



NOAA Plans for Advanced Models and Assimilation Systems and Implications for Satellite Data

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Director

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NCEP: “where America’s climate, weather, and ocean services begin”

Overview

- **EMC Organization**
 - What do we do?
 - What are we going to do?
- **Some more specifics on what are we going to do**
 - **Collaborative software development**
 - Data assimilation
 - **GFS**
 - **Mesoscale forecasting**
 - **Hurricane Forecasting**
 - **Land Surface Modeling & Data Assimilation**
 - **Real-time Ocean Forecasting**
 - **Global Coupled Climate Forecast System**
 - **JCSDA**
- **Summary**

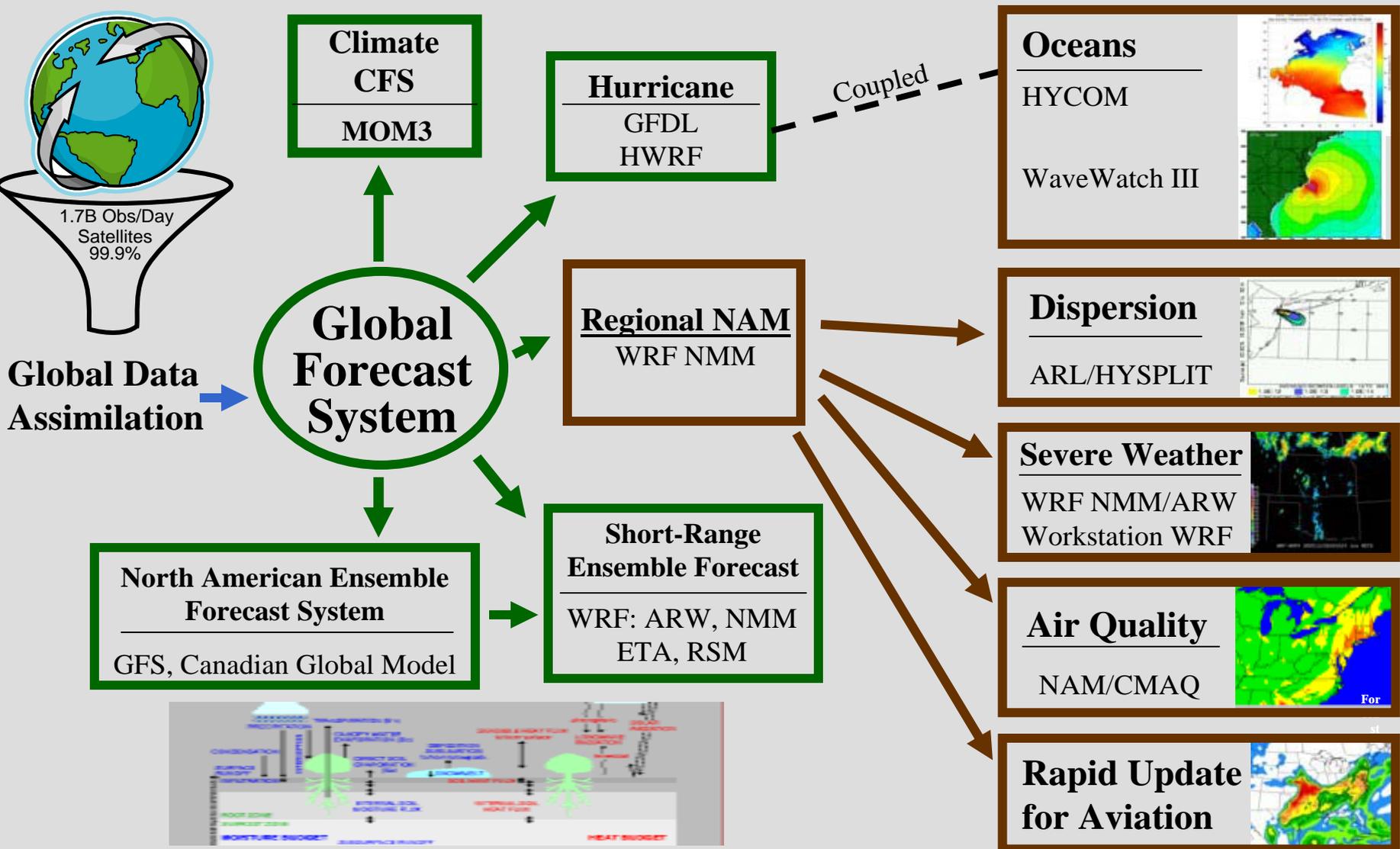
EMC Mission

In response to operational requirements:

- **Maintain**
 - the scientific correctness and integrity of operational forecast systems
 - modify current operational system to adapt to ever-present external changes
- **Enhance** numerical forecasts
 - Test and improve NCEP's numerical forecast systems via
 - Scientific upgrades
 - Tuning
 - Additional observations
- **Transition and Develop** operational numerical forecast systems
 - **transform & integrate**
 - Code
 - Algorithms
 - Techniques
 - from research status to operational status** on NCEP computers



NOAA's NWS Model Production Suite



NOAH Land Surface Model

Ingredients for Improved Numerical Forecast Systems

- **Primary ingredients**
 - Observations
 - Data Assimilation & Model technology
 - Computing resources
- **Secondary ingredients**
 - Post-processing and dissemination
 - Research to Operations (R2O) process
 - Operations to Research (O2R) process

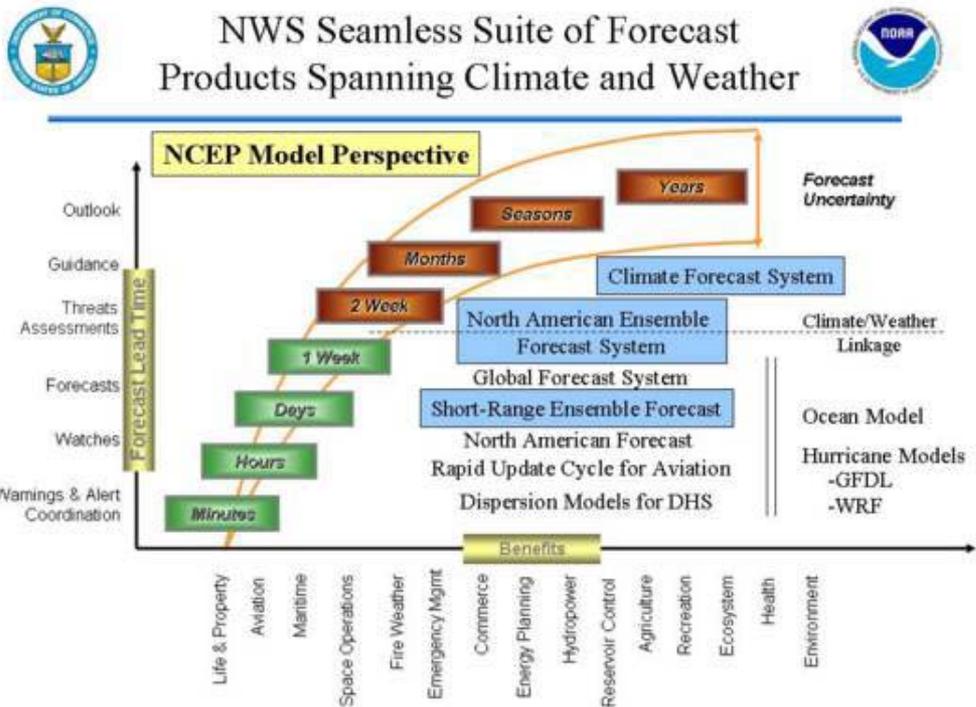
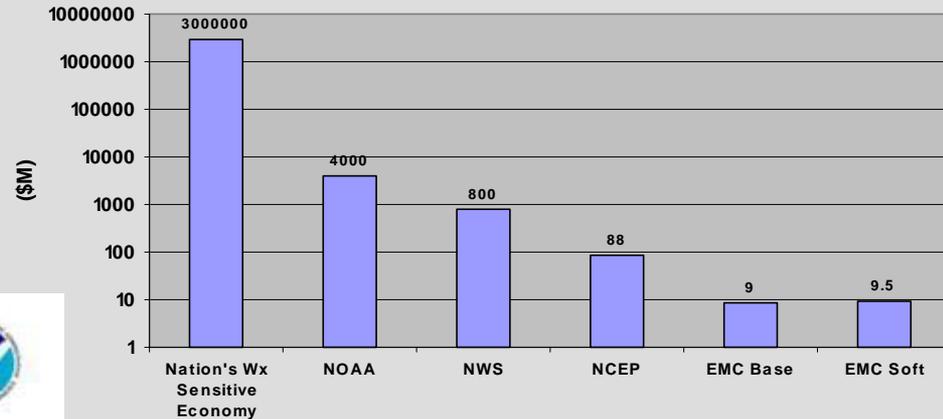
Ingredients for Improved Numerical Forecast Systems

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 - Research to Operations (R2O) process
 - Operations to Research (O2R) process

Need a balanced program among these items

What Are We Going To Do?

EMC Support for the U. S. Economy



Enhance NWS forecast services

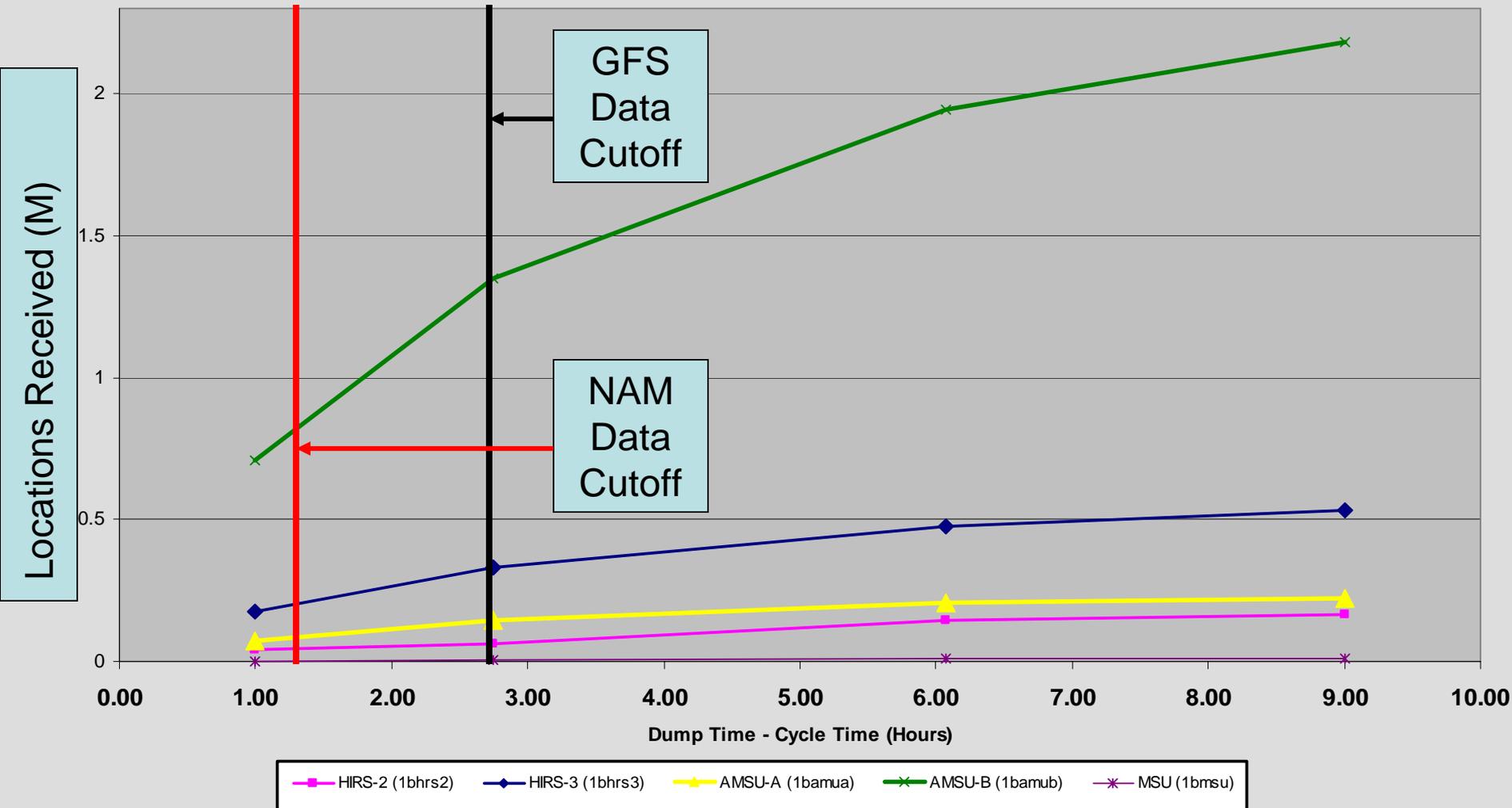
- Provide **greater focus on high-impact events**
- **Increase information content** in NWS guidance products
 - Probabilistic and ensemble methods
- **Accelerate accuracy** of numerical guidance
- Take on **additional environmental information service responsibilities**
- **Increase analysis and verification services** for NWS field offices
 - Efficient Grid Initialization
 - Analysis of Record (and RTMA)
 - Gridded Verification

Forcing and enabling factors

- **Computing**
 - ~1,000 processors → 10,000 processors
 - Emphasis on highly scalable processes
 - Ensembles scale linearly and “perfectly”
- **Common Modeling Infrastructure**
 - ESMF-based system
 - Provides maximum flexibility for dynamics and physics components
 - Common post-processor and product generator, configured as ESMF components
 - Concurrent coupling
 - Concurrent ensemble runs
- **Observations (number and availability)**
 - Advanced Polar and Geostationary sounders (~100 X greater)
 - NPOESS (<60 minutes globally) – 2015 (or later)
 - METOP (1-4) – 2007
 - NPP (90-120 minutes globally) – 2009
 - GOES-R – 2013 (or later)
 - Next-generation Doppler radar
- **Next-Generation Air Traffic-control System (NEXTGEN)**
 - Geographically consistent solutions
 - Global to terminal scales
 - At least hourly updating globally
- **“Completing the Forecast,” “Fair Weather” reports**

