The Future of NWP

Stephen J. Lord
NCEP Environmental Modeling Center

Senior Staff
Fred Toepfer
John Derber
Hua-Lu Pan
Ken Mitchell
Geoff DiMego
Naomi Surgi
D. B. Rao

Overview

- Seasonal to Interannual (S/I) Climate
- Global Forecast System
- Real-Time Ocean Forecasting
- NASA-NOAA-DOD Joint Center for Satellite Data Assimilation
- Mesoscale Forecasting & WRF
- Regional Reanalysis
- Land surface and Hydrology
- Hurricanes

S/I Climate

A new global Coupled atmosphere-ocean Forecast System (CFS) has recently been developed at NCEP/EMC.

Components

a) T62/64-layer version of the current NCEP atmospheric GFS (Global Forecast System) model and

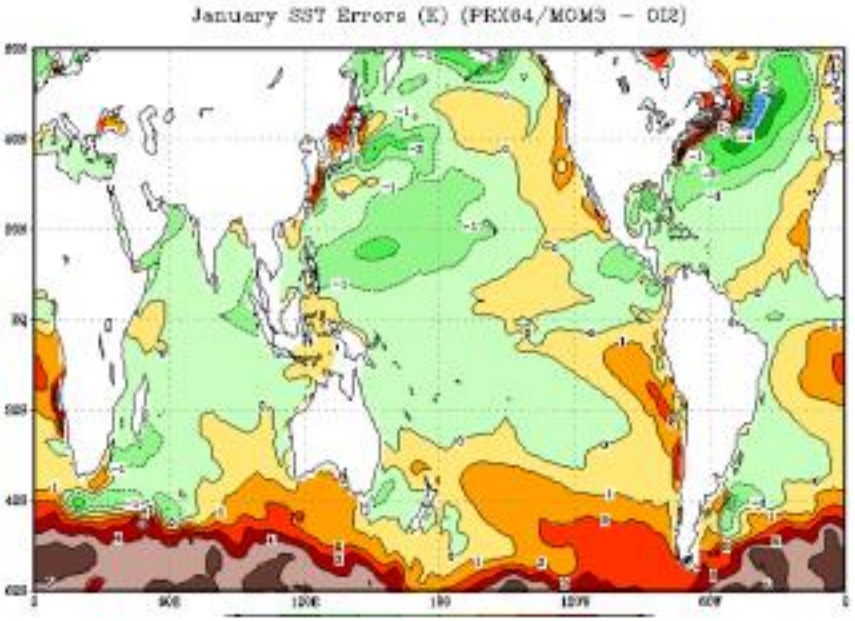
b) 40-level GFDL Modular Ocean Model (MOM, version 3)

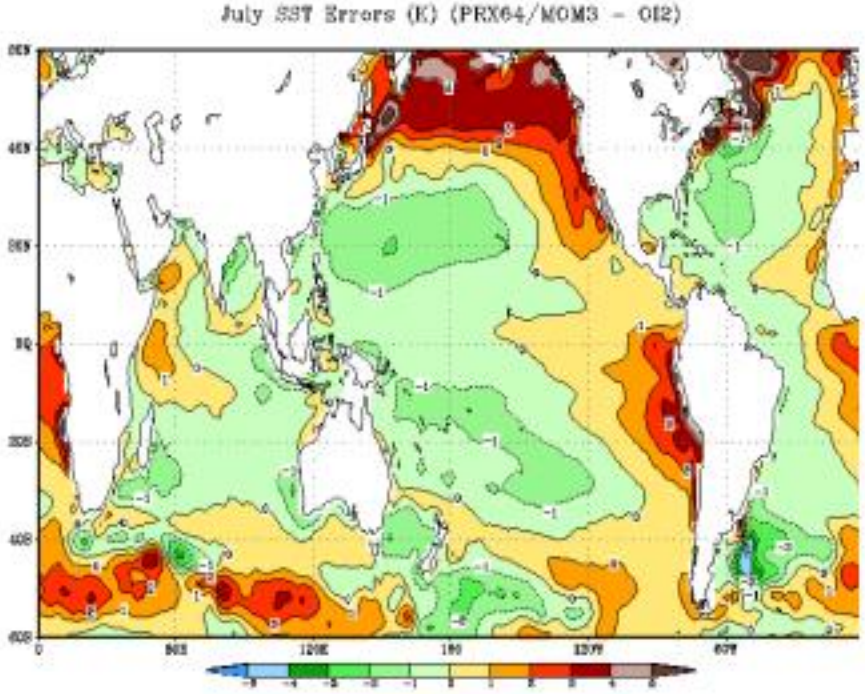
c) Global Ocean Data Assimilation (GODAS)

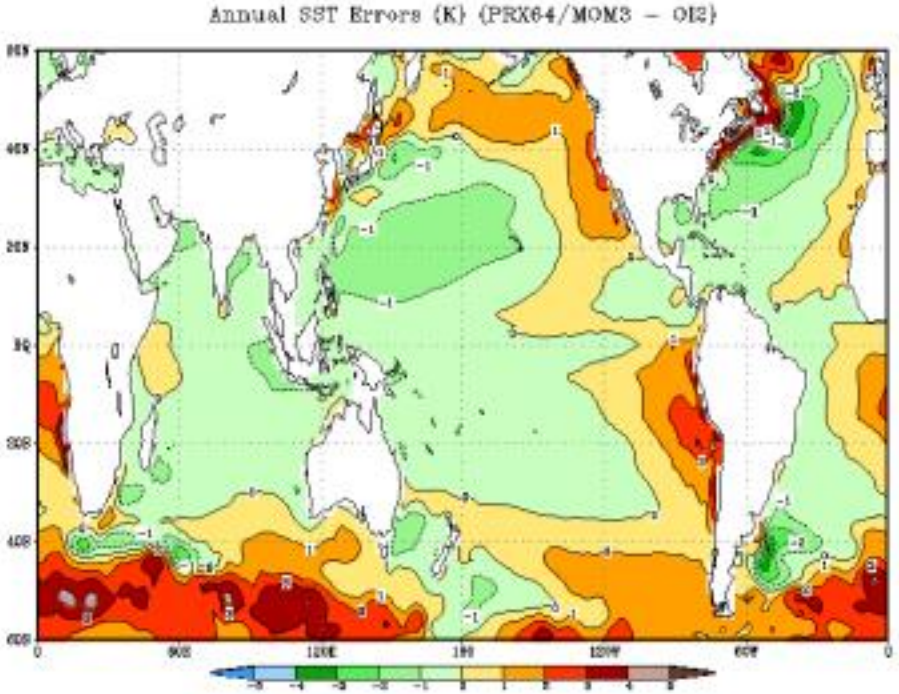
Notes:

- CFS has direct coupling with no flux correction
- GODAS
  - Implemented September 2003, runs daily
  - Salinity analysis, improved use of altimeter data
  - Real time global ocean data base in WMO standard format
  - Ready for GODAE

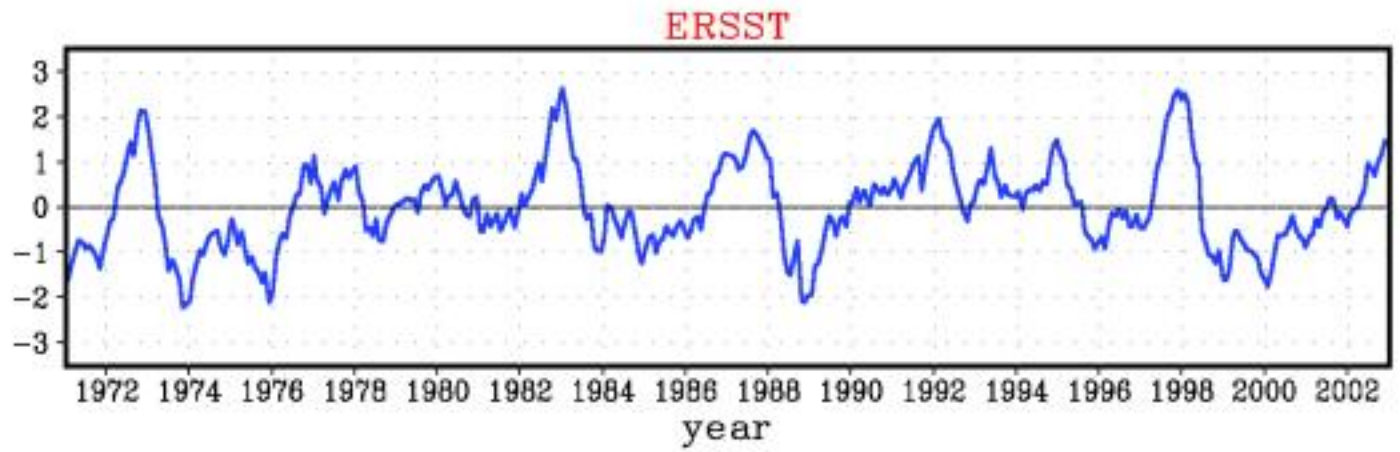
CFS
Simulation
38 Year Mean
SST Bias



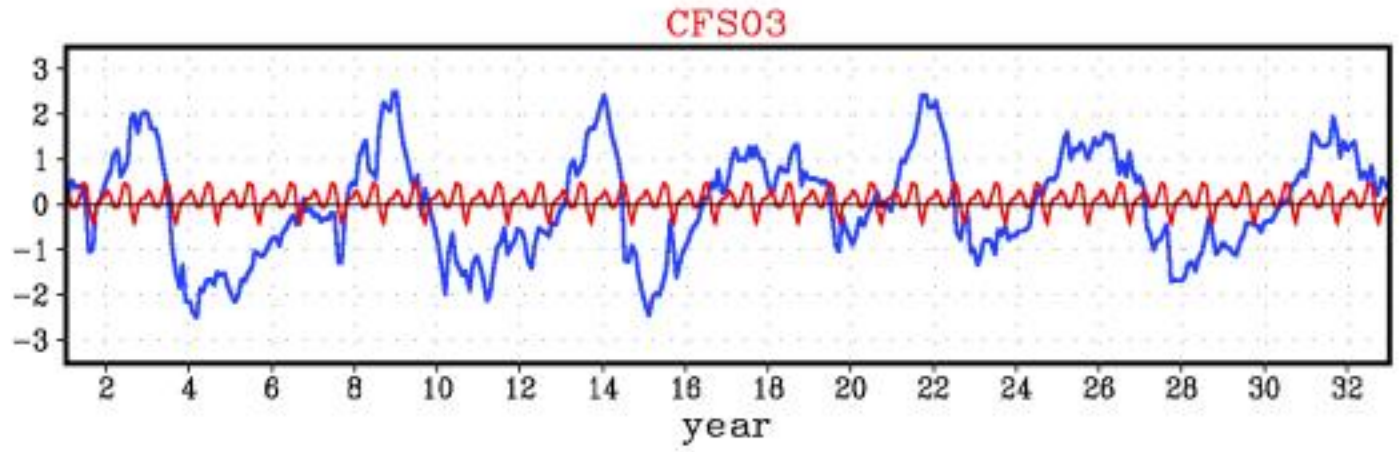




CFS Simulation
ENSO SST cycles
Nino 3.4 SST Anomalies



Observed

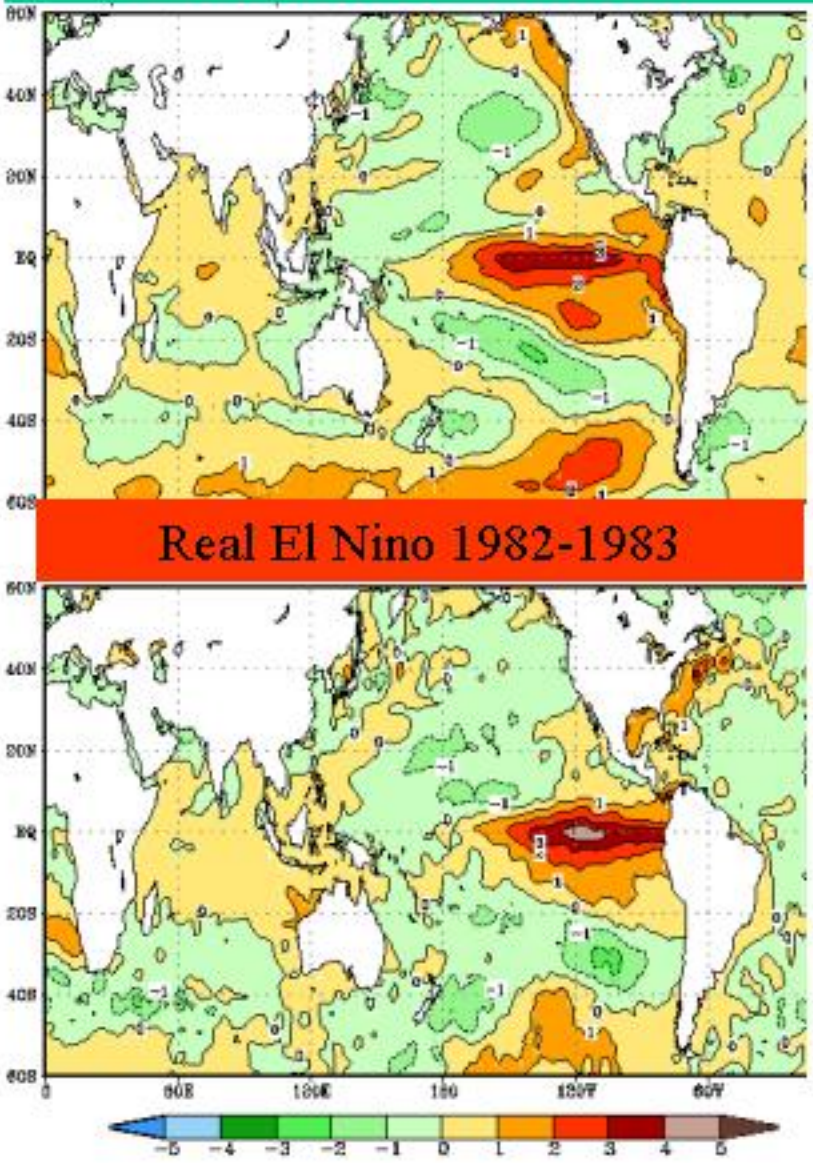


Coupled

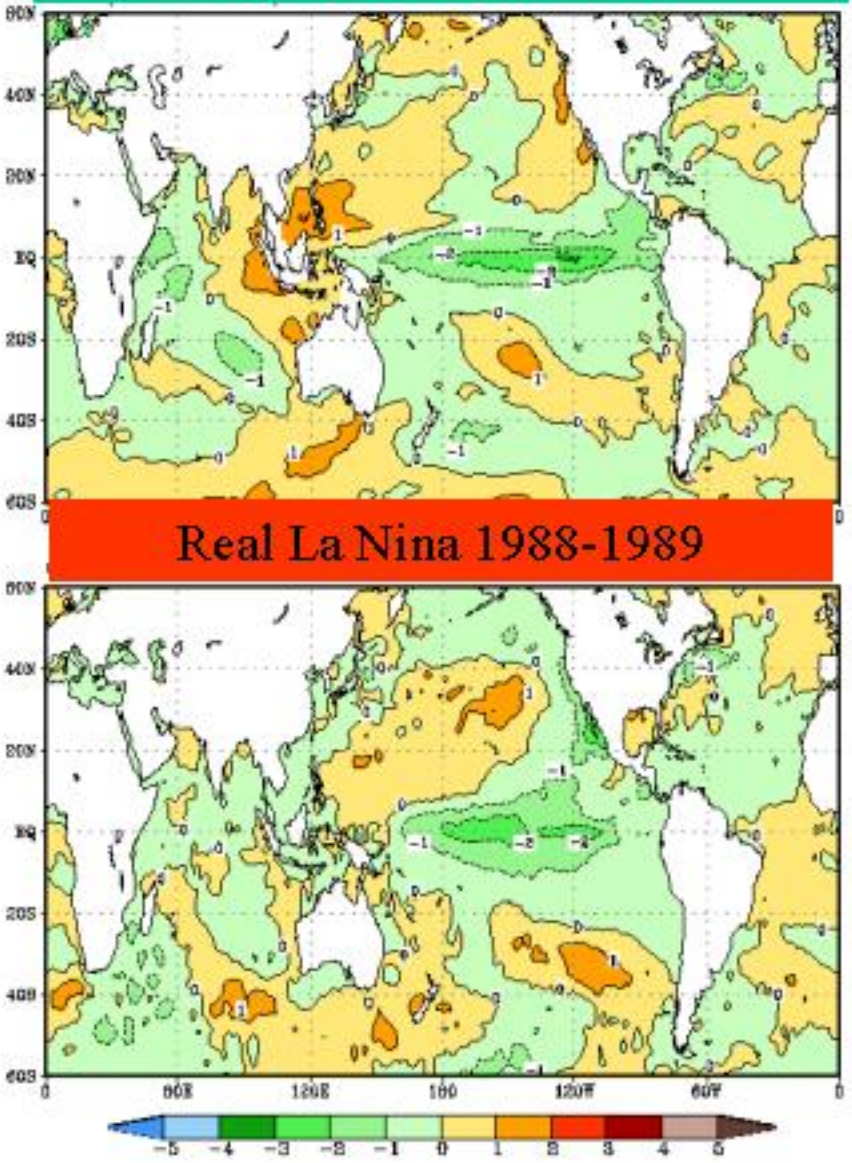
Red: monthly bias

Examples of ENSO events

CFS Simulated El Nino

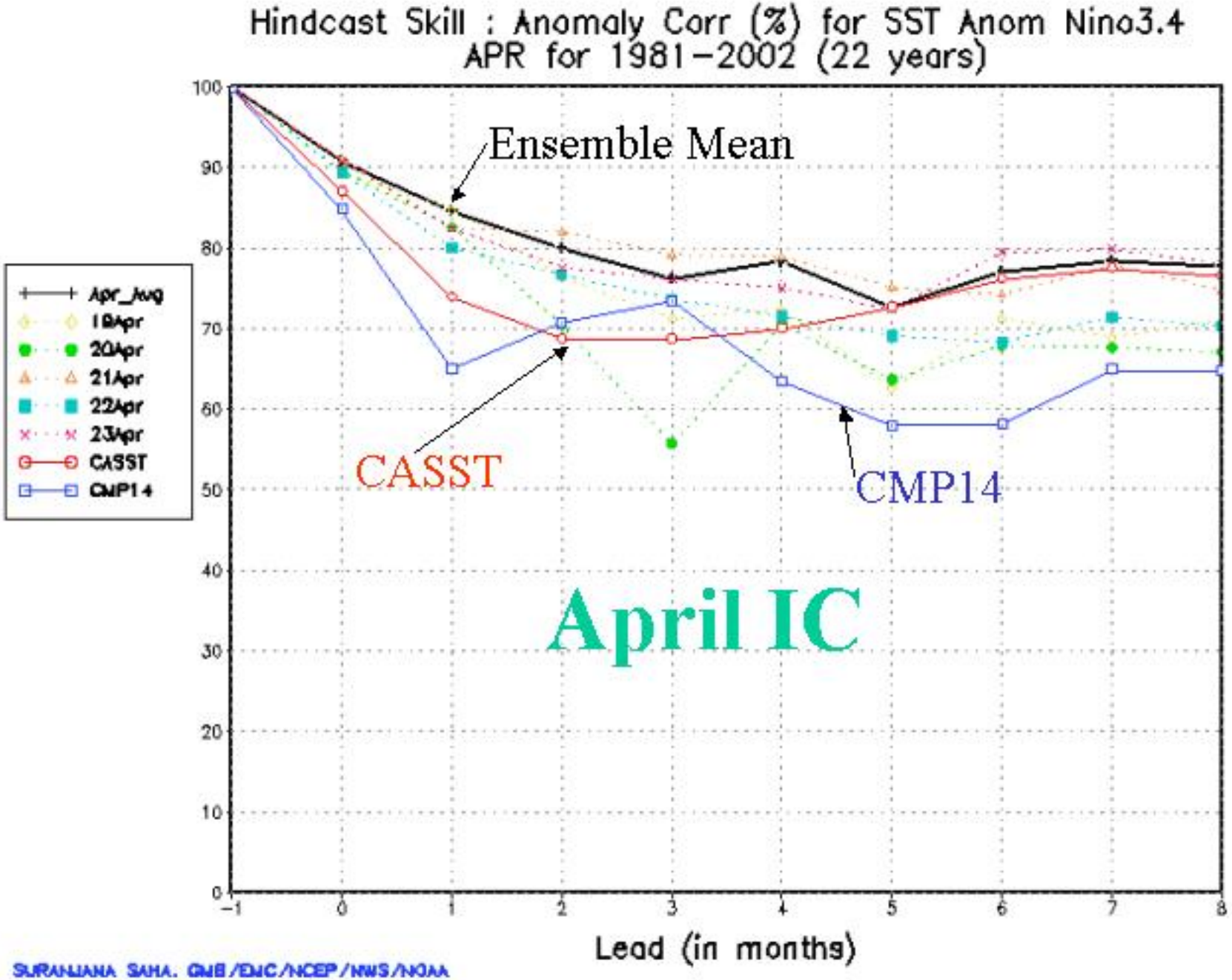


CFS Simulated La Nina

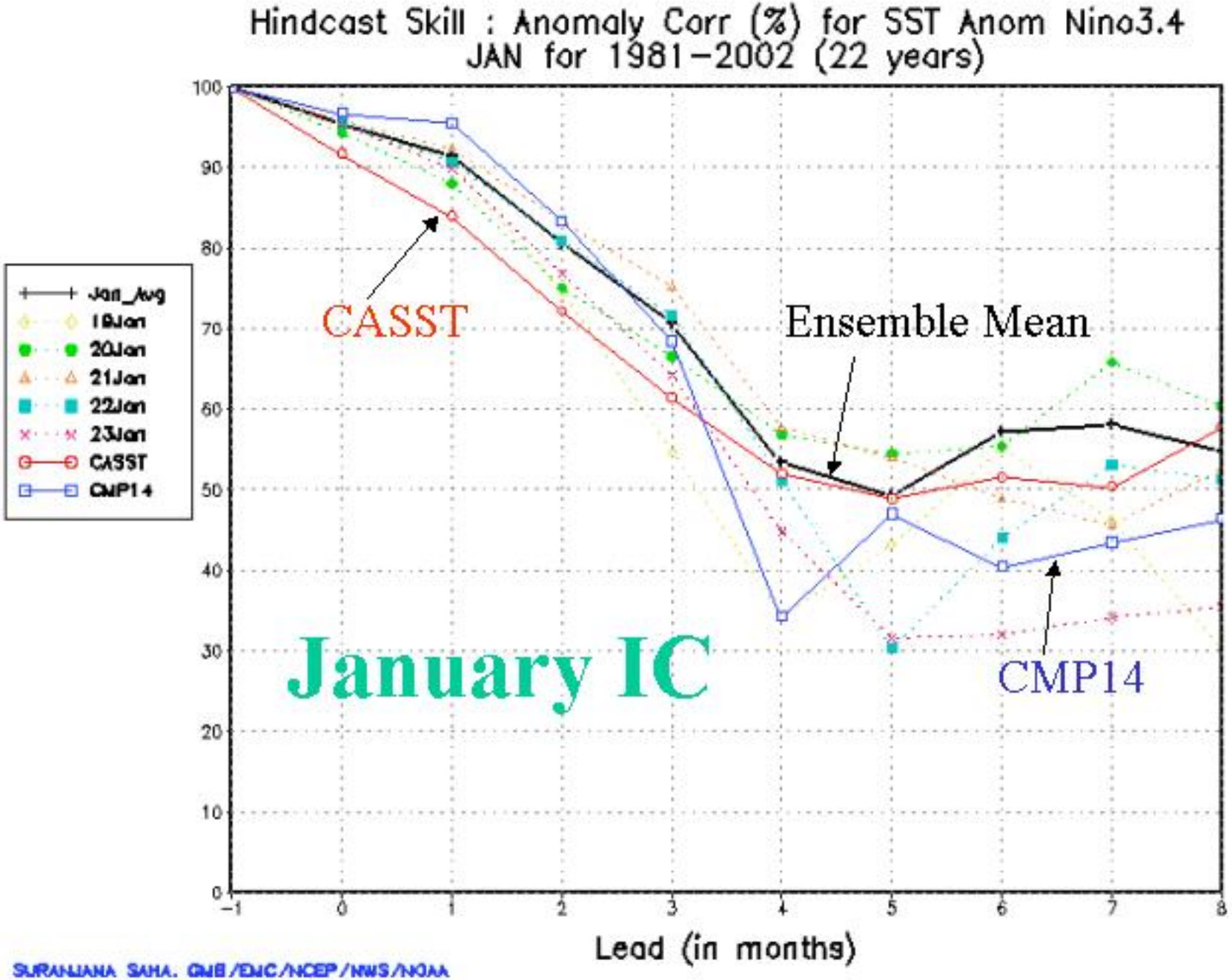


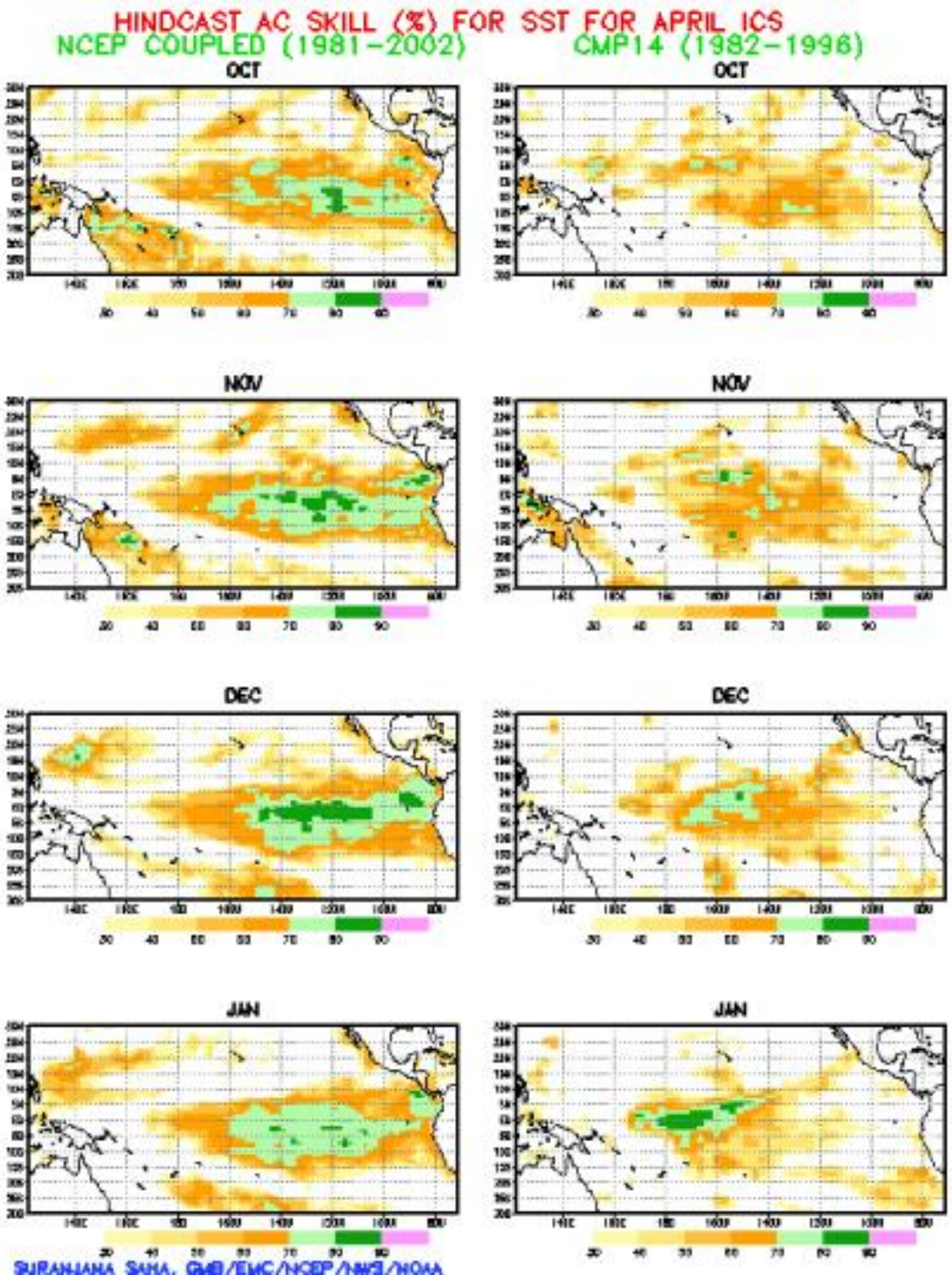
Real El Nino 1982-1983

Real La Nina 1988-1989



Hindcast Skill : Anomaly Corr (%) for SST Anom Nino3.4
APR for 1981-2002 (22 years)
Ensemble Mean
CASST
CMP14
April IC
Apr_Avg
19Apr
20Apr
21Apr
22Apr
23Apr
CASST
CMP14
Lead (in months)
SURANJANA SAHA. GMB/EMC/NCEP/NWS/NOAA


Hindcast Skill : Anomaly Corr (%) for SST Anom Nino3.4
JAN for 1981-2002 (22 years)
Jan_Avg
18Jan
20Jan
21Jan
22Jan
23Jan
CASST
CMP14
CASST
Ensemble Mean
January IC
CMP14
Lead (in months)
SURANJANA SAHA. GMB/EMC/NCEP/NWS/NOAA

