Review of the NCEP production Suite: Recent Changes and Plans

Marine Modeling and Analysis Branch

EMC/NCEP

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WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

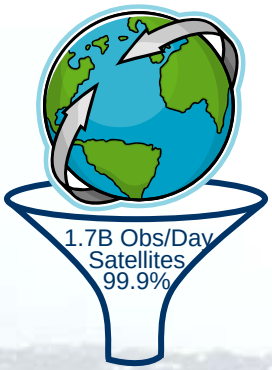
Mission Statement

- The Marine Modeling and Analysis Branch is part of the Environmental Modeling Center.
- MMAB provides analysis and real-time forecast guidance (1 – 16 days) on marine meteorological, oceanographic, and cryospheric parameters over the global oceans and coastal areas of the U.S.
- Evaluates quality of retrievals of ocean surface data from satellite borne sensors, improves their quality as needed, and examines the impacts of the data on forecast models.
- Monitors performance of operational guidance products.

Why MMAB ?

- Traditionally part of the EMC support to the NWS (OPC, TPC, Regions, WFOs). Justification:
  - General support of meteorological mission.
    - From weather to Earth System modeling.
  - Safety Of Life At Sea (SOLAS) 1974:
    - NWS responsible for wind waves.
  - NOAA SAB on Ocean modeling 2004.
    - NCEP to be the backbone for ocean modeling within NOAA in strong partnership.
    - Focus on global scales (NOPP, Navy, ….).
    - Enable/perform regional/coastal (NOS, IOOS, …)
    - Enable ecosystem modeling.

The big picture



Global Data Assimilation

Global Forecast System

Climate
CFS
MOM3

Hurricane
GFDL
HWRF

Coupled

Oceans
HYCOM
Wavewatch III

Regional
NAM
WRF NMM

Dispersion
ARL/HYSPLIT

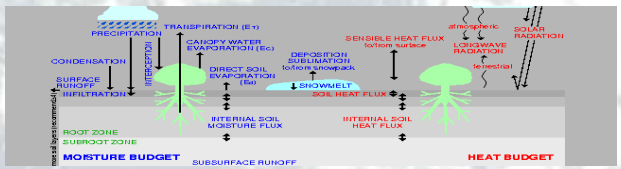
Severe Weather
WRF NMM/ARW
Workstation WRF

North American Ensemble Forecast System
GFS, Canadian Global Model

Short-Range Ensemble Forecast
WRF: ARW, NMM
ETA, RSM

Air Quality
NAM/CMAQ

Rapid Update for Aviation



NOAH Land Surface Model

The big picture 2

Executing the weather-climate strategy

develop / integrate marine products

NCEP Operational Global Weather-Climate ("Seamless") Forecast System
July 23, 2007

A. Operational forecasts

1. **All forecasts are Atmosphere-Land-Ocean coupled**
2. **All systems are ensemble-based except daily, high-resolution run**
3. **All forecasts initialized with LDAS, GODAS, GSI from GFS initial conditions**
4. **Physics and dynamics packages may vary**
   a. **Anticipated that the weekly forecast will have most rapid implementations and code changes, seasonal configuration may be one (or at most two) versions behind weekly**

Forecast Product	Number of members per refresh period	Runs/day	Membership refresh period	Horizontal resolution (ratio, current value)	Forecast Length	Initialization technique	Computing resource ratio*
Daily-hires	1	4	daily	1.0, T382	15 days	GSI	1.0
Weekly	80	80	daily	0.5, T170	15 days	ET breeding	2.5
Monthly	56	8	weekly (7 days)	0.5, T170	60 days	??	1
Seasonal	60	2	monthly	0.33, T126	1 year	Lagged analysis 2x daily	0.44

Calculated from ratio of runs/day * forecast length * expense of each forecast#
expense ratio is resolution**3

Wind wave modeling

Waves [1]

- Summer 2007 operational NOAA WAVEWATCH III v. 2.22.
  - NWW3: Global, 1.25x1°, 180h, 3-hourly GFS winds, assimilation of buoy and altimeter data and with a 10 member ensemble.
  - AKW: Alaskan Waters, 0.5x0.25°, 180h forecast based on 3h GFS winds.
  - WNA and ENP: W. North Atlantic and E. North Pacific, 0.25x0.25°, 180h forecast based on 3h GFS winds.
  - NAH and NPH: Hurricane version of WNA and ENP, 0.25x0.25°, 126h forecast, 1h GFS+GFDL winds.
  - GLW: Great Lakes wave forecast system, 4km, 84h forecast, NAM winds.
- All models: 24 directions, 25 frequencies, 4 daily cycles (00z, 06z, 12z, 18z) with 6h hindcasts for continuity. Regional models obtain boundary data from global model.

Waves 2

- 2006 state (WW3 v. 2.22):
  - Global NWW3 (GFS)
    - Regional AKW, WNA and ENP (GFS).
  - After GFDL winds are available
    - Regional NAH and NPH models (GFS+GFDL).
  - Great Lakes Waves model (NAM).

- Will become (WW3 v 3.14):
  - Early multi-grid ocean waves (GFS). 2007
  - Late multi-grid ocean waves (GFS + HWRF + other ?). 2008/9
  - Early Great Lakes Waves (NAM). 2008 Q2
  - Late Great Lakes Waves (NDFD). 2008 Q2 P
- Port ensembles. 2008 Q3
- Port assimilation. ????

The multi-grid model [1]

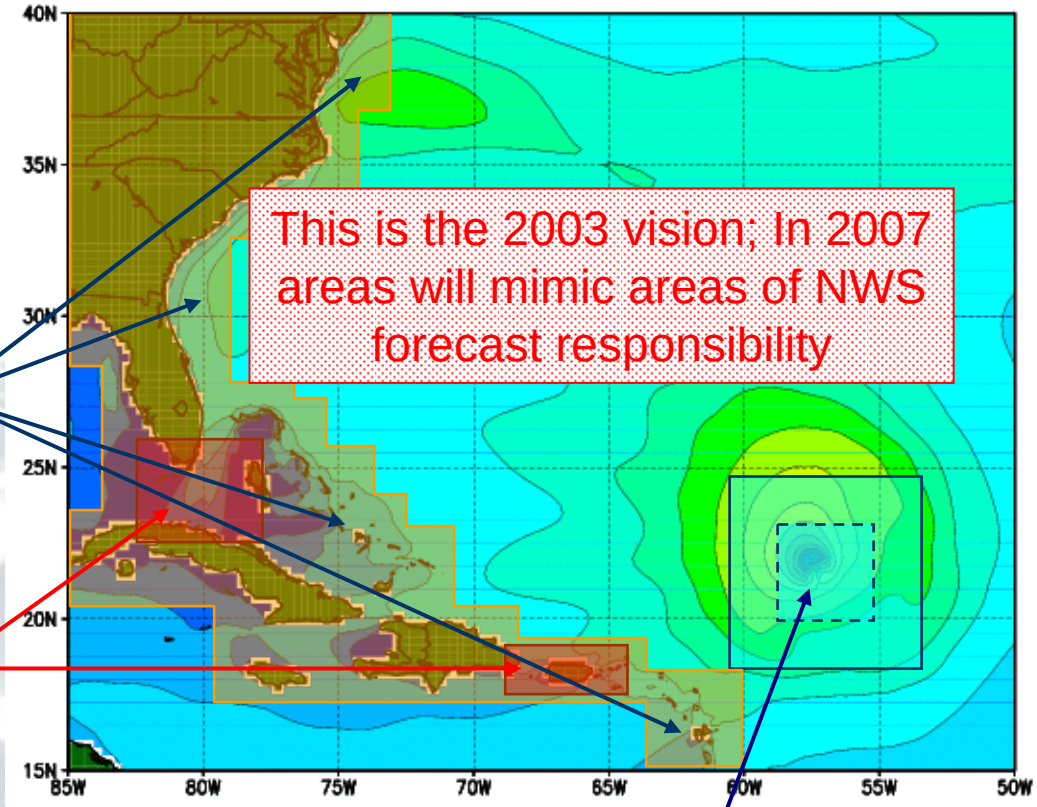
- Virtually all present wave models consider one-way nesting only.
- NDFD requires guidance at a range of scales that is fully consistent (i.e., two-way nesting)
- Hurricanes require high resolution in generation area, but not for swells (i.e., two-way nesting is much cheaper).
- NCEP: We need to build upon the present operations, therefore we have designed a multi-grid system.
  - No more large regional models.
  - Benefits ensemble wave forecasting.
- AWIPS 8.3.
- Added initial growth and shallow water physics.

The multi-grid model 2

Deep ocean model resolution dictated by GFS model

Higher coastal model resolution dictated by model economy

Highest model resolution in areas of special interest

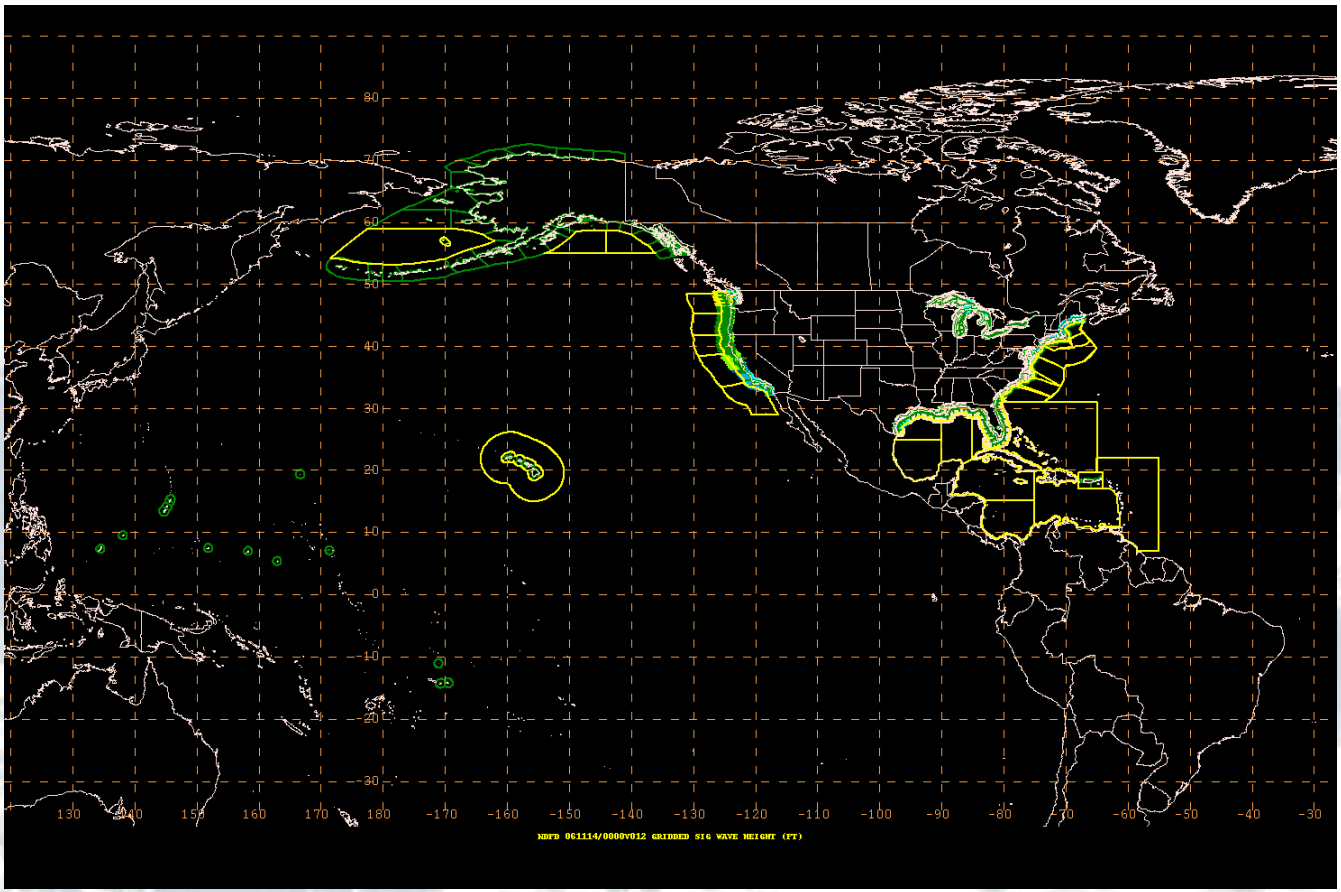


Hurricane nests moving with storm(s) like GFDL and WRF

The multi-grid model 3

- To each grid a rank is assigned based on similar (but not necessarily identical) resolution. Lower rank means lower resolution.
  - Data flow from low rank to high rank by means of boundary conditions.
  - Data flow from high rank to low rank by spatial averaging.
  - Data flow within rank by reconciliation (interpolation).
- All data flow internal to the program (no files).
- Internal wave model in essence unchanged.
- Relocatable grids will be relatively simple in this context, but not yet implemented.

