Brief at NUWC-NP, May 31, 2011

Oceanography for USW

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Outline

- (1) Empirical Mode Decomposition (EMD) for Mine Detection/Change Detection

- (2) Overview of the Navy's Ocean Modeling for ASW

- (3) Ocean Nowcast/Forecast Systems for USW

  (NPS-NUWCNP Joint Research Project)

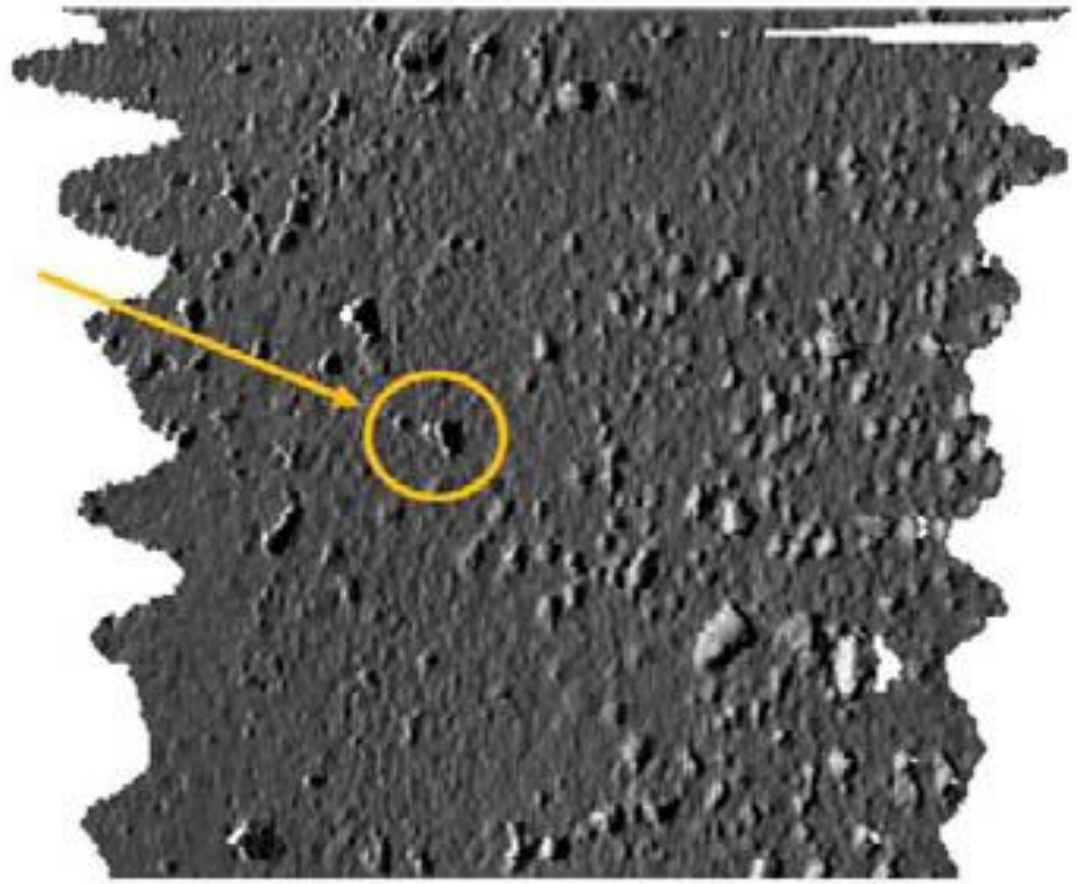
(1) MIW

Empirical Mode Decomposition (EMD) for Mine Detection and Change Detection

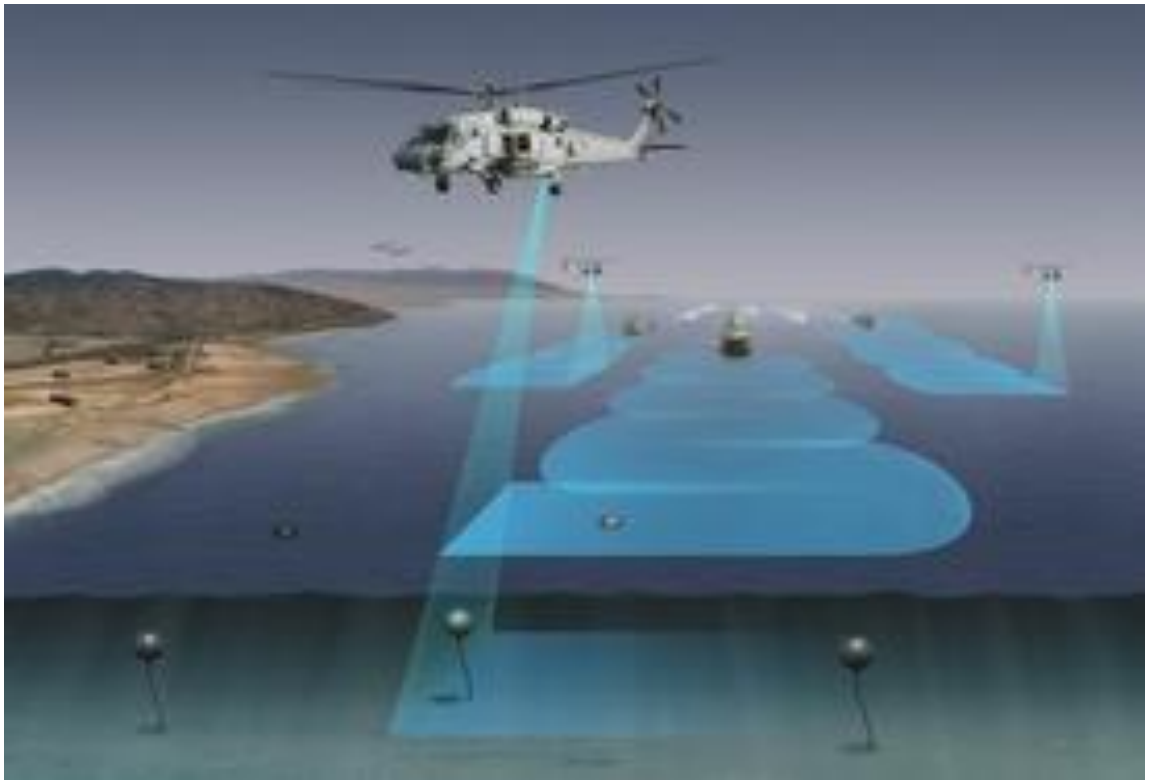
L3-Klein 5500 Sidescan Sonar



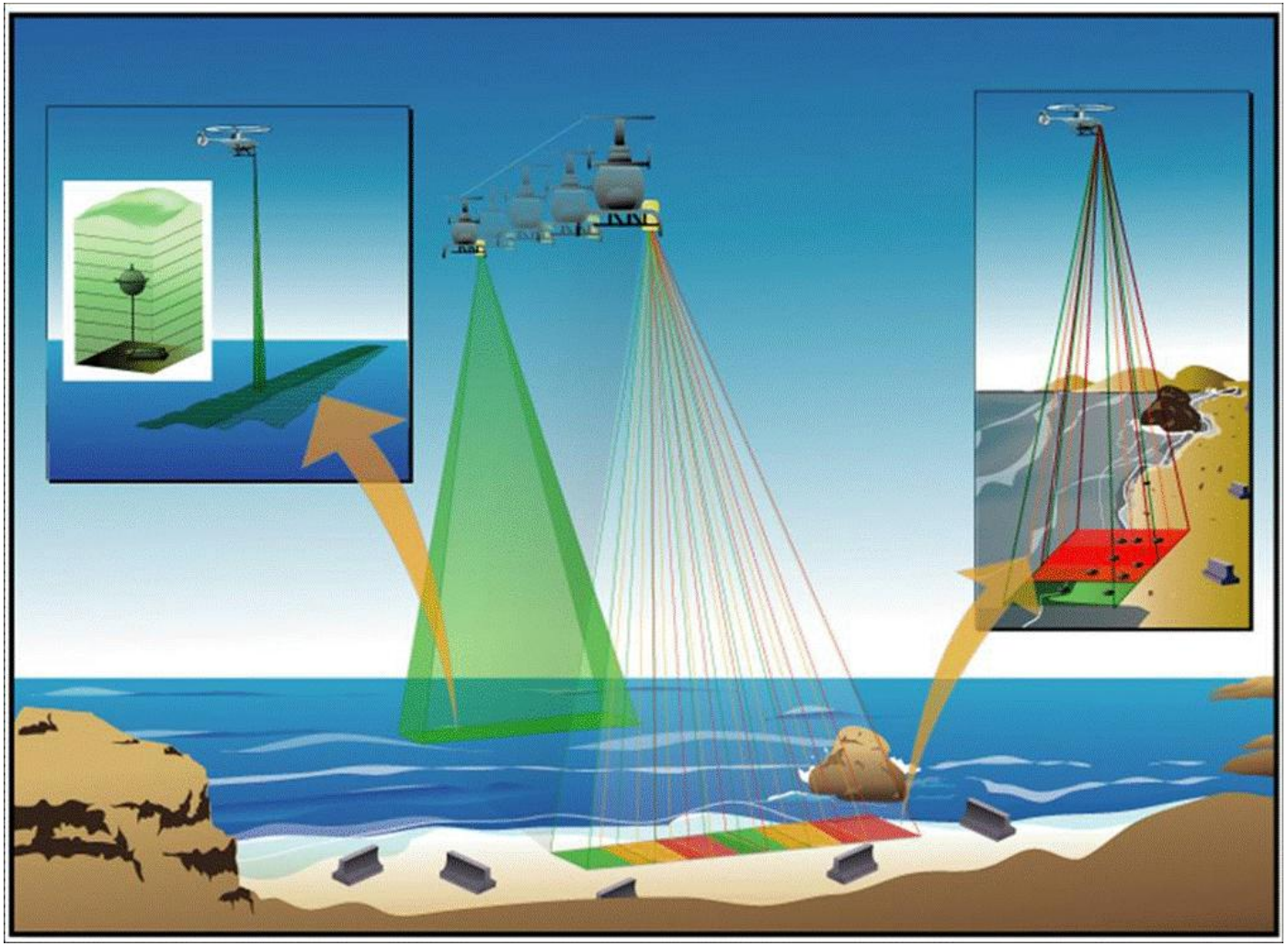
How can we detect mine from image such as sidescan sonar?



Airborne Laser Mine Detection System (ALMDS)



Rapid, Overt, Airborne, Reconnaissance (ROAR)



An Efficient Method →

Empirical Mode Decomposition

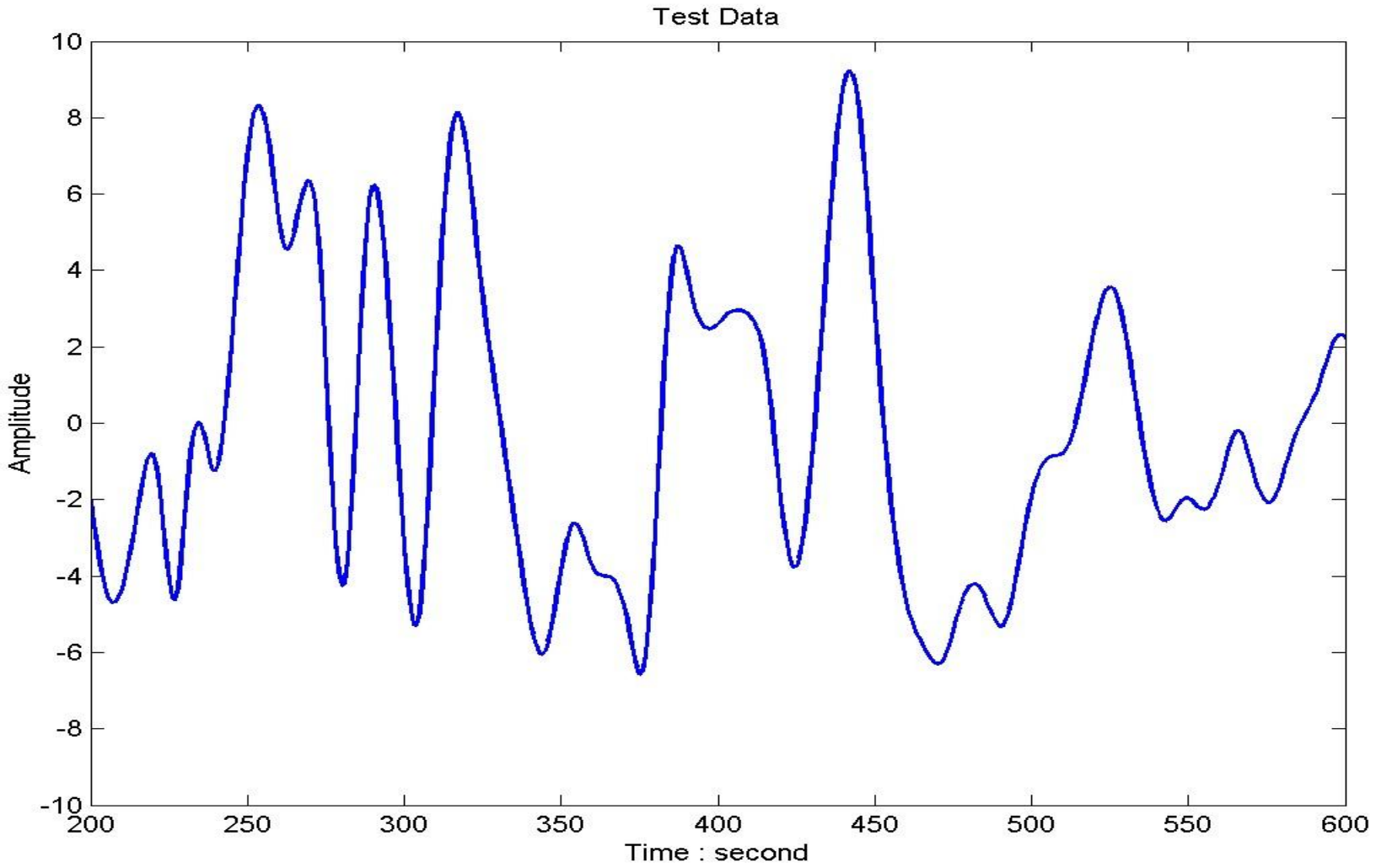
(Huang et al., 1998)

One Dimensional EMD →

Time Series Analysis

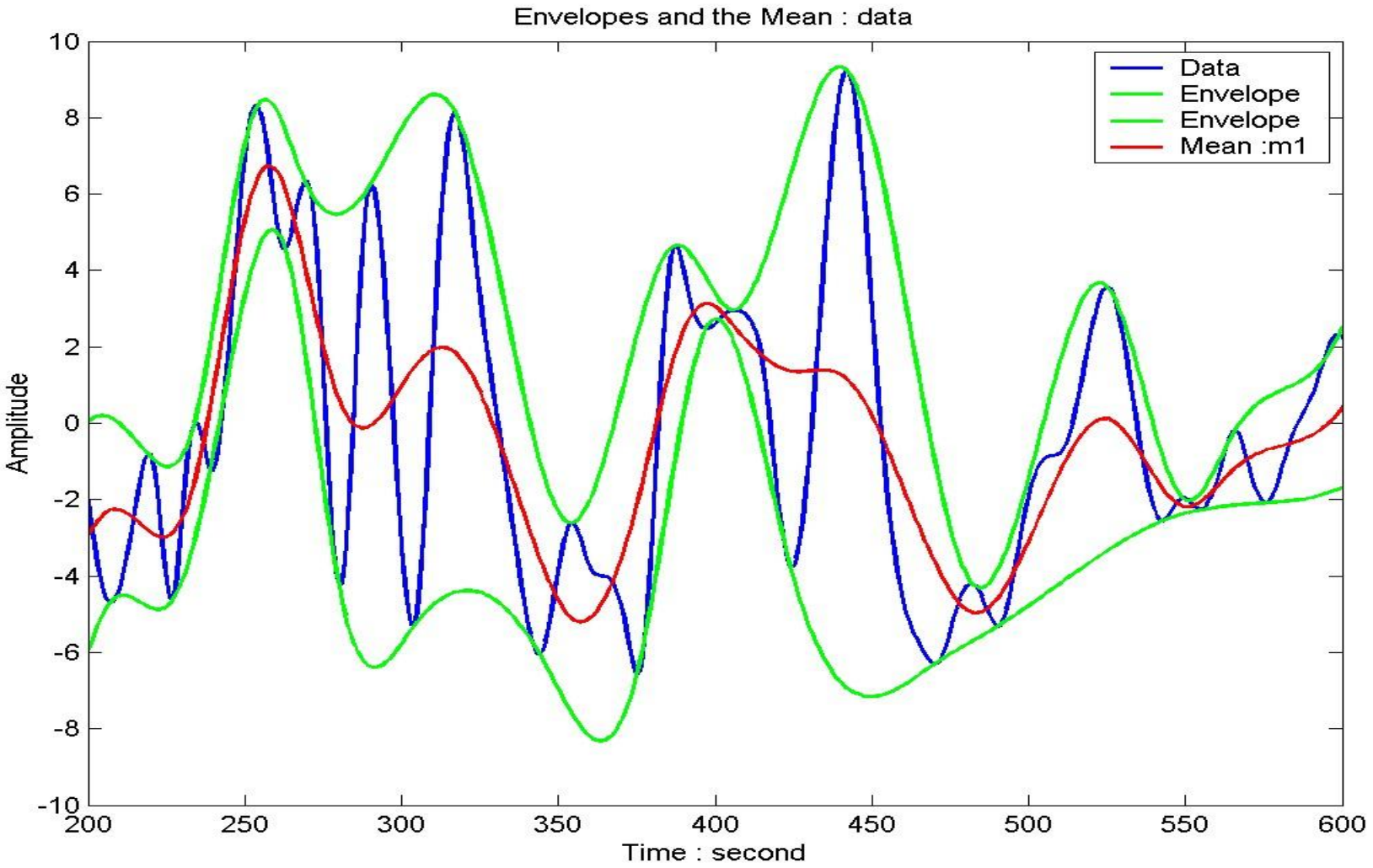
Empirical Mode Decomposition:

Methodology : Test Data



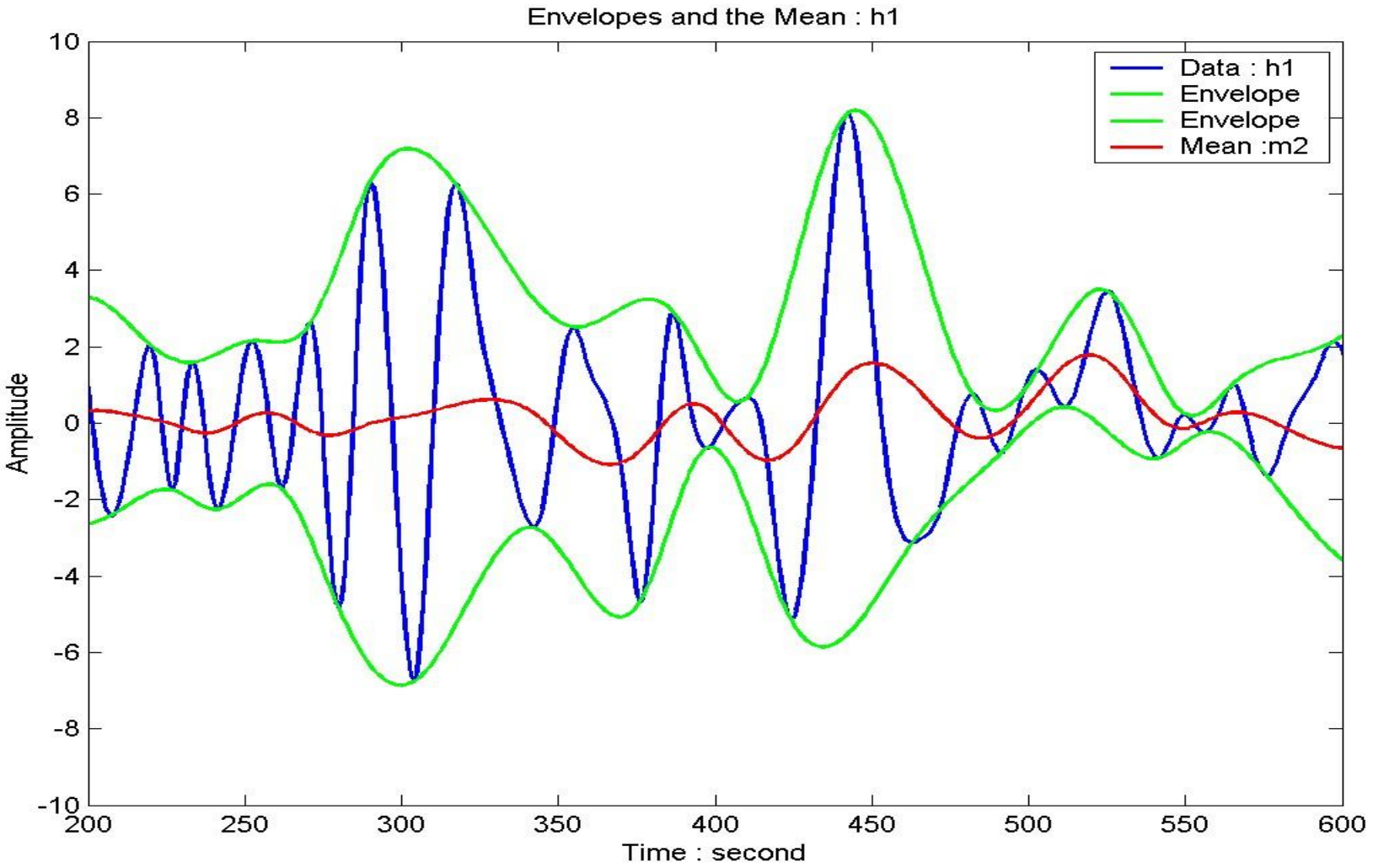
Empirical Mode Decomposition:

Methodology : data and m1



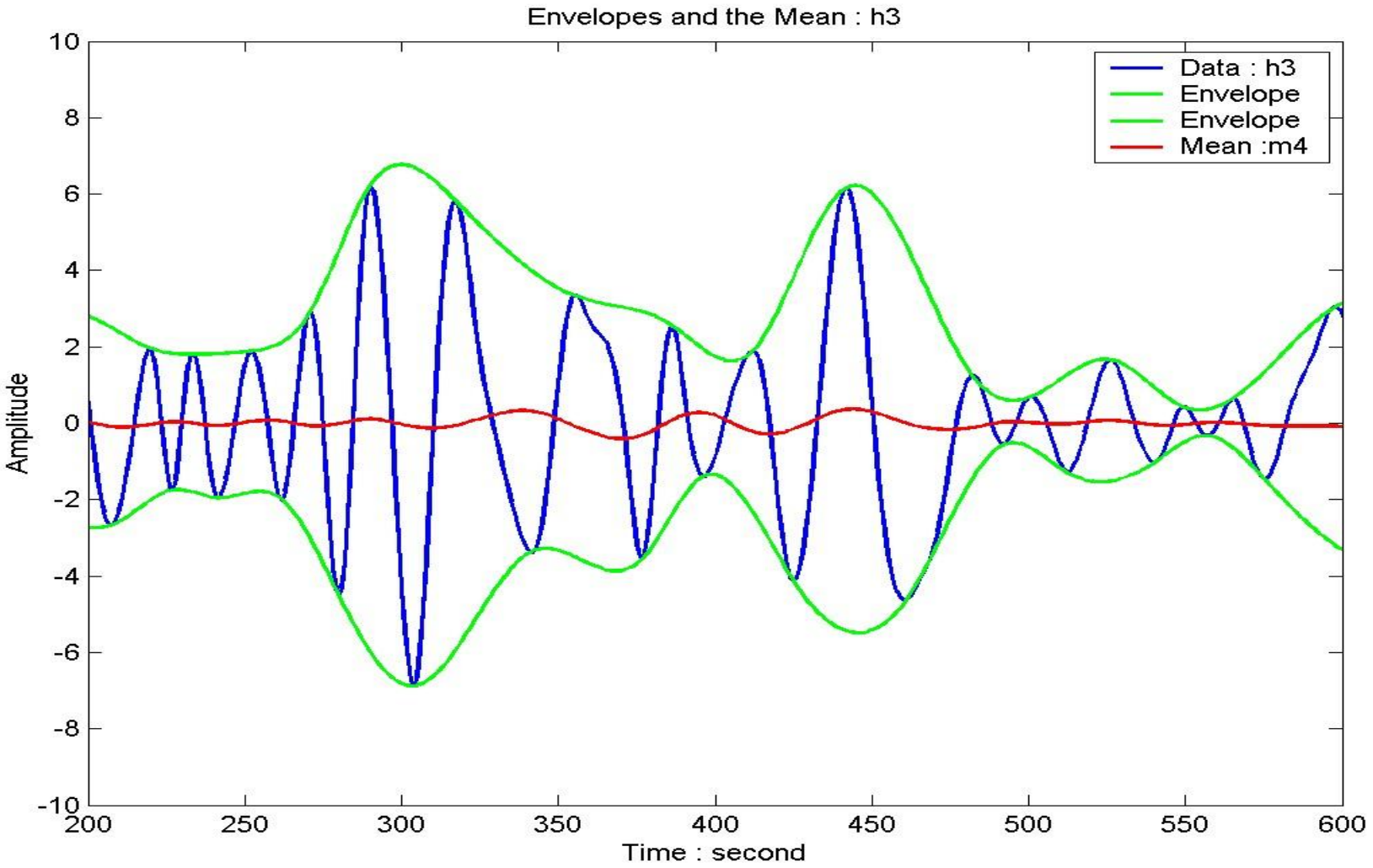
Empirical Mode Decomposition:

Methodology : h1 & m2



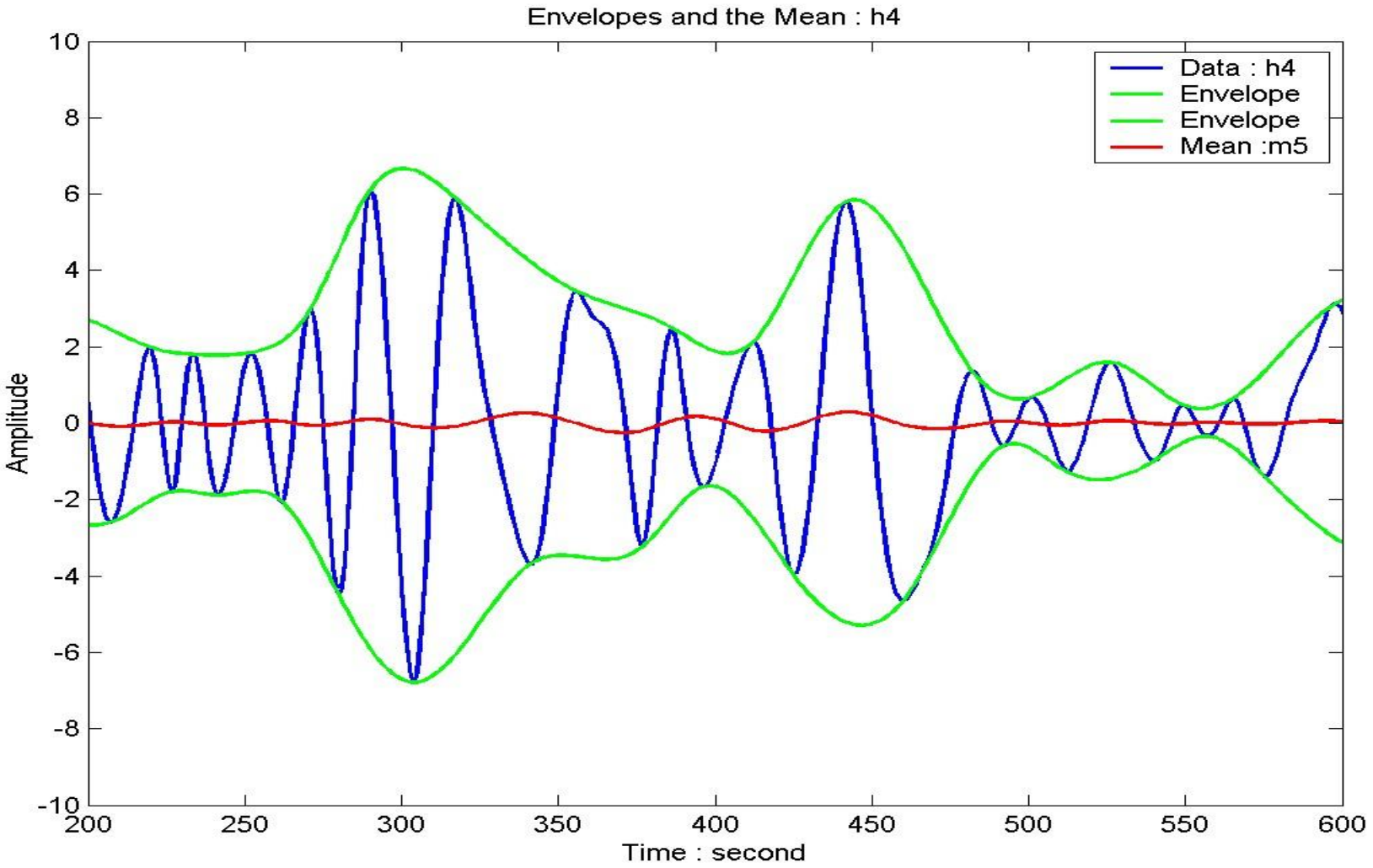
Empirical Mode Decomposition:

Methodology : h3 & m4



Empirical Mode Decomposition:

Methodology : h4 & m5



Empirical Mode Decomposition

Sifting : to get one IMF component

$$x(t) - m_1(t) = h_1(t),$$

$$m_1(t) - m_2(t) = h_2(t),$$

$$\cdots\cdots$$

$$m_{k-1}(t) - m_k(t) = h_k(t).$$

$$\Rightarrow \quad x(t) = m_k(t) + \sum_{i=1}^{k} h_i(t).$$

h_i (t) → Intrinsic Mode Function (IMF)

m_k(t) → Trend

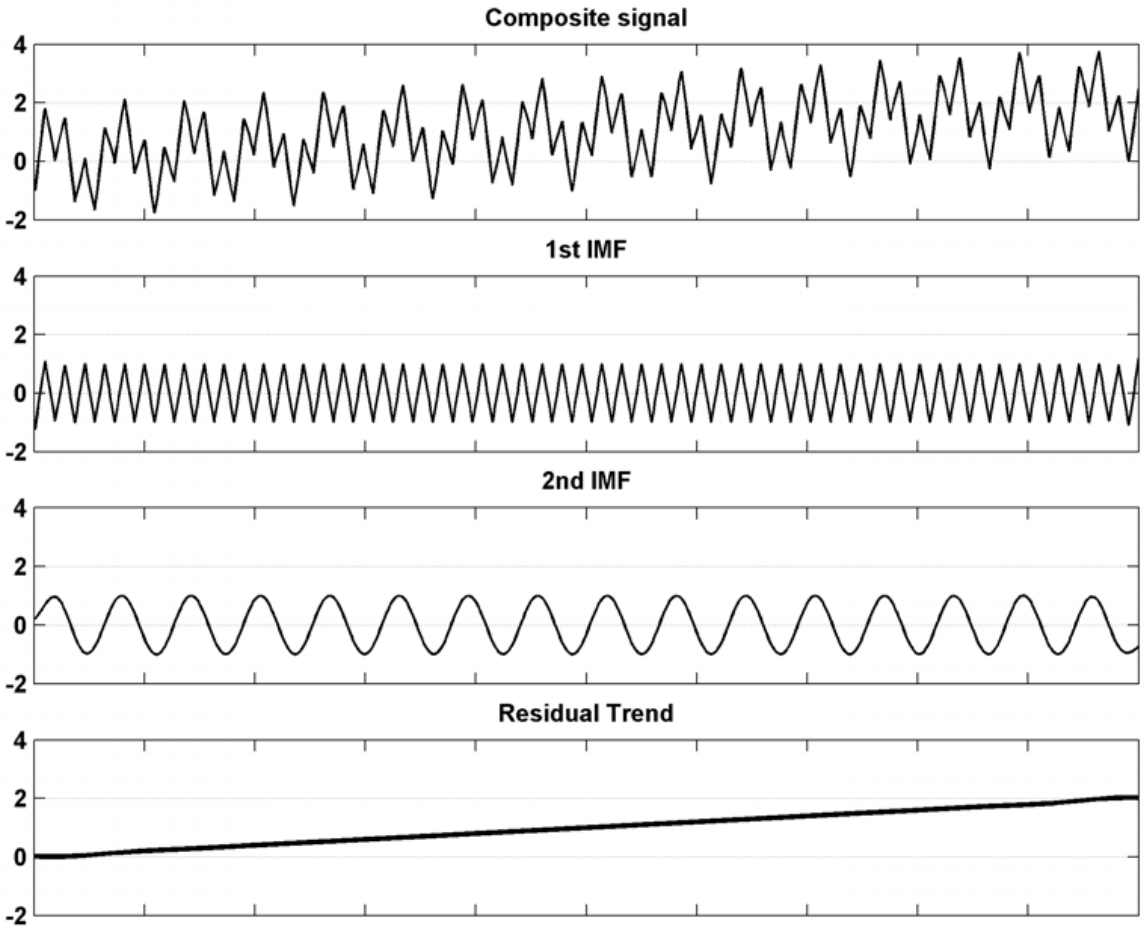
The Stoppage Criteria

The Cauchy type criterion:

when SD is small than a pre-set value, where

$$SD = \frac{\sum_{t=0}^{T} \left| h_{k-1}(t) - h_k(t) \right|^2}{\sum_{t=0}^{T} h_{k-1}^{\ 2}(t)}$$

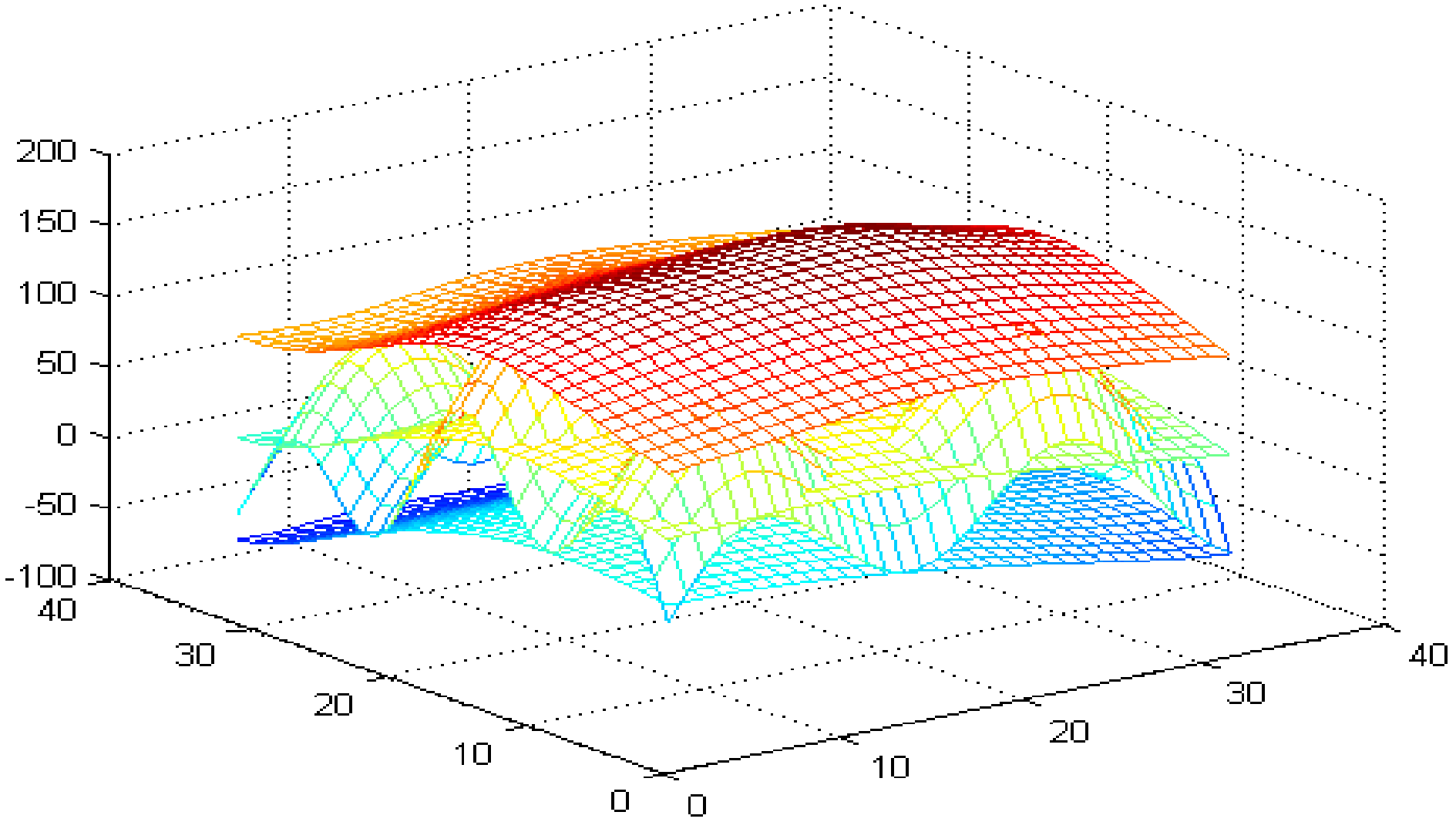
EMD → two modes



Bi-dimensional EMD (BEMD)→

Image Data Analysis

“2D Spline”



Methods for Spline in BEMD

- Radial Based Function
- Thin Plate Interpretation
- Delaunay Triangulation
- By Slicing
- NURBS : NonUniform Rational B-Spline

Radial Based Function

Linear	$\phi(r) = r$
Cubic splines	$\phi(r) = r^3$
Thin plate splines	$\phi(r) = r^2 \log(r)$
Hardy's multiquadrics	$\phi(r) = \left(r^2 + c^2\right)^{1/2}$
Inverse multiquadrics	$\phi(r) = \left(r^2 + c^2\right)^{-1/2}$
Exponential splines	$\phi(r) = \exp(-cr)$
Gaussian splines	$\phi(r) = \exp(-cr^2)$
Compactly supported spline	$\phi(r) = (1-r)^m + p(r)$

Thin Plate Smoothing

Thin plate smoothing spline calculates the function f(x,y) so that it minimizes the integral bending norm, I_f, over the entire image

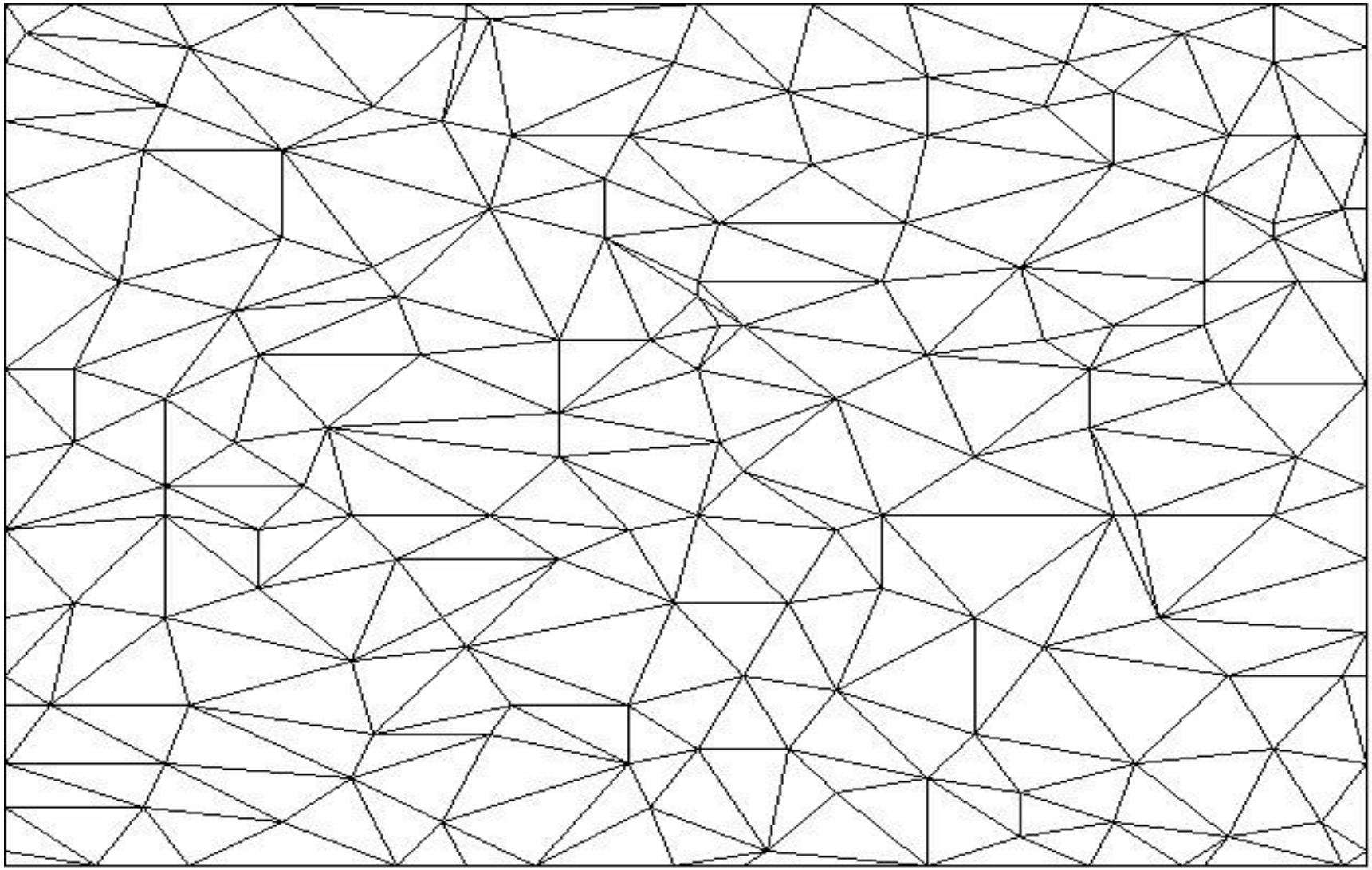
$$I_f = \iint_R \left[\left(\frac{\partial^2 f}{\partial x^2} \right)^2 + 2 \left(\frac{\partial^2 f}{\partial x \partial y} \right)^2 + \left(\frac{\partial^2 f}{\partial y^2} \right)^2 \right] dxdy$$

This means the solution of a linear system with as many unknown as there are data points.

