



NCEP Air Quality Forecast System Upgrades for the Summer 2005

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**NOAA/NCEP
Environmental Modeling Center*

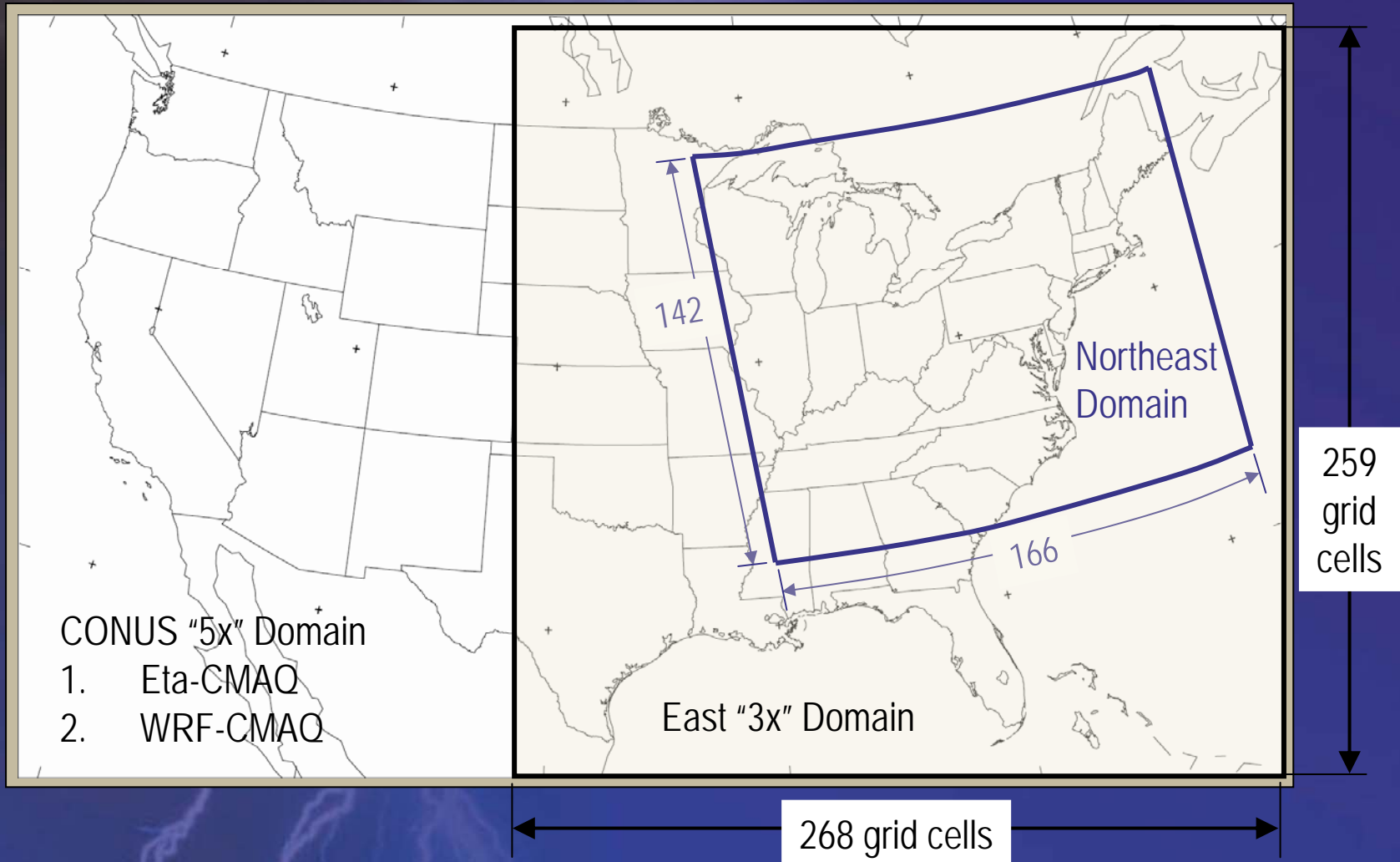
Rohit Mathur, Daiwen Kang, Shoicai Yu and Hsinn-Mu Lin
NOAA/ARL and EPA/ASMD

Paula Davidson, Nelson Seaman

NWS/OST



Forecast Domains (2005)





2005 NOAA AQ Forecasts



Air Quality Forecasting

Expanded Domain Configuration 3X

- **Eastern US** : 48 hour forecasts of ozone (O_3) : 06 and 12 UTC runs

- ✓ **3x expanded domain** (East of Rockies, 268x259x22) run in parallel

- ✓ Same Configuration as NE US Run except:

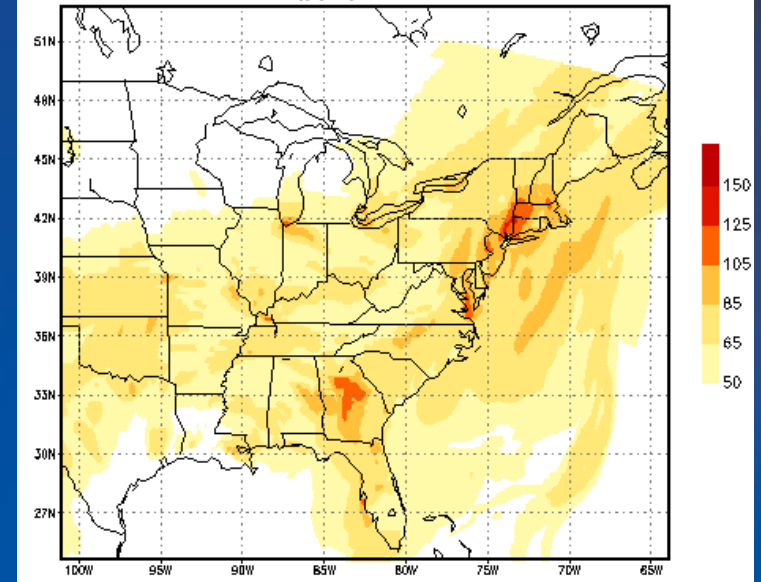
- ✓ Convective Cloud Mixing from cloud top = 0