The multi-grid model



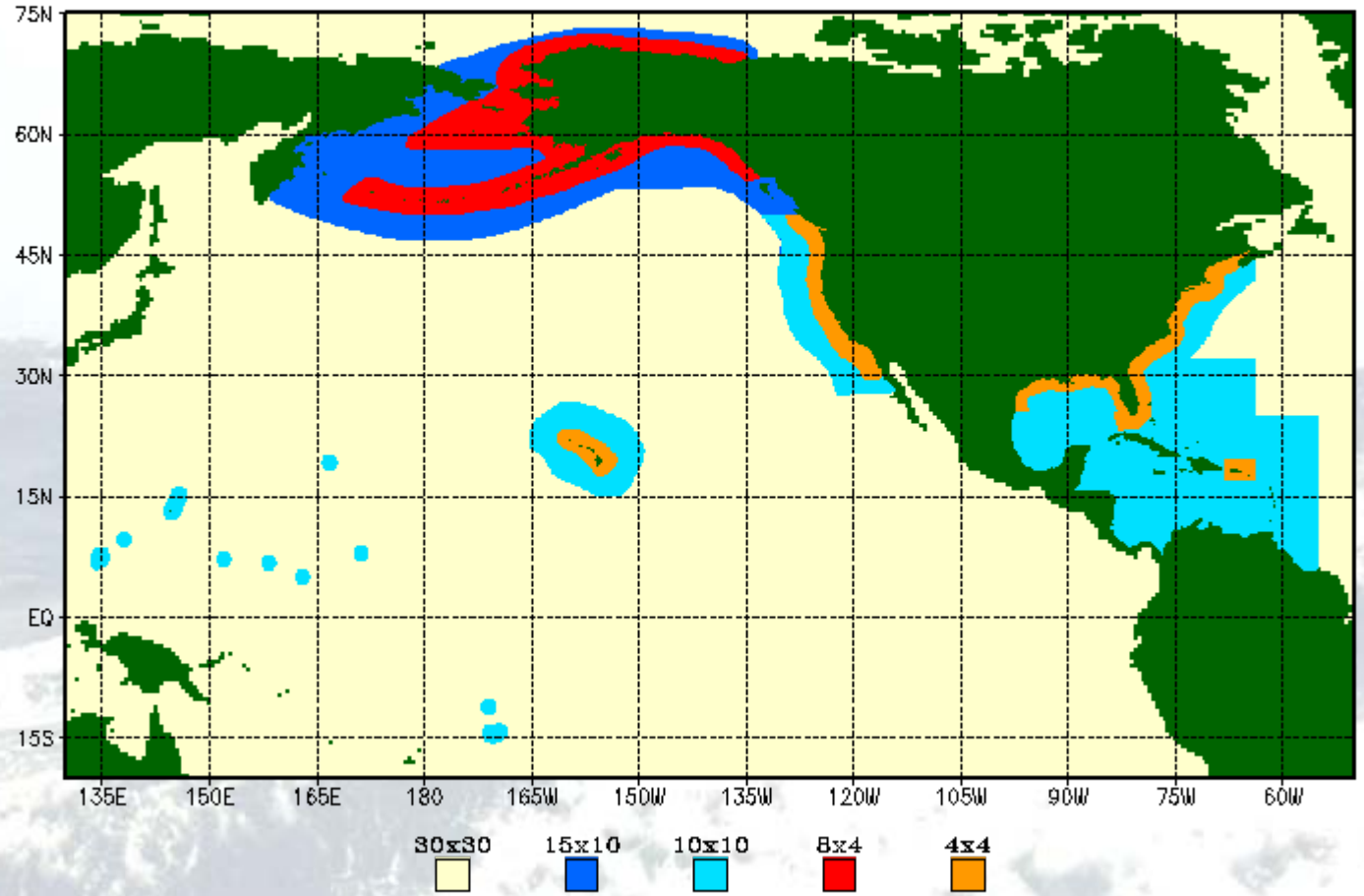
NWS areas of responsibilities and NDFD grids

Courtesy Joe Sienkiewicz

The multi-grid model

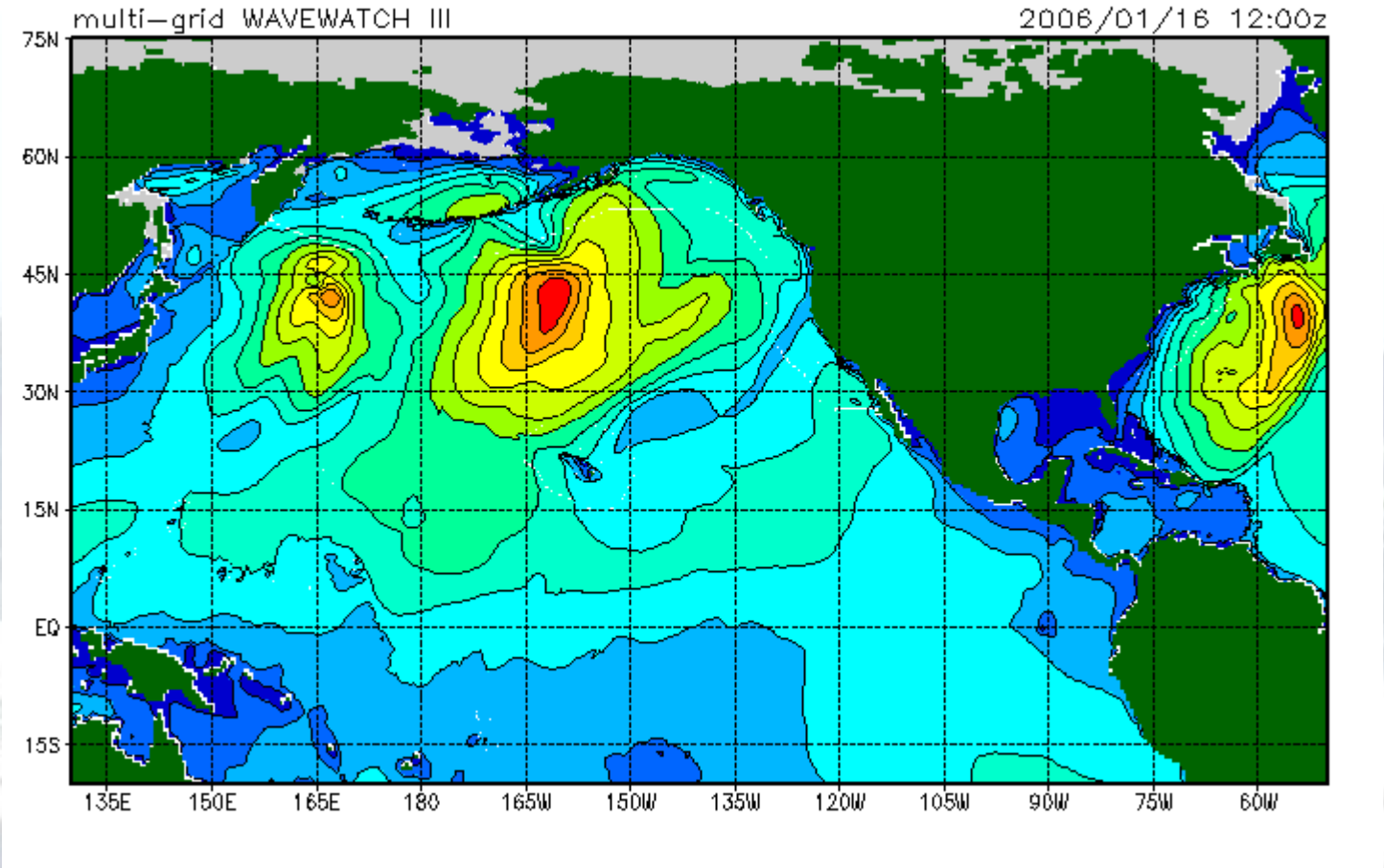
- To provide consistent guidance for all these areas, the new operational NCEP model will consist of a mosaic of 8 grids:
  - A global 30’ grid.
  - An offshore Atlantic 10’ grid.
  - An offshore West Coast 10’ grid.
  - A west Pacific 10’ grid.
  - An Alaskan 10’x15’ grid.
  - A coastal Atlantic 4’ grid.
  - A coastal West Coast 4’ grid.
  - A coastal Alaskan 4’x8’ grid.

The multi-grid model



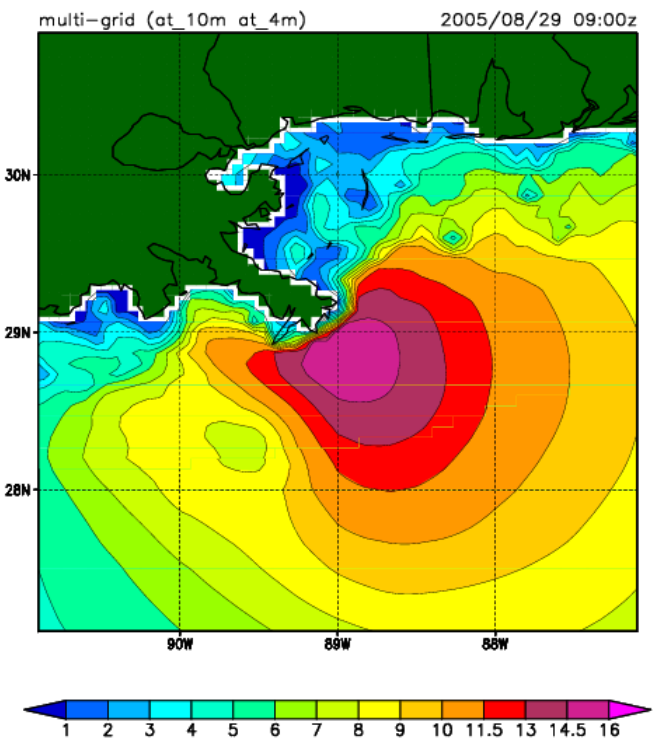
Available resolution in NCEP multi-grid model (minutes).

