



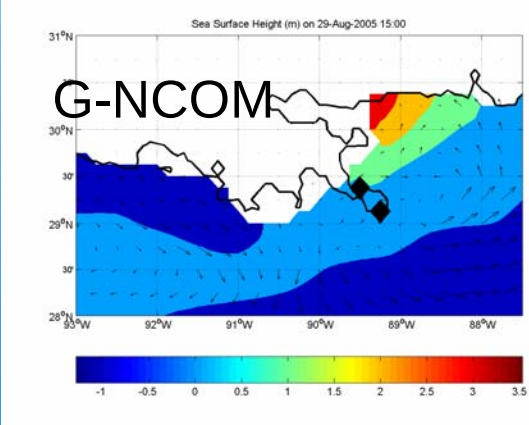
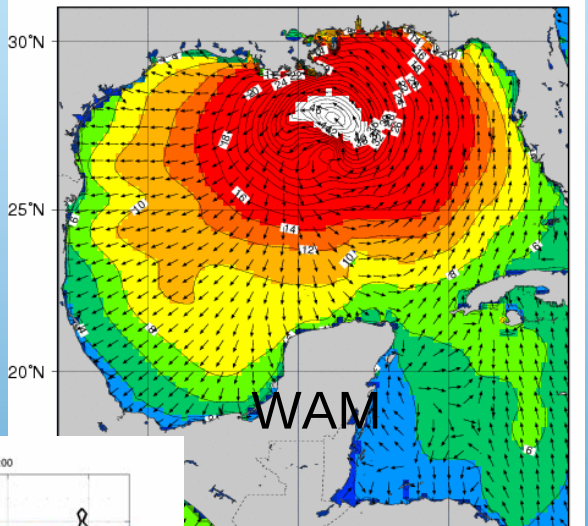
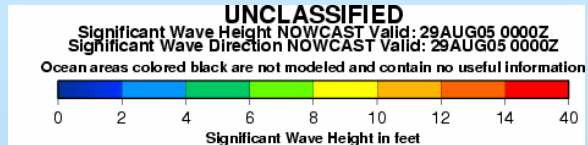
The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)

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

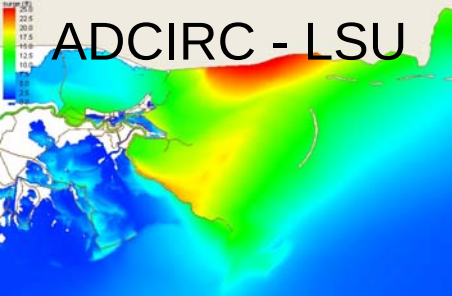
frank.bub@navy.mil

228-688-4758

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



WAVE Model (WAM)
/AL OCEANOGRAPHIC OFFICE
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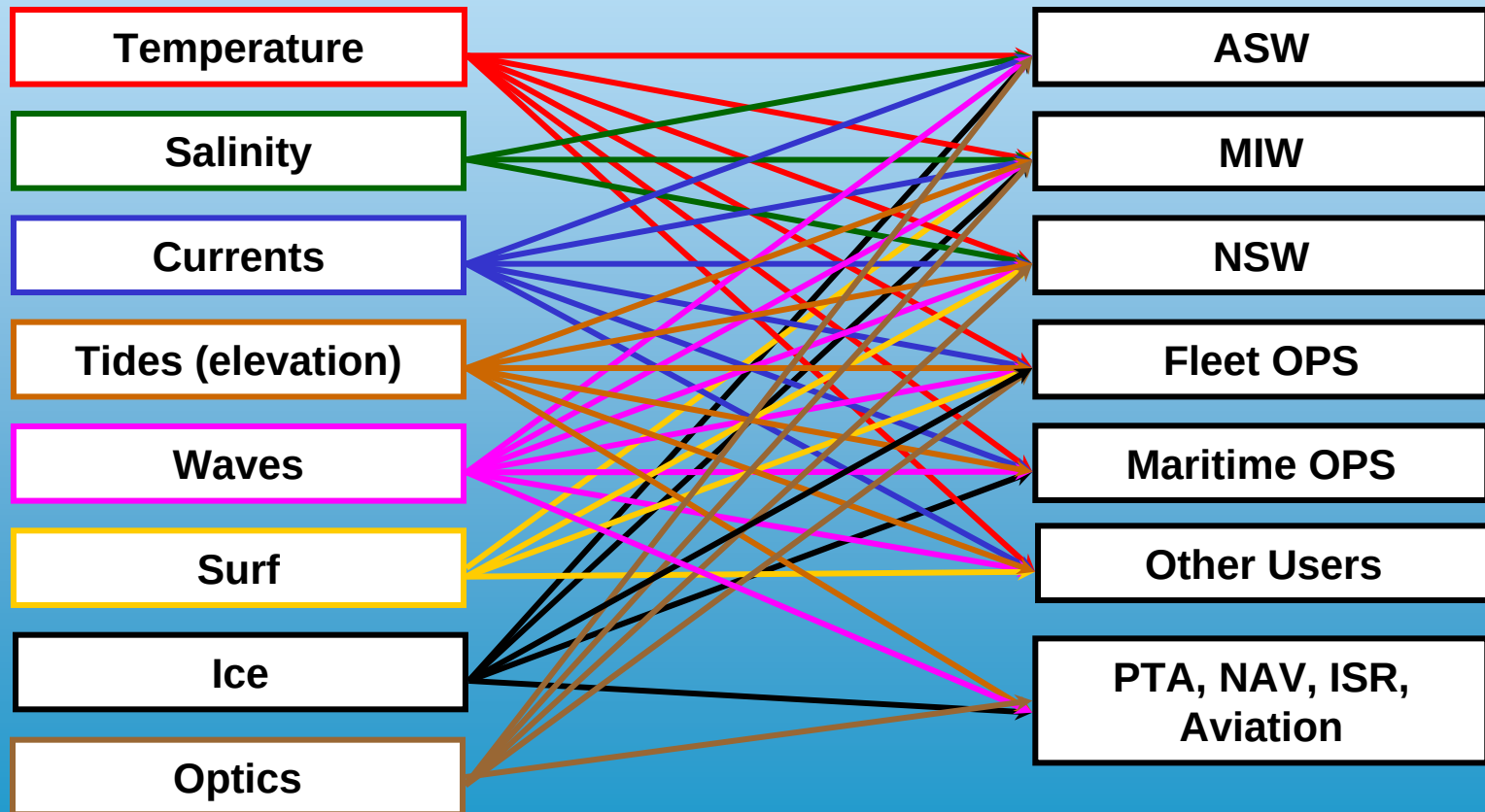
Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE DEC 2005		2. REPORT TYPE		3. DATES COVERED 00-00-2005 to 00-00-2005	
4. TITLE AND SUBTITLE The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)				5a. CONTRACT NUMBER	
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15. SUBJECT TERMS					
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a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Basic Product Suite Mapped to Navy Lines of Operation

