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Critical Research Issues at the Environmental Modeling Center

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NCEP Environmental Modeling Center

Overview

- EMC Organization
- Scientific highlights
  - Weather Research & Forecast (WRF) System
  - Hurricane Forecasting
  - Real-time Ocean Forecasting
  - Global Coupled Climate Forecast System
  - The NASA-NOAA-DOD Joint Center for Satellite Data Assimilation
  - Ensemble-based products
- Summary

EMC Mission

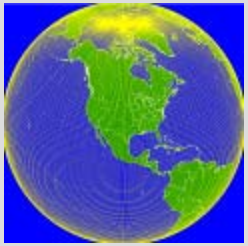
In response to operational requirements:

- **Maintain**
  - the scientific correctness and integrity of operational forecast systems
  - modify current operational system to adapt to ever-present external changes

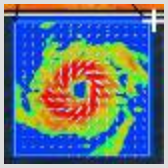
- **Enhance** numerical forecasts
  - Test and improve NCEP's numerical forecast systems via
    - Scientific upgrades
    - Tuning
    - Additional observations
- **Transition and Develop** **o**perational numerical forecast systems
  - **transform & integrate**
    - Code
    - Algorithms
    - Techniques

    from research status to operational status on NCEP computers

NOAA's NWS Model Production Suite

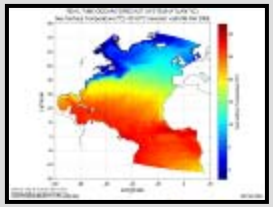


Global Ensemble Forecast System (w/ Canada)

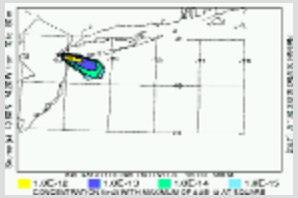


Hurricane Forecasts

Real-Time Ocean Forecast System



Dispersion



Global Observations

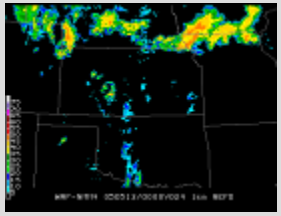
Global Analysis

Global Forecasts

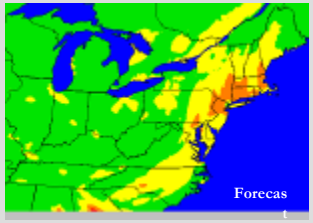
Regional Analysis

Regional Forecasts

Severe Weather



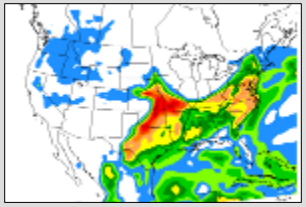
Air Quality With EPA



Climate Forecast System

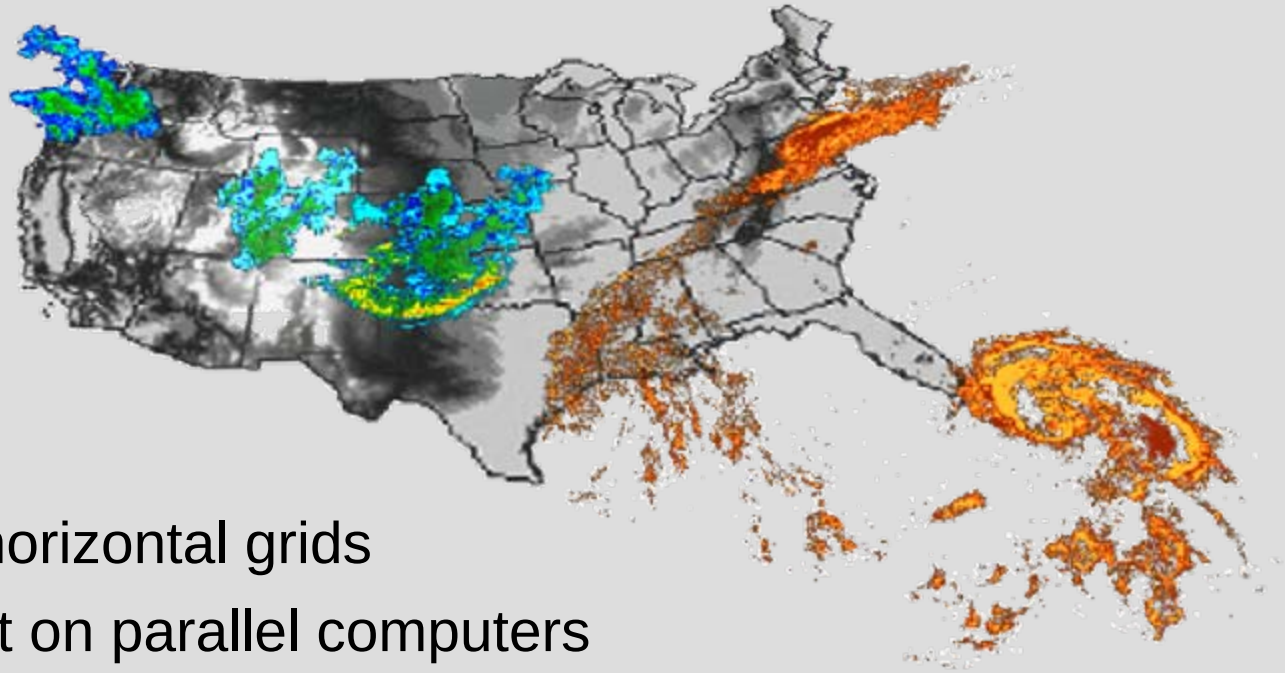
Short-Range Ensemble Forecast

Rapid Update for Aviation



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

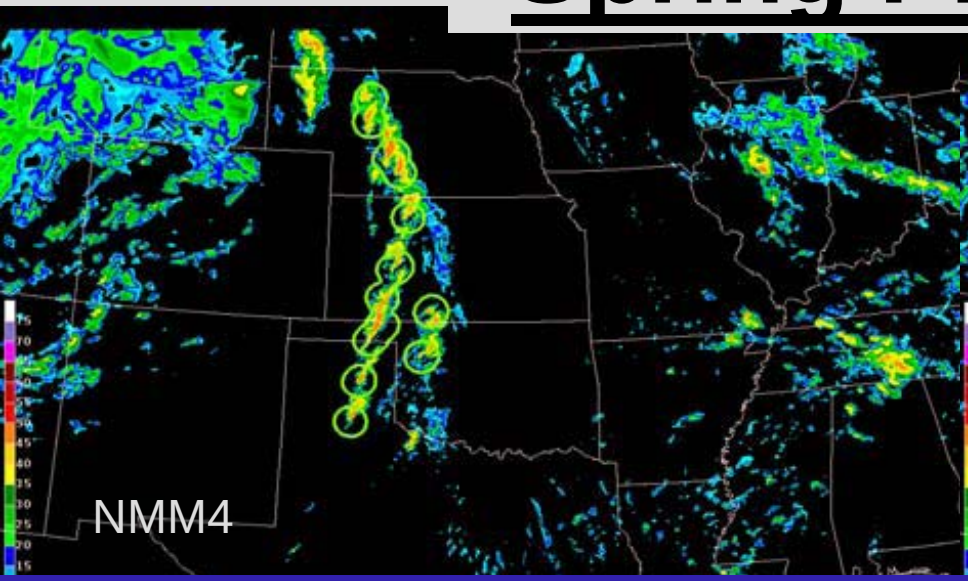
Portable and efficient on parallel computers

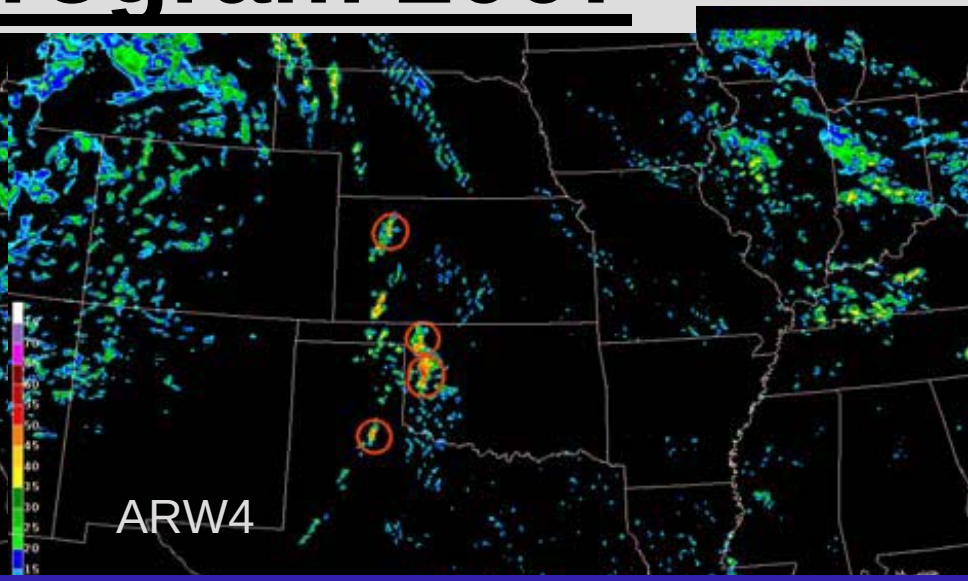
Well suited for a broad range of applications

Community model with direct path to operations

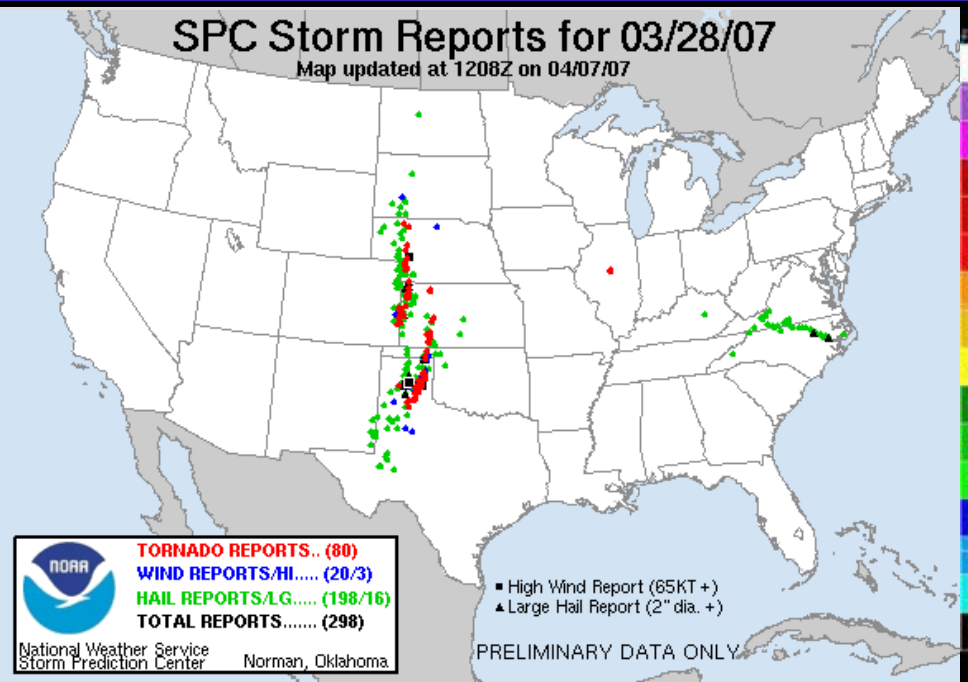
Collaborators: NCEP/EMC, NCAR, AFWA, Navy, NOAA/FSL, U. Okla.

