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WRF & WRF Ensemble Efforts in MMB

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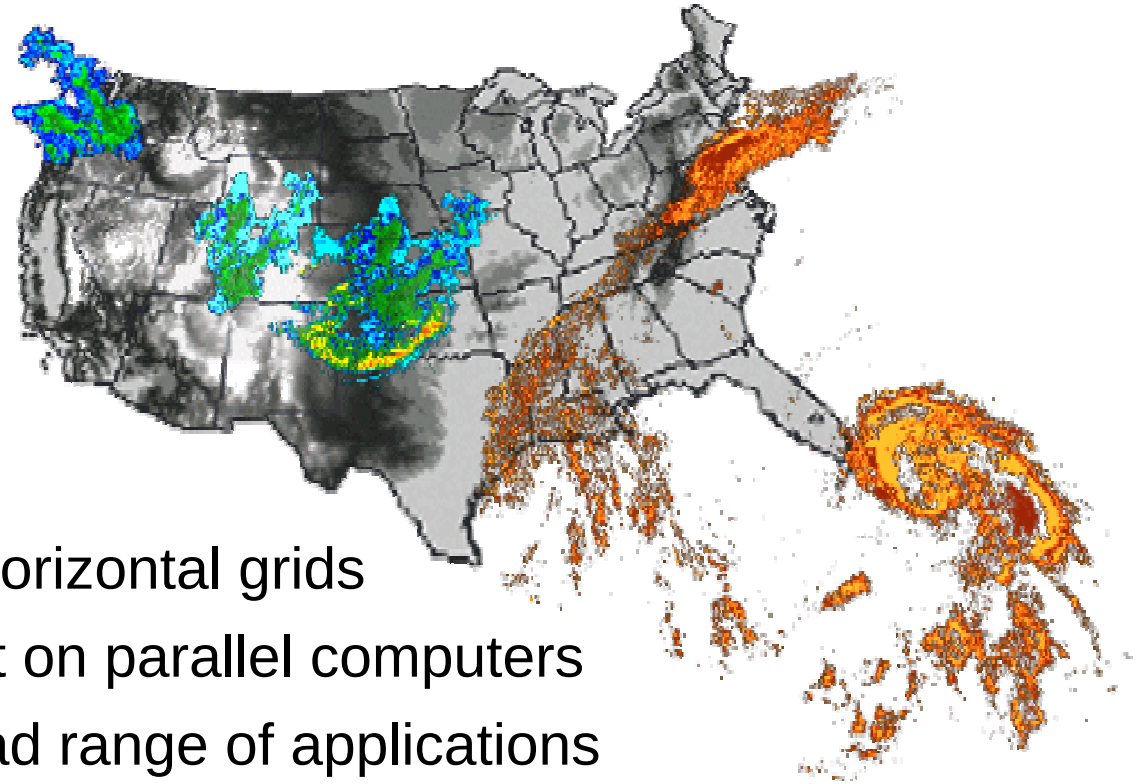
Where the Nation's climate and weather services begin

Weather Research and Forecast (WRF) Modeling System

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



Concept:

Design for 1-10 km horizontal grids

Portable and efficient on parallel computers

Well suited for a broad range of applications

Community model with direct path to operations

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

Historic Decision

- Spring 2003 – Nelson Seaman writing WRF Test Plan – i.e. rules of engagement for the BAKE-OFF between NCAR's Mass-core and NCEP's Nonhydrostatic Mesoscale Model
- Steve Lord saw the bake-off as a lose-lose situation and declared HiResWindow slot to be a WRF ensemble – i.e. better to engage the community rather than enrage them
- Test Plan reworked to a) validate dynamic cores and b) "test" possible ensemble strategies – physics diversity (cross-bred) vs initial condition breeding w/ lbc anomalies

Weather Research and Forecasting (WRF)

- End-to-end Common Modeling Infrastructure
  - Observations and analysis
  - Prediction model
  - Post-processing, product generation and display
  - Verification and archive
- For the community to perform research
- For Operations to generate NWP guidance
- USWRP sponsorship - many partners: NCAR, NCEP, FSL, OU/CAPS, AFWA, FAA, NSF and Navy

NCEP WRF Ensemble Design:

- NCEP CCS computer upgrade will be ~6x for weather
- Therefore, establish 6-member ensemble run in place of single deterministic HiResWindow run
  - 2 Control members
    - **NCEP NMM core & NCEP physics, Dx = 8 km**
    - **NCAR Mass core & NCAR physics, Dx = 10 km**
  - 4 Additional members
    - bred mode initial condition perturbations
    - SREF anomaly applied to lateral boundary condition
- Qualified cores and evaluated potential ensemble members according to the *WRF Test Plan (Nelson Seaman)*

Two cores currently in WRF Infrastructure

- **Eulerian Mass core V1.0 (Eulerian MC),**

  [V2.0 released May'03]

  - Terrain following hydrostatic mass-field vertical coordinate, arbitrary vertical resolution
  - Arakawa C-grid
  - Two-way nesting under evaluation
  - 3rd order Runge-Kutta time-split differencing
  - Conserves mass, momentum, dry entropy and scalars using 5th order (or 6th order) upwind spatial differencing to advect fluxes

- **Nonhydrostatic Mesoscale Model (NMM)**

  - Hybrid sigma-to-pressure terrain following vertical coordinate
  - Arakawa E-grid
  - Two-way nesting under develop'mt
  - Adams-Bashforth time differ'cing, time splitting
  - Conserves rotational kinetic energy, total energy, mass, enstrophy and momentum using 2nd order nine-point differencing for advection

Two WRF Physics Packages

- ***Eulerian Mass-Core:*** **NCAR physics package** (MM5 & Eta conversions) (w/options)
  - NOAH unified 5-layer land-surface model
  - Ferrier gridscale cloud and microphysics
  - Kain-Fritsch convection
  - Yong-Sei University PBL
  - Dudhia shortwave
  - RRTM longwave
  - [Also adapted to use NCEP physics]
- ***NMM Core*****: NCEP physics package** (NMM = modified Eta)
  - NOAH unified 5-layer land-surface model
  - Ferrier gridscale cloud and microphysics
  - Betts-Miller-Janjic convection
  - Mellor-Yamada-Janjic 2.5 PBL
  - Lacis-Hansen shortwave
  - Fels-Schwartzkopf longwave
  - [Also adapted to use NCAR physics]

Evaluation Studies: The WRF Test Plan

Purpose: **Rigorously evaluate principal configurations of WRF** to validate model for future research and operations.

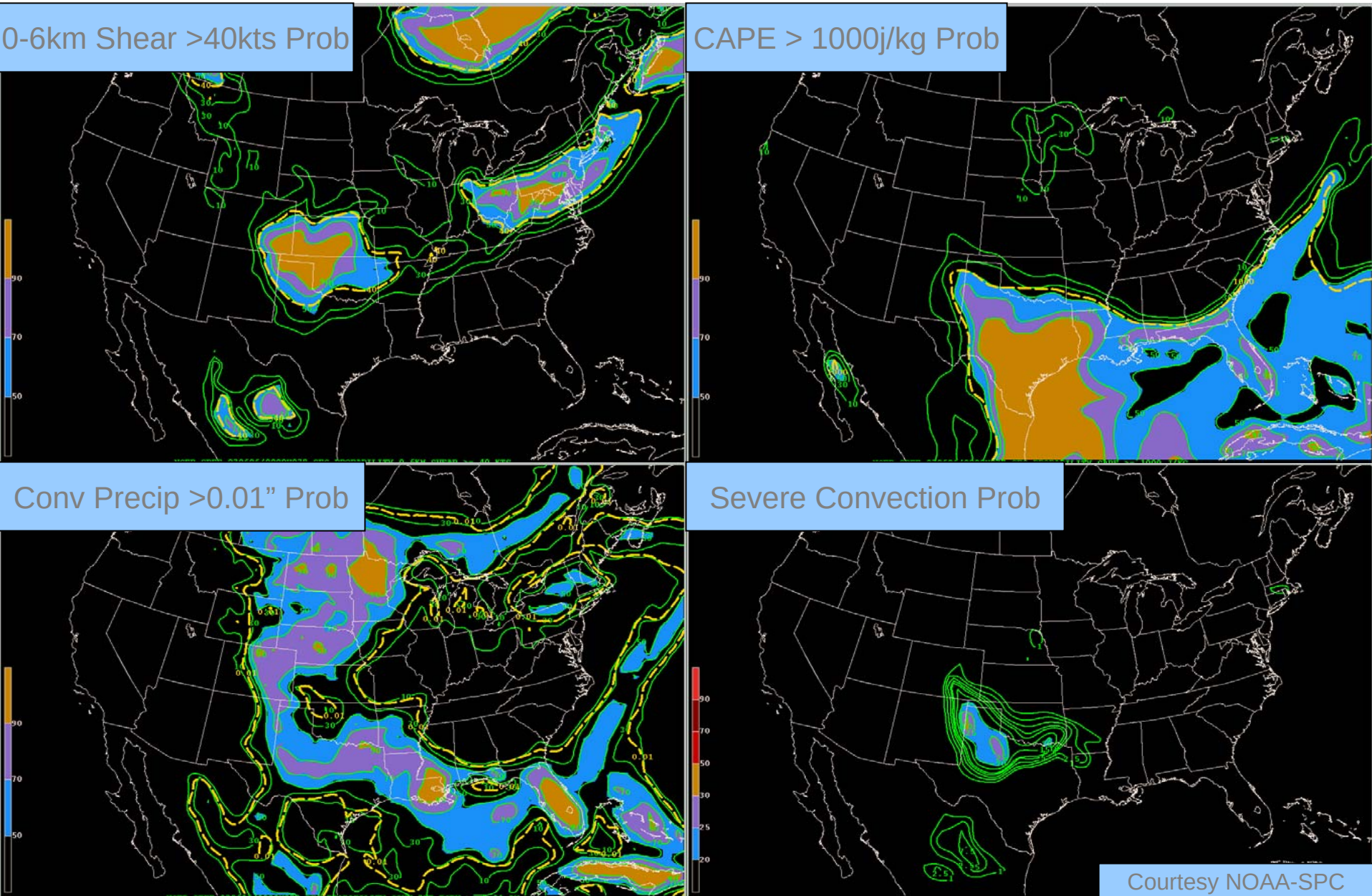
Results: NCEP will select six members for its **initial WRF ensemble** in Hi-Resolution Windows from **eight options** run under the WRF Test Plan:

- **2 Control members:**
  - WRF-NMM with NMM physics and Eta IC/BCs
  - WRF-MC with NCAR physics, RUC ICs, Eta BCs
- **2 Cross-bred physics members:**
  - WRF-NMM with NCAR physics and Eta IC/BCs
  - WRF-MC with NMM physics , RUC ICs, Eta BCs
- **2 WRF NMM runs**, like NMM control, but with positive and negative **bred perturbations.**
- **2 WRF MC runs**, like MC control, but with positive and negative **bred perturbations.**

The WRF Test Plan: A collaboration of AFWA, NAVO, FSL, NCAR and NCEP for 1936 runs covering all seasons and 4 domains at 8 km

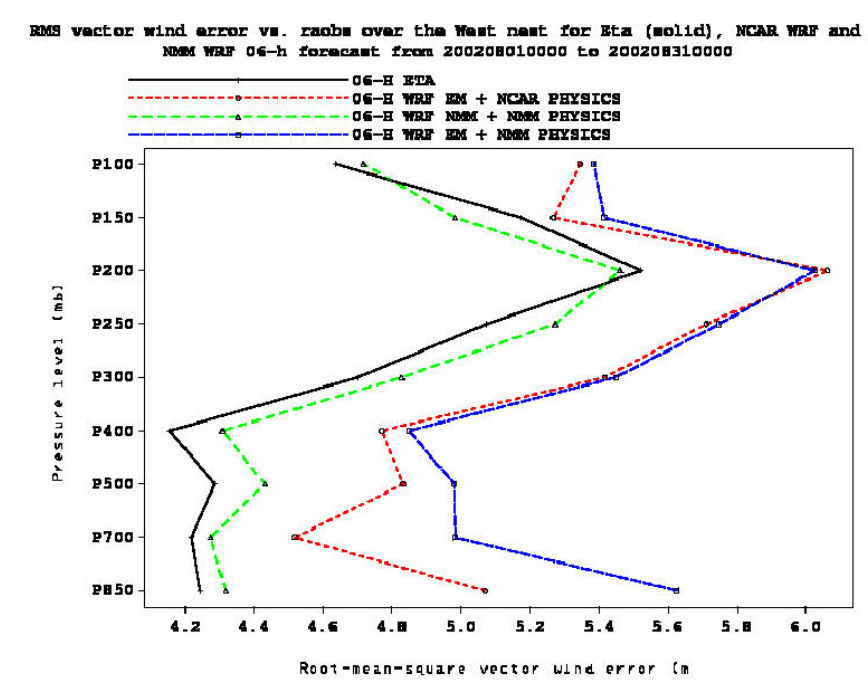
Month/ Year & Source	U.S. Hi-Resol. Domains	WRF-EM & NCAR Physics	WRF-EM & NCEP Physics	WRF-EM & NCAR Phys + perturba.	WRF-EM & NCAR Phys - perturba.	WRF-NM & NCEP Physics	WRF-NM & NCAR Physics	WRF-NM & NCEP Physics + perturba	WRF-NM & NCEP Physics +- perturba
Feb '03 FSL	East	28/28	28/28	28/28	28/28	28/28	28/28	28/28	28/28
Feb '03 FSL	West	28/28	28/28	28/28	28/28	28/28	28/28	28/28	28/28
May'03 AFWA	Central	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31
May'03 AFWA	East	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31
Aug'03 AFWA	Central	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31
Aug'03 AFWA	West	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31
Oct '03 AFWA	East	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31
Oct '03 AFWA	Alaska	31/31	31/31	31/31	31/31	31/31	31/31	31/31	31/31

Example of Ensemble Probability Product

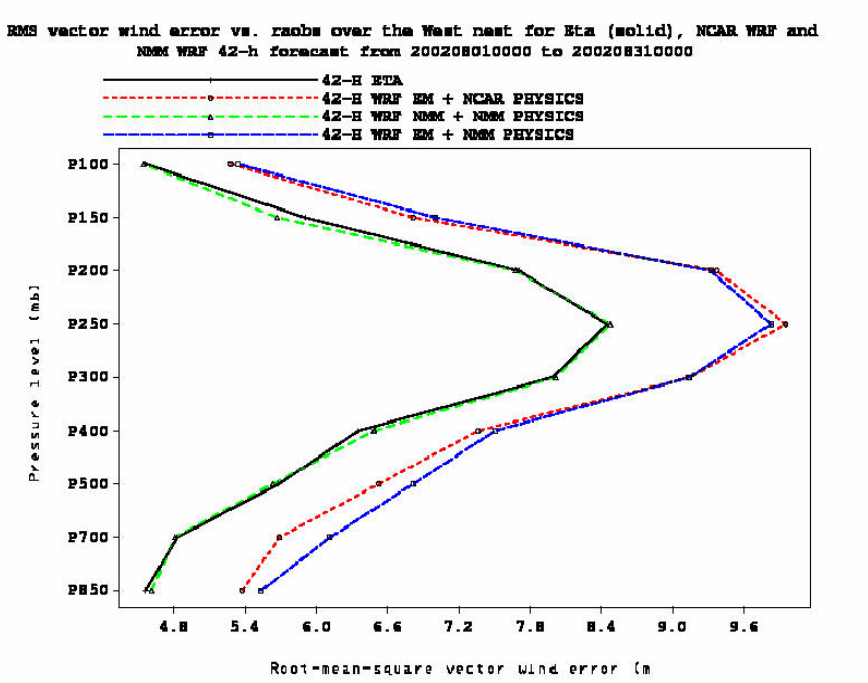


WRF Test Plan Evaluations: Average RMSE for Wind Speed vs. Pressure August 2002

6-h Forecast, West Domain



42-h Forecast, West Domain



Operational Eta

WRF-NMM, NCEP Physics

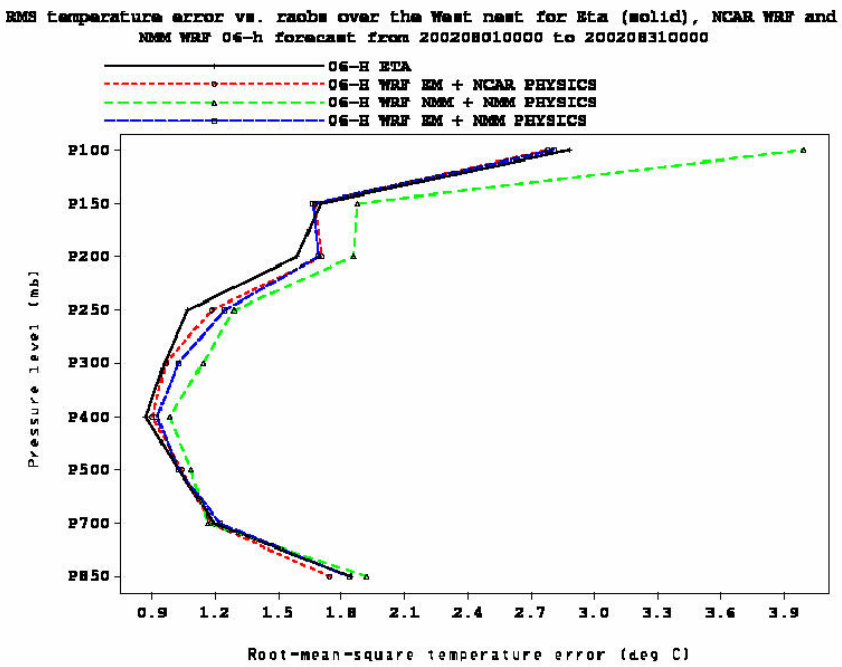
WRF-MC, NCAR Physics

WRF-MC, NCEP Physics

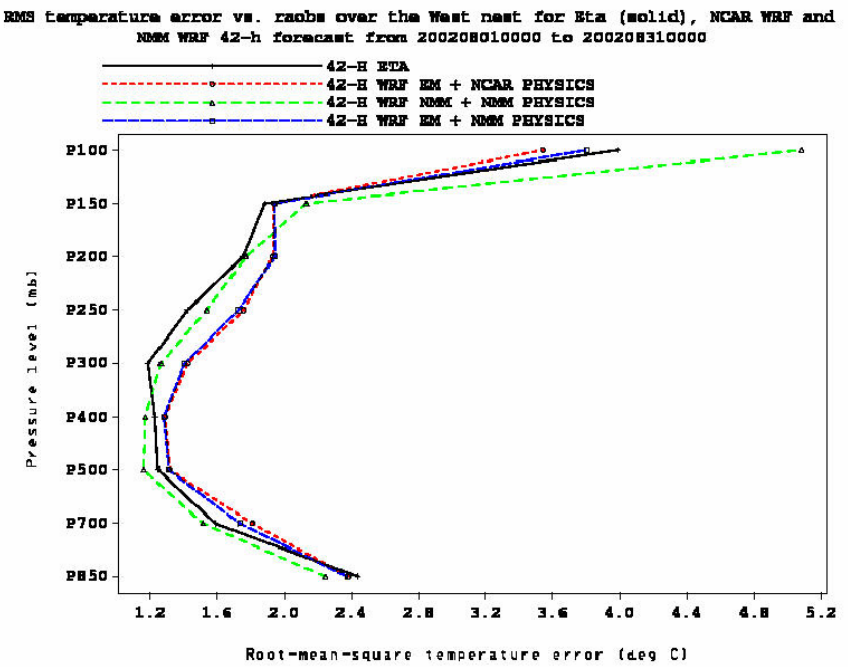
http://wwwt.emc.ncep.noaa.gov/mmb/WRFretro/html/test.html

