



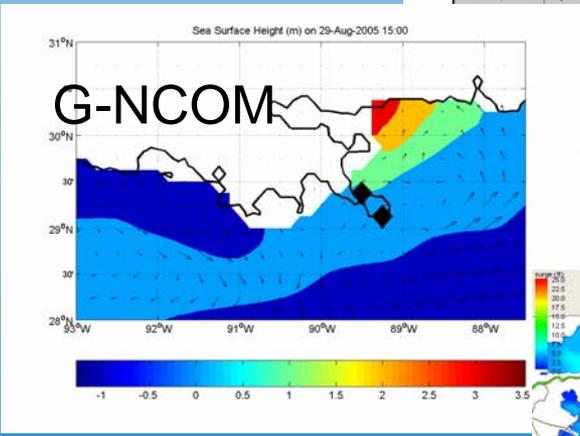
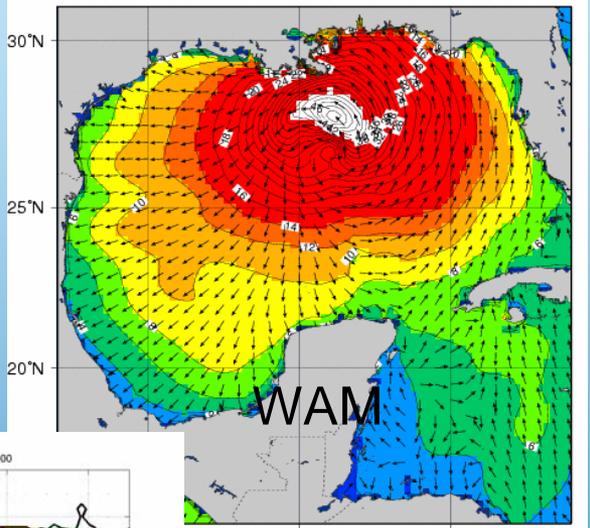
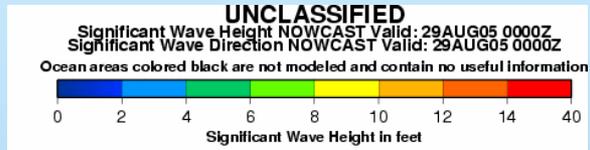
# The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)

Frank L. Bub,  
Head, Ocean Modeling  
Division (N33)

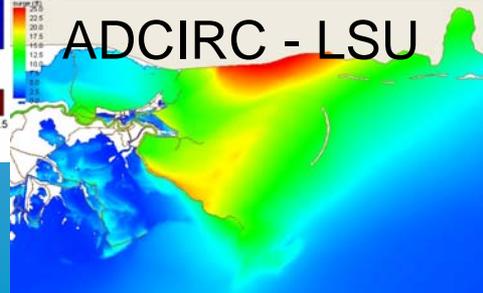
[frank.bub@navy.mil](mailto:frank.bub@navy.mil)

228-688-4758

<https://www.navo.navy.mil/ops.htm>



WAVE Model (WAM)  
/AL OCEANOGRAPHIC OFFICE  
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# Report Documentation Page

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<b>unclassified</b>	<b>unclassified</b>	<b>unclassified</b>	<b>Same as Report (SAR)</b>	<b>35</b>	

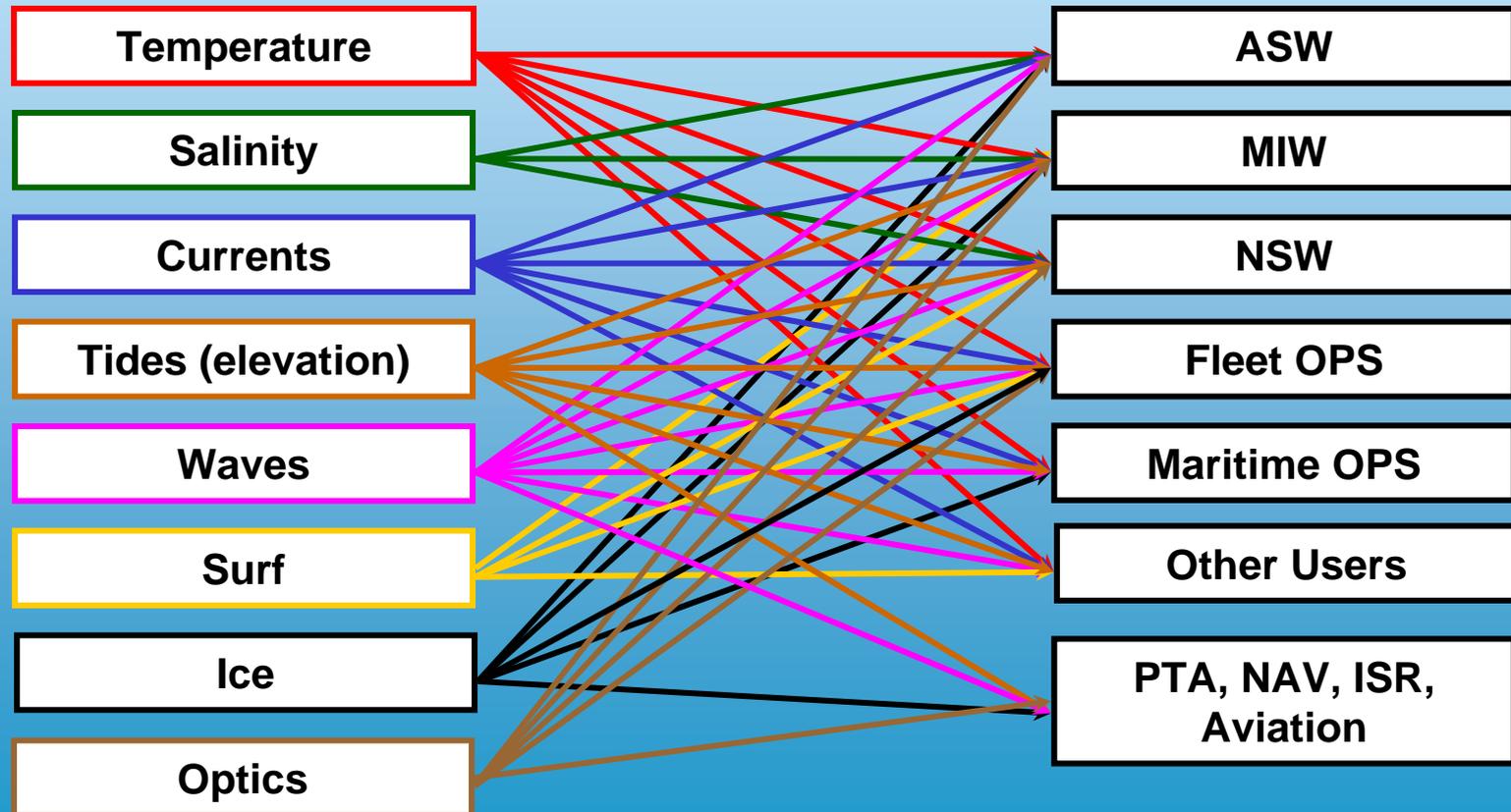
# Basic Product Suite Mapped to Navy Lines of Operation



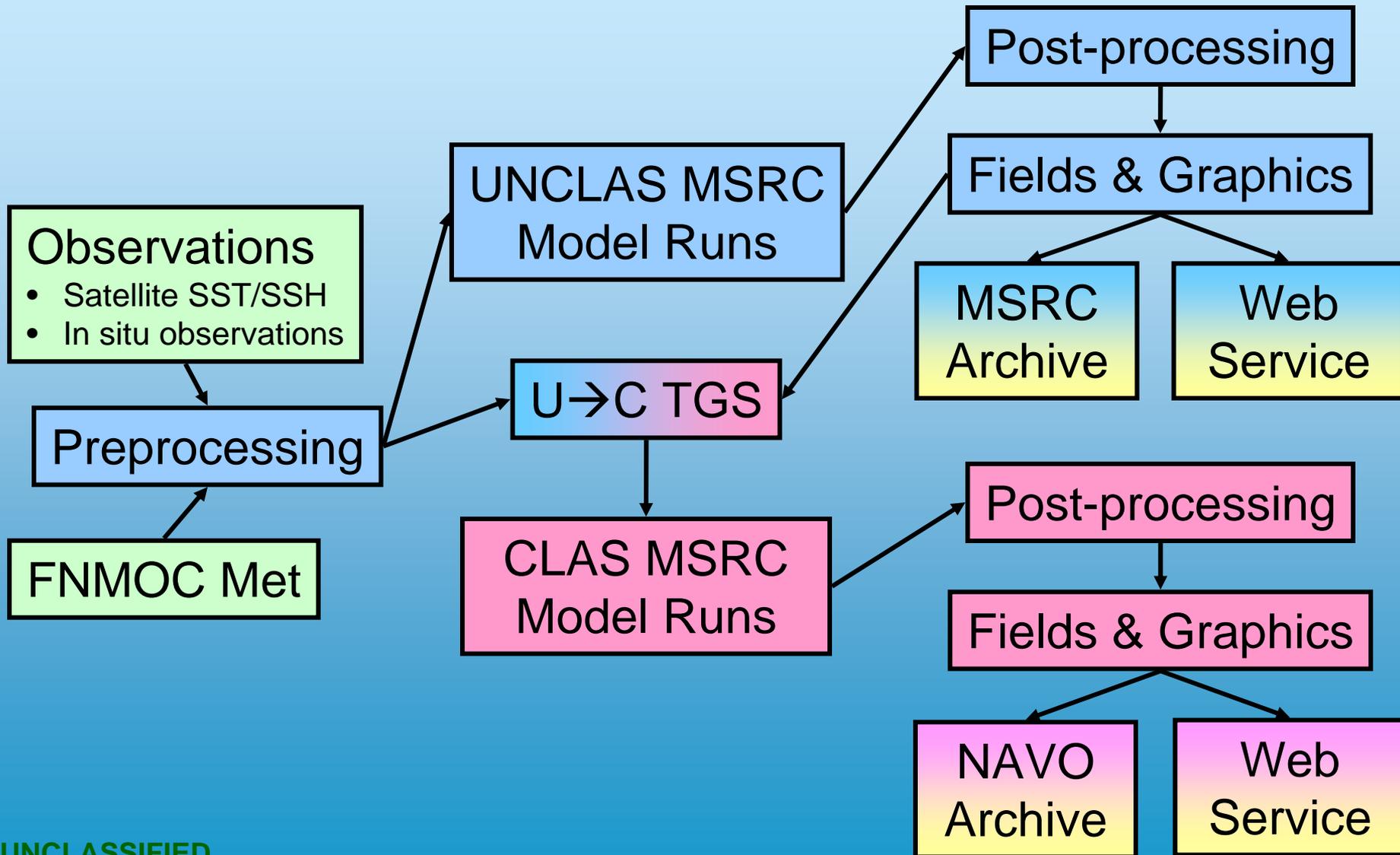
*NAVOCEANO's business is to*

- Collect or acquire observations & information for the....
- Analysis and prediction of....