Delaunay Triangulations

- On the basis of Delaunay triangulation we will calculate maximum envelop using the Bernstein-Bezier fitting and interpolation The Bernstein-Bezier calculation includes an optimal fitting around any maximum point and first order smooth connecting along each adjacent edge of Delaunay triangles.

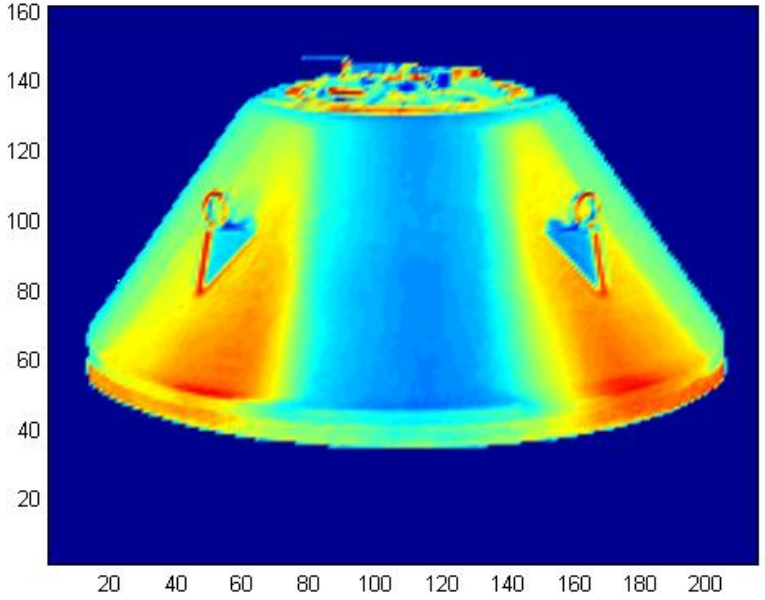
The basis of Delaunay triangulation



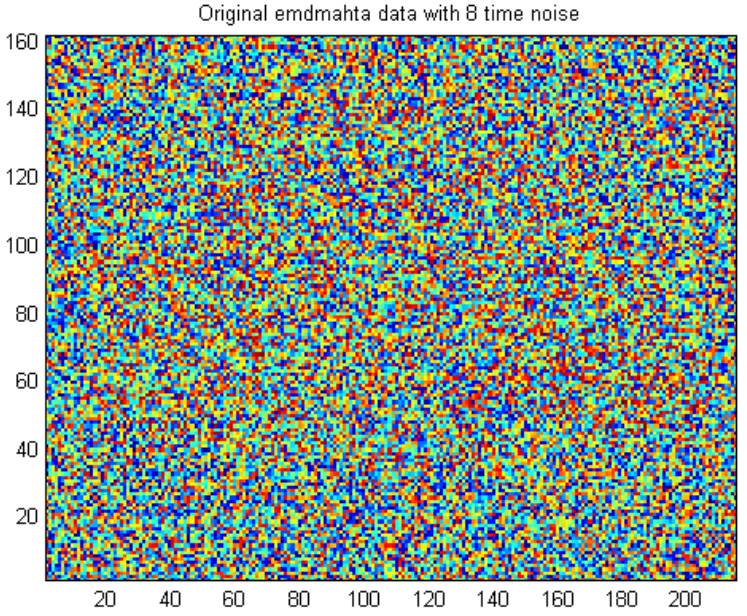
BEMD for Processing Sidescan Sonar (or other) Data → Mine Detection/Change Detection

Manta Mine

- Manta Mine



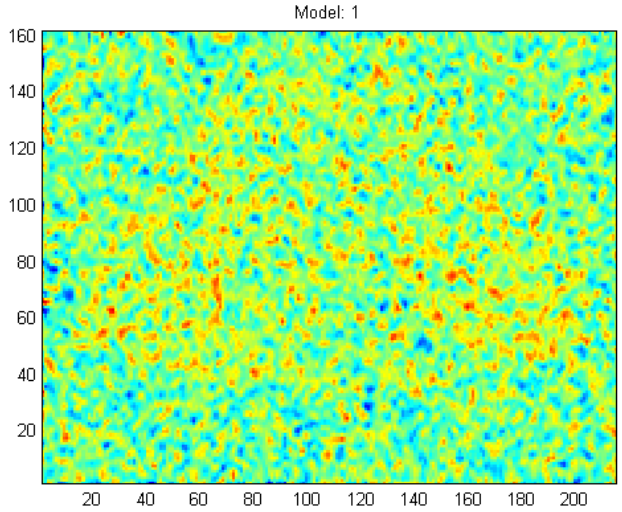
- Manta Mine + Random Noises (Noise/Signal ~ 8) by MATLAB



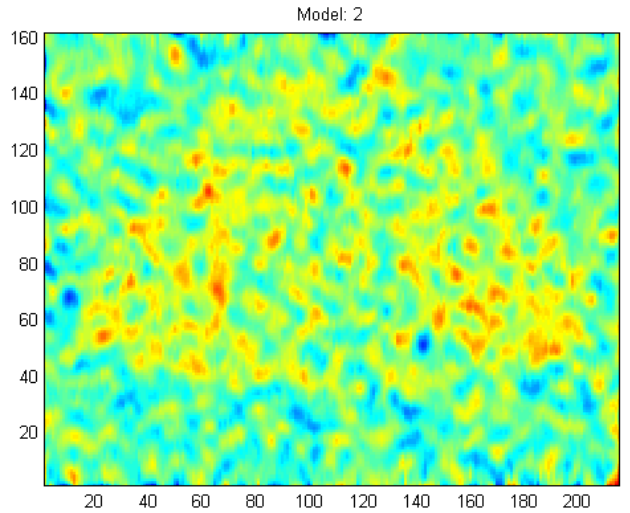
Can we recover the signal (left) from the noisy image (right)?

First Four BEMD Modes

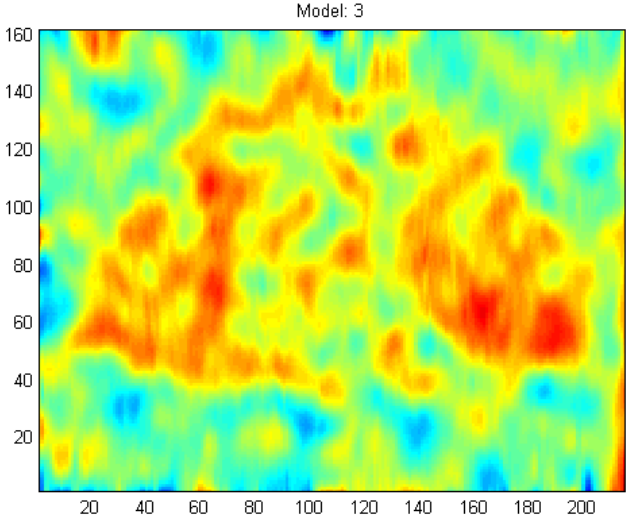
Mode 1



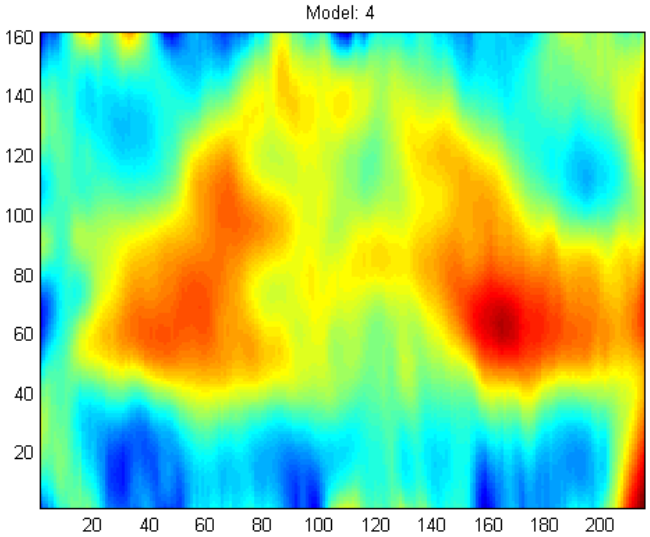
Mode-2



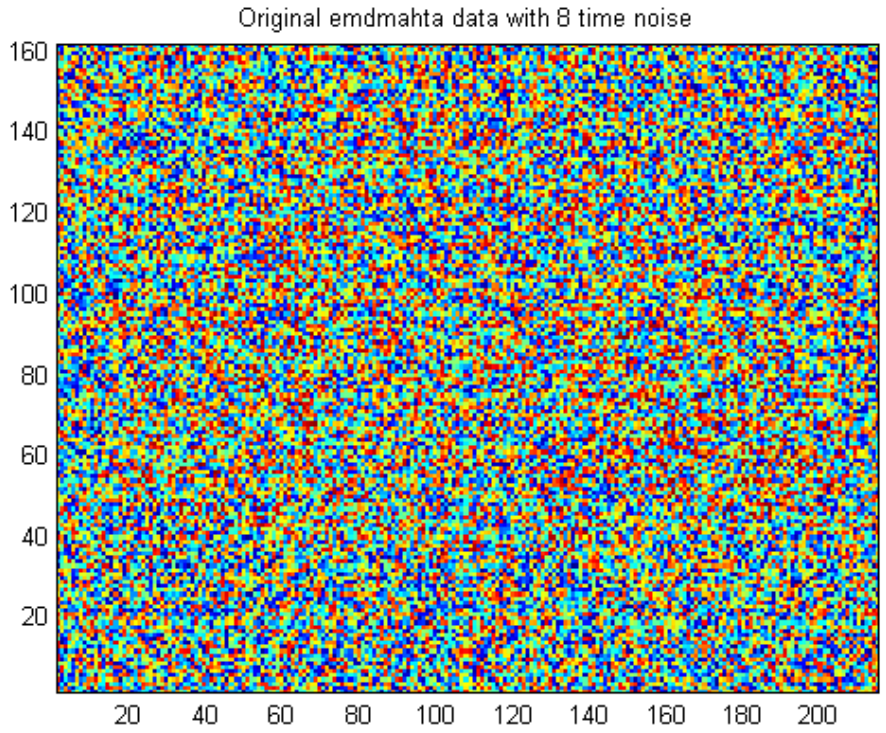
Mode-3



Mode-4

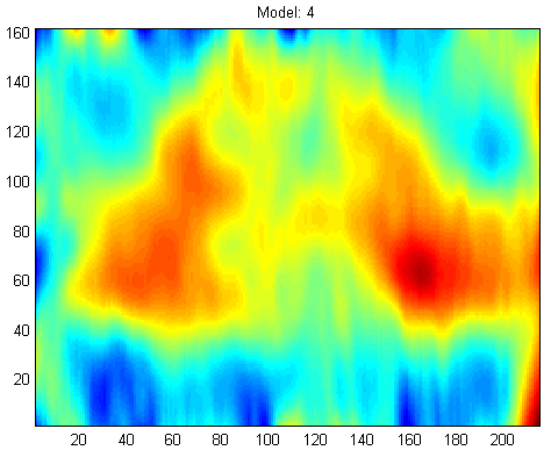


Mode-1 + Mode-2 + Mode-3 + Mode-4 →

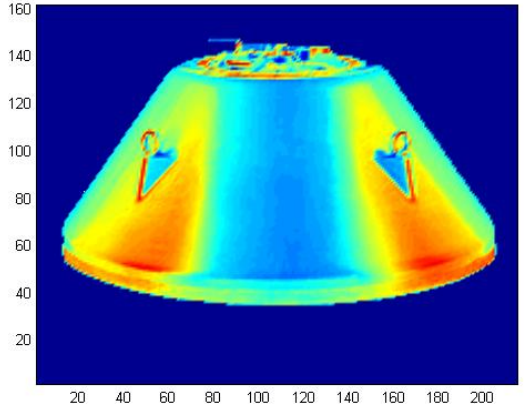


Comparison between Mode-4 and Manta Mine Image

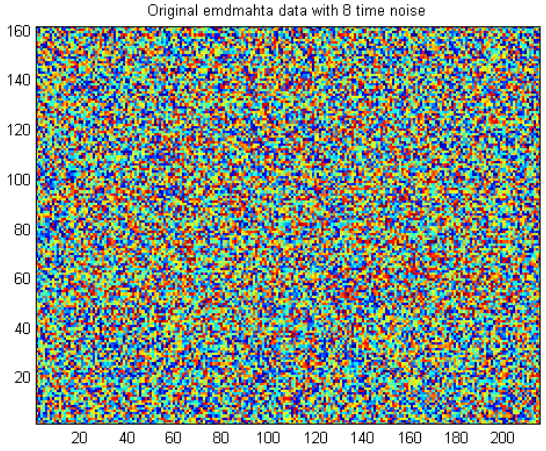
Mode-4



Manta Mine



Original Image



Ongoing Work

- (1) Developing efficient BEMD software for analyzing 2D images
- (2) Developing codes specially for analyzing NAVO image data (sidescan sonar, laser, radar, …)
- (3) Implementing the software into Navy mine detection platforms such as sidescan sonar, ALMDS, …
- (4) Developing simple and efficient method for identifying change detection

(2) Overview of the Navy's Ocean Modeling for ASW

Many Thanks to Dr. Frank Bub at the Naval Oceanographic Office for Providing Useful Information

Passive Sonar Equation

$$SE = SL - PL - LE - RD$$

where:

SE = Signal Excess
SL = Source Level
PL = Propagation Loss
LE = Total Background Noise
RD = Recognition Differential

ASW Success Foundation



Figure of Merit

- Often a **detection threshold** is established such that a trained operator should be able to detect targets with that $L_{S/N}$ half of the time he hears them. Called "**Recognition Differential.**" **(RD)**
- Passive sonar equation is then solved for TL allowable at that threshold. Called "**Figure of Merit.**" **(FOM)**

$$TL_{allowable} = \text{Figure of Merit} = SL - L_{S/N\ Threshold} - RD$$

- Any $L_{S/N}$ above the Recognition Differential is termed "**Signal Excess**." **(SE)** Signal Excess allows detection of targets beyond the Range of the Day.

Environmental Checklist

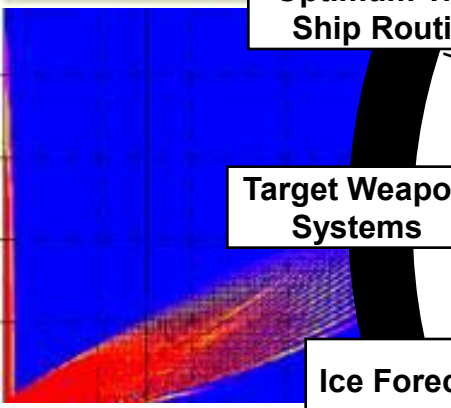
- Sample environment early
  - Water sampler flights, SSN , AN
    - (4-7) dB area environmental tuning advantage
- Be aware of mutual interference
  - Increased sonobuoy RF interference
  - Multiple platform active (reverb) (4-8 dB)
- Be aware of and use fronts, geography, topography
- Integrate acoustic and non-acoustic sensor employment for the force based upon environment
- Update environment/predictions on-station

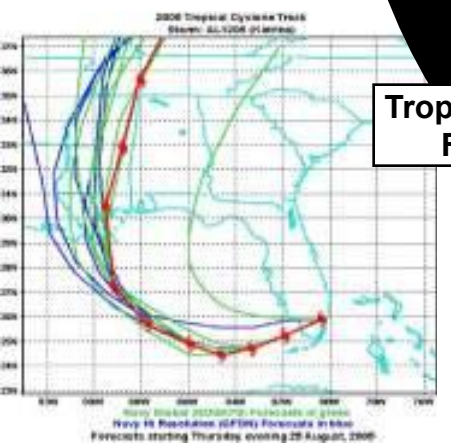
  * BT * Weather *AN *FOM *EM/EO

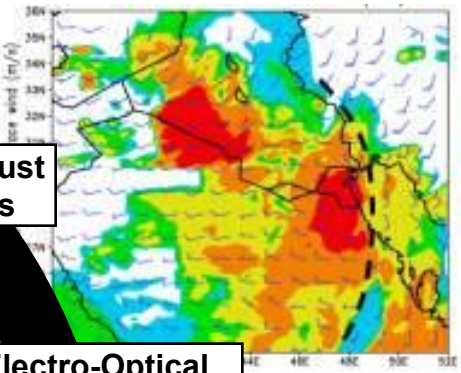
UPDATE, UPDATE, UPDATE

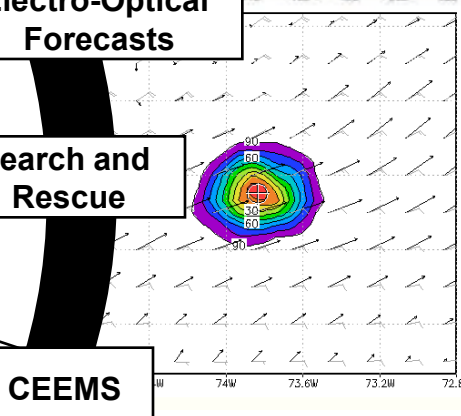
FNMOC Models and Applications

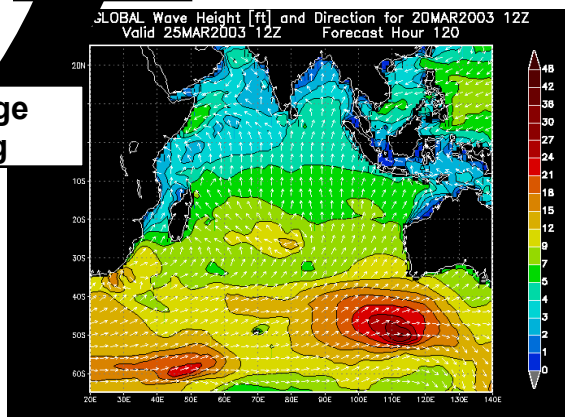












Ocean Acoustic Forecasting

Aircraft Routing

Automated High Seas / Wind Warnings

Visibility/Dust Forecasts

Optimum Track Ship Routing

Aerosol Modeling

Electro-Optical Forecasts

Target Weapon Systems

Global Models

NWP

Regional Models

Search and Rescue

Ice Forecasts

CEEMS

Ensemble Models

Tropical Cyclone Forecasts

Long-Range Planning

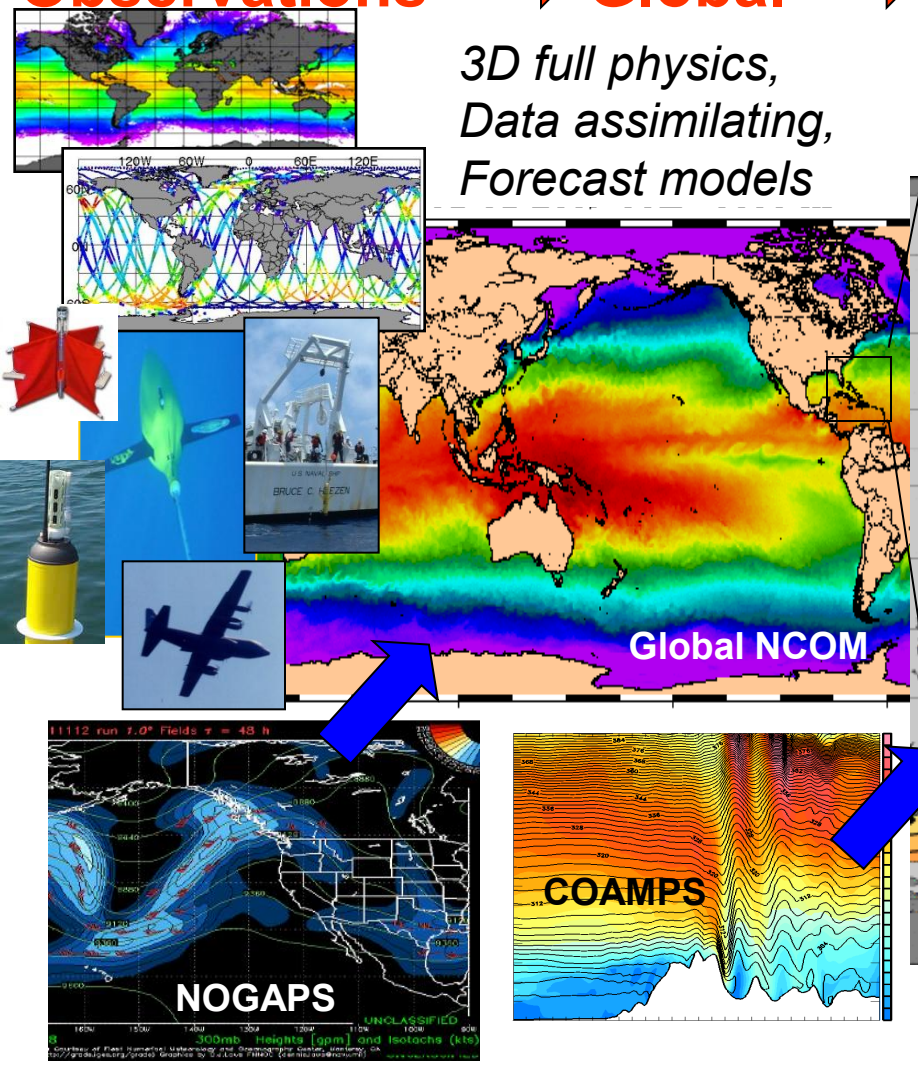
Ballistic Wind Computations

WRIP

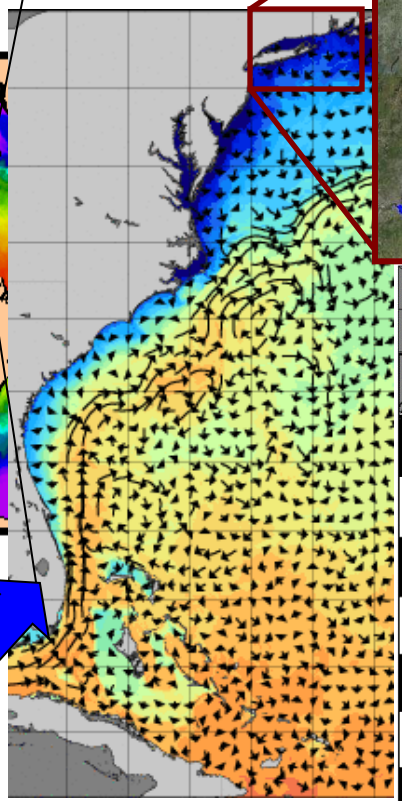
The Grand View - Ocean and Atmosphere Circulation Modeling