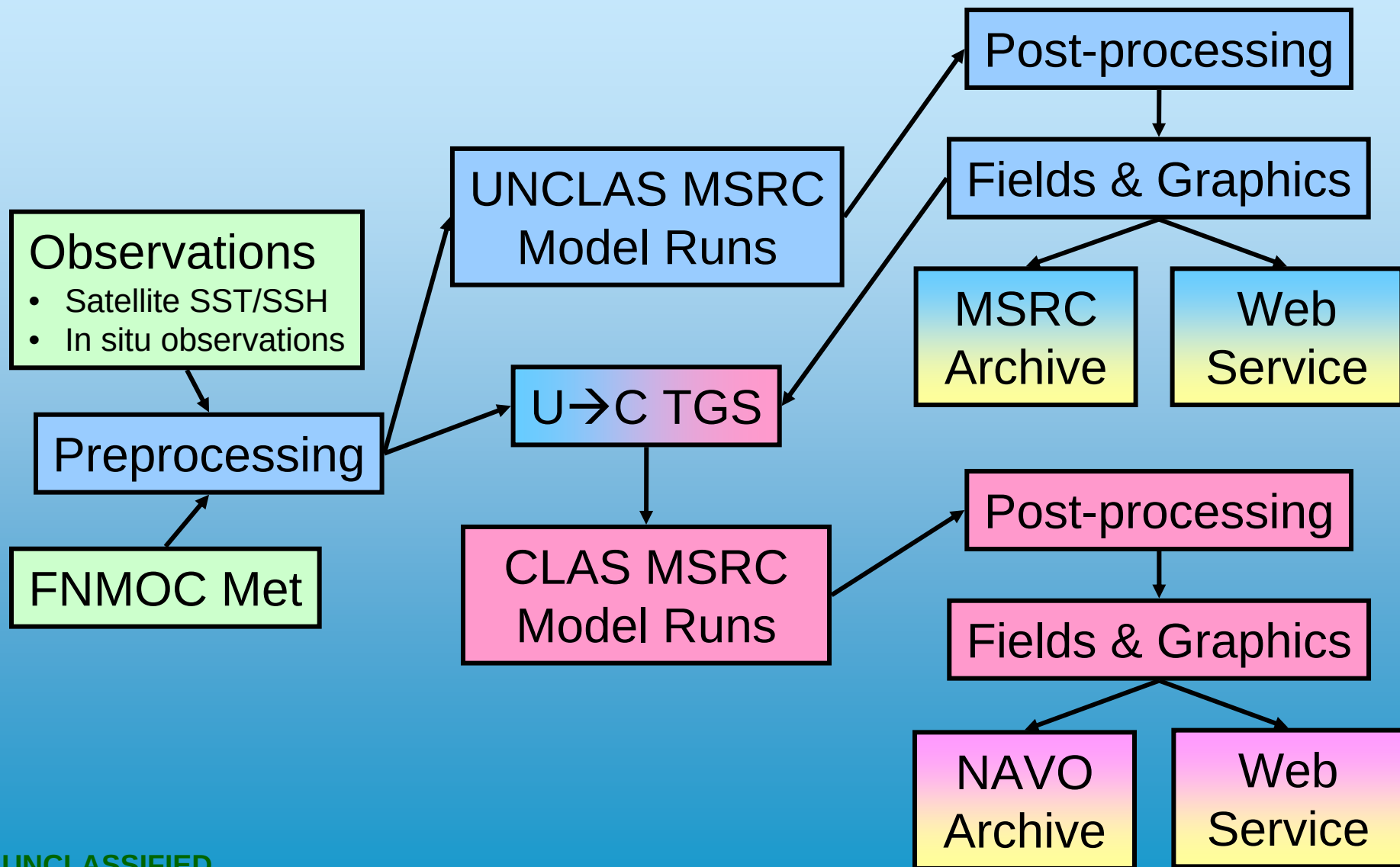


NAVOCEANO's business is to

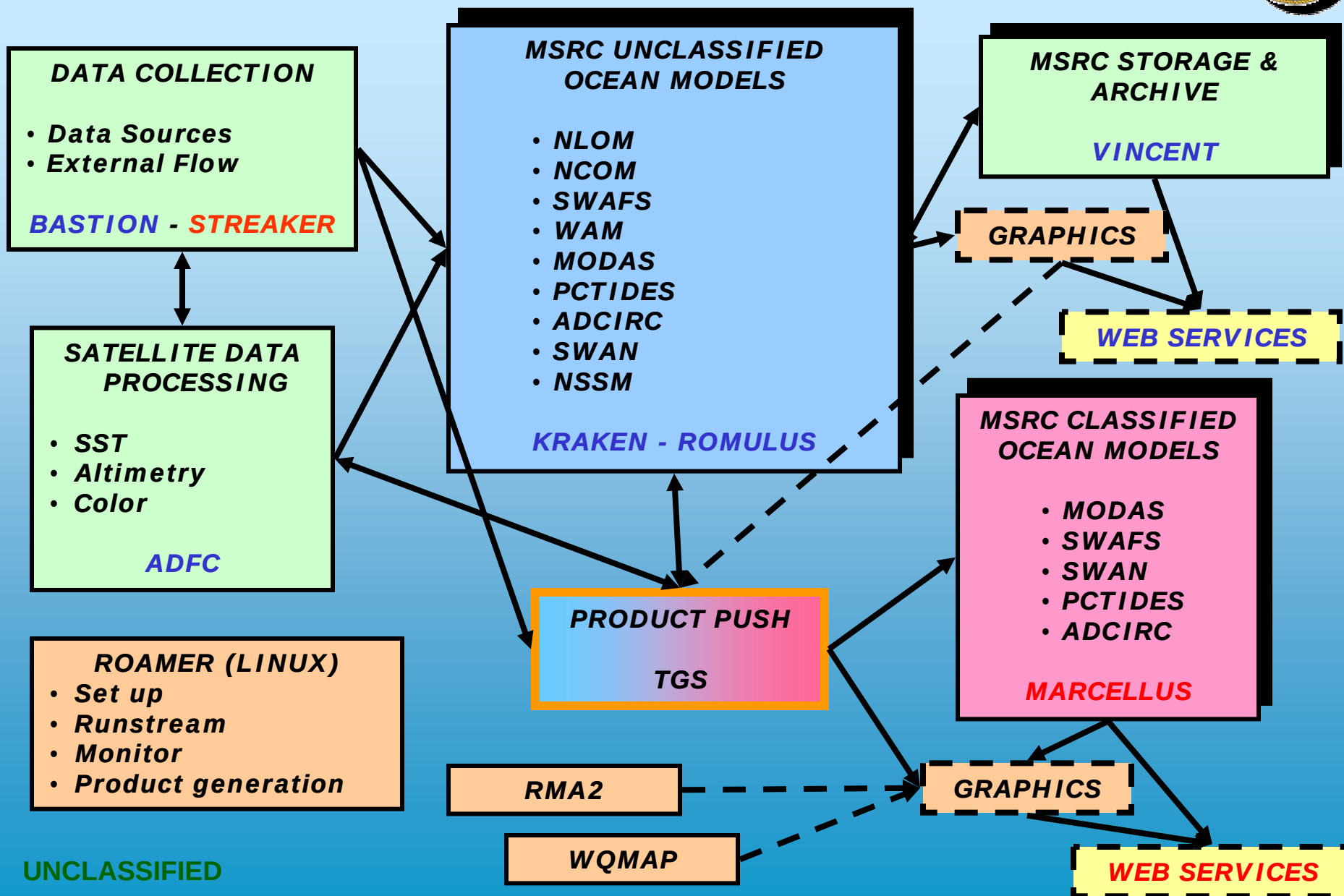
- Collect or acquire observations & information for the....
 - Analysis and prediction of....
- Currents, Temperature, Salinity, Sound Speed, Waves, & Optics.



NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



NAVOCEANO MSRC Assets - CY2005



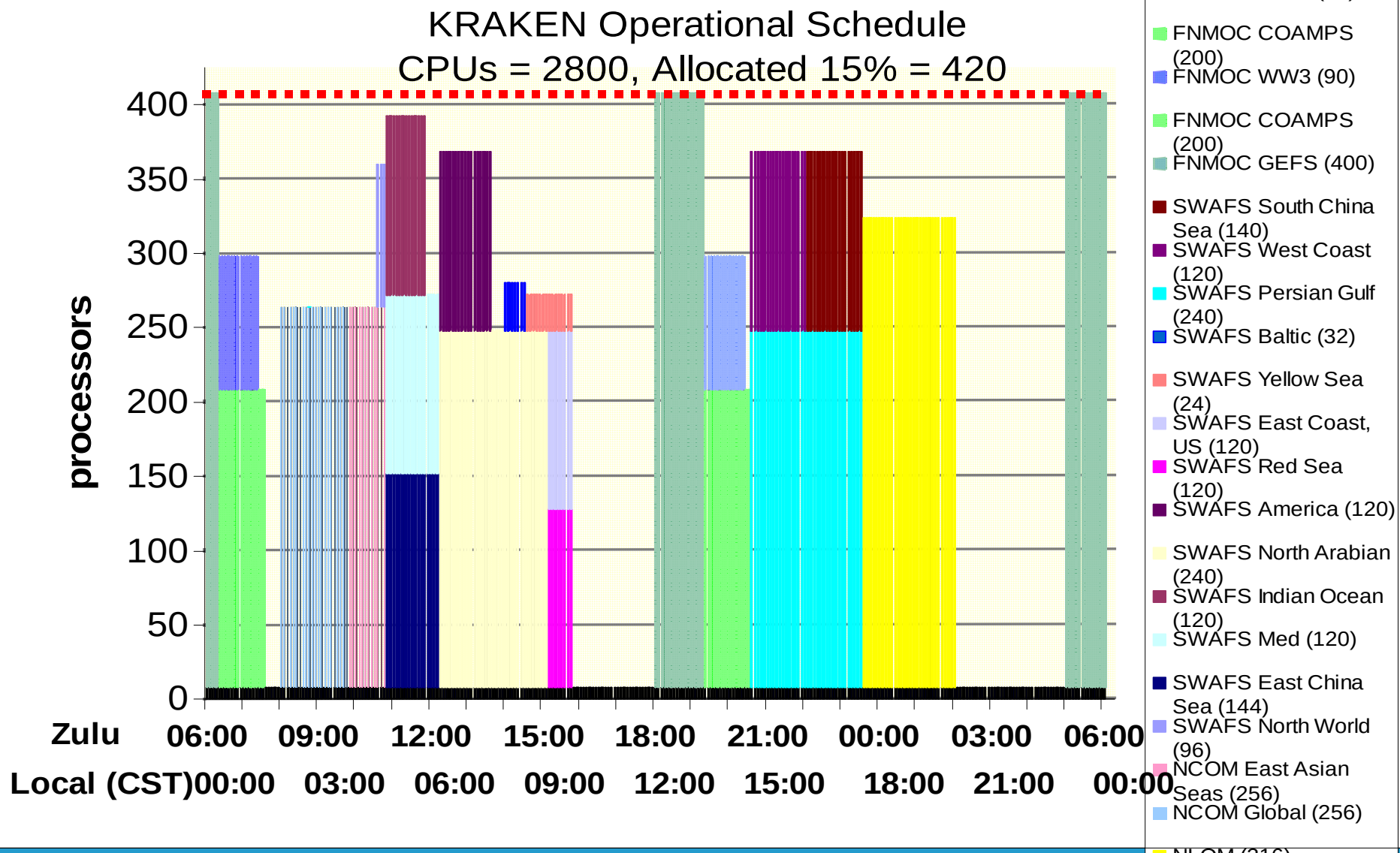
SYSTEM		Speed	CPUS		15%	GFLOPS *			
NAME	MODEL	MHZ	TOTAL	AVBL	CNMOC	PER cpu	AVBL	CNMOC	CLAS
2005									
Kraken	IBM Power-4+	1,700	2,944	2,832	425	6.8	19,258	2,889	U
Romulus	IBM Power-4+	1,700	512	464	70	6.8	3,155	473	U
Marcellus	IBM Power-4	1,300	1,408	1,328	199	5.2	6,906	1,036	C
2004									
Habu	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
		TOTALS	End 2004		354		8,493	1,274	
			End 2005		694	+196%	29,318	4,398	+345%