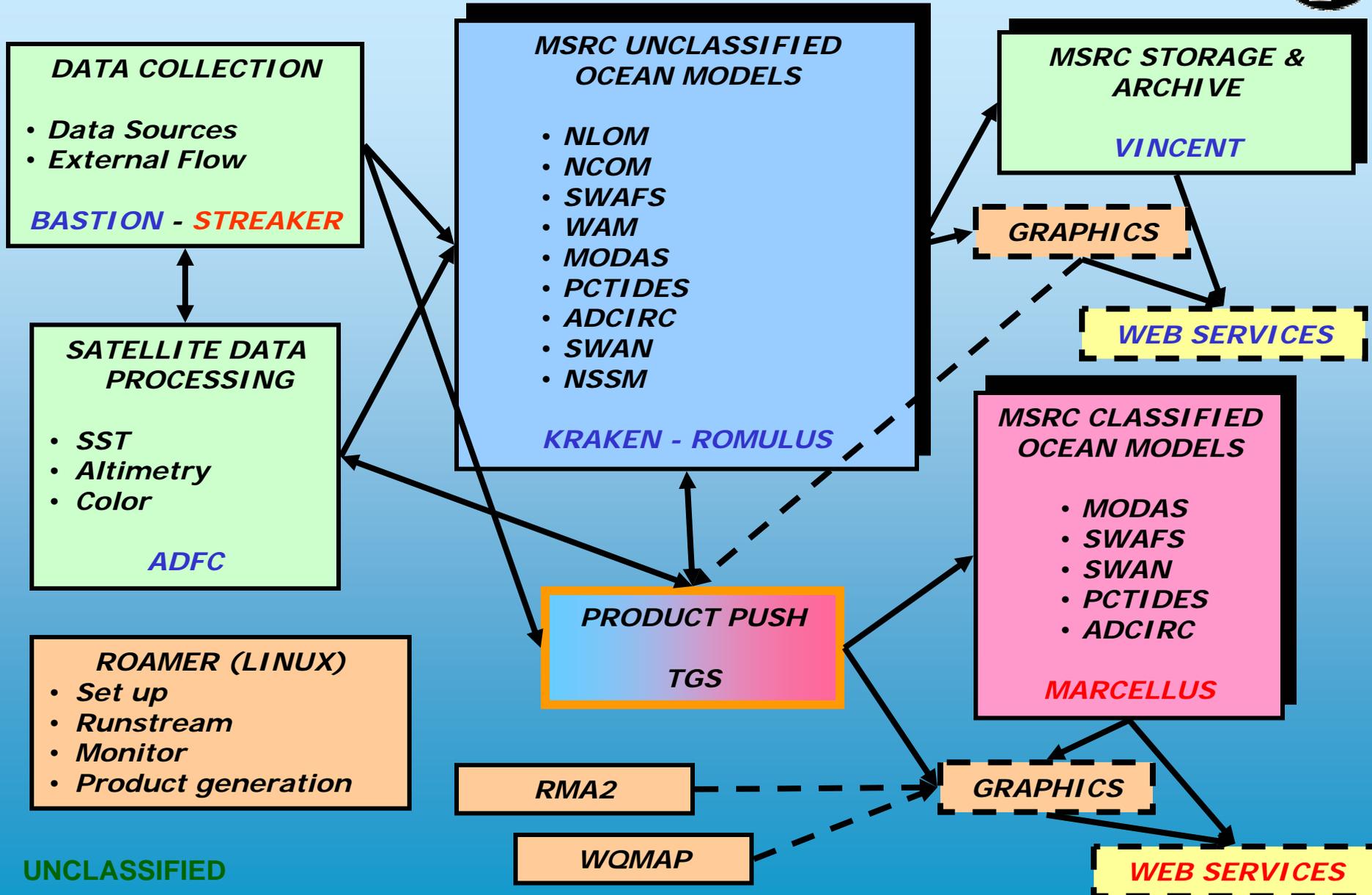
Currents, Temperature, Salinity, Sound Speed, Waves, & Optics.



# NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



# NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



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# NAVOCEANO MSRC Assets - CY2005



SYSTEM		Speed	CPUS		15%	GFLOPS *			
NAME	MODEL	MHZ	TOTAL	AVBL	CNMOC	PER cpu	AVBL	CNMOC	CLAS
<b>2005</b>									
Kraken	IBM Power-4+	1,700	2,944	2,832	425	6.8	19,258	2,889	U
Romulus	IBM Power-4+	1,700	512	464	70	6.8	3,155	473	U
Marcellus	IBM Power-4	1,300	1,408	1,328	199	5.2	6,906	1,036	C
<b>2004</b>									
Habu	IBM SP Power 3	375	976	928	139	1.5	1,392	209	U
Poseidon	Cray SV-1EX	500	64	64	10	2.0	128	19	U
Camille	Cray SV1	300	32	32	5	1.2	38	6	C
Butch	Sun F1200	900	8	8	1	3.6	29	4	C
		<b>TOTALS</b>	<b>End 2004</b>		<b>354</b>		<b>8,493</b>	<b>1,274</b>	
			<b>End 2005</b>		<b>694</b>	<b>+196%</b>	<b>29,318</b>	<b>4,398</b>	<b>+345%</b>

\* A **gigaflop** is defined as a billion ( $10^9$ ) Floating Point Operations. This is calculated by multiplying the speed of a processor (CPU) times the number of CPUs used, times the wall clock time in seconds, to determine model “cycles” required. This is multiplied by 4 flops/cycle.

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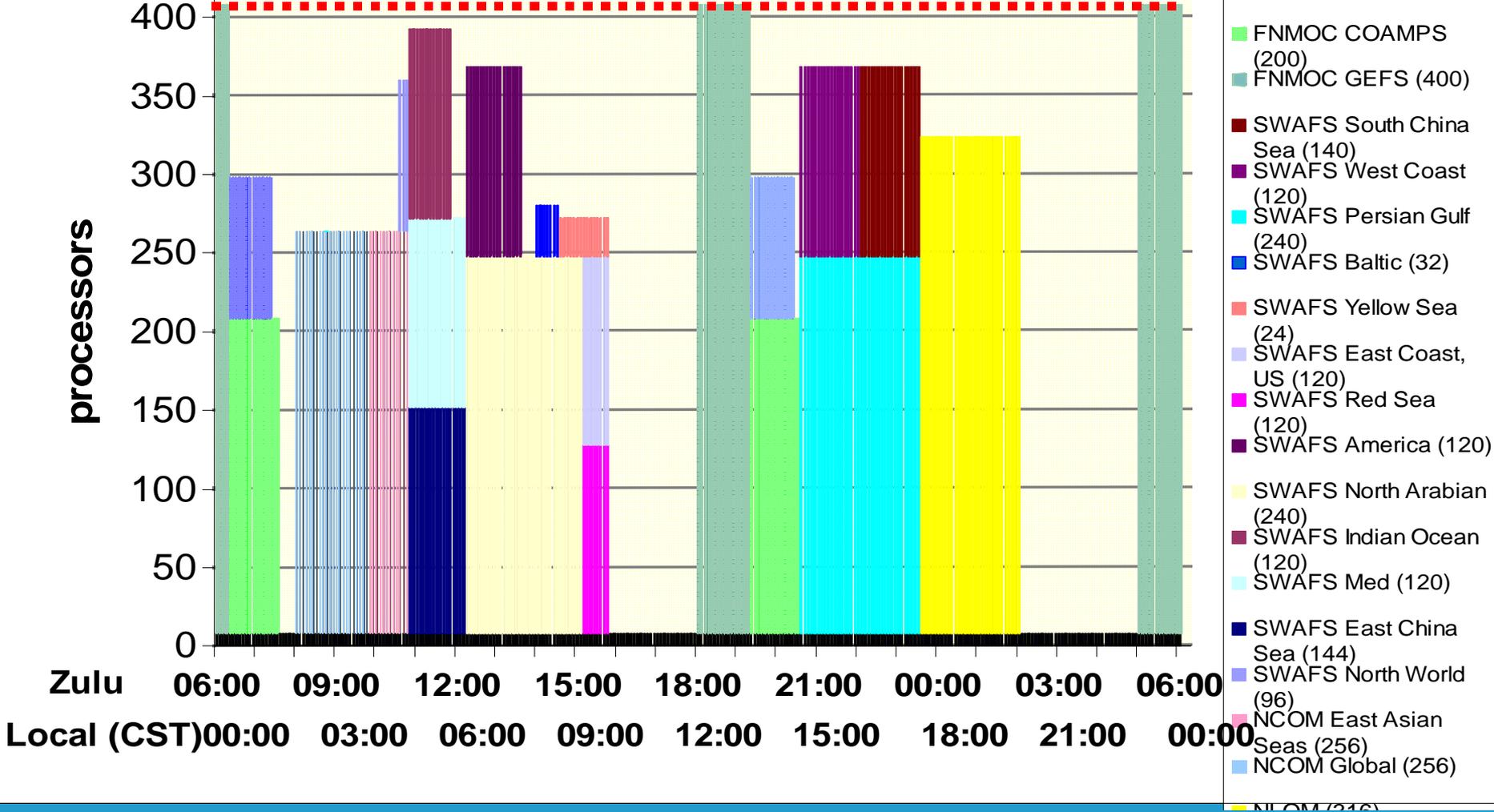
# NAVOCEANO MSRC Schedule

## Kraken – AUGUST 2005



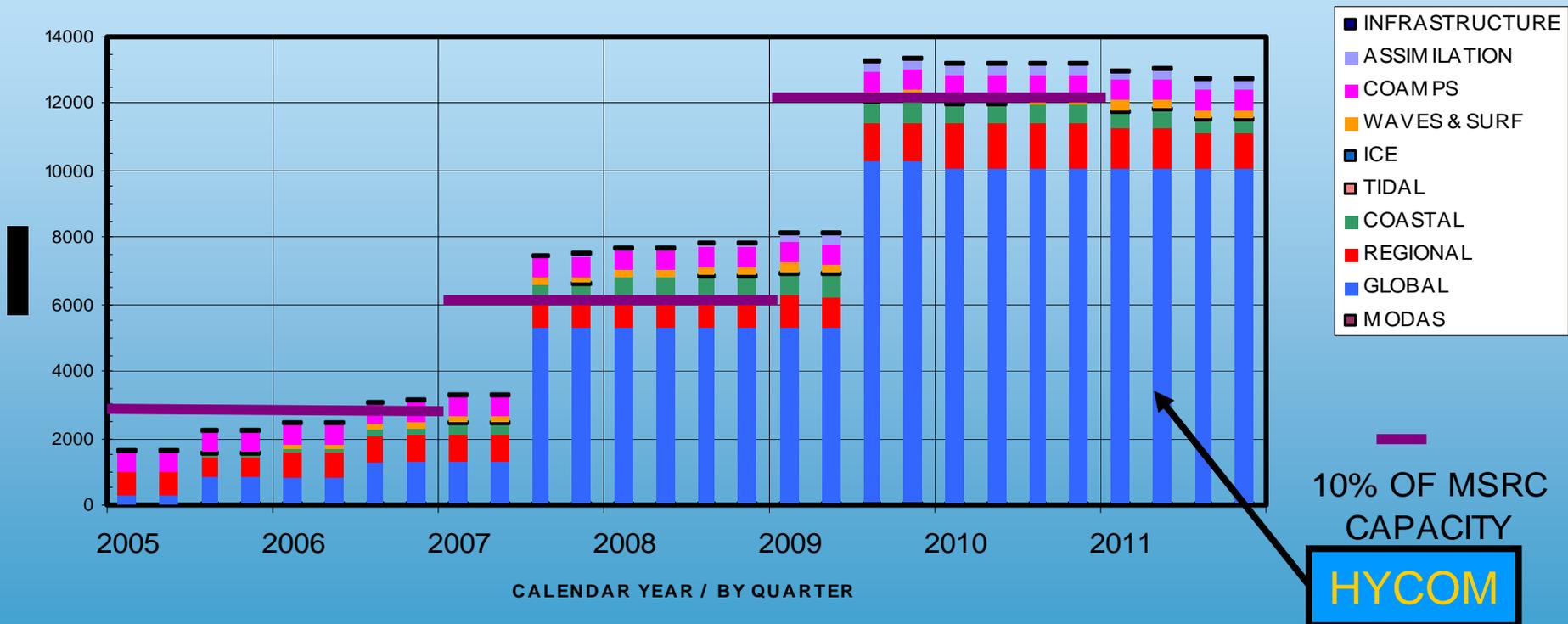
### KRAKEN Operational Schedule

CPU = 2800, Allocated 15% = 420



- FNMOC WW3 (90)
- FNMOC COAMPS (200)
- FNMOC WW3 (90)
- FNMOC COAMPS (200)
- FNMOC GEFS (400)
- SWAFS South China Sea (140)
- SWAFS West Coast (120)
- SWAFS Persian Gulf (240)
- SWAFS Baltic (32)
- SWAFS Yellow Sea (24)
- SWAFS East Coast, US (120)
- SWAFS Red Sea (120)
- SWAFS America (120)
- SWAFS North Arabian (240)
- SWAFS Indian Ocean (120)
- SWAFS Med (120)
- SWAFS East China Sea (144)
- SWAFS North World (96)
- NCOM East Asian Seas (256)
- NCOM Global (256)
- NCOM (256)

