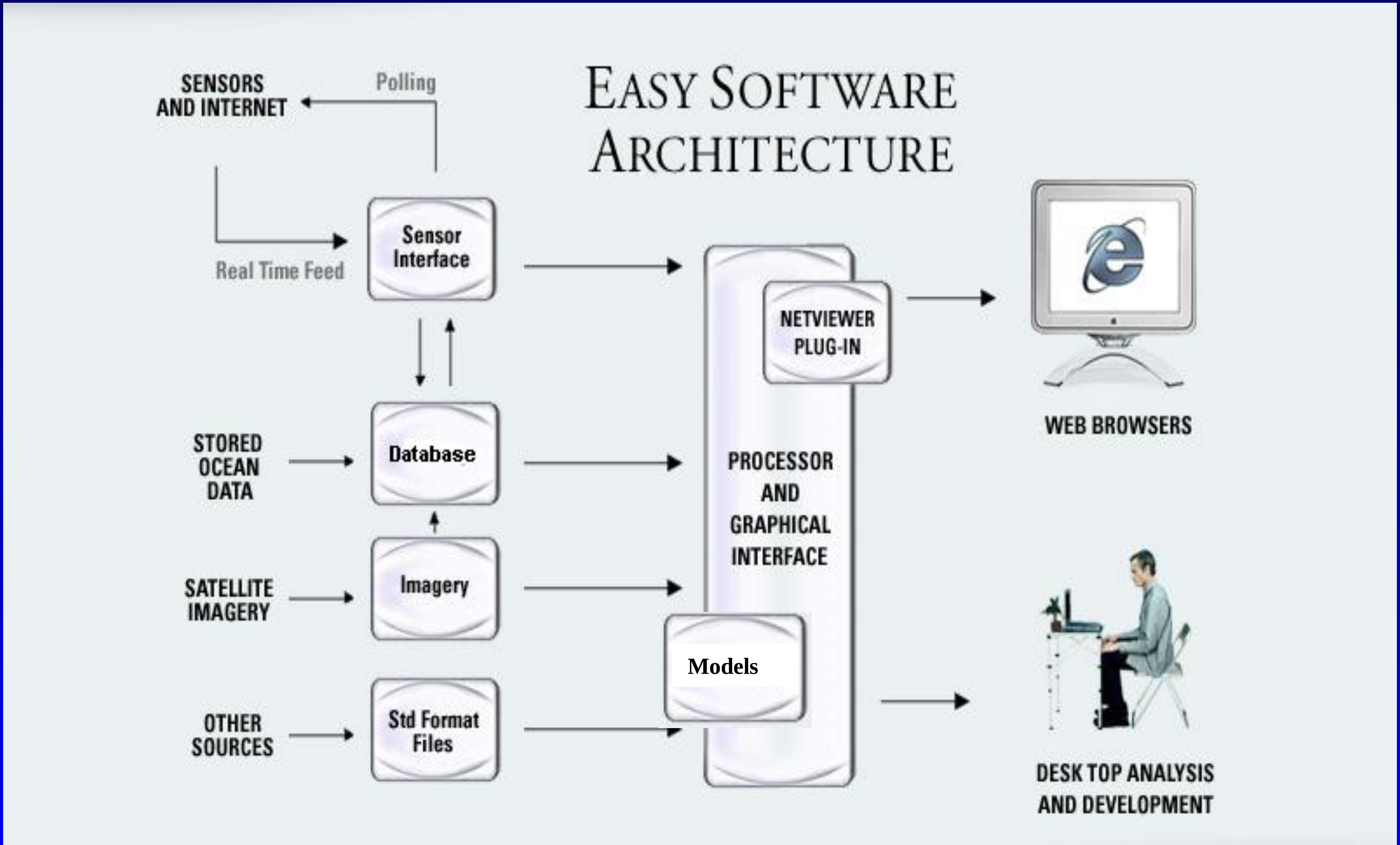
AquaModel Simulation of Fish Mariculture, Water and Sediment Effects in Near and Far Fields

Chile Workshop: Viña del Mar, Chile 6 – 9 May 2013

System Science Applications, Inc.
Dale Kiefer Jack Rensel

Presentation Topics

- EASy GIS Introduction
- AquaModel Introduction and Components
- Near and far field AquaModel
- Model Demonstrations
- Prior and Ongoing Validation
- Future Direction



- 4-D GIS for marine applications, visual, video-like output of spatial & temporal effects
- Compatible with other GIS (ESRI Arc-Info)
- Interfaces for models, spreadsheets, databases, and Internet
- AquaModel: a “plug-in model” to the EASy GIS, one of several aquatic software packages

EASy Graphical Environment

AVHRR SST imagery for the Gulf of Maine Biogeographic Information System

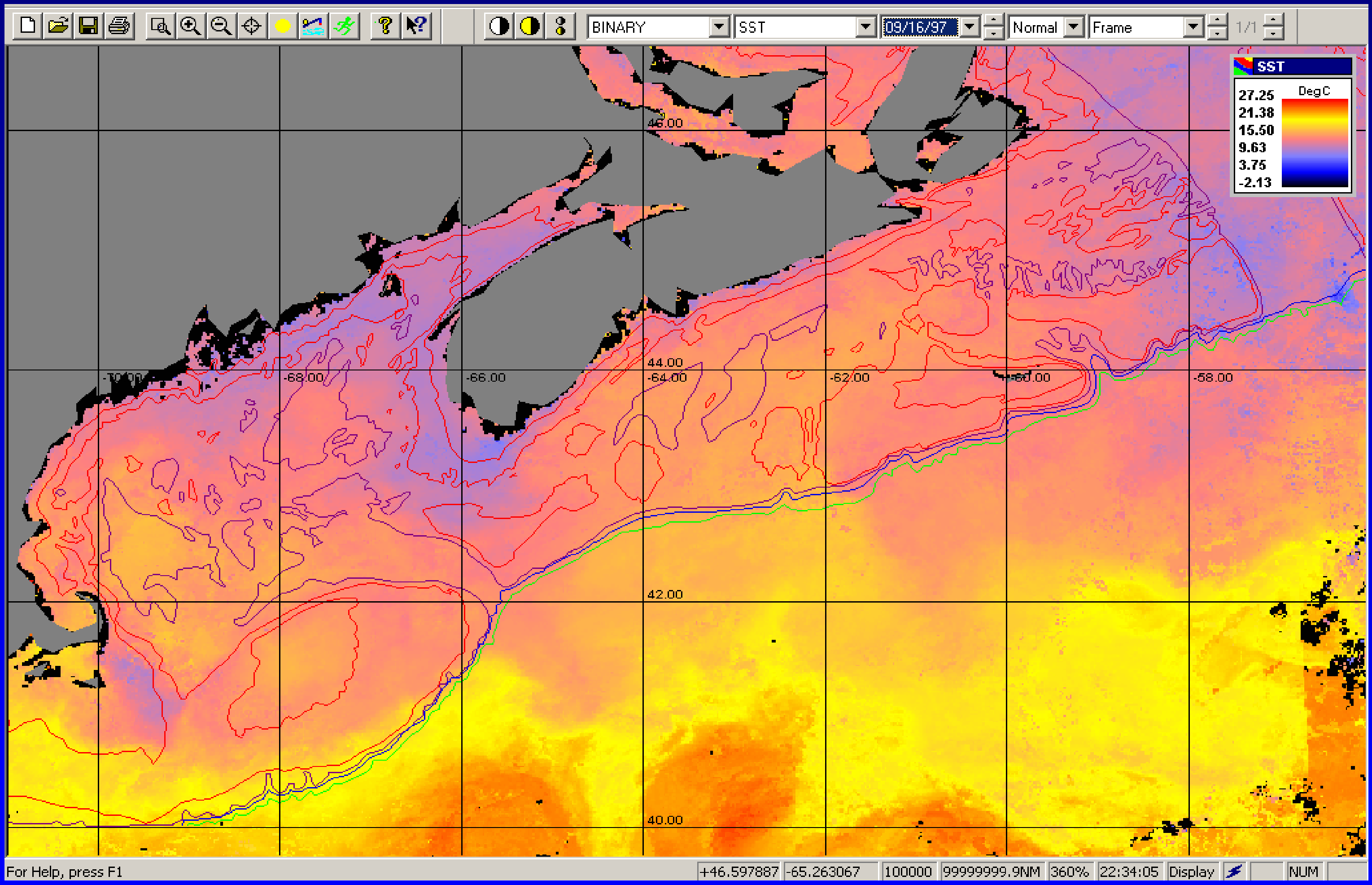
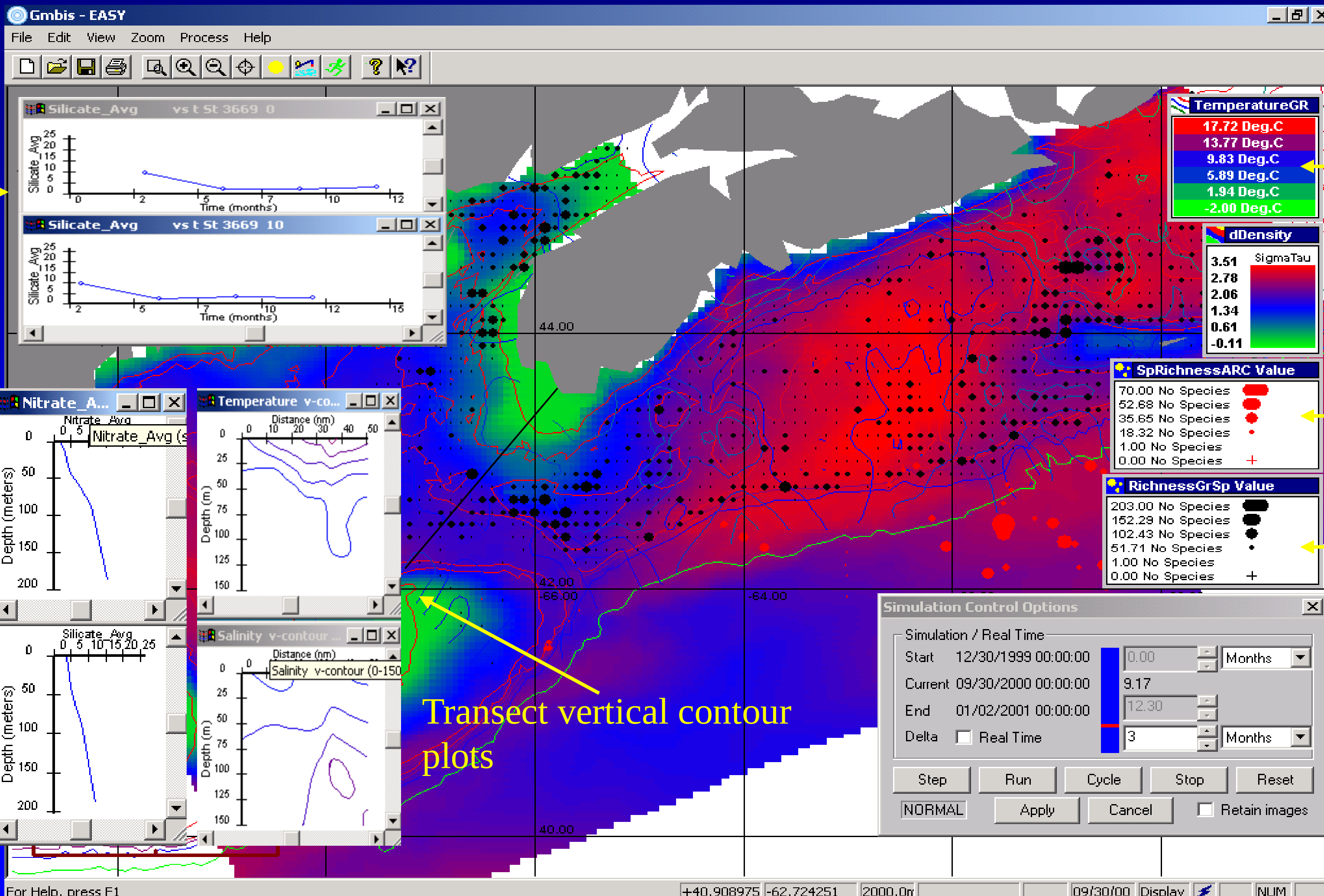


Image Browse Toolbar

Tsontos, V. M. and D. A. Kiefer. 2000. Oceanography 13(3): 25-30.

EASy Graphical Environment

Species richness relative to bathymetry, water density differentials & bottom temperature



Time Series plots

Depth profile plots

Transect vertical contour plots

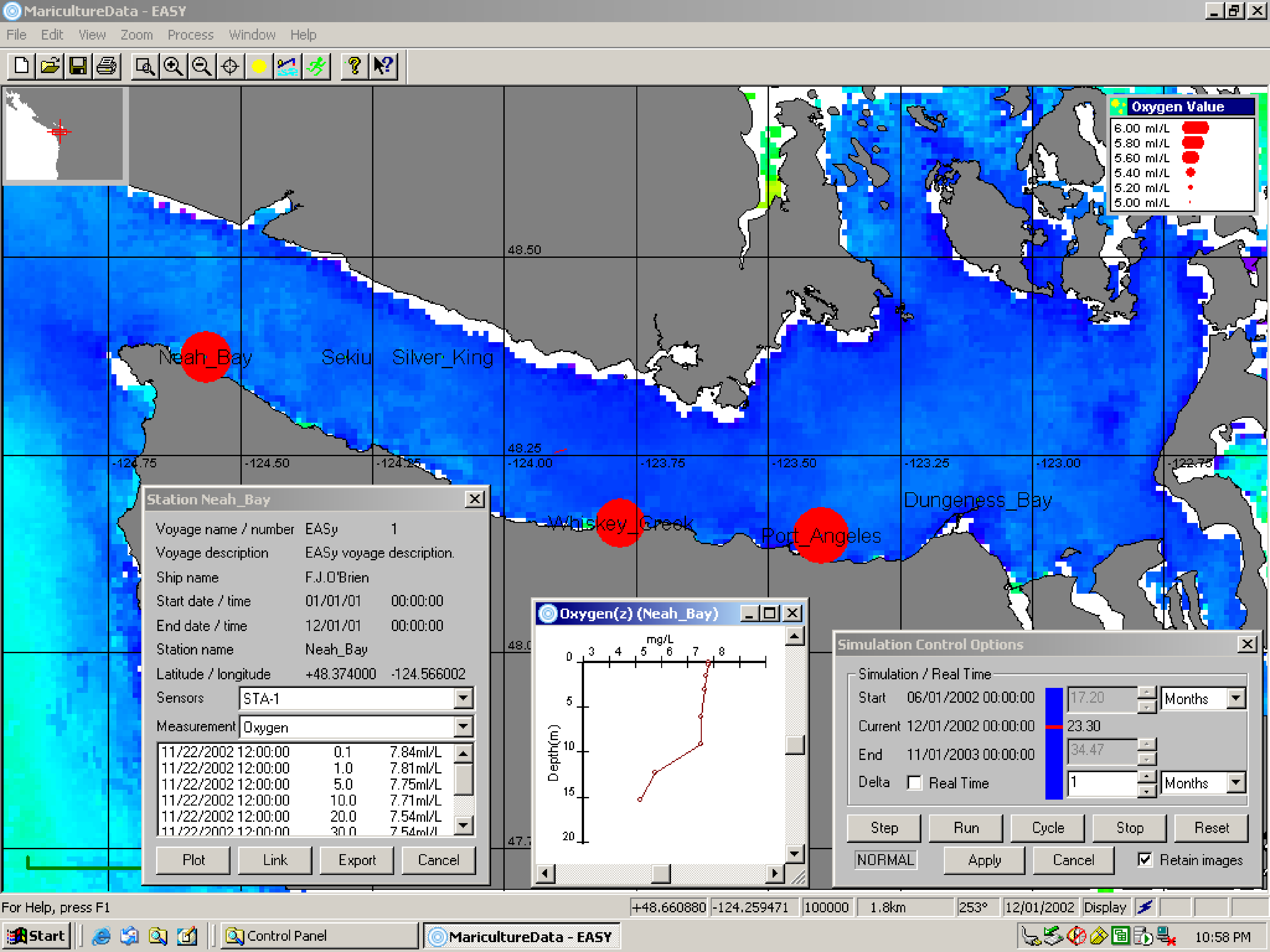
Contour plot

False colour plot

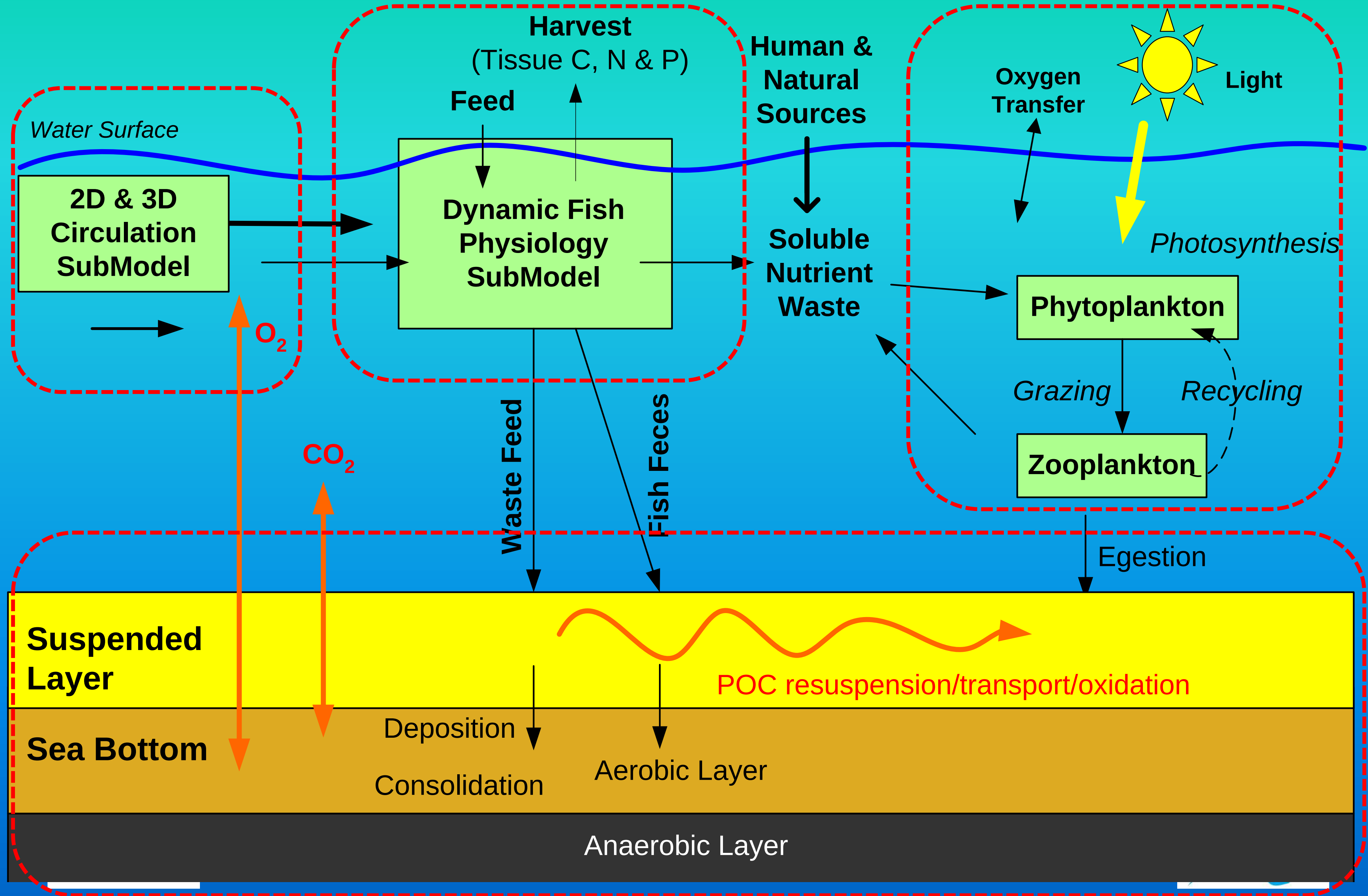
Bubble Plots

Simulation control panel

Tsontos, V. M. and D. A. Kiefer. 2000. Oceanography 13(3): 25-30.