- ✓ 7/26/05: GFS ozone limited to top BC

- ✓ 12 z Available by 16:10 UTC

- ✓ **Made Operational On August 31, 2005**

24h 1h max sfc O3 (ppb) 24H VALID 12Z 23 JUL 2004



3X Physics Coupling



Current Capability	Met Model (Eta, WRF/NMM)	AQ Model (CMAQ)
Core/Dynamics	Rotated Arakawa E grid	Arakawa C Grid
Clouds	Full Ferrier Cloud Microphysics	Eta cloud water for aqueous chemistry
Convective mixing	Betts-Miller Janjic	<i>Entrainment from top turned off</i>
Radiation	NAM Lacis-Hansen	<i>CMAQ J Tables for photolysis</i>
PBL	Mellor-Yamada 2 nd order TKE	NAM PBL hgt for Pleim-Xiu 1 st order K
Land Surface	NOAH common LSM w 1 km land-use	NAM canopy conductance terms for Pleim-Xiu LSM



Analysis of Production Resources



Job	Production		Proposed	
	Nodes/Tasks	Runtime (minutes)	Nodes/Tasks	Runtime
aqm_extract_gfs	2/8	19	1/8	16
aqm_assim_gfs	1/1	12	1/1	13
aqm_nam_prep	1/1	50	1/1	52
aqm_premaq	1/1	9	1/1	20
aqm_forecast	5/33	17	9/64	35
aqm_post	1/1	5	1/1	5

Current Air Quality Forecasting *Research Aerosol Domain Configuration*

- **Eastern US** : 24 hour forecasts of O_3 & Aerosols: 12 UTC run only

- ✓ Same system as operational except

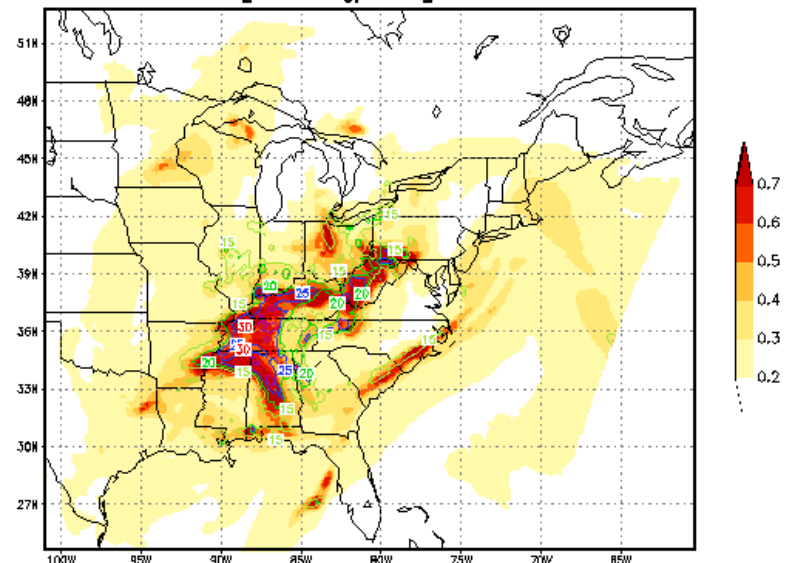
- ✓ **3x expanded domain** (East of Rockies) run

- ✓ **24 hr cycling**

- ✓ **33 processors on Development Machine**
(less reliability, 8x5)

- ✓ Available by 21 UTC

AOT & PM2.5 contours [micro-g/m³] 12H VALID 00Z 09 JUL2005



Air Quality Forecasting User Access

✓ Eastern U.S. Domain :

✓ **Public:** NWS/NDGD and TOC ftp server

✓ *Surface ozone predictions*

✓ **State Forecasters:** NCEP/HPC web site

✓ *Sfc O3 & met plots*

✓ *Daily (2pm) conference calls*

✓ *HPC forecasters trained*

✓ Developmental Domain (CONUS):

✓ **Focus group:** NCEP/EMC & PSU web site

✓ *Expanded met plots (pbl hgt, sw rad, ventilation index....)*

✓ *Sfc & upper level O3 and precursor plots (NO_x, NO_y, CO, SO₂)*

✓ Research (Aerosols)