* 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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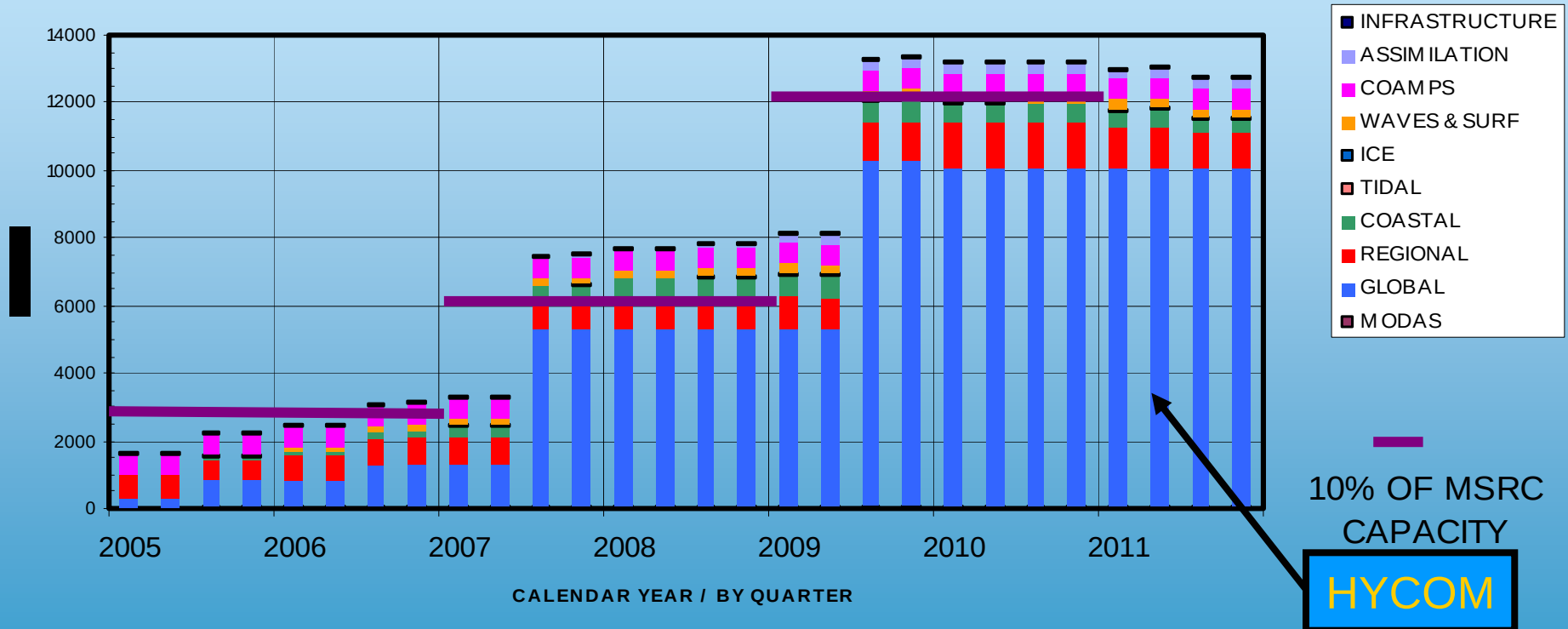
NAVOCEANO MSRC Schedule

Kraken – AUGUST 2005



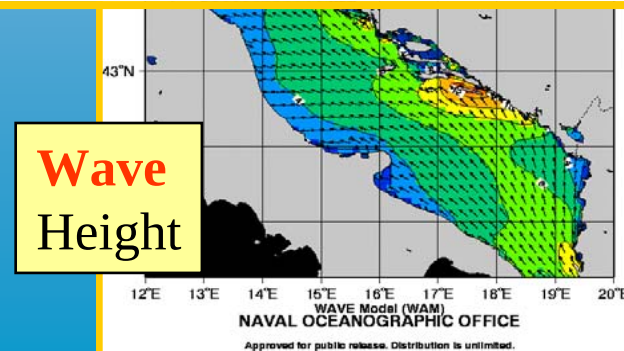
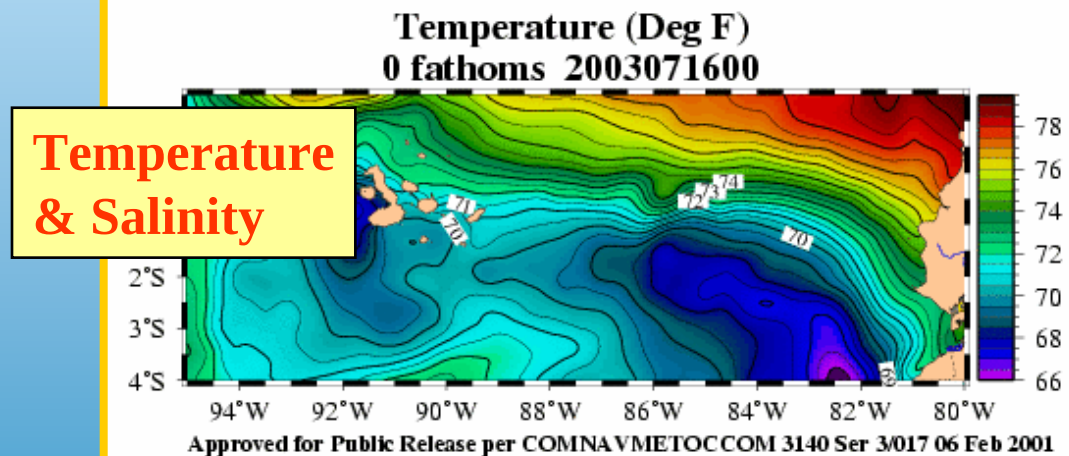
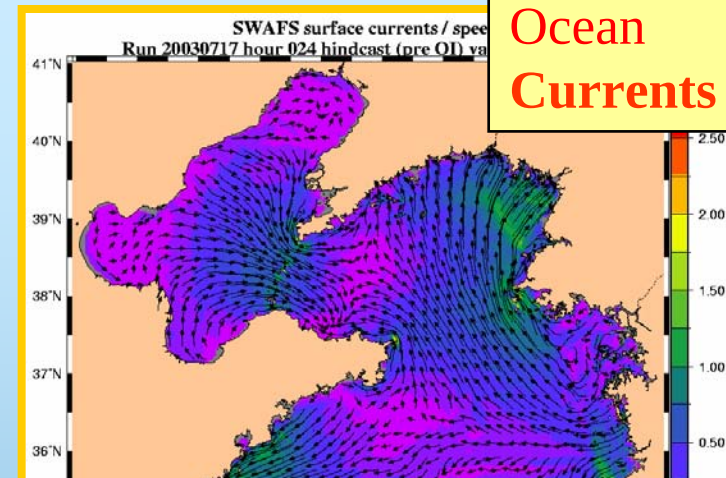
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NAVOCEANO MSRC Requirements through CY2011 in gigaflops (billions of floating point operations)

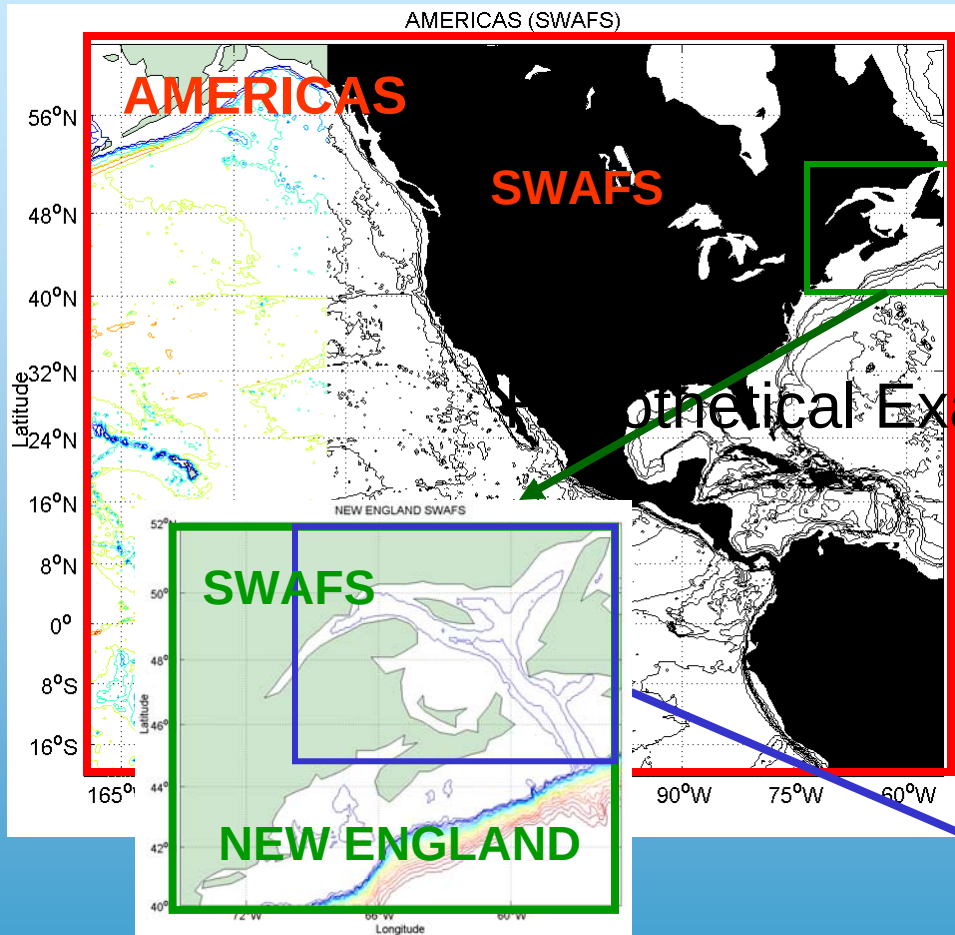


Operational Modeling distinct from R&D Modeling

- 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



Arbitrary Example

Global NCOM

- ~14km resolution
- 2.6 mil gridpoints

AMERICAS (2:1)

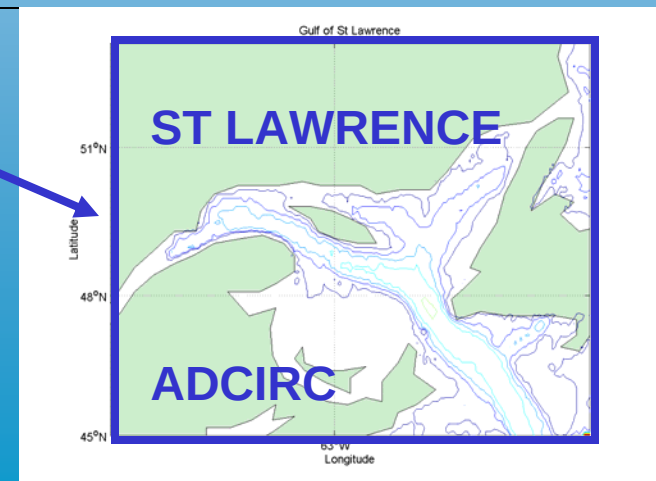
- ~8km resolution
- 1.4 mil grid points

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)

