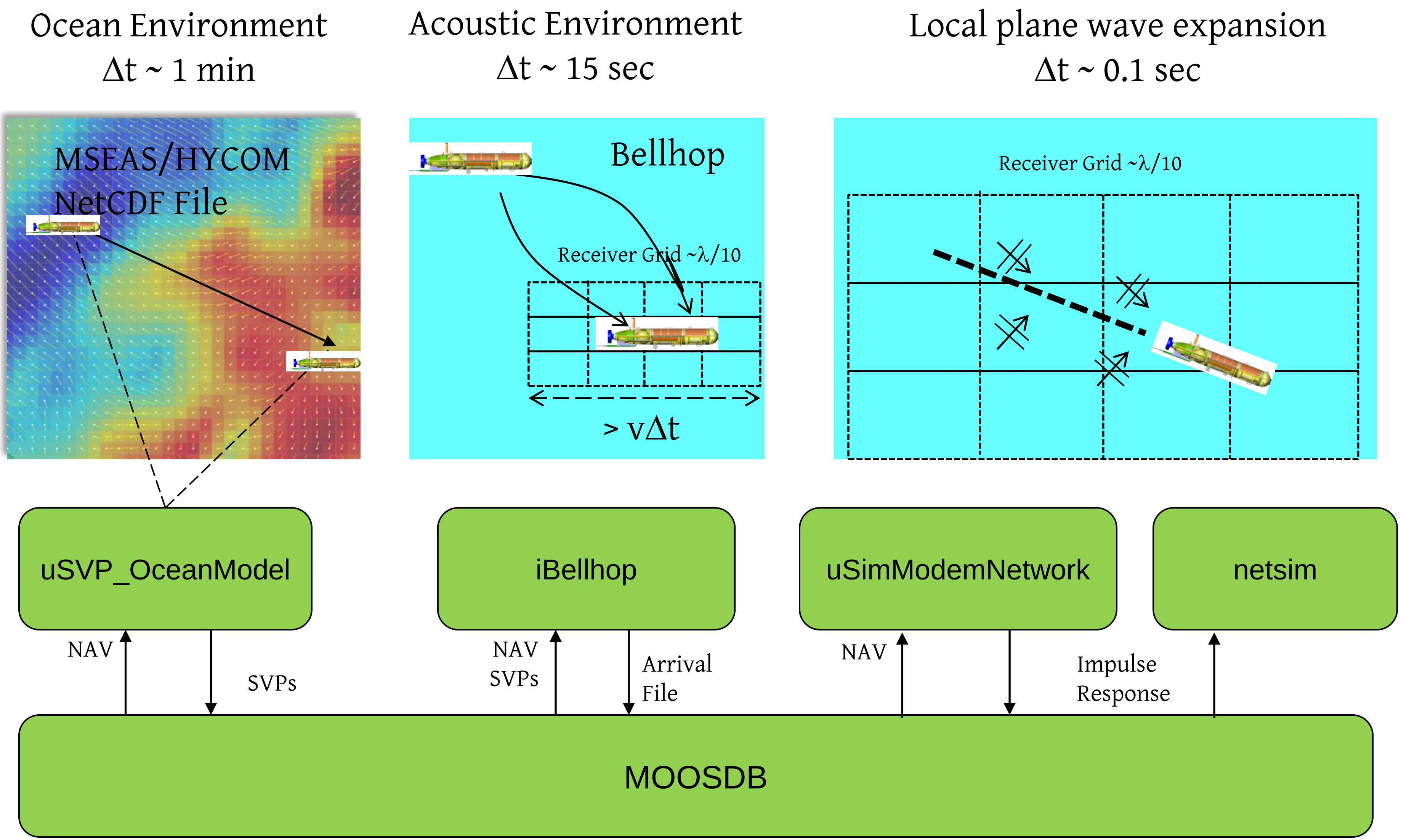
Real-time simulation for t_1 > 0.2 s.

