Autonomous and Adaptive Front Tracking using AUVs in an MSEAS Dynamic Ocean Model

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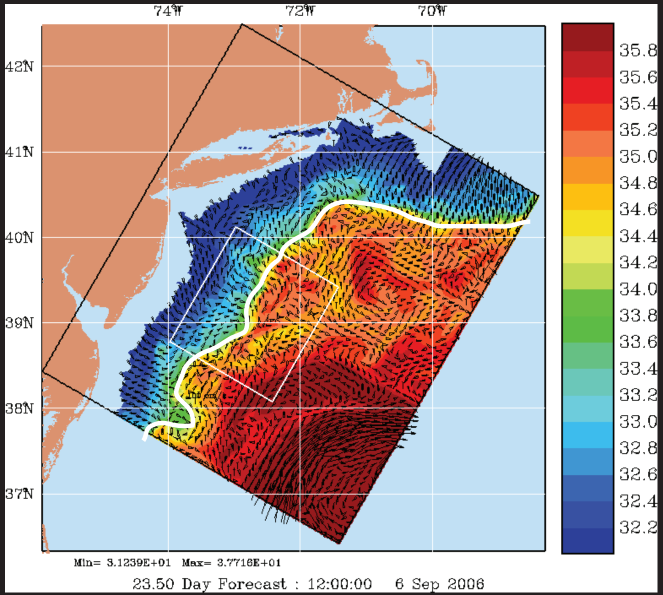
Goal

Develop methods for locating & tracking underwater fronts using AUVs

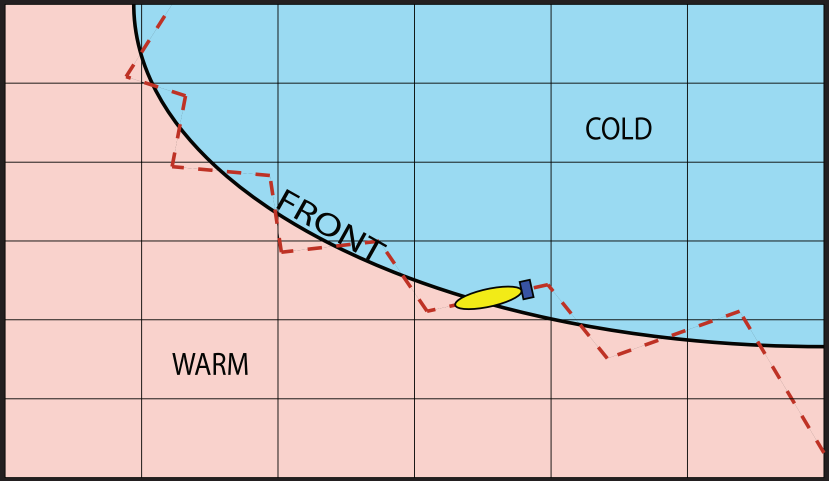
- Adaptive to the environment
- Collaborate multiple AUVs
- Autonomous
- All data processed onboard



First, develop a simulation using one AUV in a dynamic ocean model environment to detect & track a 2D front boundary...

Enabled by MOOS, IvP Helm, C++, Octave, NetCDF, etc.

Approach



2D Front Tracking:

- Constant depth
- Zig-zag across front boundary

3D Front Tracking:

- Single- & multiple-AUV approaches
- Incorporate depth variation
- Zig-zag or helix motion across front boundary

4D Simulation Environment:

- MSEAS model environment readily available & includes a time-dynamic thermal shelf break front
- Incorporated into the realistic LAMSS AUV simulation environment using Octave & pOctaverMIT

MSEAS Simulation Environment

SW'06 gridded data (522 km x 447 km)

