ADAPTIVE MESHING TO ENHANCE SEDIMENT PLUME SIMULATIONS

Mohammad Madani[1], Derek Eden[1], Tom Foster[2], Josh van Berkel[2] and Michael Clark[3]

1. **DHI Water & Environment, Inc.**, PO Box 32120 Preston, Cambridge, ON N3H 5M2, Canada
2. **DHI Water and Environment, Inc.**, 141 Union Blvd. Suite 320, Lakewood, CO, 80228, USA
3. **The Metals Company**, 595 Howe Street, Vancouver, BC V6C 2T5, Canada

Agenda

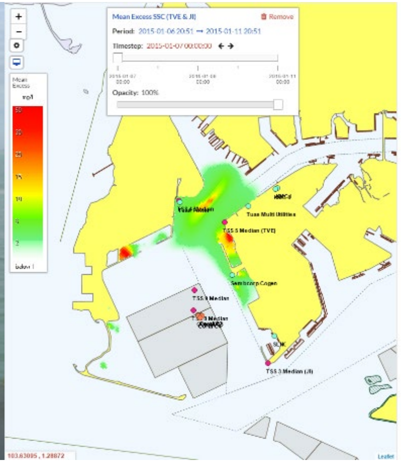
- Introduction / Problem Statement – Adaptive Meshing
- Deep Sea Mining (Example Project)
  - Resources
  - Example Project
    - Location and Collection Technique (Collector / Dredging)
    - Receptors and Sediment Plume Management
- Sediment Plume Modelling with Adaptive Meshing
  - Methodology
  - Example Project – Adaptive Meshing
  - Example Project – Adaptive Meshing Results and Performance Comparison
- Conclusion

Introduction – Problem Statement

- Dredge plumes at the near-field/far-field boundary are typically confined laterally based on hydrodynamic conditions
- Adequate resolution of the plume (both laterally and vertically) is crucial for accurately simulating transport, dispersion, and settling
- A fine model mesh, approximately 10 to 20m, is required for this purpose
- A fine mesh over the operating area is computationally manageable for stationary sources

Introduction – Problem Statement

- Fine mesh can be generated over a large area, such as the use of a nominal 25m mesh for major dredging and reclamation projects in Singapore
- Computational demands of a large high-resolution mesh pose challenges for turn around time in using the model for environmental management decisions
- The adequacy of 25m mesh resolution in resolving the near-field/far-field boundary remains a question



For a moving source e.g., a trailing suction hopper dredger (TSHD) operating over a larger borrow area, the computational challenge becomes more acute as a larger area must be simulated in high resolution

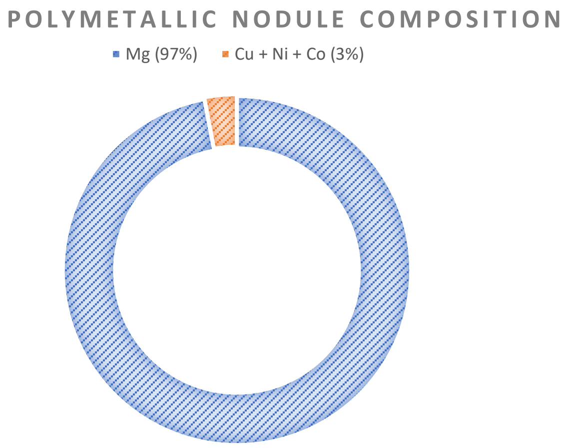
Introduction – Problem Statement

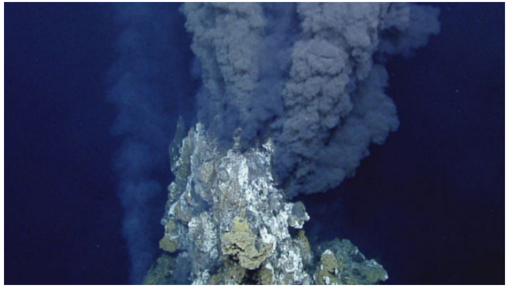
- The resolution vs. computational efficiency problem has recently reached a critical point as sediment plume models are applied to the new frontier of deep-sea mining of polymetallic nodules

- For deep sea mining, the work areas are much larger, up to 10,000 km^2 and the project does not last 5 years, but 20 years, with the added complication of operating in a complex 3D environment at 4000m depth or greater

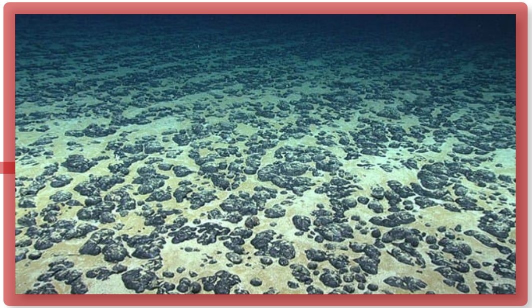
- It is clear that a brute force approach of a high-resolution mesh over the entire work area is not feasible. To address this problem a new approach using an adaptive mesh that follows the sediment spill source has been developed