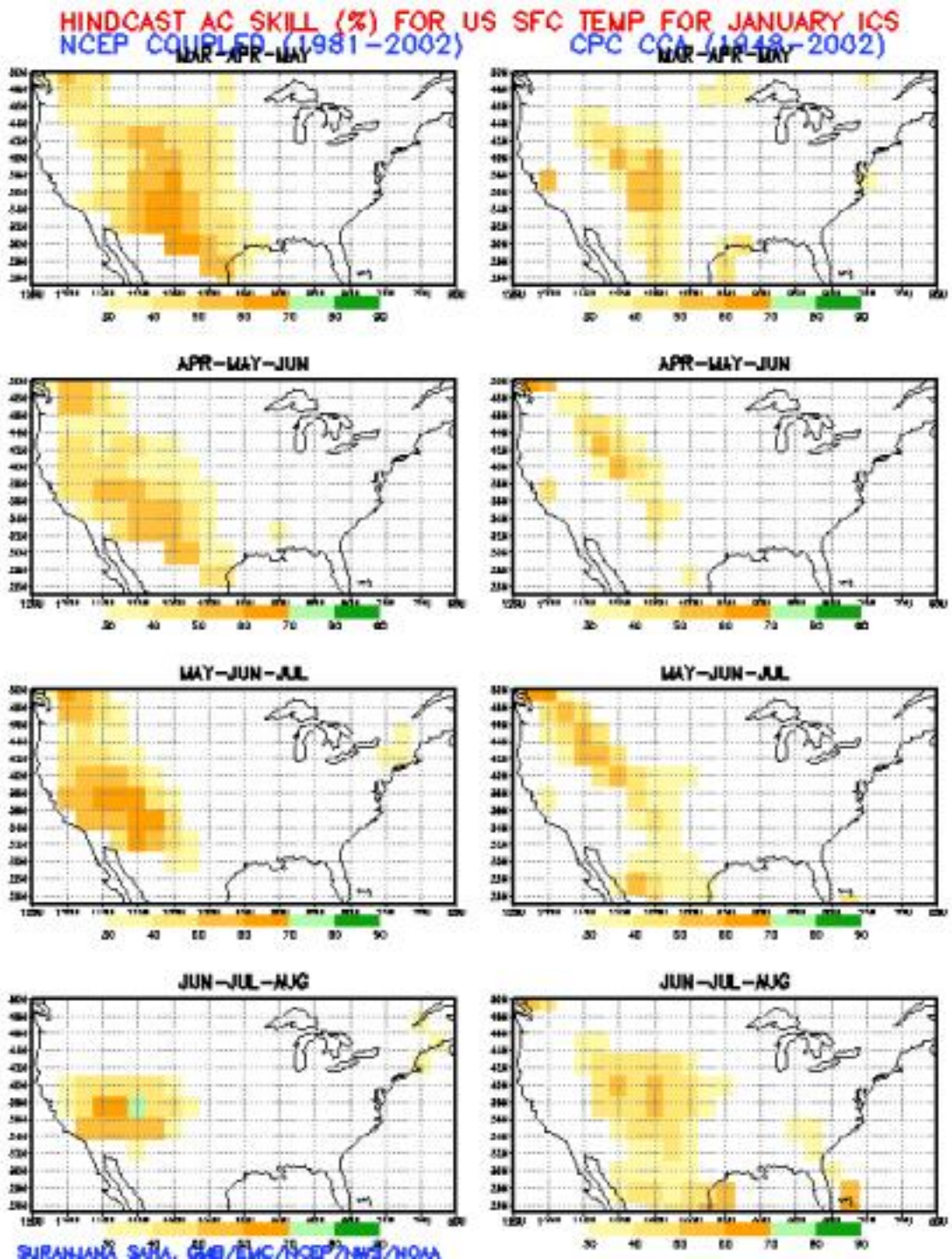


Hindcast
Monthly Averaged
SST Anomaly Correlation
April IC
October-January

Left: New Coupled System
Right: CMP14
(operational system)

More persistent forecast
Skill in tropics

Similar result for January IC



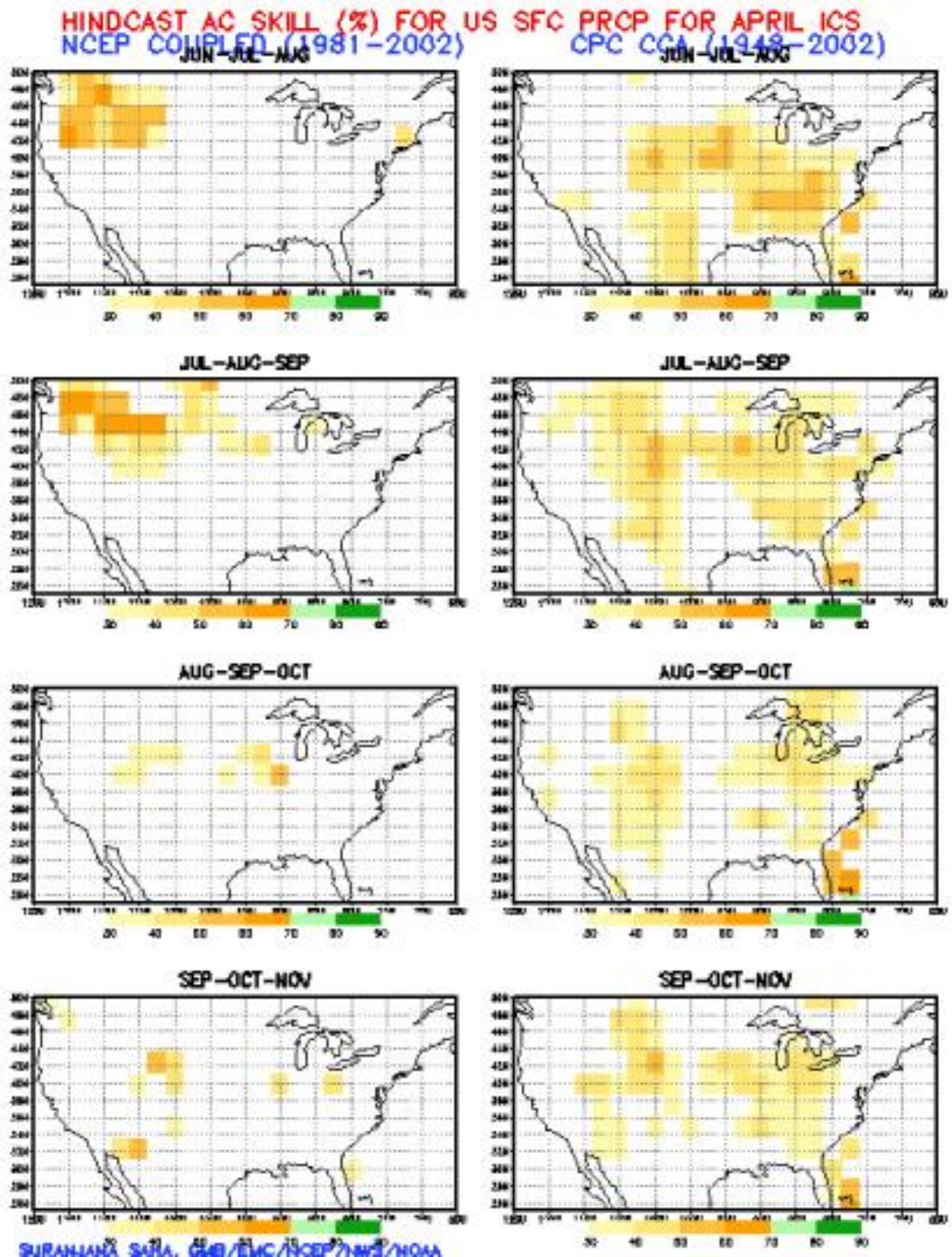
U. S. Surface Temperature Hindcast Skill

3 Month Averages

January IC

Comparison with CPC CCA Method (right)

Coupled System skill may be complementary to CCA

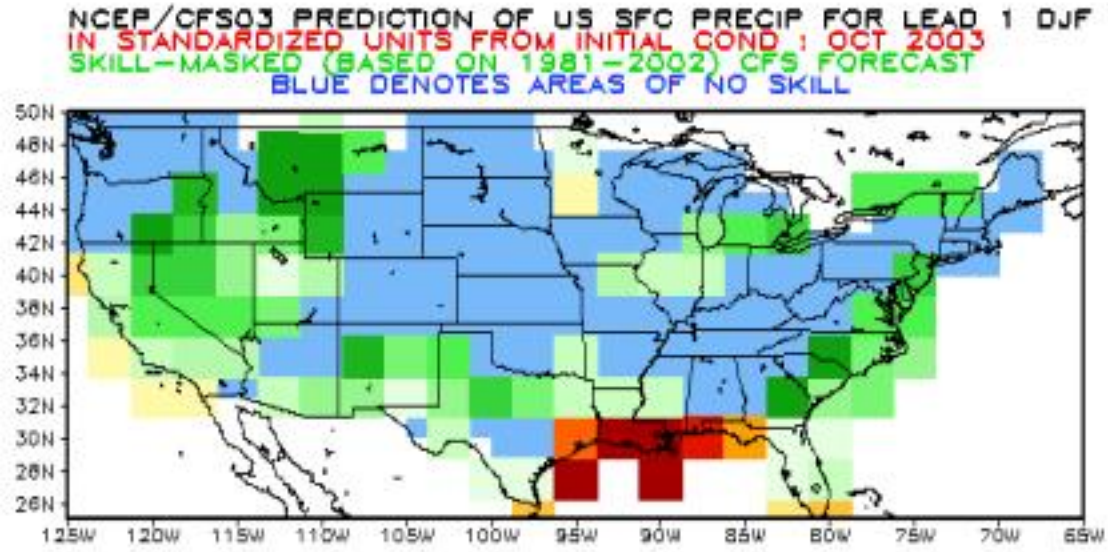


U. S. Precipitation Hindcast Skill

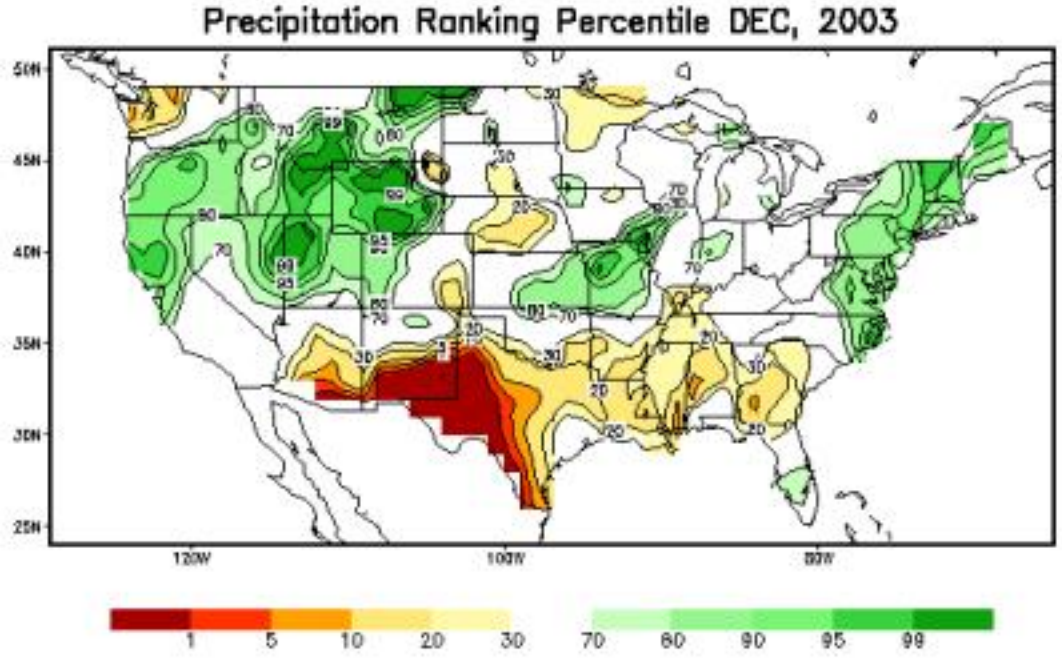
3 Month Averages April IC

Comparison with CPC CCA Method (right)

Coupled System skill may be complementary to CCA



New Coupled System
Forecast from October IC
Valid DJF
Precipitation normalized by
Climatology



Verifying Precipitation
Analysis
Percent of Climatology

Next Steps S/I Forecasting

- Complete calibration runs (2070 years of runs)
- Implement system (2004Q4)
- Upgrades
  - MOM4 (polar caps)
  - Sea Ice model
  - Atmospheric model
    - Stratus clouds
- Evaluate predictability
  - PNA, AO, MJO, NAO, AAO etc.
  - Use indices as skill measure in addition to standard (AC) scores
- Higher resolution experiments

Global Climate and Weather Branch Development

- Sub-grid scale orographic drag
  - Parallel run shows 1% improvement in NH & SH
  - Late winter implementation
- Sigma-pressure hybrid dynamic core
  - Improved performance in upper troposphere and stratosphere
- Gridpoint Statistical Interpolation (GSI)
  - Improved scores and efficiency in preliminary tests
  - Opens way for flow-dependent background errors and unified NCEP analysis across global and regional applications
  - 2004 implementation

Global Climate and Weather Branch Development (cont)

- Implement the 06Z and 18Z ensemble with T126 going to 180 hours
  - 40 members daily from 4 cycles
  - Improved scores from all members
- Collaboration with Canada on combined ensemble product system
- Implement a week-2 forecast system imported from the Climate Diagnostics Center
  - Ensemble system based on 1997 forecast model
  - Calibrated over 22 years of hindcasts
  - 15 member ensemble
  - Improved synoptic scores, including precip
- THORPEX participation

Global Climate and Weather Branch Development (cont)

- Land surface model (Noah for GFS & CFS & WRF)
- Ferrier cloud scheme
  - Used in Eta and WRF
- Convection
  - RAS/SAS consolidation
  - Interaction of convective and grid-scale parameterizations (towards scale-dependent parameterization)
- PBL: stable boundary layer problem

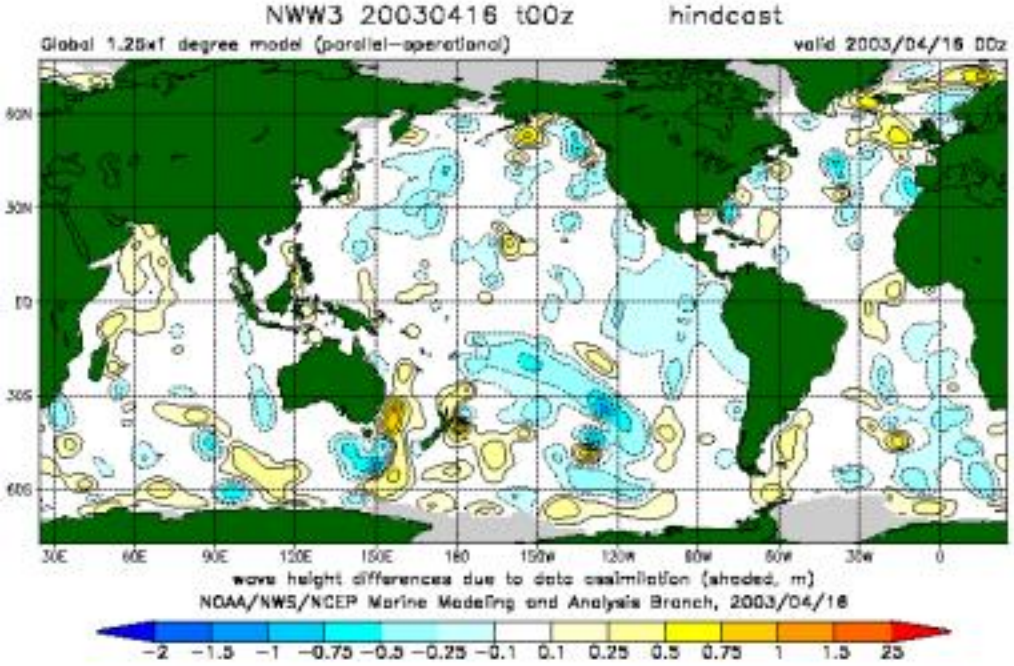
Real Time Ocean Forecasting

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

NOAA Wavewatch III (NWW3)

- Developed from community WAM
  - More modern software design
  - More complete governing equations (wave current interactions
  - Improved numerics (propagation and physics)
  - Improved physics
  - Adopted by Navy (FNMOC) 2001
- NWW3 applications at NCEP
  - Global 1.25x1 degree
  - Alaskan waters
  - Western North Atlantic
  - East Pacific
  - North Atlantic Hurricane (forced by GFS and GFDL
  - East Pacific Hurricane (forced by GFS and GFDL)

NWW3 Development and Implementations



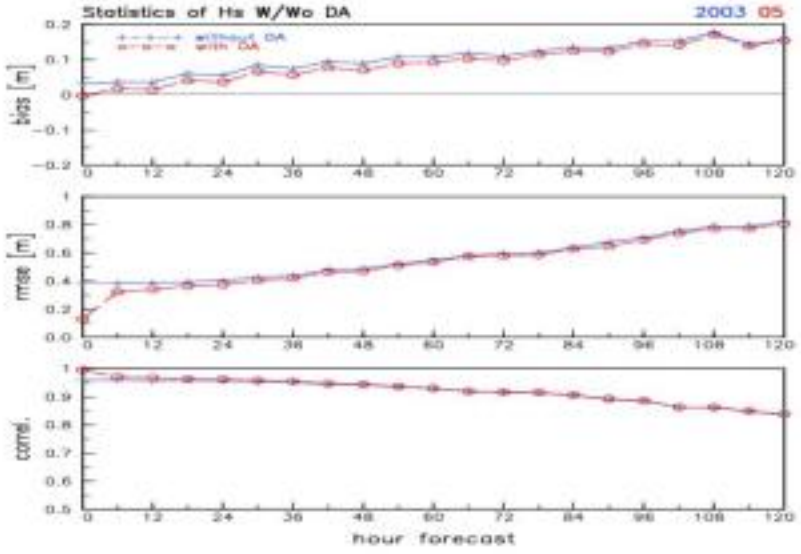
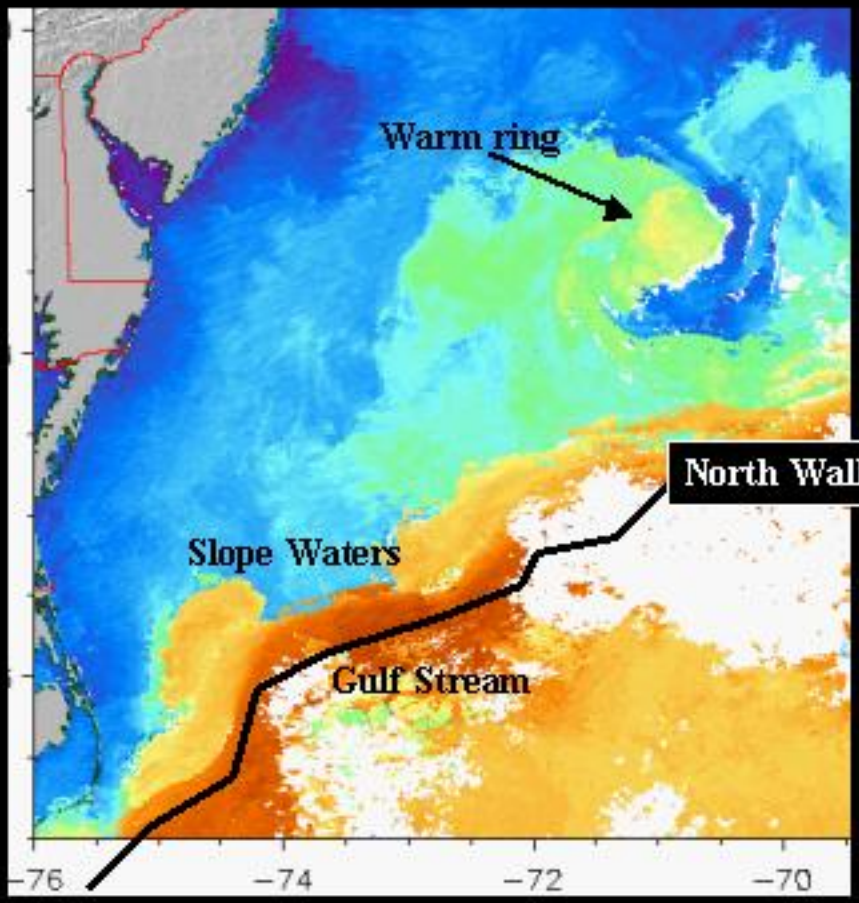


Fig. Wave Height Statistics With And Without Data Assimilation,
Number of data points for each hour forecast > 17k.

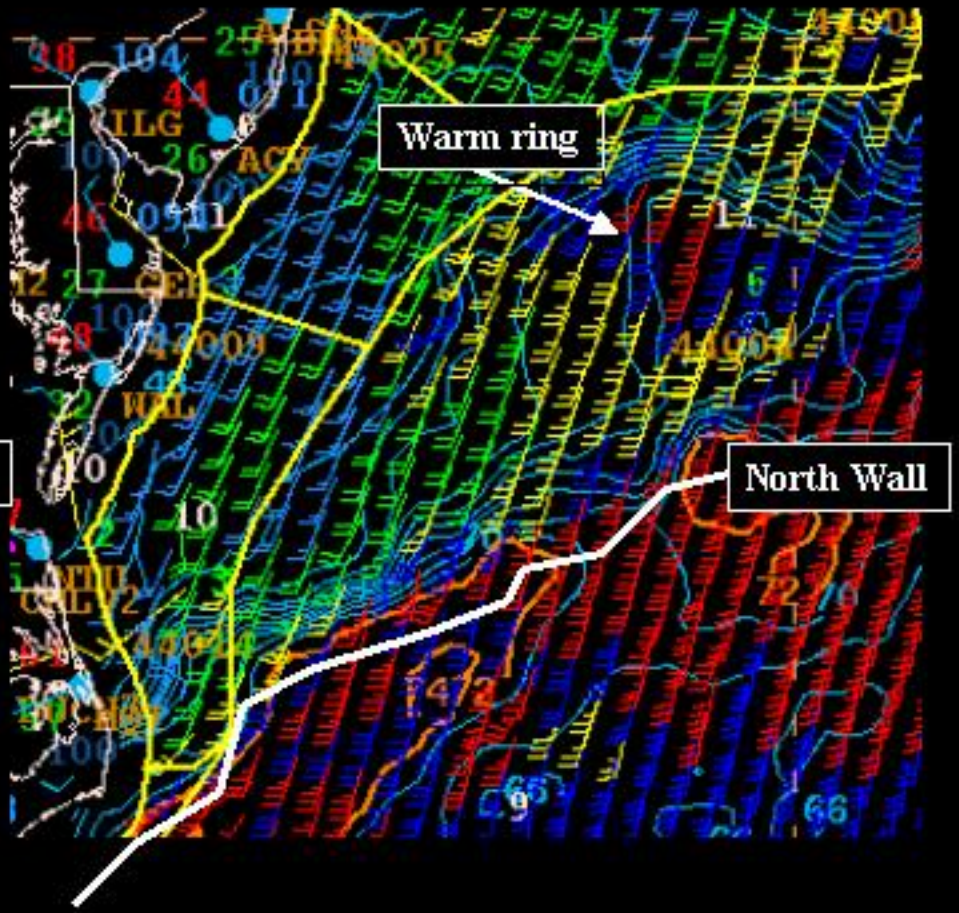
- **Altimeter data assimilation (above)**
- **2 way nesting**
  - **Coastal applications**
  - **Hurricane (moveable nests)**
  - **Affordable ensemble forecasting**
- **Improved wave-wave interactions**
  - **Parameterized with neural network**

The Gulf Stream



Sea Surface Temperature

Wind speed (Knots)
65 50 35 30 25 20



QuikSCAT Winds

SST-dependent wind speed difference across the North Wall of the Gulf Stream

Gulf Stream Waters – 30 to 40 kt

Cooler Slope Waters – 15 to 25 kt

Sea Ice Modeling and Analysis

- Daily 25.4 km grid –
  - Both NH & SH
  - Analysis by NASA Team Algorithm on SSMI
  - NCEP -- Improved Weather Filter
  - 0.5 degree latitude-longitude cleaned ice grid for models
- Moving to 12.7 and 0.125, respectively
- Ice Dynamic/Thermodynamic Model from Max Planck Institute Modified and Implemented in NCEP
- Other sea ice models being considered for upgrades and S/I forecasting

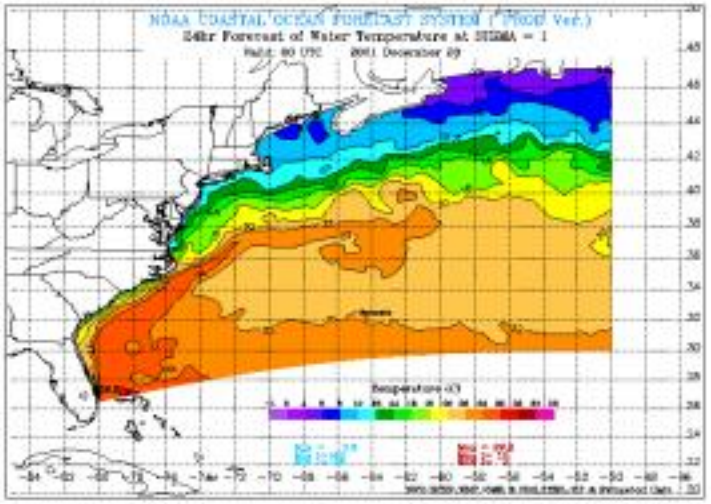
Present Real Time Ocean Forecasting –

Coastal Ocean Forecast System (COFS)

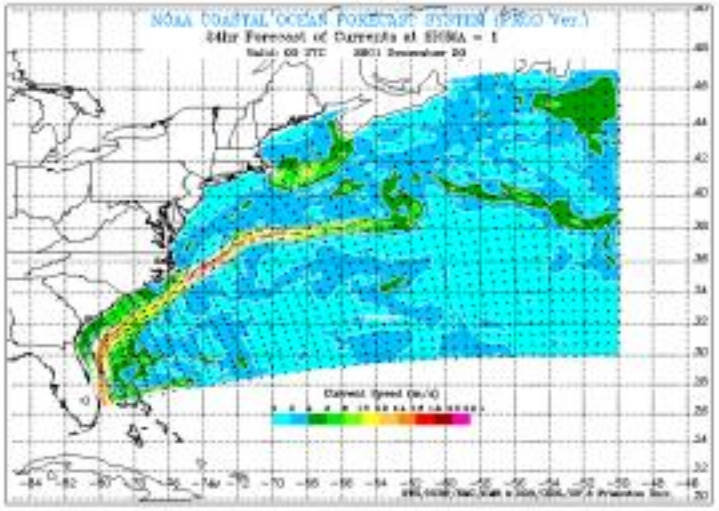
Princeton Ocean Model (POM)

- POM Partners
  - –EMC Marine Modeling & Analysis Branch
  - –NOS Coastal Survey Development Lab
  - –Princeton University
  - –NOPP Sponsorship
    - •2000 "Excellence in Partnering Award"

- 12 March 2002: implementation of first civilian run, operational, three-dimensional numerical ocean prediction system in the U. S