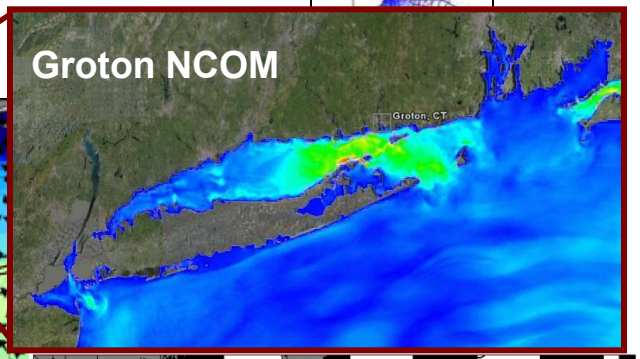
Observations ➡ **Global** ➡ **Regional** ➡ **Coastal**

3D full physics,
Data assimilating,
Forecast models

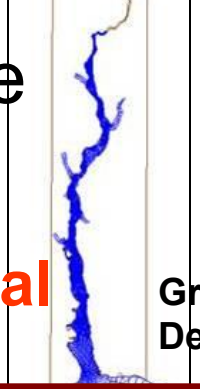


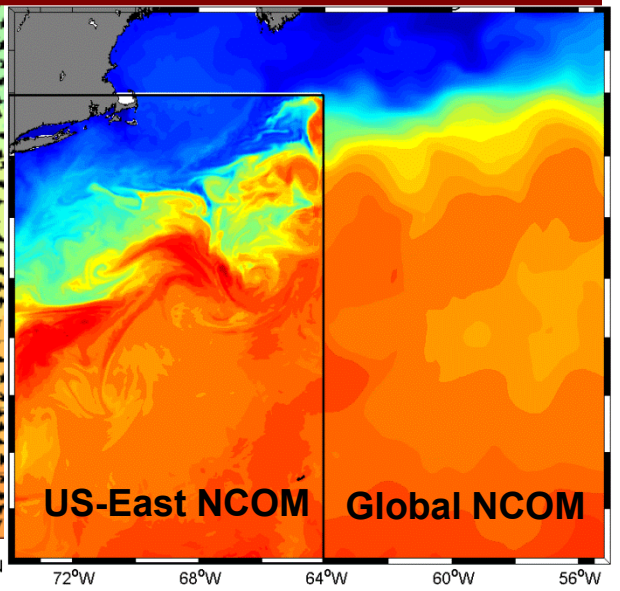
US-East NCOM





Groton Delft3D





Atmospheric Models at FNMOC

- NOGAPS – Navy Operational Global Atmospheric Prediction System; T319L42 global spectral model, at the center of FNMOC production.
- COAMPS/CAAPS – Coupled Ocean/Atmosphere Mesoscale Prediction System; regional mesoscale model, multi-nested to ~2 km resolution within NOGAPS.
- NAVDAS – Navy Atmospheric Variational Data Assimilation System; 3D-VAR data assimilation for NOGAPS and COAMPS. NAVDAS-AR 4D-VAR Weak Constraint now operational.
- GFDN – Navy implementation of the GFDL TC model; only moveable-nest TC model operational in all ocean basins (critical part of 4-member CONW and 5-member CONU for extended TC forecasts). Nested within NOGAPS.
- WW3 – WaveWatch III spectral ocean wave model; global and regional implementations, driven by NOGAPS and COAMPS.
- EFS – NOGAPS-based global 18-member 10-day Ensemble Forecast System (part of NAEFS and JEFS collaborations); includes 18-member global WW3 ensemble.
- NAAPS – Navy Atmospheric Aerosol Prediction System; only operational global aerosol model. Atmospheric optical properties output feeds Target Acquisition Weapons Software (TAWS). Driven by NOGAPS.

Ocean Models at NAVOCEANO

Global Circulation Models
- NLOM
- G-NCOM
- HYCOM

3-D Coastal Circ Models
- SWAFS →
- Regional NCOM
- Coastal NCOM
- ADCIRC
- DELFT 3D

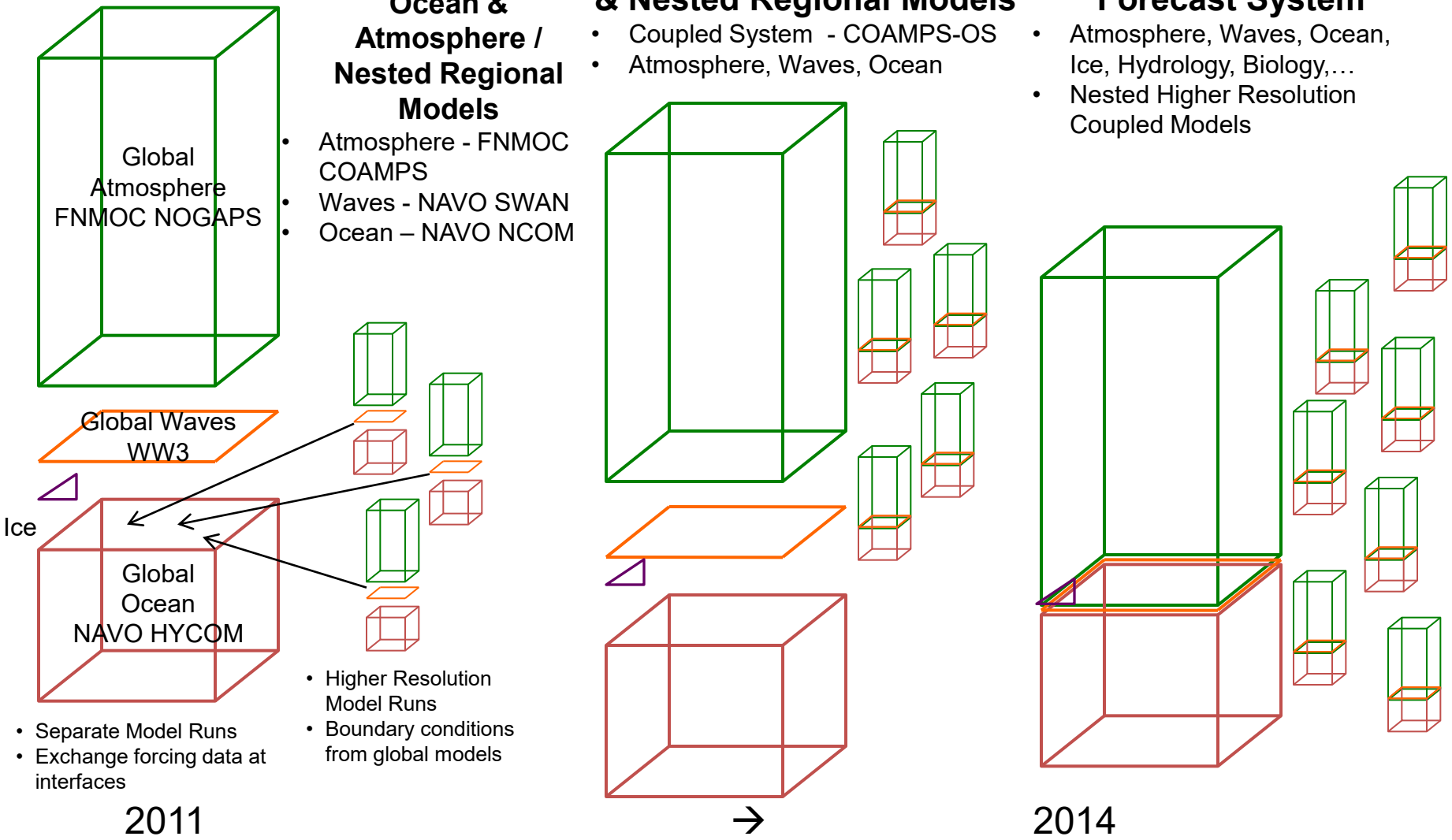
Vertical Profile (T,S) Model
- MODAS → NCOMs

Wave Models
- WAM → WW3
- SWAN
- Navy Standard Surf Model

2-D Coastal Circ Models
- PC-Tides
- ADCIRC
- WQMAP
- HydroMap
- RMA-2

Ice Models
- PIPS 2.0 →
- PIPS 3.0 (CICE)

Schematic of Ocean-Atmosphere Modeling Plans



Separate Global Ocean & Atmosphere / Nested Regional Models

- Atmosphere - FNMOC COAMPS
- Waves - NAVO SWAN
- Ocean – NAVO NCOM

- Separate Model Runs
- Exchange forcing data at interfaces

- Higher Resolution Model Runs
- Boundary conditions from global models

Separate Global & Nested Regional Models

- Coupled System - COAMPS-OS
- Atmosphere, Waves, Ocean

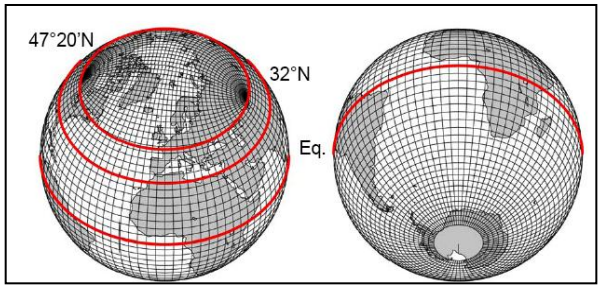
Coupled Global Forecast System

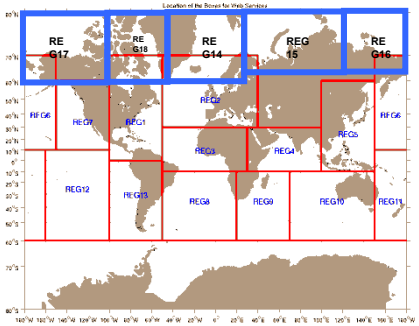
- Atmosphere, Waves, Ocean, Ice, Hydrology, Biology,…
- Nested Higher Resolution Coupled Models

2011 → ~2018 → 2014

Global Navy Coastal Ocean Model (G-NCOM)

- Daily 3D Forecasts of ocean
  - Temperature
  - Salinity
  - Currents
  - Elevation (tides)
- Resolution
  - Horizontal grid: 1/8 deg
  - 42 vertical layers
  - Including Arctic via 3-pole grid
- Forecast to 72 (96)hr @ 3hr increments
- Based on the Princeton Ocean Model
- FNMOC NOGAPS atmosphere forcing
  - Wind stress (momentum)
  - Heat fluxes (IR/visible/sensible/evaporation)
- Tides from OSU (Egbert) model added
- Coupled with the Los Alamos CICE Ice model in the Arctic



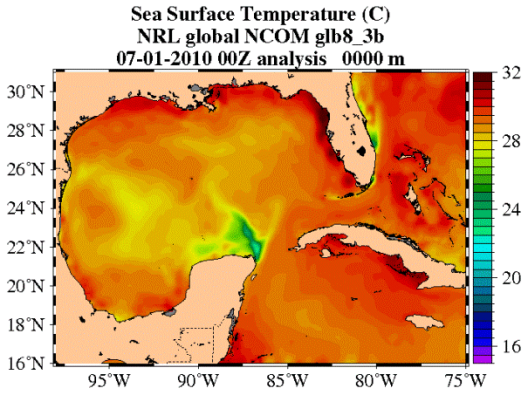


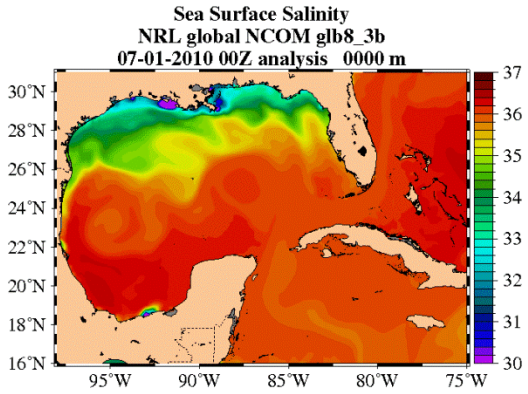
- Operational 2004, latest version 2008
- Outputs are NetCDF and wavelet files, graphics, derived products
- Assimilates
  - Sea surface temperature and elevation from satellites (SST / SSH)
  - Temperature & salinity data from surface observations and profiles (CTD, floats, gliders, marine mammals)
  - NCODA / MVOI assimilation scheme

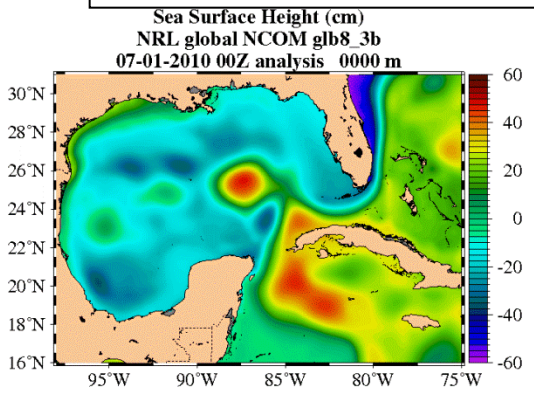
This is a deep water model

- To forecast mesoscale processes
- Resolves order ½ degree features
- Use with caution within 2-3 grid points of land

1/8 deg (14 km / 7.5 nm)

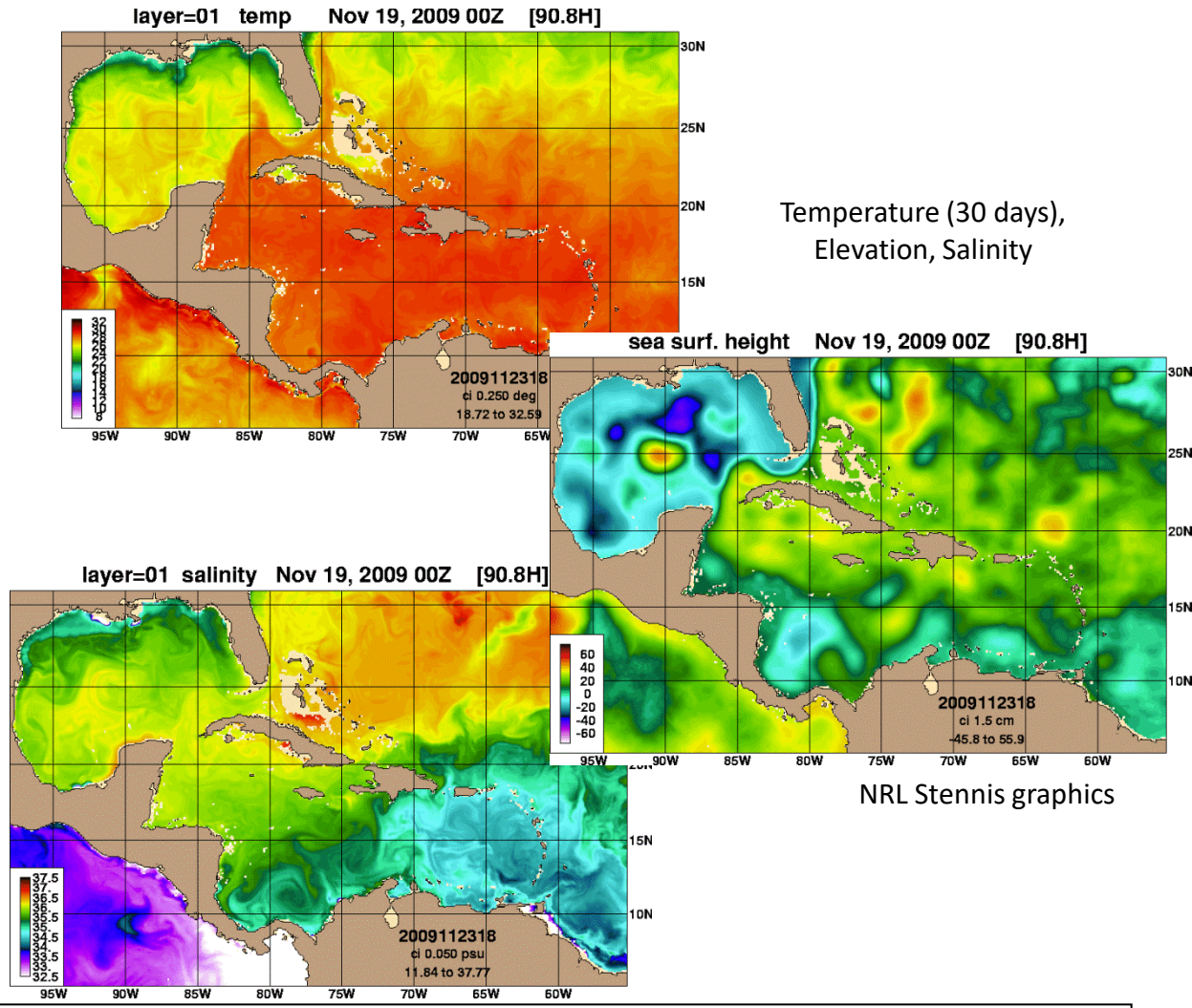






Next Generation: Global Hybrid Coordinate Ocean Model (G-HYCOM)

- Next generation dynamic model
- POM-based / variable vertical coordinates
- NOPP Consortium
  - NRL lead,
  - U Miami, Los Alamos, French, NOAA/AOML, etc.
- Forecasts 3D Temperature, Salinity, Currents, Elevation
  - To 120 hours
  - ESMF backbone
- Initial global resolution 1/12 deg (2010)
  - Final resolution 1/25 deg (2012)
  - 40+ vertical layers
  - Pressure, depth, sigma coordinates as needed
- FNMOC NOGAPS atmospheric forcing
- Assimilates SST / SSH / surface obs / profile data – using NCODA
- Planned to replace global NCOM & some regional domains
  - Running pre-operational at NAVOCEANO
  - VTR completed
  - OPTEST FY11
- Global service to NOAA, others



Temperature (30 days), Elevation, Salinity

NRL Stennis graphics

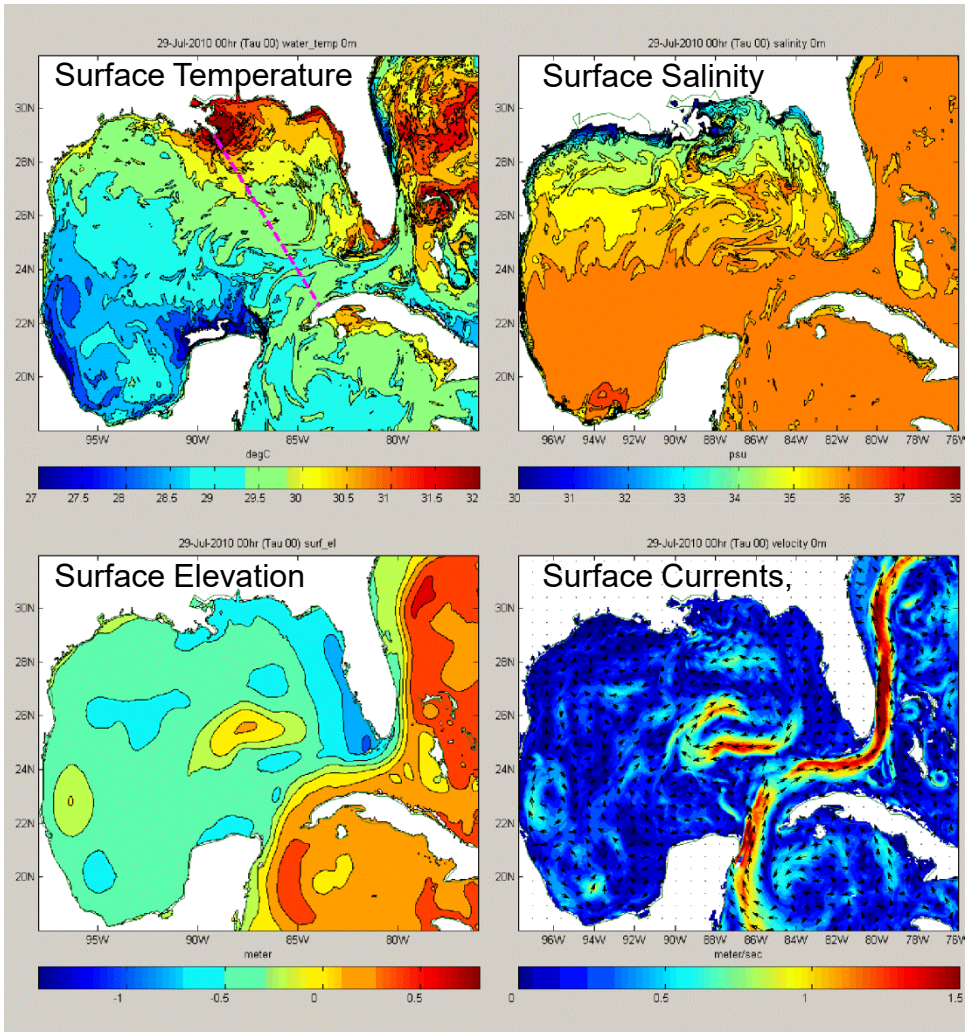
1/12 (9 km / 5 nm) → **1/25 deg** (3.8 km / 1.8 nm) in 2014