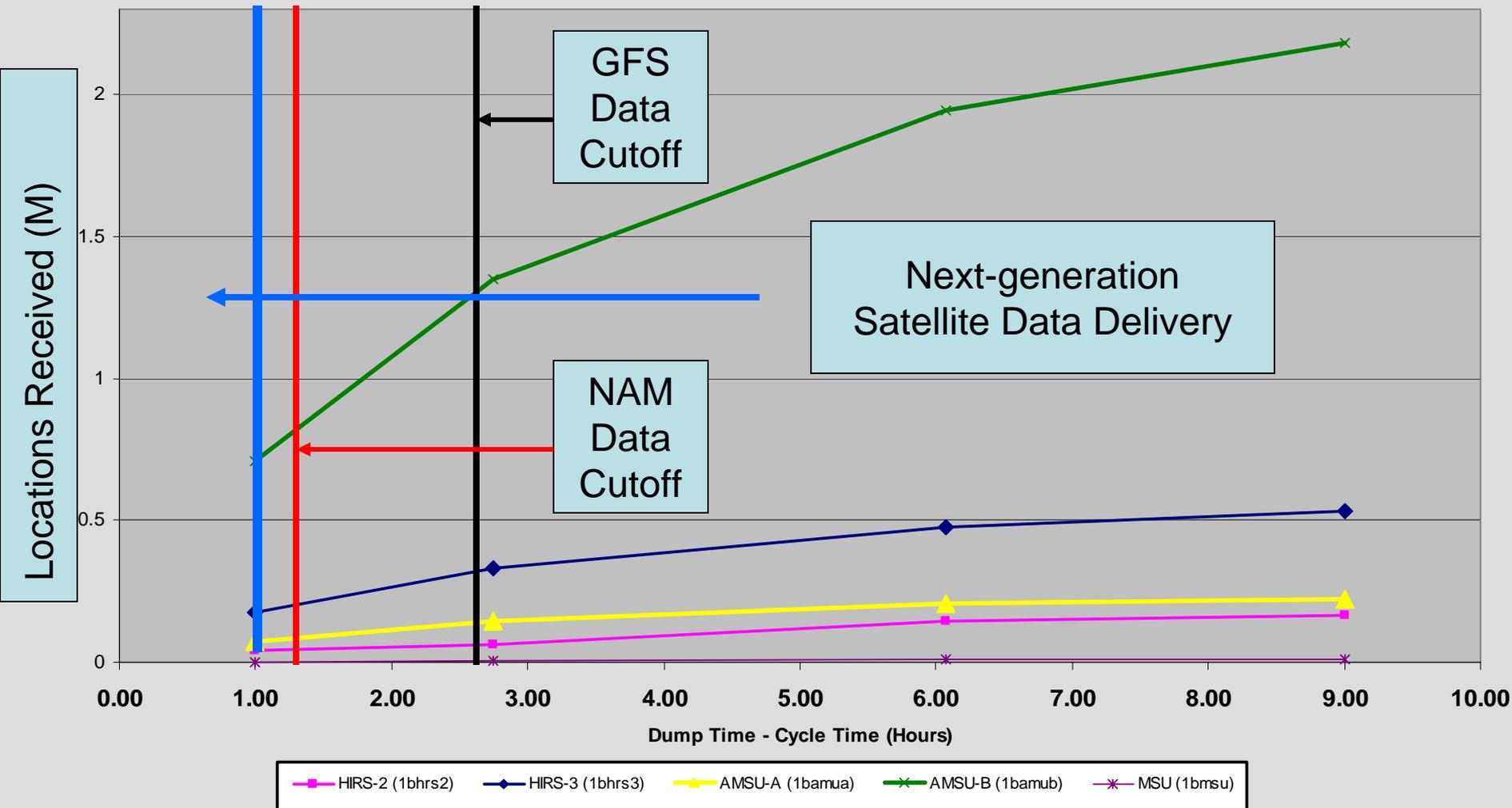
POES Data Delivery

00Z Average 1B Data Counts



POES Data Delivery

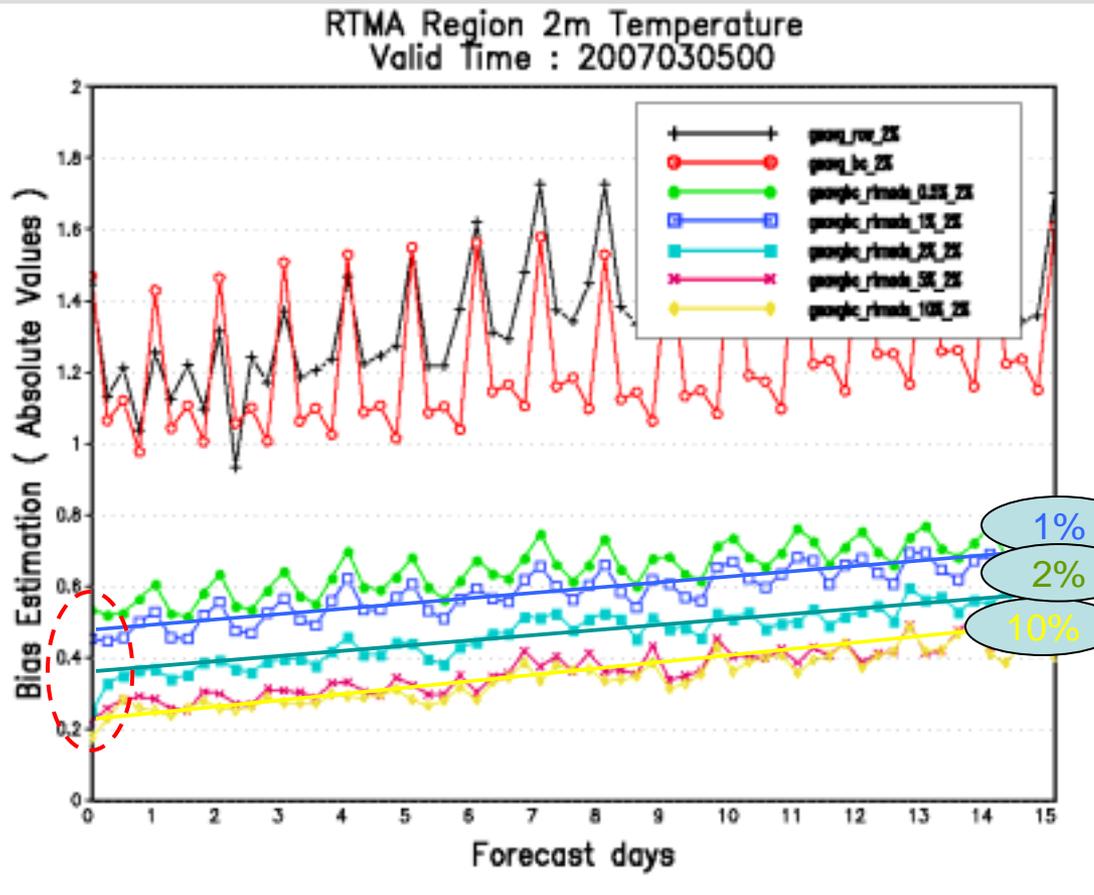
00Z Average 1B Data Counts



Forcing and enabling factors (cont)

- Advanced probabilistic (post-processing) techniques becoming available through NAEFS project
 - Bias correction
 - 2nd moment correction
 - Classical (frequentist) and **Bayesian** techniques
- Advanced dissemination strategies
 - E.g. NOMADS
- Maturing, ensemble-based, probabilistic systems offer the most potential benefit

2m Temperature: Accumulated Bias Before/After Downscaling



Black- control 1, operational ensemble mean

Red - control 2, NAEFS bias corrected ensemble mean

Blue- downscaled & bias corrected ensemble mean, 1%

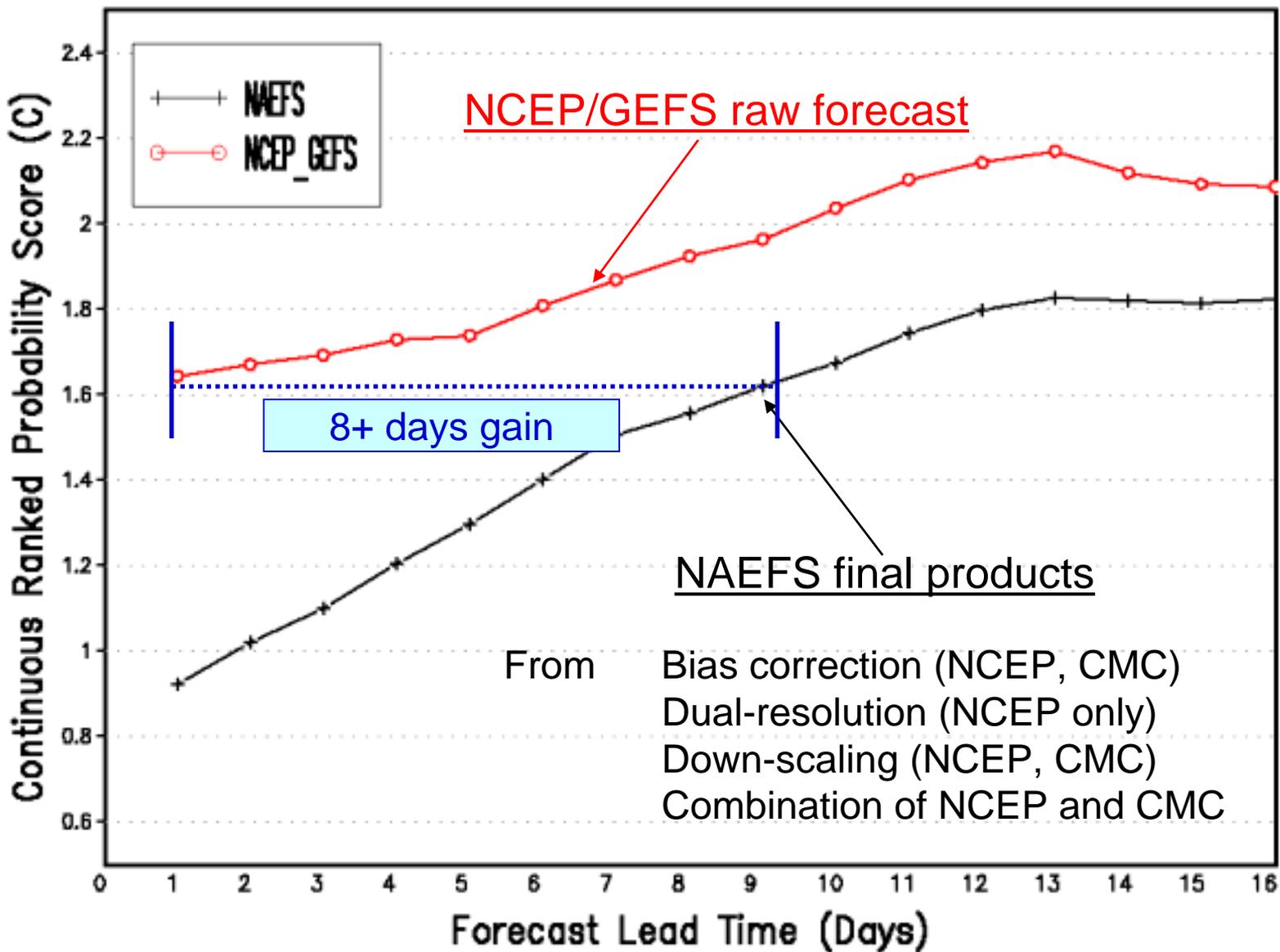
Green- downscaled & bias corrected ensemble mean, 2%

Yellow- downscaled & bias corrected ensemble mean, 10%

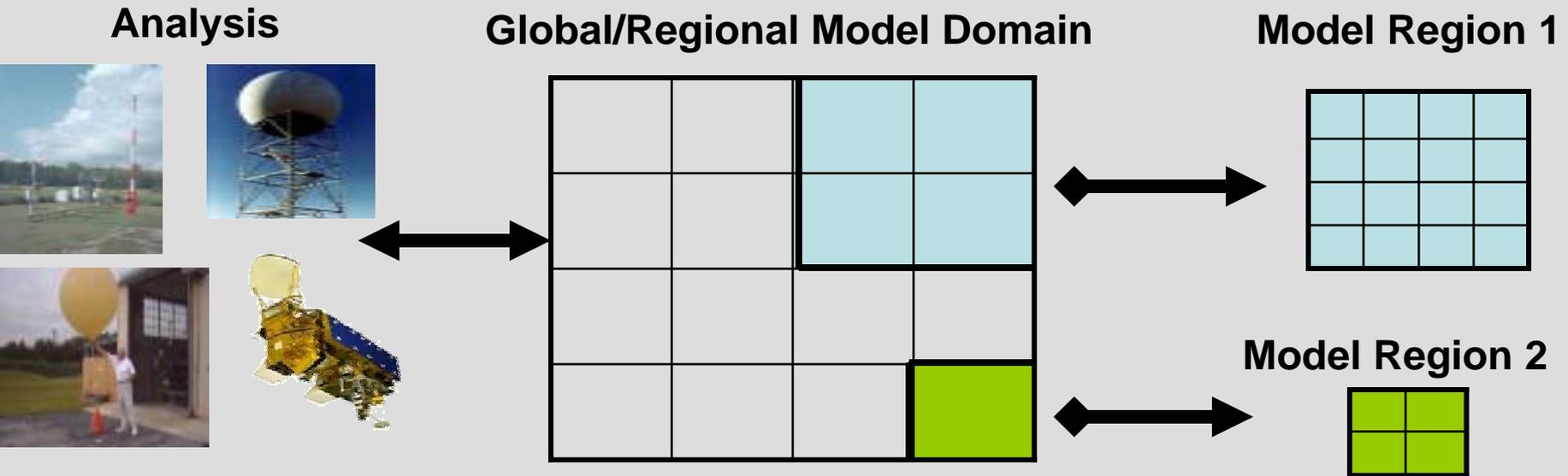
Domain average bias on fine grid

- bias range comparison
 - control 1: 1.1- 1.7
 - control 2: 1-1.6
 - 1%: 0.5-0.6
 - 2%: 0.3- 0.5
 - 10%: 0.2-0.4
- downscaling can effectively reduce systematic forecast errors on fine grid
- 10% weighting has the best performance, ~ 70% of systematic errors are reduced
- **00 hr bias comparison:** create fine res information based on coarse res fields. Possibility to predict high res analysis from low-res analysis

NAEFS NDGD Probabilistic 2m Temperature Forecast Verification For 2007090100 – 2007093000



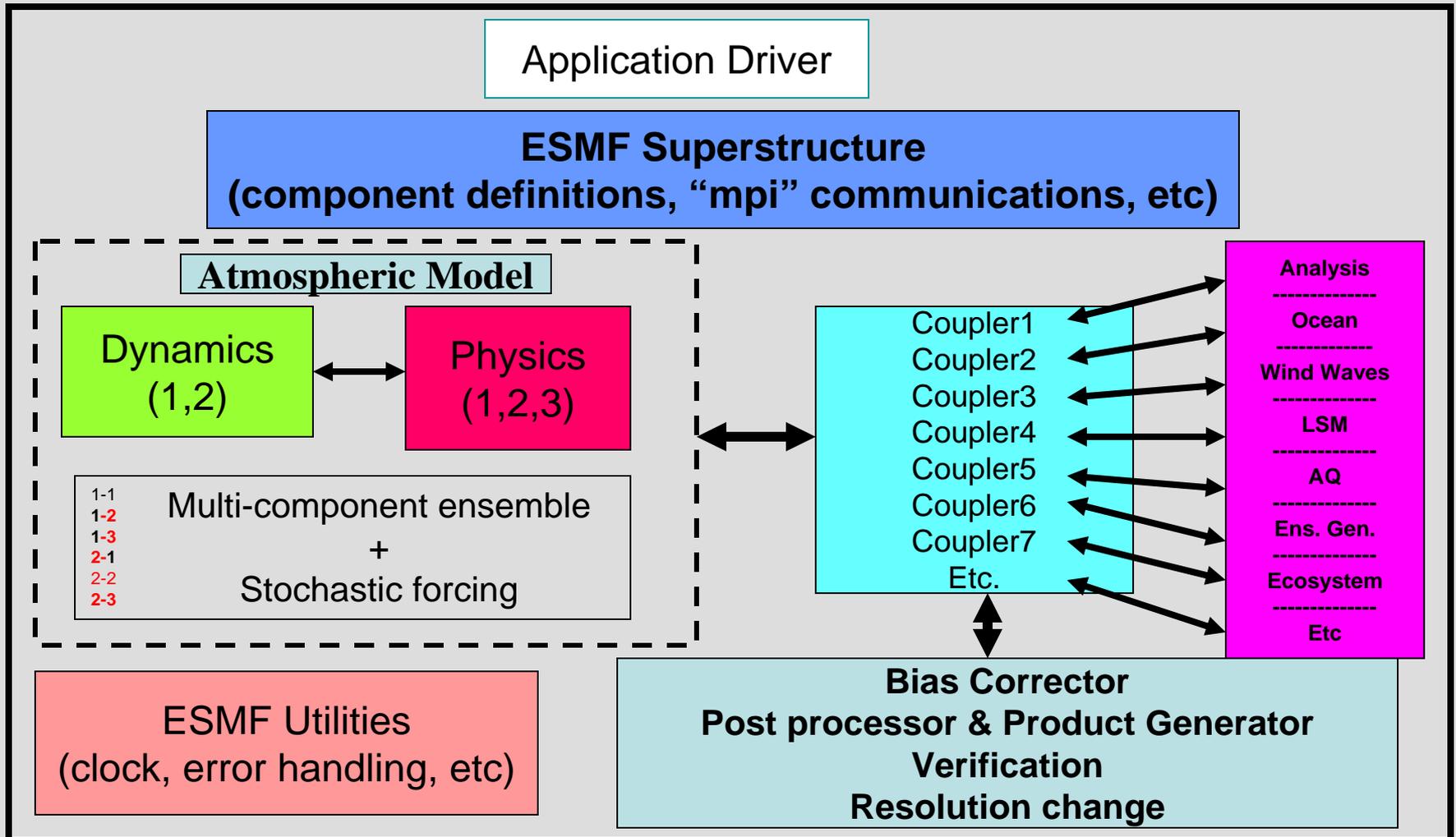
Concurrent execution of global and regional forecast models (Phase 1)