WRF Test Plan Evaluations: Average RMSE for Temperature vs. Pressure August 2002

6-h Forecast, West Domain



42-h Forecast, West Domain



Operational Eta

WRF-NMM, NCEP Physics

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WRF-MC, NCEP Physics

http://wwwt.emc.ncep.noaa.gov/mmb/WRFretro/html/test.html

Verification Statistics for the NCEP WRF Pre-implementation Test: Part 2 Ensemble Results

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The Remainder of the Developmental Testbed Center Team

P U R P O S E

- Combine various groups of the 8 retrospective runs into ensembles
- Evaluate ensembles
  - Verify mean using deterministic scores
  - Verify using ensembles scores
- Choose best 6 member combination

Eight WRF Retrospective Runs

- Four Physics Diversity (PD) runs of WRF Ensemble:
  - Initial conditions
    - RUC for WRF-MC runs
    - Eta for WRF-NMM runs
  - Crossbred physics
    - WRF-MC run with NCAR & NCEP physics
    - WRF-NMM run with NCEP & NCAR physics
  - Lateral boundary conditions from Eta
- Four Initial Perturbation (IP) runs of WRF Ensemble:
  - Initial condition breeding cycle produces a *pair of runs* for each core
    - WRF-MC with NCAR physics and RUC base initial conditions
    - WRF-NMM with NCEP physics and Eta base initial conditions
  - Apply 4 SREF based anomalies to Eta Lateral boundary conditions

WRF Ensemble Processing

- Based on NCEP experience with SREF, the five state variables (u, v, T, q and Ps), are perturbed
- Accomplished within the WRF common modeling infrastructure via a single utility - diffwrf
- Given three input files: File0 (the base field), File1 and File2, the general functionality of diffwrf can be written

$$\begin{bmatrix} \text{Modified} \\ \text{variable} \\ \text{in File0} \end{bmatrix} = \begin{bmatrix} \text{Original} \\ \text{variable} \\ \text{in File0} \end{bmatrix} + \alpha \begin{bmatrix} \text{variable} - \text{variable} \\ \text{in File1} \quad \text{in File2} \end{bmatrix}$$

Initial Condition Breeding Cycle

- Required modification of WRF restart file processing.
- File1 and File2 are forecasts made from a pair (+/-) of perturbed states from previous cycle.
- The factor, α, depends on the domain-averaged magnitude of the difference field.
- Rescaling ($\alpha < 1$) is only done if the magnitude is larger than a prescribed value (~ analysis error standard deviation) following procedures developed for NCEP's medium-range ensemble forecast system (Toth and Kalnay, 1997).
- The breeding cycle involves adding scaled perturbations in positive and negative sense from the pair of 24 hours forecast onto initial conditions of the next cycle yielding 2 runs from each control.

Lateral Boundary Condition Anomaly

- WRF-SI outputs and NeTCDF variables modified
- File1 and File2 are forecasts made from a perturbed state and the control of NCEP's SREF (basically the SREF member's anamoly with respect to its control run)
- The factor, α, is usually set to 1

Breeding Pairs with LBC Anomalies

- Lateral boundary condition anomaly applied to WRF-SI's vinterp NeTCDF outputs using 4 SREF forecasts, namely, p1, p2, n1 and n2 and the control applied to either Eta12 or RUC initial condition forecast, yielding 4 perturbed forecasts, i.e.,

$$eta12 = eta12 + \alpha\,[p1 - ct1] \rightarrow \text{NMM core}$$

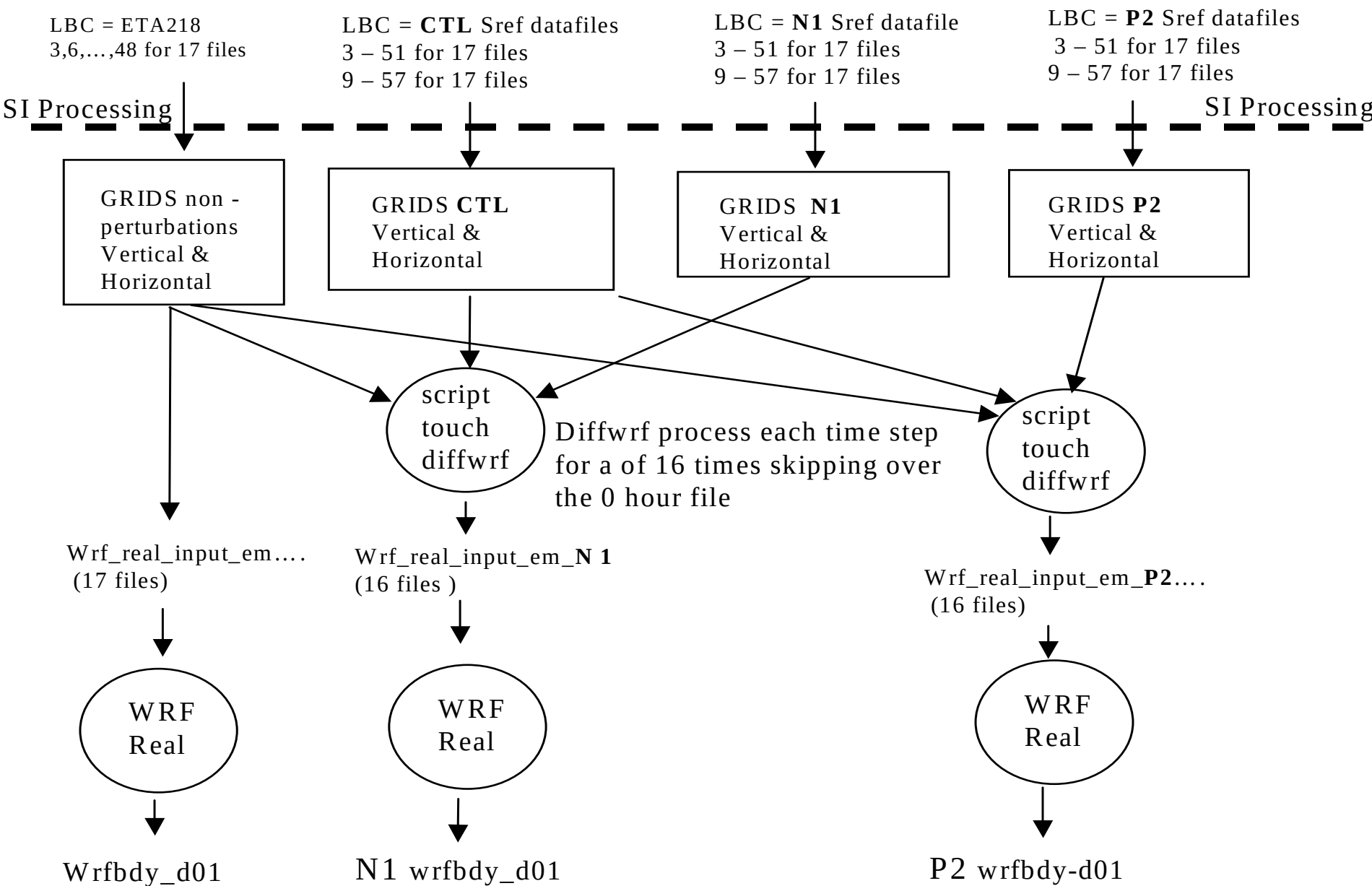
$$eta12 = eta12 + \alpha\,[n2 - ct1] \rightarrow \text{NMM core}$$

$$eta12 = eta12 + \alpha\,[p2 - ct1] \rightarrow \text{Mass core}$$

$$eta12 = eta12 + \alpha\,[n1 - ct1] \rightarrow \text{Mass core}$$

WRF Ensemble Processing

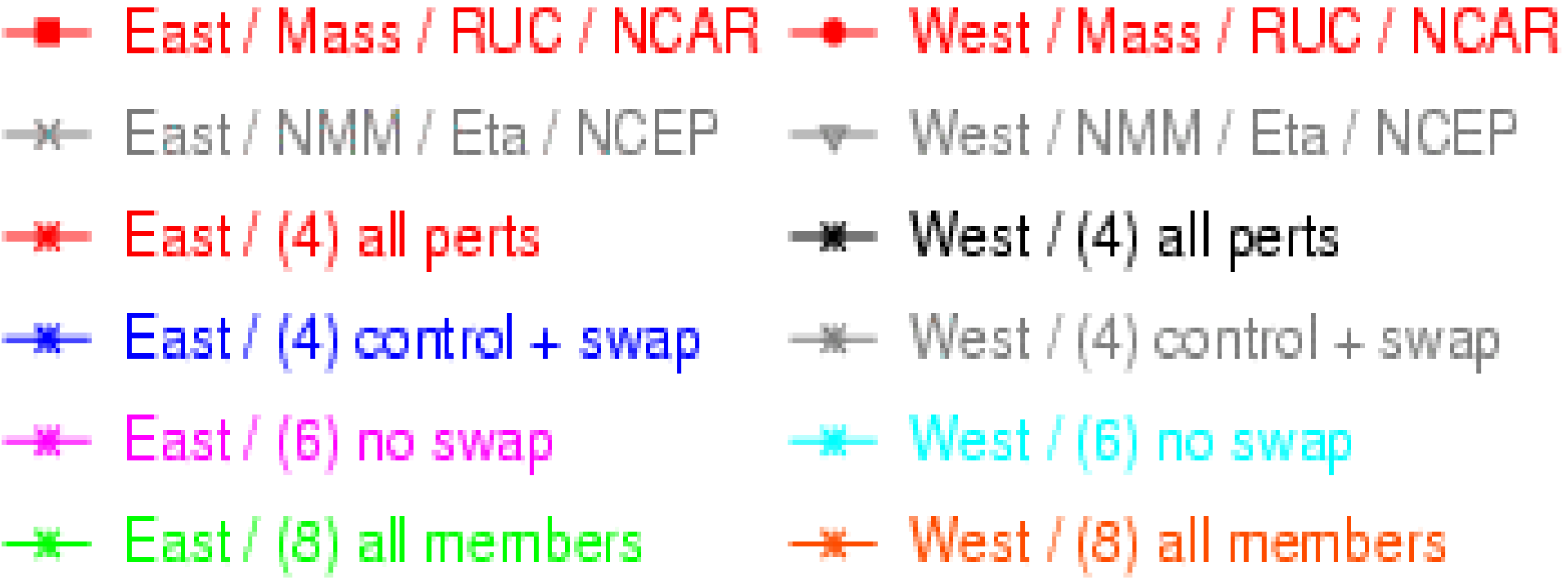
Breeding – Perturbation Data Flow -- Schematic

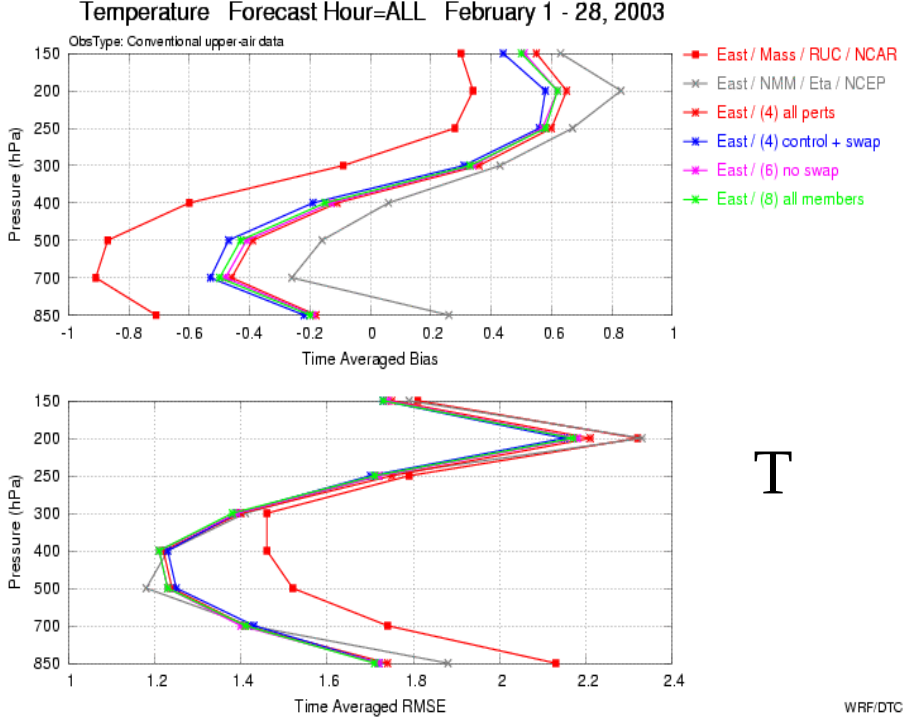


FSL’s Verification Website

http://www-ad.fsl.noaa.gov/fvb/rtvs/wrf/retro_runs/

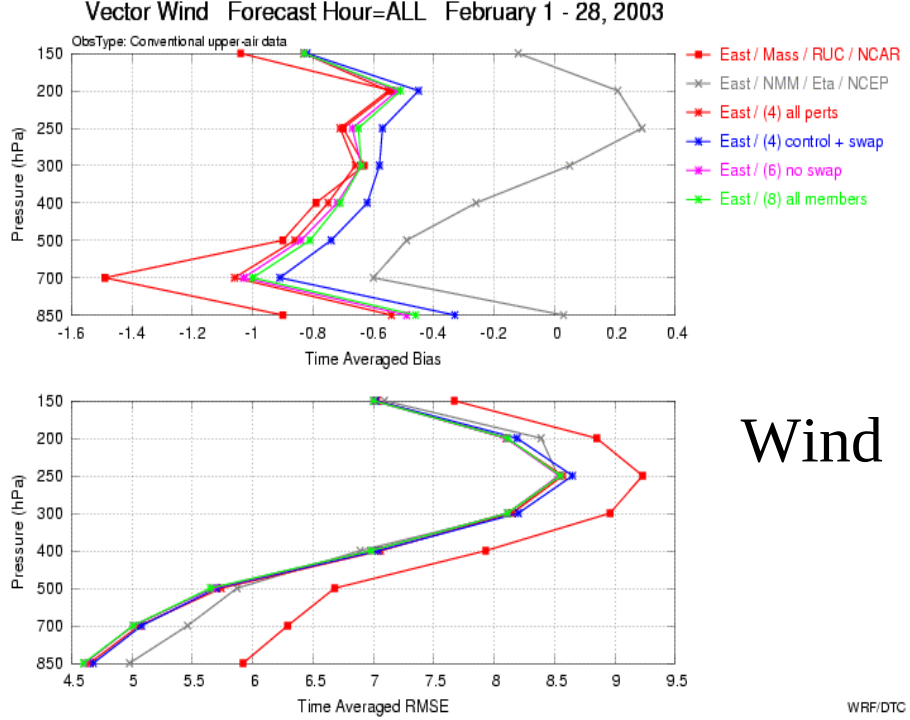
Deterministic Verification of Ensemble Means Versus Radiosonde Obs Color Codes




Temperature Forecast Hour=ALL February 1 - 28, 2003
ObsType: Conventional upper-air data
East / Mass / RUC / NCAR
East / NMM / Eta / NCEP
East / (4) all perts
East / (4) control + swap
East / (6) no swap
East / (8) all members
Pressure (hPa)
Time Averaged Bias