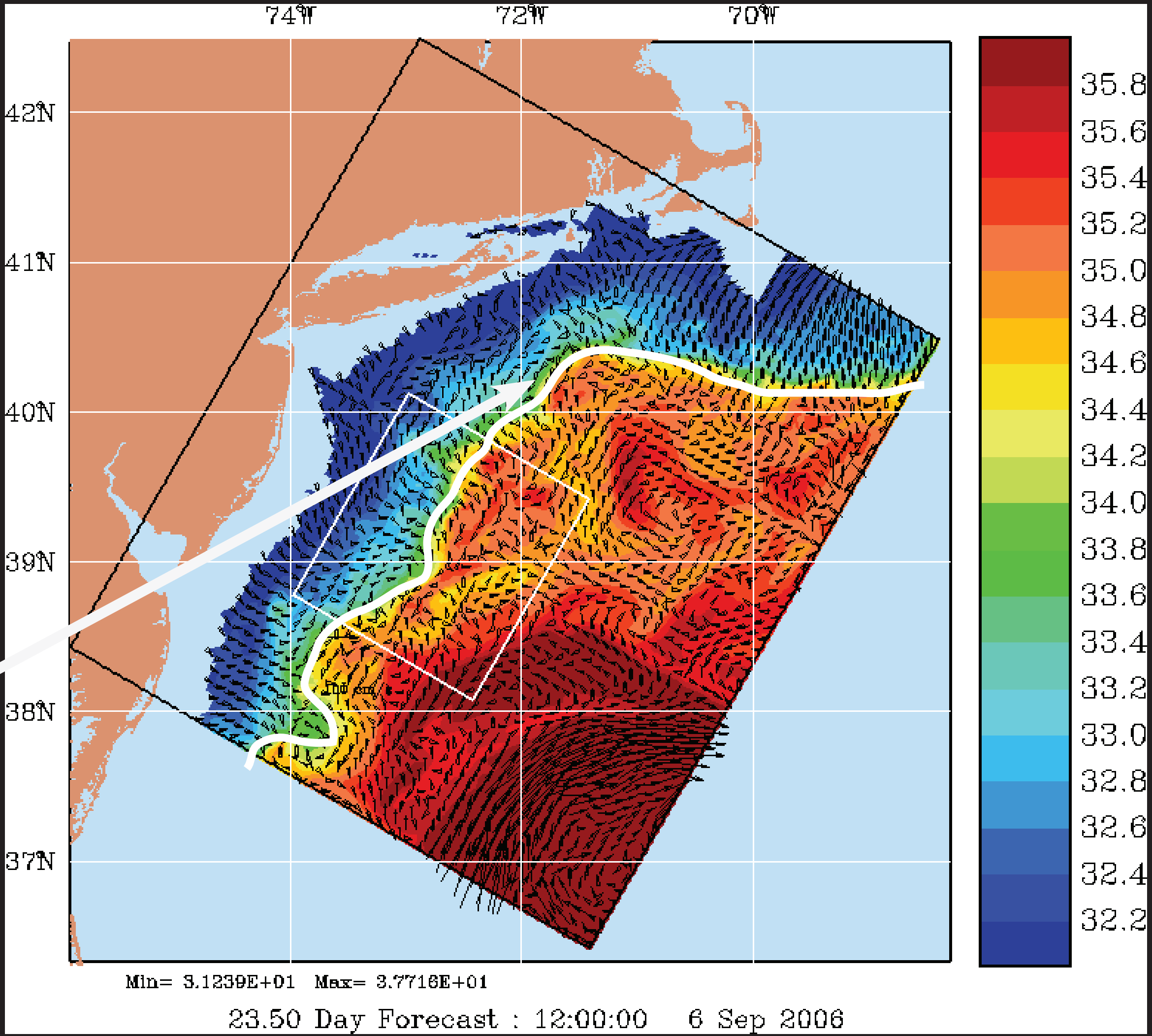
3 km resolution

Mid-Atlantic Bight

Aug/Sep 2006

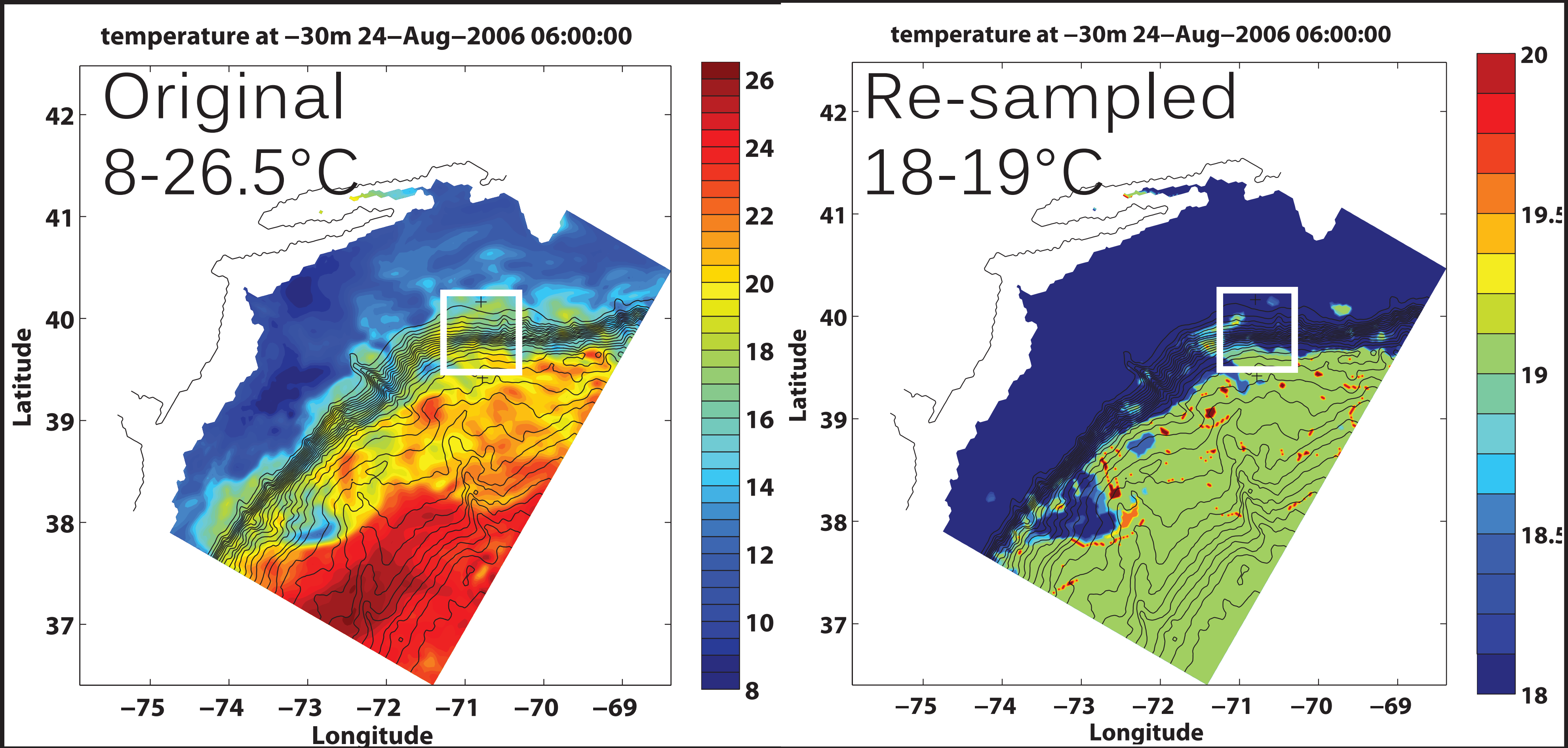
Space- & time-dynamic model

Shelf-Break Front



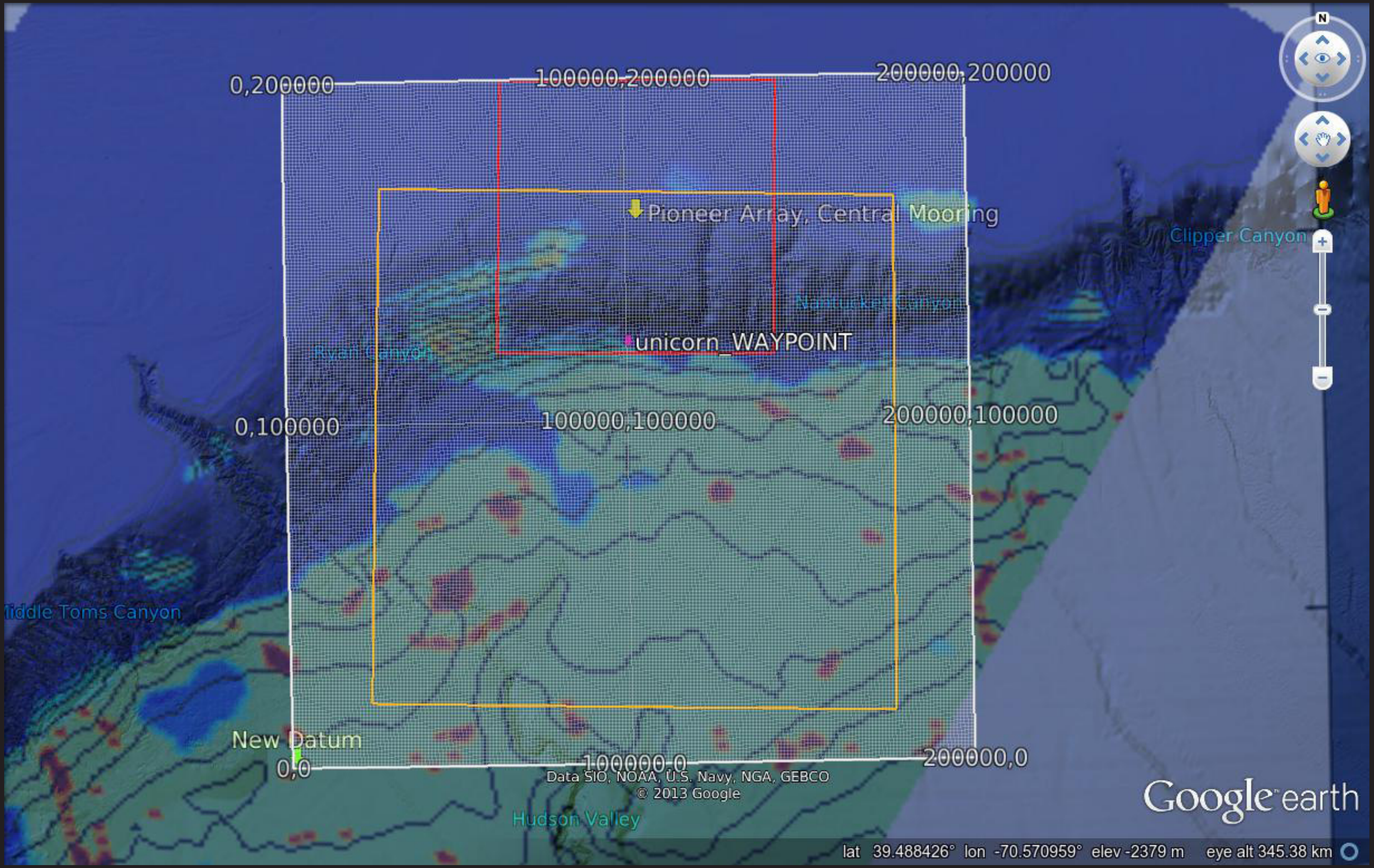
MSEAS Simulation Environment

