Overview of The Environmental Modeling Center

Stephen J. Lord
Director
NCEP Environmental Modeling Center

NCEP: "where America's climate, weather, and ocean services begin"

Overview

- EMC organization
- Role of models in the forecast process
- Strategic highlights
  - Mesoscale system consolidation (WRF)
  - Next-generation
    - Global forecast model (ESMF)
    - Data assimilation (JCSDA)
  - Daily ocean forecasting (HYCOM)
  - Hurricanes (HWRF)
  - Ensembles (NAEFS, SREF, THORPEX)
  - Land surface modeling and hydrology (GAPP)
- Proposed strategic plan elements
- Summary

EMC Mission

In response to operational requirements:

- **Maintain** the scientific correctness and integrity of operational forecast systems
  - Adapt to format changes and other changing operational requirements
  - Adapt to new computing hardware
  - Monitor and ensure the integrity of operational observing systems
- **Enhance** (Test & Improve) Numerical Forecasts Through Advanced
  - Data assimilation techniques
  - Model physics (parameterizations)
  - Numerical methods
  - Computational efficiency
- **Transition and Develop Operational Numerical Forecast Systems** for:
  - Weather prediction (domestic, global, 1-15 days)
  - Ocean prediction (daily to annual, coastal to global)
  - Climate prediction (seasonal to inter-annual)

Maintain: Modify current operational system to adapt to ever-present external changes	**Enhance**: Test and improve NCEP's numerical forecast systems via scientific upgrades, tuning, additional observations, in response to user requirements	**Transition and Develop**: transform & integrate code, algorithms, techniques from research status to operational status on NCEP computers

Mission Requirements & Forecast Suite Elements

Suite Elements	Global NWP	Reg. NWP	Fire Wx Rapid Update Reg. Hurricane	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

Environmental Modeling Center

Director
Deputy Director
Team Leaders
Administrative Staff

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Marine Modeling & Analysis Branch	Mesoscale Modeling Branch	Global Climate & Weather Modeling Branch
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9	9	18

EMC Contractors

69
EMC Visiting Scientists

18

Science Community
Universities
NOAA Labs & OGP
NASA
NCAR
World NWP Centers
FAA

JCSDA
Test Beds

Environmental Modeling Center Service-Science Linkage

<u>Service</u>

Marine & Coastal Ocean DB Rao	Mesoscale Atmosphere G. DiMego	Global Climate & Weather Atmosphere & Ocean M. Iredell	<u>Science</u>
X	X	X	**Data Assimilation** Leader: J. Derber
	X	X	**Climate** Leader: H.-L. Pan

X	X	X	**Model**
			    Atmosphere/Ocean/Ice
			        Dynamics
			        Physics

X	X	X	**Land Surface/Hydrology** Leader: K. Mitchell
X	X	X	**Ensembles & Probabilistic Guidance** Leader: Z. Toth
X	X	X	**Hurricanes** Leader: N. Surgi

X	X	X	**Products**
			    Development
			    Utilization

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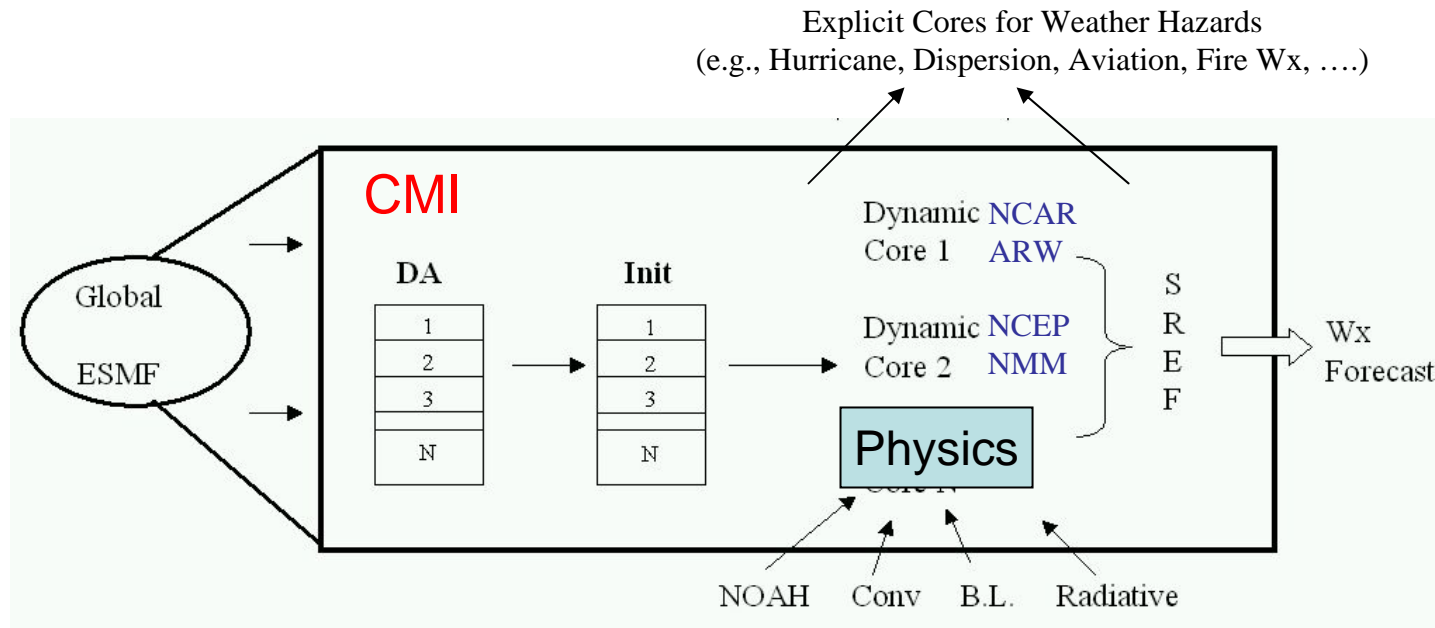- Strategic highlights
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Why Models?

"As go the models, so go the forecasts"
Impact of Models on Day 1 Precipitation Scores
(DOC GPRA goal)

Correlations
Of HPC with:

Eta: 0.99
GFS: 0.74
NGM: 0.85
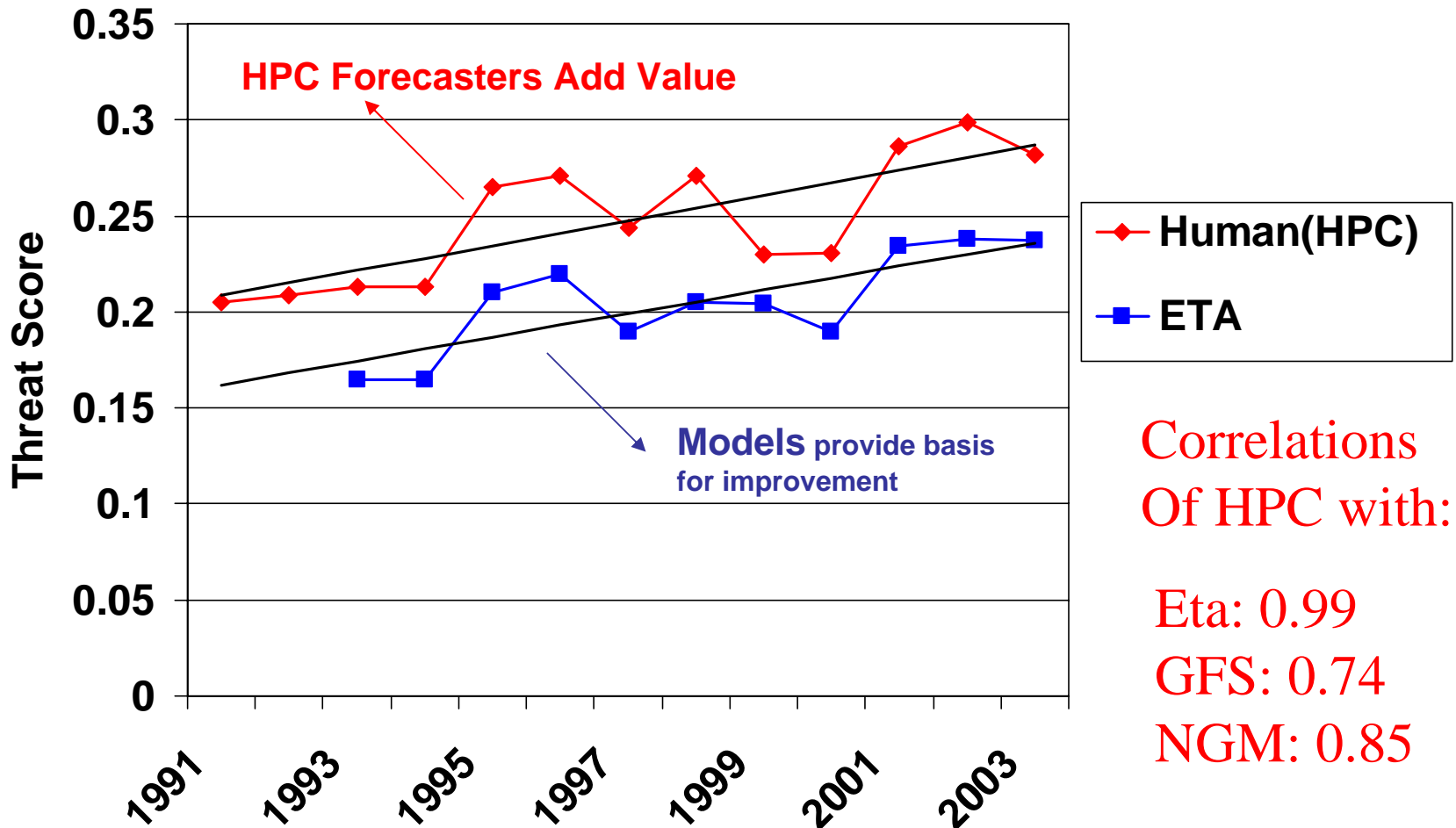
The Environmental Forecast Process
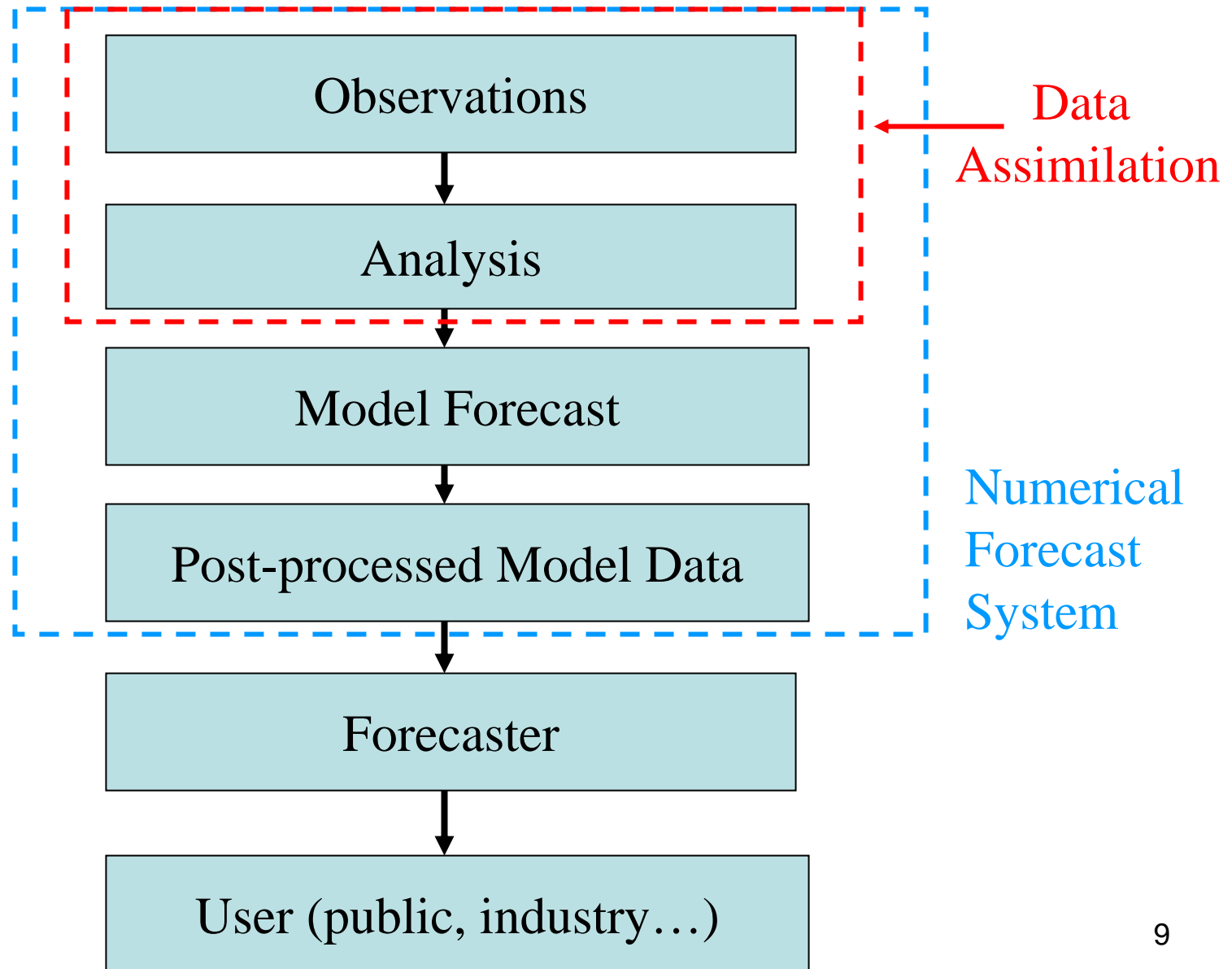
Ingredients for Improved Numerical Forecast Systems

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

Impact of Observations and Numerical Forecast System Technology Growth on Global Forecasts

NFS Tech Growth + Obs

Obs only
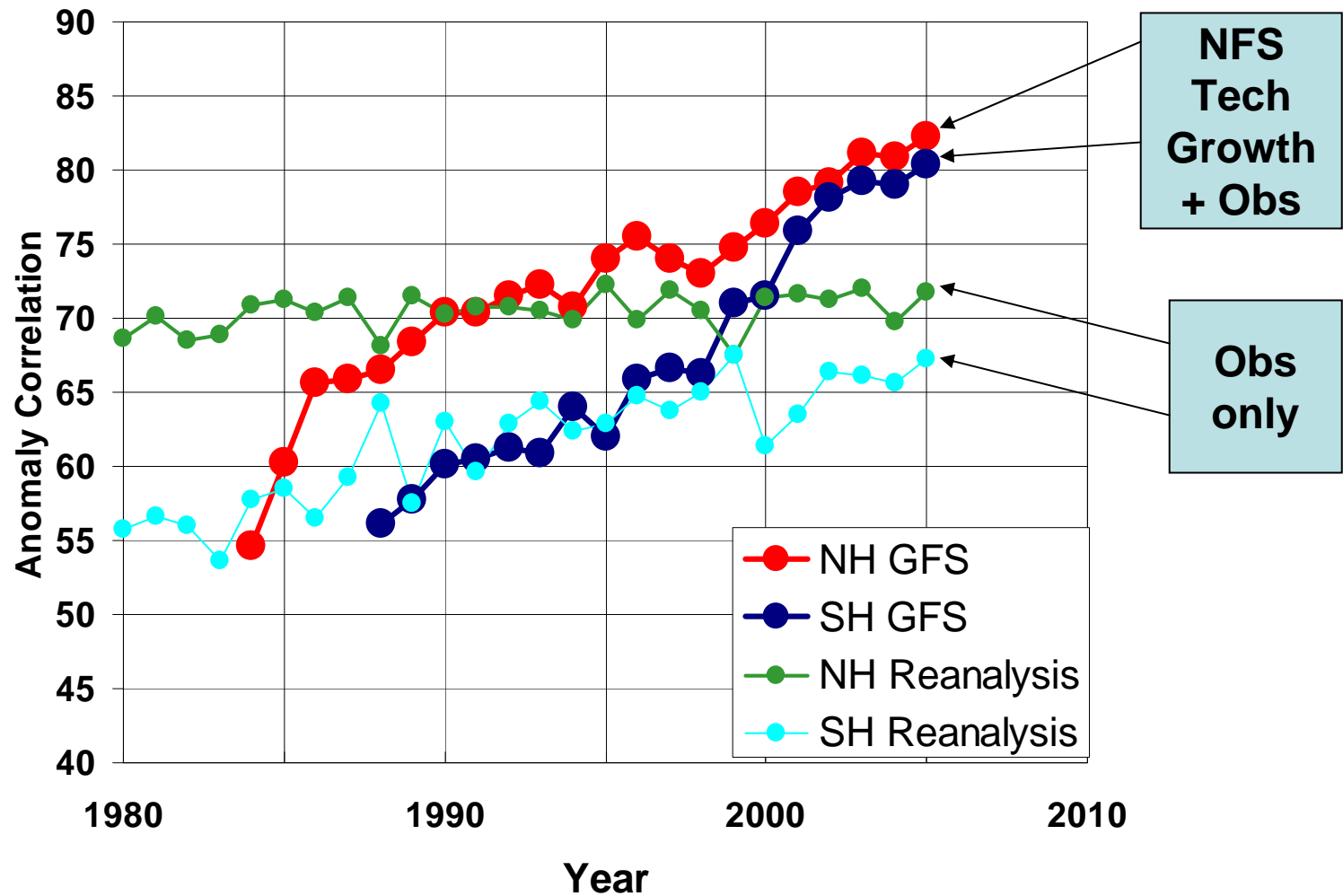
NFS Tech Growth: Computing Data Assim. Models Ensembles

- NH GFS
- SH GFS
- NH Reanalysis
- SH Reanalysis

Anomaly Correlation

Year

NCEP Production Suite
Weather, Ocean & Climate Forecast Systems
Version 3.0 April 9, 2004

Strategic Highlights

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WRF

Explicit Cores for Weather Hazards
(e.g., Hurricane, Dispersion, Aviation, Fire Wx, ….)

CMI

Global ESMF

DA — Init — Dynamic Core 1 (NCAR ARW), Dynamic Core 2 (NCEP NMM) — SREF — Wx Forecast

Physics

NOAH   Conv   B.L.   Radiative
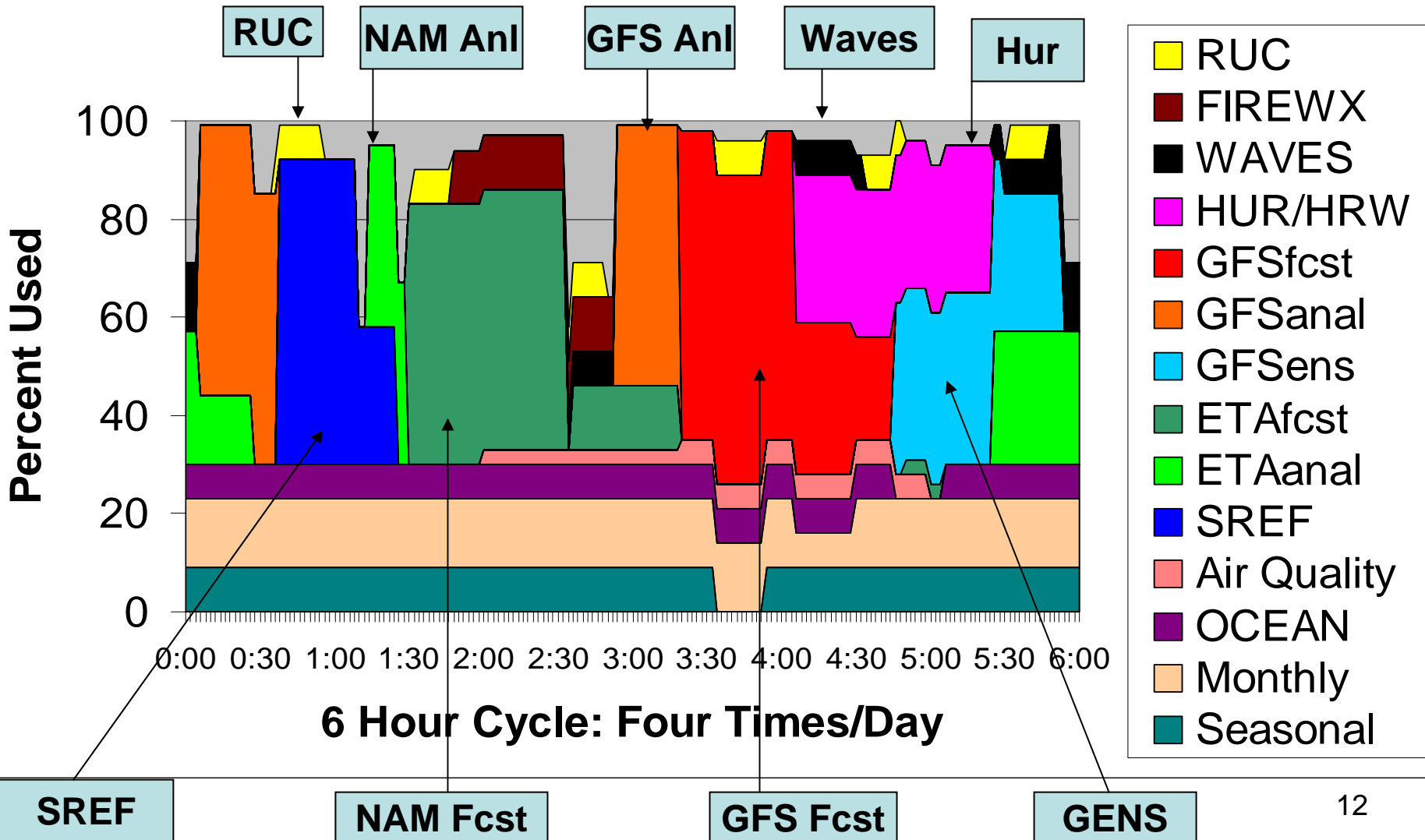
- Mesoscale community model: in development since 1997 – supported through USWRP, NOAA, DOD, FAA, UCAR, NSF

