



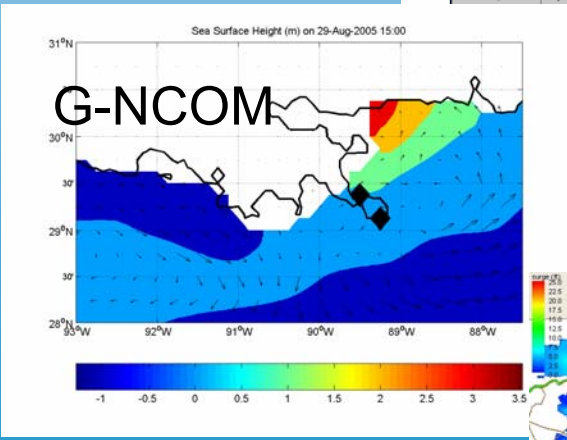
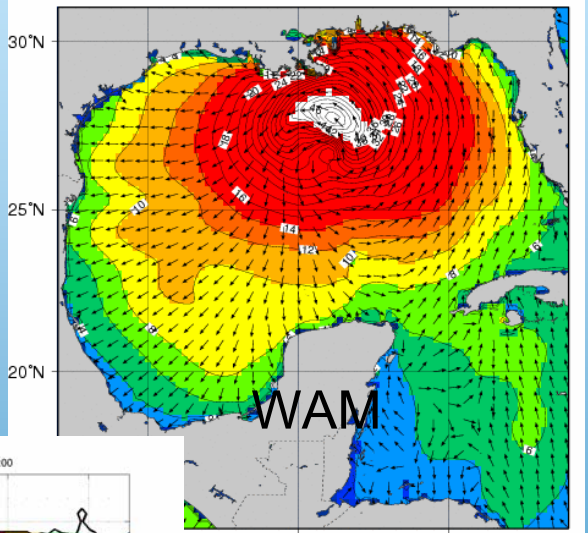
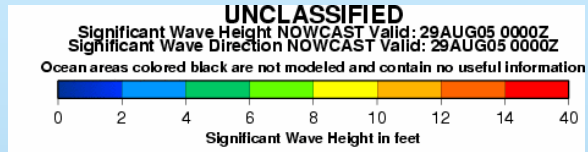
The Status of Ocean Modeling at The Naval Oceanographic Office (NAVOCEANO)

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

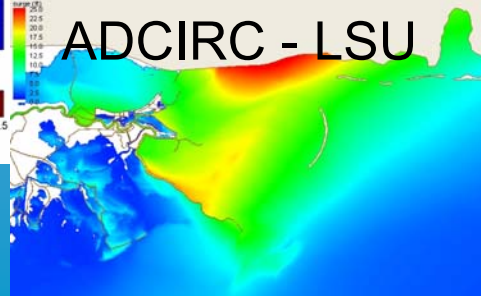
frank.bub@navy.mil

228-688-4758

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



WAVE Model (WAM)
/AL OCEANOGRAPHIC OFFICE
oved for public release. Distribution is unlimited.