Multipath Doppler in Ocean Waveguides

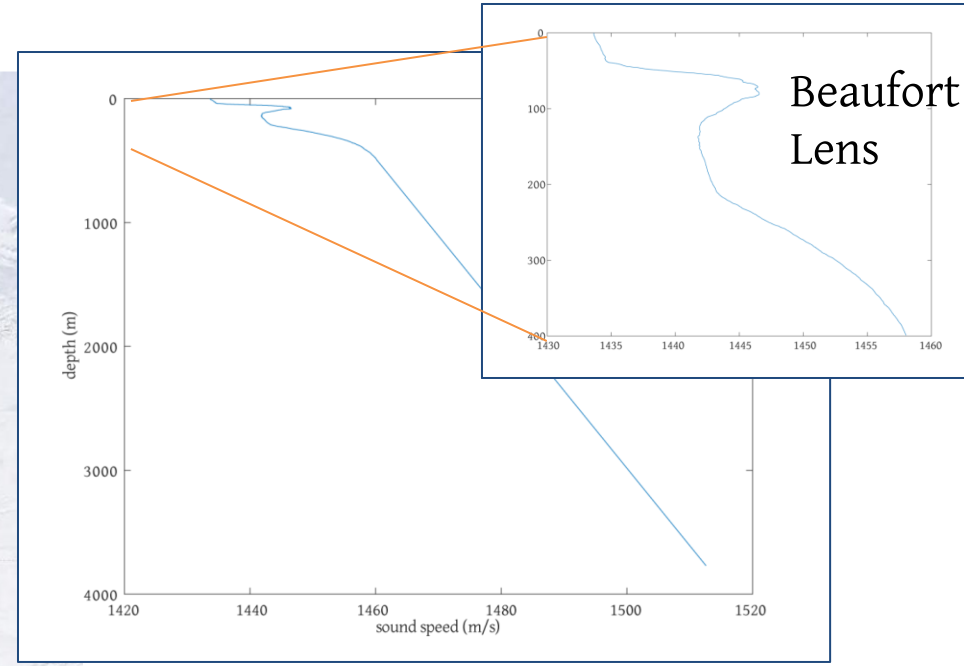


Virtual Ocean Modem Stimulator

Asynchronous Nested Acoustic Modeling (each contact)