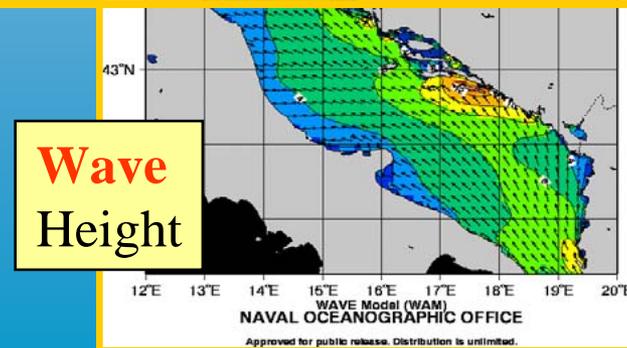
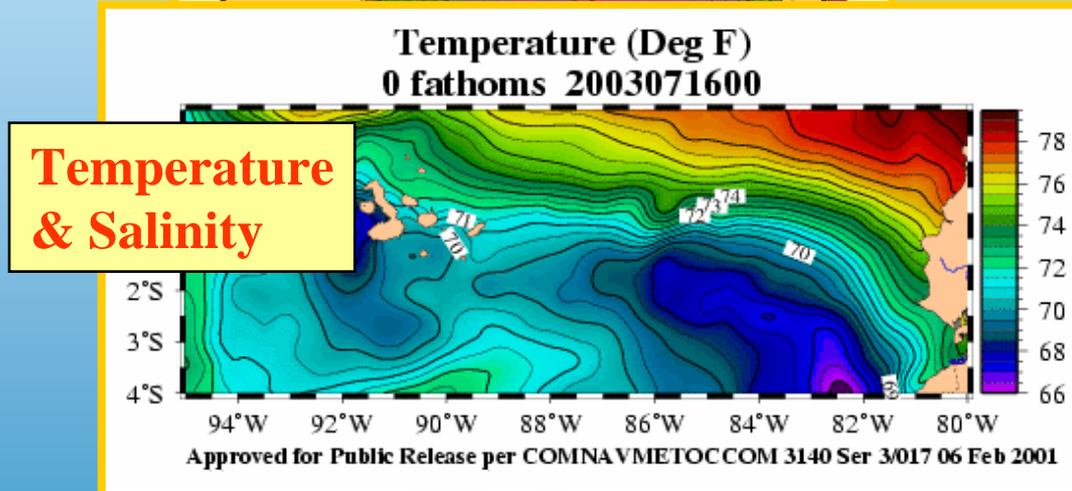
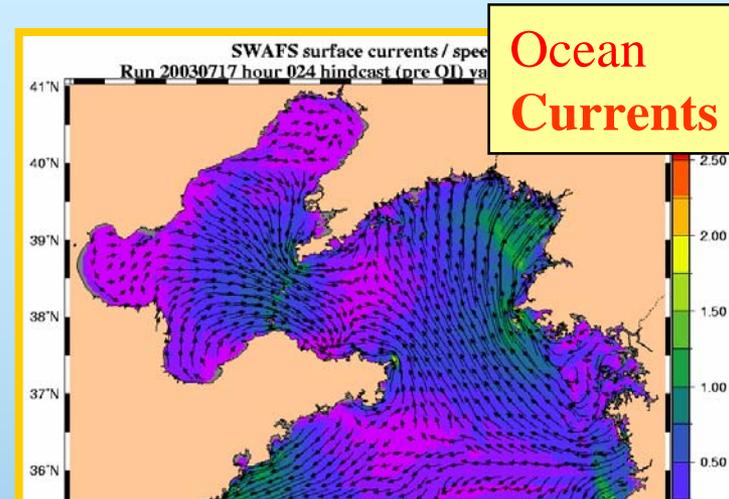
# NAVOCEANO MSRC Requirements through CY2011 in gigaflops (billions of floating point operations)



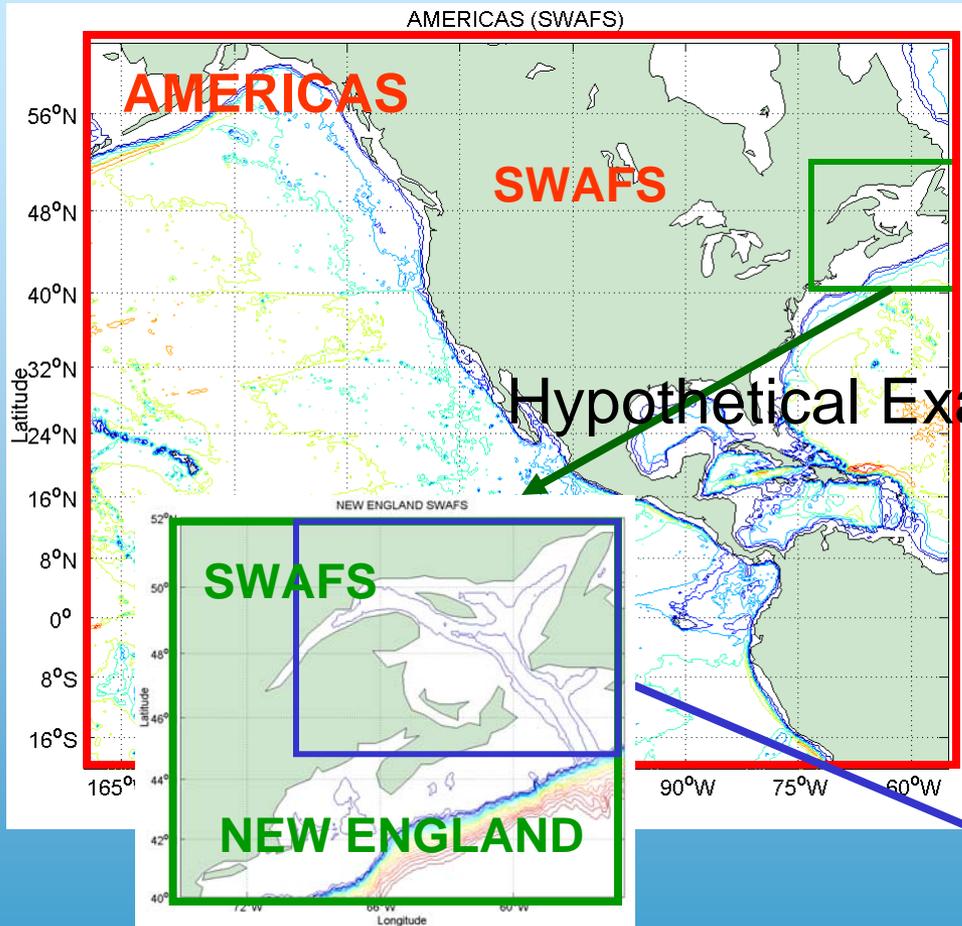


# Operational Modeling distinct from R&D Modeling

- Daily Product Generation (focus on Navy Fleet)
- Products support real needs, operations
- Reliability expected
  - Timely
  - Accurate



# To Achieve Needed Resolutions, We Nest Boundary & Initial Conditions



## Global NCOM

- ~14km resolution
- 2.6 mil gridpoints

## AMERICAS (2:1)

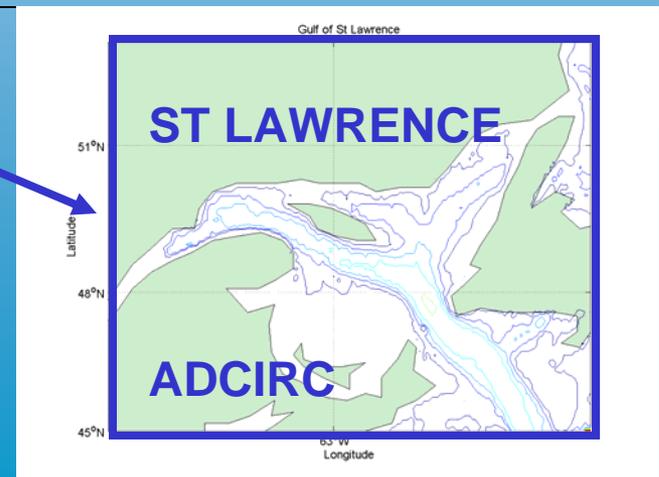
- ~8km resolution
- 1.4 mil grid points

## NEW ENGLAND (3:1)

- ~3km resolution (3:1)
- 230K grid points

## ST LAWRENCE (3:1)

- ~1km resolution
- 820K grid points



Notes: Recent Arabian Gulf SWAN – 3 WAM & 3 SWAN nests (9 hr computation time)

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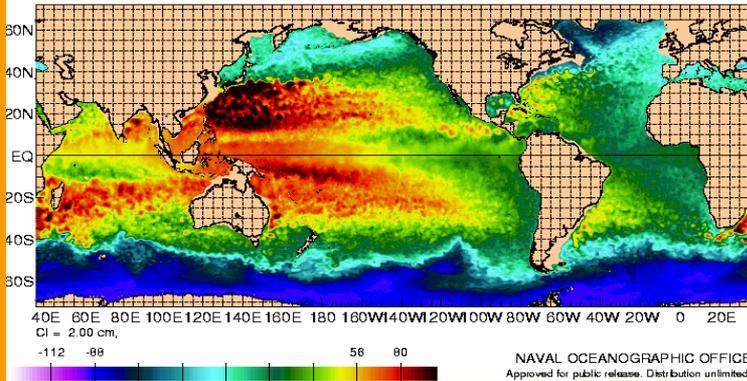


# Global

# Regional

# Local

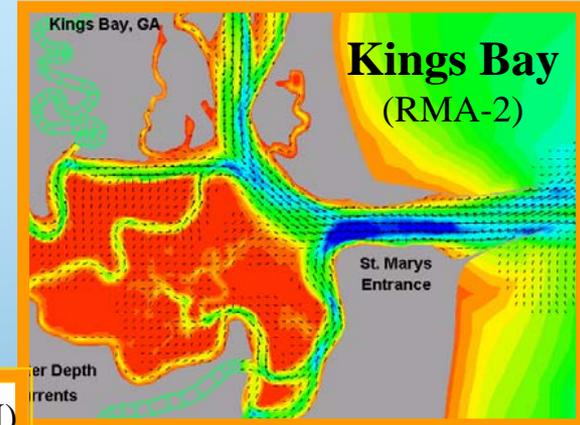
UNCLASSIFIED: 1/16° Global NLOM  
SSH ANALYSIS: 20020420



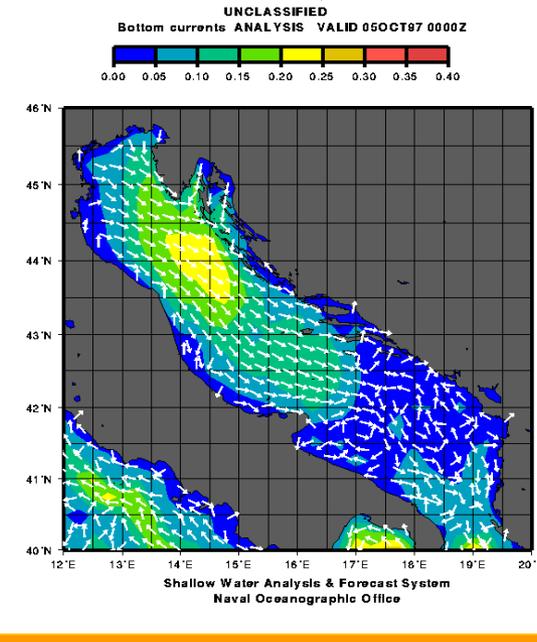
- ### Global Deep Ocean Models:
- Regional models boundary conditions
  - Transit planning
  - Filling gaps

UNCLASSIFIED

- ### Regional Littoral Models:
- High-resolution processes
  - Theatre Operations



### Adriatic Sea (SWAFS-POM)



- ### Coastal - Local - Estuary Models:
- Coastal operations
  - NSW
  - MIW

# Ocean Models at NAVOCEANO



## Global Circulation Models

- NLOM / G-NCOM

## 3-D Coastal Circ Models

- SWAFS --> Rgnl-NCOM (FY07)
- EAS NCOM (FY06)

## Vertical Profile (T,S) Model

- MODAS

## Wave Models

- WAM
- ST-Wave --> SWAN
- Navy Std Surf Model
- Delft3D SWAN/FLOW (FY06?)