MaricultureData - EASY
File Edit View Zoom Process Window Help
Oxygen Value
6.00 ml/L
5.80 ml/L
5.60 ml/L
5.40 ml/L
5.20 ml/L
5.00 ml/L
48.50
48.25
-124.75
-124.50
-124.25
-124.00
-123.75
-123.50
-123.25
-123.00
-122.75
Neah_Bay
Sekiu
Silver_King
Whiskey_Creek
Port_Angeles
Dungeness_Bay
Station Neah_Bay
Voyage name / number EASy 1
Voyage description EASy voyage description.
Ship name F.J.O'Brien
Start date / time 01/01/01 00:00:00
End date / time 12/01/01 00:00:00
Station name Neah_Bay
Latitude / longitude +48.374000 -124.566002
Sensors STA-1
Measurement Oxygen
11/22/2002 12:00:00 0.1 7.84ml/L
11/22/2002 12:00:00 1.0 7.81ml/L
11/22/2002 12:00:00 5.0 7.75ml/L
11/22/2002 12:00:00 10.0 7.71ml/L
11/22/2002 12:00:00 20.0 7.54ml/L
Plot Link Export Cancel
Oxygen(z) (Neah_Bay)
mg/L
Depth(m)
Simulation Control Options
Simulation / Real Time
Start 06/01/2002 00:00:00 17.20 Months
Current 12/01/2002 00:00:00 23.30
End 11/01/2003 00:00:00 34.47
Delta Real Time 1 Months
Step Run Cycle Stop Reset
NORMAL Apply Cancel Retain images
For Help, press F1
+48.660880 -124.259471 100000 1.8km 253° 12/01/2002 Display
Start
Control Panel
MaricultureData - EASY
10:58 PM

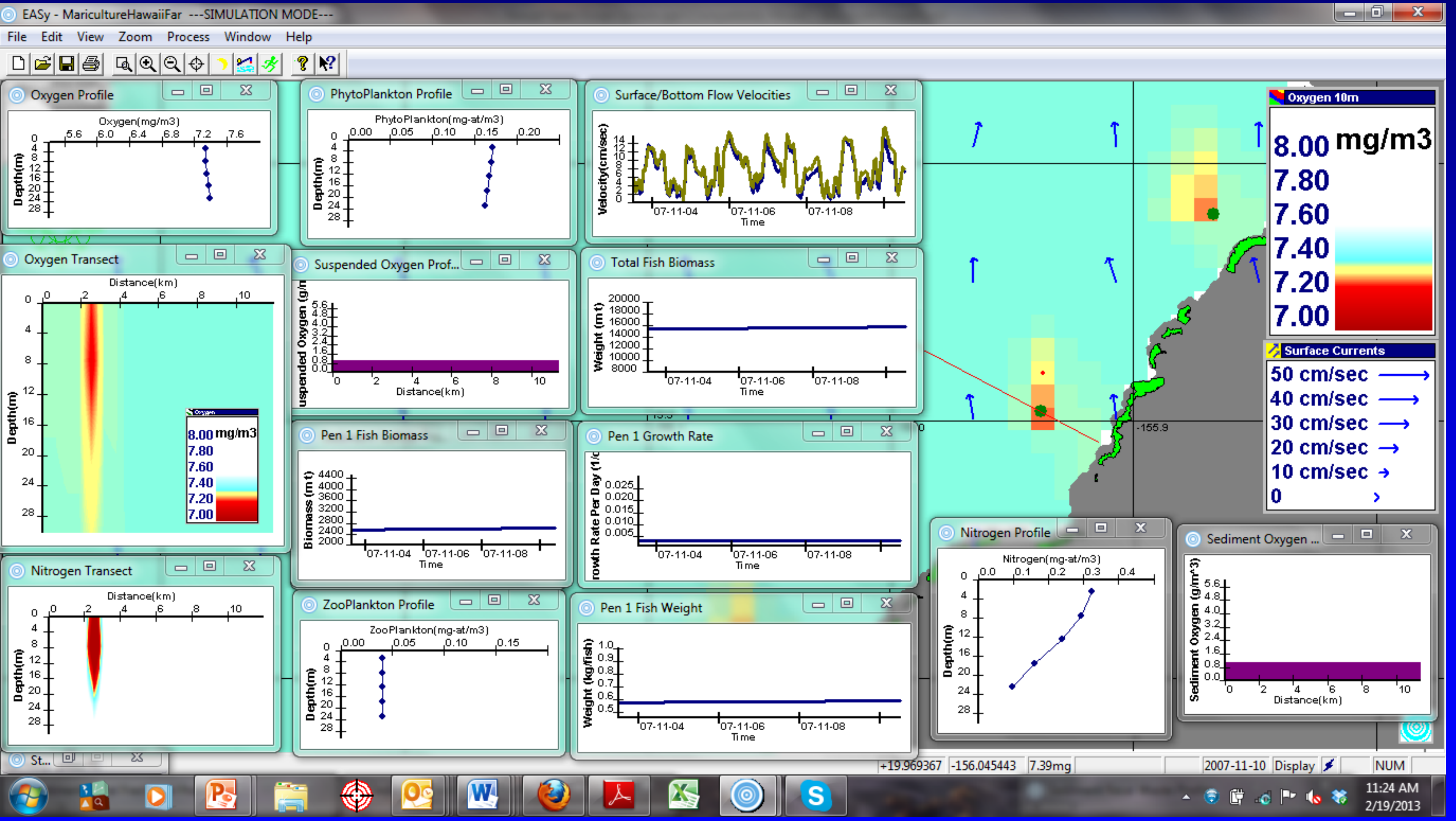
AquaModel Compartments



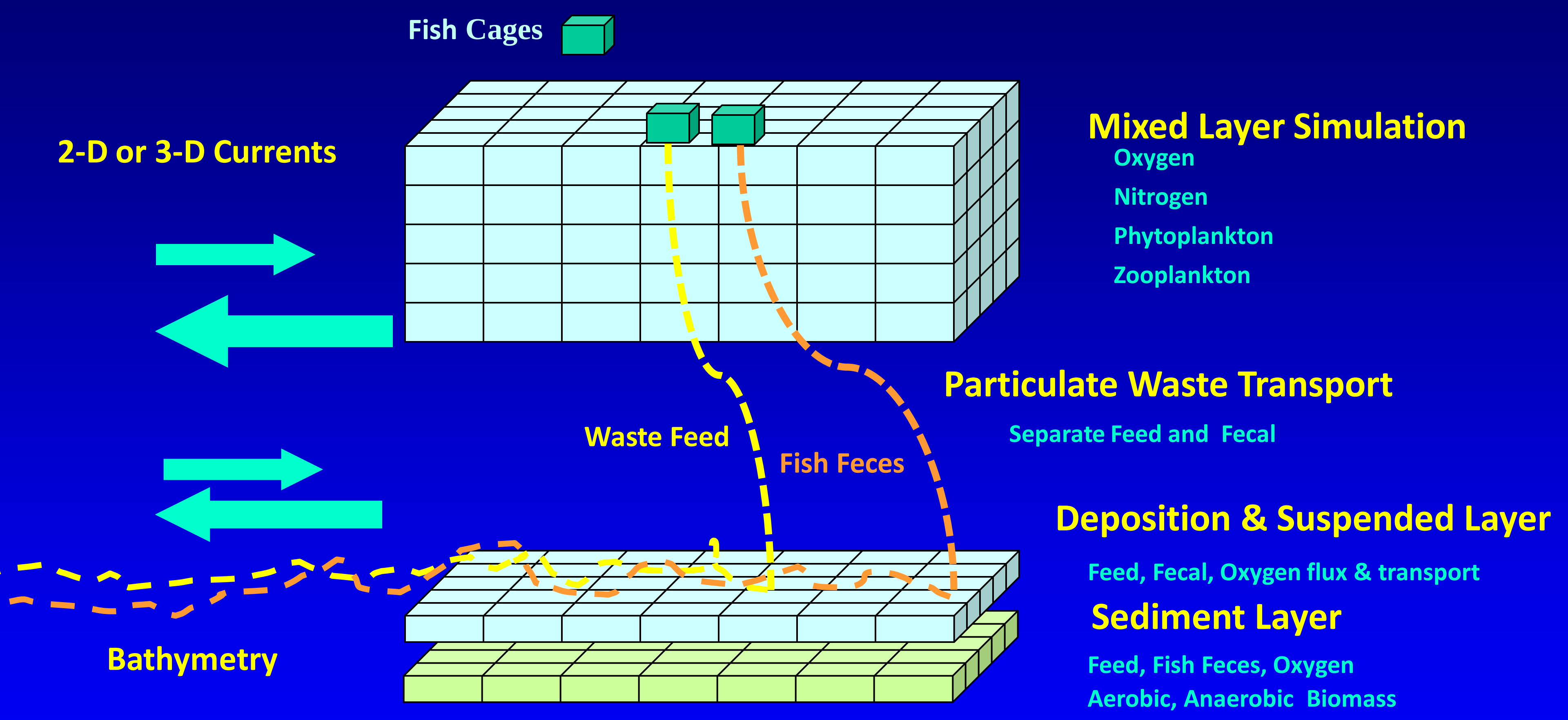
Quantitative Analysis

50+ parameters, 20+ tools.

300+ types of satellite imagery

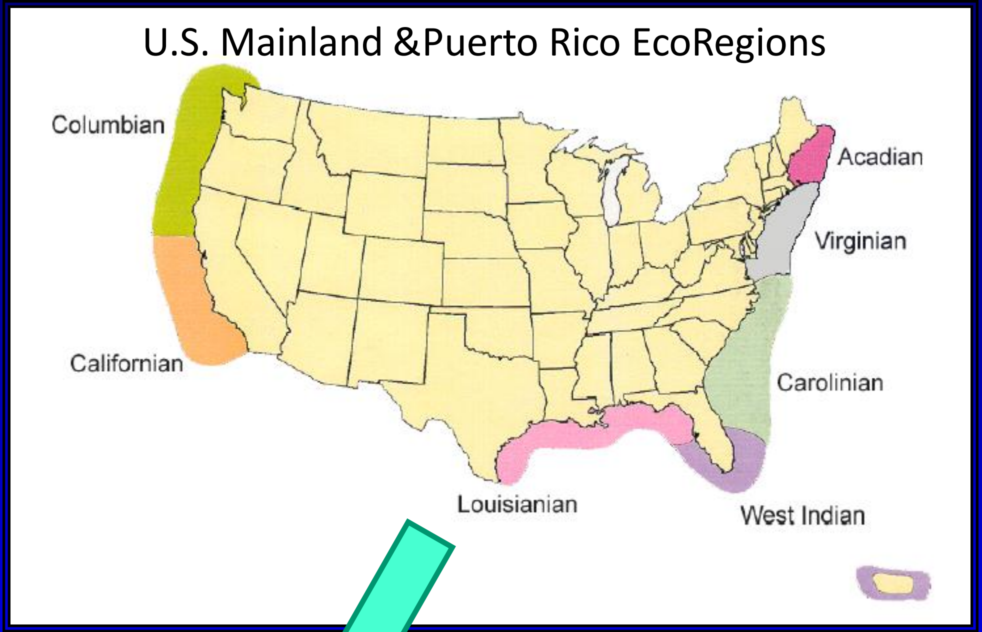


AquaModel Circulation & Fluxes



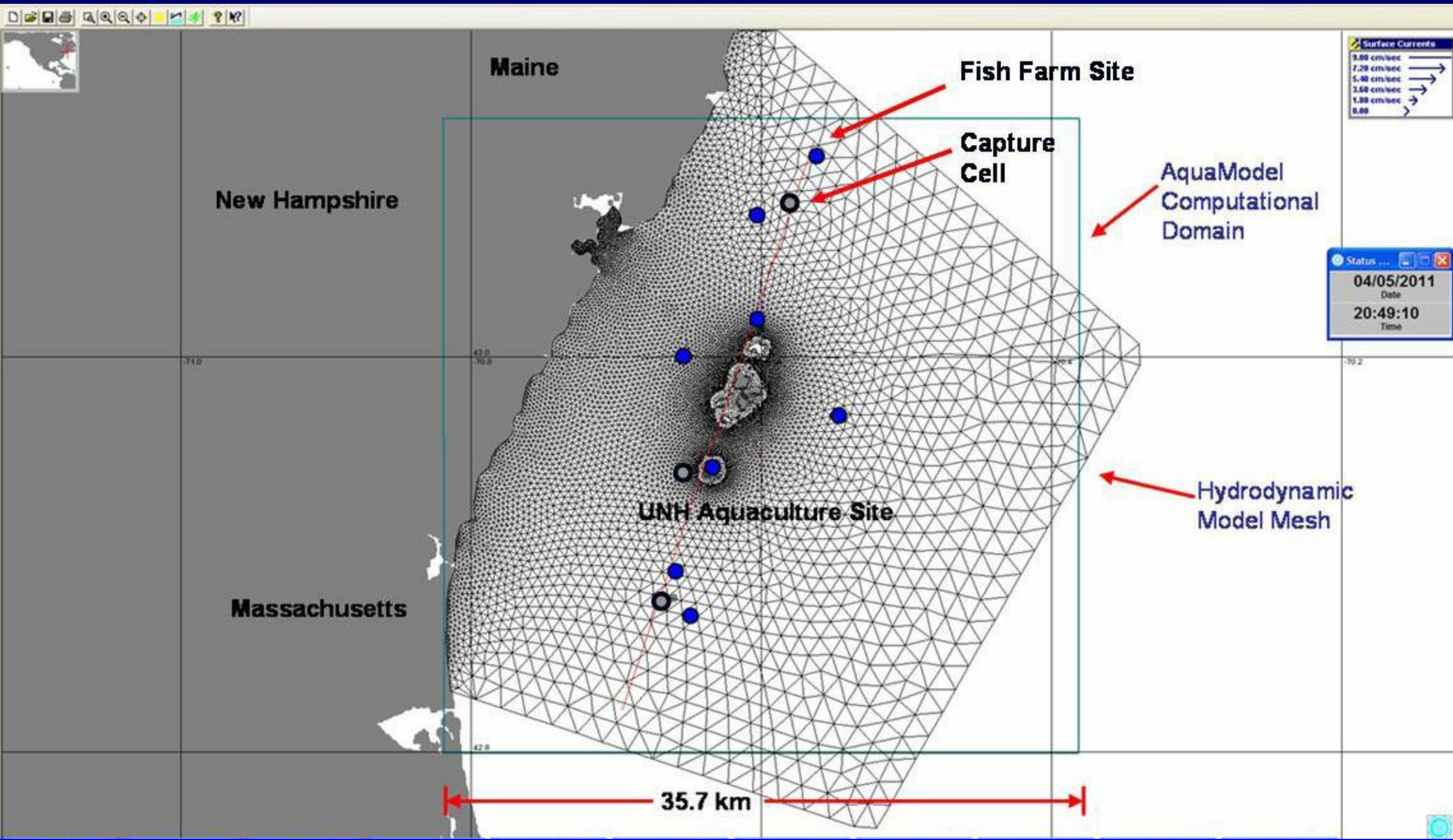
Current meter, ROMs circulation models, simple estimates method
Adjustable diffusivity, mixed and deep layers seasonal settings

U.S. Integrated Ocean Observation System (IOOS)
+ EcoRegion Calibrated Biological Models



Aquaculture Models
(Biophysical Coupling)

But every regions uses different models or construction !



Far Field Gulf of Maine Modeling Domain

Near field and Far Field AquaModel Versions

Near Field focus: single or multiple current meters

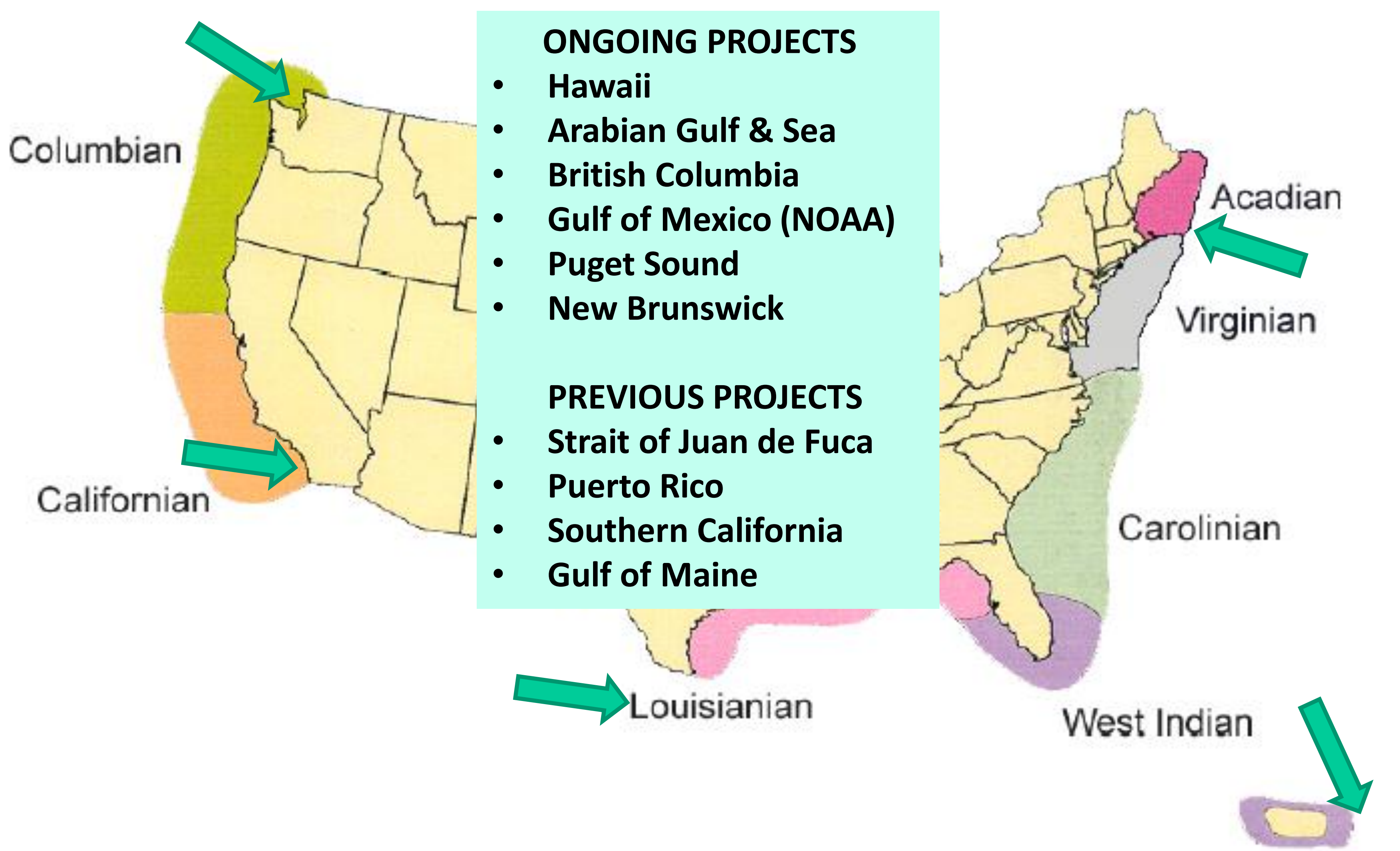
- Single farm, contiguous or spaced cages using fine grid
- Benthic effects (TOC, sulfides, waste feed and/or fecal tracking, etc.),
- Dissolved oxygen, Dissolved Inorganic or Total Filtered Nitrogen

Far Field focus: regional circulation driven

- Many farm concurrently, over entire coasts with variable grid
- Cumulative effects: nitrogen/phytoplankton/zooplankton
- Model within GIS: will nitrogen affect littoral zone (ulvoid algae) or coral reefs (epiphytes), sea grass meadow, habitats of special significance, etc.?

Both:

- Farm to farm or pen to pen interactions
- Similar setup, operation, tools available



ONGOING PROJECTS

- Hawaii
- Arabian Gulf & Sea
- British Columbia
- Gulf of Mexico (NOAA)
- Puget Sound
- New Brunswick

PREVIOUS PROJECTS

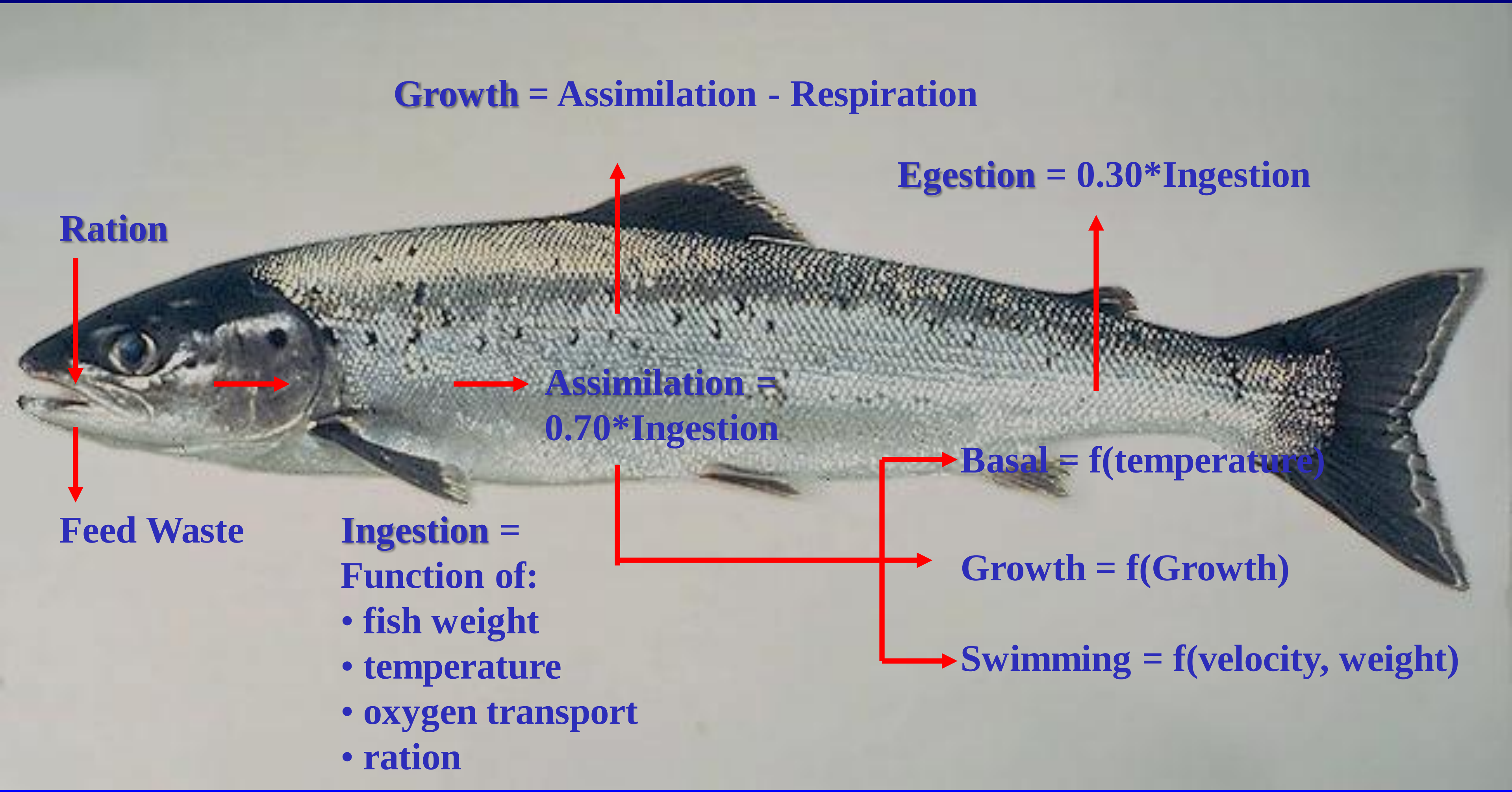
- Strait of Juan de Fuca
- Puerto Rico
- Southern California
- Gulf of Maine

Applications of AquaModel: Ecoregions Worldwide

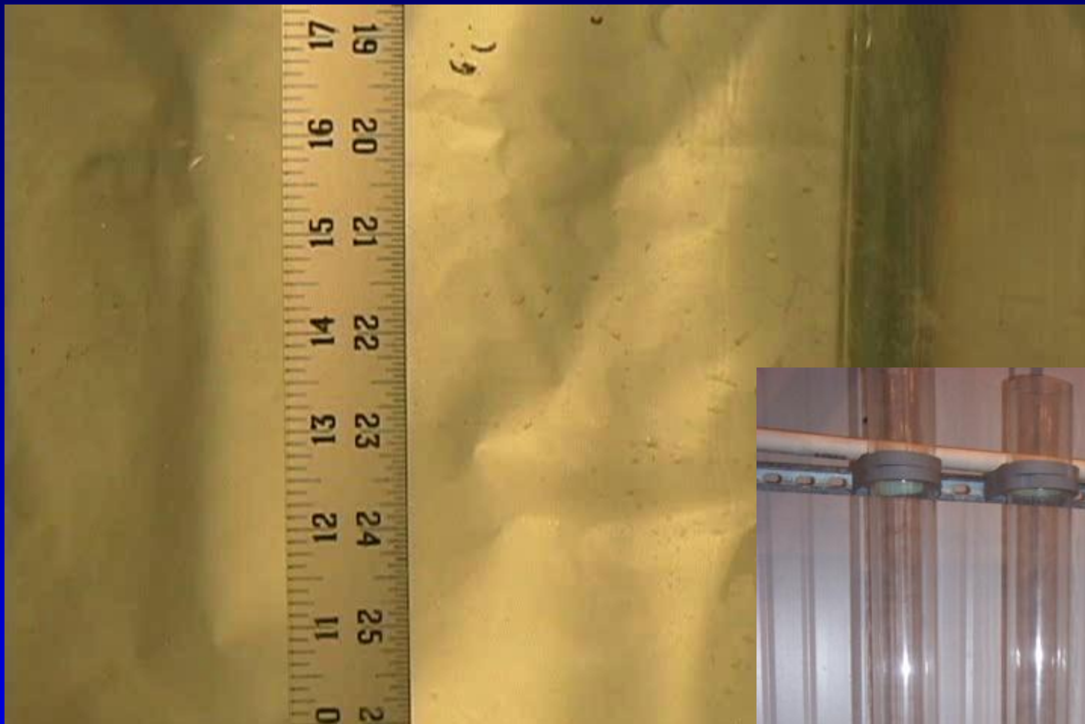
Underlying Basis of Fish Physiology Model: Carbon/Nitrogen/Oxygen Mass Balance and Rates