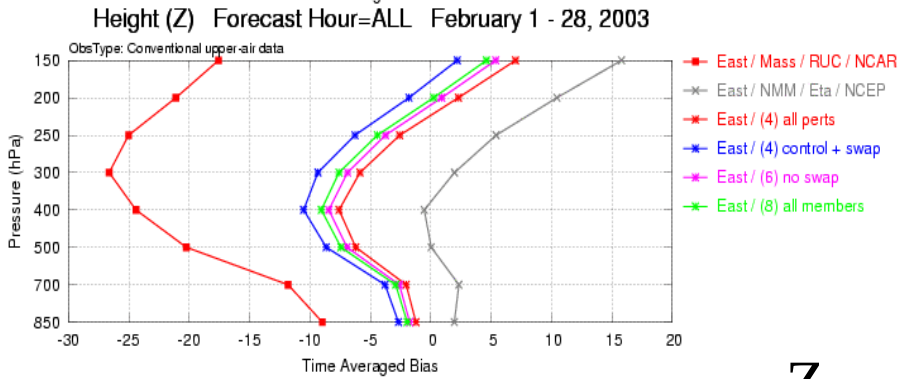
Pressure (hPa)
Time Averaged RMSE
WRF/DTC

T


Vector Wind Forecast Hour=ALL February 1 - 28, 2003
ObsType: Conventional upper-air data
East / Mass / RUC / NCAR
East / NMM / Eta / NCEP
East / (4) all perts
East / (4) control + swap
East / (6) no swap
East / (8) all members
Pressure (hPa)
Time Averaged Bias

Pressure (hPa)
Time Averaged RMSE
WRF/DTC

Wind


Height (Z) Forecast Hour=ALL February 1 - 28, 2003
ObsType: Conventional upper-air data
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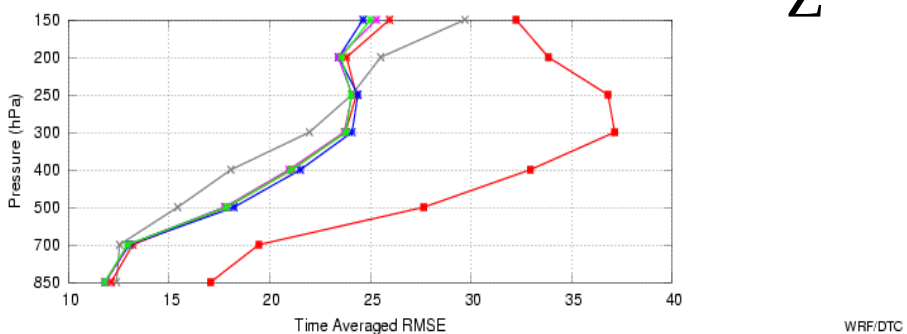
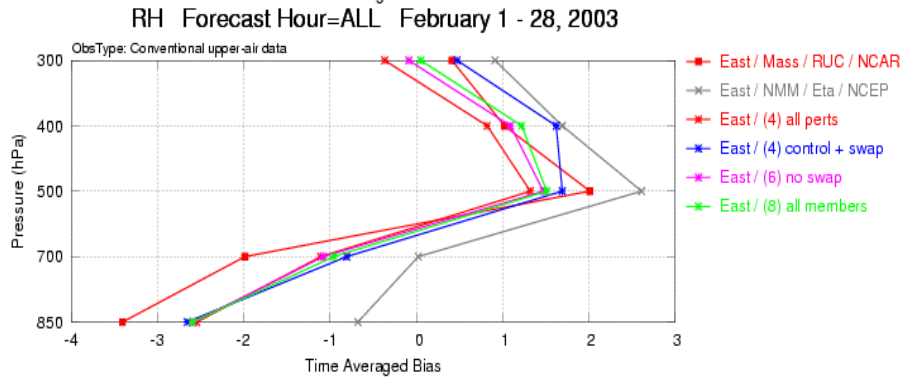
East / NMM / Eta / NCEP
East / (4) all perts
East / (4) control + swap
East / (6) no swap
East / (8) all members
Pressure (hPa)
Time Averaged Bias


Pressure (hPa)
Time Averaged RMSE
WRF/DTC

Z


RH Forecast Hour=ALL February 1 - 28, 2003
ObsType: Conventional upper-air data
East / Mass / RUC / NCAR
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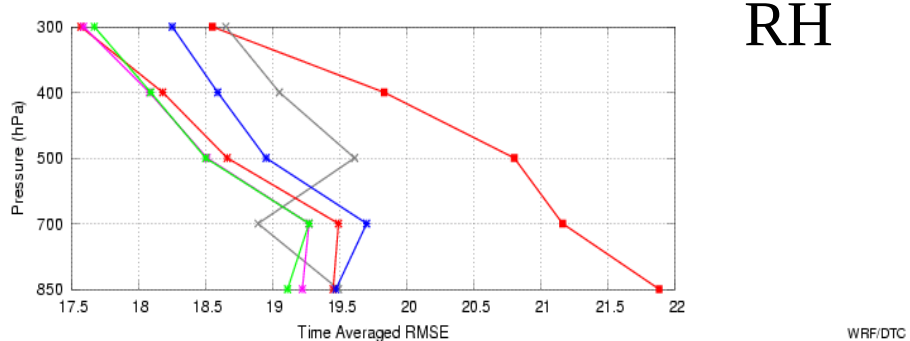
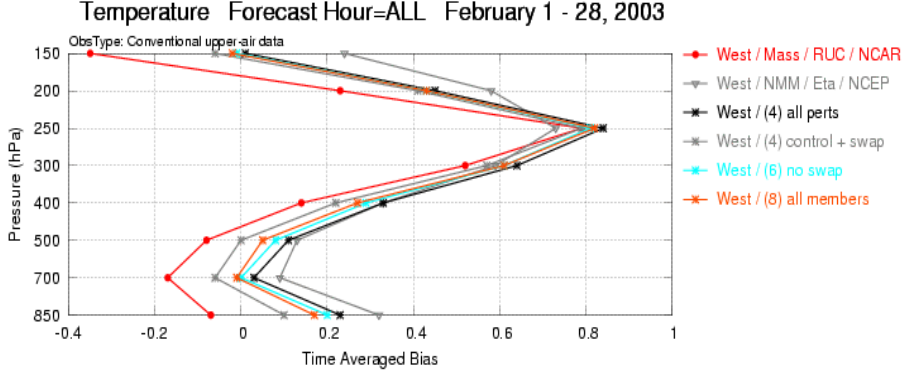
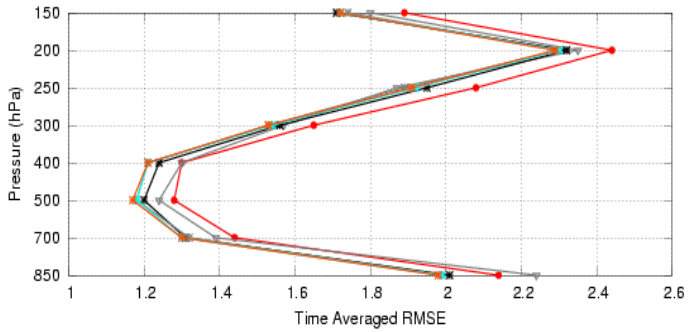
East / (4) all perts
East / (4) control + swap
East / (6) no swap
East / (8) all members
Pressure (hPa)
Time Averaged Bias


Pressure (hPa)
Time Averaged RMSE
WRF/DTC

RH





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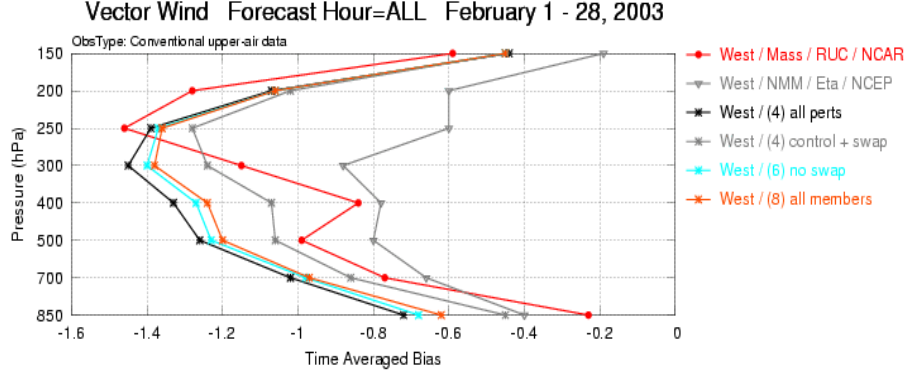
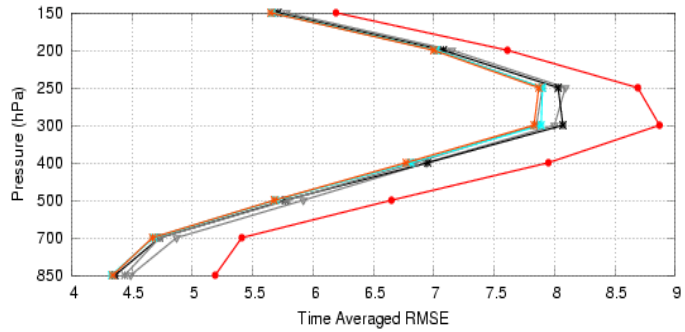
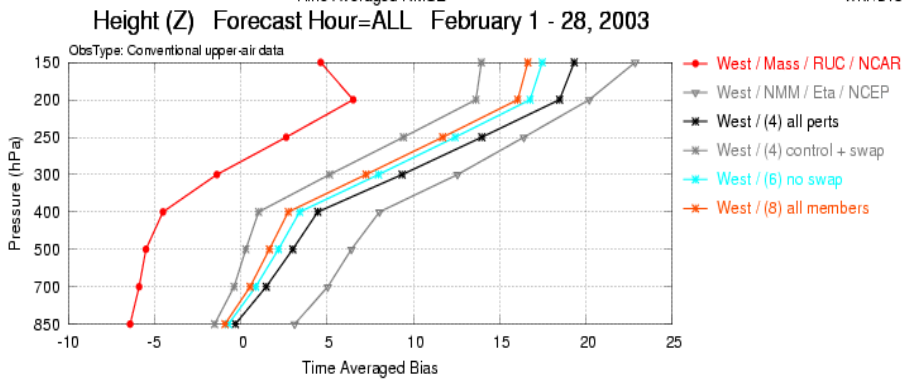
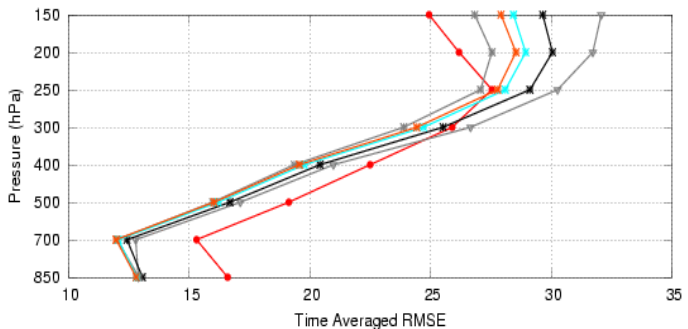




Wind

WRF/DTC





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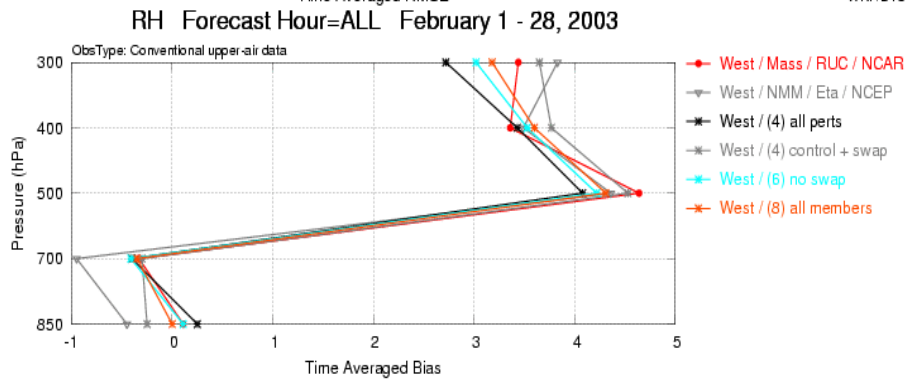
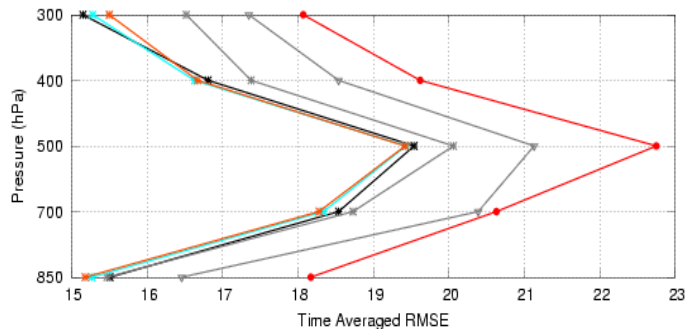
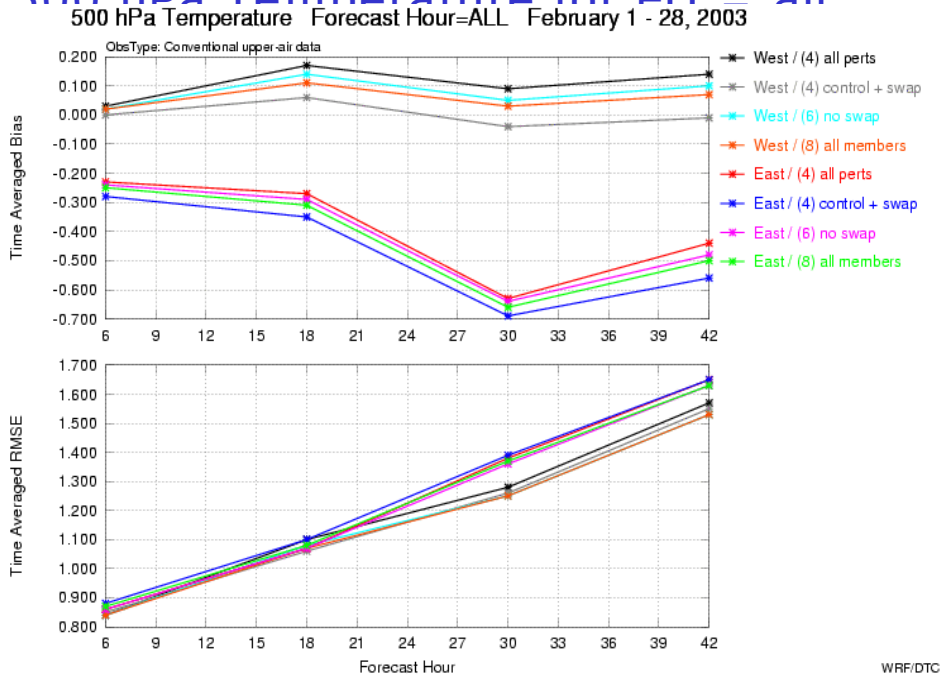




