Modeling, Data and Visualization of Deepwater Horizon Oil Spill

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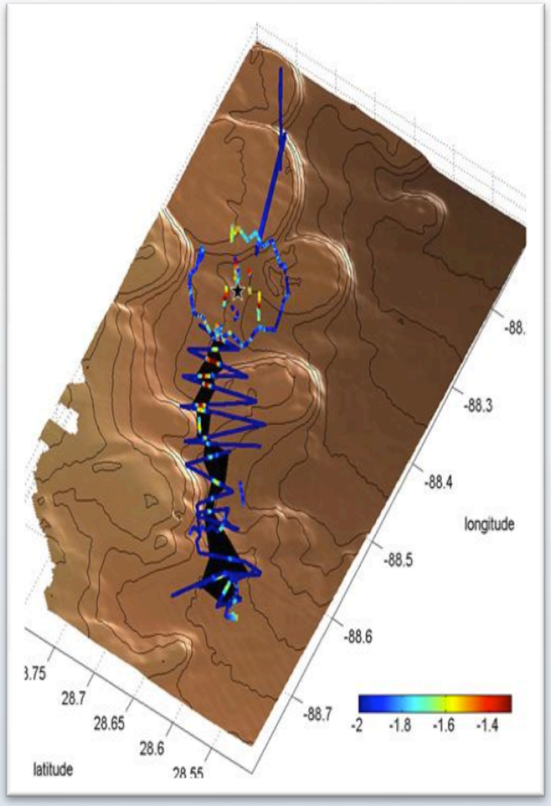
Need to add website reference…

Motivation

- Oil spills and plumes are inherently multi-component/phase (oil/gas/water), unsteady, locally-turbulent, with buoyancy, Coriolis, phase change, chemistry and other complex physics. Scales ranging from mm to km are involved.
- It is important to understand the fate, transport and physical distribution of the oil/gas discharge under realistic sea and atmospheric-wind conditions. Knowledge of this distribution impacts marine life, pollution, and health and safety.
- Physical data under these conditions is limited and difficult to obtain. But the data is very useful in guiding and validating model development and simulations.
- High fidelity simulation tools are needed!



http://i.usatoday.net/communitymanager/_photos/science-fair/2010/08/19/plumeoilx-large.jpg

Oil Plume Trajectory

Simulation Strategy

- High fidelity simulation tools are needed! Plume dispersion is based on the physics of 3D unsteady multi-component flow with complex physics. Two approaches include:

- High fidelity numerical simulations that need the solution of the physics-based governing transport equations (coupled non-linear PDE's) with appropriate resolution.

- Lagrangian-based plume trajectory calculations with suitable input models for entrainment, trajectory, thermodynamics etc.

- Need to solve a large system of coupled equations (6 or more set of equations) on a large grid (order of millions of grid nodes) on a large computing cluster– physics based results but time consuming

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Use physics based results to develop input models for the Lagrangian calculations

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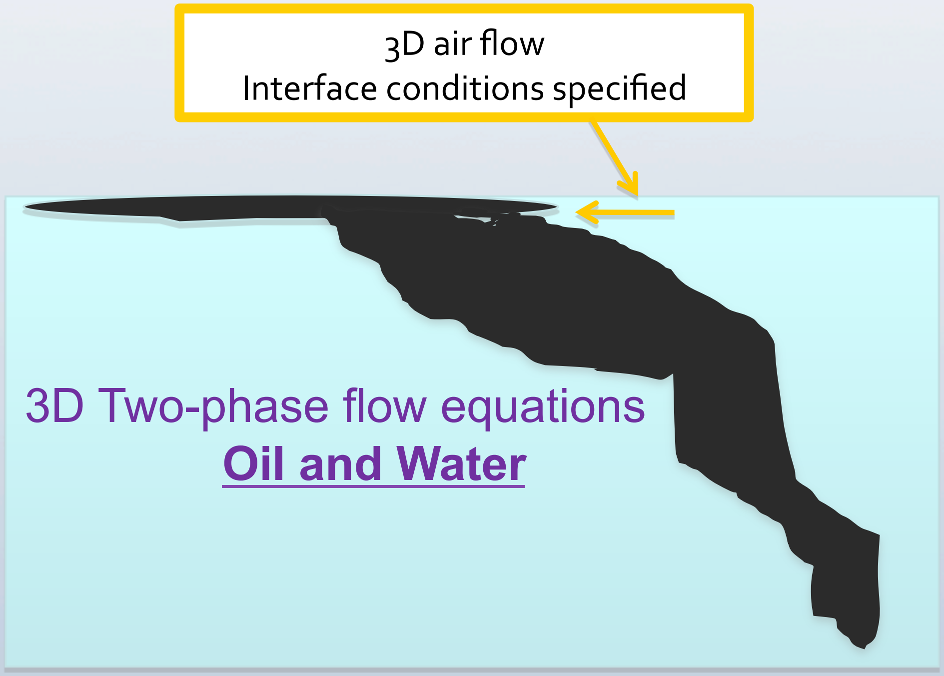
- Lagrangian calculations can be done relatively rapidly, but fidelity depends on the models used.

3 Component (Oil, Water, Air) Flow Model

- Coupled fluid-air calculations
- Free-surface modeling for the ocean surface (interface conditions)
- Multi-phase modeling for oil-water (fully Eulerian with interface tracking)
- Turbulent modeling using Large-eddy simulation technique
- 3D modeling for horizontal and vertical movement of oil fronts
- Particle tracking method for locating oil fronts in the ocean

A parallel multi-block three-dimensional flow code in Acharya's group will be used to resolve the three component (oil, water, air) flow.

- Acharya's group has been developing computational fluid dynamics (CFD) code for two decades
- State of the art codes including turbulence, fast reactions (burning oil spill), chemistry reactions (solvents, dispersants), and flow-structure interactions (riser vibrations and rupture)



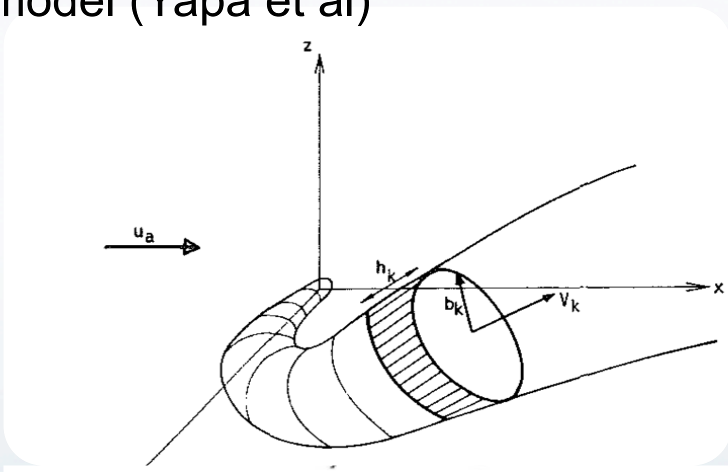
Lagrangian Integral Method

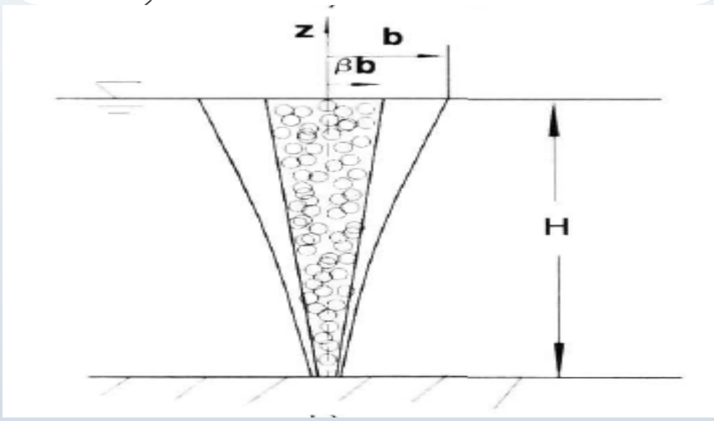
❖ Improving an existing underwater oil/gas plume model (Yapa et al)

Assumption:

❖ the cross-section of the oil buoyant jet is round and perpendicular to the trajectory
❖ the control volume has the shape of a bent cone
❖ the variables included in the model represent the average values for the cross-section (top-hat profile);
❖ the forced entrainment of ambient fluid into the buoyant jet occurs from the 'windward' side of the buoyant jet
❖ the effect of oil viscosity is neglected

Coriolis force is included in this study





The model considers: Hydrodynamics and thermodynamics of jet/plume; 3-dimensional unsteady ambient current; density stratification of ambient environment; diffusion of oil from the jet to the ambient fluid; kinetics and thermodynamics of hydrate formation and decomposition; dissolution loss of gases; non-ideal behavior of gases; gas separation from the main plume due to strong cross flow