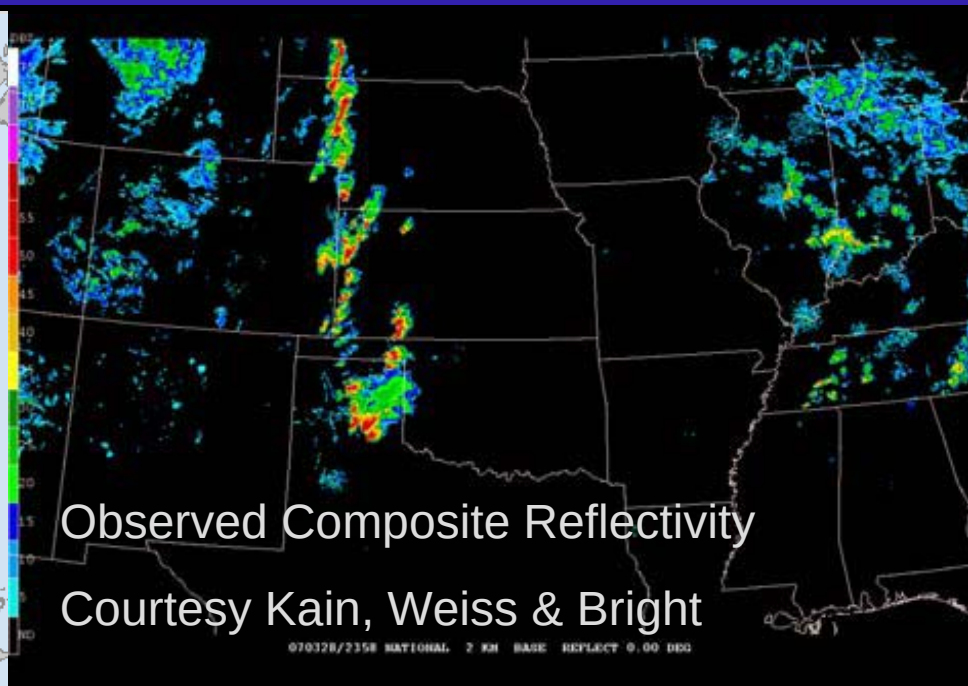
Spring Program 2007





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





Observed Composite Reflectivity

Courtesy Kain, Weiss & Bright

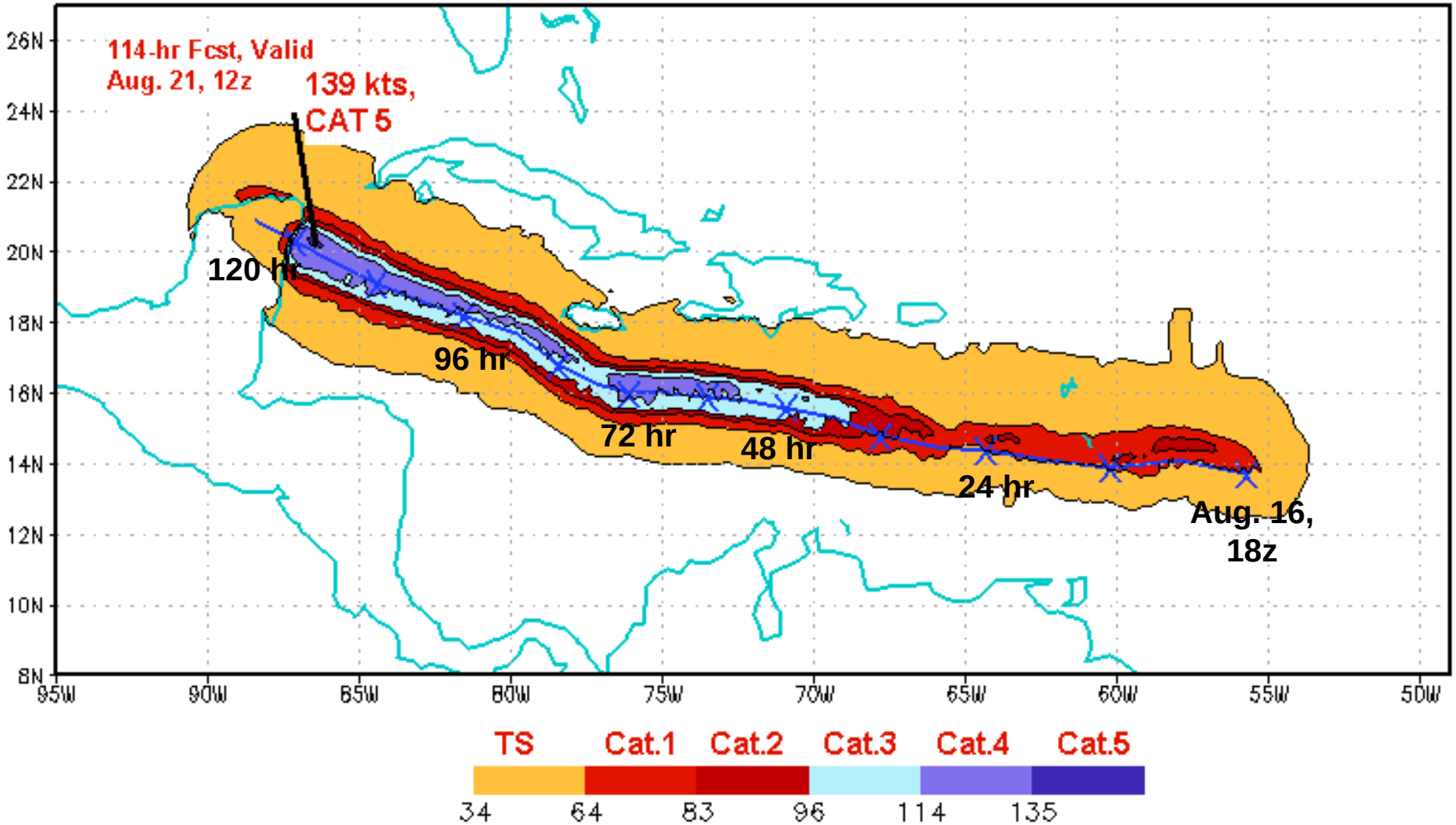
NCEP's Hurricane Forecast Guidance

- 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**

INIT 2007081618Z for 126 h FCST VALID 2007082200Z

START POS (13.70 LAT, −55.70 LON) FINAL POS (20.90 LAT, −88.40 LON) X=12 h POS

HWRF 10M MAX WIND (KTS) SWATH DEAN04L



MAX WIND (KTS) 139.495

NCEP Hurricane Forecast Project

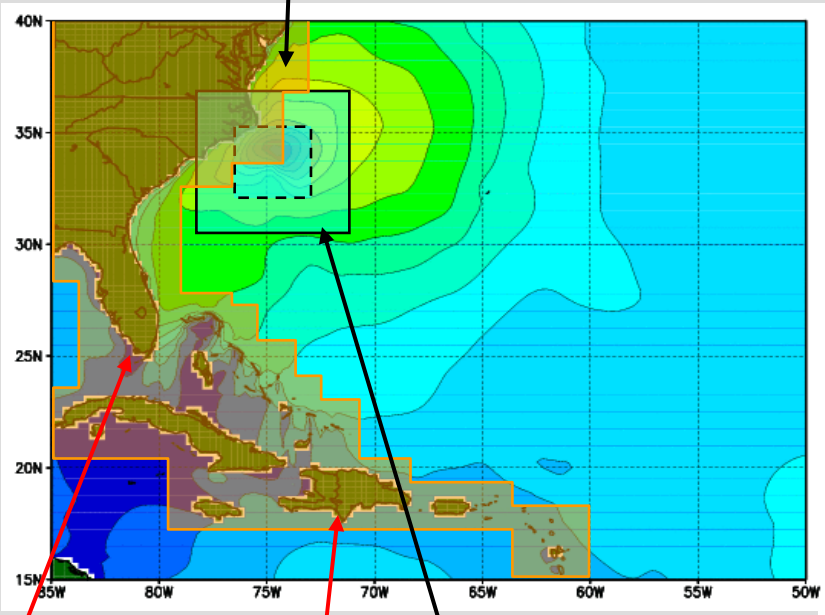
Real Time Ocean Forecasting

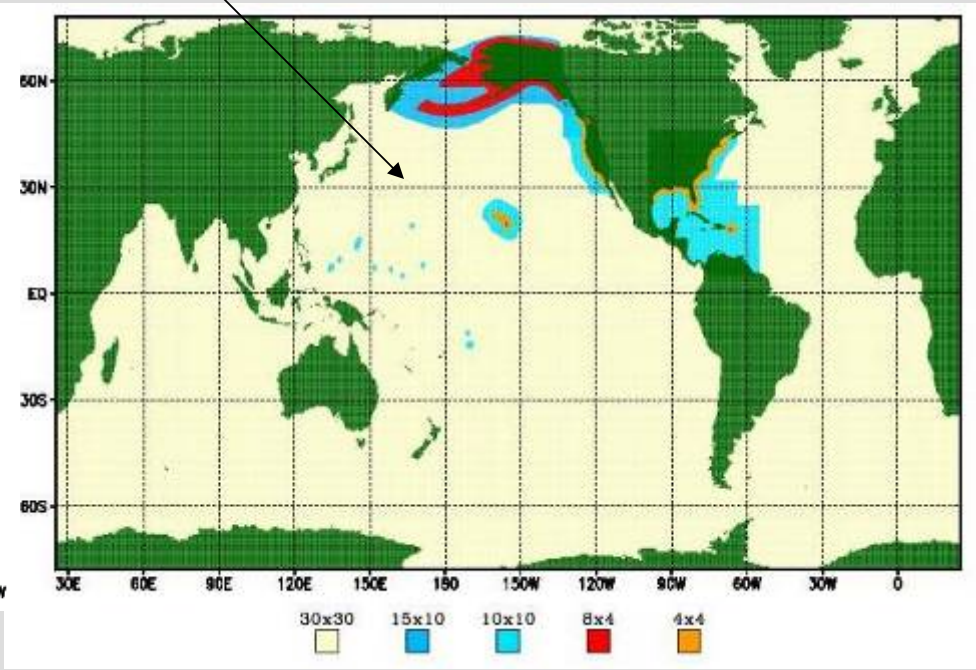
- Wave Modeling
  - Global and Regional
  - Unified model approach
  - NOAA Wavewatch III
- Basin-scale Ocean Model (new system)
- Sea Surface Temperature & Winds
  - NCEP Ocean Prediction Center support
    - Gulfstream analysis & forecast
- Real-time Sea Ice products
  - Alaska Region support (fishing)