Deep Sea Mining - Resources

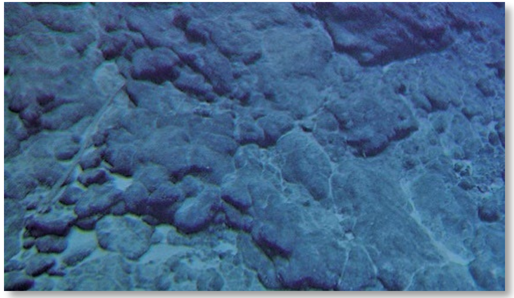




Polymetallic Sulphide Crusts



Polymetallic Nodules

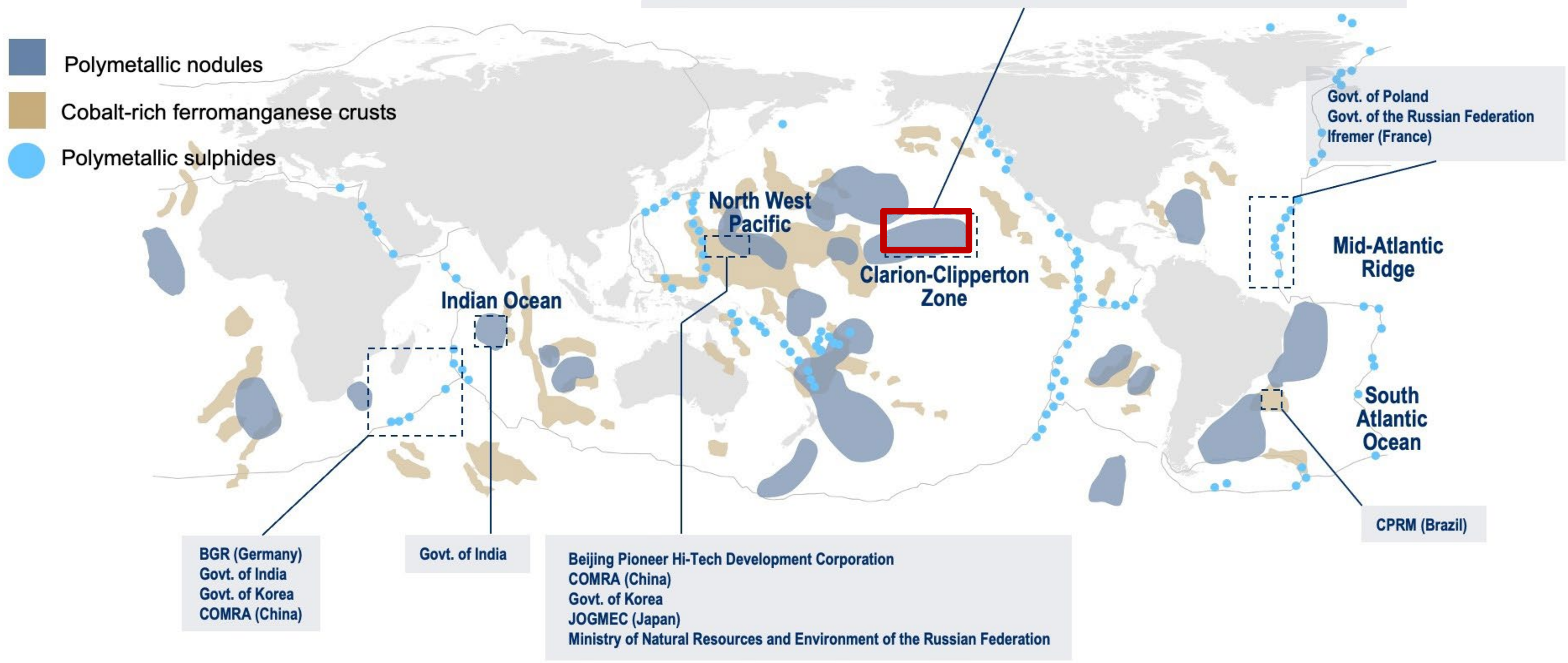


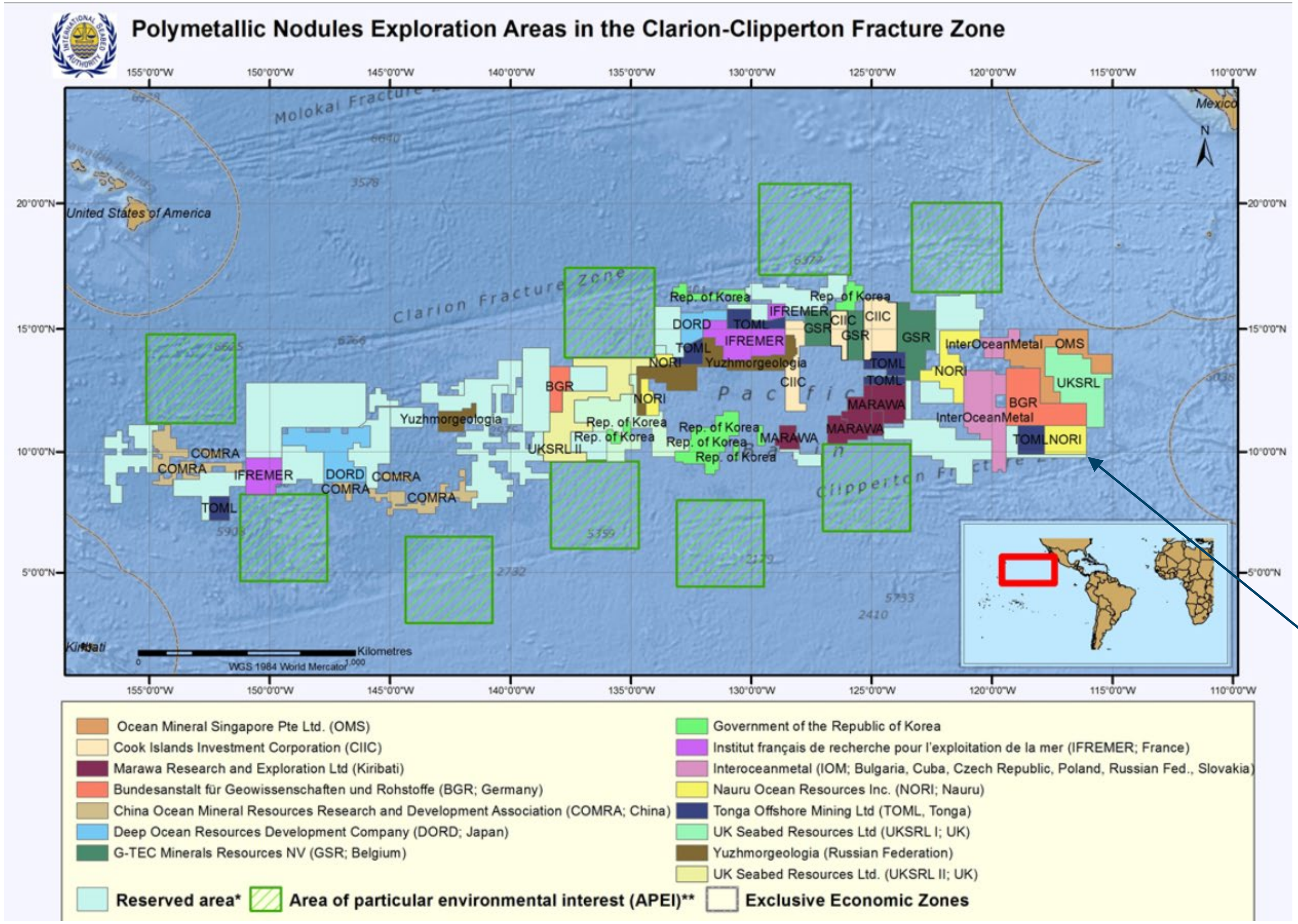