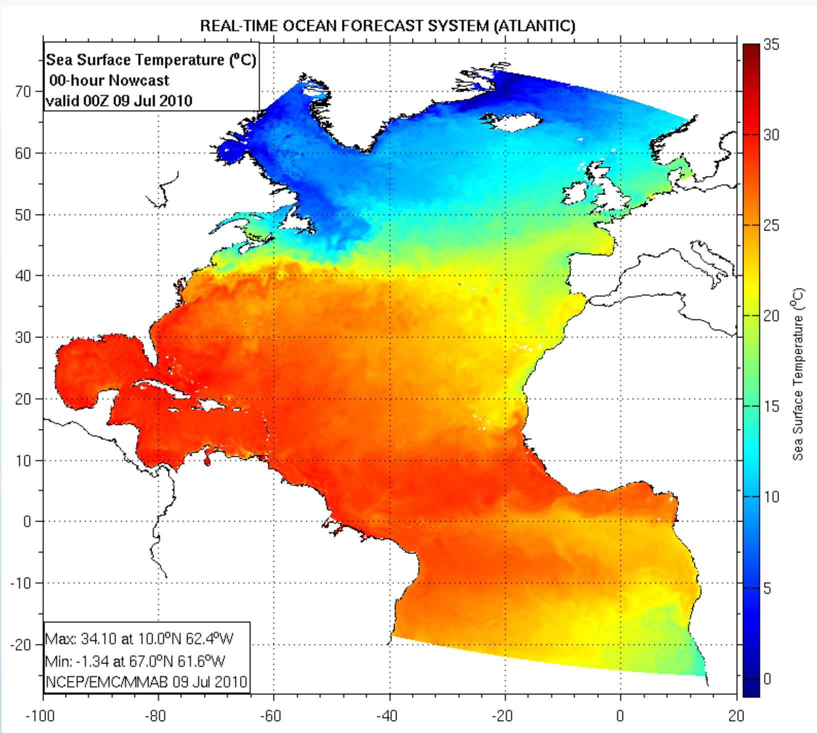
Field Data

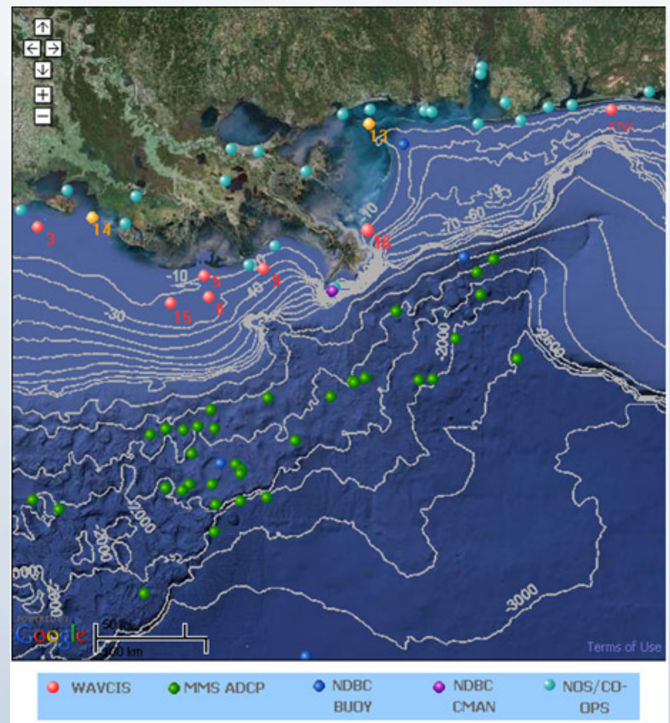
❖ Ocean model verification

Ocean daily forecast from NOAA Real Time Ocean Forecast System for the North Atlantic Ocean (RTOFS-Atlantic). Ocean (RTOFS-Atlantic).

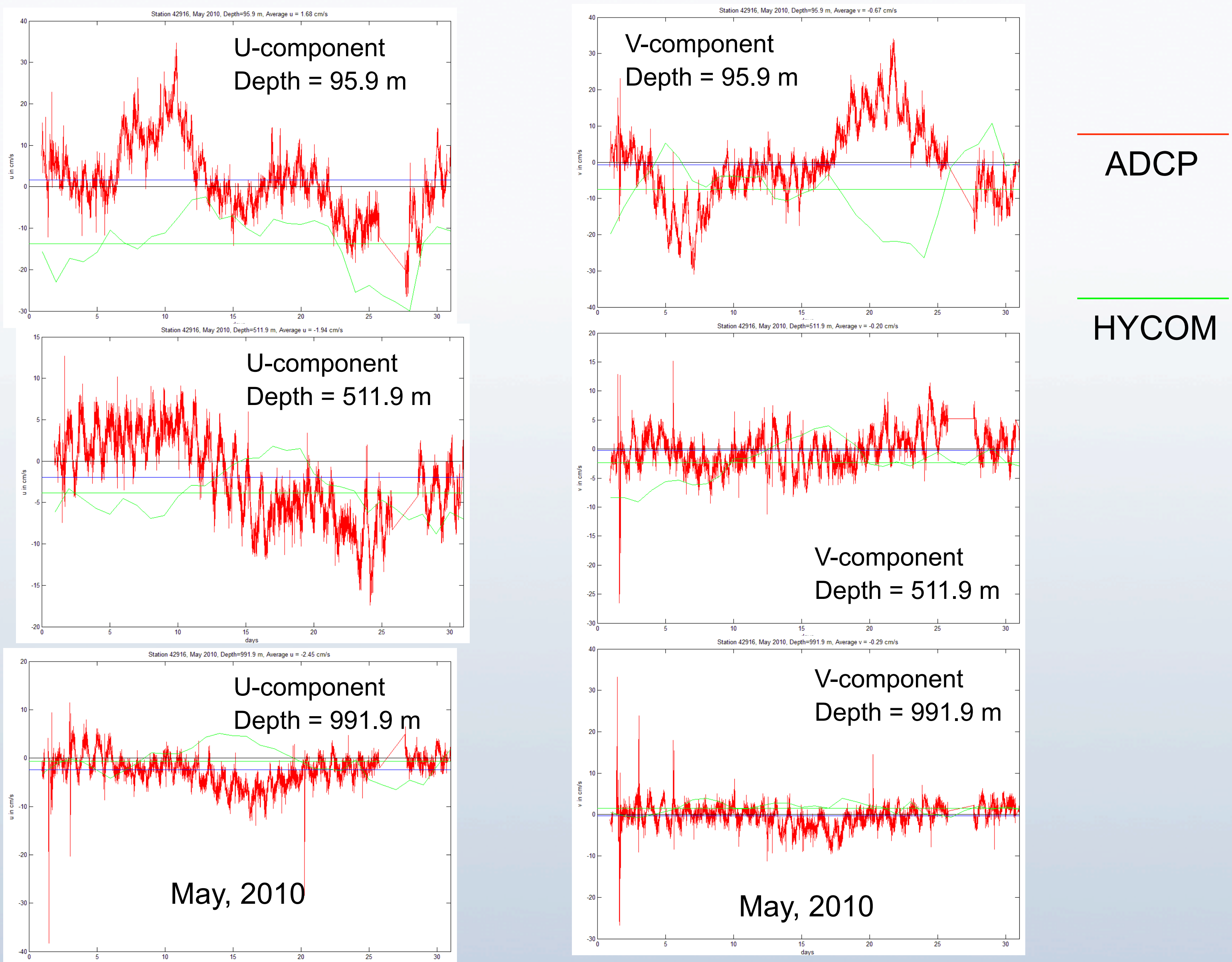
http://polar.ncep.noaa.gov/ofs/

WAVCIS stations





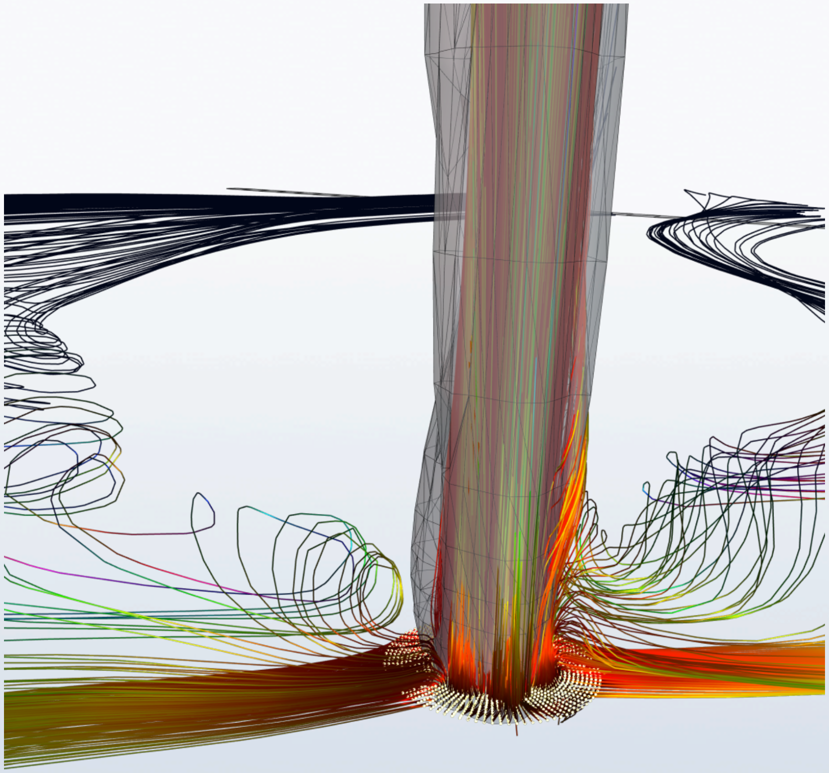
❖ Model-observation comparison at DH location



Field Data Needed for Validation and Boundary Conditions

Visualization and Analysis

- **The analysis and interpretation of 3D unsteady flowfields with complex physics requires:**
  - **Identification of flow features via mathematical representation**
  - **Feature extraction from the data set, visualization and interpretation**

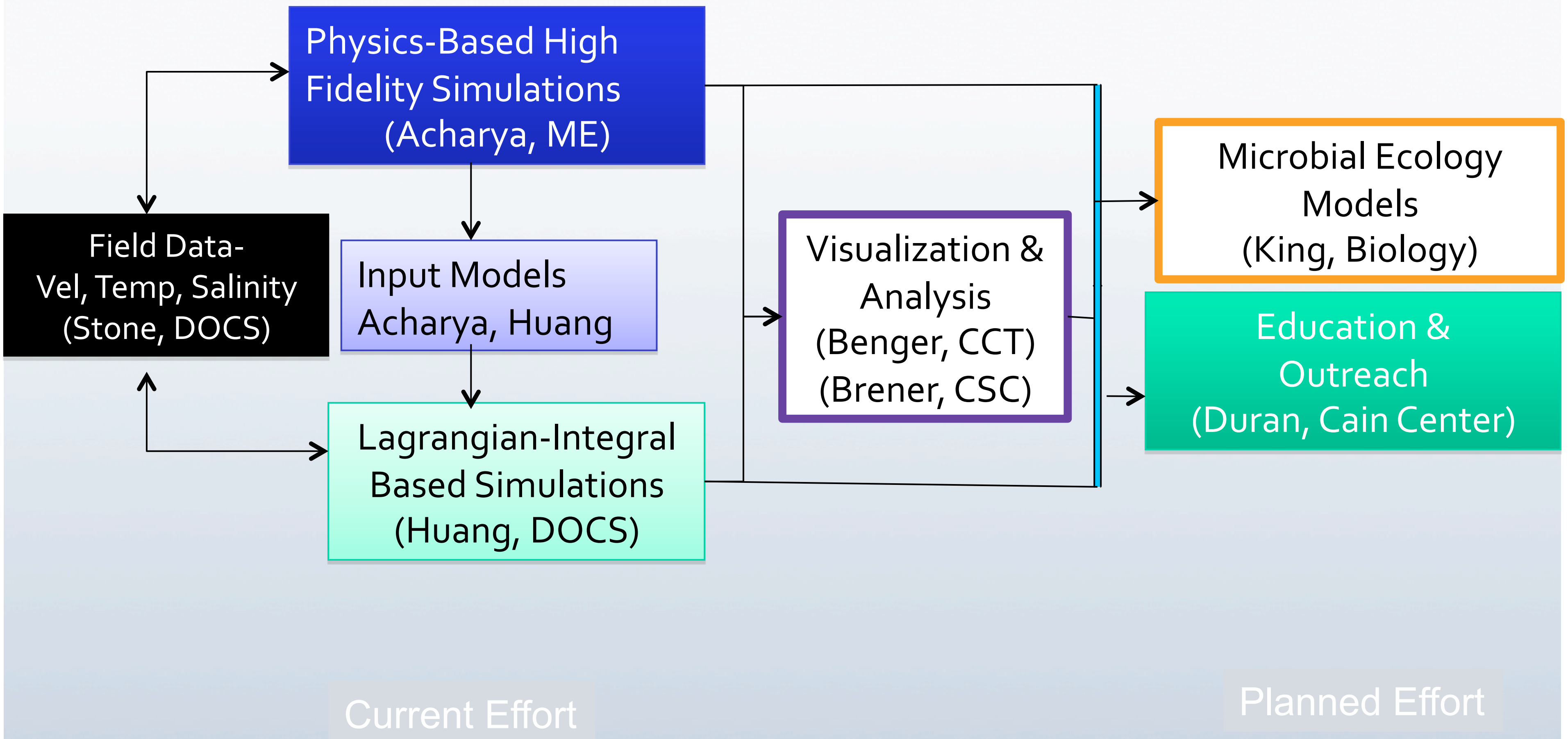


Simulated Oil Plume Data-Visualization of Streamlines (current work)