Multi-Grid Wave Modeling

Higher coastal model resolution

Deep ocean model resolution dictated by GFS model





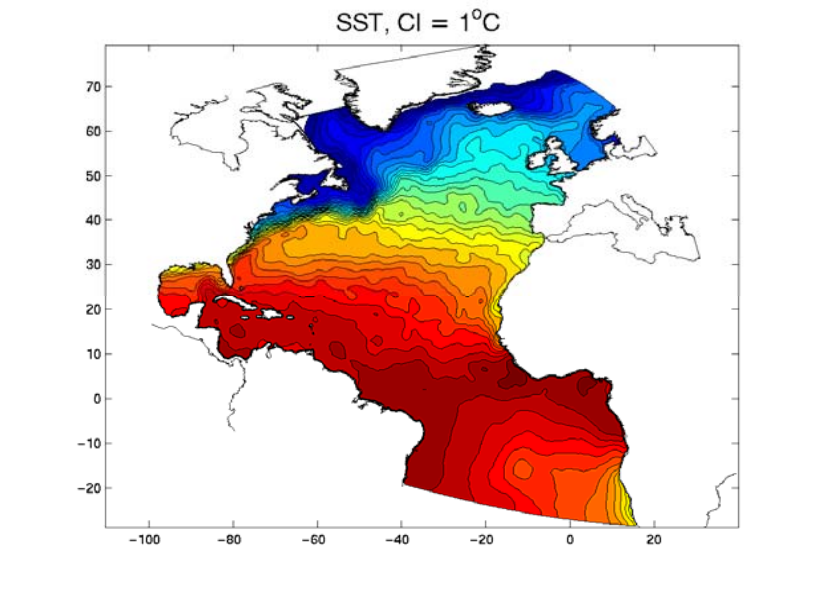
Highest model resolution in areas of special interest

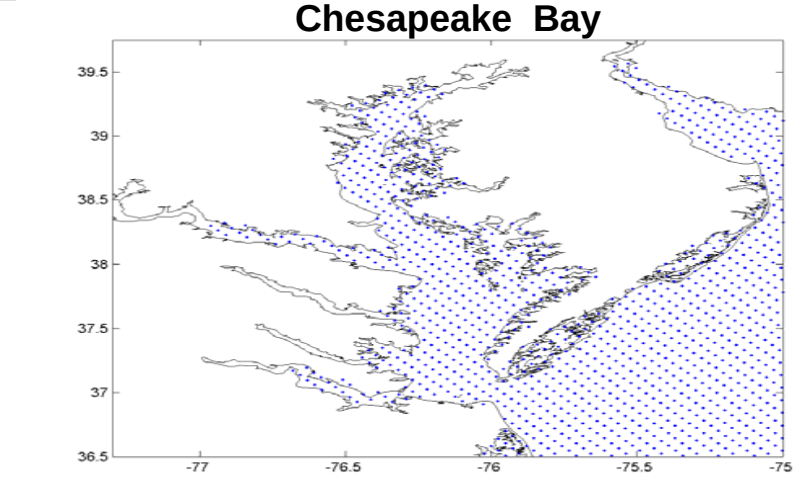
Hurricane nests moving with storm(s) like GFDL and HWRF

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

NCEP Real-Time Ocean Forecast System (RTOFS) Operational December 2005, upgraded June 2007

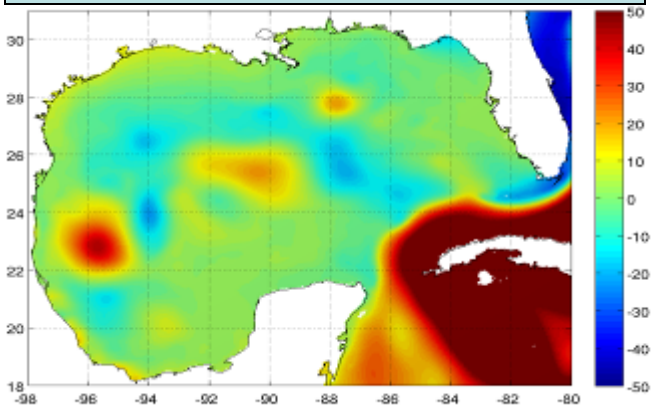
- RTOFS provides
  - Routine estimation of the ocean state [T, S, U, V, W, SSH]
    - Daily 1 week forecast
  - 5 km coastal resolution
  - Initial and boundary conditions for local model applications
- Applications
  - Downscaling support for water levels (with NOS) for shipping
  - Water quality
  - Ecosystem and biogeochemical prediction
  - Improved hurricane forecasts
  - Improved estimation of the atmosphere state for global and regional forecasts



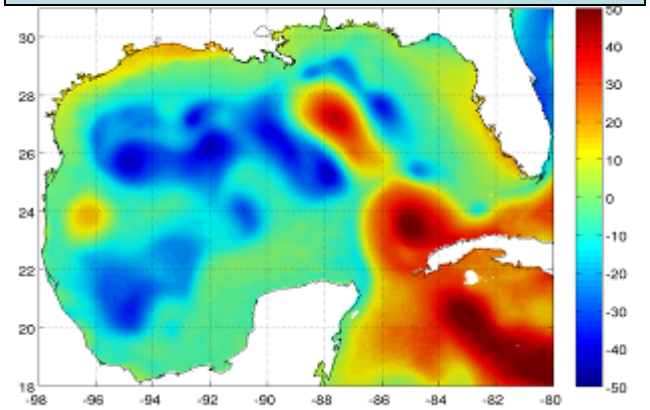


Real-Time Ocean Modeling Example

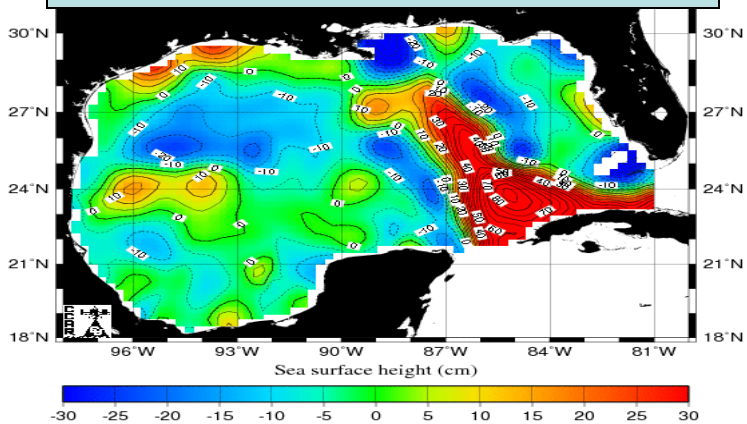
Model without SSH assim.



Model with SSH assim.