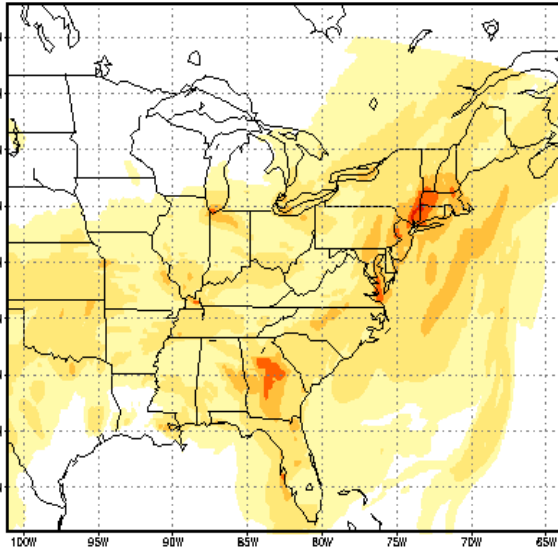
✓ *Sfc PM, AOT*



NCEP Graphical Products

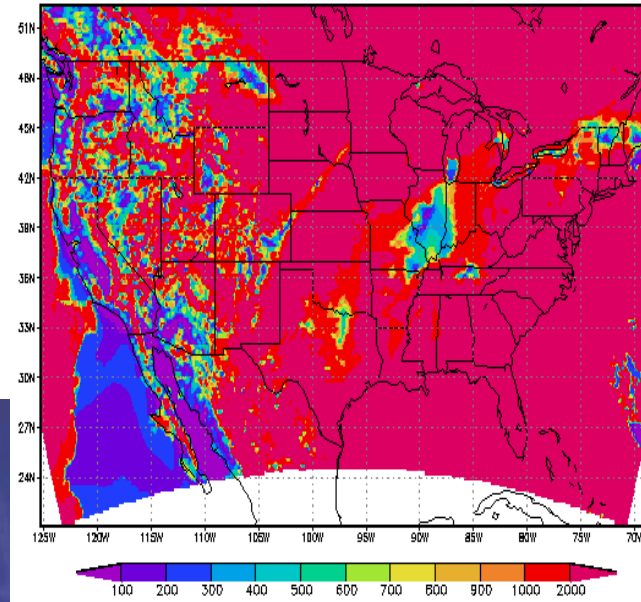


24h 1h max sfc O3 (ppb) 24H VALID 12Z 23 JUL 2004

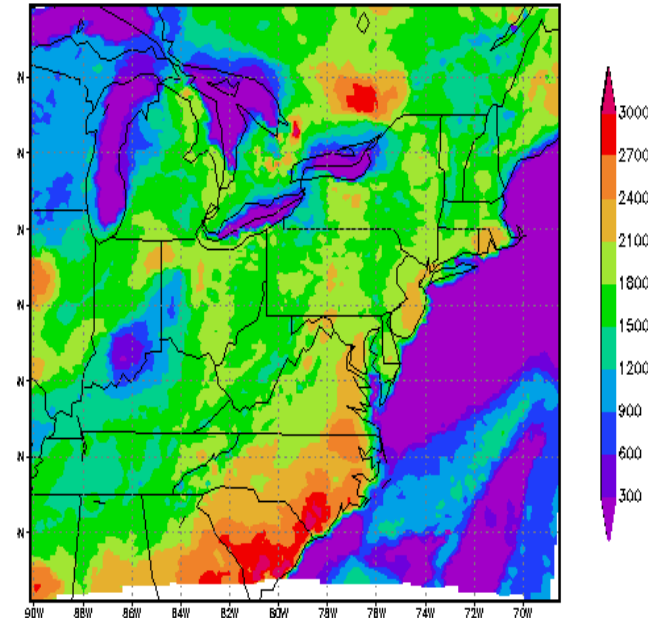


Predicted Sfc Ozone
(1, 8h, max)

V-index (m2/s) 09H VALID 15Z 06 SEP 2005



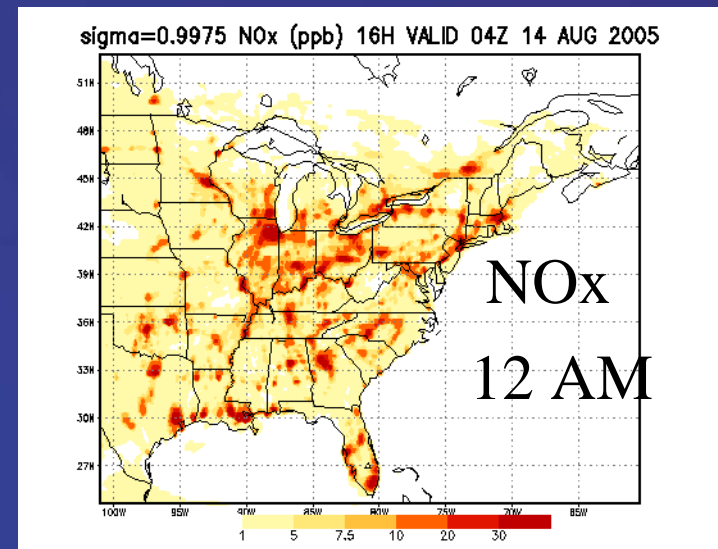
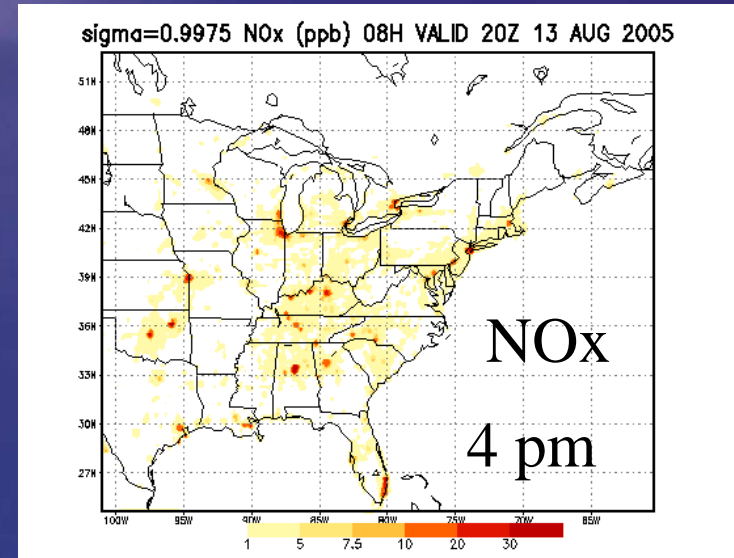
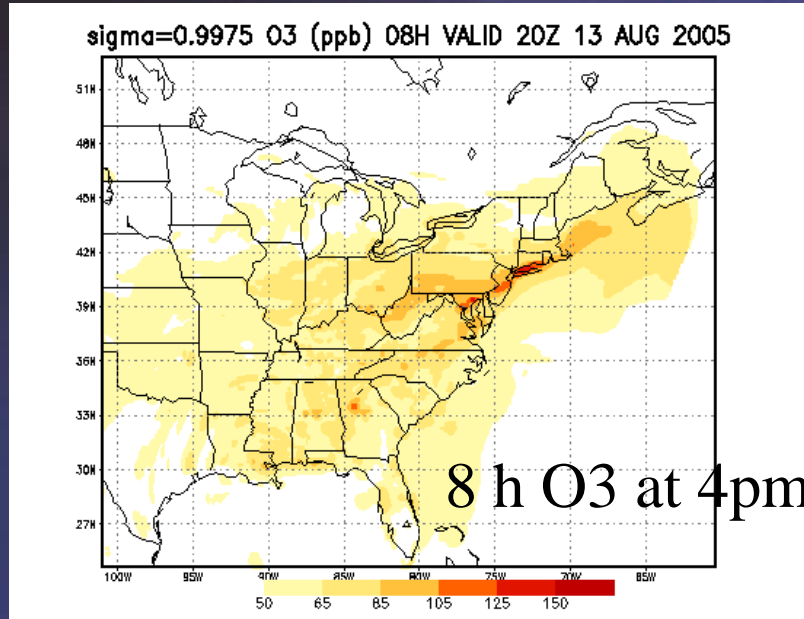
Eta Ventilation Index