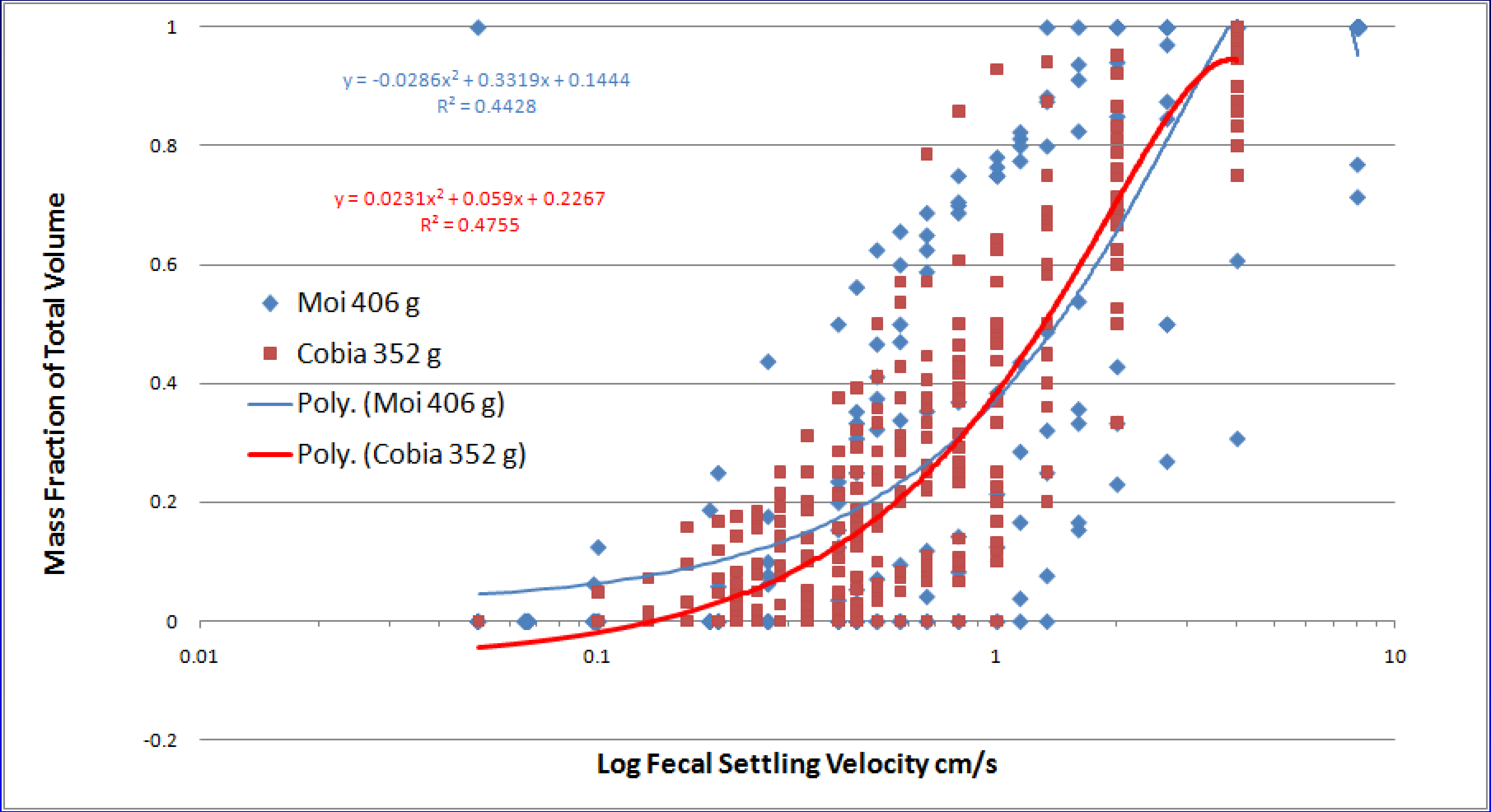
- Ingestion rate = egestion rate + assimilation rate
- Fish feces production = egestion rate
- Assimilation rate = rate of respiration + rate of growth
- Respiration rate = resting rate of respiration (i.e. basal) + respiration rate of activity (swimming) + respiration rate of anabolic activity (growth)
- Most limiting metabolic process and Scope for Metabolism

A Carbon/Nitrogen/Oxygen Metabolic Model for Salmon



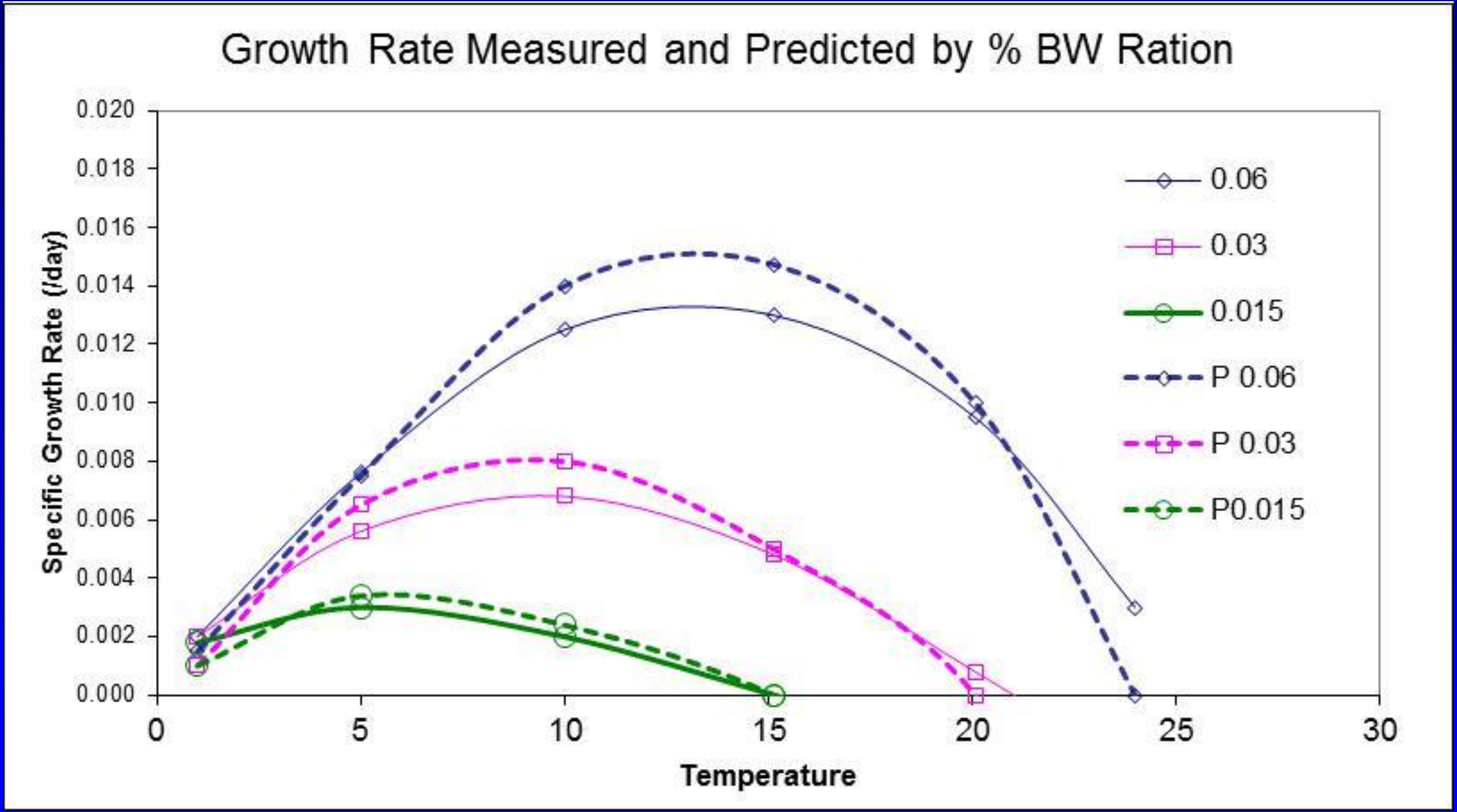
AquaModel Fish Physiology Module



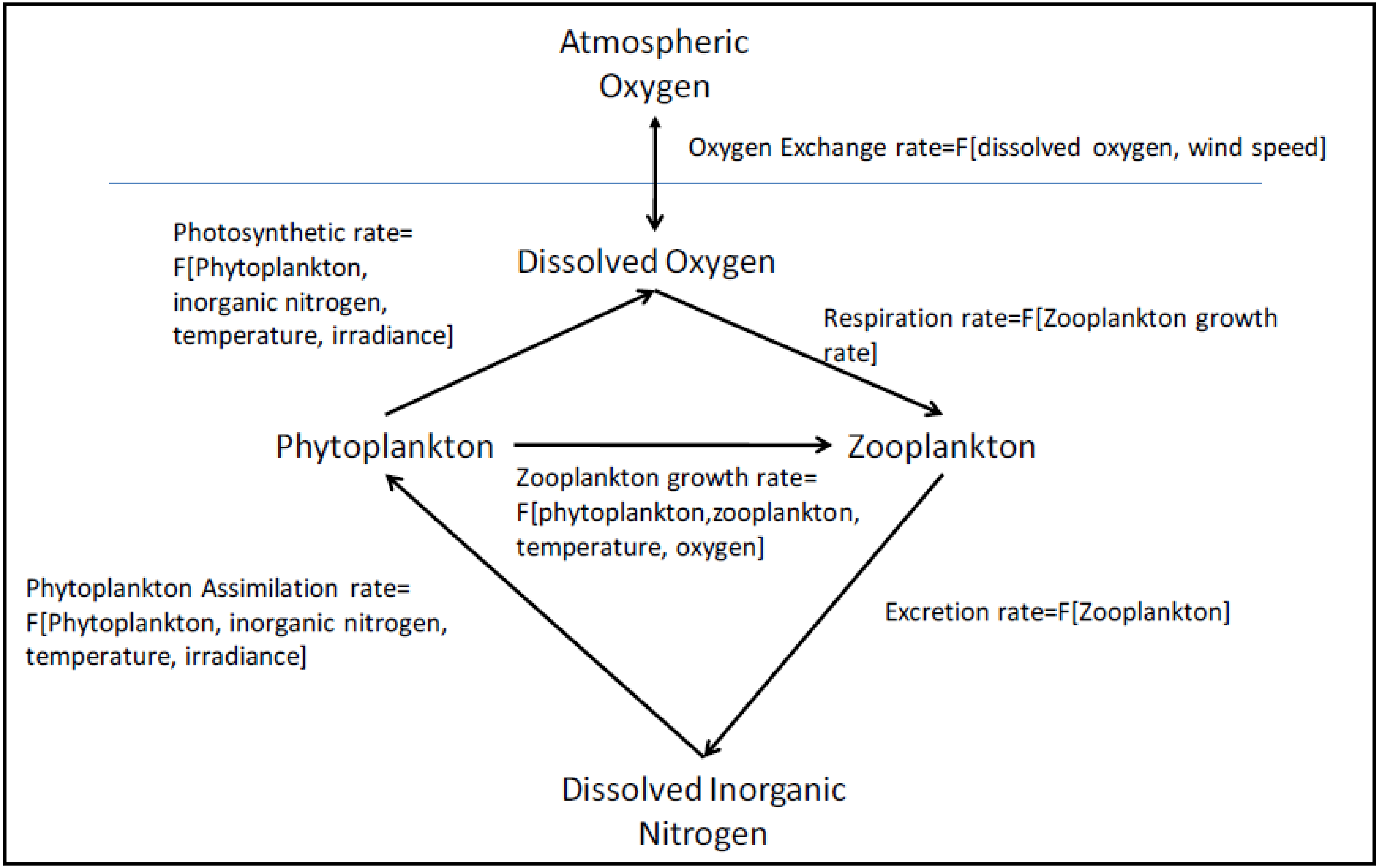


- Cobia and Moi Fecal Settling Rates
- Binomial Fit is very similar for moi and cobia
- BUT, unlike salmon feces nominal range is small (salmon~ 0.5 to 9 cm/s vs. marine fish ~ 0.1 to 1.2)

Example validations: Salmon Respiration and Growth Rates
AquaModel Predicted vs. Measured

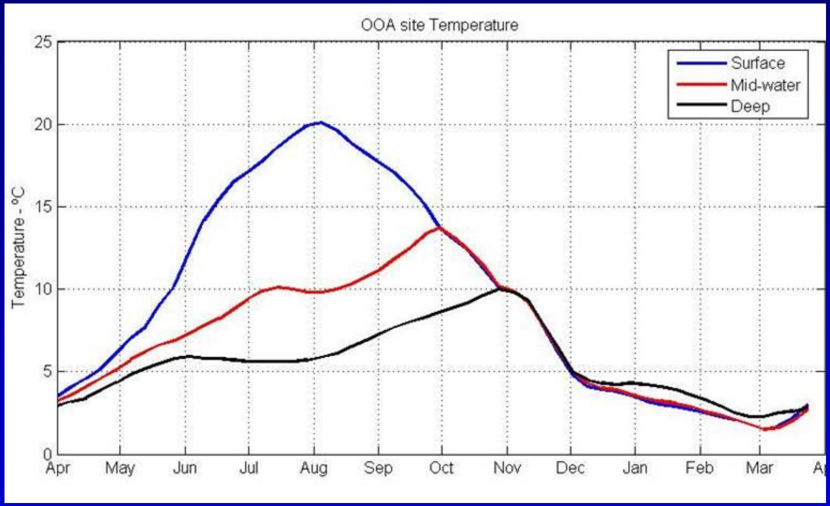


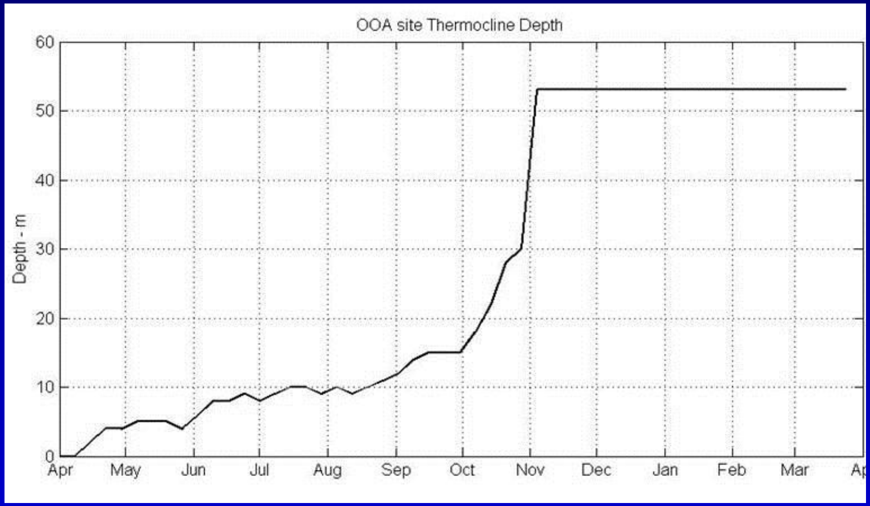
Nitrogen-Phytoplankton-Zooplankton Module

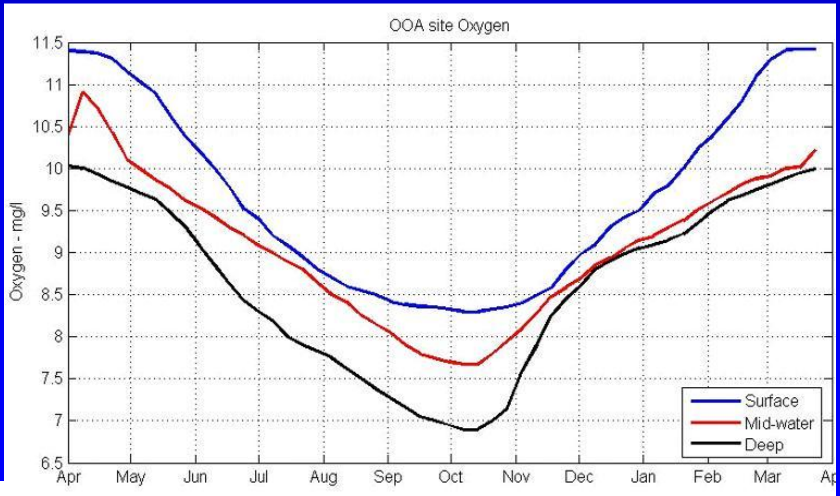


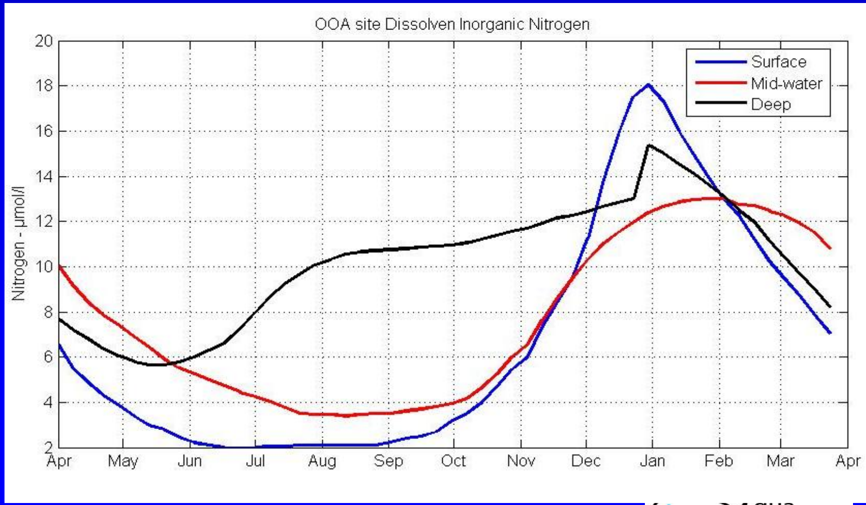
Gulf of Maine: NPZ submodel validation

Highly Variable Boundary Conditions, example parameters





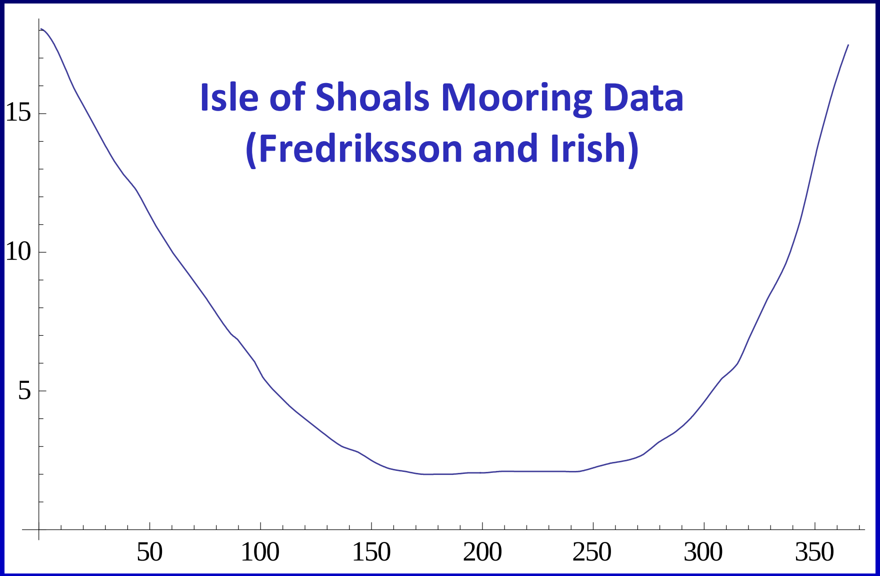




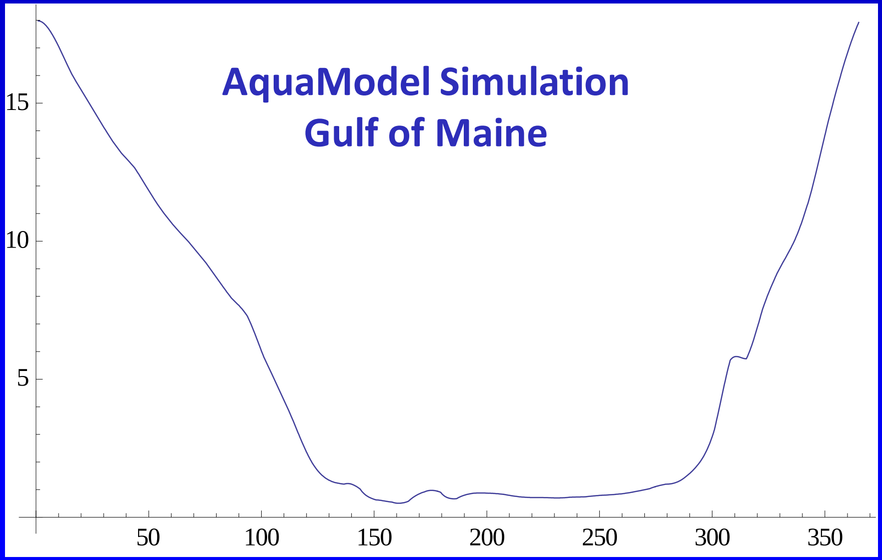
Source: Kiefer, Rensel, O'Brien ,Fredriksson and Irish, 2011

Capturing Dynamics of the Plankton Community

Dissolved Inorganic Nitrogen (mg-at/m3)



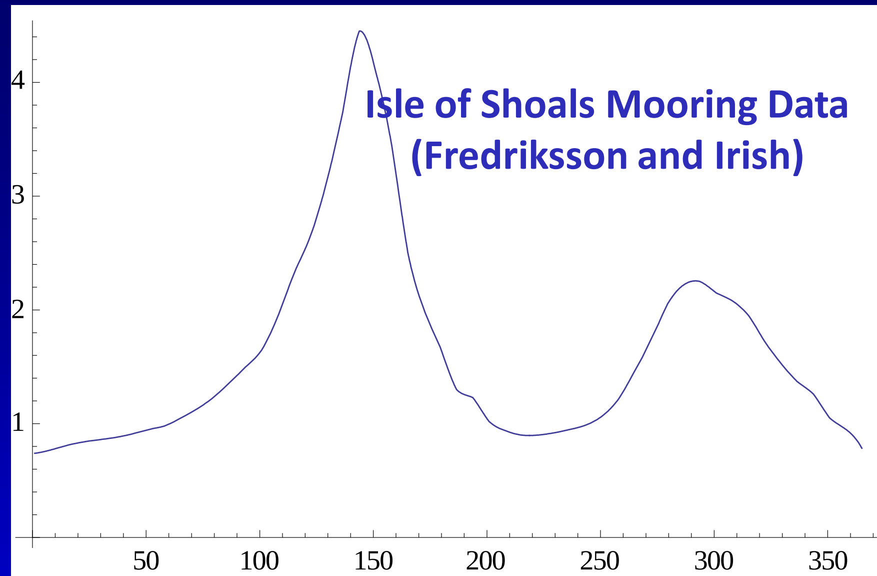
Dissolved Inorganic Nitrogen mg-at/m3



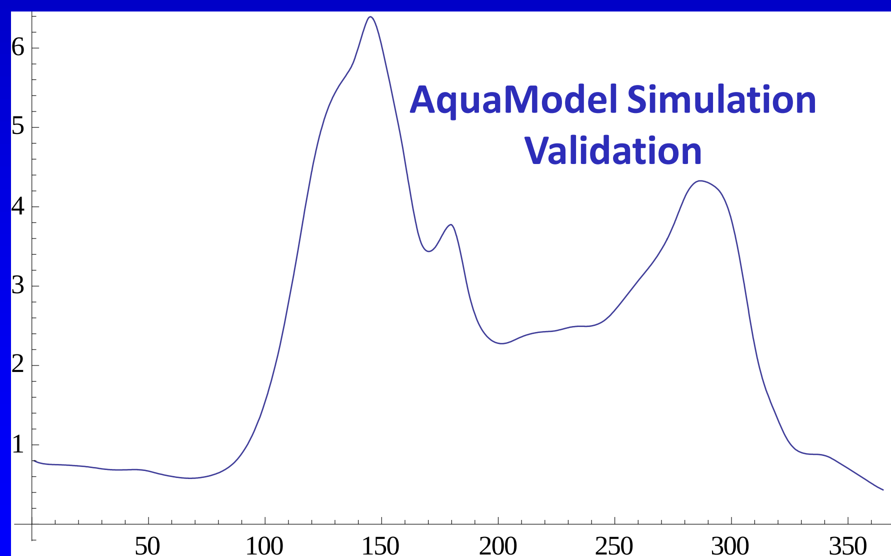
Julian Day

Capturing Dynamics of the Plankton Community

Chlorophyll a
(mg/m3)