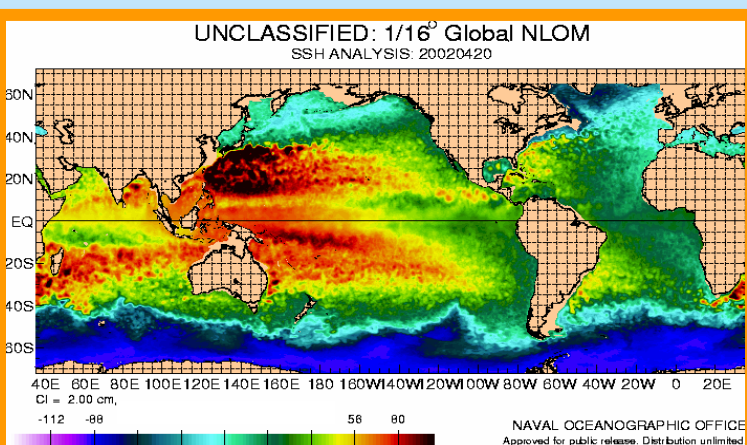
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Global

Regional

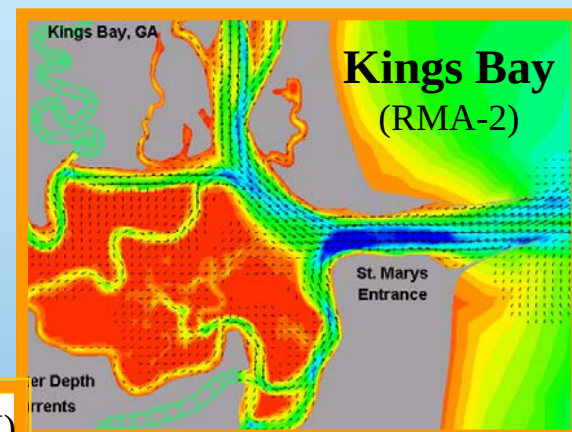
Local



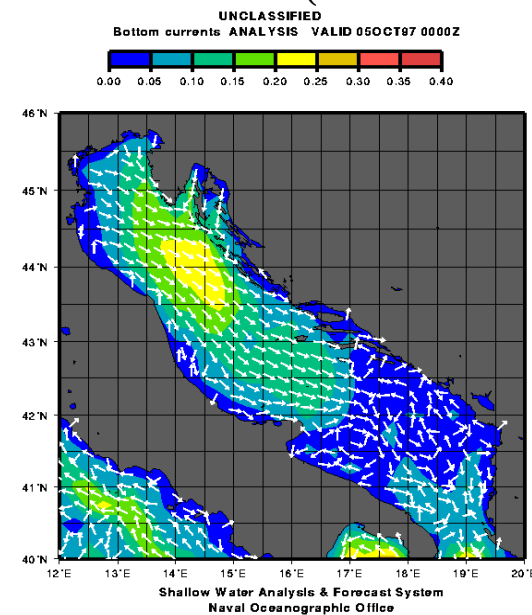
- Global Deep Ocean Models:
- Regional models boundary conditions
 - Transit planning
 - Filling gaps

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- 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



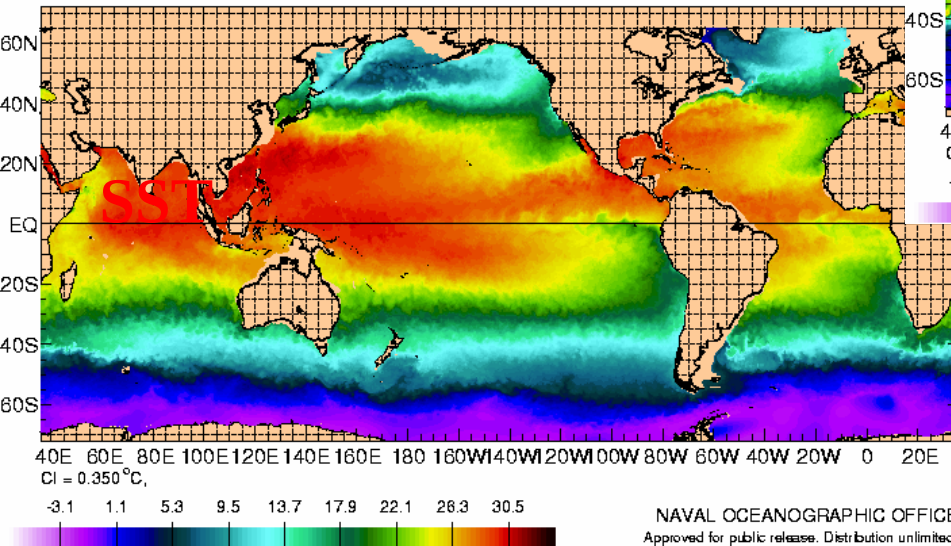
Global

Regional

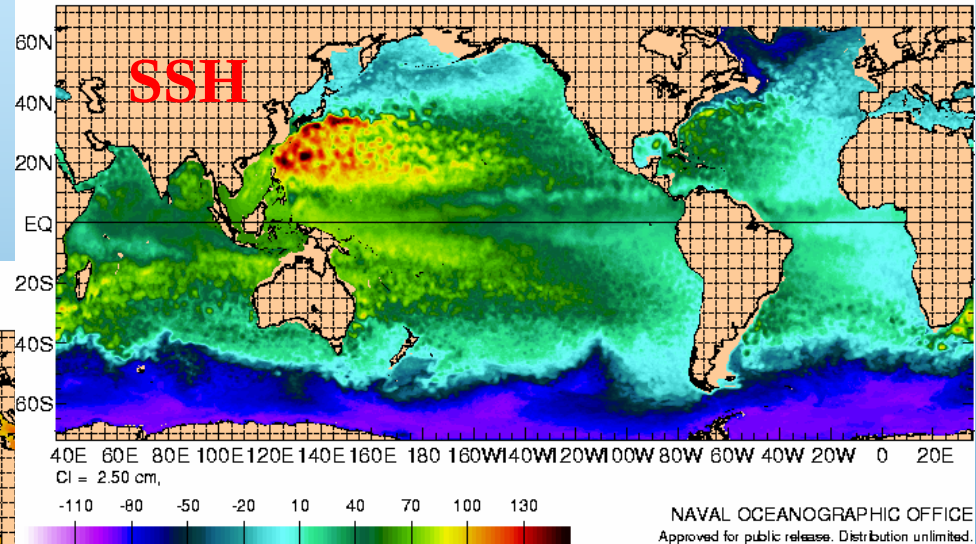
Local

NAVY LAYERED OCEAN MODEL NLOM

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



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

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

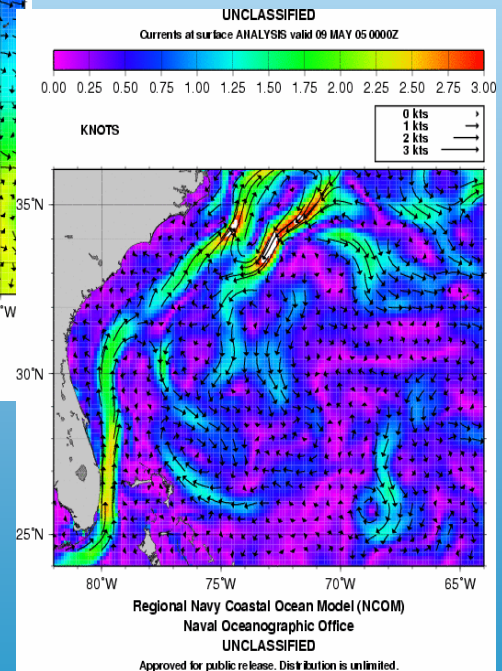
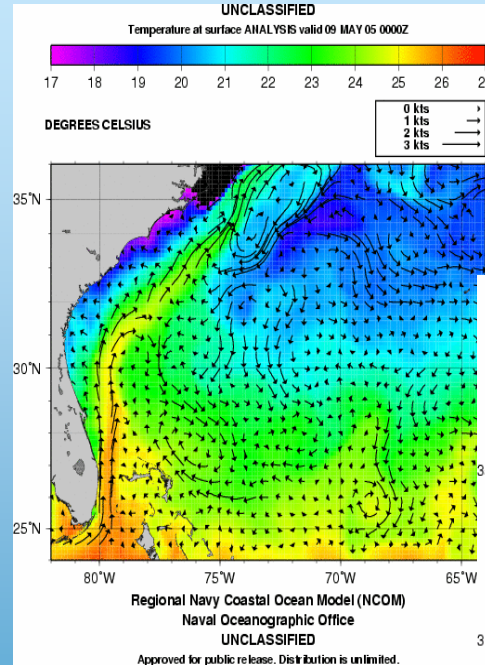
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GLOBAL NAVY COASTAL OCEAN MODEL G-NCOM

- 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)



