Application of a Three-Dimensional Hydrodynamic Model for San Quintin Bay, B.C. Mexico. Validation and Calibration using OpenDA.

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Outline

- **Calibration: an Optimization Problem**
  - **Calibration**
  - **Open DA**
    - **Dud Algorithm**
- **Hydrodynamics Model Delft3D**
- **Study Region: San Quintin Bay**
  - **Problem statement**
  - **Model Domain**
  - **Forcing Model**
    - **Tide Constituent**
  - **Numerical Results**
- **Conclusion**
- **Future Work**

Extension 42 km^2 ~ 26.0976 miles^2

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Motivation

Ocean prediction for science and operational applications has now been initiated on basin and regional scales.

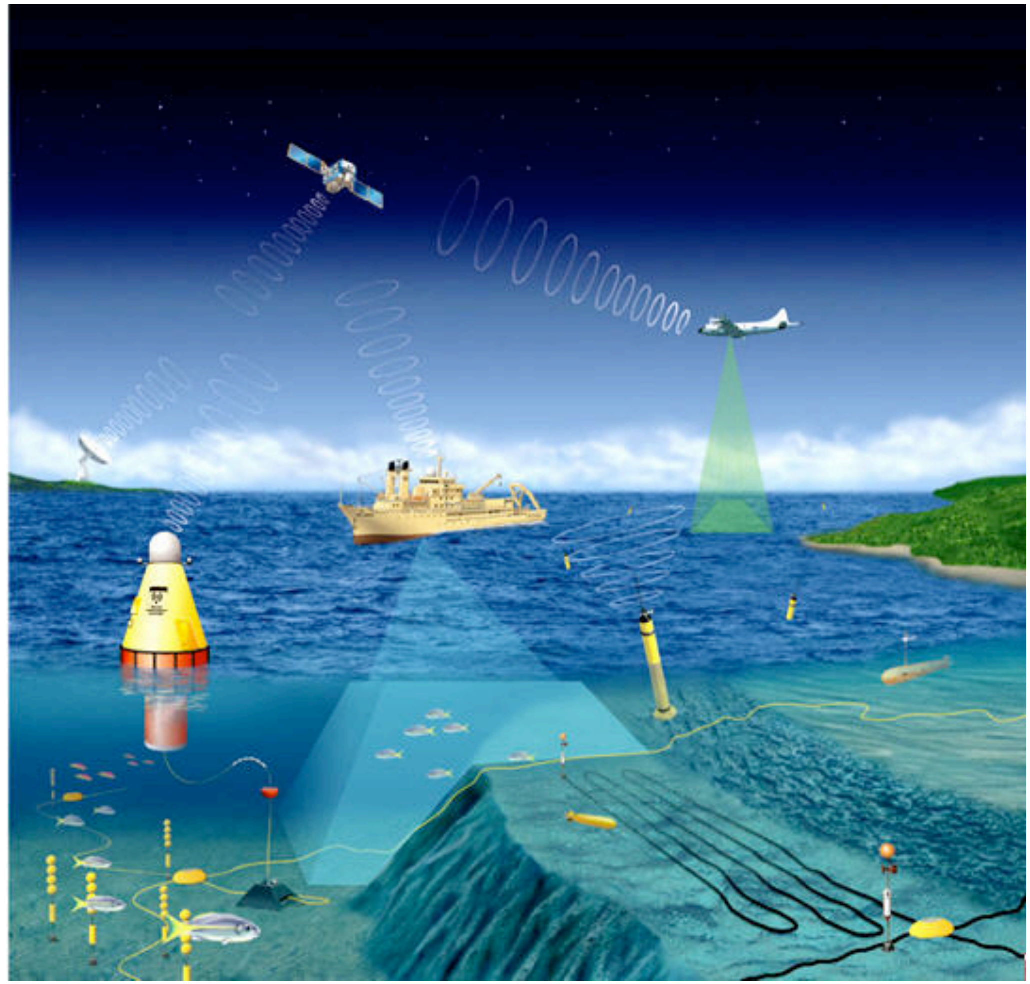

Image from: National Integrated Coastal and Ocean Observing

Uncertainty

Uncertainty quantification (UQ) is the process by which uncertainty is estimated in a system (numerical modeling and simulation).

$$\hat{X} - X^{true} = e \qquad \text{(unknown error)}$$

Uncertainty reduction (UR) which has the purpose of reducing the uncertainty in modeling and simulation.

In weather and ocean modeling UR is called

Data Assimilation.

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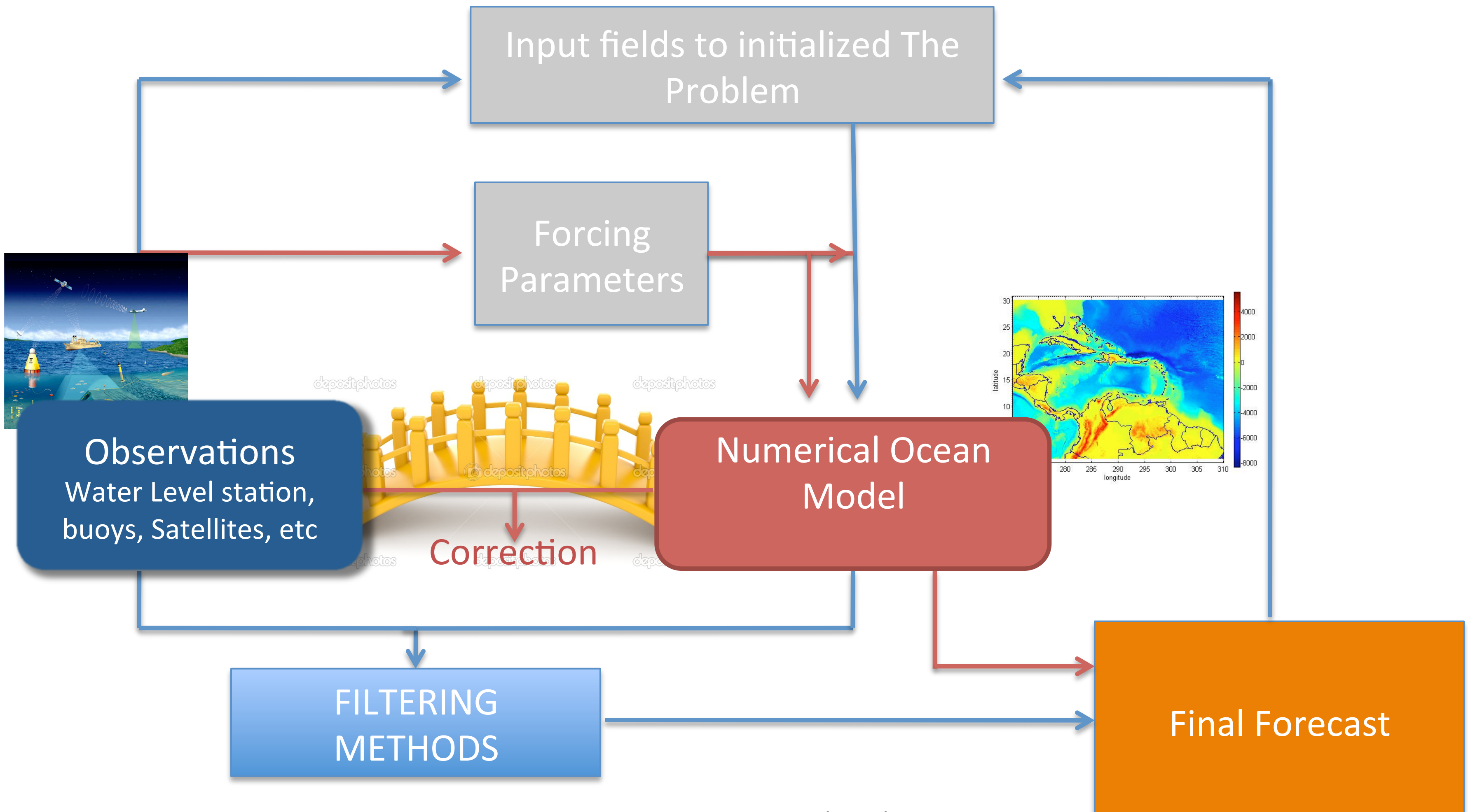
Physical Model Uncertainties

- *Bathymetry*
- Initial conditions
- BCs: surface atmospheric, coastal-estuary and open-boundary fluxes
- Parameterized processes
- Numerical errors: steep topographies/pressure gradient.

DA General Framework



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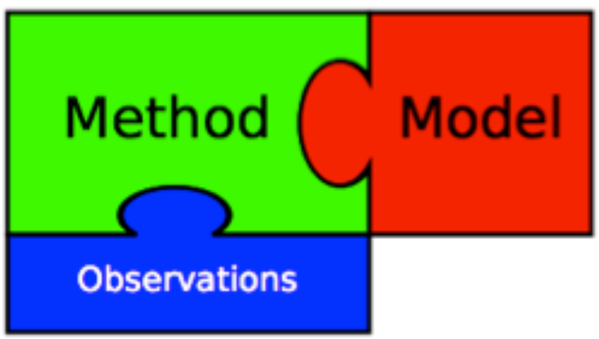
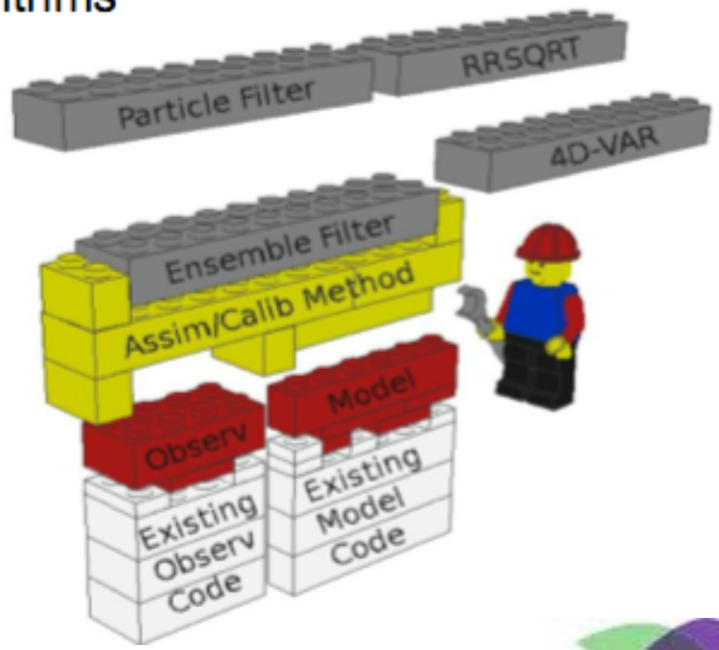
OpenDA

- Content:
  - Set of interfaces that define interactions between components
  - Library of data-assimilation algorithms
  - DA philosophy
  - Building blocks only need to be implemented once