Cobalt Rich Crusts

Driven by demand for:

- **Mn, Cu, Ni, Co**, Au, Ag, Zn, Li, Mo, REEs
- Battery Metals

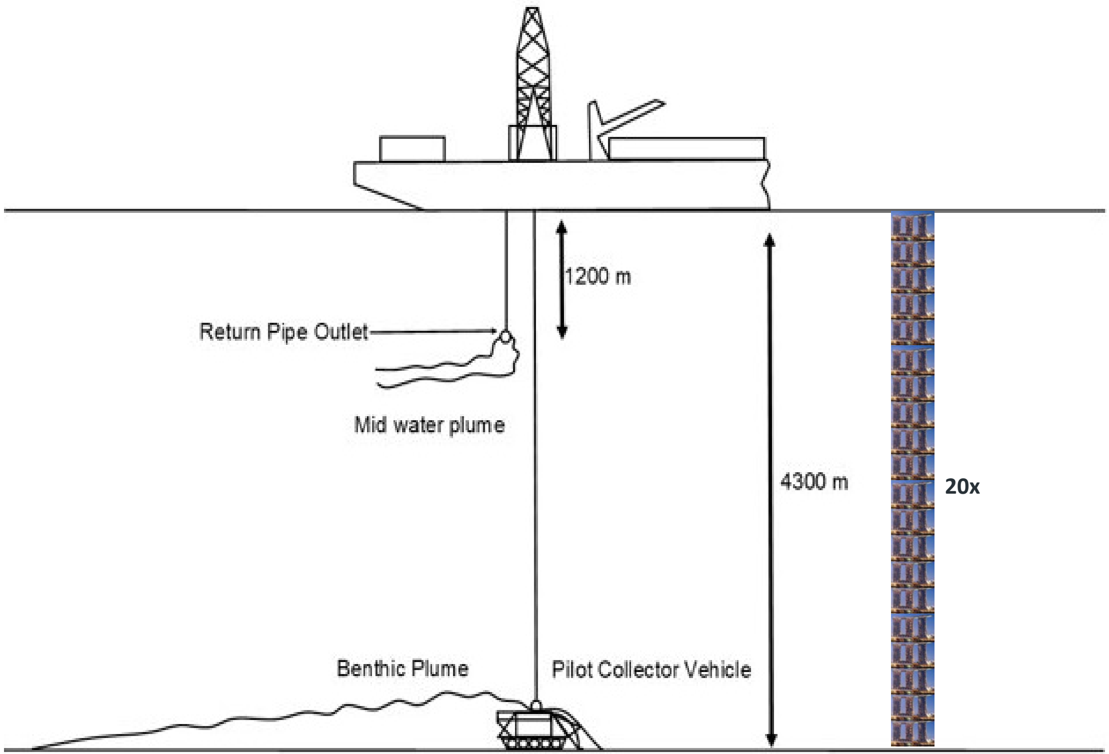
Exploration and Extraction is Governed by the International Seabed Authority