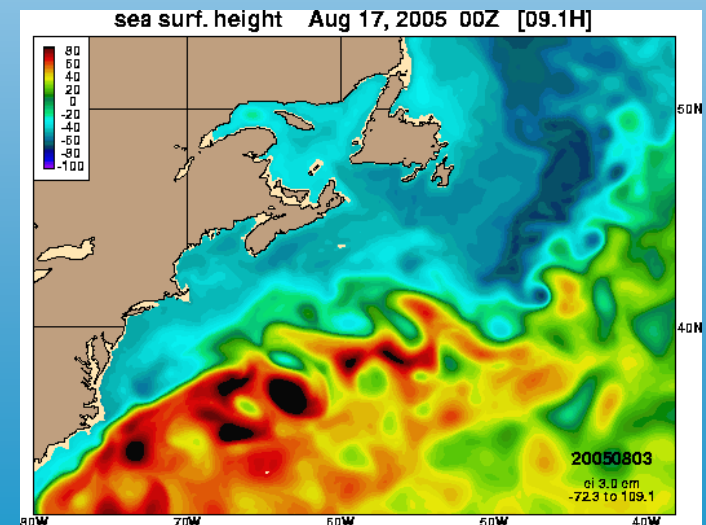
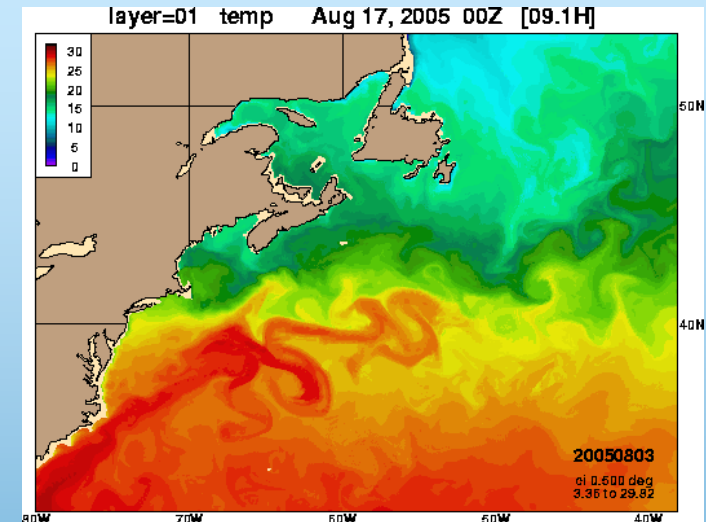
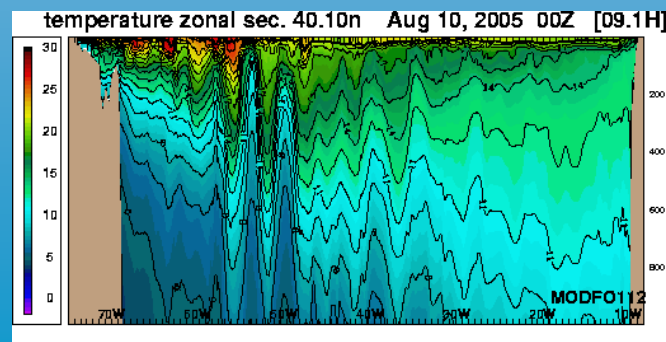
Global

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



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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							
MSRC		gigaflops	735	1235	5235	5235	10,235	10,000	10,000
				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.

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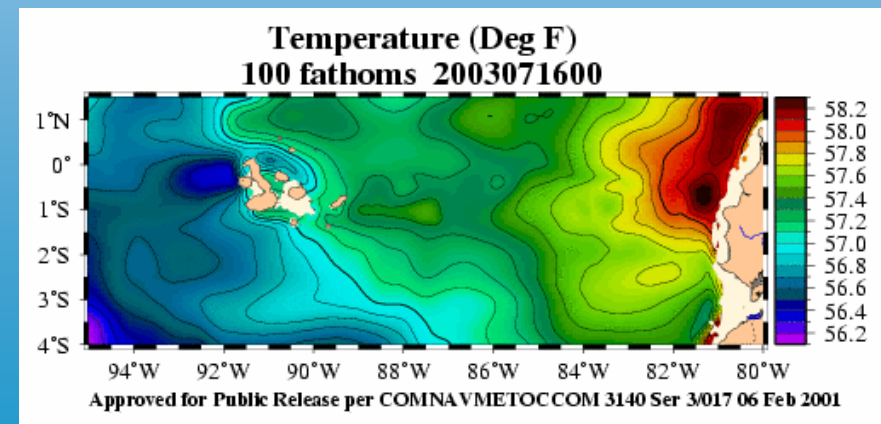
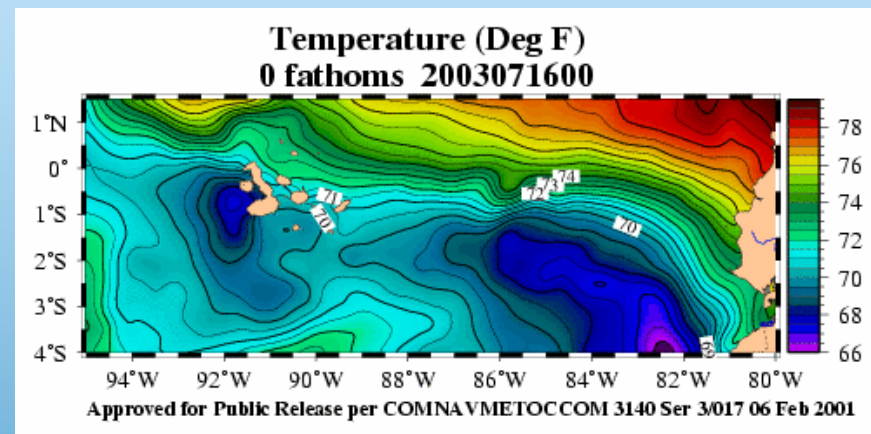
Global

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							
MSRC		gigaflops	62	62	62	81	85	55	45
				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



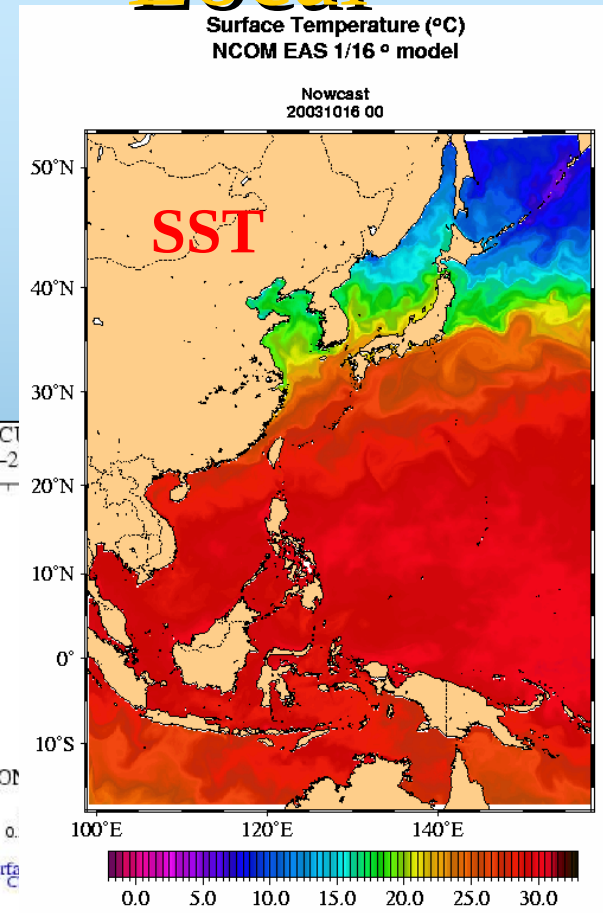
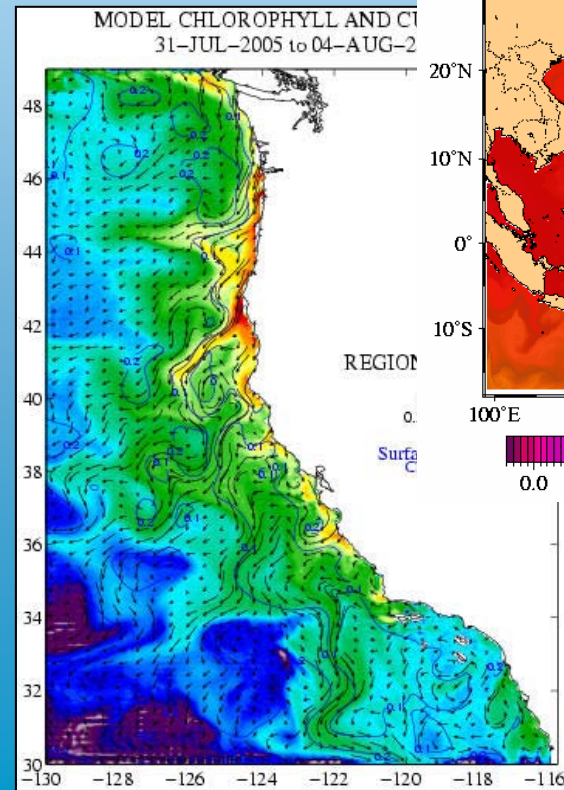
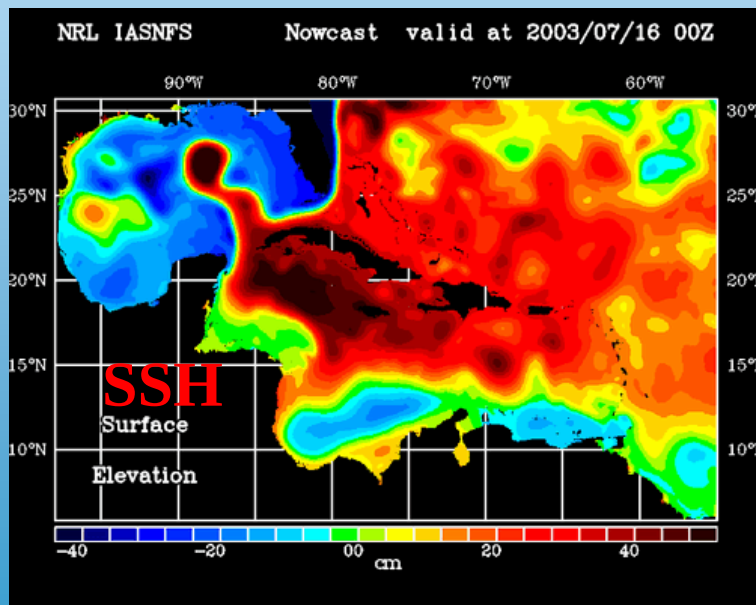
Global