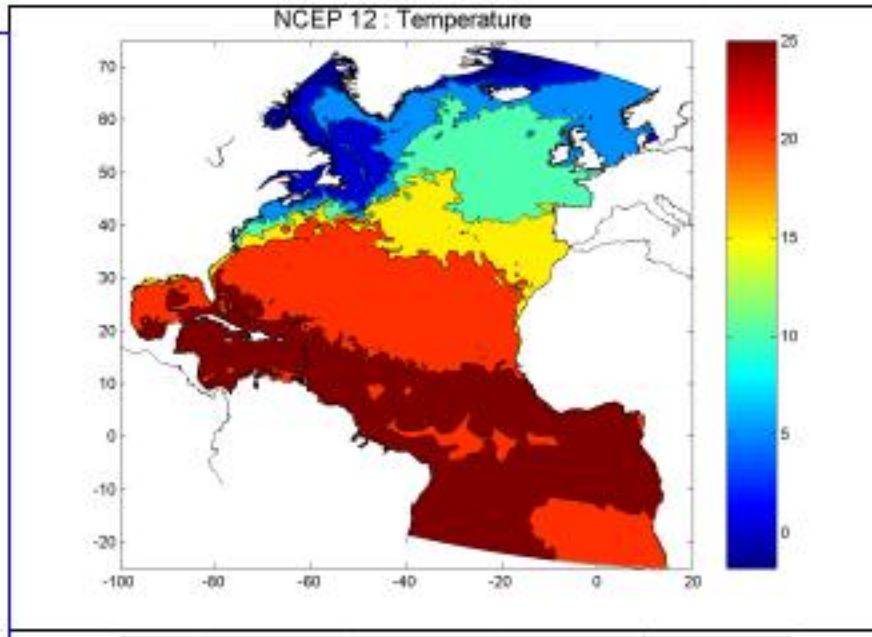
SST

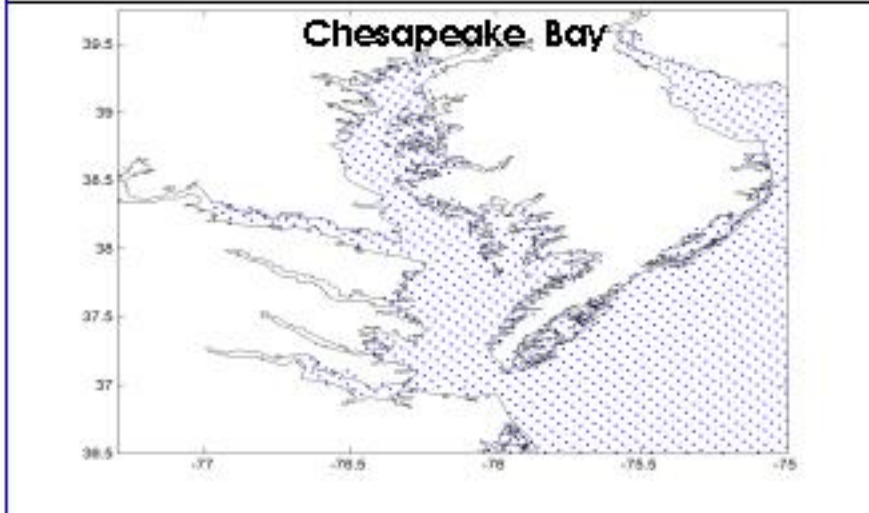


Surface Currents

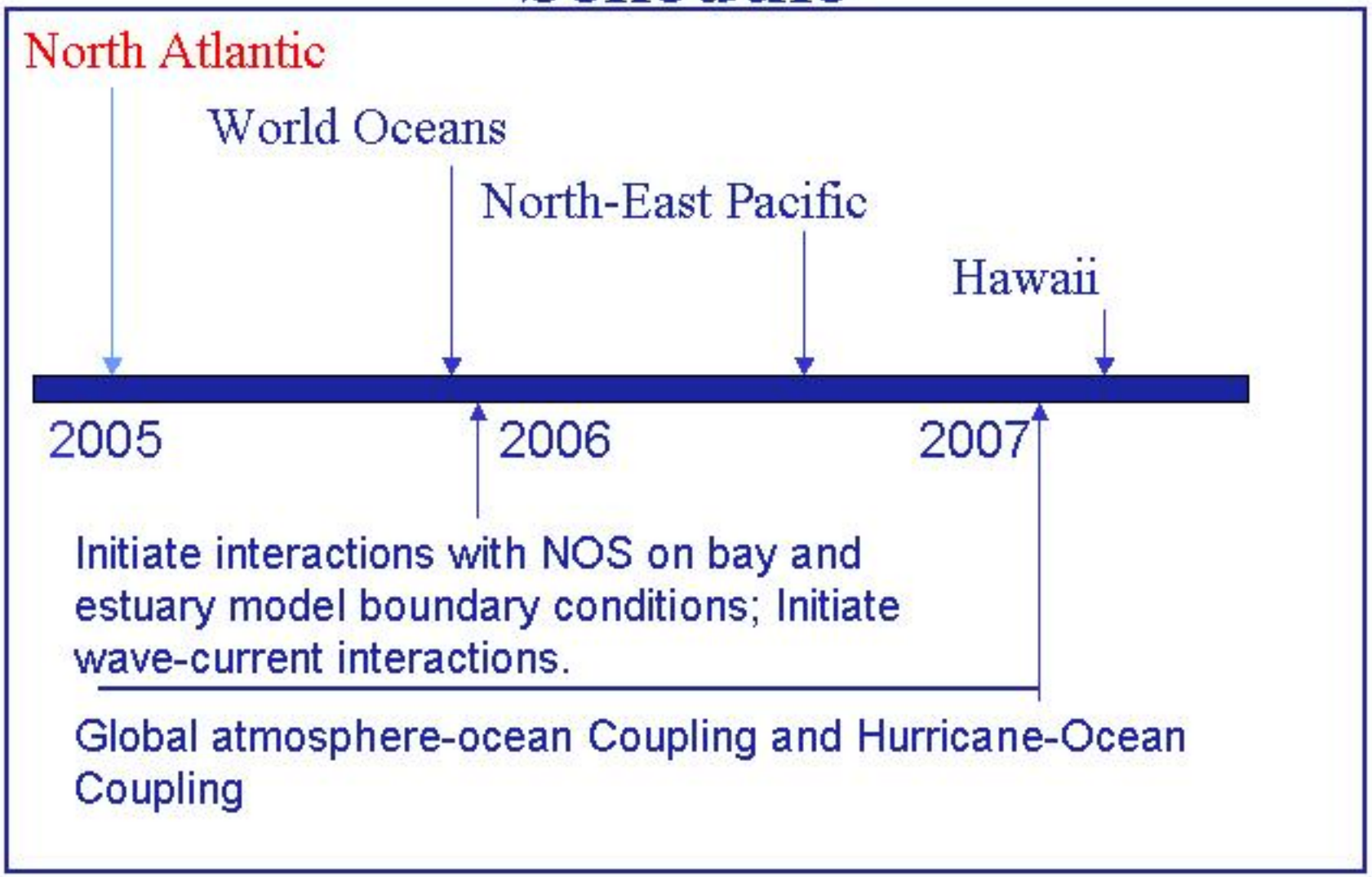
US GODAE: Global Ocean Prediction with HYCOM

- 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





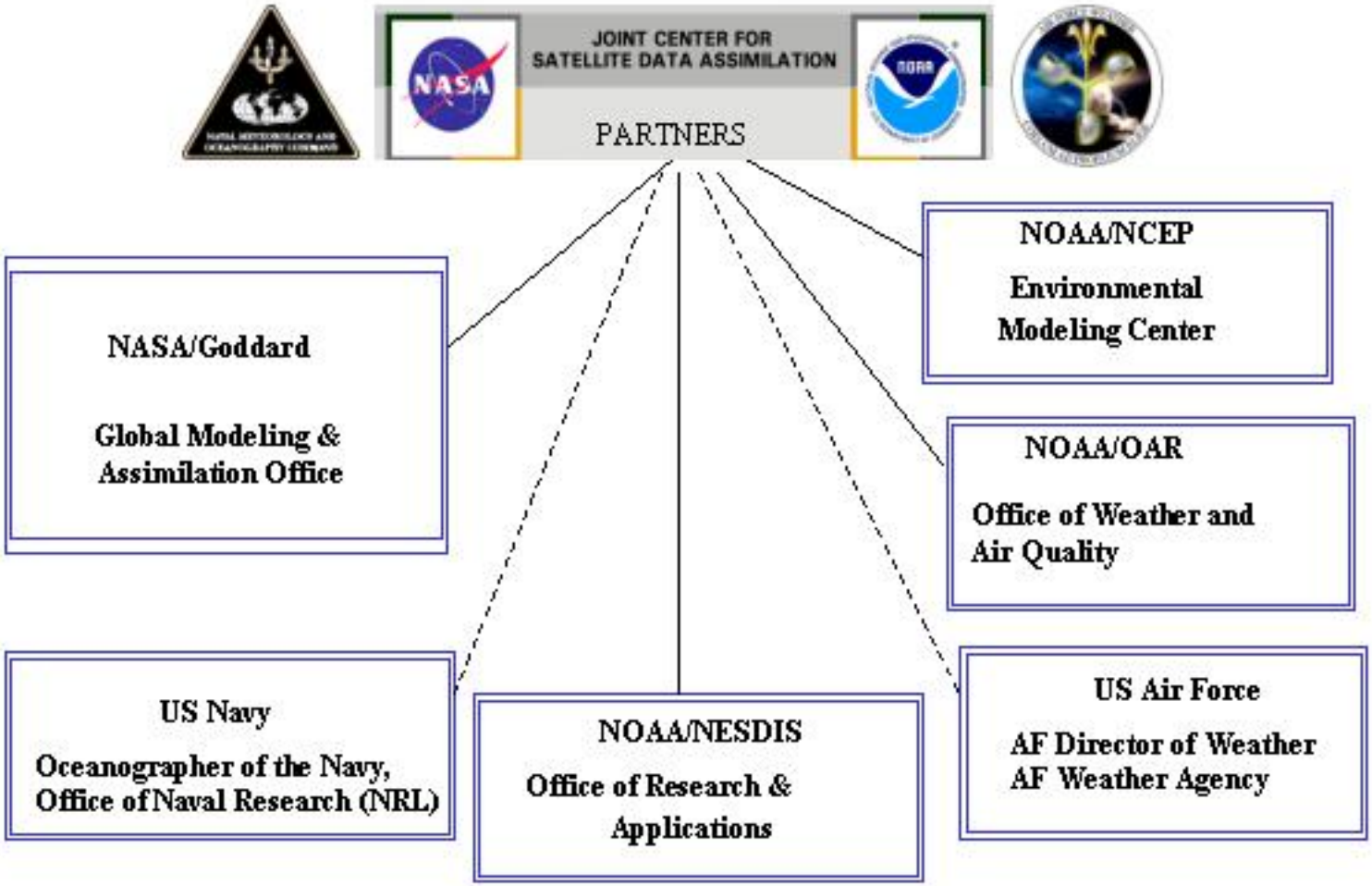
Schedule


North Atlantic
World Oceans
North-East Pacific
Hawaii
2005
2006
2007
Initiate interactions with NOS on bay and estuary model boundary conditions; Initiate wave-current interactions.
Global atmosphere-ocean Coupling and Hurricane-Ocean Coupling

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**

JCSDA Partners

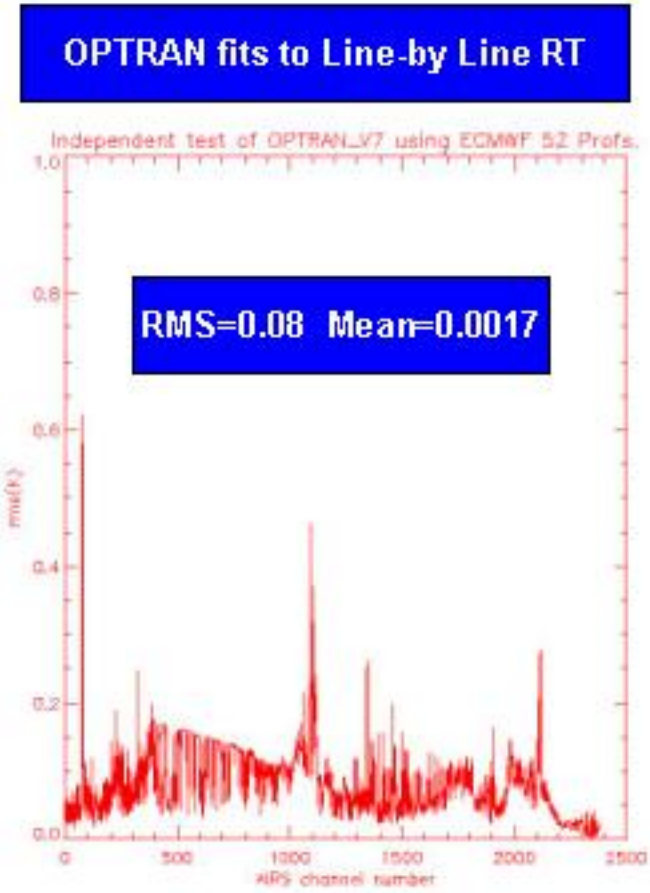


Overview of JCSDA Applied Research Areas

- Advanced radiative transfer
- Clouds and precipitation
- Assess impacts of current instruments
- Improve sea surface temperature data and use of altimeter data
- Enhance land surface data sets (surface emissivity model)
- Observing System Simulation Experiments (OSSEs)
- Improve data assimilation techniques
  - NASA/GMAO partnership for global analysis development
- Instrument specific development

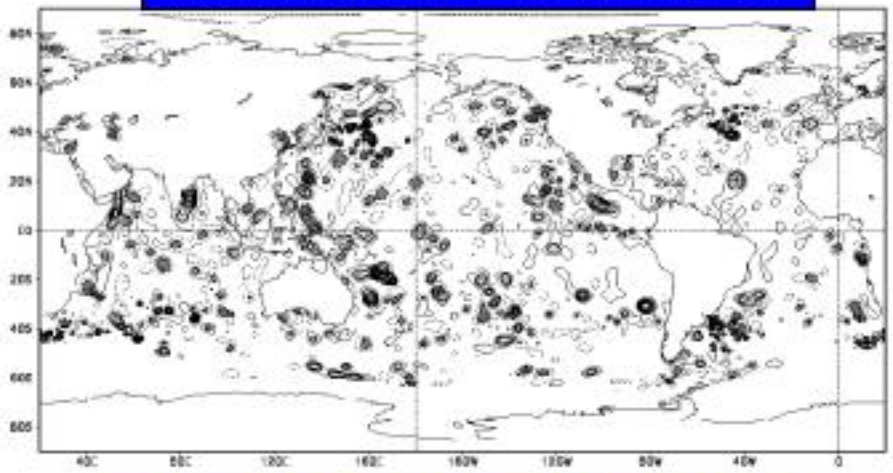
Advanced Radiative Transfer [Tahara, VanDelst, McMillin, Han]

- Increased accuracy
- Improved computation efficiency
  - Required for huge increase in data volume
- Add effects of
  - Aerosols
  - Trace gases
  - Reflection, scattering and
  - absorption by clouds

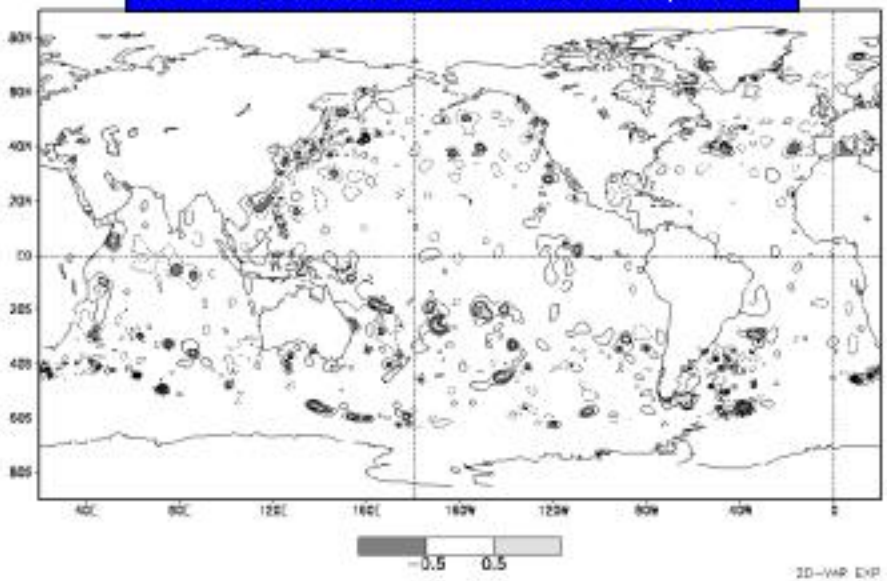


Improve Sea Surface Temperature Data [X. Li & Derber]

SST Difference 29-28 October 2003 - Control

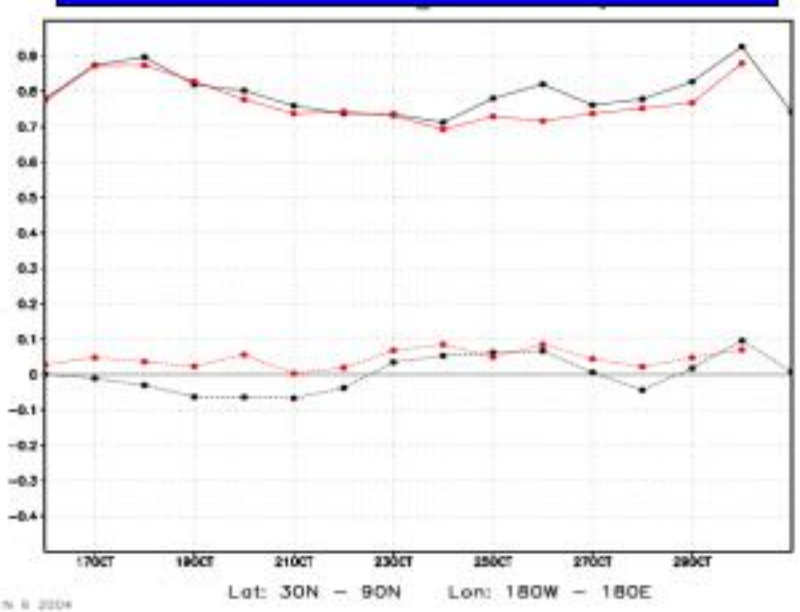


SST Difference 29-28 October 2003 - Experiment



- New physical retrieval from AVHRR data, cast as variational problem
- OPTRAN RTM & Linear Tangent Model
- Eventual direct use of AVHRR (and other) radiance data

RMS and Bias Fits to Independent Buoy SST Data



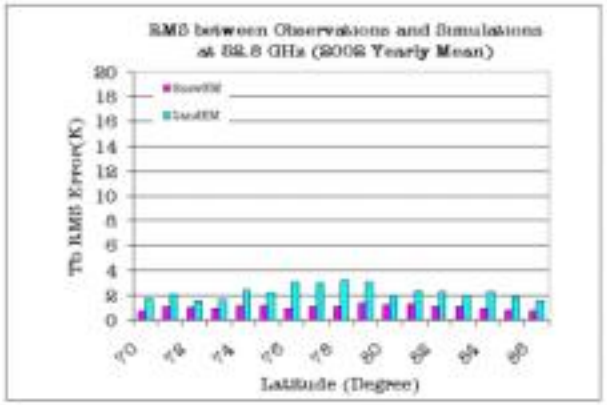
NOAA-16 AVHRR data only

Northern Hemisphere Ex. Tropics

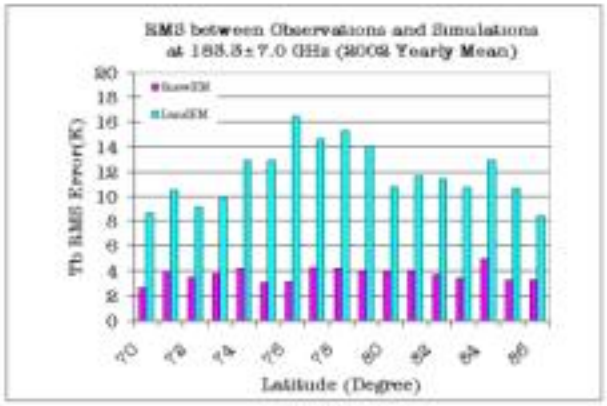
Improved Surface Emissivity Model for Snow [Yan, Okamoto and Weng)

Annual Mean RMS T_B Difference (Obs – Simulated)

(a) 52.8 GHz



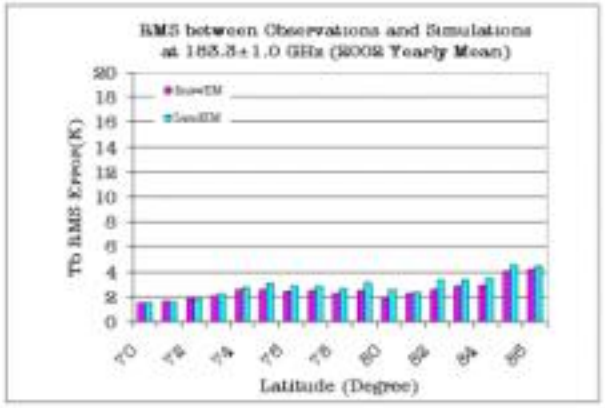
(b) 183.3±7.0 GHz



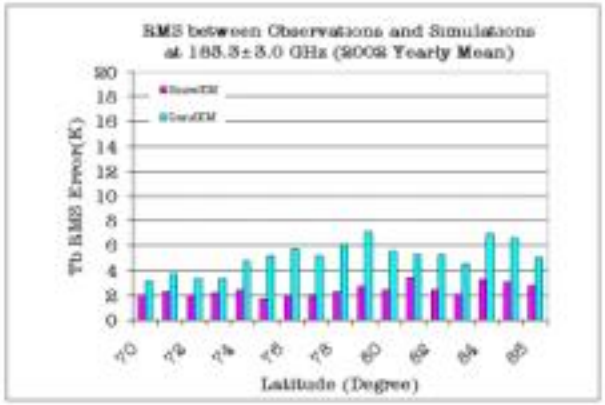
Operational

SnowEM

(c) 183.3±1.0 GHz



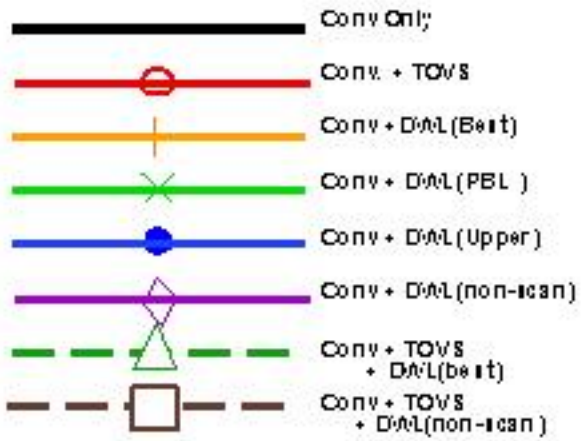
(d) 183.3±3.0 GHz



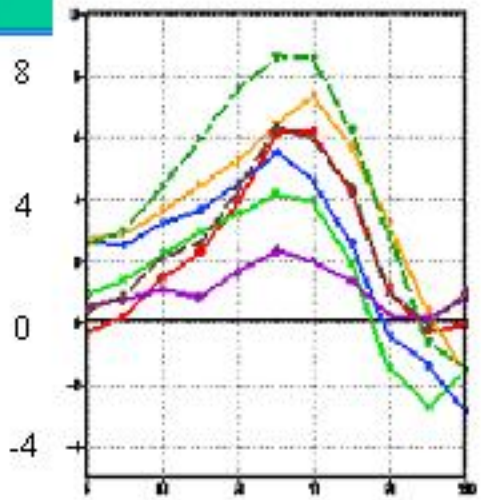
Observing System Simulation Experiments (OSSEs)

- Prepare for advanced data
  - Formatting
  - Understanding and formulation of observational errors
  - Initial quality control algorithms
- Understanding and formulation of observational errors
- Assists requirements definition, instrument design and potential instrument impact

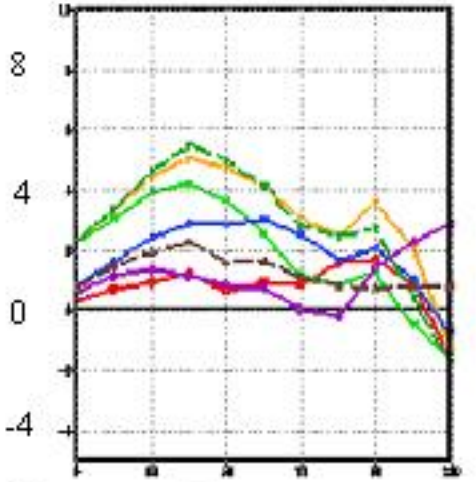
Doppler Wind Lidar (DWL) Impact



V at 200 hPa



V at 850 hPa



Time averaged anomaly correlations between forecast and NR for meridional wind (V) fields at 200 hPa and 850 hPa. Anomaly correlation are computed for zonal wave number from 10 to 20 components. Differences from anomaly correlation for the control run (conventional data only) are plotted.

Improve Data Assimilation Techniques [Derber, Treadon, Parrish, Wu, Kleist Ferrier, Moorthi, **NASA/GMAO**]

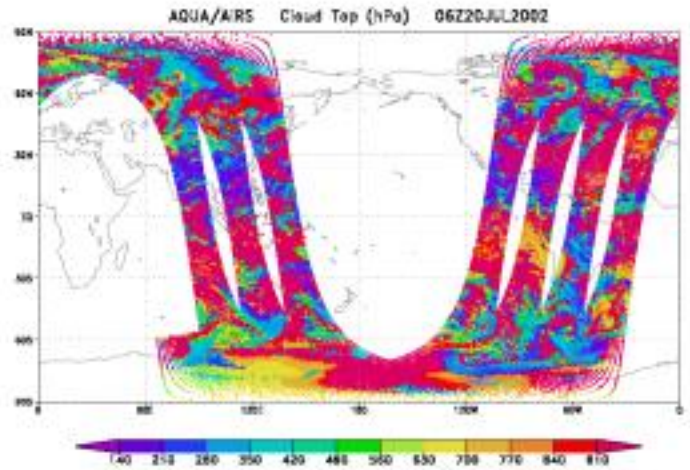
- Extract additional information from observations (emphasis on satellite data)
- Unified global and regional system based on Gridpoint Statistical Interpolation (GSI)
- Improve model physics (emphasis on clouds)
- Improve background and observational error estimates
- Assess computational resources for future data assimilation systems

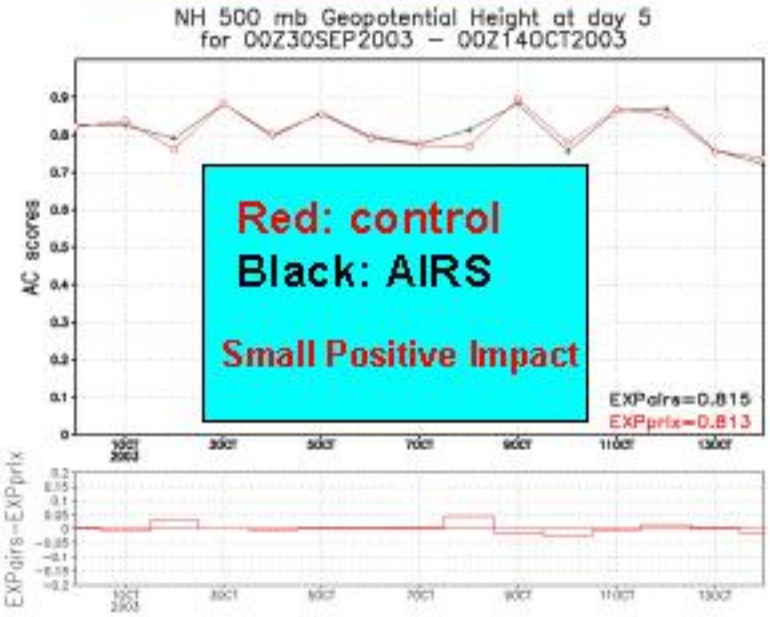
Examples of Instrument-Specific Development at the JCSDA

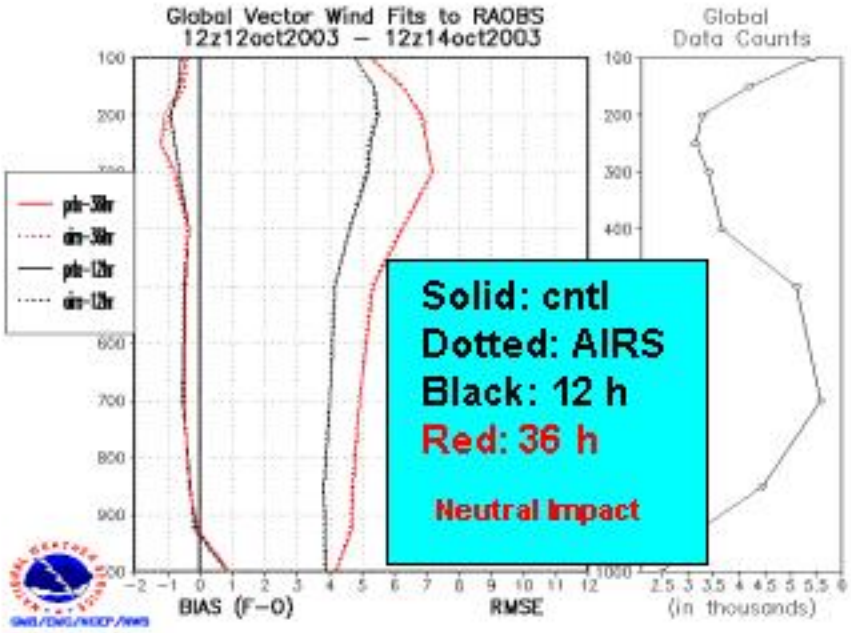
- **GPS Occultation (COSMIC)**
  - NCAR-sponsored Post-Doc at JCSDA
  - High vertical resolution, low horizontal res. (different from any other satellite data)
  - Forward model to derive index of refraction developed
  - Preparing for use of data within NCEP analysis
  - Preparing for COSMIC using CHAMP and SAC-C data (available 12/03)
- **AIRS**

AIRS Testing at NCEP

[Derber, Treadon]







- T254/L64 Parallel testing has begun
- 254 out of 281 channels
- Initial results show small positive/neutral impact
- Testing will continue and additional improvements and uses (such as for SST and cloud analysis) will be developed

Mesoscale Forecasting

- Data processing
  - ENDIAN independent BUFR processing
    - Increases portability
    - Applications to WRF
  - New data sources
    - Upgrade of NEXRAD data to level II.5
    - Mesonet, GPS-IPW, RASS, boundary layer profilers
    - Advanced sounder (AIRS)

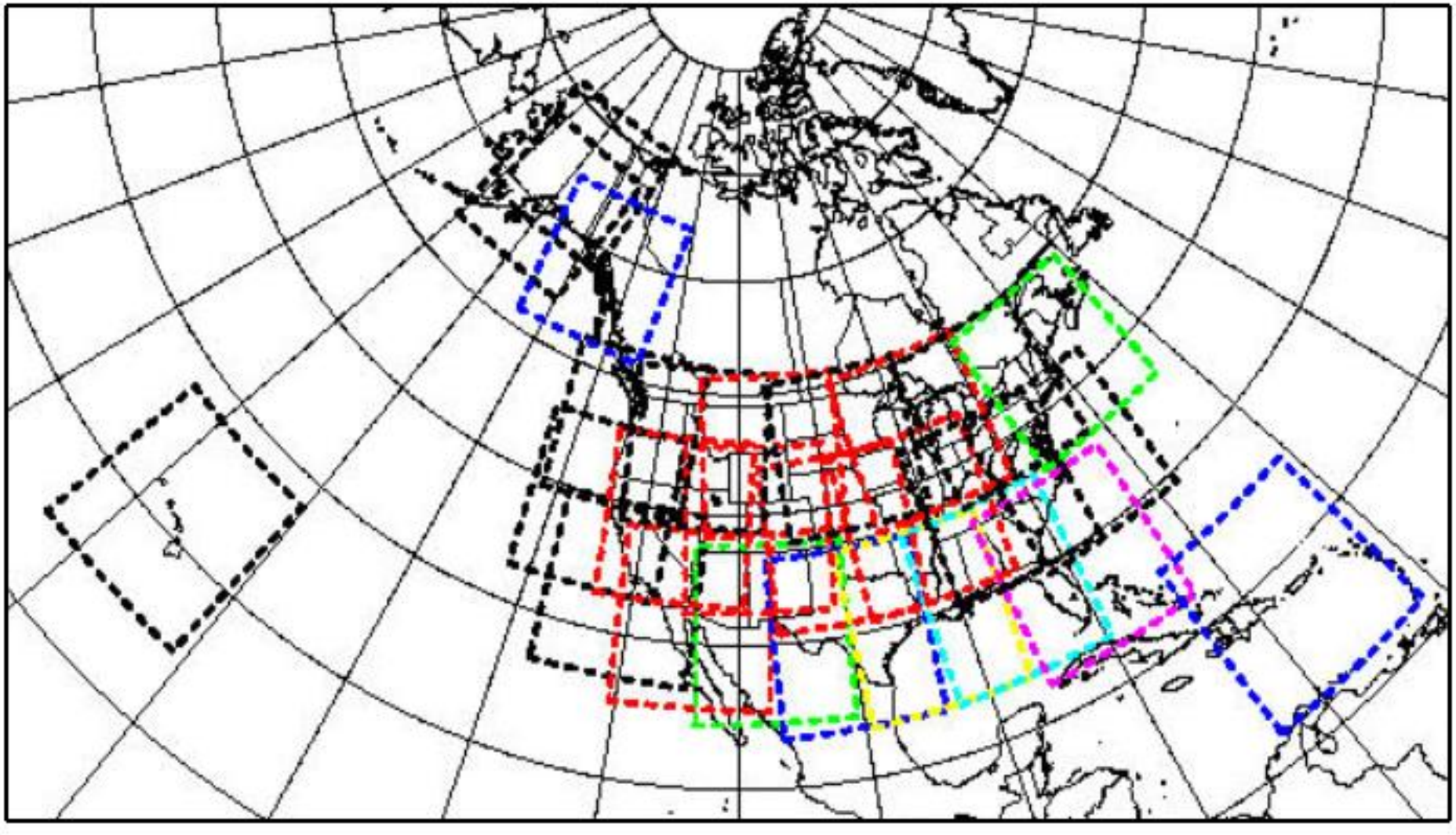
Nonhydrostatic Mesoscale Model (NMM)