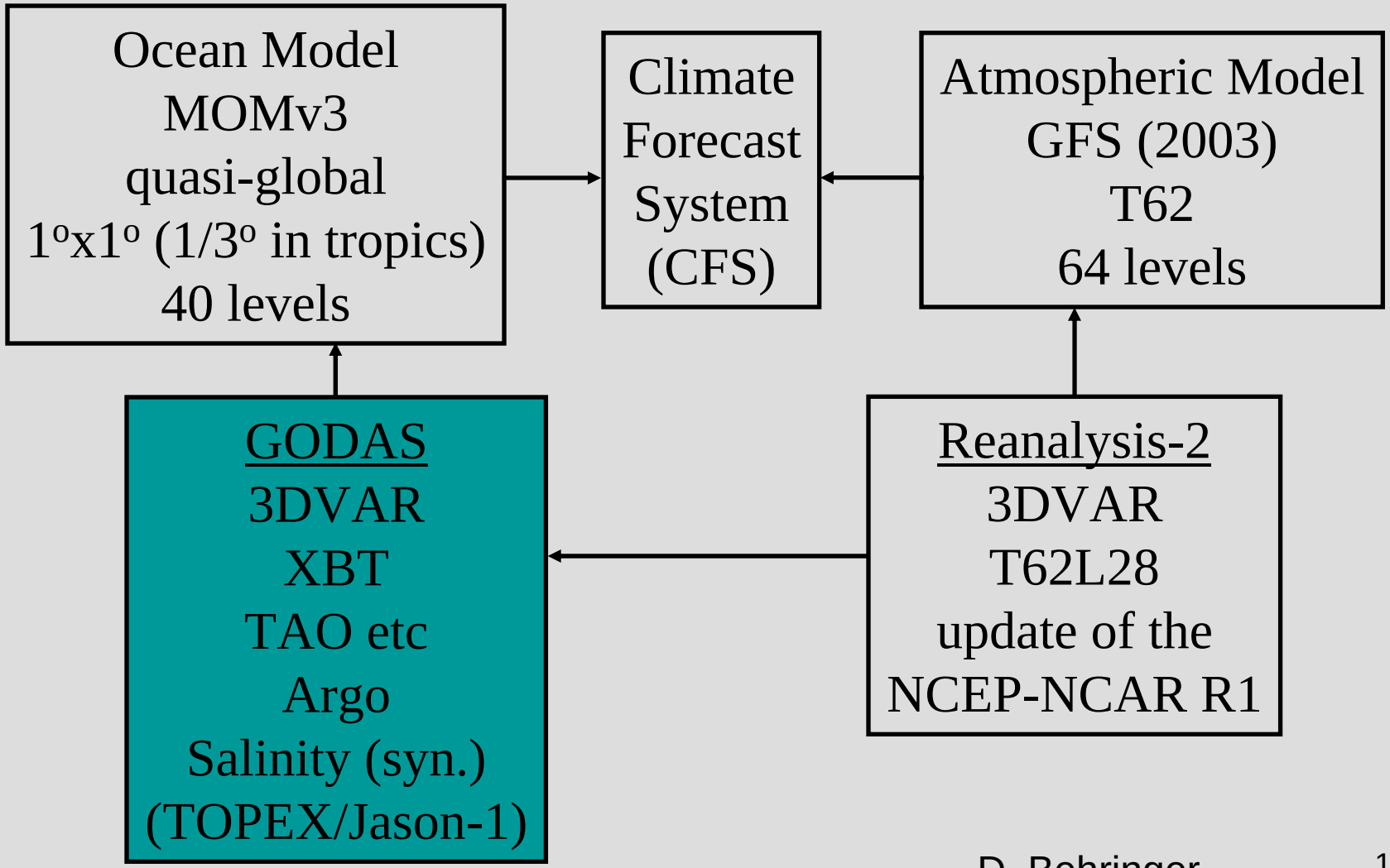


Altimeter only analysis



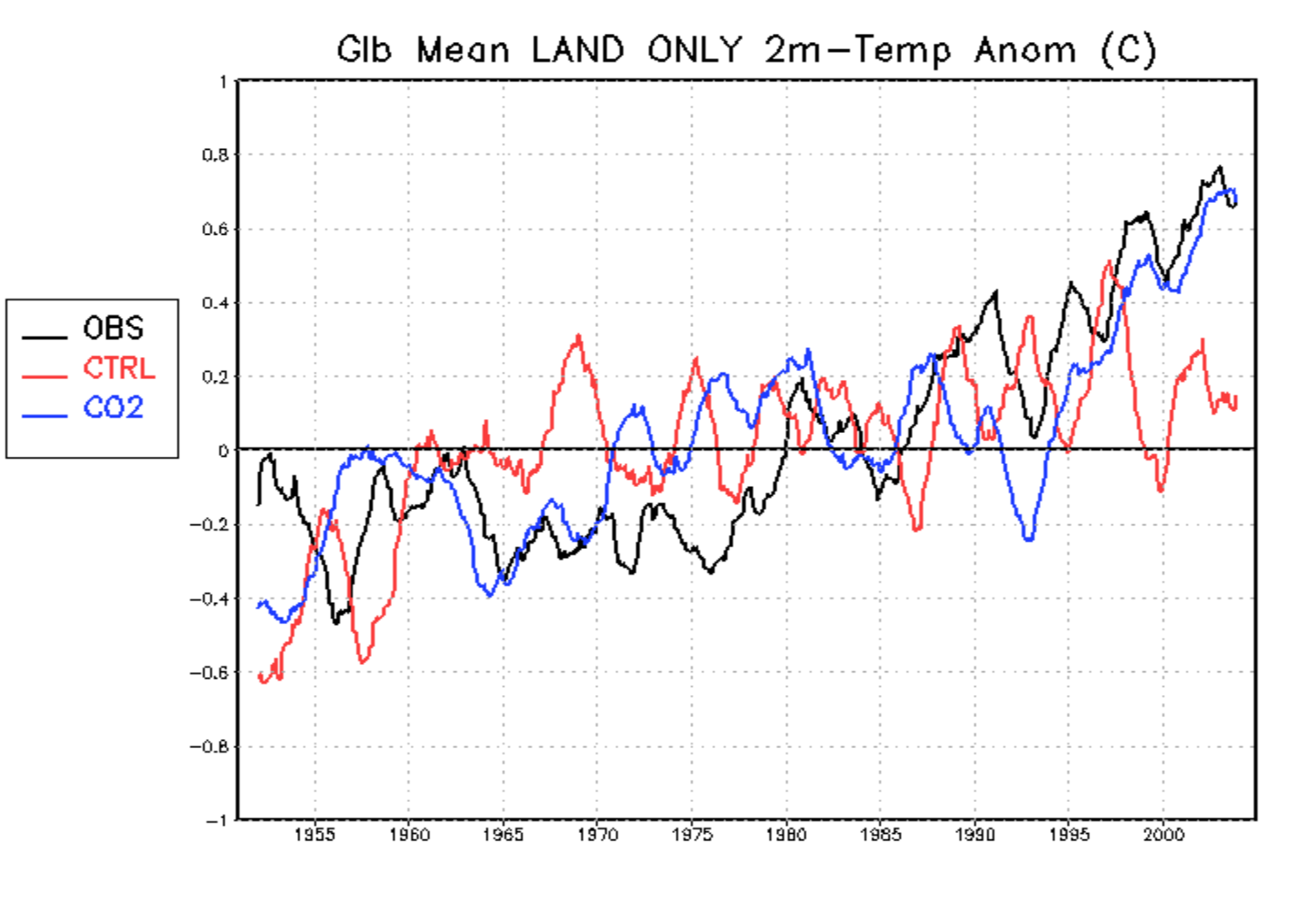
Analysis shows loop current being cut-off. Model without altimeter data does not show Loop Current and has no practical forecast value. Model with altimeter SSH assimilation shows cut-off Loop current and forecast skill.

Seasonal to Interannual Prediction at NCEP



D. Behringer

Testing with CMIP Runs (variable CO2)



OBS is CPC Analysis (Fan and van den Dool, 2008)

CTRL is CMIP run with 1988 CO2 settings (no variations in CO2, current operations)

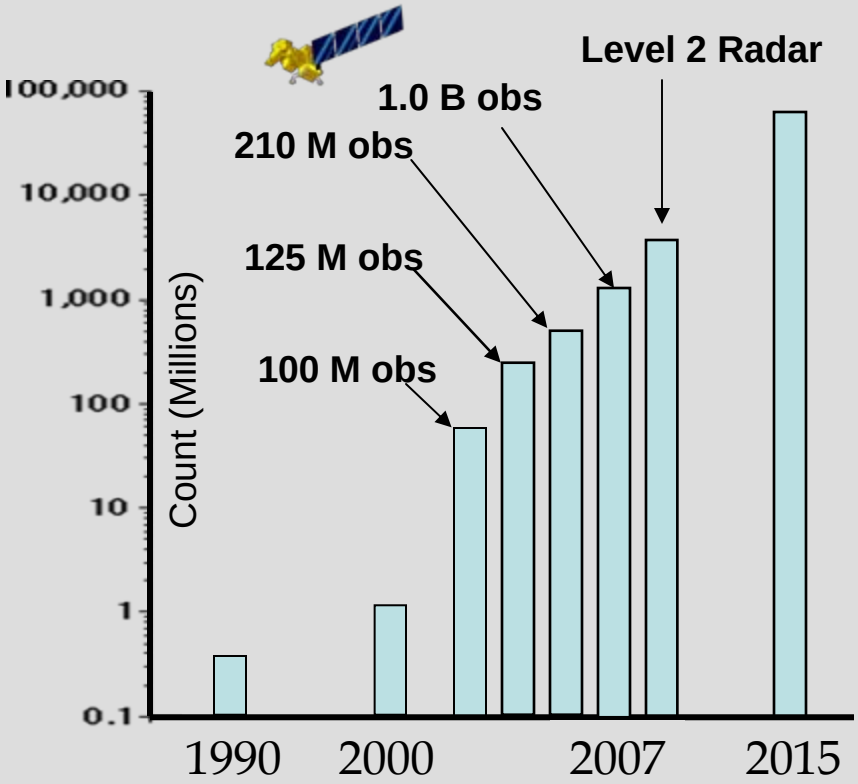
CO2 run is the ensemble mean of 3 NCEP CFS runs in CMIP mode

- realistic CO2 and aerosols in both troposphere and stratosphere

Processing: 25-month running mean applied to the time series of anomalies (deviations from their own climatologies)

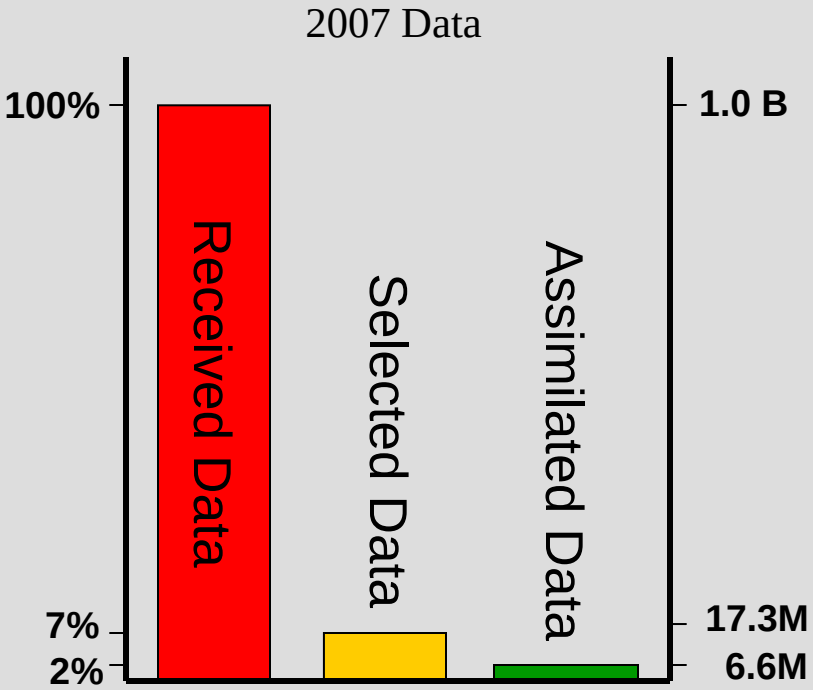
Satellite Data Ingest

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

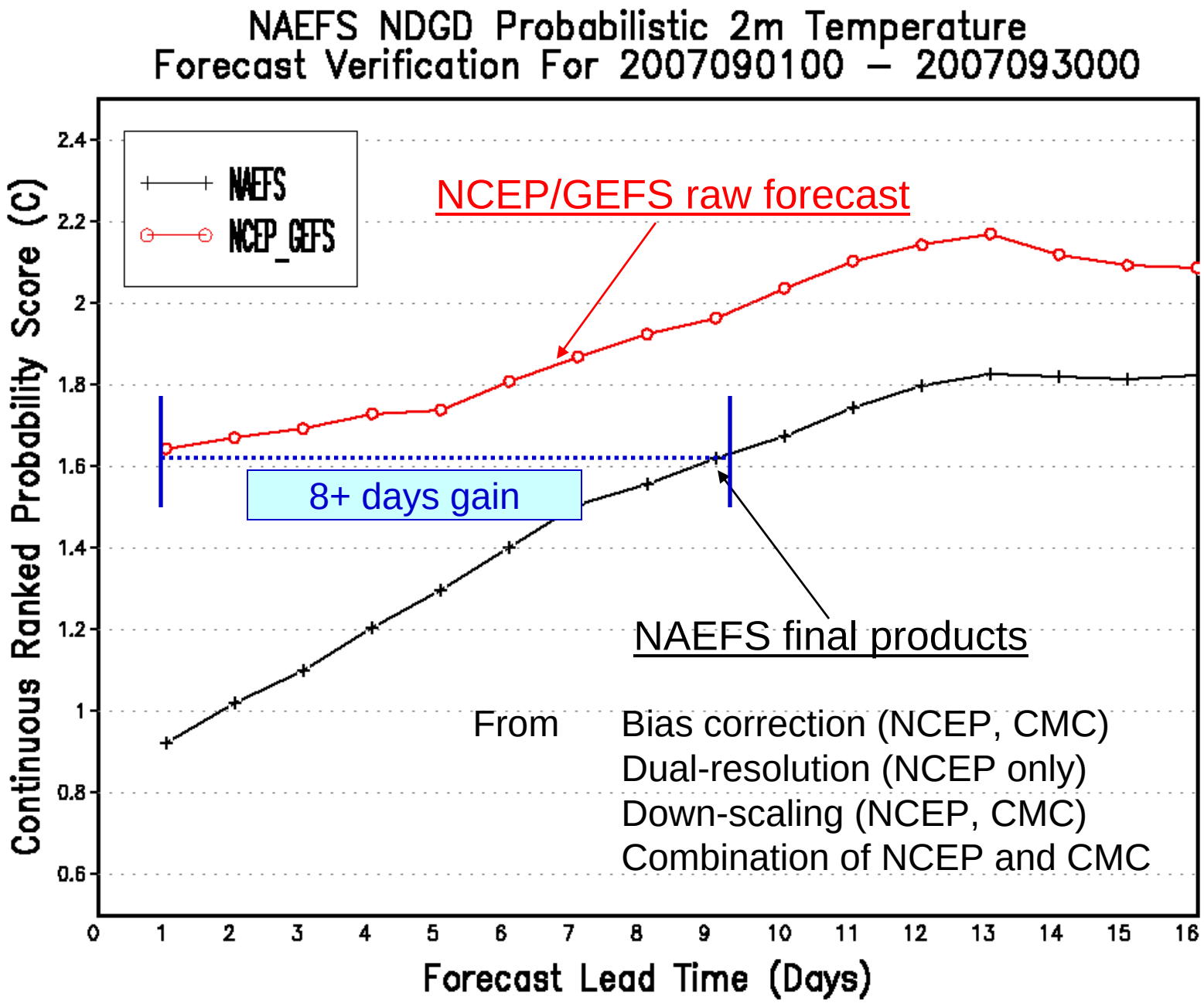


Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models

JCSDA and EMC Satellite Data Assimilation Development Projects 2007-09

- **New observations**
  - Implemented 1 May 2007
    - **COSMIC**
    - **AIRS (all FOV)**
  - Implemented 29 May 2007
    - **METOP AMSU, HSB, HIRS**
    - **GOES 1x1 FOV sounder radiances**
  - December 2007
    - **JMA high density winds**
    - **SBUV-8**
  - Summer 2008
    - **Windsat**
    - **Reintroduce AQU AMSU-A**
- **Observations under development 2008 – Q1 FY09 implementation**
  - **IASI longwave channels**
  - **ASCAT**
- **Observations under development 2008- Q3 FY09**
  - SSMIS
  - CHAMP, GRACE
  - AMSR-E
  - GOME-2
  - OMI
  - EUMETSAT-9 winds
- **New analysis variables**
  - Constituent gas assimilation
  - **Aerosols**
- **Improved radiative transfer**
  - **Surface emissivity models (MW & IR)**
  - **Cloud absorption & reflection**
- **Data sets (albedo, vegetation, land type)**
  - **Unified land surface treatment (data assimilation, model)**

METOP advanced instruments



BO CUI, GCWMB/EMC/NCEP/NOAA

Examples of Active Contributions to Operational Transition

- IASI testing (Jim Jung, UW)
- ASCAT testing (Li Bi, UW)
- Cloud diagnostics (Z. Li, UMD)
- Climate and Health products (de Magny, UMD)
- Numerical methods (F. Mesinger, ESSIC)
- Hurricane intensity & structure (DeMaria, CSU)

Other Research Areas

- Evaluation of CFS for decadal climate applications (not NCEP's mission, but…)
- Mid-latitude predictability on 2-8 week time scales (AO, PNA, …)
- Skilled scientific programmers to work on
  - Software system design
  - Data assimilation
    - Atmosphere (4d-var)
    - Ocean
    - Land surface
  - Performance evaluation and where to improve
  - Model physics
    - Convection
    - PBL

Can Be Most Useful If…

- Working with operational codes (“Operations To Research”)
- Close coordination with EMC personnel to define and execute work

Thanks
Questions?