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

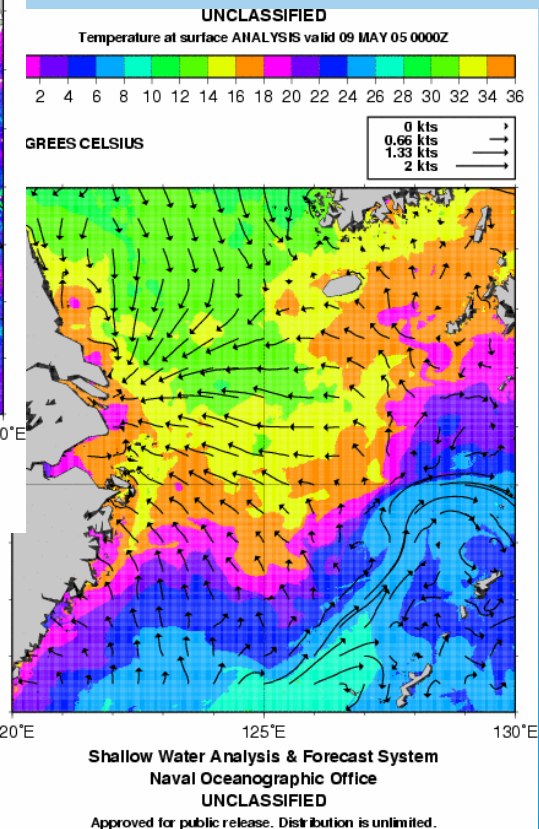
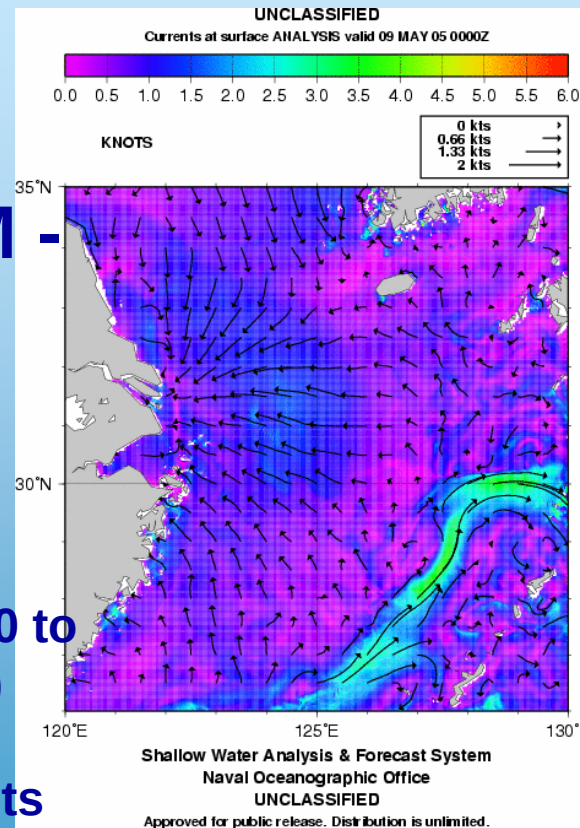
Regional

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

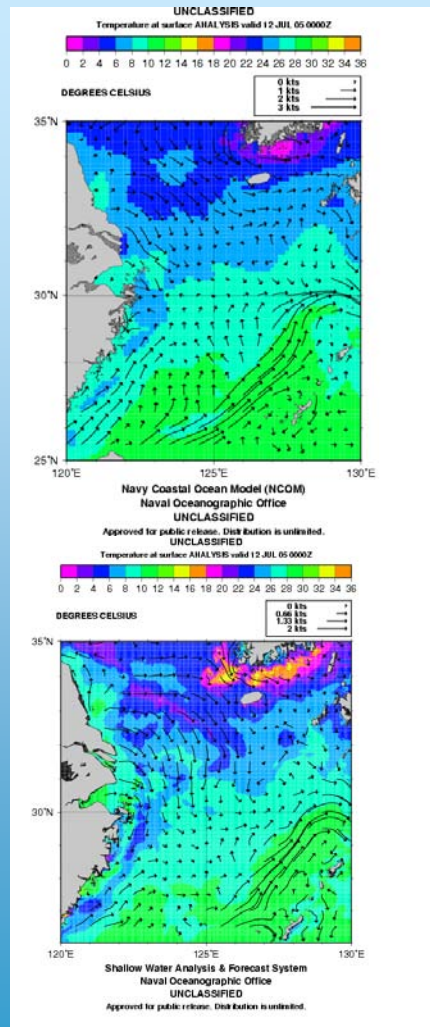
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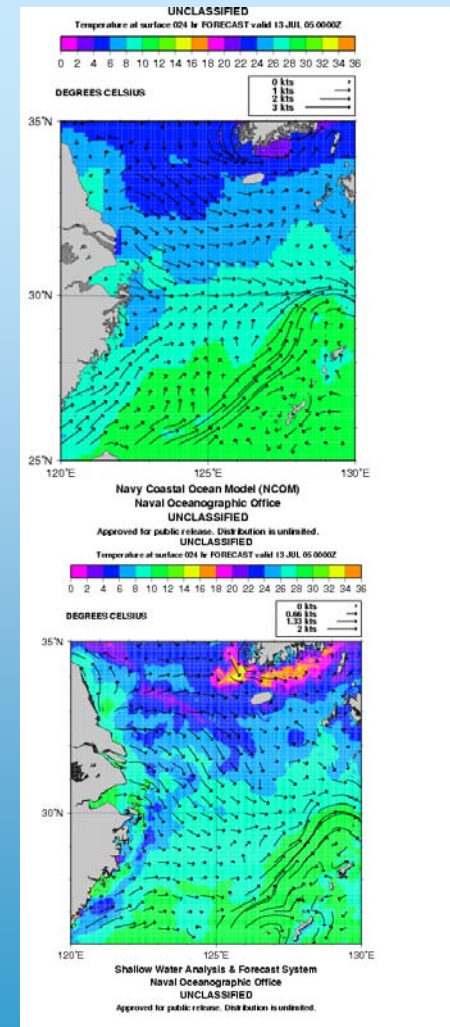
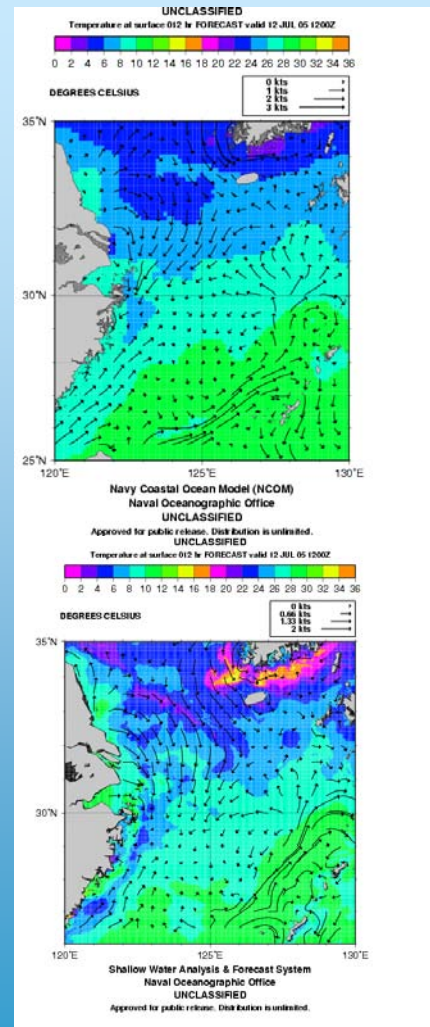
GNCOM and SWAFS Surface Currents over Temperature Runs 00Z 12JUL05 taus 00 – 12 – 24 hrs