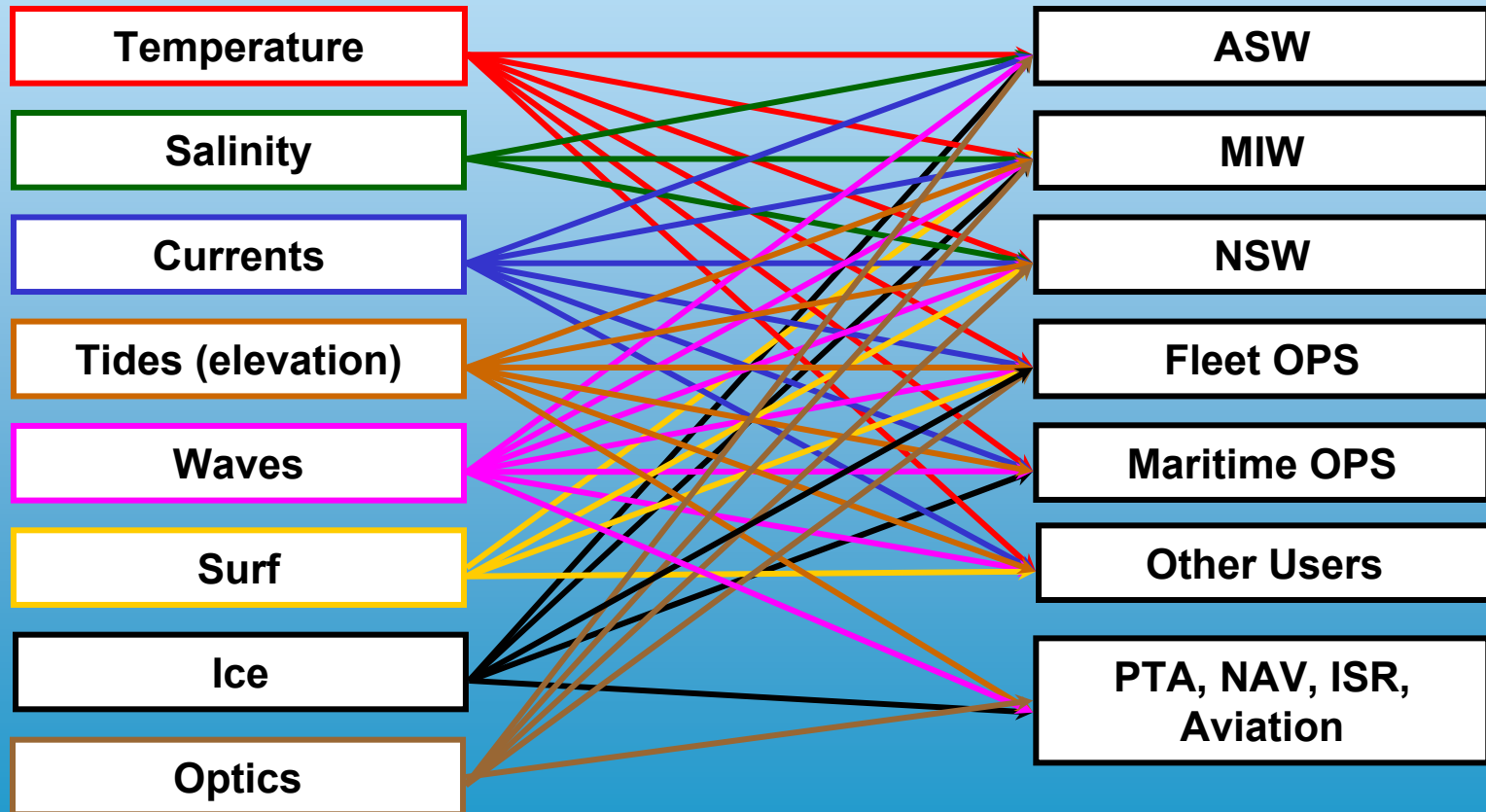


Basic Product Suite Mapped to Navy Lines of Operation

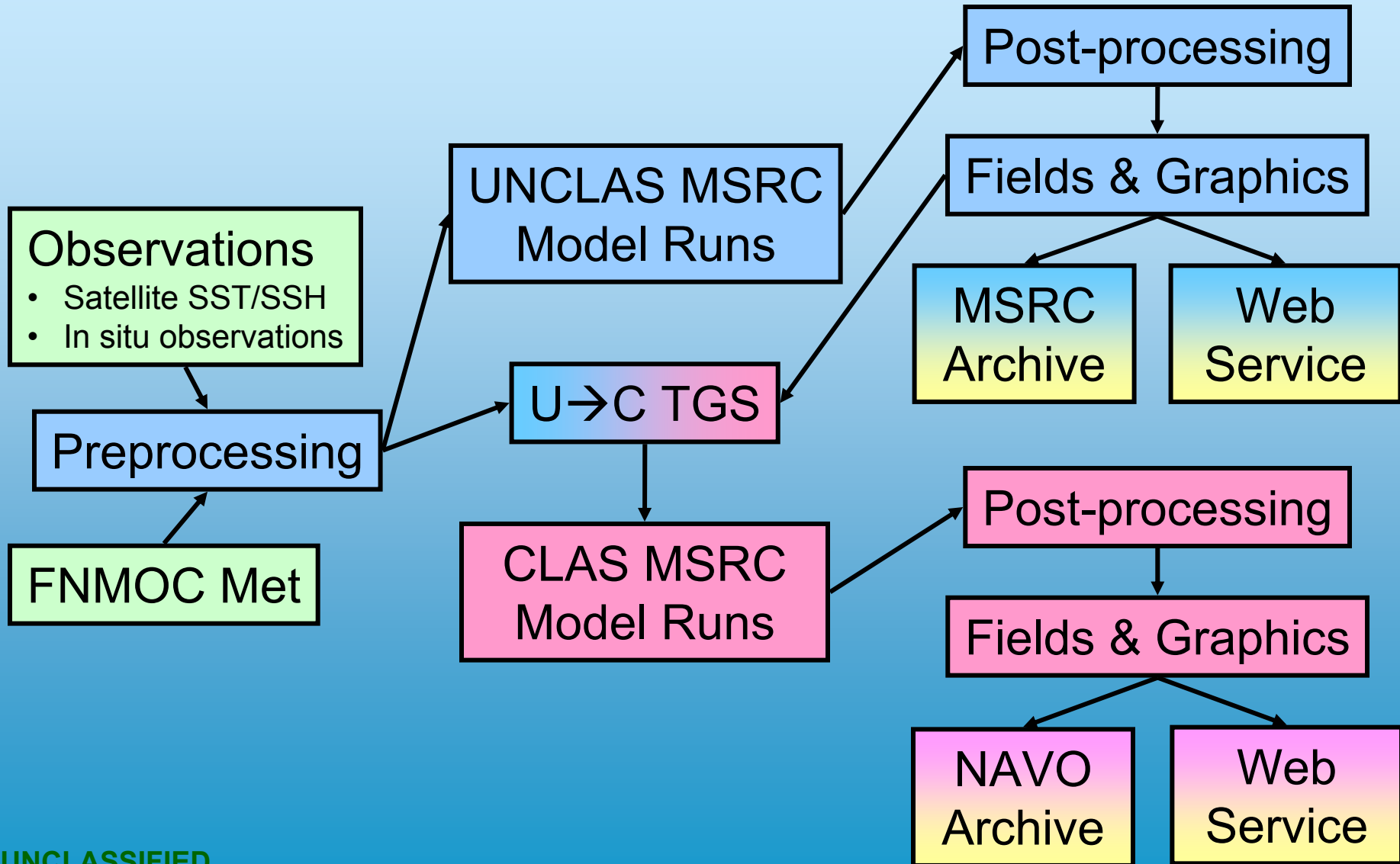


NAVOCEANO's business is to

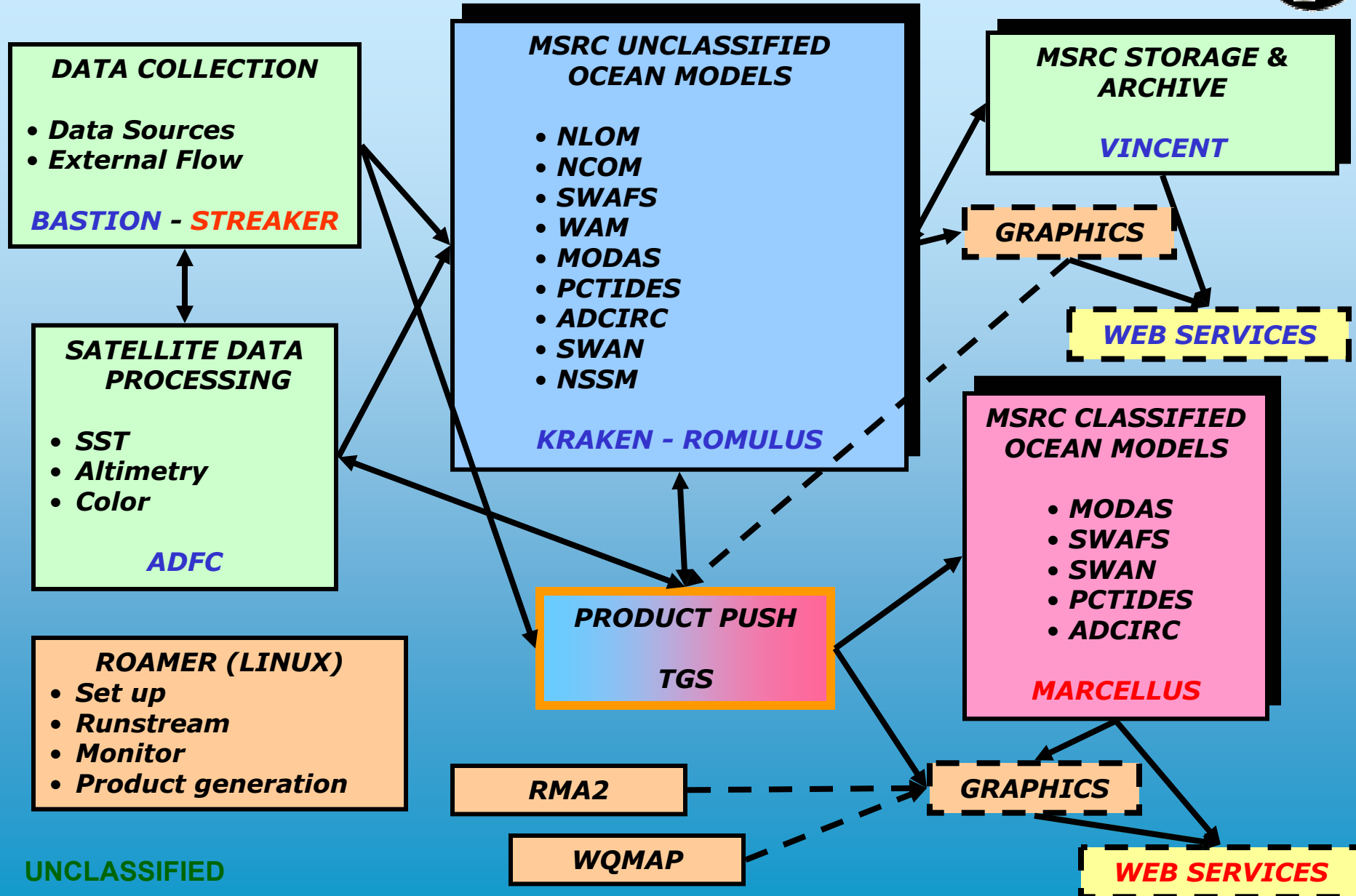
- Collect or acquire observations & information for the....
 - Analysis and prediction of....
- Currents, Temperature, Salinity, Sound Speed, Waves, & Optics.



NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



NAVOCEANO Models Data-Flow Wiring Diagram (Simplified Version)



UNCLASSIFIED

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.