- Supported at Boulder Development Testbed Center (DTC); operational implementation at NCEP and DOD

- Same code run at DTC and NCEP

Implementation Schedule

- HiResWindow: WRF Ensemble in FY04 & FY05
- North American WRF: Operational in FY06
- Hurricane WRF: Operational in FY07*
- Rapid Refresh WRF: Operational in FY08*
- WRF SREF : Operational in FY07
- FireWeather/IMET Support and Homeland Security*

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* As resources allow

WRF at NCEP
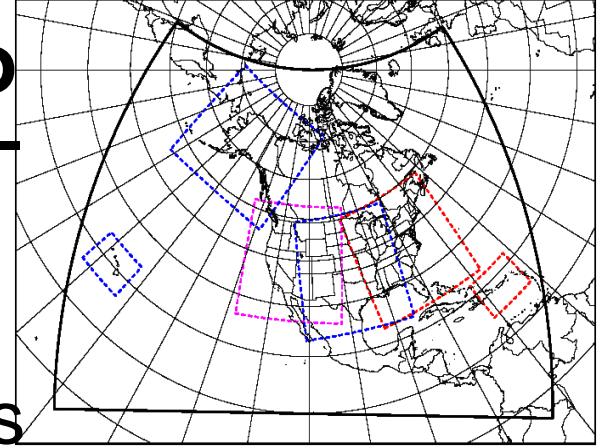
- **21 September 2004**: 8 km WRF ARW & NMM into HiRes Window runs

- **April 2004 to present**: explicit 4.5 km NMM runs for SPC/NSSL Spring Programs

- **28 June 2005**: 5-6 km HiResWindow explicit runs

- **November 2005**: Added 6-member WRF ensemble to SREF (6 = 3 ARW +3 NMM

- **June 2006**: WRF-NMM and WRF-GSI will replace Eta Model and its 3D-Var in North American Mesoscale (NAM) runs

2006 NCEP Production Suite Atmospheric Model Dependencies
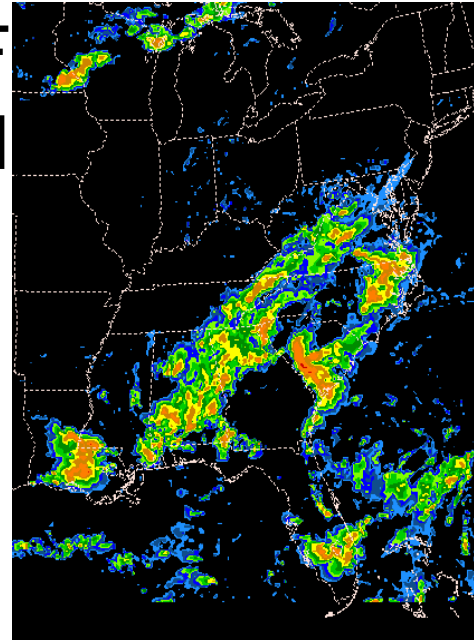
2007 NCEP Production Suite Atmospheric Model Dependencies
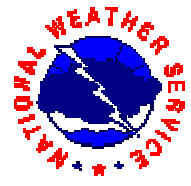
GENS

Hurricane WRF

GGSI

GFS

SREF — WRF-NMM / WRF-ARW / ETA / RSM

Dispersion

CFS

RGSI NAM - WRF

Sev Wx — WRF-NMM / WRF-ARW

Chem WRF* Air Quality

NOAH Land Surface Model

Rapid Refresh WRF
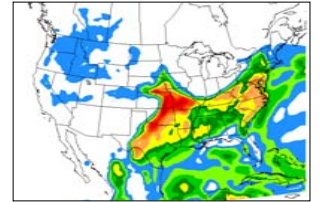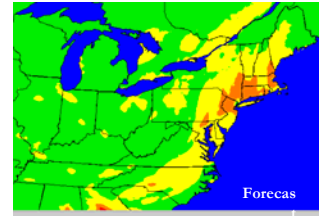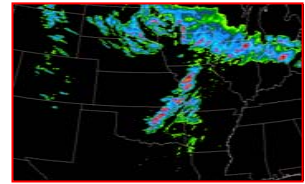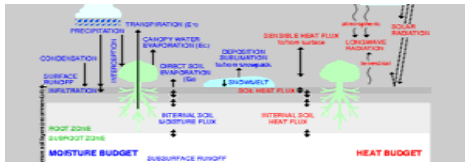
L D A S

*FY08

Strategic Highlights
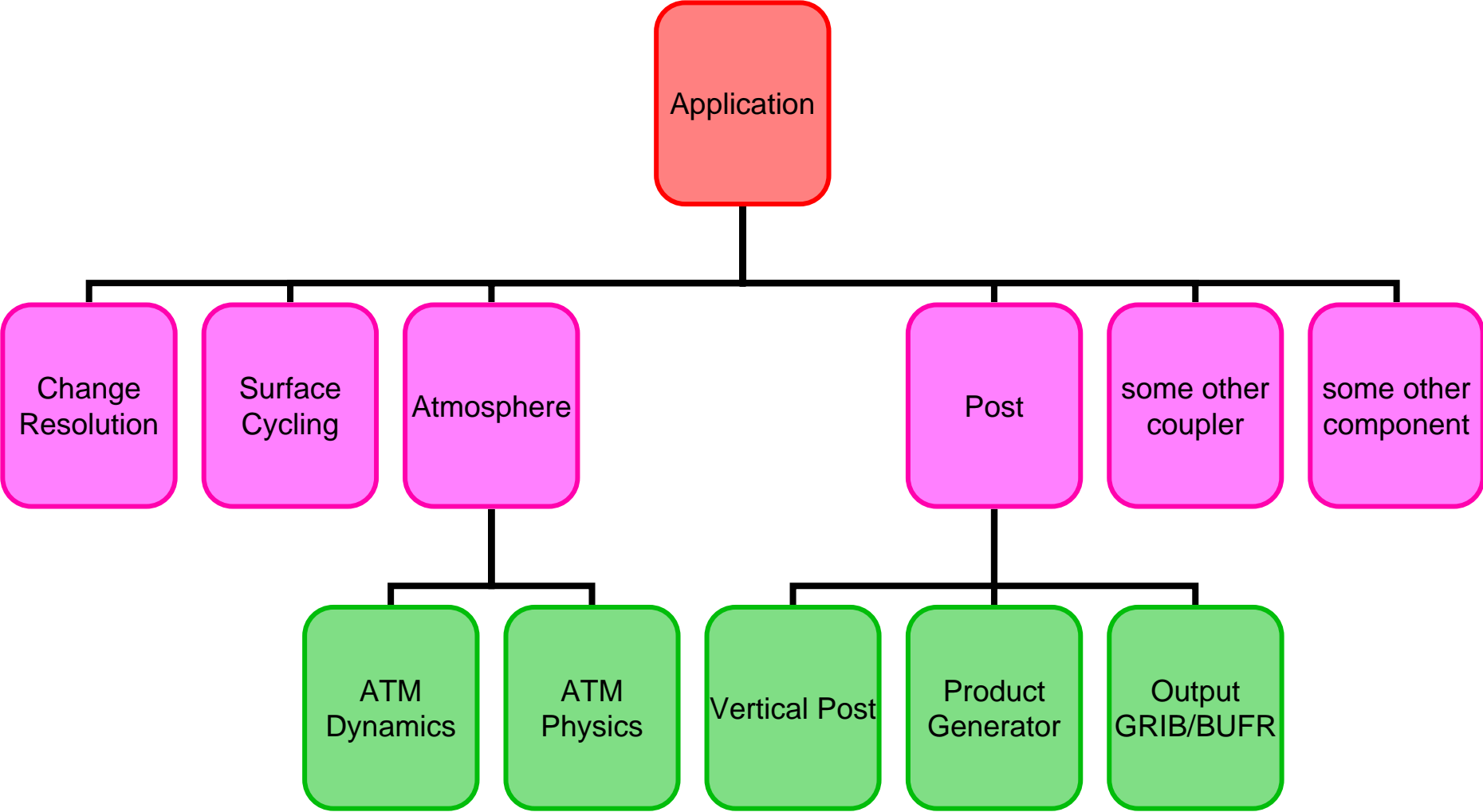
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ESMF

Earth System Modeling Framework

ESMF Component Framework

# Next Generation Global Model Development EMC, ESRL

- Upgrades to current GFS
  - Hybrid sigma-theta vertical coordinate (Juang)
  - Semi-lagrangian advection (Sela)
  - Finite-element vertical discretization (Juang, Kar)
- Upscale NMM to global domain with Lat/Lon grid & Fourier filtering and ESMF compliance
  - Janjic
  - Code keeper (Black)
- Develop Fully Implicit SemiLagrangian (FISL) and SISL techniques within the NMM model structure
  - Kar
  - Janjic
- Apply "baseball" grid to NMM
  - Purser
  - Janjic
- Apply icosahedral and Fibonacci grids to Finite Volume dynamics
  - Purser
  - ESRL staff

29.11.2004. 12 UTC + 00168
Acummulated Precipitation
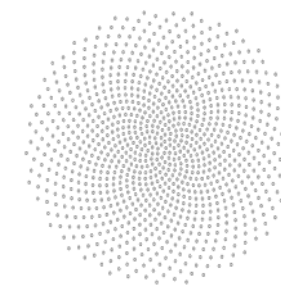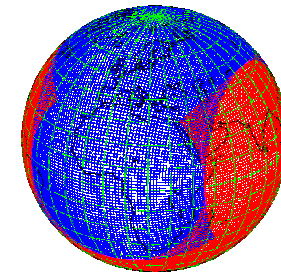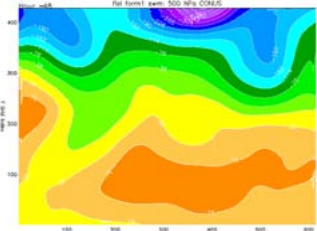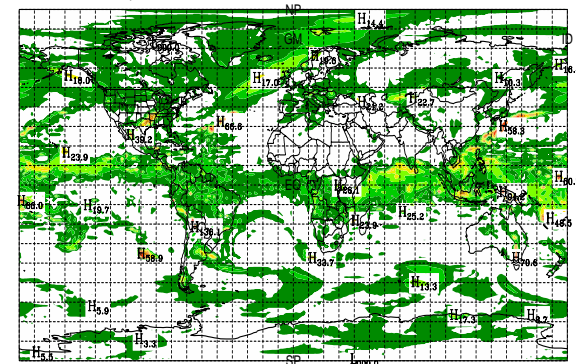
Icosahedral Geodesic Grid (362)
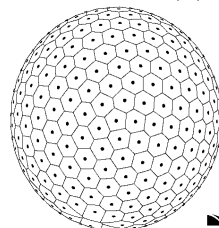
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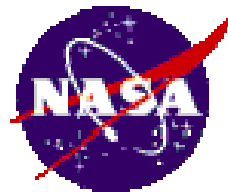# Joint Center for Satellite Data Assimilation

John LeMarshall - Director

Stephen J. Lord (NCEP/EMC)

Jim Yoe (NESDIS/ORA)

L.P. Riishojgaard (NASA/GMAO)

Pat Phoebus (NRL)

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** 24

Advanced Data Assimilation Strategy and Design Considerations (NCEP/EMC, NESDIS/STAR, NASA/GMAO)

- <u>Common elements</u> promote collaboration and accelerate progress

- <u>Managed diversity</u> provides more information on system performance

- <u>Inclusive development strategy</u> required due to advanced nature of work and **"THE"** answer is unknown
  - EMC: Evolutionary approach through incremental changes → "Simplified" 4-D Var
  - GMAO: Adjoint based techniques → "Classical" 4-D Var similar to ECMWF
  - THORPEX: Revolutionary technique (Ensemble Data Assimilation) different from variational approach

- <u>Disciplined code management</u> is essential for progress
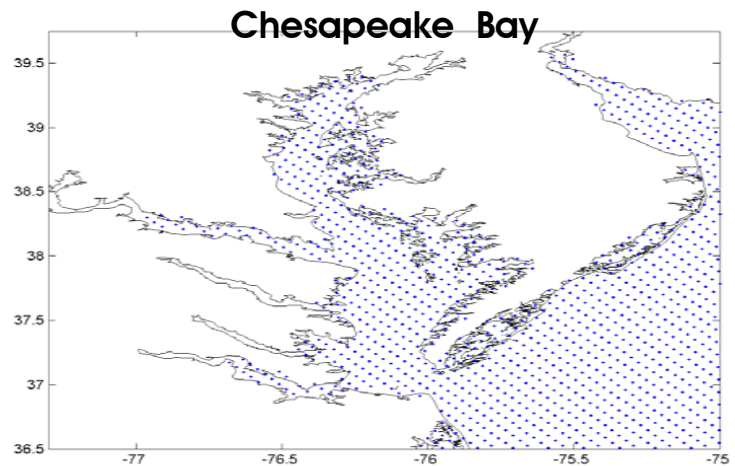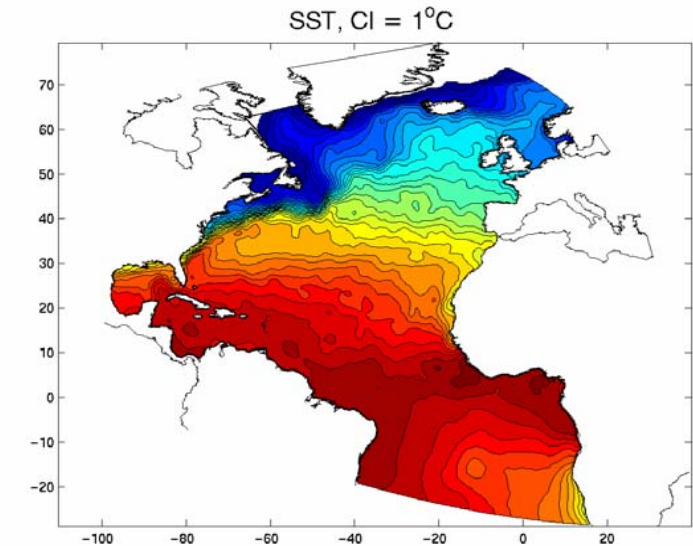
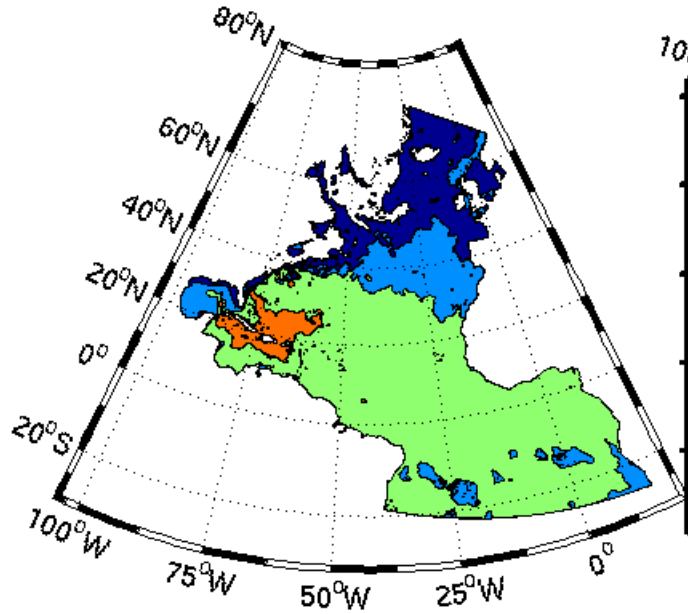# Strategic Highlights

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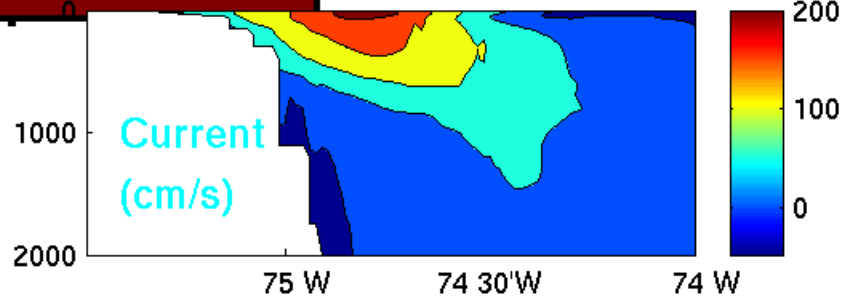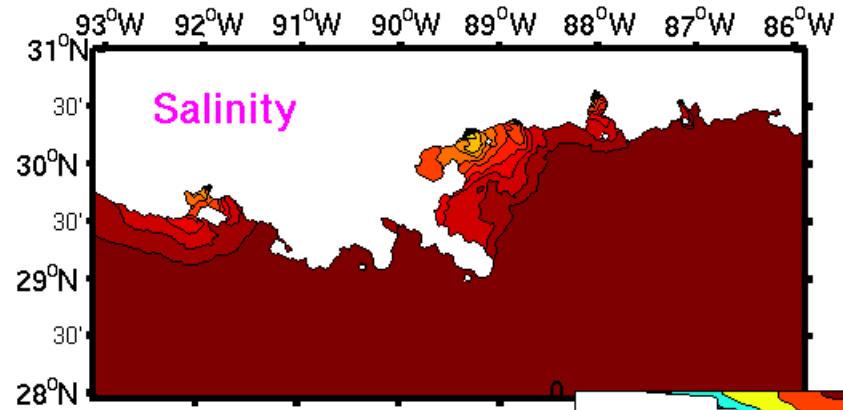- Land surface modeling and hydrology (GAPP)

US GODAE: Global Ocean Prediction with HYCOM Operational December 2005

SST, CI = 1°C

- Goal: to develop and demonstrate real-time, operational, high resolution ocean prediction systems for the Global Oceans and Basins

- NCEP Partners with

  - University of Miami/RSMAS

  - NRL Stennis, NRL Monterey, FNMOC

  - NOAA PMEL, AOML

  - Los Alamos National Laboratory

  - Others (international, commercial)

- Hybrid isopycnal-sigma-pressure ocean model (called Hybrid Coordinate Ocean Model – HYCOM)

- Funded FY 2003-2007 by NOPP

Chesapeake Bay

Atlantic Ocean Model Domain

Surface Elevation

Temperature

Salinity

Current (cm/s)

200

100

0

Deployment Schedule

North Atlantic

World Oceans

North-East Pacific

Hawaii

FY 2006   2007   2008

Initiate interactions with NOS on bay and estuary model boundary conditions; Initiate wave-current interactions. Storm Surge Modeling

