DHI – MIKE Models

How do Methods, Assumptions and Conclusions Translate to the Nantucket Shoals Region

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Why are we here

- DHI was asked in 2019 by BOEM to do a study on the cumulative impact of offshore wind in US Mid-Atlantic Bight lease areas on hydrodynamics and selected species (1) *(Contract #: 140M0120C0004)*
- DHI is under contract with BOEM extending this study to include accumulated impacts on hydrodynamics and selected species for all US East coast leases *(Contract #: 140M0122C0010)*

- Today we will discuss our best modelling practices as developed from these 2 studies

1: BOEM Contract No. 140M0120C0004 Hydrodynamic Modeling in the U.S. Mid-Atlantic Bight (https://espis.boem.gov/final reports/BOEM_2021-049.pdf)

Who is DHI?

- We're **an independent, private and not-for-profit** global company
- 1,100 qualified people, headquarters in Hørsholm, Denmark
- 25 offices worldwide including US (Denver and Portland)
- Our knowledge represents 50+ years of **dedicated research** worldwide
- We make this knowledge globally accessible - through our local teams, digital solutions and software

DHI offices

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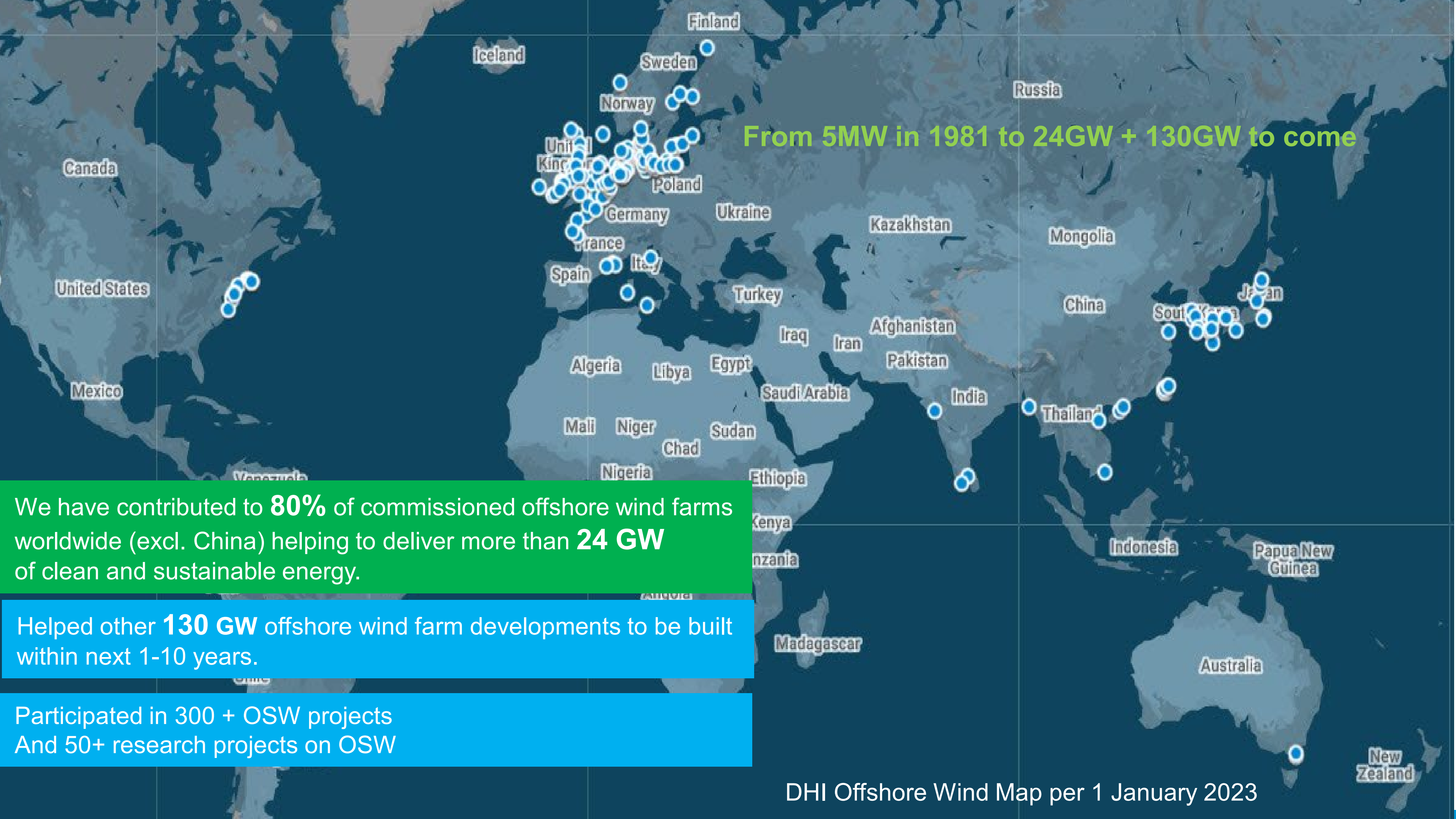
The first Offshore wind farm in Vindeby DK (1991-2017), owner: Orsted, 11 x 450 kW = 5MW

Sustainable and faster development of energy offshore

DHI has supported offshore wind since the first OSW Farm in Vindeby in 1991

7 AFFORDABLE AND CLEAN ENERGY — Affordable & Clean Energy
8 DECENT WORK AND ECONOMIC GROWTH — Decent work and economic growth
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Industry, Innovation &
12 RESPONSIBLE CONSUMPTION AND PRODUCTION — Responsible consumption
13 CLIMATE ACTION — Climate action
14 LIFE BELOW WATER — Life Below Water
17 PARTNERSHIPS FOR THE GOALS — Partnerships for the goals



From 5MW in 1981 to 24GW + 130GW to come

We have contributed to **80%** of commissioned offshore wind farms worldwide (excl. China) helping to deliver more than **24 GW** of clean and sustainable energy.

Helped other **130 GW** offshore wind farm developments to be built within next 1-10 years.