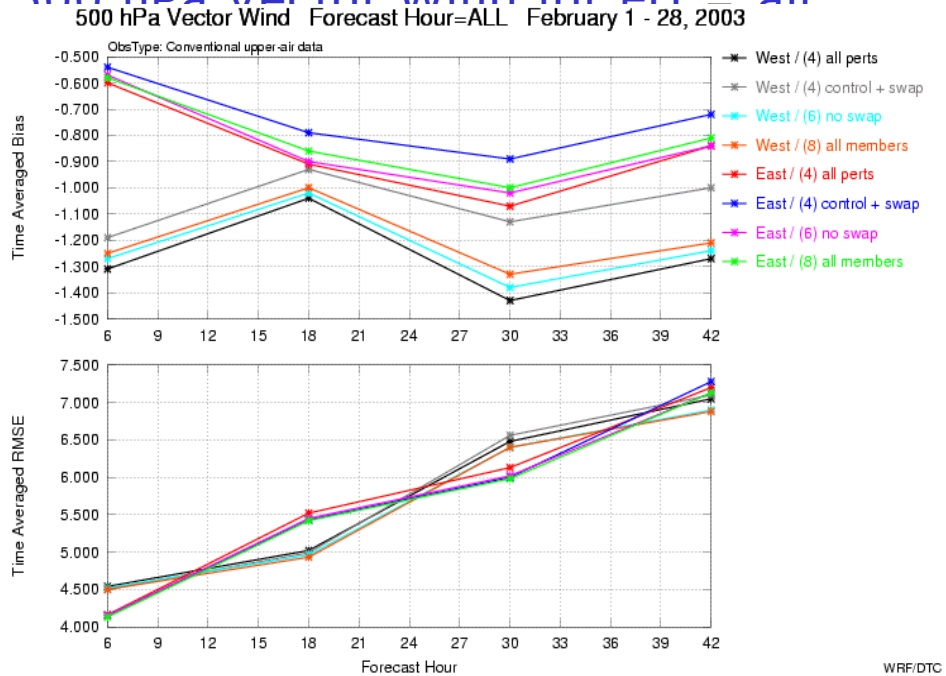
RH

WRF/DTC

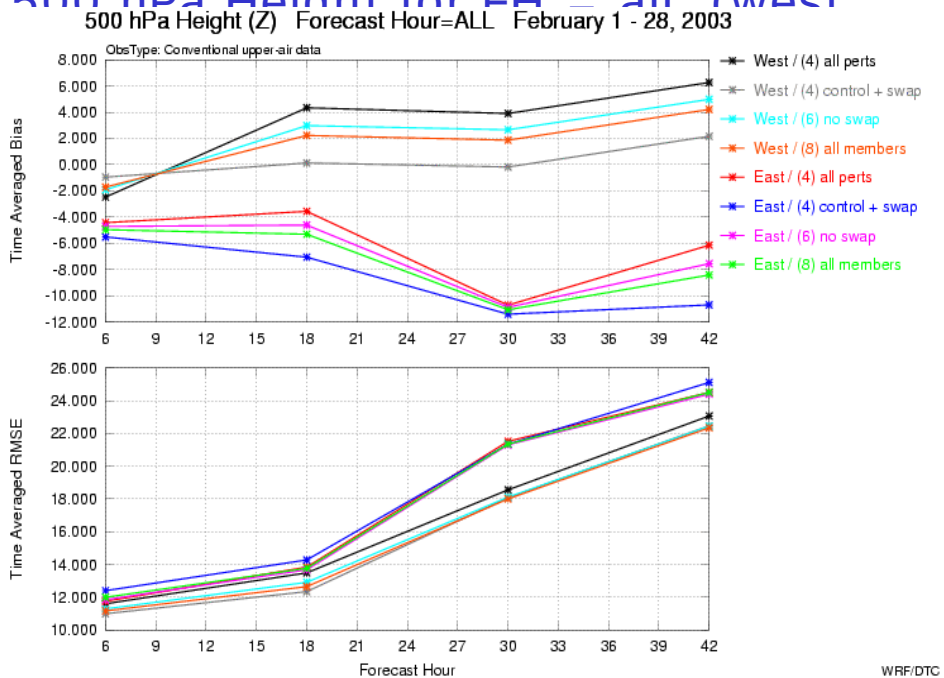
500 hPa Temperature for FH = all



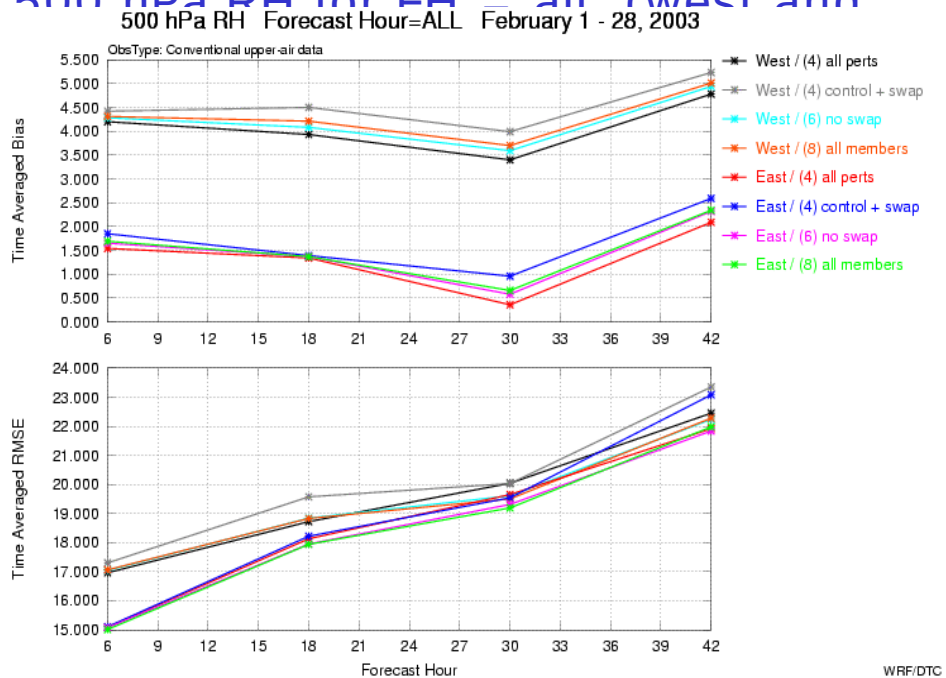
500 hPa Vector Wind for FH = all



500 hPa Height for FH = all (west



500 hPa RH for FH = all (west and



Ensemble Verification

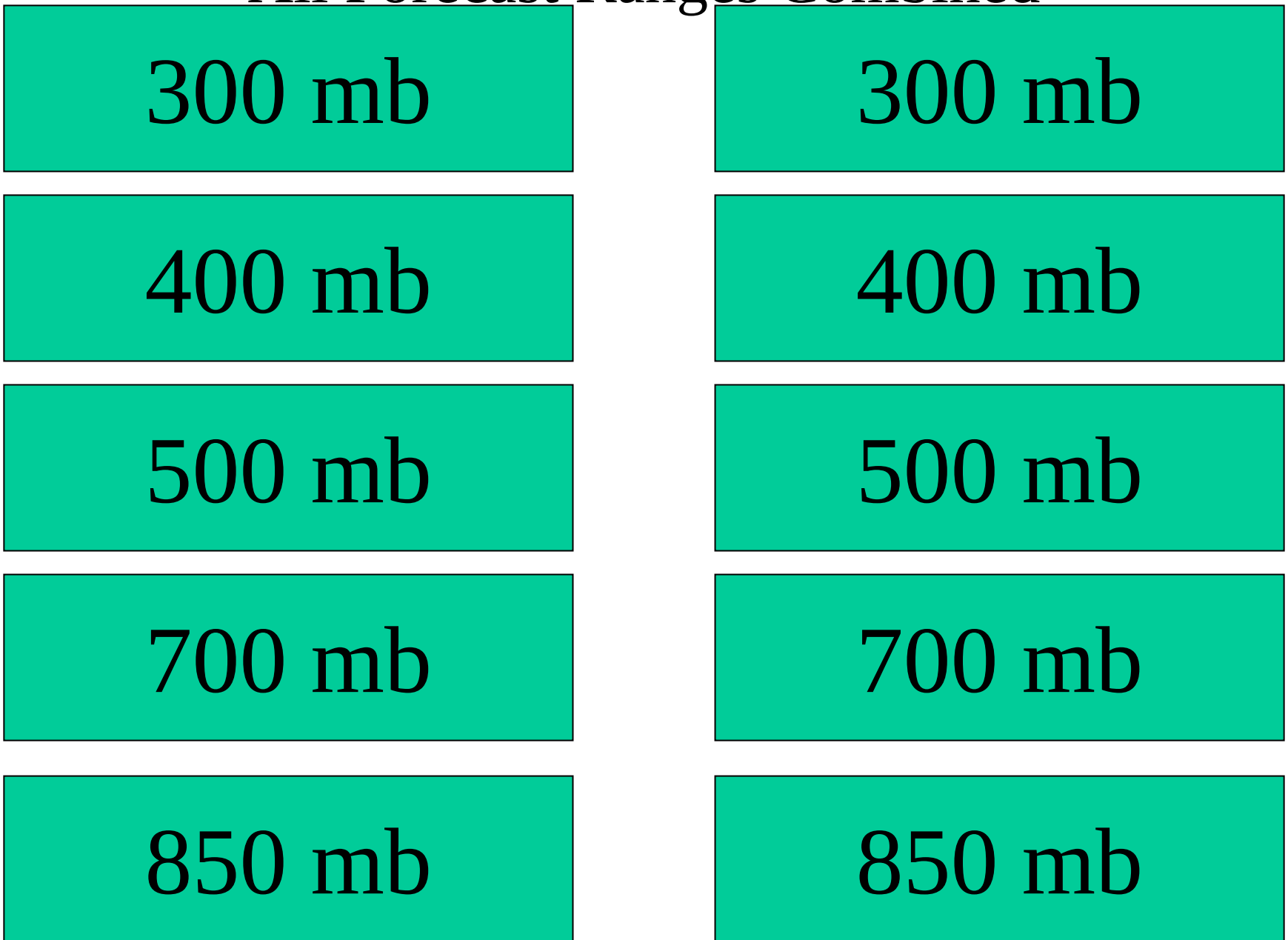
Based on verification vs radiosonde obs

4 Initial Perturbation (IP) vs 4 Physics Diversity (PD)

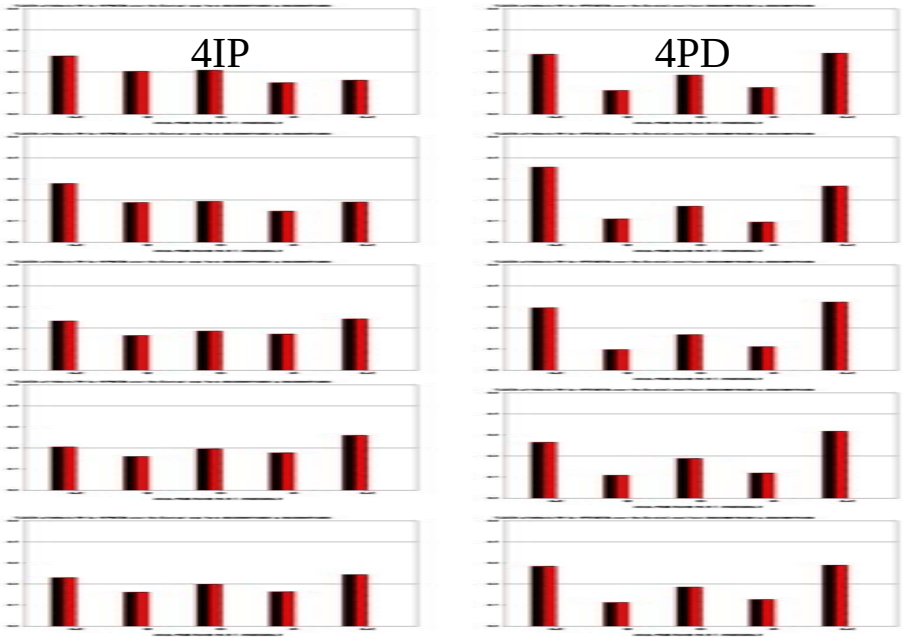
IP More Uniform Ranked Histograms

Legend for Subsequent Summaries

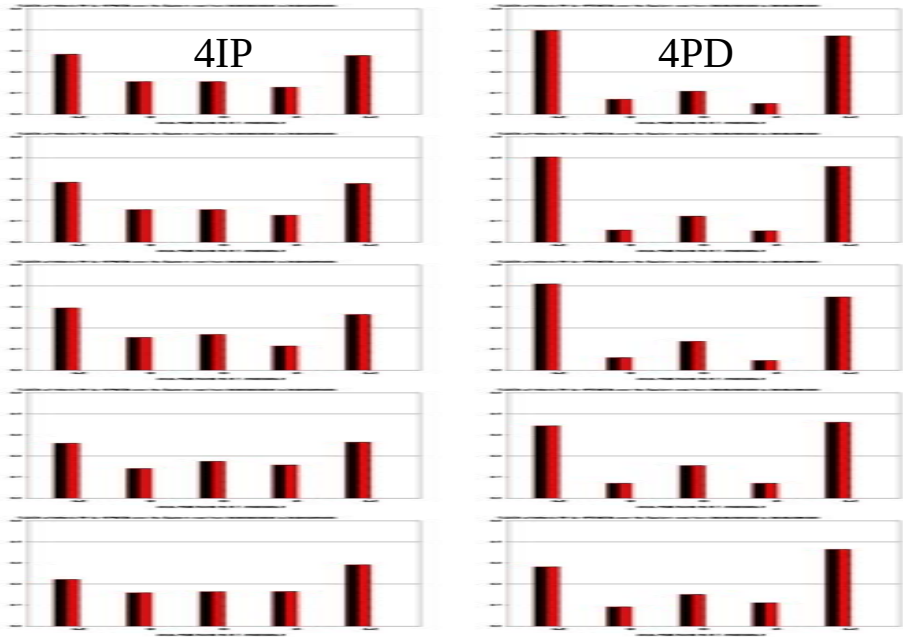
All Forecast Ranges Combined



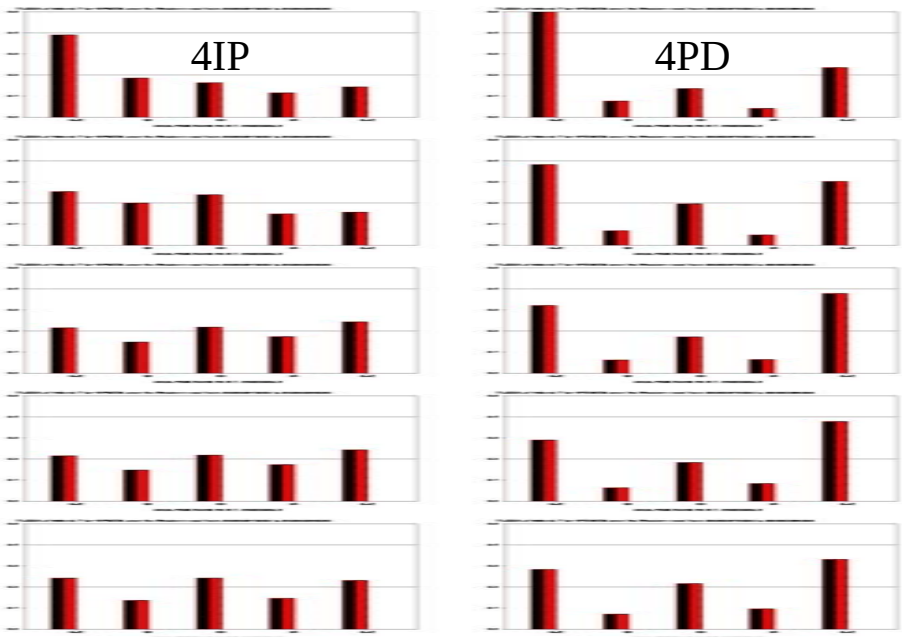
Equally Likely Central Summer RH



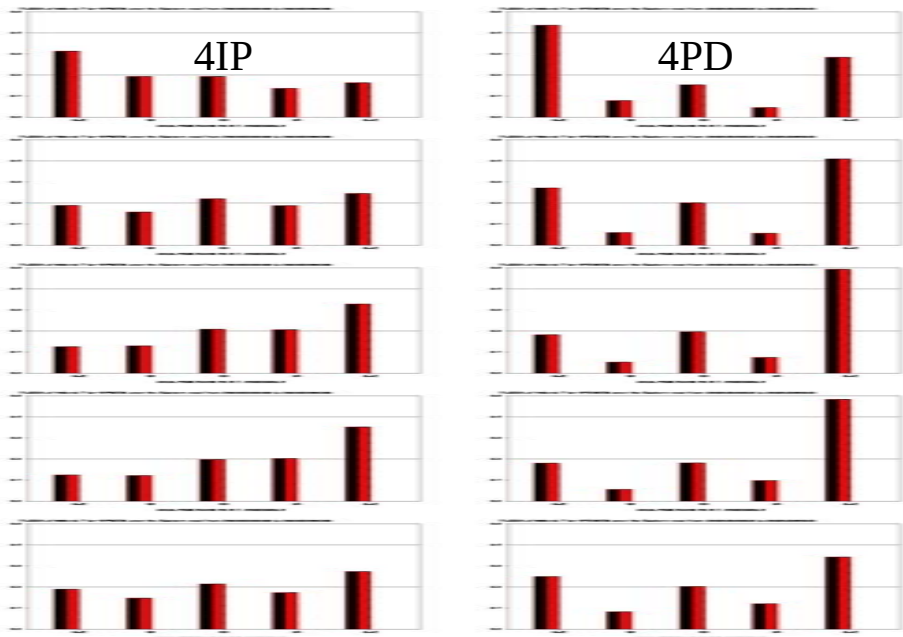
Equally Likely Eastern Winter RH



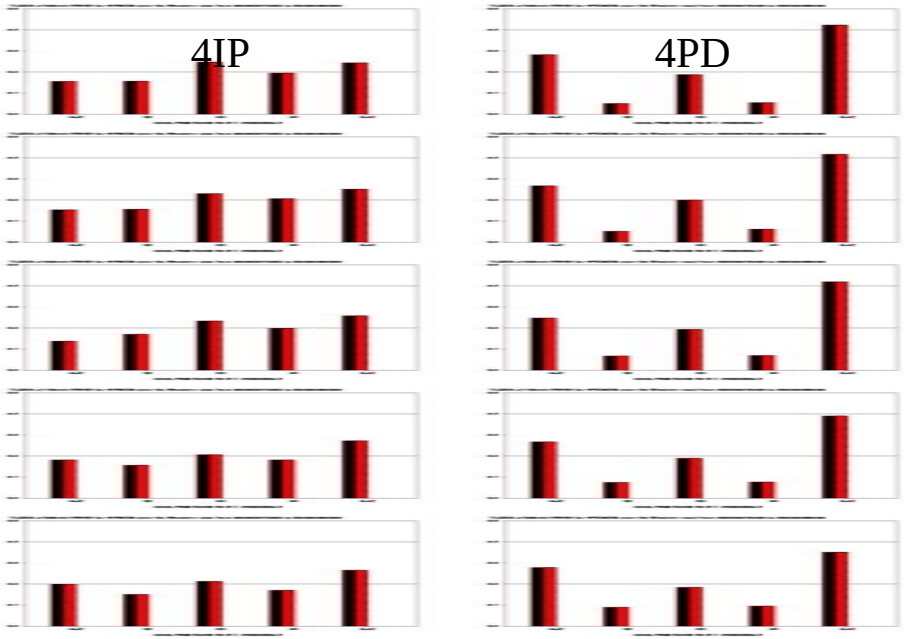
Equally Likely Western Winter Temp



Equally Likely Eastern Winter Temp



Equally Likely Western Winter Wind



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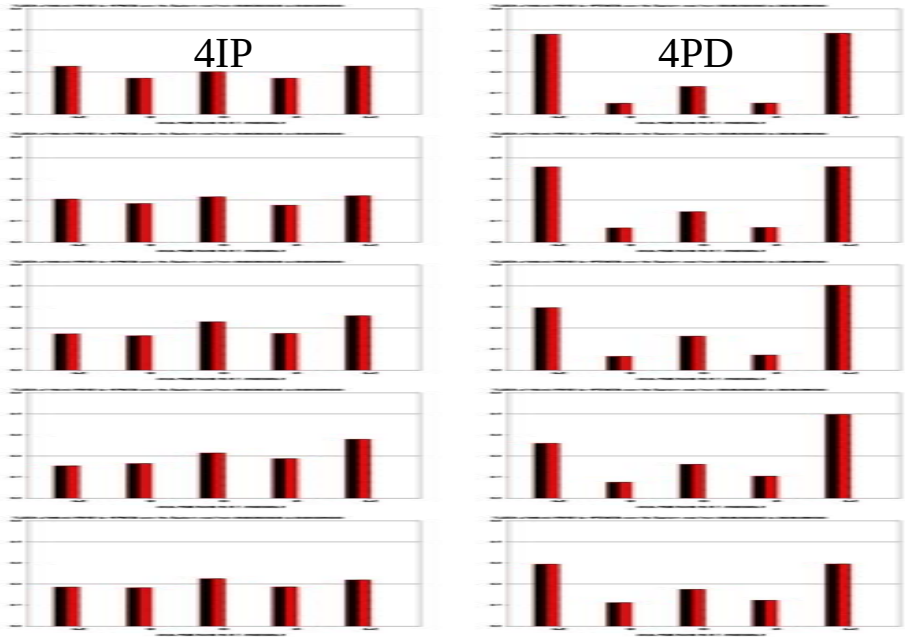
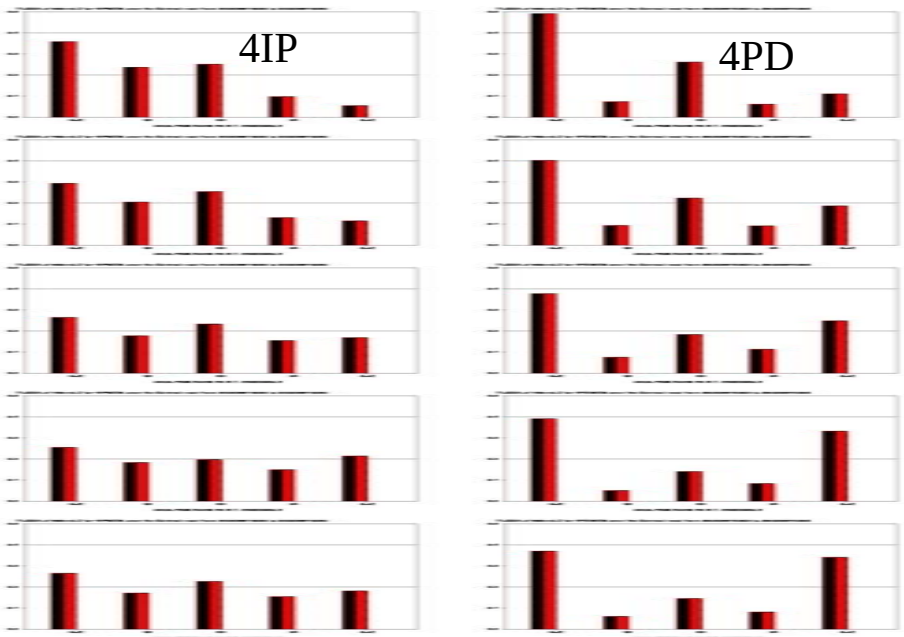
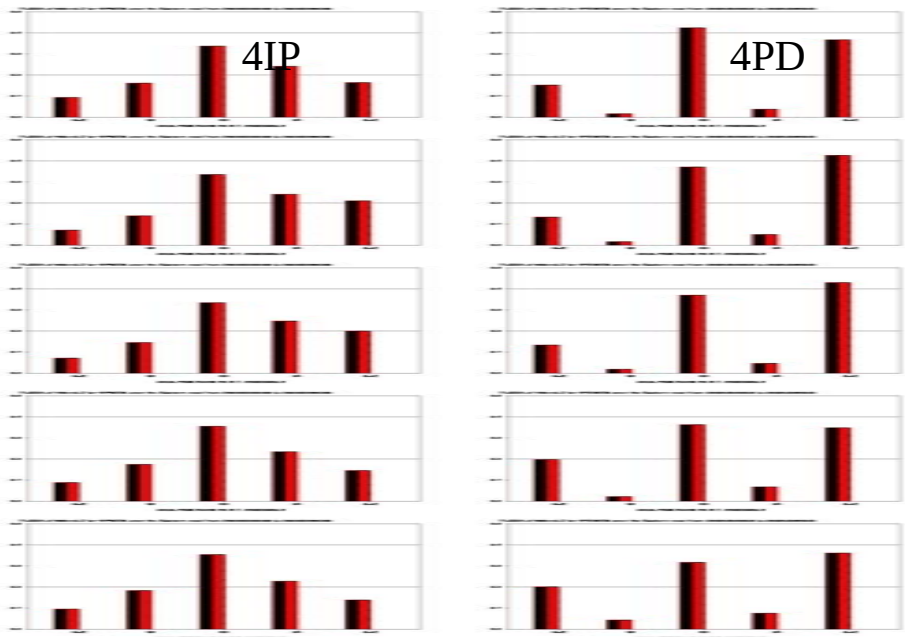


Equally Likely Central Summer Height



Equally Likely Eastern Winter Height

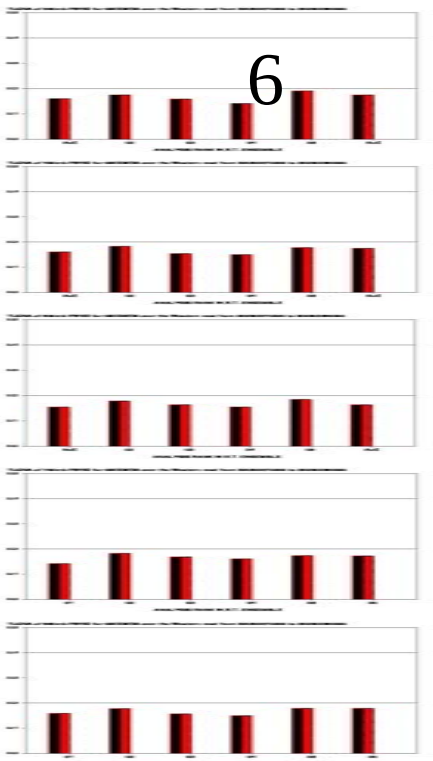


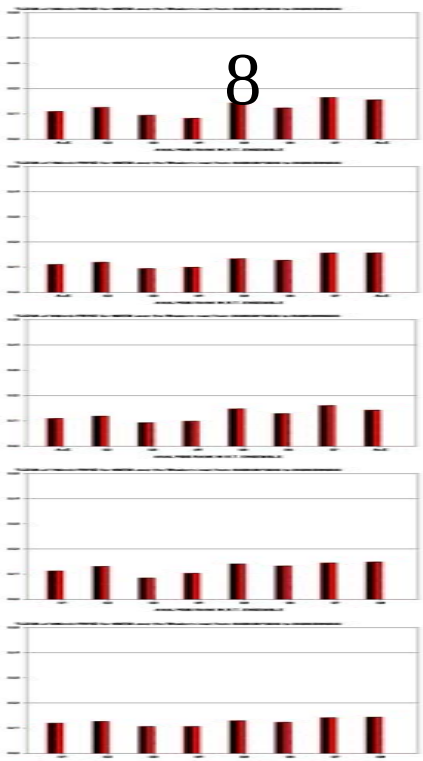
CHOICE OF SIX MEMBERS

2 Controls + 2 IP-Breeding Pairs

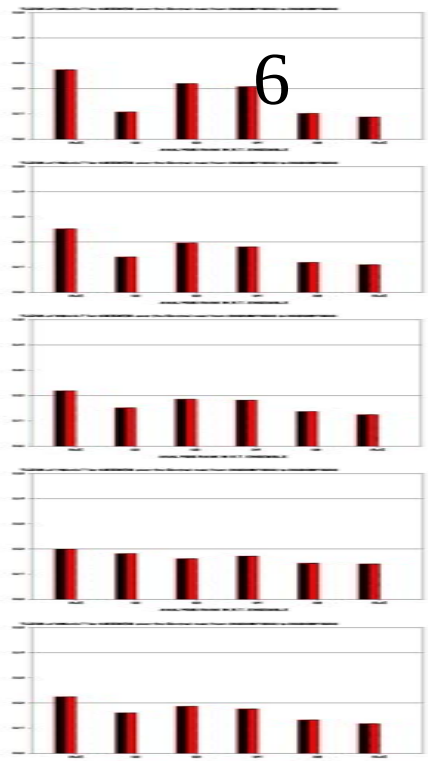
This 6 Member Ensemble Is Almost As Good As The Complete 8 Member Ensemble

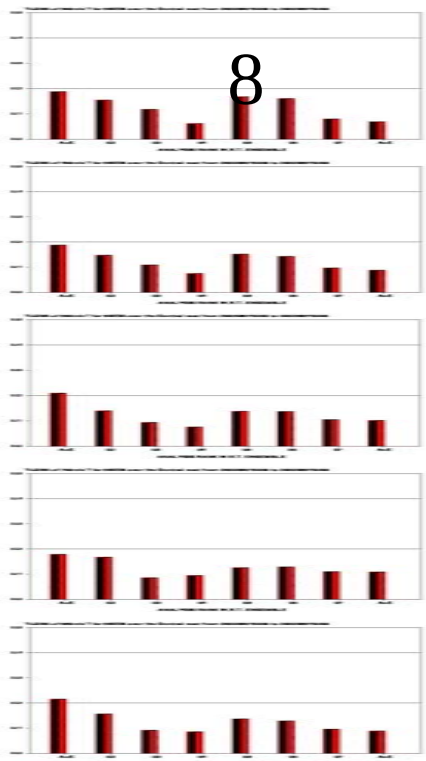
Nearest Truth Western Winter Wind





Nearest Truth Central Summer Temp





WRF System Description – HRW Implementation

Description: The WRF modeling system consists of…

Component	Source	Code History
• Two dynamical cores	NCEP & NCAR	new
• Two complete physics suites	NCEP & NCAR	modified MM5 & Eta
• Preprocessing for ICs/BCs	FSL & NCEP	new
• Post-processing for product generation	NCEP	modified Eta
• Statistical evaluation package	NCEP	modified Eta
• Software engineering infrastructure	NCAR	new
• Ensembling software	NCEP	new

Implementation Strategy – Phase 1

- **Phase 1— Implement new model (Threshold): IOC (21 September 2004)**

  - **Two deterministic "control" versions** of WRF will run four times daily, once for each of four large windows (twice for small windows).

    - NCAR EM core: 10-km horizontal resolution, 50 layers
    - NCEP NMM core: 8-km horizontal resolution, 60 layers