Ecosystem Modeling

Global atmosphere-ocean Coupling and Hurricane-Ocean Coupling
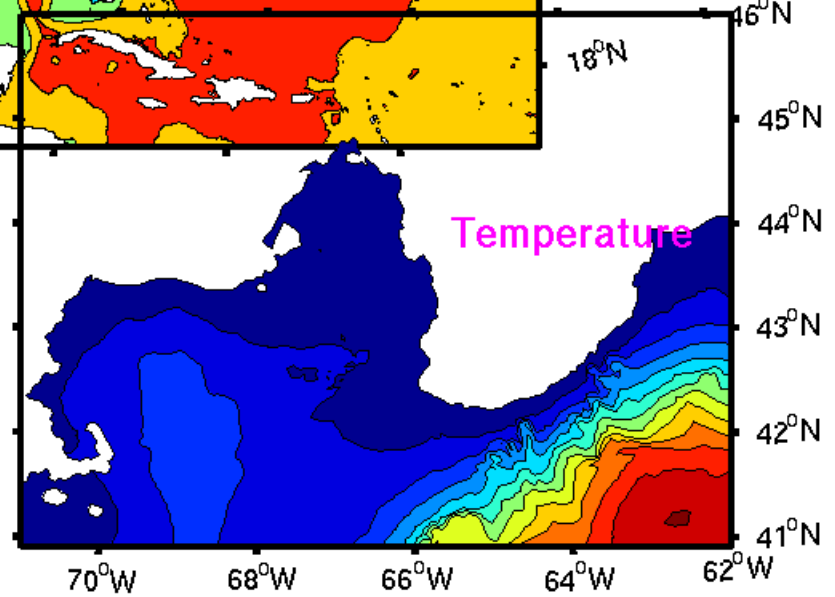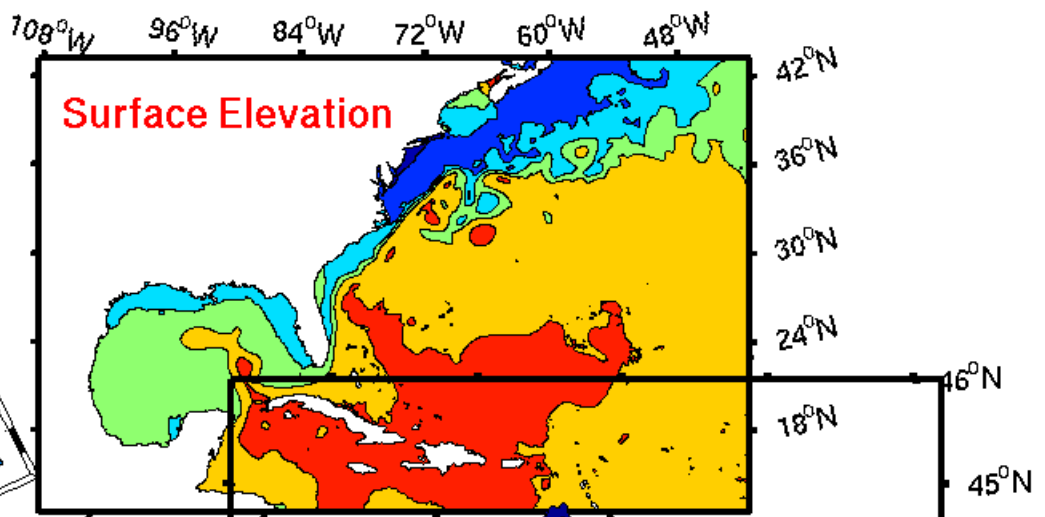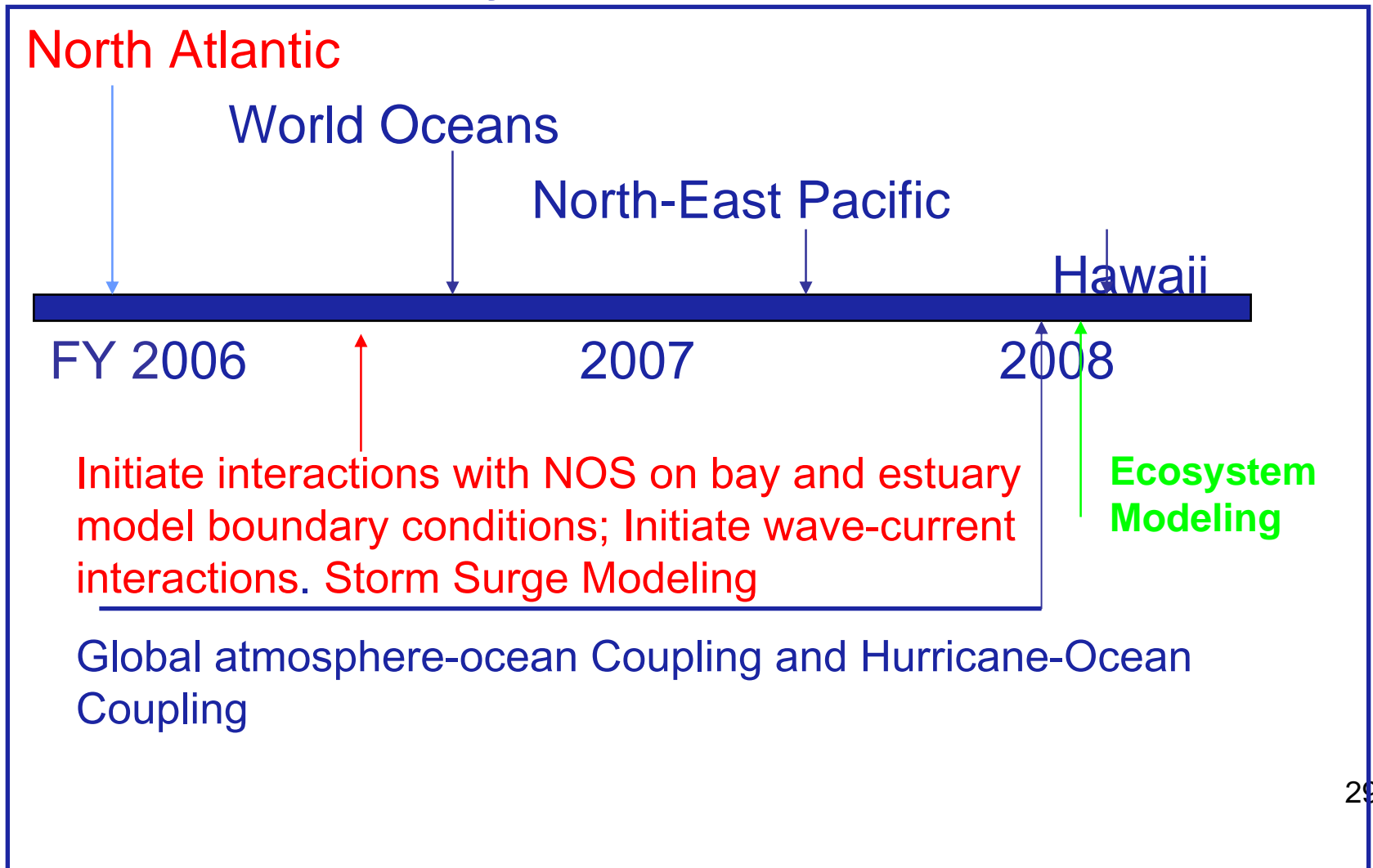
Observations

NASA-NOAA-DOD JCSDA
AMSR, GOES, AIRS, JASON, WindSat, MODIS
Advanced ODA Techniques
$1451 K (total)
$341 K (direct)

Satellite
(AVHRR, JASON, QuikSCAT)

In situ
(ARGO, Buoys, Ships)

Data Cutoff

CFS: 2 week data cutoff

RTOFS: 24 hour data cutoff

OCEAN DATA ASSIMILATION

CFS-GODAS
NCO/ODA -$446 K
EMC- $170 K
NOPP-JPL (ECCO)- $34 K

Shared history, coding, and data processing

RT-OFS-GODAE
NOPP- $285 K
EMC- $350 K

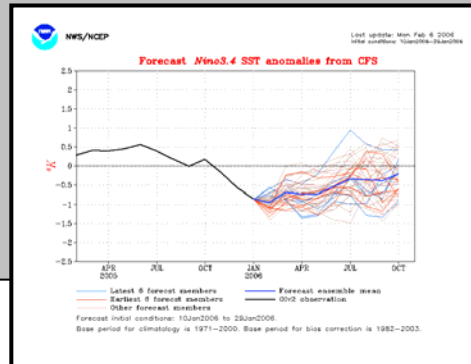**CLIMATE FORECAST**   **OCEAN FORECAST**

MOM-3 → MOM-4 → HOME   **OPNL OCEAN FORECASTS**   HYCOM → HOME

Climate Forecast System

Real-Time Ocean Forecast System
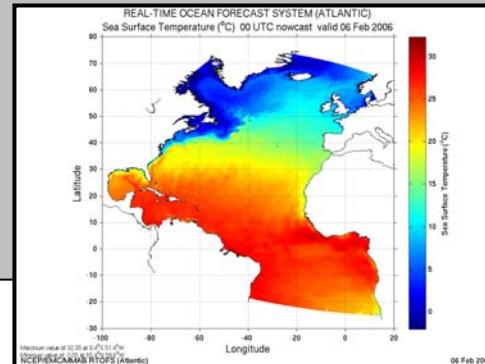
30

http://cfs.ncep.noaa.gov/   http://polar.ncep.noaa.gov/ofs/

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The Hurricane Program

- Highly visible forecasts
  - Protection of life & property
  - Numerical products provide "guidance" for forecasters
  - Extremely competitive
    - Met Office
    - Navy
    - ....
- Global system (GFS) & regional model (GFDL)
  - Annual upgrades
  - Implementation before 1 June of each year
- USWRP support critical for operational system
- Recent beneficiary of supplemental $1 M

Operational GFDL Model
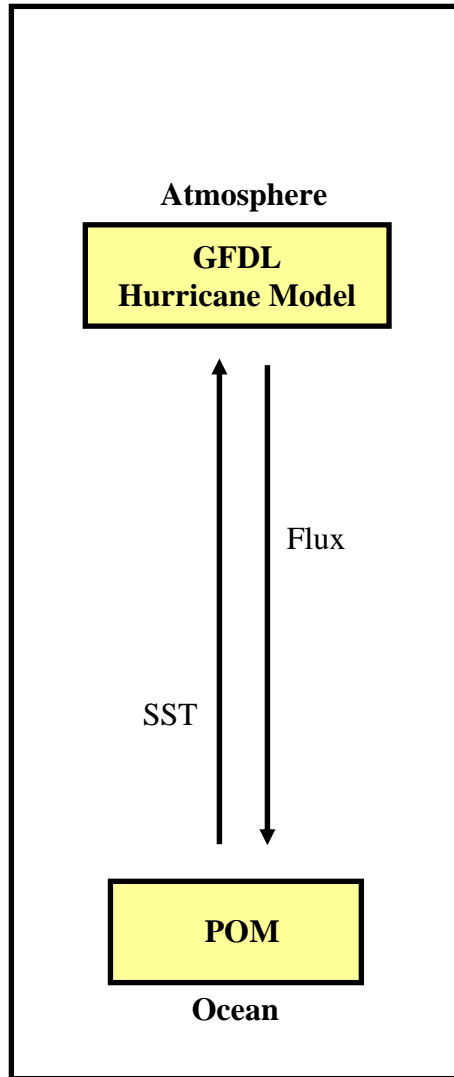
Future Coupled Hurricane-Wave-Ocean Model

URI & U. Miami partnerships

Hurricane-Wave-Ocean-Surge-Inundation Coupled Models
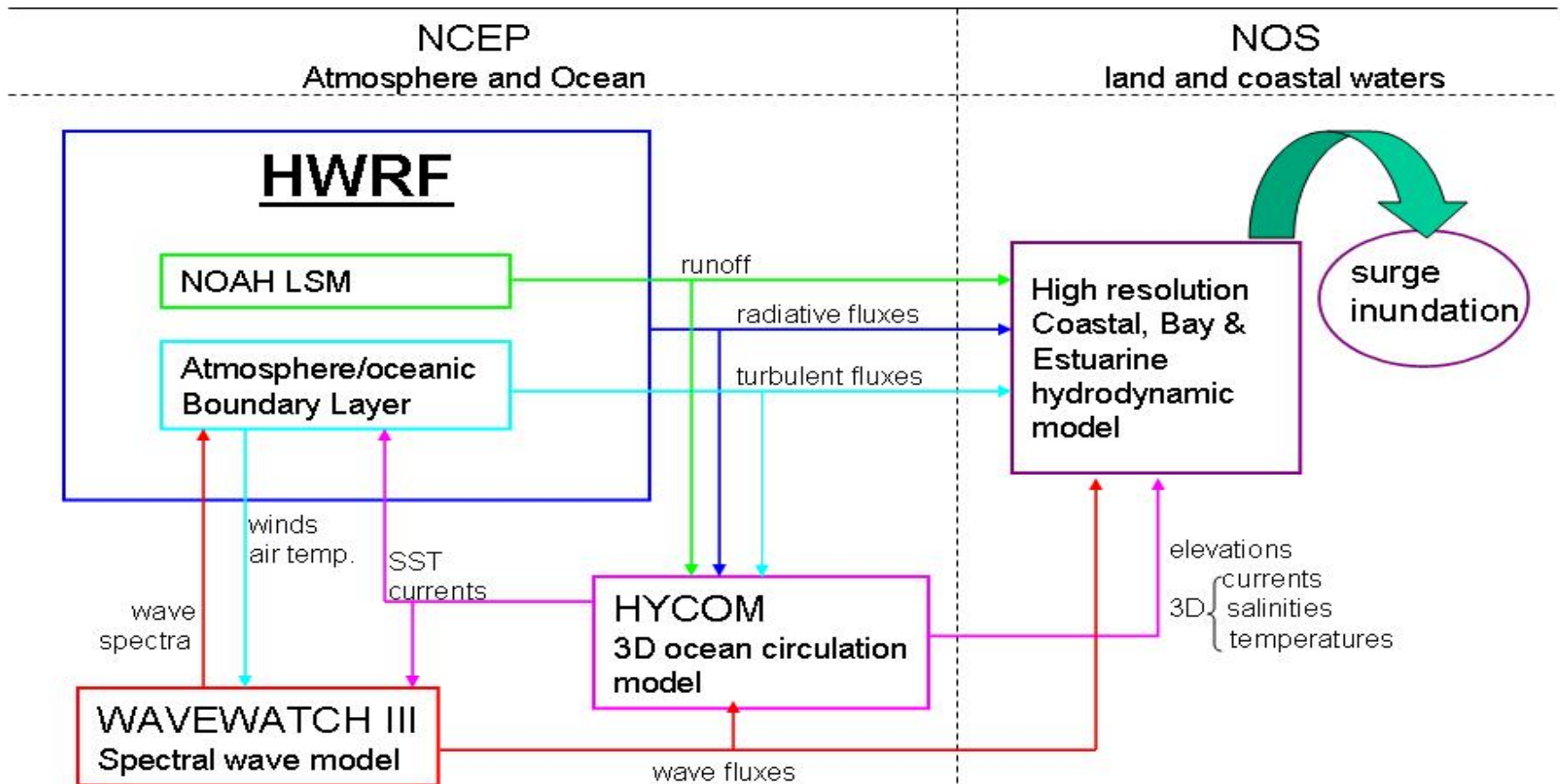
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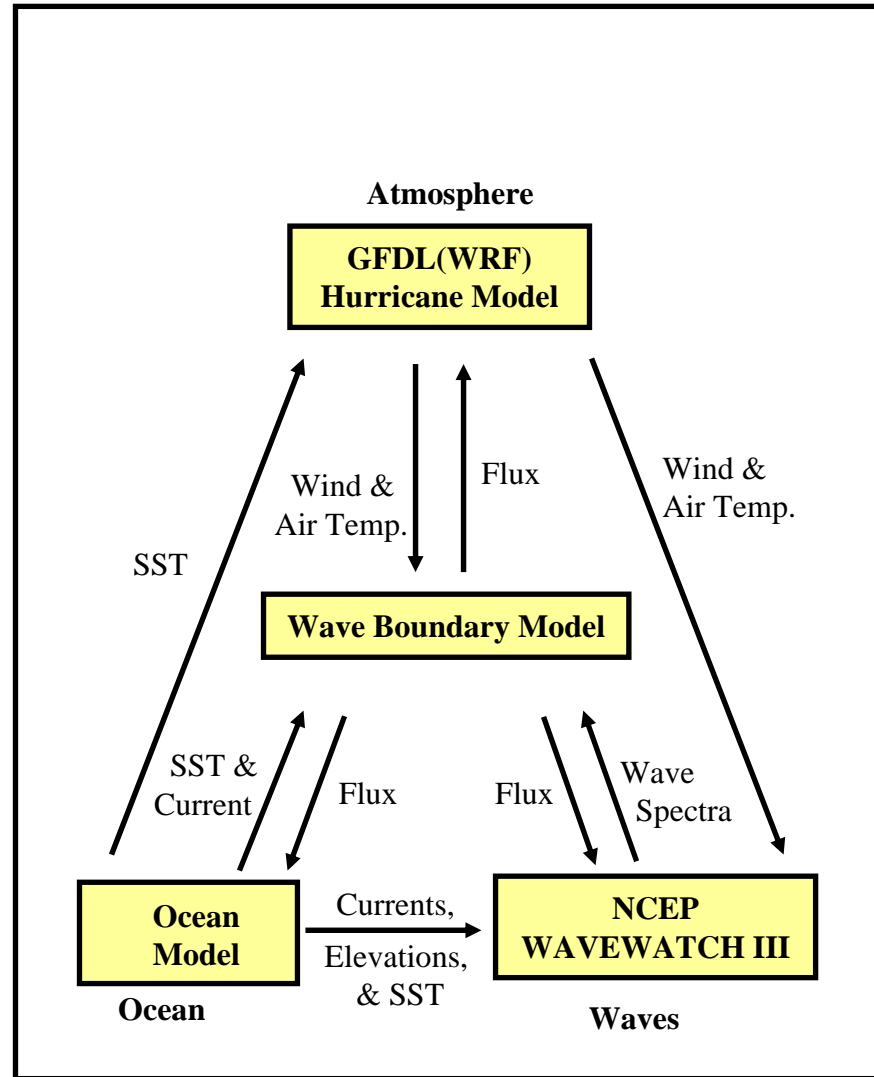- Land surface modeling and hydrology (GAPP)

NORTH AMERICAN ENSEMBLE FORECAST SYSTEM (NAEFS)

International project to produce operational multi-center ensemble products

- Combines global ensemble forecasts from Canada & USA
  - 40+ members per cycle, 2 cycles per day from MSC & NWS
    - 6-hourly output frequency (instead of current 12-hourly)
    - Replaces current 26 members once a day setup

- Generates products for
  - Intermediate users
    - Weather forecasters at NCEP Service Centers (NWS)
  - Specialized users
    - E.g., hydrologic applications in all three countries
  - End users
    - E.g., forecasts for public distribution in Canada (MSC) and Mexico (NMSM)

- Prototype ensemble component of THORPEX Global Interactive Forecast System (GIFS)
  - Operational outlet for THORPEX research using THORPEX Interactive Grand Global Ensemble (TIGGE) archive
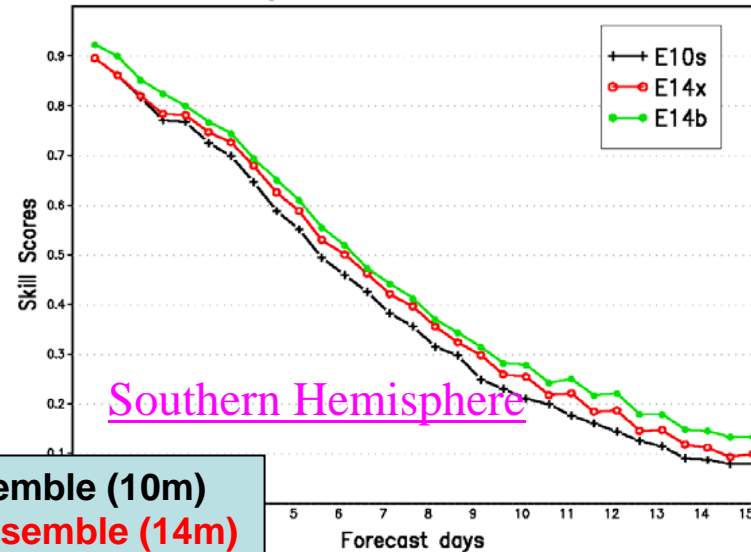
NAEFS Ensemble: Improved Probabilistic Skill

Northern Hemisphere 500 mb Height (ROC area)
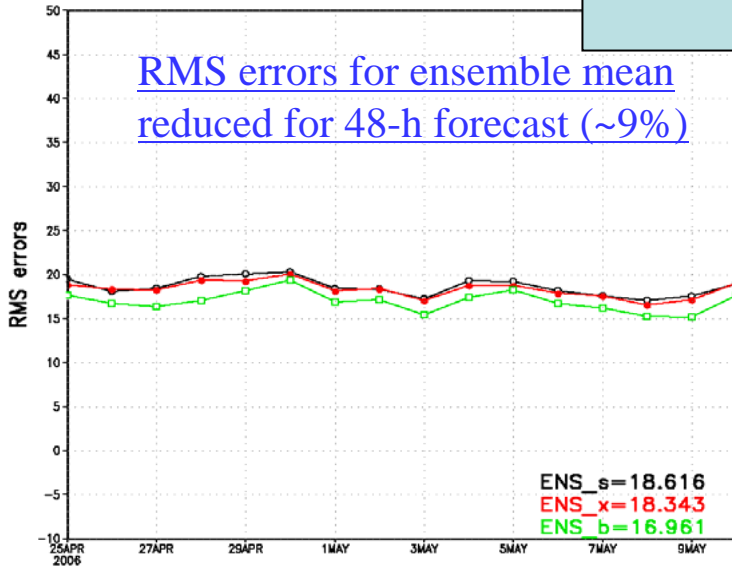Average For 20060425 – 20060510
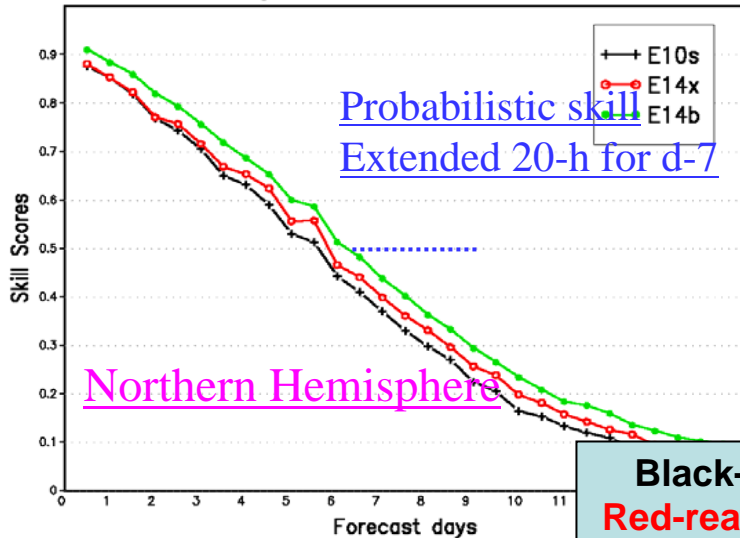
Probabilistic skill
Extended 20-h for d-7

Northern Hemisphere

Southern Hemisphere 500 mb Height (ROC area)
Average For 20060425 – 20060510

Southern Hemisphere

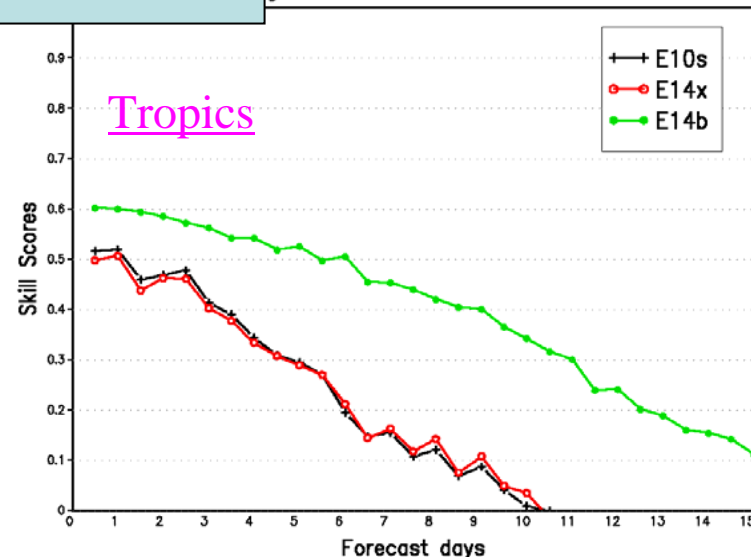**Black-operational ensemble (10m)**
Red-real time parallel ensemble (14m)
Green-real time parallel ensemble after
bias correction (14m)
16 Cases

NH 500 mb Geopotential Height at d...
for 00Z25APR2006 – 00Z10MAY200...