Participated in 300 + OSW projects
And 50+ research projects on OSW

DHI Offshore Wind Map per 1 January 2023

DHI empowers water decisions in offshore wind development

Strategic site selection
- Assessment of environmental sensitivity
- Undertake environmental surveys
- Assessment of metocean and load conditions

Planning and feasibility
- Secure planning consents
- Planning of design and engineering aspects incl. ports
- De-risk critical development decisions

Environmental consent
- Environmental Impact Assessments (EIAs)
- Marine bird and mammal environmental surveys
- Brokering consenting between regulators and developers

Engineering & design basis
- Establishment of environmental design criteria
- Loads and response analyses
- Scour/seabed mobility analyses and mitigation

Installation and construction
- Operational metocean forecasting
- Metocean and environmental monitoring
- Smart vessel planning

Operation and maintenance
- Post construction environmental monitoring
- Operational metocean forecast
- Smart vessel planning

Decommissioning
- EIA of decommissioning plans
- Operational metocean forecast
- Smart vessel planning

We support an ***efficient, accelerated*** and ***sustainable*** development of offshore wind

An example: Paving the way to successful Dutch offshore wind power development (dhigroup.com)

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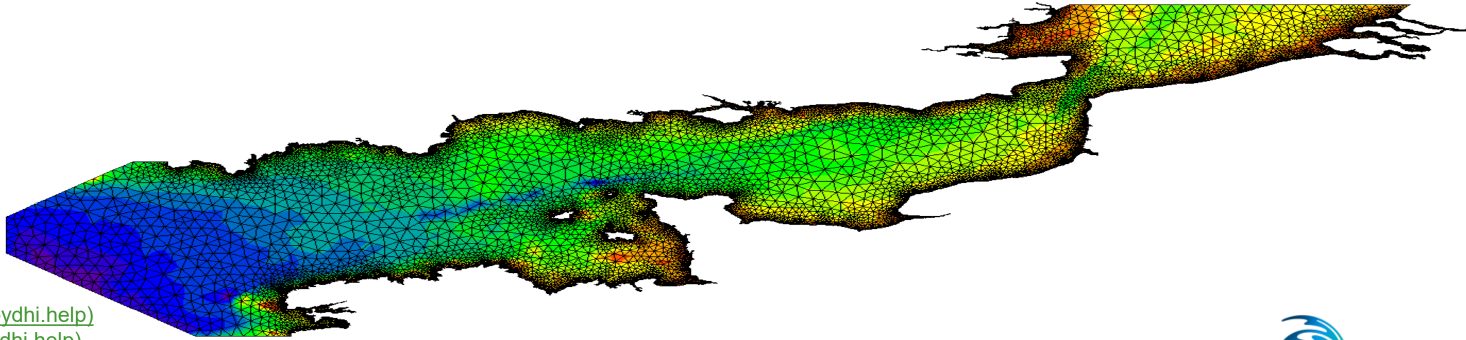
Modelling is a key
MIKE Marine modelling framework

- DHI started hydrodynamic modelling in 1964 and has developed the MIKE model suite since 1980
- Today it includes facilities for hydrodynamics, environment and a wide variety of sectors

- In this hydrodynamic study is used:
  - MIKE 21 Spectral Wave model
  - MIKE 3 3D hydrostatic flow model



1: MIKE 21 Documentation (mikepoweredbydhi.help)
2: MIKE 3 Documentation (mikepoweredbydhi.help)

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Accumulated marine effects of OSW

- Wind wake effects reduce surface stresses and affect waves, currents or air-sea interaction
- Drag from foundations impacts waves, currents and turbulent mixing
- Cables induce heating and disturbance of the seabed
- New habitats may form on scour protection, foundations, etc.

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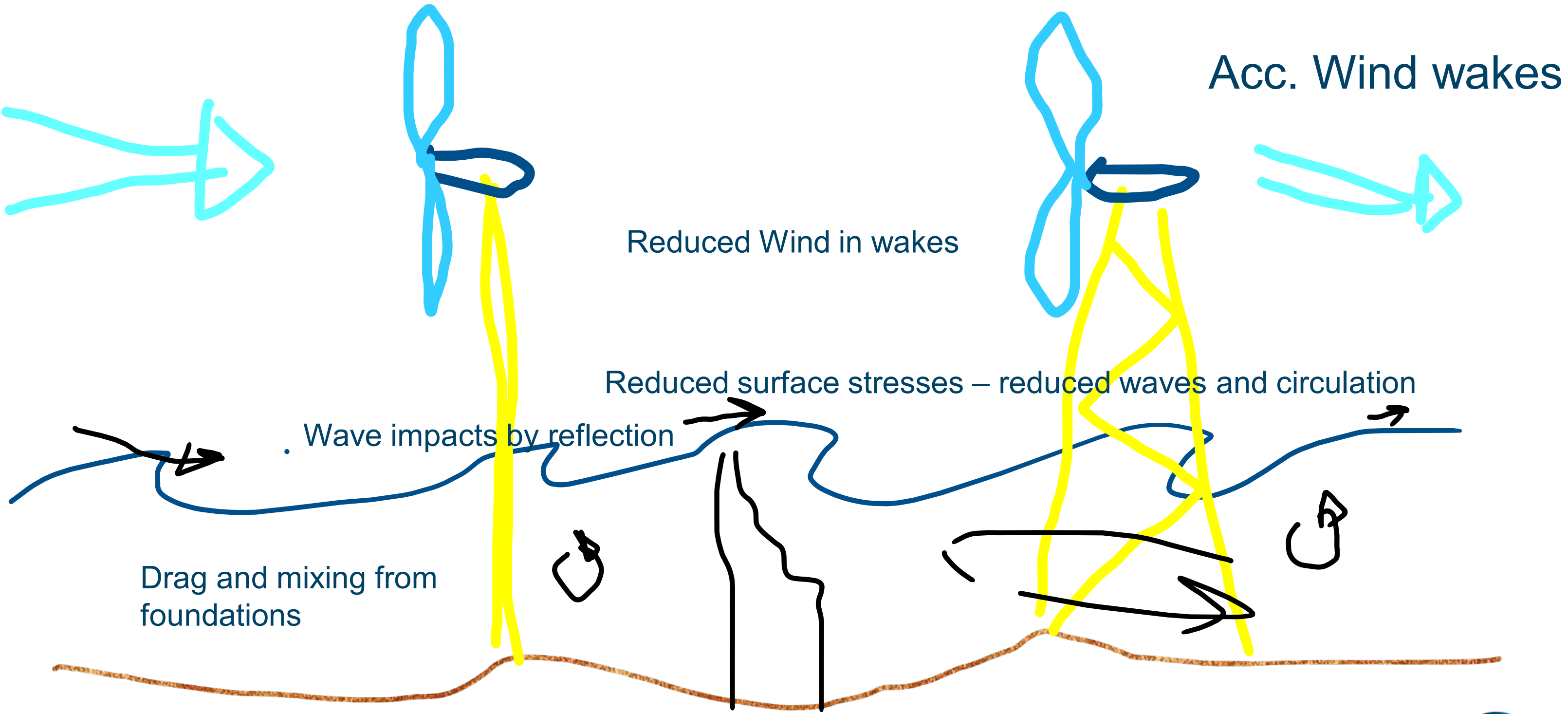
Wind turbine wake effects