  - **80-min run window (clock time) shared** with GFDL Hurricane model
  - **Availability contingent** on tropical weather situation.
    - If 1 tropical storm present, WRF runs for HI & PR will be dropped out.
    - If 2 tropical storms present, WRF-EM run will be dropped.
    - If 3 or more tropical storms present, both WRF runs will be dropped.

Implementation Strategy – Phase 2

- **Phase 2— Implement 6 member WRF ensemble** **target Feb/March 2005**

  - **Two "control" versions & two breeding cycle pairs** will run four times daily, once for each of four large windows (twice for small windows).

    - NCAR EM core: 10-km horizontal resolution, 50 layers
      Positive bred mode plus Negative bred mode
    - NCEP NMM core: 8-km horizontal resolution, 60 layers
      Positive bred mode plus Negative bred mode

  - **80-min run window (clock time) shared** with GFDL Hurricane model but with increased computer power with CCS upgrade complete
  - **Availability** still **contingent** on tropical weather situation.
    - If 1/2 tropical storm present, WRF-EM bred mode runs will be dropped.
    - If 3/4 tropical storms present, WRF-NMM bred mode runs will be dropped.

- Two control versions ALWAYS run

Review of Operational Readiness:
1. Objective Verification

Key:

Compared to the operational NMM, WRF has…

- Significant positive impact:	++	(2)
- Small positive impact:	+	(1)
- About neutral impact:	⟷	(0)
- Small negative impact:	-	(-1)
- Significant negative impact:	--	(-2)

Good to Go	Area has Some Risk	Remedial Action Required

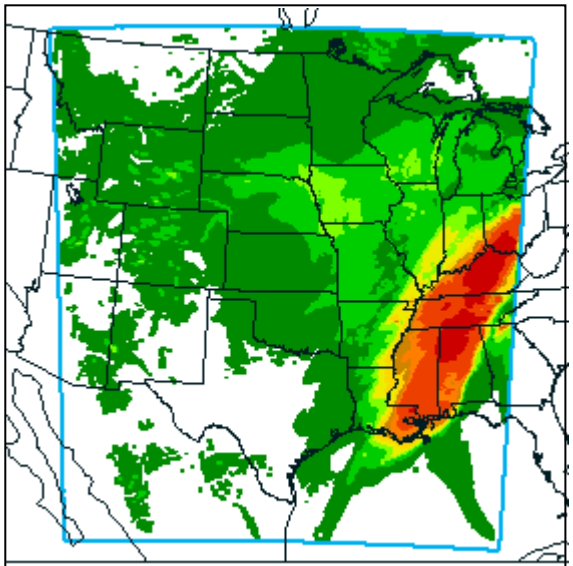
Review of Operational Readiness:

1. Objective Verification

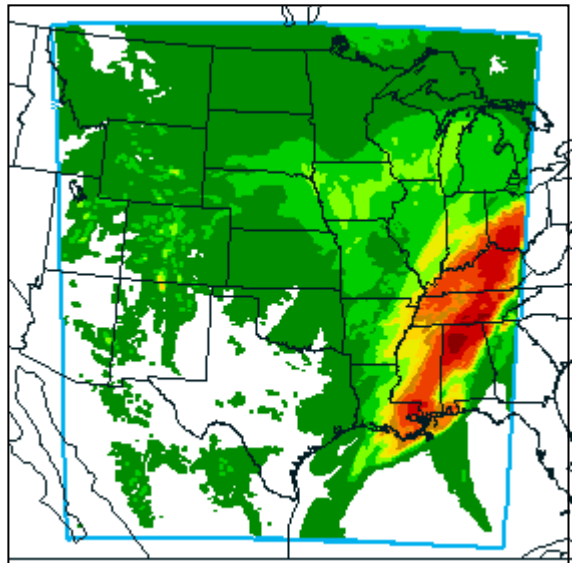
Variable	Season	West HRW Domain		East HRW Domain		NET
Wind profile	Jan-Mar 04	Bias: ++	RMSE: -	Bias: ++	RMSE: ↔	3
Height profile	Jan-Mar 04	Bias: --	RMSE: ↔	Bias: ++	RMSE:++	2
Temp. profile	May-Aug 04	Bias: -	RMSE: -	Bias: -	RMSE: -	-4
Rel. Hum. profile	May-Aug 04	Bias: ↔	RMSE: ↔	Bias: +	RMSE ↔	1
10-m Winds	Jan-Mar 04	Bias: ++	RMSE: +	Bias: +	RMSE: -	3
2-m Temp.	All	Jan-Aug ↔ Fcst-Obs.	May-Aug:+ Fcst-Obs.	Jan-Aug+ Fcst-Obs.	May-Aug+ Fcst-Obs.	3
Large Scale* Precipitation	Jan-Mar 04	ETS: -	Bias: --	ETS: ↔	Bias: +	-2
Large Scale* Precipitation	May-Aug 04	ETS: ↔	Bias: --	ETS: +	Bias: --	-4

*No mature objective score for SMALL Scale Precipitation

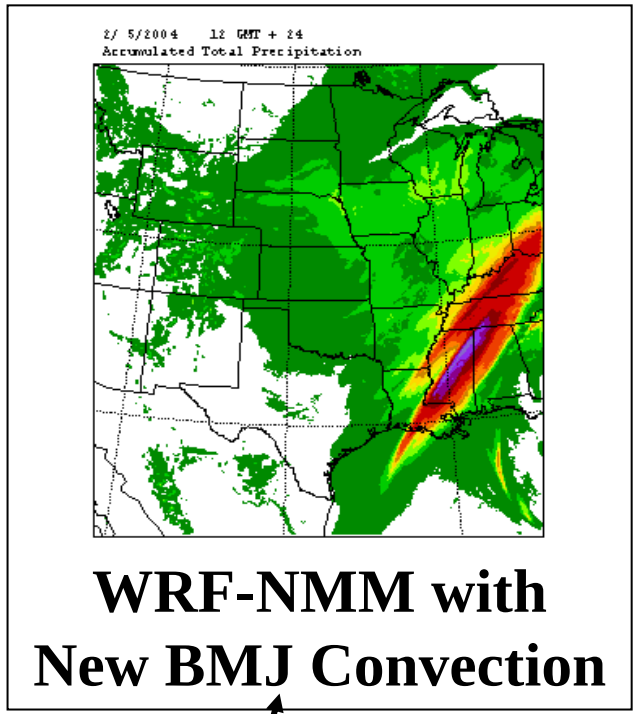
"WRF-NMM has more fine-scale precip structure than oper. NMM"