- See Janjic, Gerrity,and Nickovic, 2001 for model equations, solution techniques & other test results [MWR,Vol. 29, No. 5, 1164-1178]
- Highly refined version of nonhydrostatic option released in May 2000 upgrade to NCEP's workstation Eta
- NMM retains full hydrostatic capability
  - Incorporate nonhydrostatic effects through ε where ε=(1/g) dw/dt
  - Then split prognostic equations into:
    - hydrostatic parts plus
    - corrections due to vertical acceleration
  - Set ε to zero to run in hydrostatic mode

Nonhydrostatic Mesoscale Model
Feature Comparison With Meso Eta

Feature	Meso Eta Model	Nonhydrostatic Meso Model
Dynamics	Hydrostatic	Hydrostatic plus complete nonhydrostatic corrections
Horizontal grid spacing	12 km E-grid	8 km E-grid for FireWx/IMET 4 km E-grid for Homeland Security
Vertical coordinate	60 step-mountain eta levels	60 sigma-pressure hybrid levels
WRF compatible	No	Yes Coded into the WRF Infrastructure (Black & Michalakes)

26 Selectable 8 km Domains For Fire Weather / IMET Support Identical To 4 km Homeland Security Domains



July Upgrade Package for Eta-12 (Rogers)

- Gridscale cloud & precipitation (Ferrier)
  - Begin proper cycling of total condensate & ice/water rain/snow ratios
  - Upgrade microphysics and improve cloud - radiation interaction
- 3DVAR analysis (Parrish)
  - Add direct analysis of WSR-88D radial velocity from NWS Multicast
  - Upgrade radiance processing – begin use of NOAA-17 – 20x more
- Precipitation assimilation (Ying Lin)
  - Assimilation of GOES cloud top pressures
  - Assimilate Stage IV instead of Stage II hourly precip
- Increased output frequency and content (Manikin +)

http://wwwt.emc.ncep.noaa.gov/mmb/tpb.spring03/tpb.htm

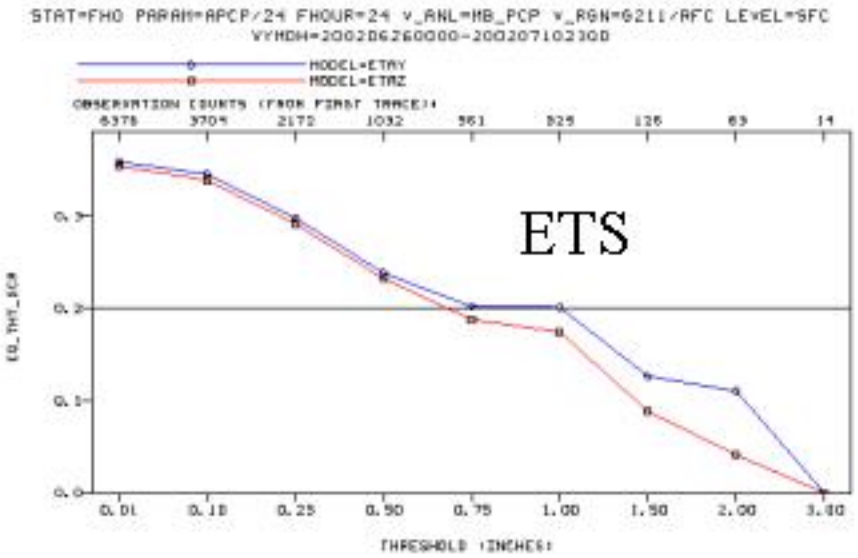
http://wwwt.emc.ncep.noaa.gov/mmb/mmbpll/etapllsup12.etax/

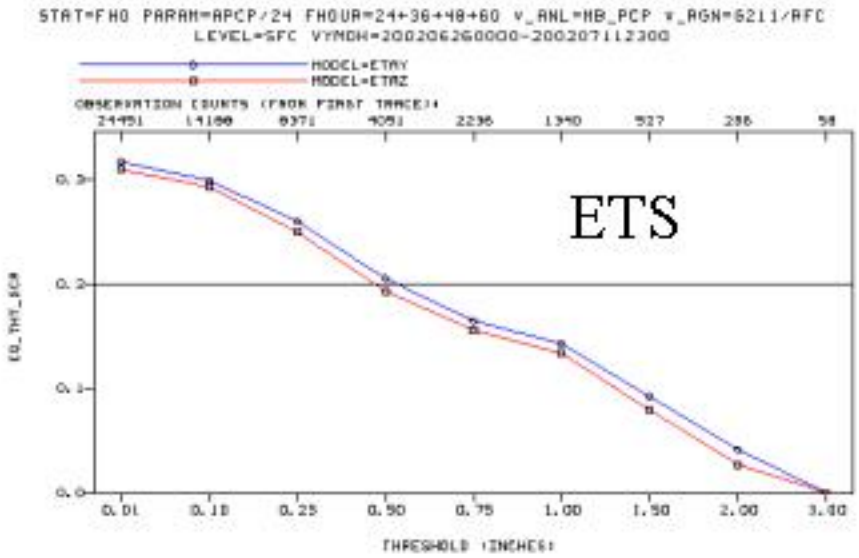
Impact of Use of Cloud-Top on 24 hr QPF Scores

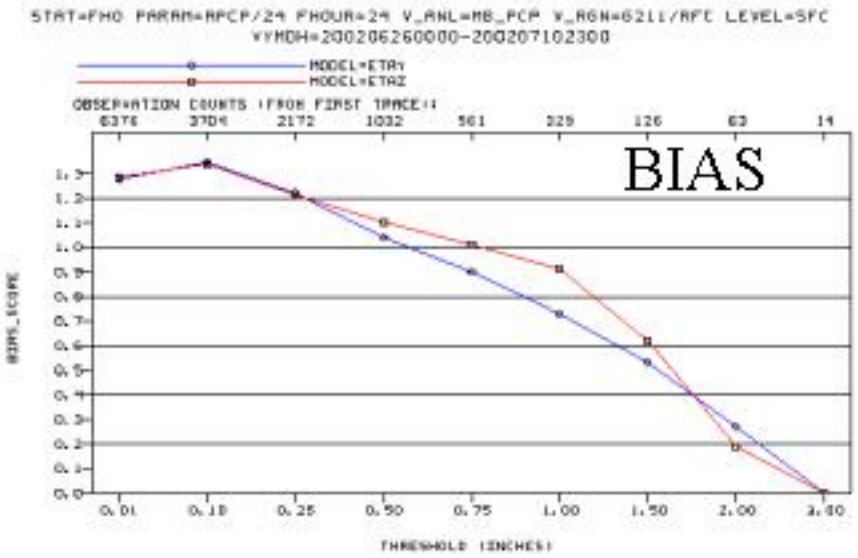
24 hour forecasts

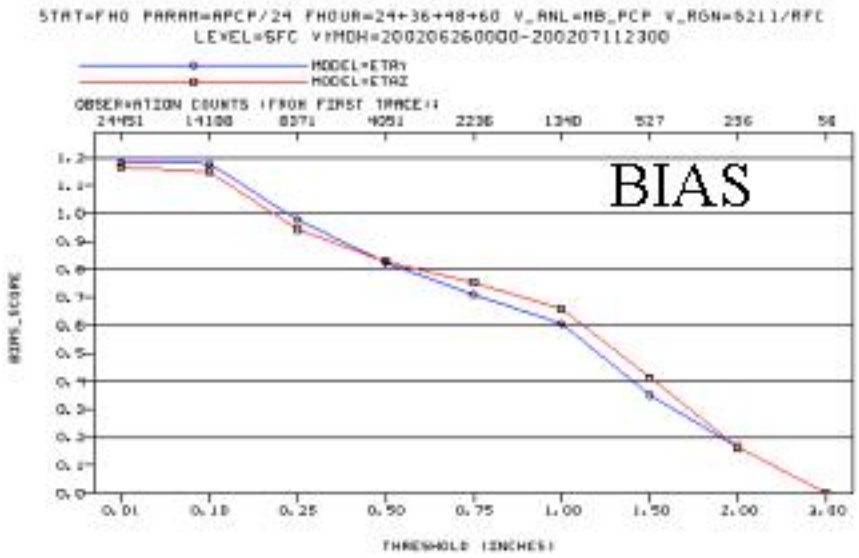
24+36+48+60 hour forecasts

Blue: cloud top assim; Red: Control

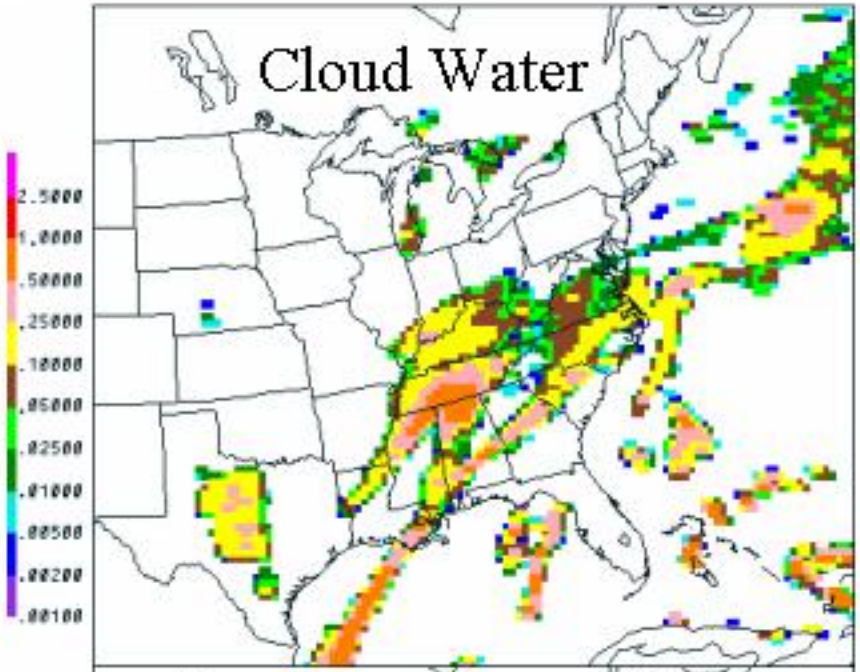








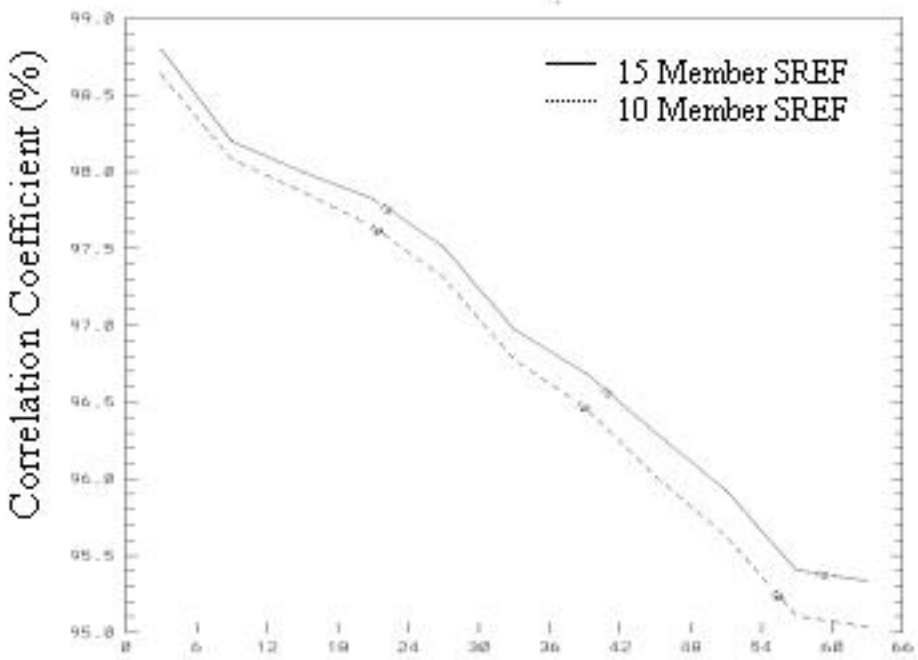
Example of Hydrometeor Fields from Eta

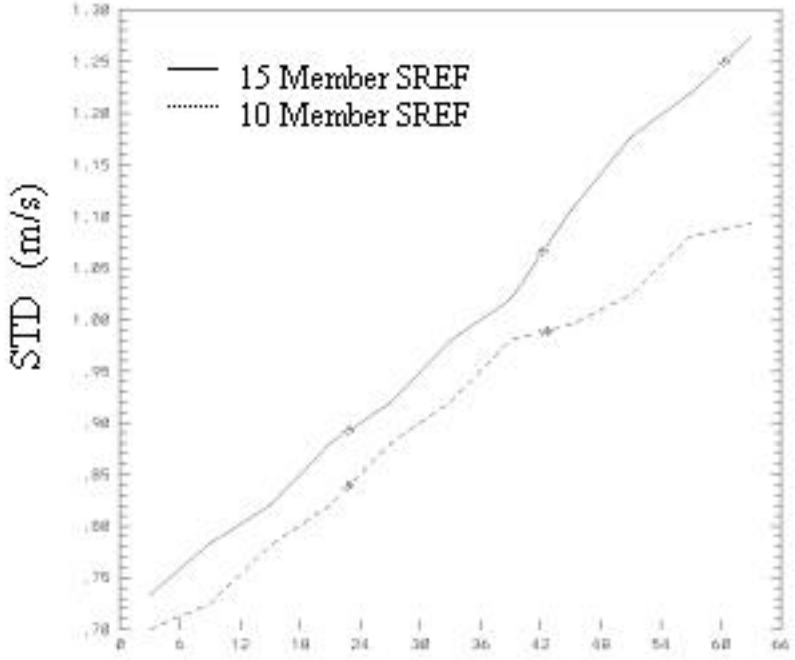


September Upgrade to Short Range Ensemble Forecast (SREF) System

(J. Du, B-B Zhou)

- **Added 5 members based on Eta using Kain-Fritsch**
  - Improved spread and accuracy

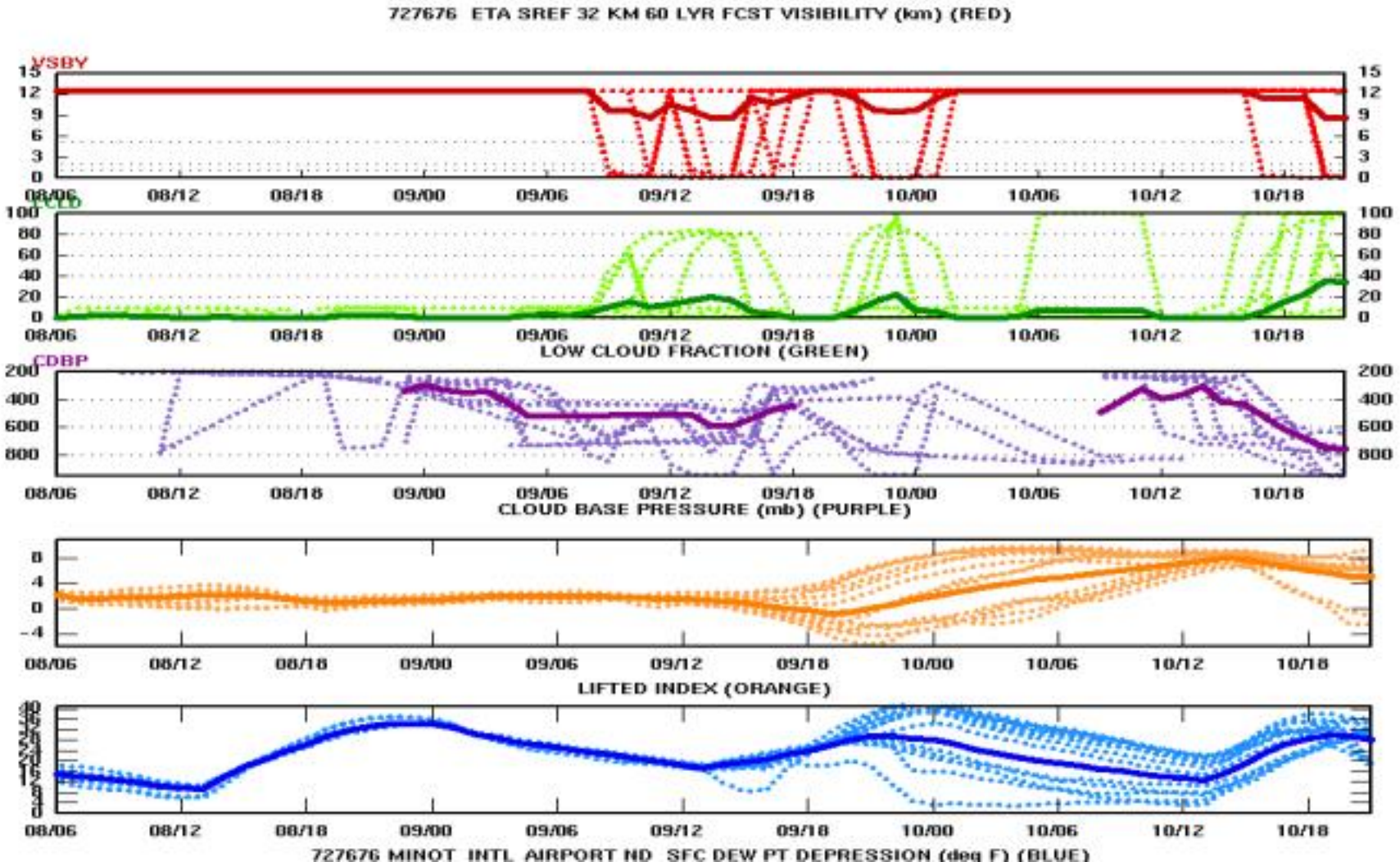




850 mb Temperature

September Upgrade to Short Range Ensemble Forecast (SREF) System (cont)

- **Upgraded products including BUFR soundings**



Short Range Ensemble Forecast (SREF) System For January 2004 Implementation

- Combines value of initial condition breeding, physics diversity and improved horizontal resolution
- 3 Meso Eta Model (BMJ) members
- 3 Regional Spectral Model (SAS – new GFS & MPI)
- 2 Meso Eta with Kain-Fritsch members
- 2 Meso Eta with Relaxed Arakawa-Schubert (RAS)
- 2 Regional Spectral Model with RAS
- 2 Meso Eta with Kain-Fritsch Full Detrainment
- 1 Meso Eta with Ferrier Modified Shallow Convection
- BUFR soundings from RSM members as well as Eta
- Domain is full North American continent
- Resolution is 32/35 km versus 48 km

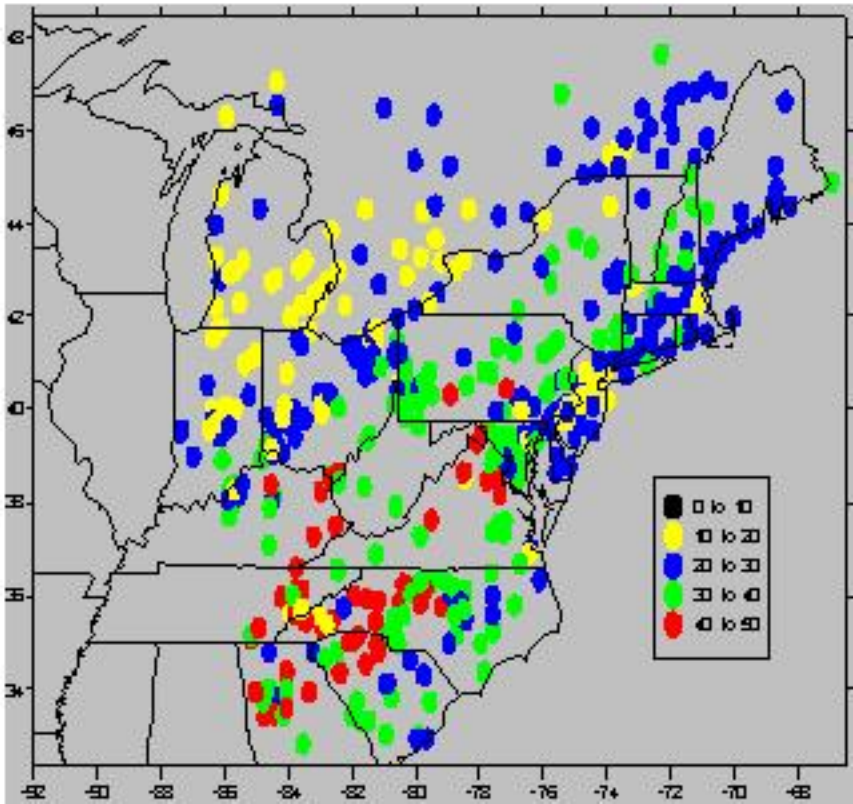
Air Quality Prediction at NCEP

Jeff McQueen, Pius Lee, Marina Tsildilko, with Geoff DiMego, Hui-Ya Chuang and Eric Rogers

Paula Davidson – NWS/HQ/OST Program Manager

- Initial (1-5 years started FY2003) :
  - –1-day forecasts of surface ozone (O_3) concentration
  - –Develop and validate in Northeastern US in 2 years
  - –Deploy Nationwide within 5 years
- Intermediate (5-7 years):
  - –Develop and test capability to forecast particulate matter (PM) concentration
- Longer range (within 10 years):
  - –Extend air quality forecast range to 48-72 hours
  - –Include broader range of significant pollutants
- Program has purchased additional computer power to perform AQF and promised this increment for perpetuity

Spatial Evaluation vs Obs Hourly Ozone (rms srror)

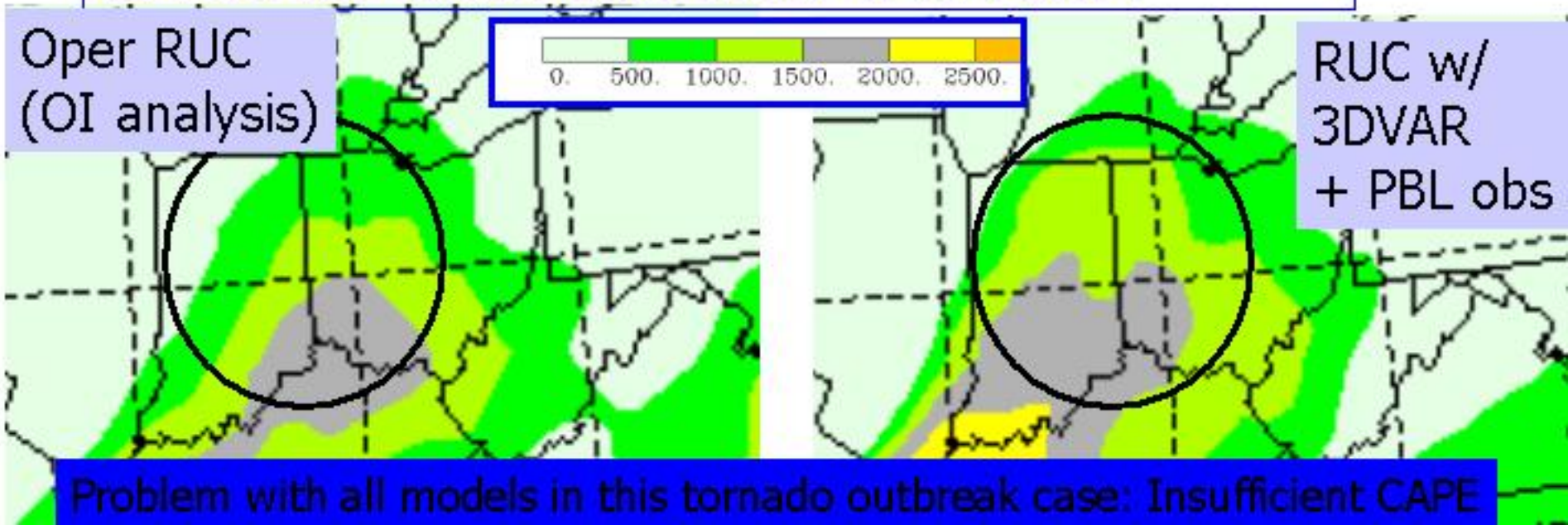


RUC - Key parts of planned Jan 04 changes

- Vertical advection of moisture
  - improved precip, moisture, clouds
- Use of boundary-layer depth in METAR assimilation
  - improved CAPE, surface dewpoint/temp/wind forecasts

Effect of PBL-based METAR assimilation

RUC 6h CAPE fcsts Valid 2100z 10 Nov 2002



Problem with all models in this tornado outbreak case: Insufficient CAPE

RUC planned changes after Jan 2004

- **Later in 2004**
  - Assimilation of surface cloud obs/current weather/vis,
  - Assimilation of GPS precipitable water, PBL profilers, mesonet
  - Cloud microphysics, cumulus parameterization changes
  - Hourly forecasts extended to 9h projection
- **early 2005**
  - 13km RUC (in testing at FSL – Fall 2003)
- **early 2007 (goal)**
  - WRF-based Rapid Refresh

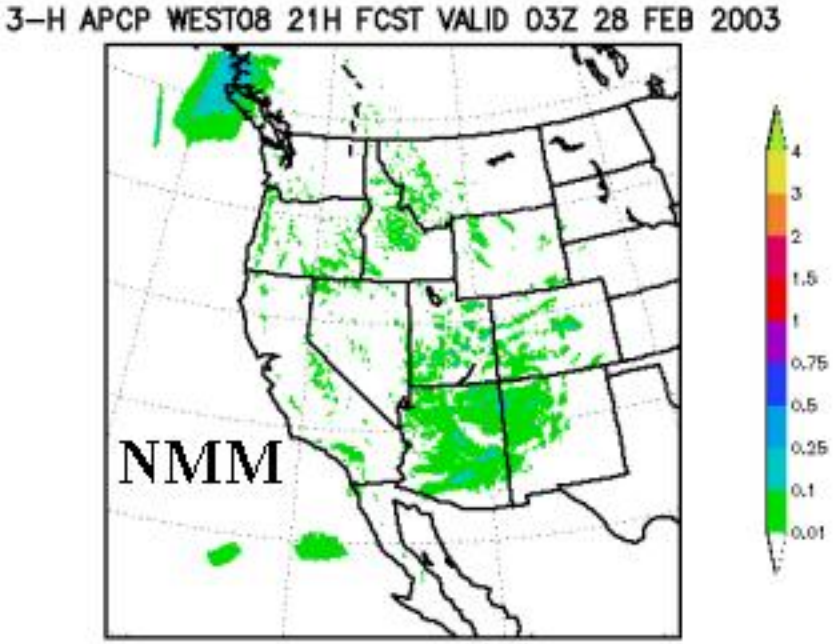
WRF Implementation Schedule

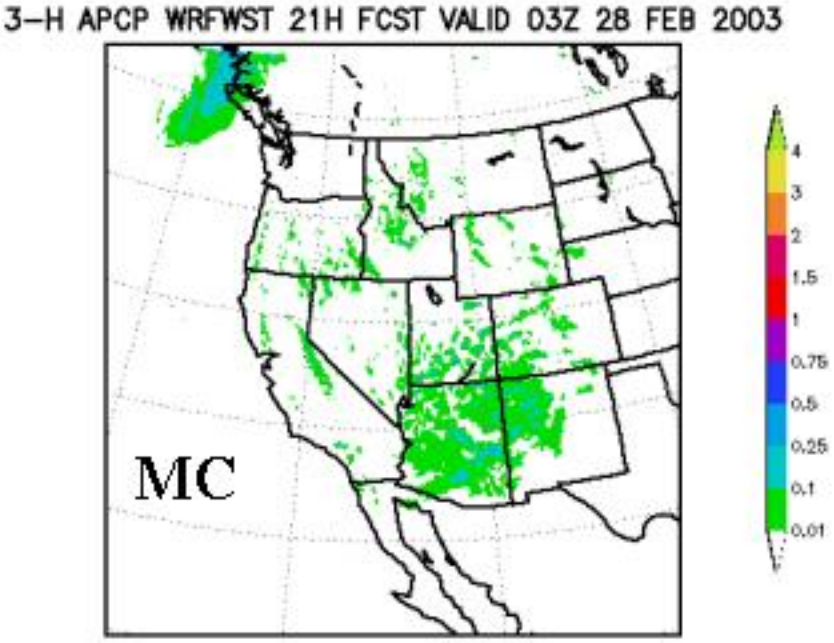
- HiResWindow: WRF Ensemble in FY04
- North American WRF: Operational in FY05
- Hurricane WRF: Operational in FY06*
- Rapid Refresh WRF: Operational in FY07*
- WRF SREF : Operational in FY07
- FireWeather/IMET Support and Homeland Security*