Summary

- Increasingly interdisciplinary and integrated forecast systems to support weather, water and S/I climate (e. g. WRF)
- Increased emphasis on
  - Advanced data assimilation
  - Ocean forecasting
  - S/I climate
  - Severe weather
  - Ensemble systems
  - Postprocessing
- Transition of community research to operations at NCEP is accelerating
  - Advanced satellite data assimilation through the JCSDA
  - Testbeds for climate, hurricane, hydromet, …

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

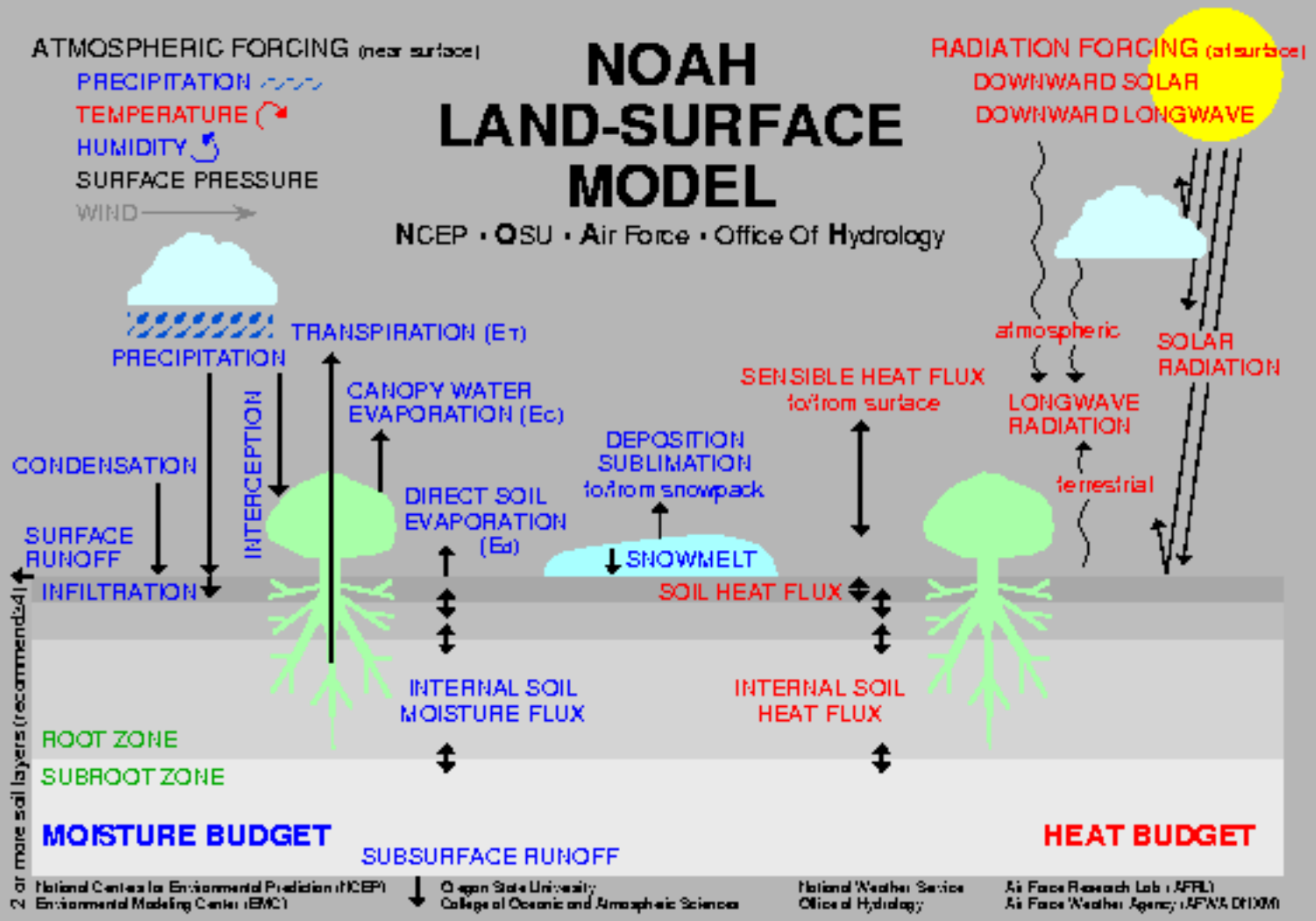
- **NOAA, NASA, DOD partnership**
- **Mission**
  - **Accelerate and improve the quantitative use of research and operational satellite data in weather and climate prediction models**
    - **Current generation data**
    - **Prepare for next-generation (NPOESS, METOP, research) instruments**
- **Supports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

Mission Requirements & Forecast Suite Elements

Suite Elements	Global NWP	Reg. NWP	Hurricane Rapid Update Fire Wx	Air Quality	Global Ensembles	Regional Ensembles	Real Time Ocean	S/I Climate
NCEP	X	X	X	X	X	X	X	X
UKMO	X	X		X		X	X	
ECMWF	X				X			X