OpenDA

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http://www.openda.org

OpenDA Tools

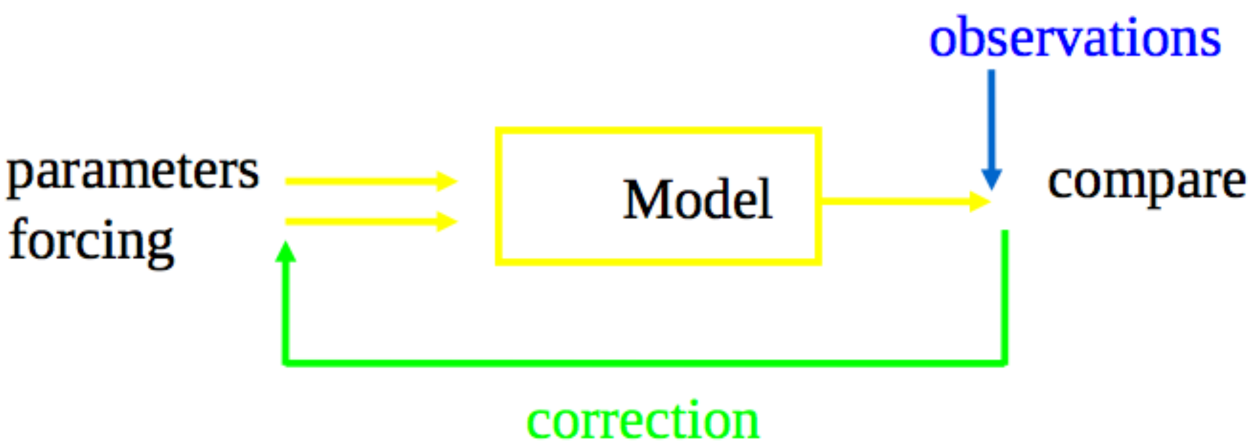
OpenDA is an open interface standard for (and free implementation of) a set of tools to quickly implement data-assimilation and calibration for arbitrary numerical models.

Calibration: The aim is to tune a set of parameters that is fixed in time. Ex: Depth, Amplitude, Phase, roughness

Data Assimilation: Aims to improve the starting position of the model for a forecast, so the estimates are different each cycle.

Calibration

- **Many models contain uncertain parameters, often related to friction, boundary conditions.**
- **Model output can be validated against observations.**



Question: How can we optimize in the sense of get a very good set of parameter?

Optimization of a Cost Function

- Calibration is defined as an optimization problem.
- Elaborate background in statistics: log-likelihood function.
- Measure distance or misfit of model to observations
- Depends on uncertainty of observations.

$$J_p = \sum_t \frac{(y_o(t) - y_m(t))^2}{\sigma_o^2}$$

Calibration tools only try to minimize the cost function.

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DUD algorithm

DUD **(Doesn't Use Derivative)**[(1)]

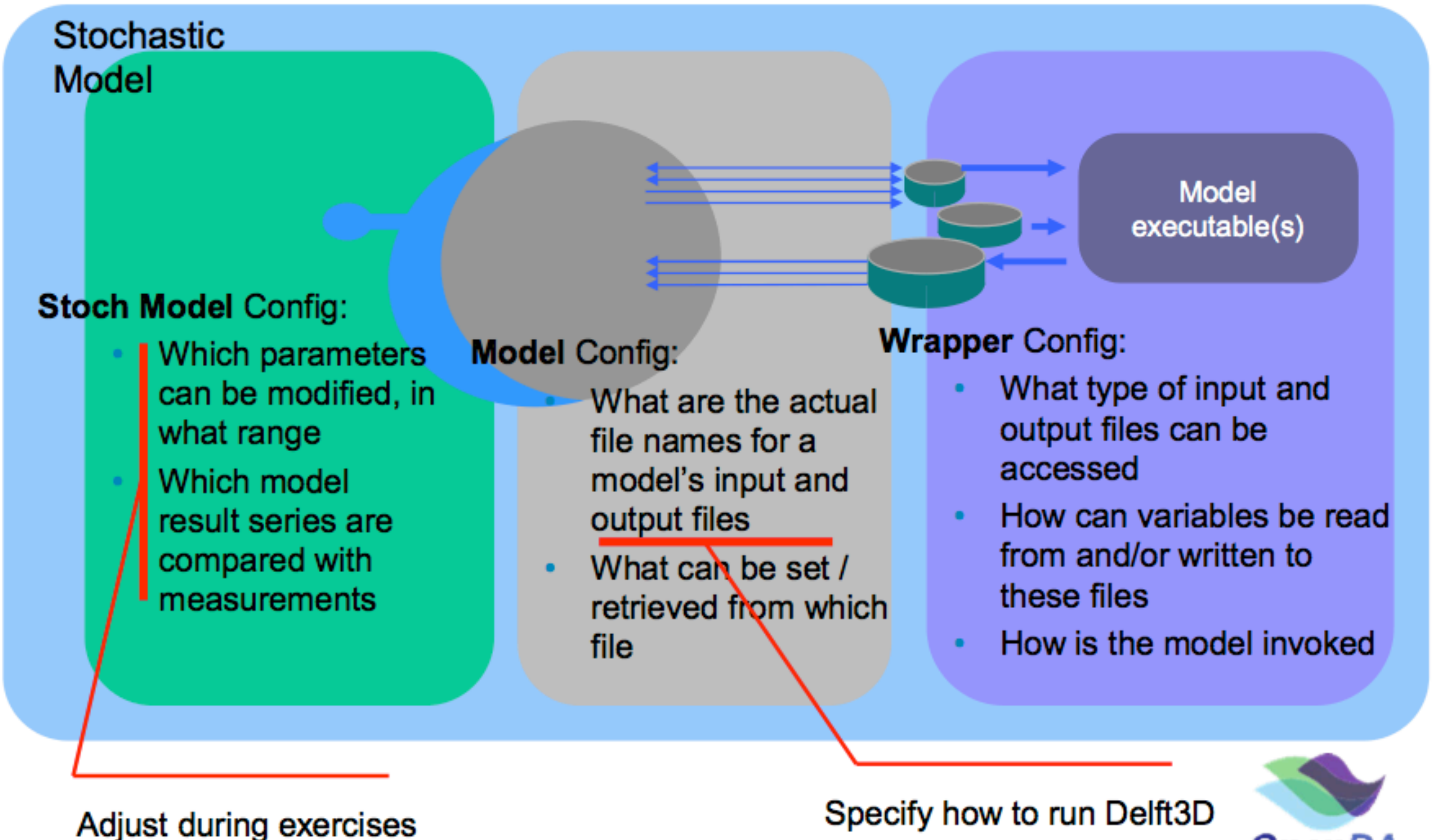
Non-linear Square Method

*Start with running first guess & modified run for each parameter

- Linearize the model around these values.
- Solve linear problem (LS)
- If this is an improvement
  - --> update linearization with new point
- Else do
  - --> a line-search (only until there is improvement)

(1) Ralston, Mary L. and Jennrich, Robert I (1978). Dud, A Derivative-Free Algorithm for Nonlinear Least Squares. American Society for Quality

Open DA Components



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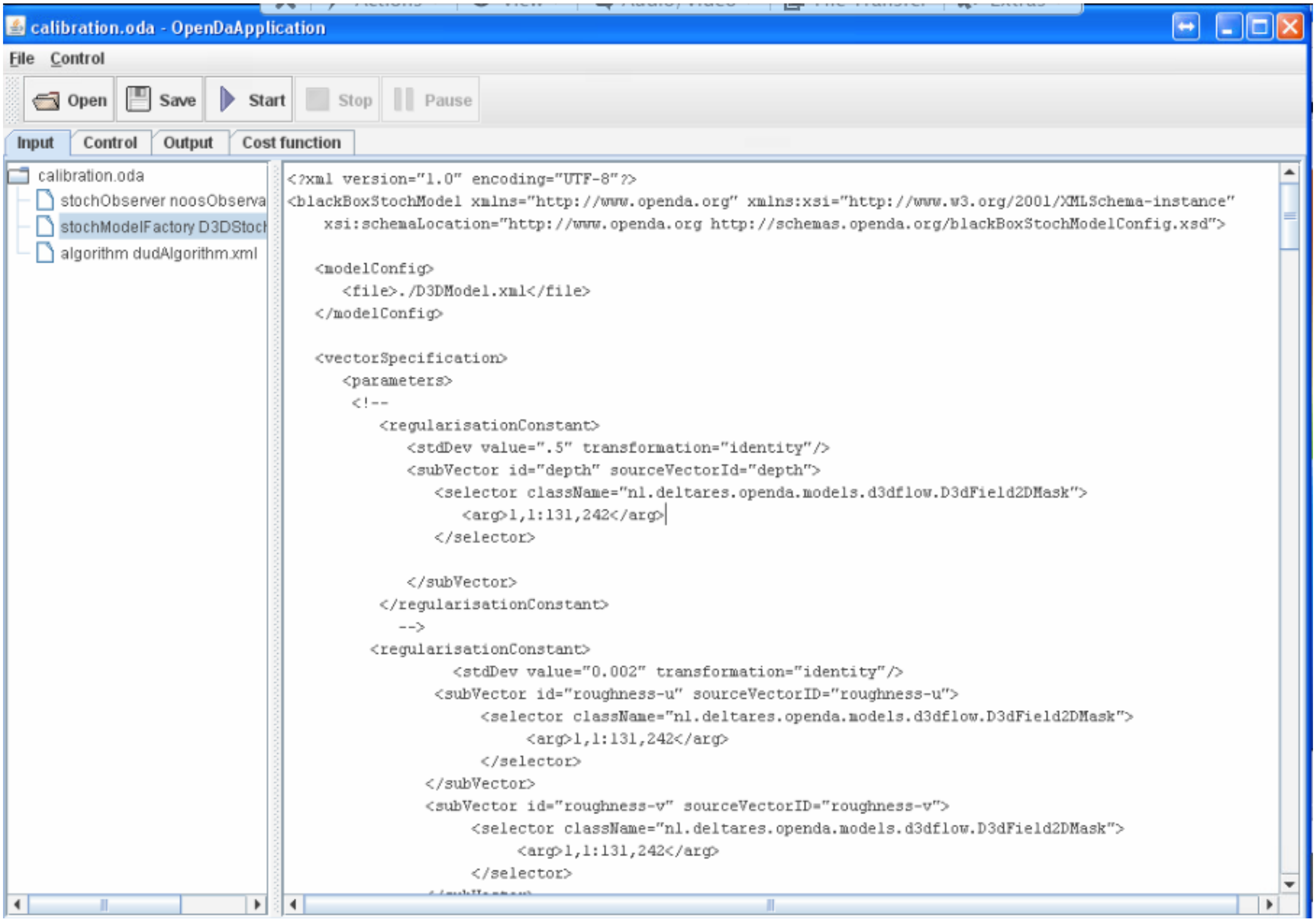