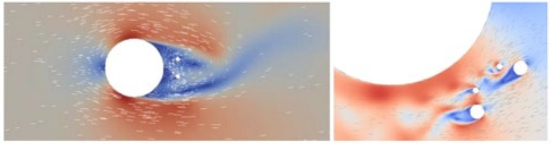
For a more complete list see: Akhtar, N., Geyer, B., Rockel, B., Sommer, P. S. & Schrum, C. Accelerating deployment of offshore wind energy alter wind climate and reduce future power generation potentials. Sci. Rep. 11, 1–12 (2021).

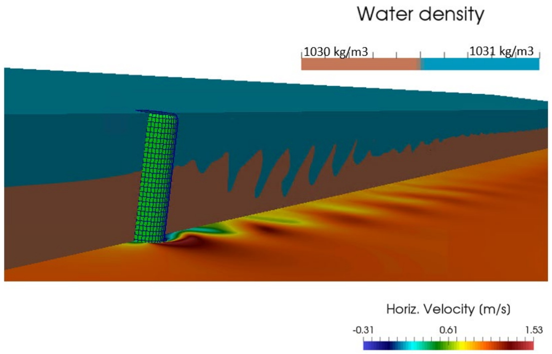
Effects of foundations

- Increased flow resistance due to drag on foundations
- Increased turbulence and vertical mixing(2)

- Effects on wave climate due to reflections/transmission (1)

- Modelled as a *sub-grid* effect using energy relations





1:Erik Damgaard Christensen , Martin Johnson, Ole Rene Sørensen, Charlotte Bay Hasager, Merete Badger, Søren Ejling Larsen (2013). Transmission of wave energy through an offshore wind turbine farm. Coastal Engineering, 82, 25-46.
2:Bjarne Jensen, Stefan Carstensen,Erik Damgaard Christensen (2018). Mixing of Stratified Flow around Bridge Piers in Steady Current, J. Hydraulic Engineering, 144(8)
3: Petersen, T. U., Mandviwalla, X., Christensen, E. D., Tarp-Johansen, N. J., Rudinger, F. (2020) Oscillatory Loads on Circular Cylinder with Secondary Structures. Journal of Fluids and Structures. Vol. 94.

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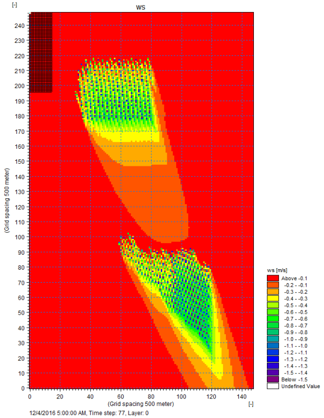
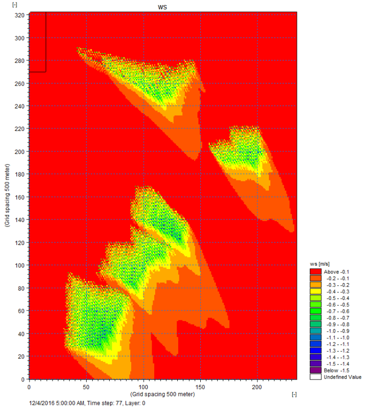
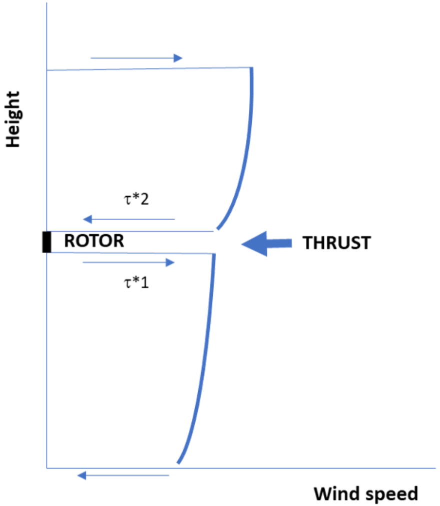
Effects of wind turbine Wind Wakes

- The influence of each wind turbine on the surface wind is modelled by a wake-loss model using PyWake (2)
- Downstream windspeed is reduced depending on turbine production, atmospheric stability conditions and hub height windspeed
- In hydrodynamic models the sea surface stress changes are implemented as modified sea surface wind fields
- In the 2019 study only impacts inside the OSW area were included



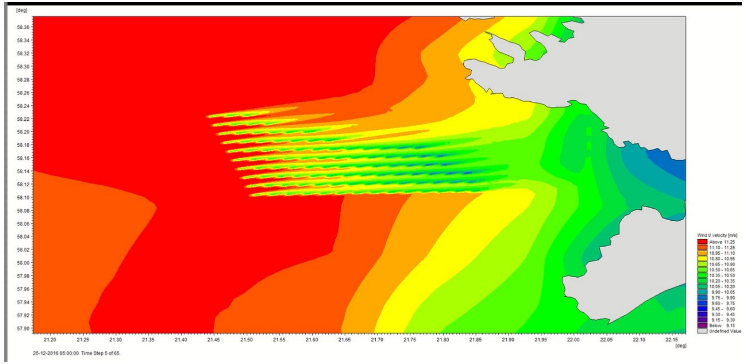




Conceptual framework of the wind wake loss model (1)

1: Infinite Wind-Farm Boundary-Layer (IWFBL) model (Frandsen 1992) with atmospheric stratification modifications (Peña and Rathmann 2014)
2: Fischereit, J., Hansen, K. S., Larsén, X. G., van der Laan, M. P., Réthoré, P.-E., and Murcia Leon, J. P.: WRF and PyWake configuration iles for publication "Comparing and validating intra-farm and farm-to-farm wakes across different mesoscale and high-resolution wake models", https://doi.org/10.5281/ZENODO.5570397 2021b.