Chlorophyll a
(mg/m3)



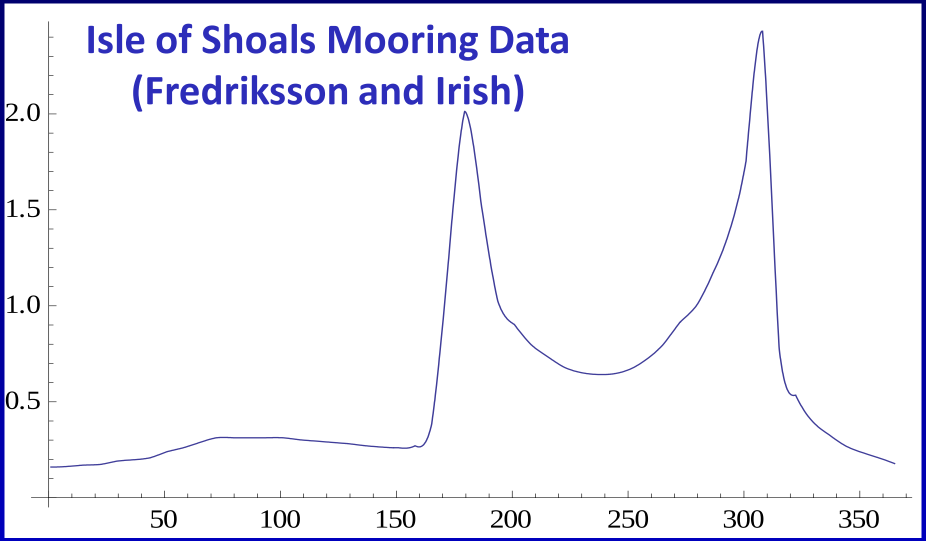
Julian Day

EASy

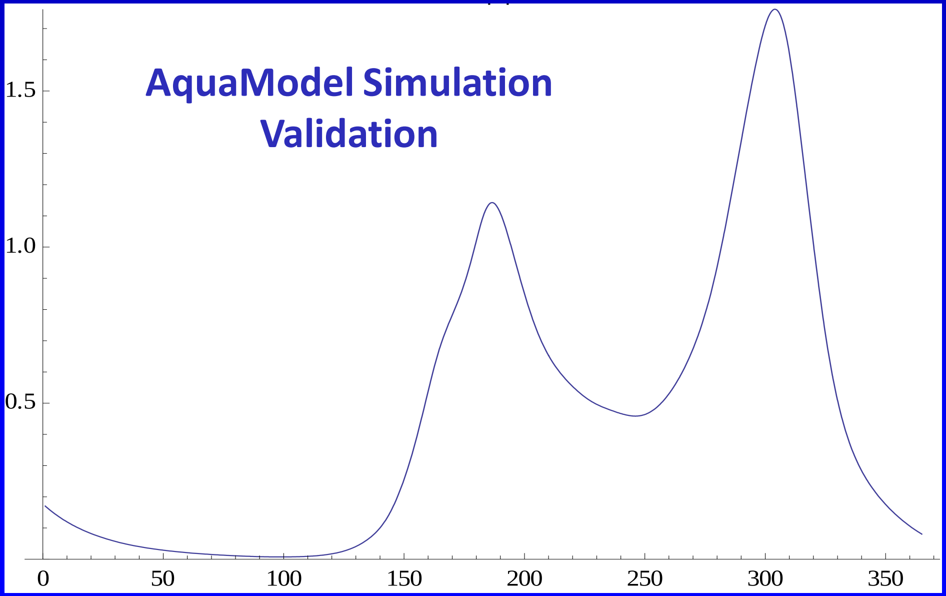
AquaModel

Capturing Dynamics of the Plankton Community

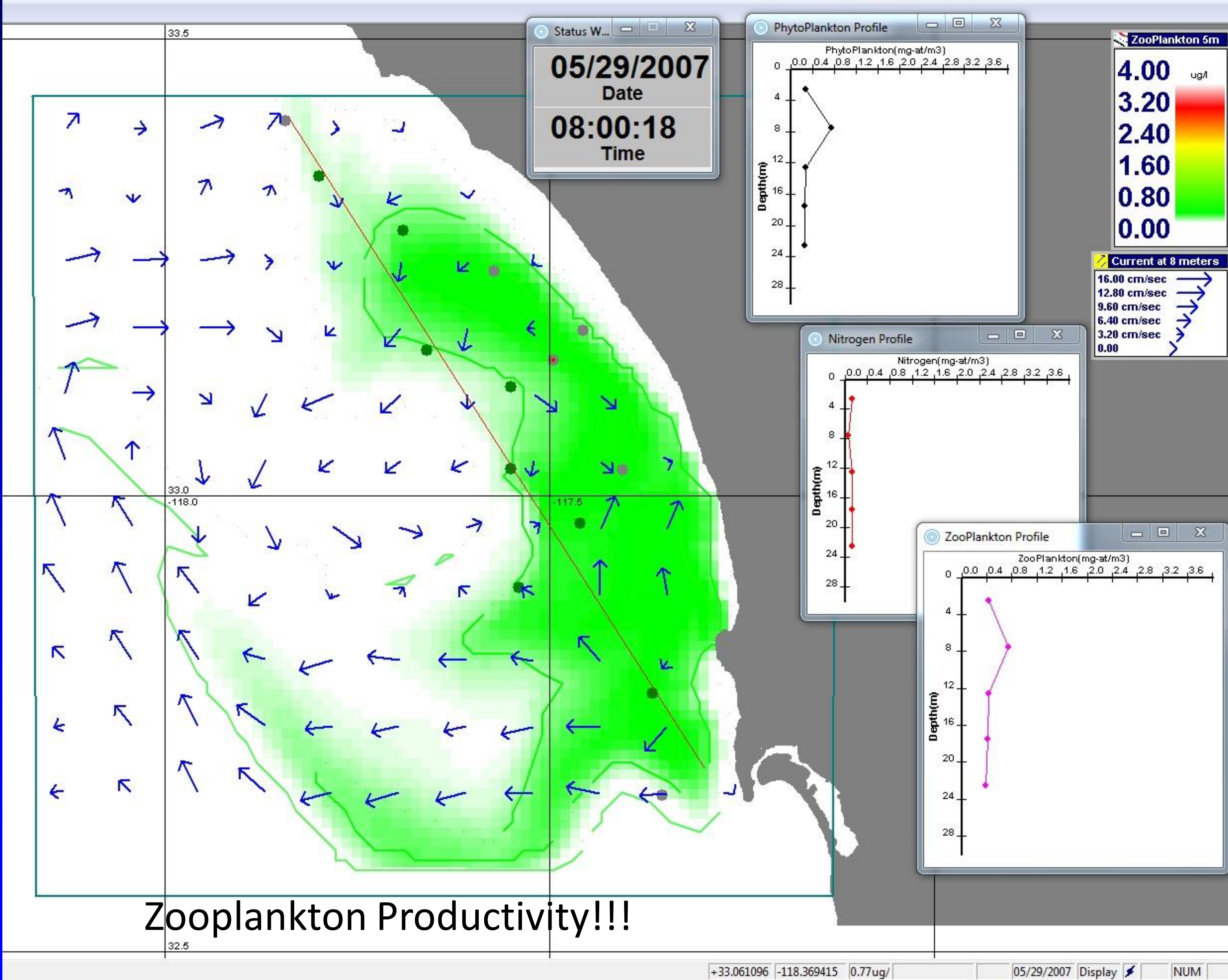
Zooplankton Nitrogen (mg-at/m3)



Zooplankton Nitrogen (mg-at/m3)

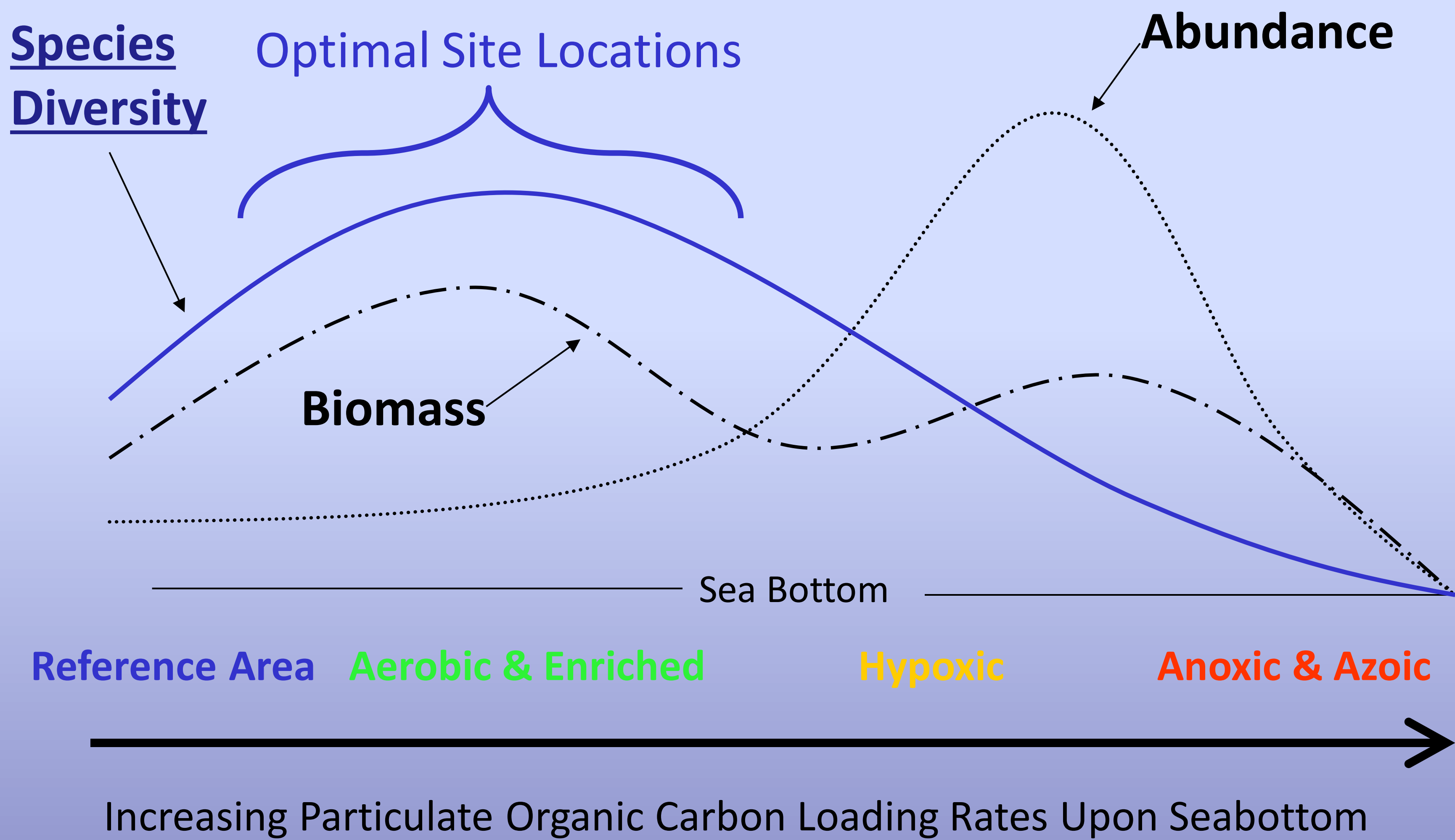


Julian Day

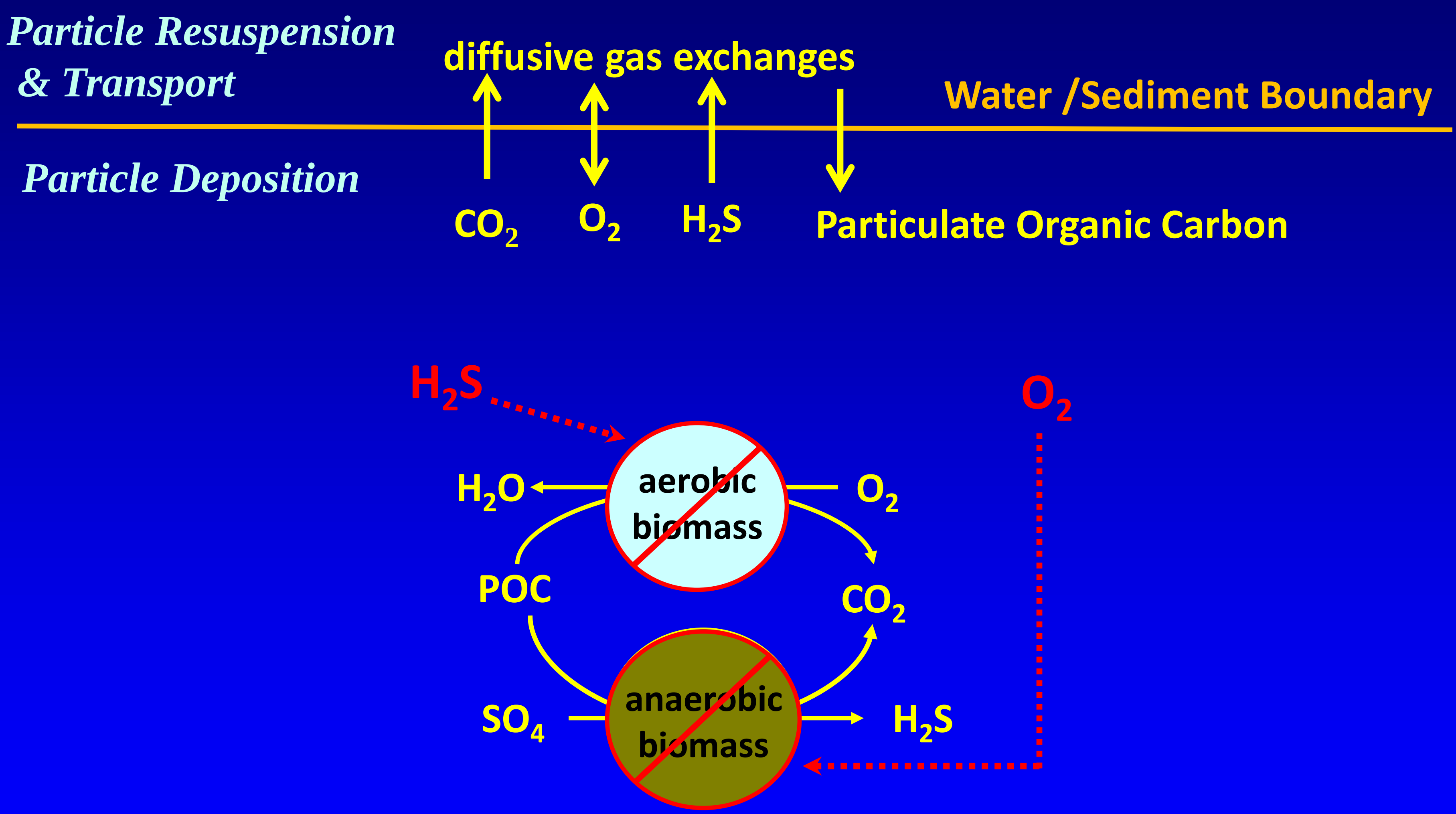


Zooplankton Productivity!!!

Sedimen Management Sustainability:
Classic Pearson-Rosenberg Organic Enrichment Effects