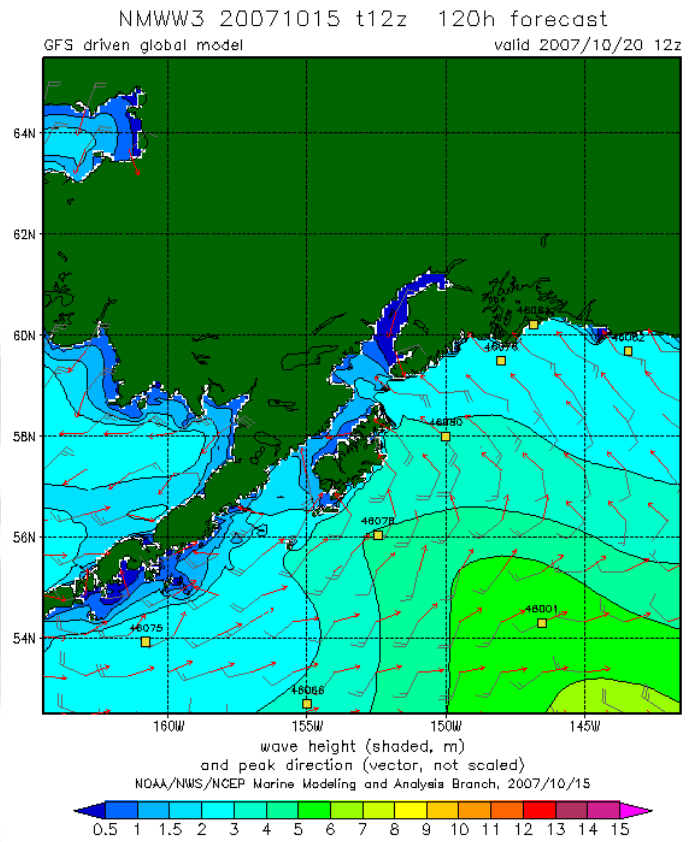
The multi-grid model



Example of consistency between grids

The multi-grid model

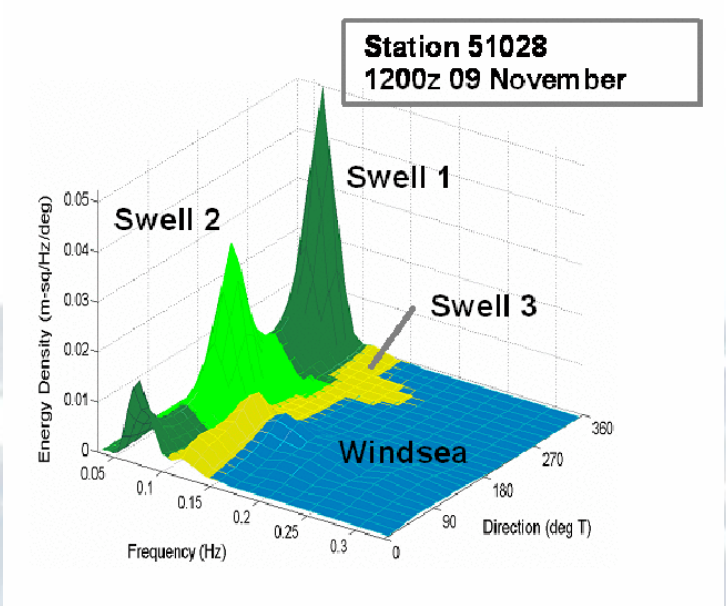




Examples of increased resolution and shallow physics

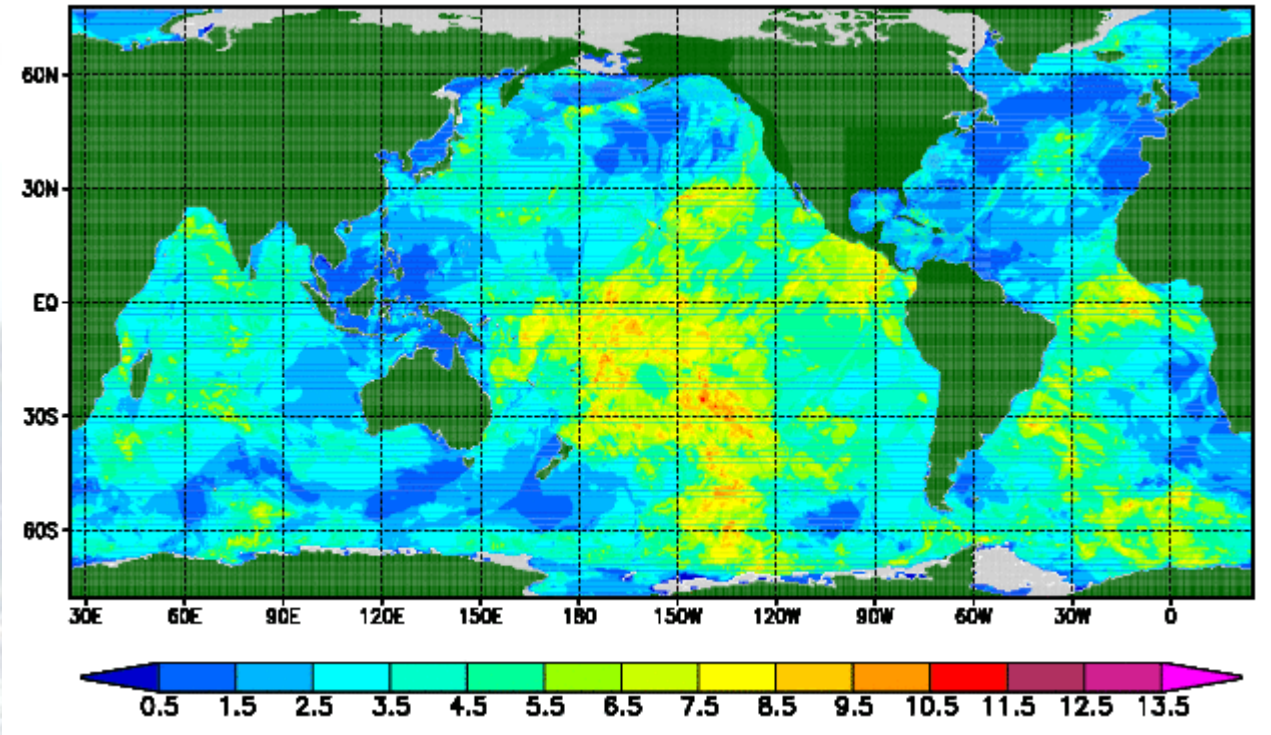
The multi-grid model

- Wave field separation:
  - Partitioning provides for each wave field:
    - H_s, T_p, L_p, θ_m, σ_m.
    - Fraction of energy that is wind-driven.
  - Conventional field output for
    - Wind sea, primary and secondary swell (all 6 parameters).
    - Overall wind sea fraction.
    - Local number of wave fields.
  - Developed at USACE.



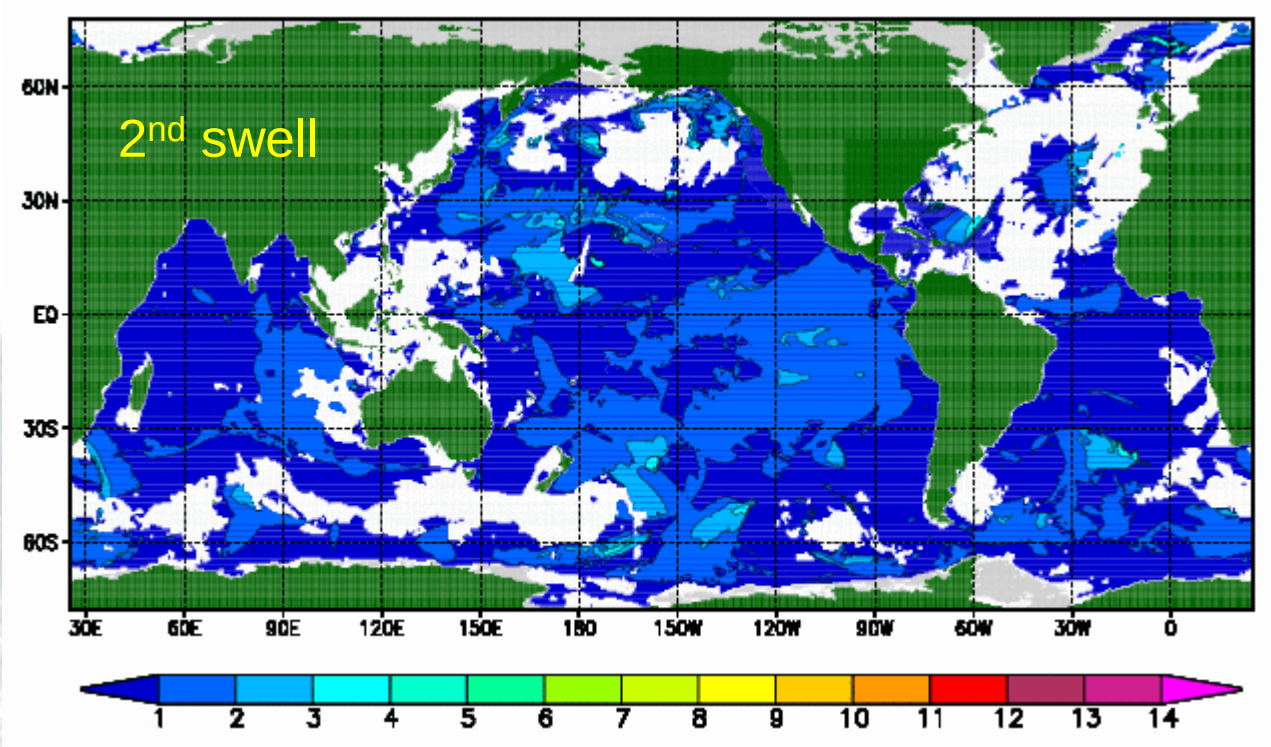
Example of partitioned spectrum, courtesy of Jeff Hanson USACE.

The multi-grid model



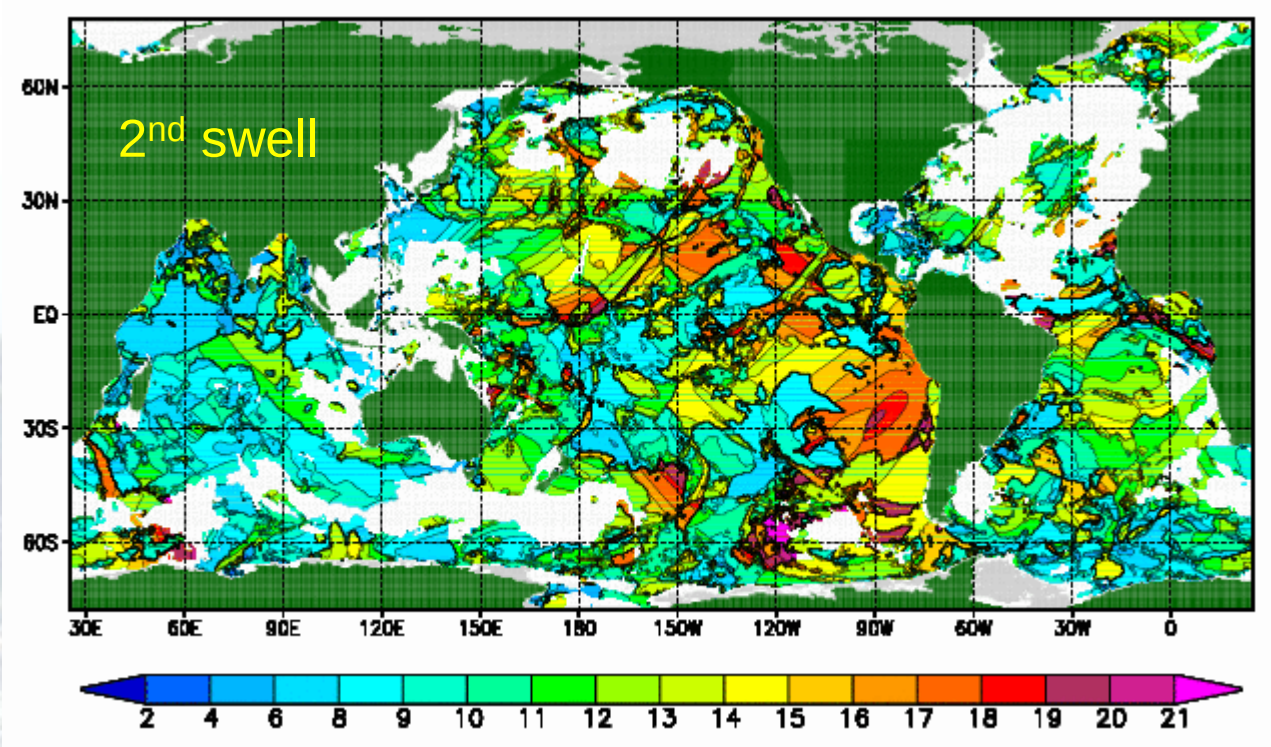
NCEP new operational setup results for Jan 16, 2006 after 16 days of model spin up. Number of fields found.