- **Common Modeling Infrastructure is ESMF-based**
- **In-core Solution**
 - Single executable for analysis, all model domains
 - No file writes to (or reads from) disk except for saving output
 - **Provides**
 - **Concurrent execution of ensembles**
 - Single executable, multiple members
 - “On-the-fly” breeding throughout the forecast from all members
 - **More efficient execution of rapid updating**
 - In-core updating for analysis increments
 - Regional (CONUS, Alaska, Hawaii, Caribbean, Guam & Puerto Rico)
 - Global (if requirements and resources)

National Environmental Modeling System (NEMS)

(uses standard ESMF compliant software)



* Earth System Modeling Framework (NCAR/CISL, NASA/GMAO, Navy (NRL), NCEP/EMC), NOAA/GFDL

2, 3 etc: NCEP supported thru NUOPC, NASA, AFWA or NOAA institutional commitments 16

Components are: Dynamics (spectral, FV, NMM, FIM, ARW, FISL, COAMPS...)/Physics (GFS, NRL, NCAR, GMAO, ESRL...)

Planned NEMS Capabilities

- Components and capabilities of the NEMS infrastructure
 - Configuration control
 - Domain
 - Resolution (horizontal, vertical)
 - Standardized fixed field generation (WPS - topography, land use, etc)
 - Tracer definition
 - Observations ingest, formatting, QC, etc libraries
 - Nesting (static and moving, telescoping, 1-way, 2-way)
 - Concurrent ensemble execution (single executable, multiple members)
 - Data assimilation (3D-var and advanced techniques)
 - In-core updating for analysis increments and boundary conditions
 - Model dynamics and physics including
 - Atmosphere
 - Ocean
 - Land surface and hydrology
 - Air Quality and trace gases
 - Post-processor and product generator
 - Standard operational verification
 - Documentation for operational and research users
- Operationally relevant codes, institutionally supported
 - Running in operations
 - Potential for transition to operations

Planned NEMS Capabilities (cont)

- Modeling Research
 - Global and regional
 - **Institutionally supported components**
 - Atmosphere (dynamics)
 - **GFS (NCEP)**
 - **NOGAPS (Navy)**
 - **FV (NASA, GFDL)**
 - **NMM (NCEP)**
 - **ARW (ESRL, NCAR, AFWA)**
 - **COAMPS (Navy)**
 - **FIM (ESRL)**
 - **FISL (NCEP)**
 - Ocean
 - **MOM4 (GFDL)**
 - **HYCOM (NCEP, Navy)**
 - **Wavewatch III**
 - Land Information System (LIS) for surface and hydrology
 - **Noah (NCEP)**
 - **VIC (Princeton, U. Wash)**
 - **Catchment (NASA)**
 - **Sacramento-HT (OHD)**
 - **Mosaic**
 - **SSiB**
 - **HySSiB**
 - **CLM**
 - Air Quality and trace gases
 - **CMAQ (EPA, ARL)**
 - **WRF-CHEM**
 - **GOCART (NASA)**
 - **NAAPS (Navy)**

Atmosphere (physics)

- **GFS**
- **NAM**
- **GMAO**
- **Navy??**

Under construction
May include in future

Planned NEMS Capabilities (cont)

- **Operational Models (NCEP only)**
 - Global Forecast System
 - GFS
 - Global Ensemble (GENS, NAEFS)
 - GFS
 - North American (NAM) & Fire Weather
 - NMM
 - Short-range Ensemble (SREF)
 - NMM
 - ARW
 - Physics diversity
 - High Resolution Window (HRW)
 - NMM
 - ARW
 - Air Quality (AQ)
 - CMAQ
 - Land Surface & Hydrology (LIS)
 - Noah
 - Rapid Refresh (RR) Ensemble
 - ARW Dynamics + GSD physics
 - NMM dynamics + NCEP physics
 - Hurricane (HUR)
 - NMM for hurricanes
 - HYCOM + Wavewatch
 - Seasonal Climate Forecast (CFS)
 - GFS for climate
 - MOM4

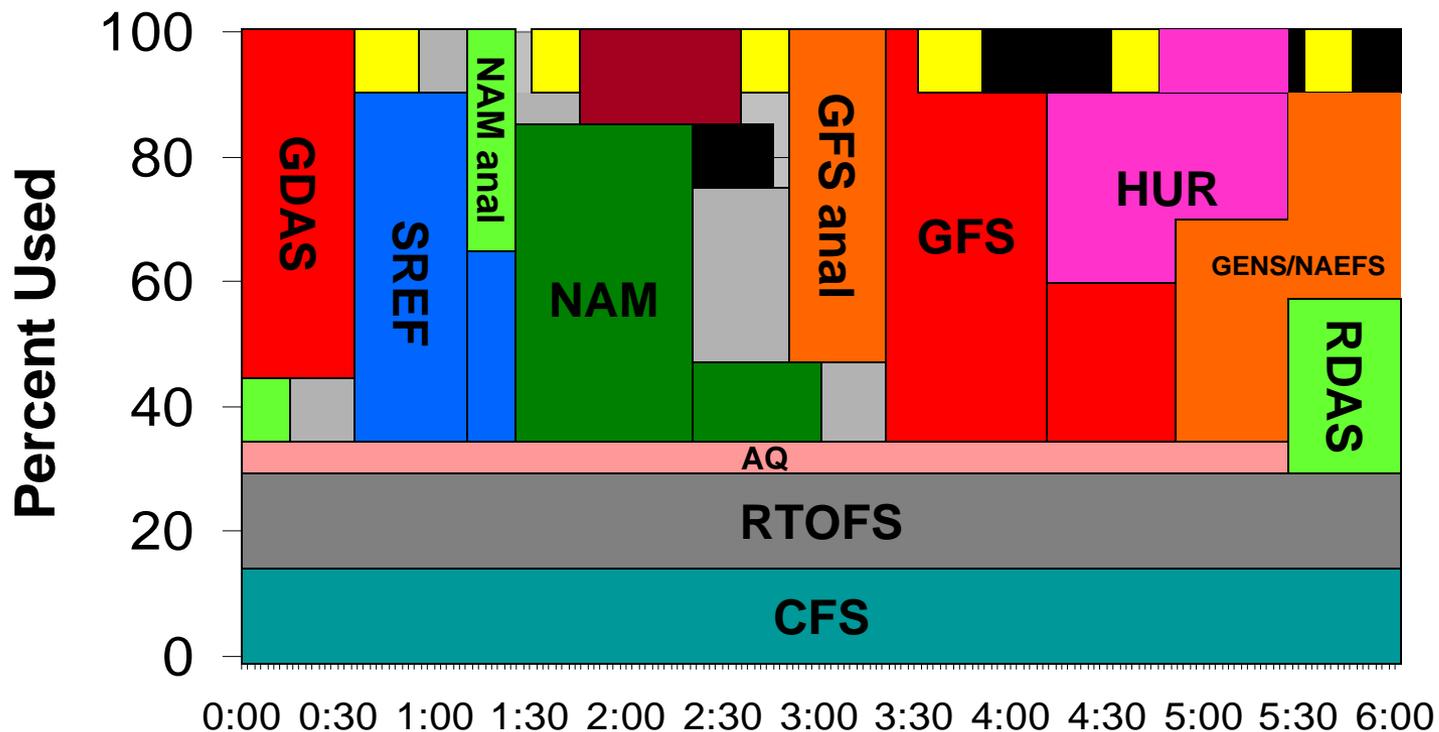
Will include in
Operational NEMS

Criteria for Inclusion in NEMS

- Research
 - Adherence to ESMF standards
 - Institutional support for code
 - Participation in system evolution
- Operations
 - Research criteria plus:
 - Standard “Transition to Operations” criteria
 - NCEP: <http://www.emc.ncep.noaa.gov/>
 - Forecast performance benefits
 - IT compatibility
 - Efficiency
 - Sustainability
 - AMOP (Navy)
 - AFWA IPT process (USAF)

NCEP Production Suite Weather, Ocean, Land & Climate Forecast Systems

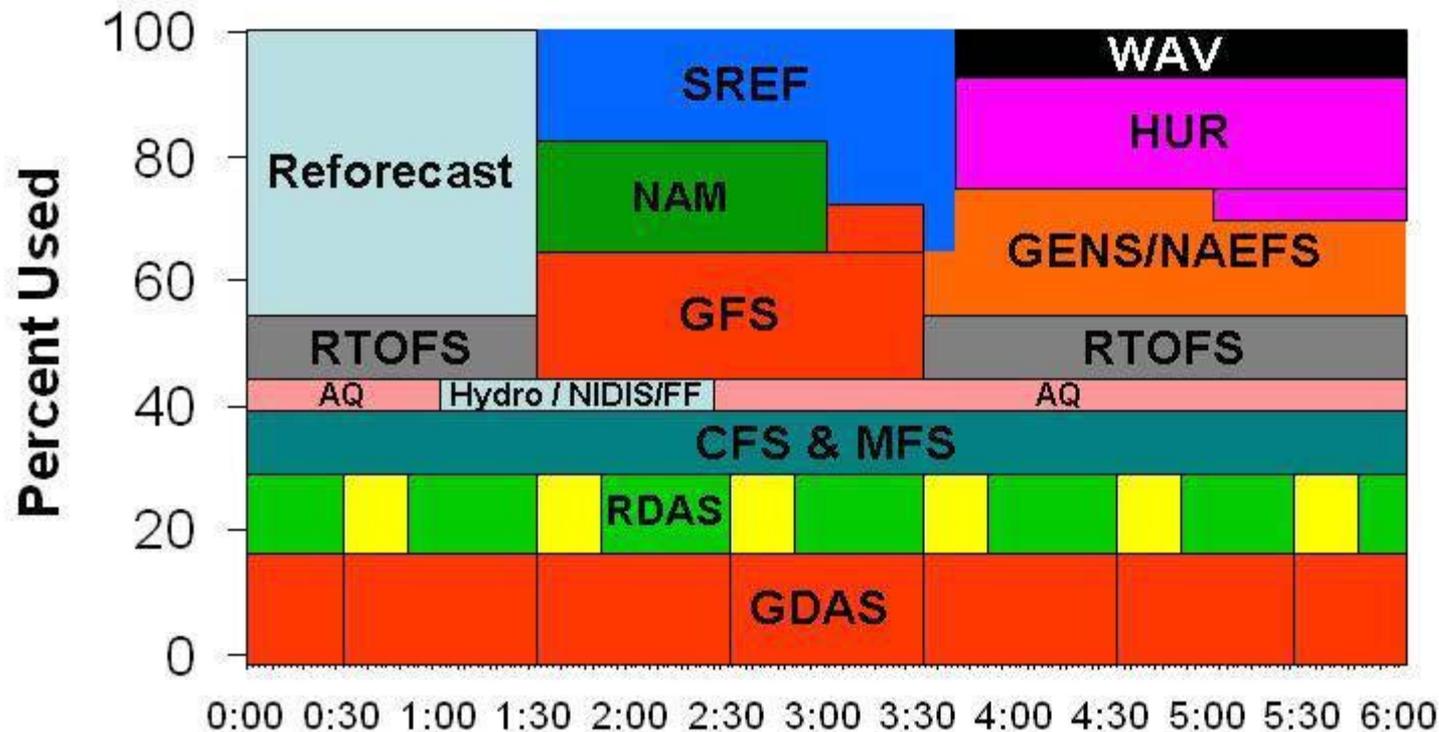
Current



6 Hour Cycle: Four Times/Day

NCEP Production Suite Weather, Ocean, Land & Climate Forecast Systems

Next Generation Prototype



6 Hour Cycle: Four Times/Day

The Gridpoint Statistical Interpolation (GSI) System

- Capabilities
 - Currently 3d-var
 - Simplified 4d-var (First Order Time-extrapolation To Observations – FOTO) in final testing
 - Future 4d-var for global and regional applications
- Operational for
 - Global Forecast System (GFS)
 - North American Model (NAM)
 - Real-Time Mesoscale Analysis (RTMA)
- Major focus of NCEP/EMC and NASA/GSFC/GMAO collaborative atmospheric analysis development

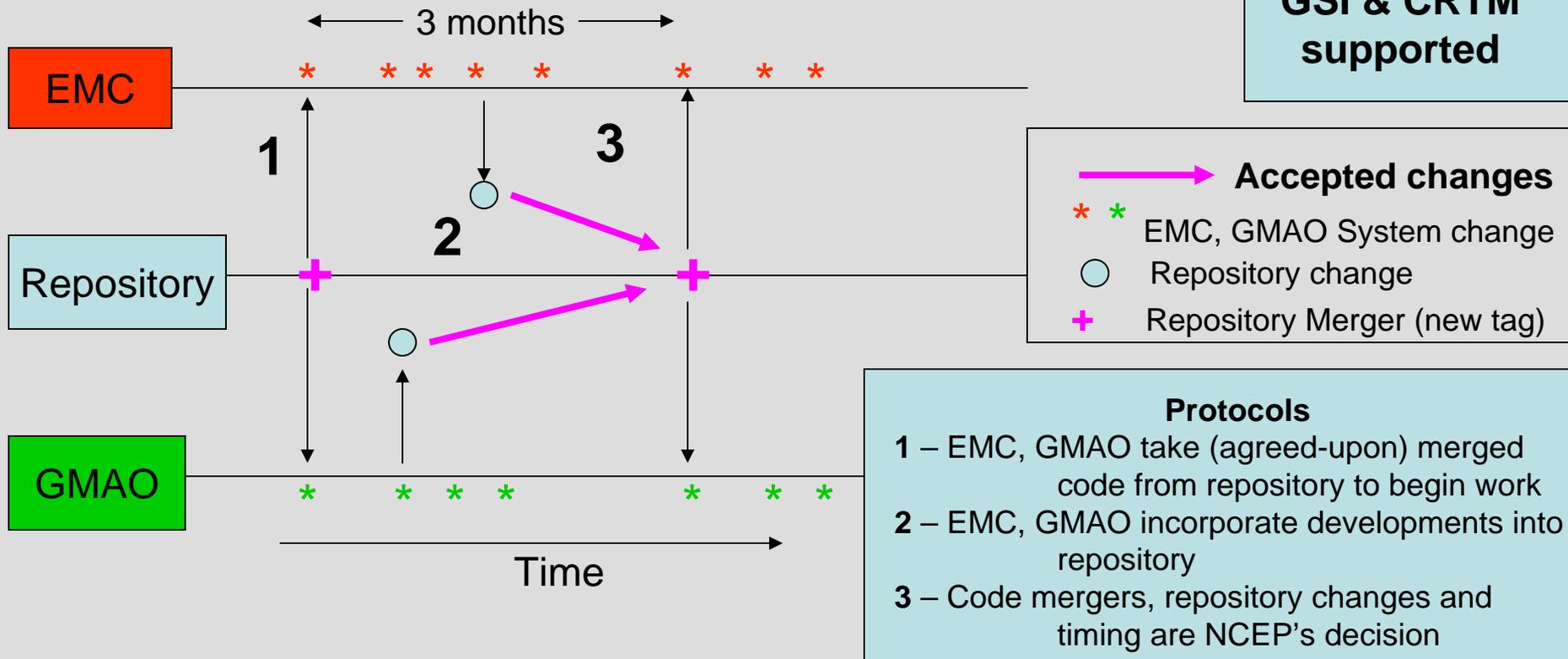
Collaborative Software Development

- GSI intended for both operations and research applications
 - Community-based code with multi-agency users
- Code Management
 - Minimize redundant development
 - Establish code development standards and procedures
 - Principal Code Manager (EMC)
 - Associate Code Manager (partners)
 - Criteria for accepting code updates
 - Code managed by subversion repository
 - Establish areas of responsibility and milestones among partners
 - Technical oversight group, representatives from
 - EMC
 - GMAO
 - GSD (Boulder)
 - AFWA
- Example: EMC-GMAO collaboration
 - Same code for operations (EMC) and research (GMAO)
 - Bi-weekly progress reports at group meetings
 - GMAO: 4d-var infrastructure
 - EMC+JCSDA: adding capabilities for new satellite data
 - Quarterly code mergers