Visualization & Analysis

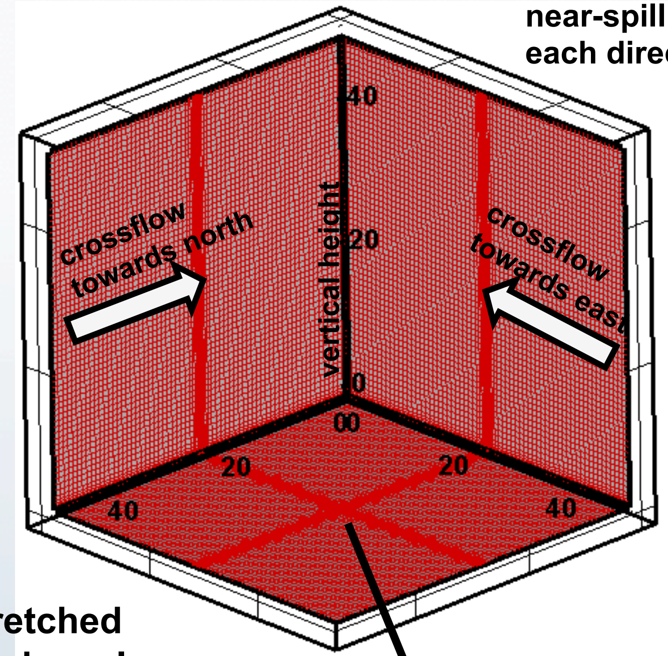
- Providing a collaborative extensible framework for systematic analysis of vector field properties:
  - pathlines, streamlines, time-surfaces, …
  - Energy, proper time, curvature, torsion, …
- Suitable for large datasets
- Integration of observational data
- Support for complex data types:
  - multiblock, rectilinear, curvilinear

Ongoing Research Plan

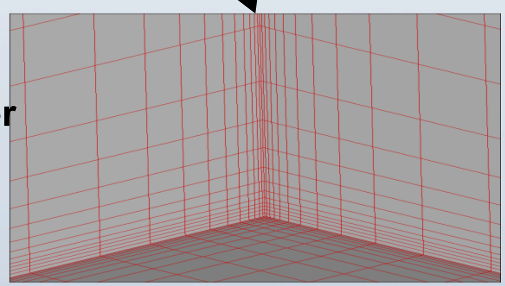


Preliminary Simulation Results: Near-field Modeling of the BP Spill

near-spill domain 50 m in each direction



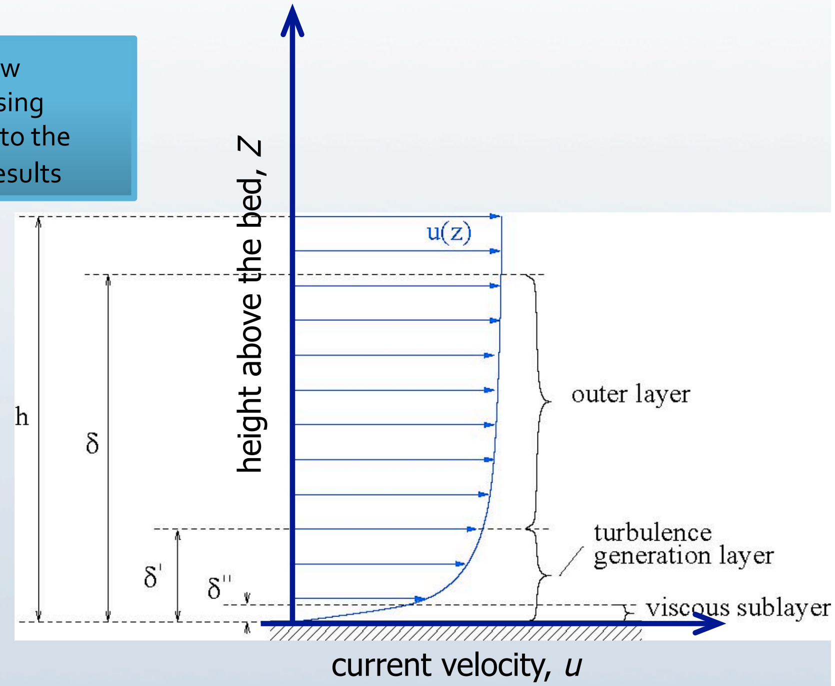
grid stretched from inch scale near the spill-head to a meter scale at the outer domain



Computational Domain

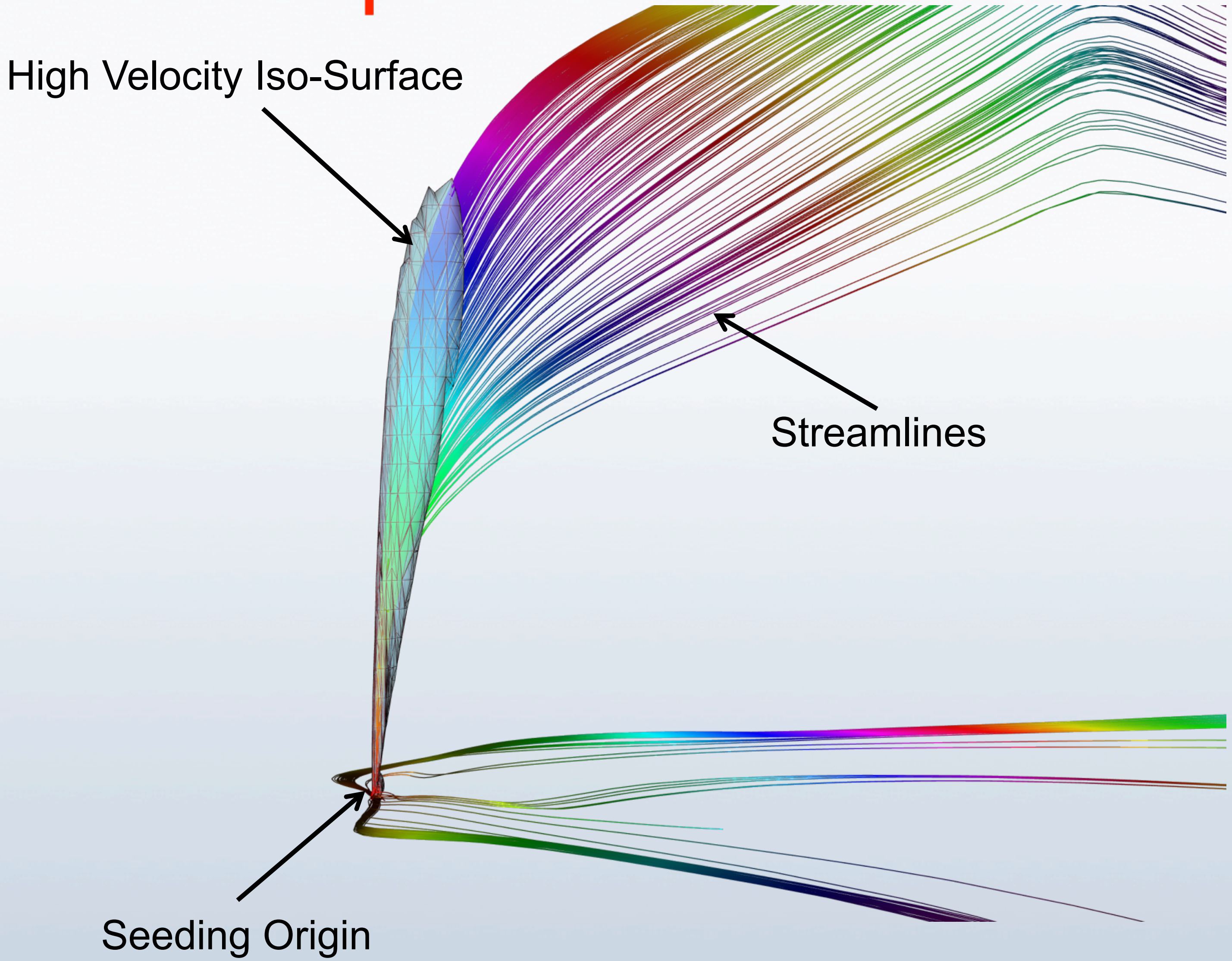
Logarithmic profile at boundary to define cross flow

BC in the ocean-flow direction applied using logarithmic profile to the wall and HYCOM results