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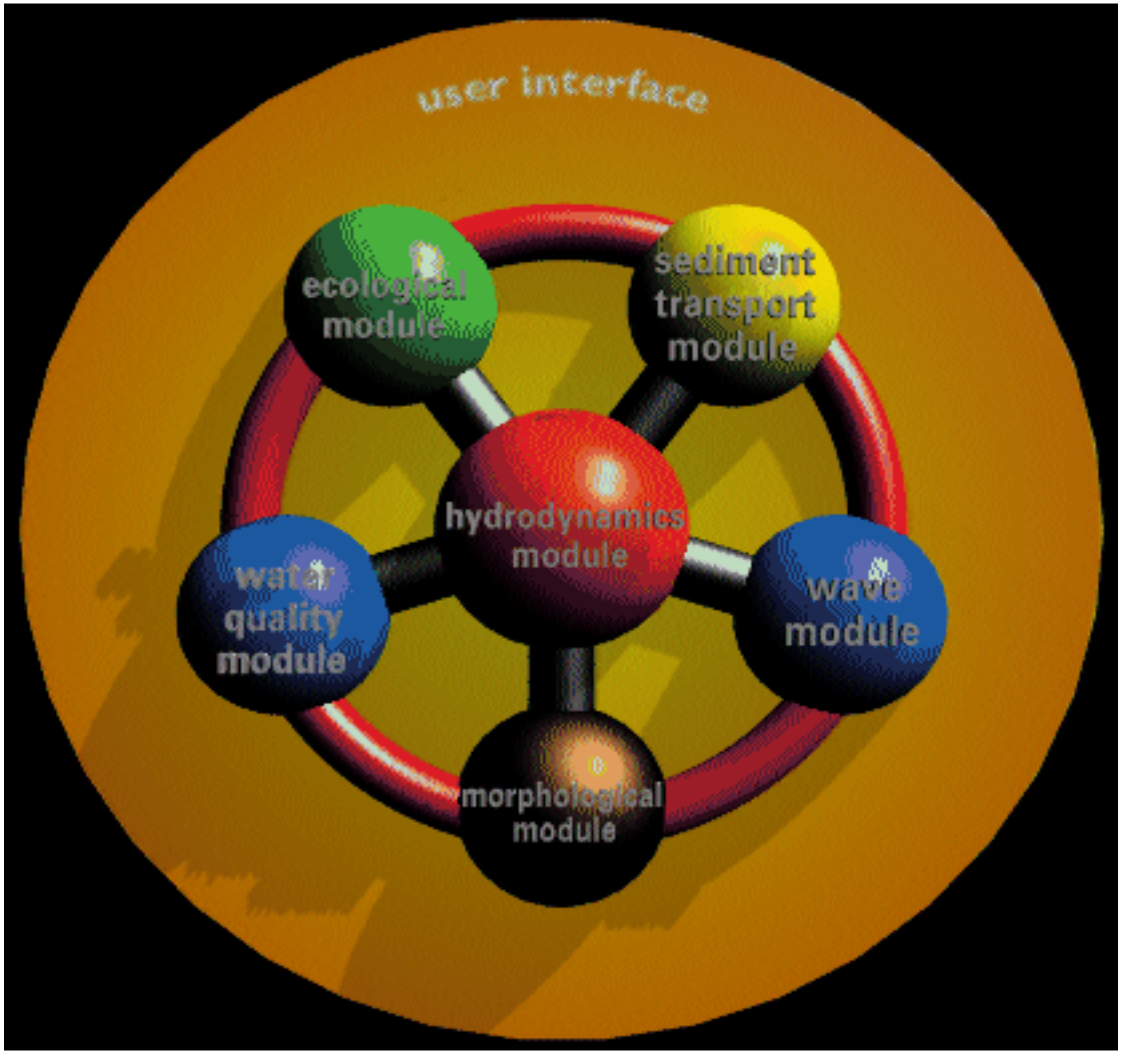
Coastal Morphodynamic Modeling using Delft3D



- Cartesian and spherical co-ordinates
- 2D and 3D (σ or fixed layers in the vertical)
- salinity and temperature
- Online Morphology
- turbulence closure (incl. k-L and k-ε) models
- drying and flooding
- sediment and morphology
- Dredging and dumping
- Rain fall and evaporation
- Thermal discharge and heat fluxes
- drogue tracks
- domain decomposition
- Wave – Current interactions
- Particle tracking
- Sediment tracking

http://oss.deltares.nl/web/delft3d
http://publicwiki.deltares.nl/display/OET/DelftDashboard

Problem Statement

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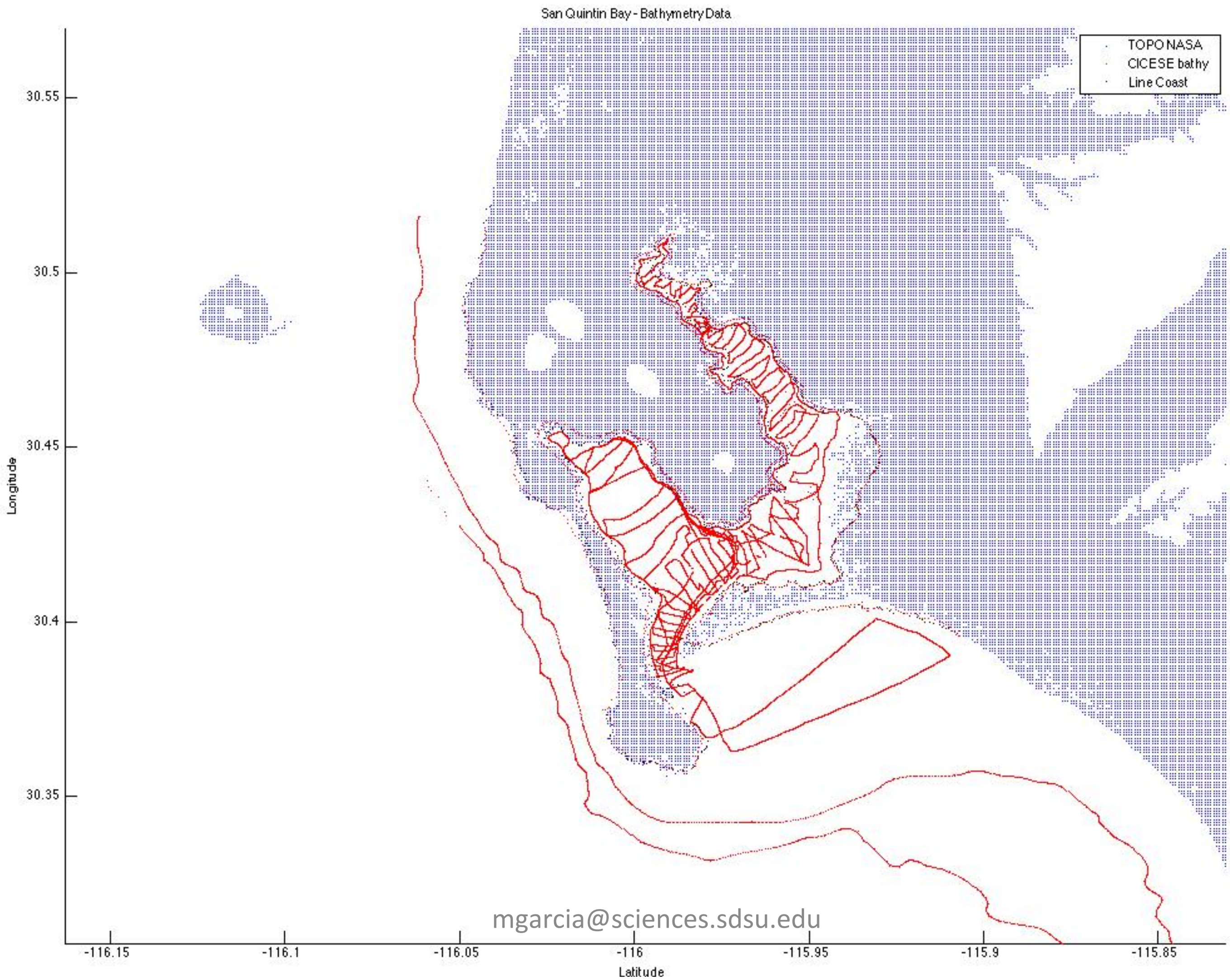
SQ Domain



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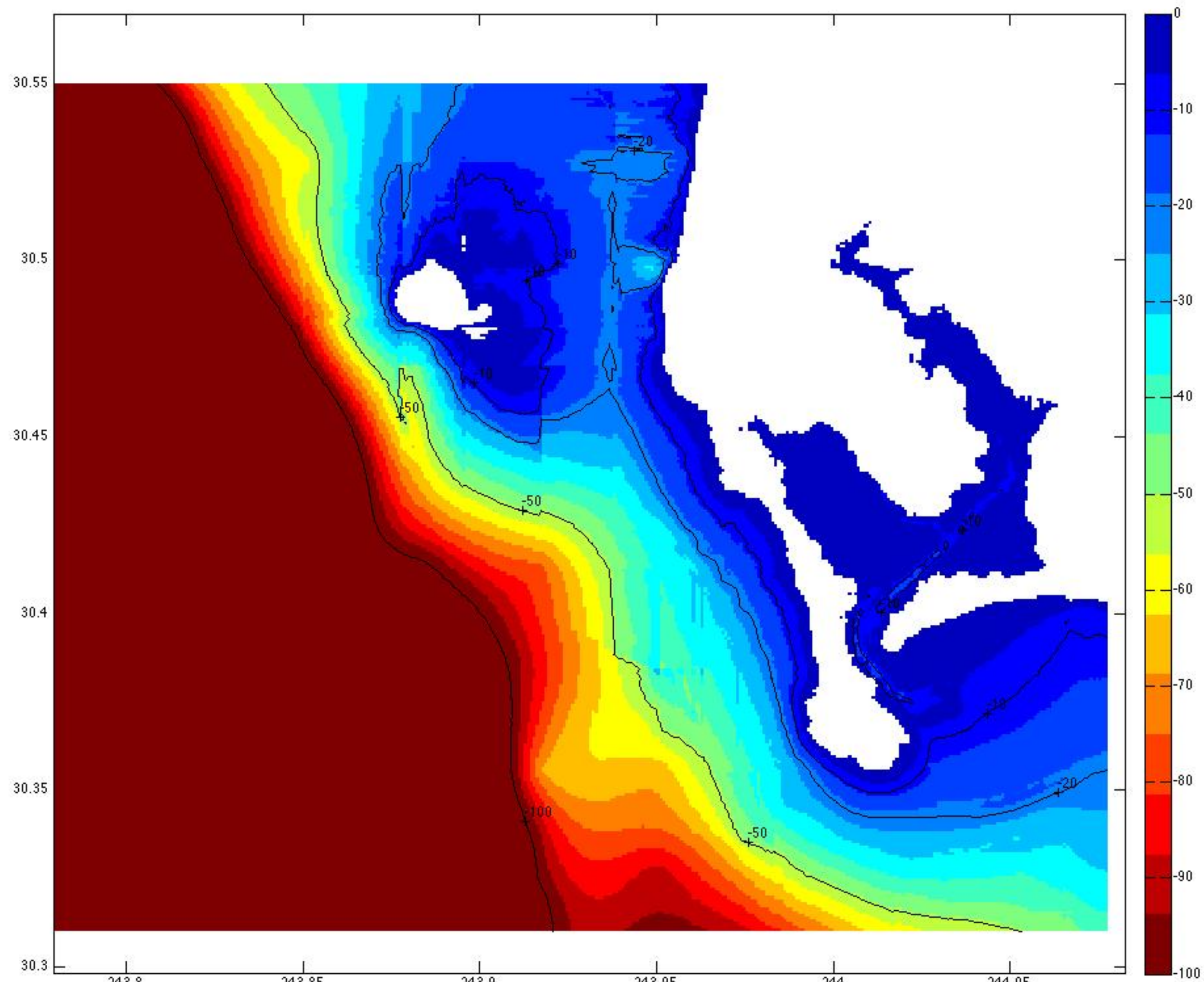
Bathymetry