Eta PBL hgt



NCEP Graphical Products



August 13, 2005

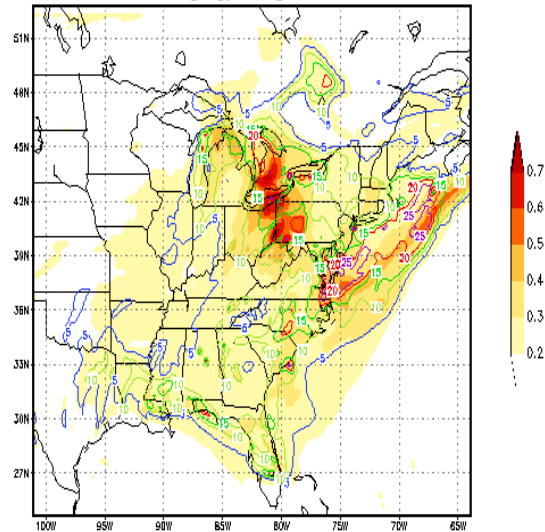


NCEP Graphical Products

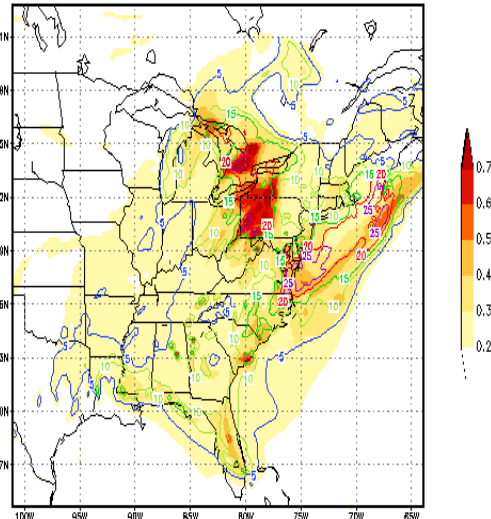
AOT / PM



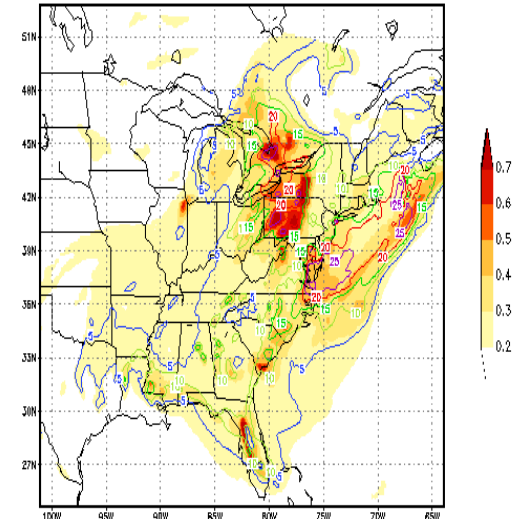
AOT and PM2.5 contours [mg/m³] 06H VALID 18Z 21 JUL2004



AOT and PM2.5 contours [mg/m³] 09H VALID 21Z 21 JUL2004



AOT and PM2.5 contours [mg/m³] 12H VALID 00Z 22 JUL2004





RETROSPECTIVE TESTING

Runs: P. Lee, M. Tsidulko

Analysis: R. Mathur, D. Kang, J. Pleim,...