The multi-grid model



Wave heights and wave height partitions for wind sea, primary and secondary swells.

The multi-grid model

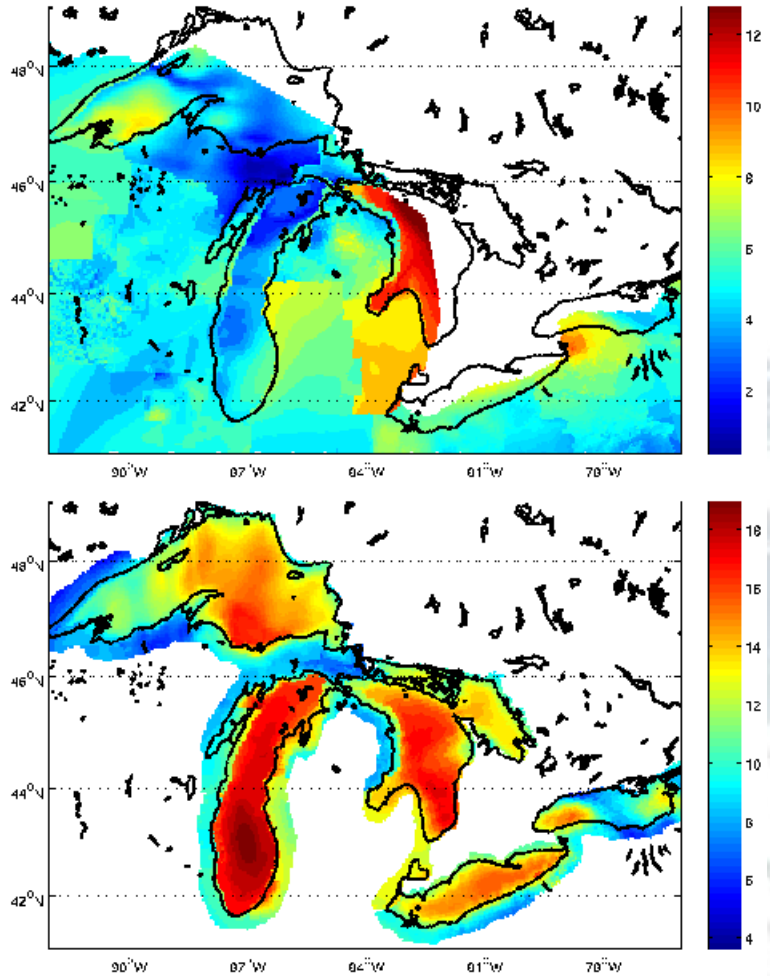


Peak periods from F(f) and from partitions for wind sea, primary and secondary swells.

Great Lakes [1]

- Operational model will be converted to WW3 version 3.14 in FY 2008 Q2.
  - We are working on wind downscaling approaches to get land-water boundary layer transition represented better. (possibly FY 2009).
  - Great Lakes Waves model(s) to go into AWIPS 9.0.
- Second Great Lakes Waves model to be run with NDFD winds to start as parallel run in FY 2008 Q2.
  - Issues with NDFD data coverage.
  - Issues with data flow from WFOs to NCEP.
    - Data flow, NCO ops concepts.

Great Lakes 2



- Timeliness of product is a major issue.
  - 30 min window agreed upon.
- Mostly technical issues outside NCEP.
  - Full NDFD grids to NCEP.
  - Hourly winds for entire forecast period.
  - NCO ops concept.
- New paradigm, evaluate as long as needed.
- Retain local WFO capability for off-cycle needs.

Wave Ensembles

- Operational since March 2006.
  - Latest validation results show:
    - Comparable to ECMWF ensembles.
    - Increased skill compared to control.
    - Insufficient spread in wave data.

- Upgrade to model version 3.14 in FY2008 Q3.
  - Combine with FNMOC ensemble (NAEFS / NUOPSC).
  - More members and longer lead time.
  - Cycling of initial conditions.
  - Possibly applying ensemble wind bias corrections.
  - More detailed validation approaches.

Assimilation

- We are insufficiently funded to do both assimilation and ensembles. Assimilation therefore is low priority unless explicit funding is provided.
  - Adding additional altimeters.
  - Improving monitoring and validation.
  - Porting to multi-grid model.

- Development of wave-specific assimilation techniques potentially expands impact of assimilation from 12h to several days, but will require dedicated funding.

Coastal Modeling

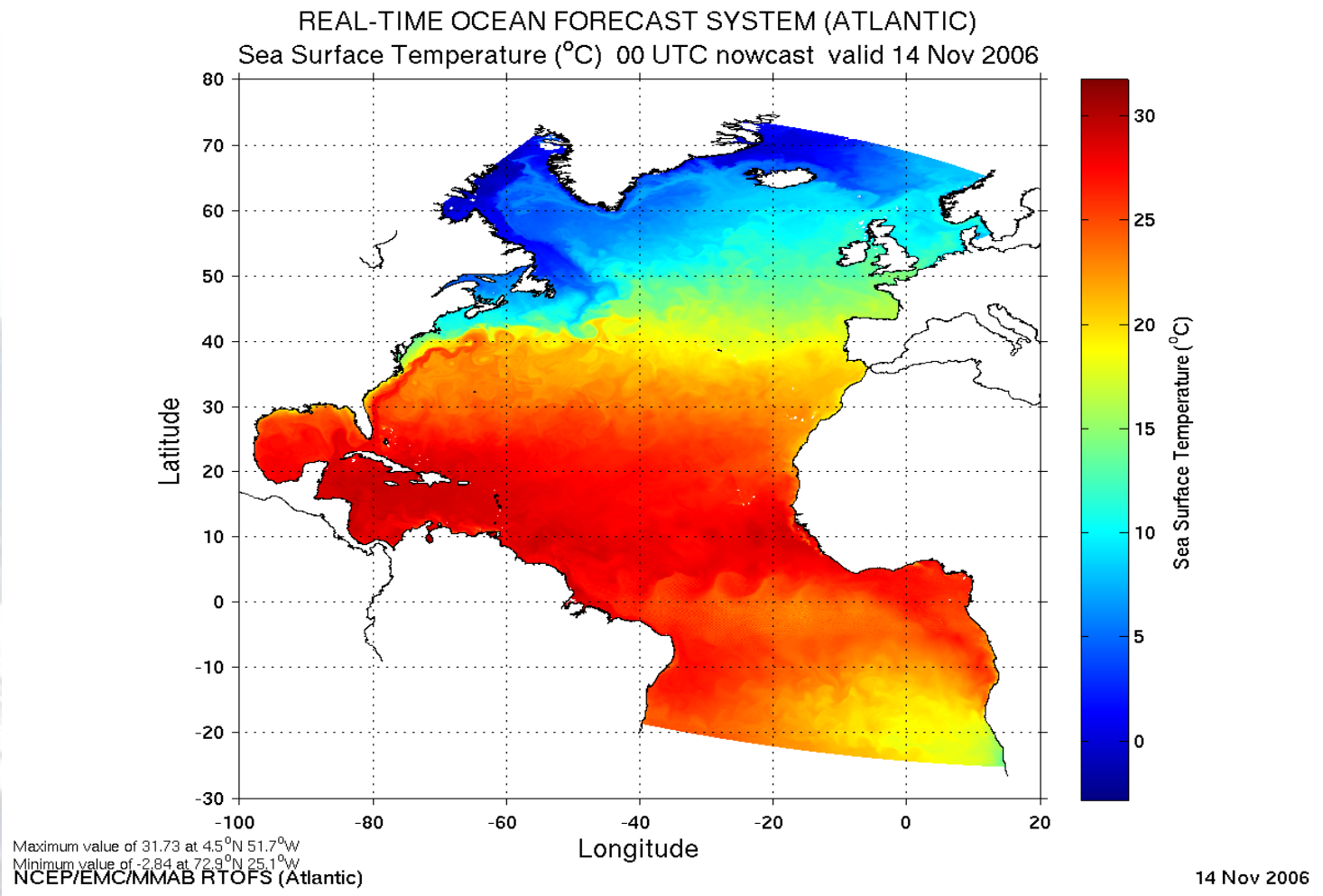
- Coastal wave modeling is becoming a focal point of MMAB:
  - Large public impact at km and sub-km scale.
  - Coupling to surge and inundation modeling.
- Dedicated funding required to implement a whitepaper road map to coastal wave modeling at NCEP and WFOs.
- Leveraged ongoing research includes:
  - Curvilinear and unstructured grids.
  - Shallow-water physics.
  - Quasi-steady model approaches.
- Local modeling approaches need to be coordinated with NCEP for sustainability and system integration.

Ocean Modeling

RTOFS-Atlantic [1]

- HYCOM application:
  - Primitive equation with free surface.
  - Sub-grid scale parameterizations. Vertical and horizontal eddy viscosity and mixing. Diapycnal mixing.
  - Tides & river outflow (USGS, RIVDIS).
  - Atmospheric fluxes (GFS).
  - North Atlantic grid with 4-7km US coastal resolution (ETOPO2, NGDC)
  - Open boundaries: T,S from climatology
  - SSH and barotropic velocity from tidal model (TPX06) and climatology.