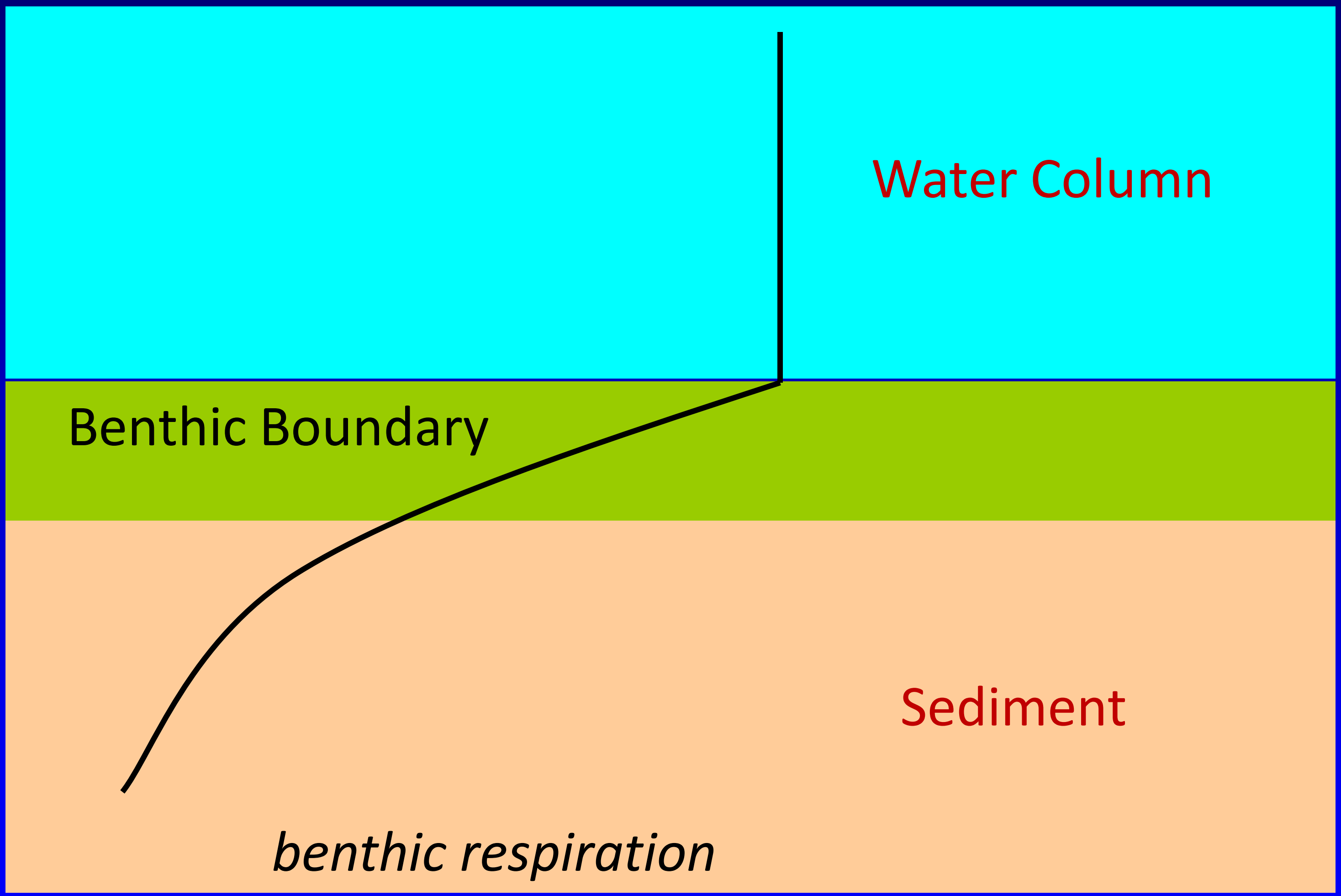


Benthic Module Concept

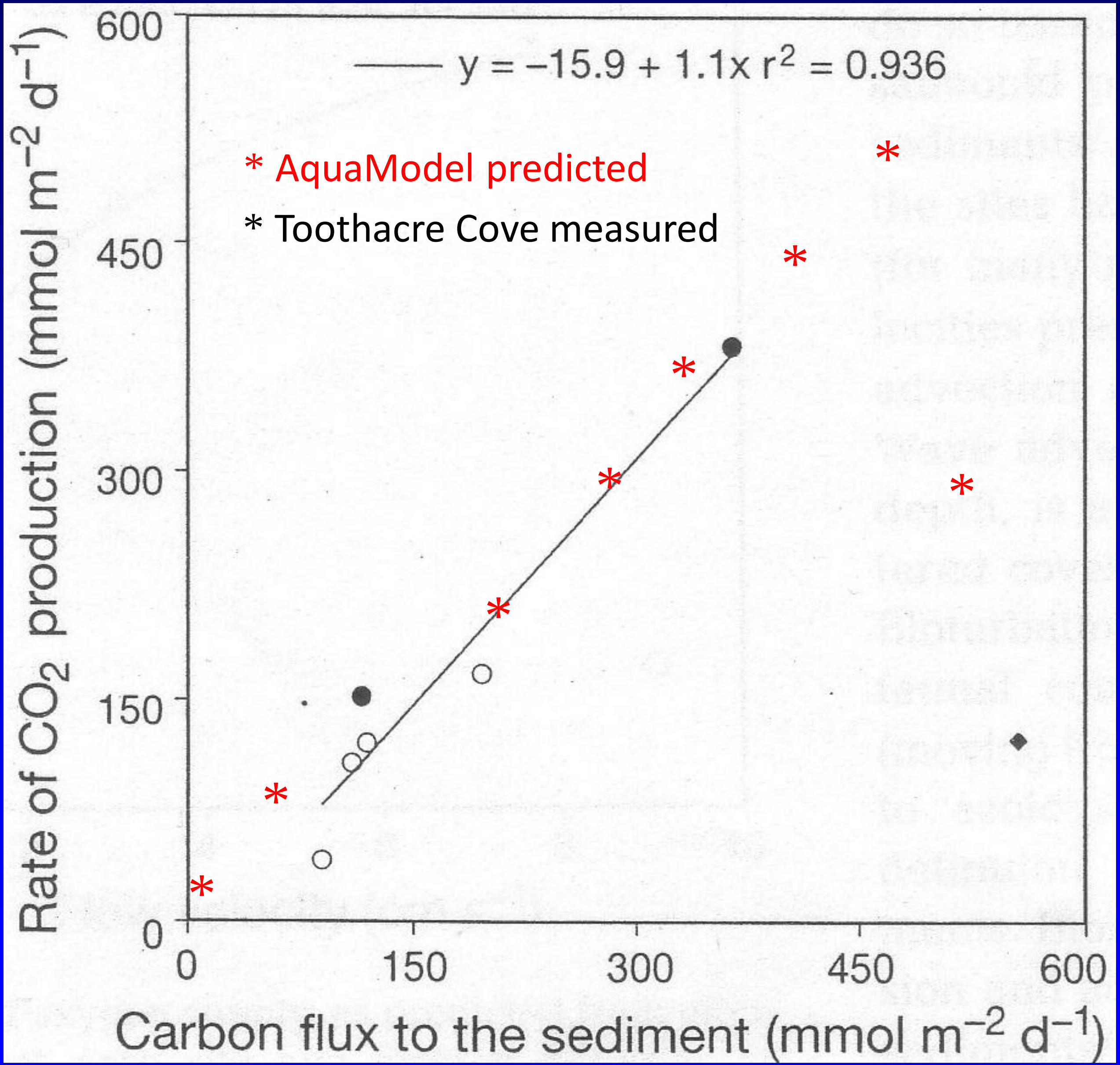


benthic respiration

Oxygen Profile at Benthic Boundary Layer

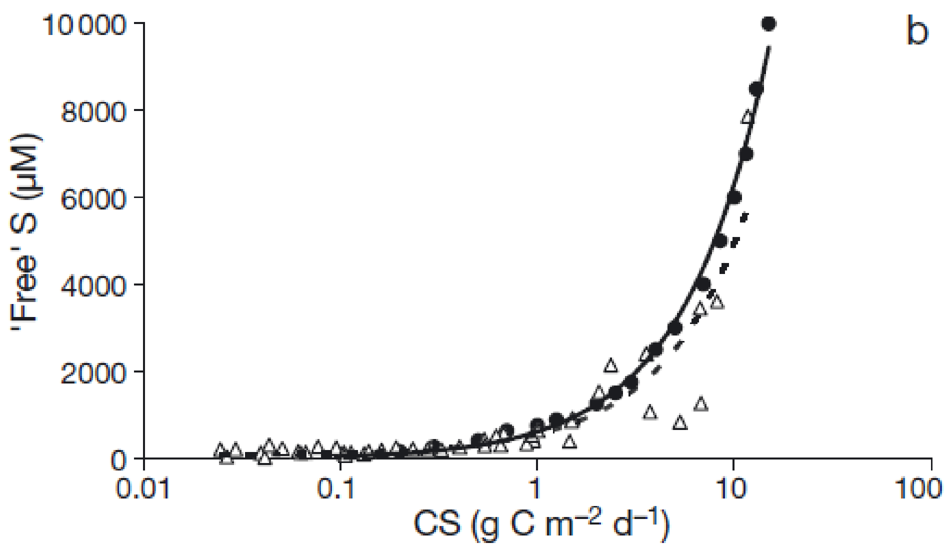


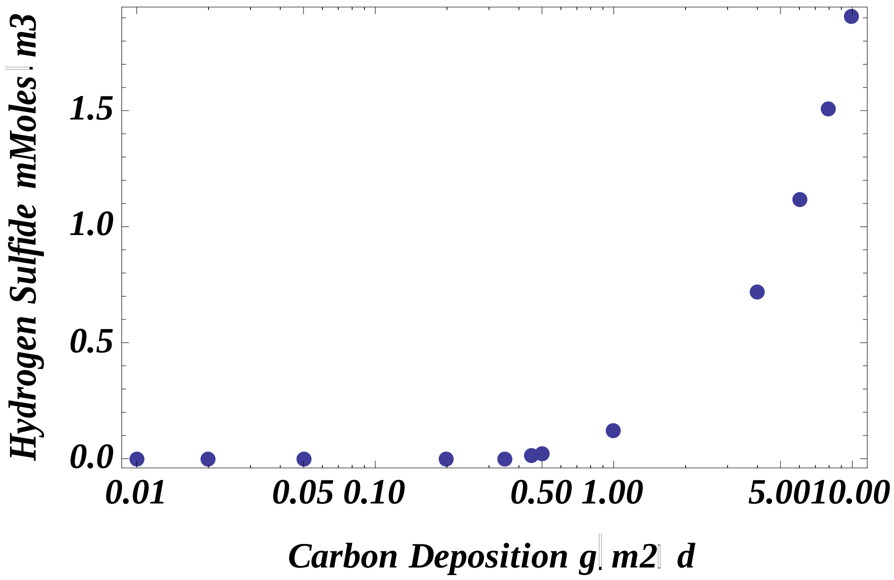
CO_2 Production vs. Carbon Deposition



Measured from Findlay and Watling 1997

Field measurements of sulfide concentration as a function of organic carbon loading calculated with DEPOMOD (Hargrave, 2010) & *AquaModel* general predictions of concentrations in upper 2 cm of sediment.





EAS y

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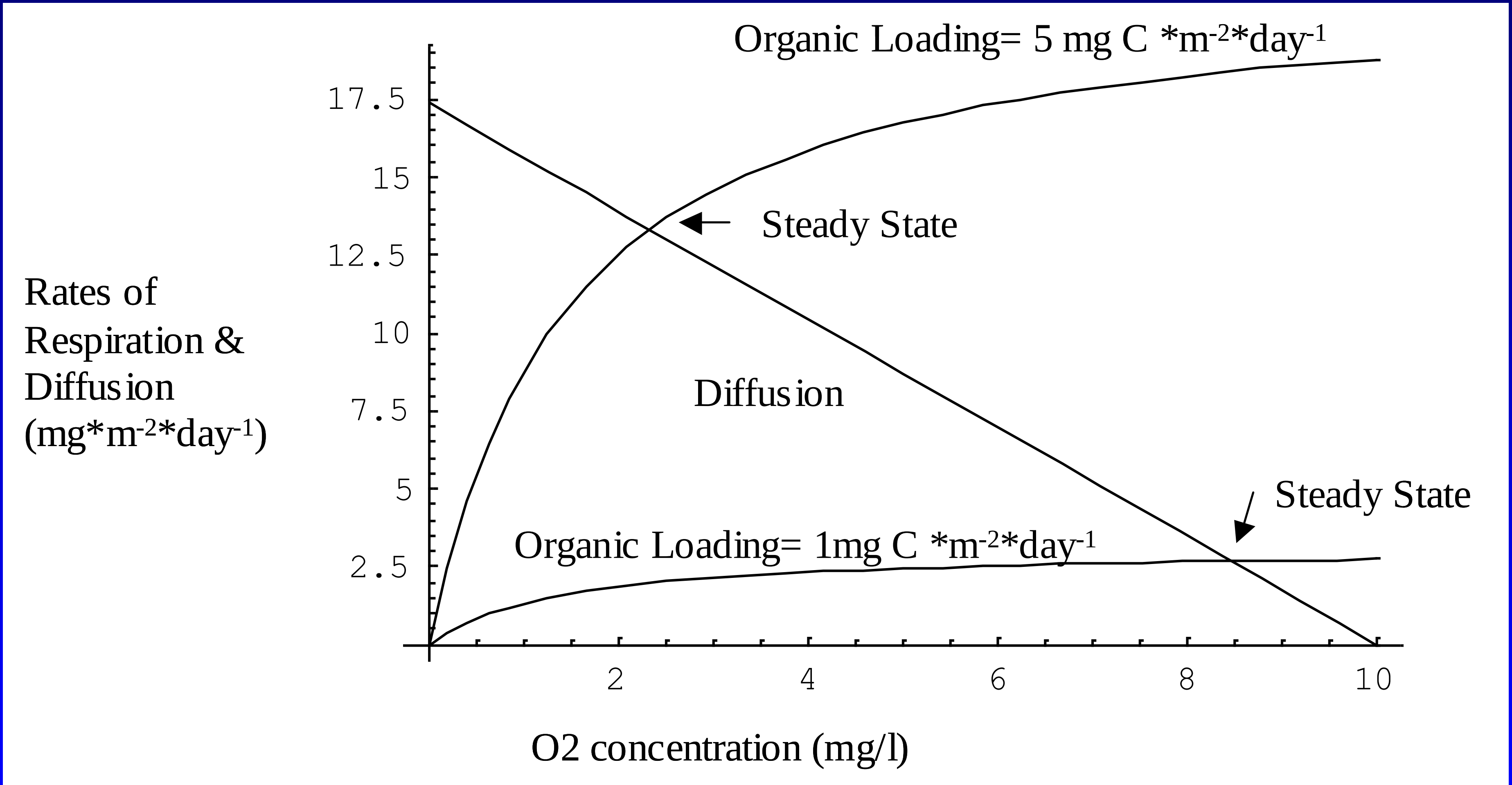
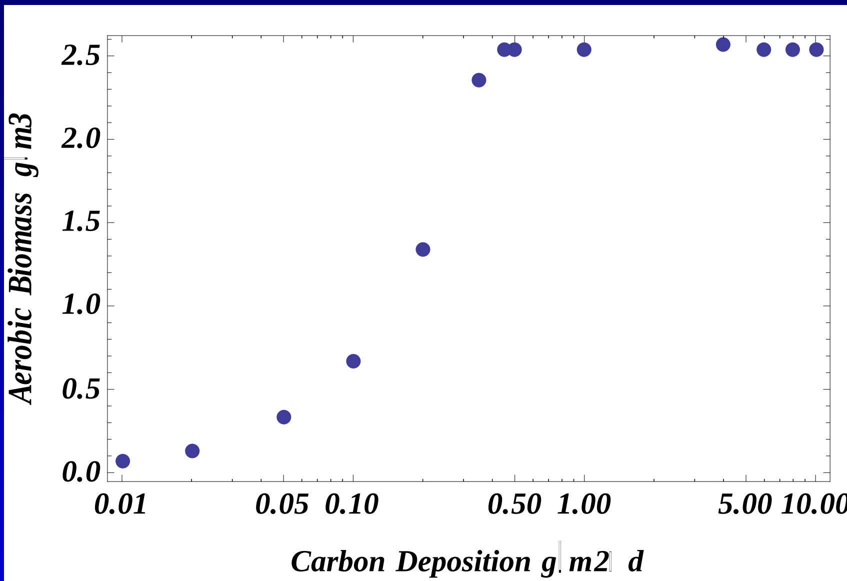
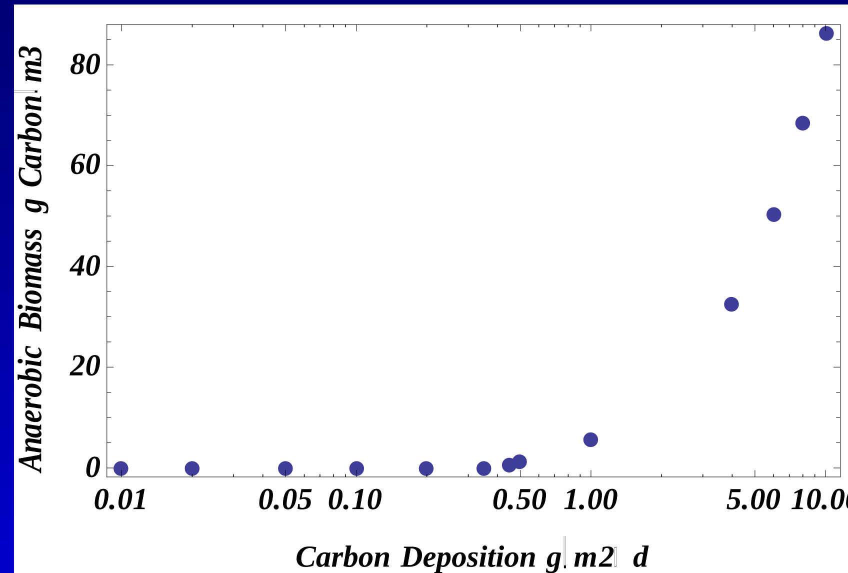
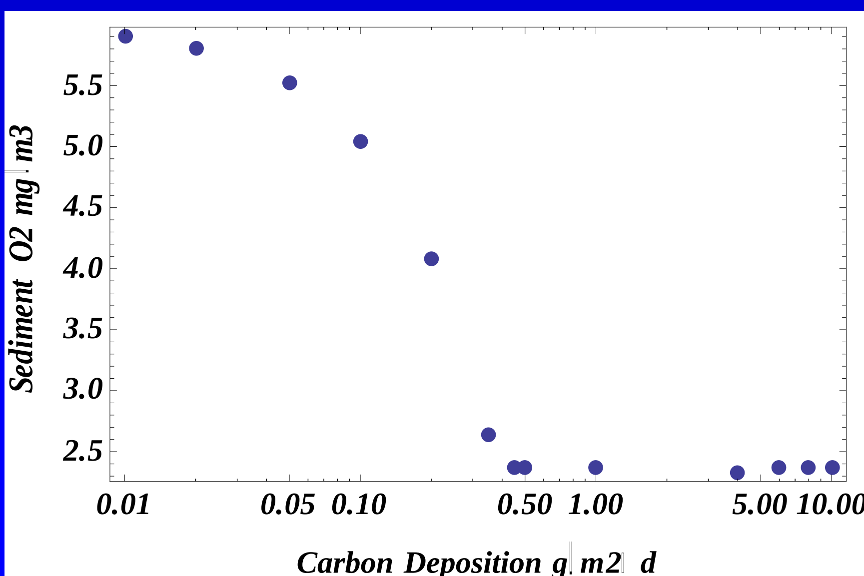
Behavior of benthic subroutine: steady state conditions defined for low and high rates of loading

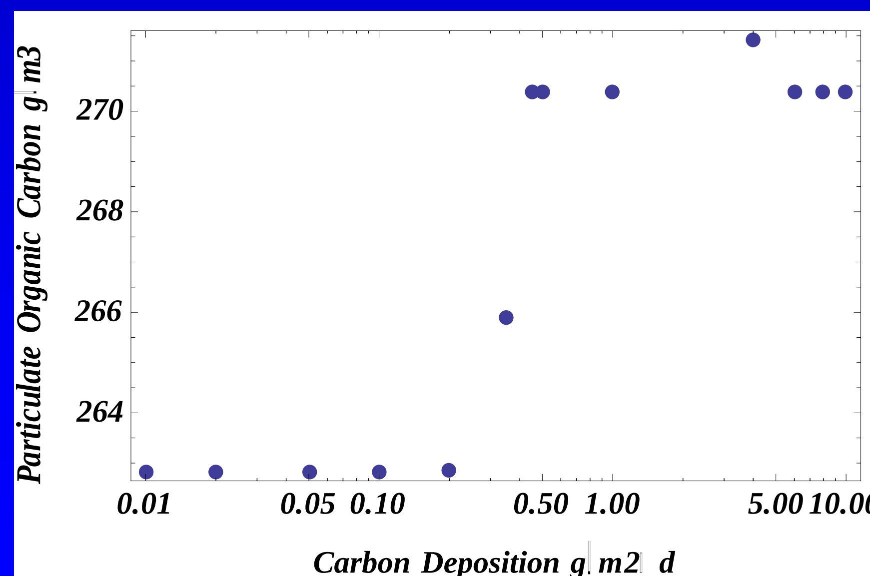


Steady state solutions of the benthic module in response to rates of organic carbon deposition.