Wind wake – eastward 10m wind



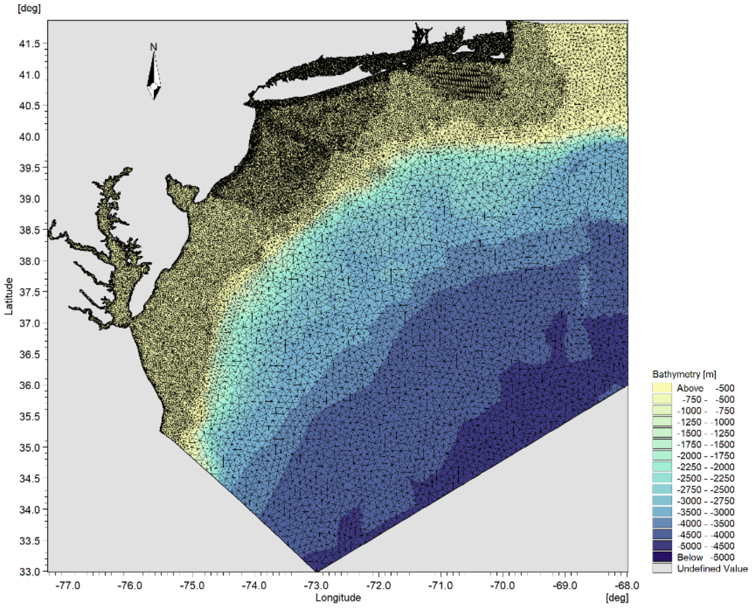
U10m adjusted by PY-Wake to give the correct sea surface stress when applied in the wave and current models

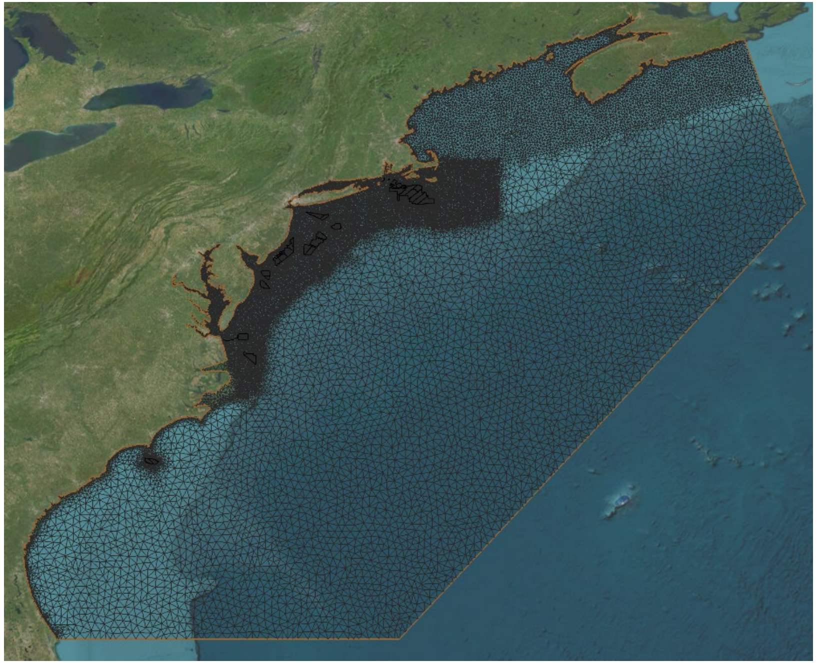
Hydrodynamic models

Geographic extent of the regional HD 2019 was from offshore Massachusetts (Cape Cod) to offshore North Carolina (Cape Hatteras)

The model was established in hindcast mode, using MIKE 3 FM HD three-dimensional model

Targeted localized resolution in the project area (i.e., the OSW leases located off Massachusetts and Rhode Island).





Geographic extent of the regional HD 2023 is from offshore Nova Scotia to the Bahamas

The model was also established in hindcast mode, using MIKE 3 FM HD three-dimensional model

Targeted localized resolution in the project areas (i.e., the OSW leases from the Carolinas to off Massachusetts & Rhode Island).

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Modelling of accumulated hydrodynamic impacts of OSW

- Our concept to quantify impacts is to:
  - Develop a validated baseline model of waves and currents
  - Implement impacts of OSW build out scenarios
  - Simulate a historic period ~ 1 to 3 years (depending on the project)
  - Quantify the hydrodynamic model (HD model) baseline (no OSW developments) to the selected OSW build-out scenarios
  - Investigate changes in the dispersion of fish larvae by comparing the changes in the patterns of settlement