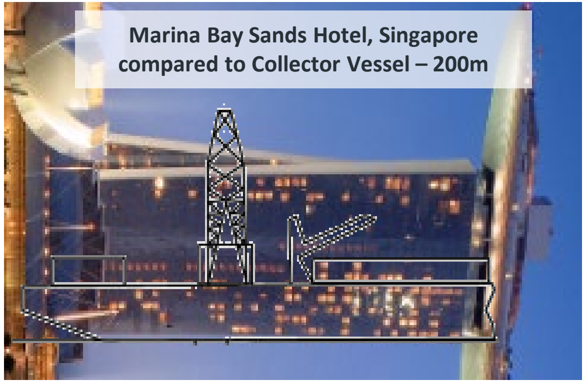


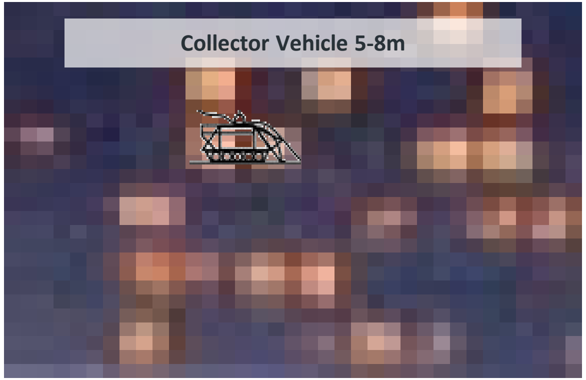


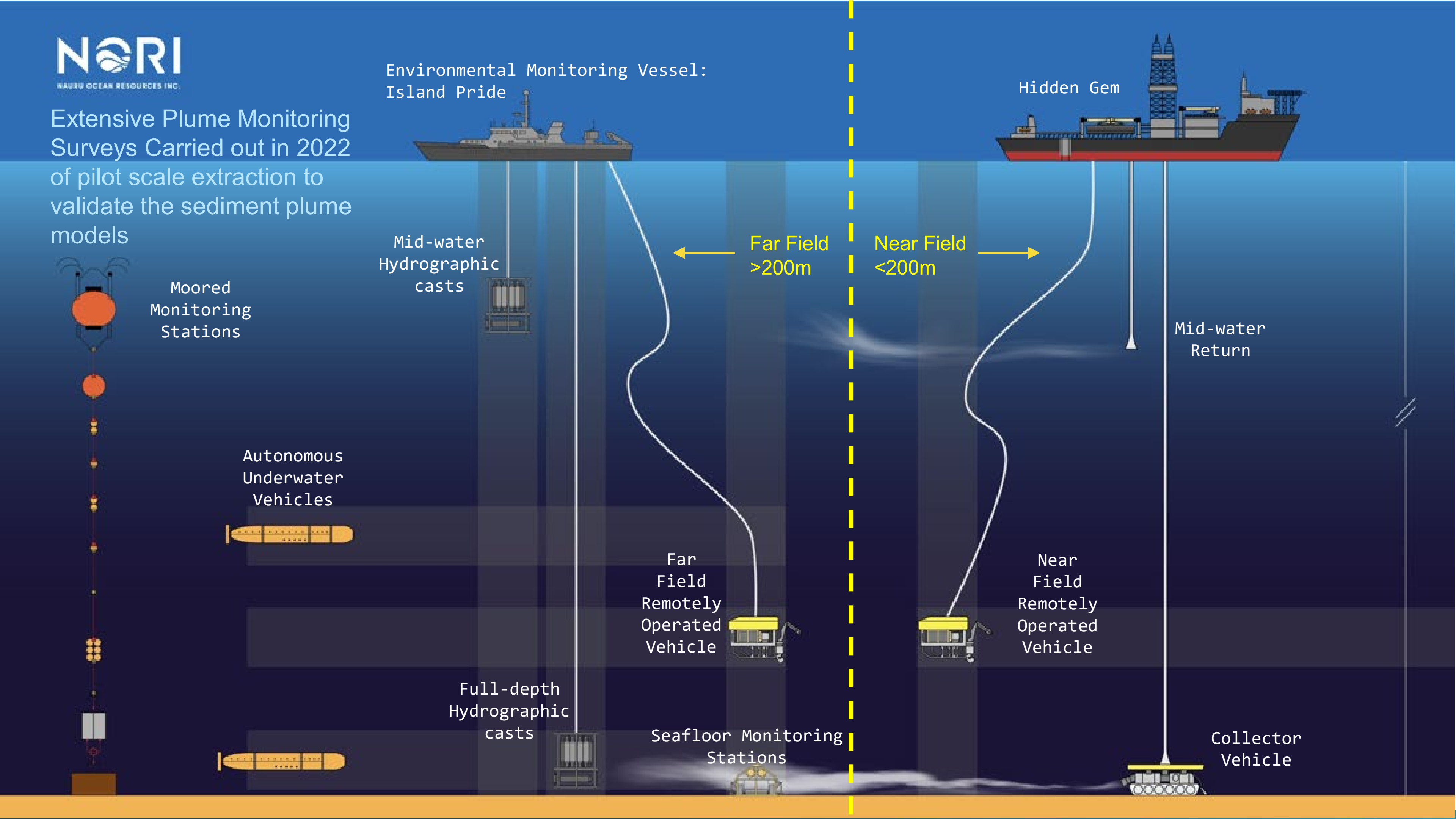
The development of the adaptive mesh approach has been carried out to support the environmental impact assessment of the NORI-D concession

Deep Sea Mining – An attempt to convey the scale

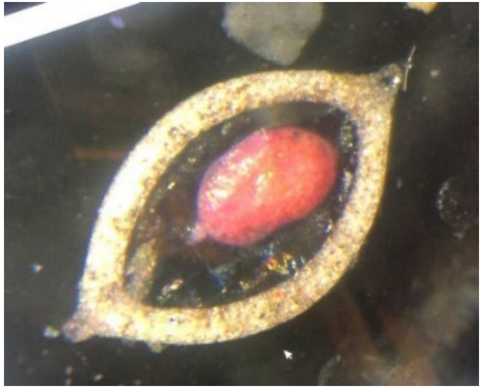


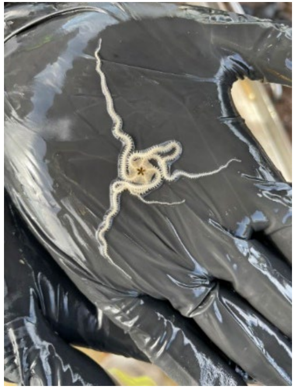
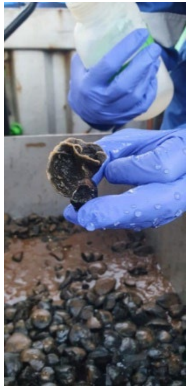





NORI
NAURU OCEAN RESOURCES INC.
Extensive Plume Monitoring Surveys Carried out in 2022 of pilot scale extraction to validate the sediment plume models
Environmental Monitoring Vessel: Island Pride
Hidden Gem
Mid-water Hydrographic casts
Far Field >200m
Near Field <200m
Moored Monitoring Stations
Mid-water Return
Autonomous Underwater Vehicles
Far Field Remotely Operated Vehicle
Near Field Remotely Operated Vehicle
Full-depth Hydrographic casts
Seafloor Monitoring Stations
Collector Vehicle