RMS errors for ensemble mean
reduced for 48-h forecast (~9%)

ENS_s=18.616
ENS_x=18.343
ENS_b=16.961

...cal 500 mb Height (ROC area)
...ge For 20060425 – 20060510

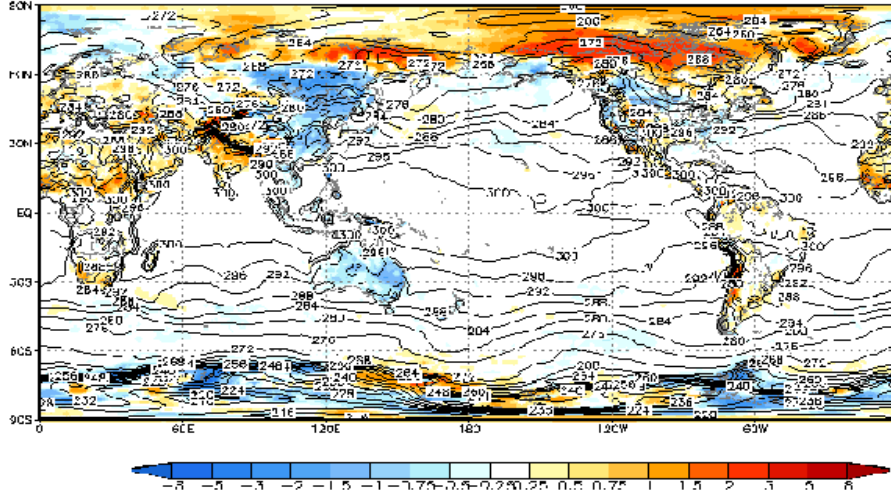Tropics

2 meter temperature: **120** hours forecast (ini: 2006043000)

Shaded: left – uncorrected   right – after bias correction

Ensemble Mean Fcst. (contour, K)
Bias Estimation (shaded, K)

Bias Corrected Ensemble Mean Fcst. (contour, K)
Bias Estimation (shaded, K)
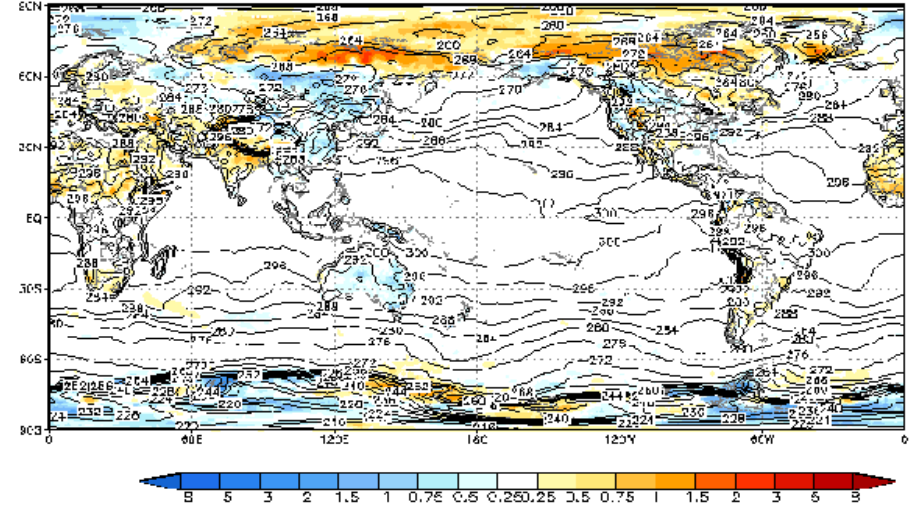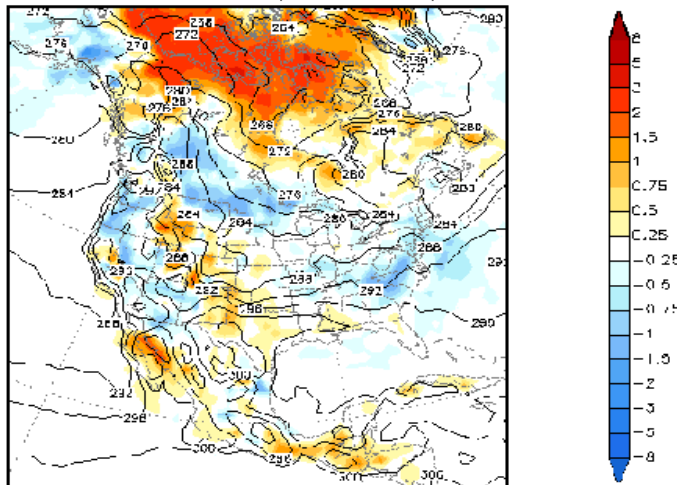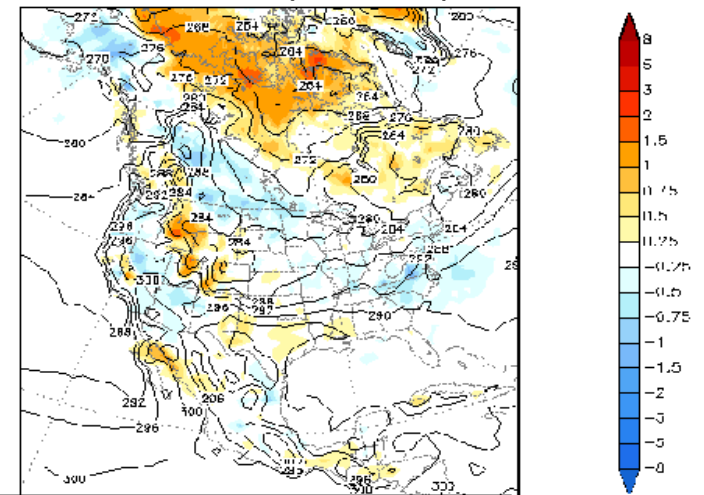
NAEFS Region Ensemble Mean Fcst. (contour, K)
Bias Estimation (shaded, K)

NAEFS Region Bias Corrected Ensemble Mean Fcst. (contour, K)
Bias Estimation (shaded, K)

Bias reduced approximately 50% at early lead time

RMS errors improved by 9% for d0-d3

NAEFS Performance Review

Appendix 6

KEY PERFORMANCE MEASURES

Improvement in Ensemble Forecasts			
Requirement		**Threshold**	**Actual** **25Apr-10May06**	**Variance**
Ensemble Mean 3-14 Day Lead Time	Bias Reduction (%)	50%	30-70%	Met or exceeded in Tropics & up to D3 elsewhere; slightly below otherwise
	RMS Error Reduction (%)	10%	Up to 10%	Met up to D3, below expected D4 and beyond
Improvement in Ensemble-based Probabilistic Forecasts	3 Day	6 Hours	12 hrs	Exceeded
	7 Day	12 Hours	16 hrs	Exceeded
	10 – 14 Days	24 Hours	48 hrs	Exceeded

SREF Enhancement with 6 WRF-based Members

RMS Error
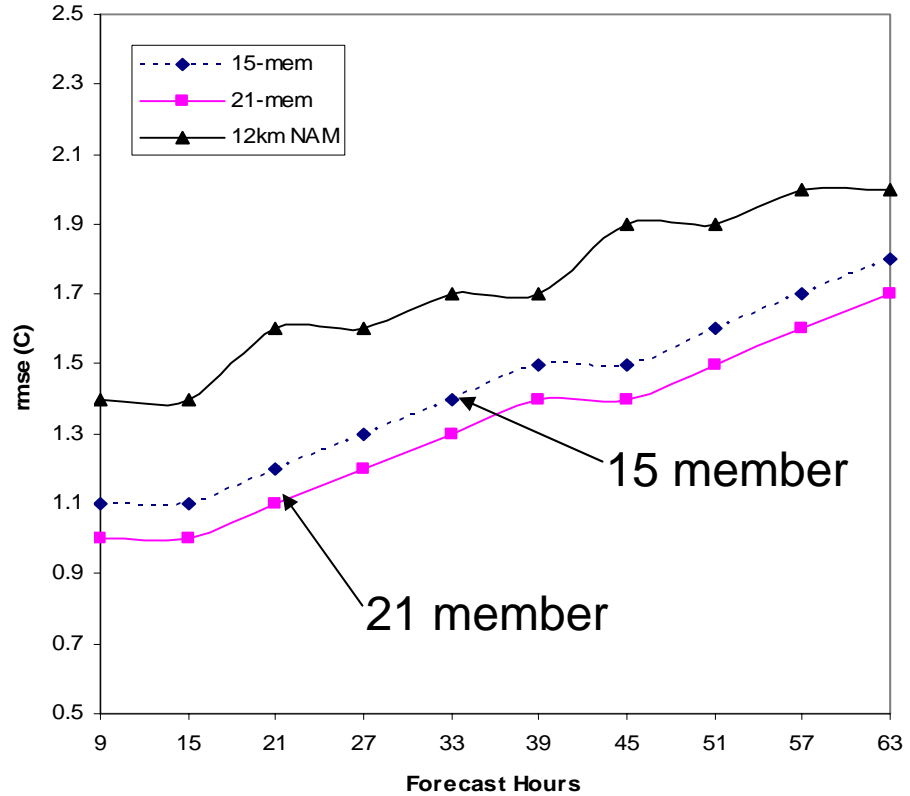
Chance that truth is outside ensemble range

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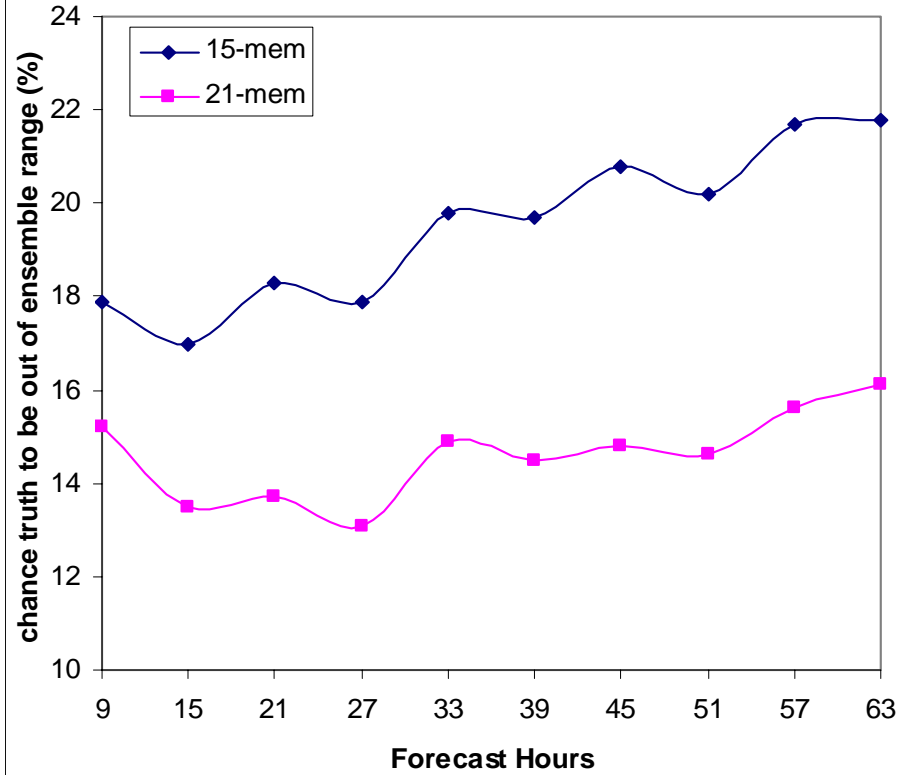- Daily ocean forecasting (HYCOM)
- Hurricanes (HWRF)
- Ensembles (NAEFS, SREF, THORPEX)
- Land surface modeling and hydrology (GAPP)

NOAH LAND-SURFACE MODEL

NCEP · OSU · Air Force · Office Of Hydrology

ATMOSPHERIC FORCING (near surface)
- PRECIPITATION
- TEMPERATURE
- HUMIDITY
- SURFACE PRESSURE
- WIND

RADIATION FORCING (at surface)
- DOWNWARD SOLAR
- DOWNWARD LONGWAVE
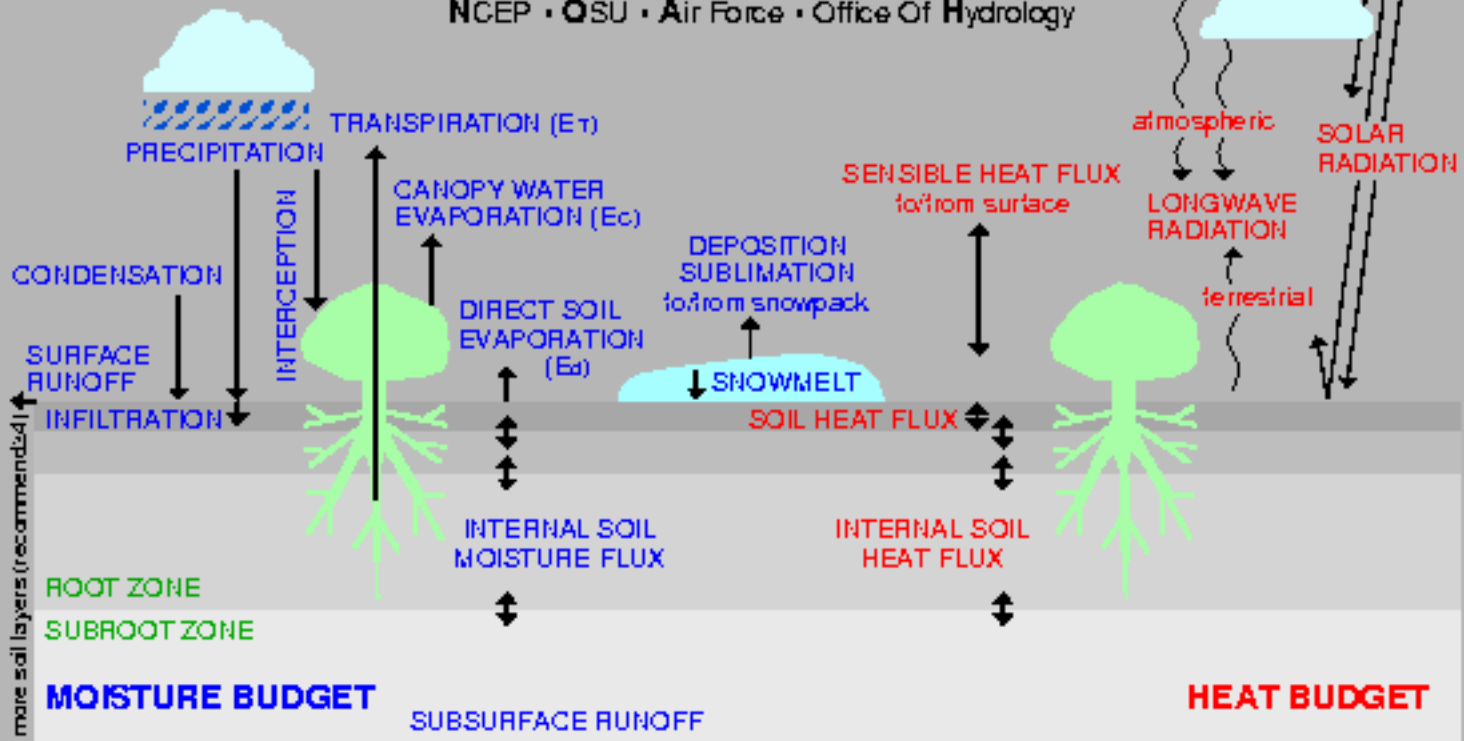
STATE VARIABLES
SKIN TEMPERATURE   CANOPY WATER
SOIL TEMPERATURE   SNOW WATER
SOIL WATER   SNOW DENSITY
SOIL ICE

SURFACE PARAMETERS
VEGETATION TYPE   ROUGHNESS
GREEN VEGETATION FRACTION   ALBEDO
SOIL TEXTURE   SLOPE FACTOR

NLDAS Simulated River System

Upstream area [log10(km^2)]
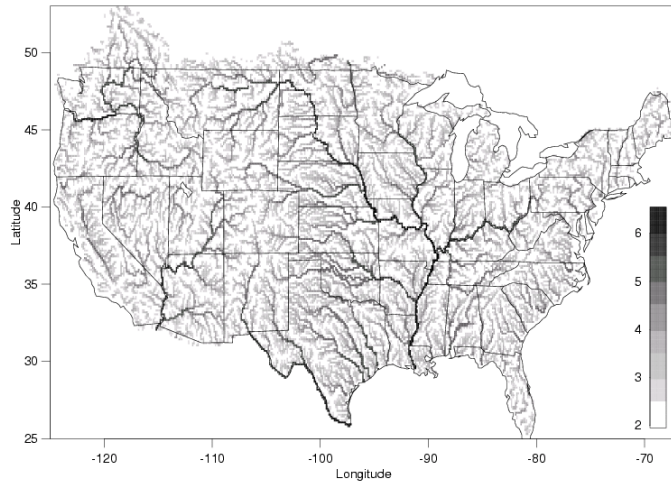
Travel time to outlet [days]
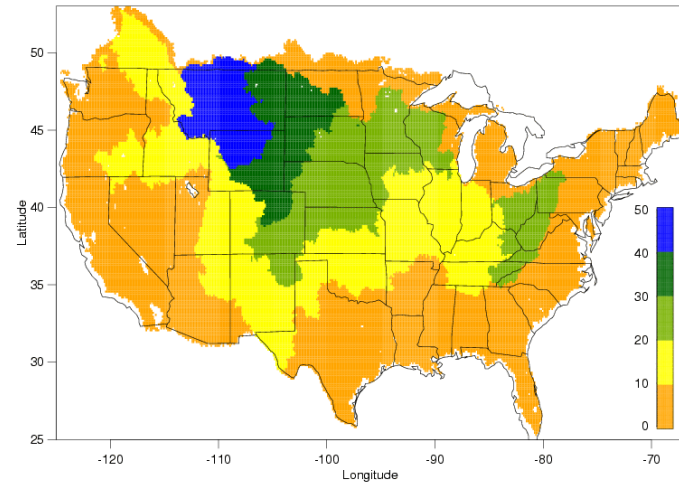
Large River basins
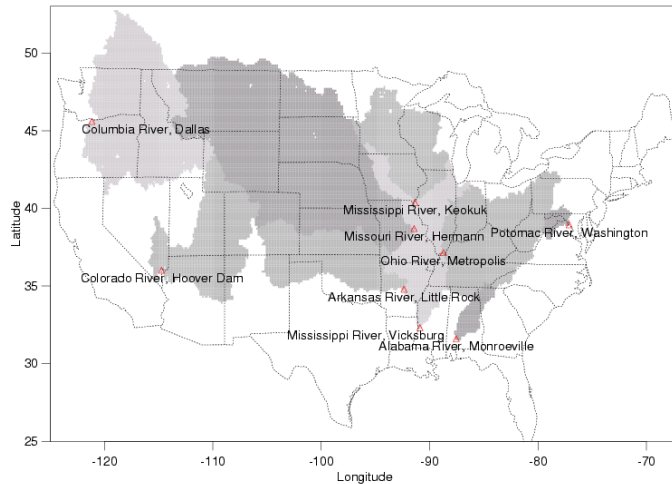
River flow direction mask

43
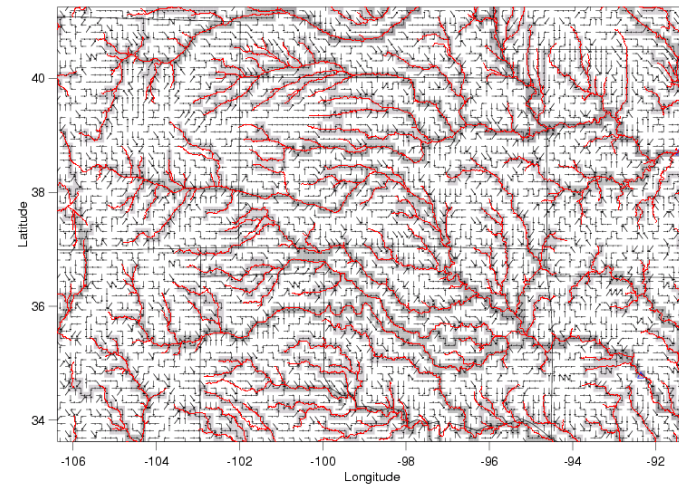
LIS: The Land Information System A joint NASA-NCEP Partnership

- A robust and flexible land/hydrology model infrastructure and testbed to support multiple needs:
  - **Leverages the pilot projects of NLDAS and GLDAS**
  - **Multiple space and time scales**
    - 1-km to 2-deg resolution globally
    - Integrations of a few days to multiple years
    - Multiple land models: Mosaic, Noah, VIC, CLM, Catchment
    - Fast multi-processing computation design
  - **Support multiple programs:**
    - ESMF: Earth System Modeling Framework
    - JCSDA: Joint Center for Satellite Data Assimilation
    - WRF: Weather Research and Forecast Model
  - **Examples:**
    - LIS coupled to WRF model via ESMF for execution of Noah LSM in WRF
  - **Needs/Opportunties**
    - Add JCSDA Community Radiative Transfer Model (CRTM)
    - Add community Kalman Filter data assimilation component
    - **Add stable "core" funding of NASA-NOAA Research & Operations Transition**

Overview

- EMC organization
- Role of models in the forecast process
- Strategic highlights
  - Mesoscale system consolidation (WRF)
  - Next-generation
    - Global forecast model (ESMF)
    - Data assimilation (JCSDA)
  - Daily ocean forecasting (HYCOM)
  - Hurricanes (HWRF)
  - Ensembles (NAEFS, SREF, THORPEX)
 - Land surface modeling and hydrology (GAPP)
- Proposed strategic plan elements
- Summary