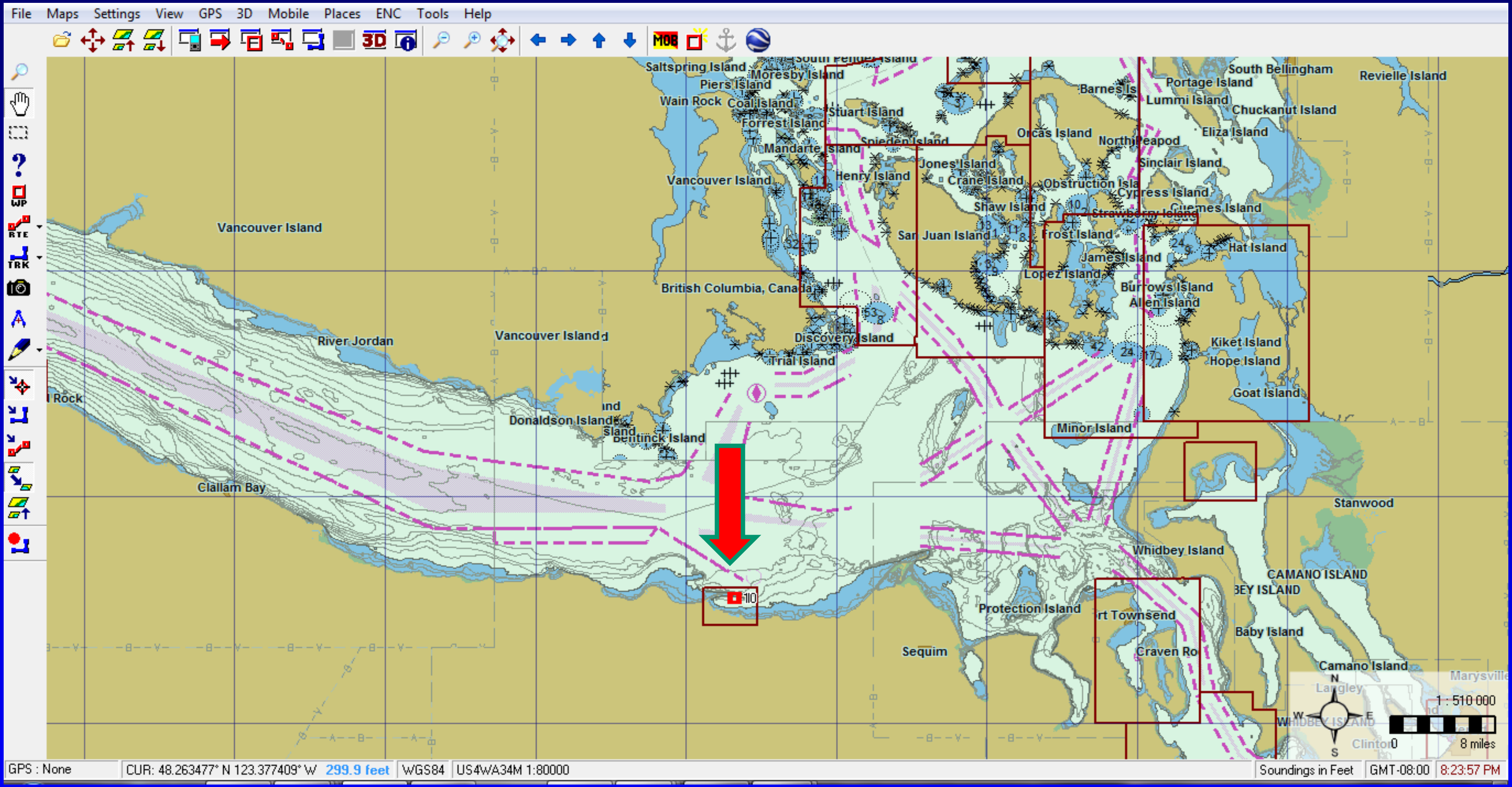


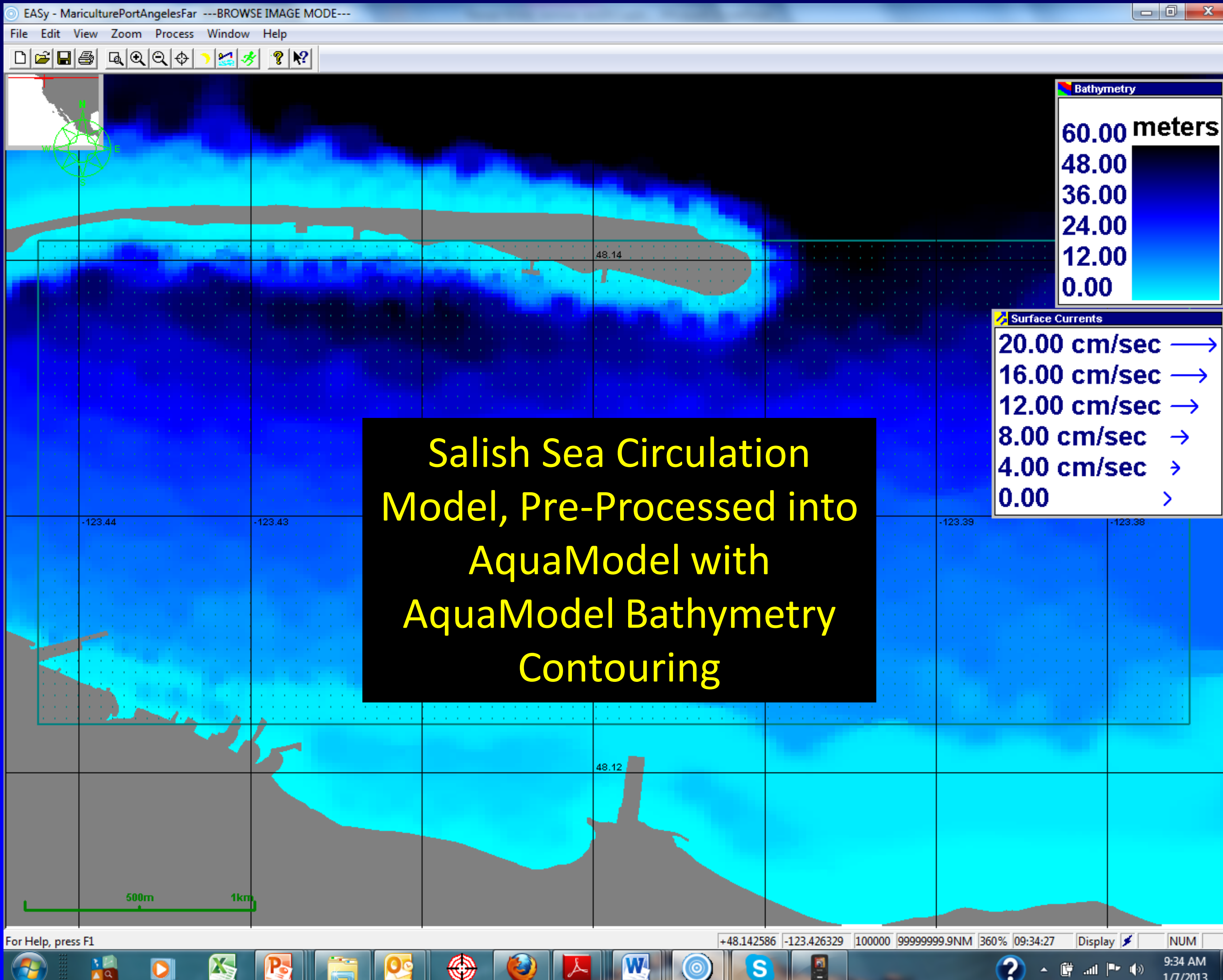




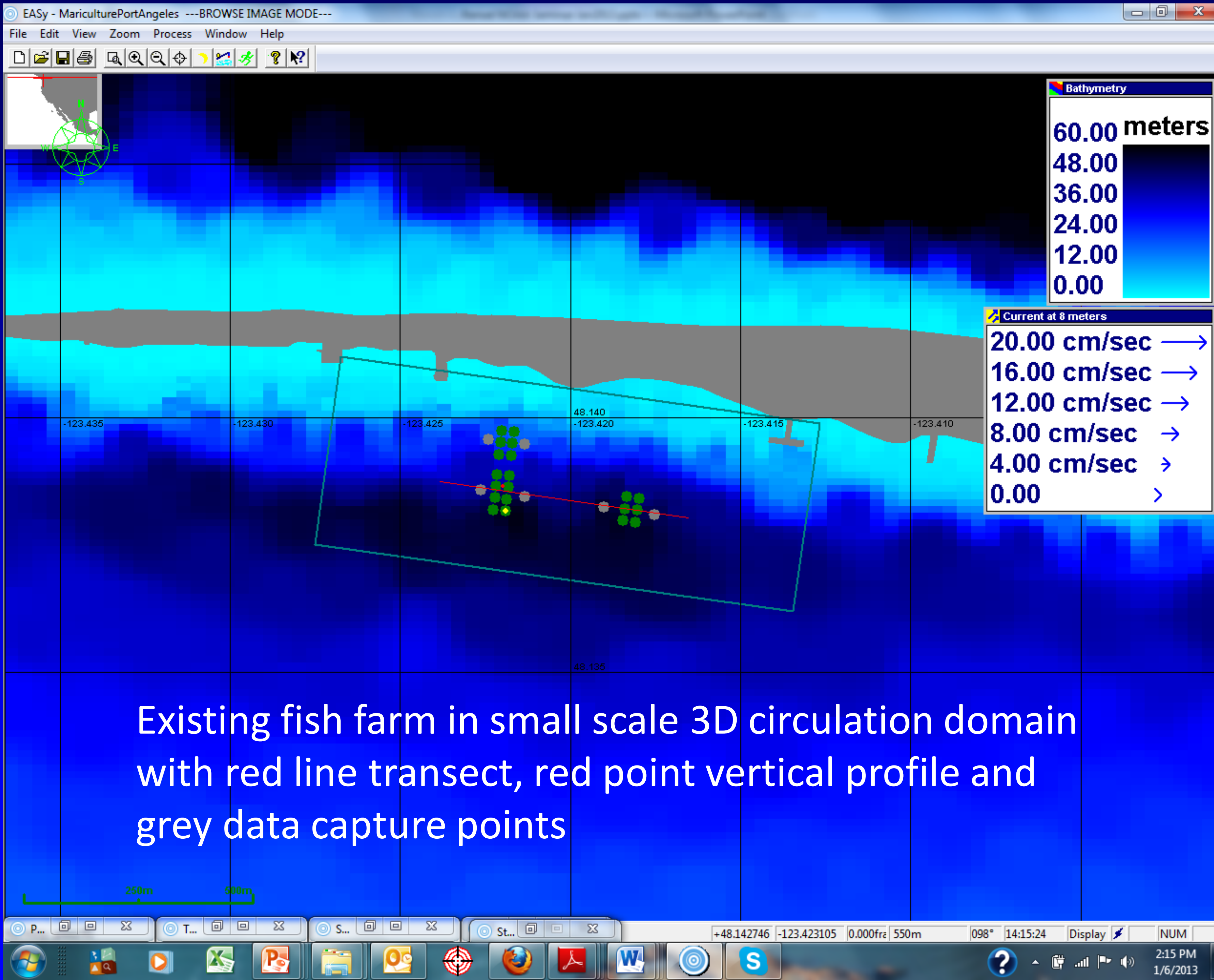


3D Nearfield Demonstration

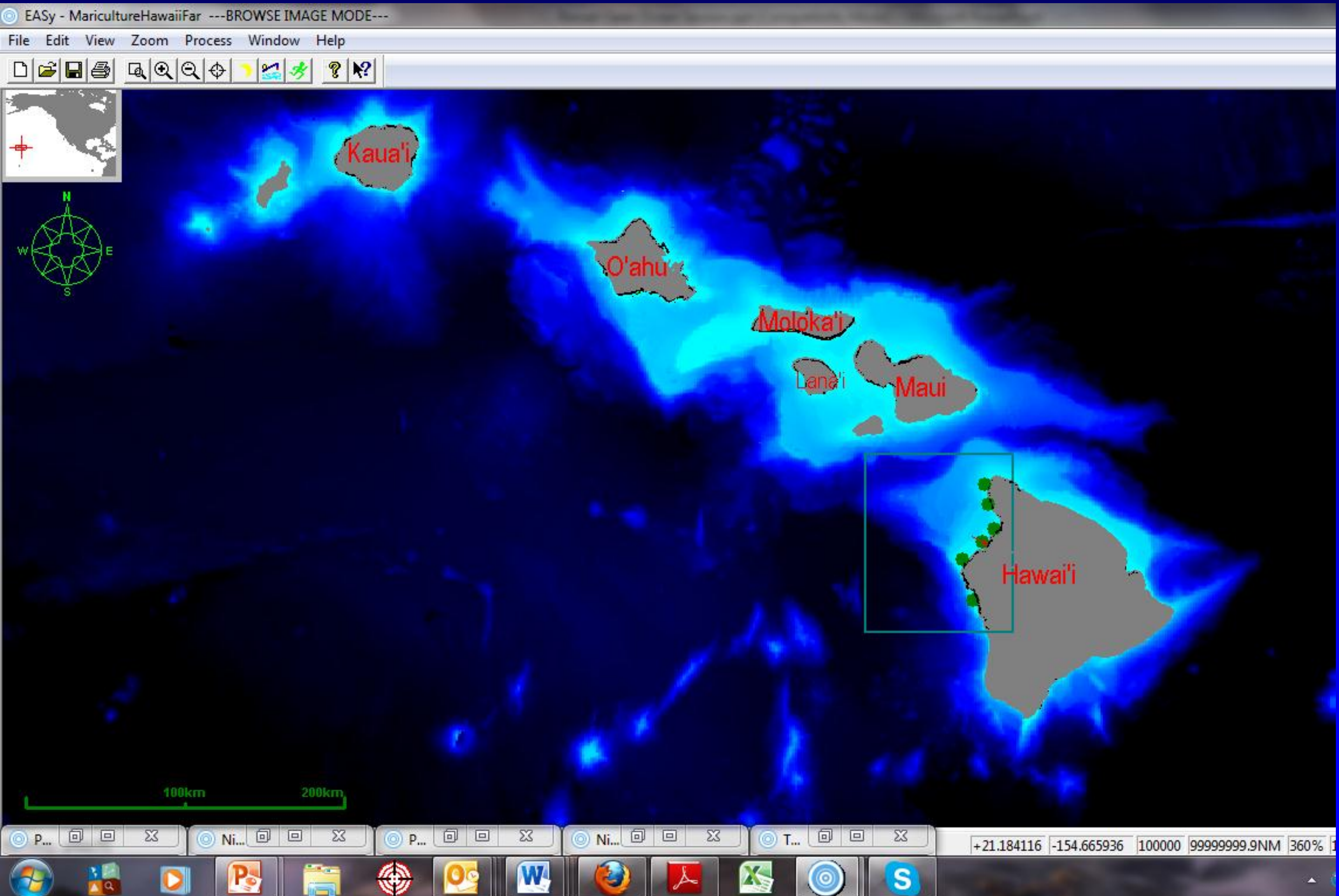




Salish Sea Circulation Model, Pre-Processed into AquaModel with AquaModel Bathymetry Contouring



Existing fish farm in small scale 3D circulation domain with red line transect, red point vertical profile and grey data capture points


EASy - MaricultureHawaiiFar ---BROWSE IMAGE MODE---
File Edit View Zoom Process Window Help
Kaua'i
O'ahu
Moloka'i
Lana'i
Maui
Hawai'i
N
W
E
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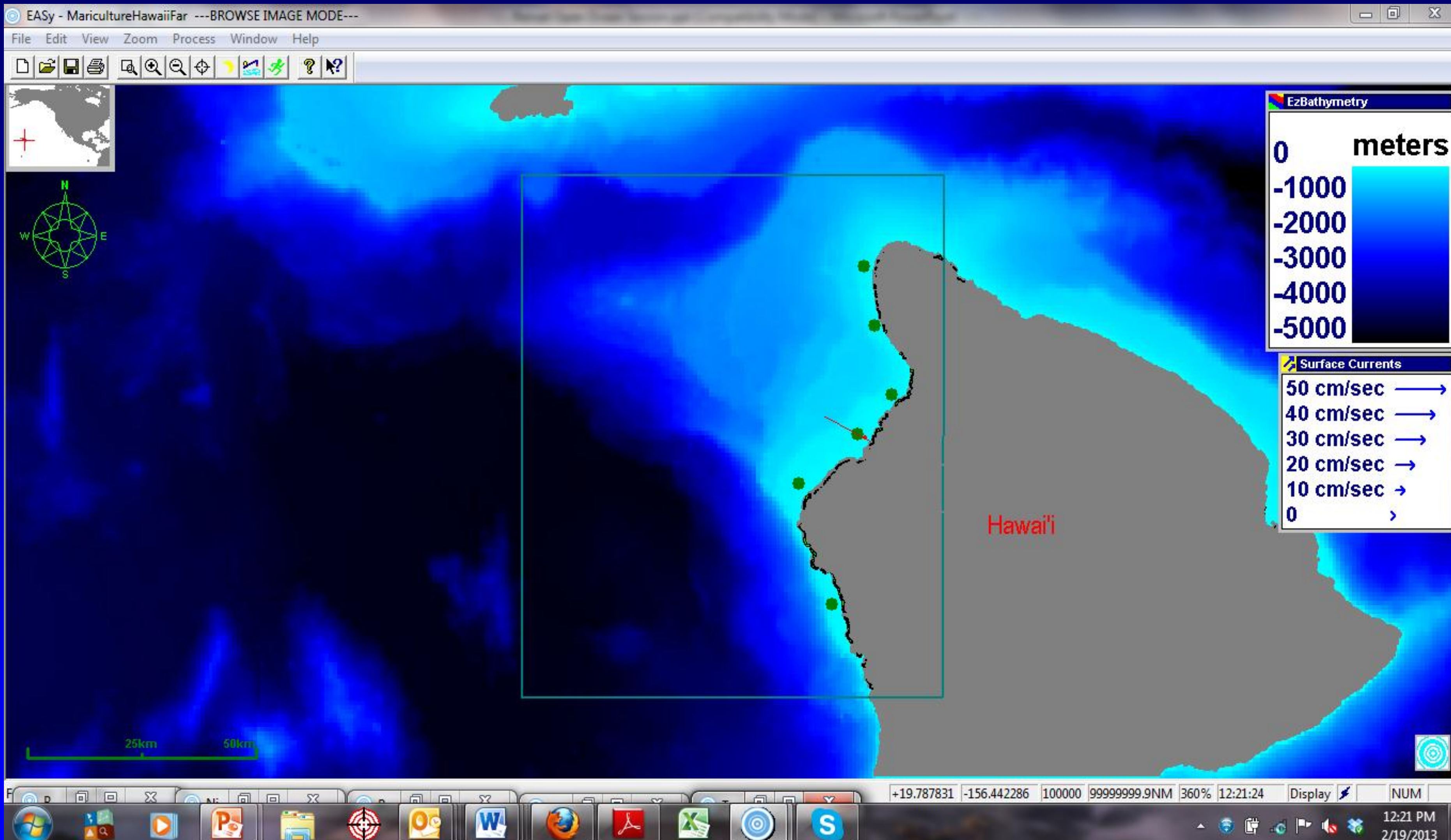
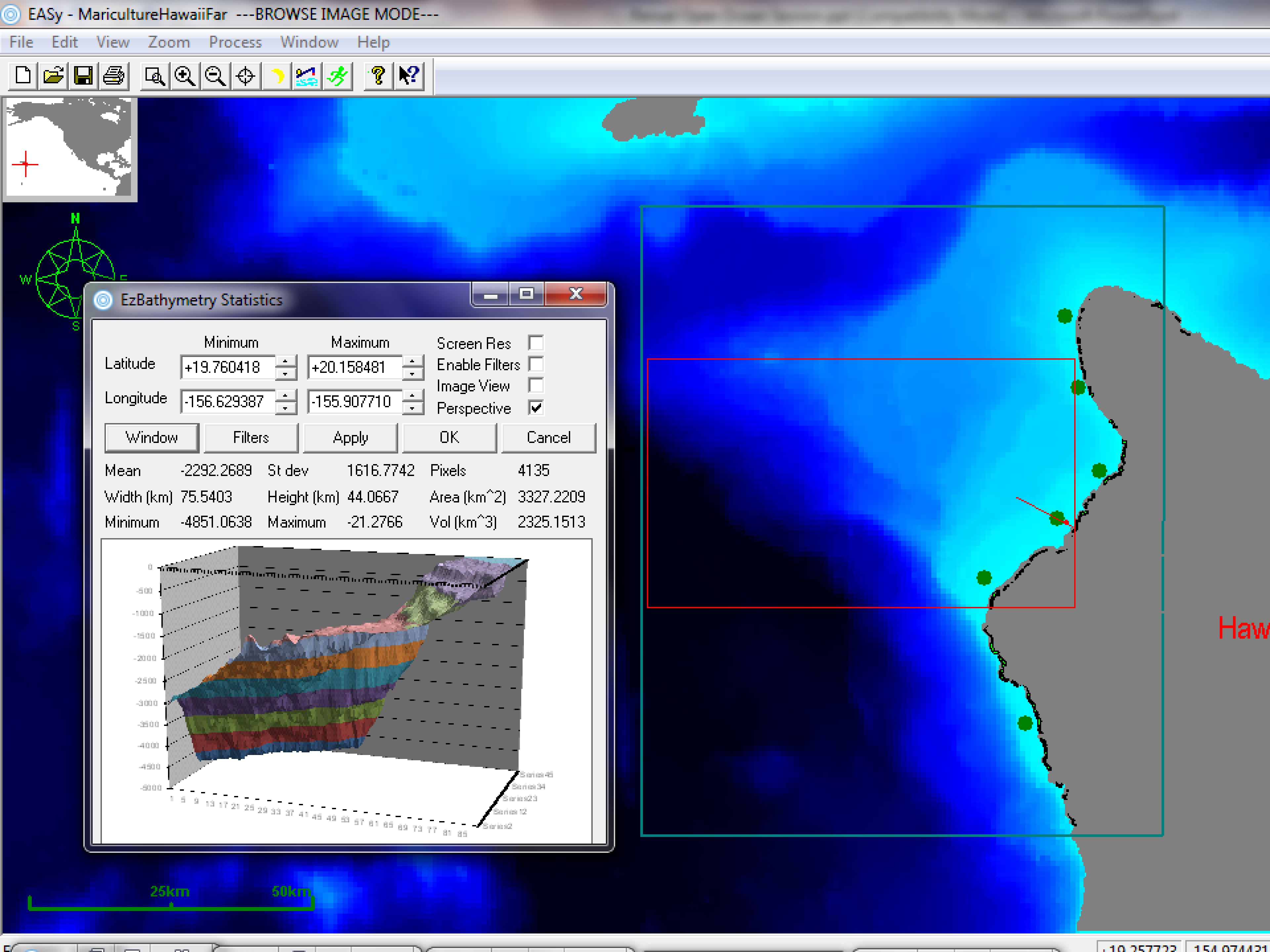
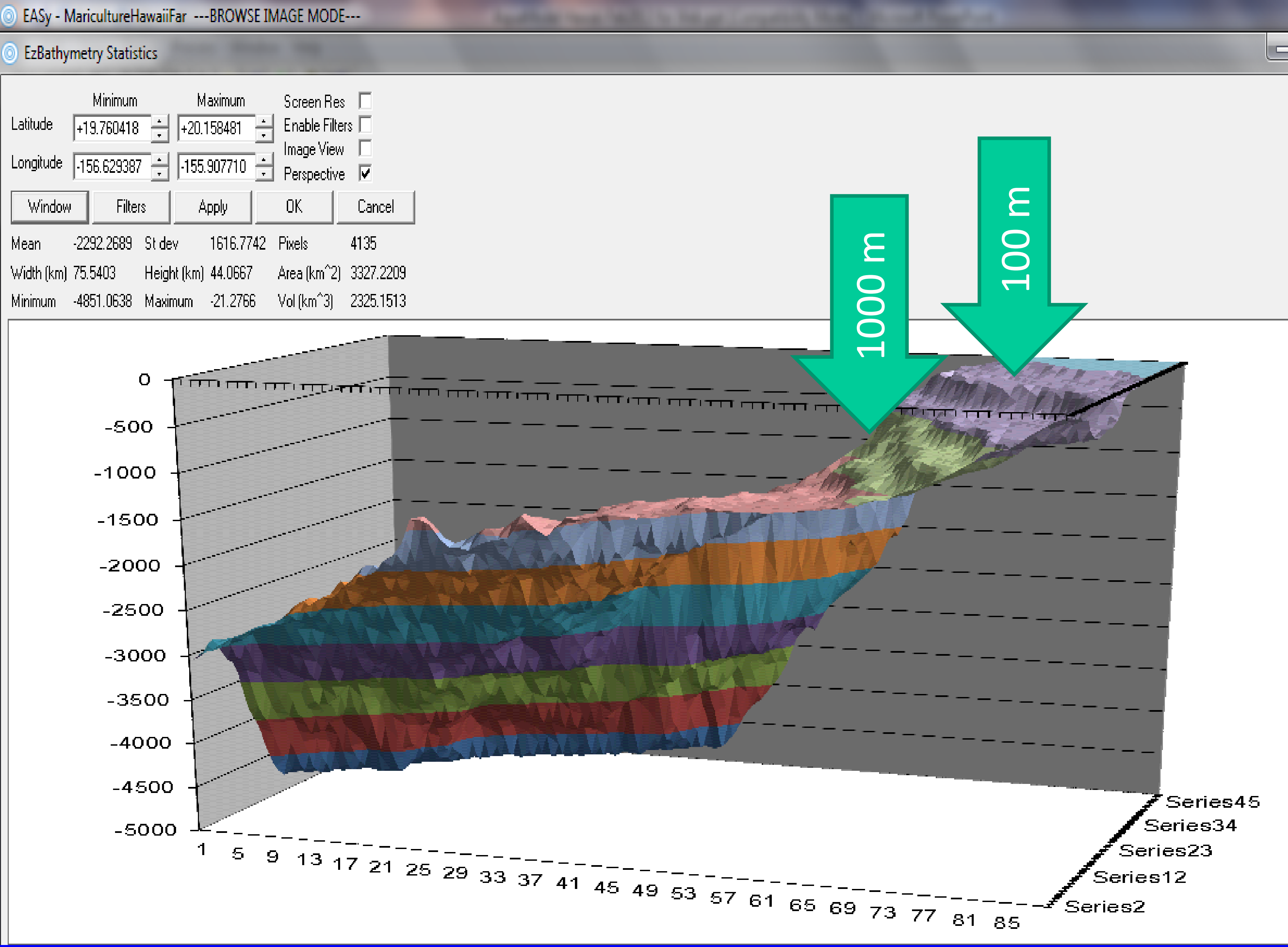
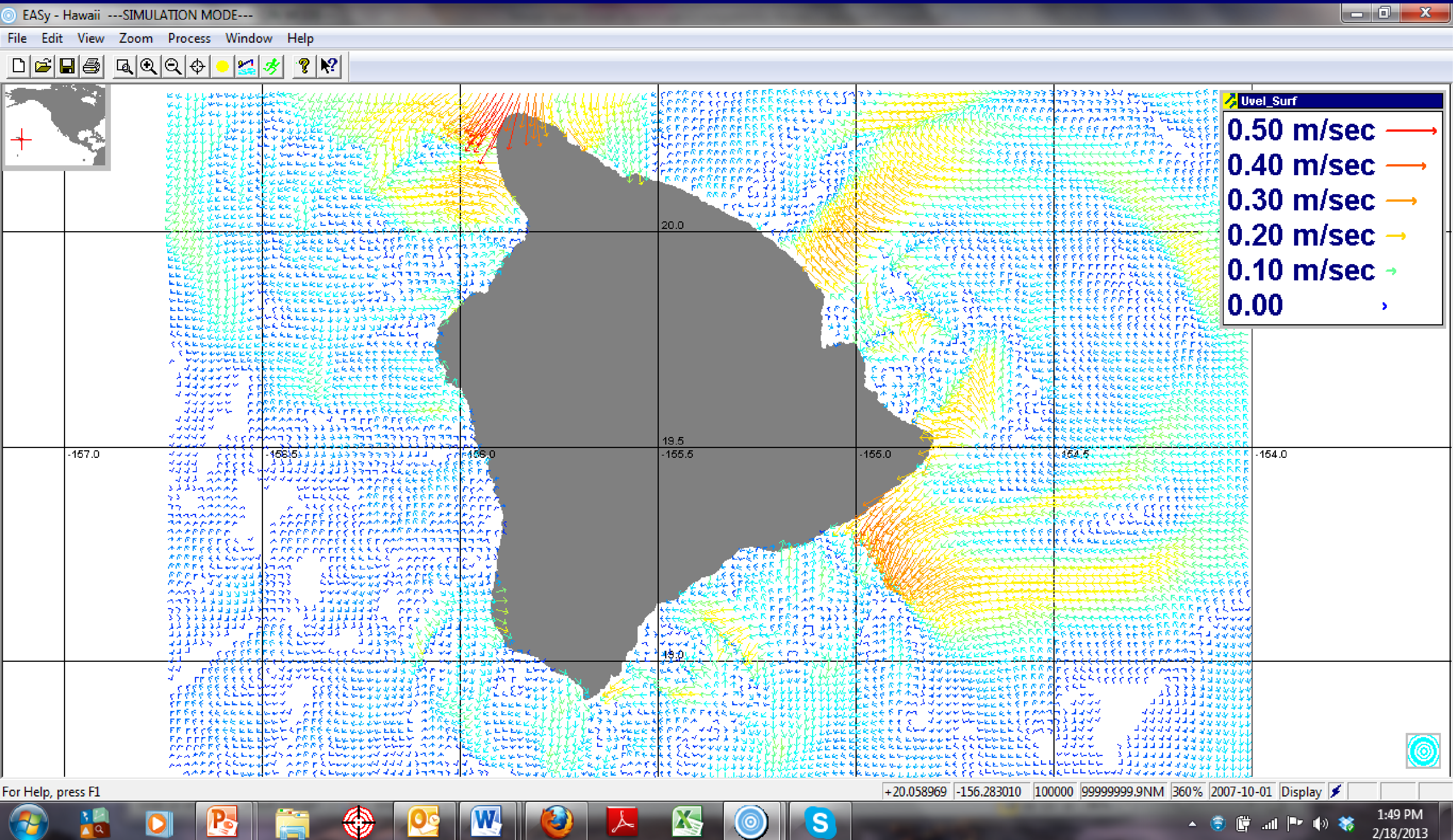
100km
200km
+21.184116
-154.665936
100000
99999999.9NM
360%


EASy - MaricultureHawaiiFar ---BROWSE IMAGE MODE---
File Edit View Zoom Process Window Help
EzBathymetry
0 meters
-1000
-2000
-3000
-4000
-5000
Surface Currents
50 cm/sec
40 cm/sec
30 cm/sec
20 cm/sec
10 cm/sec
0
Hawai'i
25km
50km
+19.787831 -156.442286 100000 99999999.9NM 360% 12:21:24 Display NUM
12:21 PM
2/19/2013