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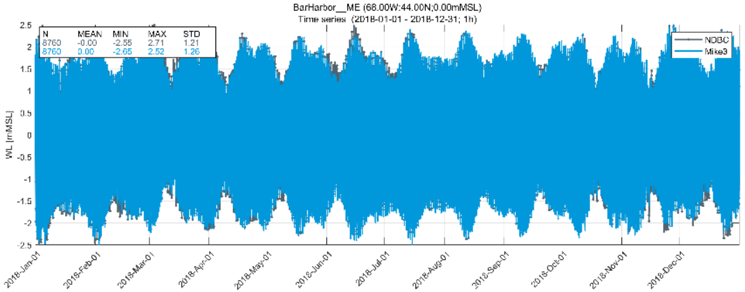
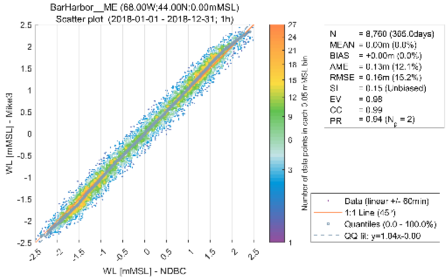
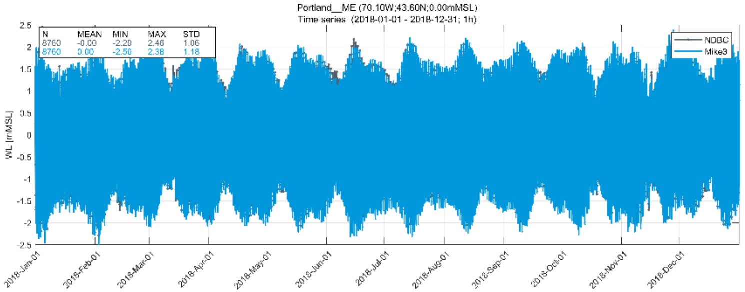
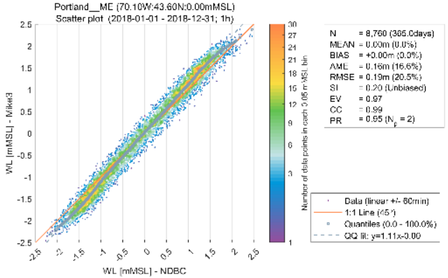
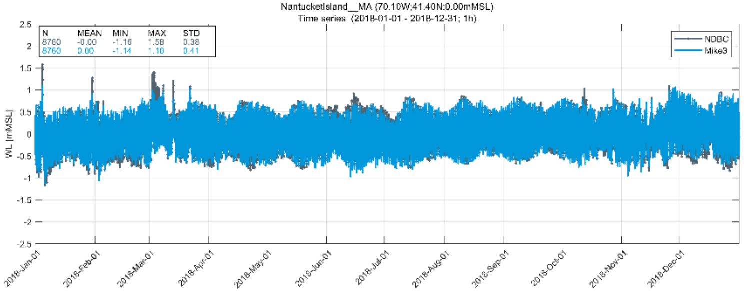
Water Levels

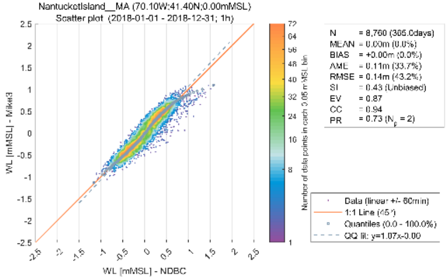


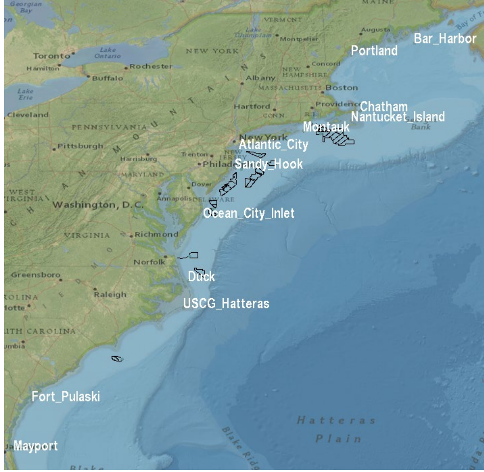




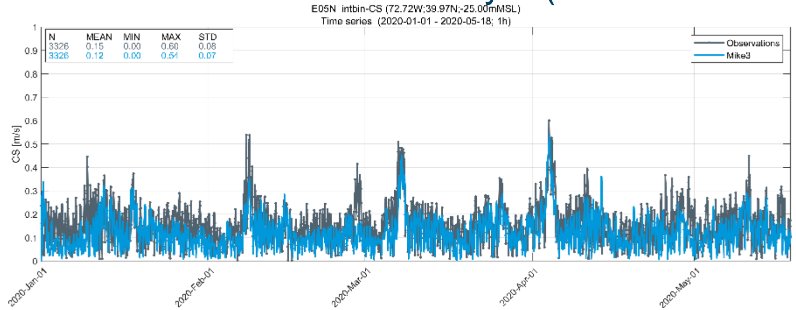


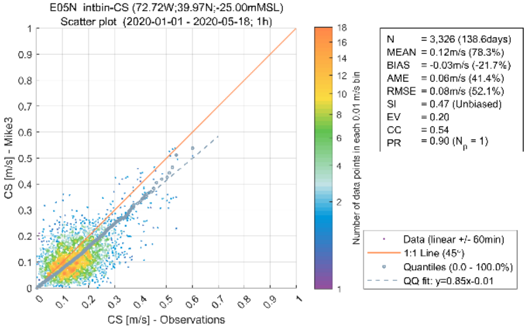


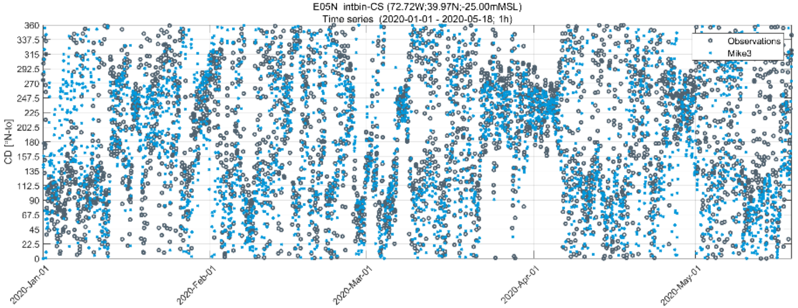


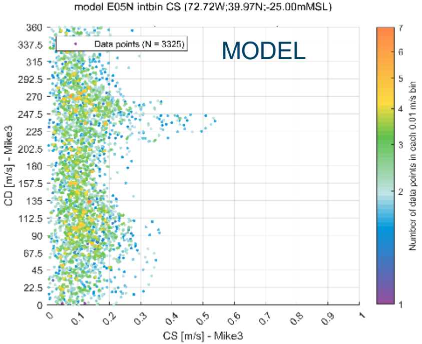


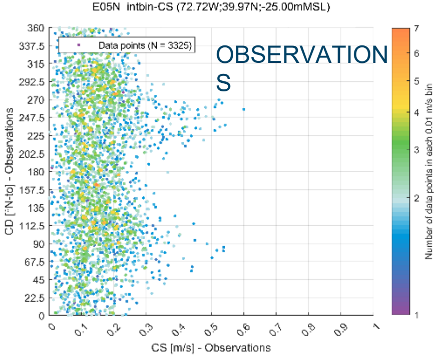
NYSERDA N05– Midwater Layer (5 months - 2020)