Socio-Economic Benefits of
Seamless Weather/Climate Forecast Suite

46
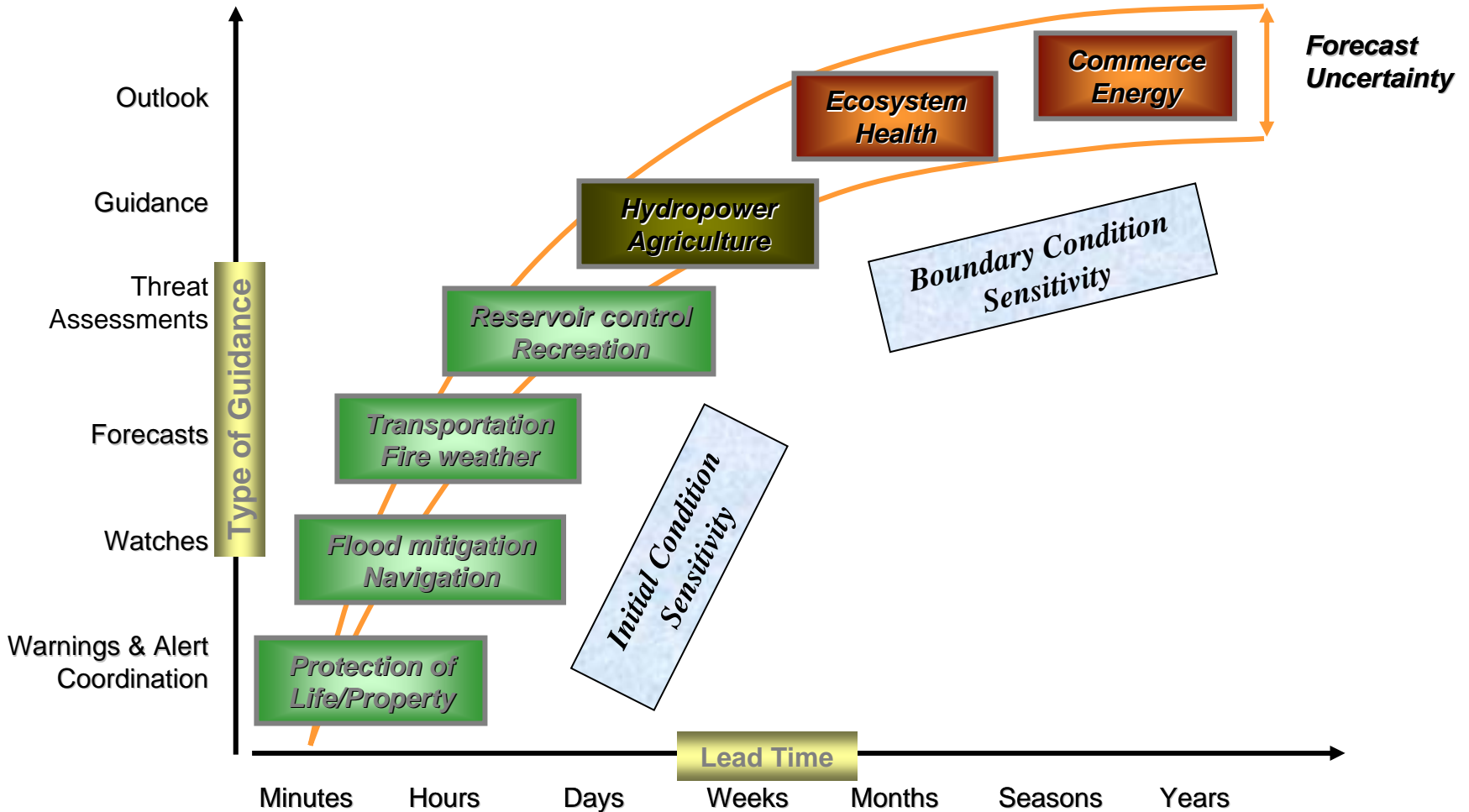
TRADITIONAL NWP PROCESS
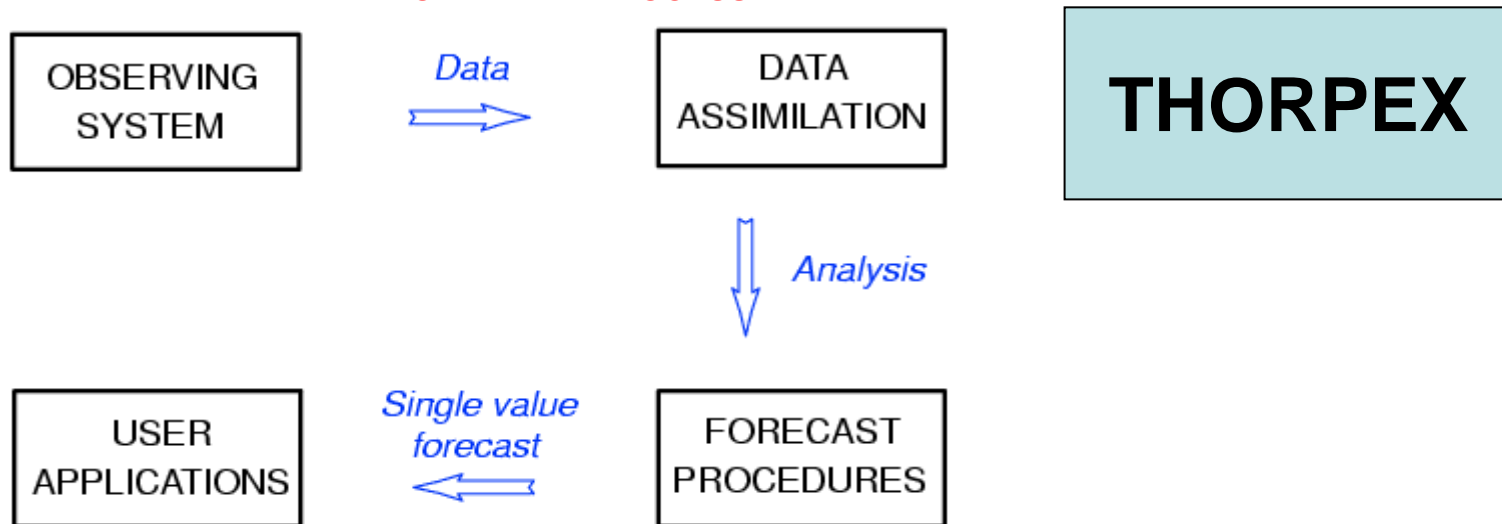
Fig. 2. Schematic diagram illustrating the one-way flow of initial value related information in a traditional NWP forecast process.
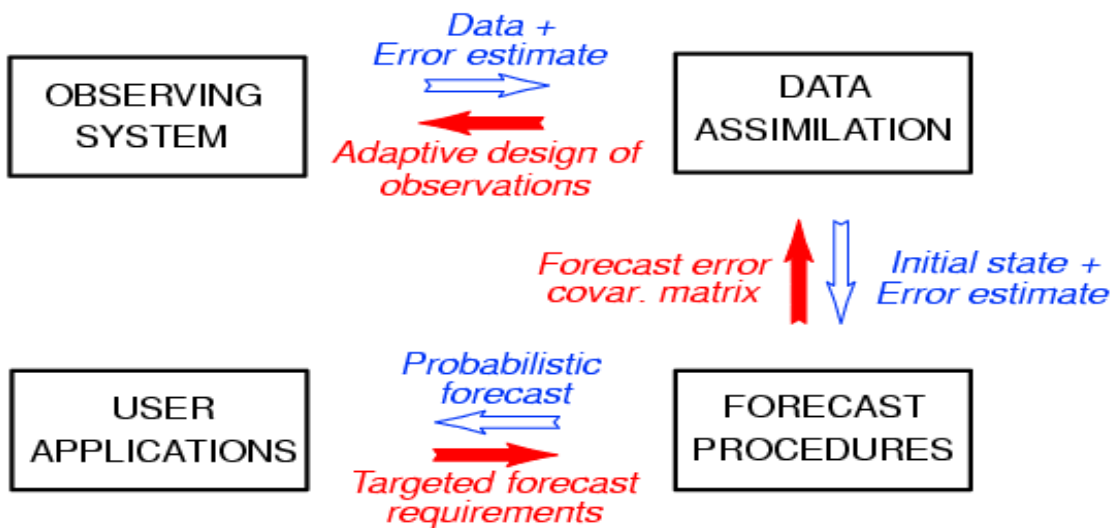
INTEGRATED NWP PROCESS

47

Fig. 4. Schematic diagram illustrating the two-way flow of initial condition related information in the proposed new, integrated NWP forecast process.

Proposed Strategic Plan Elements

- Improved Services
- Verification and Product Feedback
- Projection Prioritized Seamless Suite
- Information and Dissemination
- Spectrum of Provided Services

Improved Services

- Increased Numerical Forecast System (NFS) capabilities - examples are:
  - AOR for sensible weather
    - Dew Point
    - Maximum Temperature
    - Minimum Temperature
    - Precipitation Amount
    - Probability of Precipitation (POP 12)
    - Significant Wave Height
    - Sky Cover
    - Snow Amount
    - Temperature
    - Weather
    - Wind Direction and Speed
  - Surface transportation
  - Environmental monitoring (AQ + Atmos. Constituents)
  - Ocean (SAR, water levels)
  - Hydrology (water quality)
- Improved forecast accuracy with advanced
  - Observations processing (e.g. quality control)
  - Data assimilation (e.g. advanced techniques)
  - Model accuracy (e.g. dynamics and physics)
  - Post-processing (e.g. bias correction)
- Products characterizing all sources of forecast uncertainty
- More user-relevant products (e.g. radar and satellite view formats)
- Increased use of available observations
- Contributing to observing system design and evaluation for future systems

Verification and Product Feedback

- Verify all products
  - Maintain long term historical data base
    - Demonstrate product improvement
    - Comparison with international and domestic service providers
    - Common methodology across weather, climate, water, ocean, land applications
  - Conduct annual product review
    - Key users participate actively
    - Sets requirements and subsequent actions
    - Provides strategic direction for users (where we are going)

Projection-Prioritized Seamless Suite

- Seamless Suite of Forecast Products
  - Focus depends on forecast projection (e.g. Weather → Climate)
  - Examples are:
    - 0-24 h
      - Severe weather (precipitation, winds, temperature)
      - Sensible weather focus
      - Aviation
      - Surface transportation
      - Hazards
    - 1-3 days
      - Synoptic systems
      - Jet streams
      - Define amplitude of extreme events
      - Oceans (waves, ocean state)
    - 1-5 days
      - Hurricane track & intensity
    - 4-15 days
      - Likelihood of extreme events
      - Regional scale impacts
    - 16-60 days
      - Changes in continental-scale regimes (AO, PNA)
      - MJO and tropical forcing
    - 2-12 months
      - ENSO events
- All applications have a probabilistic component

Information and Dissemination

- "Model of the day" is not a future, scientifically supportable, solution.
- Instead, consider the following maxims:
  - Model output bias-corrected and in terms of climate anomaly
  - Information from all available sources
    - Domestic and international models
  - **Provide maximum usable information from operational NFS with three levels of information**
    - **Most likely forecast**
    - **Description of forecast uncertainty through probability density function (pdf)**
    - **Ensemble-based products for all suites**
  - Disseminate maximum user-relevant information
    - Deliver
      - Both 3-dimensional (horizontal and vertical) fields
      - Pointwise information with time series and vertical sounding capability as appropriate
      - Most likely forecast
      - Description of pdf
    - Make available for user access ("NWS Digital Services")
      - All NFS output including individual ensemble members
      - Ability for user to capture arbitrary collection of 5 dimensional information space (x, y, z, t, variable)
      - Publicly served
        » User pays for transmission capability
        » NOAA pays for load-balanced servers and disk farm

Spectrum of Provided Services

- Provide new products and services
  - In response to societal needs
    - Annual review
  - **Commensurate with available resources**
    - **Computing**
    - **Data assimilation and model personnel and technology**
    - **Observations**
  - Annual strategic presentation to upper NOAA Management
    - Environmental Modeling Program
- **Provide training services to enhance product use**
  - **Annual workshops**
  - **User guides to products**
    - **E.g.: use of pdf information**
    - **E.g.: how "most likely" product is constructed**
  - **Routinely available verification statistics**
  - **Product improvements**
- Outreach to scientific community
  - Unified Test Bed concept
    - Covers all aspects of NCEP and NOAA product suites
    - Supports transition to operations
    - Sets national guidelines for supporting research
  - NOAA NFS software fully supported to scientific community for all applications (hourly to decadal; atmosphere, ocean, land, hydrology, sea ice)
    - ESMI
- International outreach
  - Support NCEP's NFSs for international use
  - Fully documented systems with training
  - Robust retrieval of boundary condition and initial condition files for local, foreign users
  - Regular user workshops to provide information and discuss problems

Summary

- **WRF**
  - First major foray into community modeling
  - Enables consolidation of mesoscale systems
- **Next-generation global system**
  - Planned to be multi-component system with ESMF glue
  - Data assimilation techniques in collaboration with NASA/GMAO and JCSDA
- **Daily ocean forecasting (HYCOM)**
  - Provides basis for full atmosphere-ocean coupling for weather, including hurricanes
  - Opens door to marine ecosystem forecasting
- **Hurricane WRF**
  - Coupled ocean and waves
  - Already progress on hurricane intensity
- **NCEP systems**
  - Are ensemble based
  - THORPEX is providing ground-breaking studies
- **Land surface modeling and hydrology**
  - Global and domestic hydrological forecasts (drives river runoff for coastal models)
  - Terrestrial ecosystem (e.g. dynamic vegetation) impacts
- **Proposed strategic plan is aligned with NWS CONOPS**

Backup

Overview

- EMC Organization
- Performance of Global System for Weather & Climate
- Strategic highlights
    - Mesoscale system consolidation (WRF)
    - Next-generation
        - Global forecast model (ESMF)
        - Data assimilation (JCSDA)
    - Daily Ocean Forecasting (HYCOM)
    - Hurricane Forecasting (HWRF)
    - Ensembles (NAEFS, SREF, THORPEX)
    - Land Surface Modeling & Data Assimilation (GAPP)
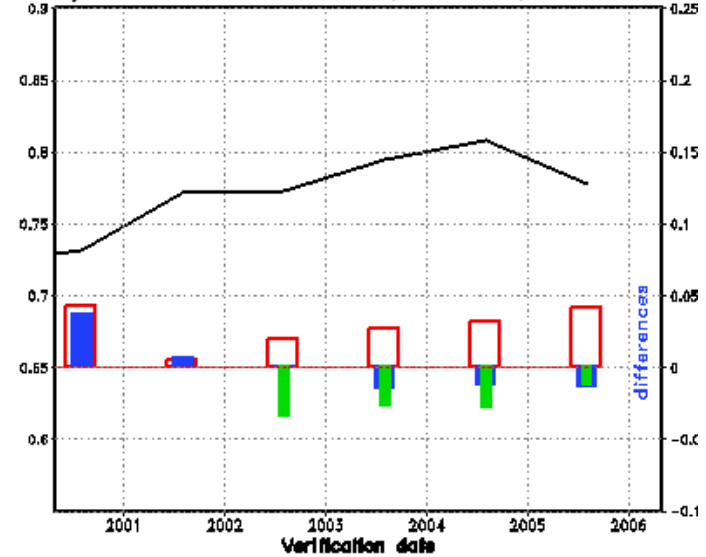- Strategic plan elements
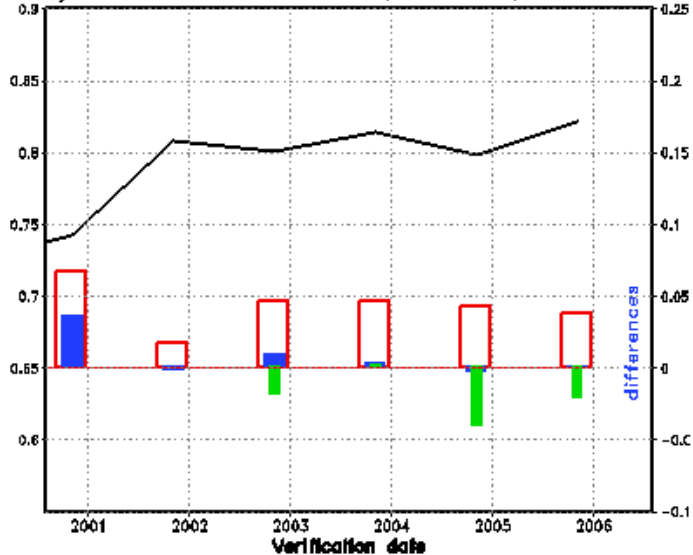- Summary
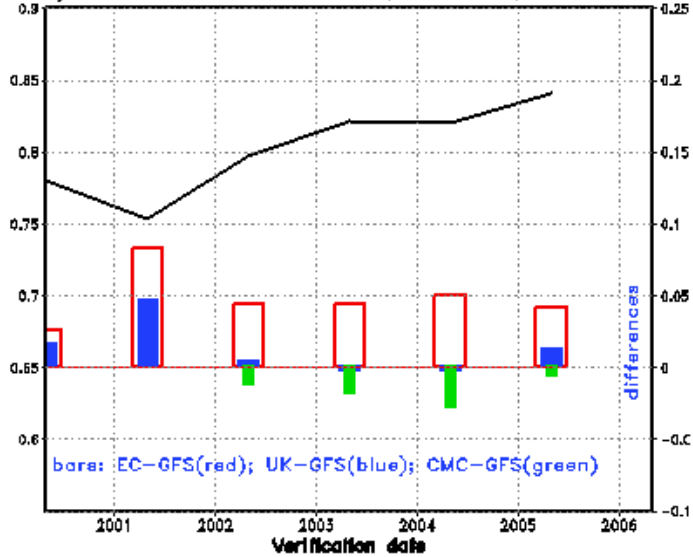
Performance Comparison
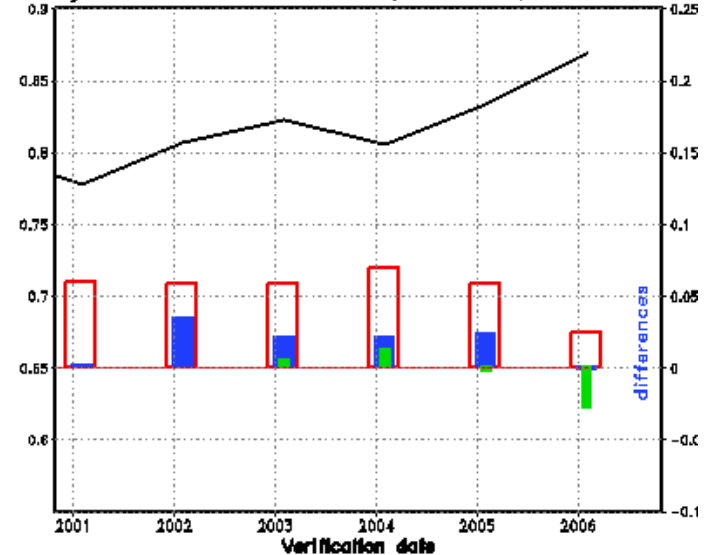
Global Models
1 July 2005 – 30 September 2005
24 – 72 h Forecasts
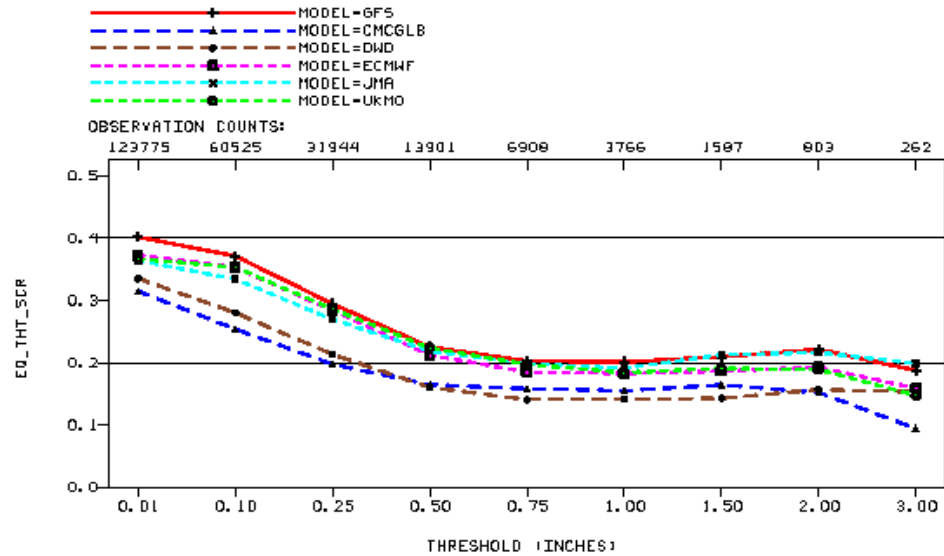
58
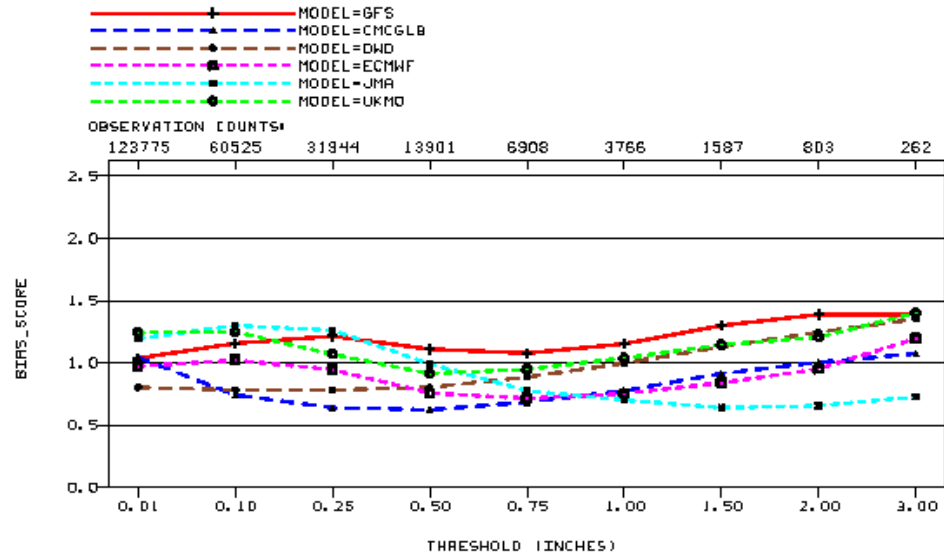
NCEP Performance Comparison Seasonal Forecasts