Environmental Receptors



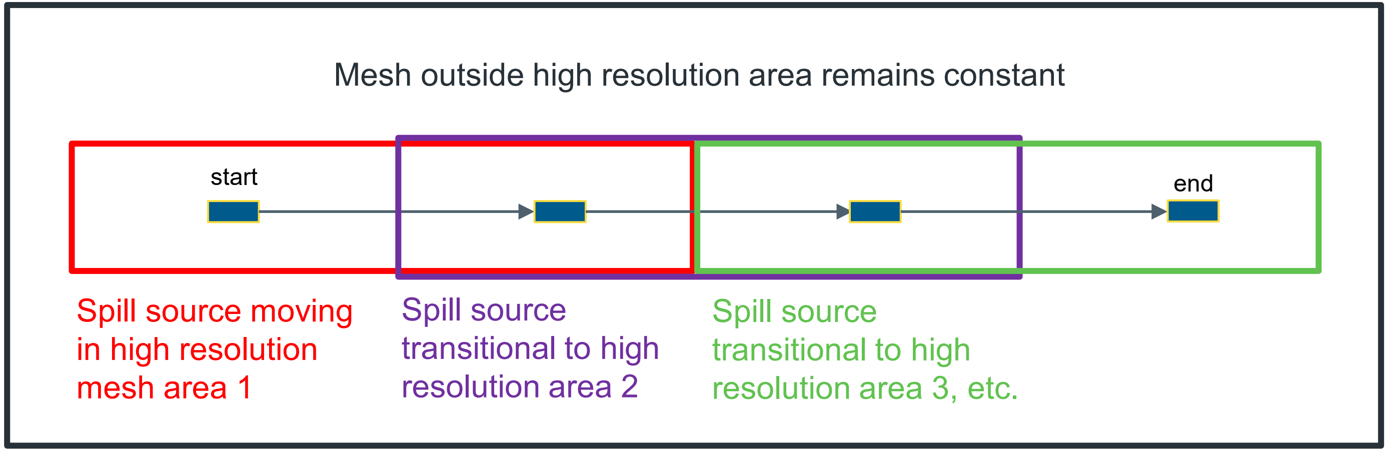
While abundance is low, the deep-water ecosystem is rich in diversity.

As little is known of the tolerance of these organisms to sediment plumes a precautionary approach is being taken with a target of not more than 10% of background sedimentation and suspended sediment concentration outside direct footprint impact area. Robust sediment plume models are essential to ensuring that this target is met.

Adaptive Mesh Modelling Strategy

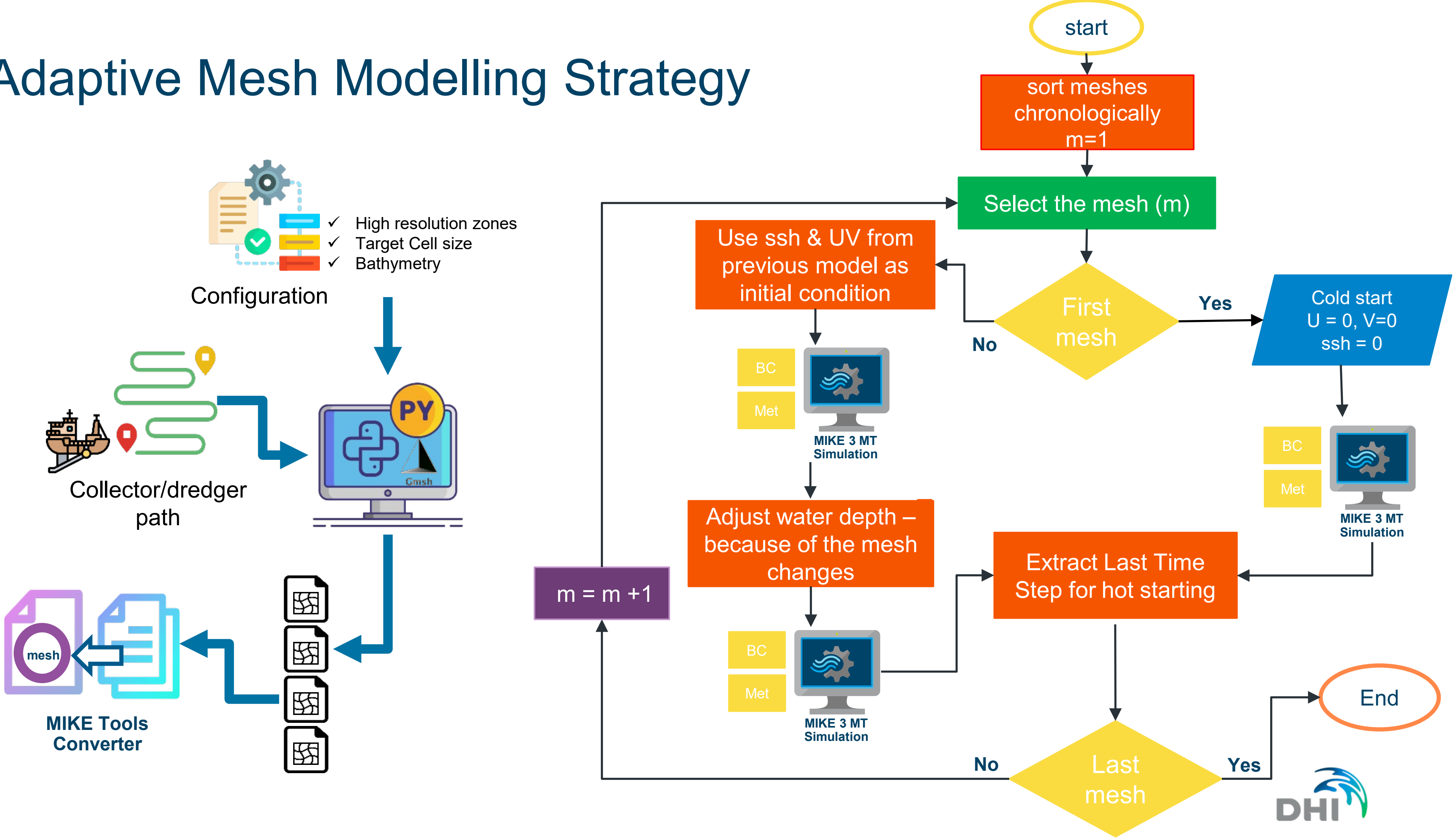
As the spill source track is known in advance (either as part of the mine plan (forecast for the EIA) or from measured positions (Hindcast for adaptive management) a number of high resolution meshes can be prepared (with overlap) covering the entire spill source path. The model can then step though these pre-defined meshes as the spill source progresses through the domain over the simulation.