UNCLASSIFIED

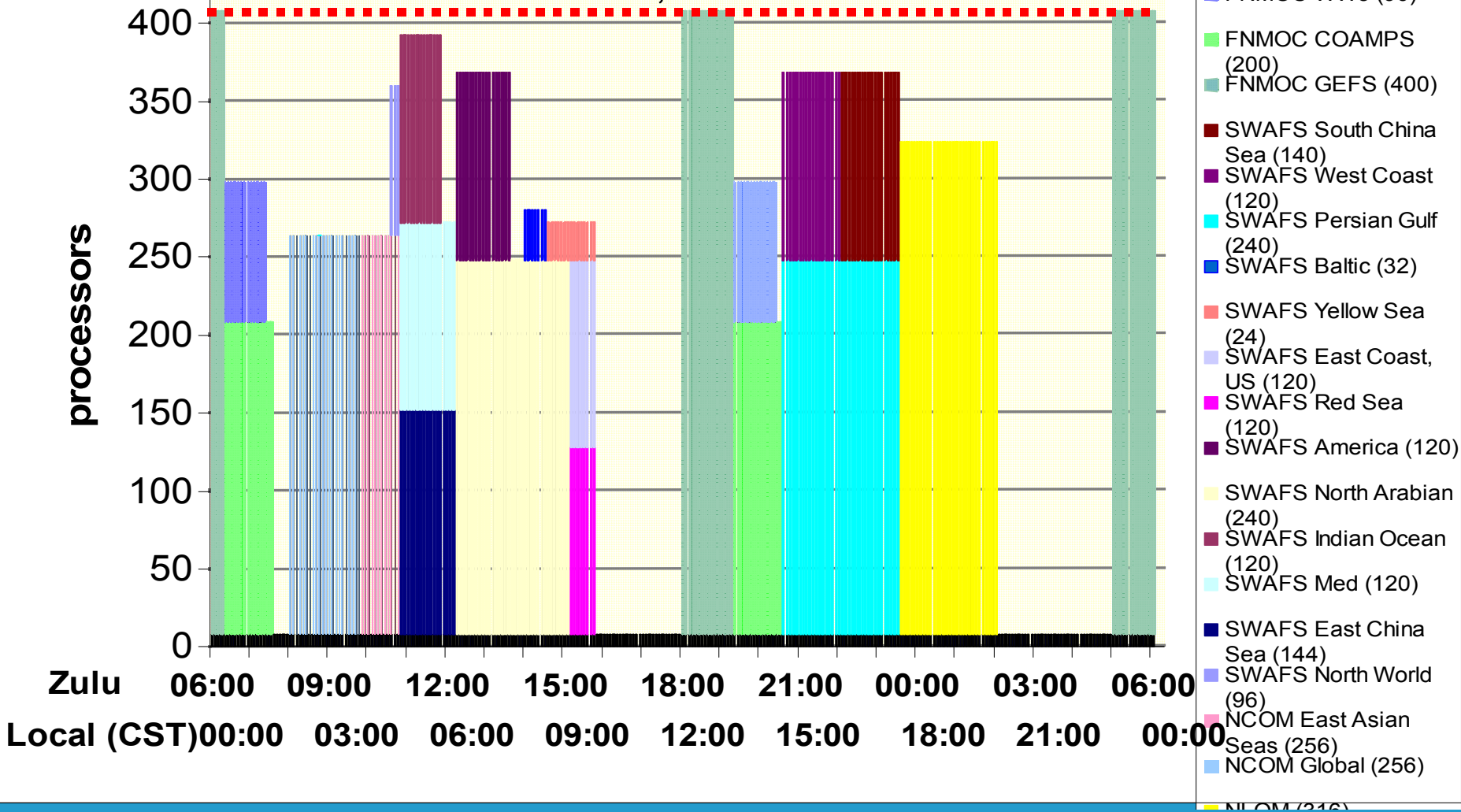
NAVOCEANO MSRC Schedule

Kraken – AUGUST 2005

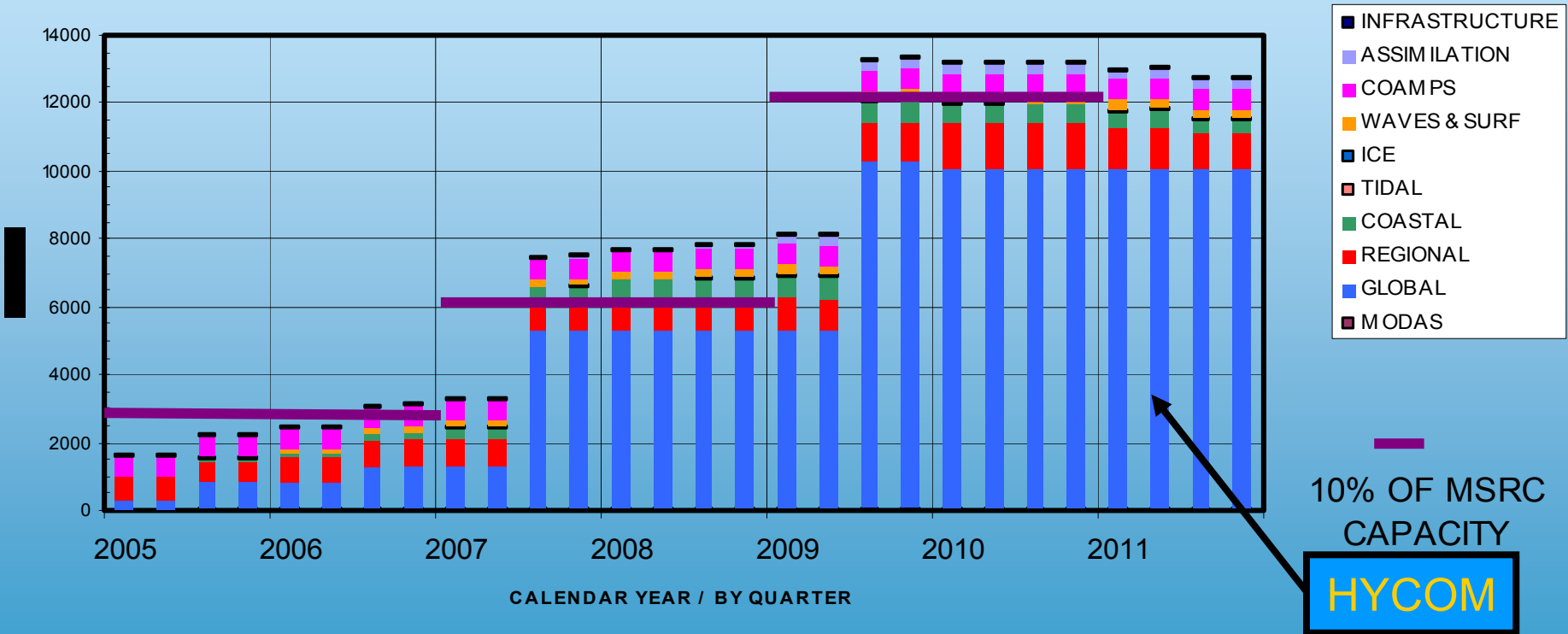


KRAKEN Operational Schedule

CPU = 2800, Allocated 15% = 420



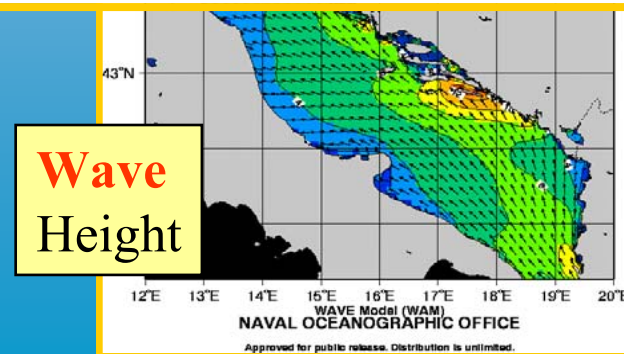
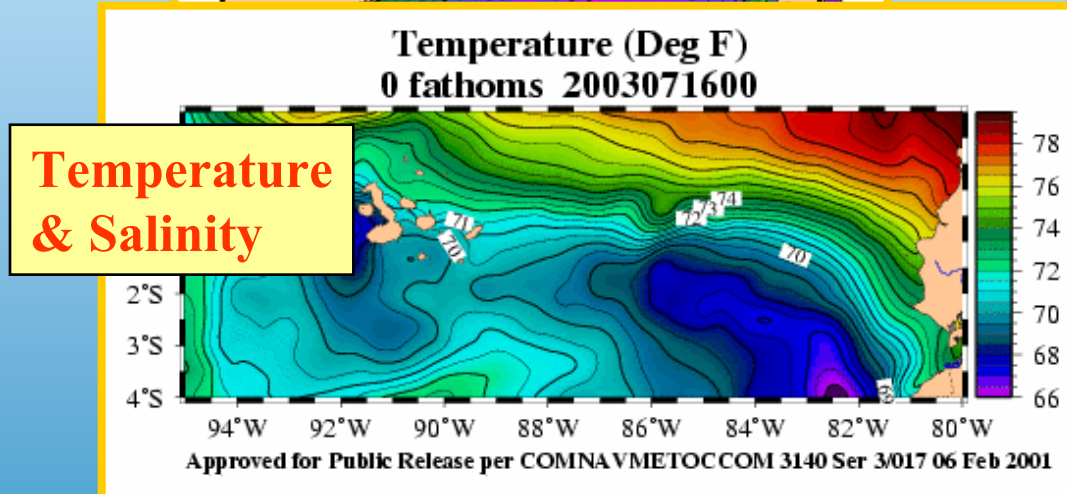
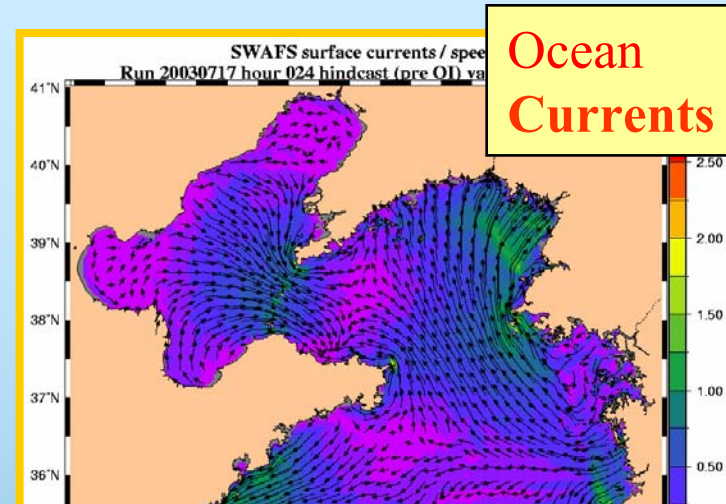
NAVOCEANO MSRC Requirements through CY2011 in gigaflops (billions of floating point operations)



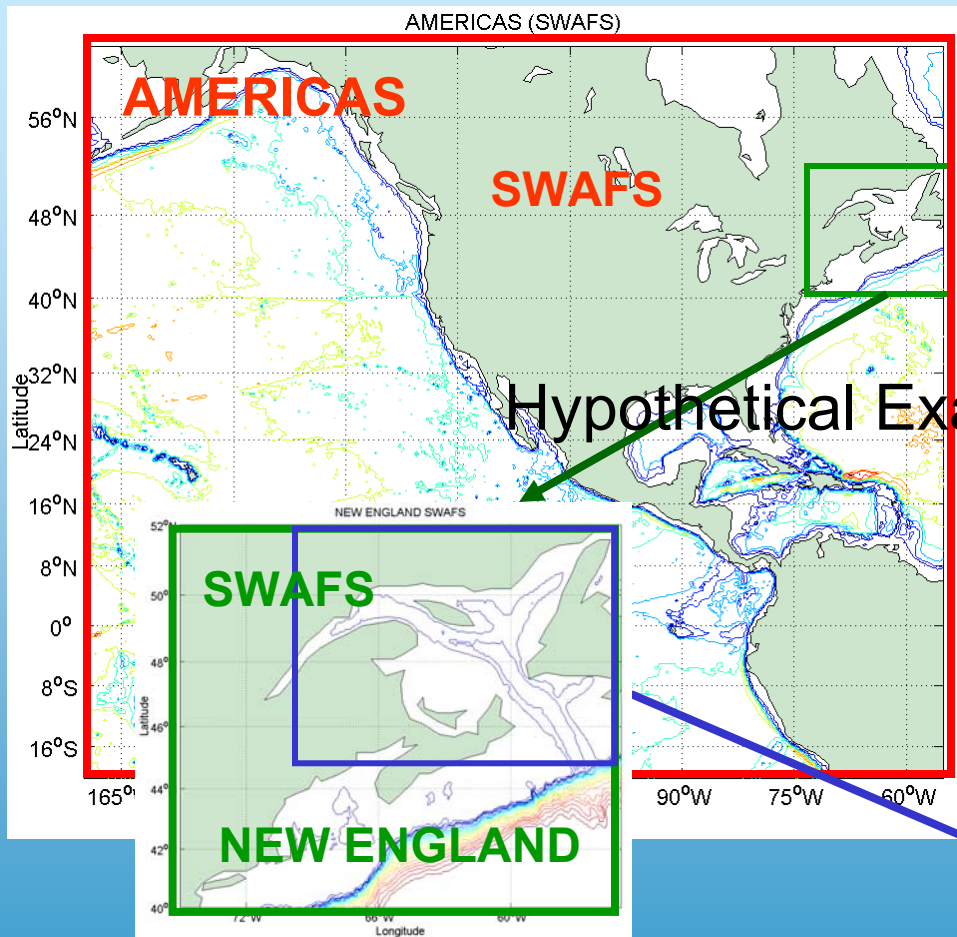


Operational Modeling distinct from R&D Modeling

- 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)