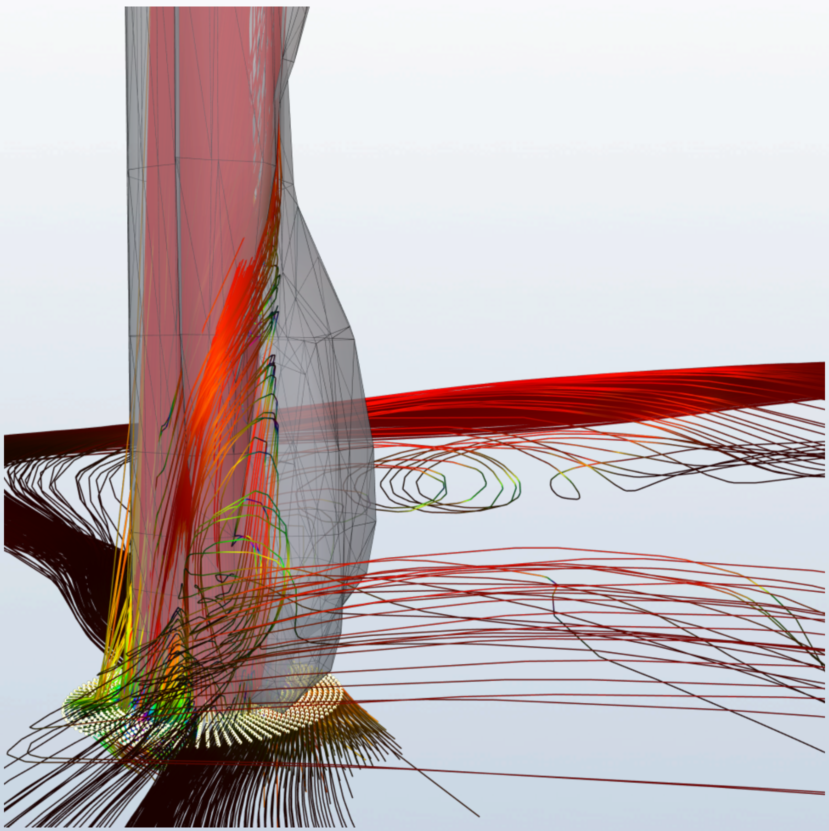
Boundary Conditions

Oil-Spill Plume Flow

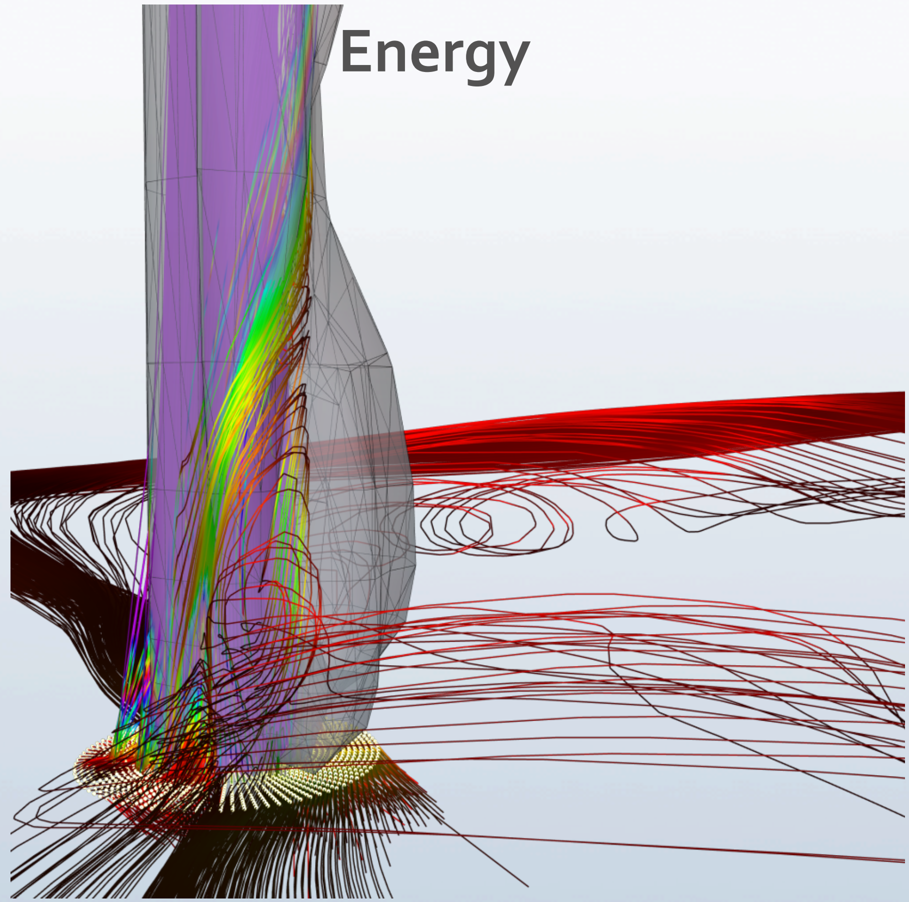


Higher Order Statistics

Curvature



Energy

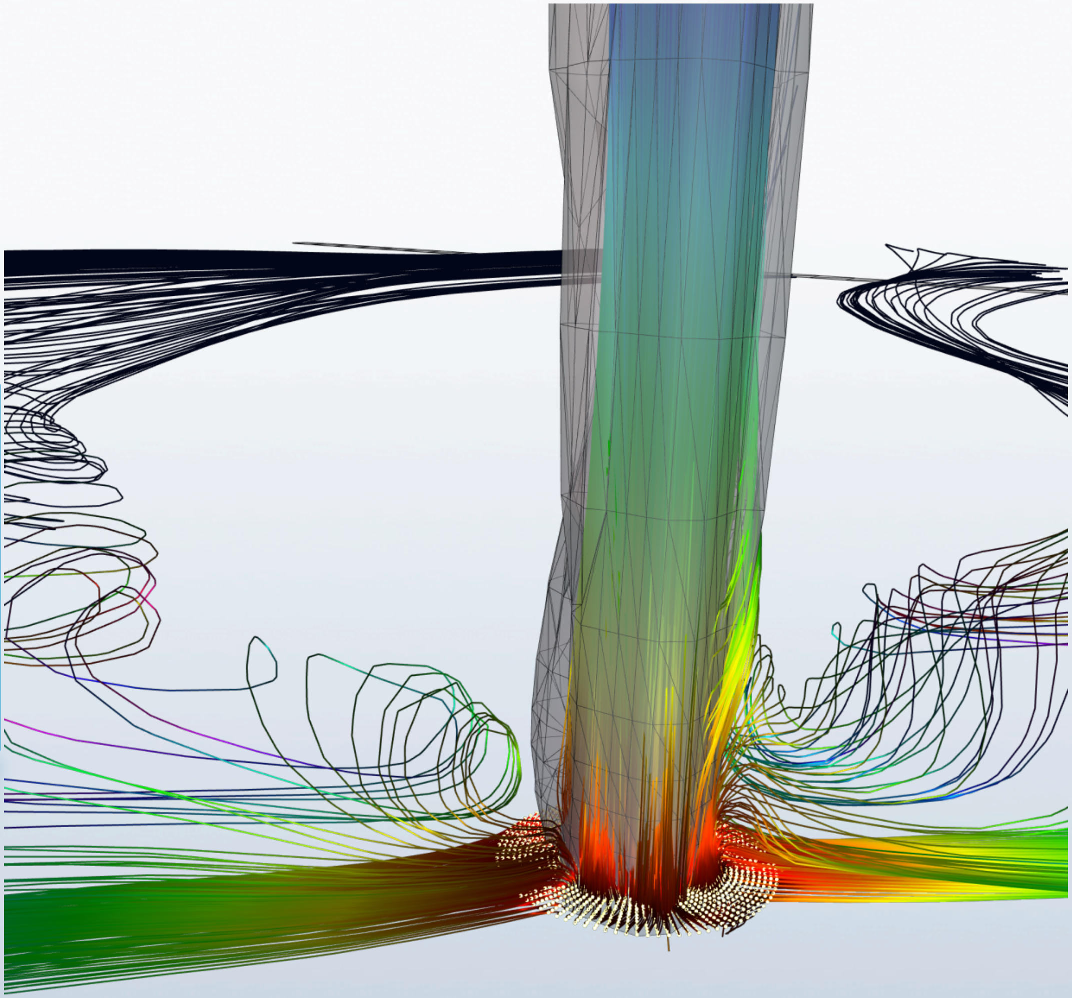


Well-Head Closeup

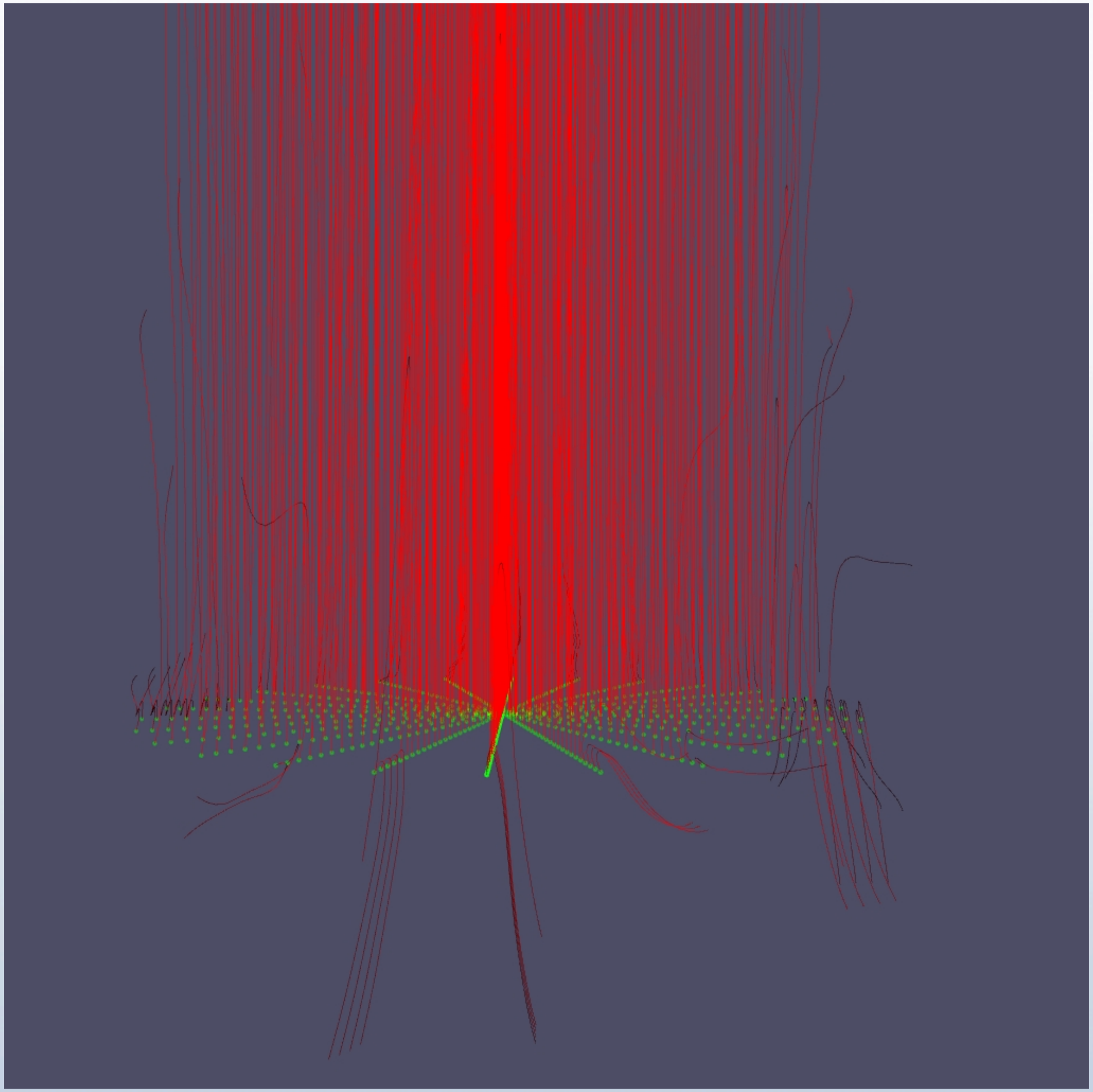
Streamlines

Color coding by arc length (distance from the well head)