NOAH LAND-SURFACE MODEL

NCEP • OSU • Air Force • Office Of Hydrology



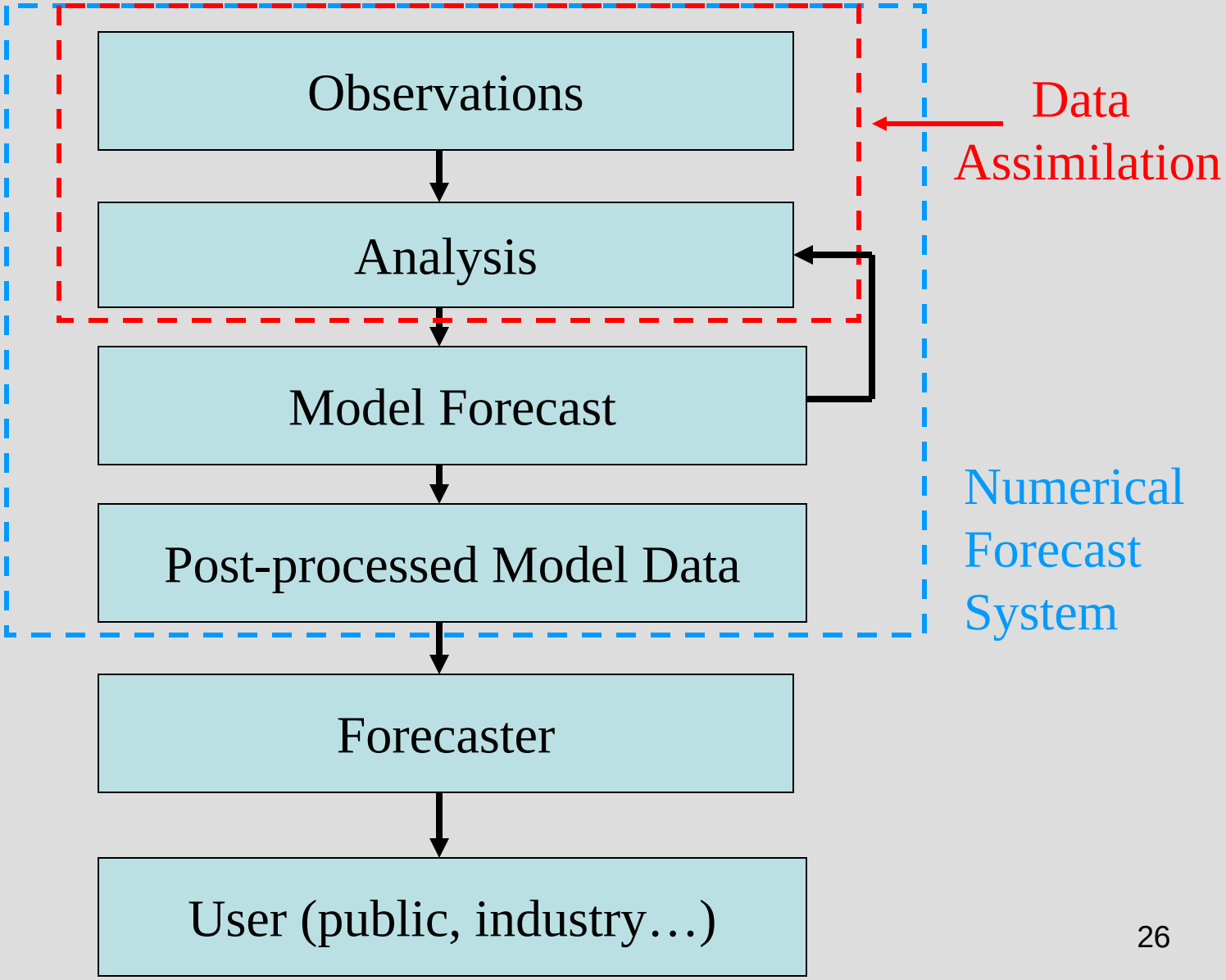
STATE VARIABLES

- SKIN TEMPERATURE
- SOIL TEMPERATURE
- SOIL WATER
- SOIL ICE
- CANOPY WATER
- SNOW WATER
- SNOW DENSITY

SURFACE PARAMETERS

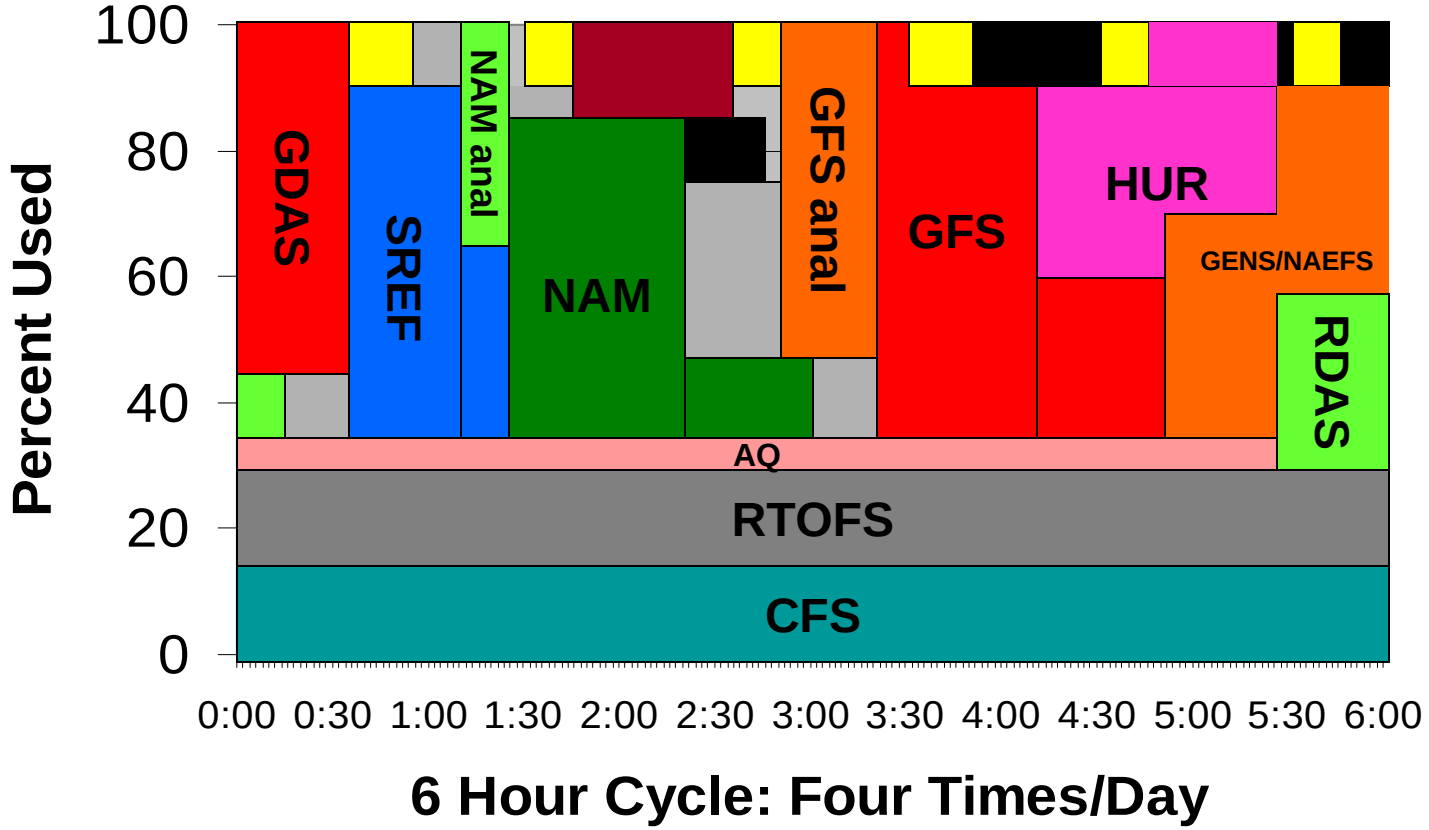
- VEGETATION TYPE
- GREEN VEGETATION FRACTION
- SOIL TEXTURE
- ROUGHNESS
- ALBEDO
- SLOPE FACTOR

The Environmental Forecast Process



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

Current - 2007



Ingredients for Improved Numerical Forecast Systems

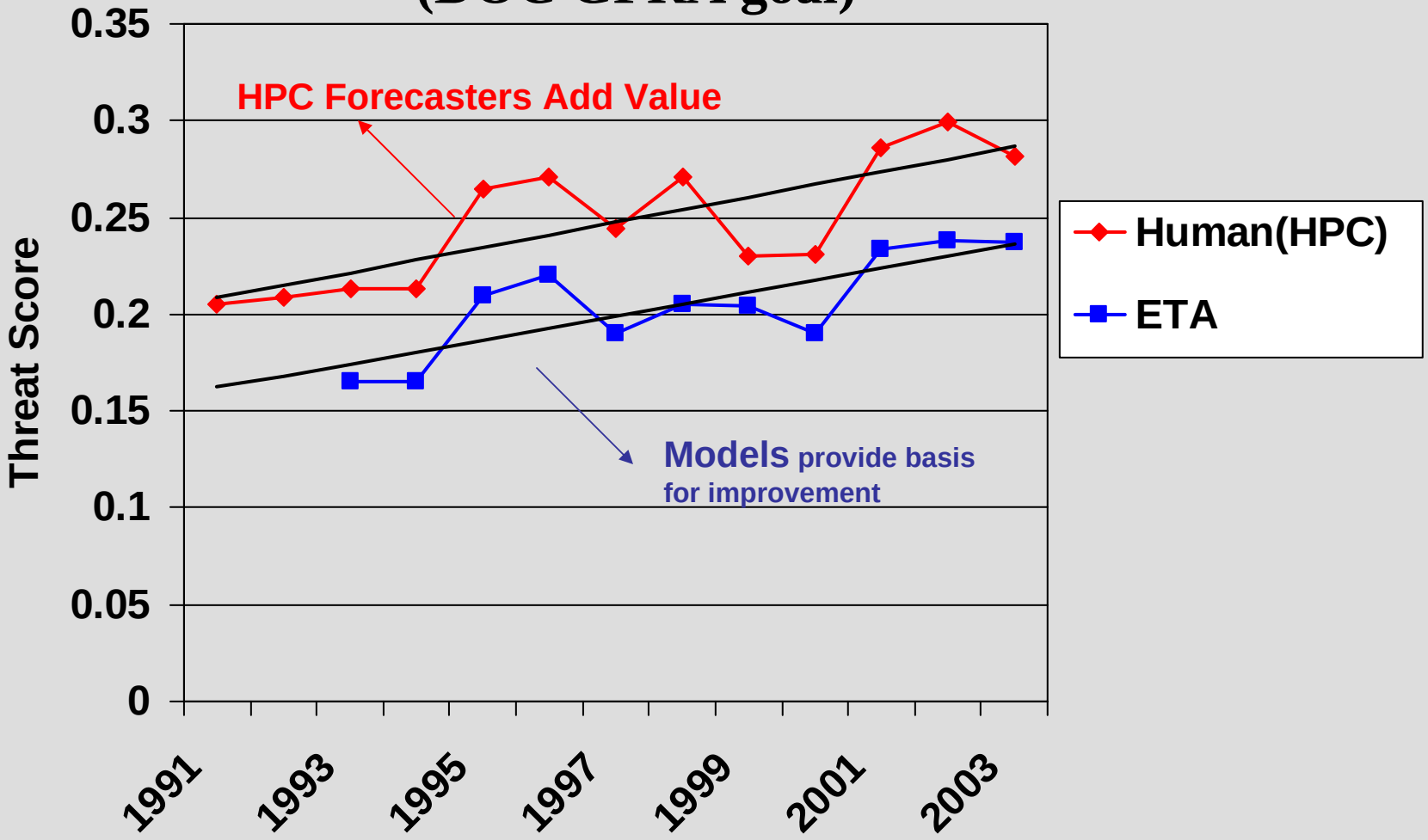
- **Primary ingredients**
  - **Observations**
  - **Data Assimilation & Model technology**
  - **Computing resources**
- **Secondary ingredients**
  - **Post-processing and dissemination**
  - **Research to Operations (R2O) process**

Why Models?

"As go the models, so go the forecasts"

Impact of Models on Day 1 Precipitation Scores

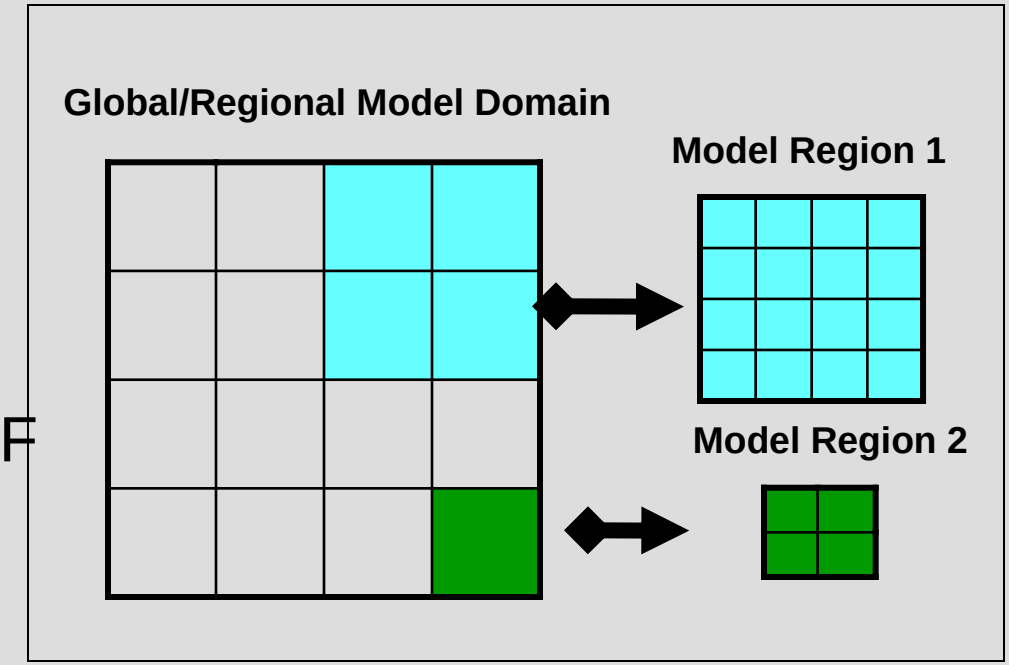
(DOC GPRA goal)



Forces for Change

- Increasing emphasis on ensemble approaches
  - Multi-model ensembles
    - SREF
    - NAEFS
    - Climate Forecast System
- Entering the NPOESS era
  - More rapid access to hyperspectral data
  - GPS soundings
  - Higher resolution surface radiance data
- All models run within ESMF
  - Models run concurrently
  - Hybrid vertical coordinate
  - Coupled
  - Spanning all scales
- Operational Earth System model – more explicit hydro, climate and ecosystems applications