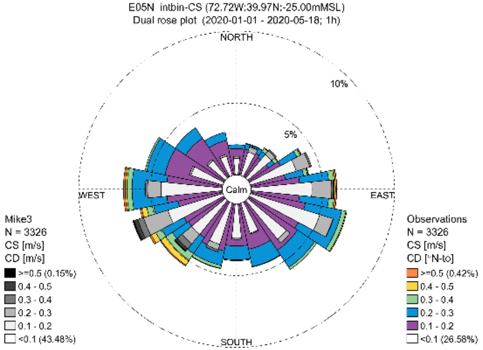












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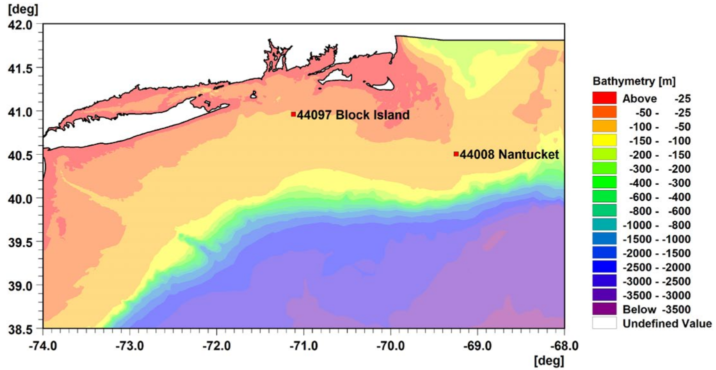
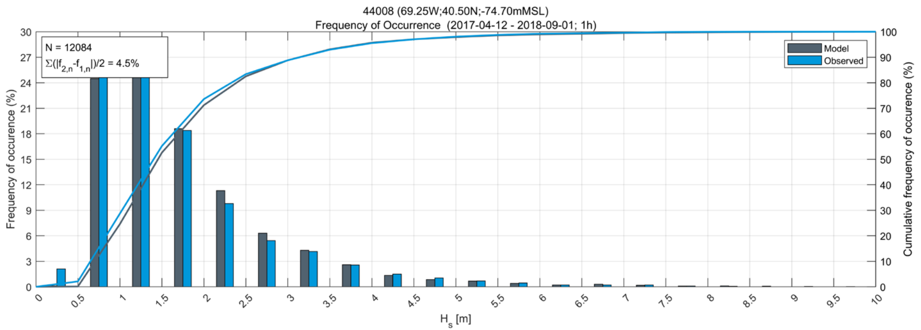
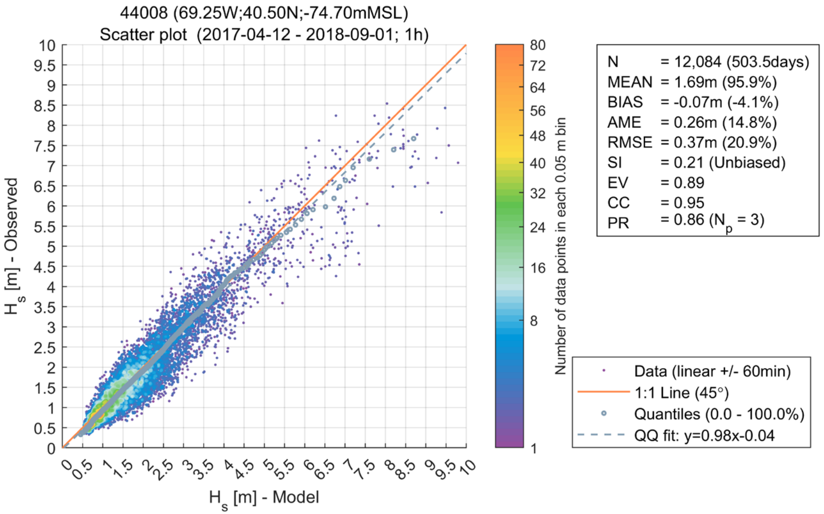
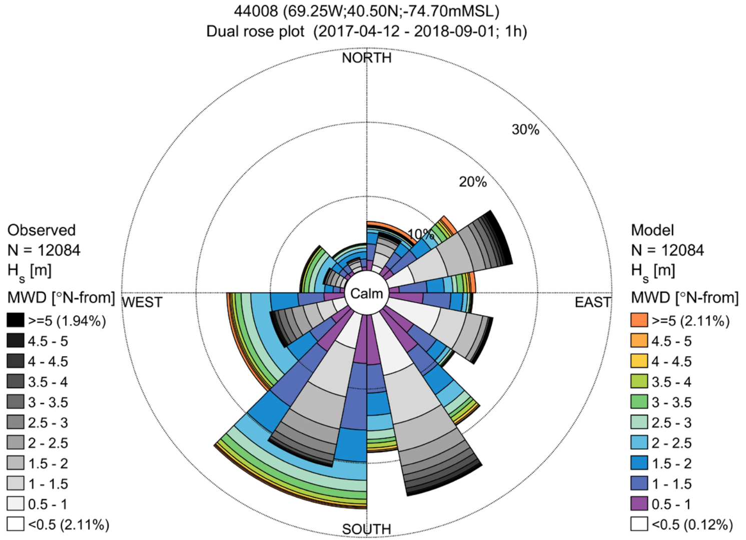






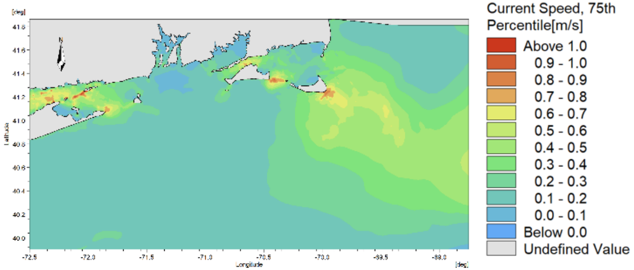


Baseline Wave Validation (Example: Nantucket (NDBC 44008))