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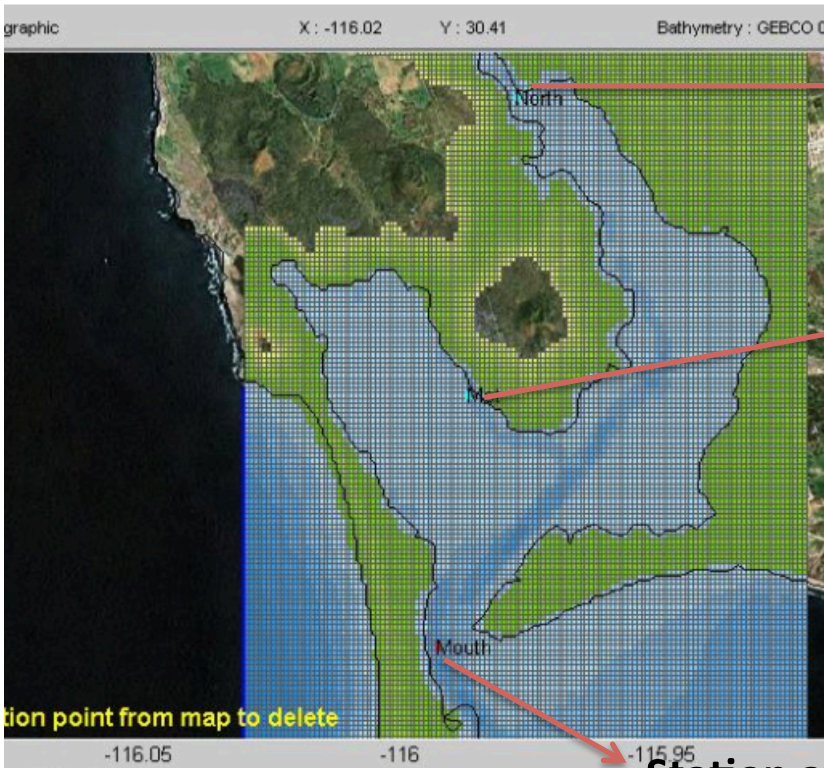
Observation Data
IR Campaign 2010 Wet Season



North Station
Water Level from Model MARV0.9 201(
CICESE MX

Atmospheric Station
ID: Atm
Variables:
- Air Temperature
- Velocities Components
- Atmospheric Pressure
- Humidity
- Rain

Station at the Bay Entry
ID: Mouth
Variables:
-Pressure
-Water Temperature
-Currents from Navy Secretary of Mexico

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Forcing Parameters
&
Initial Condition

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Open Boundary Condition: Astronomical Tide Model

TPXO7.2 global model of ocean tides

The general formula for the astronomical tide is:

$$H(t) = A_0 + \sum_{i=1}^{k} A_i F_i \cos\left(\omega_i t + (V_0 + u)_i - G_i\right)$$

in which:

$H(t)$	water level at time t
A_0	mean water level over a certain period
k	number of relevant constituents
i	index of a constituent
A_i	local tidal amplitude of a constituent
F_i	nodal amplitude factor
ω_i	angular velocity
$(V_0 + u)_i$	astronomical argument
G_i	improved kappa number (= local phase lag)

Tidal Component	Period (solar hours)	Description	Nature
M2	12.42	Principal lunar	semi-diurnal
S2	12.00	Principal solar	semi-diurnal
N2	12.66	Larger lunar elliptic	semi-diurnal
K2	11.97	Luni-solar	semi-diurnal
K1	23.93	Luni-solar diurnal	diurnal
O1	25.82	Principal lunar diurnal	diurnal
P1	24.07	Principal solar diurnal	diurnal
Q1	26.87	Larger lunar elliptic	diurnal
MF	327.90	Lunar fortnightly	Long term
MM	661.30	Lunar monthly	Long term
SSA	4383.00	solar semi annual	Long term
M4	6.21		Compound
MS4	6.10		Compound

The amplitudes A and phases G of the constituents vary with the position from which the tide is observed.

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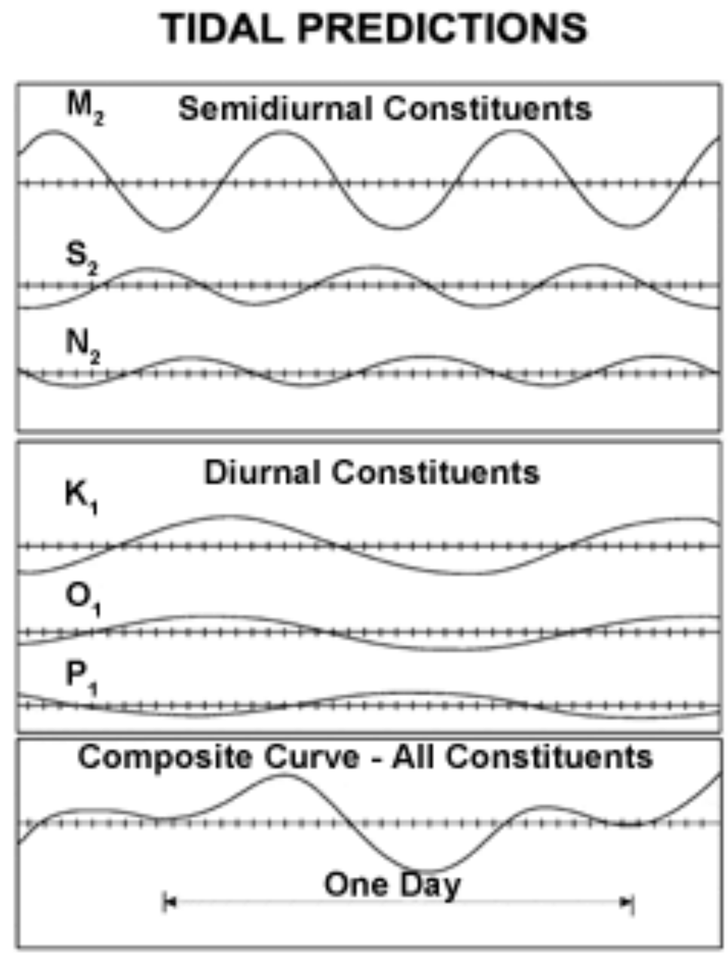
Tidal Constituents

Darwin Symbol	Name	Period
Semidiurnal		
M2	Principal lunar	12.42 h
S2	Principal solar	12.00 h
N2	Major lunar elliptical	12.66 h
K2	Luni-solar declinational	11.97 h
Diurnal		
O1	Principal lunar	25.82 h
P1	Principal solar	24.07 h
Q1	Major lunar elliptical	26.87 h
K1	Luni-solar declinational	23.93 h

"The tides are semidiurnal with maximum amplitude of 1.2 m representing about 15 percent of the volume of water introduced to the bay"



oc.nps.navy.mil

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2D Mode Shallow Water Equation

Tide Forcing

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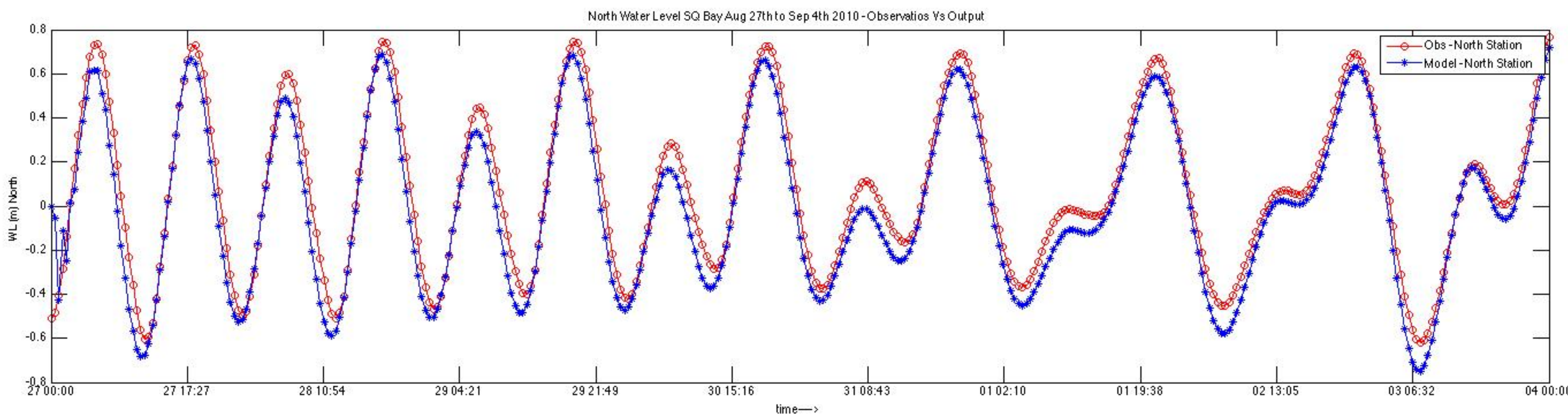
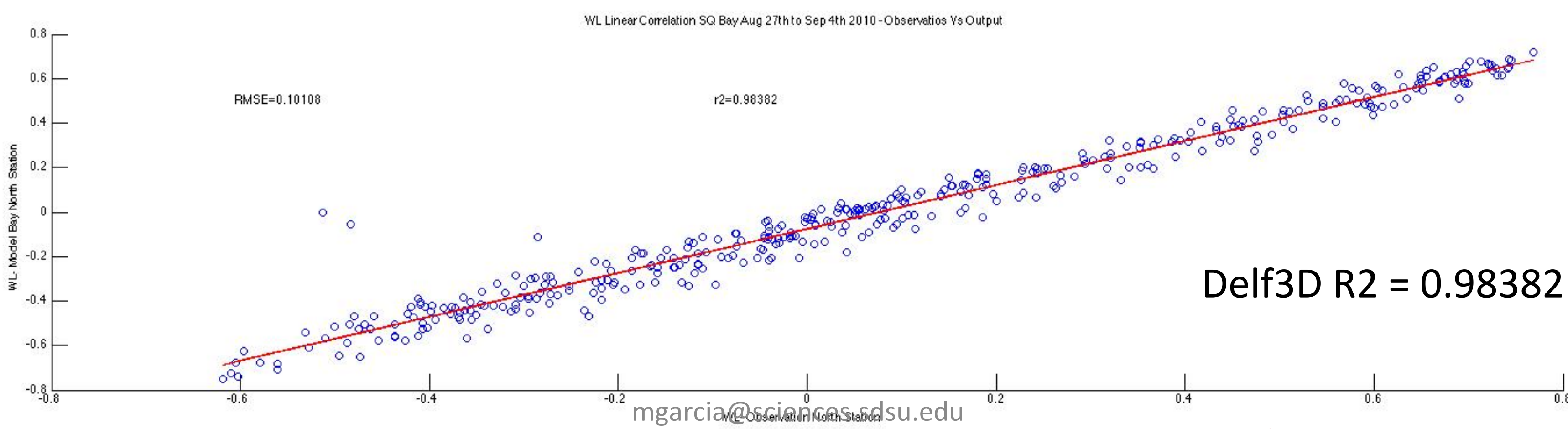
Station: North.
Model Vs ObsIR 2010
Water Level