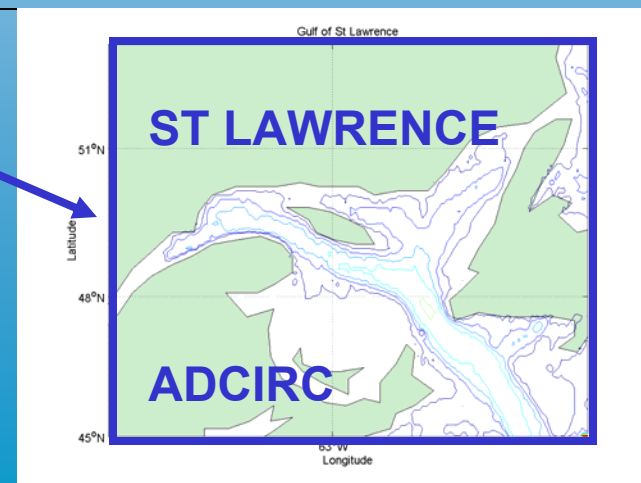
- ~8km resolution
- 1.4 mil grid points

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)

UNCLASSIFIED

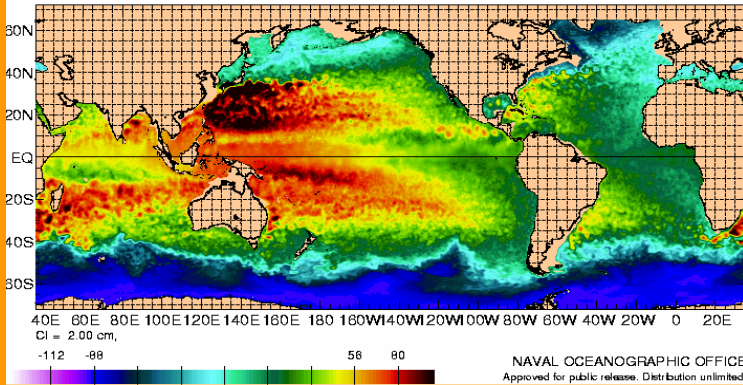


Global

Regional

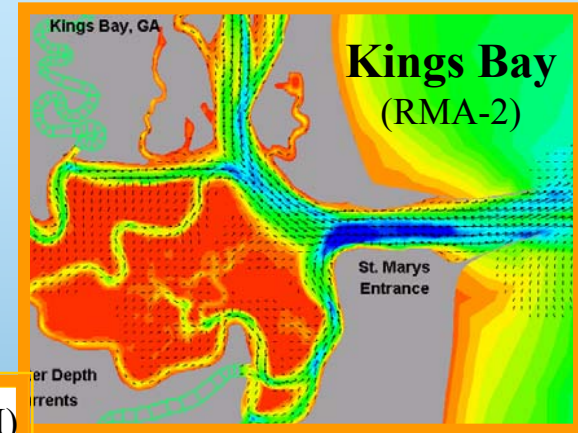
Local

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

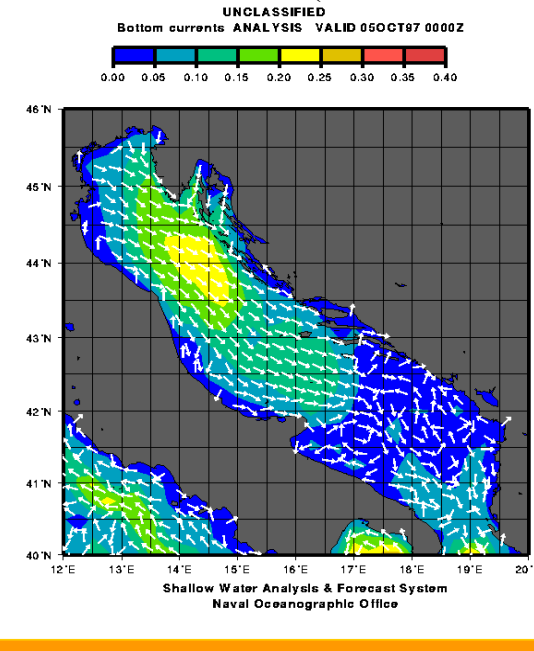


Regional Littoral Models:

- High-resolution processes
- Theatre Operations



Adriatic Sea (SWAFS-POM)



Coastal - Local - Estuary Models:

- Coastal operations
- NSW
- MIW

Global Deep Ocean Models:

- Regional models boundary conditions
- Transit planning
- Filling gaps

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

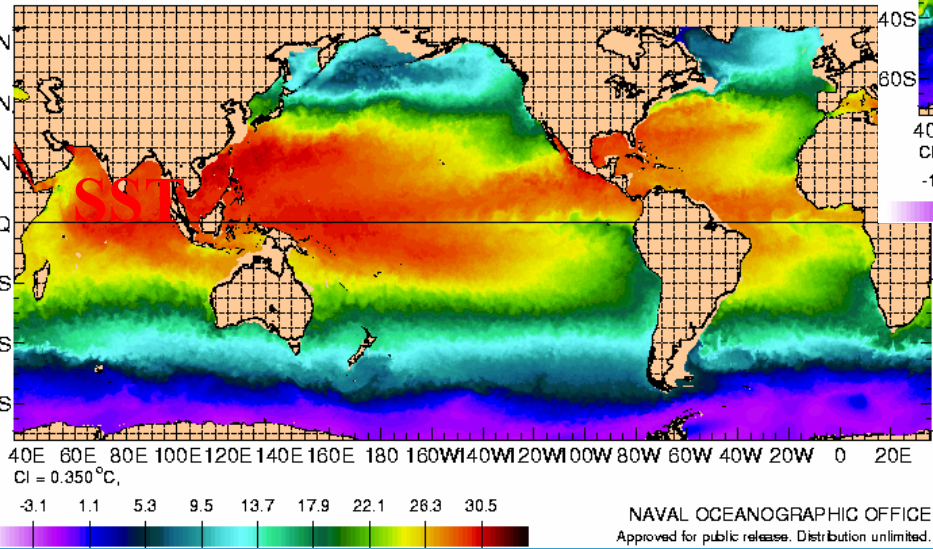
- WQMAP *
- HydroMap *
- RMA-2
- ADCIRC (FY06)*
- CU-Tides -->PC-Tides (FY05)

* 3D Capability also



**NAVY LAYERED
OCEAN MODEL
NLOM**

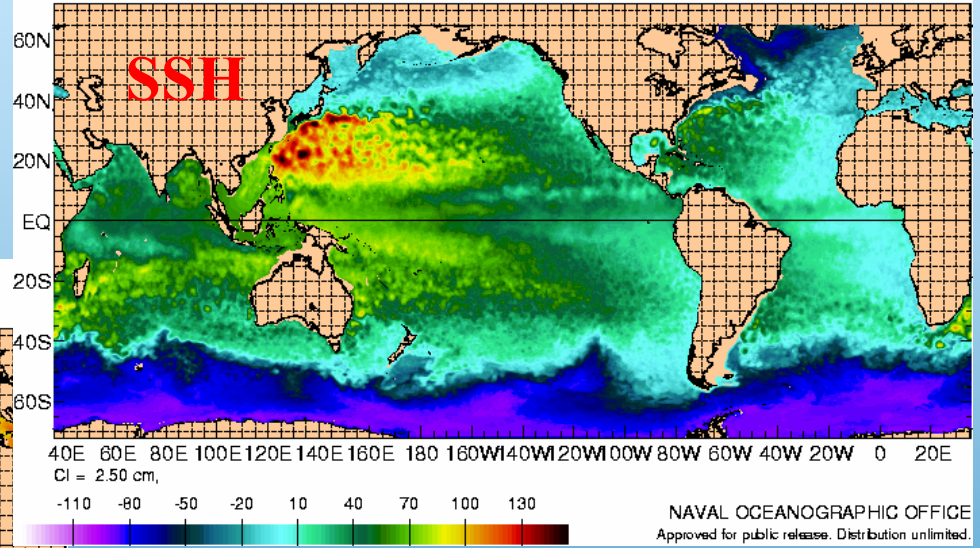
UNCLASSIFIED: 1/16° Global NLOM
SST ANALYSIS: 20030716



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

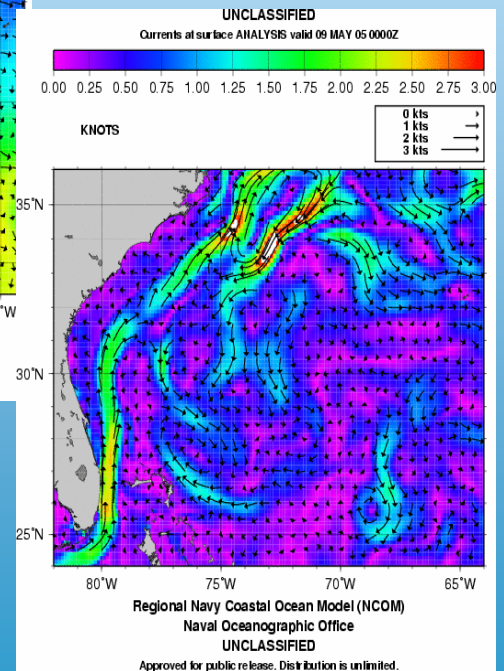
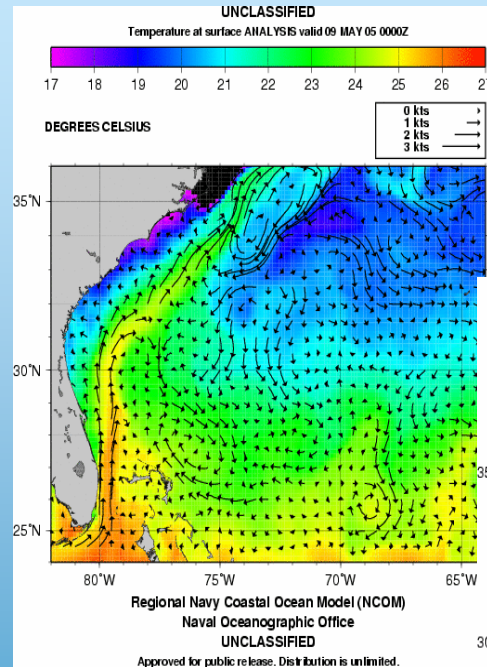
Regional