RTOFS-Atlantic 2



RTOFS-Atlantic 3

- 2007 model updates:
  - Revised vertical grid to 26 layers :
    - Higher resolution in the shallow waters.
    - Better resolution on the shelf break.
    - Better representation of Denmark & Iceland overflows.
    - Resolving 4 vertical dynamical modes in major sub-basins
  - Improved barotropic / baroclinic inputs at open boundaries
    - Updated Climatology (NCEP – version 6)
    - Mean dynamic topography (Rio 5)
    - Historical transports

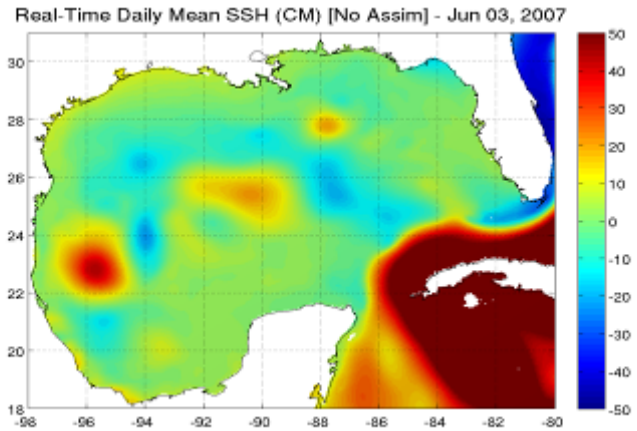
RTOFS-Atlantic 4

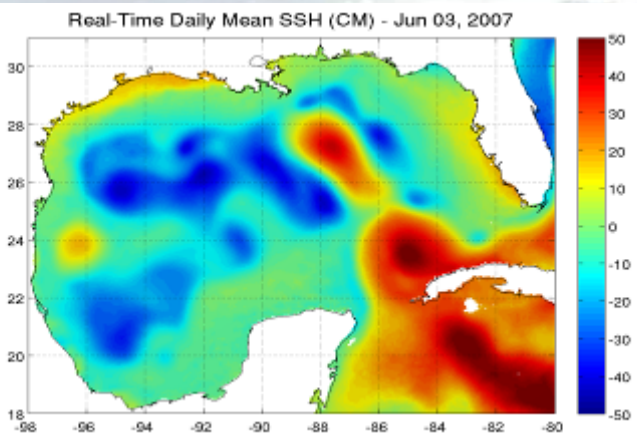
- 2007 model updates cont'ed:
  - Revise river inflow data (location and strength) from USGS
  - Remove noise in net heat flux
  - Update of model algorithms
    - Surface initialized Montgomery Potential
    - Employ two invariant external mode boundary conditions.
    - Stabilization of sigma_star.
    - Enforced salinity minimum by refreshing the water column

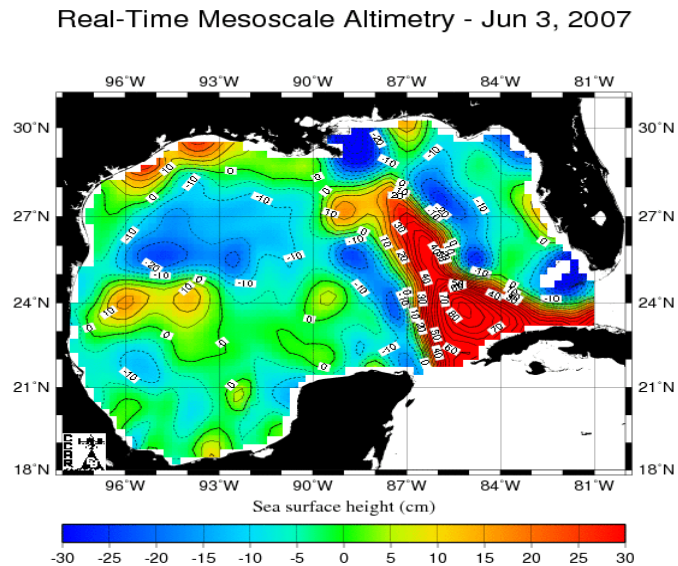
RTOFS-Atlantic 5

- 2007 model updates cont'ed:
  - Major upgrades to data assimilation
    - SST: spatially varying bias removal algorithm
    - SSH: absolute sea surface height ;
      - 2D + 1D approach, conserving momentum.
    - T&S: assimilation of vertical profiles of temperature and salinity
      - 2D density, temperature and layer thickness anomaly, preserves volume, momentum; updates mass and heat.
  - New model output:
    - GRIB files on native grids.
    - GRIB files sets for selected sub-regions.

RTOFS-Atlantic

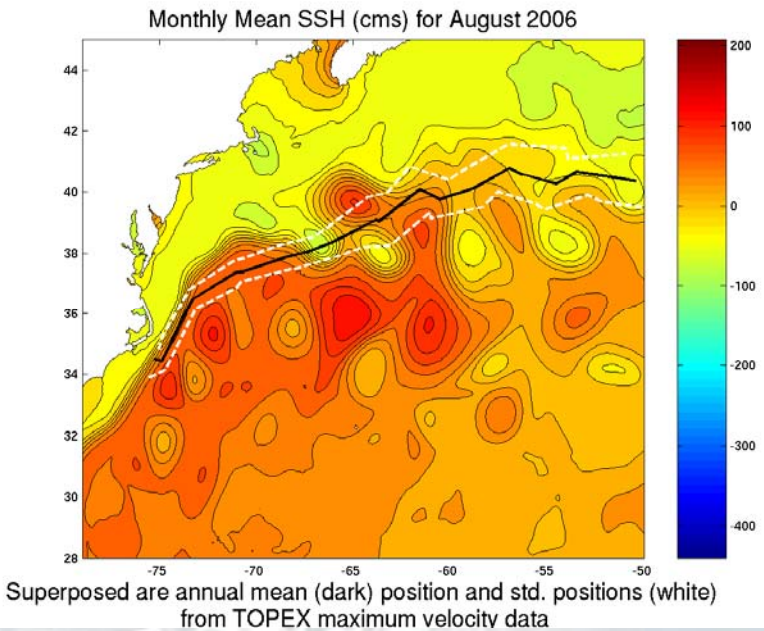


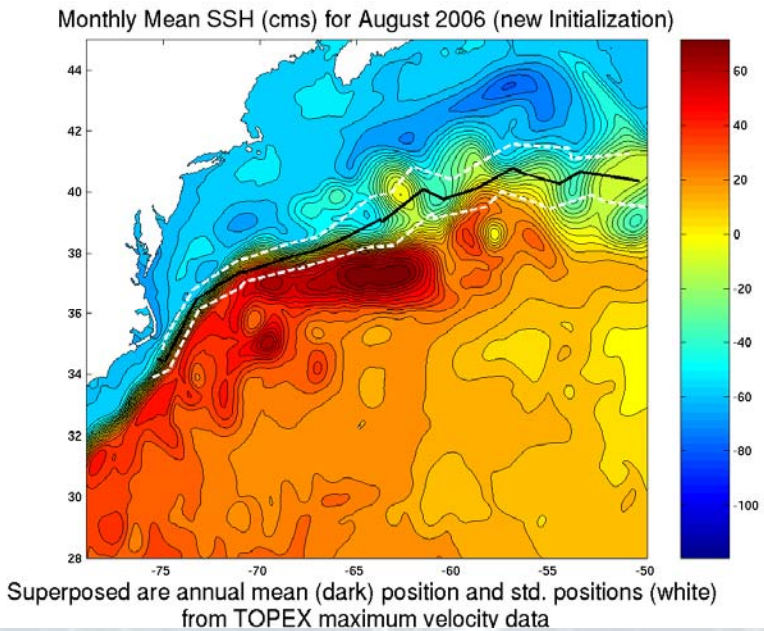




- SSH without (upper-left panel) and with SSH assimilation (lower-left panel) from RTOFS-Atlantic
- Data: JASON, GFO and RIO5 mean dynamic topography.
- U. of Colorado analyses. Uses also ENVISAT data.

RTOFS-Atlantic



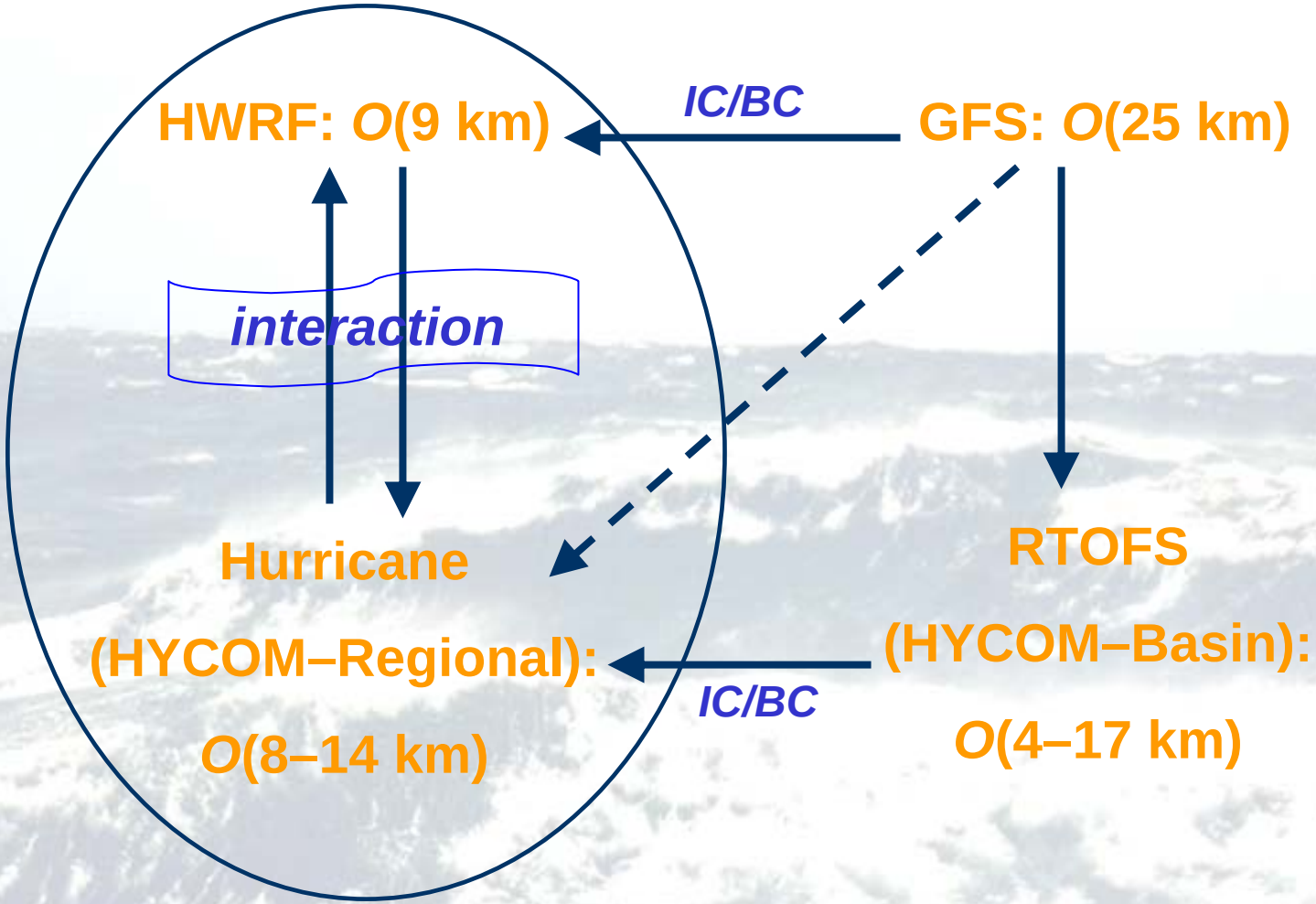


Mean Gulf Stream path from old model (left) tends to overshoot the annual mean path derived from altimetry data near 72° W as compared to the Gulf Stream location in the new implementation (right)

RTOFS-Atlantic [8]

- Product distribution
  - FTP site (ftpprd) :
    - Nowcast and 5-day forecasts available for 3 days.
  - NOMADS server:
    - Nowcasts and 5-day forecasts available for 30 days. Tools to extract sub-regions available.
    - Targeted to become operational in 2008.
  - NODC Archives:
    - Long term archival. Under construction.