Delf3D R2 = 0.98382

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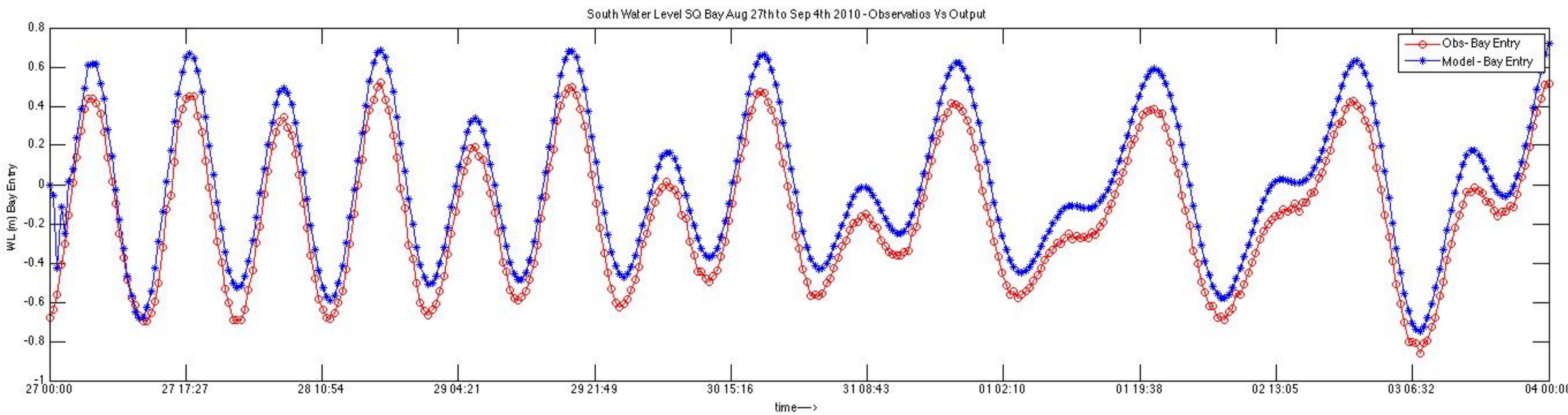
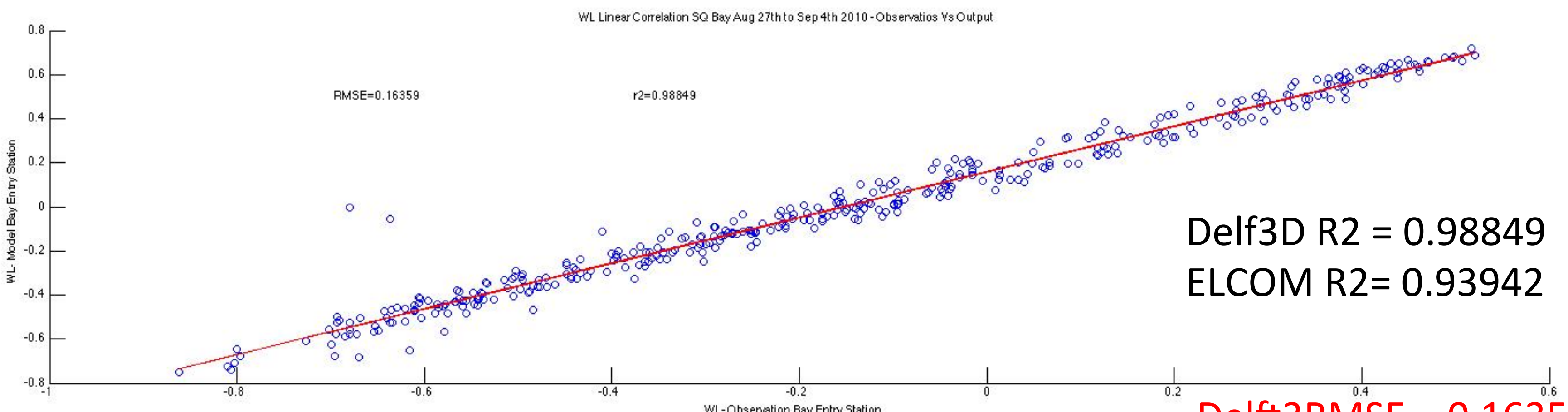
Delft3D RMSE = 0.10108

Station: Bay Entry.
Model Vs Measured (- Average 26 days)
Water Level





Delf3D R2 = 0.98849
ELCOM R2= 0.93942

Delft3RMSE = 0.16359

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Calibration Model Design

- 1 - tides: For the calibration of tides, we can neglect the stratification first and run the model in 2D mode.

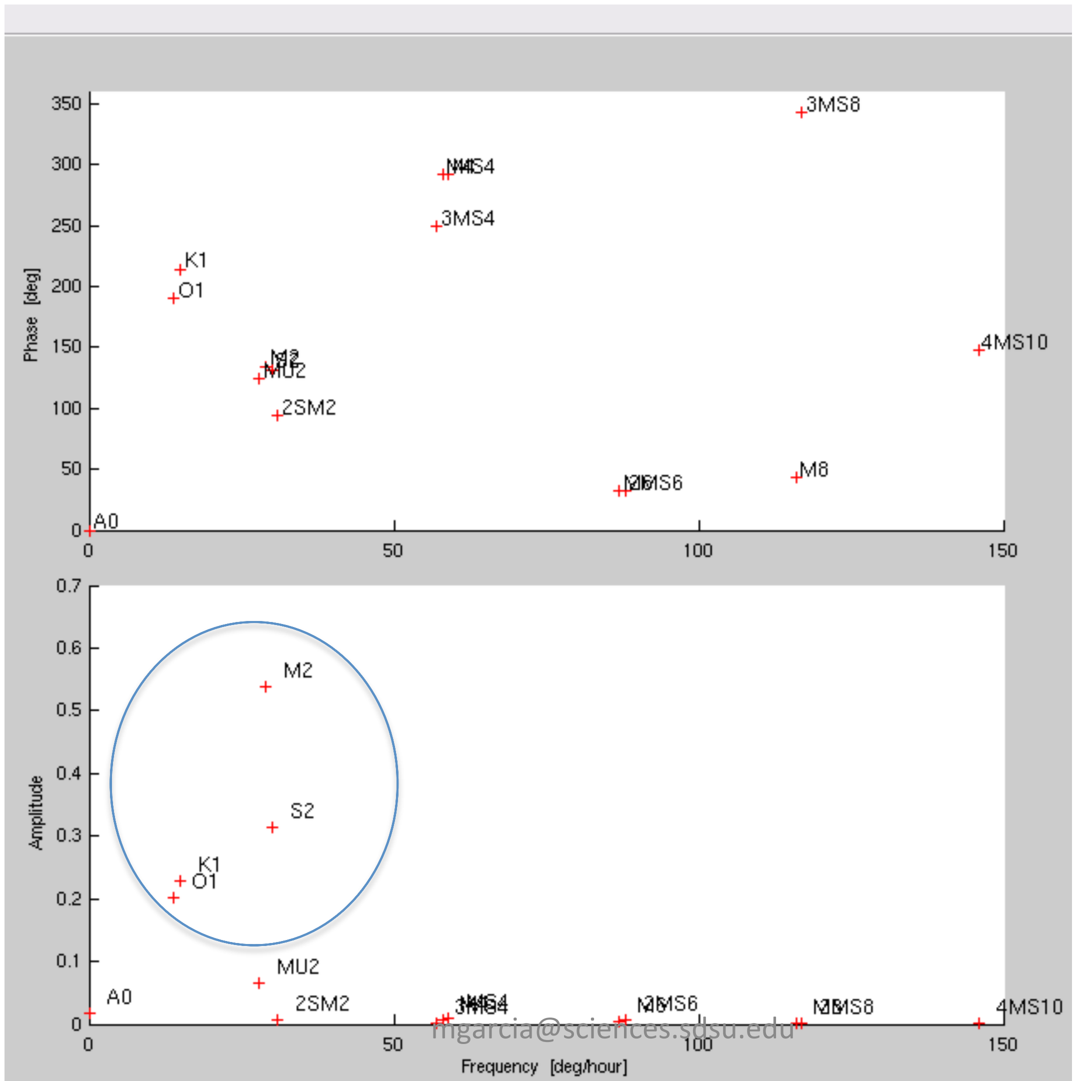
  Parameter to consider: friction, bathymetry and tidal Bcs.

- 2 - wind and surge: add wind forcing (u10 and air pressure) and calibrate the drag coefficient.

- 3 - 3D structure: The 3D structure is then the next step. The quality of the baroclinic structure depends strongly on the quality of boundary conditions for temperature and salinity in bay inflow.