Local

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)

UNCLASSIFIED



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



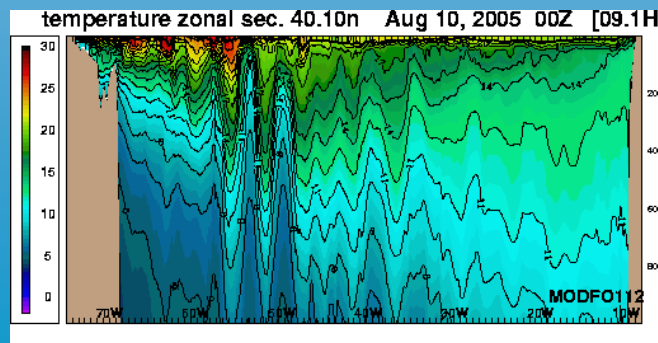
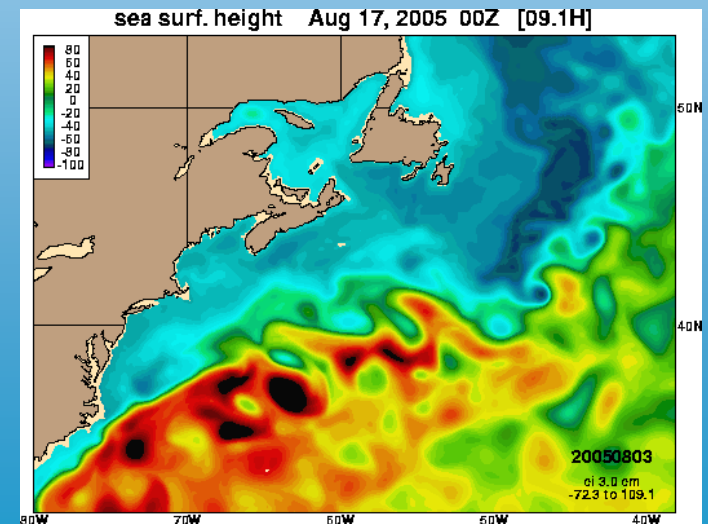
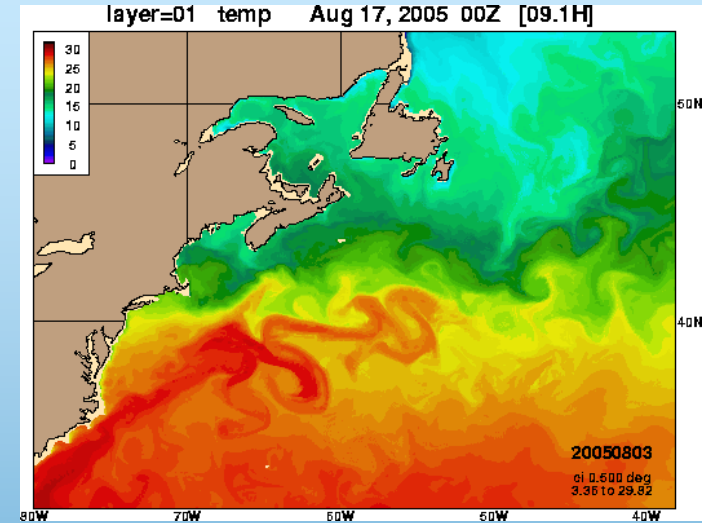
Global

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							
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.



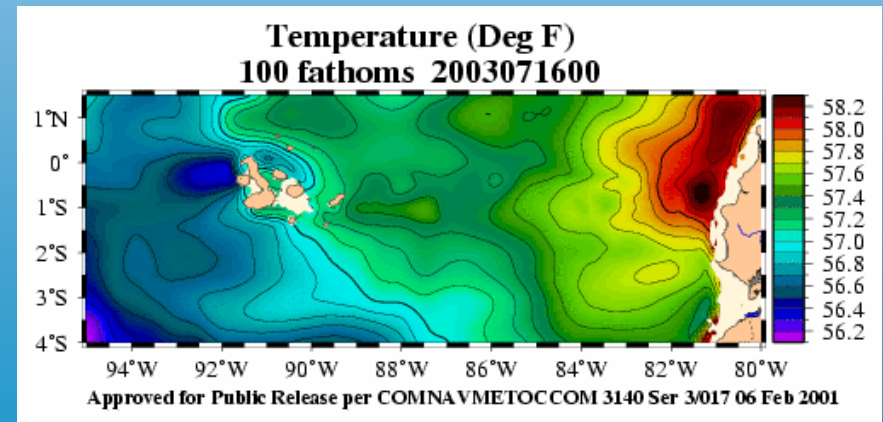
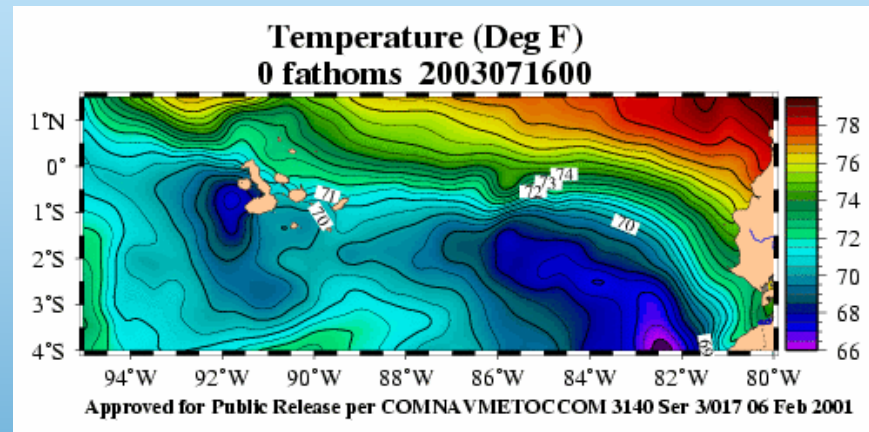
Global

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



UNCLASSIFIED

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



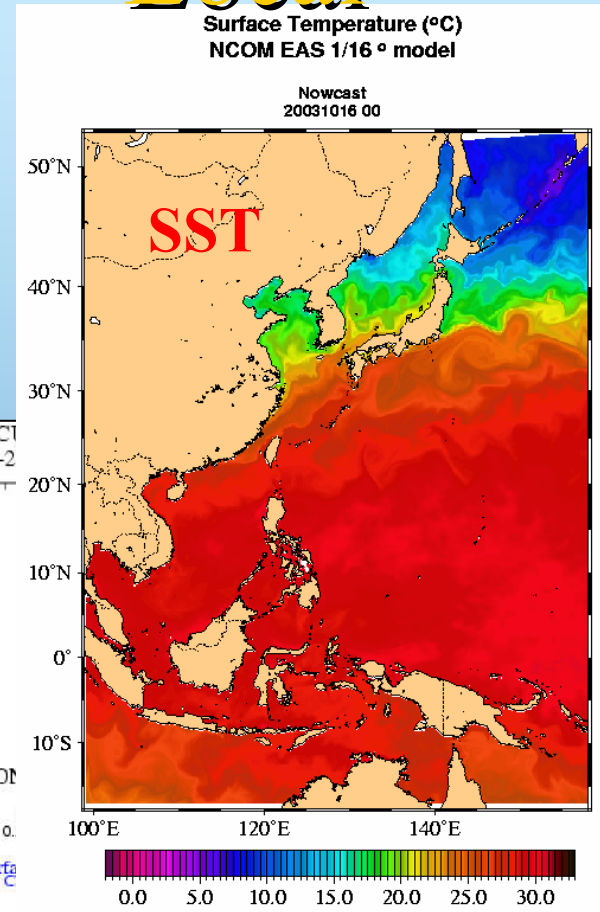
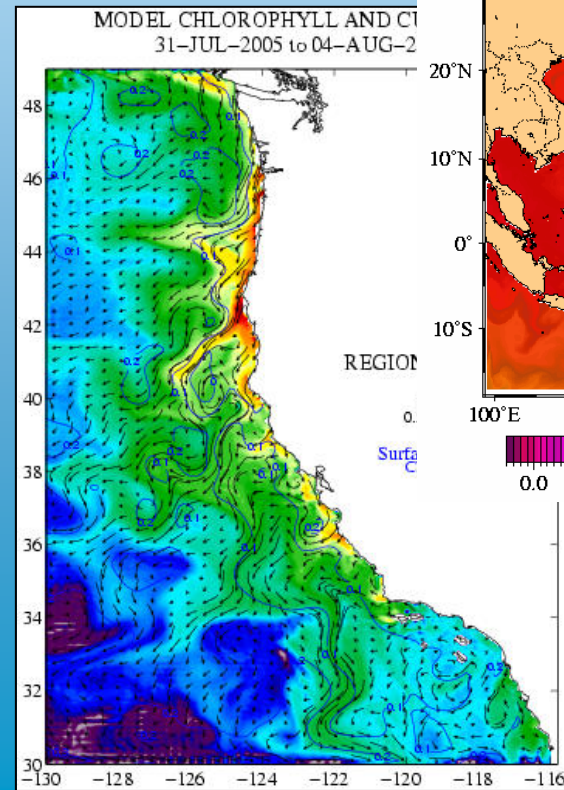
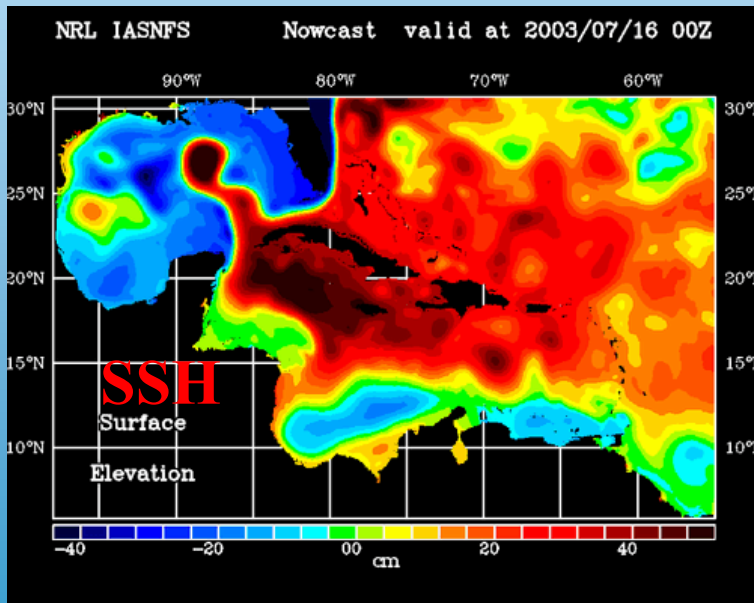
Global