Development of vortex kernels during evolution



Pathlines Near Wellhead



Future Work

- **Collaborations with Microbial Ecology Group**
- **Collaborations with Cain Center**

The feasibility of using Mississippi River Diversion to prevent oil slicks from flushing into the Coastal Bays

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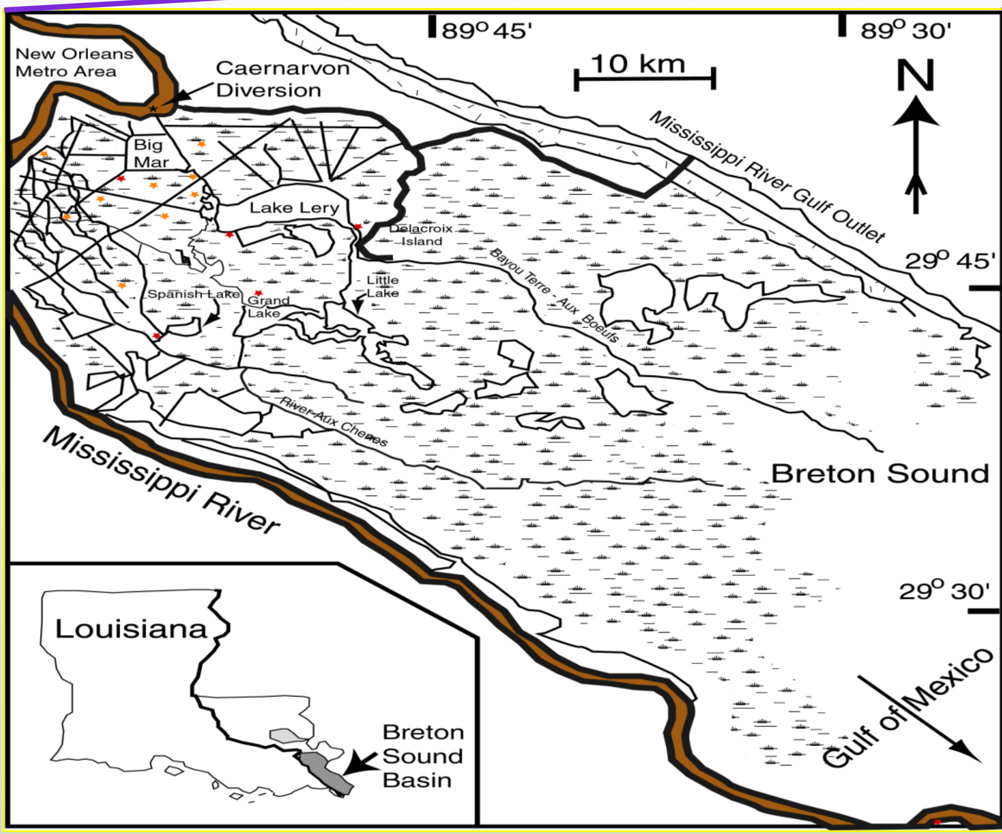
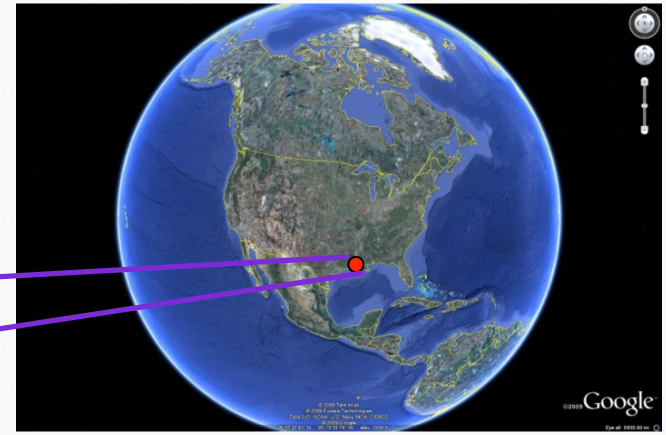
Study Area





Ever since the beginning of the oil spill the idea has emerged to open up all coastal freshwater diversions to flush oil slicks out of coastal estuaries and bays.

- Diversion maximum flow capacity (227 $m^3\ s^{-1}$ for Caernarvon Freshwater Diversion in Breton Sound).
- Tidal flux at the bay mouth (on the order of 4000 $m^3\ s^{-1}$, Swenson et al., 2006).
- Wind-driven estuary-shelf exchange (same order of magnitude as tidal flux)

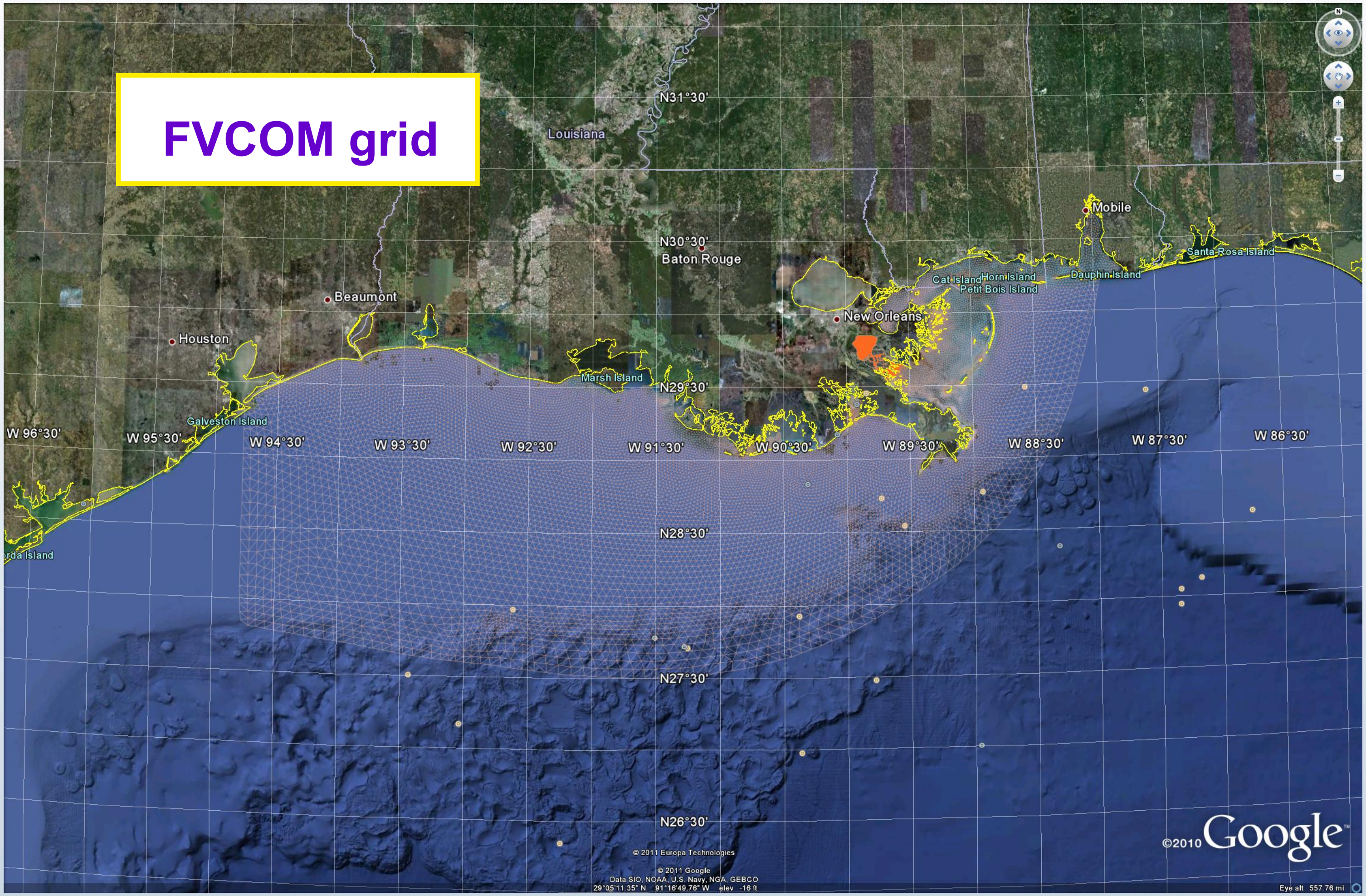
Is it possible?