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

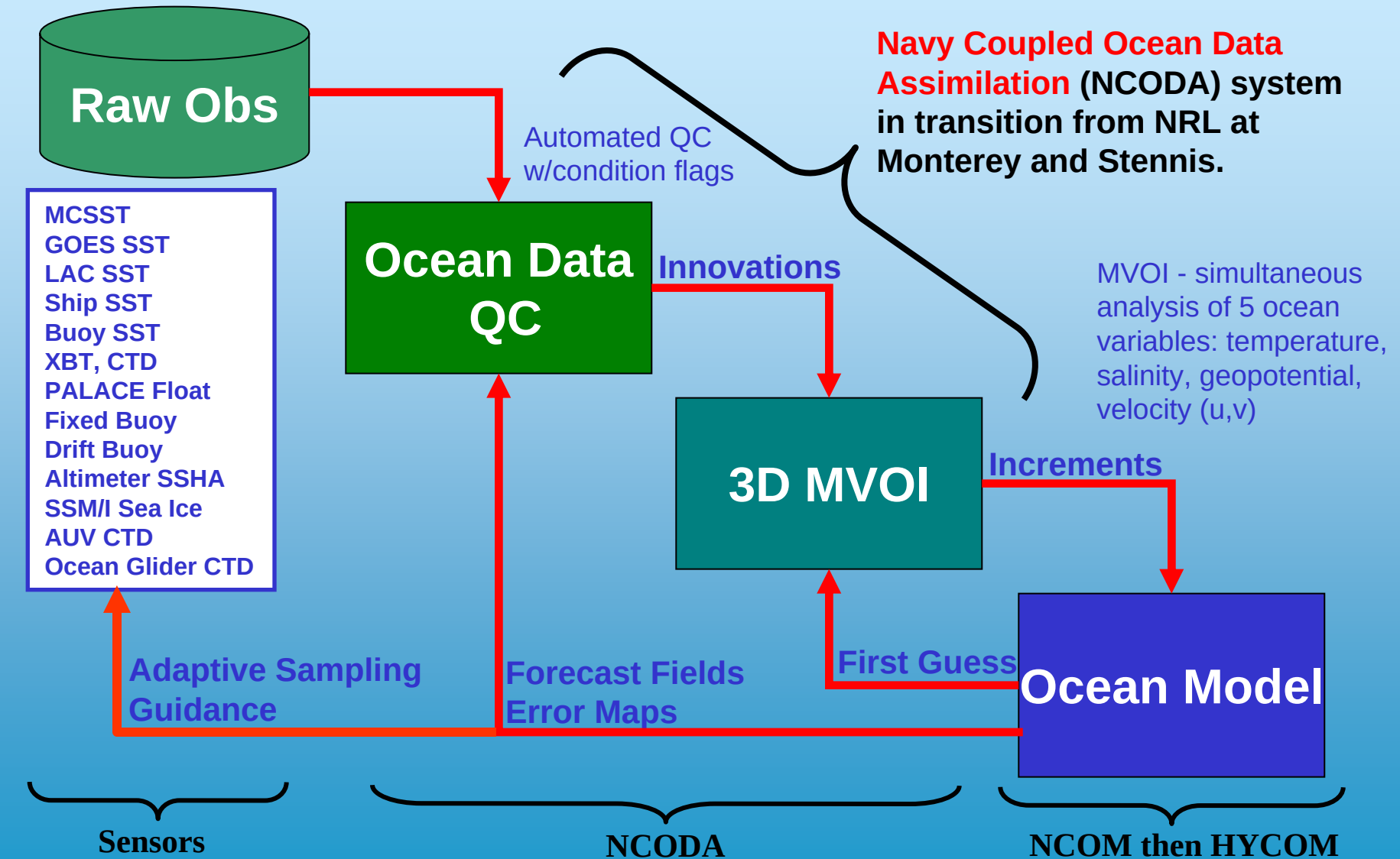


REGIONAL		YEAR	2005	2006	2007	2008	2009	2010	2011
SWAFS	U	9 NESTS				-->R-NCOM			
SWAFS	C	3 NESTS					-->R-NCOM		
R-NCOM 1/16 - 1/24	U	7 AREAS							
R-NCOM - HIRES 1/50	U	6 AREAS						-->R-HYCOM	
R-NCOM - HIRES 1/50	C	3 AREAS						-->R-HYCOM	
R-HYCOM HIRES 1/50	U	Global							
MSRC		gigaflops	675	810	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

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Real-Time Profile Assimilation w/NCODA (FY06)



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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

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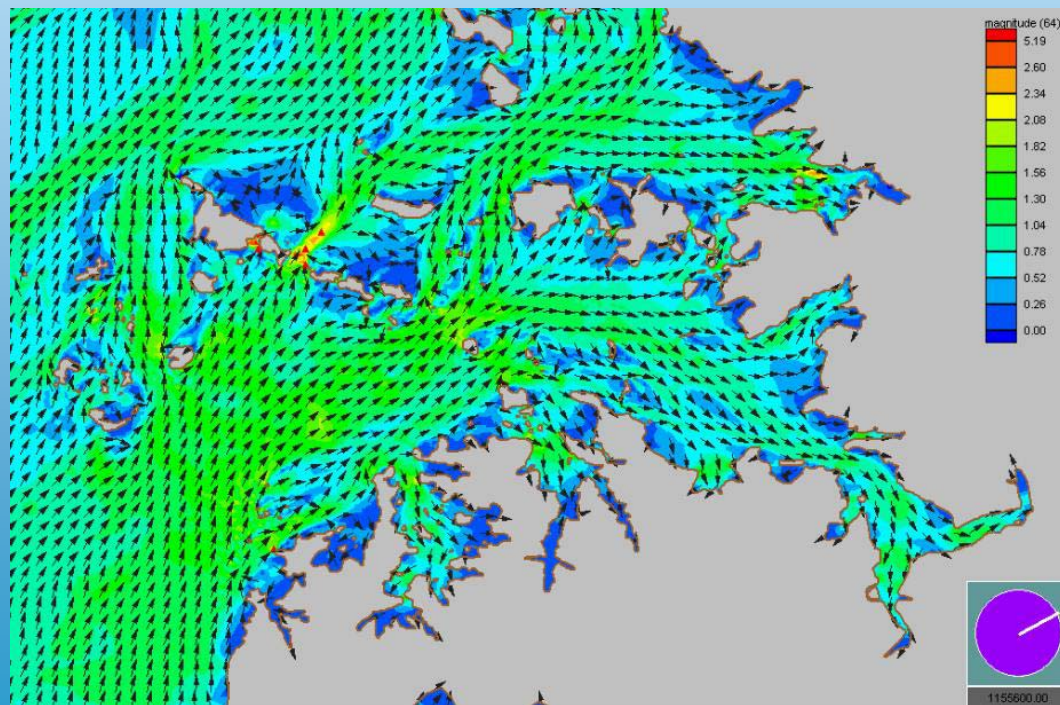
ADVANCED CIRCULATION MODEL - ADCIRC

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

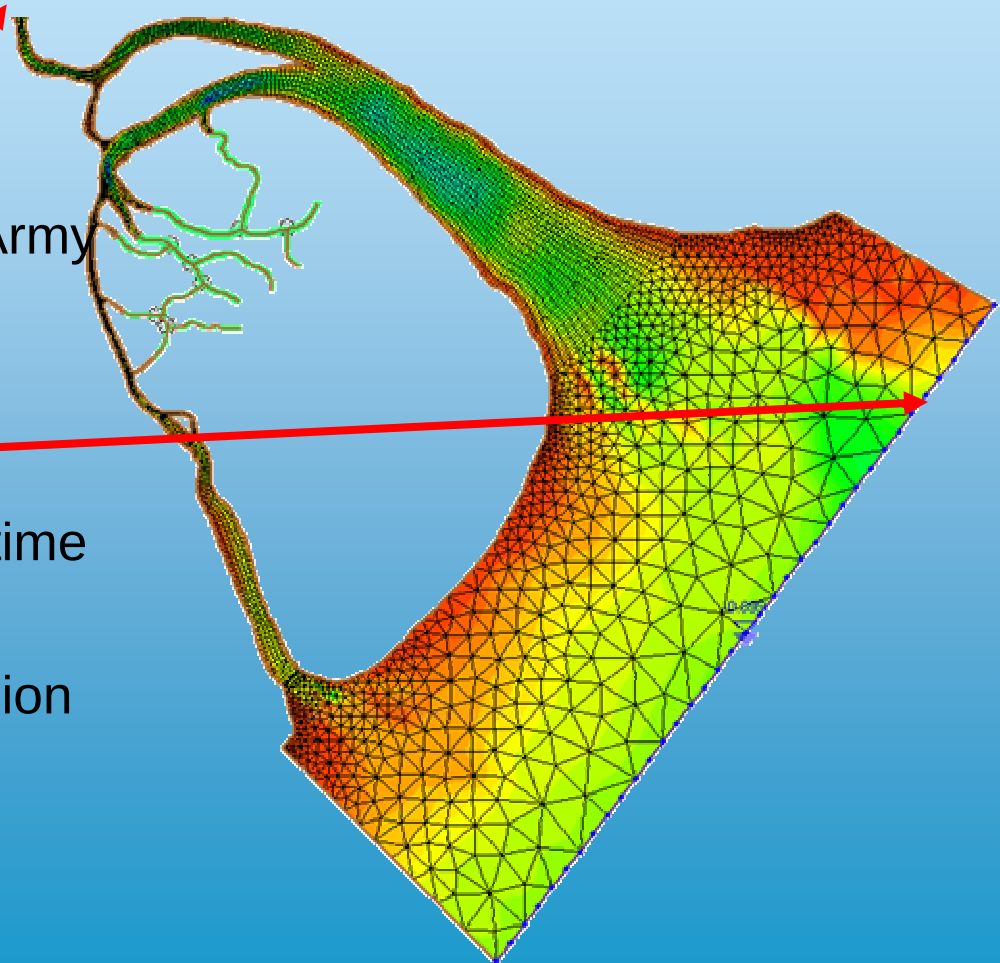
Regional

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



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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

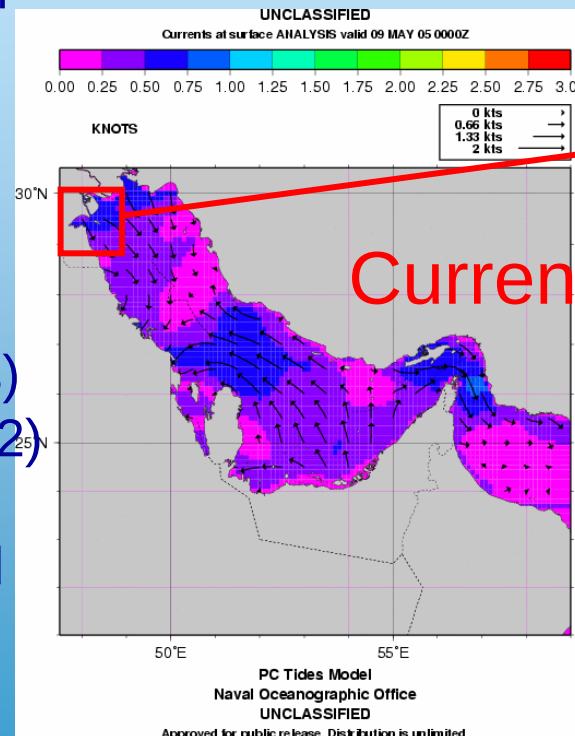
Regional

Local

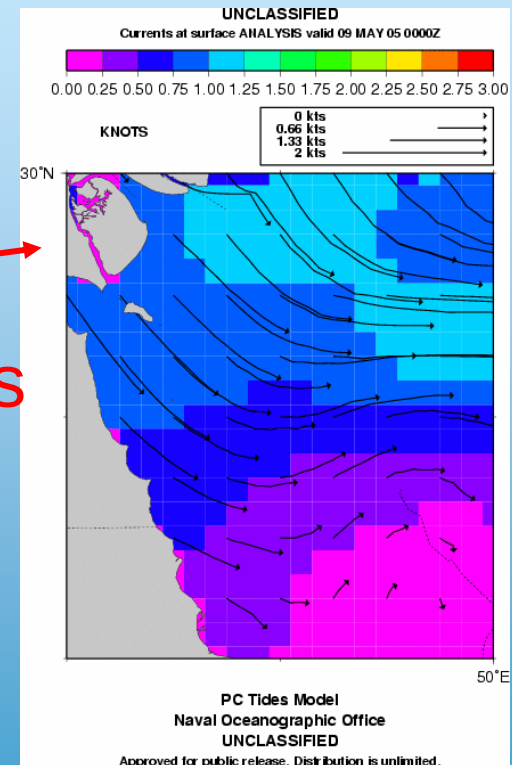


PC TIDES

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



Currents



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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