Raw Nino3.4 SST Correlation Skill
Annual Mean 1981-2001

wrt OIv2 1971-2000 climatology
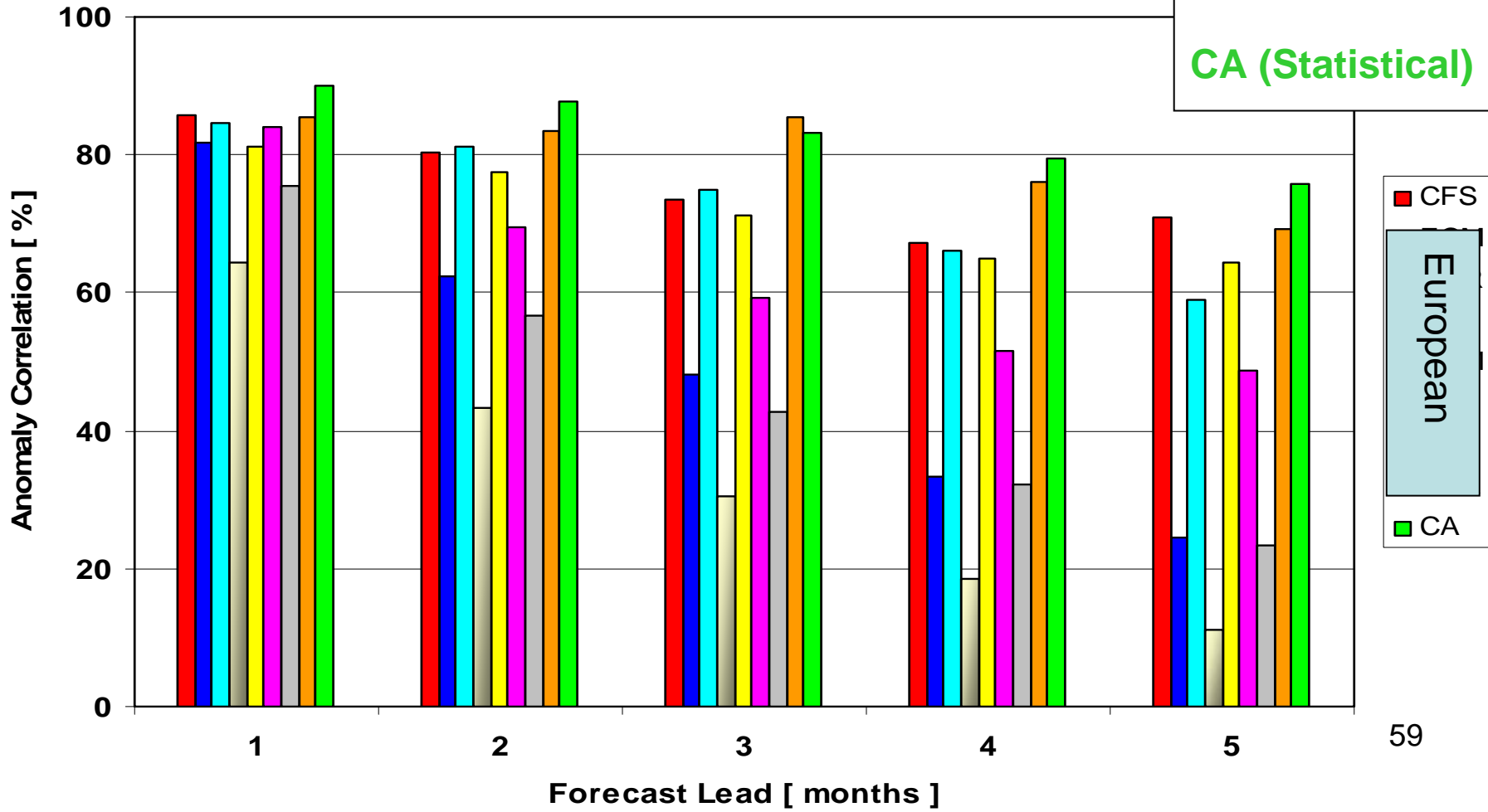
SREF Operational Performance
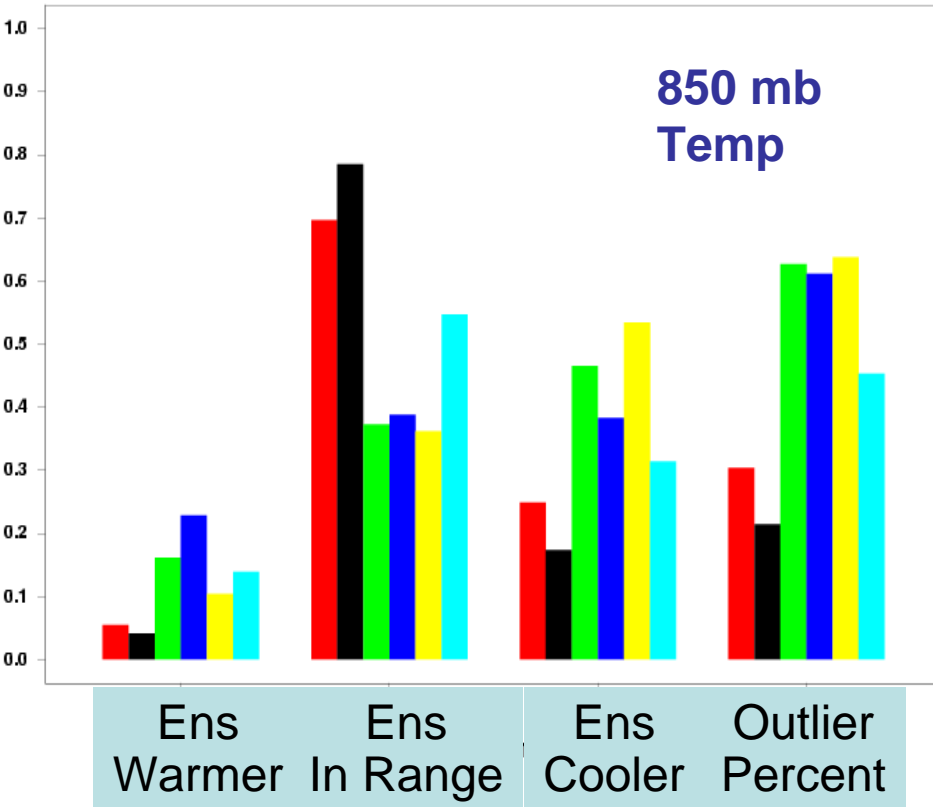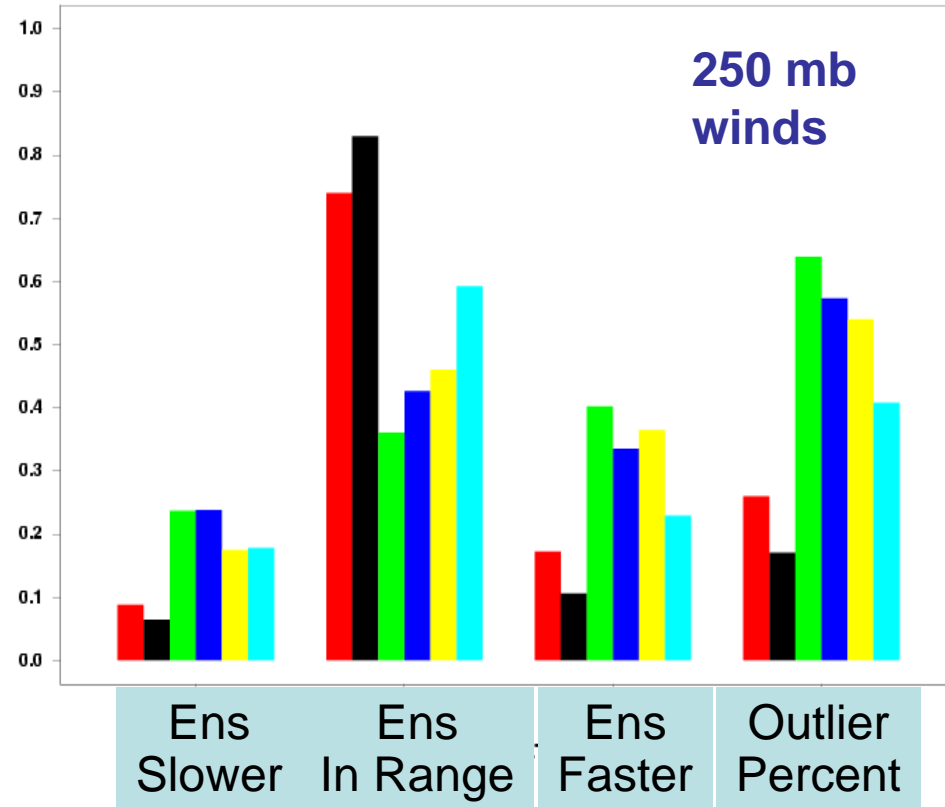
- *Outlier percentage reduced for SREF/21 system*
- *WRF sub-members agree best w/ obs as compared to Eta and RSM sub members*

Introduction to OSSEs
Basic Concepts

- Real/OSSE Data Assimilation System
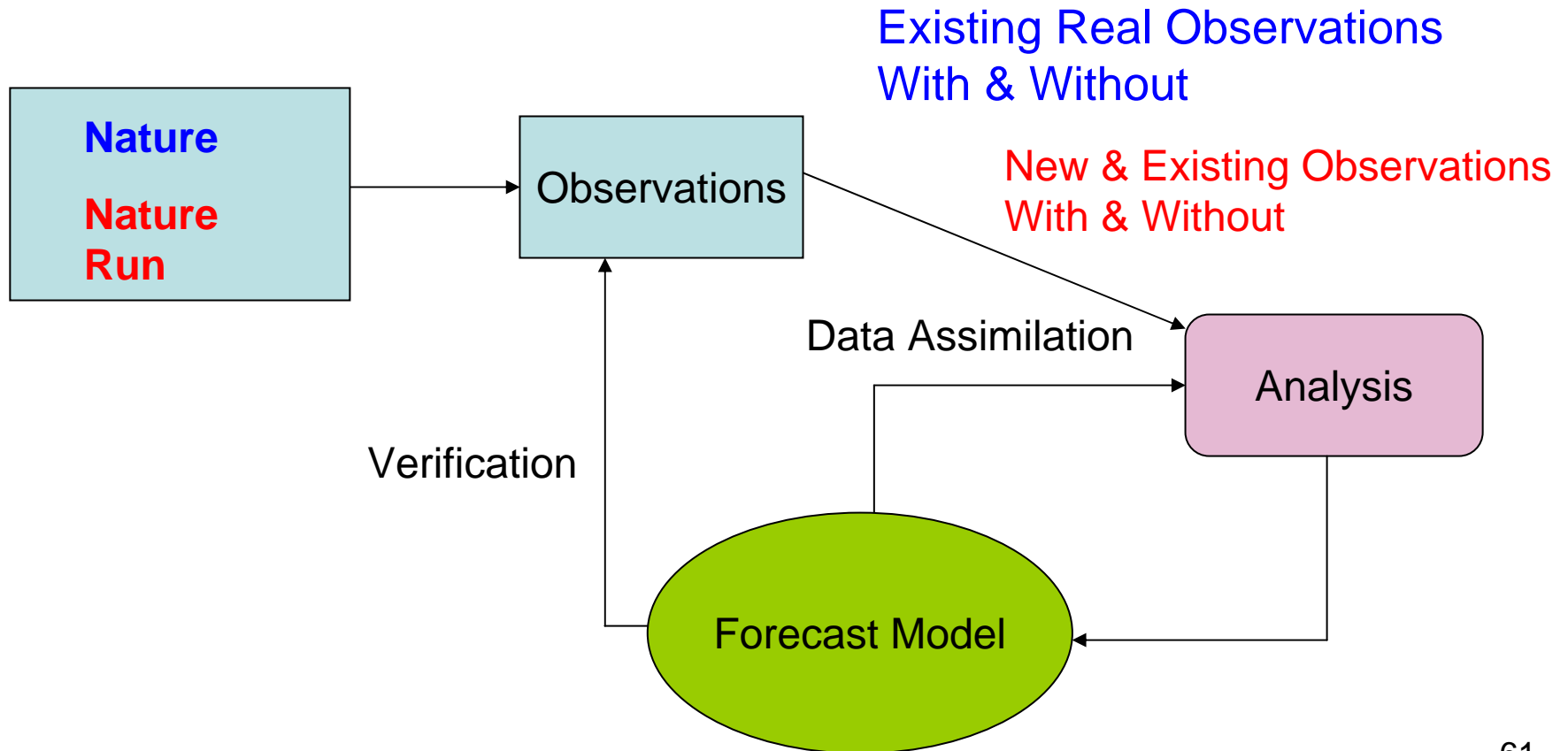
**Global 500 km Grid
2033 points**
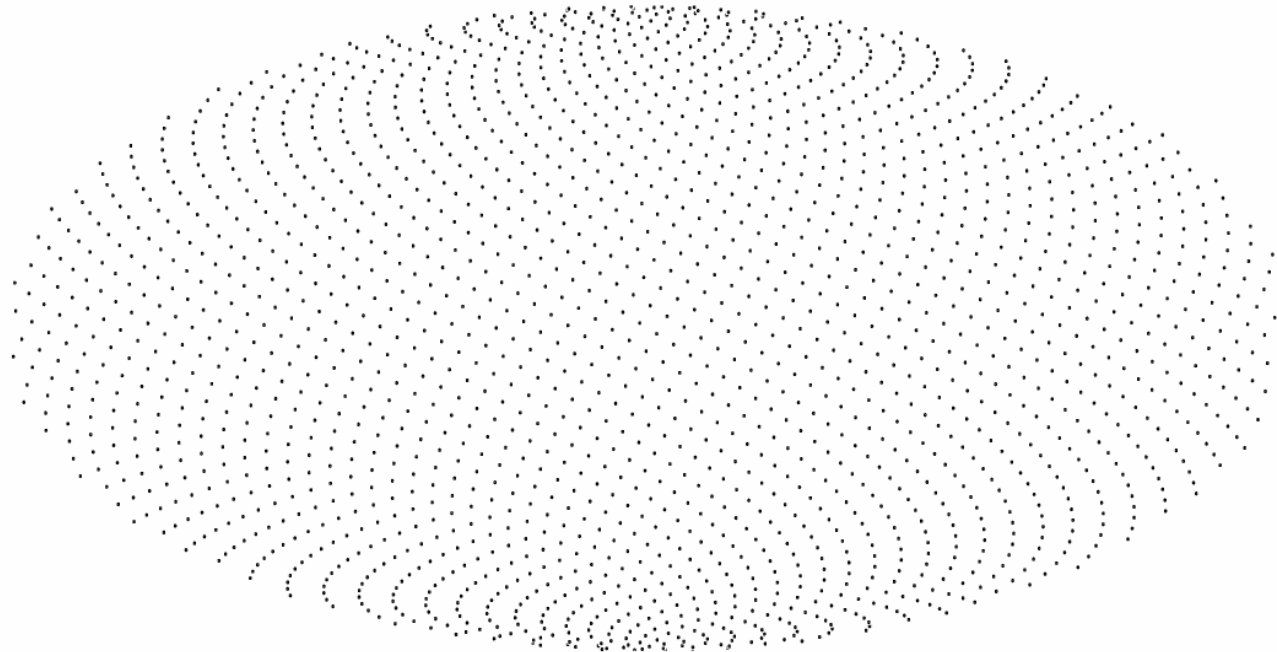
Fibonacci Grid used in the uniform data coverage OSSE

U 200 hPa

T 200 hPa

Anomaly Correlation %
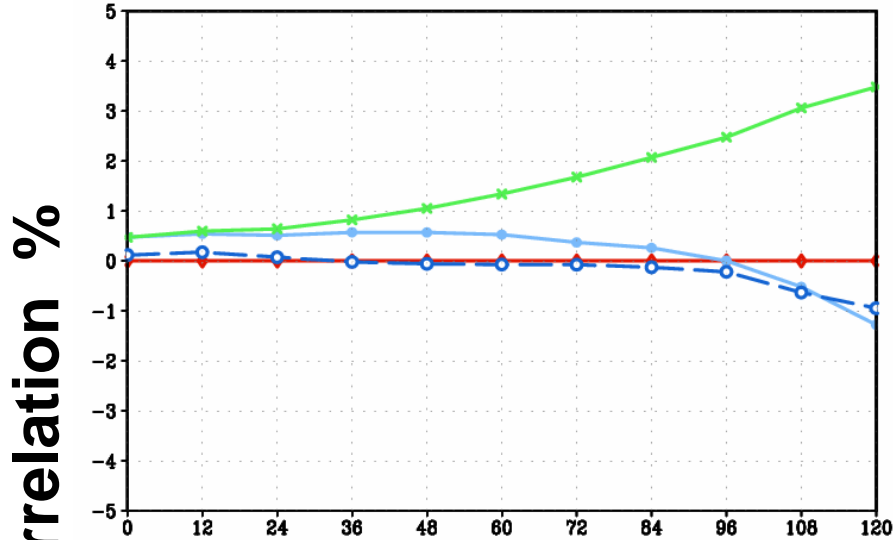
N. Hem. Forecast Skill
Upper Tropospheric Wind & Temp.
Global Rawinsondes
Compared to Today's Obs.
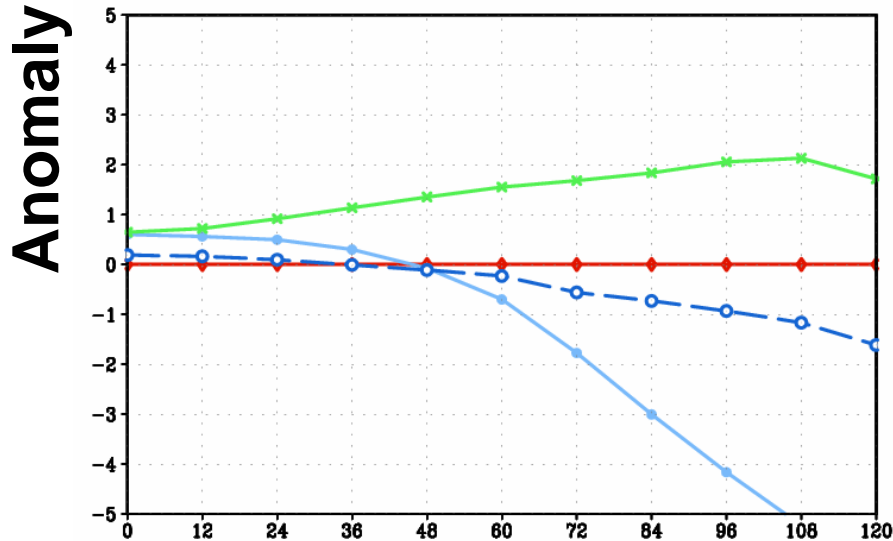
Control
Conv + TOVS
(today's obs.)
T62 model

500 km raobs
T62 model

1000 km raobs
T62 model

500 km raobs
T170 model

63

Computing Comparisons
International Operational Weather & Climate Forecast Centers
2006-2007

Center MP=Massively Parallel	Peak Power (TF)	Throughput (TF)
NCEP (IBM, MP)	16	1.0
UKMET (NEC, vector)	4	1.5
ECMWF (IBM, MP)	36.5	2.2
China (IBM, MP)	21	1.3
Korea (Cray, vector)	18	5.4
Japan (Hitachi, vector)	21.5	7.2
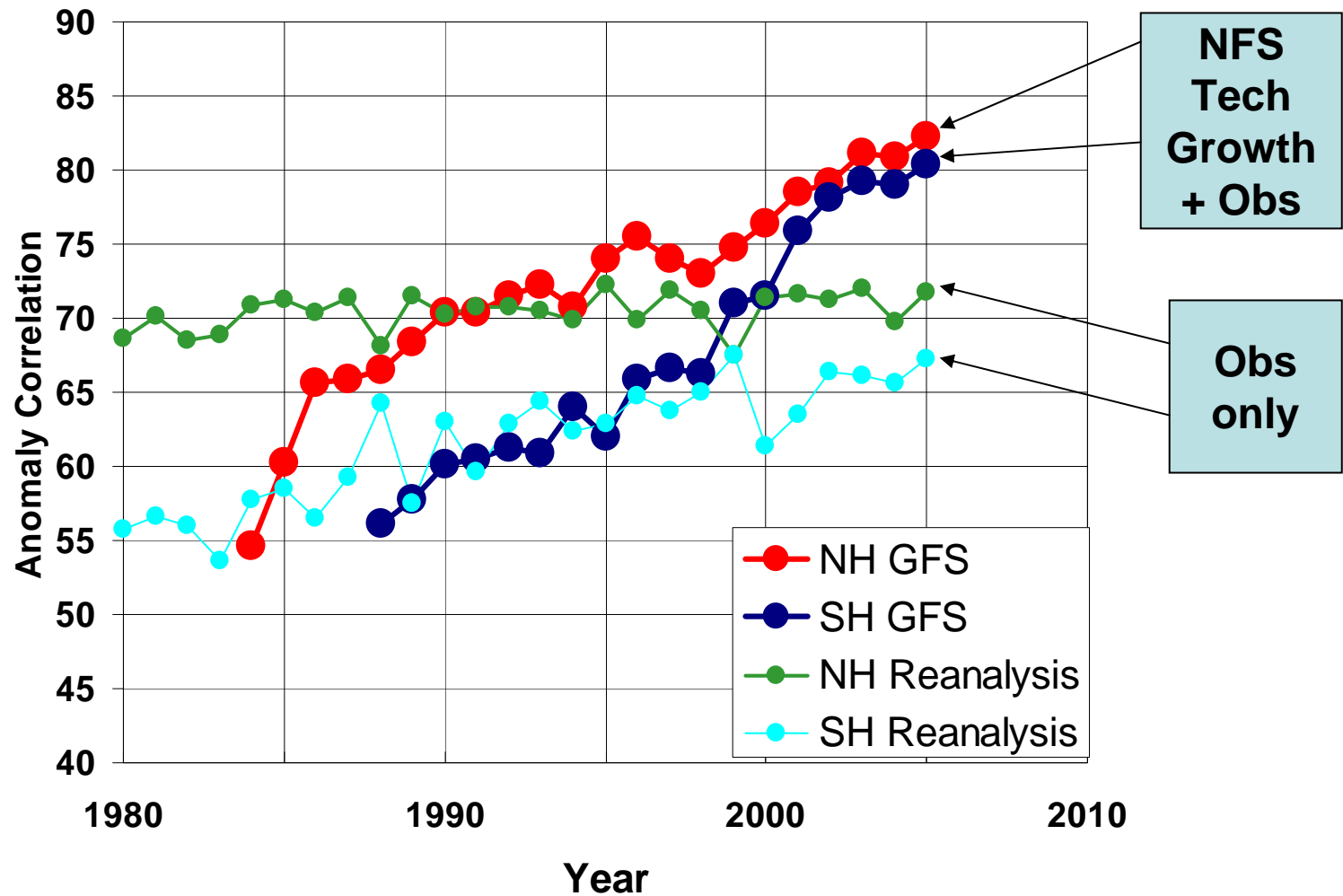
Impact of Observations and Numerical Forecast System Technology Growth on Global Forecasts