Caernarvon Diversion

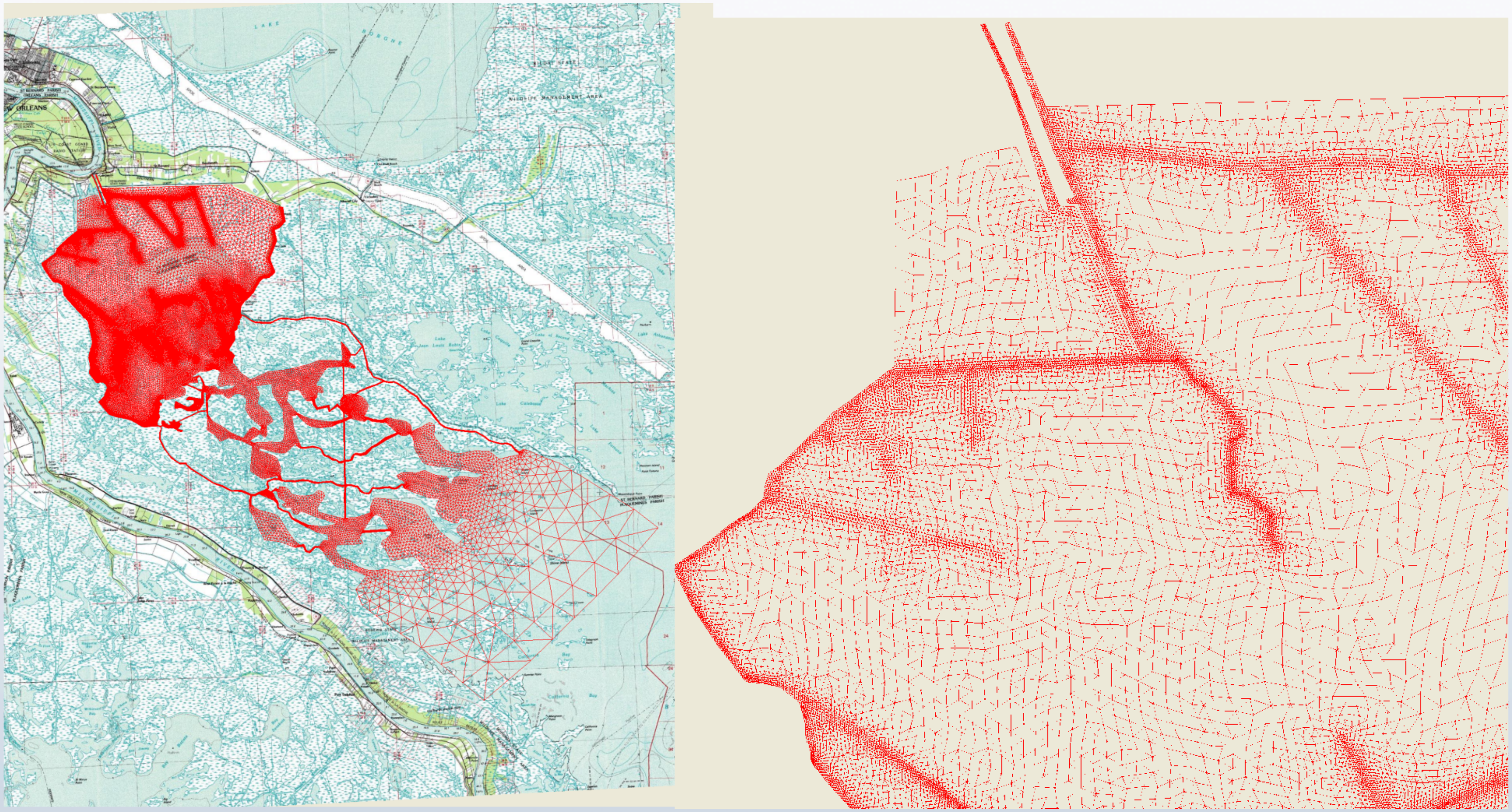
From http://www.lacoast.gov/

- In operation since 1991
- Discharge capacity is 227 m^3/sec (8000 cfs)
- Normal operation is up to 113 m^3/sec.
- During 2010 BP oil spill event, pulses are 227 m^3/sec (8000 cfs).