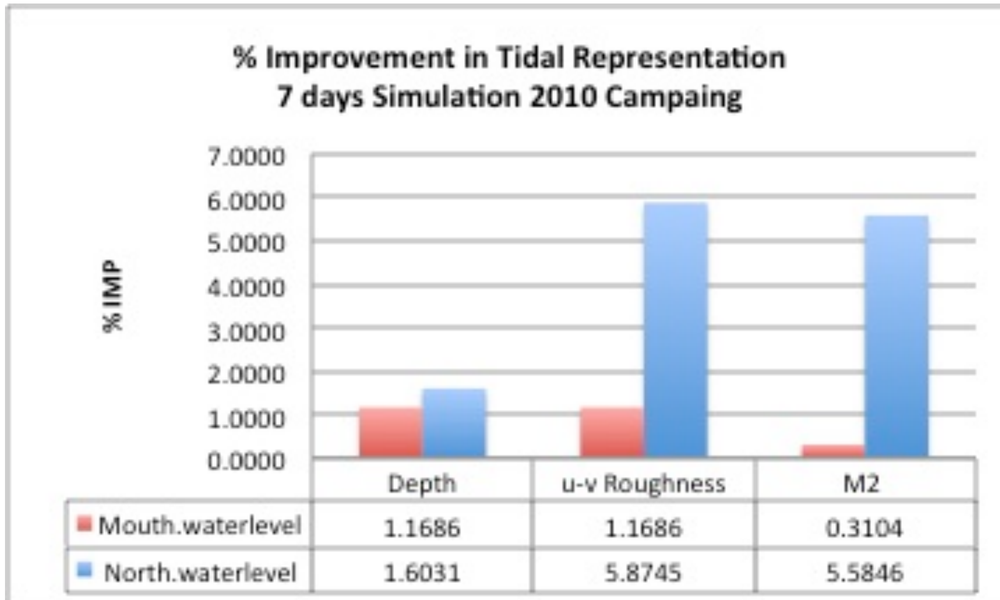
Harmonic Analysis

$$H\,(t) = A_0 + \sum_{i=1}^{k} A_i F_i cos(\omega_i + (V_0 + u)_i - G_i)$$



Improvement
7 days

	MAT Tide Observer		TPXO 7.2	
Parameter	Amplitude	Phase	Amplitude	Phase
$M2$	0.538	134.436	0.485	129.599
$S2$	0.3147	131.844	0.215	127.896
$K2$	0.0836	172.0200	0.062	121.610
$K1$	0.2297	214.343	0.308	203.941
$O1$	0.2025	190.2559	0.196	189.309
$M4$	0.0087	292.2344	0.003	272.662
$MS4$	0.0046	327.7652	0.003	301.000



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Improvement
14 days

14 Days simulation 2010 Campaign				
% ObsID	Parameter	STD	RMSE	IMP %
Mouth.waterlevel	Before Calibration 14 days	0.1681	0.1837	n/a
	M2, S2, K1, 01	0.1446	0.16327	12.54576
	Roughness + M2, S2, K1, 01	0.1446	0.16329	12.53115
North.waterlevel	Before Calibration 14 days	0.1394	0.1451	n/a
	M2, S2, K1, 01	0.0557	0.0720	101.4792
	Roughness + M2, S2, K1, 01	0.0554	0.0720	101.7253

Table 3: Sensitivity analysis of Roughness + M2, S2, K1, 01 - 14 days simulation

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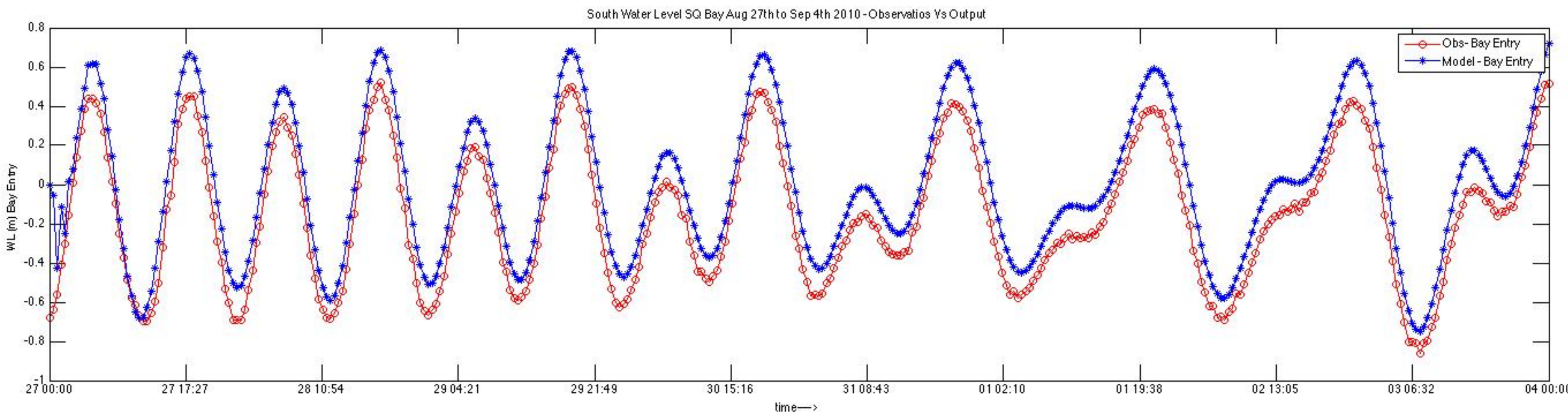
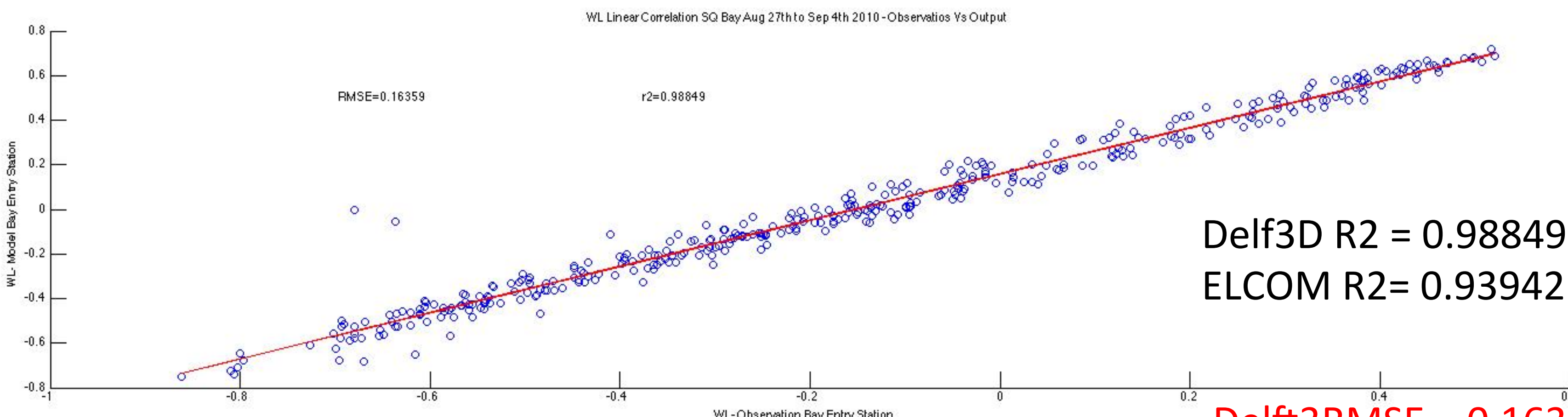
Station: Bay Entry.
Model Vs Measured (- Average 26 days)
Water Level





Delf3D R2 = 0.98849
ELCOM R2= 0.93942

Delft3RMSE = 0.16359

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Open Boundary Condition: Astronomical Tide Model

The general formula for the astronomical tide is:

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in which:

$H(t)$	water level at time t
A_0	mean water level over a certain period
k	number of relevant constituents
i	index of a constituent
A_i	local tidal amplitude of a constituent
F_i	nodal amplitude factor
ω_i	angular velocity
$(V_0 + u)_i$	astronomical argument
G_i	improved kappa number (= local phase lag)

Table 1: Primary Tidal Components

Tidal Component	Period (solar hours)	Description	Nature
M2	12.42	Principal lunar	semi-diurnal
S2	12.00	Principal solar	semi-diurnal
N2	12.66	Larger lunar elliptic	semi-diurnal
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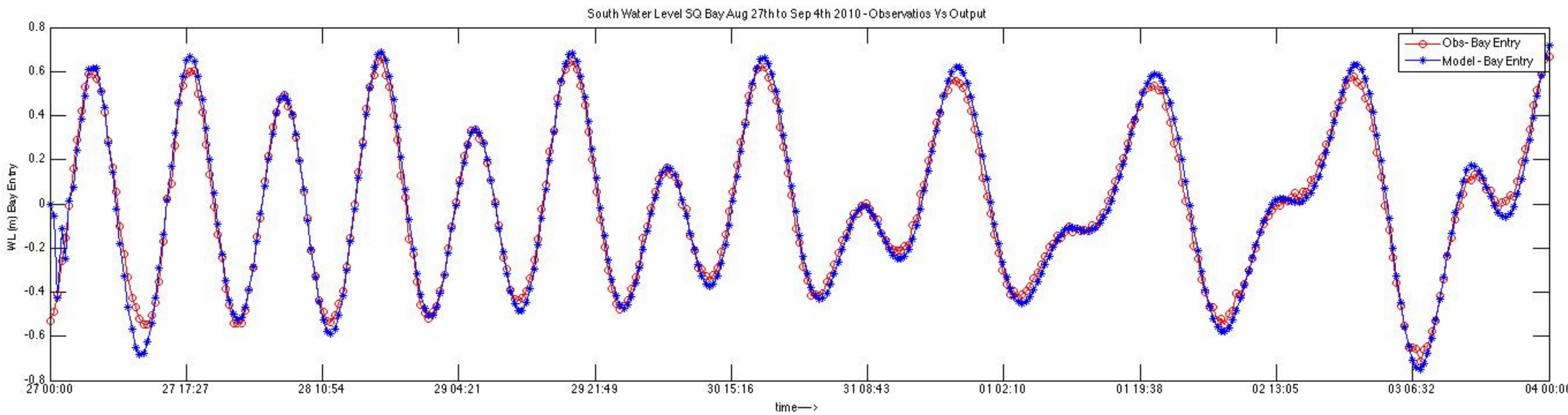
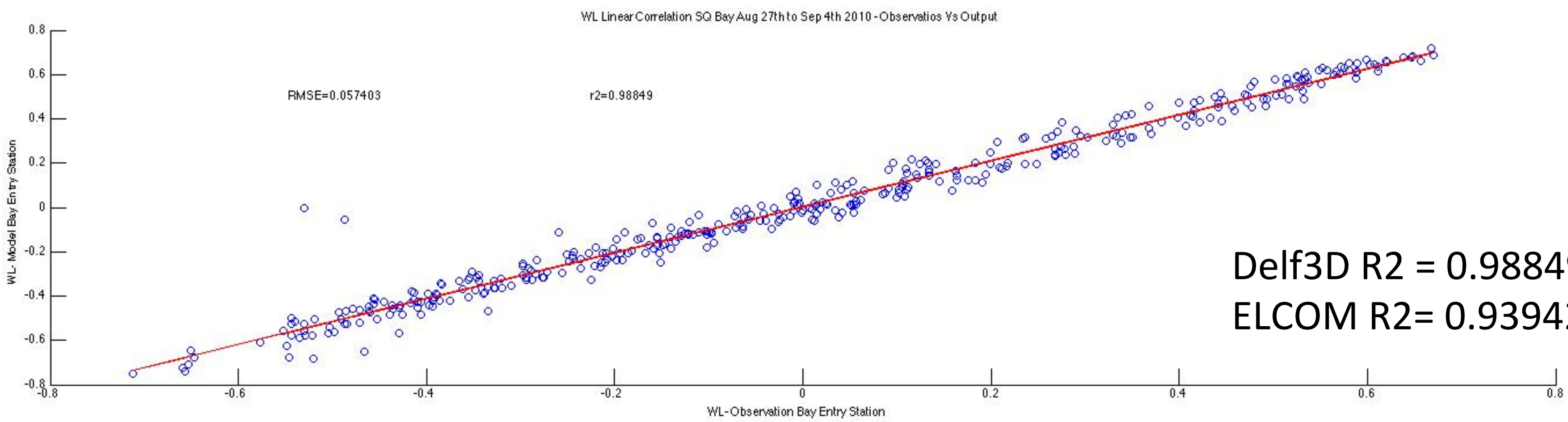
M4	6.21		Compound
MS4	6.10		Compound

The amplitudes A and phases G of the constituents vary with the position from which the tide is observed.