Regional Navy Coastal Ocean Models (R-NCOM)

- Same structure / algorithms as GNCOM
- Boundary Conditions provided by GNCOM
- FNMOC COAMPS forcing
- 3D Forecasts
  - T, S, Currents, Elevation
  - Resolution varies (~1 / 36 deg)
  - 55 vertical layers
  - Forecast to 72/96 hr @ 3hr increments
- Assimilates data from
  - Satellites (SST, SSH)
  - *insitu* obs (XBTs, CTDs, floats, buoys)
- First - East China Sea (ECS) NCOM operational MAR08
- Replaced MODAS for ASW support
- Implement 3 - 4 regions/year
- Eventual transition to COAMPS-OS (coupled atmosphere—ocean—waves)

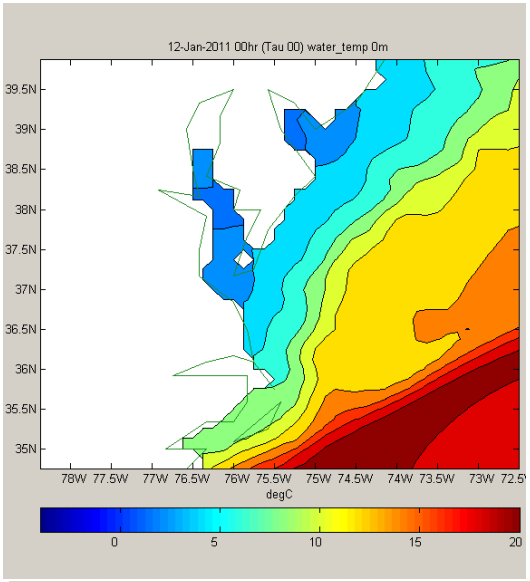
1/36 deg (3 km / 1.7 nm)

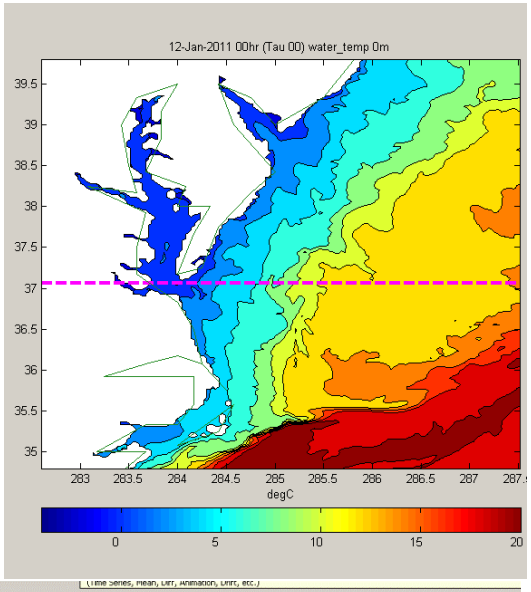
American Seas R-NCOM 96-Hr Series

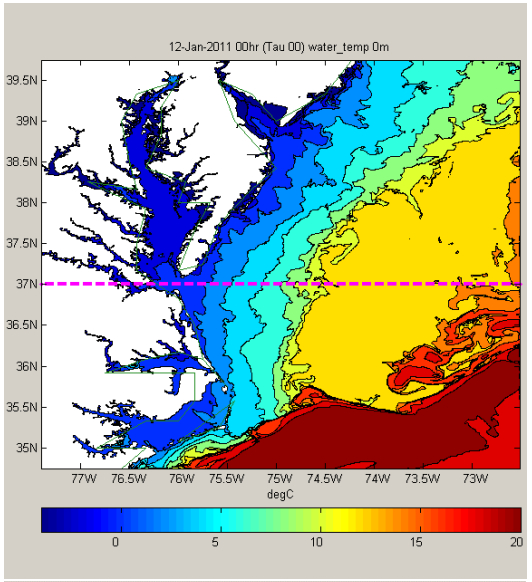


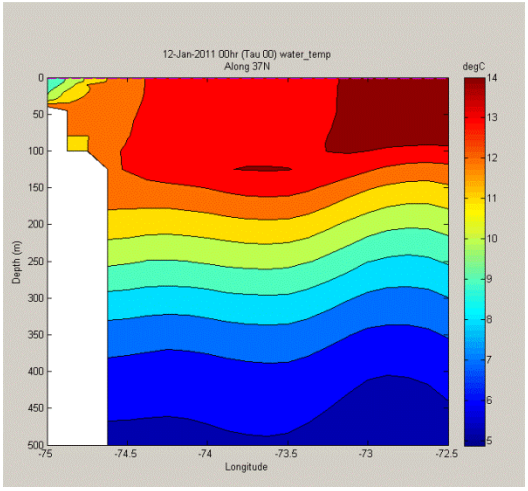
Sea Surface Temperature & 500m Section along 37°N

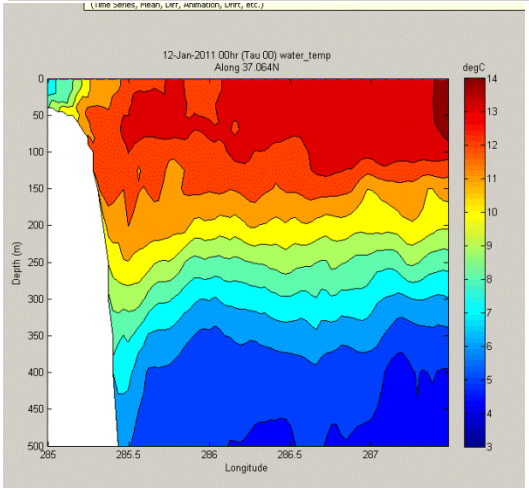
Global NCOM (1/8°) – USEAST-NCOM (1/36°) Chesapeake NCOM (1/216°)

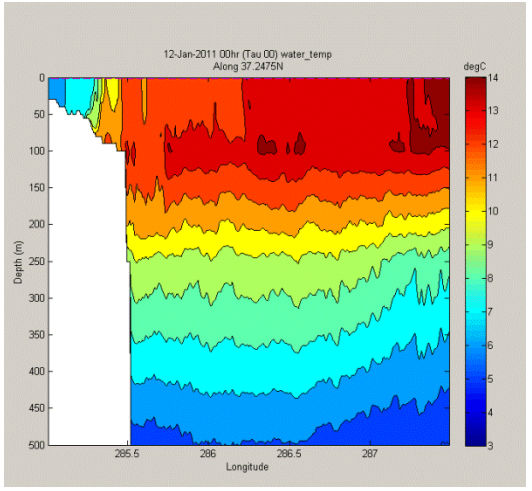






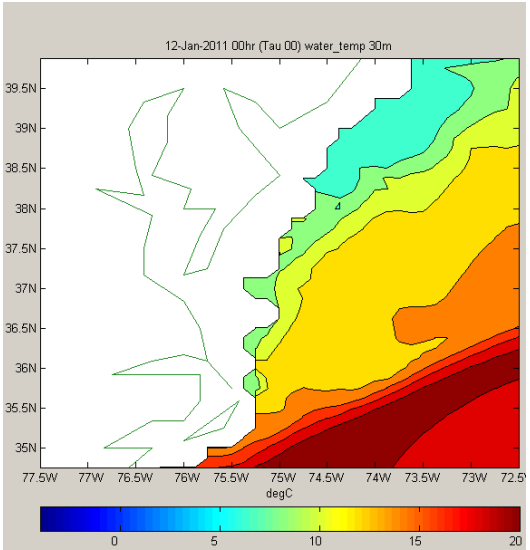


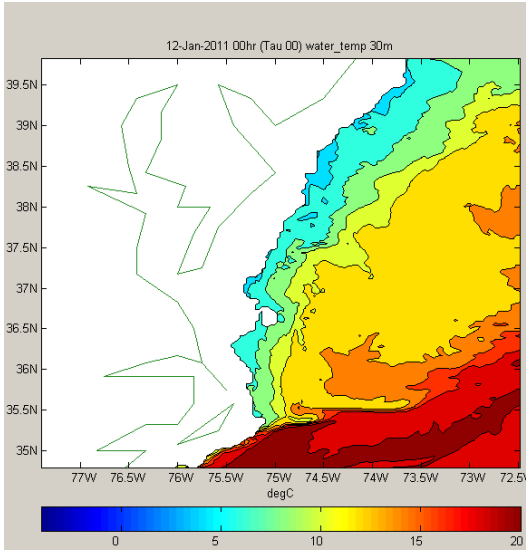


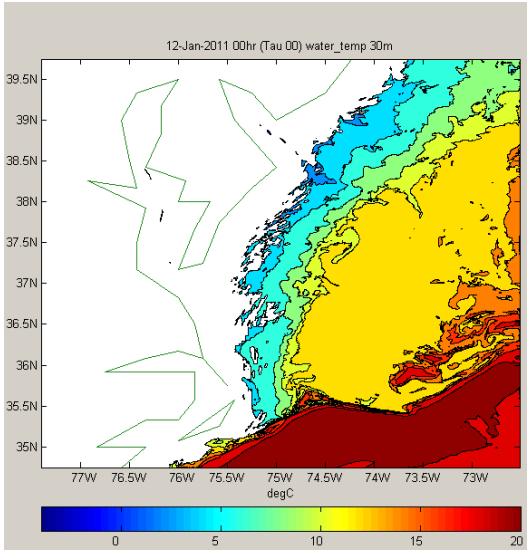


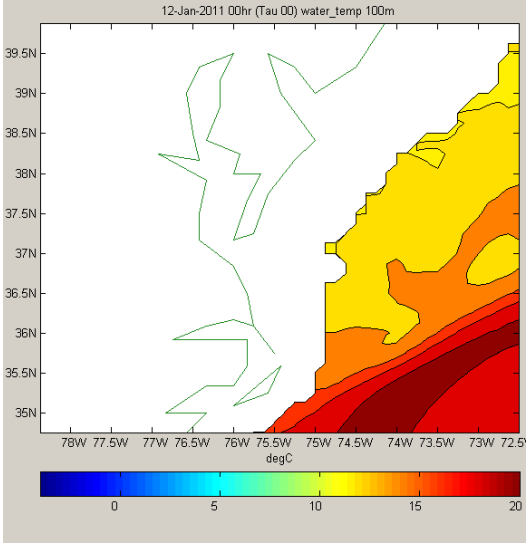
Temperature at 30m (100ft) and 100m (330ft)

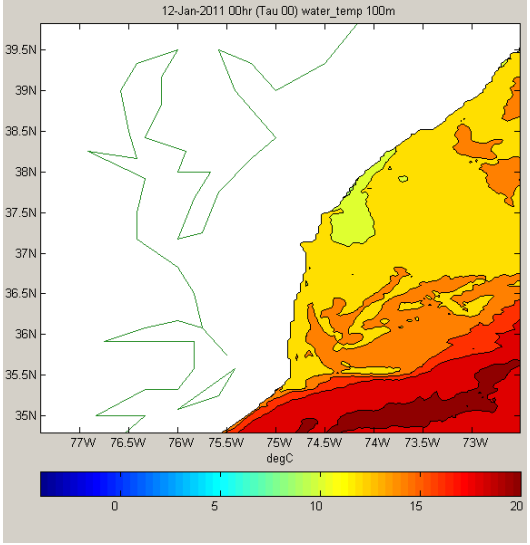
Global NCOM (1/8˚) – USEAST-NCOM (1/36˚) Chesapeake NCOM (1/216˚)

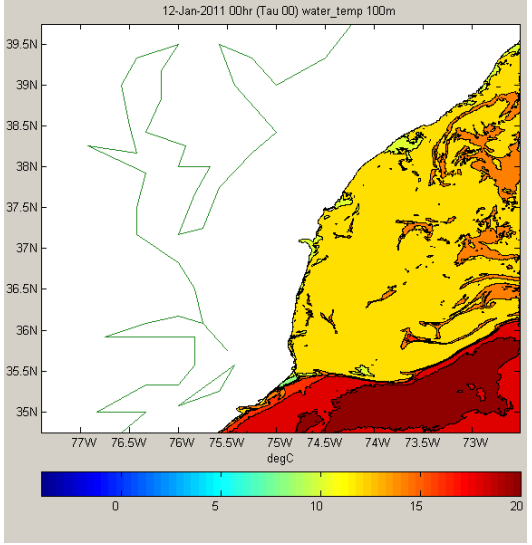






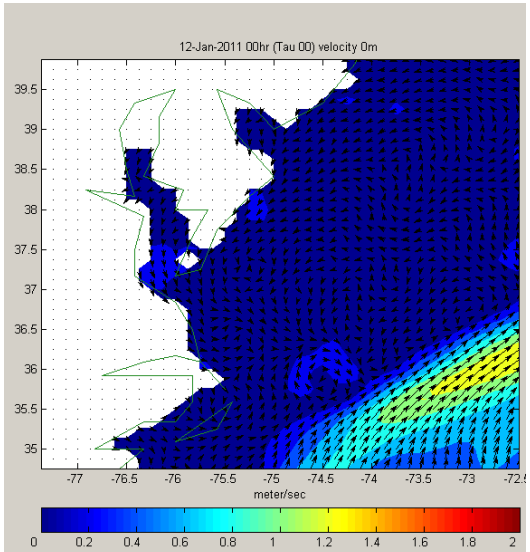


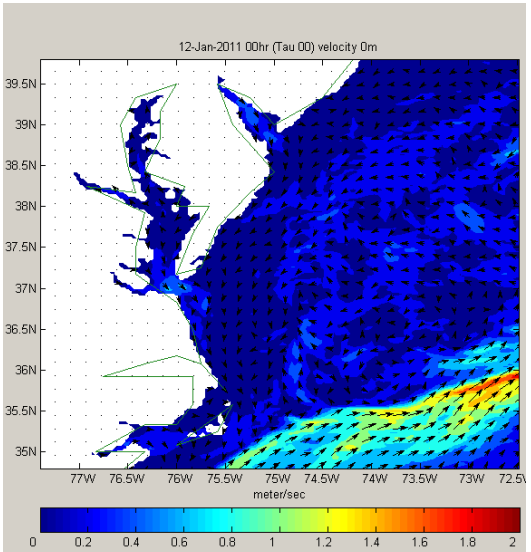


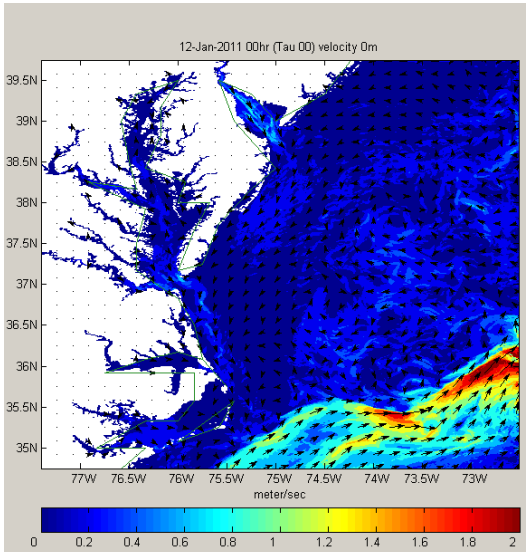


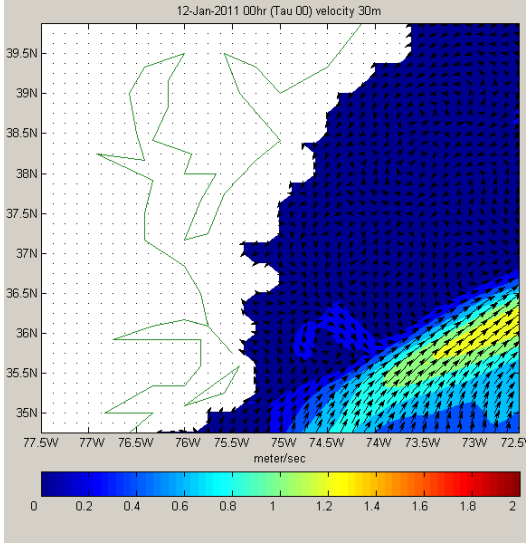
Sea Surface & 30m (100ft) Currents

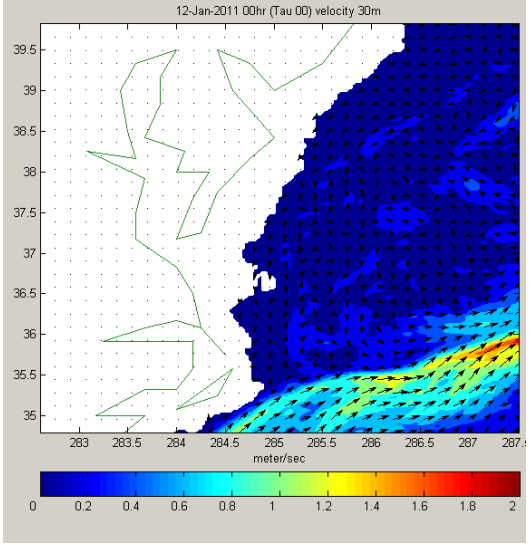
Global NCOM (1/8°) – USEAST-NCOM (1/36°) Chesapeake NCOM (1/216°)

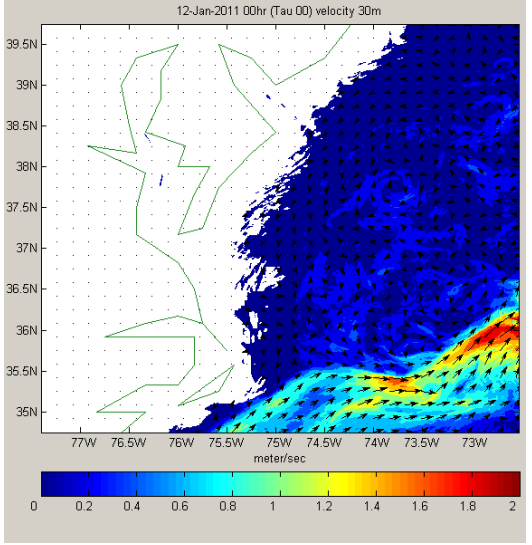




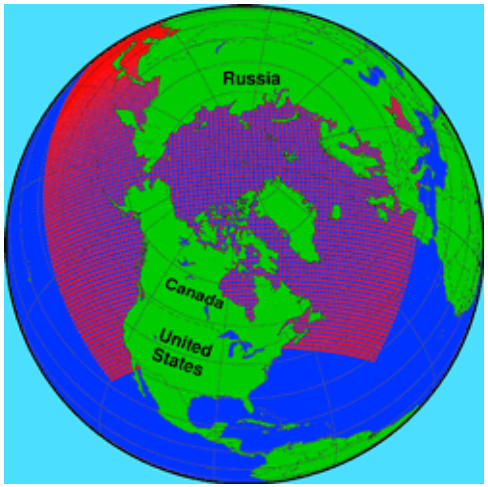


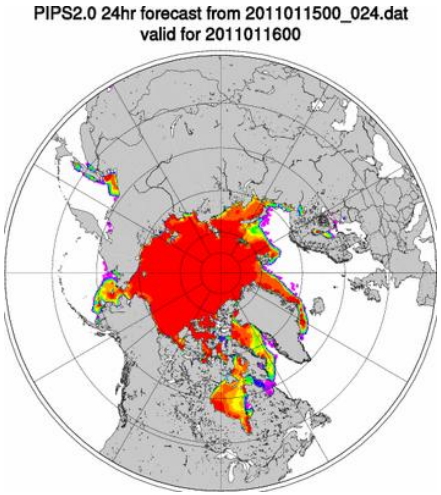




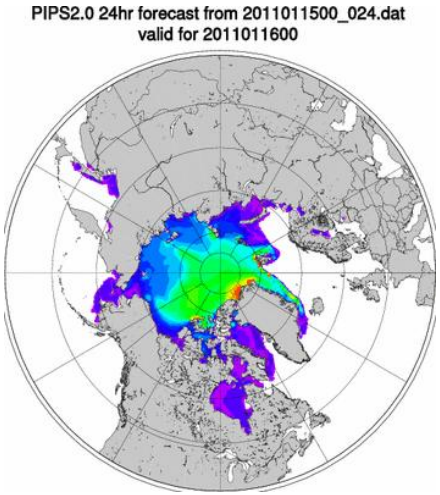


PIPS 3.0 – Community Ice CodE (CICE)