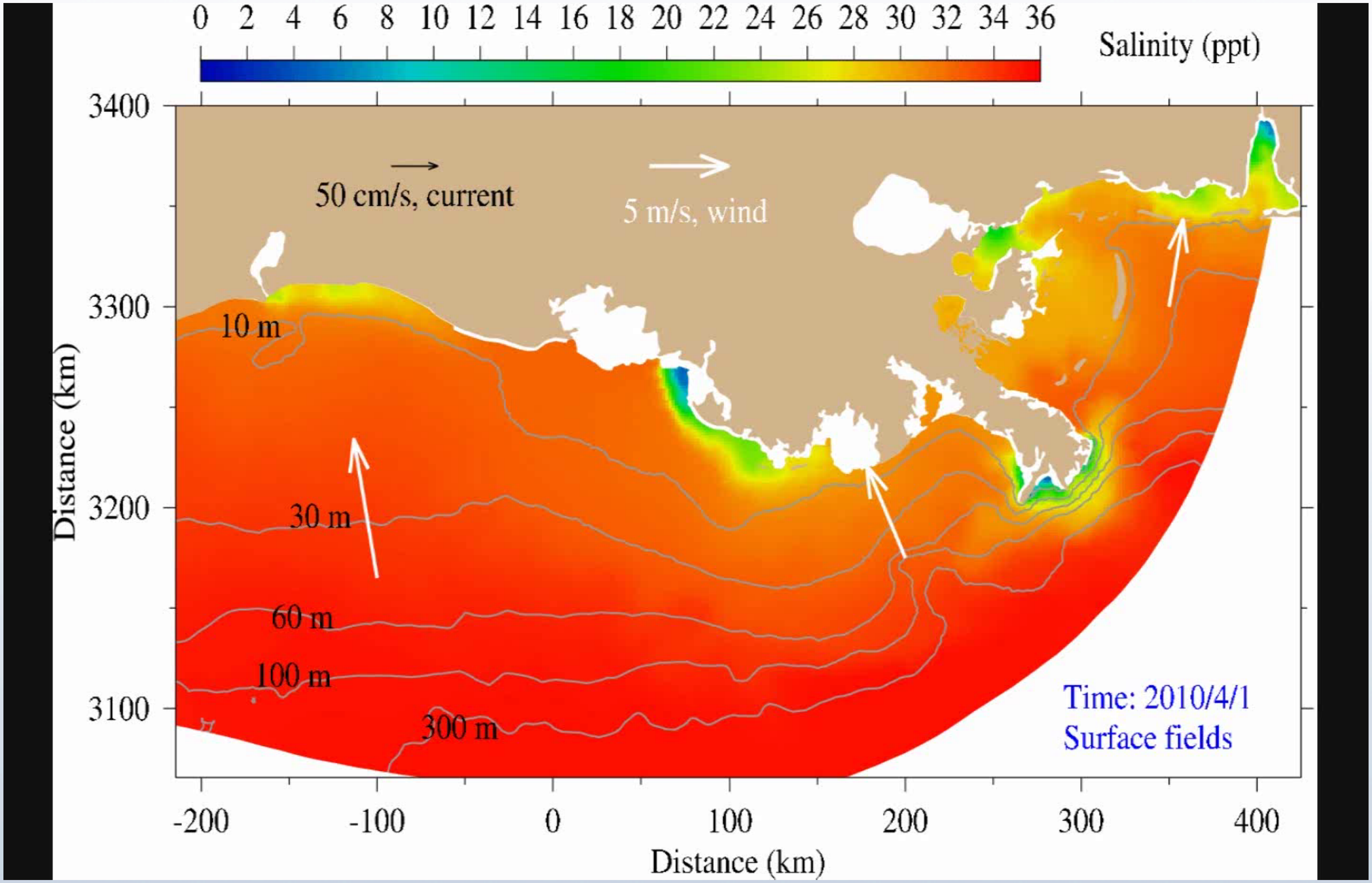
Numerical Model



Numerical Grid

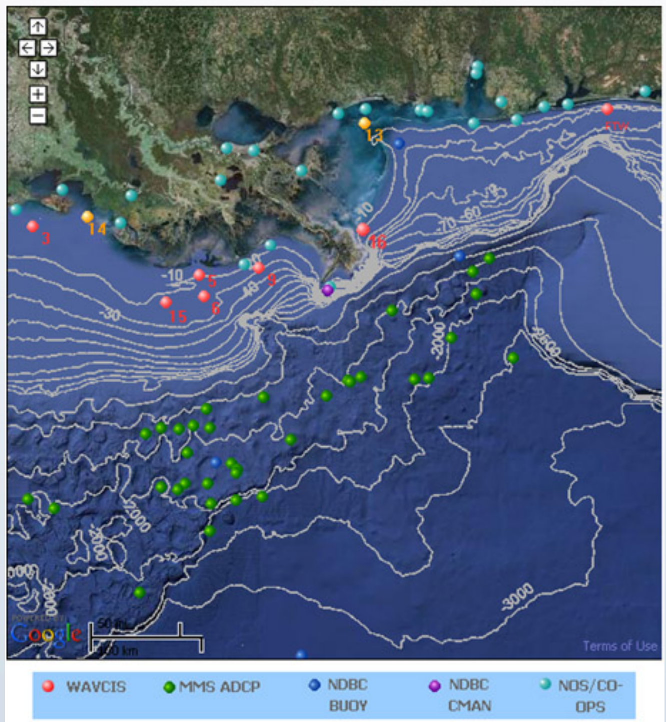


Velocity and surface salinity fields



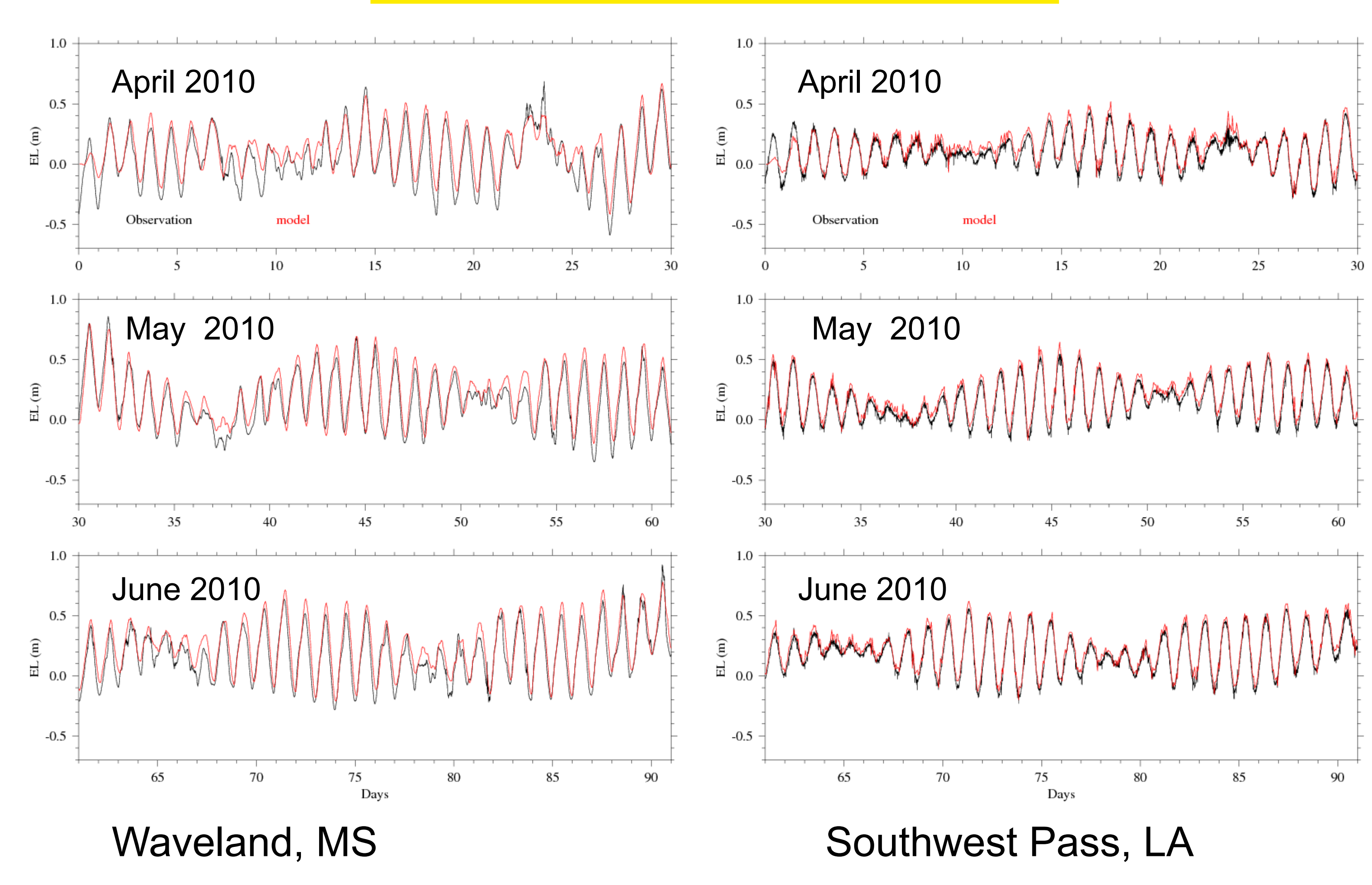
Model-Observation Comparison

WAVCIS stations



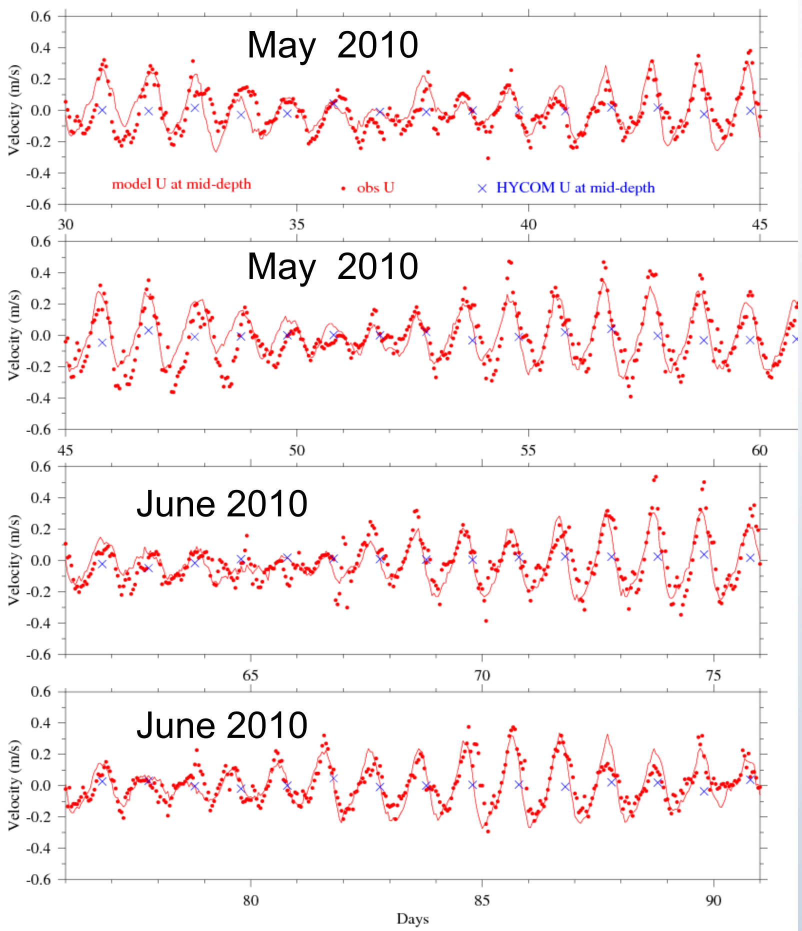
Model-Observation Comparison

Sea surface elevation

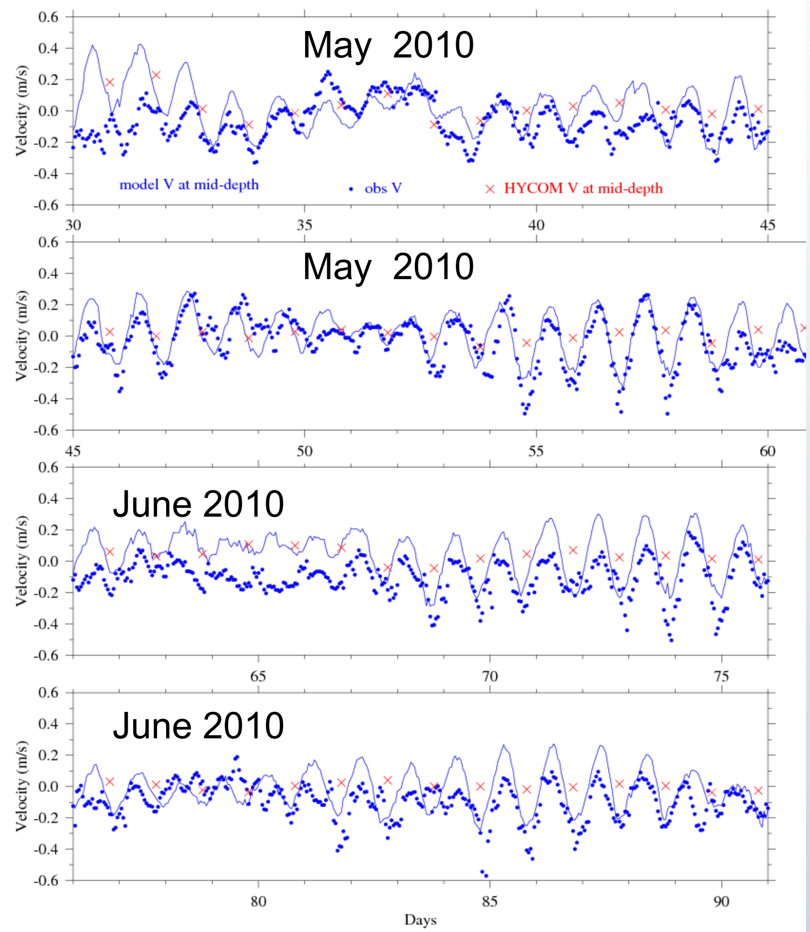


Model-Observation Comparison

Velocity components

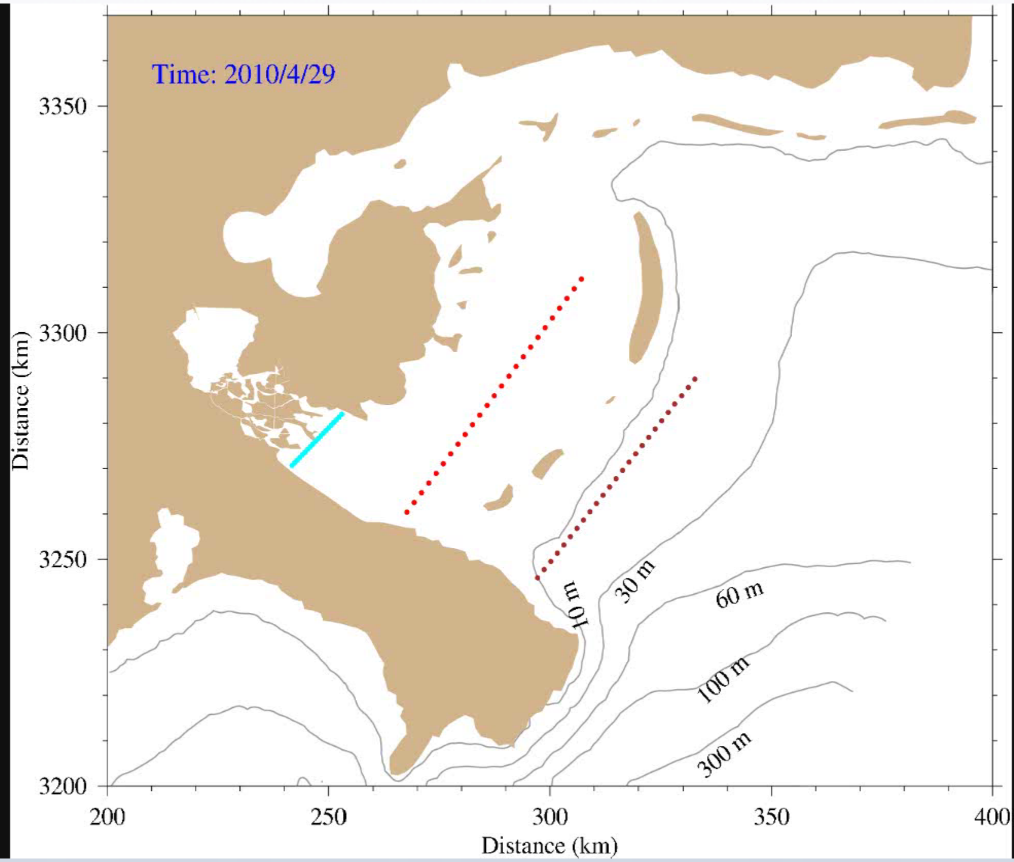


CSI16, East-West velocity component

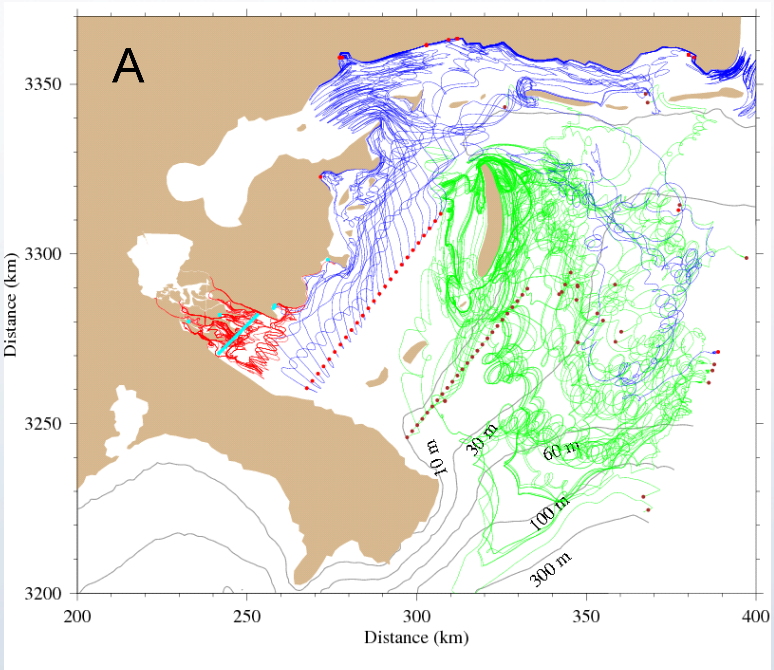


CSI16, North-South velocity component

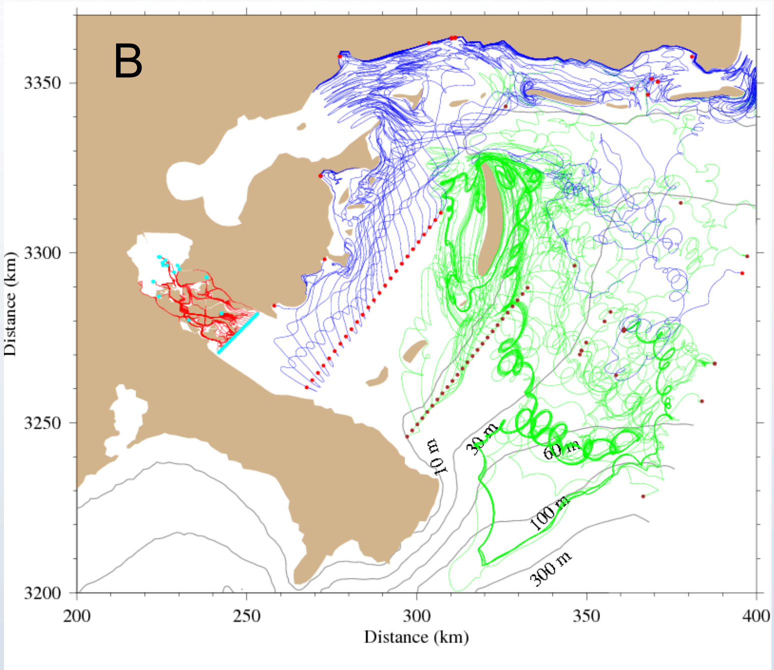
Surface oil trajectories



Surface oil trajectories

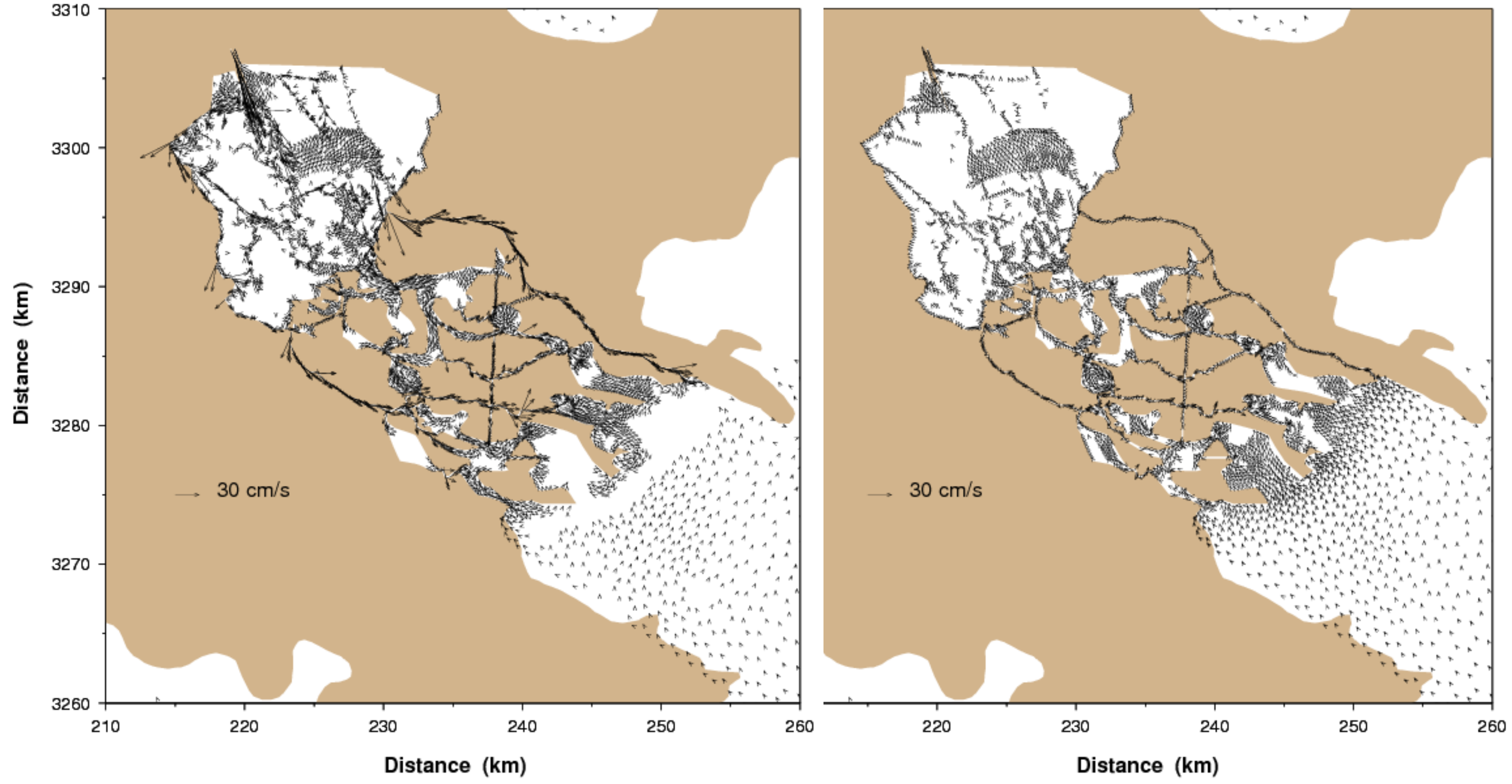


Caernarvon Diversion at its maximum discharge



Caernarvon Diversion flux is turned off

Surface residual currents



Caernarvon Diversion at its maximum discharge

Caernarvon Diversion flux is turned off

Fish movement: Game Theory Method

(Anderson, 2002; Goodwin et al., 2006)

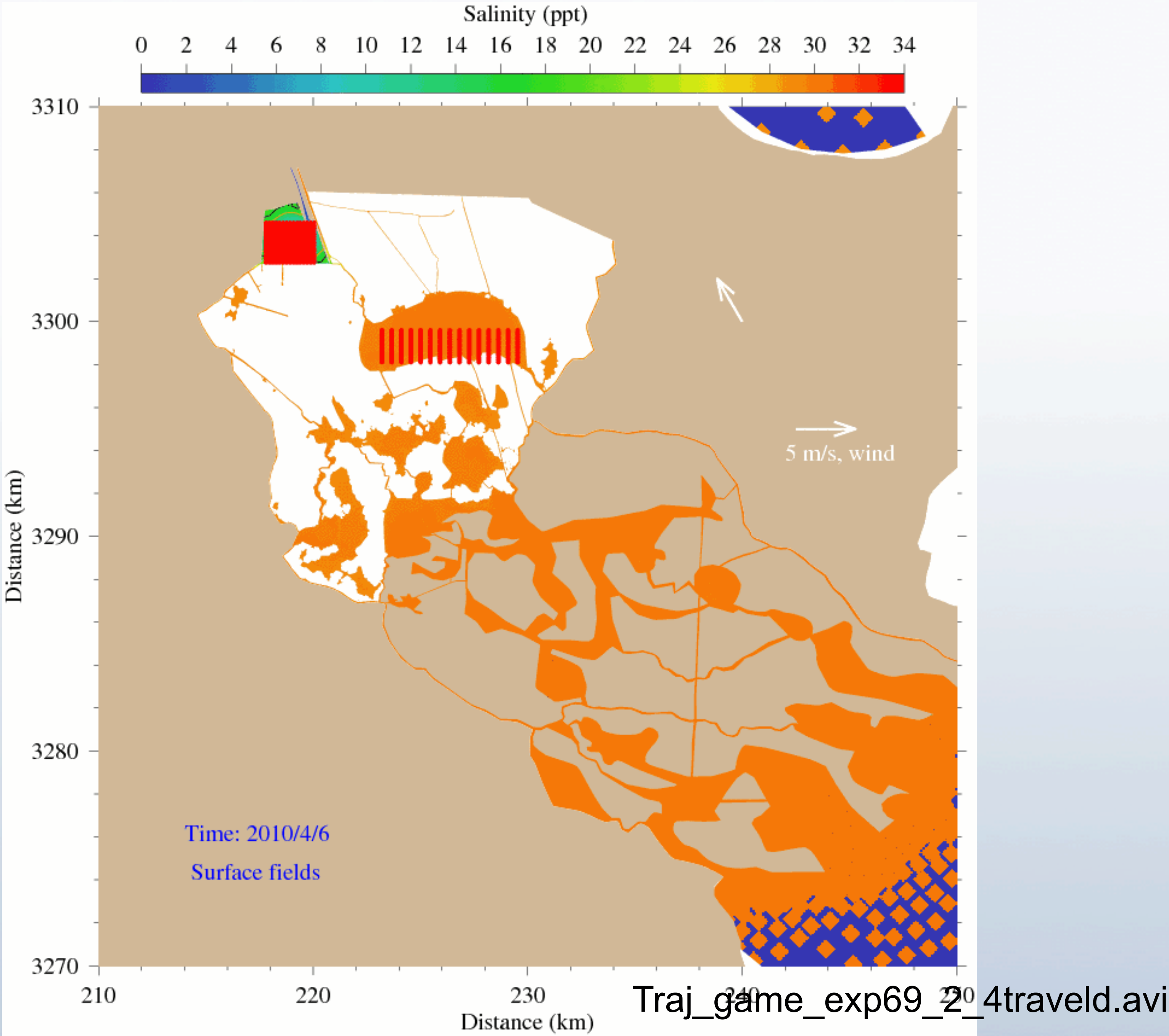
Choices among the possible behaviors are made using a game-theoretic approach based on utilities (Von Neumann and Morgenstern, 1944)