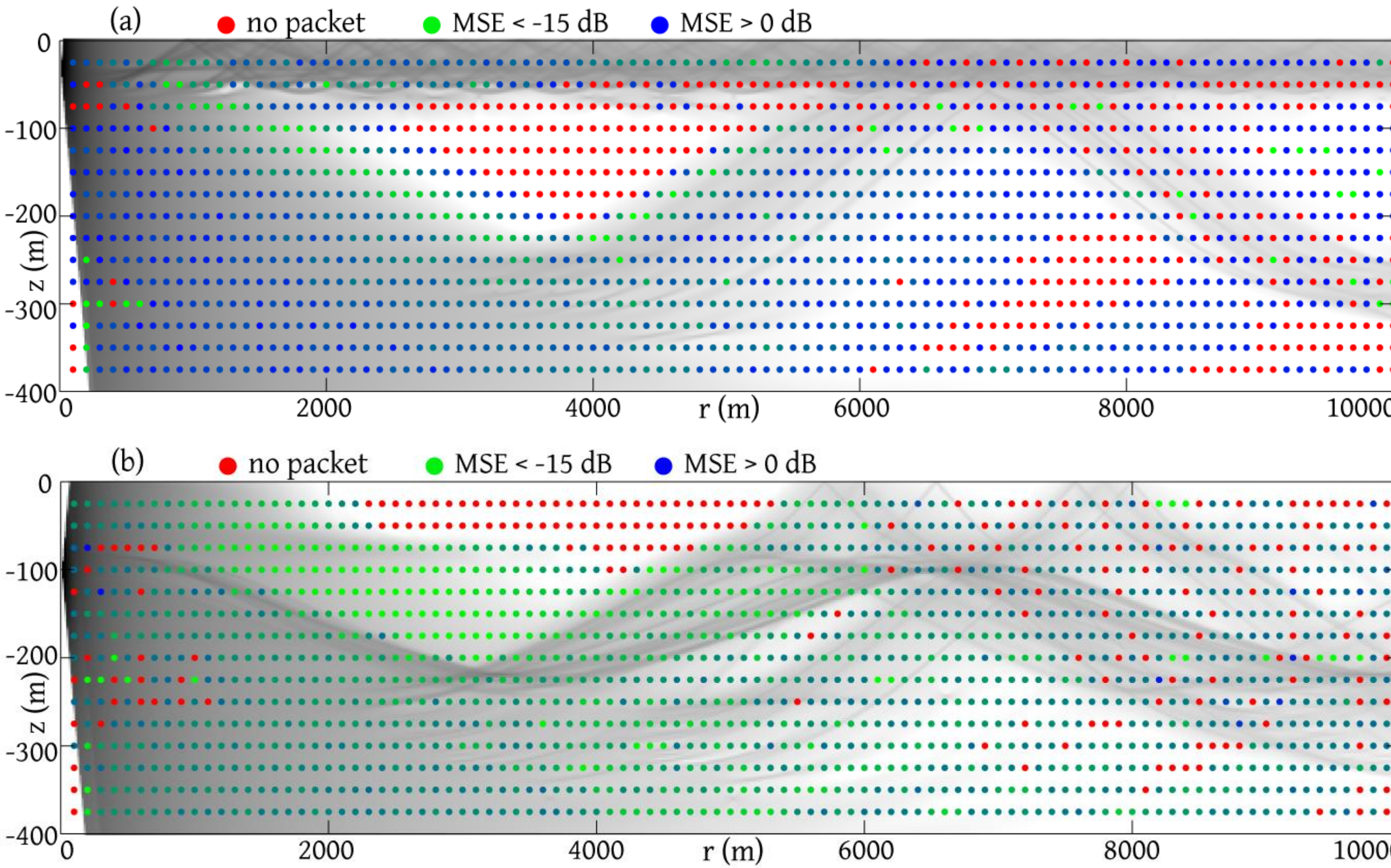


Results: Arctic Environment



AUV Communications to ice camp Sargo (33 m deep hydrophone) (Video)

Results: Arctic Environment



a) Fixed node at 33 m; mobile node at grid locations
b) Fixed node at 100 m; mobile node at grid locations

Sharing

- Virtual Ocean: LAMSS: https://github.mit.edu/lamss
- NETSIM: https://github.mit.edu/toby-1/netsim
- Goby3: https://github.com/GobySoft/goby3

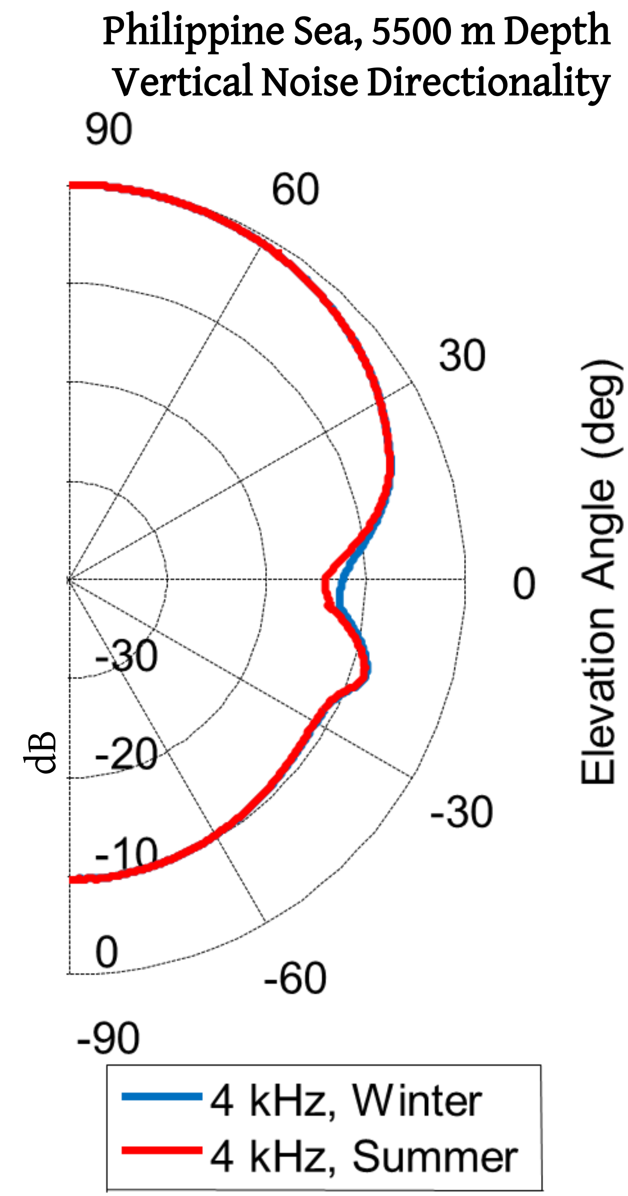
Questions?