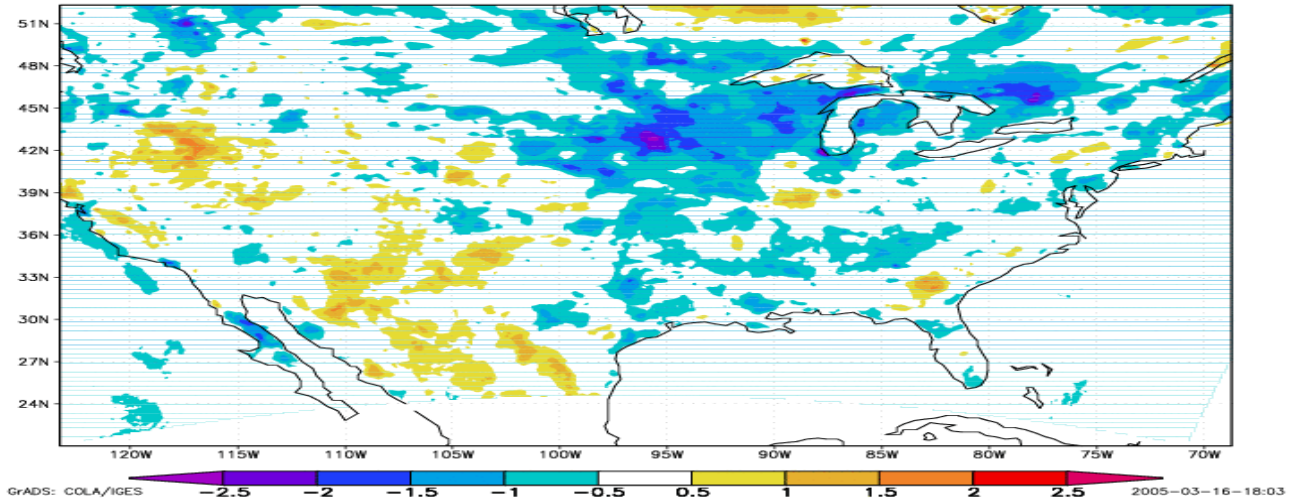


- 2004 Base: 2004 Operational run
- S0: Reflects changes due to Eta-X
- S1: S0 + photolysis attenuation based on Eta radiation fields
- S3: S0 + Mixing from above clouds turned-off
- S5: S1+S3