Station: Bay Entry.
Model Vs Measured (average 7 days)
Water Level





Delf3D R2 = 0.98849
ELCOM R2= 0.93942

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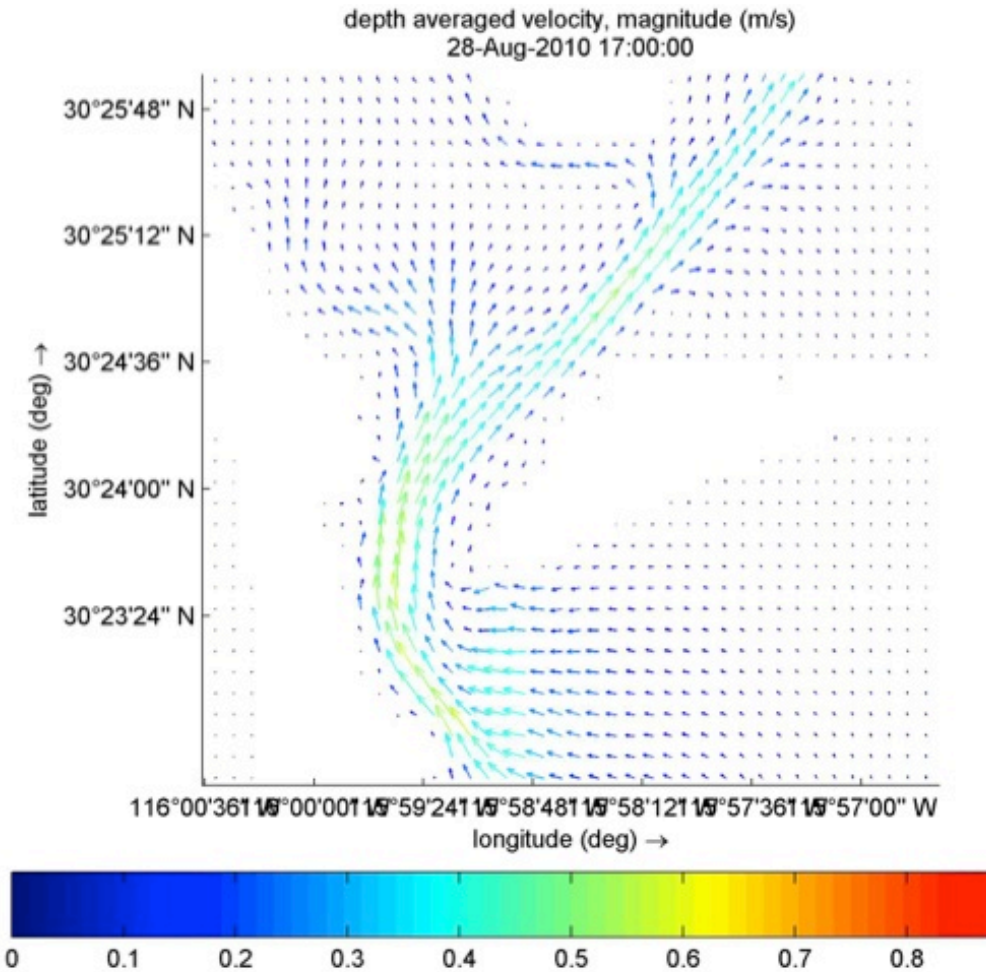
Delft3RMSE = 0.0574

Improvement

14 Days simulation 2010 Campaign				
% ObsID	Parameter	STD	RMSE	IMP %
Mouth.waterlevel	Before Calibration 14 days	0.1681	0.1837	n/a
	M2, S2, K1, 01	0.1446	0.16327	12.54576
	Roughness + M2, S2, K1, 01	0.1446	0.16329	12.53115
	Roughness + M2, S2, K1 (Bias Removed)	0.1449	0.14487	26.8300
North.waterlevel	Before Calibration 14 days	0.1394	0.1451	n/a
	M2, S2, K1, 01	0.0557	0.0720	101.4792
	Roughness + M2, S2, K1, 01	0.0554	0.0720	101.7253
	Roughness + M2, S2, K1 (Bias Removed)	0.0539	0.0538	169.4833

Table 3: Sensitivity analysis of Roughness + M2, S2, K1, 01 - 14 days simulation

During High Tide



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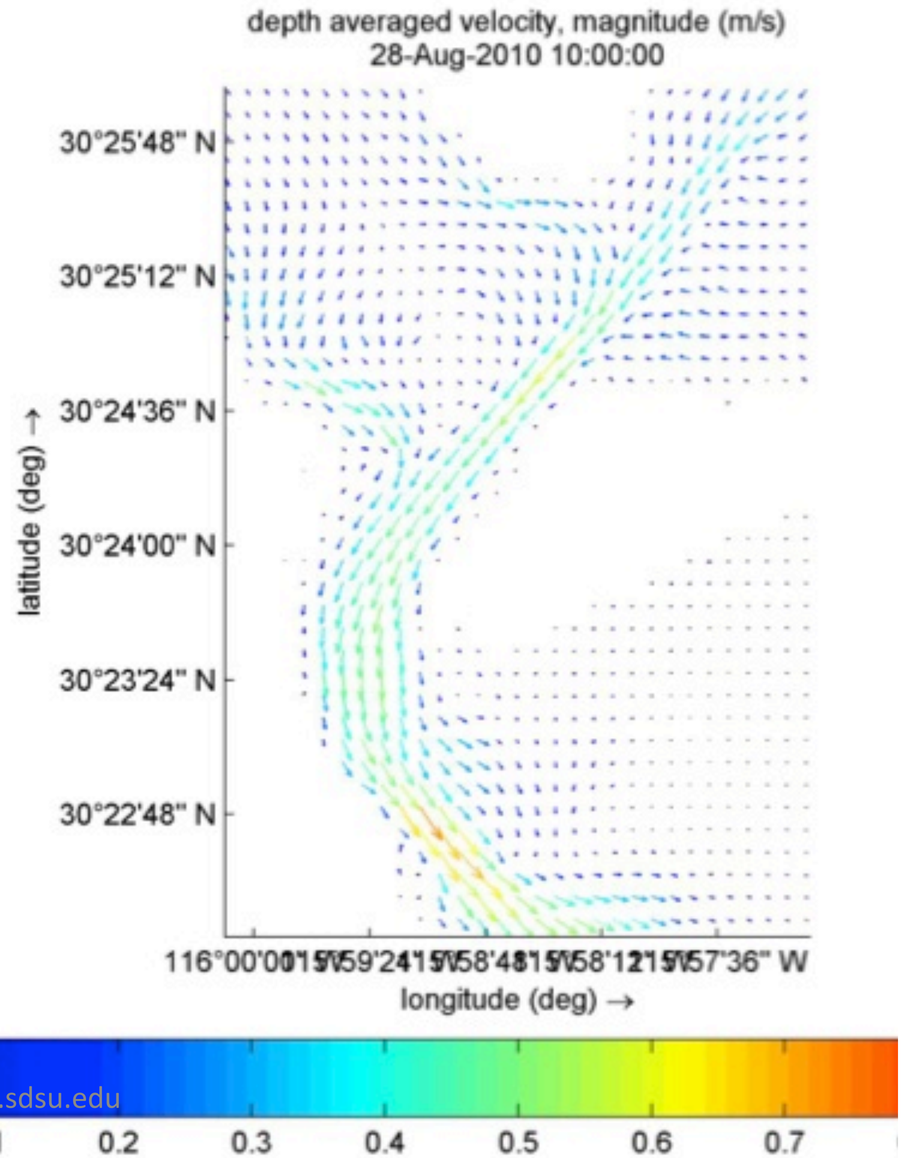
During LowTide