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



Global

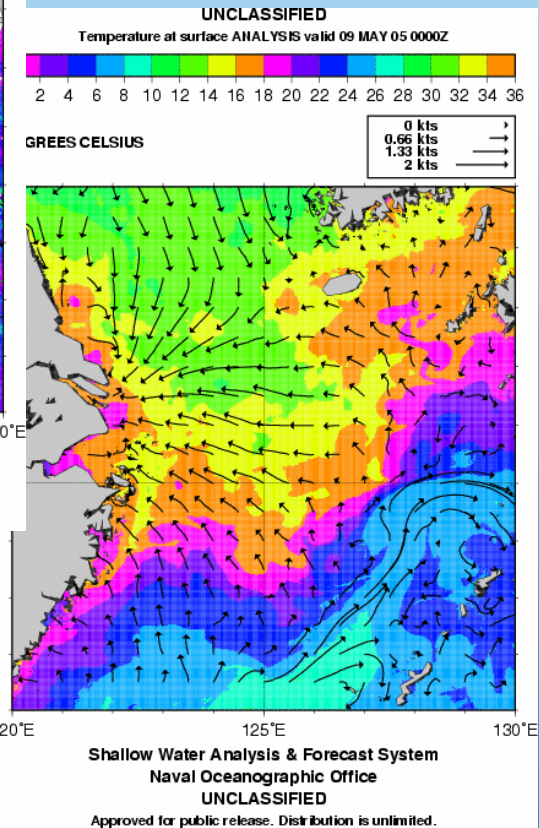
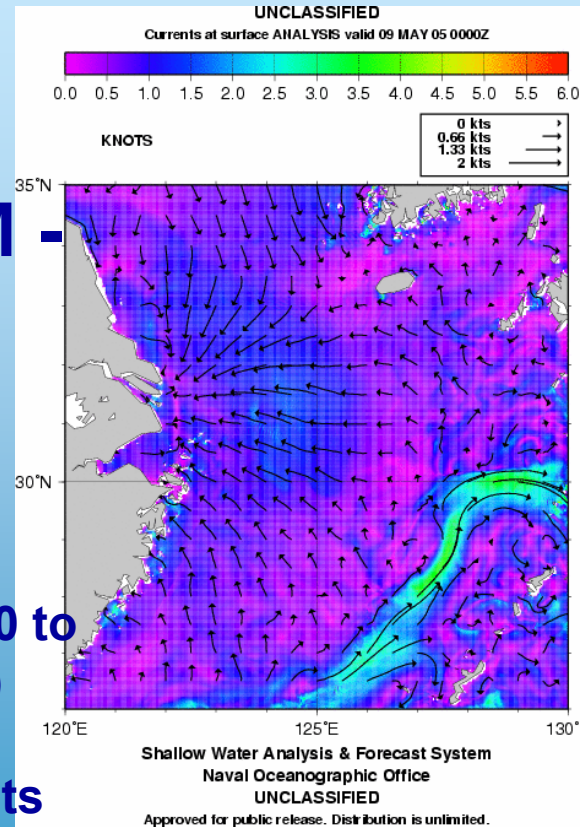
Regional

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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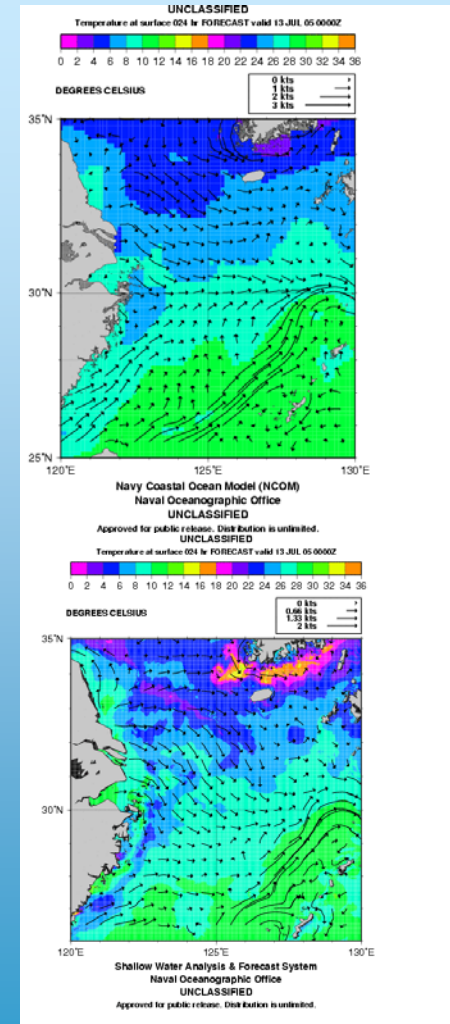
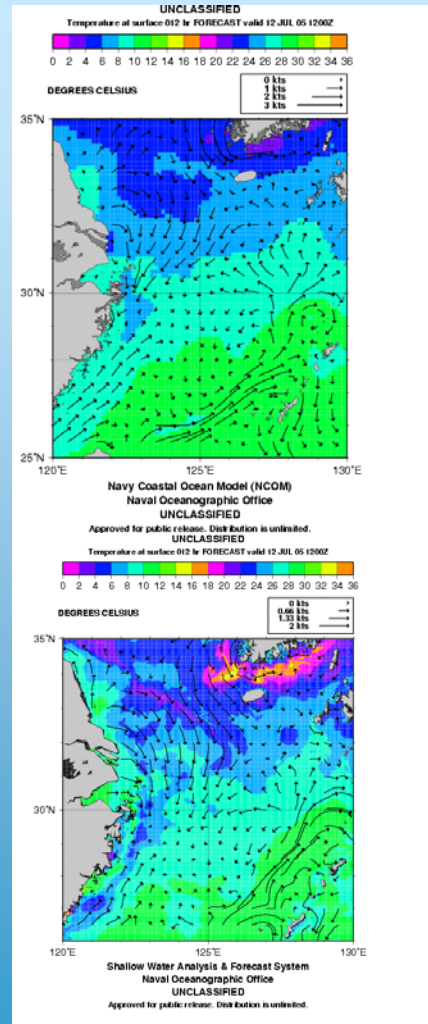
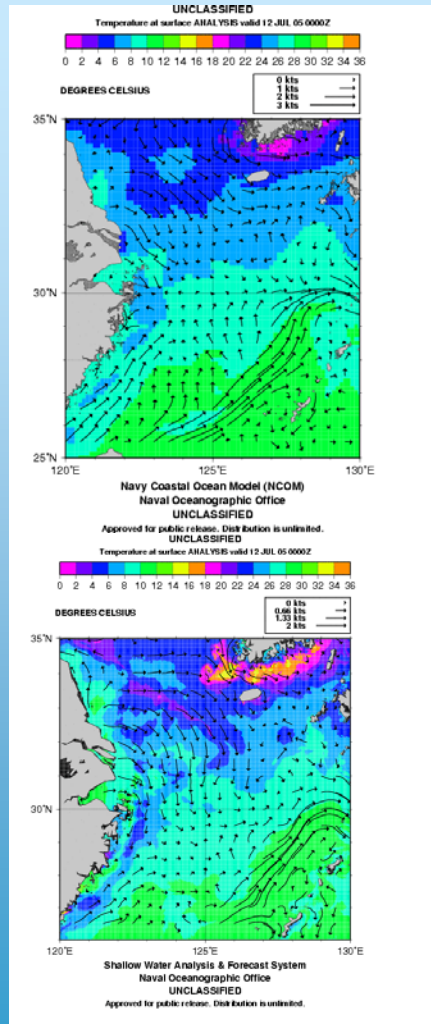