Virtual Ocean Environment Simulator

- General Features
  - Compatible and consistent topside and embedded versions
  - Real-time element level timeseries for virtual stimulation of general volumetric arrays
    - Computation time less than travel time using nested architecture
  - Range-dependent ocean waveguide multipaths
    - BELLHOP/KRAKENC Legacy Acoustic Models
  - Full 3D Ocean dynamics through interface to MSEAS/HYCOM modeling and date assimilation frameworks
    - Direct NetCDF interface for simulator or onboard baseline environment
    - EOF coefficient updates transmitted to UUV via modem
  - Moored VLA, HLA or volumetric arrays
  - Hull-mounted or towed arrays coupled with AUV dynamic model
  - Correlated ambient noise for 3D volumetric arrays
    - 3D Noise correlation simulated through spectral decomposition of OASES/Kuperman-Ingenito (OASN) model
    - Timeseries realization through Cholesky factorization
  - Temporal and spatial doppler shift (Schmidt and Kuperman, 1994)
- Active Sonar Simulator
  - Sea surface reverberation (Gauss, NRL)
  - Seabed reverberation (in progress)
  - CW, FM and customized waveforms
- Passive Sonar Simulator
  - Hydrophone or vector sensor arrays
  - Pseudo-random sources (ships, submarines)
  - Coded communication and navigation signals
- Modem Network Simulator
  - HITL Modem pool linked with acoustic model
  - Multipath doppler and fading
  - Surface scattering jitter

Correlated Surface Noise Modeling

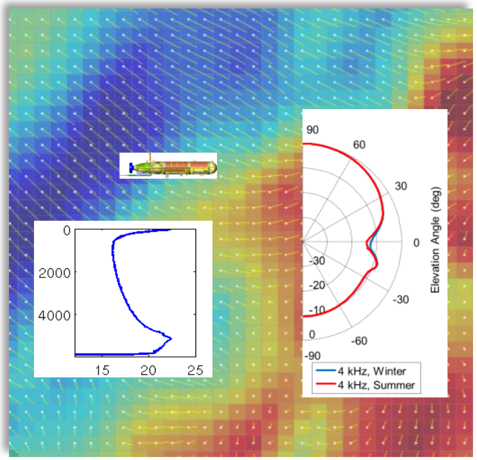
- Kuperman-Ingenito noise model
  - Implemented using environmental parameters
  - Infinite surface of monopole sources just below ocean surface
    - Becomes sheet of dipole sources
  - Noise spatially stationary in range, but not in depth
  - Normal mode representation
    - Ignores continuous spectrum
  - Wavenumber integration (OASES)
    - Accounts for full wavenumber spectrum, but computationally intensive
- Spherical decomposition of noise field
  - Azimuthally isotropic noise
  - Any vertical spatial noise distribution:
    - Noise spectrum independent of azimuth angle ϕ, but dependent on elevation angle θ
    - Same approach can be used to model ducted noise (distant shipping), etc.
  - Spatially stationary in range and depth
  - Computationally efficient for arbitrary volumetric arrays
- Element-level noise timeseries
  - Use OASES/OASN (wavenumber integral representation of Kuperman-Ingenito model) to generate noise dependence with elevation
  - Use the vertical noise directionality as an input to the spherical decomposition of the noise for generating noise covariance for arbitrary volumetric arrays.
  - Real-time Generation correlated noise timeseries using Choleski factorization of covariance matrix and gaussian random process.



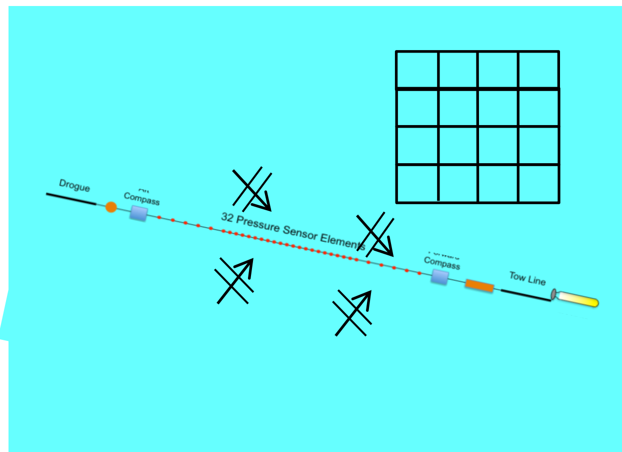
Virtual Ocean Array Stimulator

Asynchronous Nested Ambient Noise Modeling

Noise Depth Dependence Directionality
Δt ~ 1h min



Noise Covariance Choleski Factorization
Δt ~ 15 sec



Random Noise Realization
Δt ~ 0.1 sec