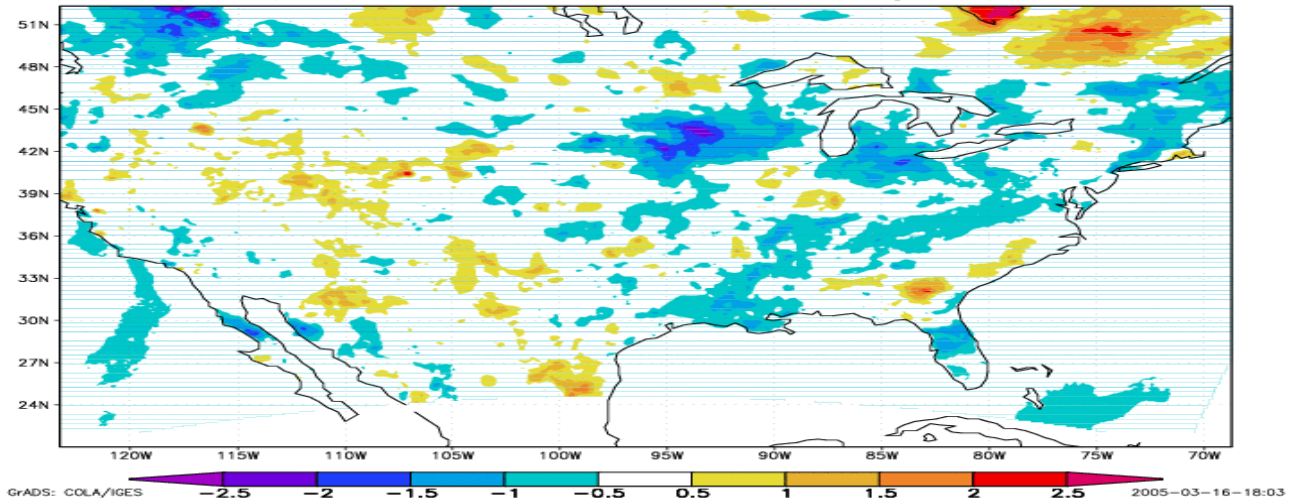
July 16-23 2004

Temp 2m diff (Eta-Etax) 16-23 Jul 12z+06h



Aug 4-11 2004

Temp 2m diff (Eta-Etax) 04-11 Aug 12z+06h



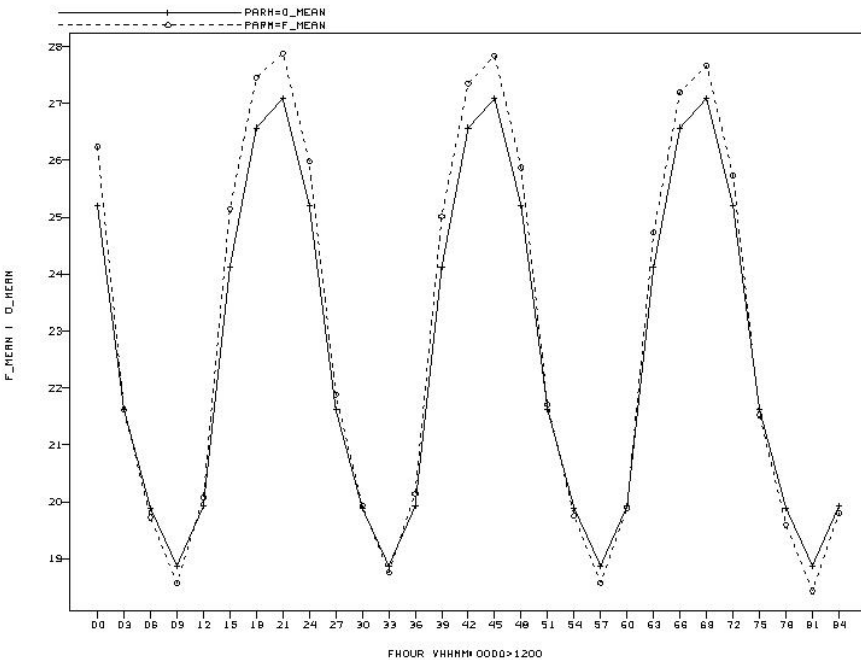


NAM Verification

June 2005

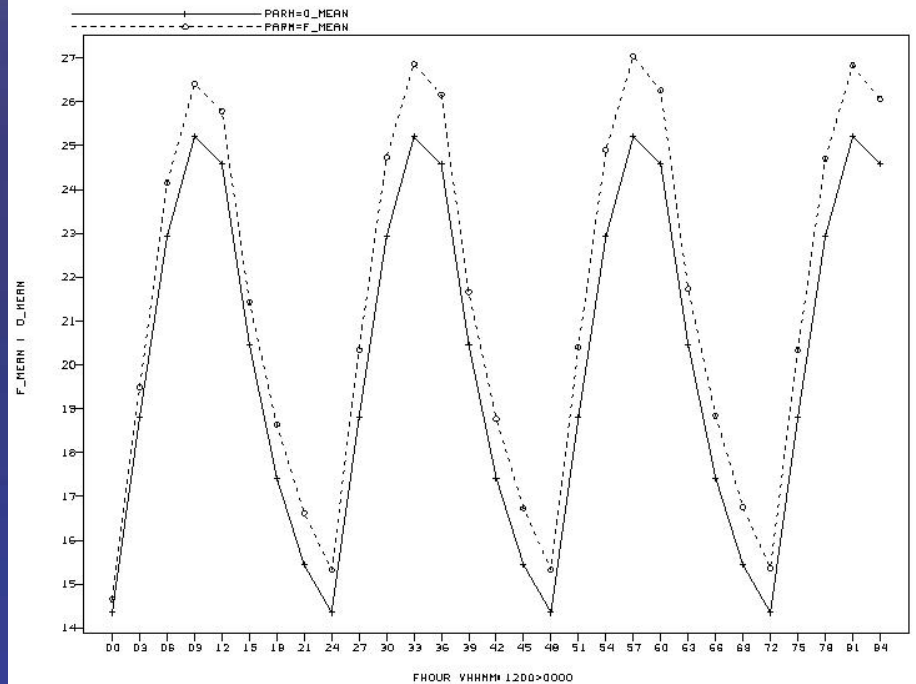


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2 m Temperature
EAST U.S.

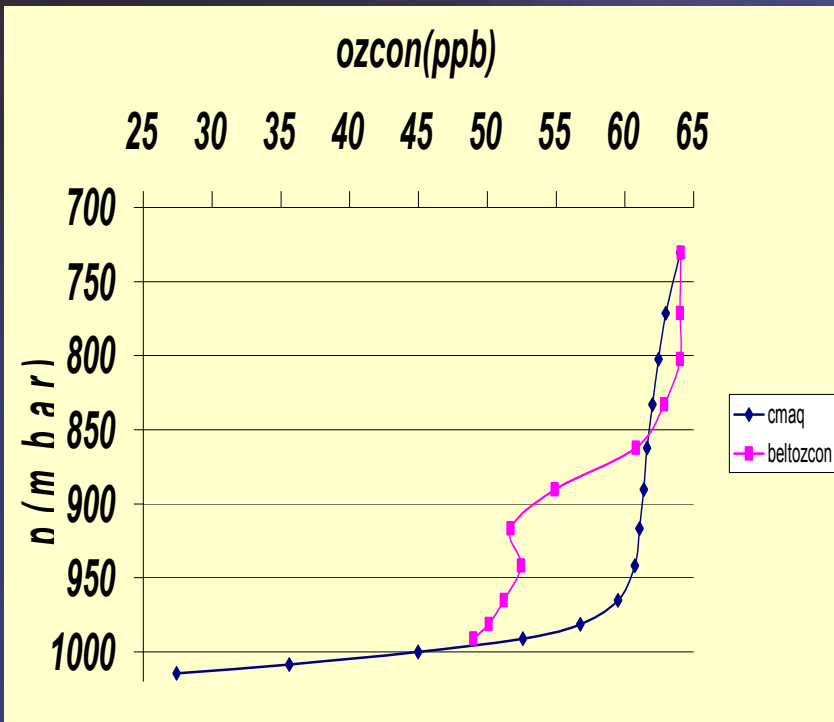
STAT=SL1L2 PARRM=T MODEL=NAH/216 V_RNL=ONLYSF V_R6N=6104/NPL+6104/NHT+6104/NHC+6104/ LEVEL=SFC VYMDH=200506010000-200507010000



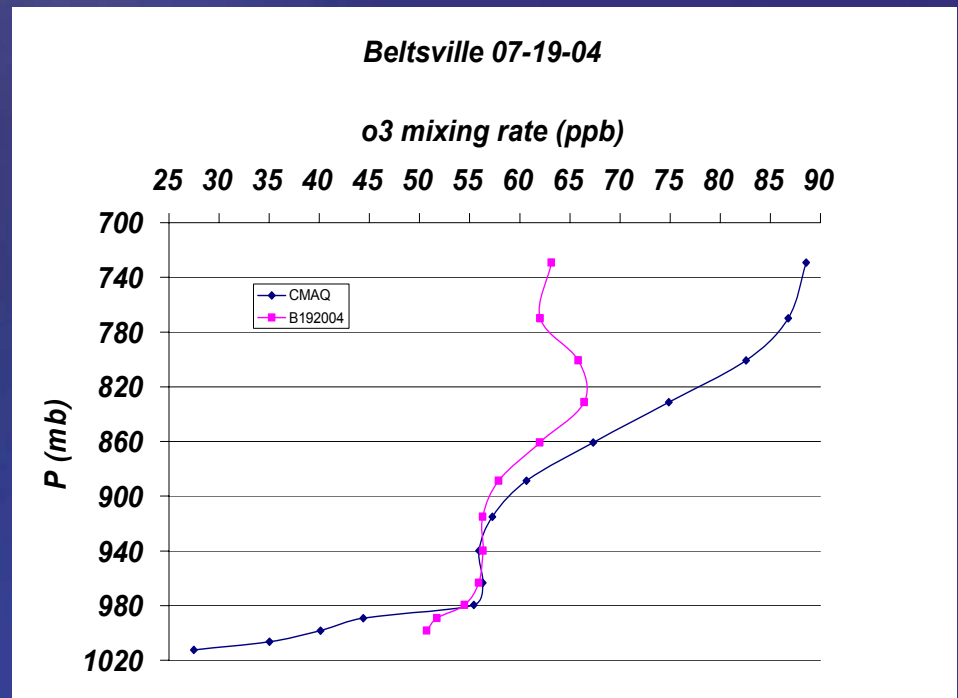
2 m Temperature
West U.S.