## 2-D Coastal Circ Models

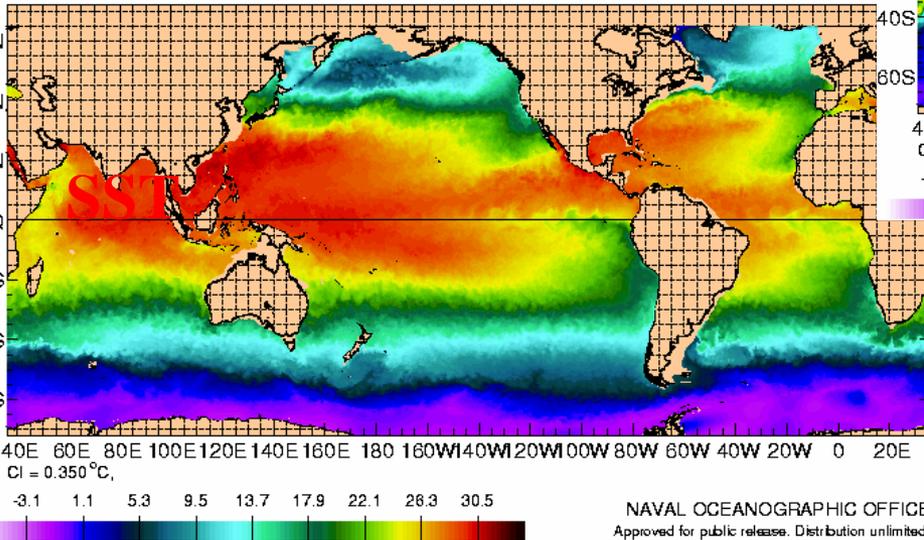
- WQMAP \*
- HydroMap \*
- RMA-2
- ADCIRC (FY06)\*
- CU-Tides -->PC-Tides (FY05)

\* 3D Capability also



# NAVY LAYERED OCEAN MODEL NLOM

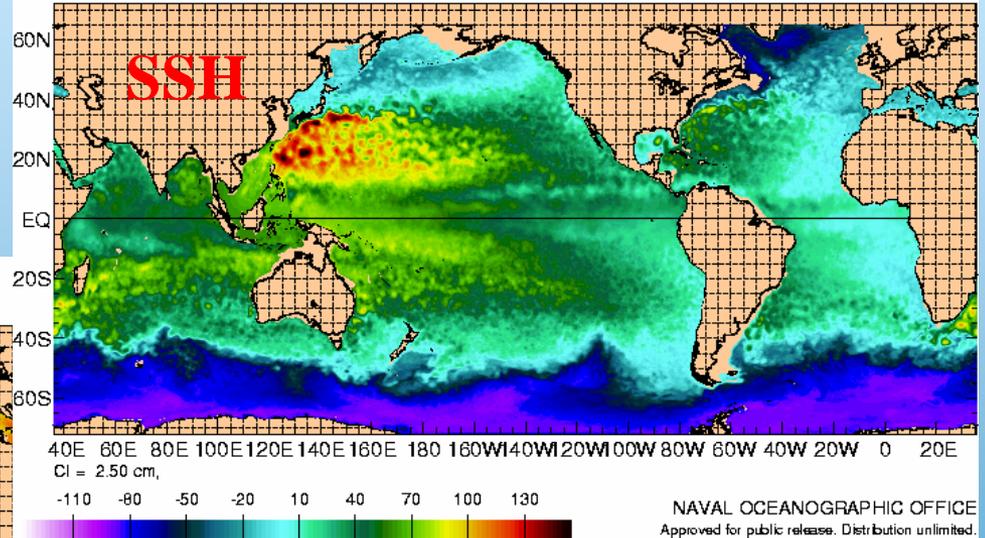
UNCLASSIFIED: 1/16° Global NLOM  
SST ANALYSIS: 20030716



**1/32 deg (~2.5 km /1.3 nm)**

**UNCLASSIFIED**

UNCLASSIFIED: 1/16° Global NLOM  
SSH ANALYSIS: 20030716



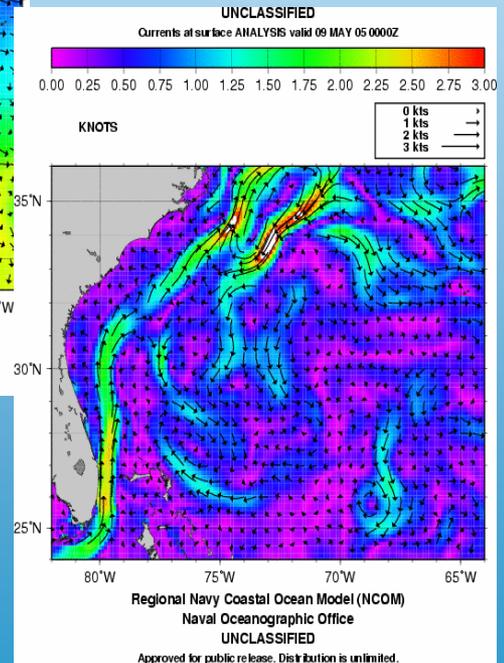
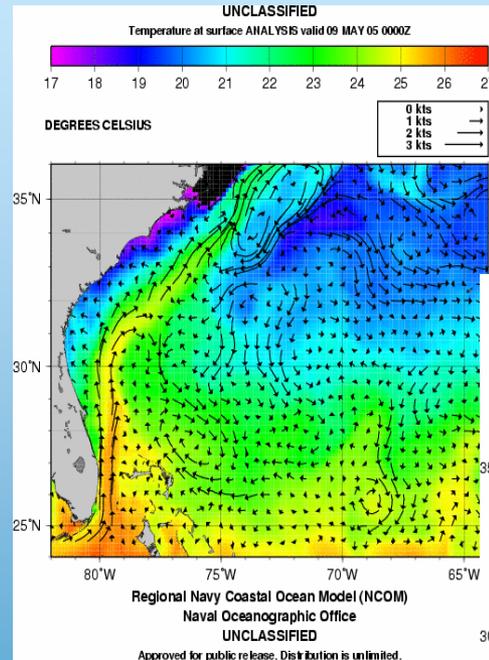
- 1/16 --> 1/32 degree resolution
- SSH for Global Circulation Models
- 4 --> 2 nm resolution
- 200m or deeper water
- 7 vertical layers
- For position of fronts and eddies
- Sea Surface Temp, Salinity & Height
- **NOT VALIDATED FOR CURRENTS**



# GLOBAL NAVY COASTAL OCEAN MODEL G-NCOM

- POM-based model
- 3D Forecasts of Temperature, Salinity, Currents, Elevation
- Resolution 1/8 deg
- 42 vertical layers
- Forecast to 72hr @ 3hr increments
- FNMOC NOGAPS atmosphere
- Assimilates SSTemp / SSHeight
- Will assimilate profiles – 2006 (NCODA)
- Deep water – mesoscale processes
- Tides from OSU (Egbert) model
- Lateral boundary conditions for higher resolution nests (SWAFS / regional NCOM)

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1/8 deg (~10 km / 5 nm)



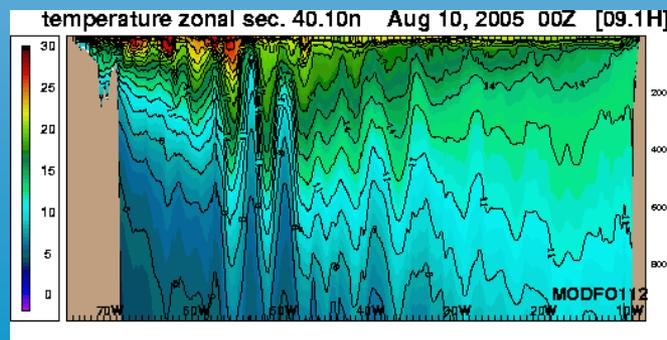
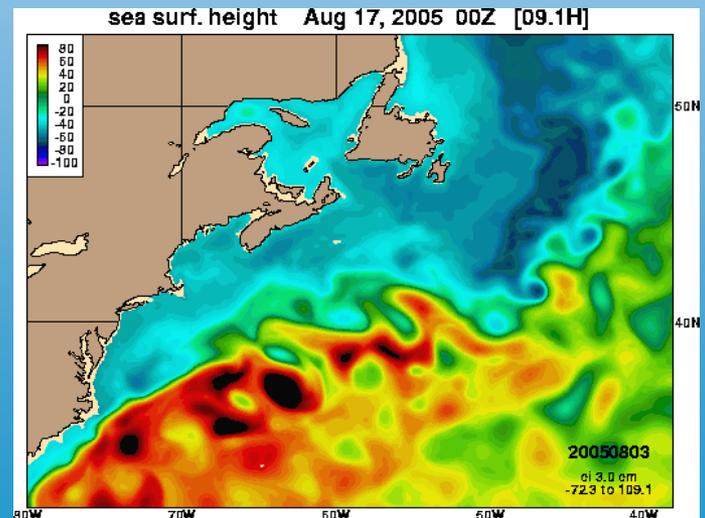
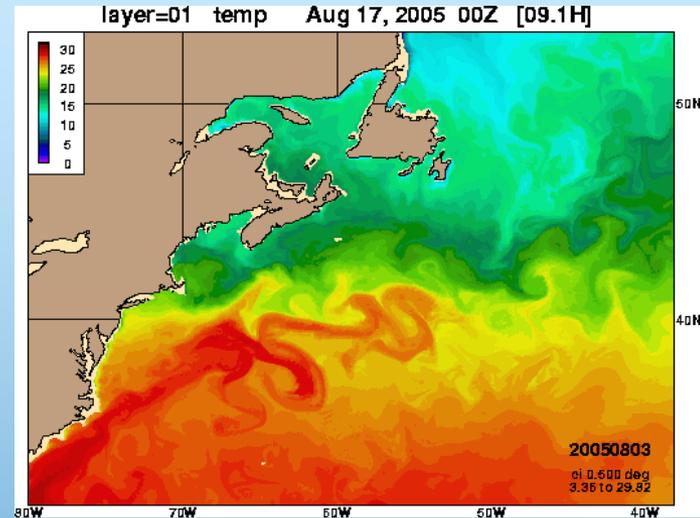
Global

Regional

Local

# HYBRID COORDINATE OCEAN MODEL HYCOM

- Next generation dynamic model
- **NOPP Consortium** – NRL lead, U Miami, Los Alamos, French, NOAA/AOML, etc.
- **Temperature, Salinity, Currents, Elevation**
- Initial global resolution 1/12 deg (6.5 km / 3.5 nm)
- Final resolution **1/24 deg** (3.8 km / 1.8 nm)
- 40+ vertical layers
- Pressure, depth, sigma coordinates as needed
- Forecast to **120hr**
- **Assimilates** SST / SSH / profile data - NCODA
- Global and regional model replacements
- Global service
- ESMF backbone



# NLOM - Navy Layered Ocean Model

## G-NCOM - Global Navy Coastal Ocean Model

## G-HYCOM - Global Hybrid Coordinate Ocean Model



GLOBAL		YEAR	2005	2006	2007	2008	2009	2010	2011
NLOM 1/16 degree	U	GLOBAL							
NLOM 1/32 degree	U	GLOBAL						-->HYCOM	
G-NCOM 1/8 degree	U	GLOBAL						-->HYCOM	
G-HYCOM 1/12 degree	U	GLOBAL							
G-HYCOM 1/24 degree	U	GLOBAL							
<b>MSRC</b>		<b>gigaflops</b>	<b>735</b>	<b>1235</b>	<b>5235</b>	<b>5235</b>	<b>10,235</b>	<b>10,000</b>	<b>10,000</b>
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
							OPERATIONAL		

- Global models will **dominate processing** requirements.
  - Until 1/24-degree HYCOM in CY2011, the main purpose is to **provide boundary conditions** for the regional models.
- HYCOM** will begin to run on MSRC in an **R&D model in CY2005** & a 1/12-degree global HYCOM will begin **OPEVAL testing in CY2007**.
  - We leap to a **10,000-gigaflop** requirement in CY2009 as we move to the 1/24-degree HYCOM.