GNCOM and SWAFS Surface Currents over Temperature

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

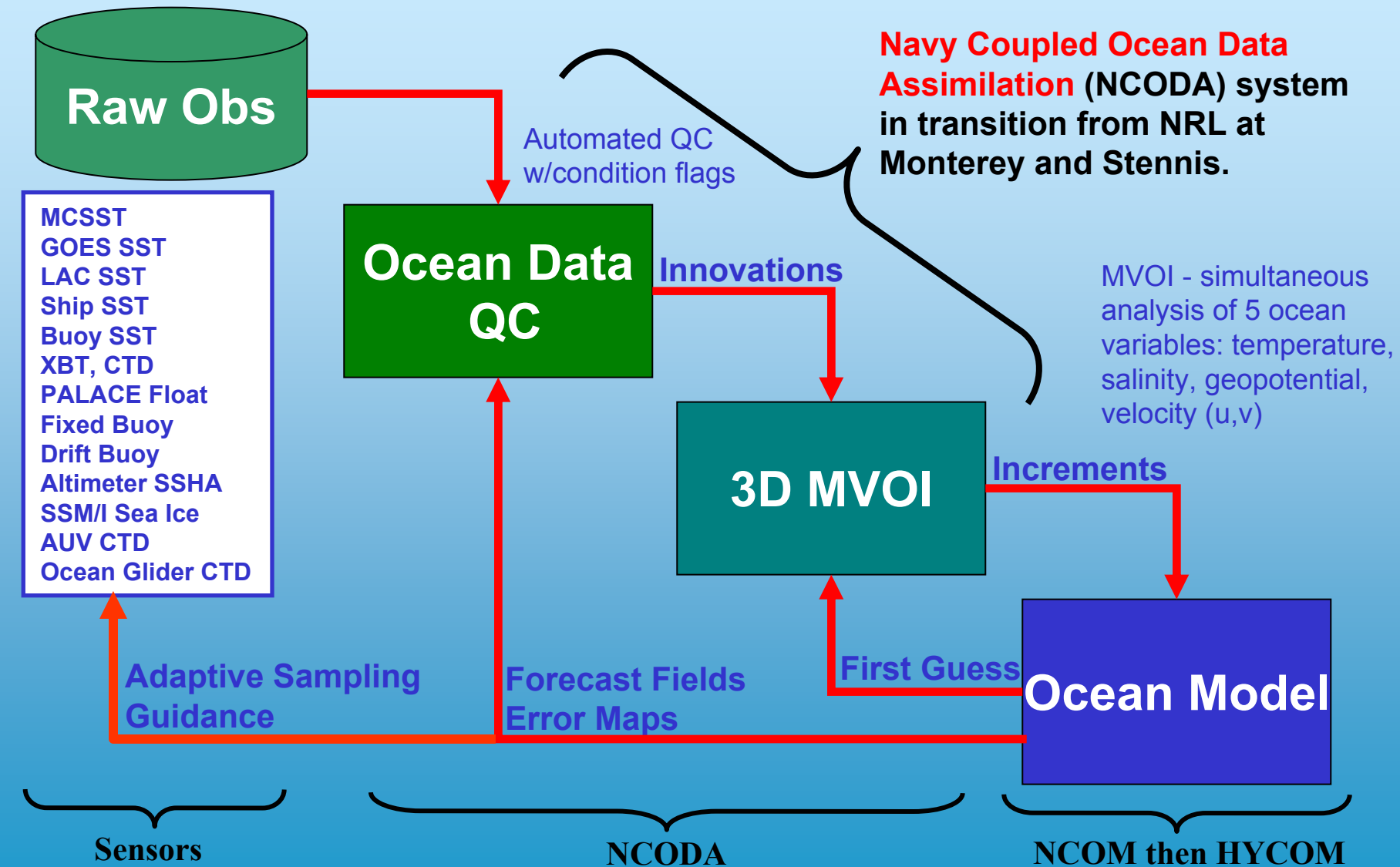
R-HYCOM - Regional Hybrid Coordinate Ocean Model



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

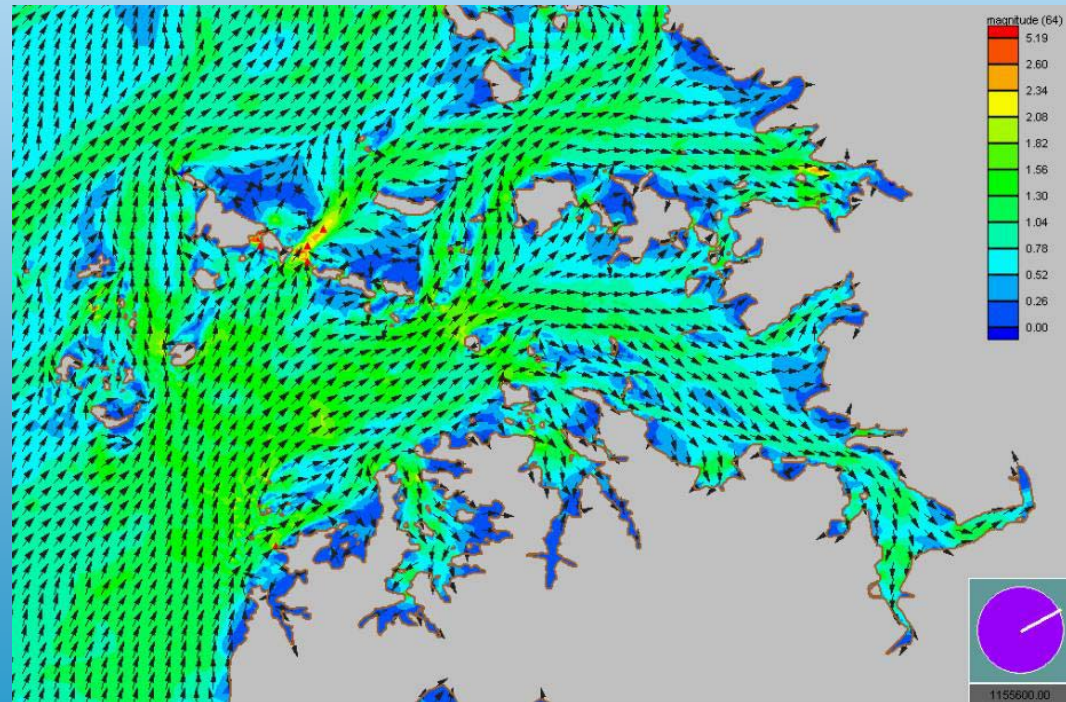
ADVANCED CIRCULATION MODEL - ADCIRC

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





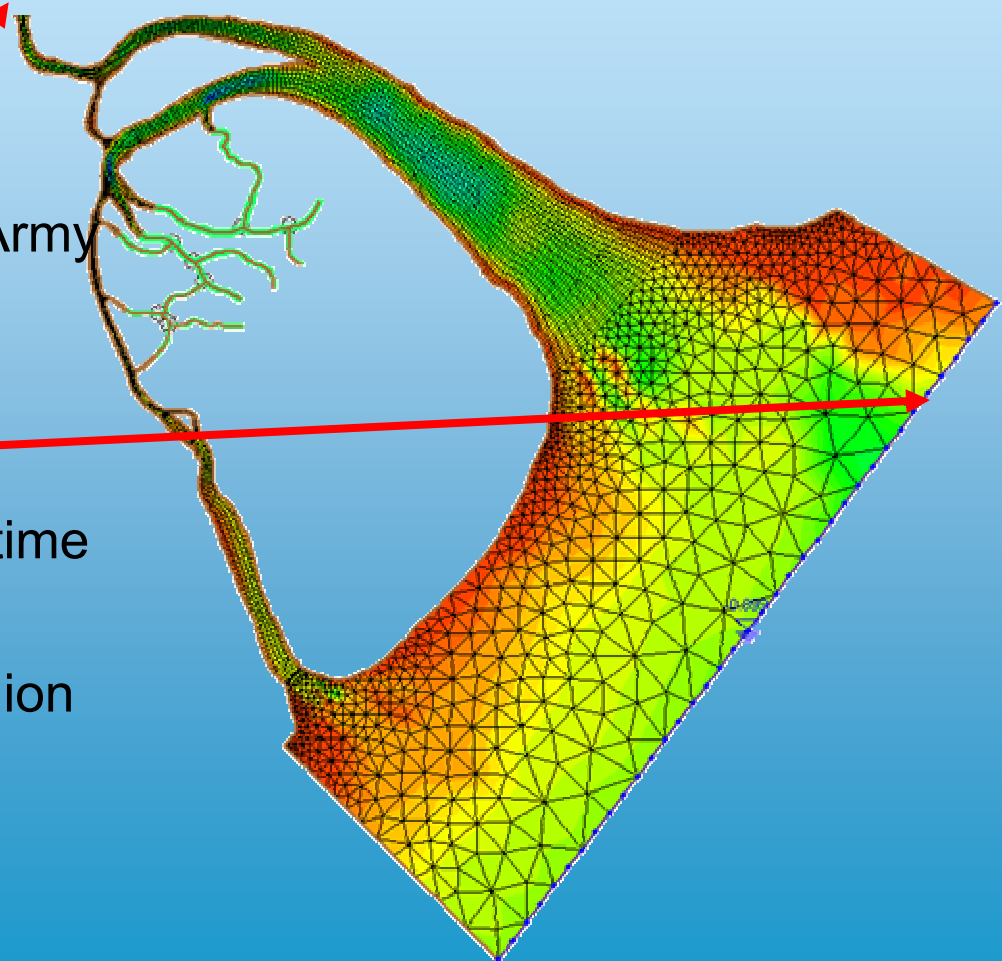
Global

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.