EMC-GMAO-STAR Code Management for Atmospheric Data Assimilation

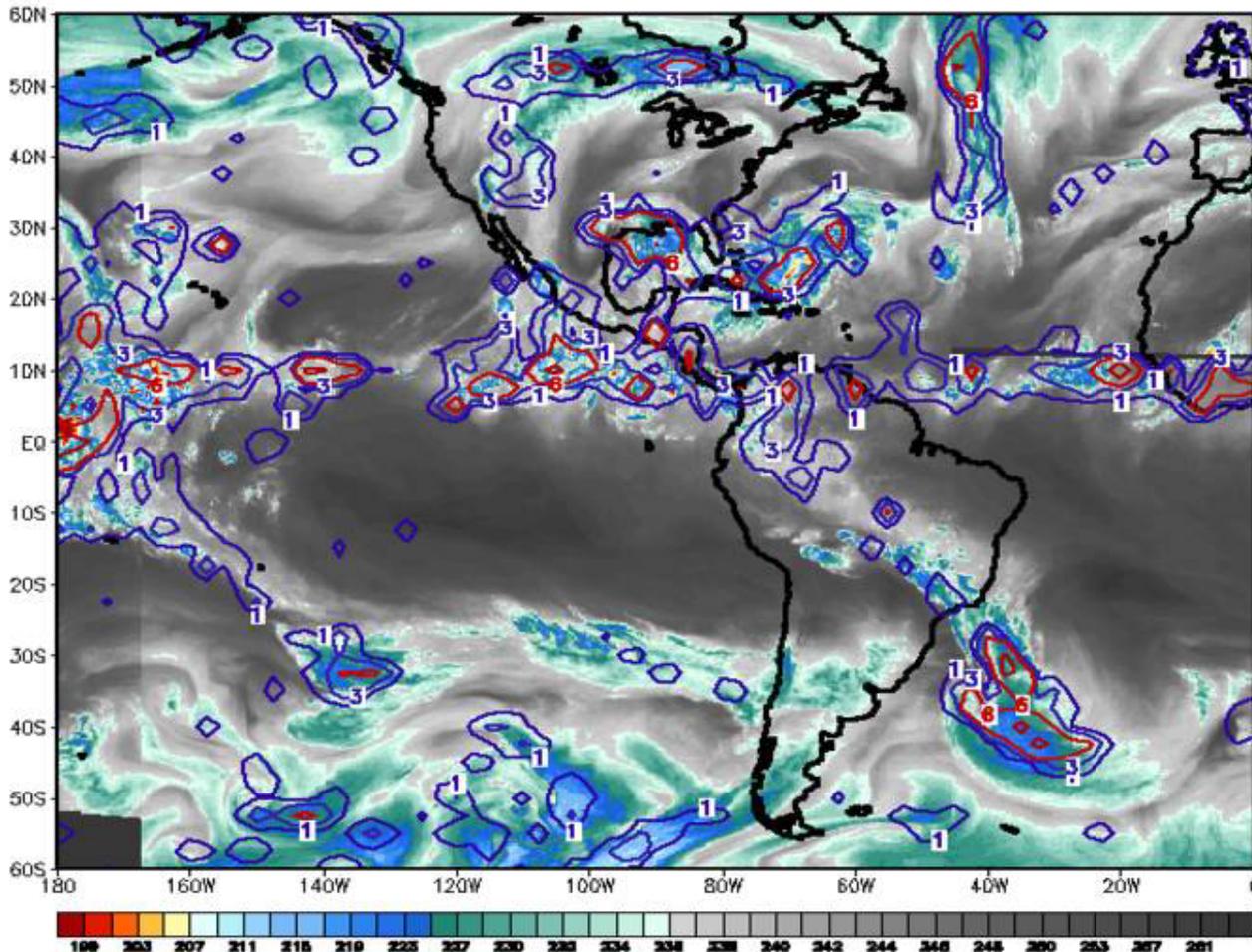
Process: similar to ECMWF & Météo-France who have annual code mergers
But, to promote collaboration, EMC and GMAO use same repository and mergers are more frequent (3 months)

GSI & CRTM supported



NCEP Global Forecast System (GFS) 6 hr Forecast and WV Imagery

6.8 micron IR (water vapor)/gfs ges 6hr-accum total precipitation (mm)
18Z 07 SEP 2002



GFS Clouds

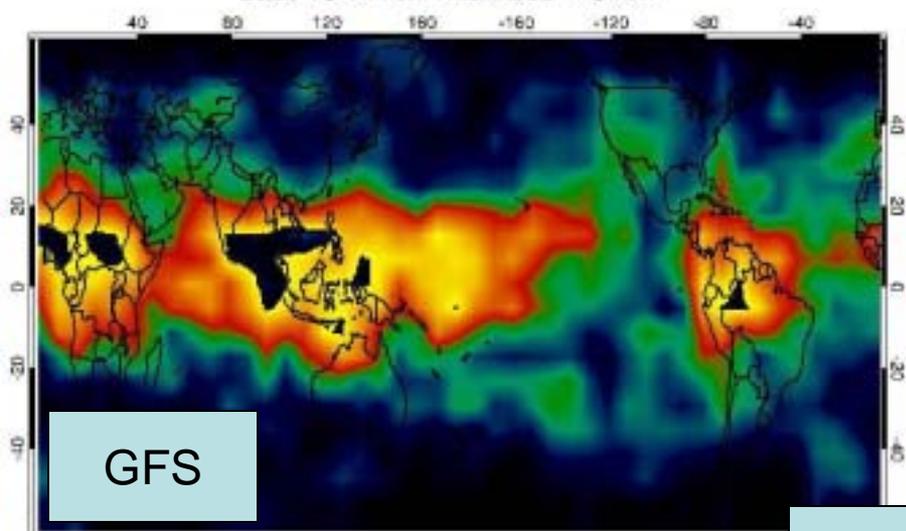
- **Evaluation by Zhanqing Li and students (UMD)**

- The spatial patterns and latitudinal variation of cloud from all three sources (MODIS, Li, GFS) bear great resemblance
- Large discrepancies exist among all three products
- In general, the GFS modeled clouds are more similar to the MODIS retrieved clouds than to CC clouds
- The GFS model tends to generate less high clouds, more middle clouds and less low clouds than C-C clouds
- The GFS produces far less cirrus cloud in the tropics
- The GFS clouds are generally too thin by about 50%
- Many regional features are yet to be explored, e.g. too much clouds over deserts, too little over cold oceans

Further contributions from NESDIS

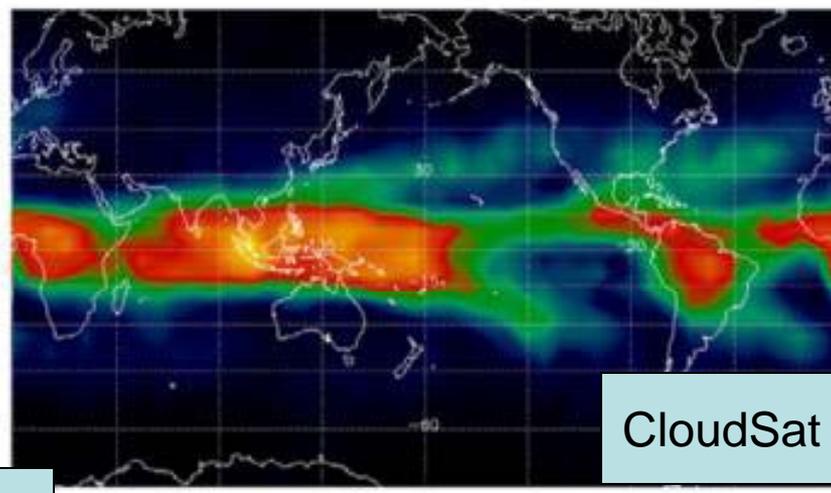
- PATMOS-CLAVR (Heidinger)
- GOES (Lazlo)

Base 10-14 Km Thickness > 0 Km



High Clouds

CloudSat/Colpo-Absolute Coverage of Layers Based 10-14km and All Thickness
Absolute Hydrometeor Coverage of Layers Based 10-14km and All Thickness, Avg Box: 6.008.0, For Period 200612-200704



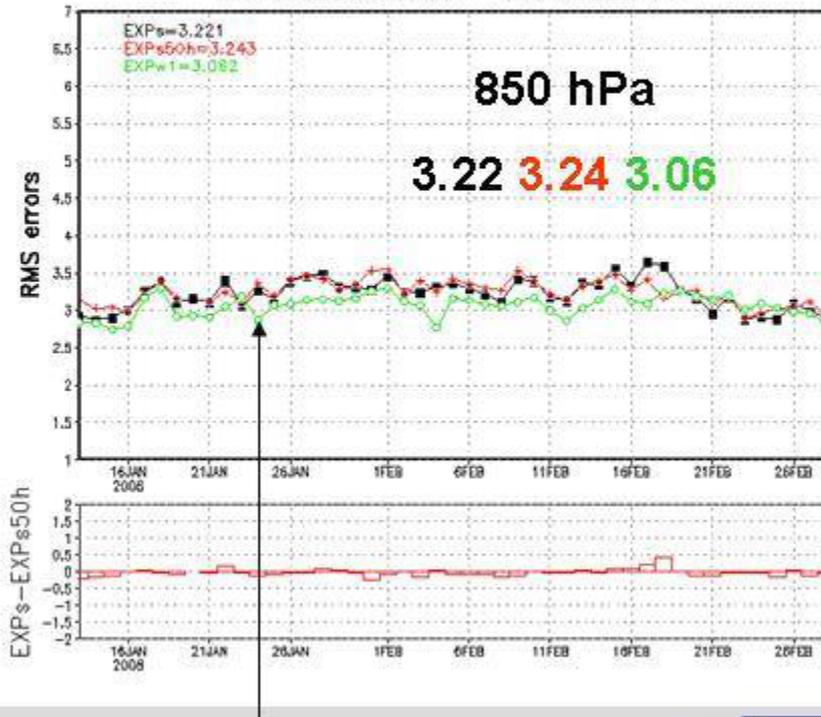
Coverage

0.10 0.20 0.30 0.40 0.50

GFS (uncoupled) Vs. CFS (coupled)

VECTOR WIND
DAY-3 RMS
WINTER

TROPICAL 850 mb Vector at day 3
for 00Z13JAN2008 – 00Z28FEB2008



TROPICAL 200 mb Vector at day 3
for 00Z13JAN2008 – 00Z28FEB2008

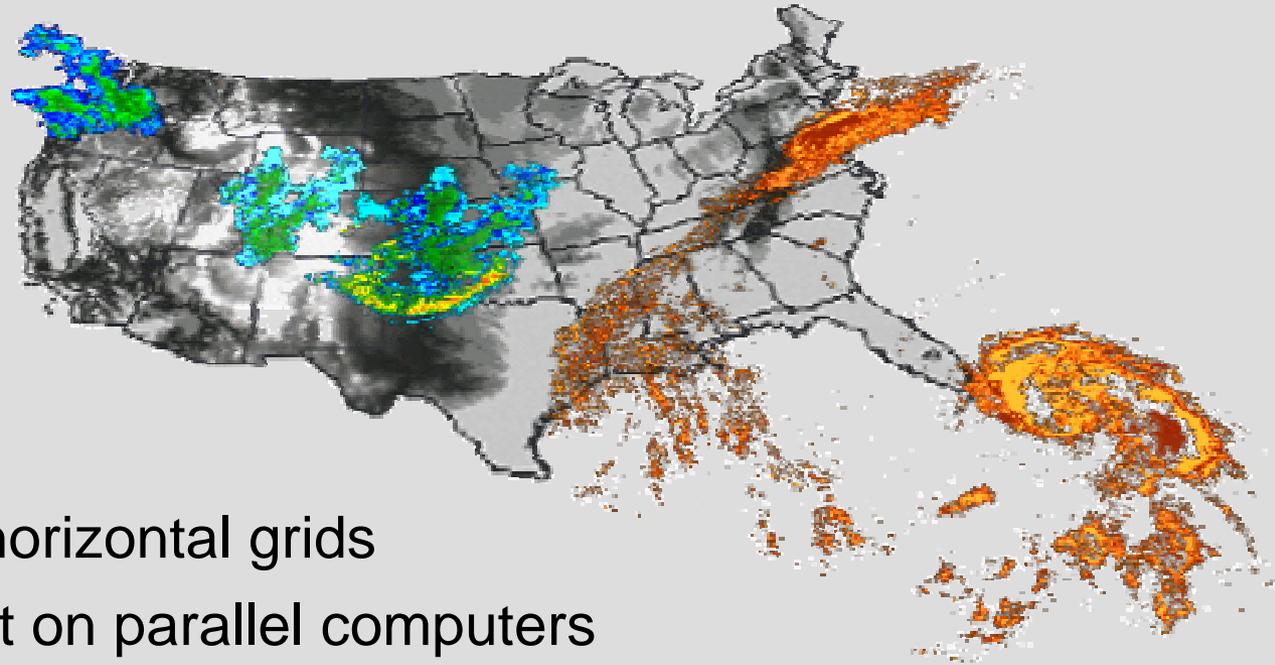


Consistent small improvement

OPR GFS CFS

Weather Research and Forecast (WRF) Modeling System

- ➔ Develop an advanced mesoscale forecast and assimilation system
- ➔ Promote closer ties between research and operations



Concept:

Design for 1-10 km horizontal grids

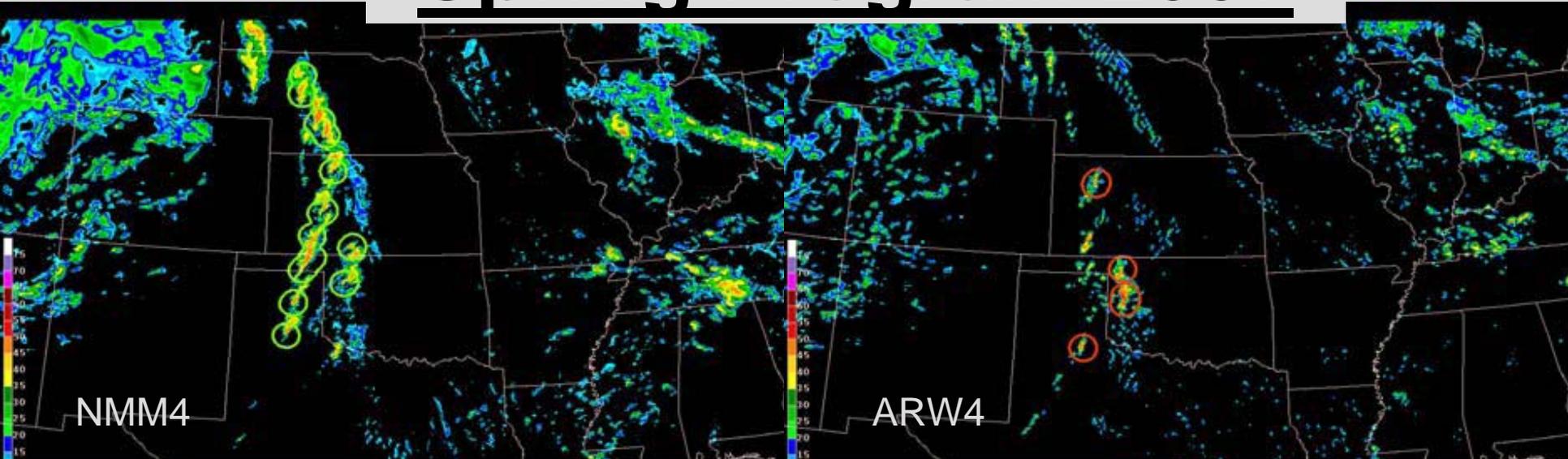
Portable and efficient on parallel computers

Well suited for a broad range of applications

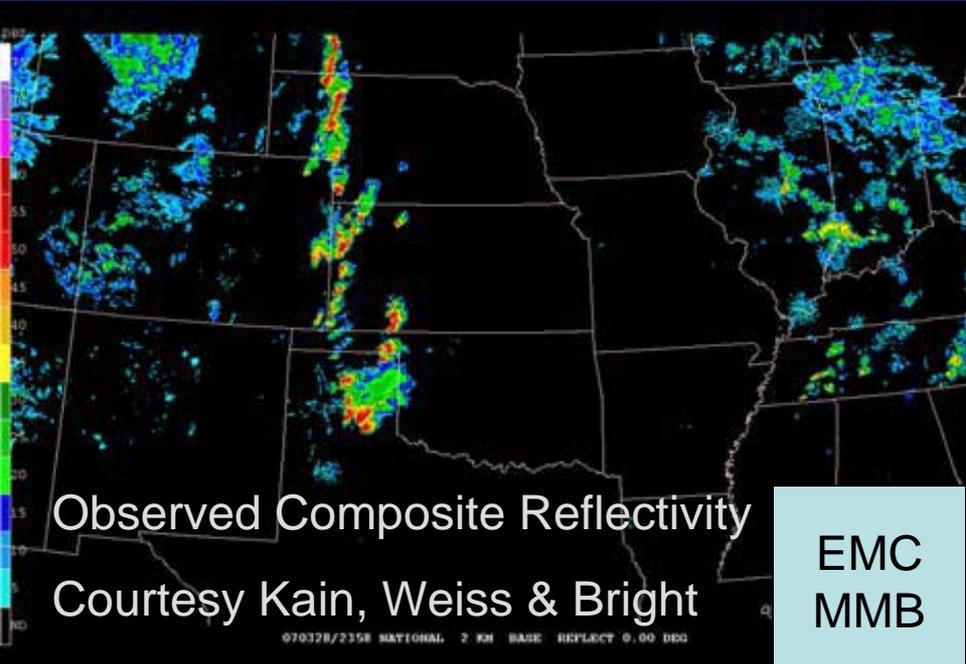
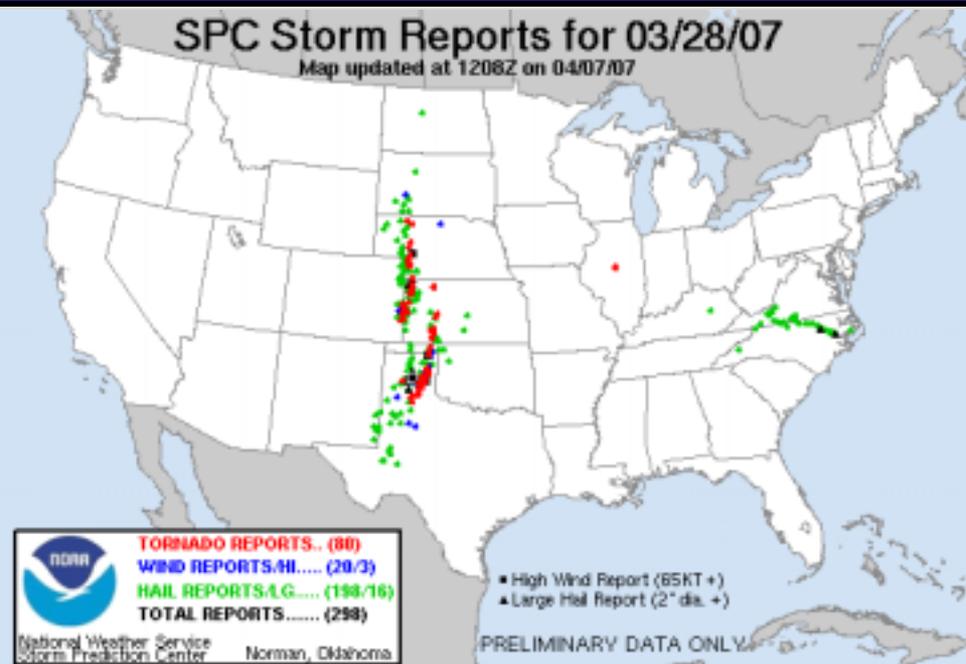
Community model with direct path to operations

Collaborators: NCEP/EMC, NCAR, AFWA, Navy, NOAA/ESRL, U. Okla.

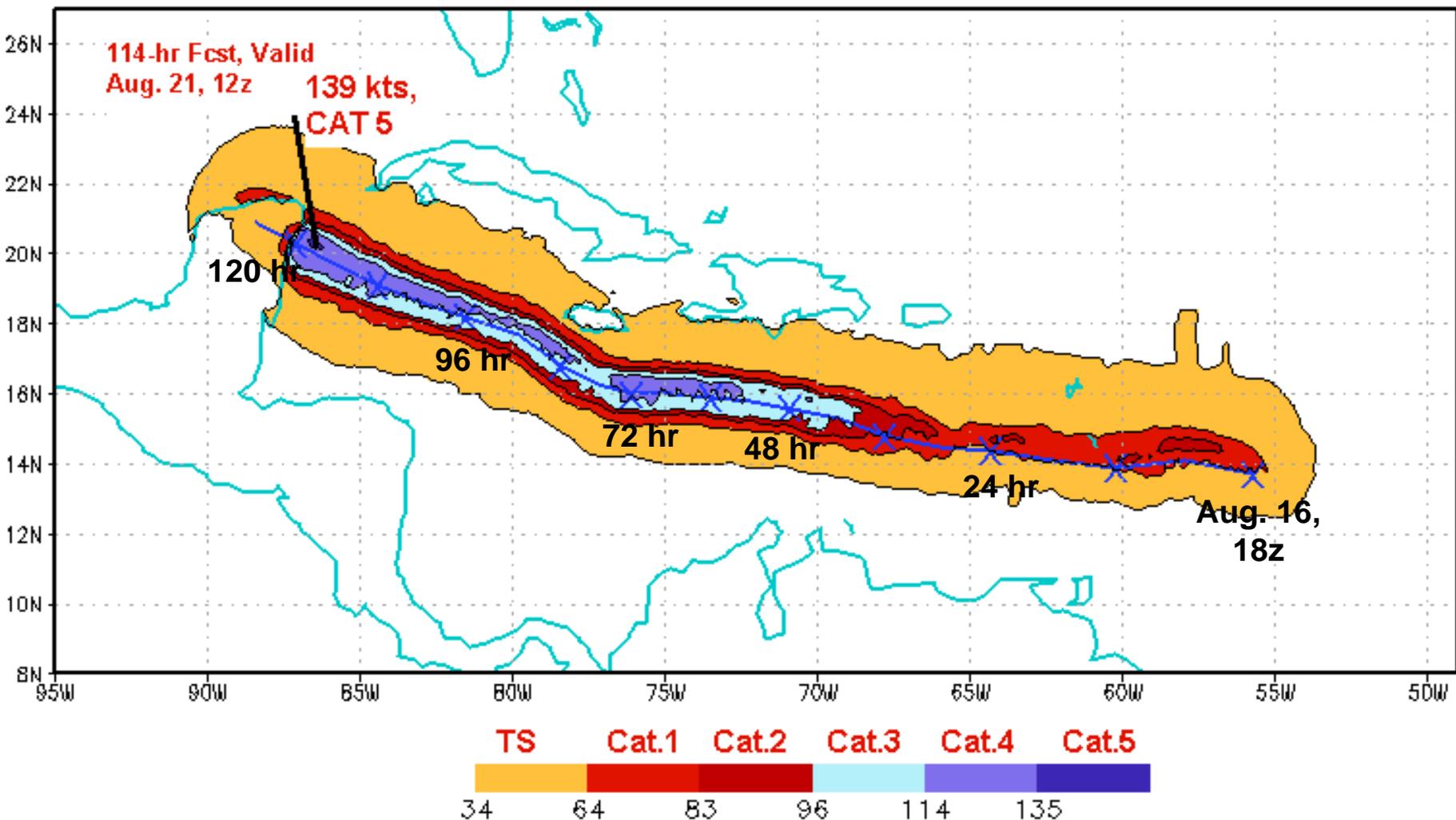
Spring Program 2007



Circles denote locations of rotating updrafts where updraft helicity is at least $50 \text{ m}^2\text{s}^{-2}$



HWRF 10M MAX WIND (KTS) SWATH DEAN04L



N. Surgi, Q. Liu, V. Tallapragada

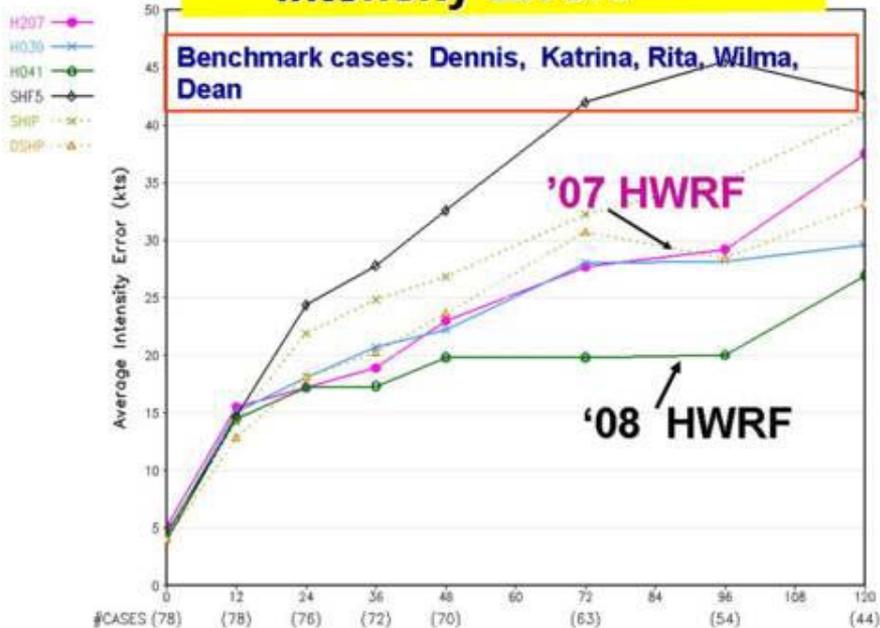
MAX WIND (KTS) 139.495

NGEP Hurricane Forecast Project

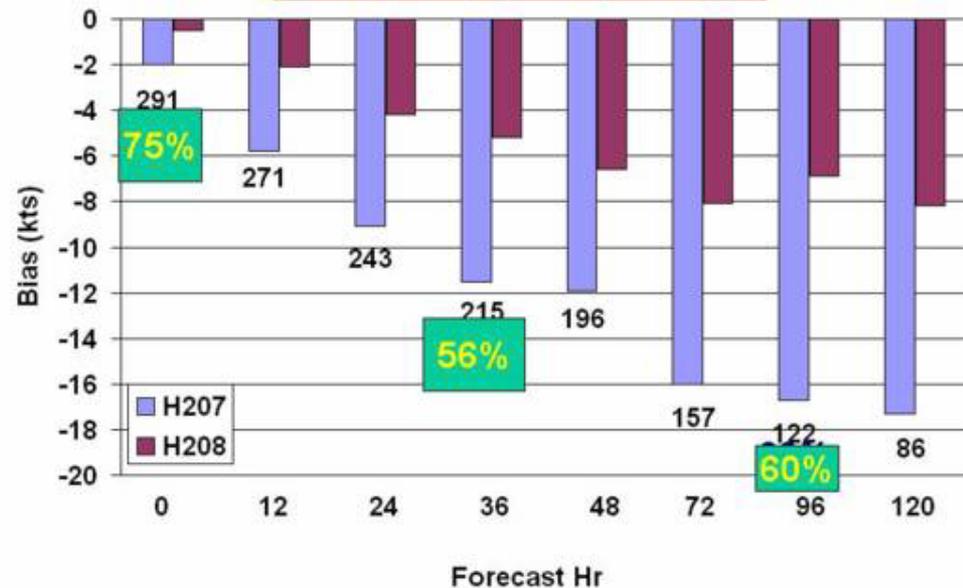
2008 HWF Implementation

- Better use of NHC's information on storm strength and vertical extent in initializing the hurricane core circulation
- 26% improvement in the 3, 4 and 5 day forecasts

Intensity Errors



Average Intensity Bias Atlantic Hurricanes, 2005-2007



Land Information System (LIS)

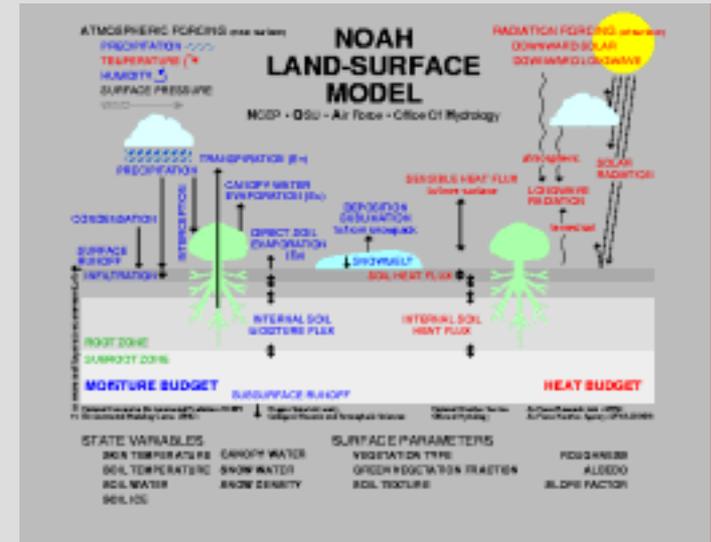
- NOAA-NASA-USAF collaboration

- K. Mitchell (NOAA)
- C. Peters-Lidard (NASA)
- J. Eylander (USAF)