Operational NMM



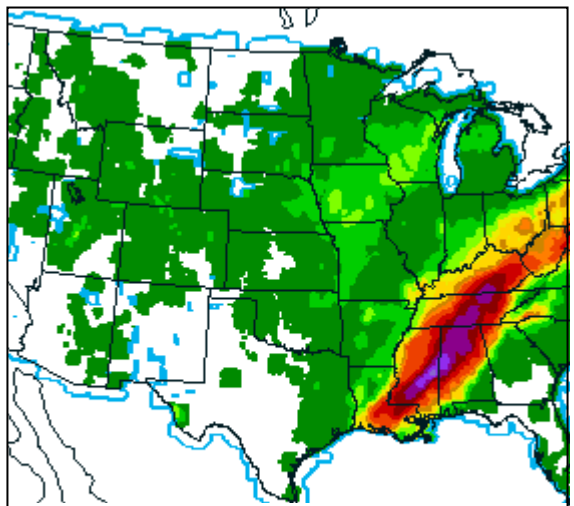
Early WRF-NMM



WRF-NMM with
New BMJ Convection

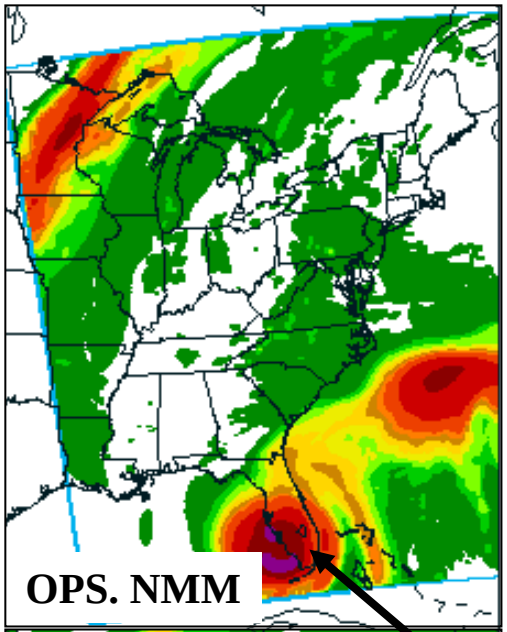
Implemented in Initial
Operational Configuration

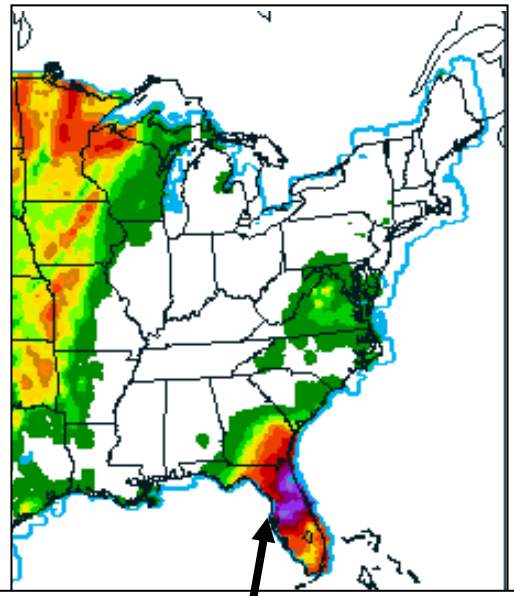
24 hour accumulations,
24-48 hours,
ending 12 Z February 6, 2004

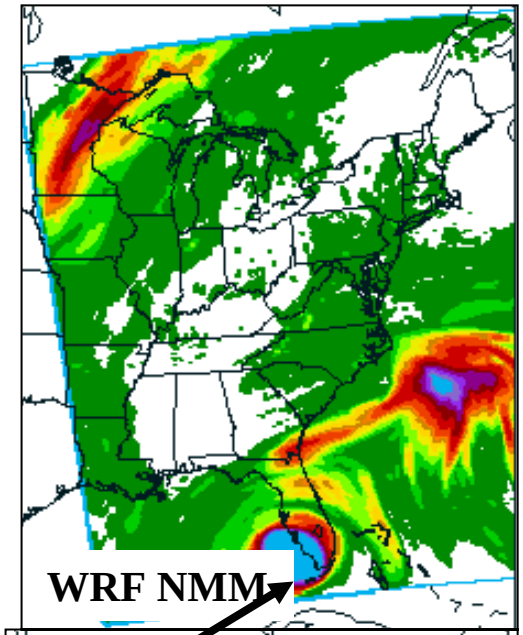


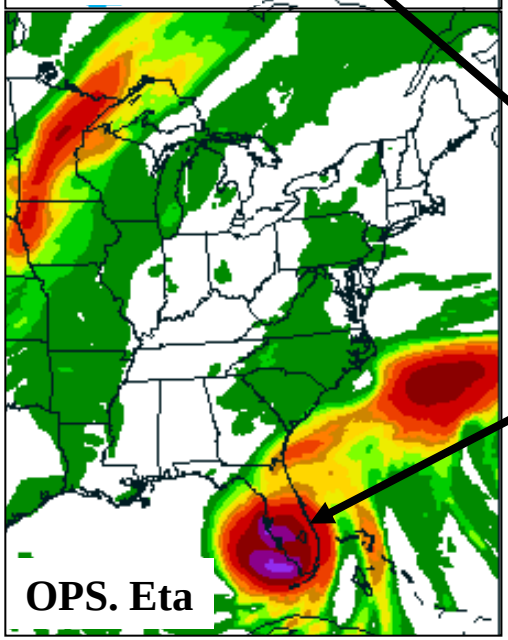
Verification

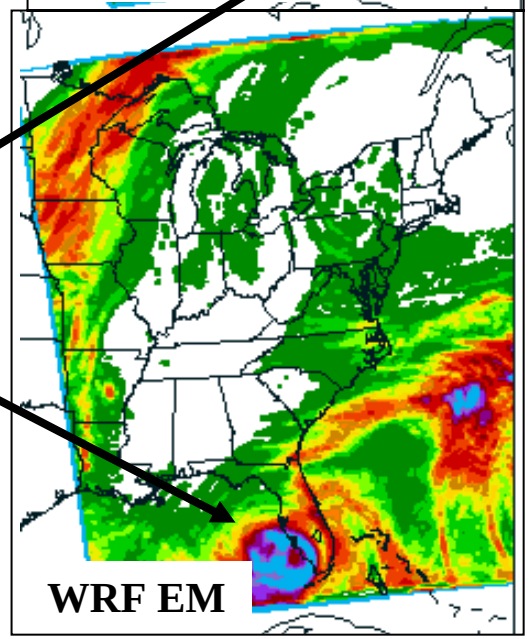
24 Hour Accumulated Precipitation Valid 12Z 6 September, 2004, 42 Hour Forecast







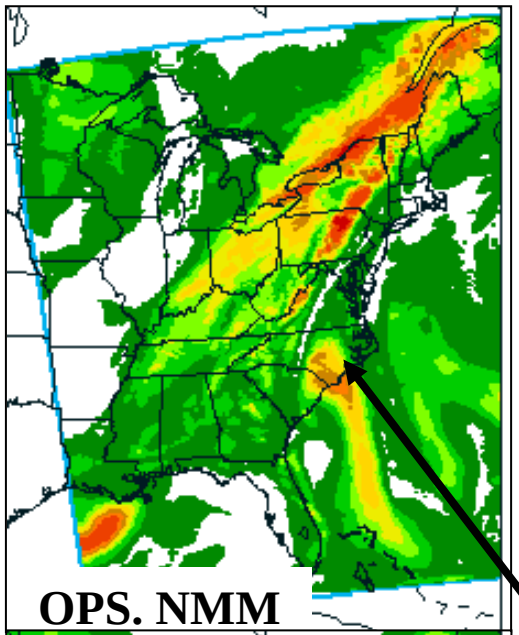


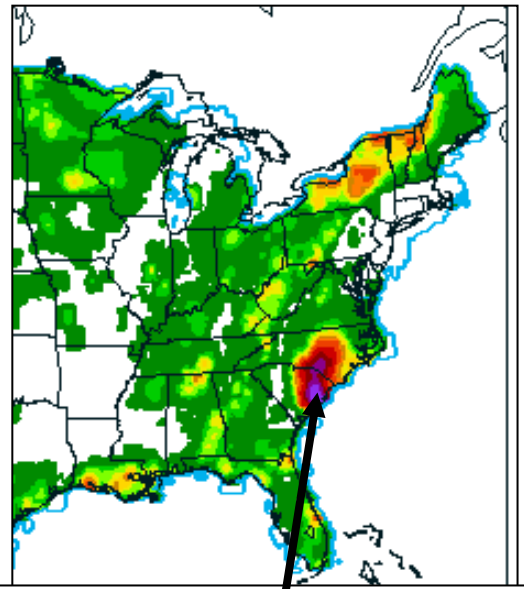


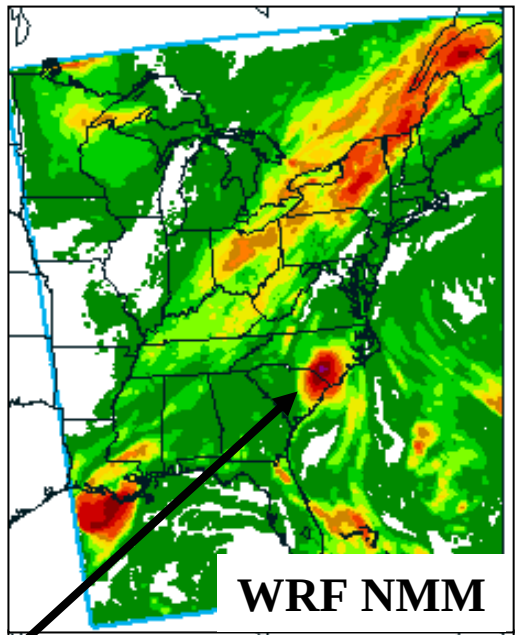
Tropical Storm Francis:

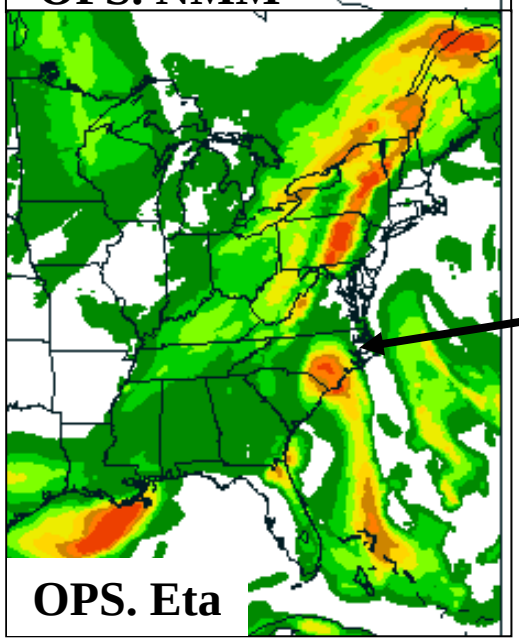
Subjective Comparison

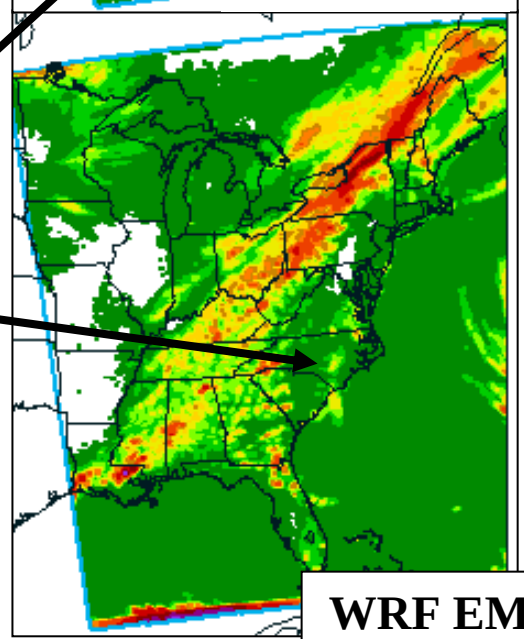
24 Hour Accumulated Precipitation Valid 12Z 30 August, 2004, 42 Hour Forecast







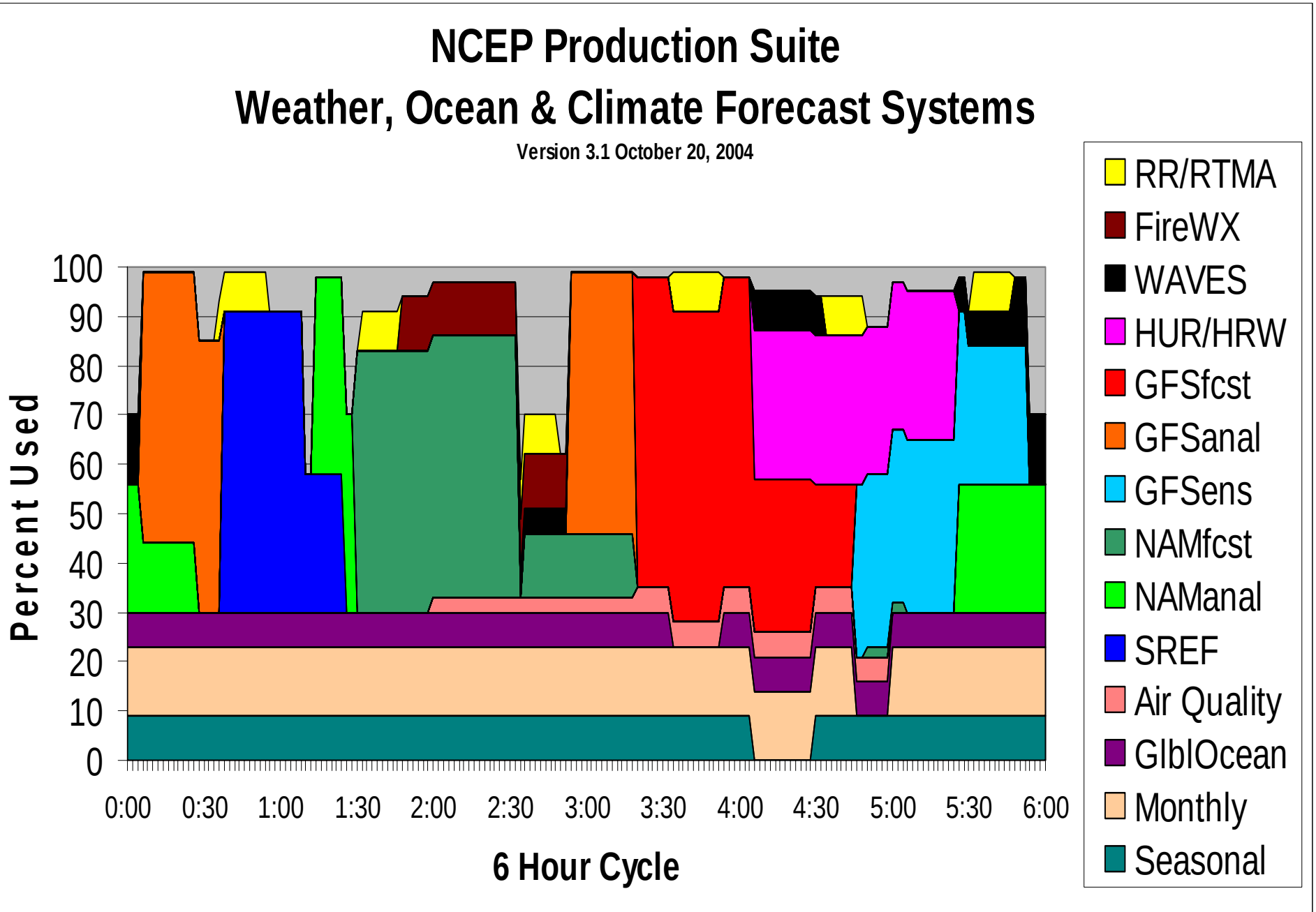




Tropical Storm Gaston:

Subjective Comparison

Production Suite Made Up of Four Uniform Cycles per Day



North American Mesoscale WRF Plans

- Date of Eta replacement moved to March 2006
- Increase horizontal resolution from 12 km to 10 km
- Move model top from 25 mb to 2 mb (will help assimilation of satellite radiances)
- Eta 3D-VAR to be replaced by Gridpoint Statistical Interpolation (GSI)
- Assimilate mesonets, GPS IPW, boundary layer Profilers and (hopefully) Level II radial velocity

North American Mesoscale WRF Plans

- Minimize transition tasks - produce complete set of existing NAM look-alike output
- Extend BUFR sounding files to 84 hour with only slight (5 minute?) delay compared to current 60 hr BUFR file delivery
- Replace non-WRF NMM applications in Fire Weather / IMET Support and On-Call Emergency Response nested runs
- Maintain ability to quickly run a replacement 12 km Eta (run 12 km EDAS in background mode) in the event of an ‘infrastructure related’ failure for which a quick solution is unlikely

PLANS FOR THE FUTURE

For each of the possible upgrades/phases of the CCS contract with IBM

North American Meso Guidance System

Prediction Model (DGEX included)	Analysis and Data Assimilation	Computer Phase
12 km 60 level Meso Eta earlier delivery	12 km 3DVAR improved use of surface observations	Current Phase I
10 km 60 level WRF 2mb top, nonhydrostatic dynamics, imp. physics called more frequently	10 km GSI analysis, 2 mb top, cloud analysis, AIRS, GOES imagery	Phase II
8 km 70 level WRF fire weather IMET support incorporated, improved physics	8 km, 88D reflectivity, hydrometeor analysis, cloud and aerosol absorption and scattering in radiative transfer	Phase III
6.5 km 85 level WRF .2 mb top, OCER incorporated, improved physics, ozone + aerosols	6.5 km .2 mb top, advanced 4DDA, NPP, NPOESS, IASI + air quality	Phase IV