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The Numerical Model

RESULTS

DELFT 3D – Sigma Coordinates Mode
IR Campaign 2010 Wet Season

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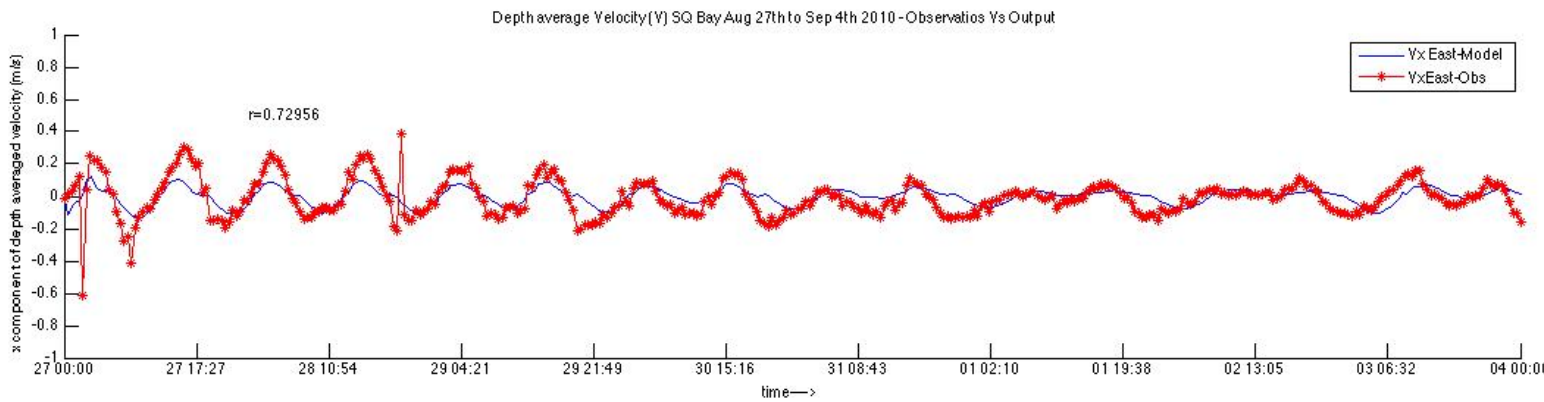
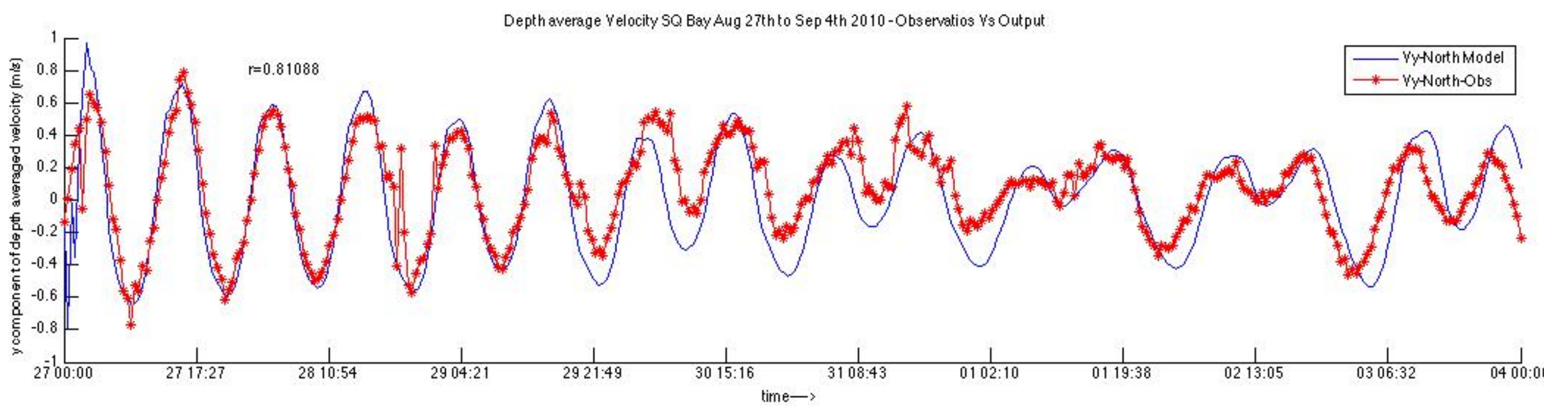
Station: Bay Entry.
Model Vs Measured
Depth Average Velocity: Eastward & Northward Direction





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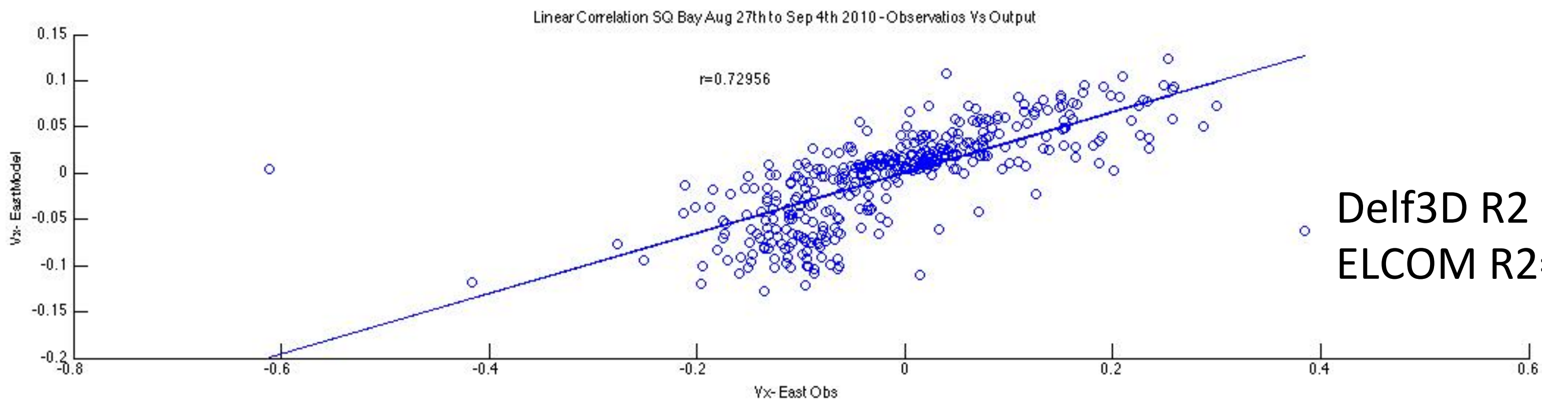
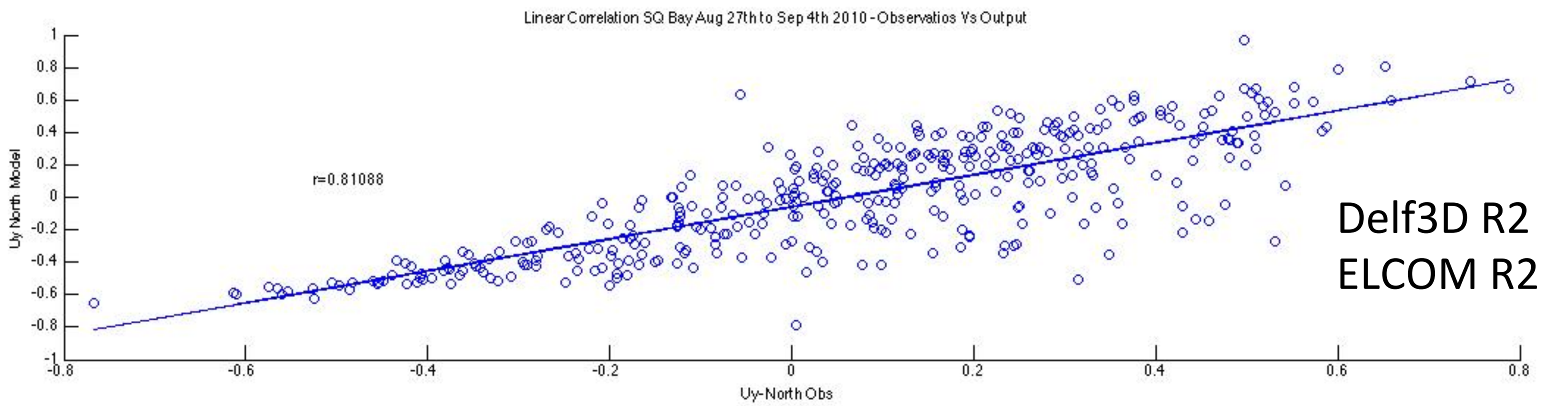
Station: Bay Entry.
Model Vs Measured Velocity Eastward & Northward Direction



Delf3D R2 = 0.72956
ELCOM R2= 0.72928



Delf3D R2 = 0.8108
ELCOM R2= 0.8366

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Conclusion

The model results so far show that the Delft3D model is capable of simulating the essential processes in the San Quintin Bay, and can be forced by the tidal model.

Calibration using OpenDA did improve the first model implementation showing that friction and changes in depth were not significant. Conversely, diurnal and semidiurnal components show that a change in their parameter have an important role in the dynamic of the bay.

OpenDA could be effectively used to rapidly calibrate a hydrological model.

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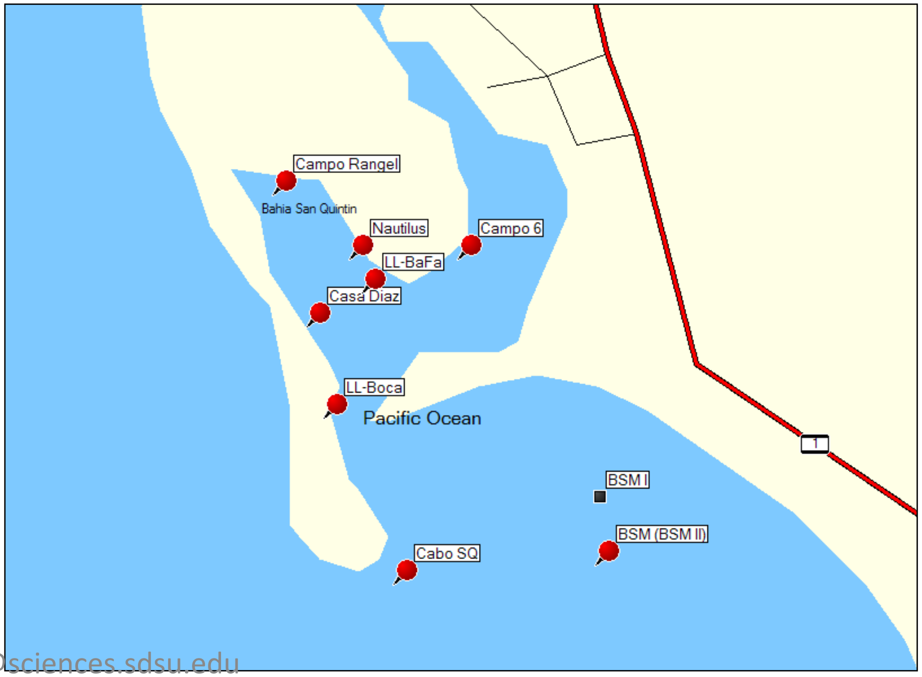
Work in Progress

- Study temperature variation along the bay to determine the best cultivation zones of these organisms.
- Introduce assimilation techniques, implementing Open DA as a tool, to be able to deliver real time forecasting capabilities in this region.



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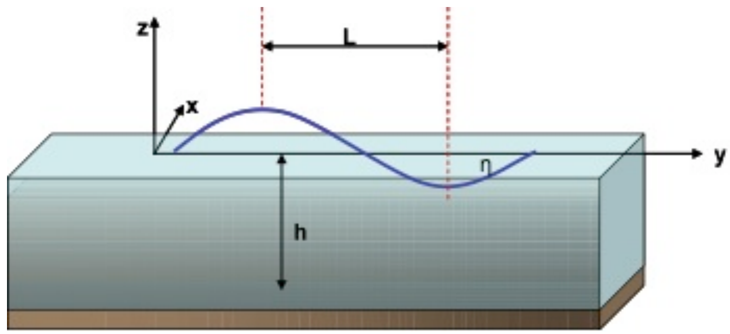
Future work: Data Assimilation Framework

- Dynamical Model
  - 3D Sigma Coordinate Model
- Parameter Equation
- Measurements Models
  - *Velocities field* at time t
  - *Temperature Profile*
- Assimilation Criterion
  - Ensemble Kalman Filter



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Question?

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