* As resources allow

NCEP Parallel System to Run WRF Test Versions

- MC or NMM cores with NCAR or NCEP physics
  - Identical 8 km HiResWindow configuration –
  - Routine runs began May 2003
  - 4 large domain nests (Western,Central&Eastern CONUS + Alaska)
  - 2 small domain nests (Hawaii and Puerto Rico)
  - http://www.emc.ncep.noaa.gov/mmb/mmbpll/nestpage/





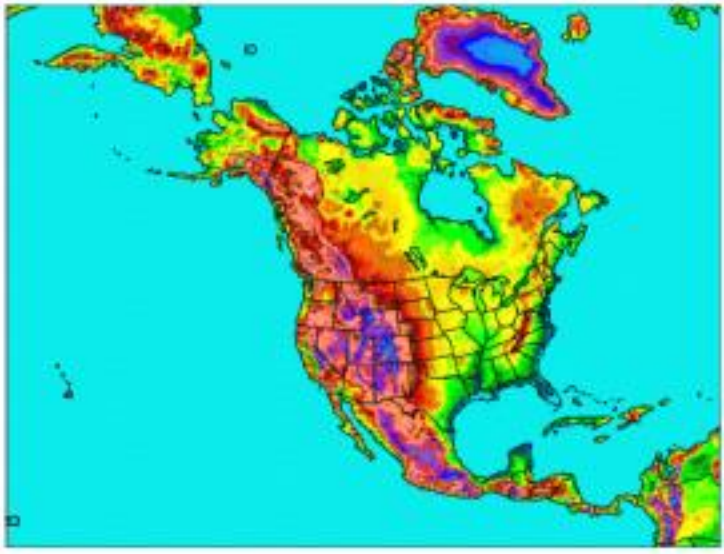
NCEP Proposal for Downscaling Model Grids for NDFD

Geoff DiMego

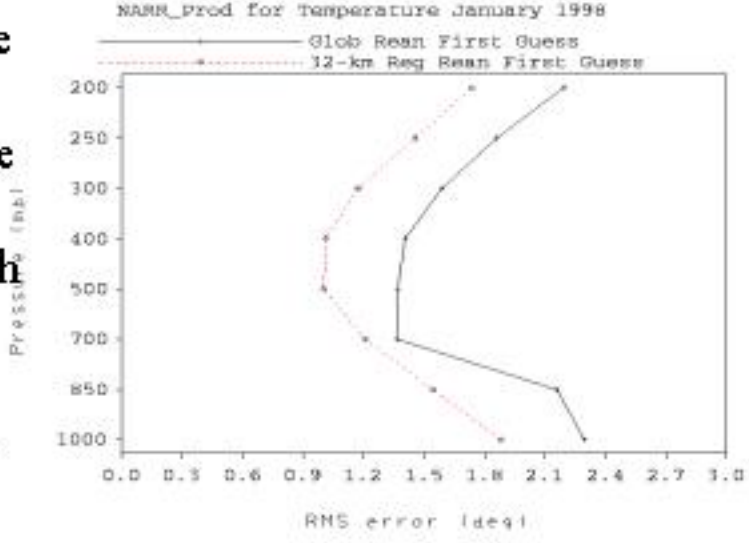
21 October 2003

North American Regional Reanalysis

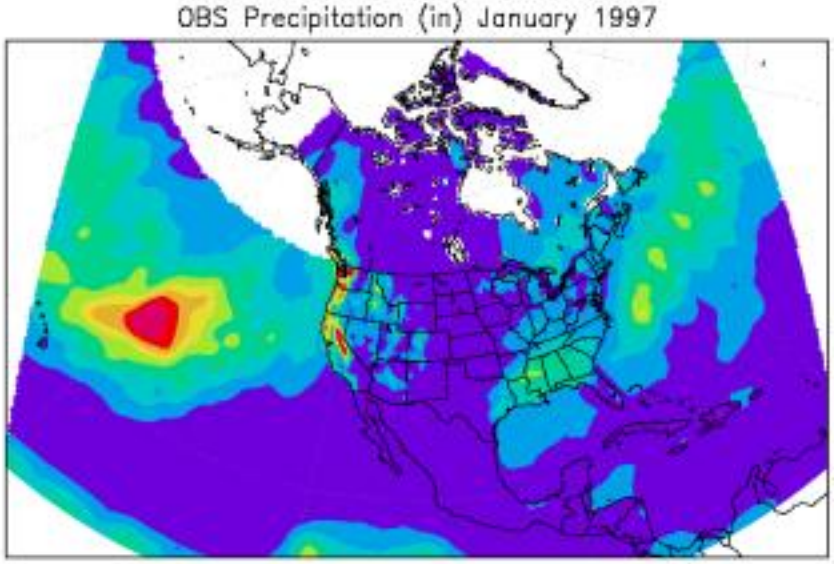
- Purpose: To create long-term set of consistent climate data on a regional scale on North American domain
- Uses Eta model
  - Precipitation assimilation
  - Direct assimilation of radiances
  - Land-surface model updates
- Completed 24 years of RR production 3+ months, running 4 streams, on IBM ASP
- Precipitation Initialization in Eta Model
  - Precipitation observations used to prescribe the latent heat profile in Eta model
  - Model uses given latent heat profile to simulate precipitation
  - Resulting precipitation pattern looks very much like the observed precipitation pattern in both summer and winter
- Real time Regional CDAS to be implemented operationally in 2004

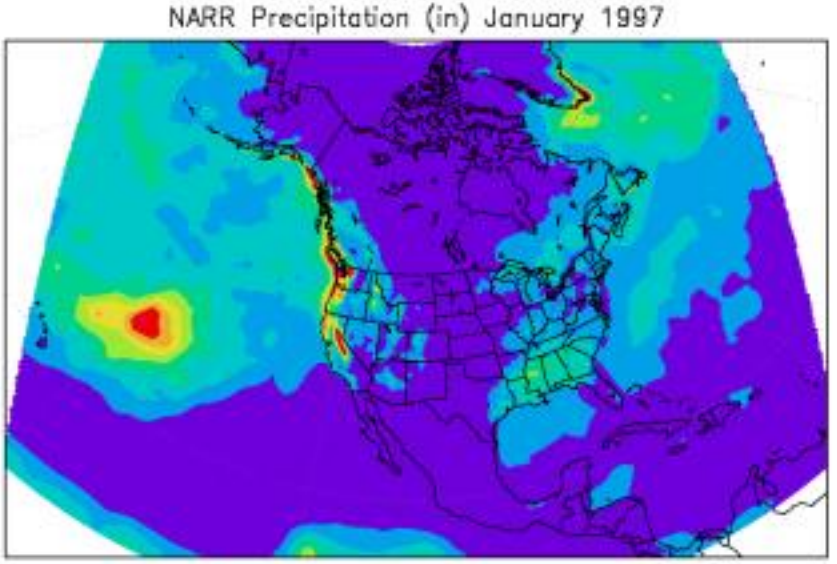


January 1998

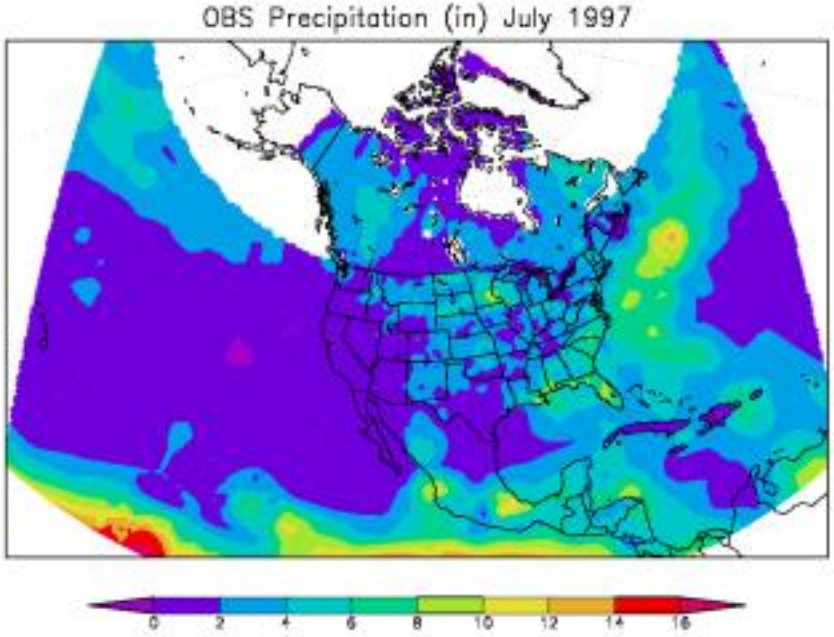


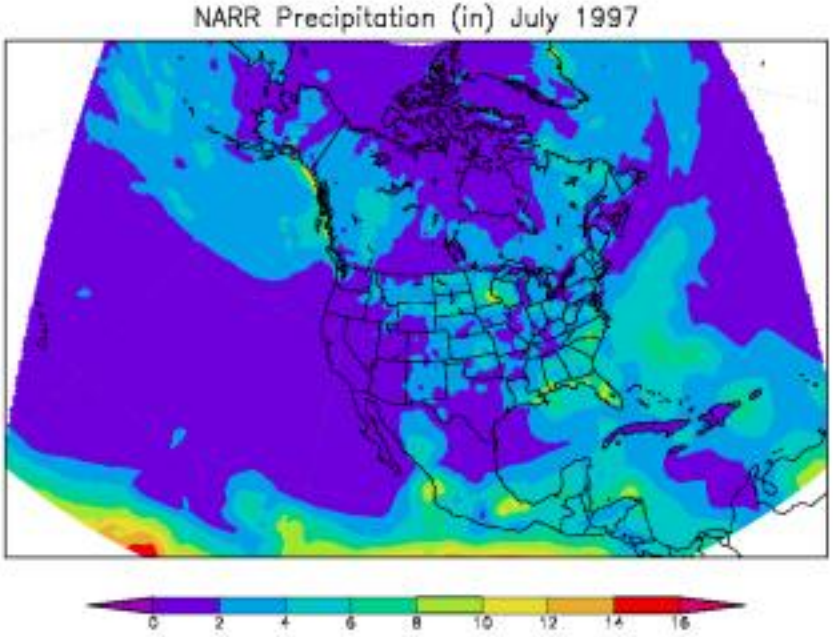
January 1997 Precipitation Results





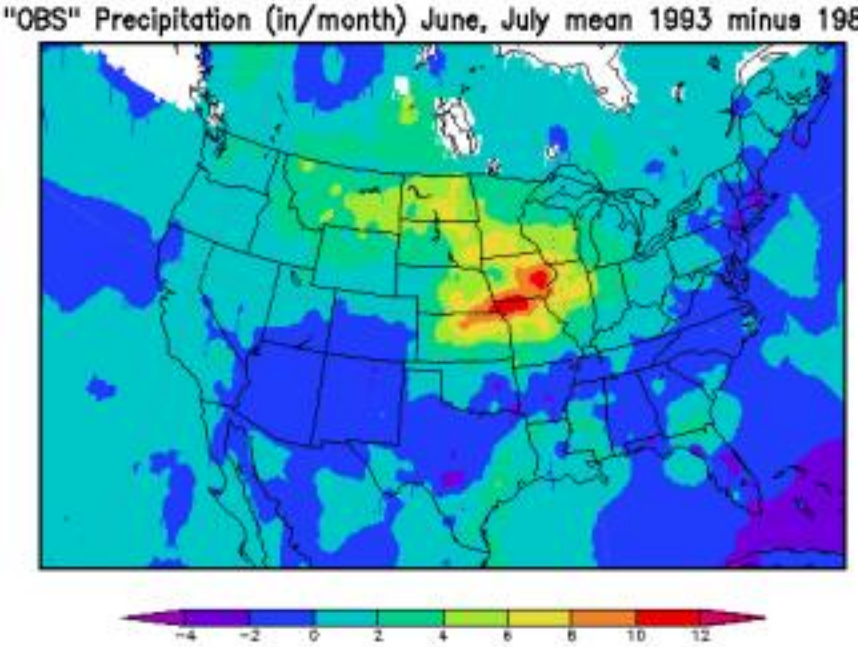
July 1997 Precipitation Results



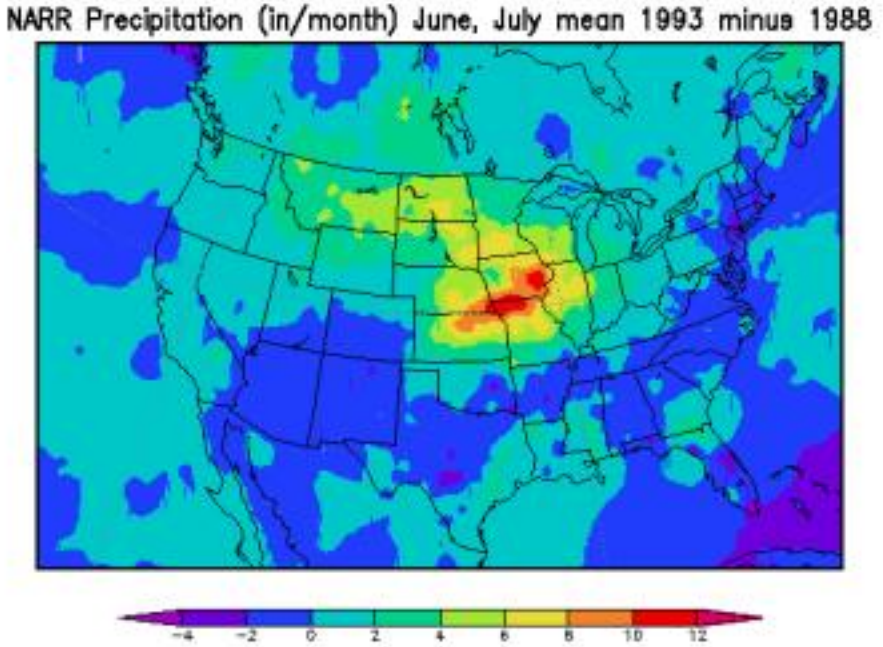


Drought of 1988 and Flood of 1993

Observed Difference



Reanalysis Difference



- Mean June/July precip of 1993 minus mean June/July precip of 1988

- Shows the success of precipitation assimilation even for drought and flood years

EMC Land-surface & Hydrology Thrusts

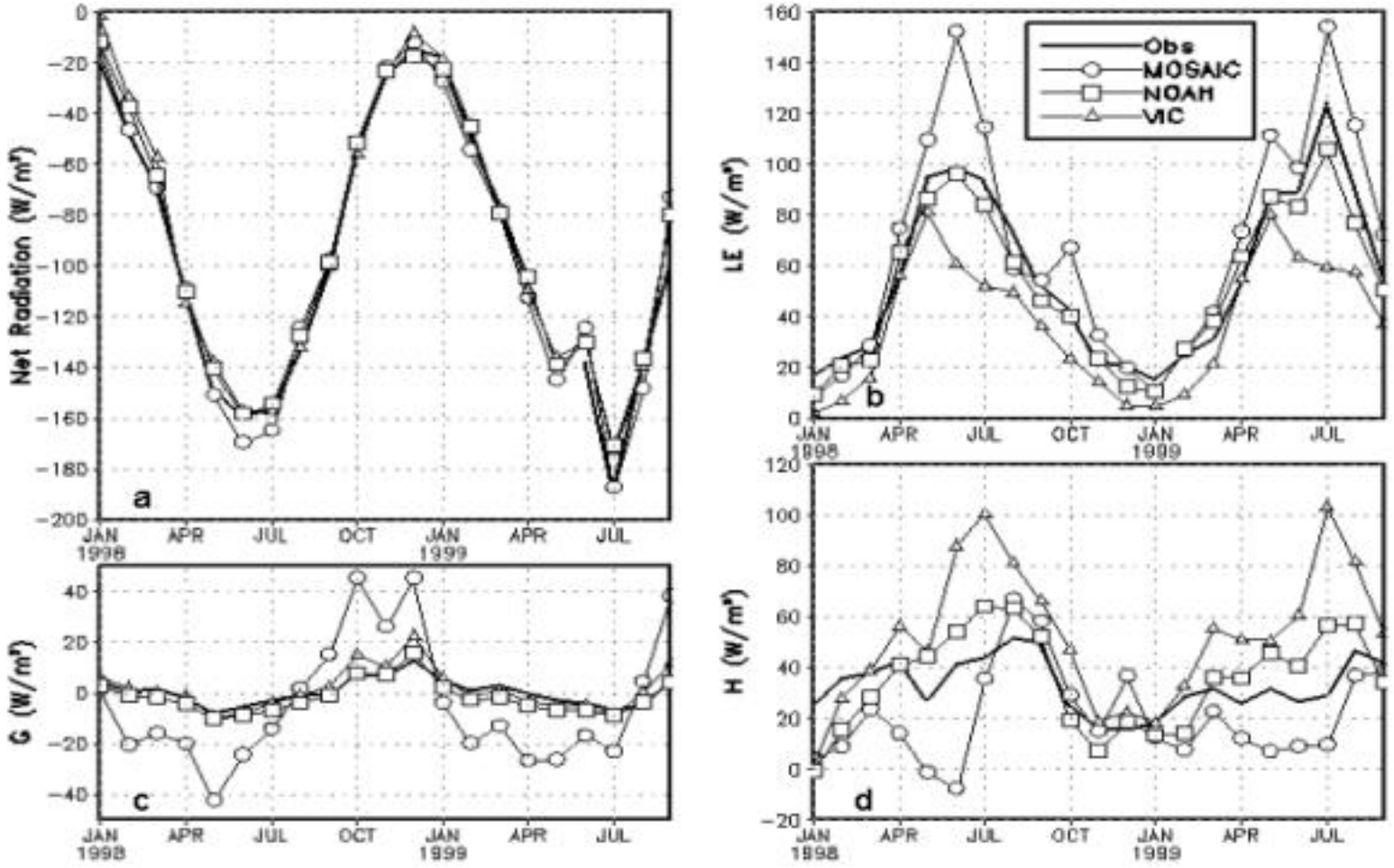
- **Improve land-surface physics & impact in all NCEP prediction models via improved Noah LSM**
  - Climate and Weather models, Global and Regional Models
  - Prediction time scales from hours/days to seasonal/annual
- **WRF Land Group: Weather Research and Forecast Model**
  - **NCAR, AFWA, NOAA/FSL partners with NCEP**
  - **Employ and jointly develop/test Unified Noah LSM**
  - **Sponsored by U.S. Weather Research Program (USWRP)**
- **Provide Land Data Assimilation Systems (LDAS) to join NCEP atmosphere and ocean data assimilation**
  - **NLDAS:** North American Land Data Assimilation System
    - Uses latest version of Noah LSM
  - **GLDAS:** Global Land Data Assimilation System
    - NASA-NCEP partnership (with COLA and Princeton U.)
    - Being ported from NASA to NCEP computing platforms
  - **Regional Reanalysis**: 32-km EDAS with latest Noah LSM
    - 1979-2002 completed: four soil layers, snowpack, vegetation

NLDAS:

Validating surface fluxes vs. 15 ARM SGP Flux Stations

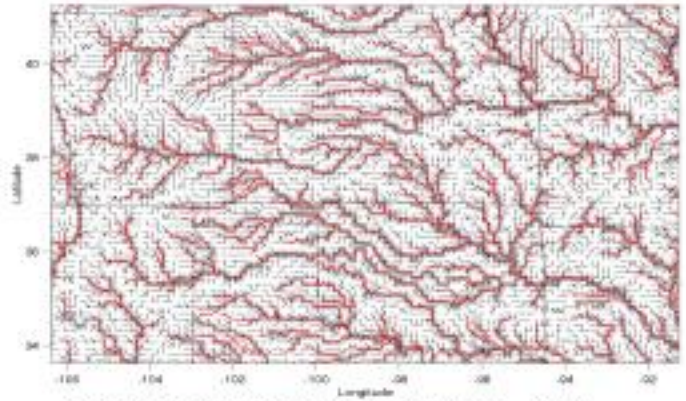
Noah LSM (open boxes) verifies well against obs (bold line):

Time series of monthly 15-station mean: Jan 98 –Sep 99



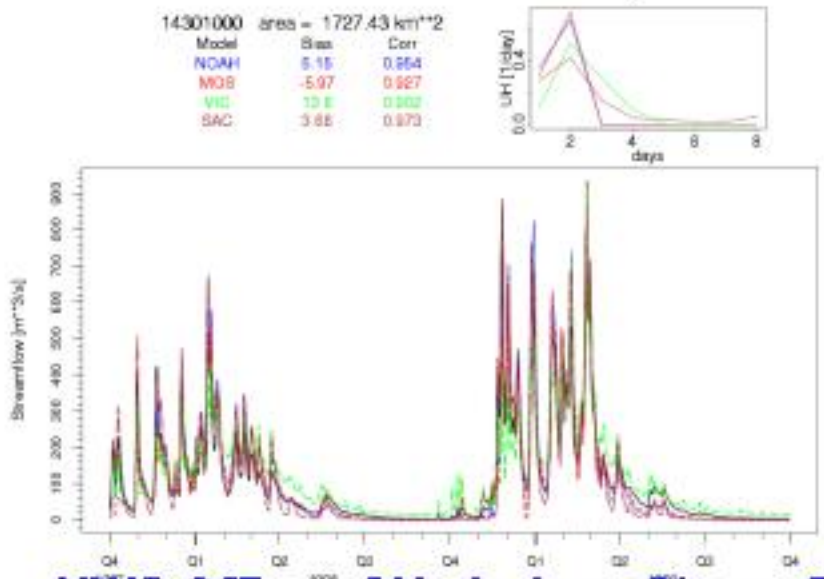
NLDAS retrospective streamflow simulation

River flow direction mask

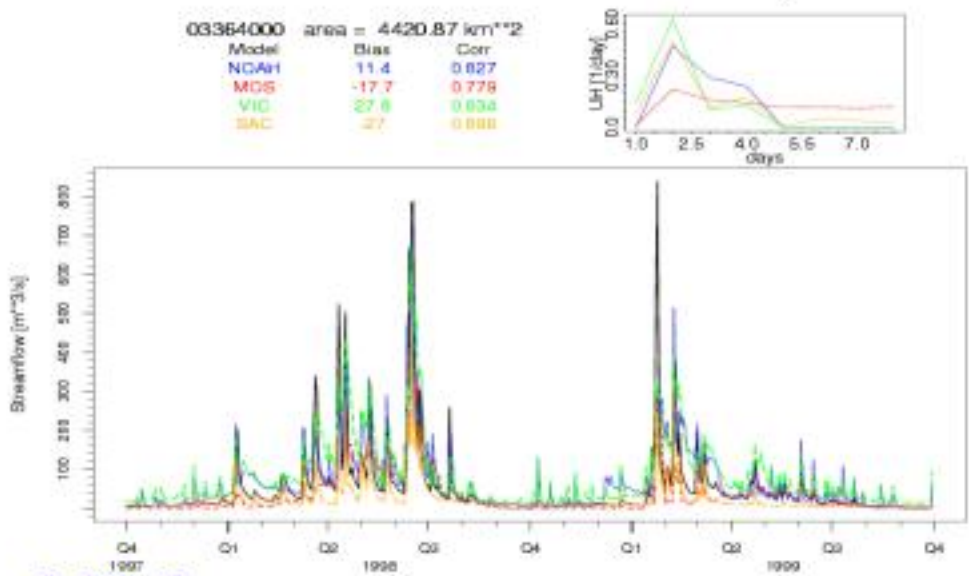


Upstream area [log10(km^2)]

Nehalem River near Foss, OR



East Fork of White River at Columbus, IN



- **NWS Office of Hydrology Streamflow Initiatives**
  - »**DMIP:** Distributed Model Intercomparison Project
  - »**MOPEX:** Model Optimization and Prediction Experiment

EMC Land-surface & Hydrology Thrusts

UTILIZE and PROMOTE MAJOR PARTNERSHIPS in NATIONAL and INTERNATIONAL EXPERIMENTS

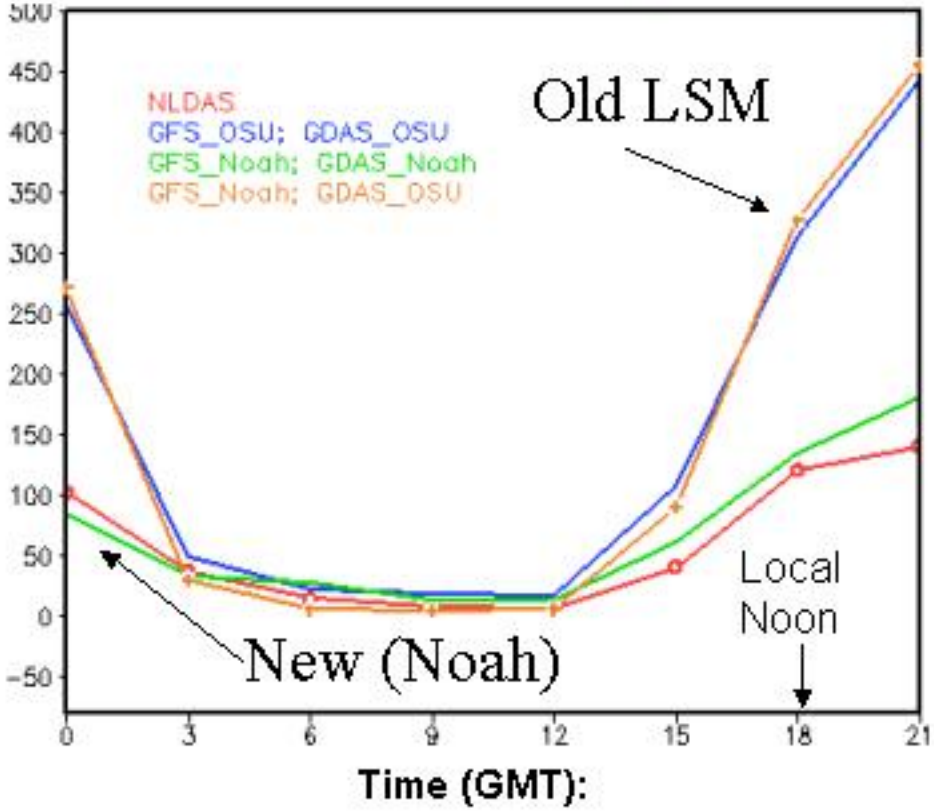
- **GAPP/GCIP (sponsor: NOAA/OAR/OGP)**
  - **NWS Office of Hydrology**
  - **NESDIS Land Team:** (snow cover, vegetation, albedo, insolation, skin T)
  - **Multiple university partners**
  - **NLDAS:** North American Land Data Assimilation System Project
  - **NAME:** North American Monsoon Experiment
    - EMC tested new Eta-model based Regional Climate Model (Eta RCM)
- **GEWEX and its major international experiments**
  - **PILPS:** Project for Intercomparison of Land-surface Process Schemes
  - **CEOP:** Coordinated Enhanced Observing Period (41 global ref. sites)
  - **GLACE:** Global Land-Atmosphere Coupling Experiment
  - **GSWP:** Global Soil Wetness Project
- **JCSDA: Joint Center for Satellite Data Assimilation**
  - **NASA and NESDIS plus university grants via annual AO**
    - Boston U.(vegetation from MODIS), U.Arizona (snowpack physics) Princeton U. (microwave surface emission modeling)

Assessing new (Noah) and old (OSU) LSM in the NCEP Global Forecast System: (Versus NLDAS as "truth" in the SGP Region)

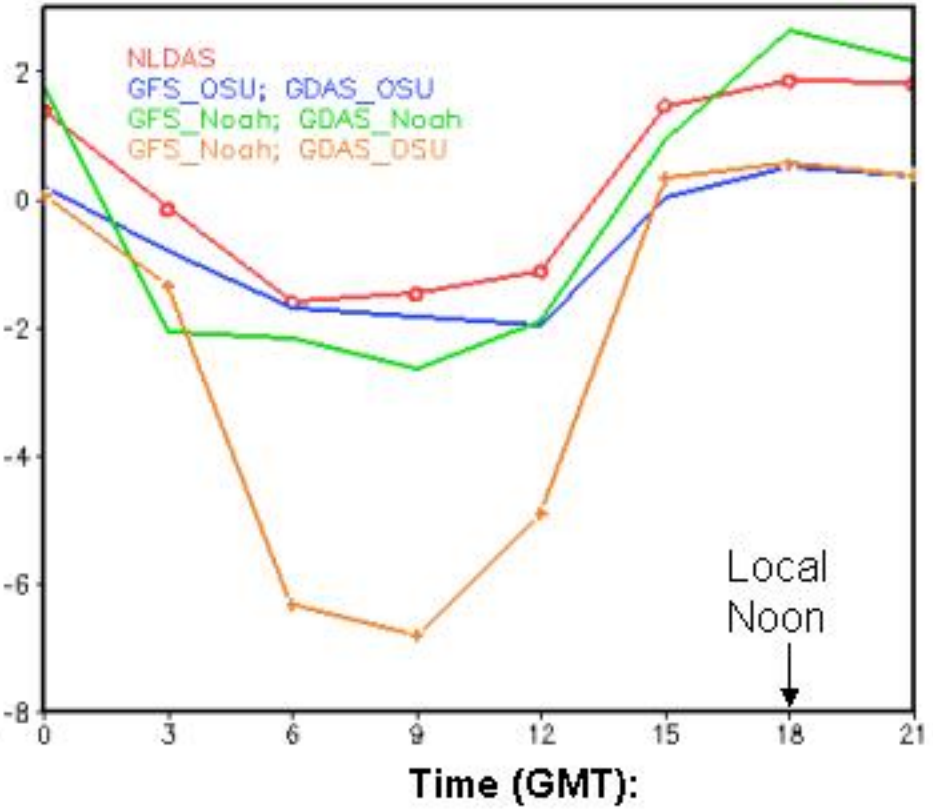
(following 12-months of respective LSM cycling in companion GFS global data assimilation system: GDAS)