Coupled HWRF-HYCOM [1]



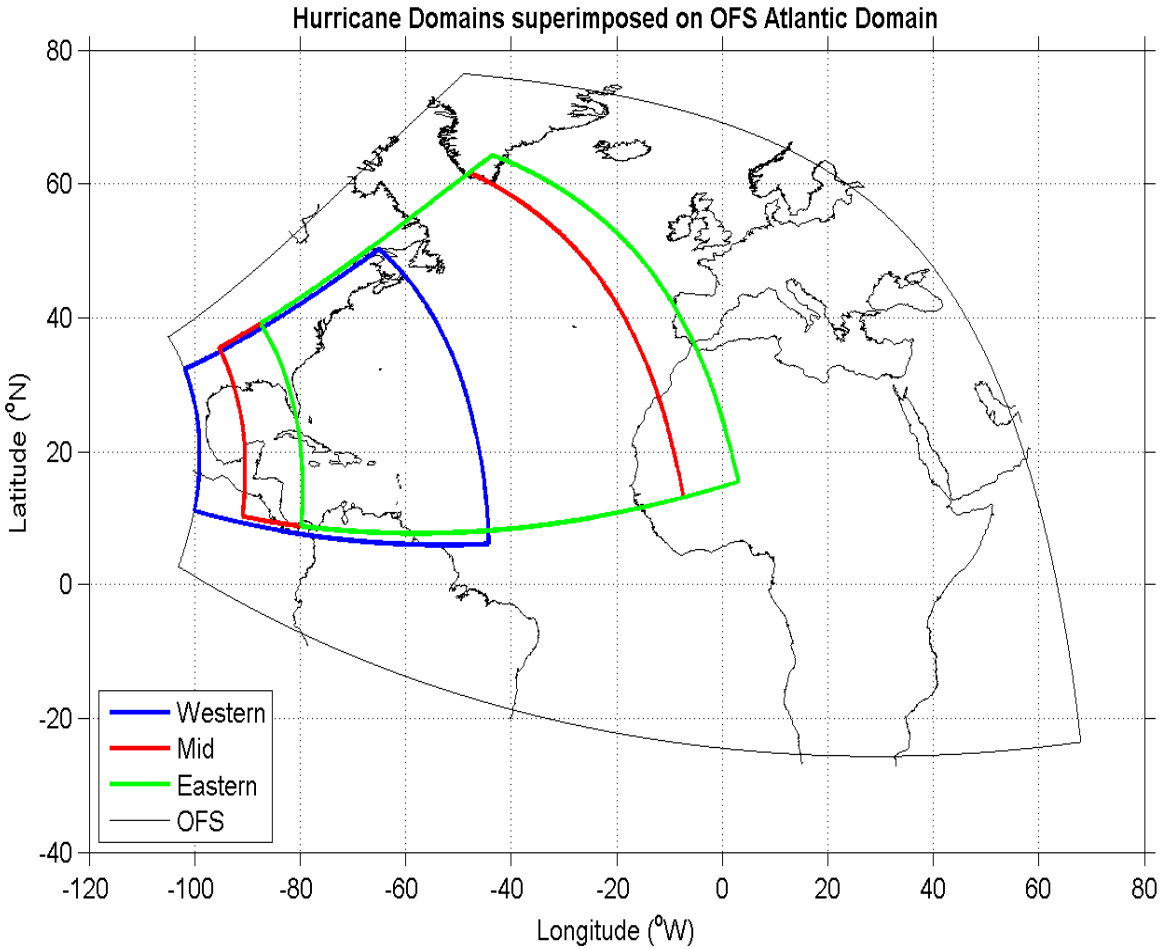
Coupled HWRF-HYCOM 2

- HYCOM versus POM in HWRF / GFDL. :
  - Common: primitive governing equations.
  - Different vertical grid (20 sigma ↔ 26 hybrid)
  - Different vertical turbulence (Mellor-Yamada 2½ ↔ GISS).
  - Testing / experience :
    - POM tested and tuned starting with coupled GFDL model.
    - HYCOM extensively tested in stand alone mode.
  - Overall system :
    - POM essentially stand-alone.
    - HYCOM integrated in operational RTOFS.

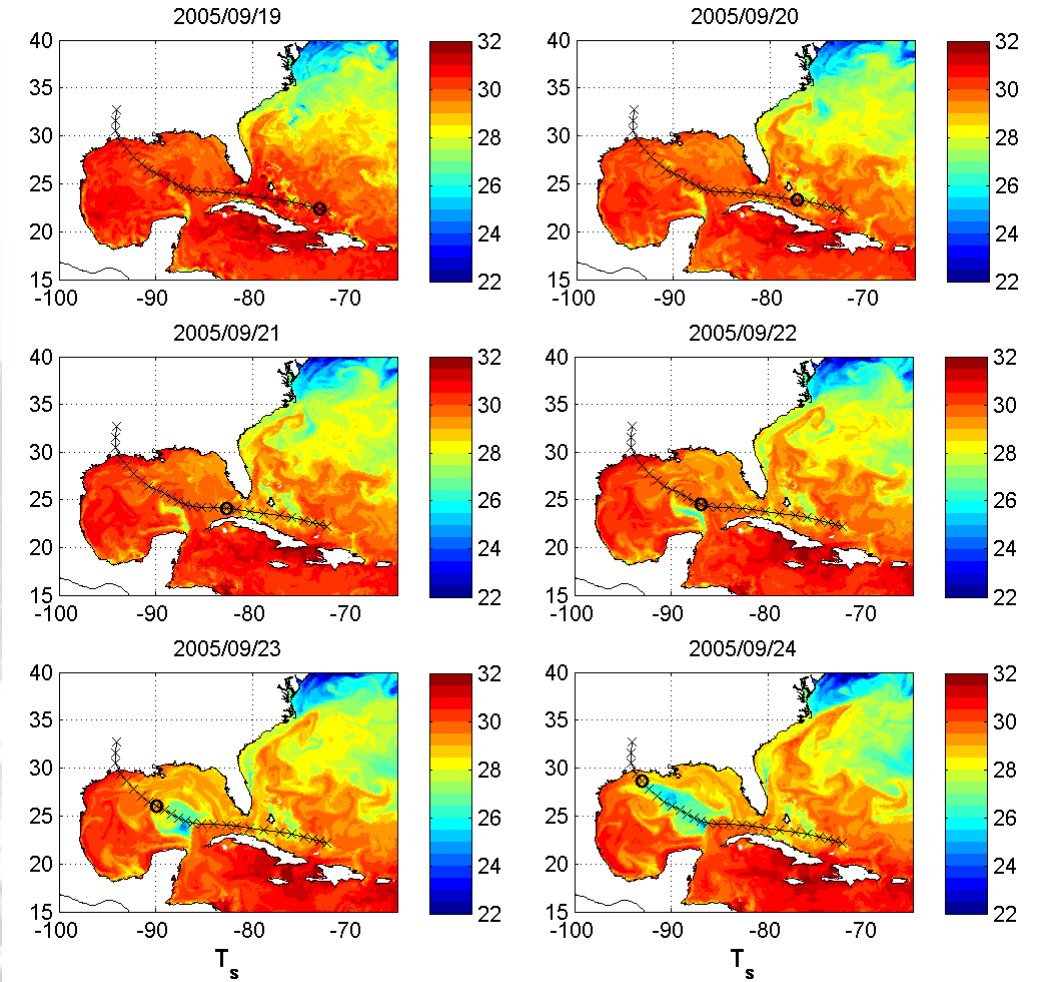
Coupled HWRF-HYCOM 3

- Initial conditions from operational RTOFS-Atlantic
  - Continuous data assimilation
    - 2D/3D Var
      - SST, SSH, CTD, XBT
- Boundary conditions are derived from RTOFS:
  - Five day forecasts are sampled for volume data six hourly and for the external velocity and surface elevations hourly.

Coupled HWRF-HYCOM 4

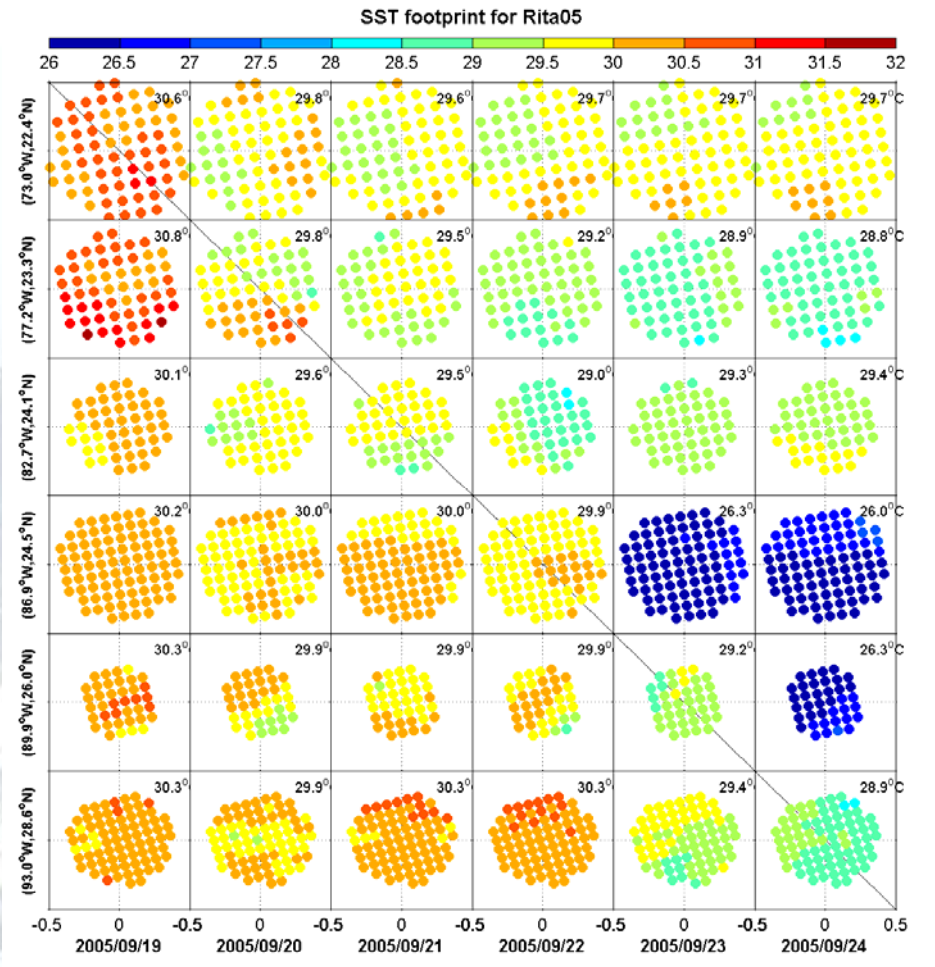


Coupled HWRF-HYCOM [5]