Create a more defined temperature front in MSEAS dynamic model based on the original data distribution

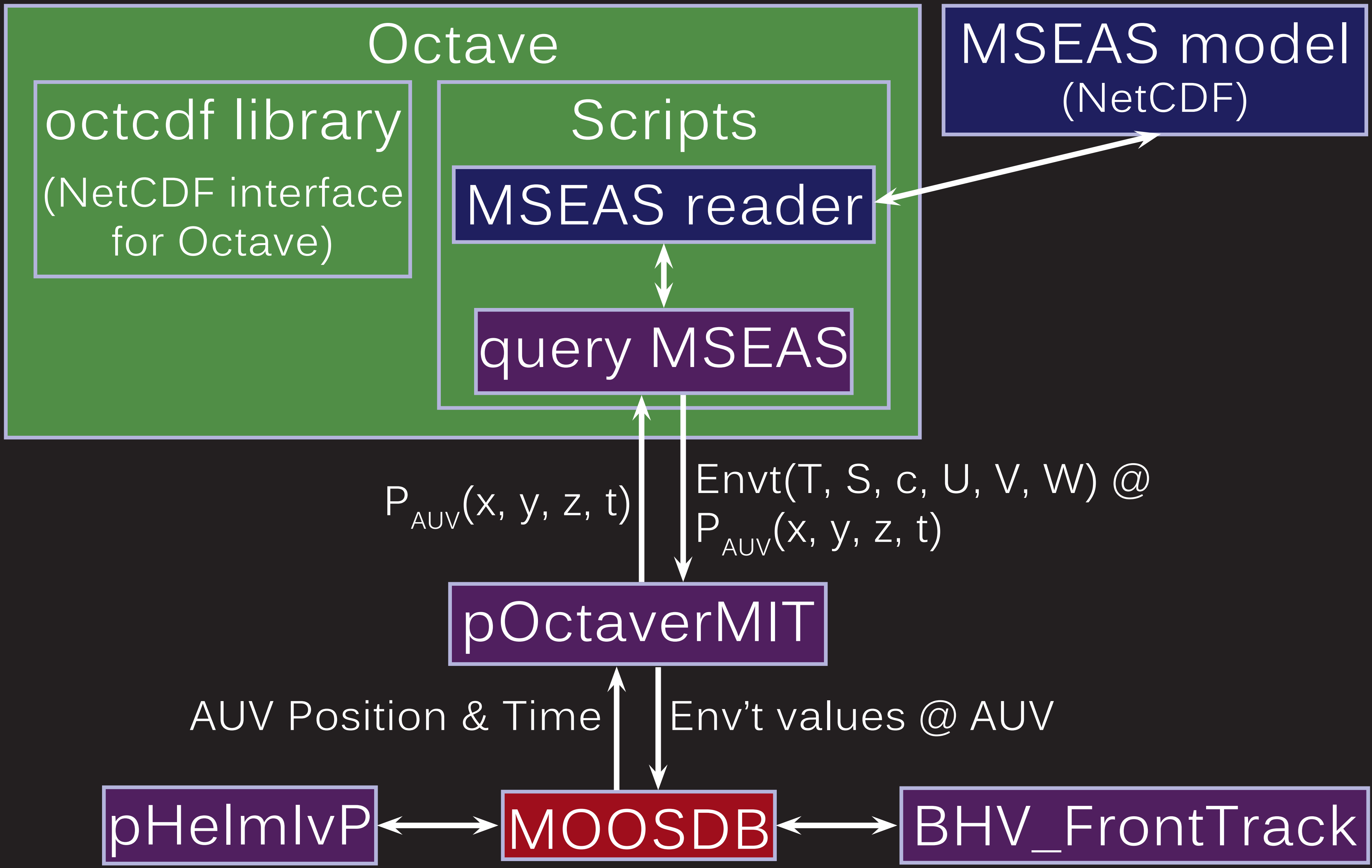


Import MSEAS model to Google Earth

Use front overlay in GE and GEOV tools to better visualize and plan front-tracking test missions