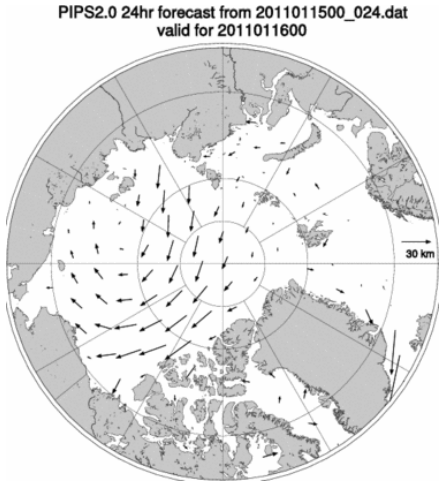




Coverage



Thickness

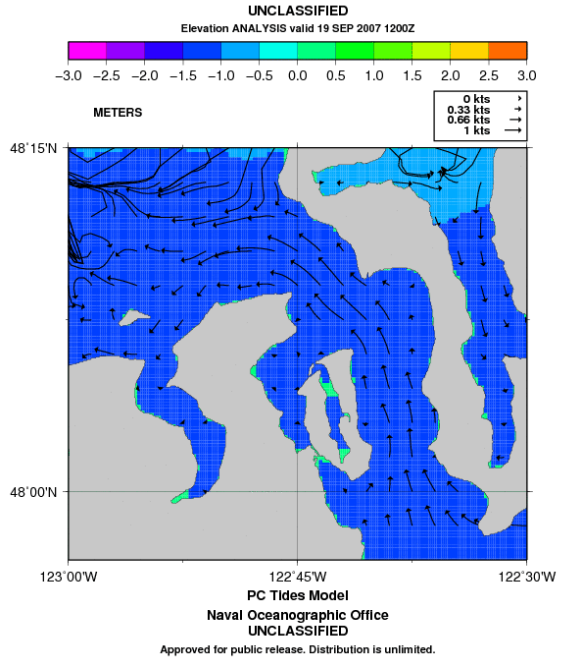


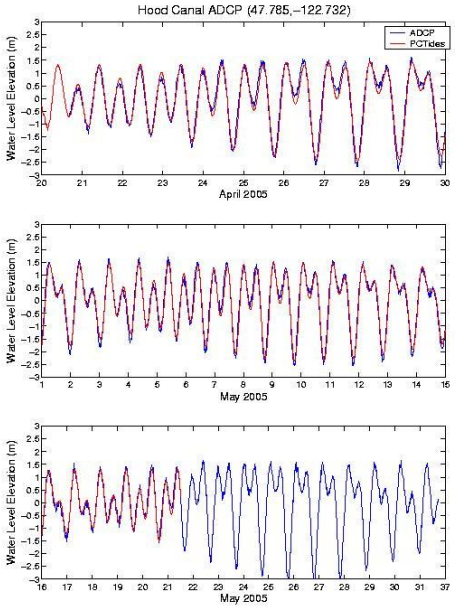
Displacement

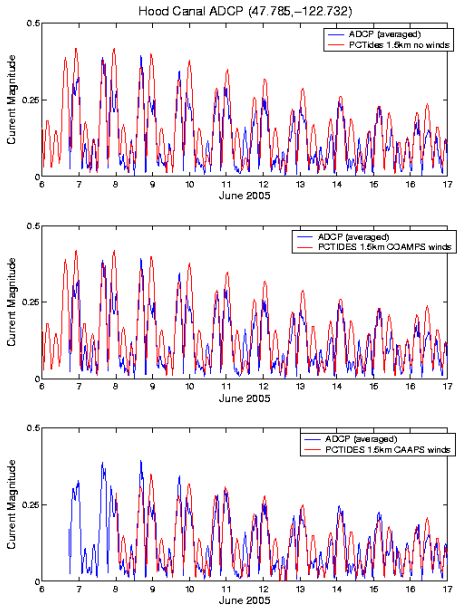
- CICE on a 9 km Arctic grid similar to the PIPS 2.0
- NRL ran CICE model (version 3.1) through a series of tests using NOGAPS 1999-2003 forcing
- ESMF version of CICE set up
- Plan is to couple PIPS 3.0 with G-HYCOM during FY127

Coastal Models - PCTides

- Application of wave equation
- 2D barotropic model
- Forced by tidal stations & FNMOC / local winds
- Tidal elevation & currents
- Assimilates nearby tidal stations (4000+ IHO stations)
- 2-minute bathymetry (DBDB2)
- Nest to needed resolution
- Provides a first guess - rapid implementation (<24 hours)
- 2D graphics, time series, constituent table outputs
- Hurricane storm surge module





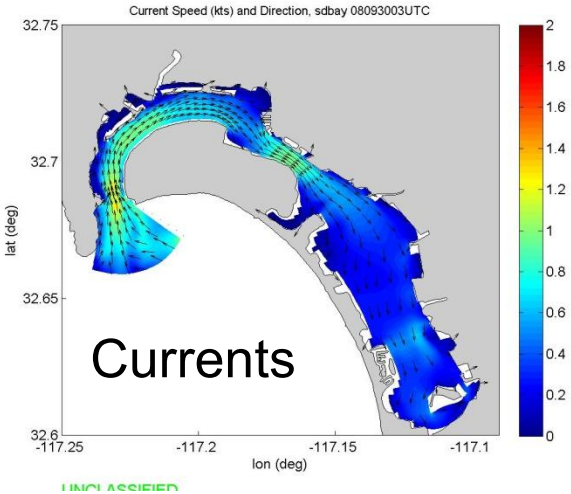


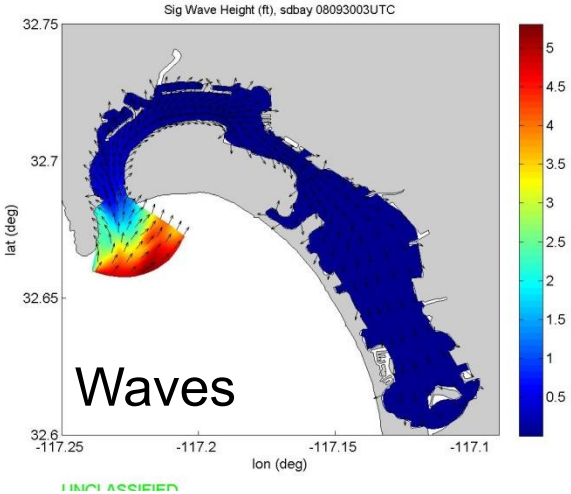
Coastal Model - Delft-3D

MIW – EXW – HLS: Port & Approaches Modeling

Required Data:

- Good bathymetry
- Winds
- Observations
- Model (FNMOC)
- Fixed measurements – real-time data stream
  - Height (tides)
  - Current
  - T & S
  - Waves
- Model output.
  - Graphics
  - Numerical fields for MEDAL





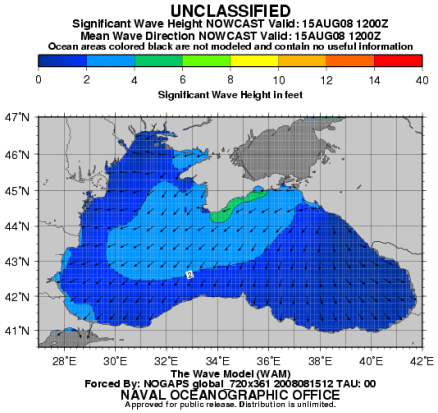
HLS Initial 12 Ports:

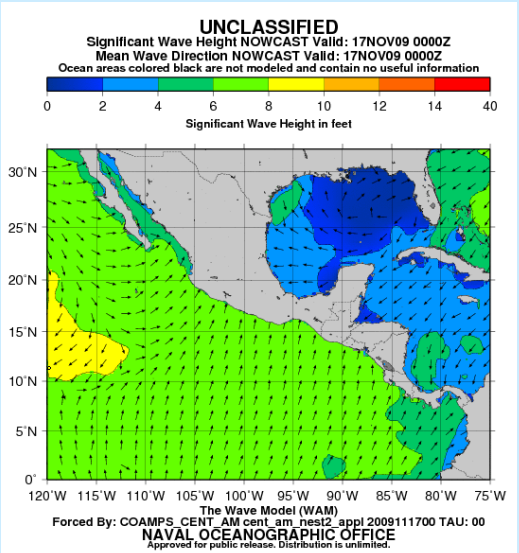
1. Norfolk (VA)
2. Little Creek (VA)
3. Newport News (VA)
4. Groton (CT)
5. King's Bay (GA)
6. Mayport (FL)
7. Bangor (WA)
8. Everett (WA)
9. Bremerton (WA)
10. Ingleside (TX)
11. **San Diego (CA)**
12. Pearl Harbor (Hawaii)

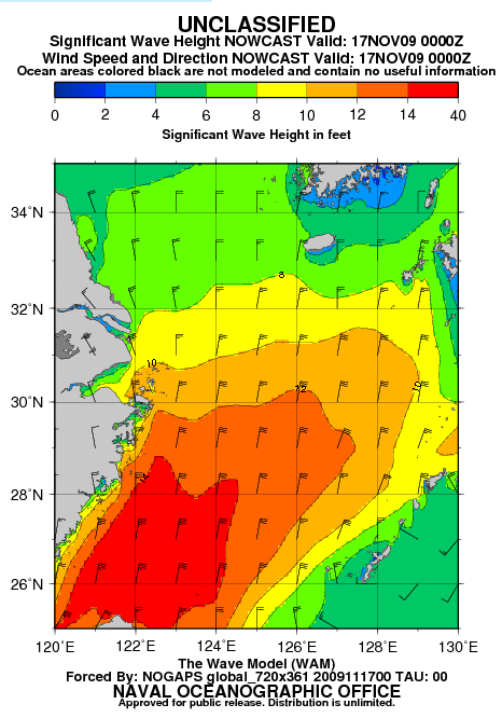
Variable 10-100m or less

Wave Modeling – Global and Regional
Wave Model (WAM) → WW3 (2012)

- Portable - easily relocated
- Variable resolution (1/4º to 1/12º)
- Forecast to 72 hours (2x daily)
- Forced by FNMOC model winds
- Deep water (> 20 m)
- Gridded set of wave parameters
  - Significant wave height & direction
  - Sea & swell wave height, direction, period
  - Wave energy spectra by direction & period

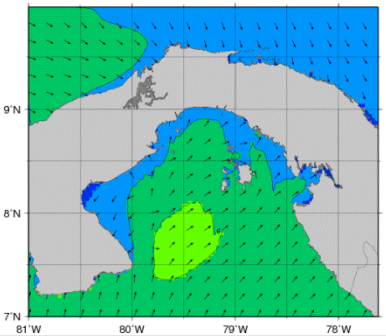


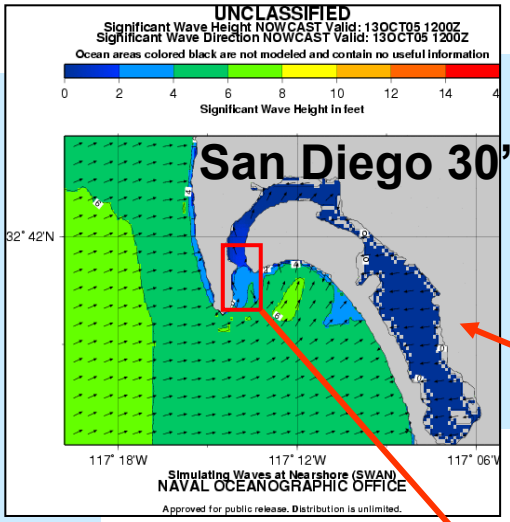


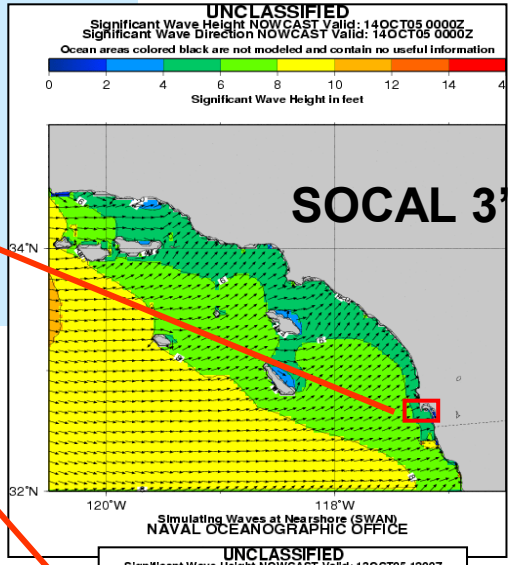


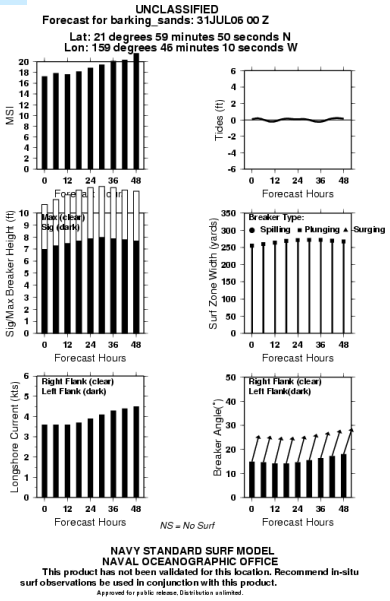
Wave Modeling - Simulating Waves Nearshore (SWAN)

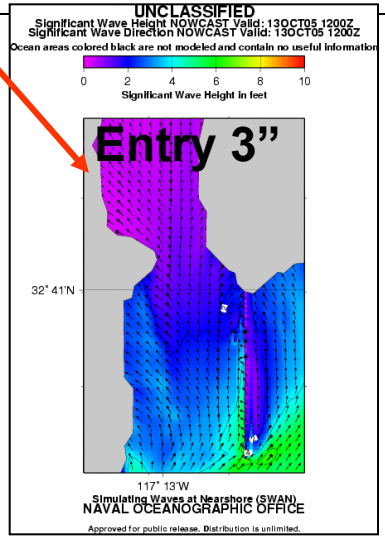
- Part of U. Delft DELFT3D package
- A 3RD generation stand-alone (phase-averaged) wave model
- Simulates waves in deep, intermediate and nearshore depths
  - Forecasts into surf zone
  - Linked to Navy Standard Surf Model (NSSM)
- Resolutions from regional (1/12 deg) to beach (~10 m)
- Deliver graphics, data (NetCDF properties similar to WAM)
- Replacing WAM domains











Time Series of Glider Profiles & Global & Regional NCOM Forecasts of Temperature, Salinity, Potential Density

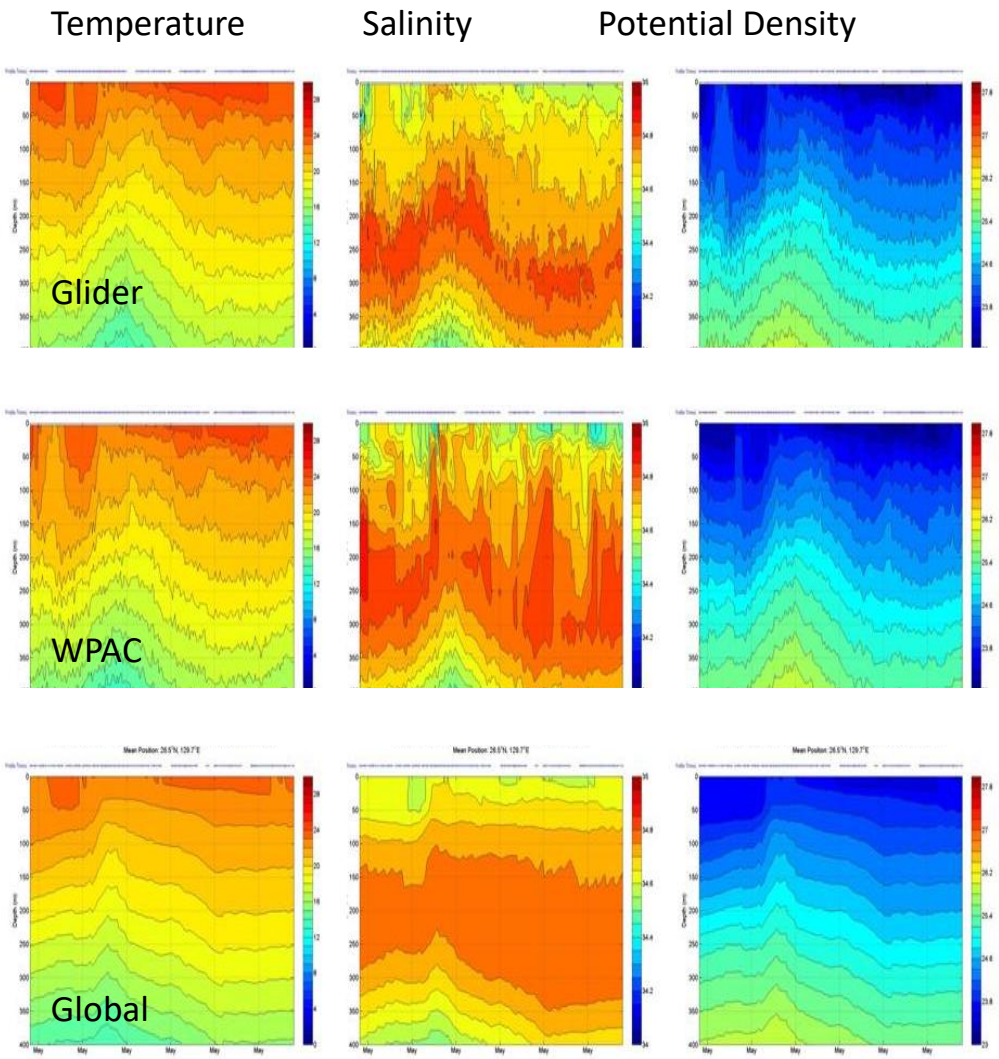
Top – Seaglider CTD observations for the period 01-30 May 2009

Center – 1/36 Degree Regional WPAC-NCOM concurrent profile data

Bottom – 1/8 Degree Global NCOM data

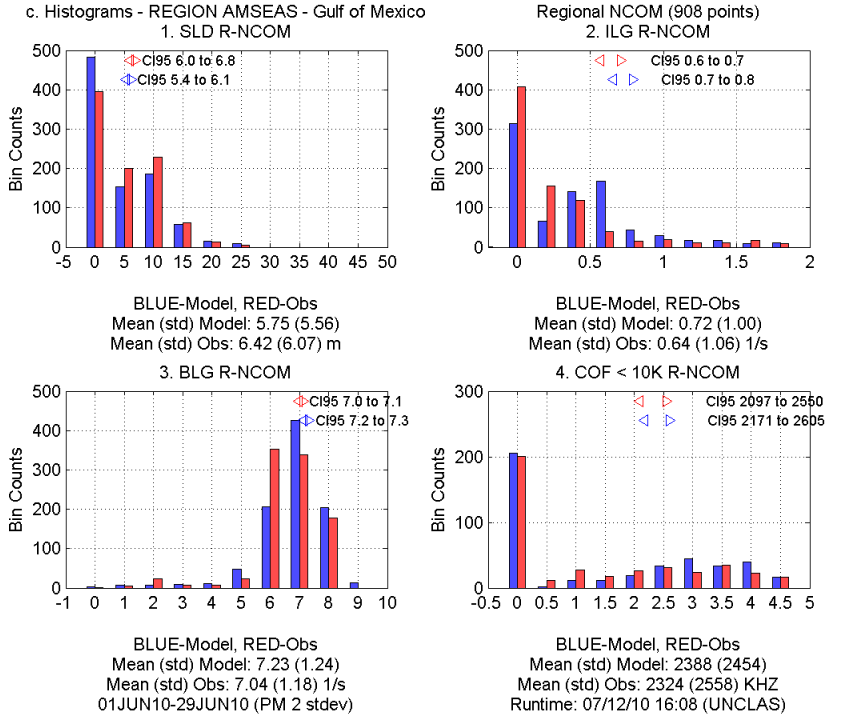
- Glider passed through a cold-core eddy
- Regional NCOM includes tides
  GNCOM does not
  - Note presence of internal tides
  - RNCOM does amplitude well
  - We need to work on phase

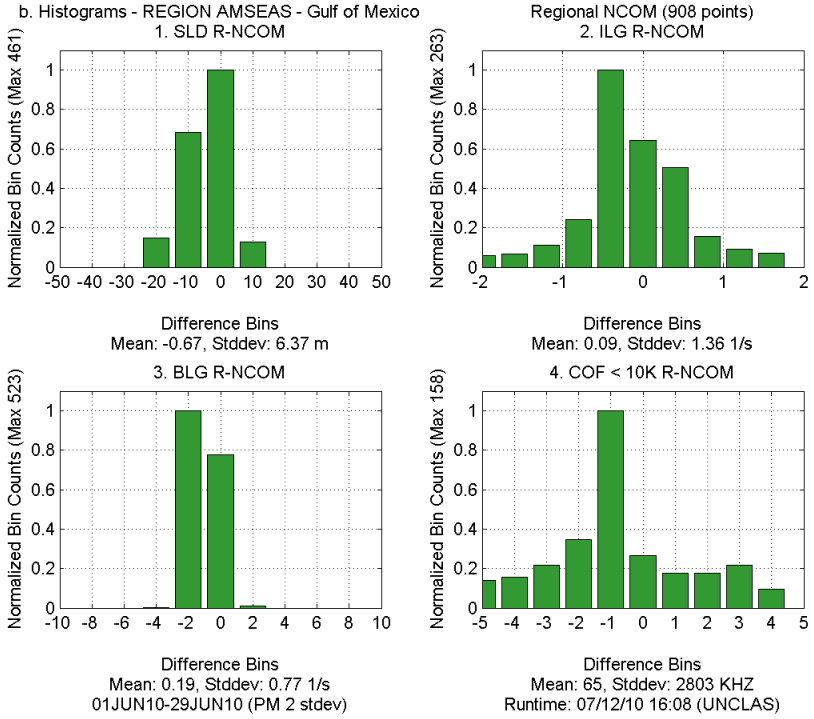
Profile Analysis Viewing Environment (PAVE), Mike Toner, NAVOCEANO



Acoustic Property Analyses
AMSEAS-NCOM – JUNE 2010

Sonic Layer Depth (SLD)	In - Layer Gradient (ILG)
Below Layer Gradient (BLG)	Cutoff Frequency (COF)