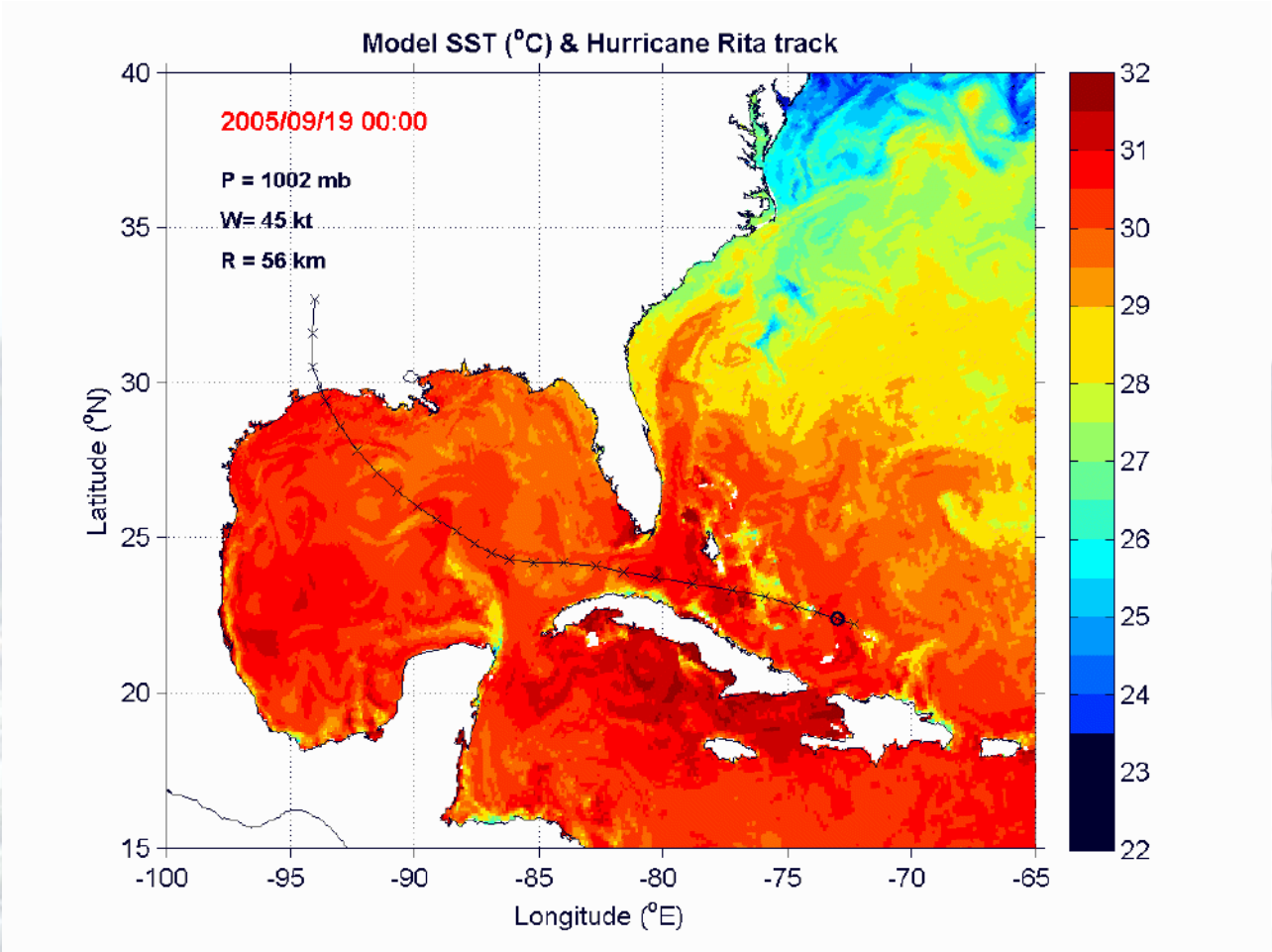
- Examples from Rita (2005).
  - Model forced with GFS only.
  - Fully coupled system is in testing mode.

Coupled HWRF-HYCOM 6



- One of the several diagnostic products as generated for HYCOM in HWRF.
- Snapshot of SST for selected location and times on the track.

Coupled HWRF-HYCOM



Future 1

- The original RTOFS development plan called for the implementation of a lower resolution global model and an additional set of regional HYCOM applications.
- We are revisiting these plans for several reasons:
  - Boundaries in regional models require undue attention.
  - Revisiting the findings of the SAB on Ocean Modeling and NOAA's response to this.

Provide a physical ocean modeling backbone within NOAA as a part of a larger national strategy

Future 2

- National backbone capability:
  - NCEP to focus on physical modeling of larger scales
    - Strong partnership (Navy, NOPP partners, …).
    - Enable ecosystem modeling (NOS lead within NOAA).
  - NCEP to be partner in coastal modeling.
    - Enable and participate in physical modeling (NOS lead within NOAA, IOOS RAs and other partners).
    - Enable ecosystem modeling inside and outside NOAA.

Future 3

- New plan in development:
  - Organizing workshop with broad participation from inside and outside NOAA to determine requirements related to previous slide (Jan 2008).
    - Part of bigger ecosystems picture as lead by NOS.
  - Plan to materialize in FY2008 Q2.
    - New roadmap for model implementations for the next 5-7 years,
    - Identify essential modeling partnerships.
    - Identify essential products to enable regional ocean and ecosystem modeling.

Future 4

- Tentative elements of the plan under development
  - Global eddy resolving capability as the deterministic centerpiece of the backbone capability. OPC
    - RTOFS-Atlantic to be nested, and to remain as a development platform for the near future. MMAB
    - Enable global applications of HWRF-HYCOM coupling.
    - Provide dynamic initialization for lower resolution HYCOM applications to be coupled to GFS models. NCEP weather mission
      - Initial focus on deterministic coupling, and mid-range ensembles in seamless weather-climate GFS model suite.

SAB vision

Sea Ice

CFSRR

- Sea Ice For Climate Forecast System Reanalysis and Reforecast
  - Daily, global 0.5° latitude-longitude
  - 26 October 1978 to present
  - Combines data from
    - Canadian Ice Service (Laurentian Lakes).
    - GLERL (Great Lakes).
    - National Snow and Ice Data Center / GSFC (most of globe) through 1996/12/31.
    - NCEP oper. analysis from 1997/01/01 (global)
  - To produce a continuous, consistent, high quality series of sea ice concentrations matching to the present day's operational analysis system.

Other ice

- Sea Ice in RTOFS :
  - Work starts on low-resolution global model (ESMF).
  - Coupled and stand-alone versions:
    - Stand alone useful considering resource ratio HYCOM – ice.
    - Stand-alone to be used for assessing flux errors in GFS.
  - Dynamic-thermodynamic ice with multiple thickness classes
- Sea ice in GFS :
  - Albedo experiments under way for an improved sea ice albedo algorithm in global model.

SST

Operational [1]

- Daily Real-time global SST (RTG_SST_HR) analysis
  - (1/12° latitude, longitude resolution) is generated every 24h (22:30 UTC) using latest 24 h of real-time data.

    Sept. 2005

- Daily Real-time global SST (RTG_SST) analysis
  - (1/2° latitude, longitude resolution) is generated every 24-h (22:30 UTC) using latest 24 h of real-time data.

    Jan. 2001

- Validations statistics are computed immediately following completion of the operational runs for both systems and are available on the MMAB SST WEB page.

Operational 2

	RTG_SST	RTG_SST_HR
Horizontal Resolution (Lon/Lat grid)	0.500 degree	0.083 degree
In-situ Data	Fixed buoys, drifting buoys, and ships	
Satellite Data	NOAA 17 AVHRR	NOAA 17 and NOAA 18 AVHRR
Satellite Processing	NAVOCEANO Retrievals	JCSDA Physical Retrievals
Correlation length scales for increments (errors)	450km – 100 km	450km – 50 km
AVHRR Limitation (Serious)	Can not see through clouds	
Satellite data bias correction	Yes	Yes
Day to day change	(Large: 0.5 to 1.0)	Greatly reduced

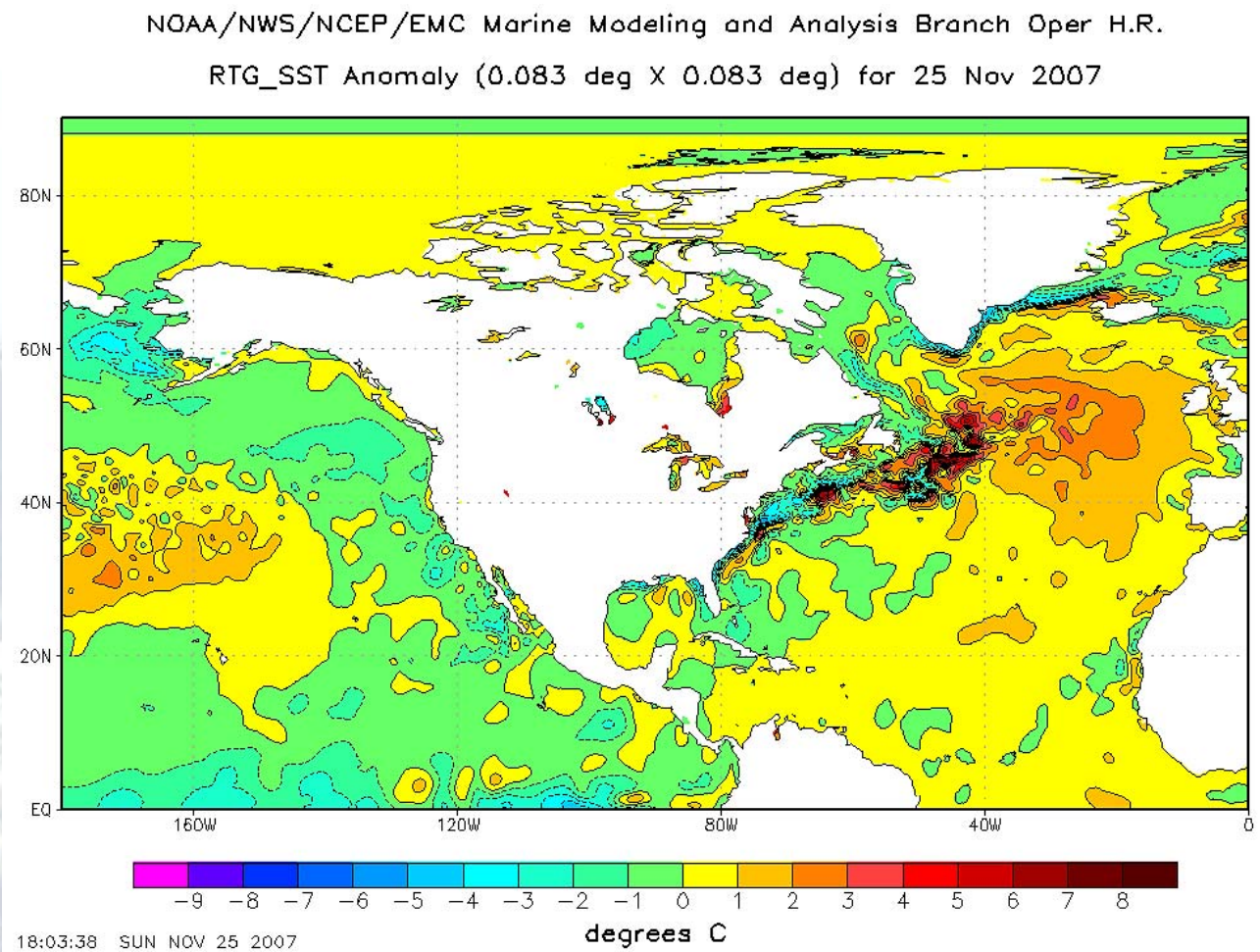
Operational 3

- JCSDA physical retrievals :
  - Based on a physical retrieval (variational) algorithm within GDAS (Derber and Xu Li).
  - Cost function minimizes the increment between;
    - Observed radiances and simulated radiances, and
    - Analyzed SST and its first guess
  - Requires radiative transfer model to simulate Brightness Temperatures for each channel using
    - SST first guess (previous analysis)
    - Air Temperature (GDAS analysis)
    - Water vapor mixing ratio (GDAS analysis)
  - New version (Xu Li) in parallel testing.