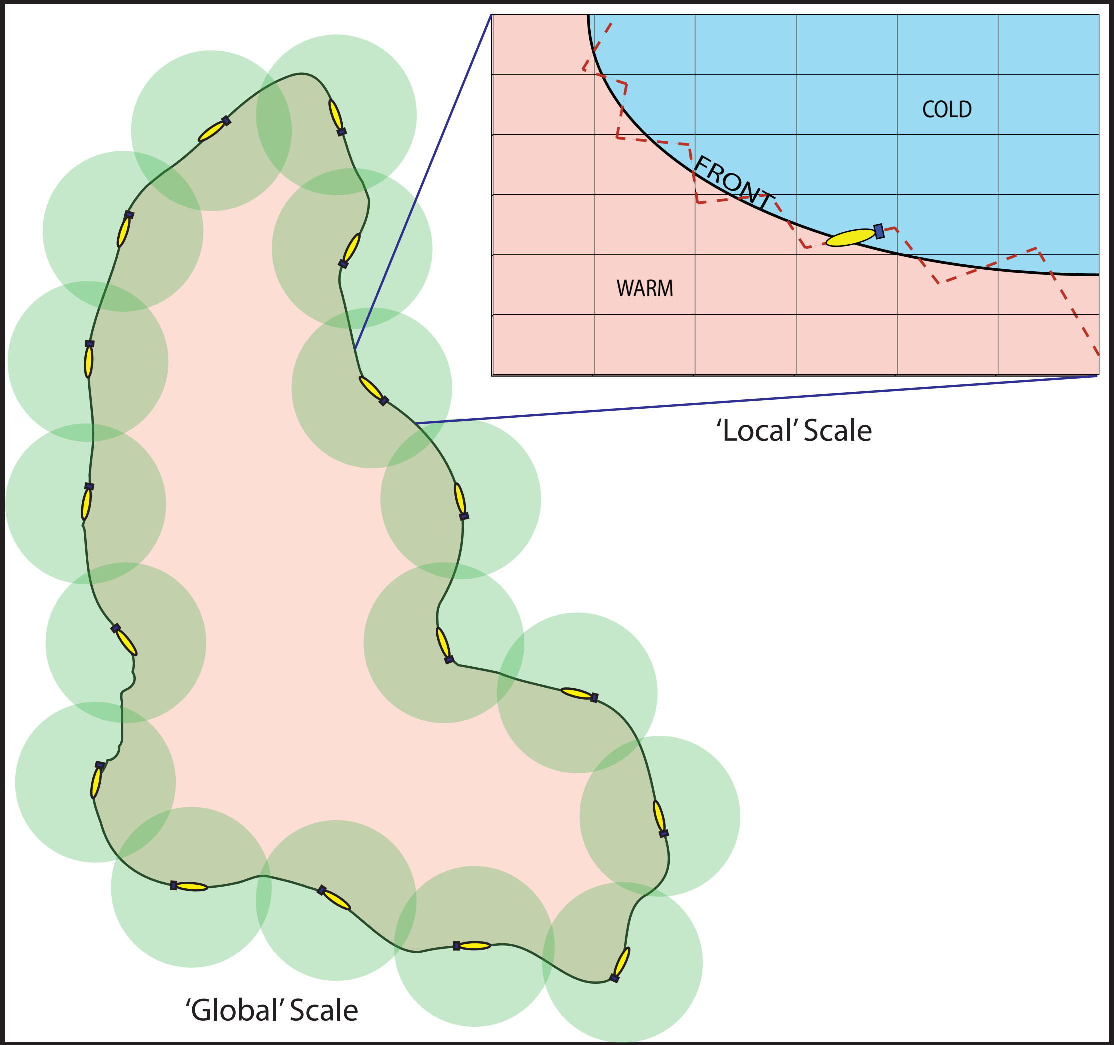
Incorporate model into AUV simulation



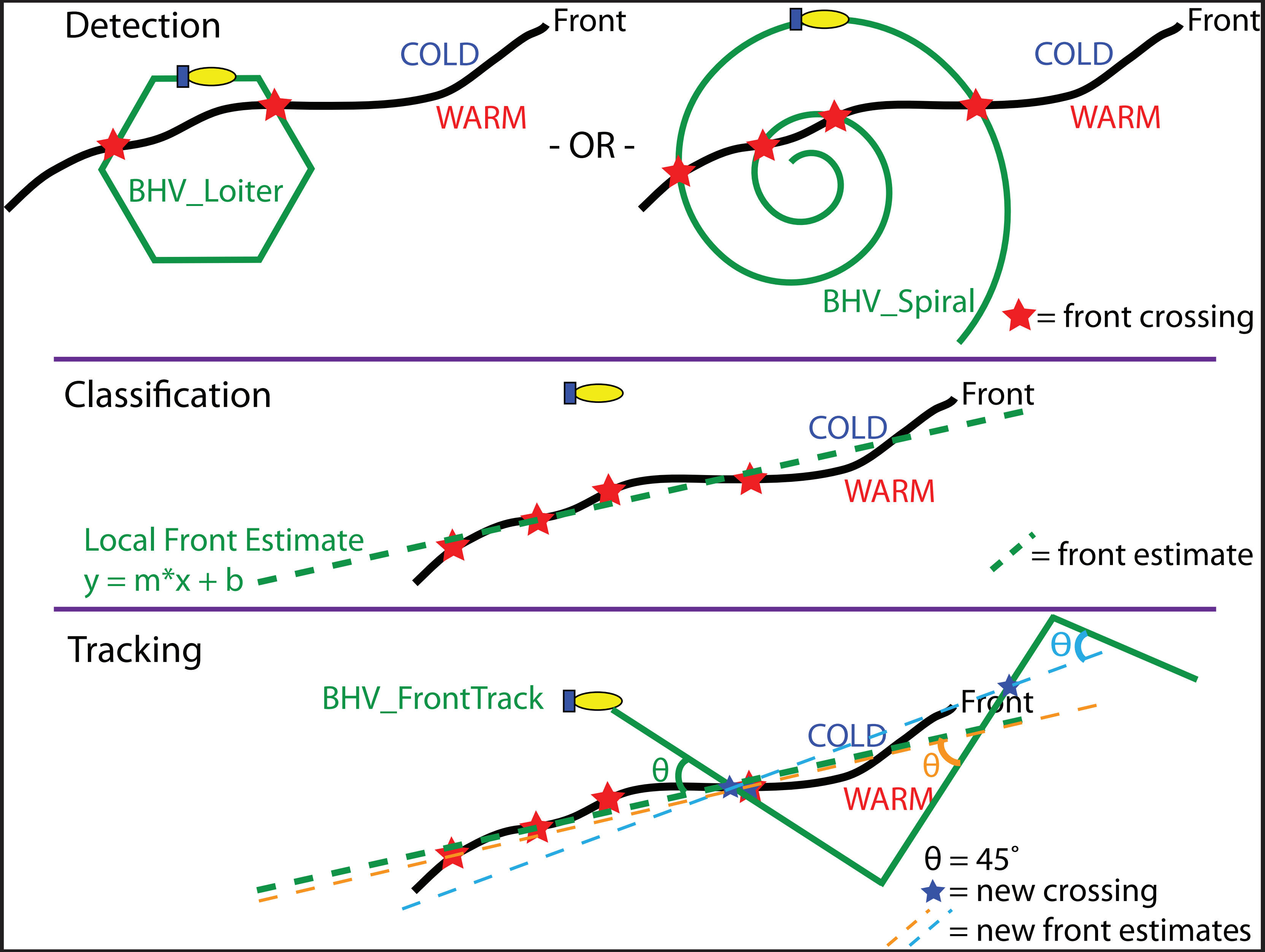
2D Front Tracking

Boundary Tracking

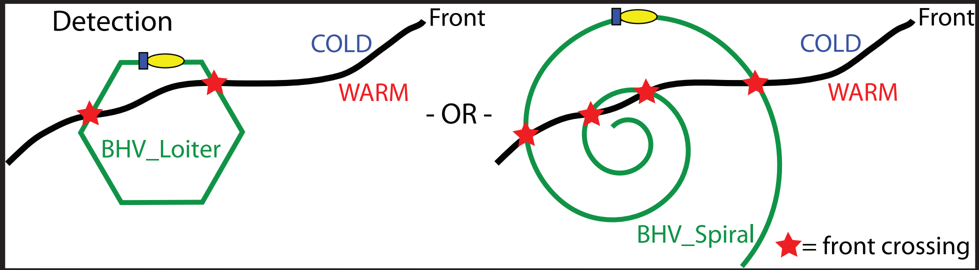
- Plume or Front -



BHV_FrontTrack (Front D-C-T)



Front Detection

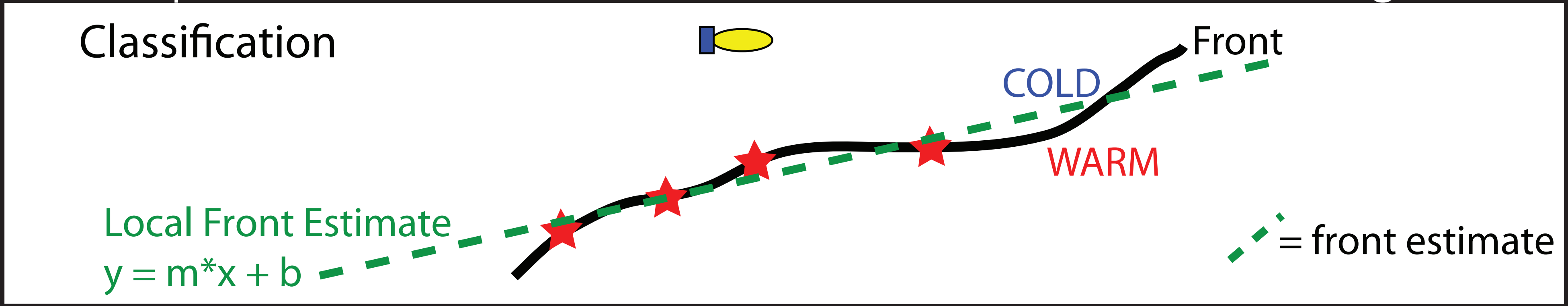


Loiter / Spiral around a point estimated to be near a front boundary