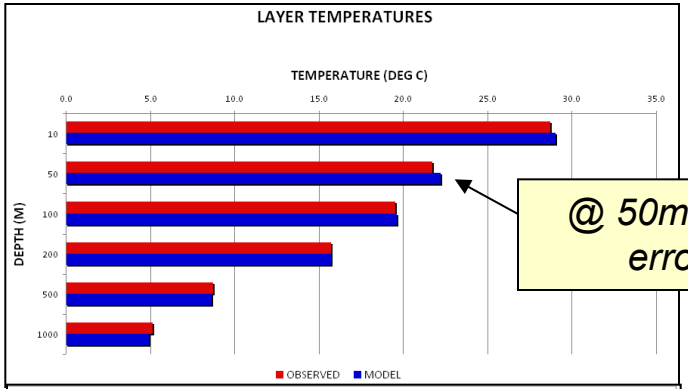


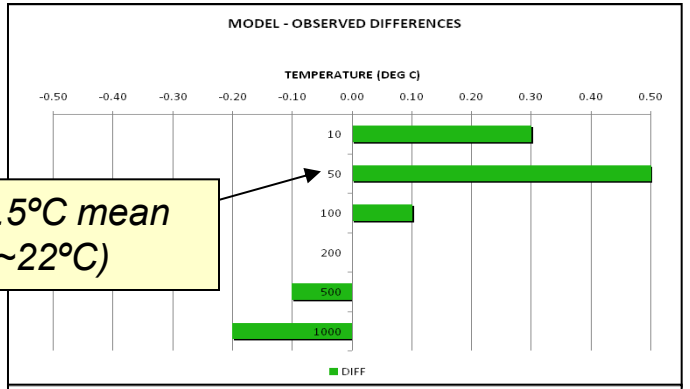
Observed (RED) & Modeled (BLUE) Temperature & Salinity
AMSEAS Comparisons During JUNE 2010 ~1000 profiles

Mean observed (RED) and model (BLUE) **temperatures** at depths of 10, 50, 100, 200, 500, 1000m and model minus observed differences

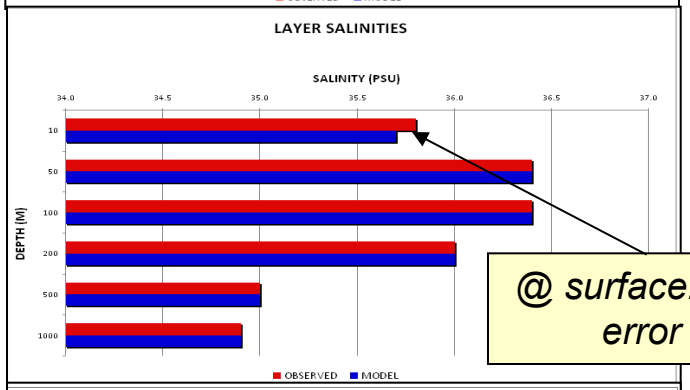
Same graphics for **salinity** (note that XBT salinities are taken from model data)

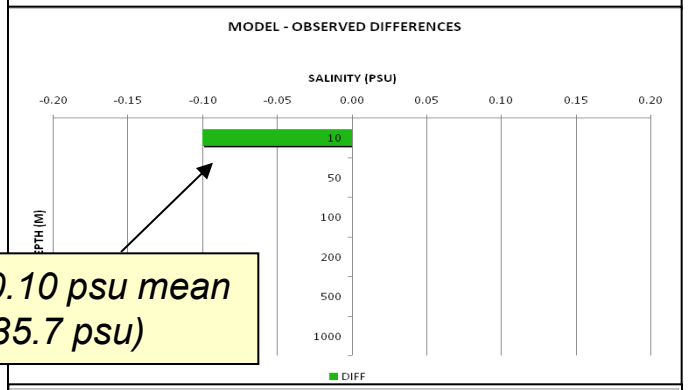
Mean observed (RED) and model (BLUE) depths (m) of **temperature** surfaces at 24, 21, 18, 15, 12, 9 and 6 degC and model minus observed differences



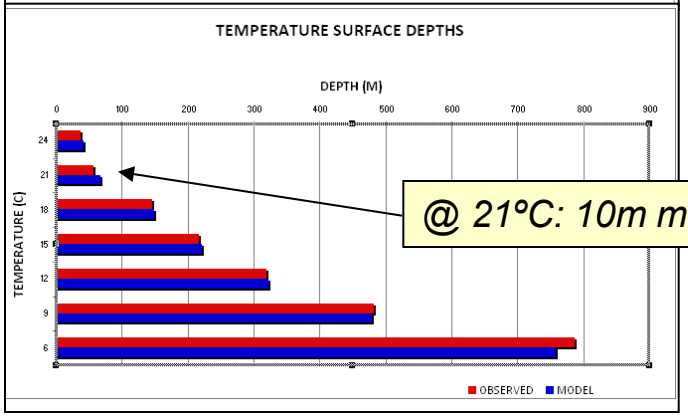


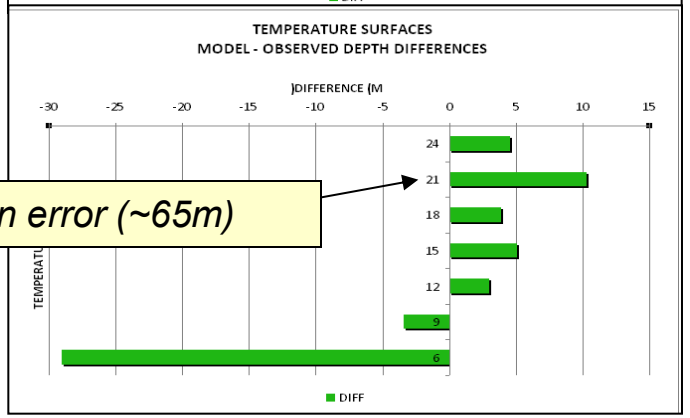
@ 50m: 0.5ºC mean error (~22ºC)





@ surface: -0.10 psu mean error (~35.7 psu)





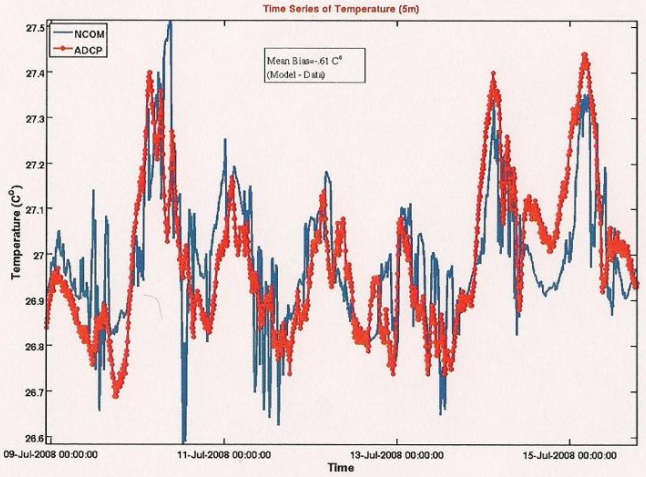
@ 21ºC: 10m mean error (~65m)

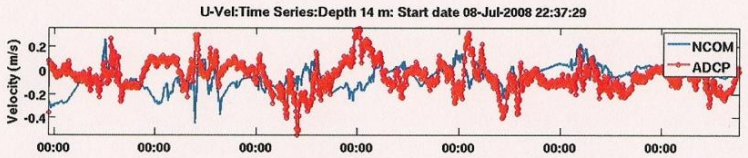
Comparison between NCOM Forecast Currents and ADCP Records

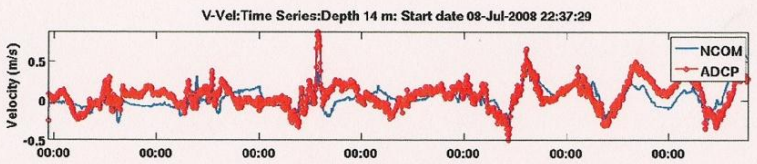
300m Resolution Nested Coastal NCOM currents (BLUE) and ADCP data (RED)

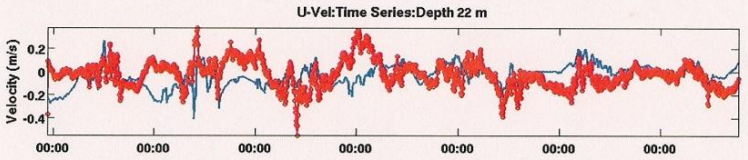
•Temperature at 5m – mean bias -0.7˚C

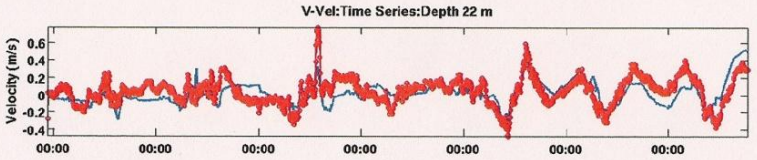
•Eastward (U, left) and Northward (V, right) current speeds at 14, 22 & 42m

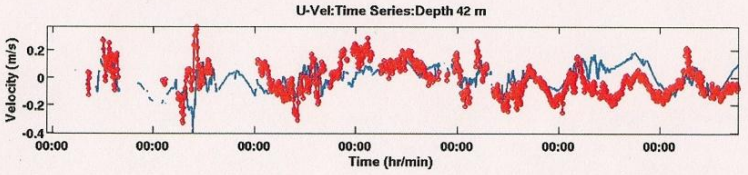


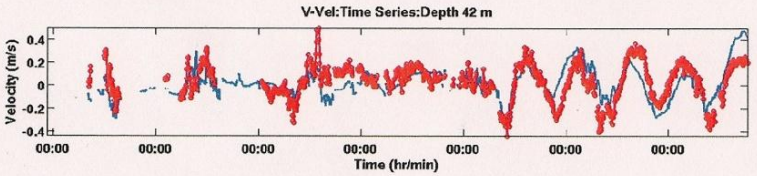










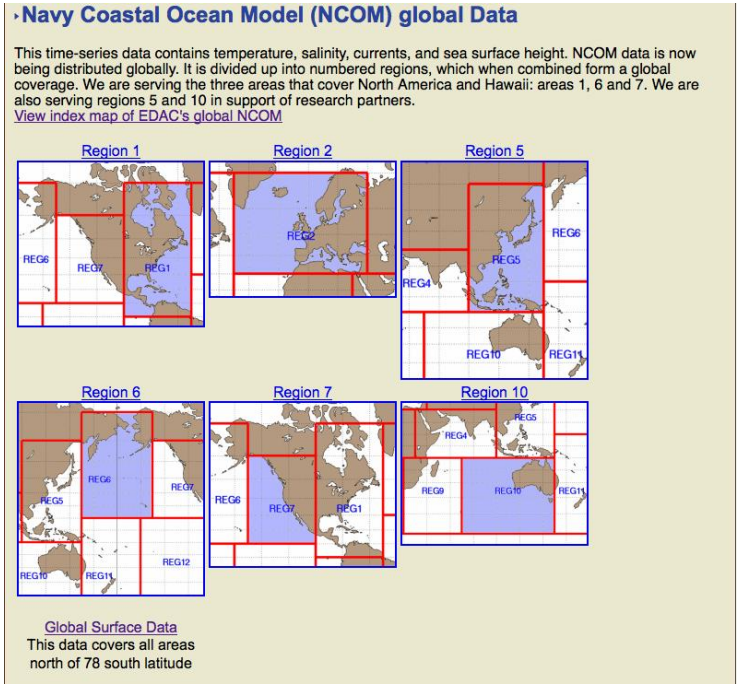


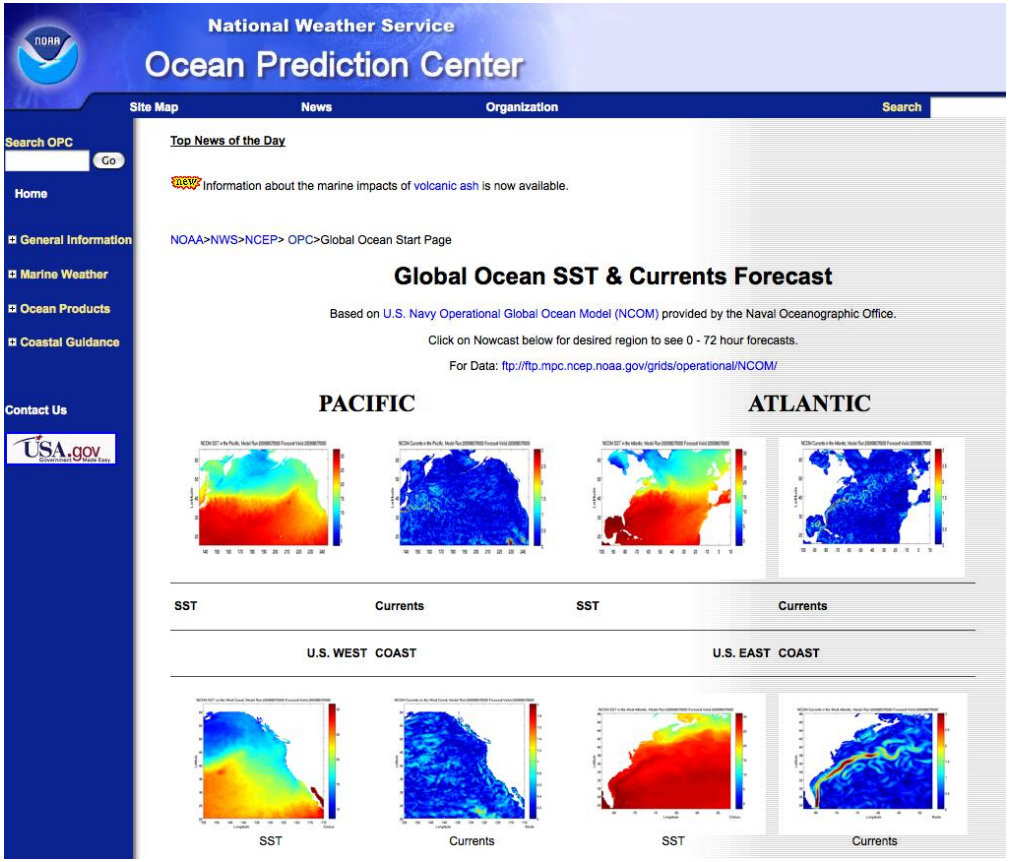
Public Service of NAVOCEANO Data Via NOAA Sites

http://edac.northerngulfinstitute.org/opendap_index.html
http://edac-dap.northerngulfinstitute.org/thredds/catalog/

http://www.opc.ncep.noaa.gov/GlobalOceanStart.shtml/







ftp://ftp.mpc.ncep.noaa.gov/grids/operational/NCOM/global/
ftp://ftp.mpc.ncep.noaa.gov/grids/operational/NCOM/regional/

(3) Ocean Nowcast/Forecast Systems for USW

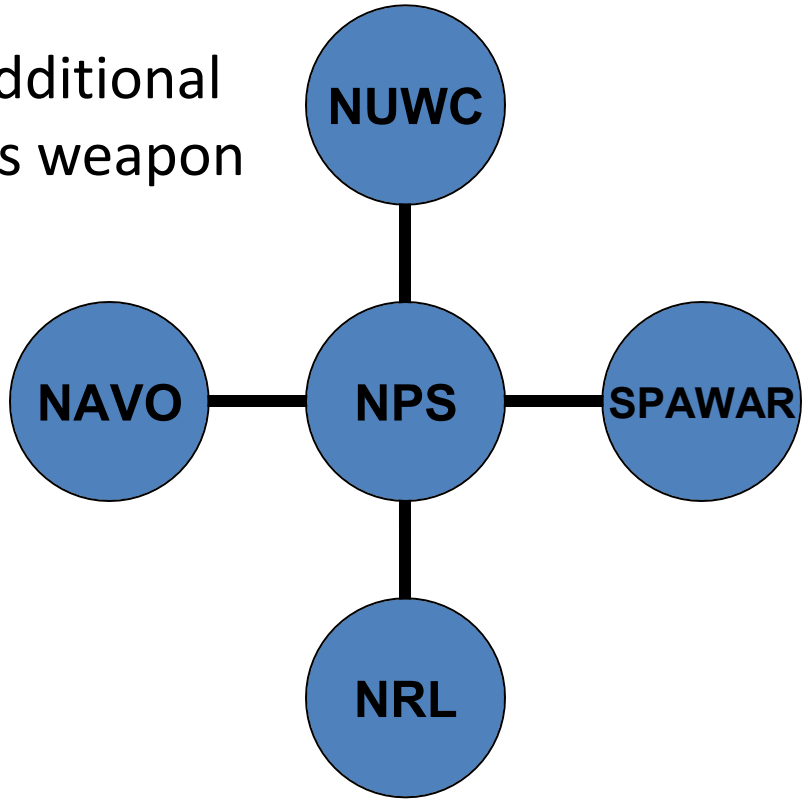
(NPS-NUWCNP Joint Research Project Sponsored by SPAWAR)

Chu, P.C., S. Mancini, E. L. Gottshall, D. S. Cwalina , C. N. Barron, 2007: Sensitivity of satellite altimetry data assimilation on weapon acoustic preset using MODAS. *IEEE Journal of Oceanic Engineering*, **32**, 453-468

Chu, P.C., G.R. Amezaga, E.L. Gottshall, and D. S. Cwalina, 2007: Ocean nowcast/forecast systems for improvement of Naval undersea capabilities. *Marine Technology Society Journal*, **41** (2), 23-30

Purpose

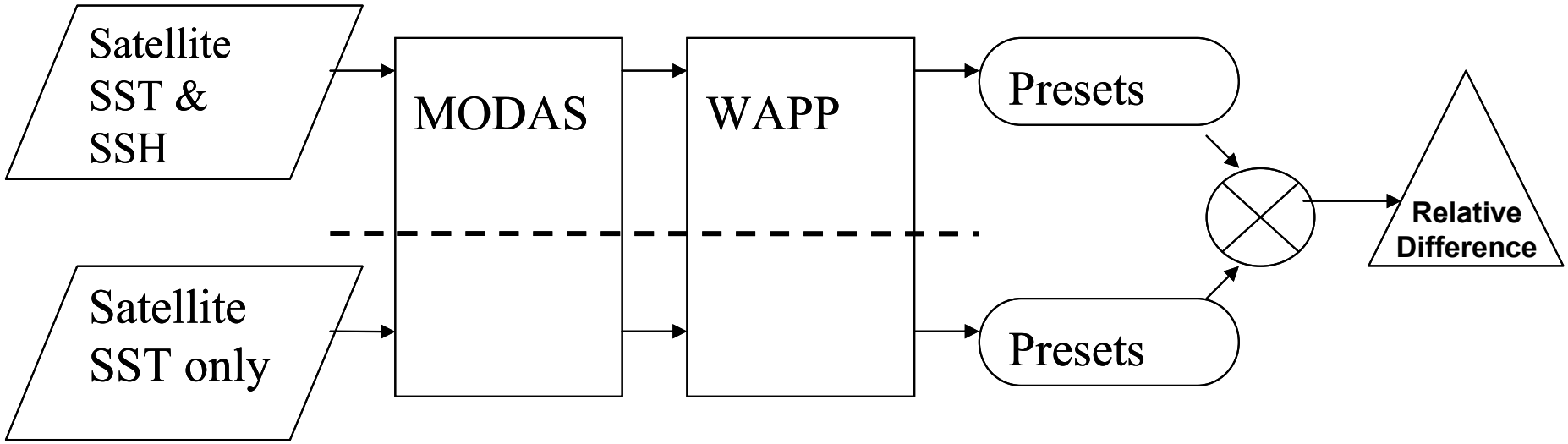
- To define Navy altimeter requirements as a minimum number of satellite altimeters necessary to ensure maximum weapon effectiveness
- To determine the point at which additional altimeter input no longer increases weapon effectiveness
- Collaboration elements



Objective

- Identify the sensitivity of satellite altimetry data assimilation on weapon presets
  - To determine if further work should be done to assess the value of the altimetry data