This limits the area requiring high mesh resolution and for any given computational effort will always produce a finer mesh size in the critical near-field / far-field boundary area than a traditional uniform mesh over the entire area of operation.



Background mesh area

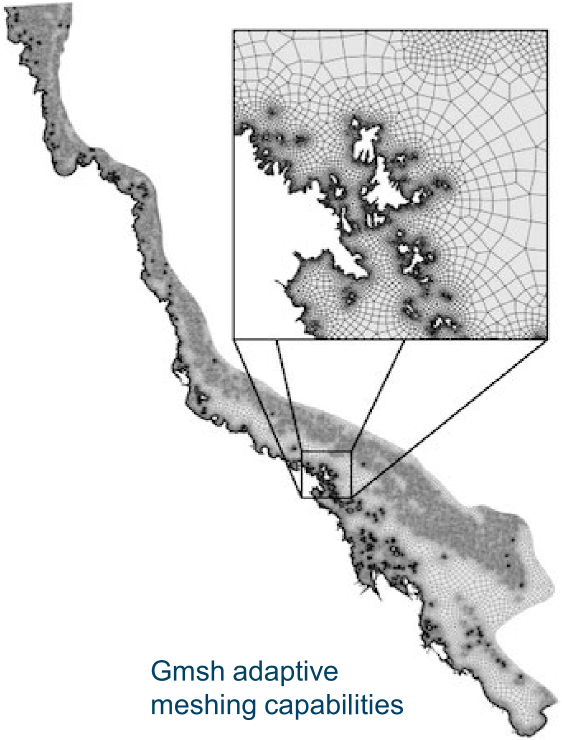
Adaptive Mesh Modelling Strategy



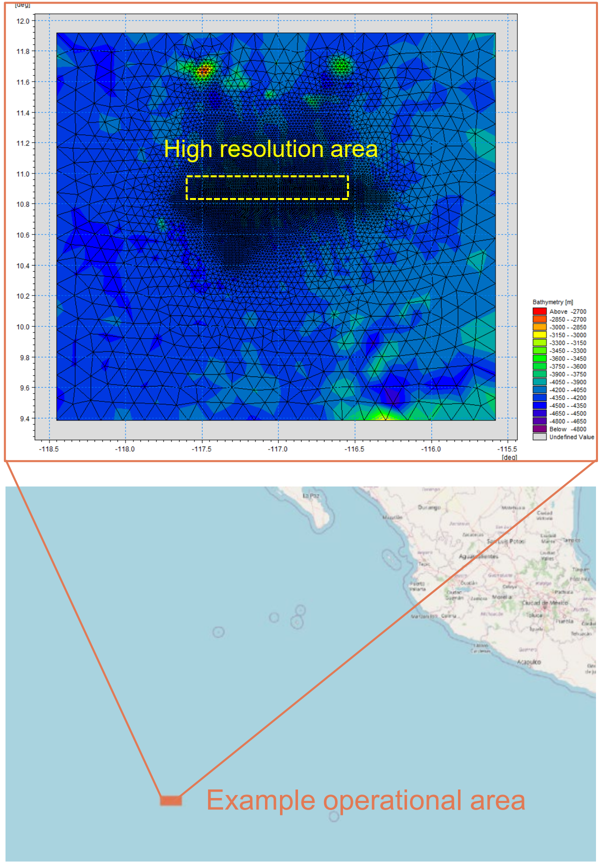
Deep Sea Mining – Adaptive Mesh Generation

Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities has been utilized to produce efficient and stable meshes