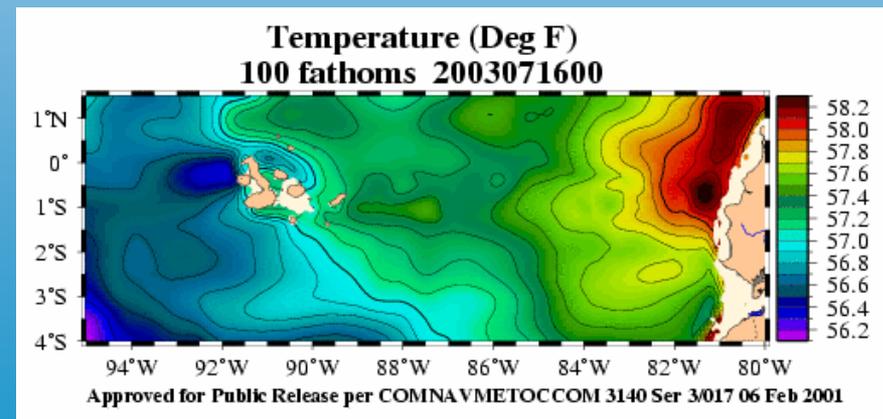
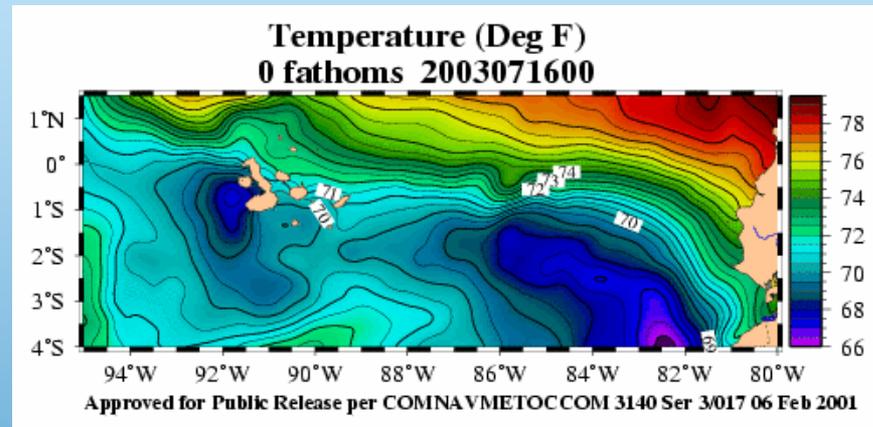
Global

Regional

Local

## MODULAR OCEAN DATA ASSIMILATION SYSTEM - MODAS

- Relocatable, variable resolution
- Statistical Analysis Model for:
  - Temperature
  - Salinity
  - Derive quantities  
(sound speed, etc.)
- Optimum Interpolation of:
  - MCSSTs
  - Altimetry
  - Gridded climatology (T,S)
  - Near-real time XBTs
- 3-D Sound Speed
  - Acoustic ranging, sensor placement
  - GF MPL
  - PC-IMAT / NITES



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# MODAS- Modular Ocean Data Assimilation System



MODAS		YEAR	2005	2006	2007	2008	2009	2010	2011
2D/3D	U	GLOBAL						-->HYCOM	
2.1 (HEAVY)	U	10 AREAS							
2.1 (HEAVY)	C	20 AREAS							
2.2 (HEAVY)	U	10 AREAS							
2.2 (HEAVY)	C	20 AREAS							
NEXT (DYNAMIC)	C	30 AREAS							
3.0 (NEXT GENERATION)	C	30 AREAS							
<b>MSRC</b>		<b>gigaflops</b>	<b>62</b>	<b>62</b>	<b>62</b>	<b>81</b>	<b>85</b>	<b>55</b>	<b>45</b>
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
						OPERATIONAL			

- MODAS upgrades:
  - Now - reduce the number of domains to 15-20 at 1/12-degree resolution.
  - MODAS-NEXT - insertion of SWAFS/NCOM fields into the MODAS framework as forecasts
  - MODAS 3.0 - a totally new assimilative scheme for 2D/3D



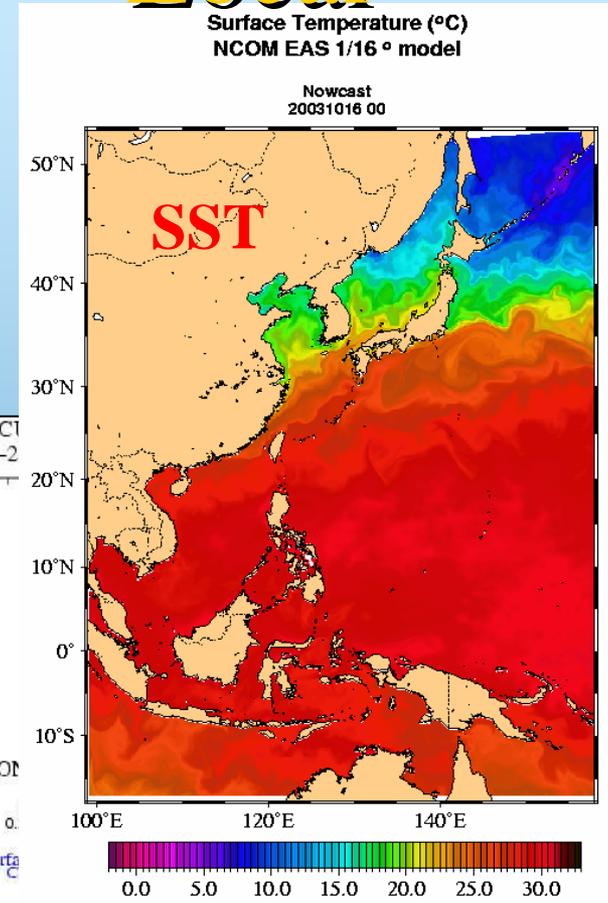
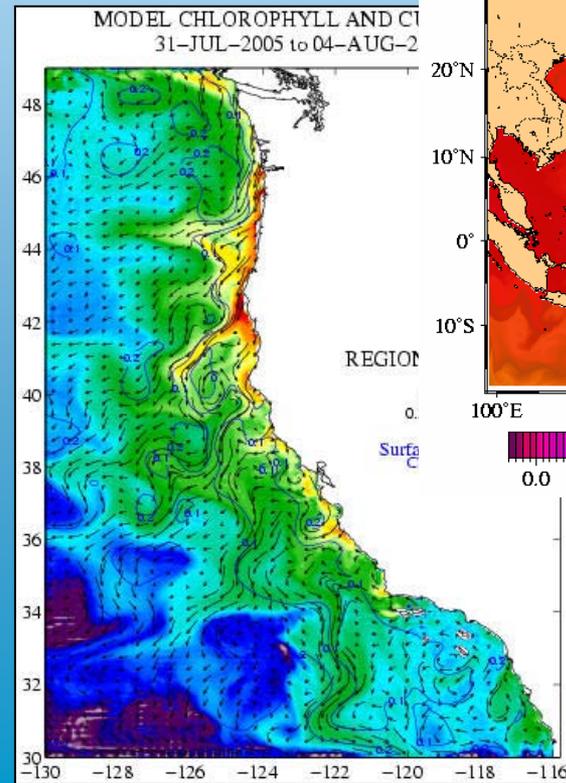
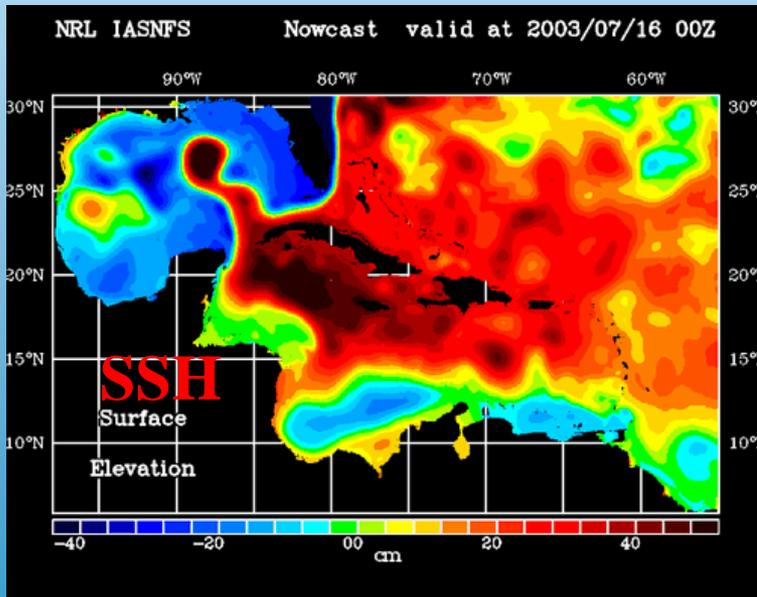
Global

Regional

Local

## Regional NCOMs

- East Asian Seas (EAS) - 1/16 deg
- Intra-Americas Seas (IAS) - 1/24 deg
- California Coastal Current – 1/12 deg