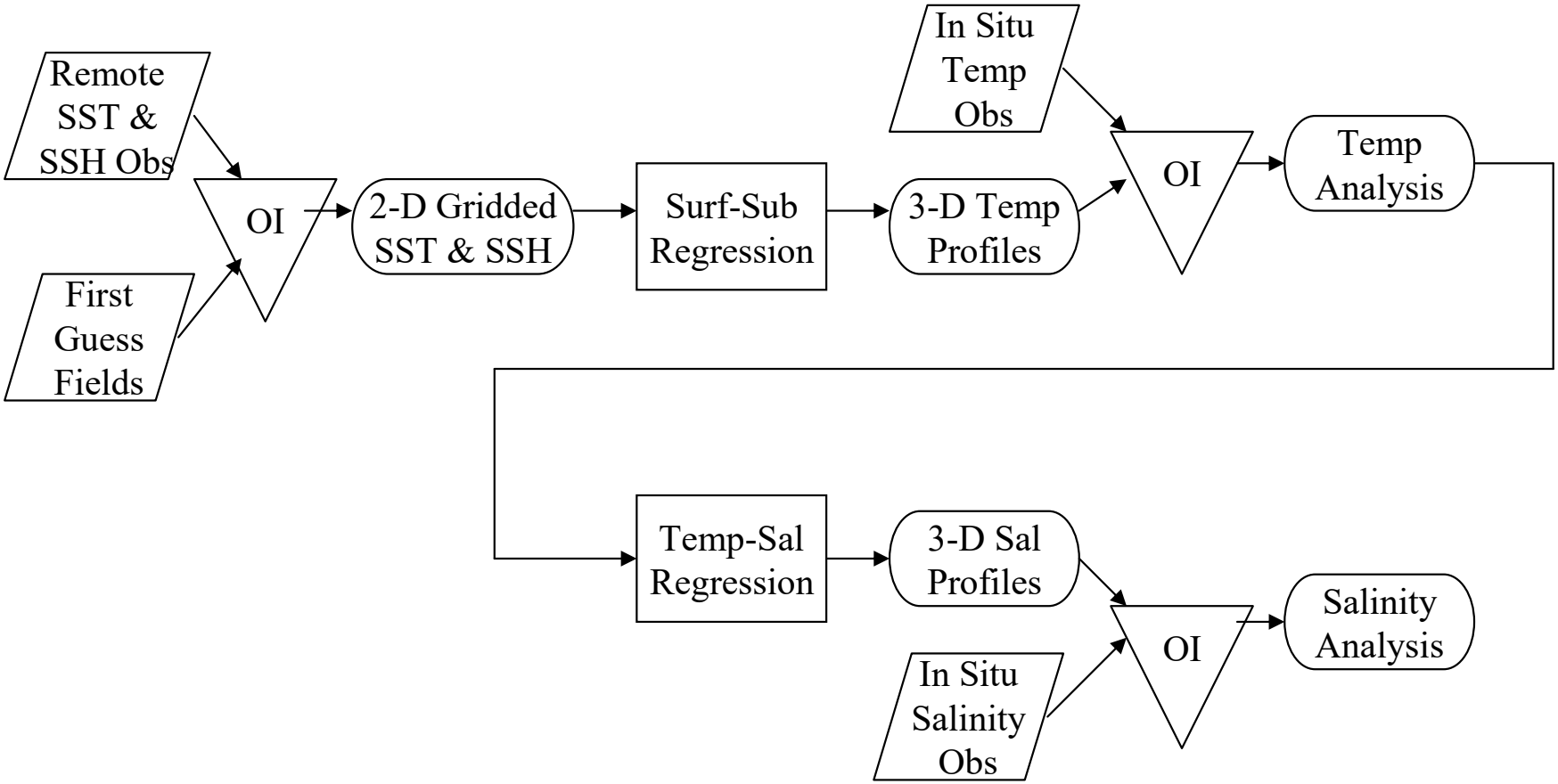
Flow chart of the sensitivity study

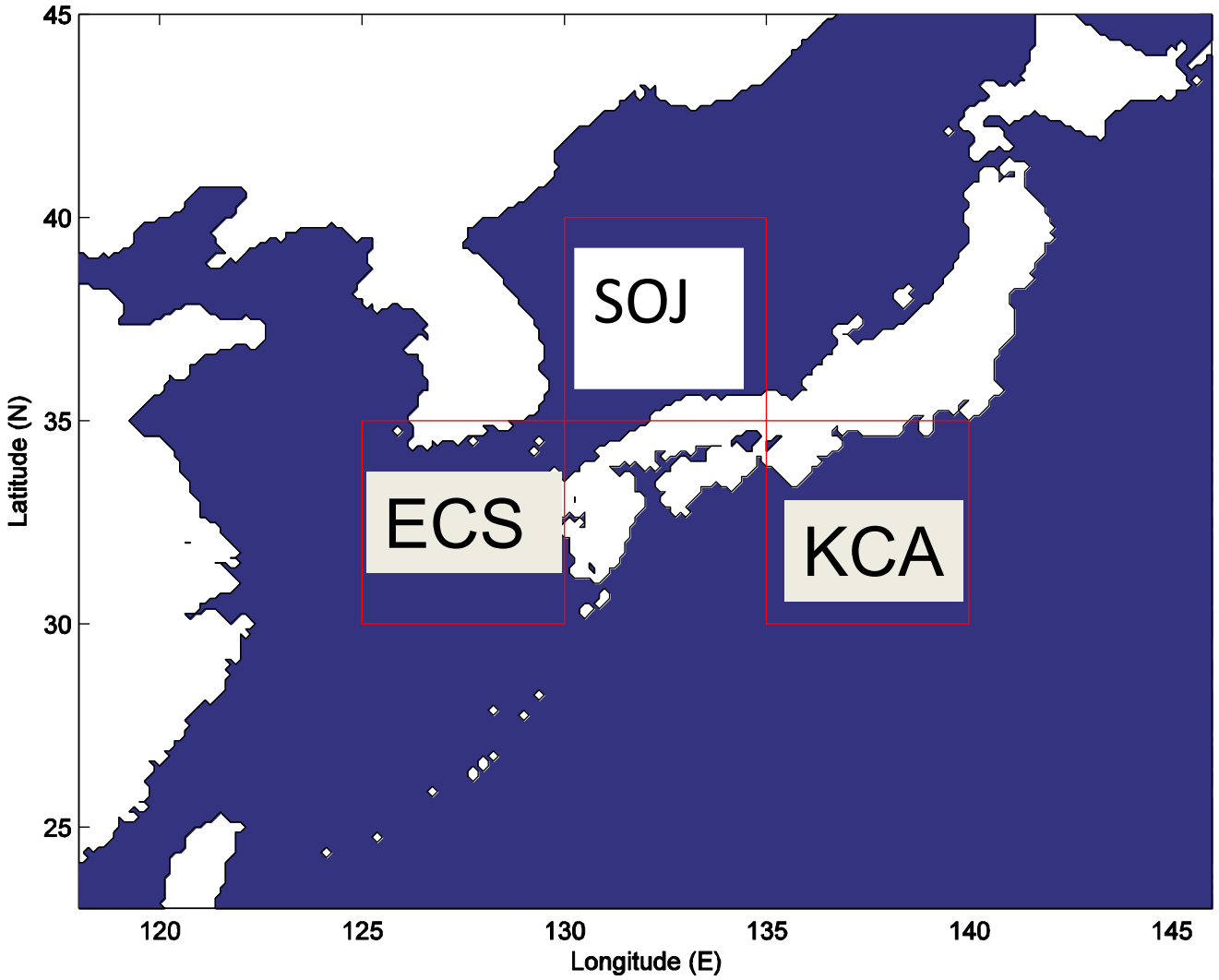


Modular Ocean Data Assimilation System (MODAS)

- Analysis tool only, predictive capability using NCOM
- Dynamic climatology uses optimum interpolation to ingest
  - SSH and SST from satellites
  - In situ measurements (XBTs, CTDs)
- Produces
  - 3-D Temp grid up to 1/8 degree resolution using surface-subsurface regressions
  - 3-D Sal grid using T-S regressions
  - Derives density, sound speed, mixed layer depth, etc.

MODAS Flowchart



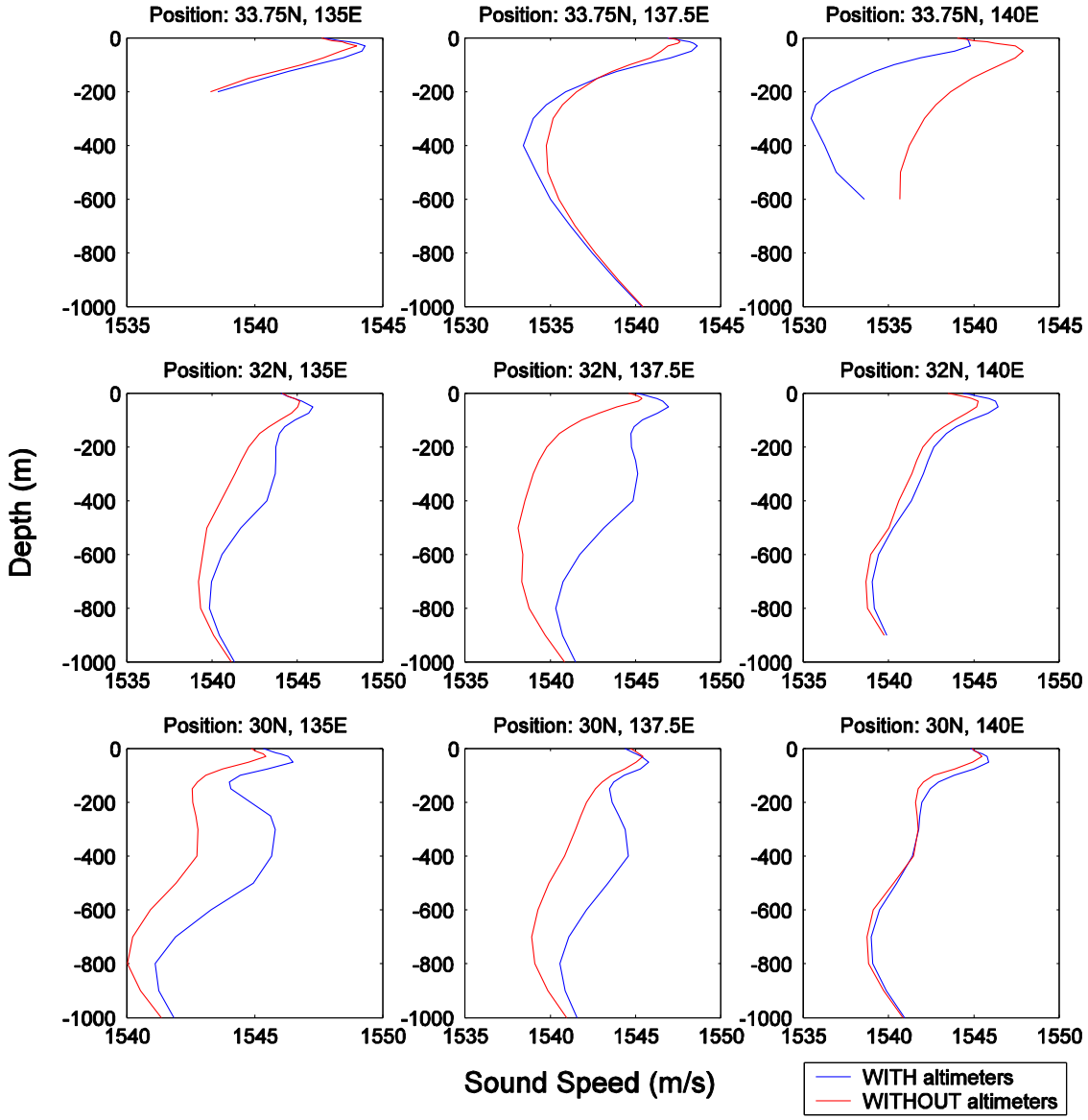


ECS → East China Sea, SOJ → Sea of Japan

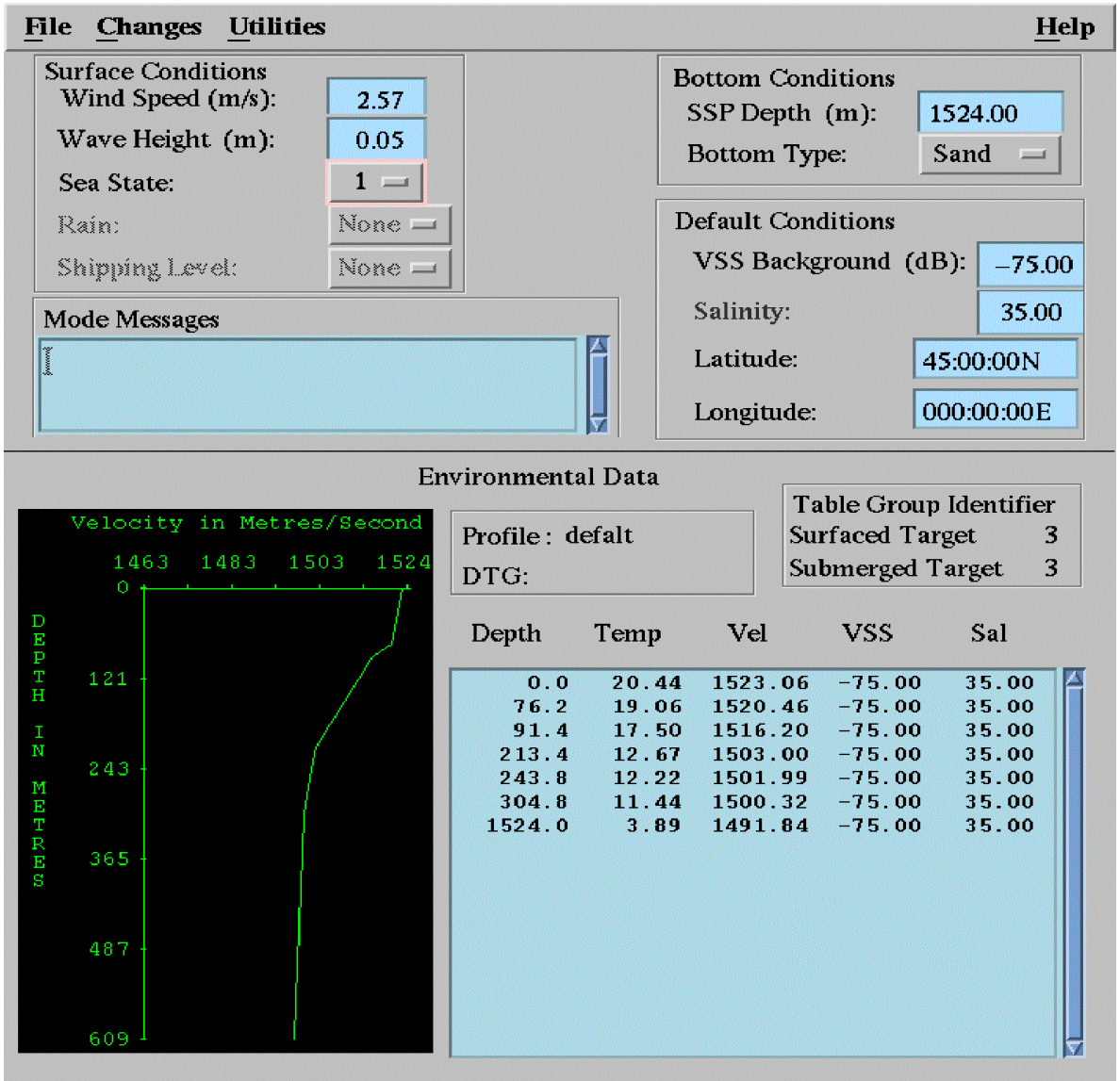
KCA → Kuroshio Current Area

4,379 pairs of water column profiles for each day

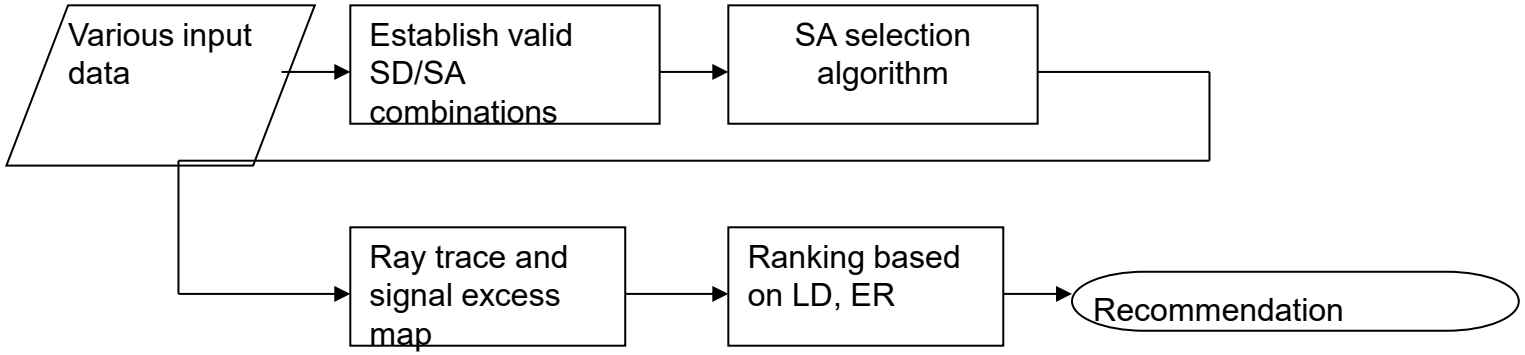
Comparison of MODAS SSPs for KCA on October 10, 2001 with and without satellite altimetry data assimilated



Weapon acoustic preset module display



Presetting Process



Signal Excess map

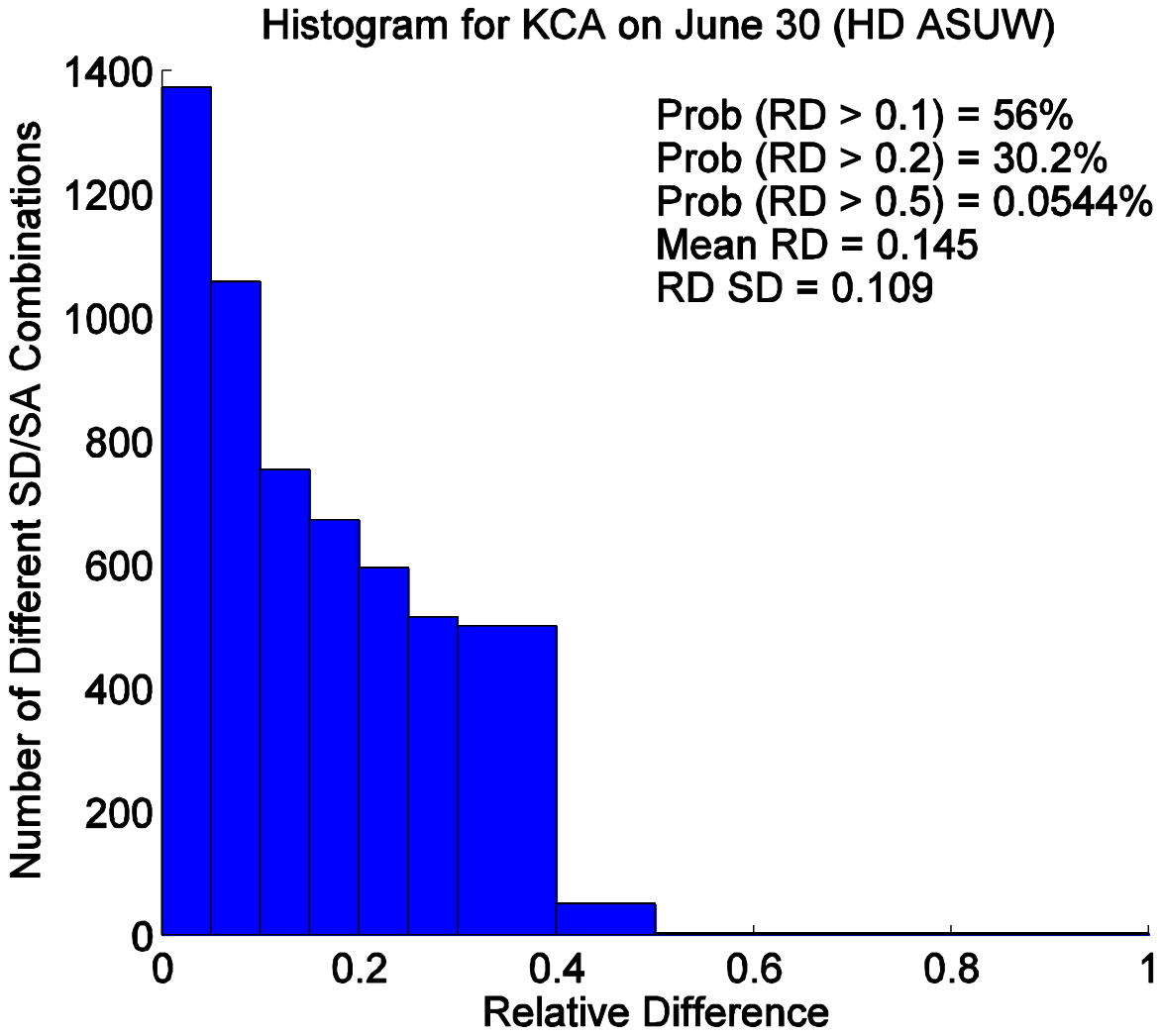
SL - 2TL + TS – RL – DT = SE

Relative Difference over a Threshold

$$RD = \frac{\left|AC_1 - AC_2\right|}{AC_1}$$

AC → Area of Coverage

Histogram of RD (example)



Probabilities of RD

$$\mu_1 = \text{Prob}\,(\text{RD} > 0.1)$$

$$\mu_2 = \text{Prob}\,(\text{RD} > 0.2)$$

$$\mu_3 = \text{Prob}\,(\text{RD} > 0.5)$$

Probabilities of RD in KCA

	KCA Jun HD Deep ASW	KCA Jun LD Deep ASW	KCA Jun LD Shallow ASW	KCA Jun HD ASUW	KCA Jun LD ASUW
Prob (RD > 0.1)	39.26	37.52	46.76	55.98	43.62
Prob (RD > 0.2)	6.63	6.44	8.46	30.19	17.20
Prob (RD > 0.5)	0.00	0.00	0.00	0.05	0.04
Mean RD	0.0924	0.0925	0.102	0.145	0.109

HD → High Doppler

LD → Low Doppler

Conclusions

- WAPP output is sensitive to satellite altimetry data assimilation
  - Especially when MODAS fields differ significantly in the depth zone of interest (due to better depiction of mesoscale features by the field with altimetry)
- Satellite altimeter data contributed as much as an 80-90% chance of having a different engagement outcome
  - Assuming RD of 0.1-0.2 in AC is enough