Ozonesonde Verification Summer 2004



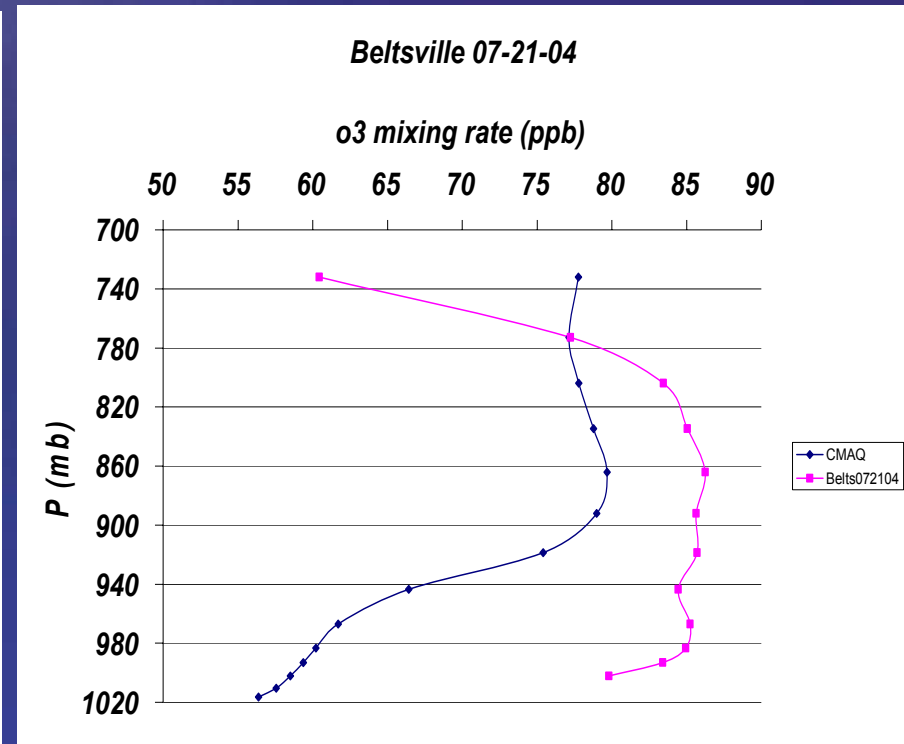
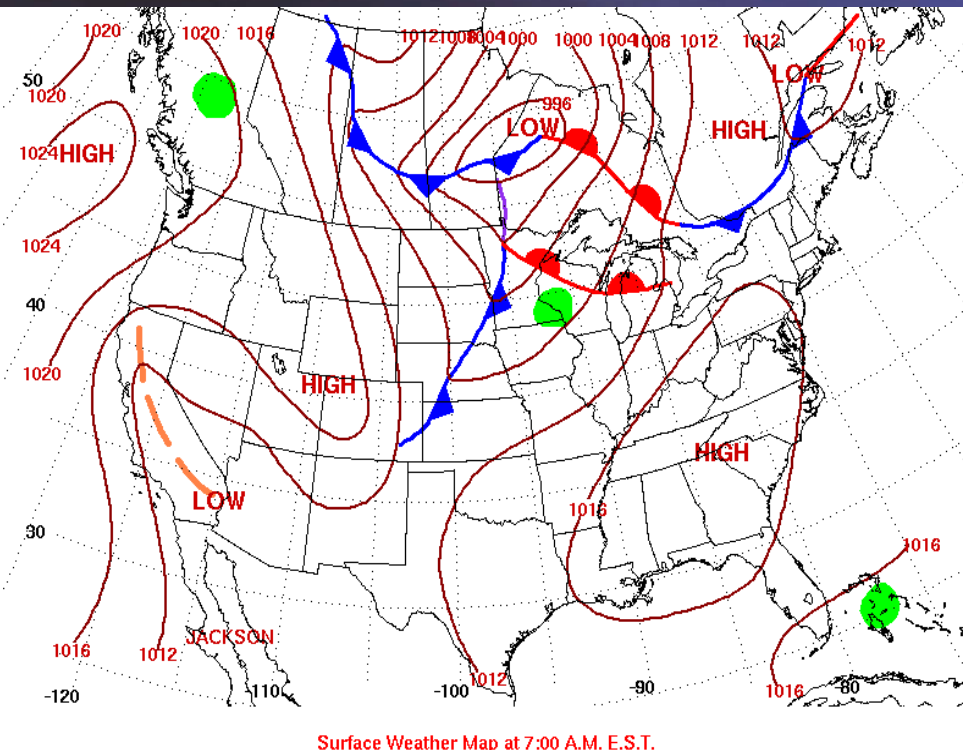
July 8, 2004