GFS/GDAS using Noah performs best in SGP region

Surface Latent Heat Flux (Aug 03): W/m2**



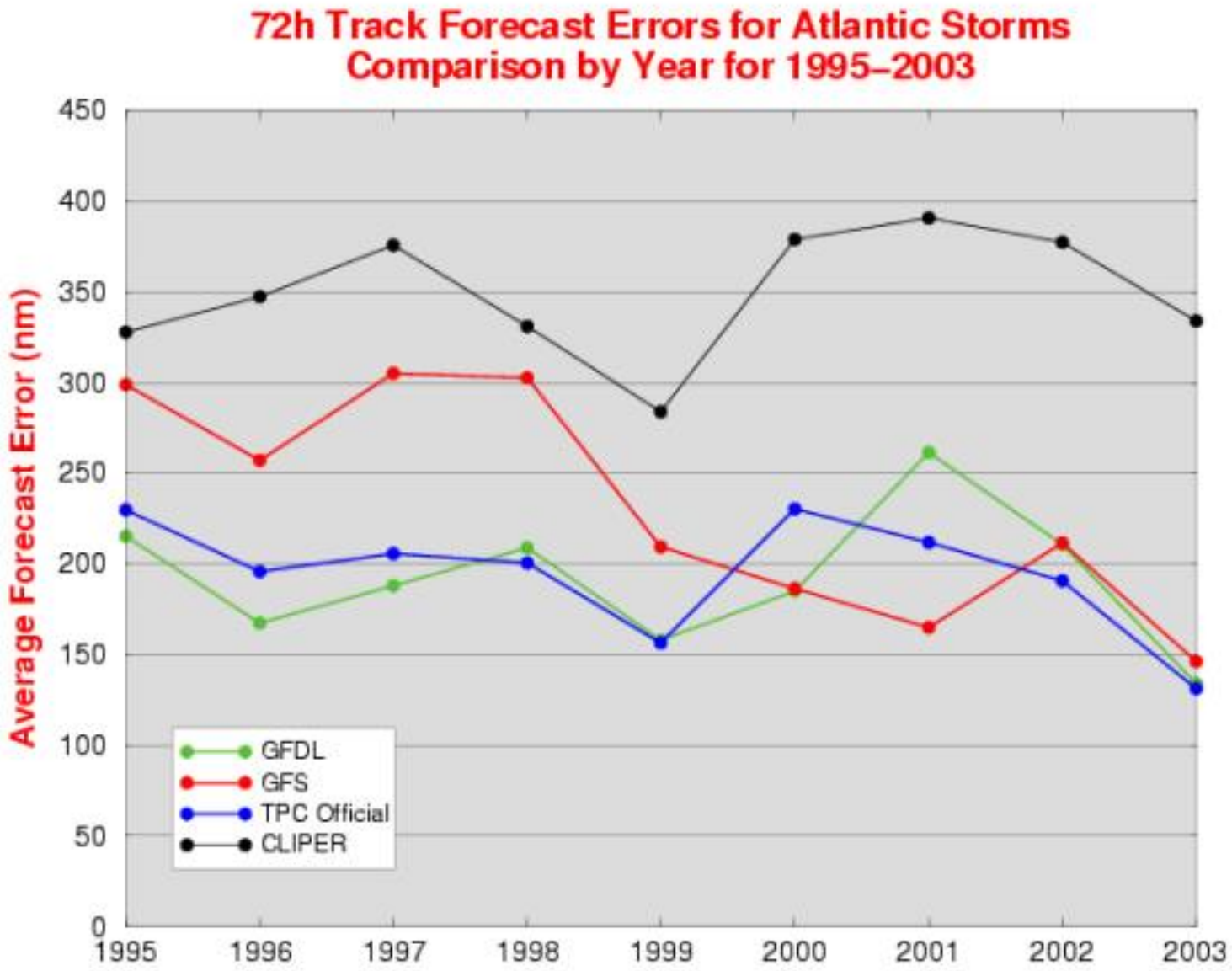
Bowen Ratio: Sensible/Latent Heat Flux (Aug 03)



New 2003 NESDIS Land-surface Products

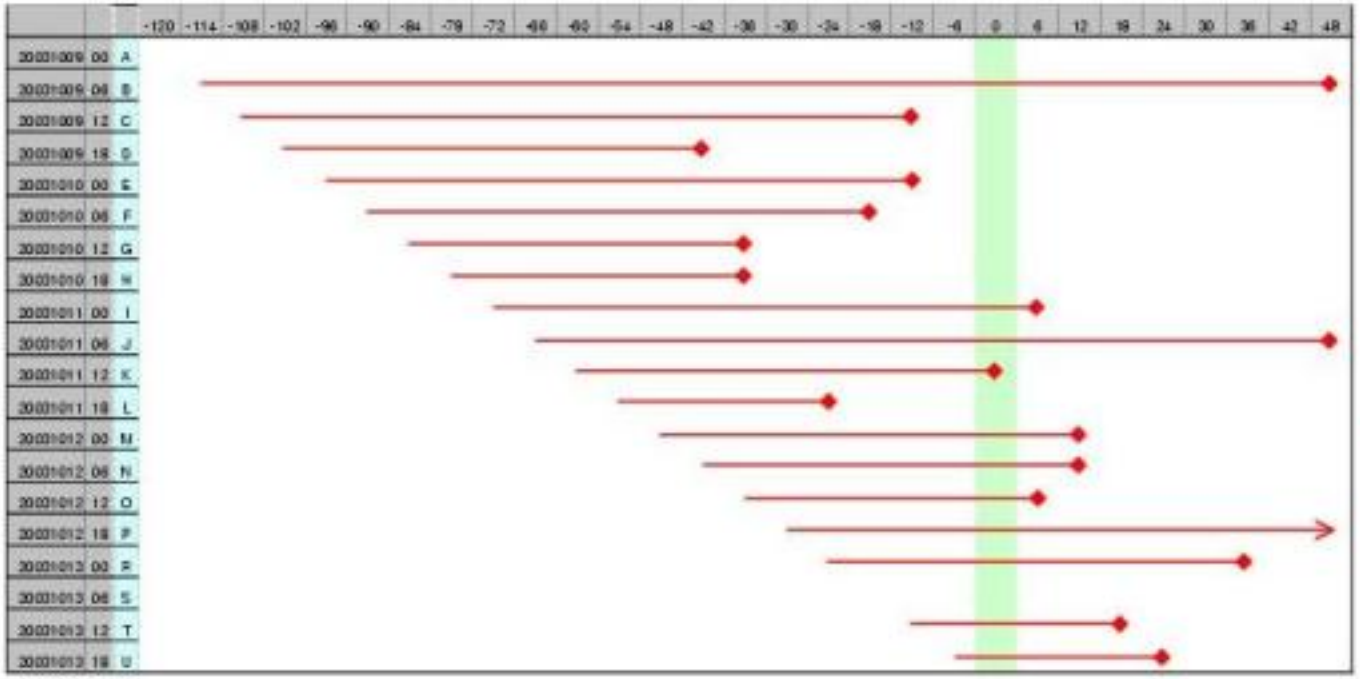
(Partnership of NESDIS/ORA-IPD-SAB and NCEP/EMC Land Teams)

- **4-km daily N. Hemisphere snow cover and sea-ice anal**
  - Is replacing presently operational NESDIS 23-km daily product
  - Produced in parallel with operational 23-km product this winter
  - Much more effective than 23-km product for resolving:
    - dendritic valley/mountain snow cover patterns
    - small Canadian lakes: i.e. lake ice
  - Acknowledge: B. Ramsay, D. McNamara, T. Baldwin, D.Tarpley
  - Follow-on effort: add daily S. Hemisphere & twice-daily CONUS
- **Realtime weekly global 14-km vegetation greenness**
  - present ops is 14-km monthly climatology (5-year)
  - EMC is preparing to test in Eta and WRF models

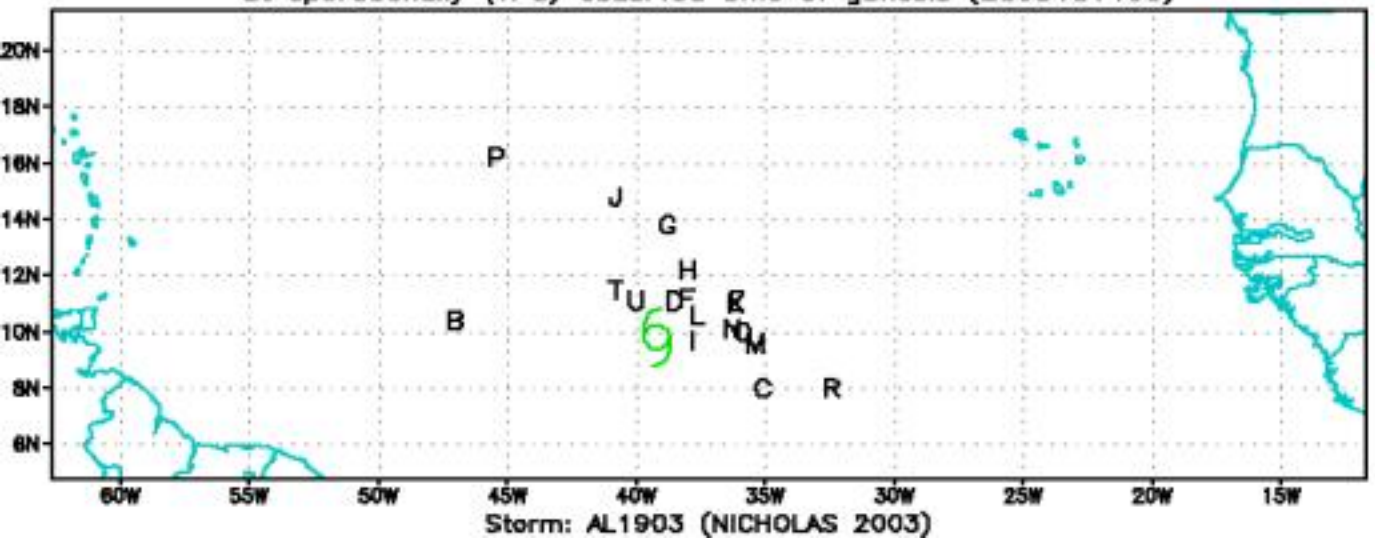

72h Track Forecast Errors for Atlantic Storms
Comparison by Year for 1995–2003
Average Forecast Error (nm)
450
400
350
300
250
200
150
100
50
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
GFDL
GFS
TPC Official
CLIPER

GFS Forecasts of the Genesis of Tropical Storm Nicholas (2003)

GFS genesis time relative to operationally (TPC) observed time of genesis (2003101400)



Forecasted storm positions from successive runs of the NCEP/GFS at operationally (TPC) observed time of genesis (2003101400)



Total genesis opportunities (t=-5 days to t=0): 19

Early or on time: 8

Late: 10

Failed to generate disturbance: 1

Timing

Within 0-6 hours: 3

Within + or - 12 hours: 7

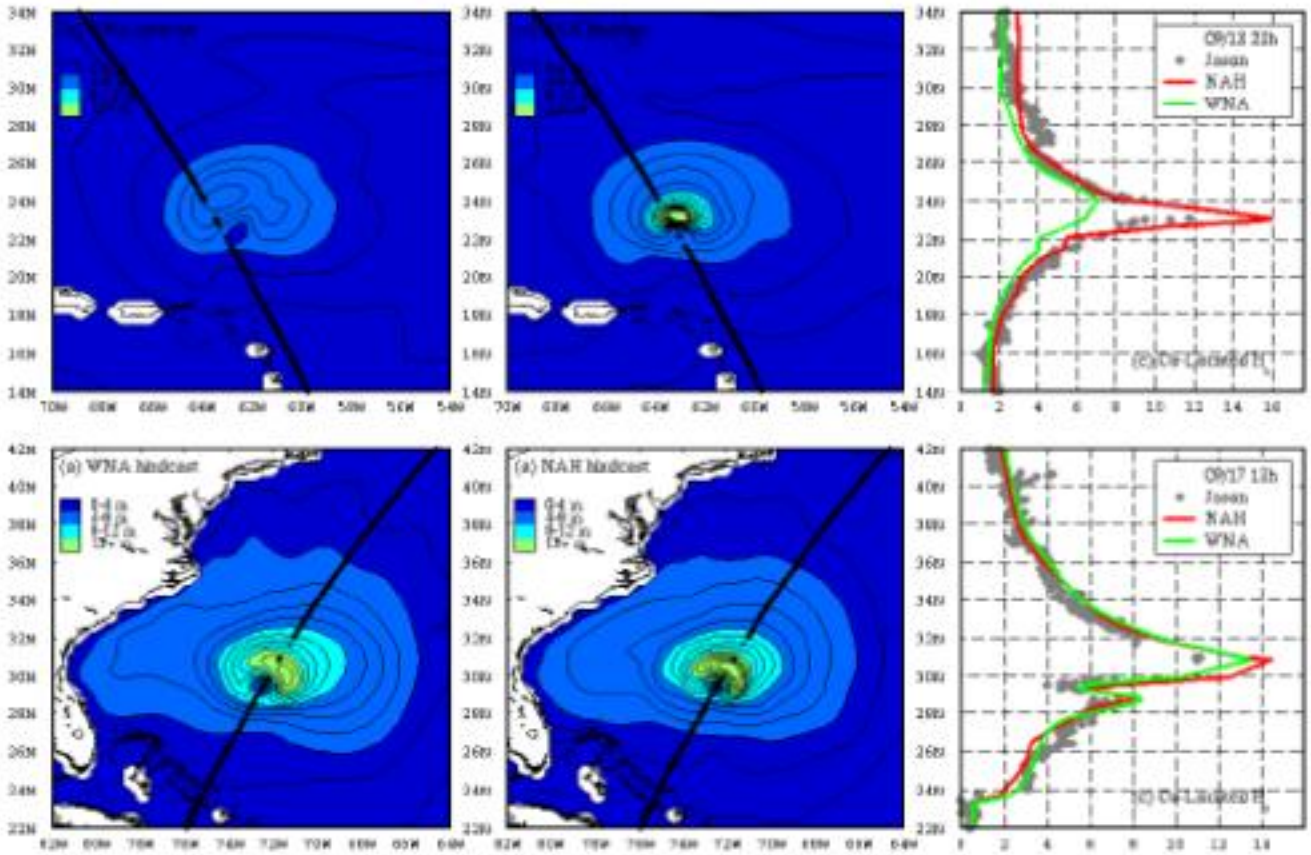
Within + or - 24 hours: 10

Location (by eyeball only):

Within ~ 300 km: 7

Within ~ 500 km: 14

Maximum Significant Wave Heights: Model vs. JASON



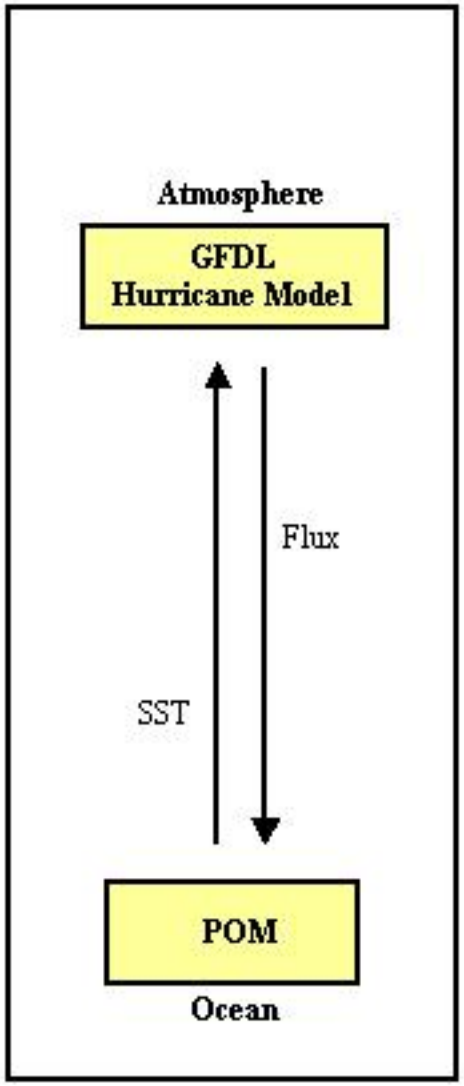
- ✓Direct hits: Altimeter through eye and maximum waves
- ✓WNA (green), NAH (red): Good track of build-up, set-down and maximum
- ✓Storm's eye (lower panel) well captured by both models
- ✓Early stages missed by WNA (green): weak GFS winds, small hurricanes

Possible GFDL Hurricane Model Upgrades for '04 season

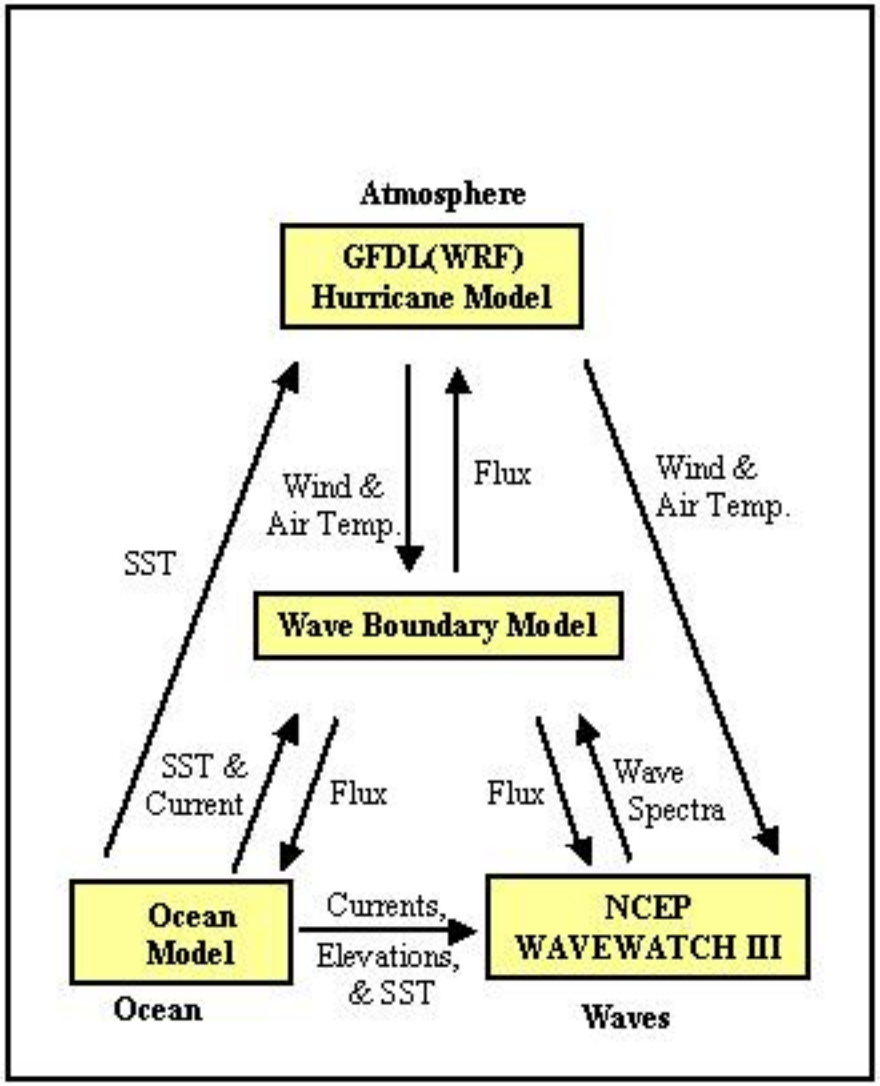
- Large Scale Condensation upgrade
  - improves intensity forecast
- Coupling to Land surface model
  - Improves precipitation forecast
  - Verification program under development
- 1-D ocean coupling in EPAC
  - U. Rhode Island collaboration (I. Ginis)

- Run parallel WRF system
  - w/o nesting
  - W/o coupling

Operational GFDL Model



Future Coupled Hurricane-Wave-Ocean Model

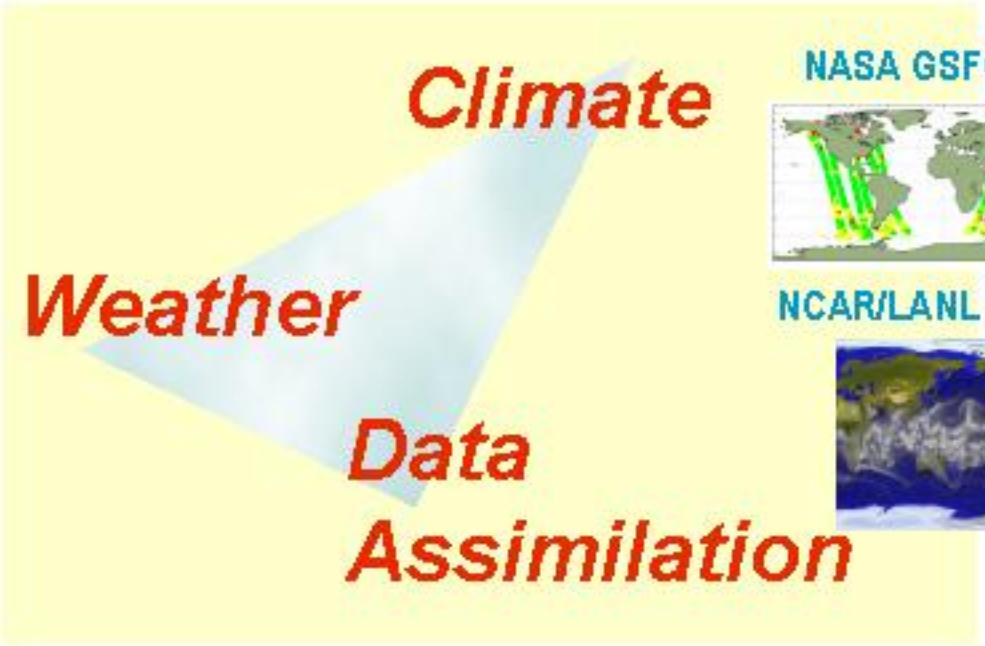


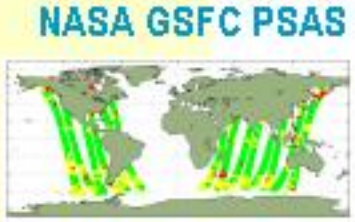
URI & U. Miami partnerships

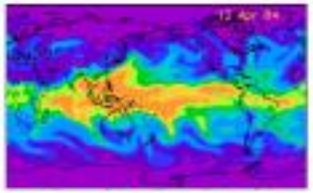
Enabling Architectures

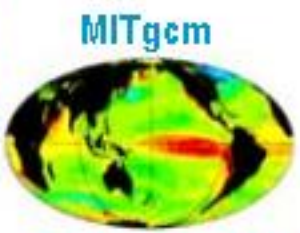
- **ESMF**
- **NOMADS**

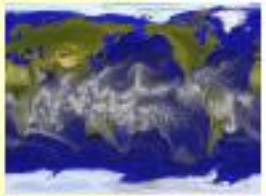
Introduction to the Earth System Modeling Framework

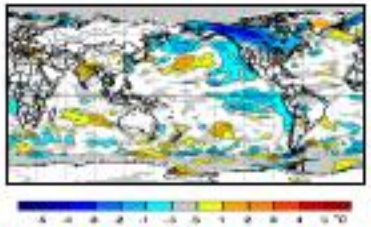


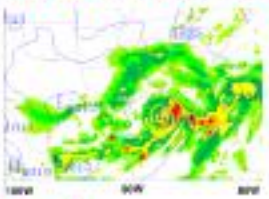

NASA GSFC PSAS


GFDL FMS Suite


MITgcm


NCAR/LANL CCSM


NASA GMAO Seasonal Forecast


NCEP Forecast

C. DeLuca/NCAR, J. Anderson/NCAR, V. Balaji/GFDL, B. Boville/NCAR, N. Collins/NCAR, T. Craig/NCAR, C. Cruz/GSFC, A. da Silva/GSFC, R. Hallberg/GFDL, C. Hill/MIT, M. Iredell/NCEP, R. Jacob/ANL, P. Jones/LANL, B. Kauffman/NCAR, J. Larson/ANL, J. Michalakes/NCAR, E. Schwab/NCAR, S. Smithline/GFDL, Q. Stout/U Mich, M. Suarez/GSFC, A. Trayanov/GSFC, S. Vasquez/NCAR, J. Wolfe/NCAR, W. Yang/NCEP, M. Young/NCEP and L. Zaslavsky/GSFC

ESMF Project Description

- Goals: to increase
  - **Software reuse through standard utilities**
  - **Interoperability among diverse scientific applications**
  - **Ease of use**
  - **Performance portability in climate, weather, and data assimilation applications**
- Products
  - Coding infrastructure
  - Reusable utilities
  - Demonstrations using community applications (coupled model components, data assimilation)

ESMF Partners

NSF NCAR

Tim Killeen, PI
Byron Boville
Cecelia DeLuca
Roberta Johnson
John Michalakes
Al Kellie

MIT

John Marshall, PI
Chris Hill

NASA DAO

Arlindo da Silva, PI
Leonid Zaslavsky
Will Sawyer

NASA NSIPP

Max Suarez
Michele Rienecker
Christian Keppenne

NOAA GFDL

Ants Leetmaa
V. Balaji
Robert Hallberg
Jeff Anderson

NOAA NCEP

Stephen Lord
Mark Iredell
Mike Young
John Derber

DOE Los Alamos National Lab

Phil Jones

DOE Argonne National Lab

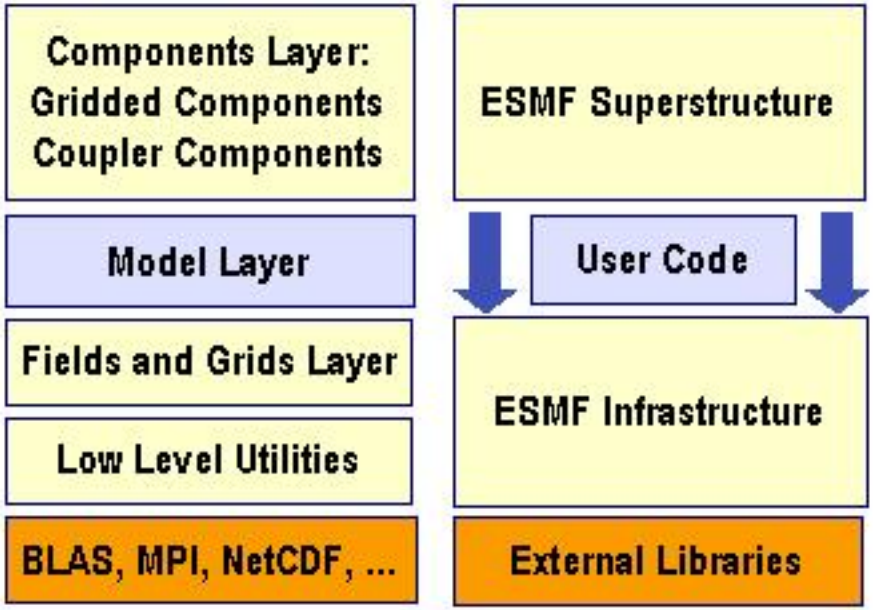
Jay Larson
Barry Smith

University of Michigan

Quentin Stout

ESMF Architecture

1. ESMF provides an environment for assembling geophysical components into applications.
2. ESMF provides a toolkit that components use to
   i. increase interoperability
   ii. improve performance portability
   iii. abstract common services