Correlation (annual removed) 1993-2003 — TpxJsn1 - GSIM, TpxJsn1 - GODAS(T,S), TpxJsn1 - GODAS(T,S,E)
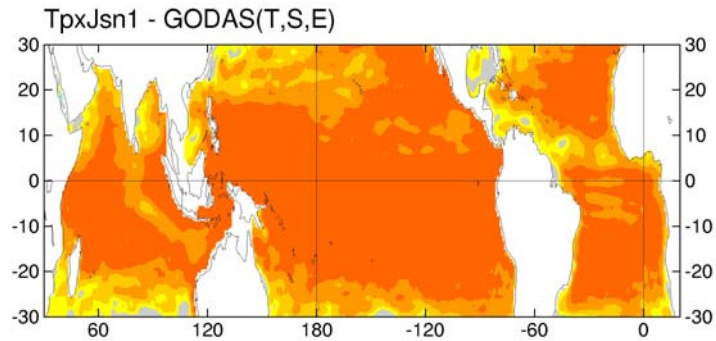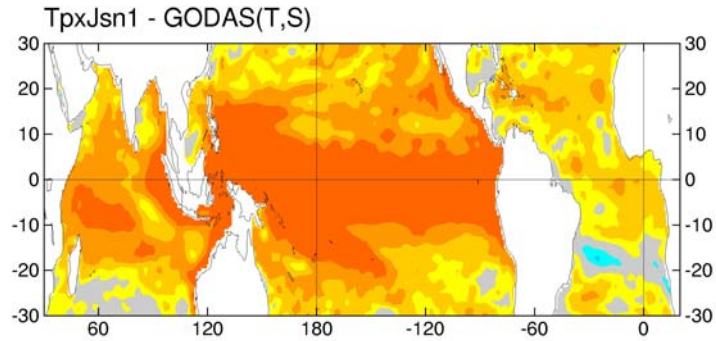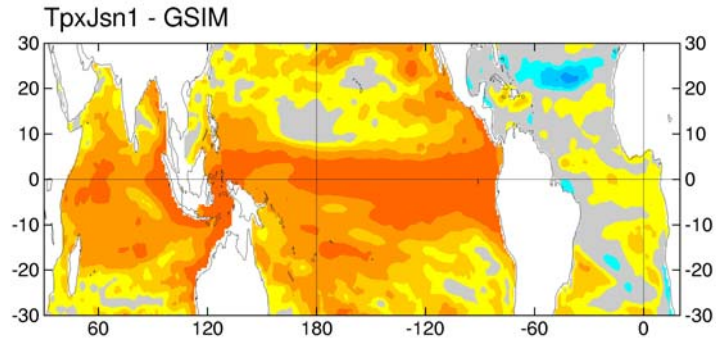
RMS Differences (annual removed) 1993-2003 — TpxJsn1 - GSIM, TpxJsn1 - GODAS(T,S), TpxJsn1 - GODAS(T,S,E)

66

FY06 EMC Budget

Total: $18.5 M
NOAA: $15.8 M
Non-NOAA: $ 2.7 M
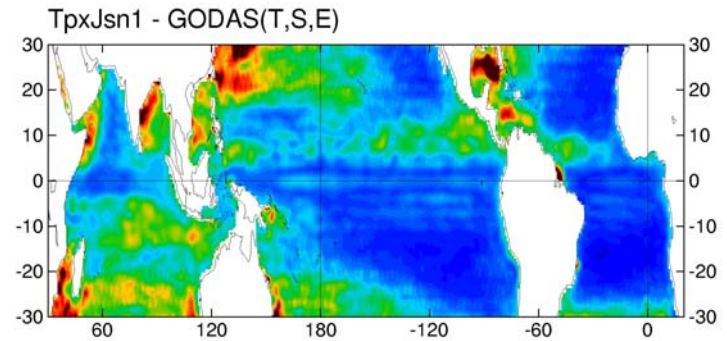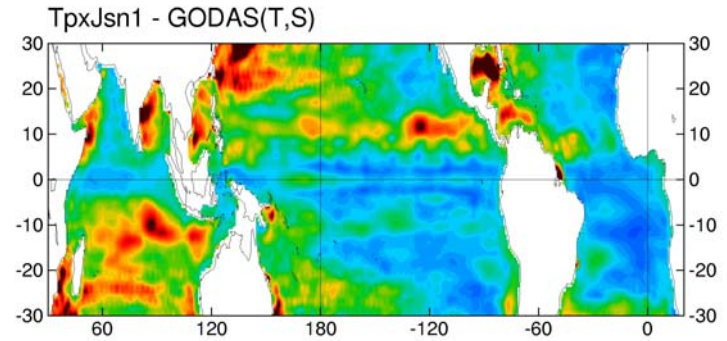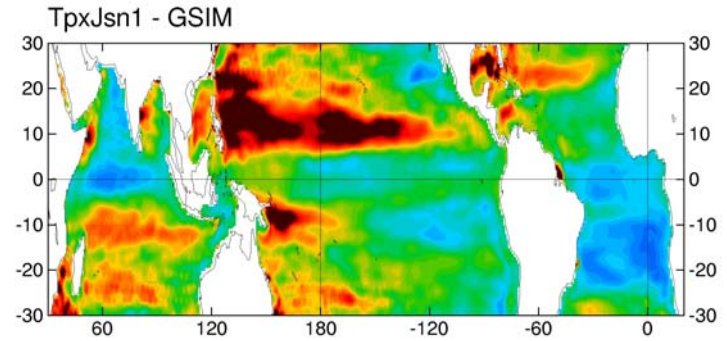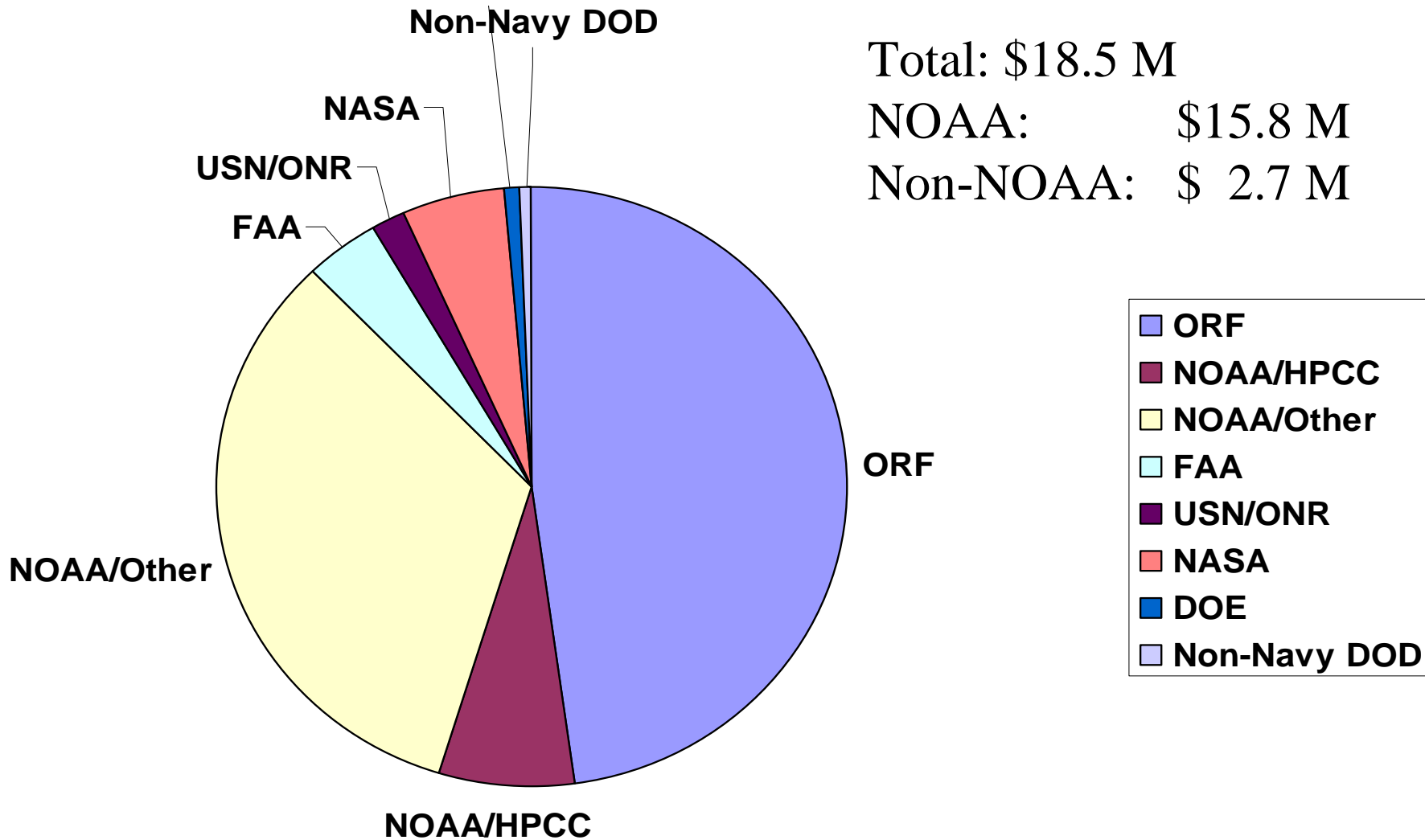
Kelly report (2000) recommendation: 75% ORF, 25% "soft"
2002 budget supplement and adjustment: $2.8 M; 2006 DA: $1.0 M

Transition Steps (Modeling)

1	Identification for Selection
2	Code/Algorithm Assessment and/or Development
3	Interface with Operational Codes
4	Level I: Preliminary Testing (Lower Resolution)
5	Level II: Preliminary Testing (DA/Higher Resolution)
6	EMC Pre-Implementation Testing (Packaging/Calibration)
7	NCO Pre-Implementation Testing
8	Implementation/Delivery
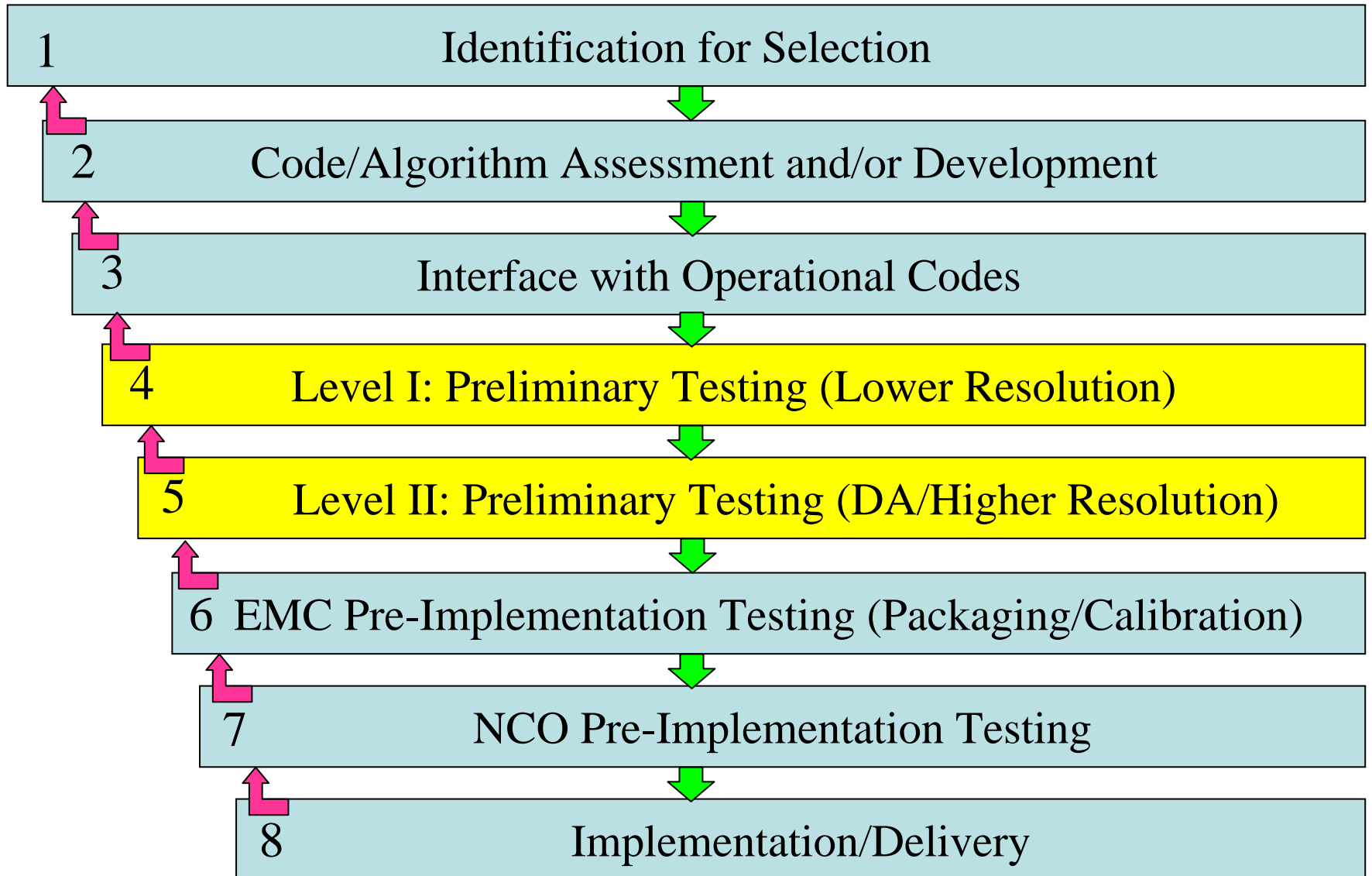
EMC-GMAO-STAR Code Management for Atmospheric Data Assimilation

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

3 months

EMC

1

3

2

Repository

GMAO

Time
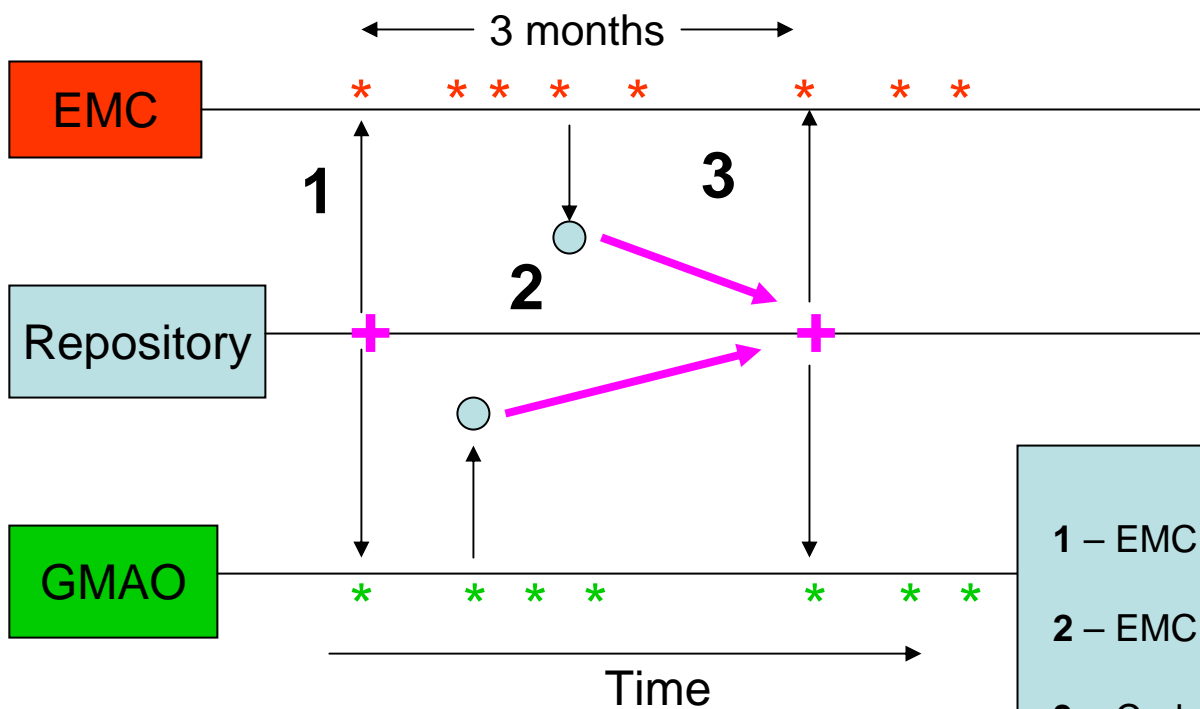
Accepted changes

* * EMC, GMAO System change

◯ Repository change

+ Repository Merger (new tag)

Protocols
1 – EMC, GMAO take (agreed-upon) merged code from repository to begin work
2 – EMC, GMAO incorporate developments into repository
3 – Code mergers, repository changes and timing are NCEP's decision

NCEP Production Suite
Weather, Ocean & Climate Forecast Systems
Version 3.0 April 9, 2004

RUC

NAM Anl

GFS Anl

Waves

Hur

Percent Used

100

80

60

40

20

0

0:00 0:30 1:00 1:30 2:00 2:30 3:00 3:30 4:00 4:30 5:00 5:30 6:00

6 Hour Cycle: Four Times/Day

Legend:
- RUC
- FIREWX
- WAVES
- HUR/HRW
- GFSfcst
- GFSanal
- GFSens
- ETAfcst
- ETAanal
- SREF
- Air Quality
- OCEAN
- Monthly
- Seasonal

SREF

NAM Fcst

GFS Fcst

GENS

70
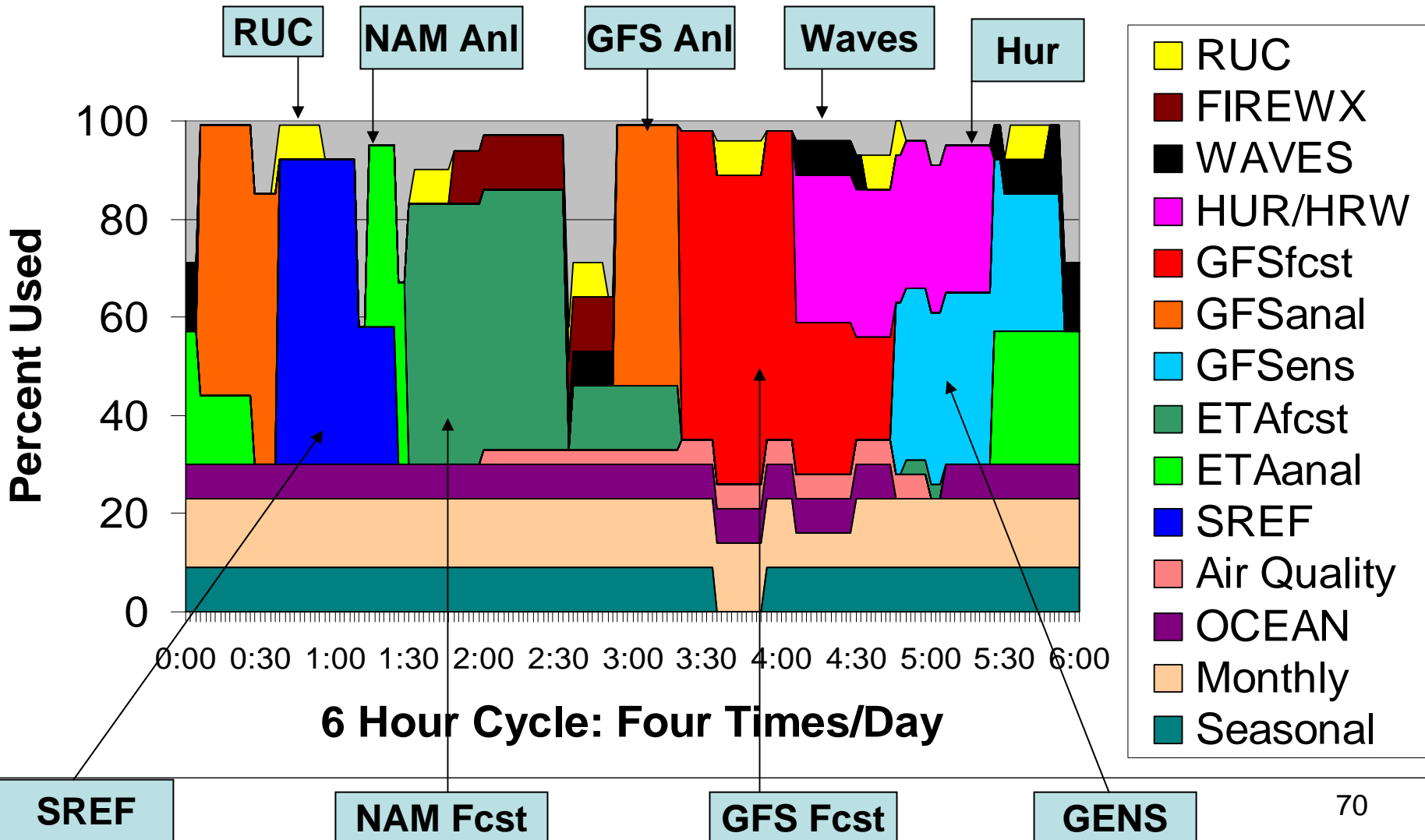
Data Assimilation Status (cont)

- Gridpoint Statistical Analysis (GSI)
  - NCEP's next generation system
    - Evolutionary combination of the global SSI analysis system and the regional ETA 3DVAR
    - Application to both global and regional analysis
    - Strong heritage to satellite, radar, profiler, surface data
  - Background error defined in grid space instead of spectral space
    - Allows use of situation dependent background errors
    - Will accept ensemble information
  - Improved balance condition
    - Adiabatic dynamics model
    - Capable of simplified 4-D Var
  - Improved and modernized code
    - F90/95 structures and utilities
    - Increased scalability of code
    - Efficiency
      - Redesigned data distribution
      - Some OpenMP
    - Better documentation
    - Less dependency on IBM
  - Community support intended but not resourced
    - Currently 15 registered groups (46 users) using GSI code
    - NASA/GMAO major group using code and to date they have provided the most updates from external users

EMC Plan for Moving Forward

- Complete NCEP ESMF Prototype Framework (PF); apply to GFS
- Generalize PF for other models

- Release to EMC personnel for testing
- Prepare for 1st implementation
- Ensemble application

Success?