- **LIS** hosts

- Land surface models
 - Land surface data assimilation
- and provides

- Regional or global land surface conditions for use in
 - Coupled NWP models
 - Stand-alone land surface applications



LIS Capabilities

- **Flexible choice of 7 different land models**
 - Includes Noah LSM used operationally by NCEP and AFWA
- **Flexible domain and grid choice**
 - Global: such as NCEP global model Gaussian grid
 - Regional: including very high resolution (~.1-1 km)
- **Data Assimilation**
 - Based on Kalman Filter approaches
- **High performance parallel computing**
 - Scales efficiently across multiple CPUs
- **Interoperable and portable**
 - Executes on several computational platforms
 - NCEP and AFWA computers included
- **Being coupled to NWP & CRTM radiative transfer models**
 - Coupling to WRF model has been demonstrated
 - Coupling to NCEP global GFS model is under development
 - Coupling to JCSDA CRTM radiative transfer model is nearing completion
- **Next-gen AFWA AGRMET model will utilize LIS with Noah**
- **NCEP's Global Land Data Assimilation utilizes LIS**



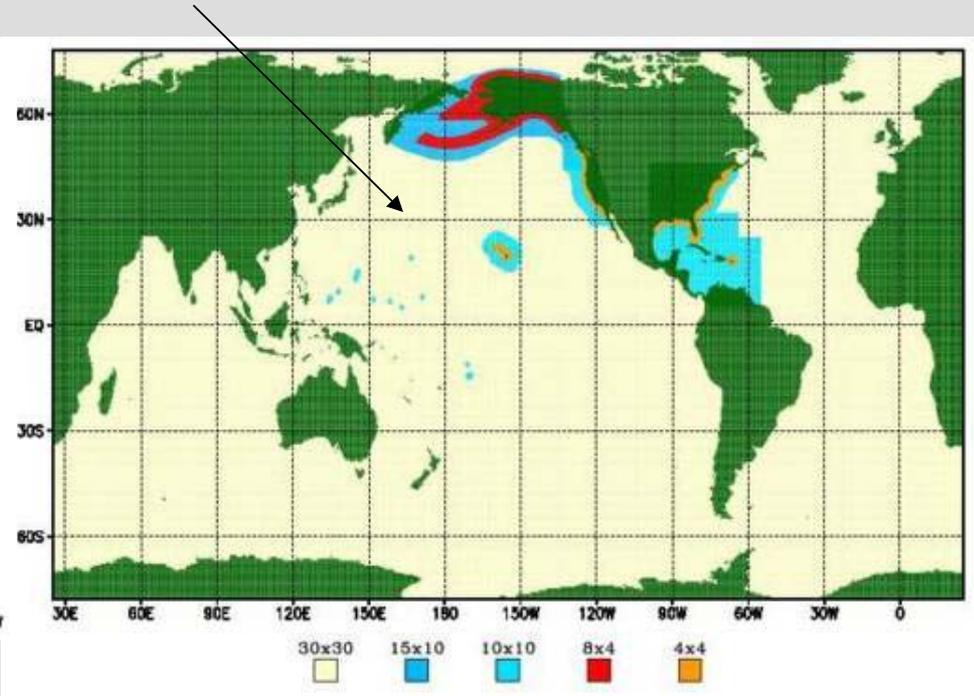
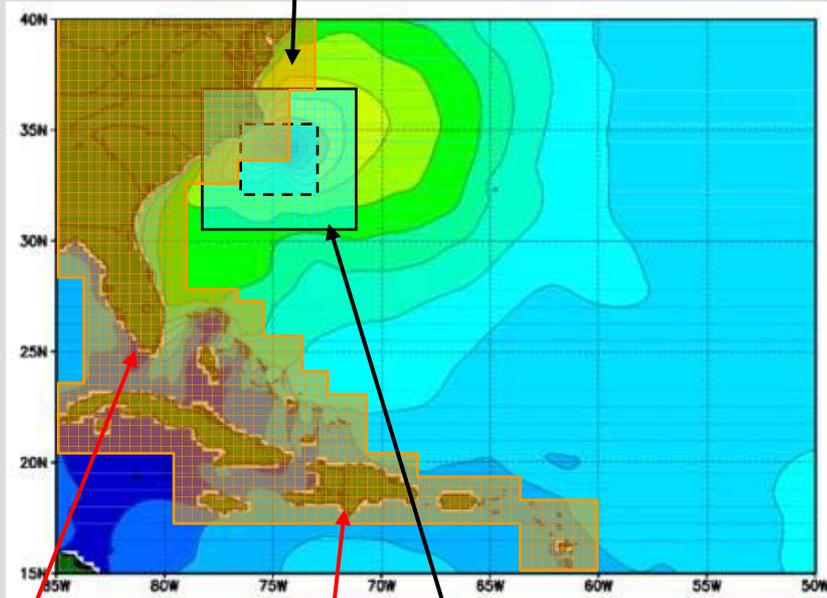
Real Time Ocean Forecasting

- **Wave Modeling**
 - Global and Regional
 - Unified model approach
 - NOAA Wavewatch III
- **Basin-scale Ocean Model**
- **Sea Surface Temperature & Winds**
 - NCEP Ocean Prediction Center support
 - Gulfstream analysis & forecast
- **Real-time Sea Ice products**
 - Alaska Region support (fishing)

Multi-Grid Wave Modeling

Higher coastal model resolution

Deep ocean model resolution dictated by GFS model



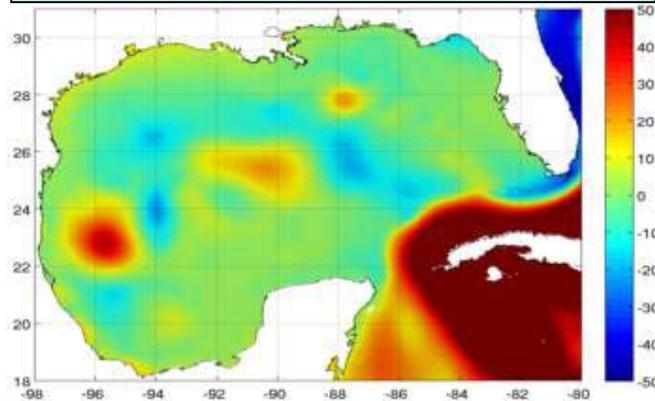
Highest model resolution in areas of special interest

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

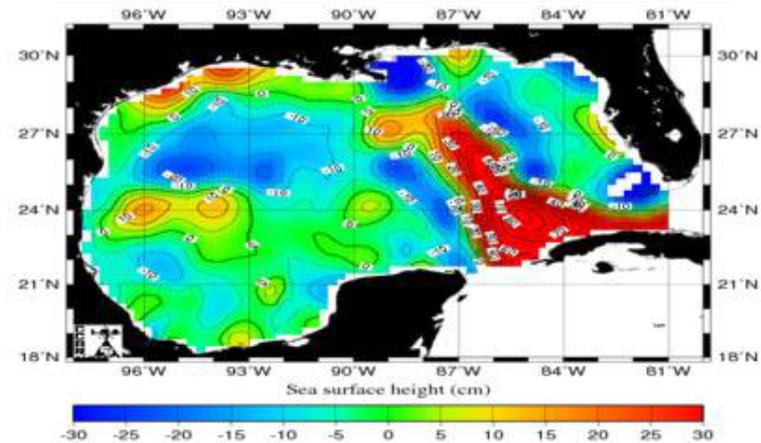
Multi-grid wave model tentative resolutions in minutes for the parallel implementation in FY2007-Q4.

Real-Time Ocean Modeling Example

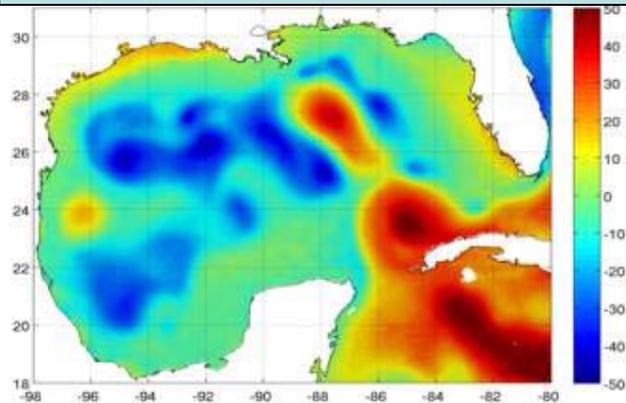
Model without SSH assim.



Altimeter only analysis

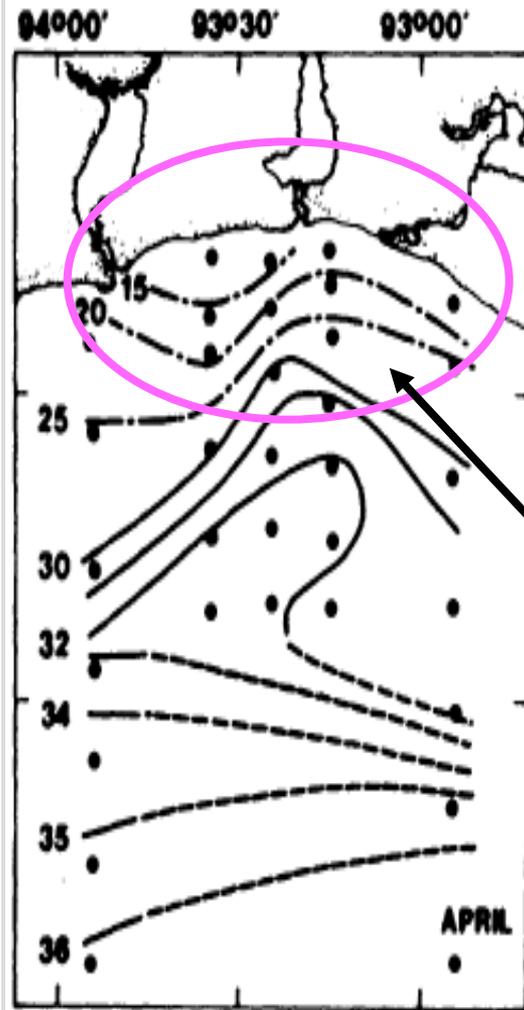
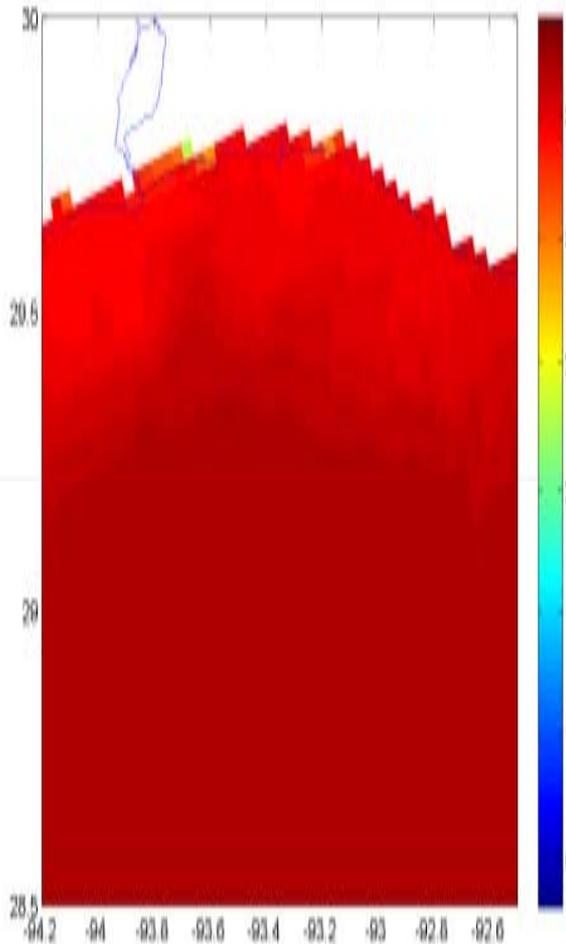


Model with SSH assim.

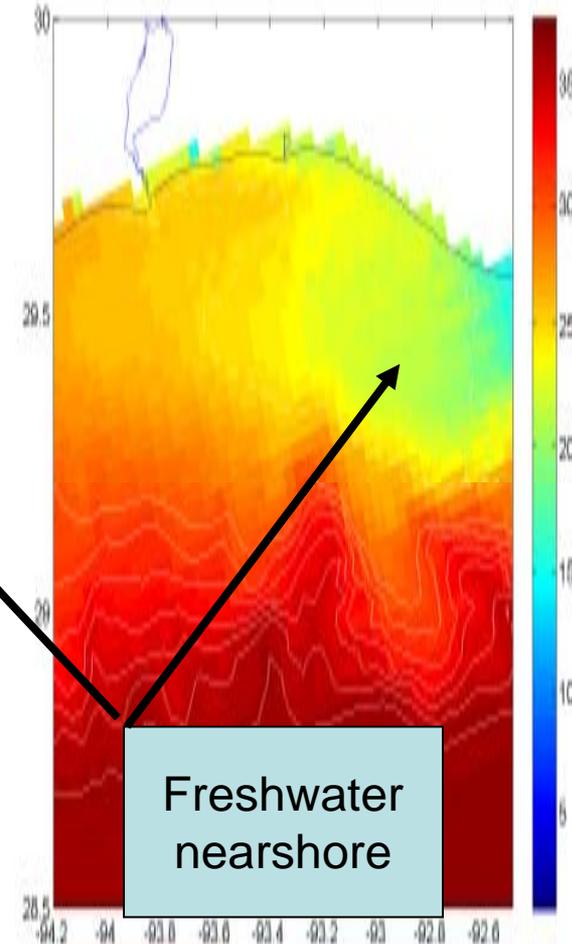


Analysis shows loop current being cut-off. **Model without altimeter data does not show Loop Current and has no practical forecast value.** Model with altimeter SSH assimilation shows cut-off Loop current and forecast skill.