HiResWindow and Fire Wx/IMET

HiResWindow	Fire Weather IMET Support	Computer Phase
8 km WRF 6 member ensemble	8 km nested WRF-NMM	Current Phase I
7 km WRF 8 member ensemble	6.5 km nested WRF with improved physics	Phase II
6 km WRF 10 member ensemble	5.5 km included in NAM-WRF run	Phase III
5 km WRF 12 member ensemble	4.5 km included in NAM-WRF run	Phase IV

Hurricane, Rapid Refresh & Air Quality

Hurricane Model	Rapid Refresh (RR)	Air Quality	Computer Phase
2 nests 18 + 55 km L 42, coupled Atl & Pac with GFS physics	20 km 50 level RUC 3DVAR	12 km Sfc ozone, New England	Current Phase I
2 nests 12 + 40 km L64 Hurricane-WRF & new ocean (HYCOM)	13 km 60 level RUC improved physics	10 km Sfc ozone National	Phase II
2 nests 8 + 30 km L64 Hurricane-WRF with 4DDA	10 km 60 level Rapid Refresh-WRF	8 km Sfc ozone, particulates	Phase III
2 nests 5 + 20 km L100 Hurricane-WRF with imp. physics & enhanced ocean model	8 km 70 level RR-WRF improved physics	6.5 km Sfc ozone, particulates	Phase IV

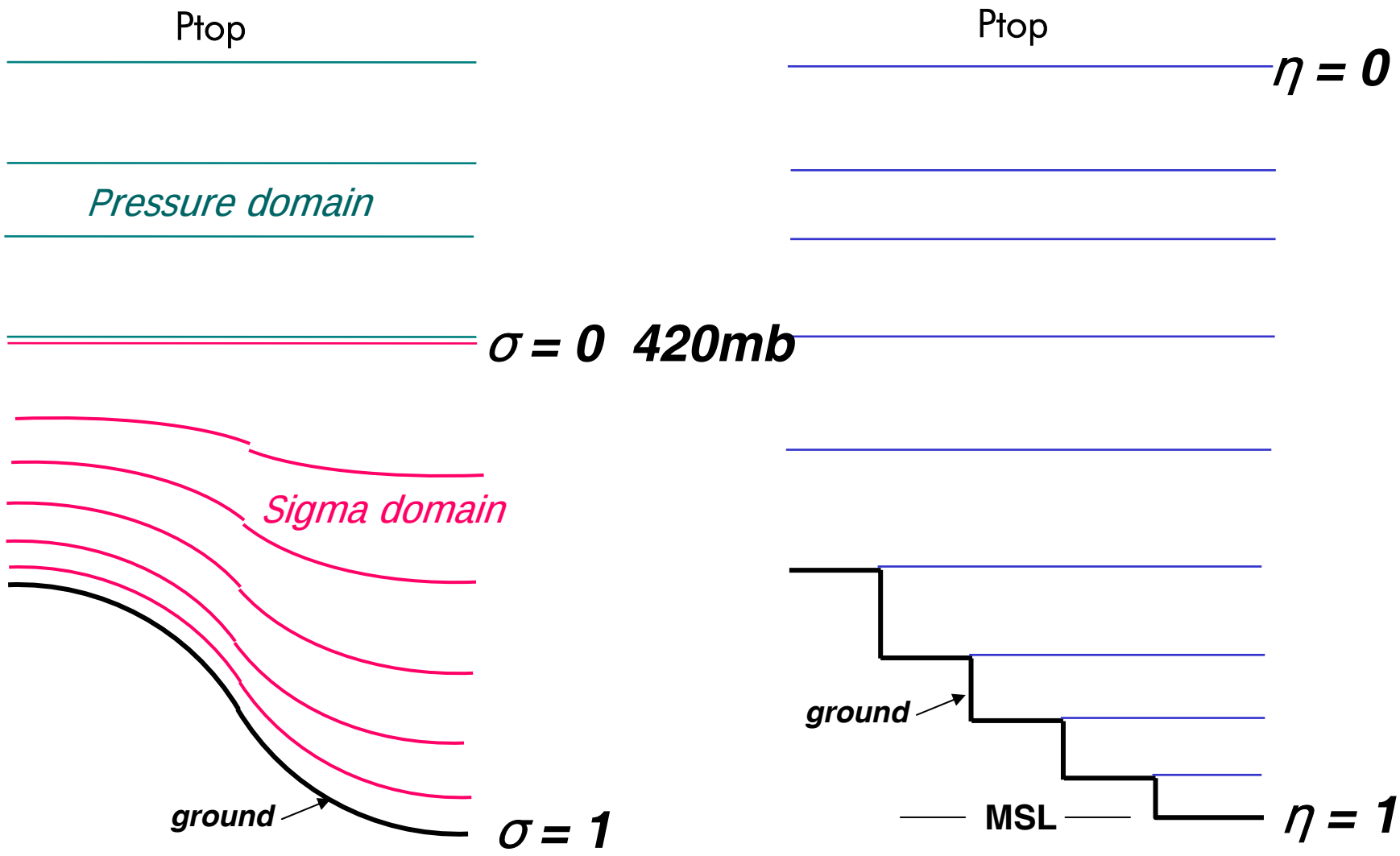
Nonhydrostatic Mesoscale Model (NMM)

- 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
Terrain	Unsmoothed with Silhouette treatment lateral boundary set to sea-level	Unsmoothed Grid-cell mean everywhere

Hybrid versus Step (Eta) Coordinates



Nonhydrostatic Mesoscale Model

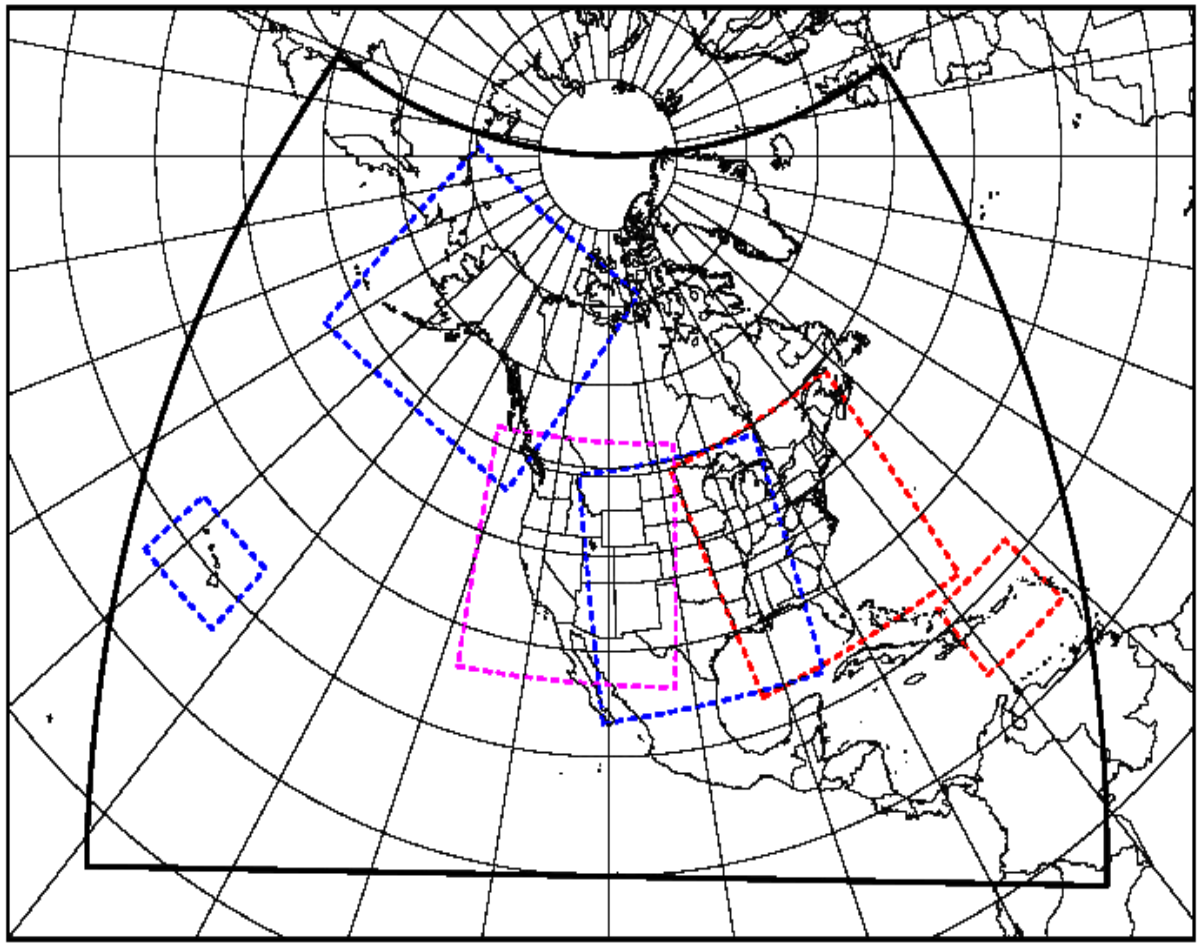
Physics Features Comparison With Meso Eta

Physics Feature	Meso Eta Model	Nonhydrostatic Meso Model
Turbulent mixing	Mellor-Yamada Level 2.5 dry	Mellor-Yamada Level 2.5 including moist processes
Surface exchange	…+ Paulson functions	…+ Holtslag and de Bruin functions
Land-sfc	NOAH LSM	NOAH LSM
Gridscale	Ferrier	Ferrier
Convective	B-M-J	B-M-J’ (some retuning)
Radiation	GFDL	GFDL’ (some retuning)

HiResWindow Fixed-Domain Nested Runs

21 September Became WRF Runs of Two Control Configurations

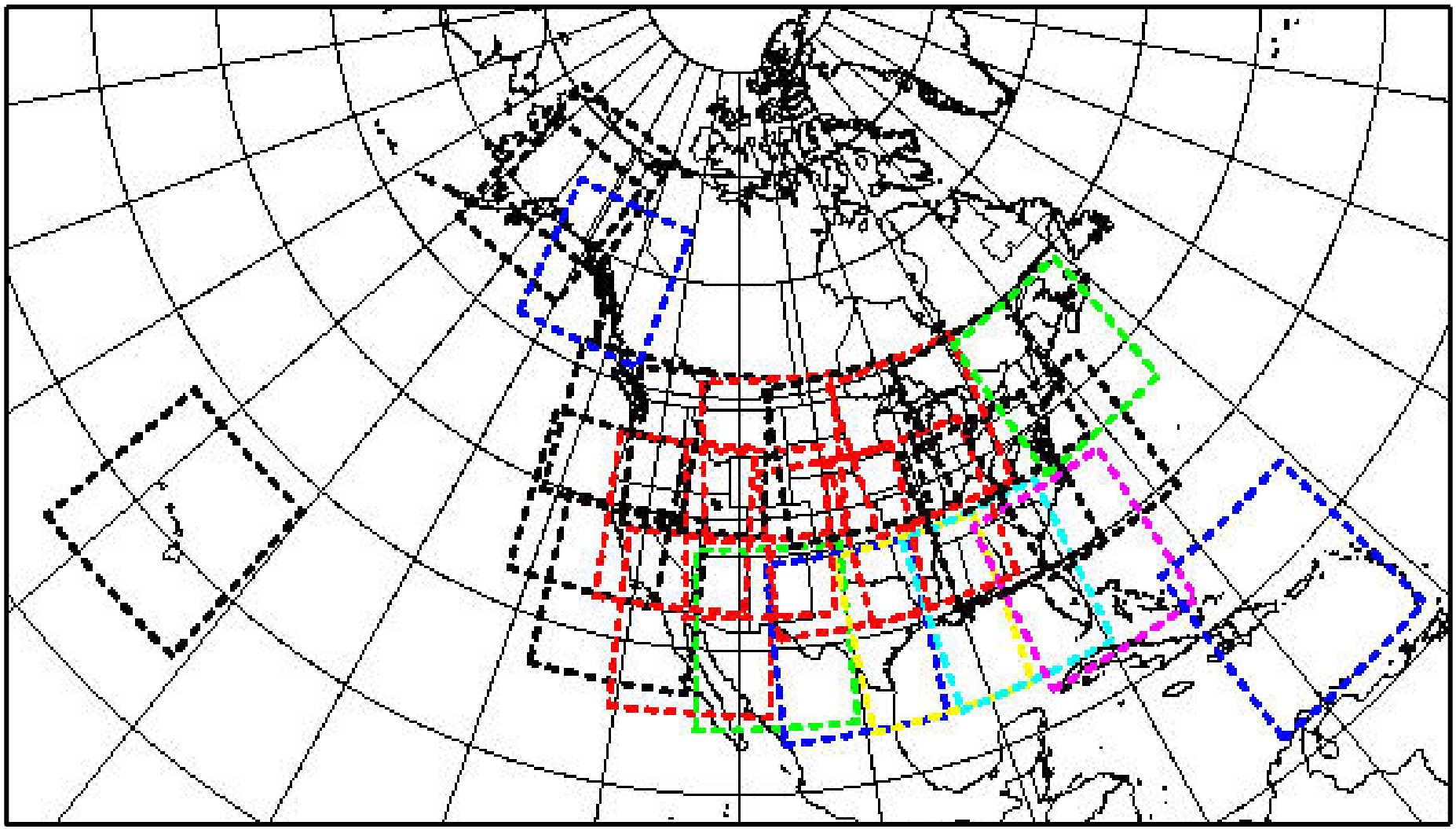
- Routine runs made at the same time every day
- 00Z : Alaska-8 & Hawaii-8
- 06Z : Western-8 & Puerto Rico-8
- 12Z : Central-8 & Hawaii-8
- 18Z : Eastern-8 & Puerto Rico-8
- Everyone gets a daily high resolution run when <2 hurricane runs need to be made



http://www.emc.ncep.noaa.gov/mmb/mmbpll/nestpage/

Alaska-8 domain is smaller than depicted

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

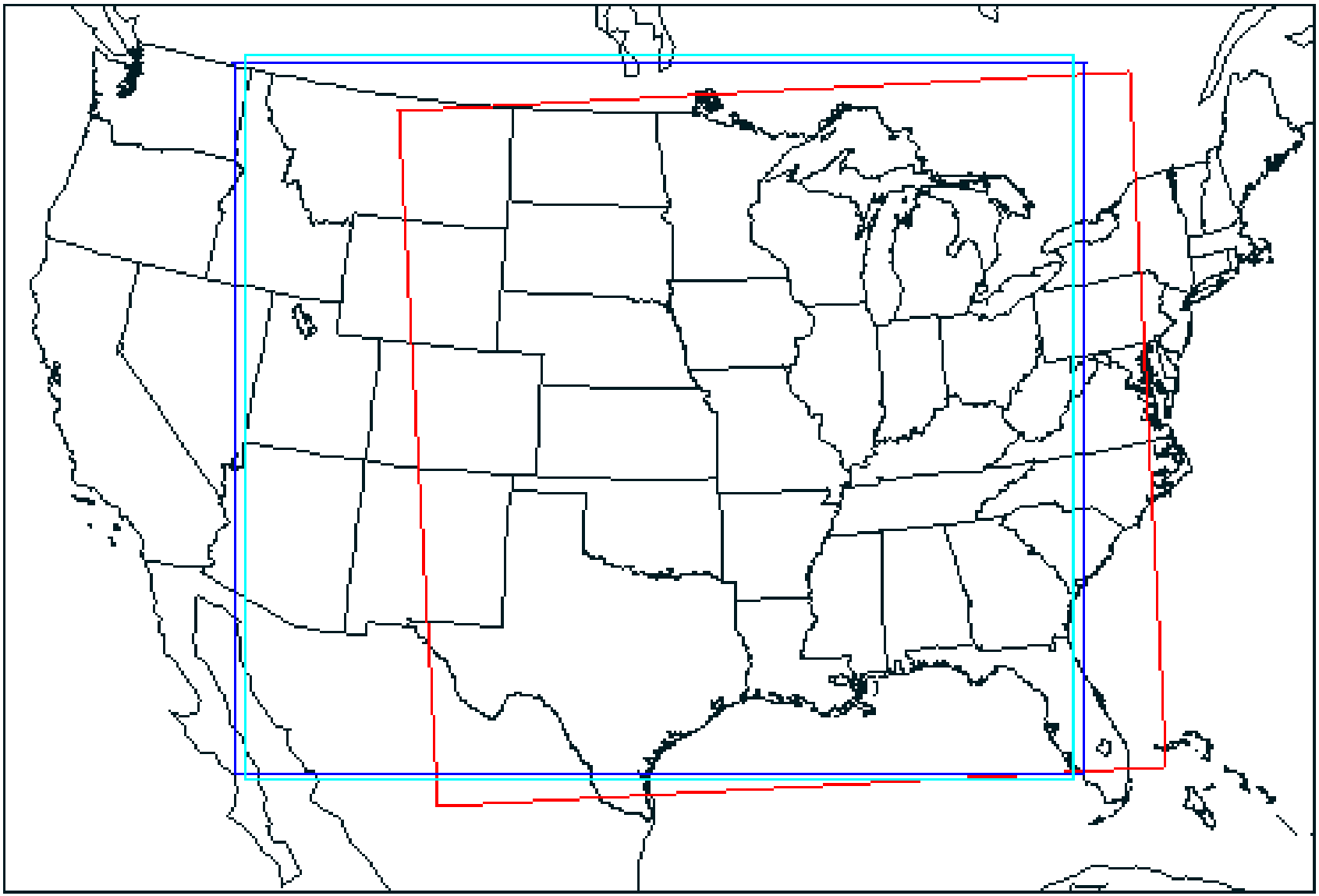


Special WRF-NMM Runs for SPC/NSSL Spring Program

- Beginning in April, EMC ran:
  - 4.5 km version of its WRF-NMM
  - Without any calls to parameterized convection
  - Initialized off 12 km Eta (at 40 km resolution)
  - Daily runs to 30 hours from 00z
  - Central/Eastern US domain
- SPC requested that this run be continued as long as possible