- Relocatable Nested Regional NCOM – FY07

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Global

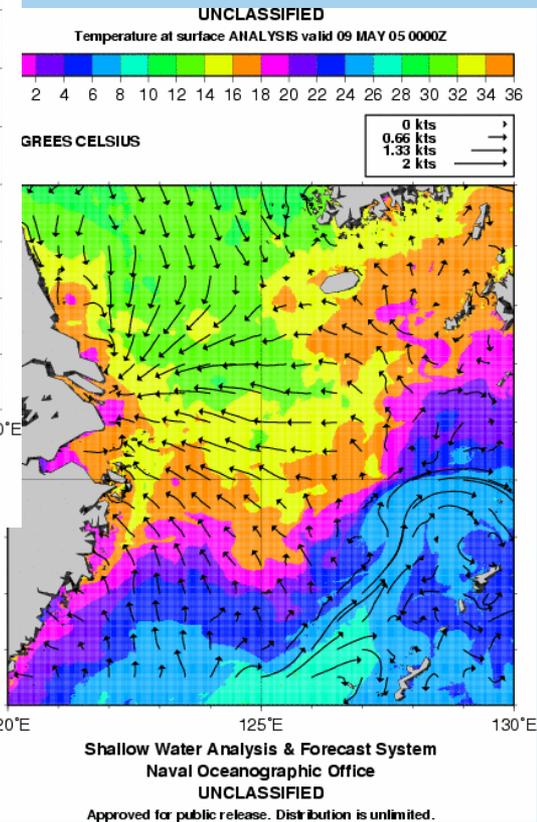
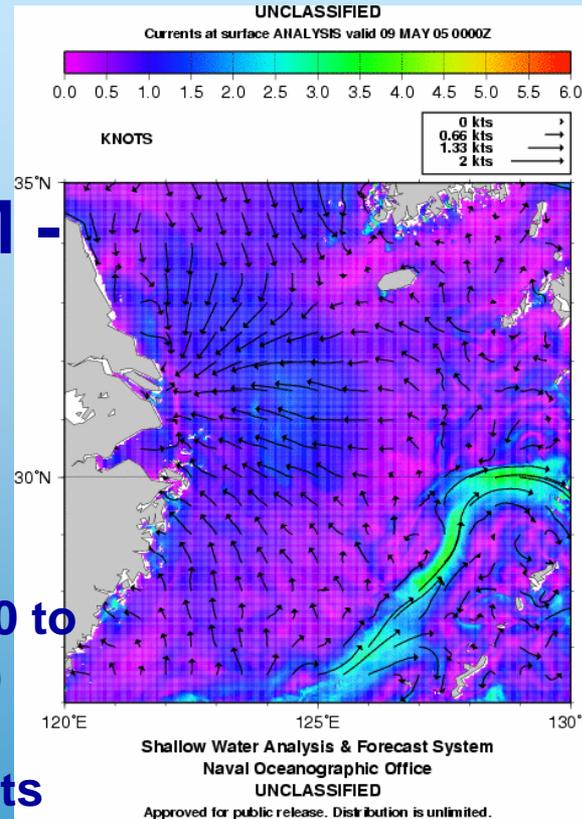
Regional

Local

# SHALLOW WATER ANALYSIS & FORECAST SYSTEM - SWAFS

- POM-based model
- 3D Forecasts
- **Currents, T-S, Elevation**
- Resolution varies by region (1/50 to 1/4 deg (0.5 to 24km / 1 to 15 nm))
- 27 to 47 vertical layers
- Forecast to 48hr @ 1hr increments
- Assimilates data from satellites (SST, SSH), *insitu* obs (XBTs, CTDs, floats, buoys), IHO tides

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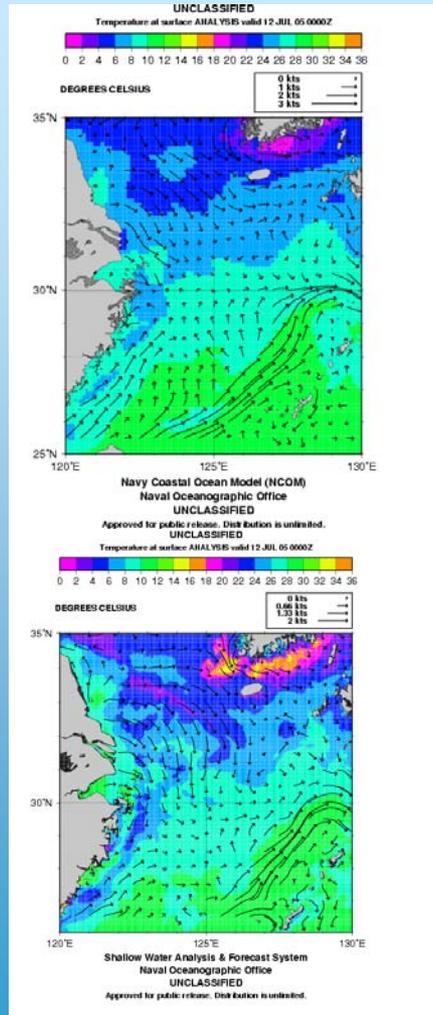


# GNCOM and SWAFS Surface Currents over Temperature

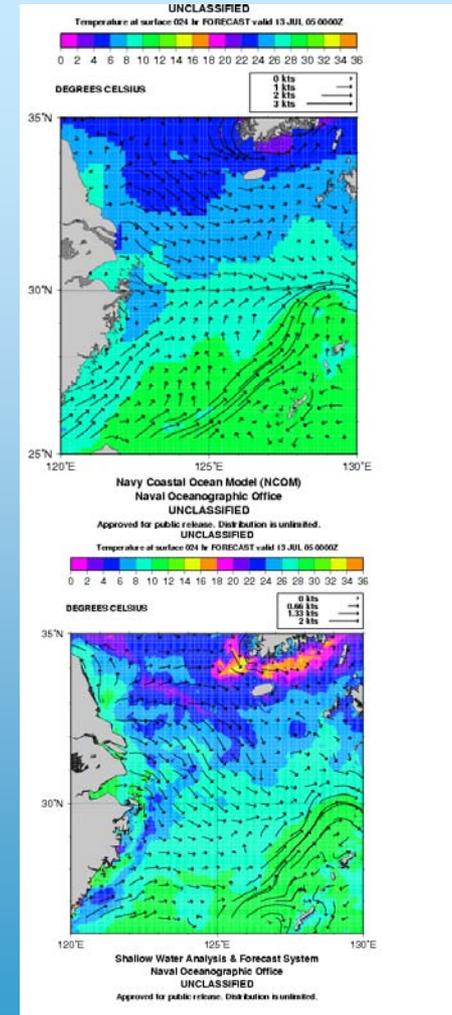
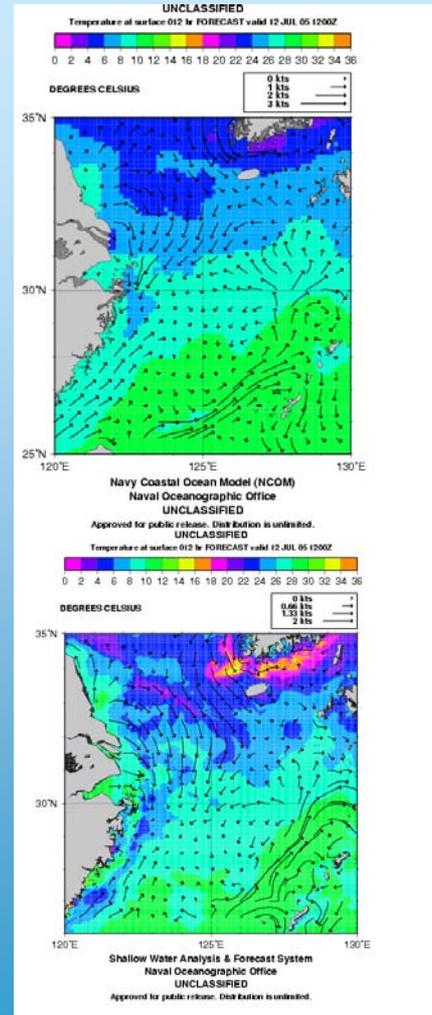
## Runs 00Z 12JUL05    taus 00 – 12 – 24 hrs



GNCOM



SWAFS



Notes: Model similarities and differences, SWAFS vectors 150% larger,  
UNCLASSIFIED GNCOM 1/8 deg and SWAFS 1/50.

# SWAFS - Shallow Water Analysis and Forecast System

## R-NCOM - Regional / Relocatable Navy Coastal Ocean Model

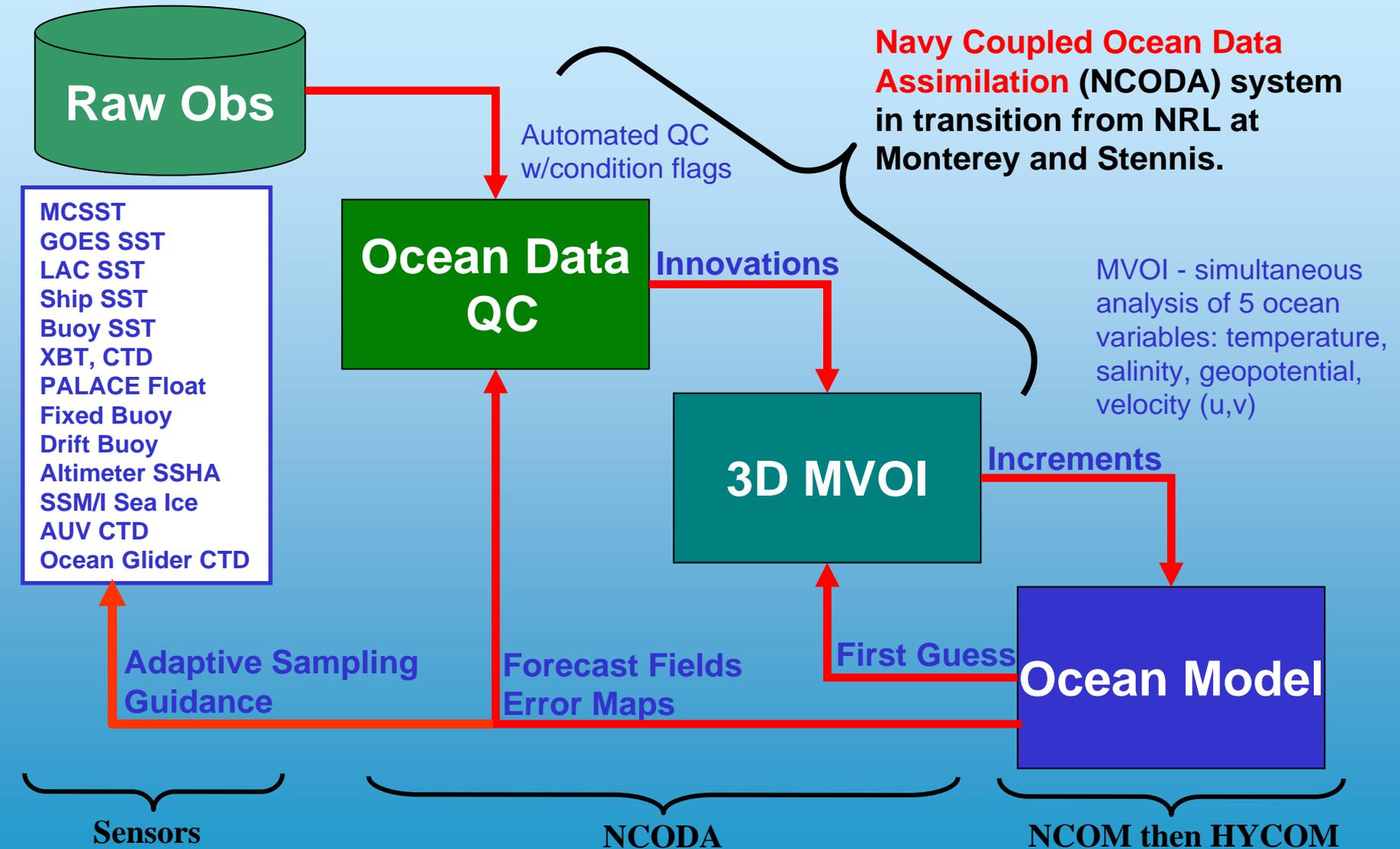
### R-HYCOM - Regional Hybrid Coordinate Ocean Model



REGIONAL		YEAR	2005	2006	2007	2008	2009	2010	2011
SWAFS	U	9 NESTS				-->R-NCOM			
SWAFS	C	3 NESTS					-->R-NCOM		
R-NCOM 1/16 - 1/24	U	7 AREAS							
R-NCOM - HIRES 1/50	U	6 AREAS						-->R-HYCOM	
R-NCOM - HIRES 1/50	C	3 AREAS						-->R-HYCOM	
R-HYCOM HIRES 1/50	U	Global							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
							OPERATIONAL		

- Currently **SWAFS** uses most of our resources @ 12 domains ~600-gigaflops
- The East Asian Seas (EAS-NCOM) starts the transition to regional NCOM models
  - NRL is developing a “**relocatable**” **NCOM** package that can nest down from G-NCOM to required resolutions fairly rapidly (CY2006).
  - ~7 medium resolution R-NCOM areas
  - ~6 small, high resolution (1/50-deg) domains of Navy interest.
  - ~3 rapidly implemented, very high-res, short-lived classified domains for special operations.
- When the **1/24-degree HYCOM** is operational by CY2011
  - Many of the NCOM regional domains will no longer be needed.
  - Will run some high to very high-resolution HYCOM domains for specific Navy-interest areas