https://gmsh.info/

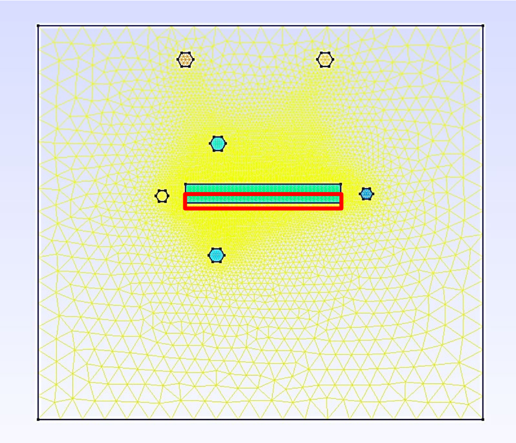


Gmsh adaptive meshing capabilities



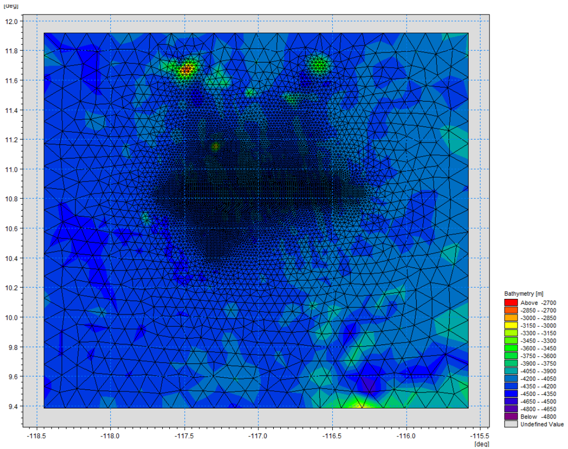
Gmsh → MIKE3 Mesh

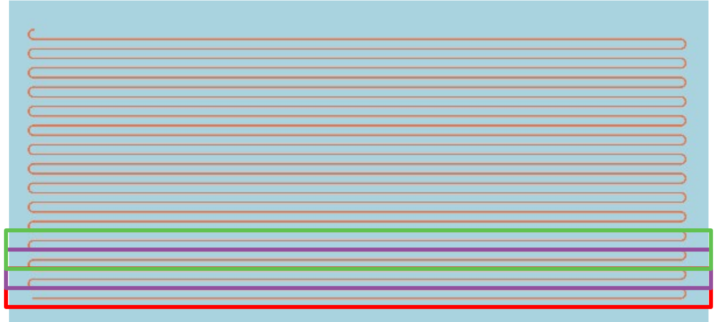
Mesh resolution control points in Gmsh



Conversion to MIKE

One Instance of the high-resolution mesh



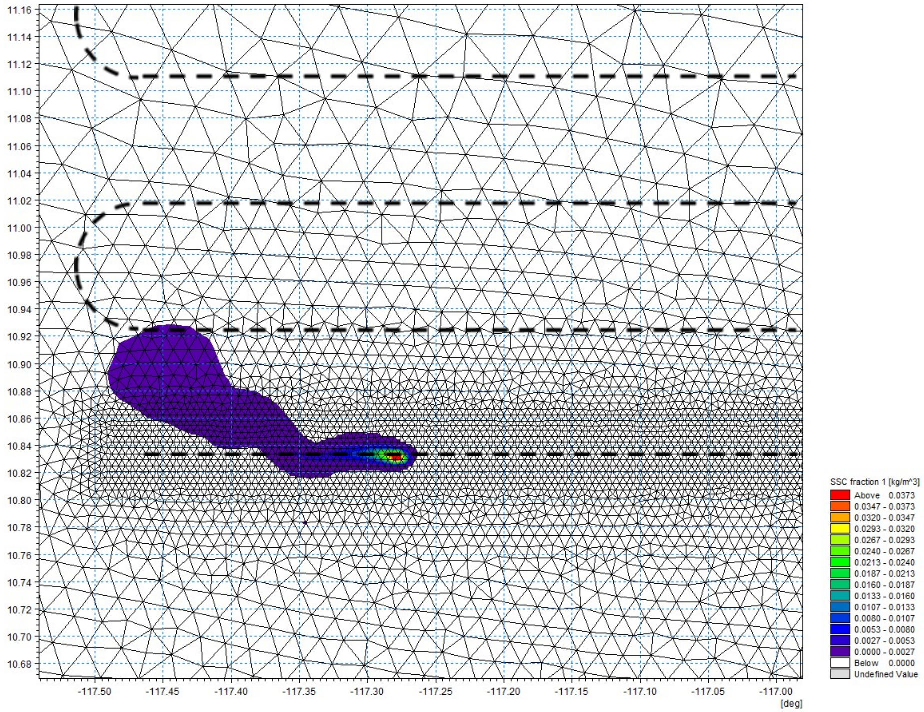


Collector Vehicle (spill source) Track

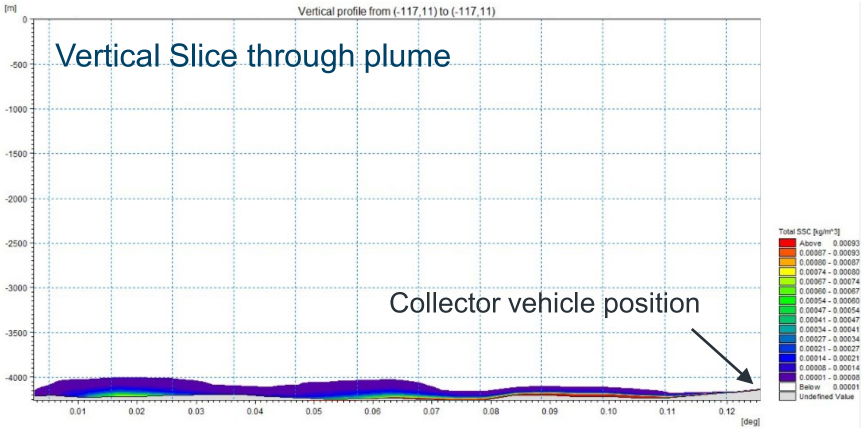
For test divided into 3 high resolution areas
For production run, will be divided to 100s of areas

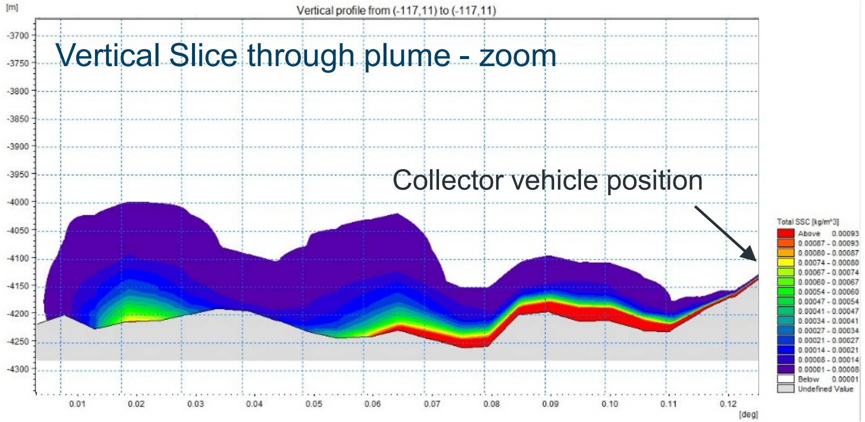
Total Instantaneous Suspended Sediment Concentration Results