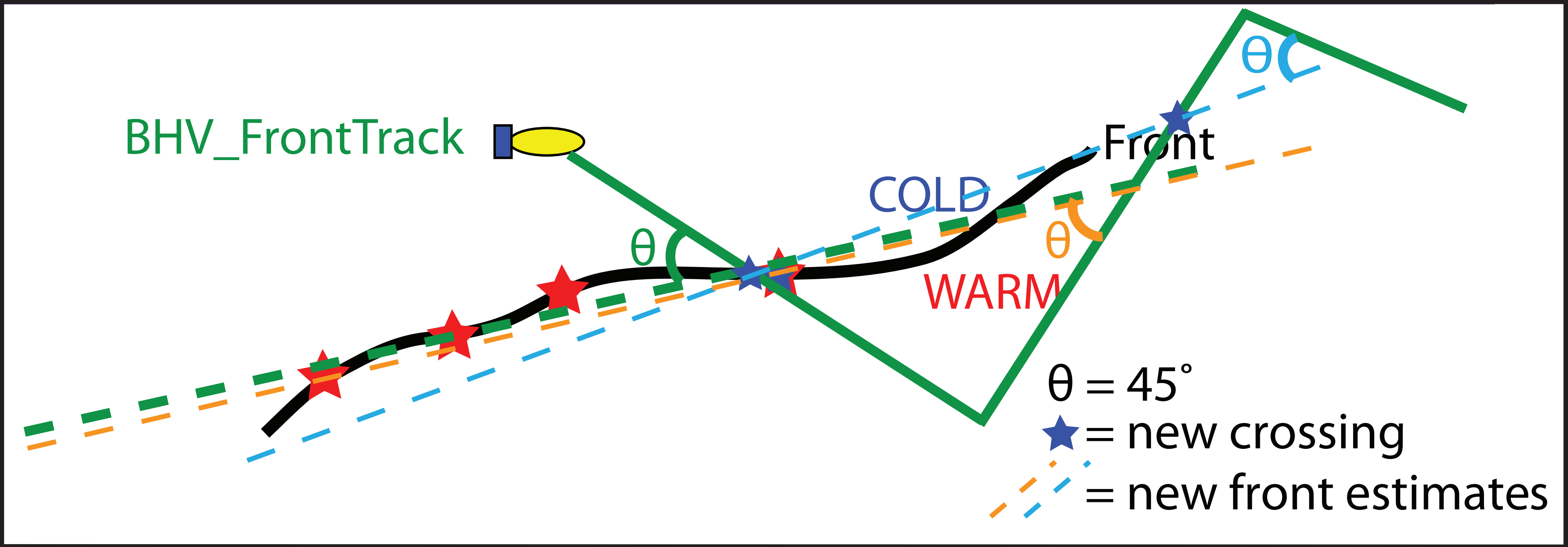
- Collect T values, constantly updating the max & min values
- Define a normalized threshold T value: 0.5
  - This will be the T value along the front
- Define a normalized T range around the threshold T: [0.4, 0.6]
  - This creates a boundary around the front, making front crossings easier to separate by reducing the effect of small temperature anomalies