# Real-Time Profile Assimilation w/NCODA (FY06)



# Data Assimilation & Infrastructure



ASSIMILATION		YEAR	2005	2006	2007	2008	2009	2010	2011
NCODA MVOI	U	GLOBAL							
NCODA MVOI	C	GLOBAL							
MSRC		gigaflops	15	30	30	30	300	300	300
INFRASTRUCTURE		YEAR	2005	2006	2007	2008	2009	2010	2011
GRAPHICS (MOGS)	U								
ARCHIVE (MDDAS)	U								
DISTRIBUTION (MDDDS)	U								
QC - NCODA	U								
ESMF (BEI)	U								
MSRC		gigaflops	43	83	75	75	75	75	75
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
						OPERATIONAL			

- **NCODA** upgrade in 2009 goes to 4DVAR
  - NCODA includes an observation QC package
- MOGS, MDDAS, MDDDS all NAVO internal pre- & post-processing on MSRC
- Earth System Modeling Framework (**ESMF**) will be information backbone for all models



Global

Regional

Local

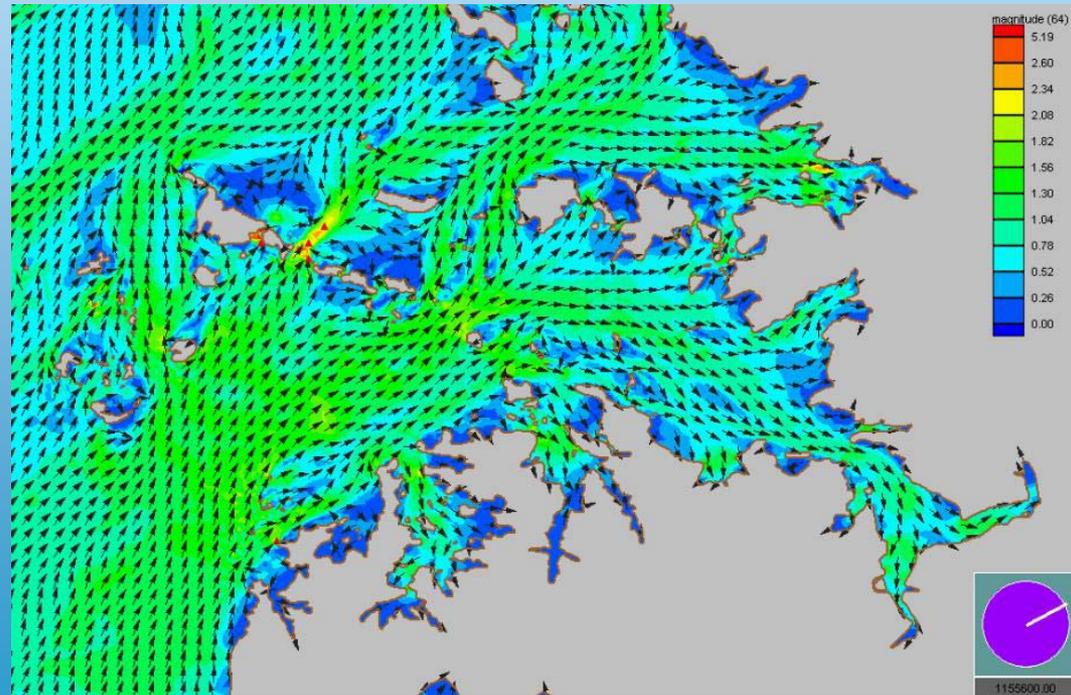
## ADVANCED CIRCULATION MODEL - ADCIRC

### 2D BAROTROPIC ADCIRC

- New generation finite element model
- Consortium model (NRL, Notre Dame, UNC, NOAA NOS, ...)
- Coastal currents, elevation
- Rapid deployment
- Inputs winds at each node
- Fully tidal
- Run on Linux or MSRC
- FY06 (NRL)

### 3D BAROCLINIC ADCIRC

- Coastal ASW tool
- T, S, currents, elevations
- FY08





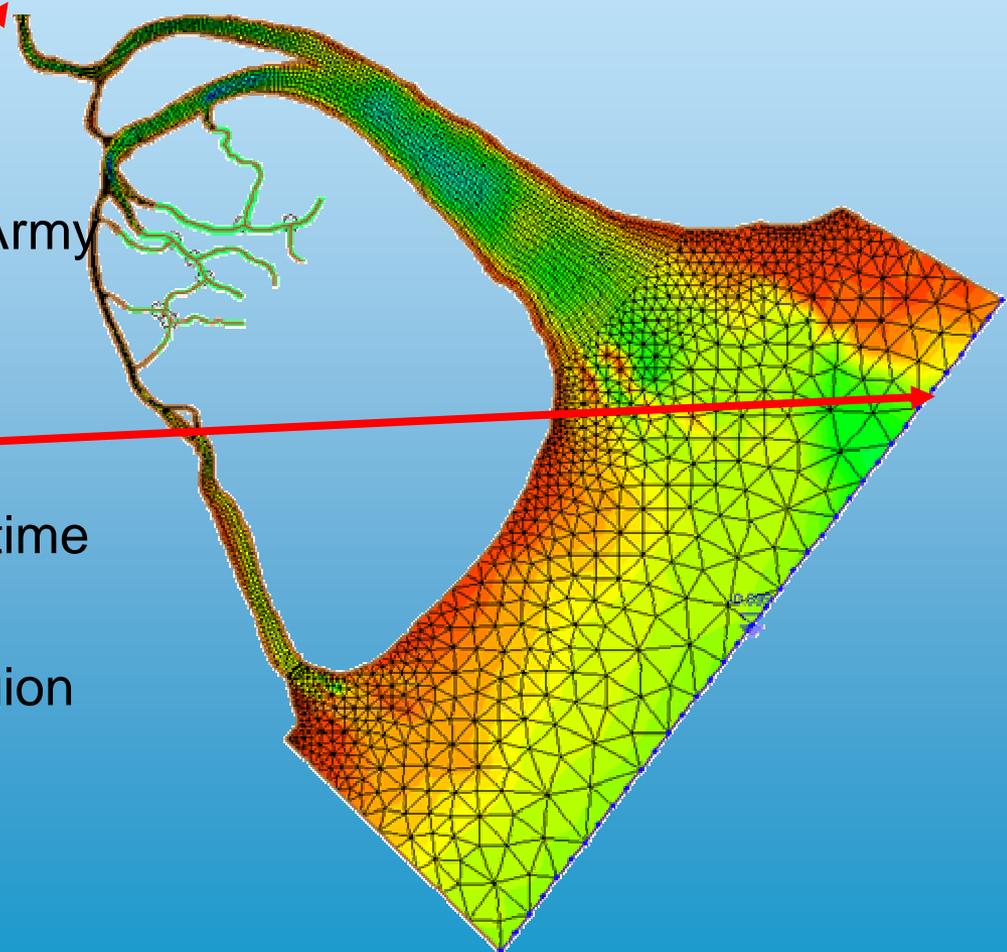
Global

Regional

Local

## RMA2 - River/Estuary 2D Model

- RMA2 Finite Element Model (US Army Corps of Engineers)
- **Forced** with river runoff & tidal constituents
- **Forecast** tidal elevations / current time series in sections through region
- Forecast current fields through region
- No Nodal Wind Speed input
- Runs on PC



# ADCIRC - Advanced Circulation Model

RMA2 - Resource Management Associates (USACE contract)

WQMAP - Water Quality Management and Analysis Package (ASA)



REGIONAL		YEAR	2005	2006	2007	2008	2009	2010	2011
ADCIRC 2D Barotropic	u	3 AREAS							
ADCIRC 3D Barotropic	u	5 AREAS							
ADCIRC 3D Barotropic	c	6 AREAS							
ADCIRC Baroclinic	u	3 AREAS							
ADCIRC Baroclinic	c	3 AREAS							
WQMAP / HYDROMAP	u/c	10 AREAS							
RAM2	u/c	11 AREAS							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
						OPERATIONAL			

- By 2008, **ADCIRC** will be a fully baroclinic 3D coastal model
  - Up to 9 domains that can be quickly deployed, depending on bathymetry.
- In addition to ADCIRC, NAVOCEANO has installed and is successfully using rapidly implementable,
  - **RMA-2** - a 2D, finite element, barotropic model
  - **WQMAP / HYDROMAP** - for nearshore and coastal circulation predictions.

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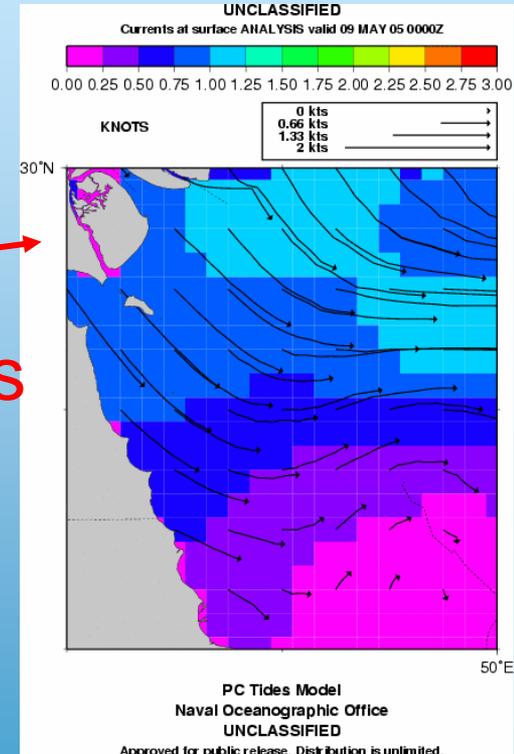
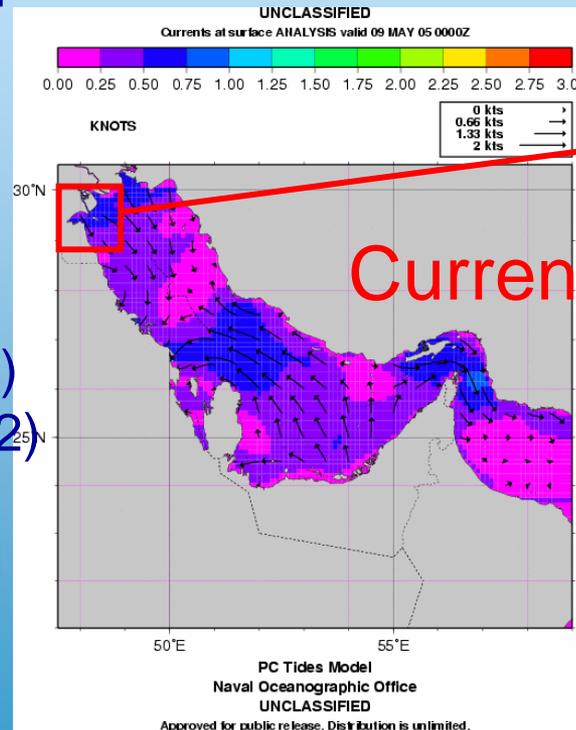
Global

Regional

Local

## PC TIDES

- Application of wave equation
- 2D barotropic model
- Forced by tidal stations & FNMOOC / 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



UNCLASSIFIED

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# PCTIDES - Advanced Circulation Model

RMA2 - Resource Management Associates (USACE contract)

WQMAP - Water Quality Management & Analysis Package (ASA)

TIDES		YEAR	2005	2006	2007	2008	2009	2010	2011
PCTIDES	u	10 AREAS							
PCTIDES	c	30 AREAS							
MSRC		gigaflops	22	36	50	50	50	50	50
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
							OPERATIONAL		