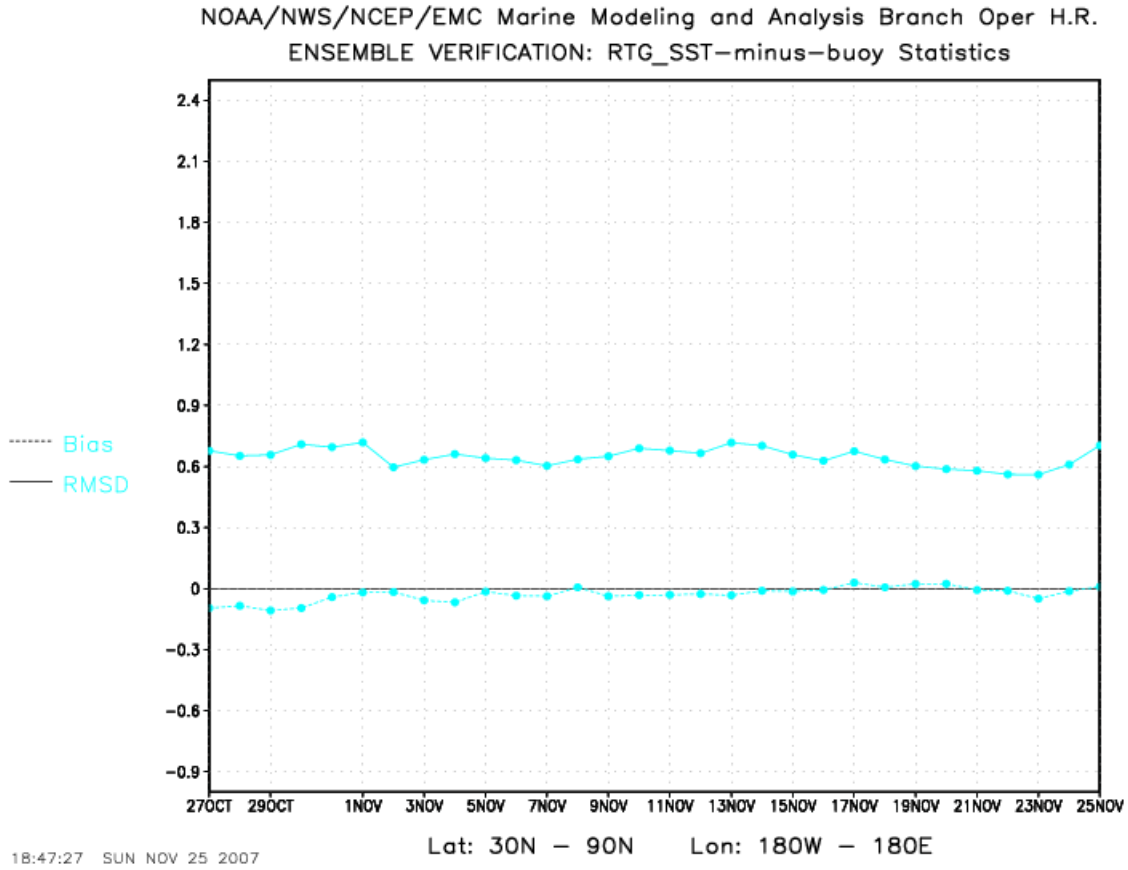
Operational 4

- Comments :
  - Statistical comparisons with buoys data shows that the daily global RTG_SST_HR is slightly better than the RTG_SST (rms).
  - The limitation of AVHRR retrievals due to clouds is serious specially in areas of persistent cloud cover (the Gulf Stream, lakes etc.)
  - SST in high northern latitudes are too cold in the RTG_SST_HR.
  - Abnormally warm SST and lowest sea ice coverage since 1900 in Arctic summer.

Operational 5



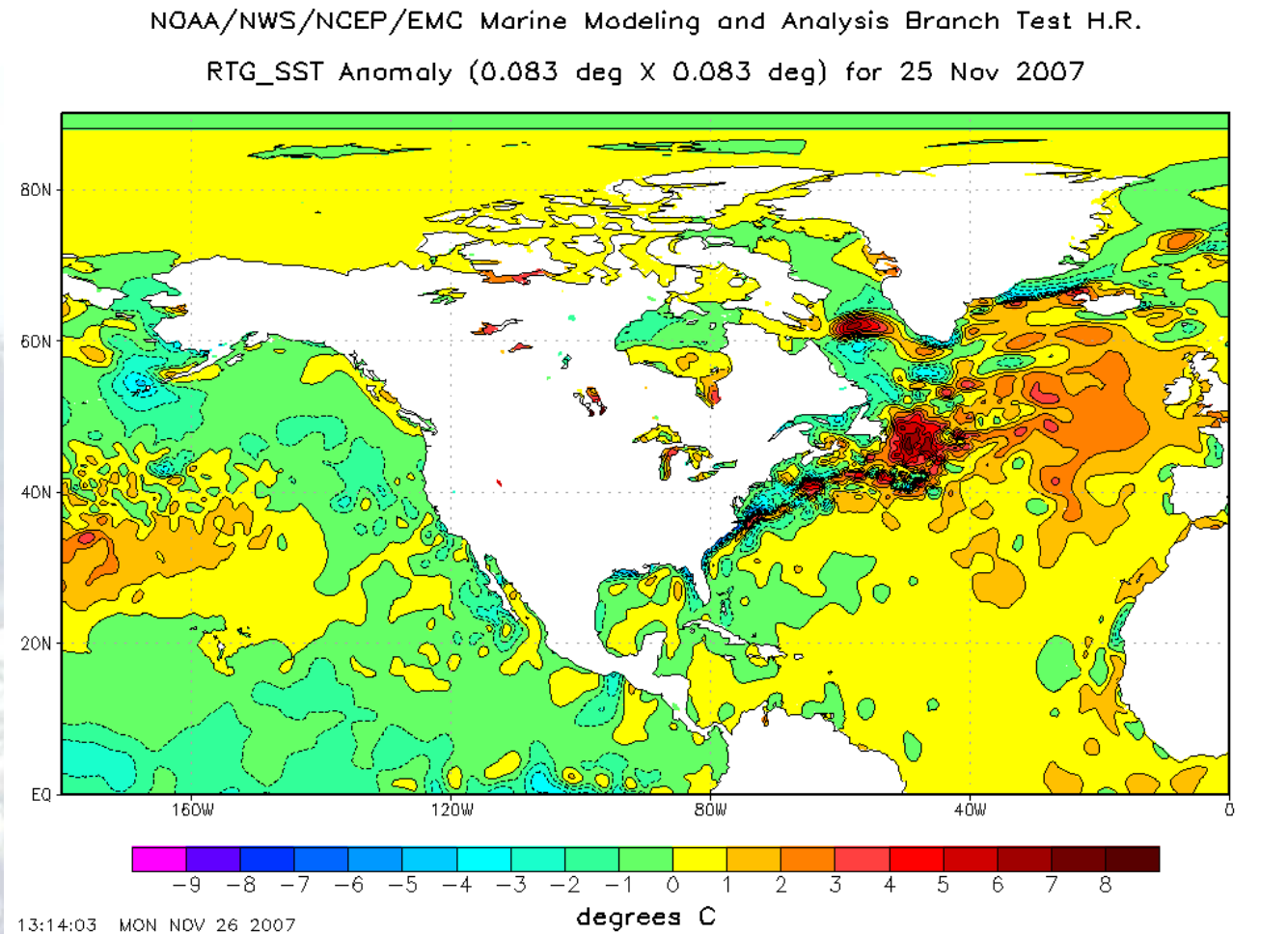
Operational 6



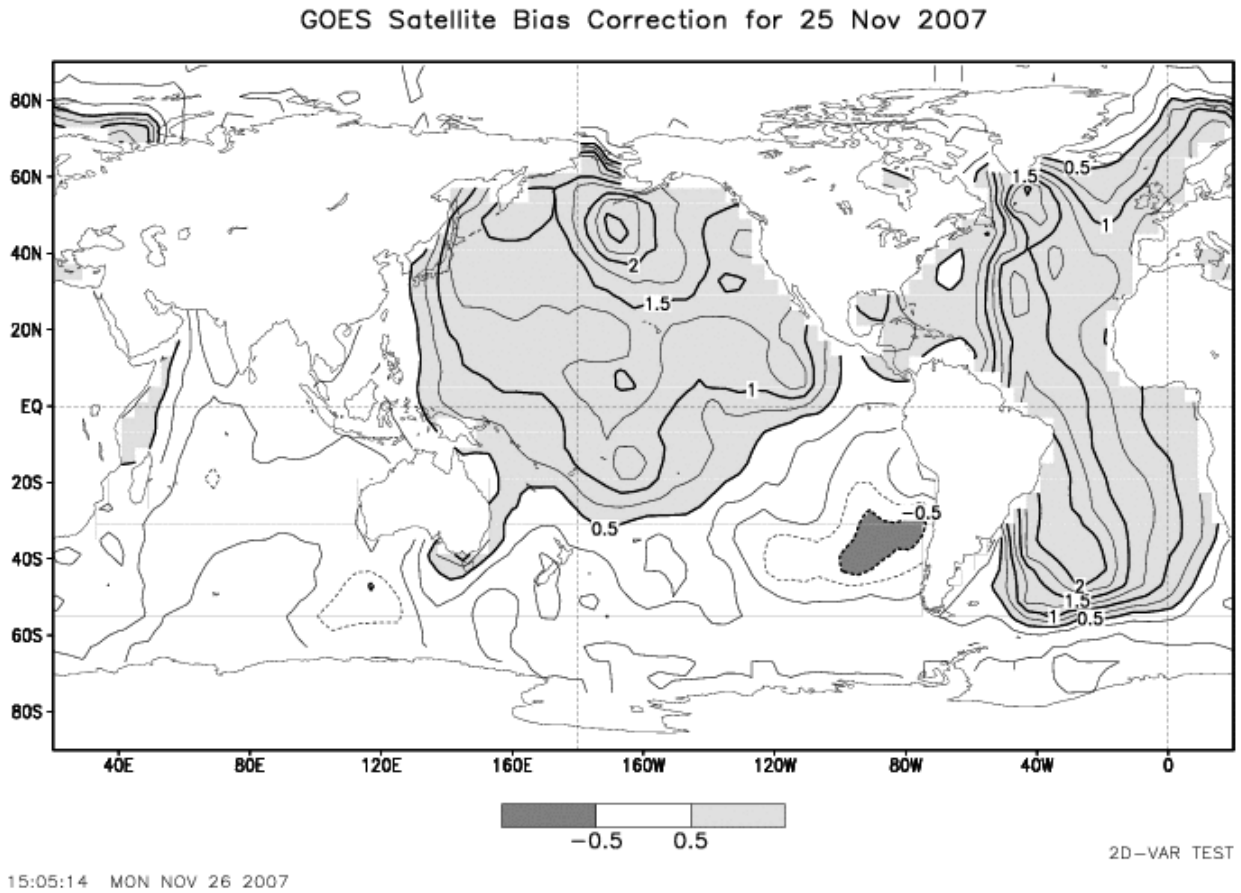
Experiments [1]

- Experiments using GOES SST retrievals only
  - RTG_SST_HR analysis system (¼°x¼°)
  - Two GOES satellites,
  - Dense but limited area coverage with 0.05° footprint
    - 60N-60S, 180W-30W.
  - Unfortunately,
    - Retrievals contain large biases > 0.5°C,
    - Bias removal procedure reduced that to 0.1°C, but the RMS was 0.8°C .

Experiments 2



Experiments 3



2008 plans

- Replace NOAA 17 with NOAA 18 in RTG_SST.
- Replace NOAA 17 with METOPS in RTG_SST_HR.
- Improve RTG_SST_HR analysis:
  - Tune; correlation length scales, data errors and analysis errors.
  - Investigating cold bias at high northern latitudes.
  - Test and incorporate the Pathfinder SST Climatology
  - Test and incorporate anisotropic length scales (important along large SST gradients and coast lines)
  - Evaluate C-man stations for use in coastal regions.
  - Evaluate AMSR and MODIS data usage.


Questions?