ESMF-based System



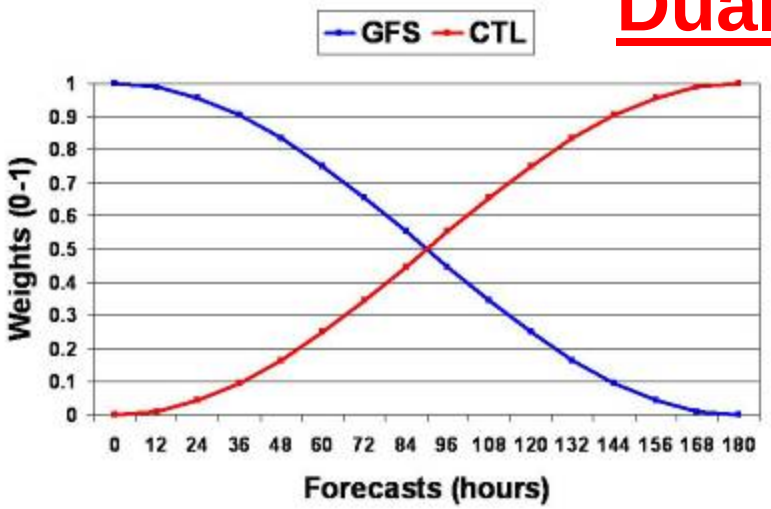
Conceptual Prototype

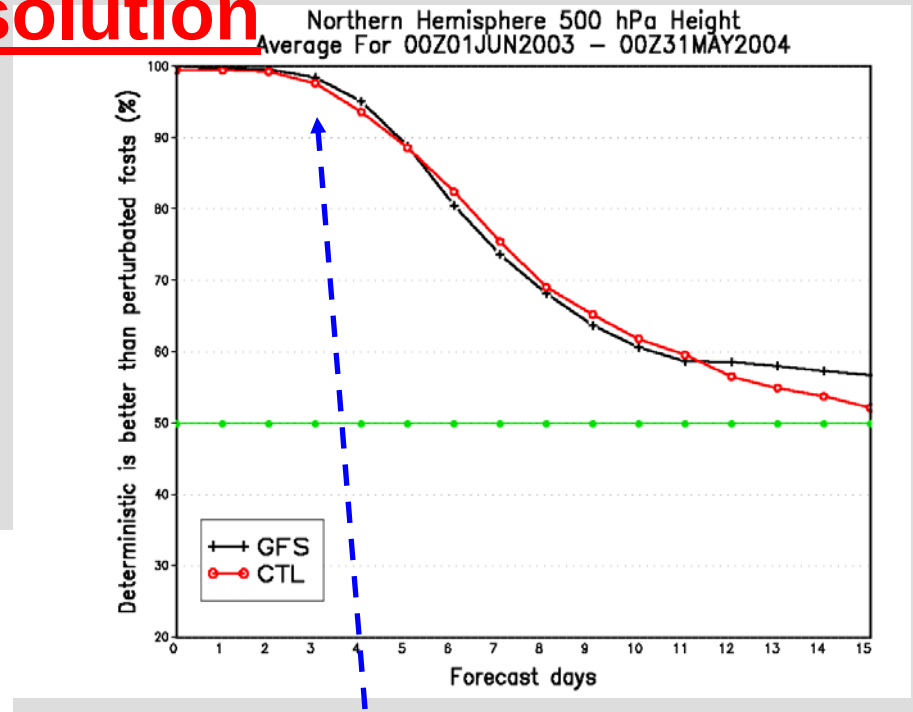
Model Guidance

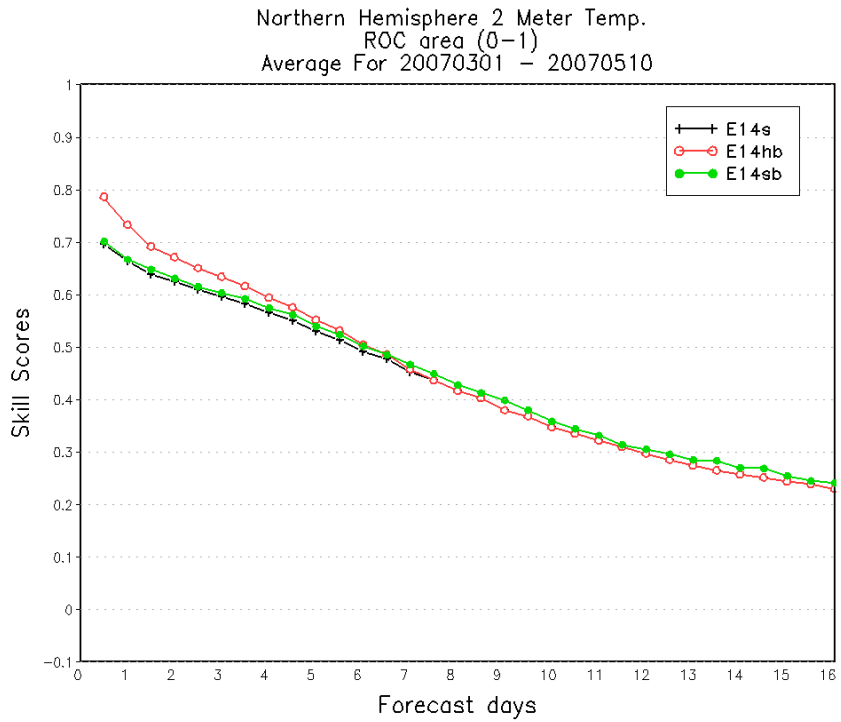
- Model guidance will be
  - Produced from ensemble-based products for all forecast suites **IF IT**
    - **Is affordable**
    - **Provides cost-effective, value-added solutions**
  - Constructed to account explicitly for all sources of forecast uncertainty
    - Observations
    - Analysis errors
    - Model uncertainty
    - Forecast fluid (e.g. chaos)
  - Bias and spread corrected
    - For 1-3 days – simple correction using most recent ~60 days of forecasts (e.g. NAEFS)
    - For > 3 days – **Historical reforecasts and reanalysis may be best (e.g. CFS)**
  - Locally downscaled using
    - Climate anomaly
    - Simplified models forced by full, dynamically-based ensemble system
  - Optimally processed in statistical sense to produce **"Most Likely Forecast (MLF)"** on all time scales

Combined GFS and GEFS forecasts at first 180hr

Dual-resolution







GFS has more skill than ensemble control for short lead time

Combined GFS and GEFS Forecast has more skill (red) than GEFS only (black)

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 (mode & 10/90 %ile)
    - Accompanying post-processed fields
      - Meteorologically consistent
      - Closest to MLF
  - "On-demand" (via publicly accessible server)
    3. Individual ensemble member forecasts available
    - Prototype: NOMADS

Conceptual Prototype:

Application Areas

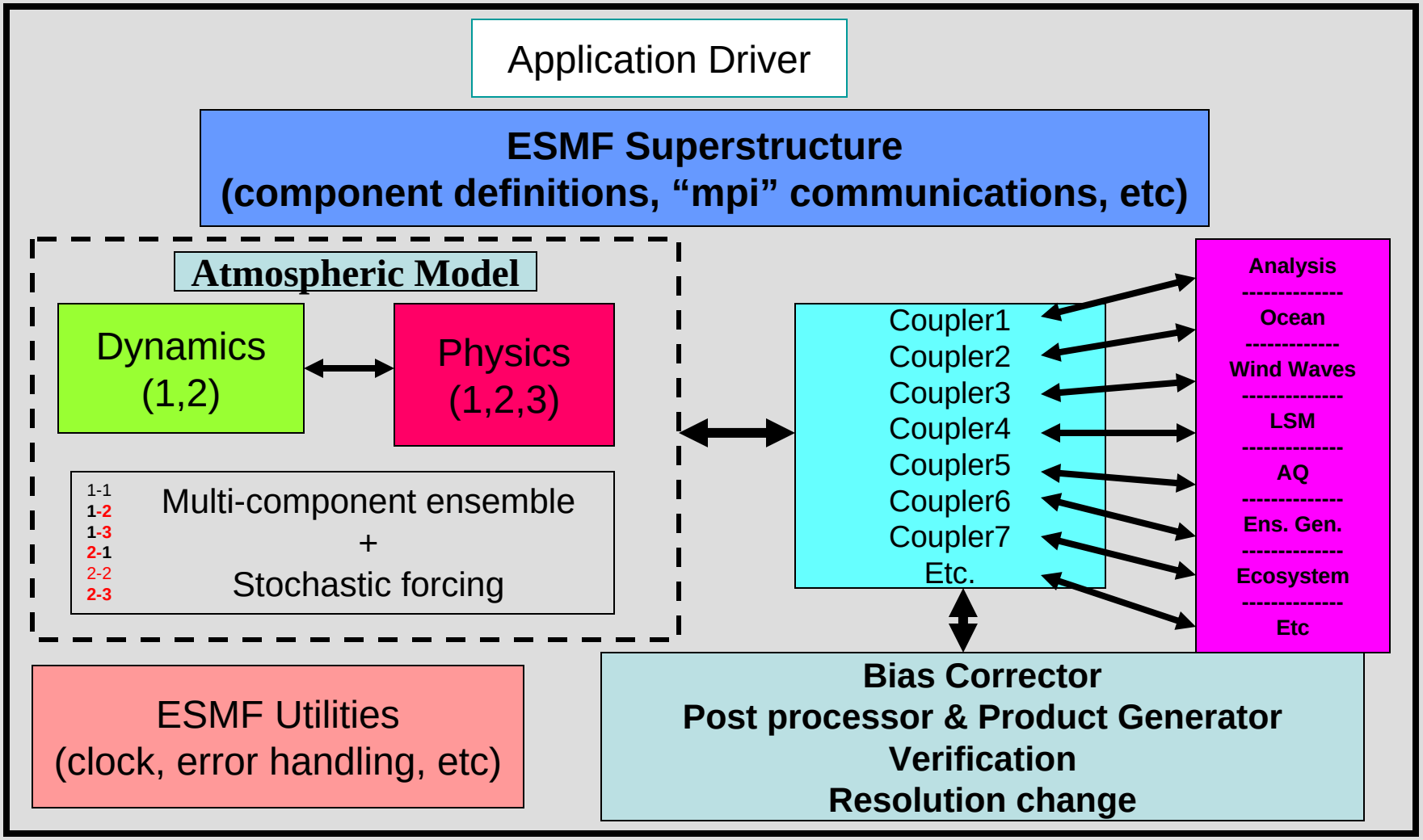
- **Focus on high impact weather**
  - RTMA analysis and forecast variables for sensible weather
    - Maximum Temperature
    - Minimum Temperature
    - Precipitation Amount
    - Probability of Precipitation (POP 12)
    - Temperature
    - Dew Point
    - Sky Cover
    - Snow Amount
    - Wind Direction and Speed
    - Significant Wave Height
  - "High impact" defined by
    - Users
    - Type of event
  - Eventually: warn on forecast for highest resolution events (e.g. tornado)
- **Examples of other new applications**
  - Surface transportation (e.g. "winter weather")
  - Environmental monitoring (AQ + Atmos. Constituents)
  - Ocean (HABs & ecosystems, fog & visibility, coastal inundation, dynamic storm surge)
  - Hydrology (water quality, drought)
- **Hourly updating**
  - RTMA → AOR (through Reanalysis/Reforecast)
  - Regional assimilation
  - Global assimilation[+]
  - NEXTGEN

+ if requirement and available computing and human resources

Conceptual Prototype:
Forecast System Development Areas

- **Observations processing**
  - JCSDA
  - Increased focus on quality control
  - Contribute to future observing system design
- **Data assimilation**
  - Coordinated development of advanced techniques
    - Simplified 4-D Var (NCEP/EMC), annual updates thru 2008
    - "Classical" 4-D Var (with NASA/GMAO)
    - Ensemble Data Assimilation (with ESRL, UMD and others)
    - Development coordinated with NASA-NOAA-DOD JCSDA
    - 2008 decision → 2010 implementation
  - Better use of high time and space density, remotely-sensed data
- **Model accuracy (dynamics and physics)**
  - Hybrid vertical coordinate (sigma-pressure-theta)
  - Semi-lagrangian, Semi or Fully Implicit
  - Advanced radiation, shallow convection, deep convection
  - Stochastic forcing
  - Land surface tiling
  - Increased collaboration with community (Test Beds)
- **Post-processing**
  - Unified system across time and space scales and models
  - Includes bias correction and downscaling

National Environmental Modeling System (NEMS) (uses standard ESMF compliant software)