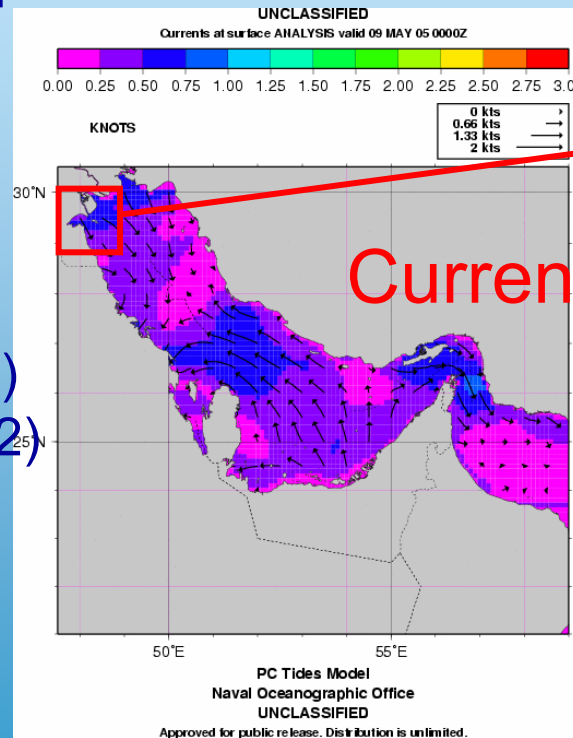
Global

Regional

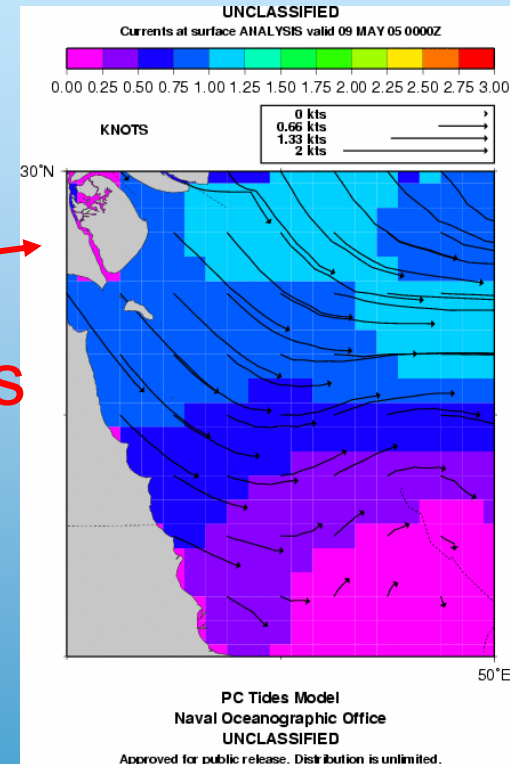
Local

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



UNCLASSIFIED

UNCLASSIFIED



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

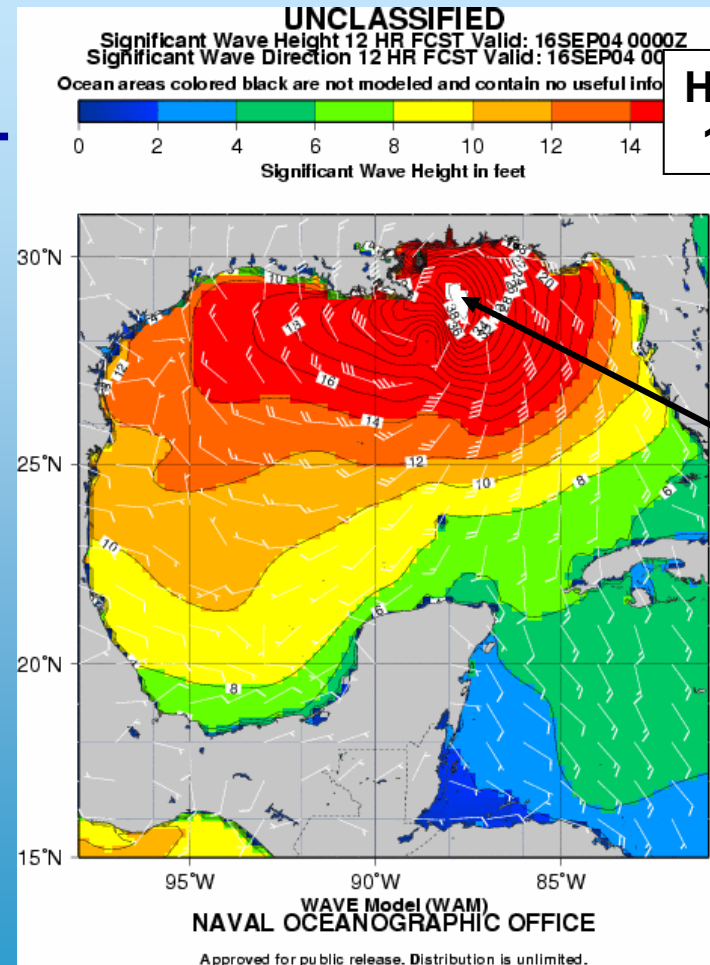
Regional

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

UNCLASSIFIED





Global

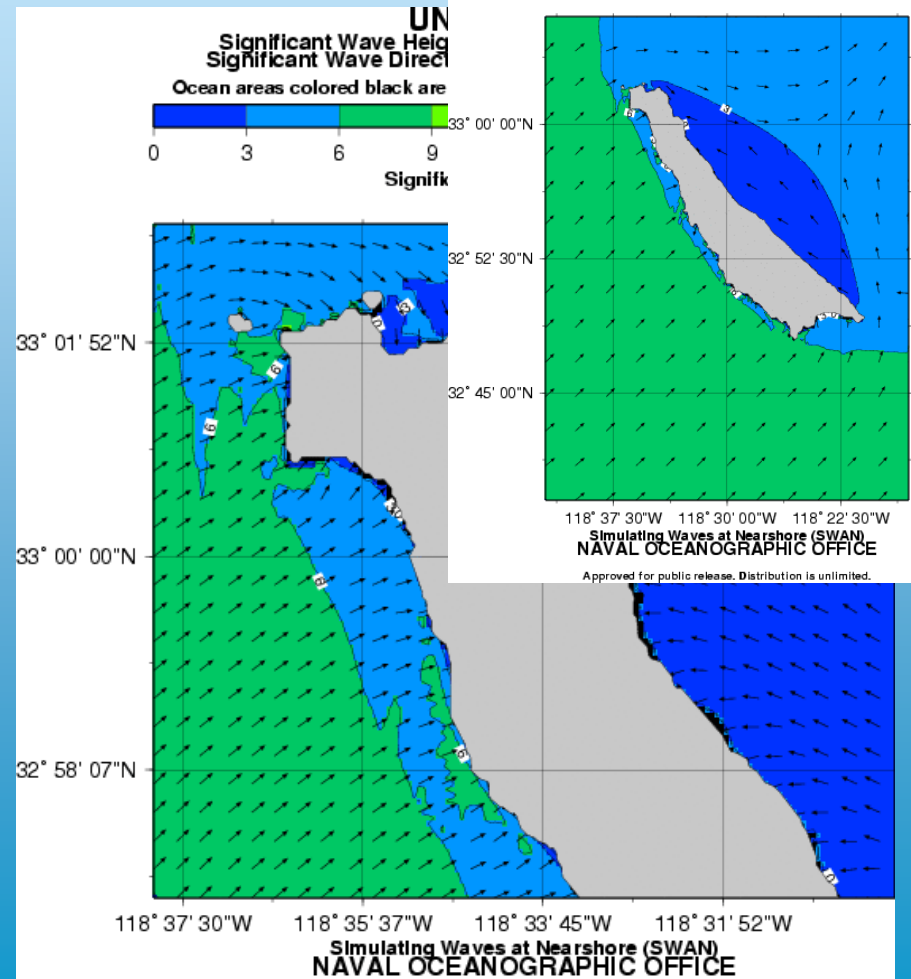
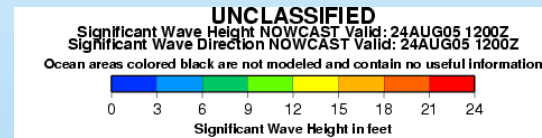
Regional

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



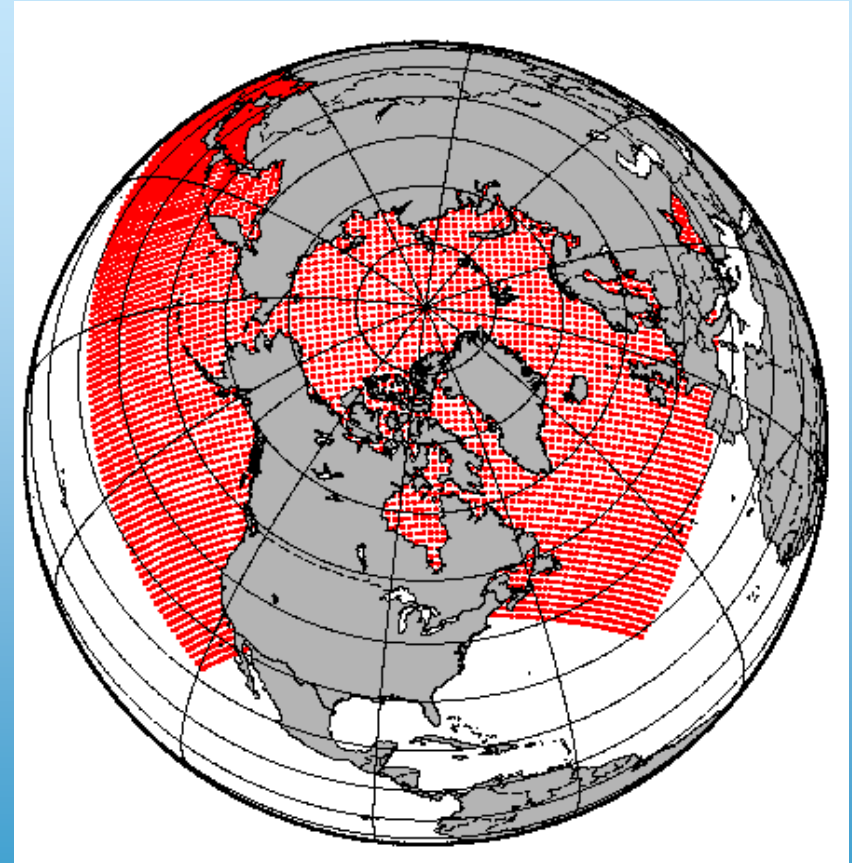
WAVES & SURF		YEAR	2005	2006	2007	2008	2009	2010	2011
WAM	U	40 AREAS			--> WW4+				
WW4+	U	GLOBE+10							
SWAN	U	15-->25							
SWAN	C	10-->30							
STWAVE	U	~10		--> SWAN					
NSSM	U	~10							
DELFT3D	U/C	20 AREAS							
MSRC		gigaflops	675	810	935	900	1,135	1,335	1,055
				DEVELOPMENT & TRANSITION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

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