Front Classification

- Keep track of the latest N (min 3, max ?) front boundary crossings: $P_{crossing} = (x, y, z, t, T)$
- Estimate the front as a straight line (locally) using weighted linear least squares (w/ vertical offsets) on the latest N crossing points 'within range'
  - y = m*x + b
  - Update the estimate with each new front crossing



Front Tracking - BHV_FrontTrack

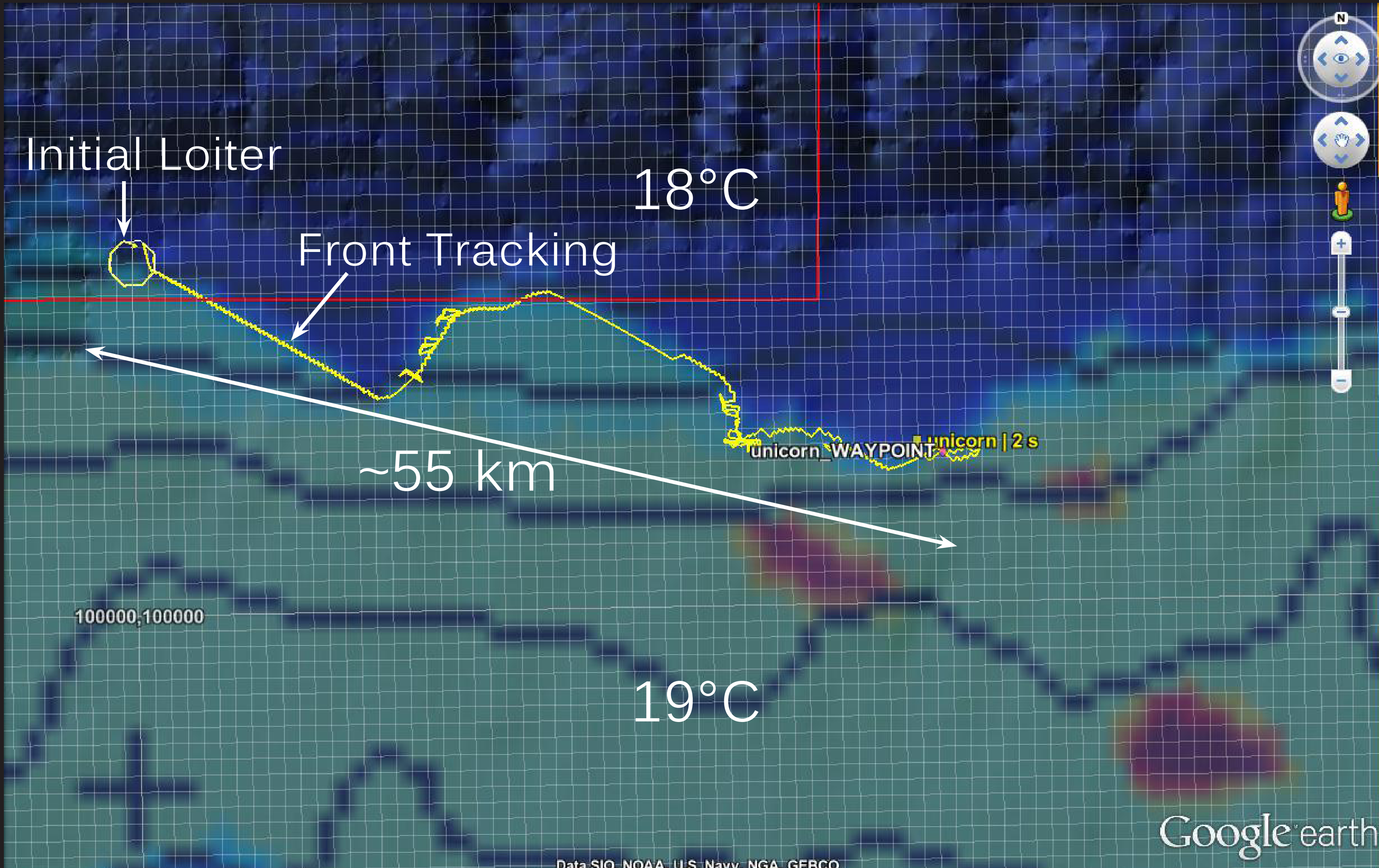


Front Tracking - BHV_FrontTrack

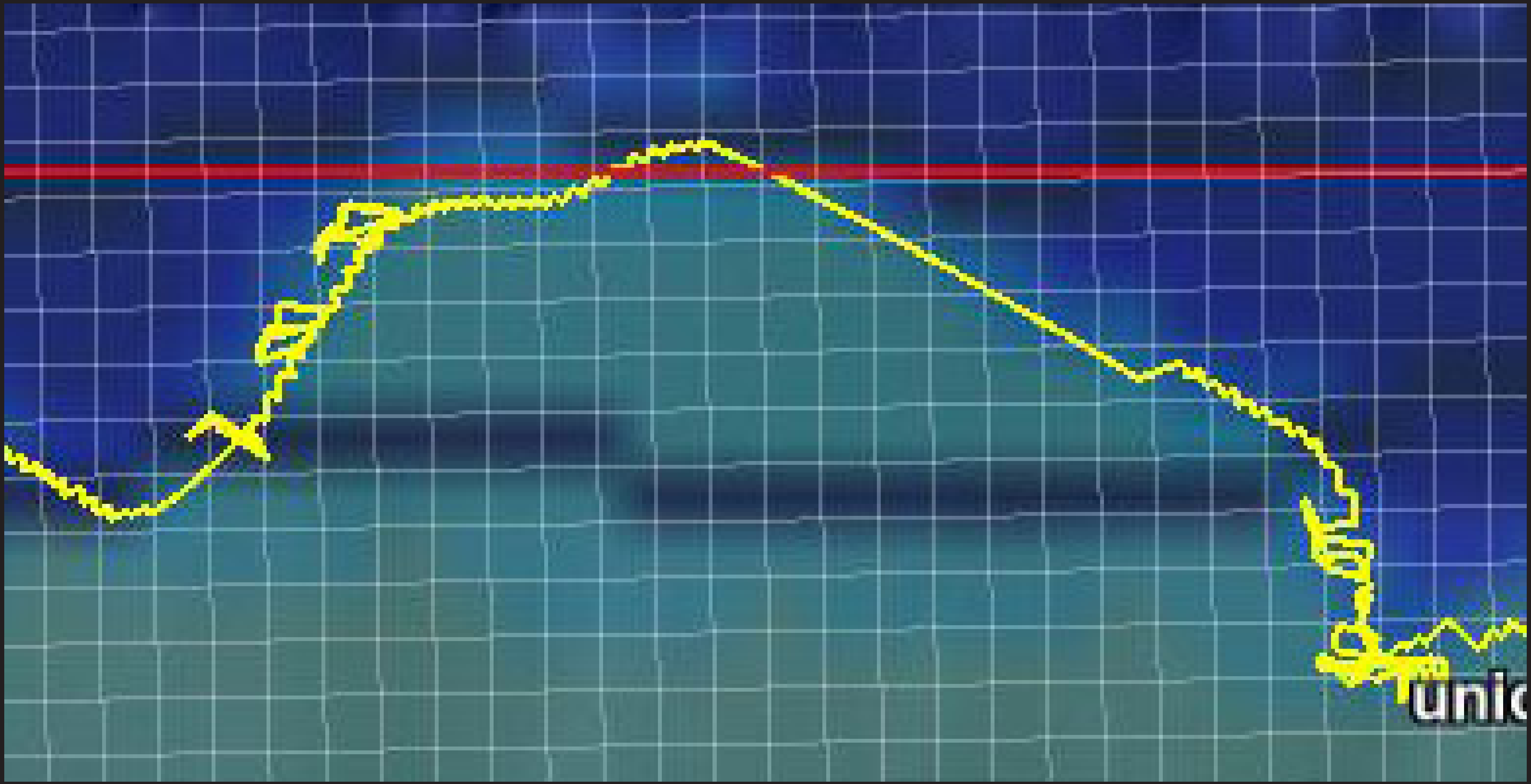
Front tracking begins when the first front classification is complete