Yes

No

- Implement ESMF version of GFS
- Install NMM into ESMF framework
- "October 2005"

- Roll back to Non-ESMF framework (NF)
- Install NMM in NF
- "October 2005"

EMC Plan for Moving Forward (cont)

- Implement ESMF version of GFS
- Install NMM into ESMF framework
- "October 2005"

- Roll back to Non-ESMF framework (NF)
- Install NMM in NF
- "October 2005"

Success?

Yes   No

Success?

Yes   No

- Adopt ESMF
- Add more   models
  (e.g. **COAMPS, FV**)

- Decide whether to retain WRF

- Adopt NF
- Reconsider ESMF and WRF concepts

- Abandon CMI concept

Spectrum of possibilities

Most favorable

Least favorable

Proposed NOAA Earth Modeling System Infrastructure

- Provide NOAA and external users access and support for operational and research ESM software components
  - Support NOAA Test Beds
  - Contributions from model groups
- Establish NOAA standards
  - ESMF compliant components
  - Data formats (GRIB, BUFS, NetCFS, converters)
- Supported categories
  - Observations
  - Model-enabling databases (e.g. topography, land-sea mask)
  - Forecast models
    - Atmosphere
    - Ocean
    - Wave
    - Storm surge
    - Sea ice
    - Land surface
    - Ecosystem
    - Stream flow
    - Air chamistry
    - Space weather
  - Data assimilation
  - Post processing and product generation
  - Verification
  - Utilities
    - Format converters
    - Basic scripts
  - Limited diagnostic packages
  - Case archive

NPOESS Era Data Volume

Daily Satellite & Radar Observation Count
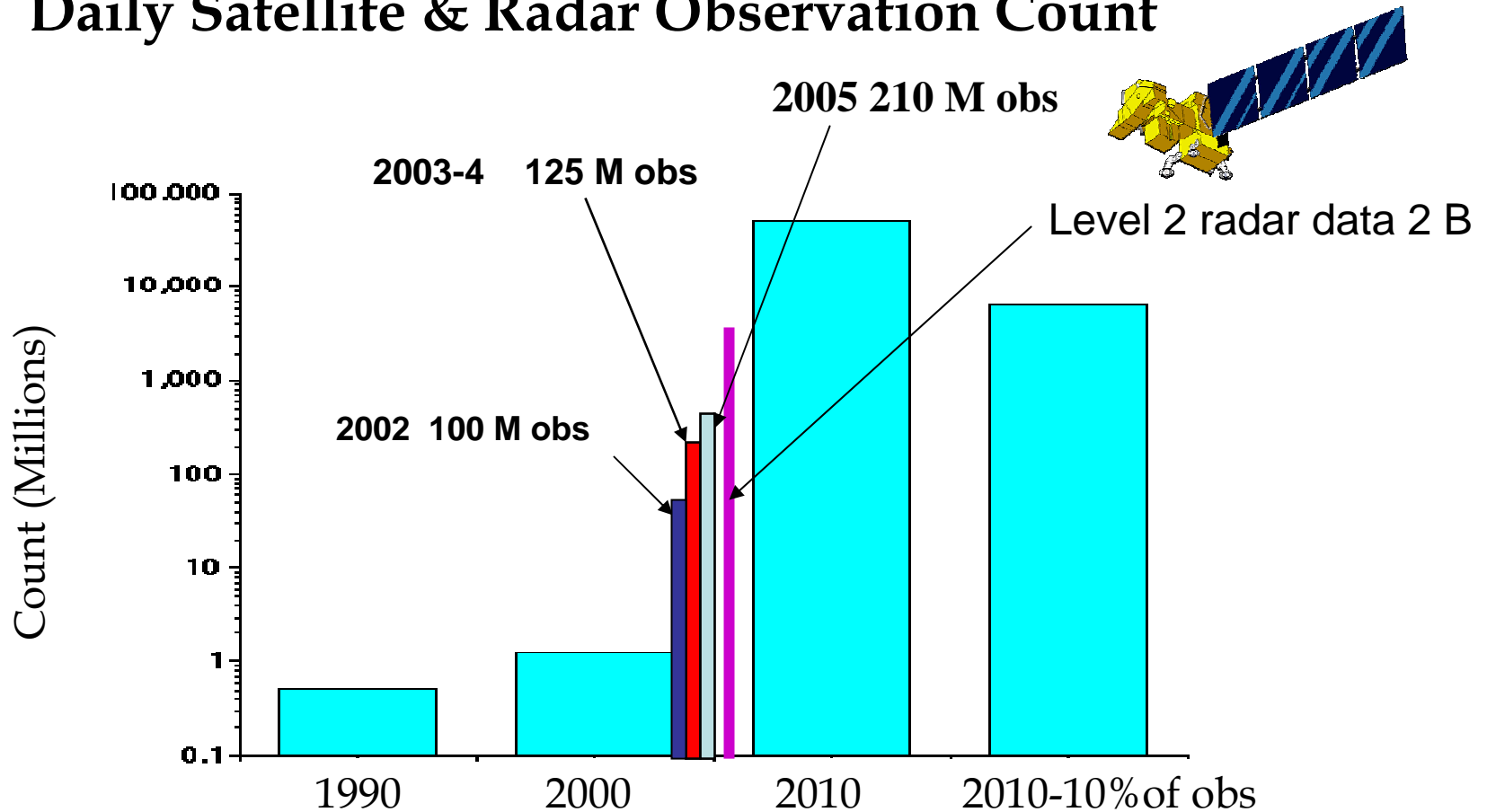
Five Order of Magnitude Increase in Satellite Data Over Next Ten Years

Strategy and Design Considerations (cont)

- Common elements
  - Analysis code
    - Gridpoint Statistical Interpolation (GSI)
    - Observations treatment
      - Formats
      - Available information from each obs. Source
    - Diagnostics, including Analysis Adjoint system
  - ESMF compliant components
    - Analysis
    - Model Dynamics
    - Model Physics
  - Testing protocols and case loads
- Managed diversity through different model components
  - Provides additional diagnostic information
  - NCEP uses Global Forecast System (GFS) Spectral Model
  - GMAO uses Finite Volume (FV) dynamics with physics components different from NCEP

Current Satellite Data Assimilation Development

- **JCSDA partnership for Community Radiative Transfer Model (CRTM)**
  - **NESDIS/ORA** leads scientific development
  - **EMC** transitions development to operations & maintains operational codes
  - **GMAO** focuses on applications to NASA instruments used in research DA systems
  - Examples of CTRM applications
    - **AIRS**
    - **MODIS**
    - **WindSat**
    - **SSM/IS**
    - **AMSR**
    - **OMI**
    - **ATMS**
    - **IASI**
    - **CrIS**
    - **OMPS**

- **JCSDA partnership for COSMIC** (results next slide)
  - Project management (**NESDIS**)
  - Data delivery, formatting (**UCAR, NCEP** Central Ops)
  - Scientific algorithms and QC (**JCSDA, NESDIS, UCAR**)
  - Testing with CHAMP data prior to launch with DA system (**JCSDA, EMC, UCAR**)

Current Satellite Data Assimilation Development (cont)

- **Improved use of satellite data for SST analysis**
  - Improved AVHRR QC and bias correction (Xu Li, A. Harris)
  - Addition of simplified ocean mixed-layer model (EMC-MMAB, GMAO)
  - Use of microwave instruments (e.g. AMSR-E)
- **Upgrades to ozone assimilation**
  - GOME and current NASA, NOAA instruments (CPC, JSDI; Stajner, GMAO, AO)
- **Land surface data assimilation**
  - Use of GMAO Catchment model as multi-Land Surface Model (LSM) system (together with Noah, VIC and Sacramento LSMs)
  - Collaboration on advanced Ensemble Kalman Filter (EKF) techniques
- **Ocean data assimilation**
  - Use of altimeter data (EMC, Behringer)
  - Impacts on S/I forecasting (EMC, Behringer)
  - GMAO uses Poseidon isopycnal model but will test developments in MOM-4
- **Observing system design and impacts**
  - Analysis adjoint diagnostic tools
  - Observing System Simulation Experiments (OSSEs) for
    - Understanding interaction between observing system and DA system
    - Defining potential impact of and preparing for future instruments

Example of Explicit 4.5 km WRF-NMM
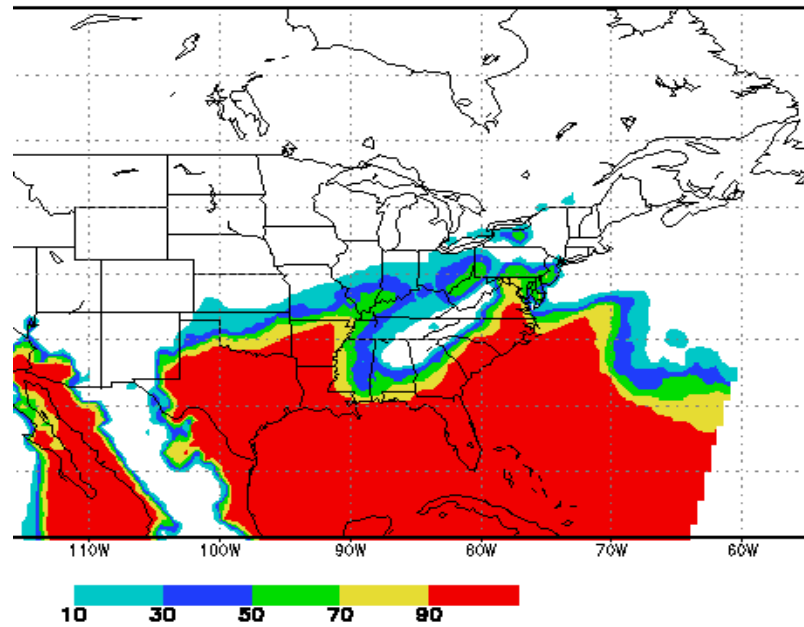
courtesy of Jack Kain

WRF 24 hour 4.5 km forecast of 1 hour accumulated precipitation valid at

00Z April 21, 2004 (better than 12 hour forecasts by operational models)
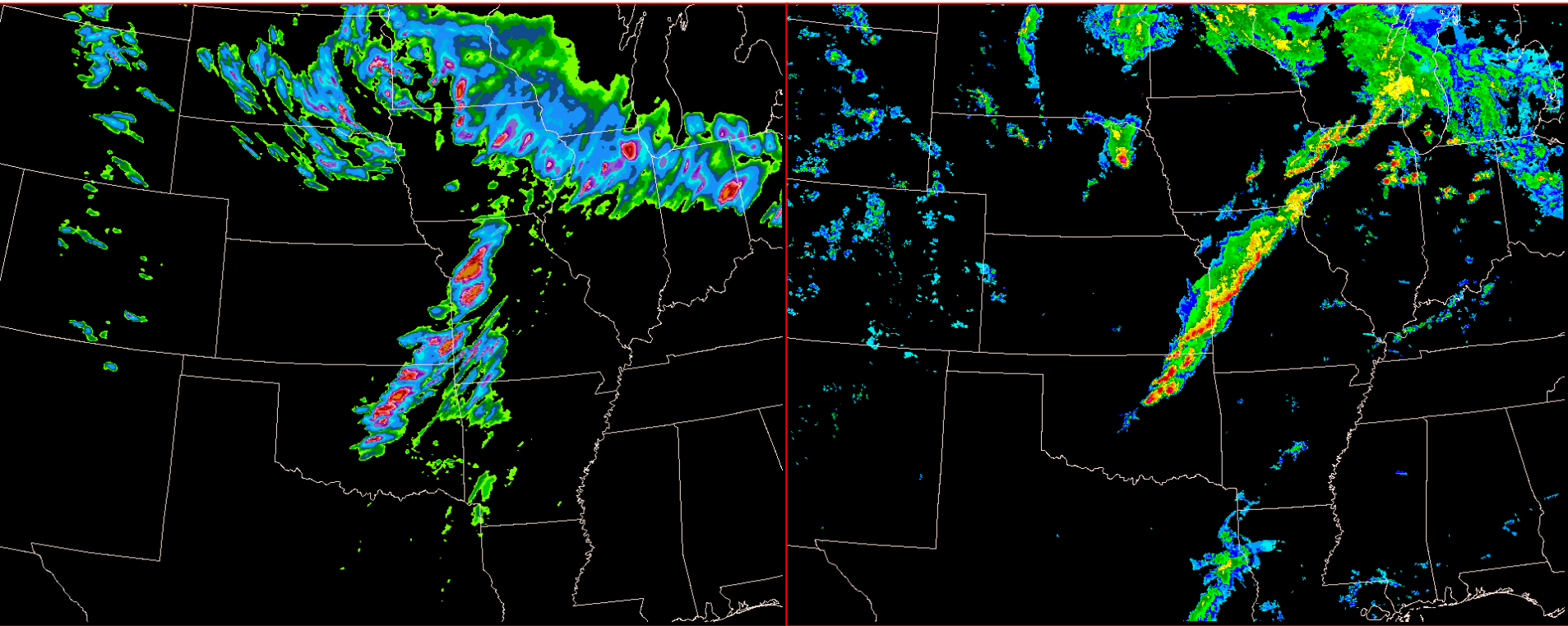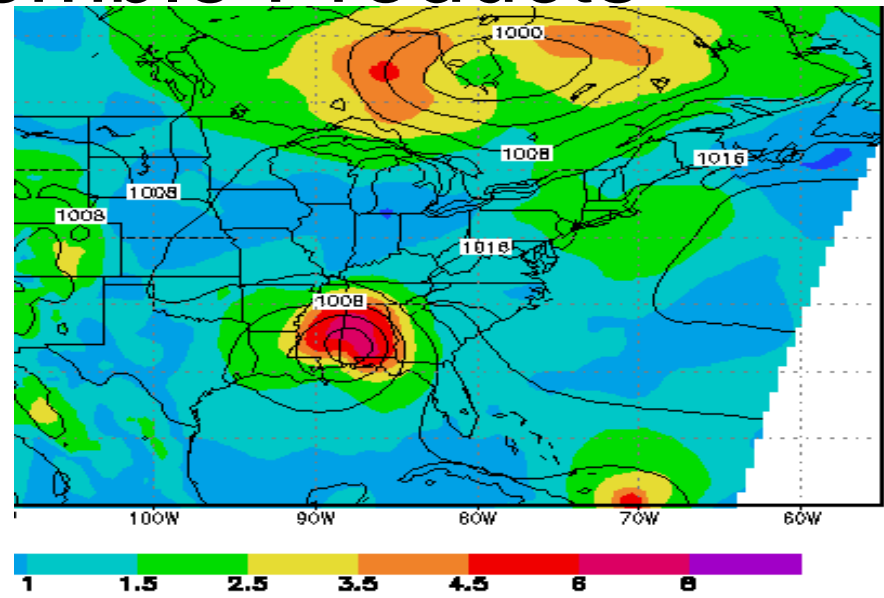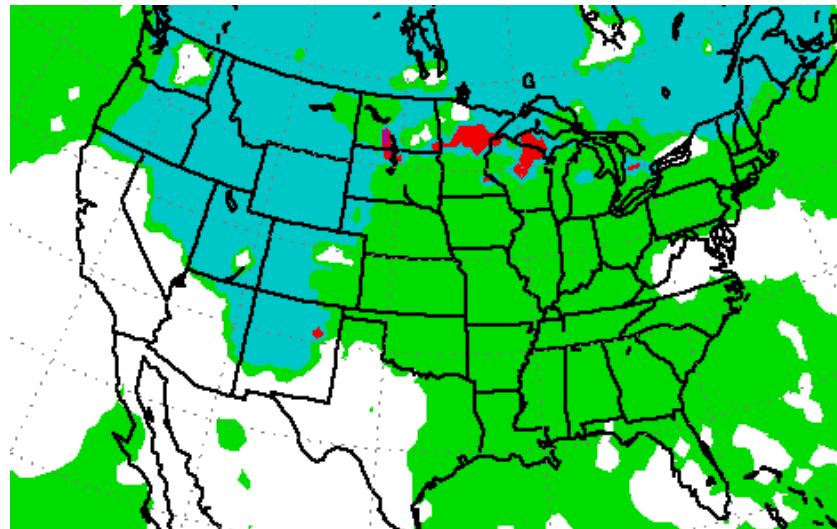

4.5 km WRF-NMM
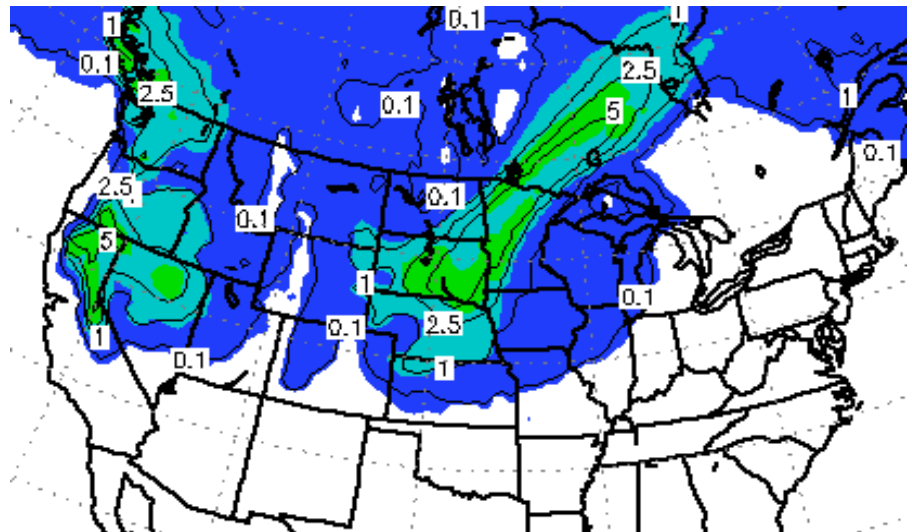
Verifying 2 km radar reflectivity

Ensemble Products

Prob. THI>75

Mean/Spread Surface Pressure

Dominant Precip Type

Mean/Spread 24 h snowfall

EMC-GMAO
Advanced DA Development (Var)

**Complementary Development Focus and
Common Architecture**

EMC
- Covariance modeling
  - Situation-dependent background errors
  - Ensembles
- Simplified 4D-var
- Satellite and conventional data

Adjoint Diagnostic Tools

GMAO
- Covariance modeling
  - Stratosphere
  - Ozone and other trace gases
- Traditional 4D-var
- NASA instruments

Evolved Next-Generation System in 2008

Design Considerations - 1
Common System architecture
- Coding philosophy (ESMF)
- Data handling (QC, etc)
- Bias treatment
- Experiment protocols and data

Design Considerations - 2
Disciplined evolution of combined system
- Synchronize design modifications
- Common system from most effective methods
- Group decisions impact evolution at both EMC and GMAO

Advanced DA Techniques - Plans

- .**Short Term Plan (0-3 years)**
  - Converge EMC and GMAO development to common analysis code (DONE)
  - Harness NESDIS/STAR(ORA) expertise for Community Radiative Transfer Model (CRTM) (DONE)
  - ESMF compliant system for major components (analysis, CRTM, model)
  - Fully coordinated software evolution with **managed system diversity**
  - Applications to **both** global and regional systems (NCEP requirement)

- **Long-Term Plan (>3 years)**
  - Implement next generation operational DA system at
    - NCEP for operations
    - NASA for research
  - Prepare for assimilation of
    - NPP instruments (ATMS, CrIS, OMPS, VIIRS)
    - Full NPOESS era suite
  - Continue focus on advanced NASA instruments for R-2-O transition
  - Expand applications beyond atmosphere to
    - Ocean
    - Land surface
    - Global environmental monitoring and Air Quality
      - Ozone
      - Aerosols
      - Trace gases

Summary of CFS Forecasts for 2005-2006 La Nina

- Monthly CFS forecasts
- Consistent forecast of cold event (-1 K) since June-July 2005
- Other models converging on cold event beginning in January

CFS