Domains of Integration for Spring Program

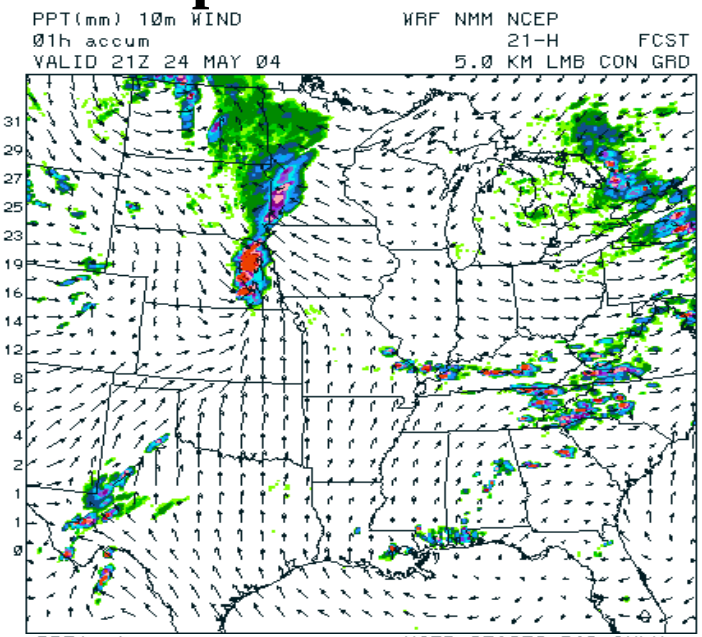
NCEP NMM (red), NCAR (blue), CAPS (cyan)

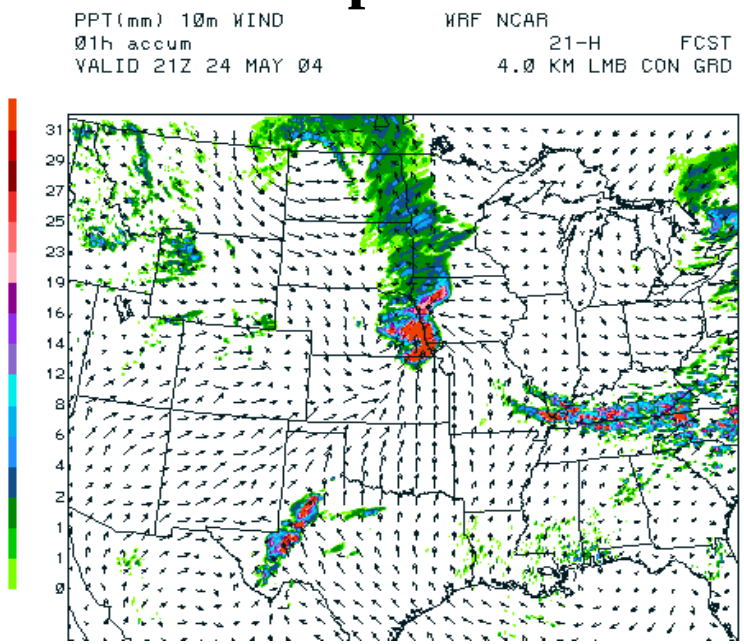


Spring Program 21 hr Forecast Example

http://www.nssl.noaa.gov/etakf/compare/wrf/

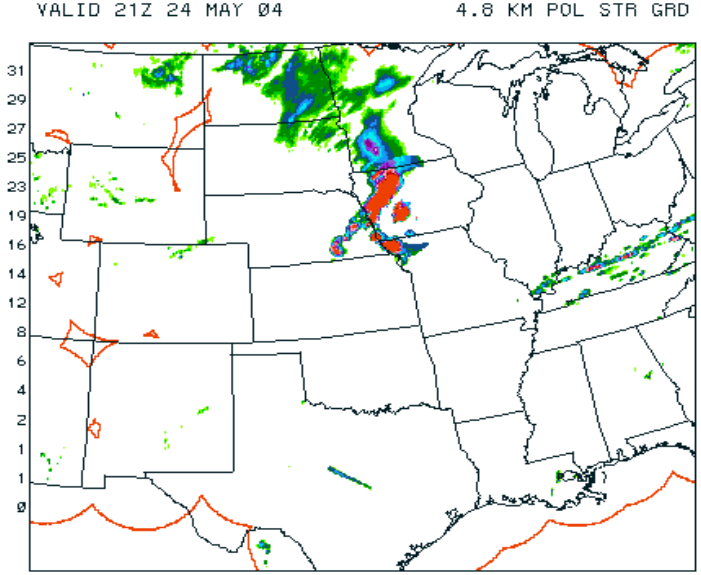
N M M

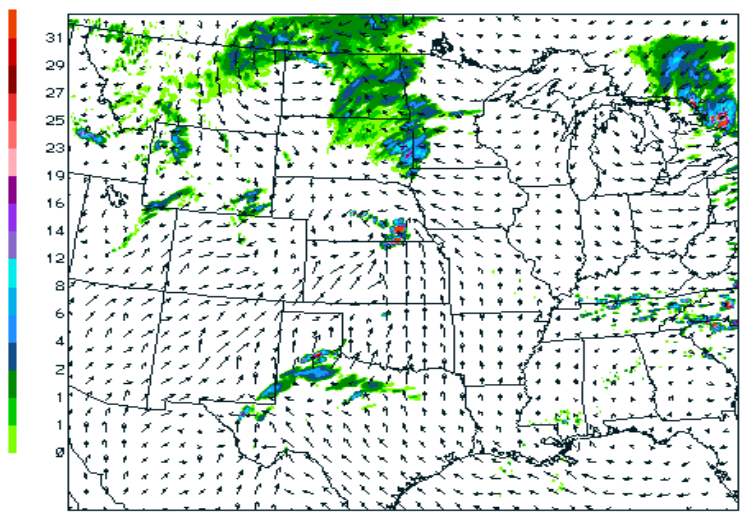




A R W

O B S





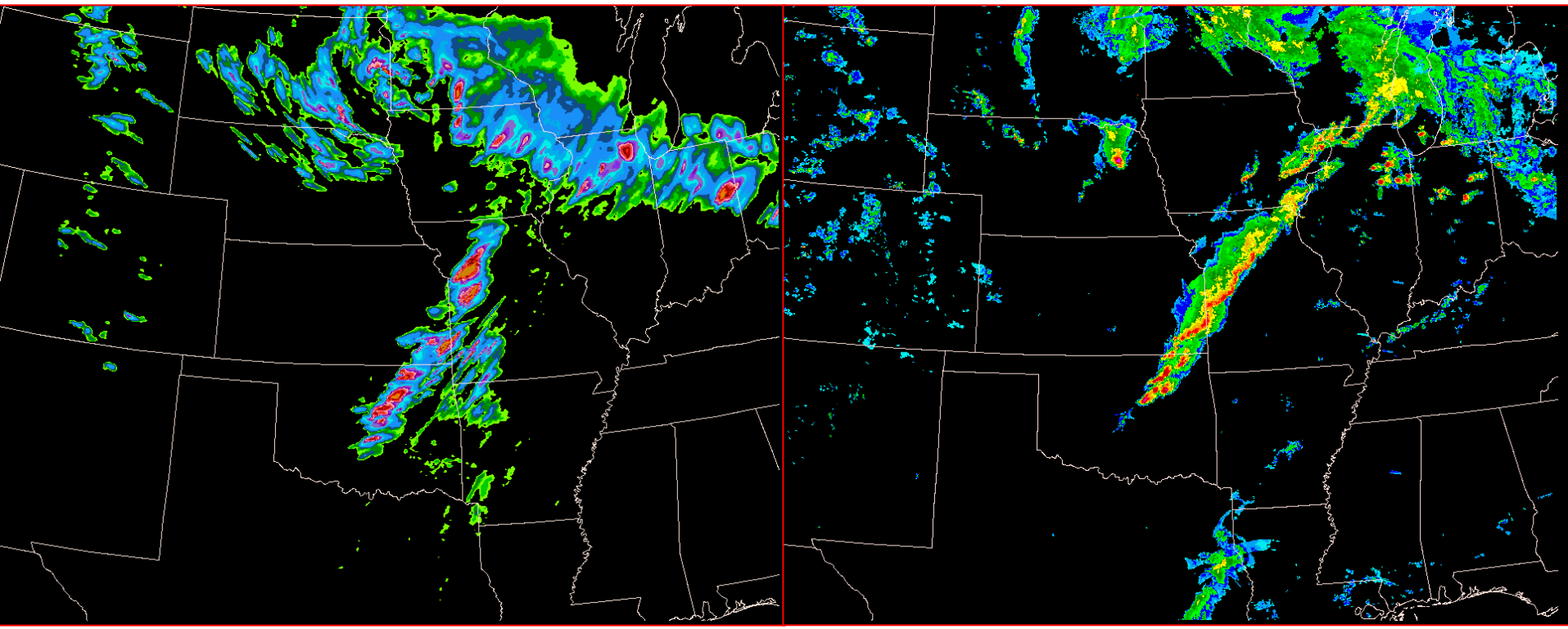
C A P S

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

Web Site Displaying 4.5 km WRF-NMM

http://www.emc.ncep.noaa.gov/mmb/mmbpll/cent4km/

1 h Precipitation totals (in.)

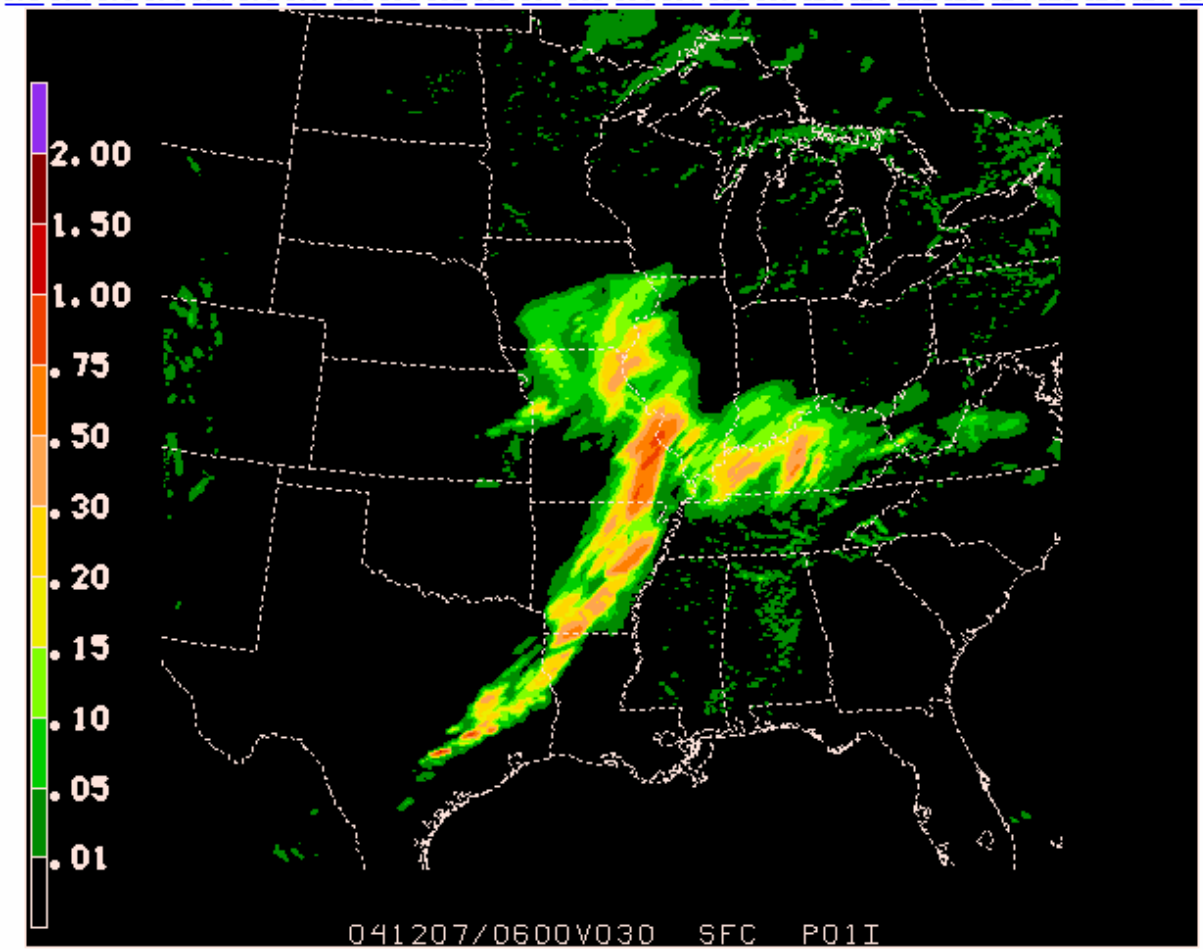
01h	02h	03h	04h
01h	06h	07h	08h
09h	10h	11h	12h
13h	14h	15h	16h
17h	18h	19h	20h
21h	22h	23h	24h
25h	26h	27h	28h
29h	30h	0-30h	NMM WRF Loop

3 h Precipitation totals (in.)

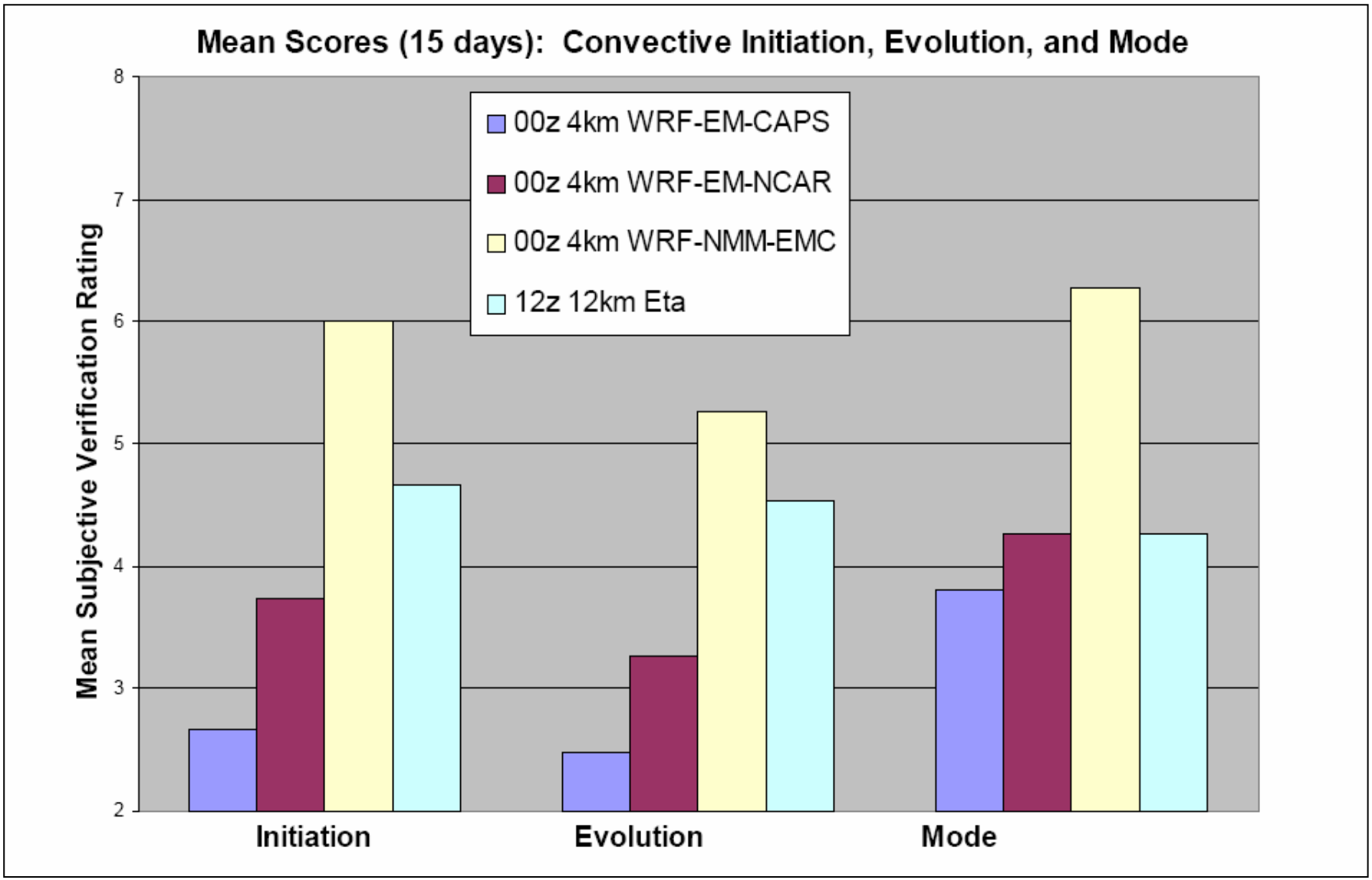
03h	06h	09h	12h
15h	18h	21h	24h
27h	30h	0-30h	NMM WRF Loop

☐ Click to animate

f01 f02 f03 f04 f05 f06 f07 f08 f09 f10 f11 f12 f13 f14 f15 f16 f17 f18 f19 f20 f21 f22 f23 f24 f25 f26 f27 f28 f29 f30



4km WRF Runs vs 12km Eta



HiResWindow WRF Runs vs Eta