S1: Nowcast for 20070405



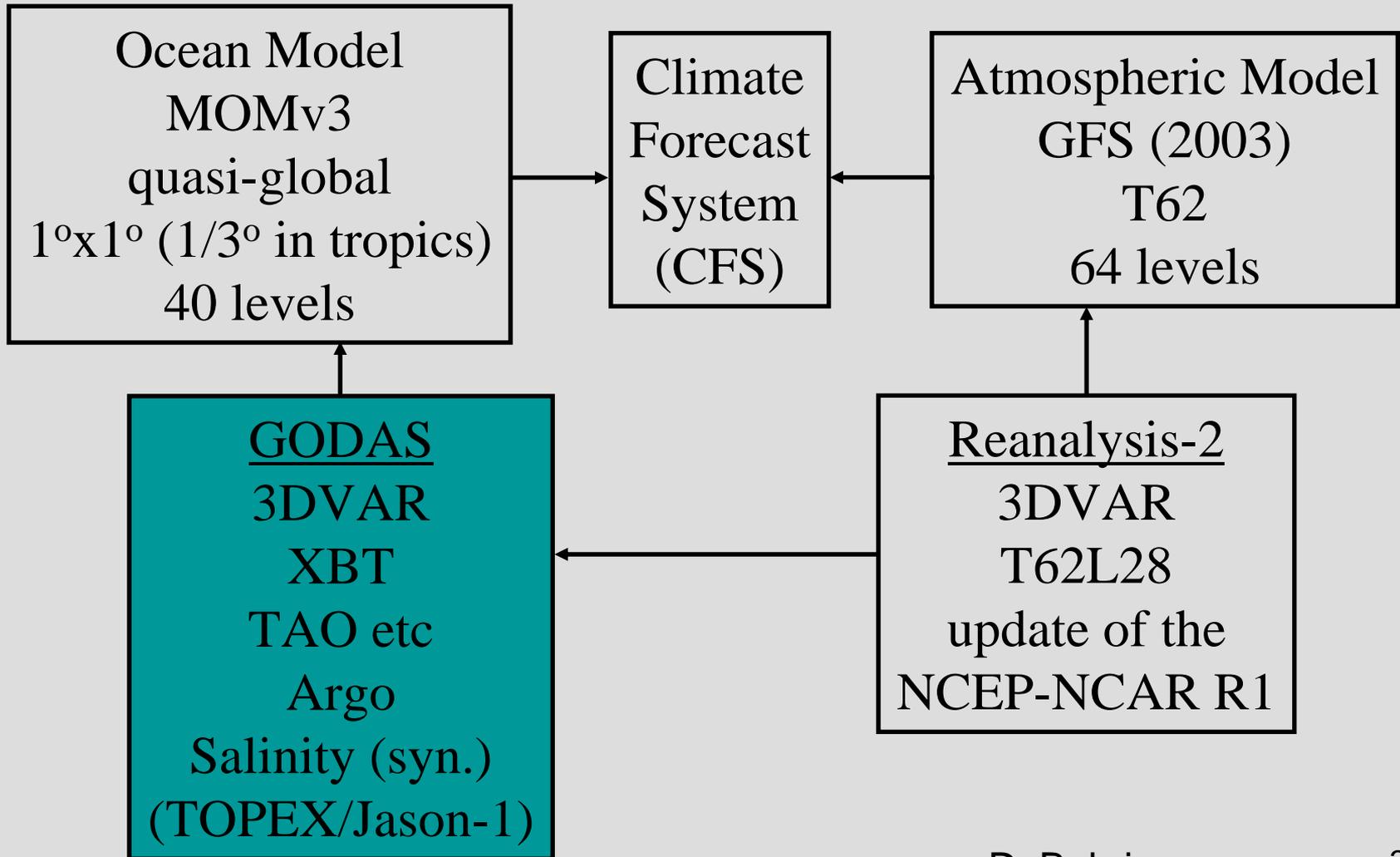
S2 Test: Nowcast for 20070405



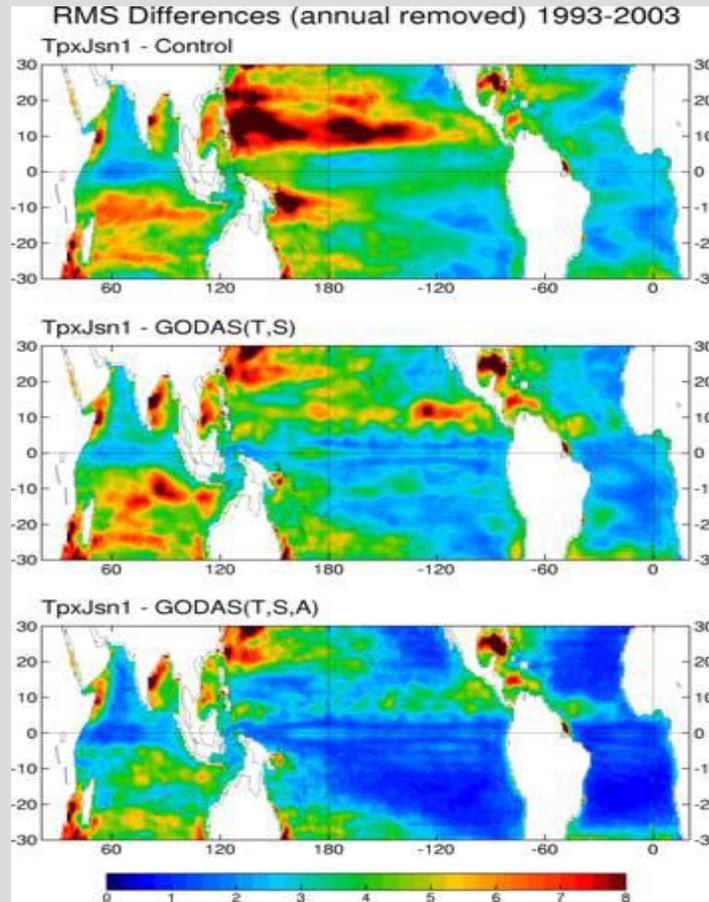
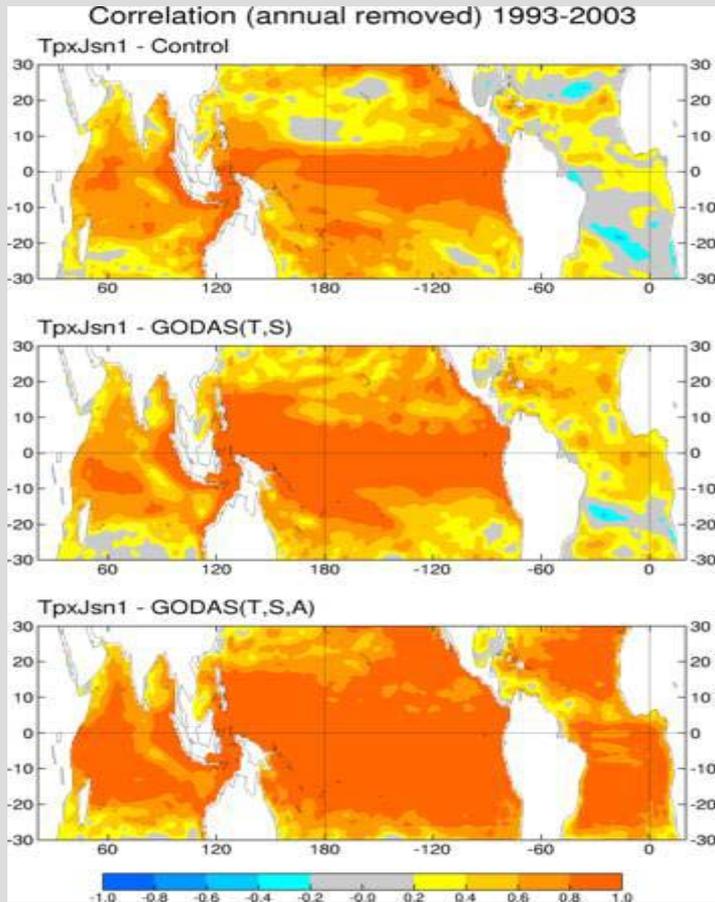
Freshwater
nearshore

Quality, Class 1: Surface Salinity map for S1 (left panel) and S2 Test (right panel) compared to surface salinity map near mouth of Mississippi based on conductivity sensors and current meters data (middle panel) collected from moorings near the LATEX coast in 1982 (Estuaries, Wiseman & Kelly, 1994). The offshore salinity front is non-existent in S1. In S2 test, it is weaker than the one observed and is located closer to the coast.

Seasonal to Interannual Prediction at NCEP



Adding TOPEX/Jason-1 satellite altimetry to NCEP GODAS



No assimilated data

In situ data
Assimilated
(operational)

Operational
Plus altimeter

Larger correlations between GODAS and Altimeter data in Indian and Atlantic Oceans

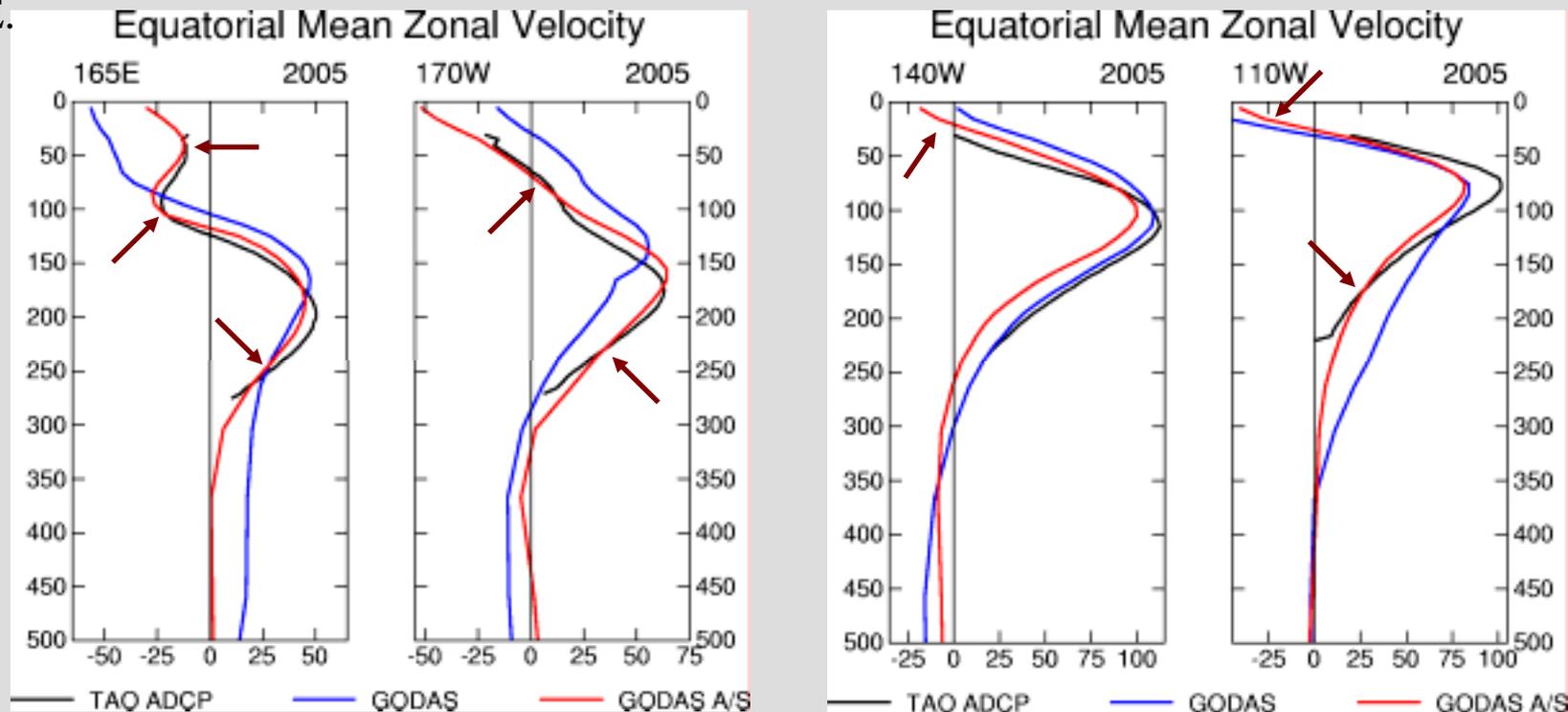
Smaller RMS errors

In the west, assimilating Argo salinity corrects the bias at the surface and the depth of the undercurrent core and captures the complex structure at 165°E.

Assimilating Argo Salinity

Comparison with independent ADCP currents.

In the east, assimilating Argo salinity reduces the bias at the surface and sharpens the profile below the thermocline at 110°W.



ADCP

GODAS

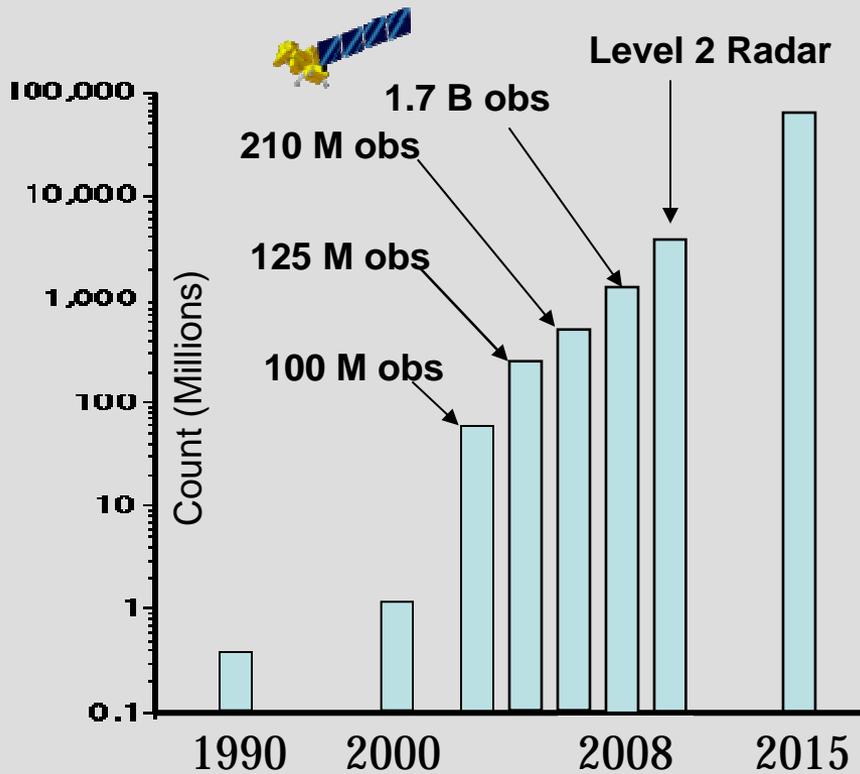
GODAS-A/S

NASA-NOAA-DOD Joint Center for Satellite Data Assimilation (JCSDA)

- NOAA, NASA, DOD partnership
- Mission
 - **Accelerate and improve** the quantitative use of **research and operational** satellite data in **weather and climate** prediction models
 - Current generation data
 - Prepare for next-generation (NPOESS, METOP, research) instruments
- Supports applied research
 - Partners
 - University, Government and Commercial Labs

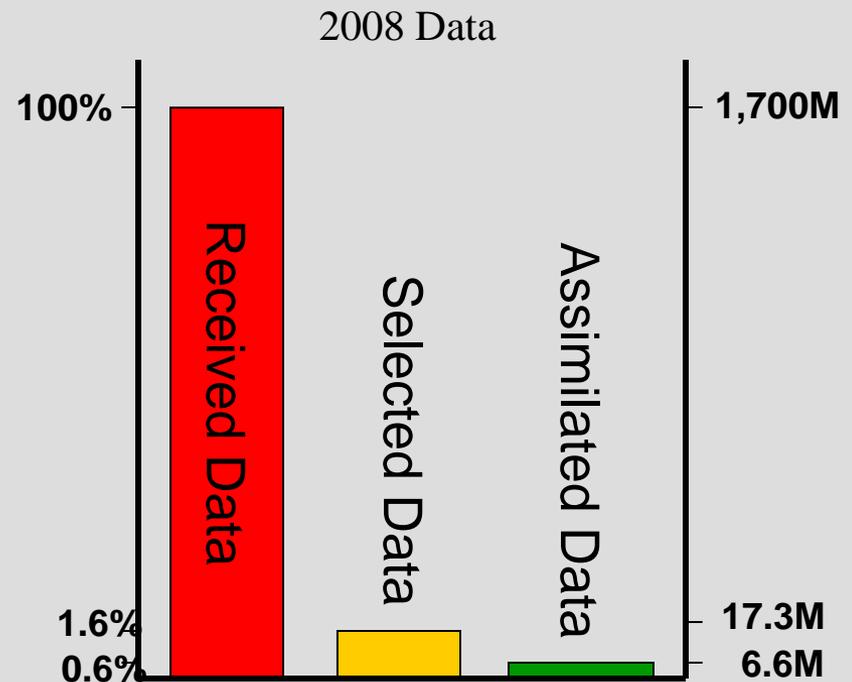
Satellite Data Ingest

Daily Satellite & Radar Observation Count



Five Order of Magnitude Increases in Satellite Data Over Fifteen Years (2000-2015)