- Based on the front classification (y = m*x + b), the AUV sets its desired heading to intersect the front line at a 45° angle (20°-70° optimal)
- AUV changes heading to ‘zag’ back across the front after (1) crossing the front on the ‘zig’ and (2) straying some distance from the latest crossing
- Front crossing points are weighted based on range from the AUV’s current position and temporal staleness

2D Front Tracking @ 30m depth



Detail



3D Front Tracking

Planar estimate of the front position:

- Simple parametrization, easy to communicate from AUV to scientist on ship via acoustics

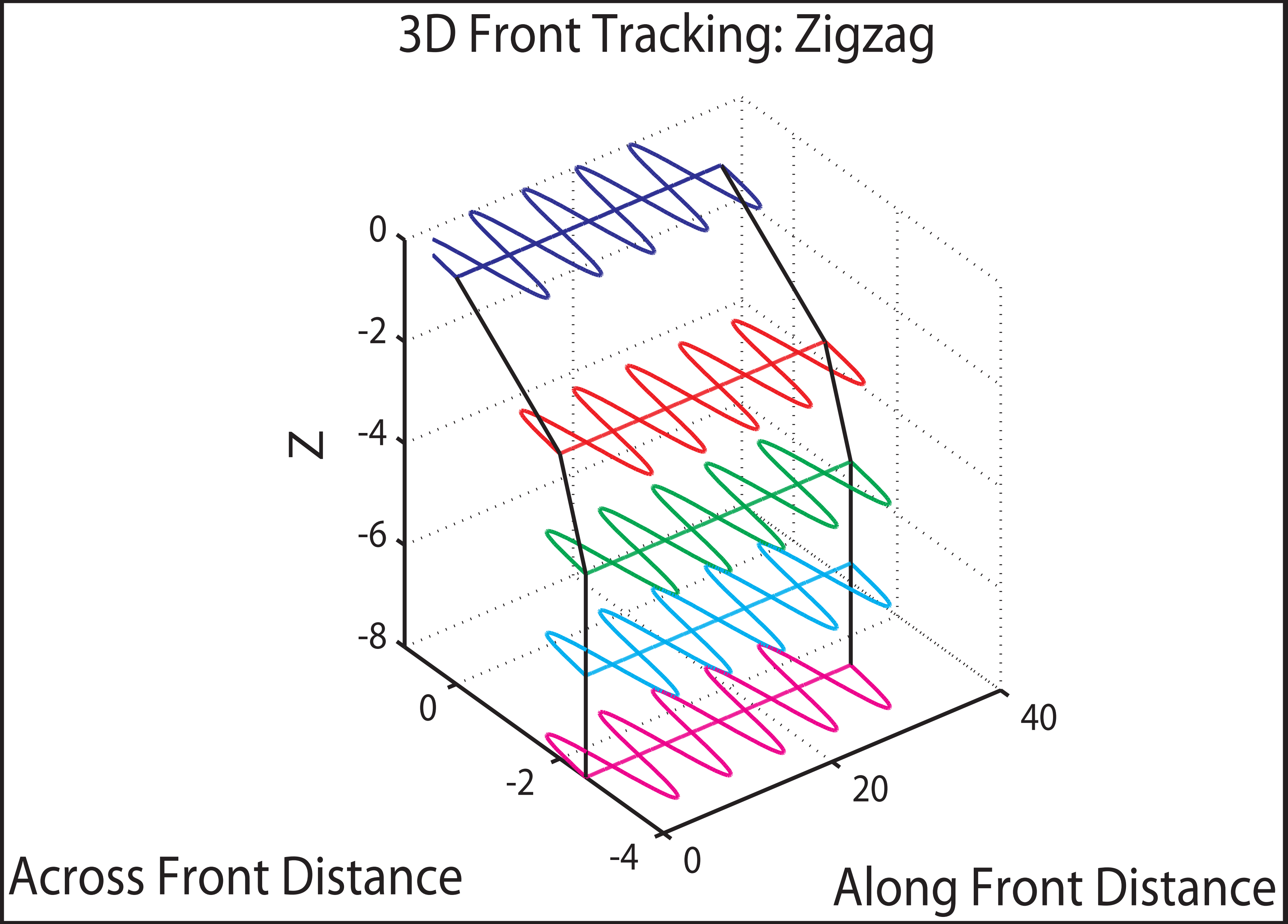
Single AUV:

- Helical motion about a line (y = m*x + b) at fixed depth (helix has fixed radius)
- Center line is calculated as for the 2D case, giving a heading along the front

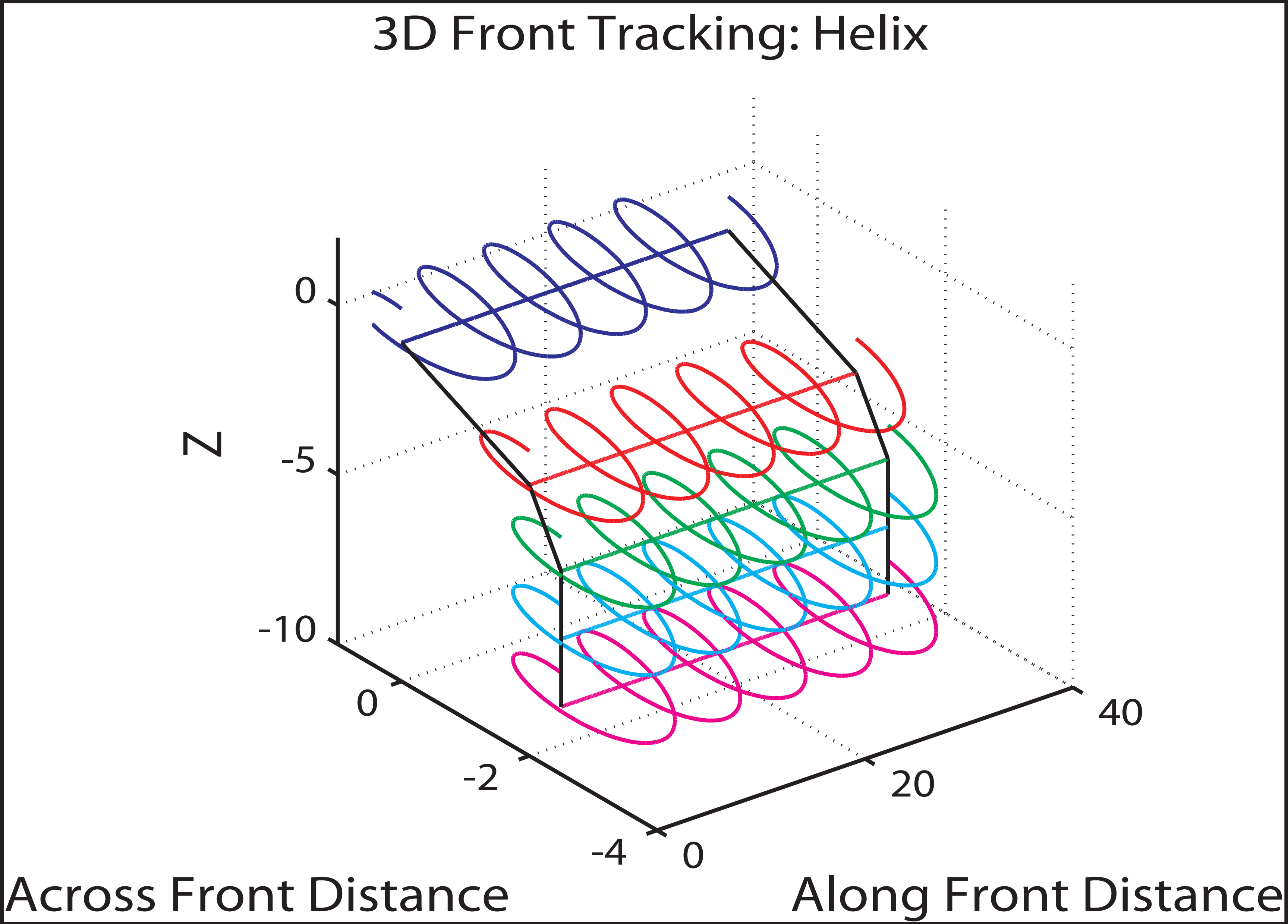
Multi-AUV:

- Each AUV performs 2D front tracking at a different depth, or helical tracking for increased depth coverage

3D Front Tracking: Zigzag



3D Front Tracking: Helix



Multi-AUV Feature Tracking

- Improve sampling efficiency & synopticity
- Follow-the-leader AUV collaboration is a simple way to increase spatiotemporal coverage in X/Y while optimizing the synopticity of data collected
- Distributing AUVs across depths adds a 3rd dimension to data with AUVs aligned in X/Y
- Implementations:
  - 2D Front tracking: follow-the-leader
  - 3D Front tracking: follow-the-leader & distributed in depth

New MOOS Behaviors

BHV_FrontTrack (2D)

- Surveys an area using BHV_Loiter to detect the presence of a front
- Autonomously & adaptively tracks along the front edge with a zig-zag motion

BHV_FollowTheLeader (in the works)

- Biases the headings of 2+ AUVs to make them all track along the front in the same general direction

BHV_Helix (3D, in the works)

- AUV moves in a helical motion with the central axis along a constant depth & changing heading

Moving Forward

Finish & polish behaviors.

Simulate & test in MSEAS 4D environment.

Verify/quantify improvement of data synopticity & data collection efficiency.

Questions?

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