- Elevations available from SWAFS and NCOM with OSU (Egbert / OTIS) model
- PCTIDES undergoing OPEVAL in CY2005.
  - A proposed upgrade is planned by CY2007.
- RMA2 and WQMAP can also provide tidal elevation and 2D current forecasts



Global

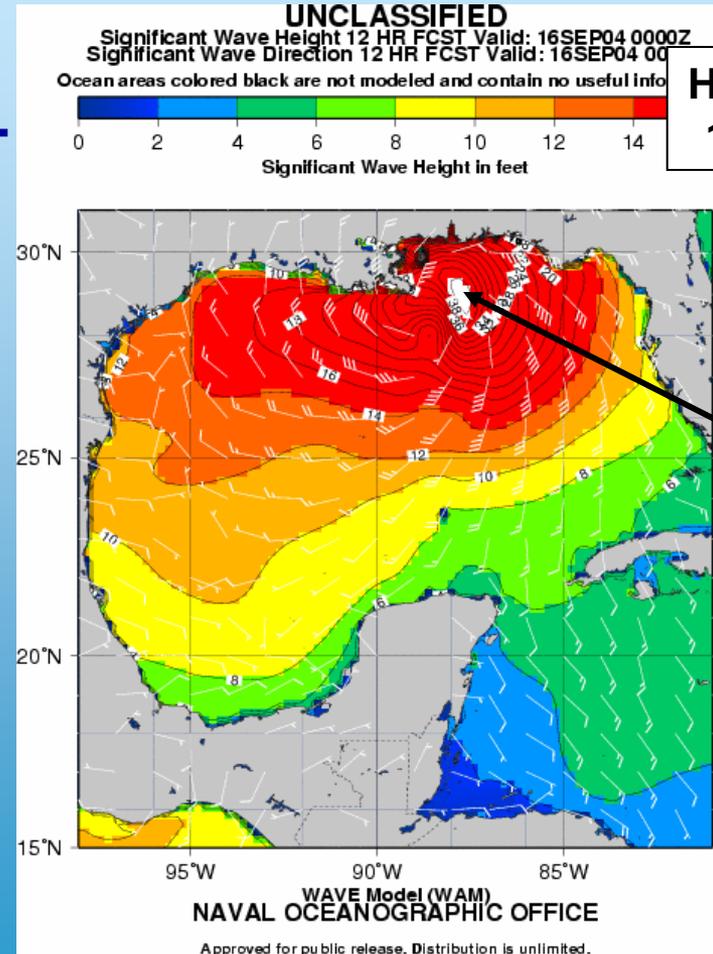
Regional

Local

## WAVE ANALYSIS MODEL WAM

- Portable - easily relocated
- Variable resolution ( $1/4^\circ$  to  $1/12^\circ$ )
- 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

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Hurricane IVAN  
16 SEPT 2004

> 40 ft



Global

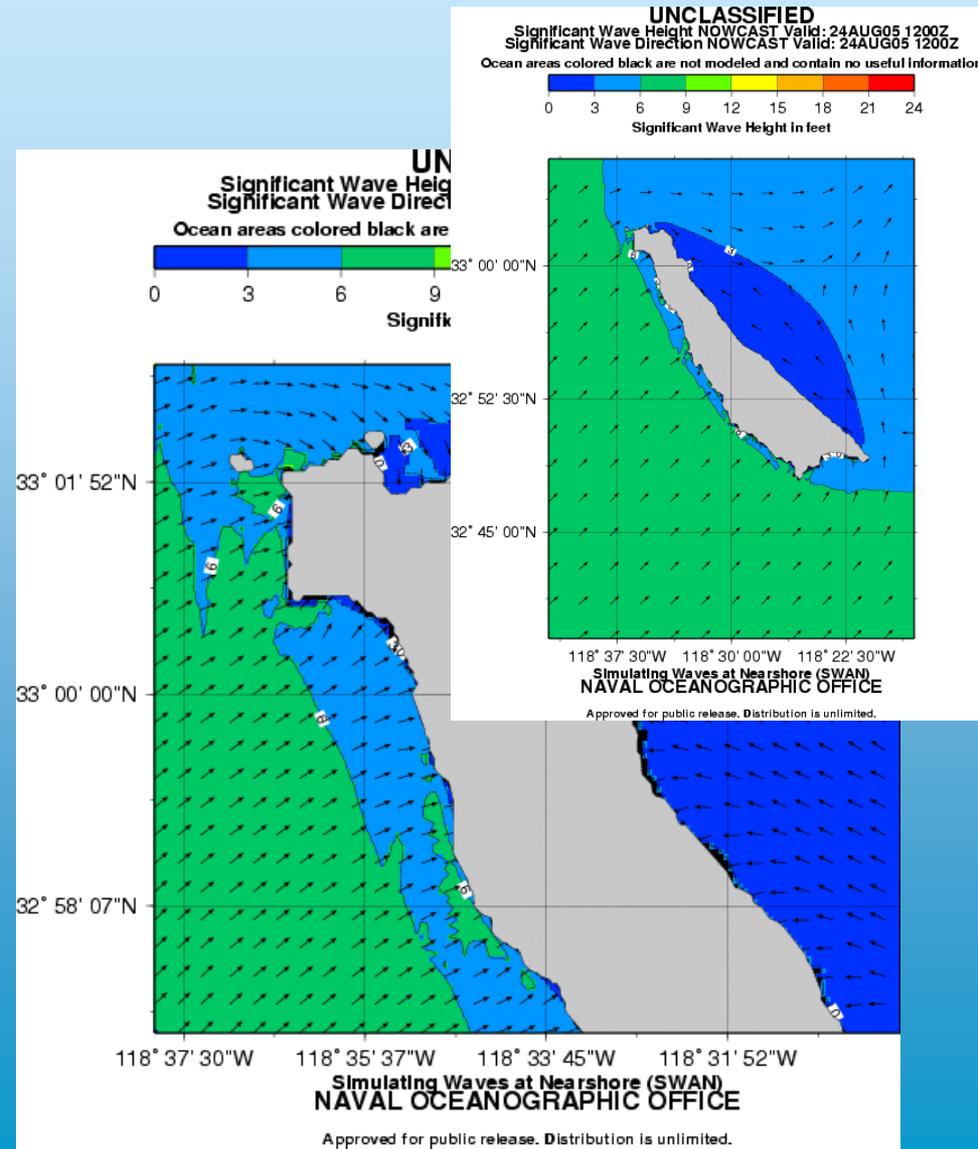
Regional

Local

## SIMULATING WAVES NEARSHORE - SWAN

- Part of U. Delft DELFT3D package
- A 3<sup>RD</sup> generation stand-alone (phase-averaged) wave model to simulate waves in waters of deep, intermediate and finite depth
- Forecasts wave properties into surf zone
- Transitioned to NAVO FY05
- Resolutions from regional (1/12 deg) to beach (~10 m)
- Deliver graphics, data (NetCDF properties similar to WAM)

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# WAM - Wave Model

## WW3 - Wave Watch 3

### SWAN - Simulating Waves Nearshore



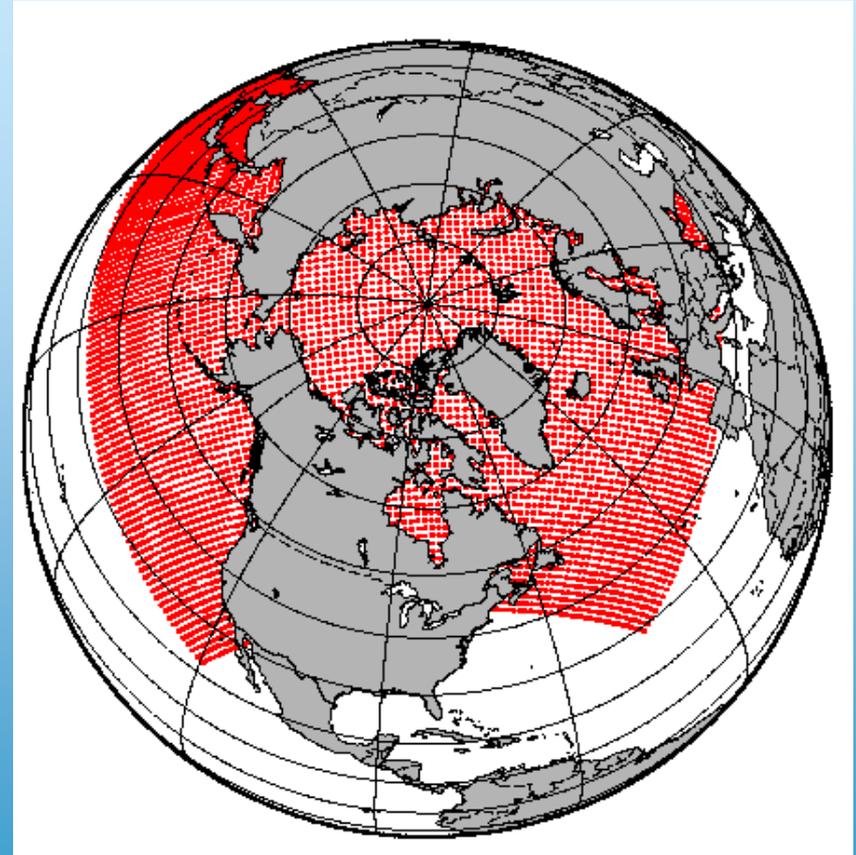
WAVES & SURF		YEAR	2005	2006	2007	2008	2009	2010	2011
WAM	U	40 AREAS			-> WW4+				
WW4+	U	GLOBE+10							
SWAN	U	15-->25							
SWAN	C	10-->30							
STWAVE	U	~10		-> SWAN					
NSSM	U	~10							
DELFT3D	U/C	20 AREAS							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION					
					UPGRADE AND IMPROVEMENT				
						OPERATIONAL			

- NAVOCEANO runs the spectral **WAM** model twice daily
  - Approximately 40 nested domains.
  - A placeholder for a **Wave Watch-4+** upgrade COULD receive from USACE CY2006
  -
- **SWAN** is being transitioned to NAVOCEANO during CY2005
- **DELFT3D**, incorporating SWAN, coastal flow, and surf modules, starts transition CY2006

# Polar Ice Prediction System - PIPS 2.0



- Coupled Ice-Ocean Model (Hibler/Cox)
- Includes all sea ice covered regions of the northern hemisphere
- 0.28 degree ( $\sim 1/4$ ) grid resolution
- 15 vertical levels
- Solid wall boundaries
- Ocean loosely constrained to Levitus climatology
- Transitioned to NAVO in FY04
- Operational Oct 2004 – on Cray Sv (Poseidon)
- Converted code from CRAY to IBM (Kraken) June 2005



Hatched lines every 4<sup>th</sup> grid point

# PIPS - Polar Ice Prediction System



ICE		YEAR	2005	2006	2007	2008	2009	2010	2011
PIPS 2.0	u	ARCTIC							
PIPS 3.0 (G-NCOM)	u	ARCTIC							
PIPS 3.0 (G-HYCOM)	u	ARCTIC							
MSRC		gigaflops	3	3	2	17	17	17	17
				DEVELOPMENT & TRANSITION					
						UPGRADE AND IMPROVEMENT			
								OPERATIONAL	

- PIPS 2.0 was transferred from FNMOC to NAVOCEANO during CY2004.
  - The upgrade PIPS 3.0, based on the Los Alamos CICE algorithms, is being installed as part of the NCOM/HYCOM suites.

# Summary



- NAVOCEANO modeling system designed to meet Navy needs
  - Span global – regional – local domains
  - Variety of models / products
  - Daily update production
- MSRC is a capable engine
  - Biennial upgrades will allow hosting of high resolution 1/24 degree HYCOM
- HYCOM will be our global & regional model of the future
- Interests from the HYCOM meeting
  - Product assessment tools
  - Latest on data assimilation

# NAVOCEANO Modeling Information Matrix