Daily Percentage of Data Ingested into Models

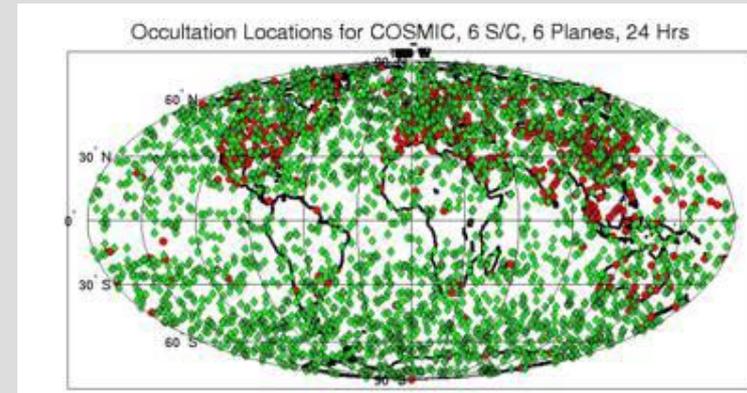
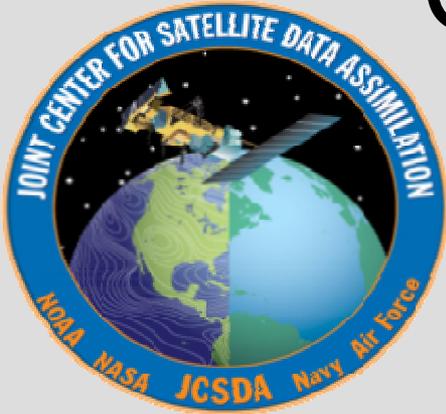


Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models

JCSDA Science Priorities

- Radiative Transfer Modeling (CRTM)
- Preparation for advanced (new) instruments
- Clouds and precipitation
- Assimilation of land surface observations
- Assimilation of ocean observations
- Atmospheric composition; chemistry and aerosol

GPSRO Assimilation

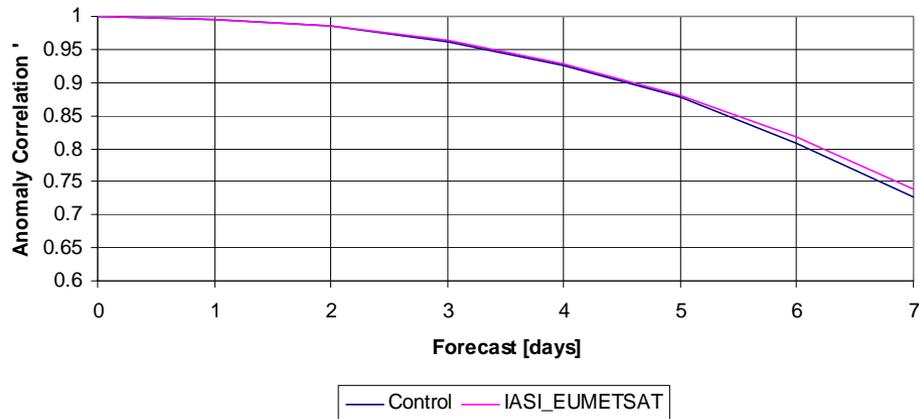


- Collaboration between **JCSDA, NCAR, EMC** (L. Cucurull, J. Derber, J. Purser, B. Kuo)
 - JCSDA provided
 - Code development, integration and testing for data assimilation software necessary to assimilate COSMIC GPSRO refractivity and bending angle
 - **Data handling** and decoding procedures
 - Complex **forward models** to simulate the observations from analysis variables and associated tangent linear and adjoint models
 - **Quality control** algorithms & **error characterization** models
 - **Verification** and impact evaluation algorithms
 - NCAR supported Visiting Scientist (L. Cucurull)
 - EMC provided computing, scientific consultation and implementation resources
- Pre-operational implementation runs showed a positive impact for COSMIC data
- **COSMIC operational at NCEP on 1 May 2007**, less than one year after real-time data availability
- **Post-implementation upgrades**
 - Refined QC
 - Additional GPSRO data (CHAMP, GRACE, SAC-C)

IASI Data Impact

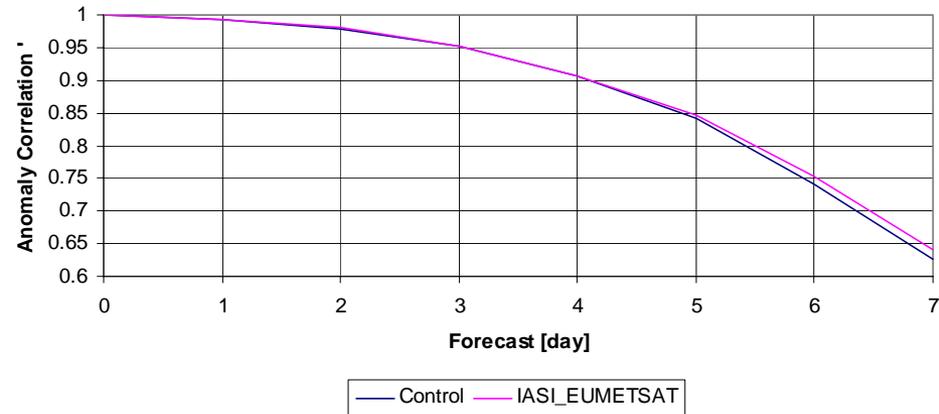
NH 500 hPa Height Anom. Cor.

N. Hemisphere 500 hPa AC Z
20N - 80N Waves 1-20
16 Dec 2007 - 15 Jan 2008



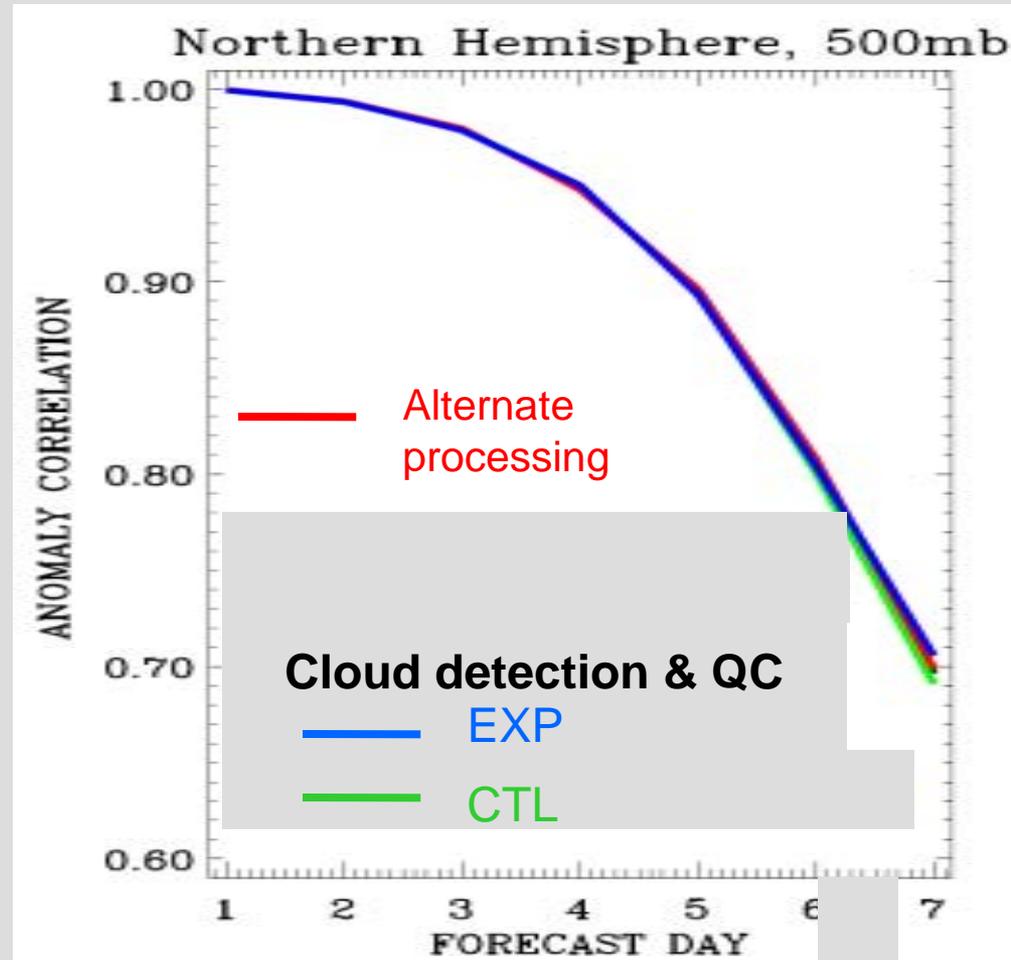
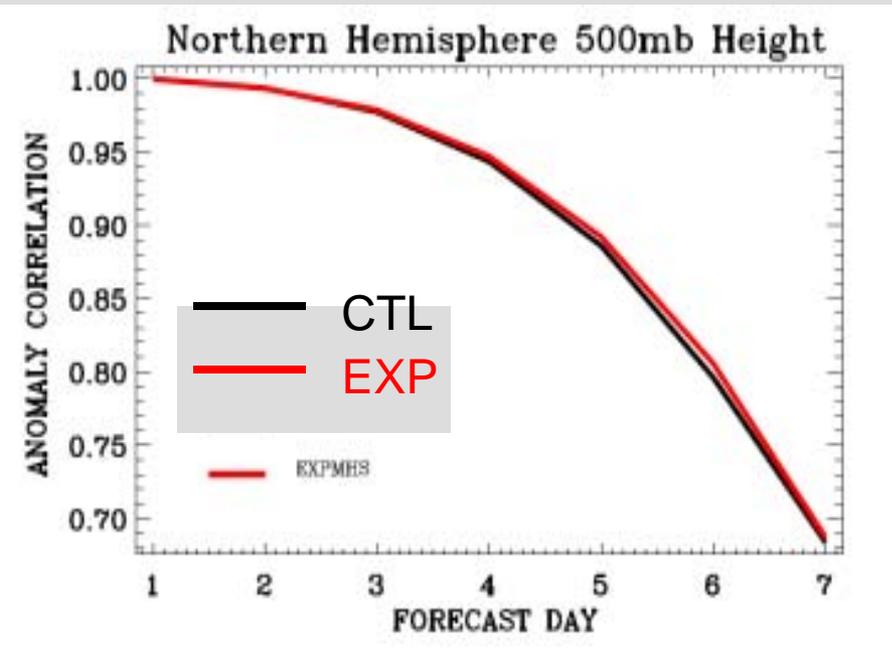
SH 500 hPa Height Anom. Cor.

S. Hemisphere 500 hPa AC Z
20S - 80S Waves 1-20
16 Dec 2007 - 15 Jan 2008



IASI
Control

Improved SSM/IS forecast impact
due to science & processing upgrades



7a Improved snow and sea ice emissivity

7b Improved cloud detection & QC

Summary

- **EMC Focused** on Multi-disciplinary Environmental Forecasting (atmosphere, ocean, land surface, cryosphere)
- Balanced program (computing, software, observations...)
- Increased community involvement (**R2O, O2R**)
- Strong partnerships in **core data assimilation activities with NASA/GMAO**
 - Potential for increased activities with NCAR
 - Successful multi-institutional code development is critical
- Preparing for future with **next-generation Production Suite** with emphasis on **ensemble-based** products

**Thanks
Questions?**

Downscaling Method with Decaying Averaging Algorithm

- **True** = high resolution analysis
 - Operational North American Real-Time Mesoscale Analysis (RTMA)
 - 5x5 km National Digital Forecast Database (NDFD) grid (e.g. G. DiMego et al.)
 - 4 variables available: surface pressure, T2m, 10m U and V
 - Other data can also be used
- **Downscaling method**: apply decaying averaging algorithm

$$\text{Downscaling Vector}^{5\text{km}} = (1-w) * \text{prior DV}^{5\text{km}} + w * (\text{GDAS}^{5\text{km}} - \text{RTMA}^{5\text{km}})$$

- *GDAS^{5km}: GDAS 1x1 analysis interpolated to RTMA^{5km} grids by using copygb command*
- *4 cycles, individual grid point, DV^{5km} = Downscaling Vector on 5km grids*
- *choose different weight: 0.5%, 1%, 2%, 5%, 10%*

Downscaling Process

$$\text{Downscaled Forecast}^{5\text{km}} = \text{Bias-corrected Forecast}^{5\text{km}} - \text{DV}^{5\text{km}}$$

- *Bias-corrected Forecast^{5km}: interpolated to RTMA^{5km} grids by using copygb*
- *subtract DV^{5km} from bias-corrected forecast^{5km} valid at analysis time*

NCEP's Hurricane Forecast Guidance

- GFS
 - T382/64L
 - 3-D var
 - Vortex relocation
 - State of the science physics
- GFDL
 - Movable nested
 - Air-sea coupled
 - Inner nest
 - 9 km/42L
 - Specialized vortex initialization,
 - Upgraded with some GFS physics (2003, 2004)
- **HWRF added to GFDL in 2007**
 - **Same physics as GFDL**
 - **Upgrade to improve intensity, June 2008**

Conceptual Prototype: Products

- Three levels of information
 - Routinely delivered
 1. Pointwise, single-valued, downscaled MLF from all available guidance on NDGD grid
 2. Description of forecast uncertainty through probability density function (pdf)
 - Accompanying post-processed fields
 - Meteorologically consistent
 - Closest to MLF
 - “On-demand” (via publicly accessible server)
 3. Individual ensemble member forecasts available
 - Prototype: NOMADS

Global Observations for Data Assimilation

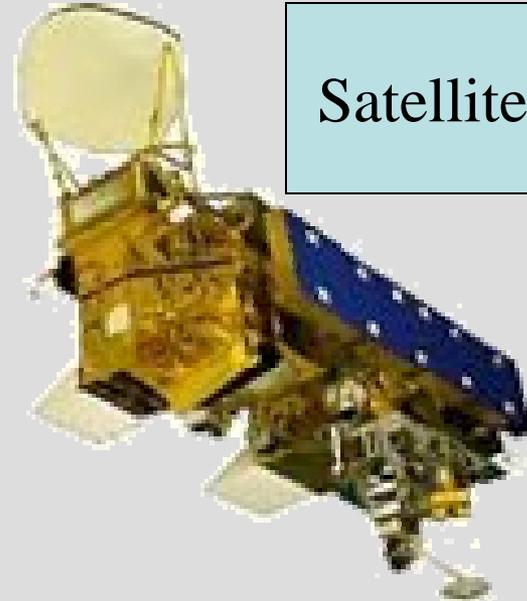
Weather
Balloons



Surface
ASOS



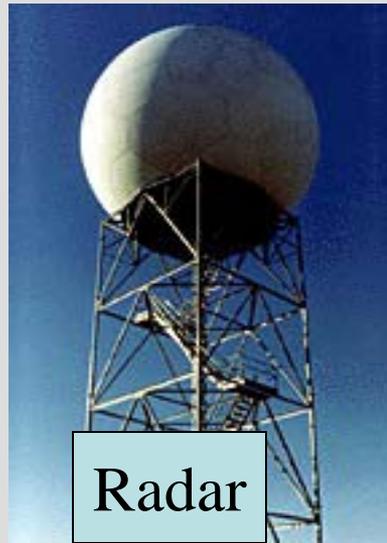
Satellite



Targeted A/C
(hurricanes)



Radar



Marine