- The fish's environment is described in terms of agents A_j ($j = 1, 2, \ldots$) -- representing prey, predators, habitats, and abiotic stimuli
- As the fish moves through its environment, it encounters agents. The encounter event in each time increment Δt is denoted with a Boolean operator

$$e_j(t) = \begin{cases} 0, & \text{if event doesn't happen} \\ 1, & \text{if enevt does happen} \end{cases}$$

- The fish has two modes of behavior for each agent $B_{j,k}$ ($j = 1, 2, \ldots; k = 0, 1$) :
  - Tactical mode behaviors (k = 0) alter the outcomes of the events
  - Strategic mode behaviors (k = 1) alter the probability of future events

- Each behavior $B_{j,k}$ has an associated utility $U_{j,k}$, which corresponds to a fitness measure
- The probabilities of successful behaviors $P_{j,k}$ are tracked via short-term (tactical), intermediate-term (strategic) and long-term (reference) memories $m_{j,k}$
- Probabilities change continually through the moment-to-moment events, and switches in behavior occur when the expected utility of one behavior exceeds that of another.


Salinity (ppt)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
3310
3300
3290
3280
3270
Distance (km)
210 220 230 240 250
Distance (km)
5 m/s, wind
Time: 2010/4/6
Surface fields
Traj_game_exp69_2_4traveld.avi

Thank you !