Collector Vehicle Track

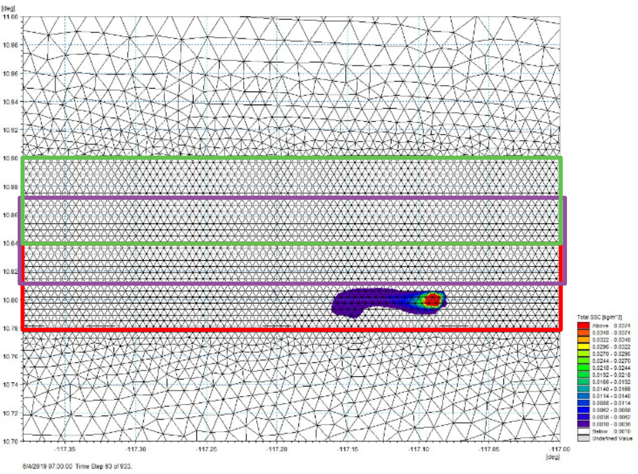


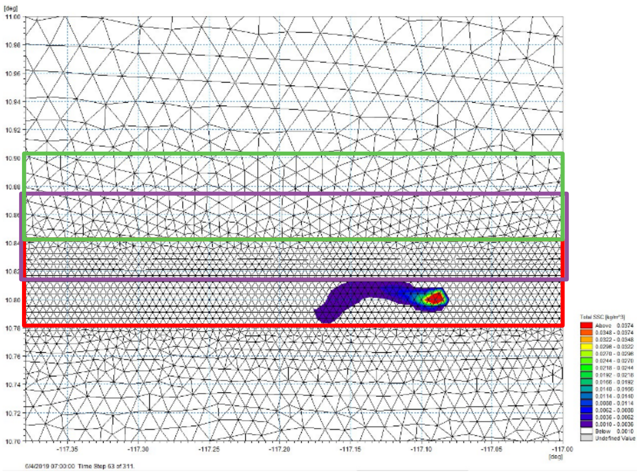
Aerial View

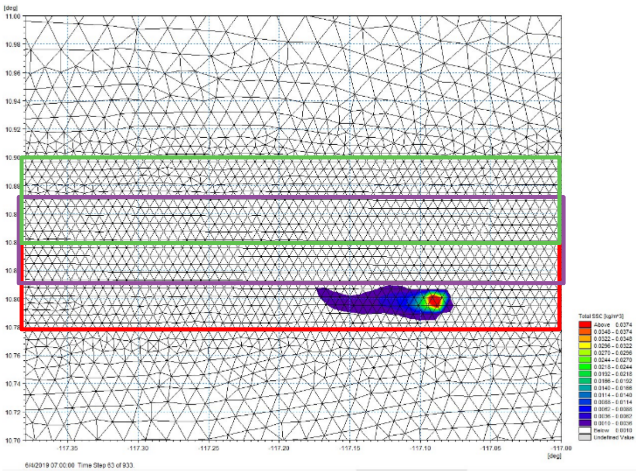




Suspended Sediment Concentration 5m from Seabed
Mesh Comparison







Brute Force

Adaptive mesh resolution across the entire spill source area

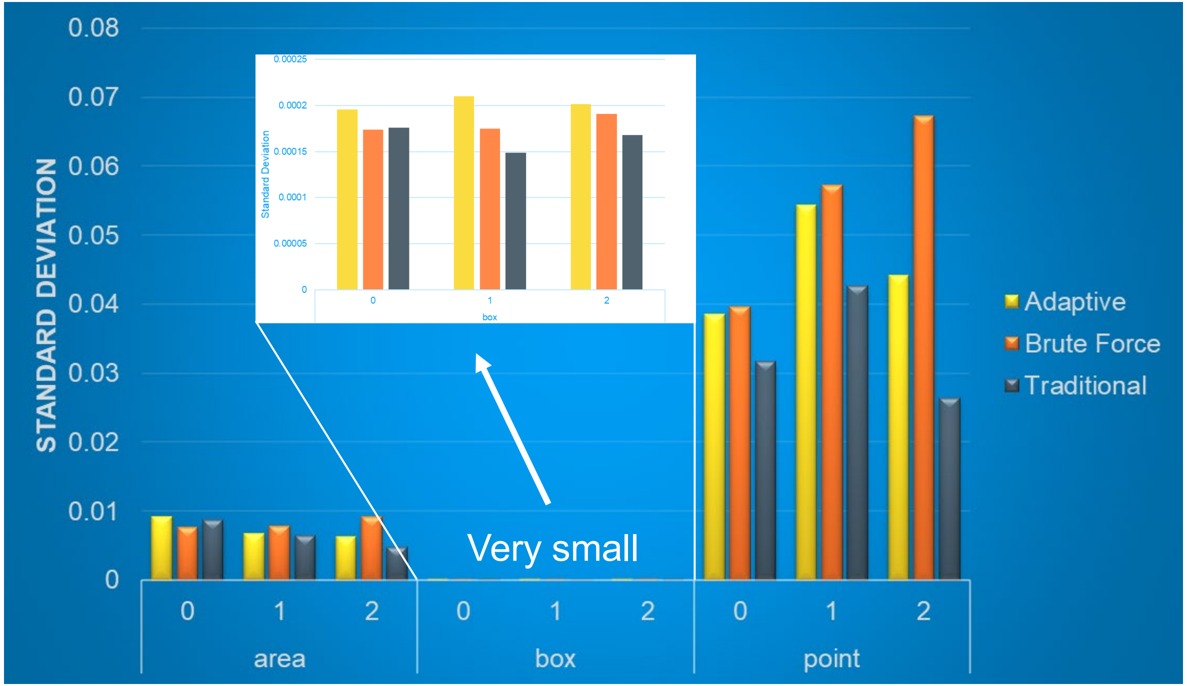
Adaptive Mesh

Offers the accuracy of brute force, with the computational requirement of traditional

Traditional

Mesh size fixed to provide the same computational time as the adaptive mesh

Model Results Comparison for 3 Different Mesh Strategies



- Mesh size has a relatively small effect on total area of influence (>10% background) or when spatially averaged
- Traditional approach underestimates variability in plume concentration at specific points
- Underprediction of variability by the traditional approach can be significant in identifying and quantifying potential plume impacts on habitat suitability

Conclusion

- A high-resolution, adaptive mesh technique for following moving spill sources was developed in MIKE
- Applicable to deep sea mining sediment plume applications
- Applicable to all dredging sediment plume applications with moving sources
- Adaptive mesh approach generates finer mesh in near-field/far-field boundary area
- Traditional approach results in a coarser mesh for the same computational requirement
- Adaptive mesh approach predicts plume variability similar to the brute force approach, but with greater computational efficiency
- Critical for determining / managing habitat related impacts (e.g., exceedance of tolerance limits)

DHI

Thank You, Any Questions?

Sunrise and Sunset on the Clarion Clipperton Zone