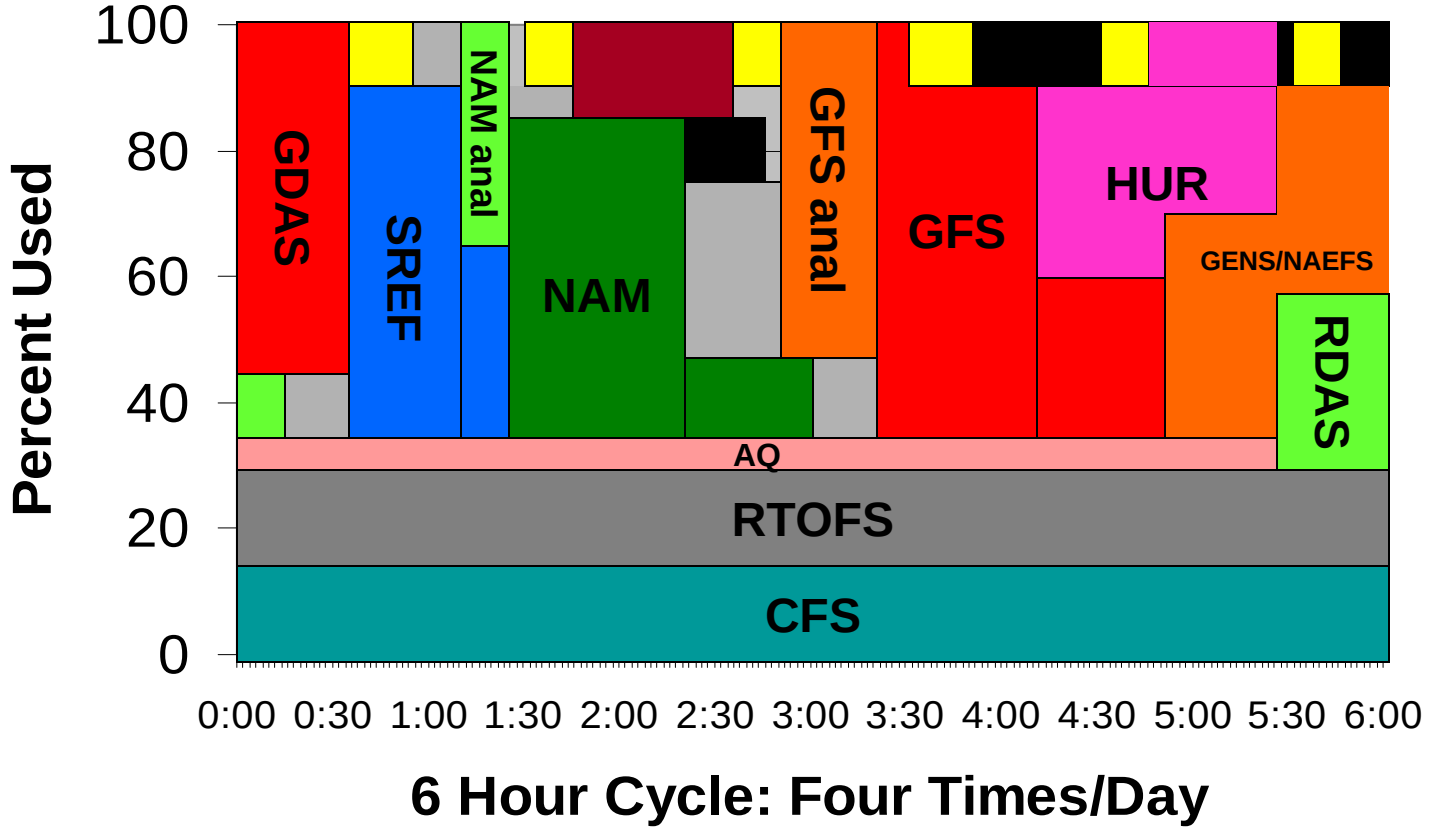
* Earth System Modeling Framework (NCAR/CISL, NASA/GMAO, Navy (NRL), NCEP/EMC), NOAA/GFDL

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

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

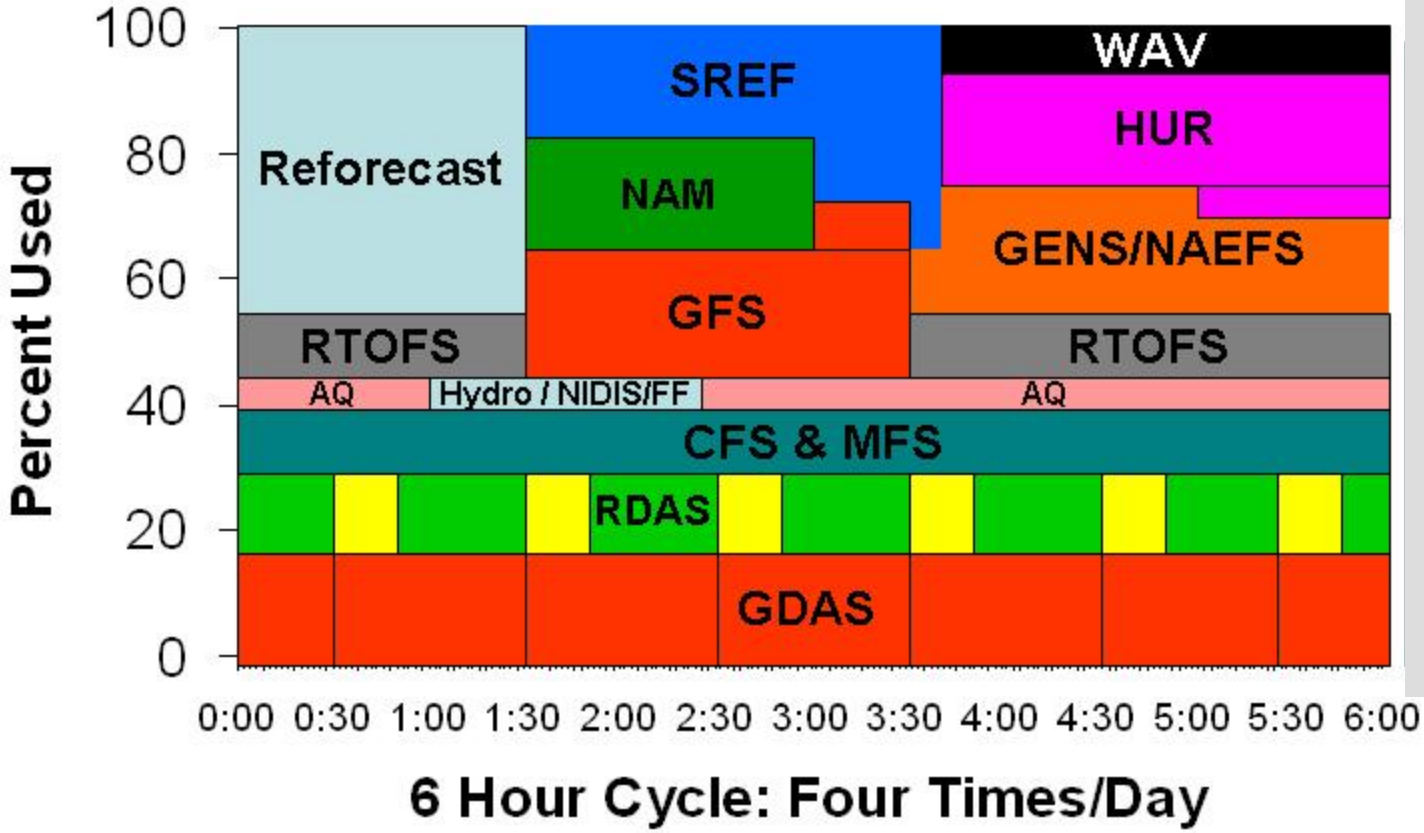
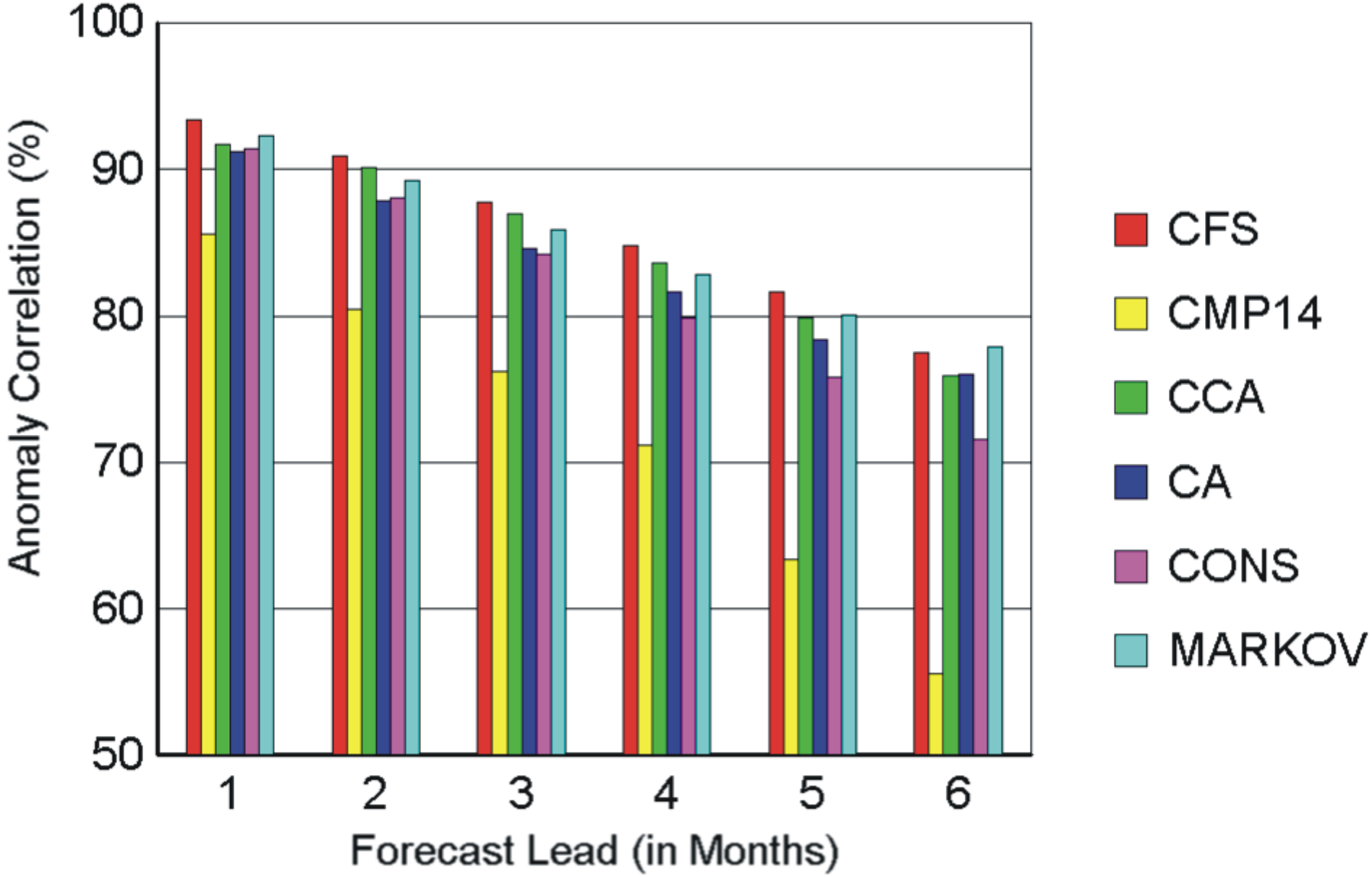
NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

Current - 2007



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

Next Generation Prototype



Skill in SST Anomaly Prediction
Nino-3.4 (DJF 97/98 to DJF 03/04)