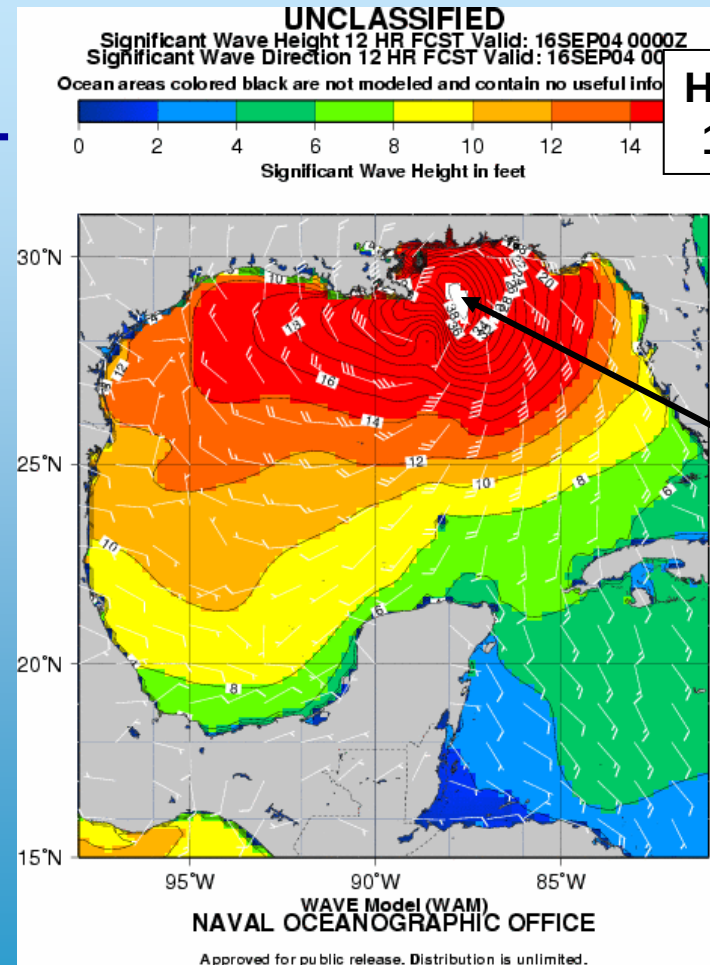
Local



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

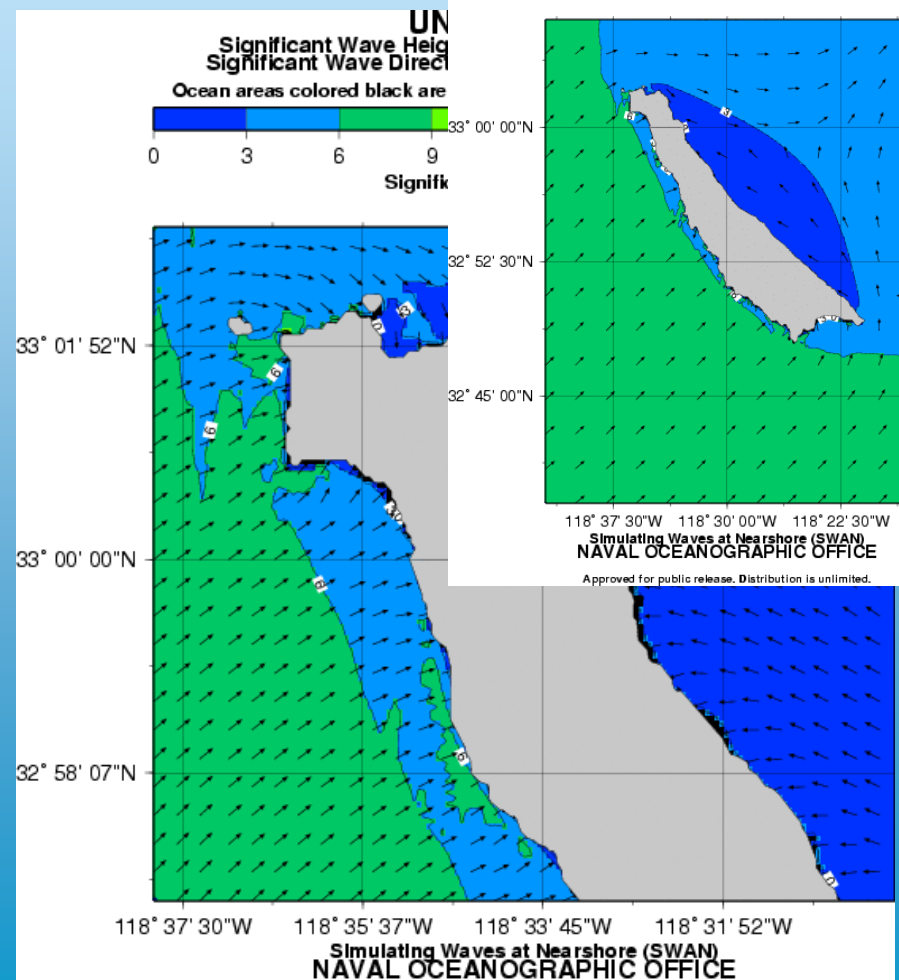
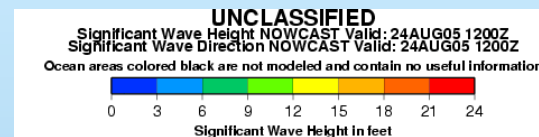
Local



SIMULATING WAVES NEARSHORE - SWAN

- Part of U. Delft DELFT3D package
- A 3RD 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		

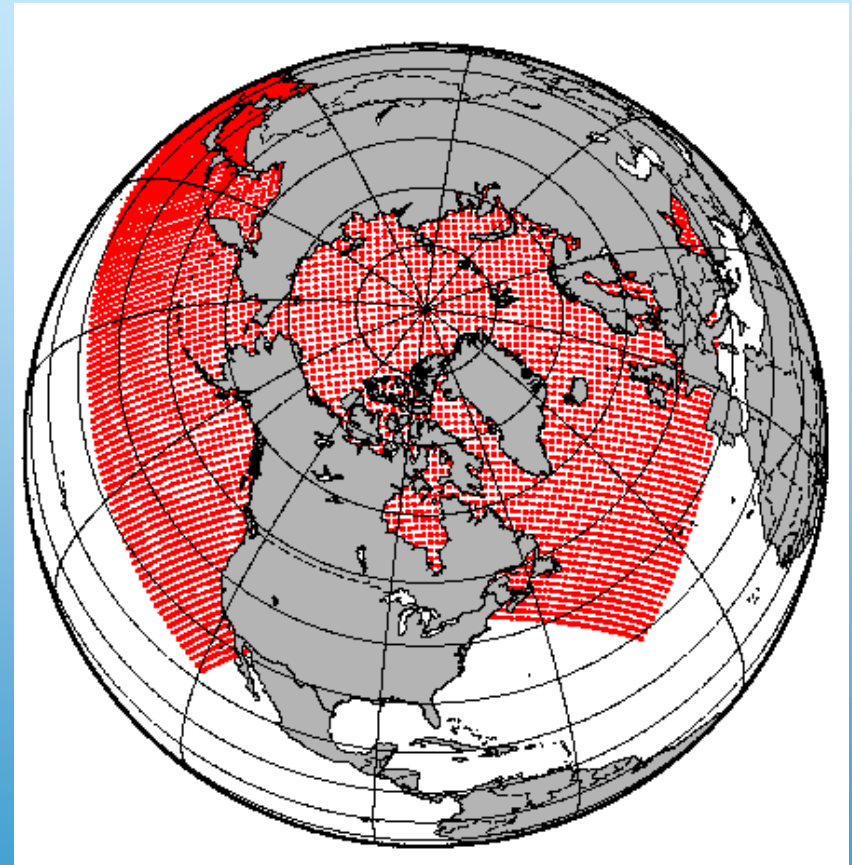
- NAVOCEANO runs the spectral **WAM** model twice daily
 - Approximately 40 nested domains.
 - A placeholder for a **Wave Watch-4+** upgrade COULD receive from USACE CY2006
 -
- **SWAN** is being transitioned to NAVOCEANO during CY2005
- **DELFT3D**, incorporating SWAN, coastal flow, and surf modules,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

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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 4th 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



DIMENSIONS

Horizontal (x,y)

Deep water, coastal, shallow, estuary, transitions

Regular grid, curvilinear, finite element

Vertical (z)

2D, 3D / Constant depth, sigma levels, hybrid

Time (tau)

Climate, history, analysis, daily, hourly (tidal), forecast length

PROPERTIES

Elevations

Tides

Currents

[U,V], [speed,direction], average, instant, drift, dispersion

Temperature & Salinity

Density & sound speed, ASW properties (MLD, SLD, DSCA, etc.), water masses, river runoff

Waves & Surf

Significant, swell, height, direction, period, surf parameters

Relevant processes

Surface layer, thermocline, deep water, ocean currents, fronts & eddies, internal waves, geostrophy, thermohaline

FORCING

Bathymetry

None, canned, bad / smooth, coastal, irregular, time varying

Atmosphere

None (tides), global-local / winds, pressure, air-sea exchanges

Other

Gravity, altimetry, tides, friction, parameterization

Boundaries

Nesting levels, surface, 2D, steady-state / time variable