Quantification of Hydrodynamic impacts

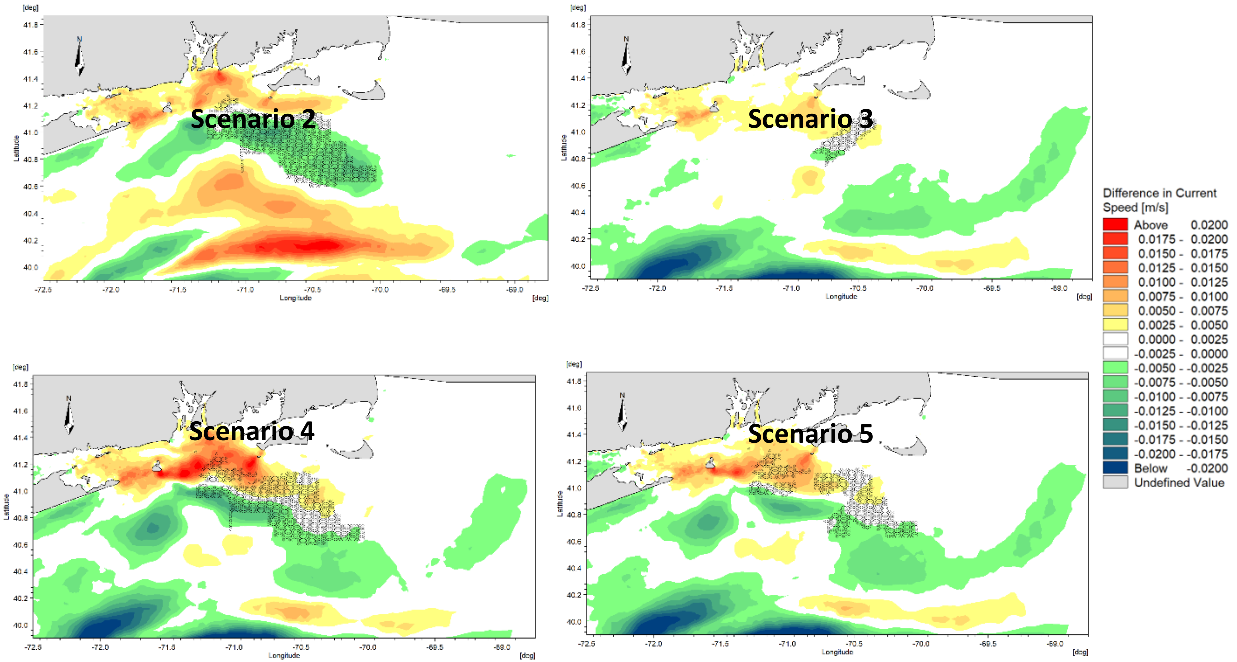
- Introduction of the turbine wind wakes and resistance
- Quantifying OSW Turbines affect on:
  - Current fields
  - Waves
  - Bed shear stress
  - Temperature Stratification
  - Particle tracking
  - Agent Based Modeling (ABM) of selected fish larvae

Impacts on Depth Averaged Current



Scenario 1: 75th Percentile depth averaged current

75th Percentile Difference Plots

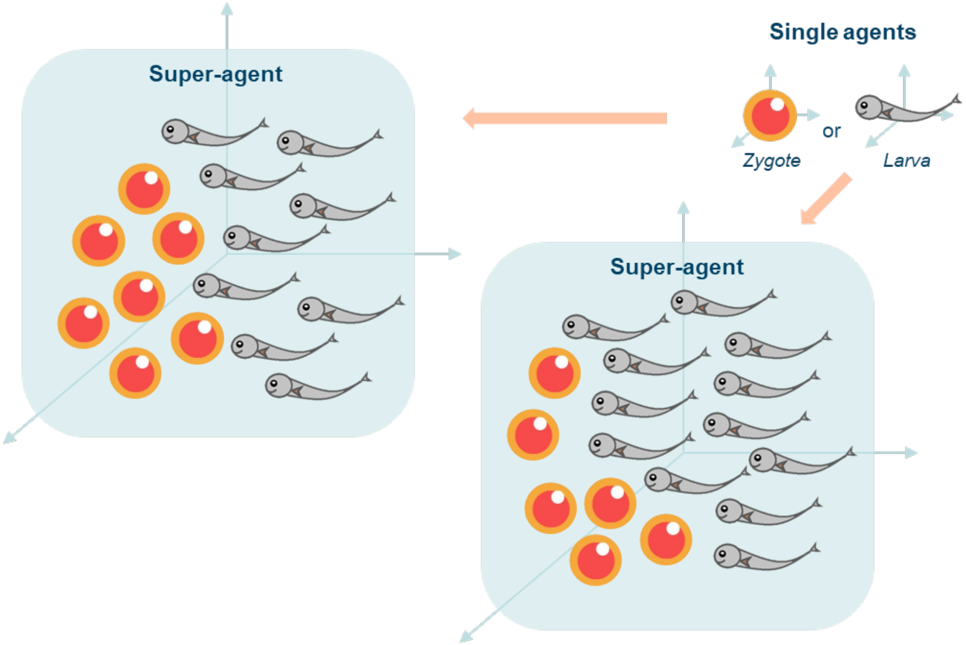


Scenario - Baseline	75th percentile increase	75th percentile decrease
2 - Baseline	+8.5%	-7.1%
3 – Baseline	+3.5%	-2.9%
4 – Baseline	+11.4%	-7.9%
5 - Baseline	+10.7%	-5%

Implication of Hydrodynamic changes on the Environment: Agent Based Modeling

Agent Based Modeling: Super-Agent Methodology

- The concept of super-agent is used due to the high fecundity rates of mature of the target fish and scallop species, each of which typically produces in the range of millions of eggs per spawning season.
  - Aggregation of individual zygotes and larvae as super-agents (move as a single unit)
  - Reduces computation load for simulation
  - Super-agent states are monitored and updated over time

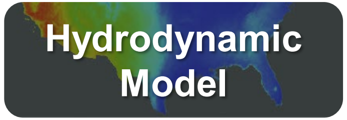


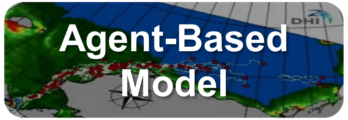
1. Customize ABM template for each species