NOMADS
NOAA Operational Model Archive and Distribution System

RT-NOMADS
Distribution of Real-Time and Retrospective NCEP Model Data Sets

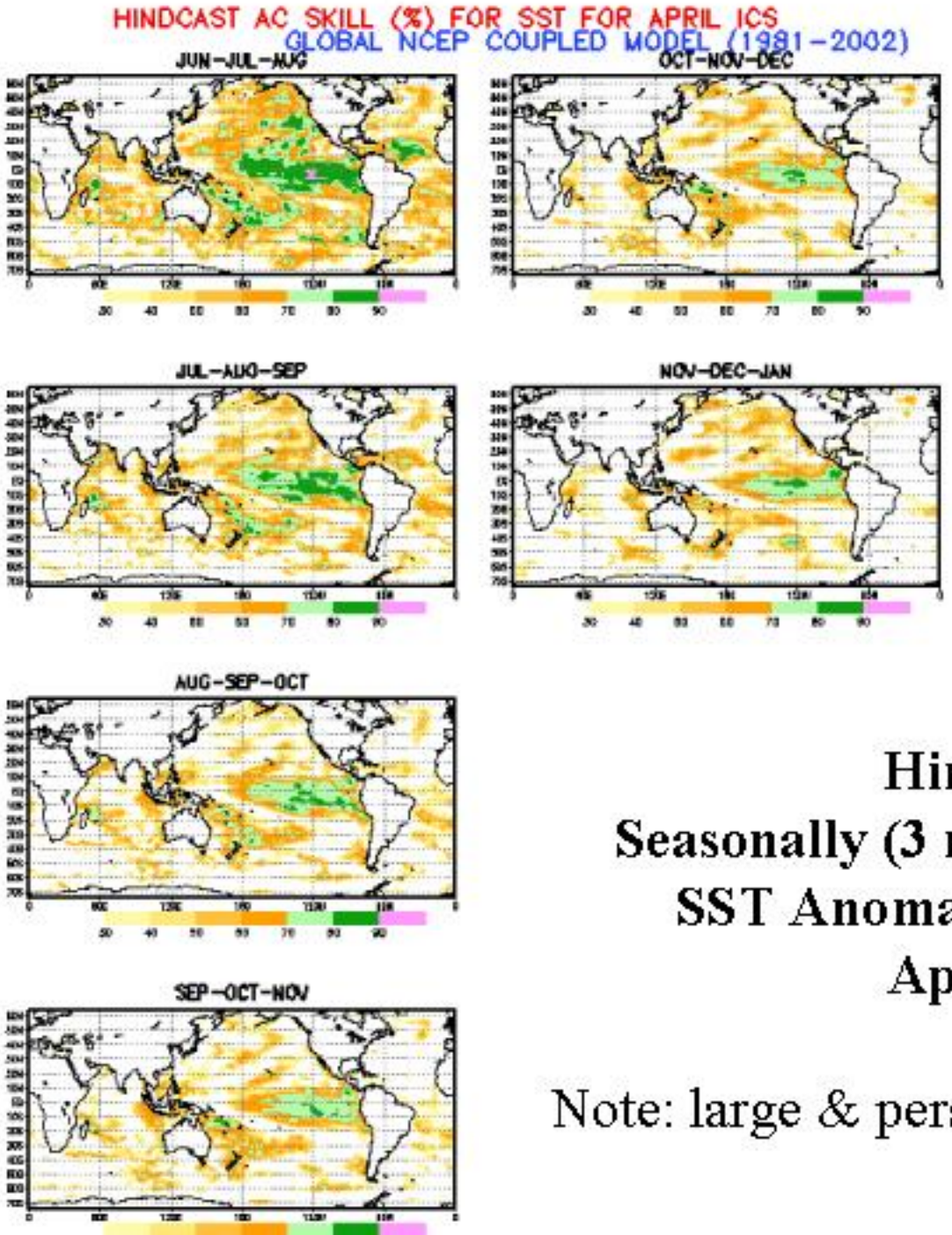
NOAA HPCC Program

Jordan C. Alpert jalpert@ncep.noaa.gov

4/22/03

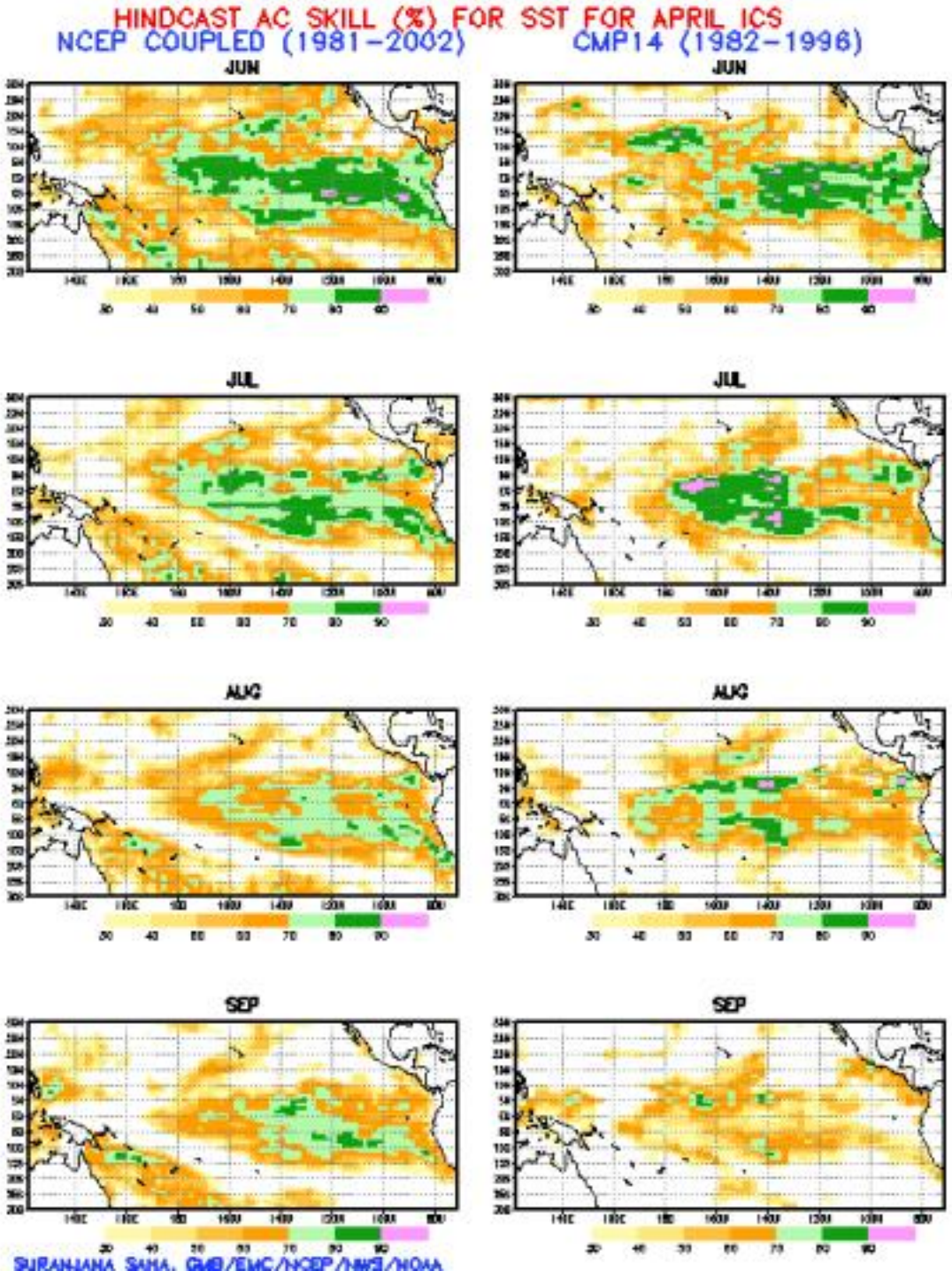
where the nation's climate and weather services begin

END



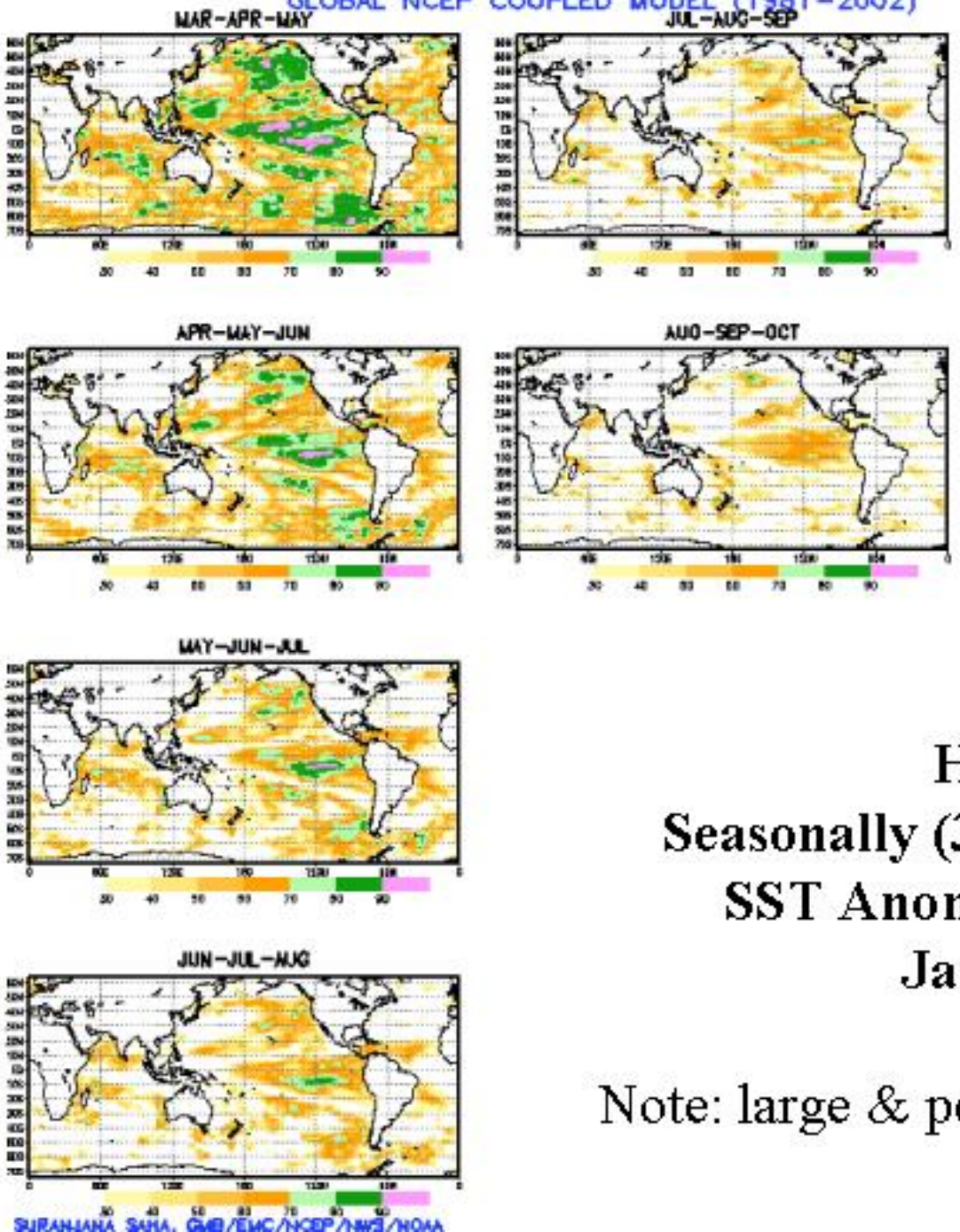
Hindcast
Seasonally (3 month) Averaged
SST Anomaly Correlation
April IC

Note: large & persistent skill in tropics



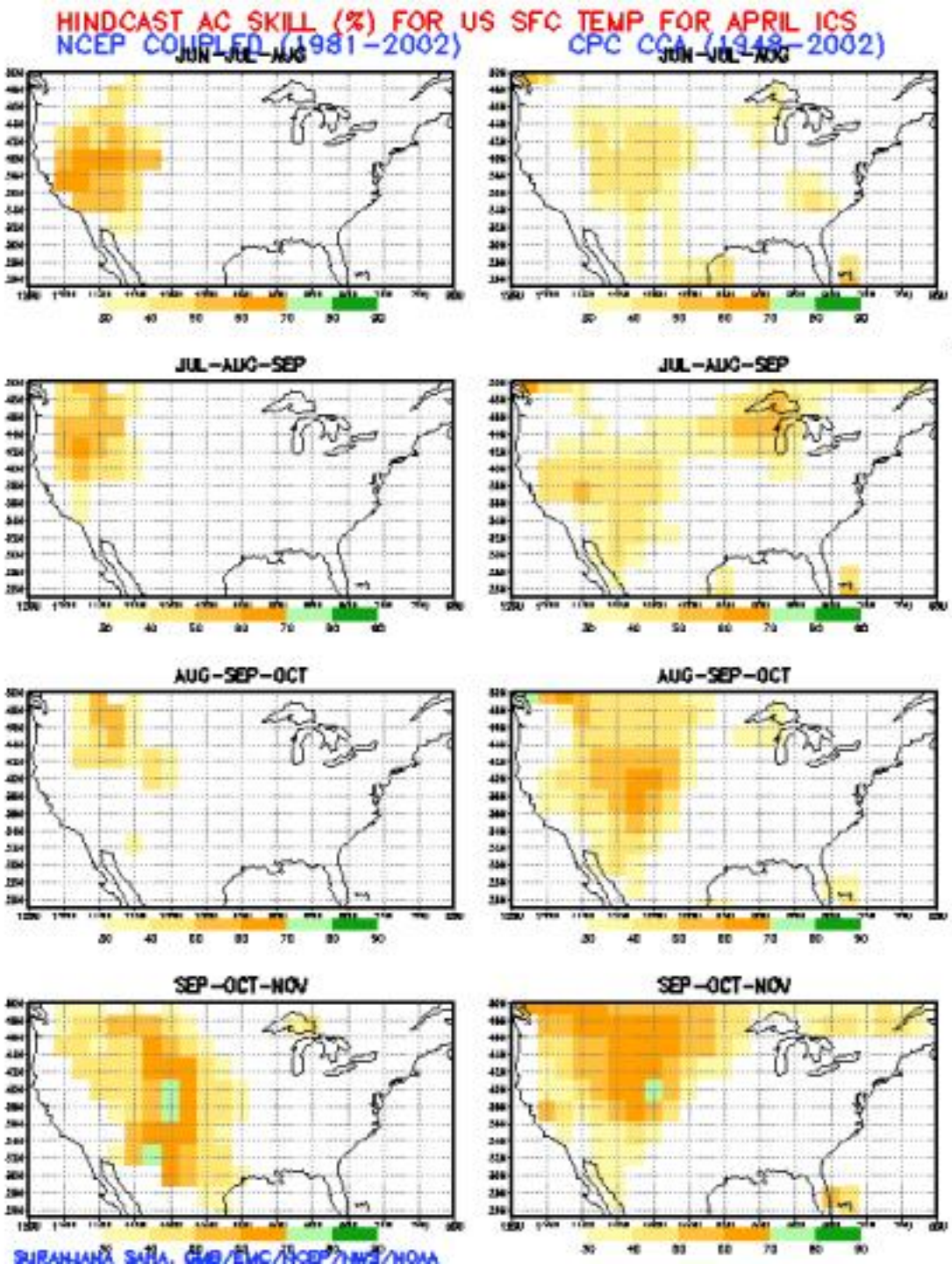
Hindcast
Monthly Averaged
SST Anomaly Correlation
April IC
June-September

Left: New Coupled System
Right: CMP14
(operational system)



Hindcast
Seasonally (3 month) Averaged
SST Anomaly Correlation
January IC

Note: large & persistent skill in tropics



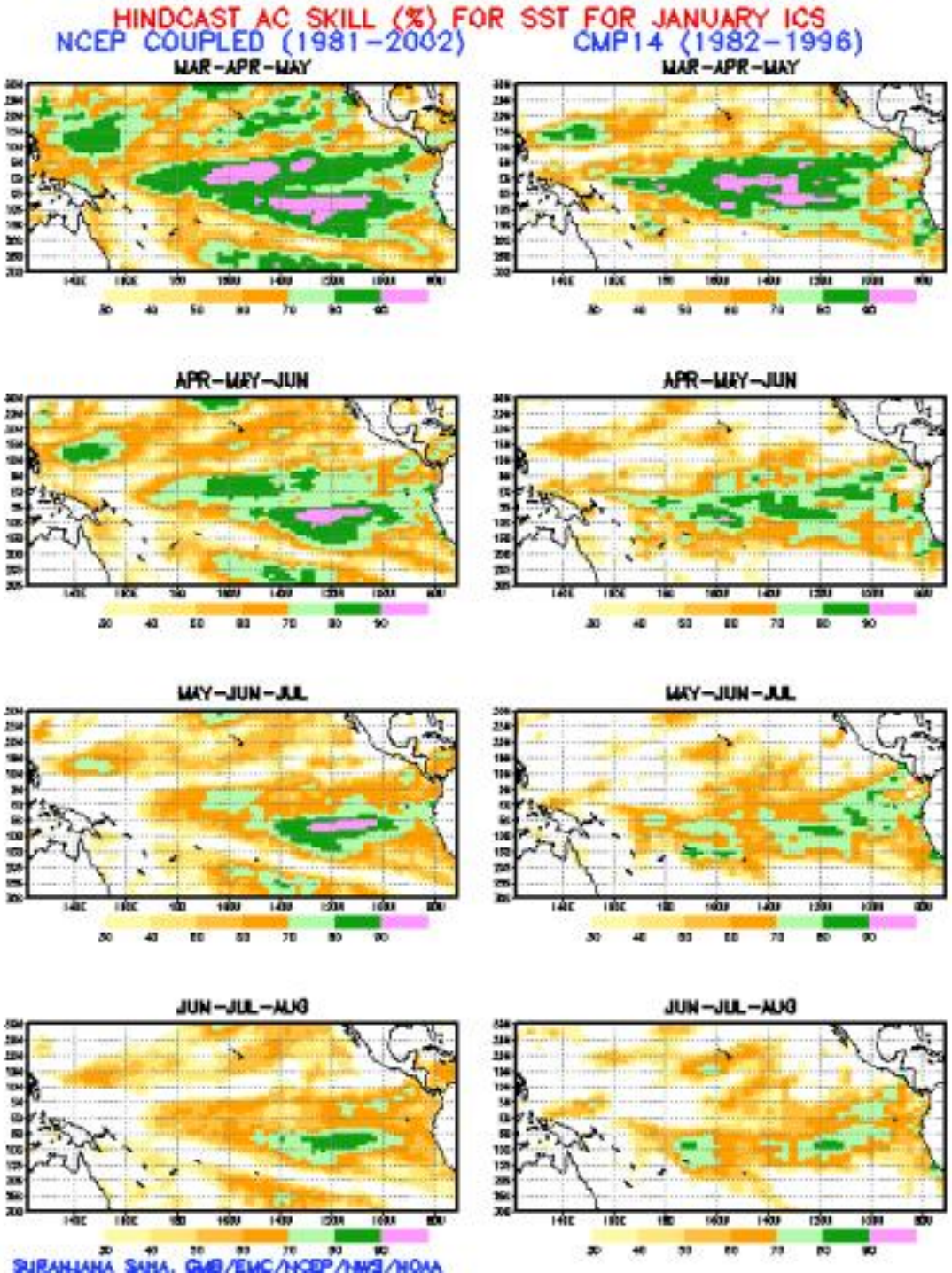
U. S. Surface Temperature Hindcast Skill

3 Month Averages

April IC

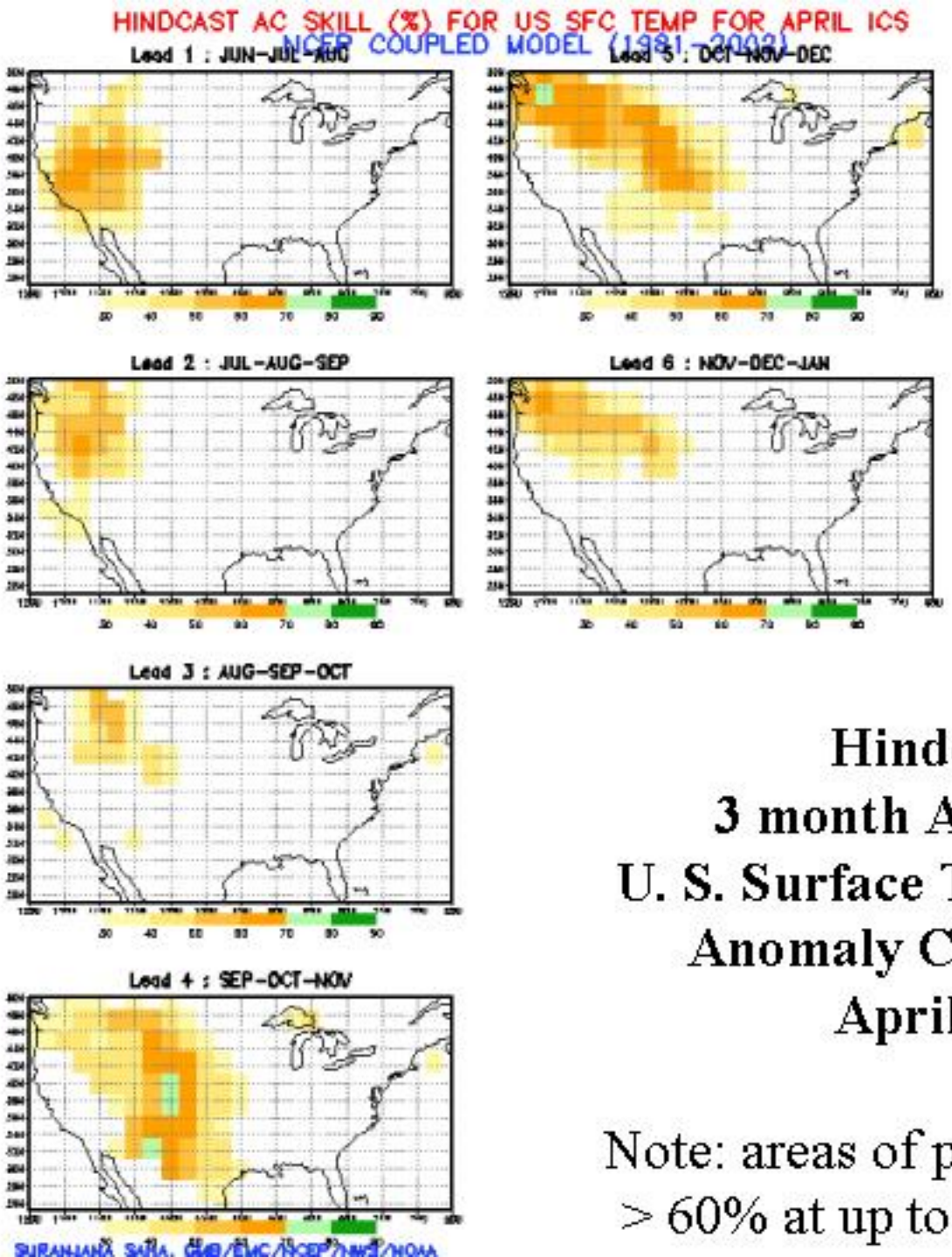
Comparison with CPC CCA Method (right)

Coupled System skill may be complementary to CCA



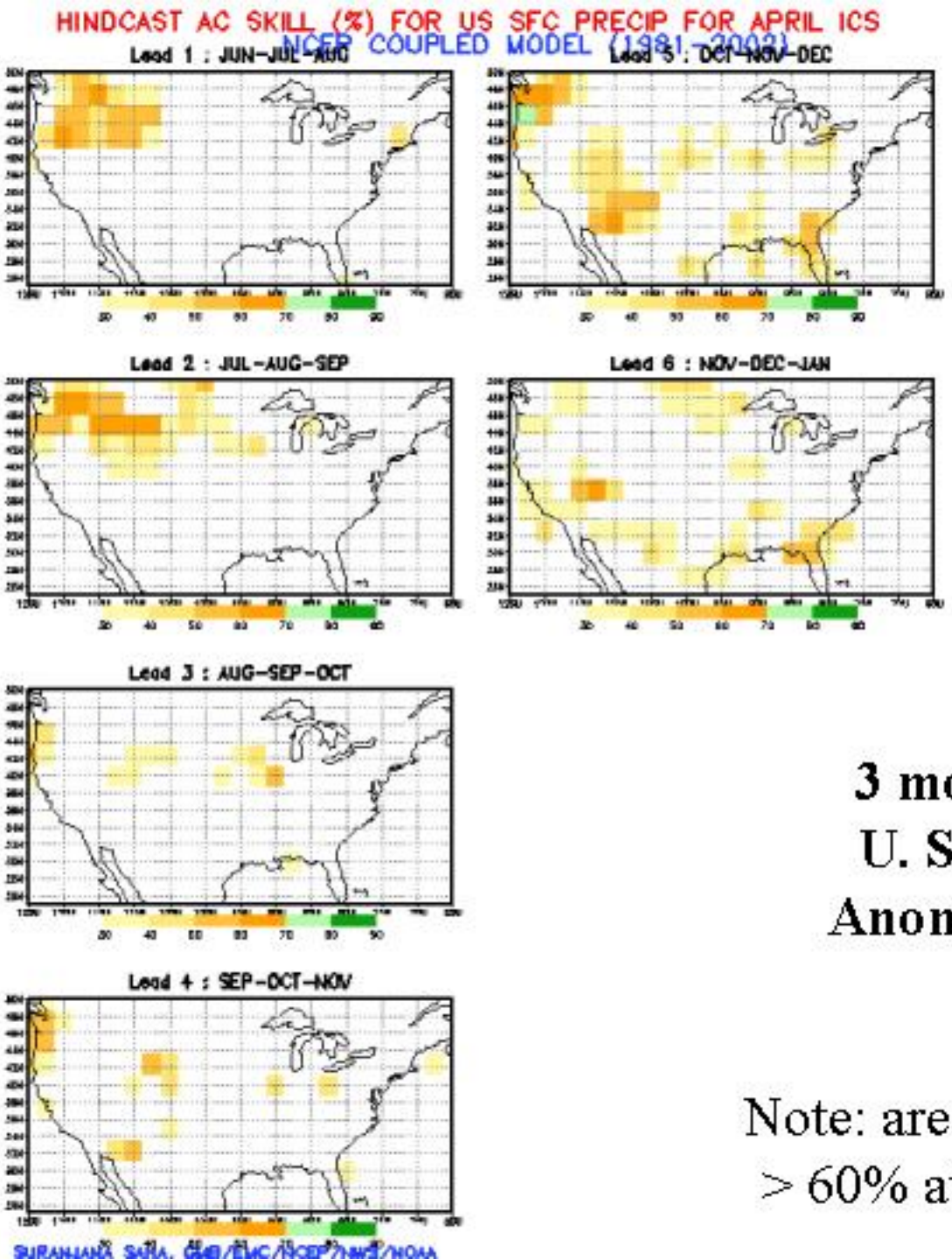
Hindcast
Seasonally Averaged
SST Anomaly Correlation
January IC

Left: New Coupled System
Right: CMP14
(operational system)



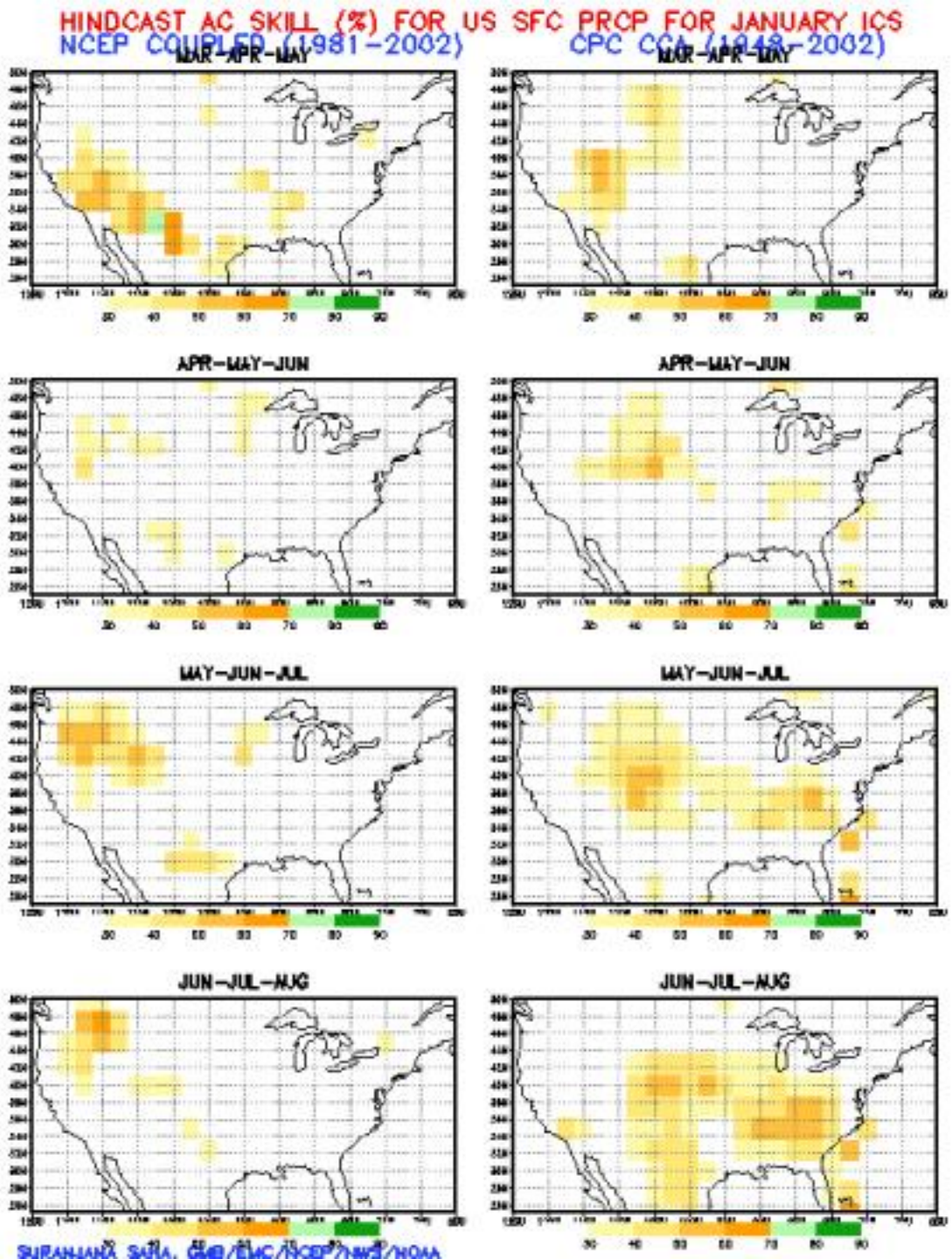
Hindcast
3 month Averaged
U. S. Surface Temperature
Anomaly Correlation
April IC