EASy - MaricultureHawaiiFar ---BROWSE IMAGE MODE---
File
Edit
View
Zoom
Process
Window
Help
N
W
E
S
EzBathymetry Statistics
Minimum
Maximum
Latitude
+19.760418
+20.158481
Longitude
-156.629387
-155.907710
Screen Res
Enable Filters
Image View
Perspective
Window
Filters
Apply
OK
Cancel
Mean
-2292.2689
St dev
1616.7742
Pixels
4135
Width (km)
75.5403
Height (km)
44.0667
Area (km^2)
3327.2209
Minimum
-4851.0638
Maximum
-21.2766
Vol (km^3)
2325.1513
25km
50km
Haw

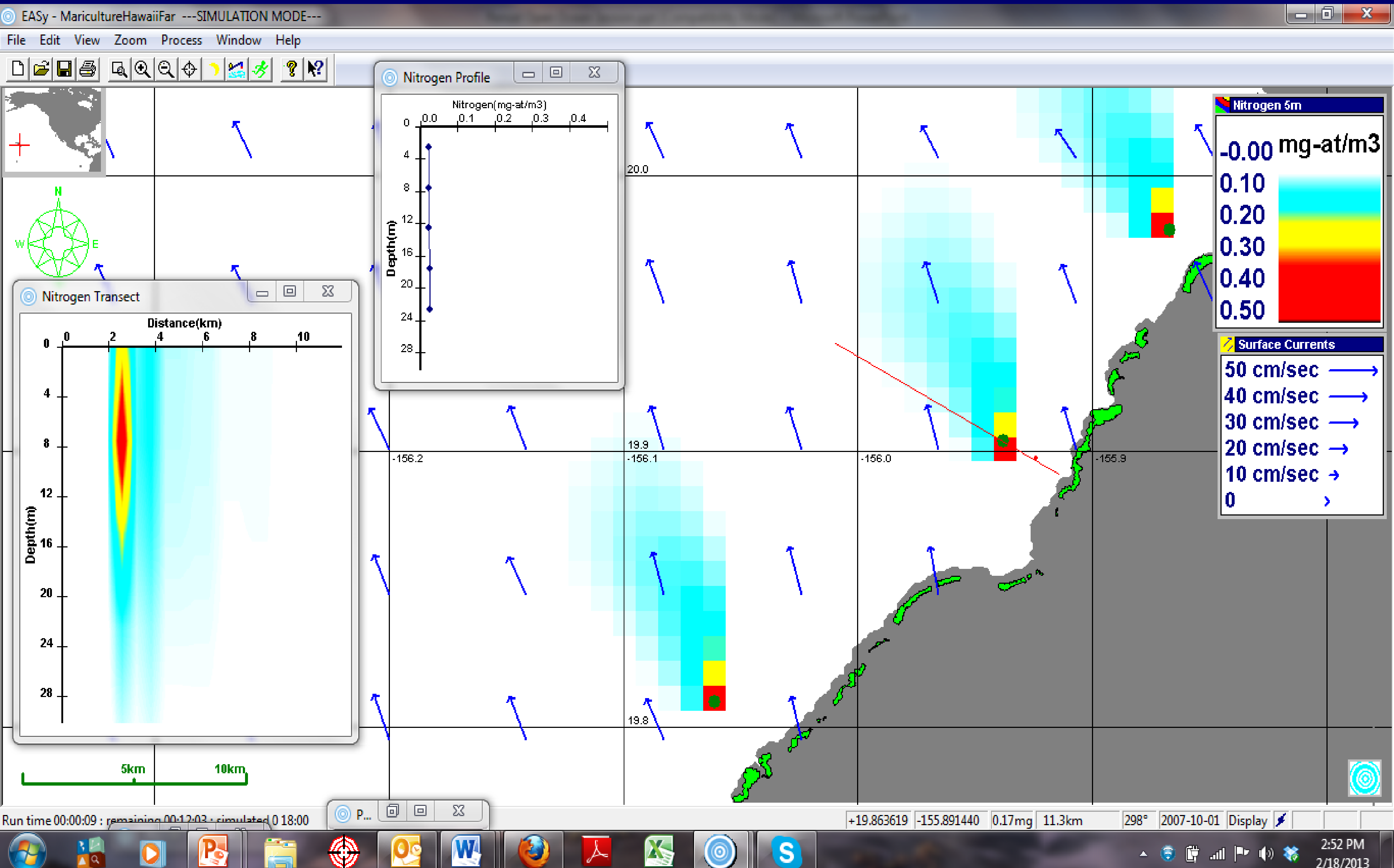

EASy - MaricultureHawaiiFar ---BROWSE IMAGE MODE---
EzBathymetry Statistics
Minimum
Maximum
Screen Res
Latitude
+19.760418
+20.158481
Enable Filters
Image View
Longitude
-156.629387
-155.907710
Perspective
Window
Filters
Apply
OK
Cancel
Mean -2292.2689
St dev 1616.7742
Pixels 4135
Width (km) 75.5403
Height (km) 44.0667
Area (km^2) 3327.2209
Minimum -4851.0638
Maximum -21.2766
Vol (km^3) 2325.1513
1000 m
100 m
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85
Series45
Series34
Series23
Series12
Series2

ROMS Model Circulation

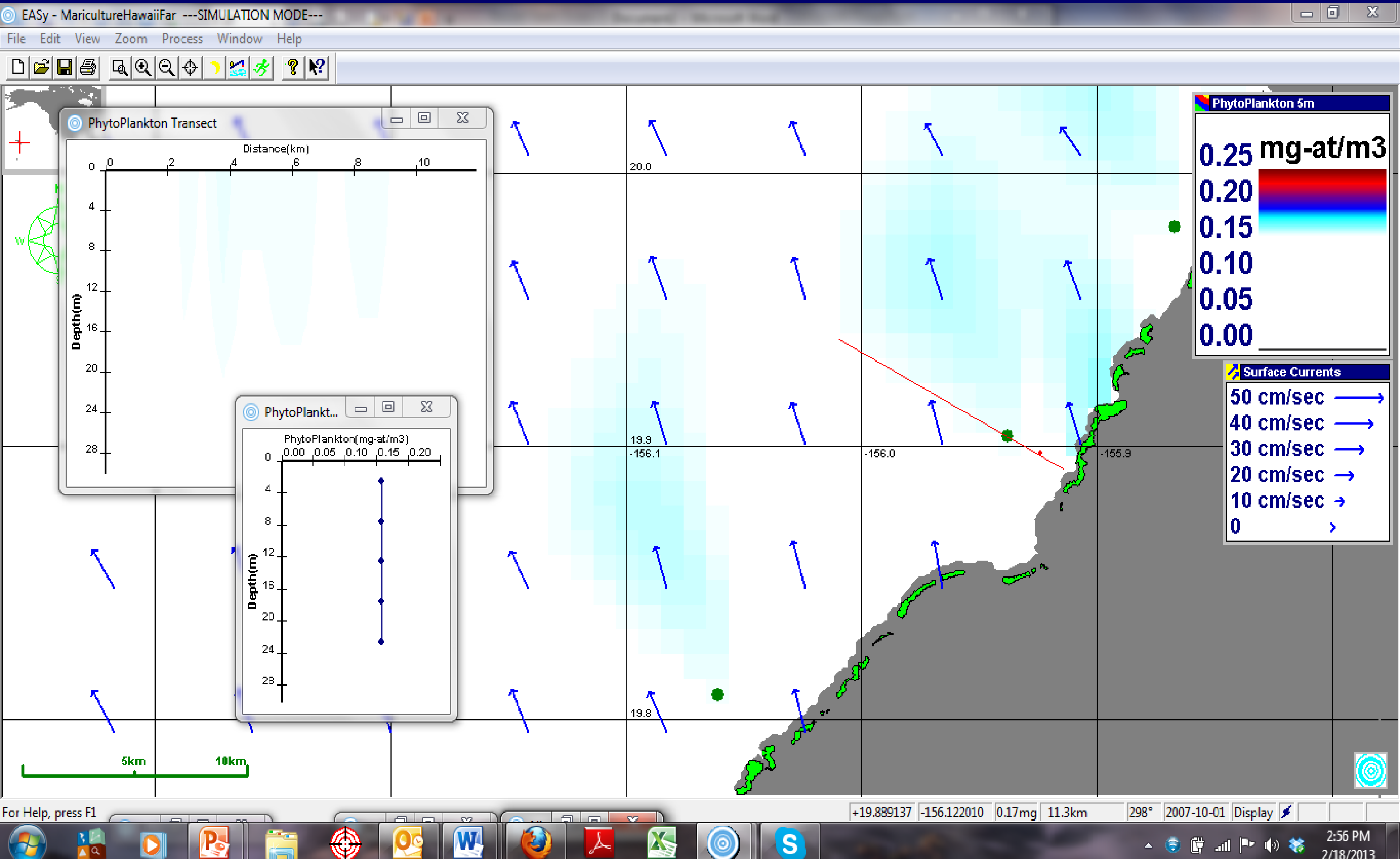


Ocean Circulation Data: PACIOOS

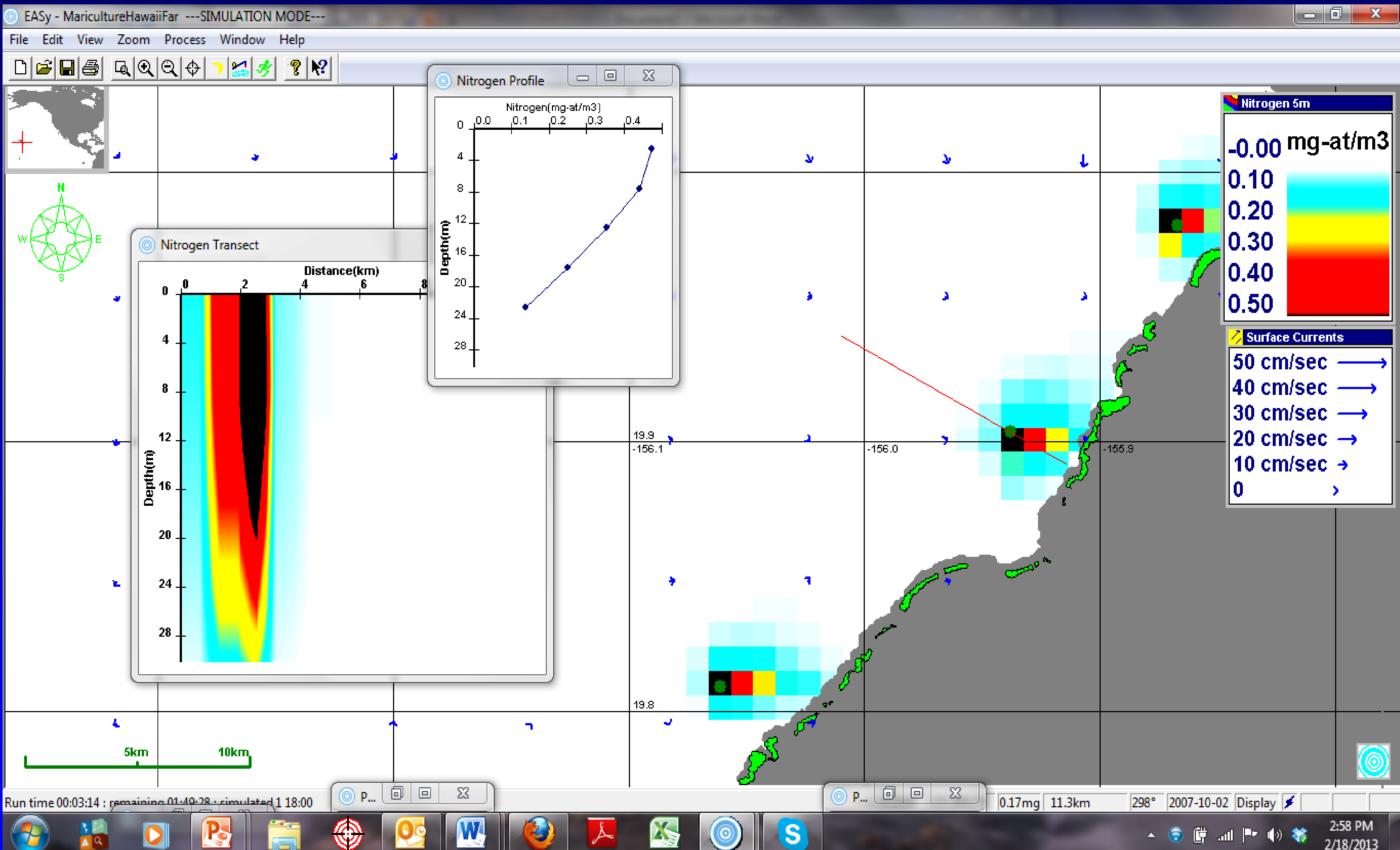
Offshore Flow: Nitrogen (DIN+). AquaModel Snapshot



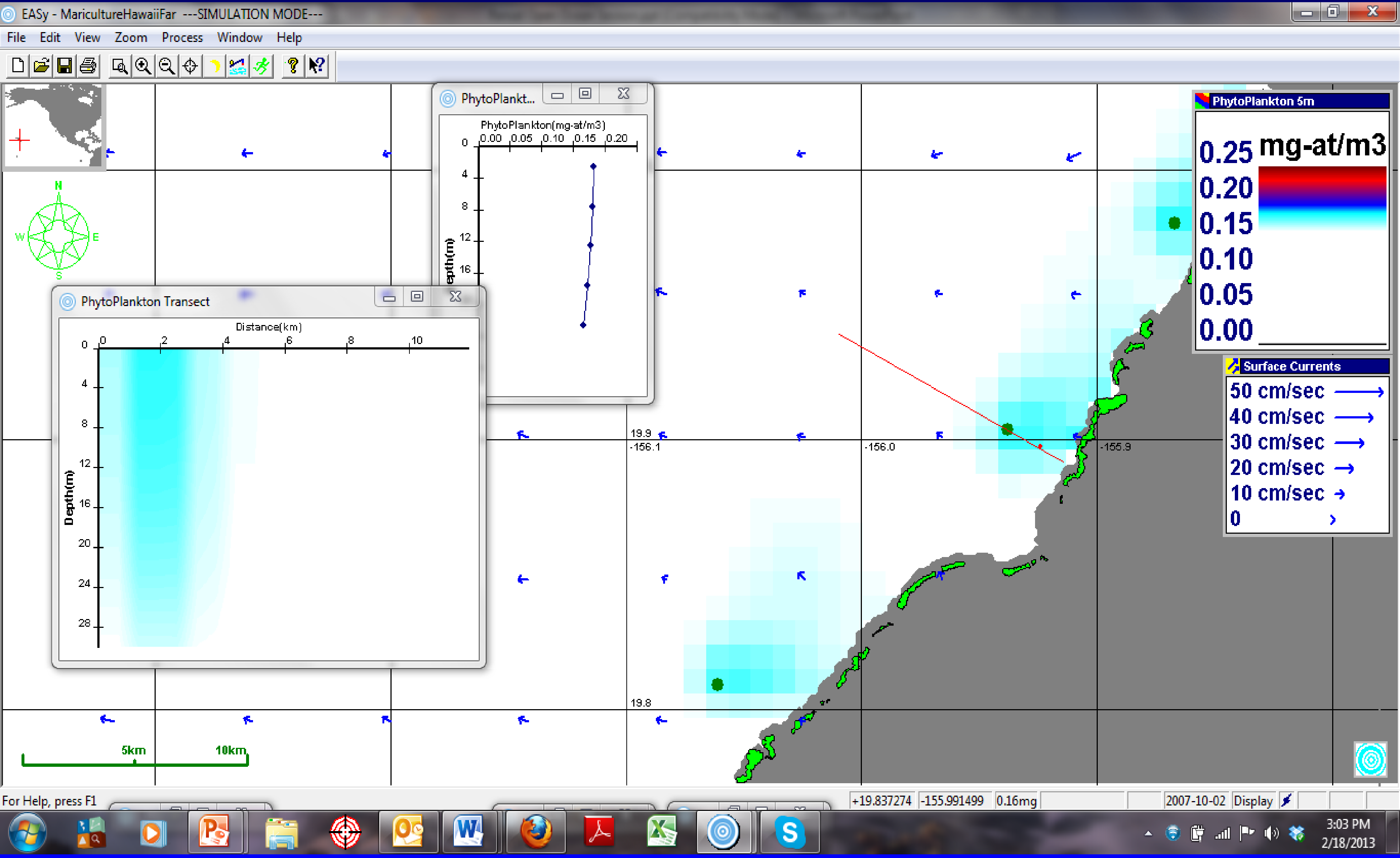
Offshore Flow: Phytoplankton (chl *a*)



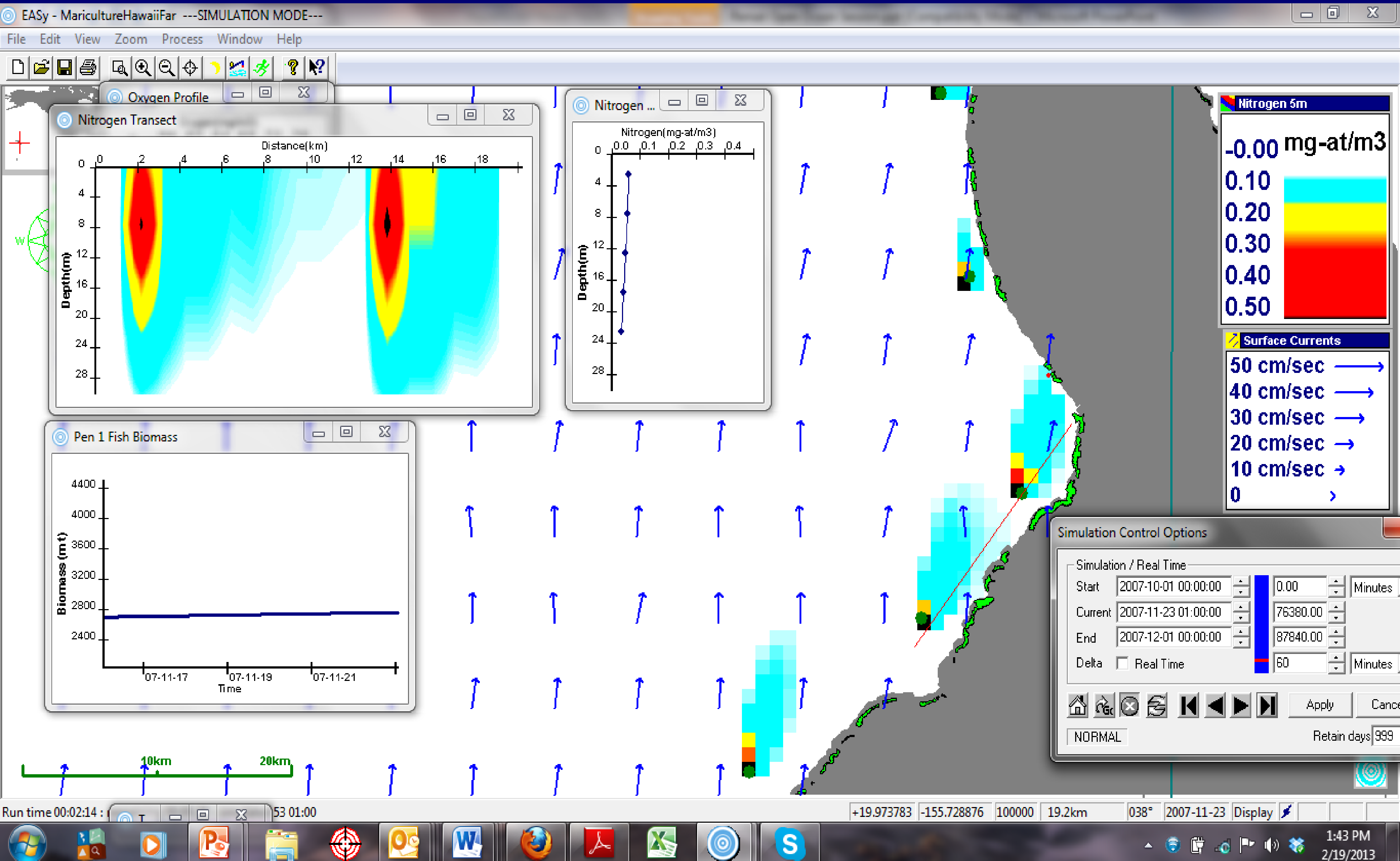
Onshore/weak Flow: Nitrogen (DIN+)

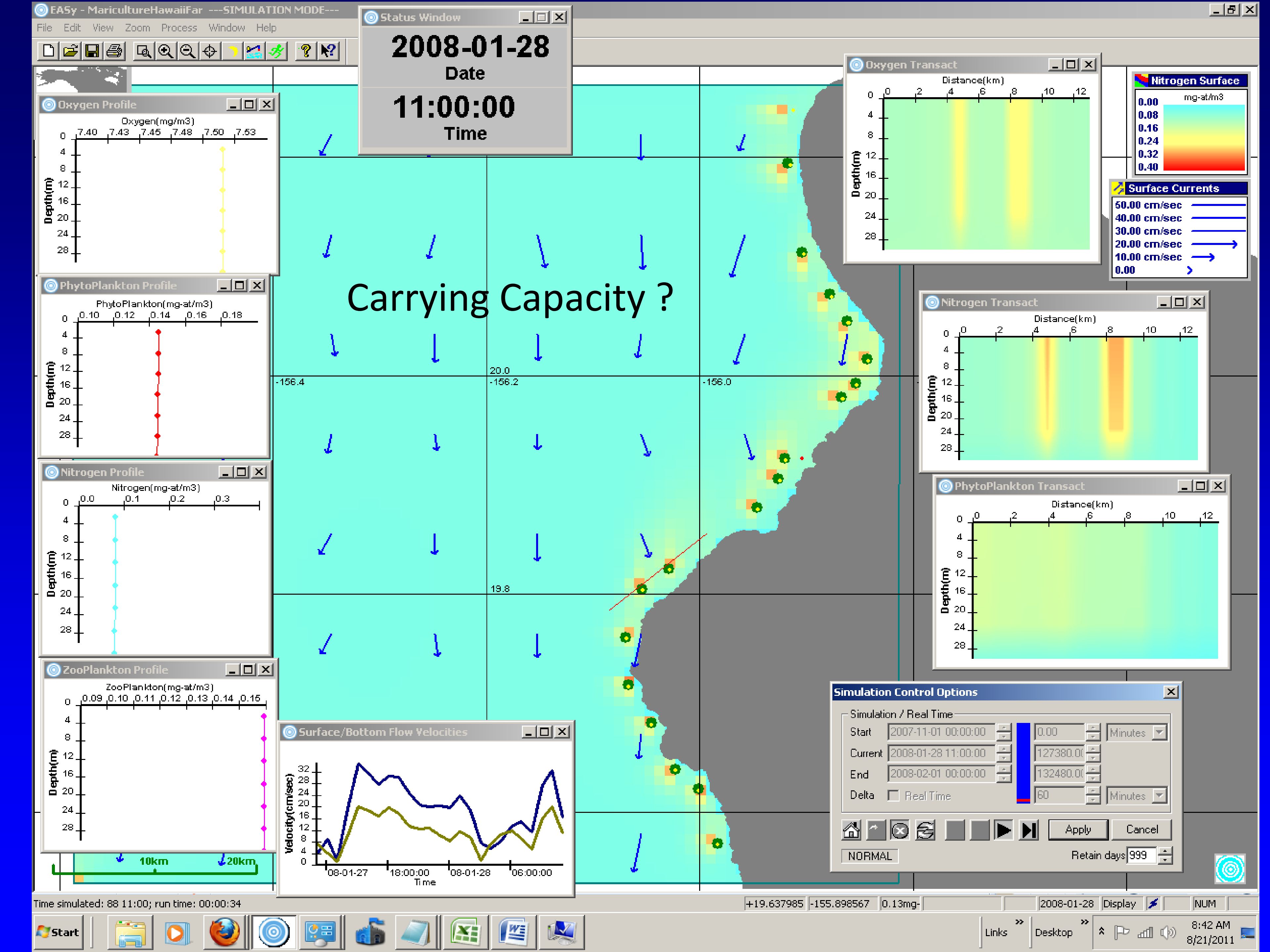


Onshore/weak Flow: Phytoplankton (chl *a*)



Farms Interacting or influencing littoral corals ? Or Not !