Sea Scallop Silver Hake Summer Flounder

Image source: NOAA

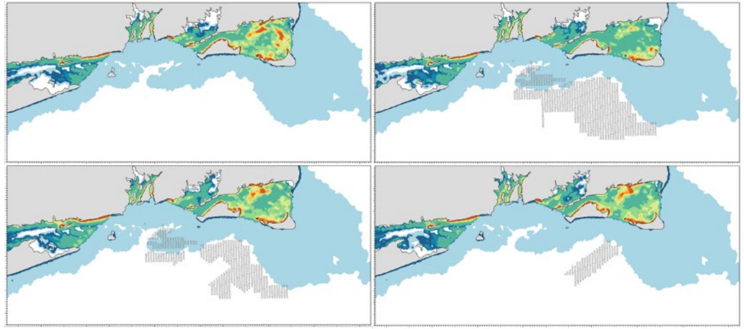
2. Coupling of ABM templates to HDM





3. Validated baseline ABM to be applied for build-out scenarios
(Summer Flounder)

Baseline (validated) *Full build-out*

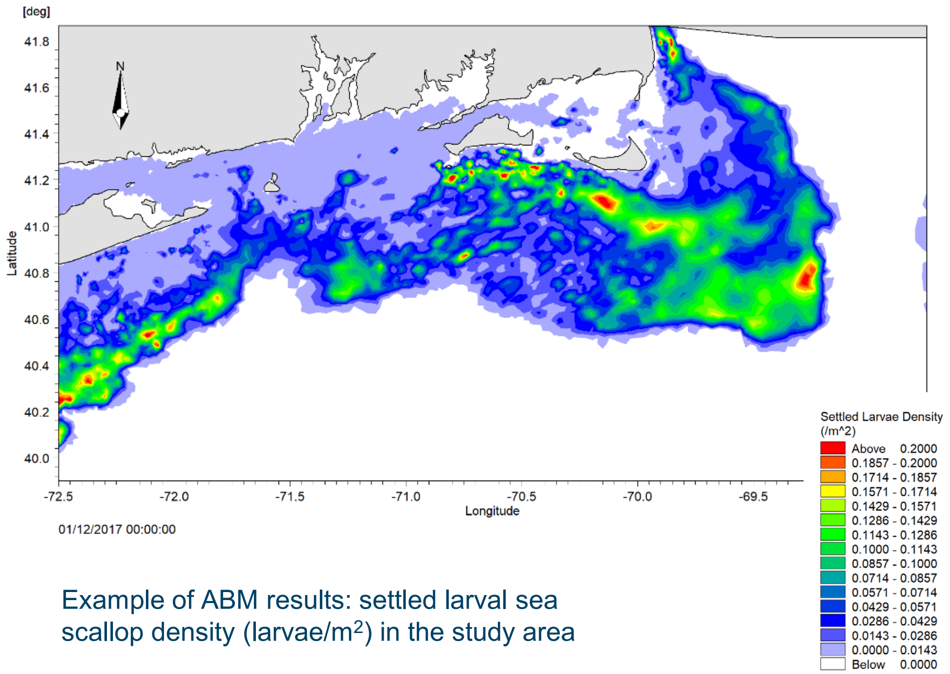


12 MW "partial build-out" *OCS-A 0501*

General ABM Steps

Agent-Based Model Conceptualization

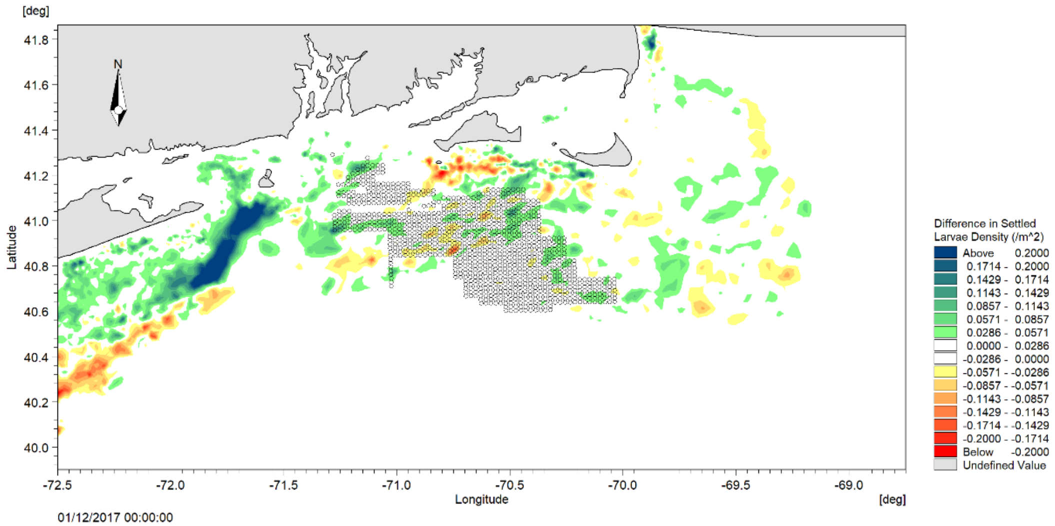
- Larval transport characteristics:
  - Settlement rate and population abundance as a function of mortality and growth parameters (Allain et al. 2007)
  - Settlement probability as a function of life stage, substrate material, and environmental variables including temperature, water depth, and salinity
  - Dispersal patterns, and hence recruitment rates at different sink areas, as a result of larval swimming speeds (Faillettaz et al. 2018)
  - Vertical migration patterns of larvae as a function of daylight and tidal conditions (Jenkins et al. 1998, Benson et al. 2021)



Example of ABM results: settled larval sea scallop density (larvae/m^2) in the study area

Determinant Oceanic Responses: Sea Scallops

- Shift in settlement to the southwest of OSW buildup areas
- Discernable / notable increases south of Block Island / east of Long Island
- Distinct areas of decrease to the south of Martha's Vineyard and, to some degree, in the Nantucket Shoals



Predicted Scenario 4 differences in settled larval sea scallop density (larvae/m^2)

Change in settled sea scallop larvae density (larvae/m2), in relation to modeled baseline levels, due to the influence of Scenario 4 (i.e., shaded green/blue = increases in density, and shades of yellow/red = decrease in density)

Acknowledgements

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