Note: areas of persistent skill
> 60% at up to 6 month lead



Hindcast
3 month Averaged
U. S. Precipitation
Anomaly Correlation
April IC

Note: areas of persistent skill
> 60% at up to 6 month lead



U. S. Precipitation Hindcast Skill

3 Month Averages January IC

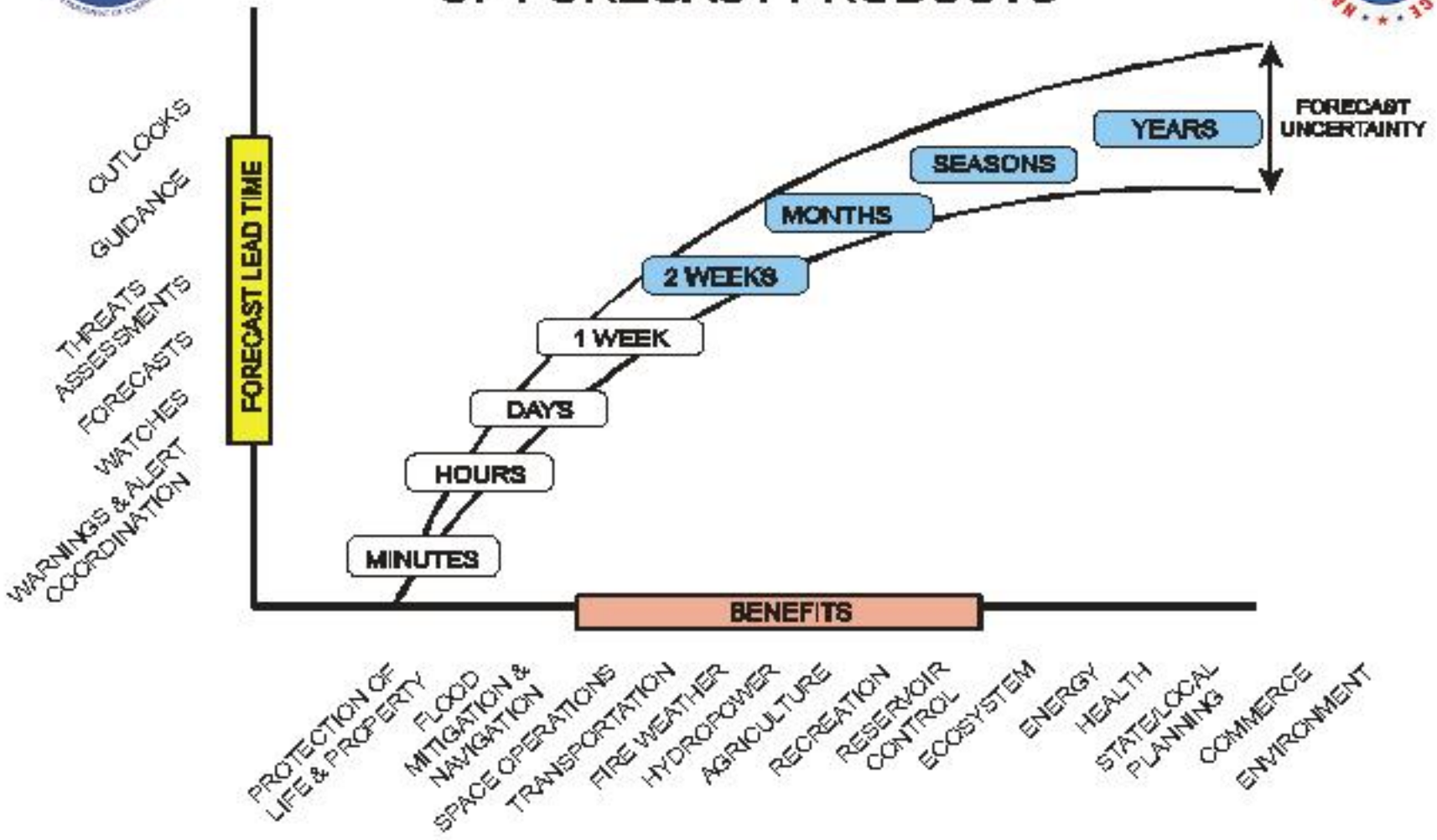
Comparison with CPC CCA Method (right)

Note: Coupled System skill complementary to CCA

Four Fundamental Operational Ocean Forecast Problems for NWS

1. Global ocean on seasonal time scale
2. Daily Global Ocean State
3. Support for coastal ocean modeling (shelf, bays, estuaries)
4. Hurricanes

NWS SEAMLESS SUITE OF FORECAST PRODUCTS



Summary of Development Projects

1. Global ocean on seasonal time scale
    - System implemented
    - Partnerships ongoing
2. Daily Global Ocean State
    - Many operational products today
    - Systems under development
    - Strong (NOPP) partnerships for GODAE
3. Support for coastal ocean modeling (shelf, bays, estuaries)
    - Prototype system in place
    - Partnerships expanding
4. Hurricanes and Extratropical Storm impacts
    - Prototype systems in place
    - Strong development path (WRF, etc)

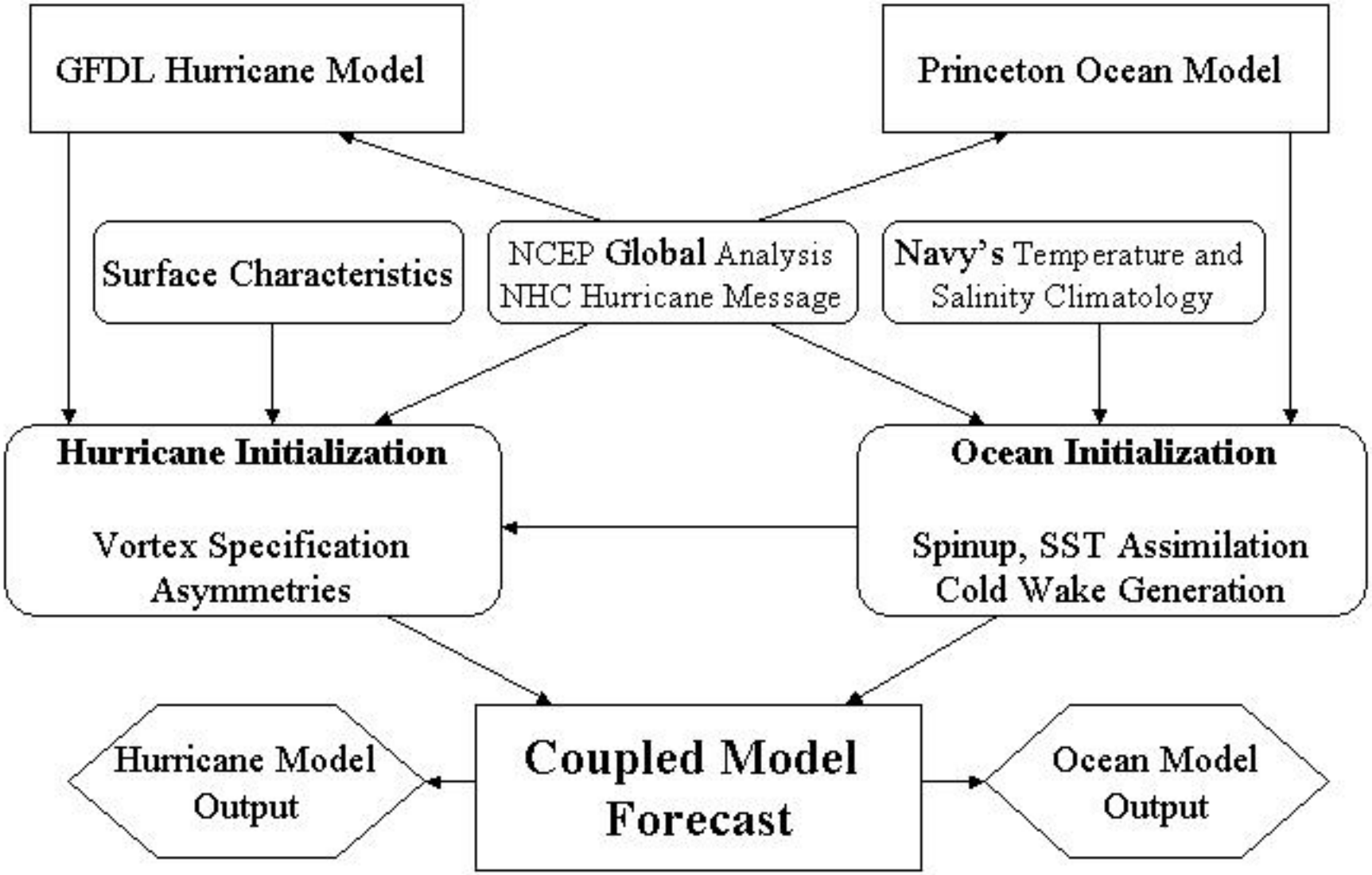
Continuing Strategy

- **Collaborate with partners for technology infusion into NWS operational modeling environment**
  - E.g. GFDL MOM3(4) for Seasonal to Interannual (S/I) problem, HYCOM for real-time applications
  - Provide feedback on new model development, observations to scientific community
- **Provide operational forecasts, analyses and observations to users**
  - Provide routine ocean state products on relevant time and space scales
  - Quality controlled, uniformly formatted ocean observations
- **Use ocean models coupled to atmosphere to improve environmental forecast systems**
- **Participate in community efforts to demonstrate capabilities**
  - International experiments
    - E. g., Global Ocean Data Assimilation Experiment (GODAE)
  - Interagency efforts
    - Ocean Data Assimilation for S/I (ODASI)
  - Catalyse unification of ocean modeling framework (HOME)
  - Software engineering, system compatibility
    - E.g., Earth System Modeling Framework (ESMF)

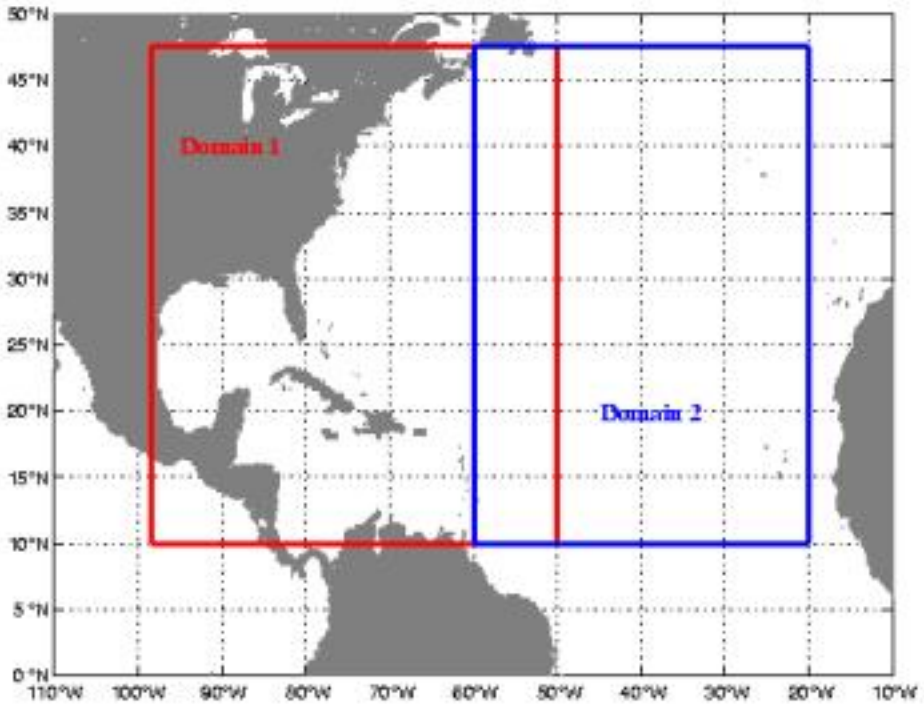
Challenges

- What's needed to establish a world-class ocean development program (analogous to atmospheric forecasting)?
- Gaps
  - Base-funded resources
    - Civil Servants for project management and code management
    - Non-labor (contract, visiting scientists)
    - NCO support for ocean products and implementations
  - Computing
    - Not accounted for in 9 year NCEP computing plan
  - World Weather Building overcrowding
  - Active Visiting Scientist program
  - Data mining (coastal ocean observing networks)
  - Outreach (providing community with NCEP products)
  - Expansion to ecosystem support (biogeochemical models, etc.)

GFDL Coupled Hurricane-Ocean Forecast System



Ocean Model Domains



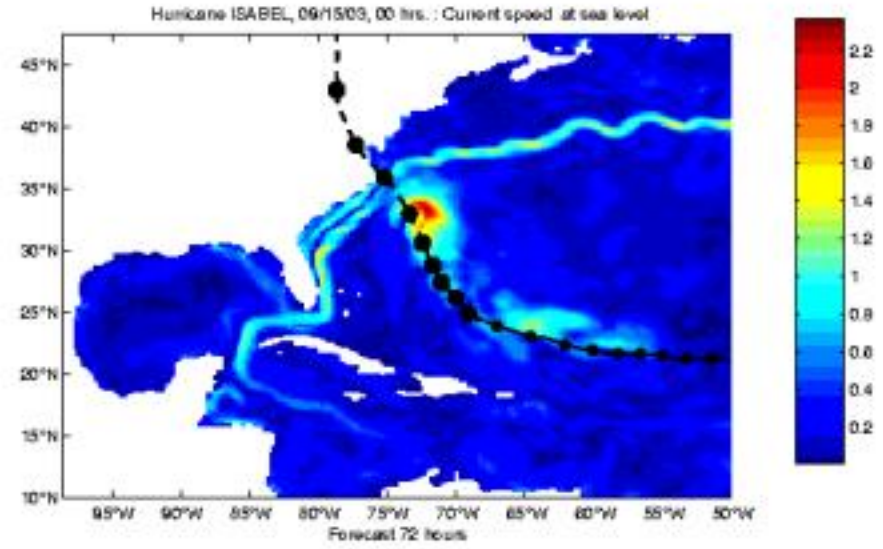
GFDL Coupled Model

- Implemented to operations at NCEP in 2001 after three years of near-real time testing in 1998-2000

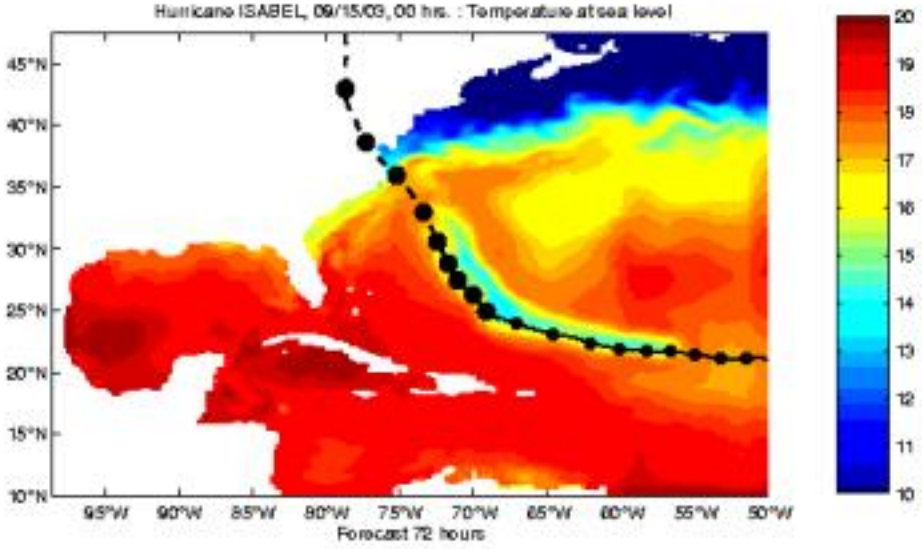
- Improved version implemented operationally in 2003 and included:
  - New ocean model domain configurations
  - Ocean coupling over entire ocean domains
  - Gulf Stream and Loop Current data assimilation

Examples of the Coupled Model 72 h Forecasts Hurricane Isabel Initial Time: *00 UTC 15 Sept, 2003*

Sea Surface Currents



Sea Surface Temperature



Future Improvements

- **GFDL coupled model in the Eastern Pacific basin**
  (development & testing– 2003, 2004; implementation - 2005)

- **Improved air-sea flux parameterization**
  (development, testing & implementation – 2003, 2004)

- **High resolution version of the GFDL model**
  (development & testing – 2003, 2004; implementation – 2005)

Future Improvements (con'd)

- GFDL coupled hurricane-wave-ocean model
  (development – 2004, testing -2005, implementation – 2006)
- Replacing Princeton Ocean Model by HYCOM Ocean Model
  (development – 2005, testing – 2006, implementation – 2007)
- Transfer coupled hurricane-wave-ocean technology to Hurricane WRF
  (development – 2006, testing – 2007, implementation – 2008)

4. Hurricane Impacts Modeling (cont)

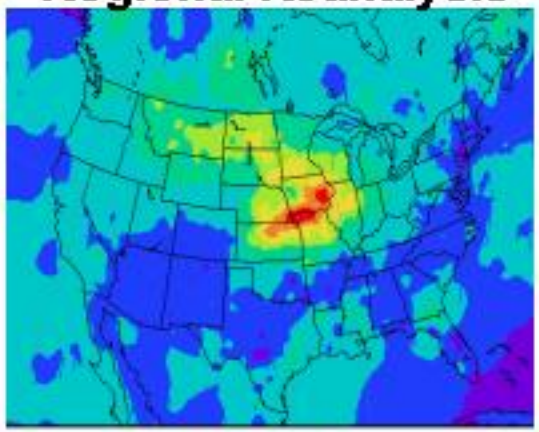
- Hurricane WRF
  - Movable nest (ocean and atmosphere)
  - High resolution (ocean and atmosphere)
  - Coupled atmosphere-ocean-land
  - Nested ocean wave model
- Ocean Coupling for HWRF
  - HYCOM based
  - Collaboration with URI & NRL-Stennis (Pat Hogan)
  - Research emphasis
    - Upper ocean mixing
    - Air sea fluxes
    - Wave-AtmPBL interactions
    - Ocean data assimilation of hurricane-specific observations (AXBTs, buoys)

Regional Reanalysis (with Noah LSM):

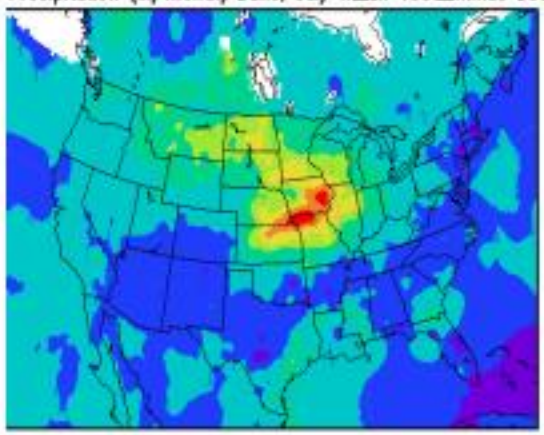
Land surface signals: 1988 drought vs 1993 flood

Precipitation Change 1993 minus 1988 (June+July Total)

Regional Reanalysis



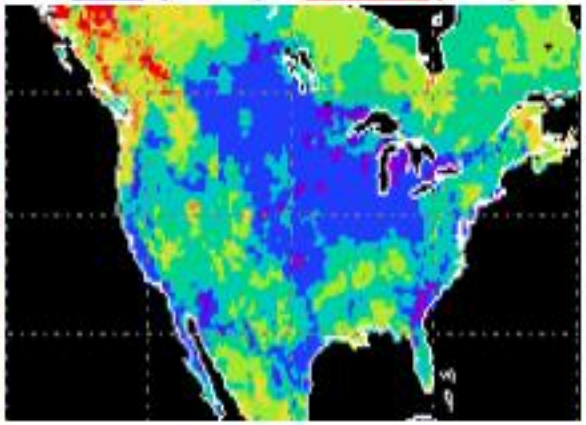
Observed (rain gauges)

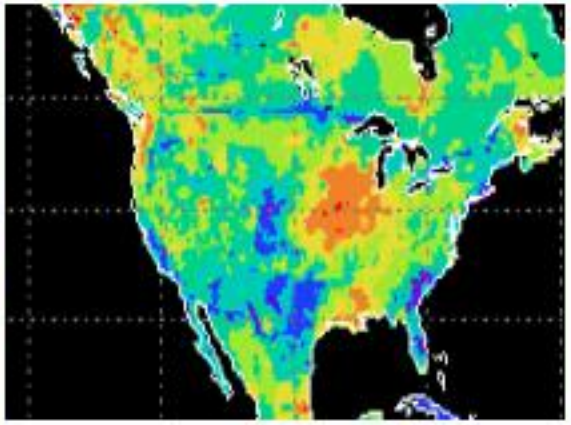


Soil Moisture (% volume):

10-40 cm soil layer

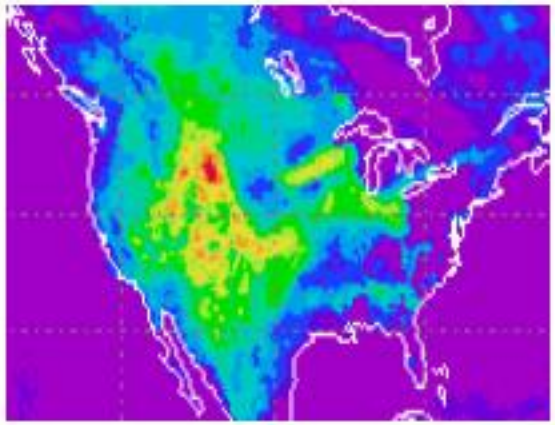
Dry (blue) / Moist (red)

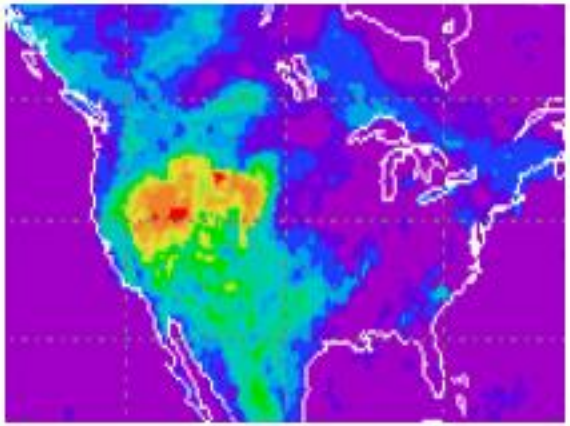




Boundary Layer Depth (m)

Green (high) / Purple (low)





15 Jul 93
21Z
FLOOD

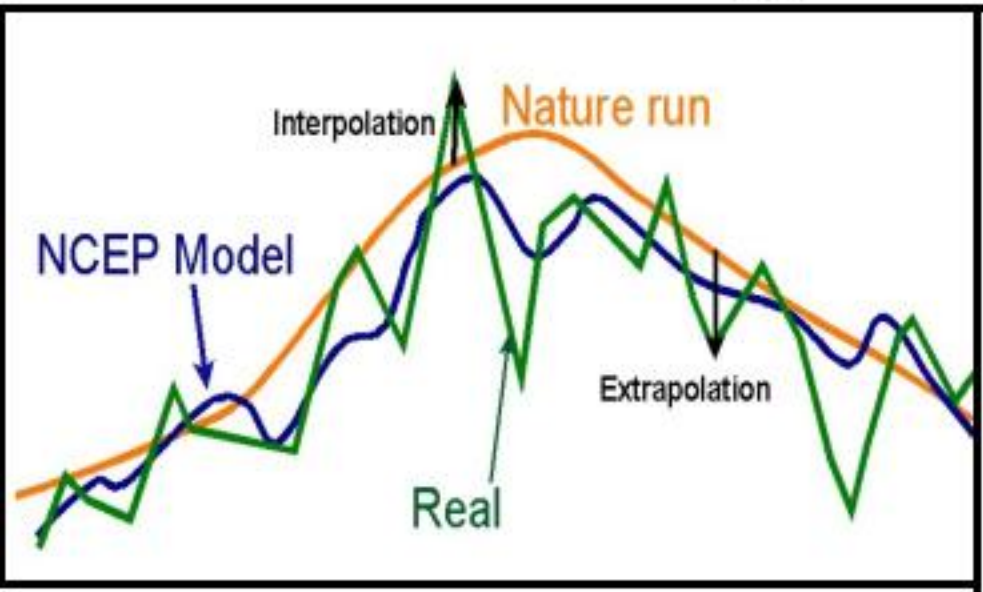
15 Jul 88
21Z
DROUGHT

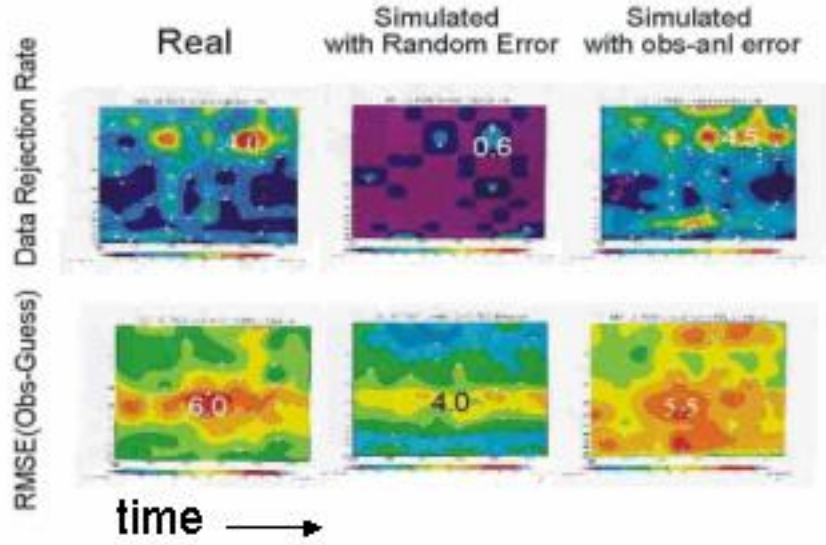
Assess Impacts of Current Instruments

- MW has largest impact on forecast scores
- IR useful in cloud free areas and for cloud top determinations
- Results in
  - Improved data sampling algorithms
  - Focused direction for future applied research
  - Improved knowledge of entire observing system and how to extract more information from all observations to improve forecasts
- Experiments ongoing with computing sponsored by NPOESS Program

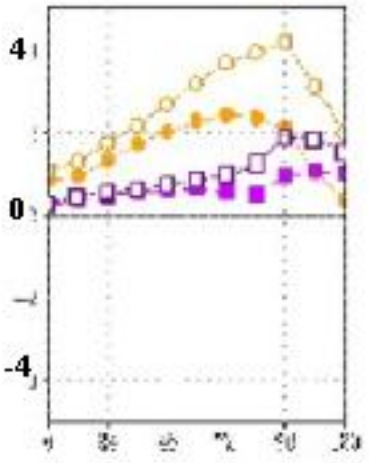
OSSEs

Observational Error Formulation
Surface & Upper Air [Woollen, Masutani]

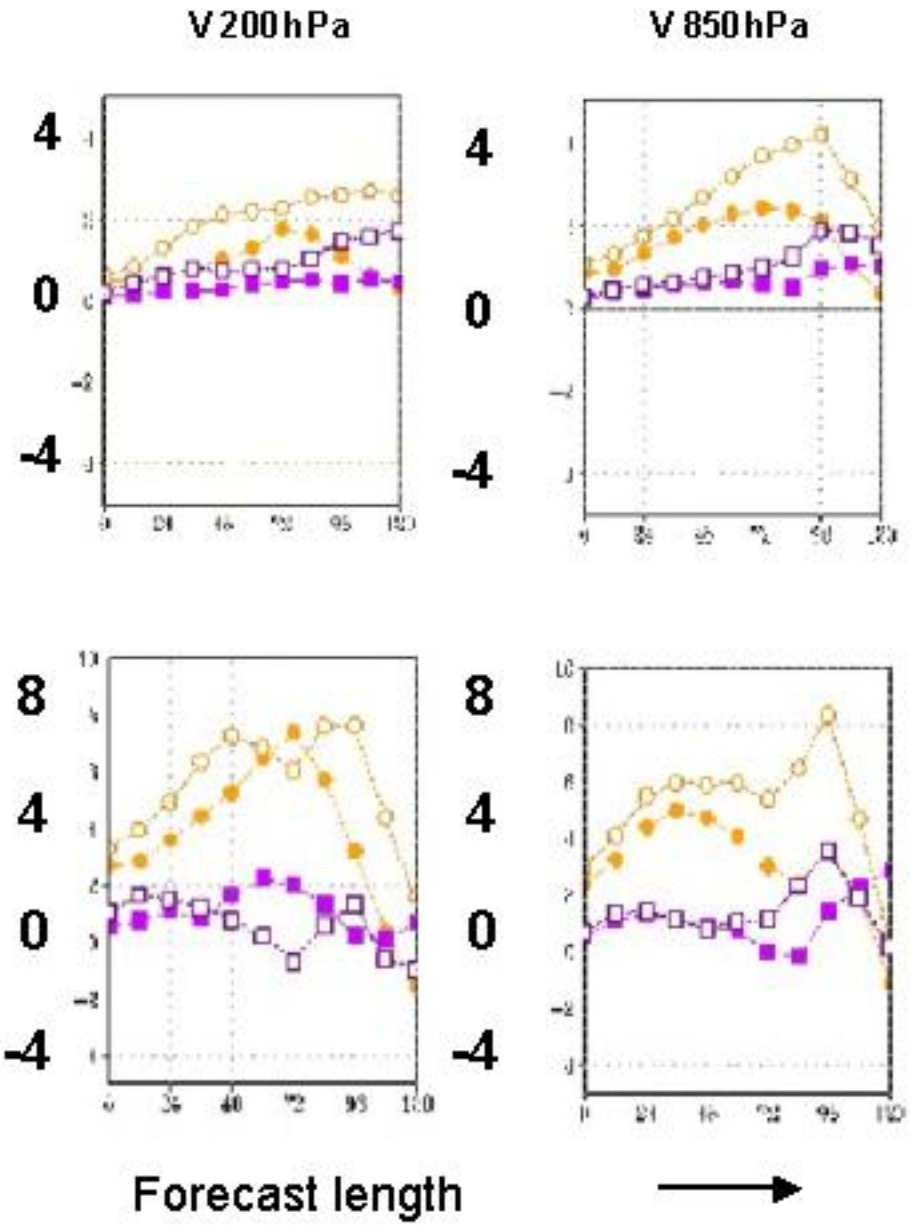




- Percent improvement over Control Forecast (without DWL)
- Open circles: RAOBs simulated with systematic representation error
- Closed circles: RAOBs simulated with random error
- Orange: Best DWL
  Purple: Non- Scan DWL



- With random error:
  - Data rejection rate too small (top)
  - Fit of obs too small (bottom)

Effect of Observational Error on DWL Impact

- Percent improvement over Control Forecast (without DWL)
- Open circles: RAOBs simulated with systematic representation error
- Closed circles: RAOBs simulated with random error
- Orange: Best DWL
  Purple: Non- Scan DWL