EASy - MaricultureHawaiiFar ---SIMULATION MODE---
File Edit View Zoom Process Window Help
Status Window
2008-01-28
Date
11:00:00
Time
Carrying Capacity ?
Oxygen Profile
Oxygen(mg/m3)
7.40 7.43 7.45 7.48 7.50 7.53
Depth(m)
PhytoPlankton Profile
PhytoPlankton(mg-at/m3)
0.10 0.12 0.14 0.16 0.18
Nitrogen Profile
Nitrogen(mg-at/m3)
0.0 0.1 0.2 0.3
ZooPlankton Profile
ZooPlankton(mg-at/m3)
0.09 0.10 0.11 0.12 0.13 0.14 0.15
Surface/Bottom Flow Velocities
Velocity(cm/sec)
08-01-27 18:00:00 08-01-28 06:00:00
Time
10km 20km
-156.4 -156.2 -156.0
20.0
19.8
Oxygen Transact
Distance(km)
Nitrogen Surface
mg-at/m3
0.00 0.08 0.16 0.24 0.32 0.40
Surface Currents
50.00 cm/sec
40.00 cm/sec
30.00 cm/sec
20.00 cm/sec
10.00 cm/sec
0.00
Nitrogen Transact
PhytoPlankton Transact
Simulation Control Options
Simulation / Real Time
Start 2007-11-01 00:00:00 0.00 Minutes
Current 2008-01-28 11:00:00 127380.00
End 2008-02-01 00:00:00 132480.00
Delta Real Time 60 Minutes
Apply Cancel
NORMAL
Retain days 999
Time simulated: 88 11:00; run time: 00:00:34
+19.637985 -155.898567 0.13mg- 2008-01-28 Display NUM
Start Links Desktop 8:42 AM 8/21/2011

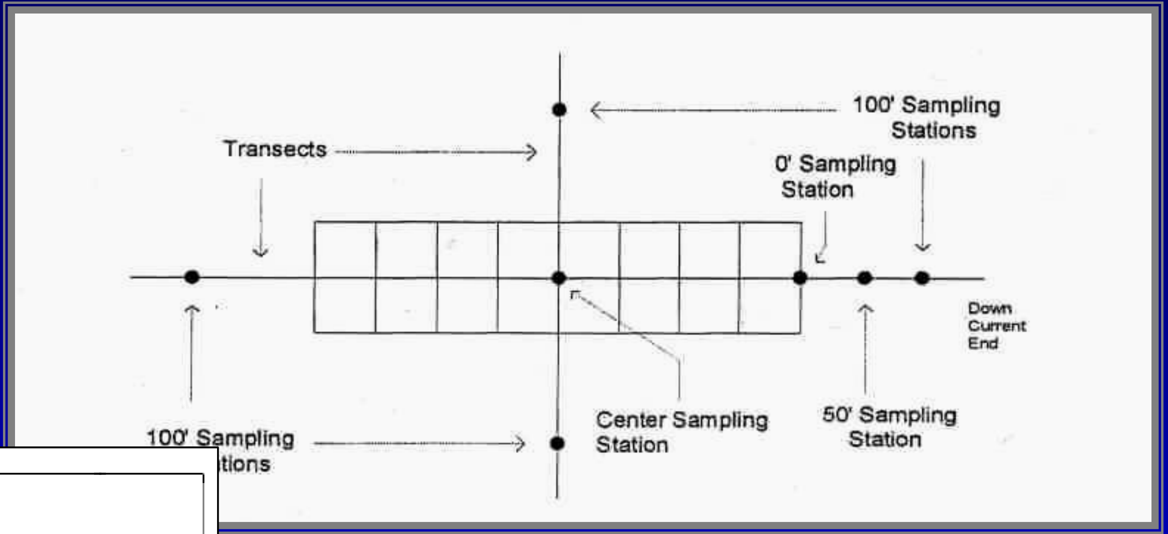
Validation of AquaModel

- WA state database, every farm, benthic/water column data collection annually for 10 years (1986-1995), variety of seabottom conditions
- Organic carbon indexed to grain size performance standards
- Now 75% of farms over sandy or coarser, but smooth seafloor
- No effects allowed beyond 30m because….. It was possible.
- Small farms (1980s) easier to model w/single current meter
- Now larger farms, need for multiple current meter input or use the PS regional model or a melding of the two.
- AquaModel validates nicely with smaller farms at 30m performance standard distance
- Not formally assessed with todays larger farms, circulation data inputs more demanding due to increased spatial range & variable flow

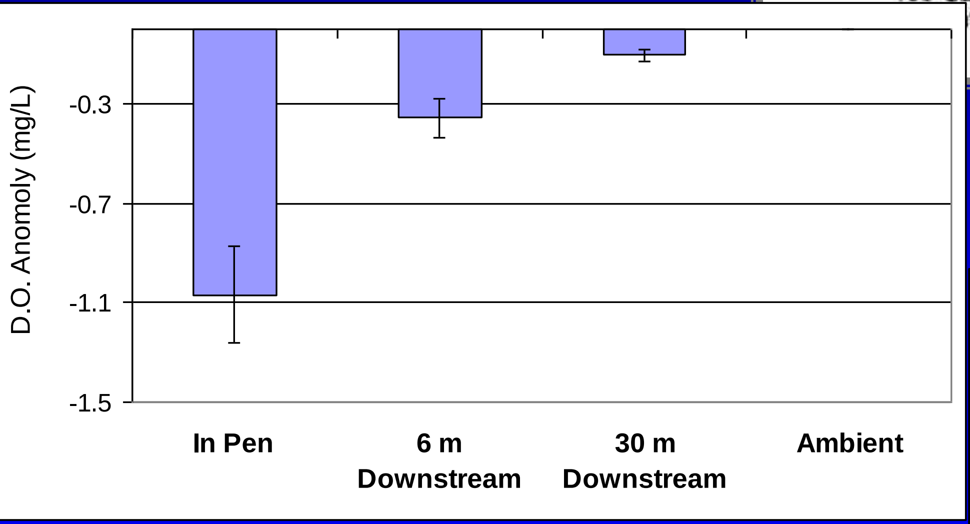
Software Validation Defined:
"checking that a software system meets specifications and fulfills its intended purpose"

- Validation possible by piecemeal or in total depending on parameter modeled
- Water column: patchiness great from turbulence, advection, diffusion effects
- Benthic validation: Surrogate measures (e.g., sulfides) greatly improved but useful only in fine sediment/slow transport areas and temporally variable.
- AquaModel physiology submodel validation best done by controlled experimental data from laboratory to compliment field data
- "Holistic" validation of benthic model remains a worthy goal, but we must not ignore the use of quality literature-based measurements & various internal model mass balance and conservation of mass checks.

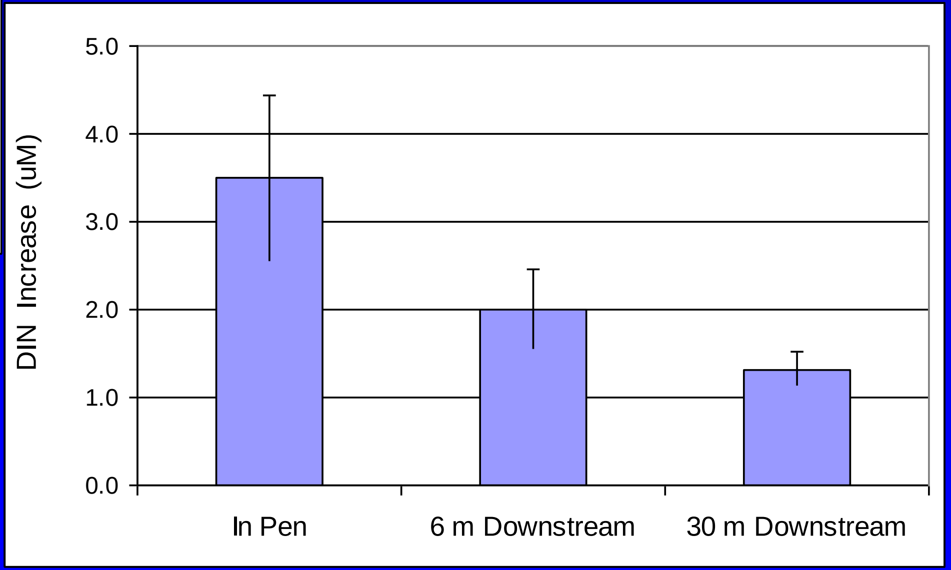
Dissolved Oxygen and Nitrogen in Water Column Validation



DO effect at 30 m Downstream



Dissolved Nitrogen (DIN) effect



12 Fish Farms Database
Effect varies with biomass, configuration, time post feeding, etc.

Validation Projects & Ecoregions

Benthic

- Salish Sea: Puget Sound (steady state TOC)
- Salish Sea: British Columbia (sulfides)
- Tropical venue: Pending (TOC)

Water Column

- Salish Sea: Puget Sound (near field)
- Gulf of Maine: Isle of Shoals (far field NPZ)

Vast majority of fish farm effects studies do not have suitable or complete data for model validation!

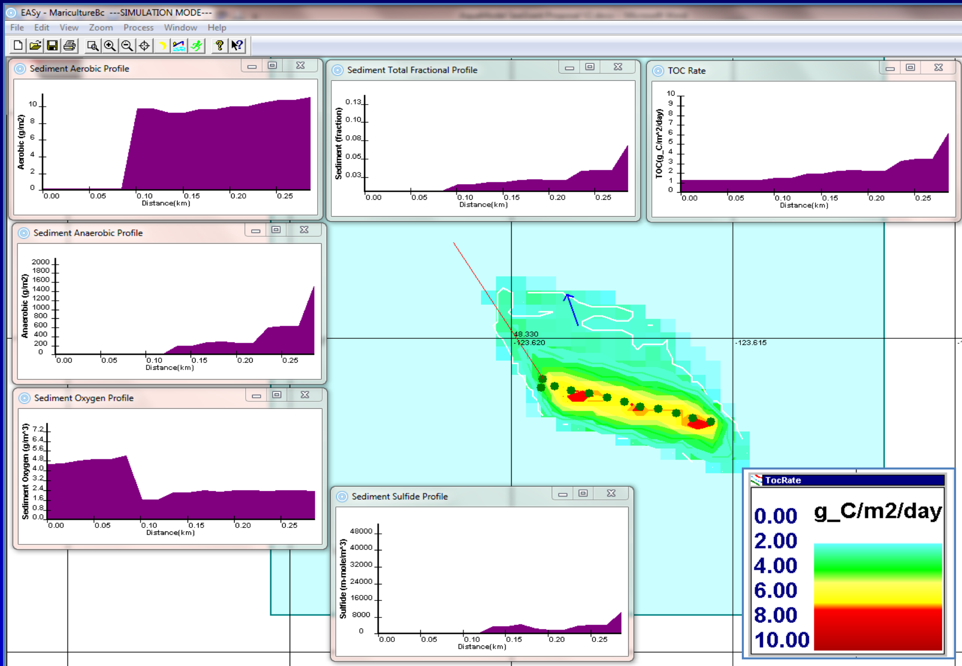
Usually missing adequate current data, almost always missing TOC.

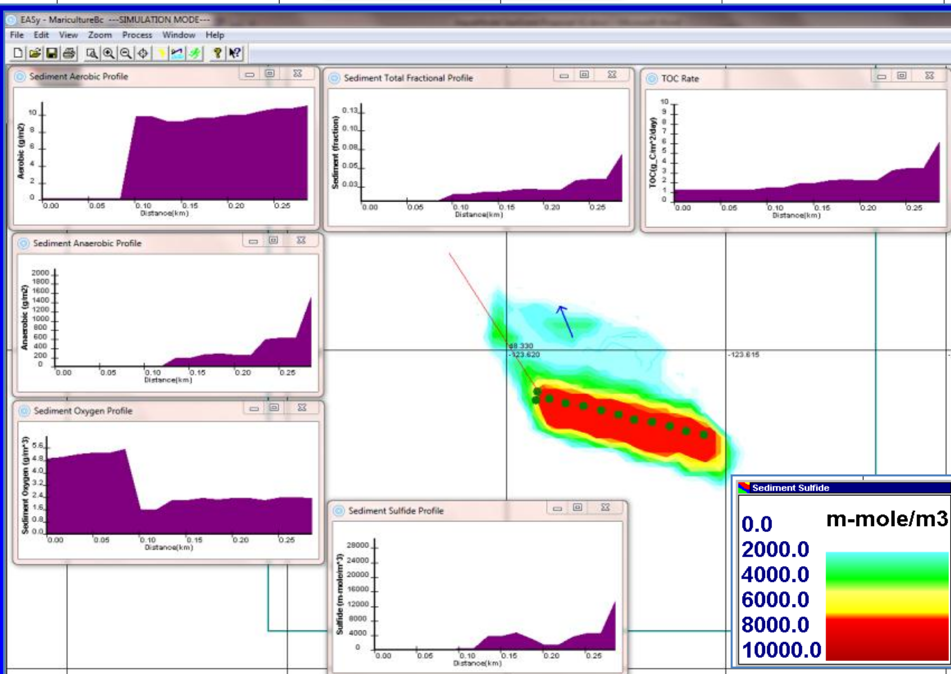
TVS & redox are poor surrogates for TOC or sediment oxygen

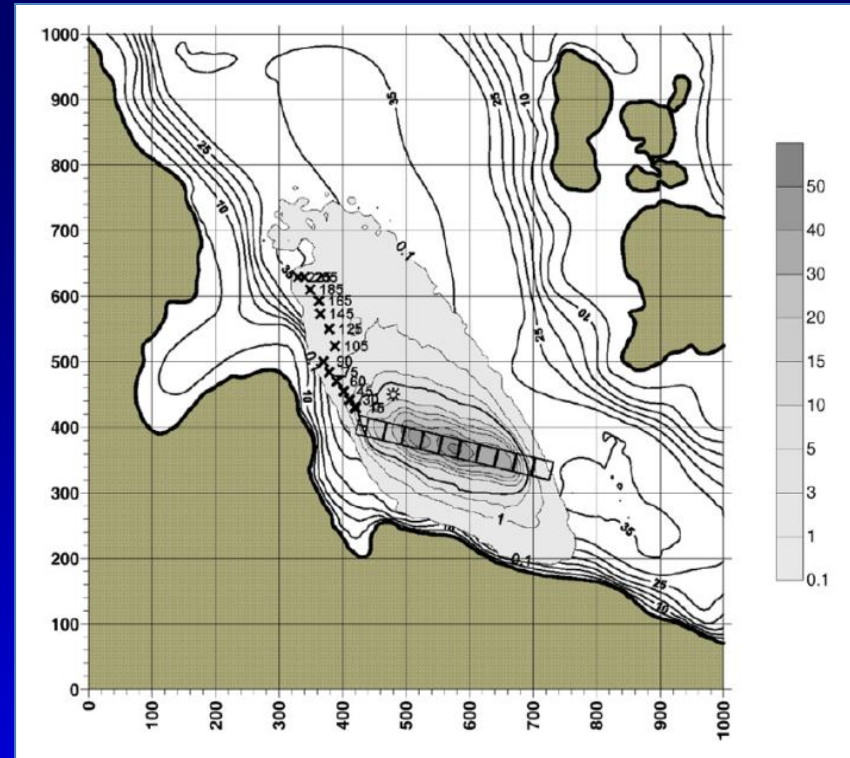
British Columbia Validation Site

- Chamberlain & Stucchi 2007: Sediment sulfides & TOC
  Necessitated new AquaModel farm grow out utility:
  - variable feed rate vs. optimum for growth model
  - transfer fish among cages
  - variable mortality and harvest rates and timing

- Initial results without above:
  - Approx. simulation of measured sulfide concentrations, work in progress.
  - Modeled sulfide concentration have high temporal variability, concurs with recent Canadian field work (Page et al. unpublished)
  - TOC flux rate to sediments very different than DEPOMOD, possibly a different definition or moving average method
  - Sediment consolidation rate sensitivity analysis findings: not a dominant factor in moderately active sites







DEPOMOD Estimated TOC rate

Estimated sulfides for comparison with measured values

Key Input parameters: near field version

- **Size and shape of farm** and cages, as many cages as needed
- **Initial density, size and species of fish** by cage and/or farm site
- **Specify bathymetry** file location or select constant depth
- **Current data** (single meter or regional model or simulated tidal forcing)
- **Initial, seasonal or more frequent water quality** input
- **Feed rate or specify optimum rate**
- **Feed waste rate and settling rate and initial resuspension rate**
- **Separate fecal settling rate and initial resuspension rate**
- **Ambient total organic carbon concentration** or estimate from TVS/GS

✓ Vary **POM consolidation rate** as key variable less well-described

✓ Other variables relatively constant on an ecoregion or sub-ecoregion basis

✓ Flexible from seasonal to every minute input via spreadsheet data

Key Input parameters far field version

Same as near field, may neglect benthic settings if focus on NPZ, plus:

- Set mixed layer depth seasonally (or use ambient file for same)

- Other variables to be set by AquaModel team and collaborators on ecoregion basis such as irradiance, min/max/ambient nitrogen, phytoplankton & zooplankton ranges, initial conditions.

Key Outputs (of total N = 43)

as vertical profiles, transects plots or raw data for all time steps, minutes to months)

Farm:

- fish weight, biomass and instantaneous growth rate, operations assessment
- pen and ambient dissolved oxygen deficit plume tracking
- dissolved inorganic nitrogen plume tracking
- optimal feed rate

Sediments:

- total organic carbon (in water column, suspended and surficial sediment layers)
- anaerobic and aerobic biomass of surficial layer
- total sulfides surficial layer
- interstitial dissolved oxygen and CO_2
- Fecal, feed, or total C waste distribution (rate and concentrations)

Plankton:

- oxygen and nitrogen
- phytoplankton biomass as chlorophyll *a*
- zooplankton biomass (as μM N)

Expectations for refinement or expansion of AquaModel

Additional model tuning and validation focus on TOC & sulfides

- *Fish farm information system:* real time polling inputs of feed use, flow rates, dissolved oxygen, water temperature, satellite imagery.
- Fish escape modeling (Mobrand/Mahnken model)
- Fish disease modeling, e.g., spatial dispersion/die-off of virus
- IMTA (fish/shellfish/algae)
- Regional calibration & validation efforts

Funding

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USDA SBIR Program
NOAA Marine Aquaculture Initiative Program
Pacific Aquaculture Inc.
Icicle Seafoods Inc.

Collaborators

Pacific Islands Ocean Observation System
David Fredriksson, U.S. Naval Academy
Jim Irish, Woods Hole Oceanographic Institution
NOAA NWFSC Staff Seattle & Mike Rust
NOAA National Ocean Service Beaufort N.C.
Hubbs Seaworld Research Institute, San Diego
American Gold Seafoods / Icicle Seafoods Seattle
David Fraser, Ocean Harvest Inc. Puerto Rico
Don Anderson, Woods Hole Oceanographic Institution
University of Washington, School of Oceanography
United Arab Emirates, Ministry of Environment & Water

UNITED ARAB EMIRATES
MINISTRY OF ENVIRONMENT & WATER

National Ocean Service

Google: *AquaModel* or go to WWW.AquaModel.org

- Extra slides follow

Types of Models used in Aquaculture

One-box

- Spreadsheet models or simple physics models, e.g., "tidal prism" flushing model
- Simplistic, easy for public to understand, sometimes accurate, often not, many assumptions

Multi-box: 2 and 3 Dimensional (Coupled)

- Multiple cells in the grid, side by side (2D) or stacked vertically (3D)
- Requires input from circulation model as inter-box exchange

Benthic, near-field (e.g., AquaModel Near Field, DEPOMOD, MUSMOD, ShellSim)

- Biophysical focus on sea or river bottom effect only
- Localized and near to farm

Geographic Information System (GIS) linked to Aquaculture Model : AquaModel Far FIeld

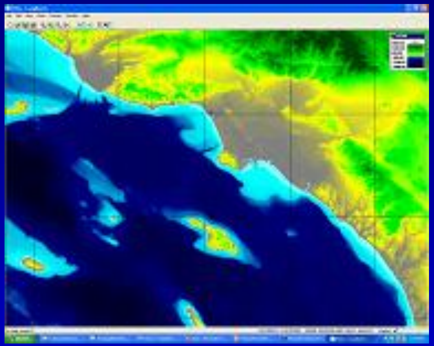
- far-field benthic and water column model with companion GIS system
- Three examples including EASy GIS and AquaModel "plug in" combination

Mainframe 3D fully coupled (circulation only) models

- Princeton Ocean Model, Finite Volume Coastal Ocean Model, several other
- Suited for future EbM models but expensive, difficult for coastal managers to initiate and use

Complexity & Power .

Mariculture Zone & Site Selection

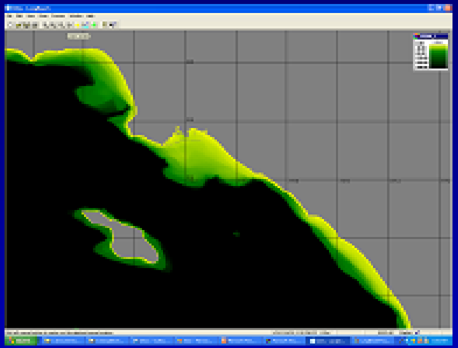


maps & imagery

Zone Selection Criteria

Currents
Bathymetry
Temperature
Restrictions
Distance
Circulation

EASy* GIS & Far Field *AquaModel



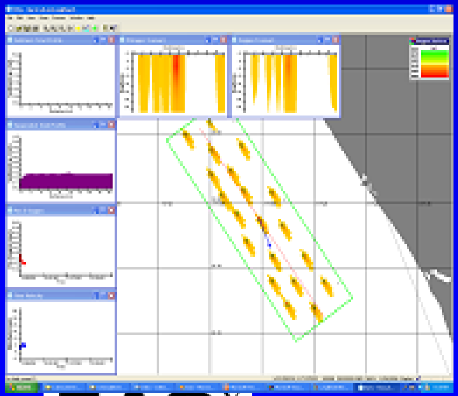
selected zones

field surveys

Site Selection Criteria

Resolved Currents
Resolved Bathymetry
Oxygen
Sediment
Species
Farm Size
Infrastructure

***AquaModel* detailed Simulations Near Field Site Selection**



optimal sites