July 19, 2004



Ozonesonde Verification Summer 2004



July 21, 2004



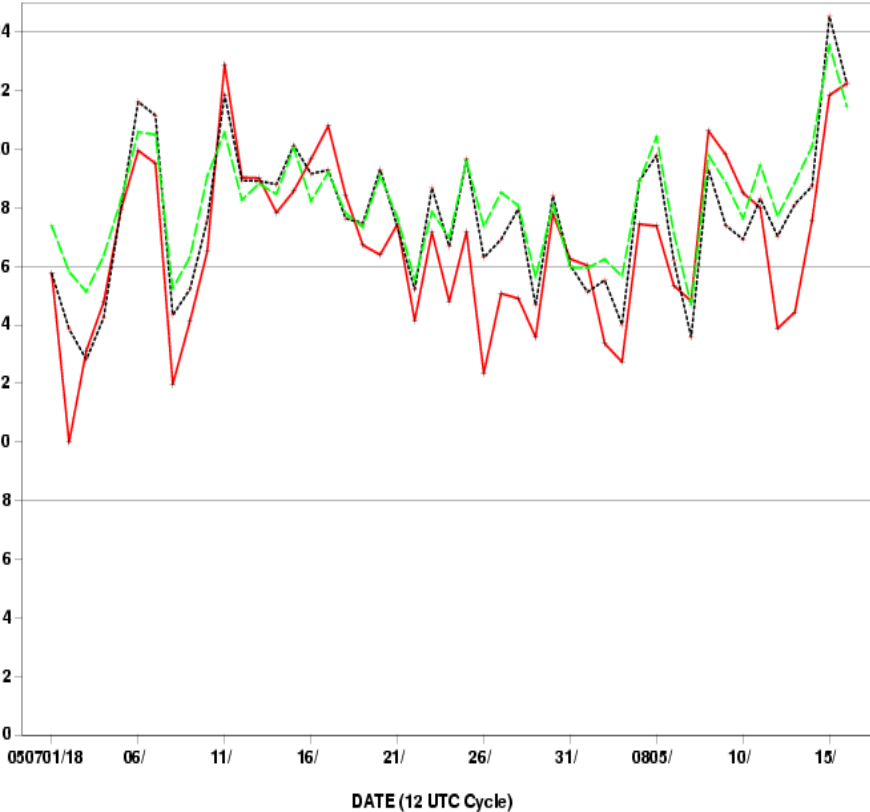
Summer 2005 Performance



1x - 3x over NE domain - 3x Full domain

rmse CMAQ Ozone Error (ppb) Averaged by day for Forecast hour: 36 Valid: 1800 GMT

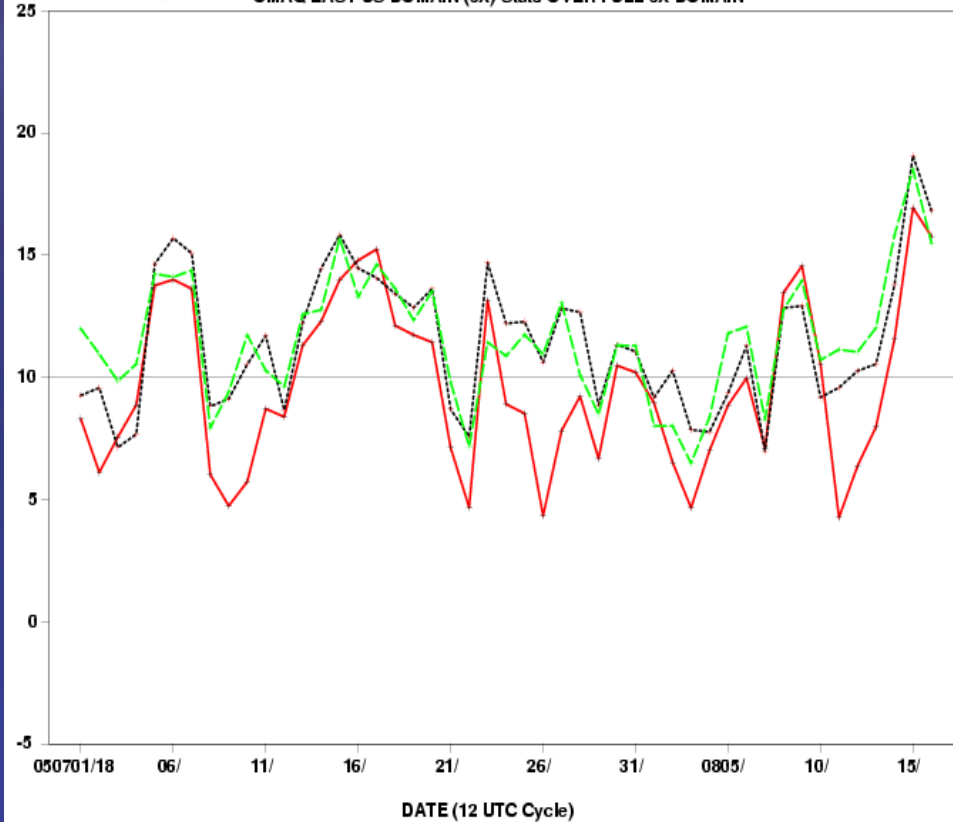
- CMAQ NE US DOMAIN (1X)
- - CMAQ EAST US DOMAIN (3X) Stats OVER NE US DOMAIN
- - CMAQ EAST US DOMAIN (3X) Stats OVER FULL 3X DOMAIN



36 h Forecast RMSE

bias CMAQ Ozone Error (ppb) Averaged by day for Forecast hour: 36 Valid: 1800 GMT

- CMAQ NE US DOMAIN (1X)
- - CMAQ EAST US DOMAIN (3X) Stats OVER NE US DOMAIN
- - CMAQ EAST US DOMAIN (3X) Stats OVER FULL 3X DOMAIN



36 h Forecast Bias

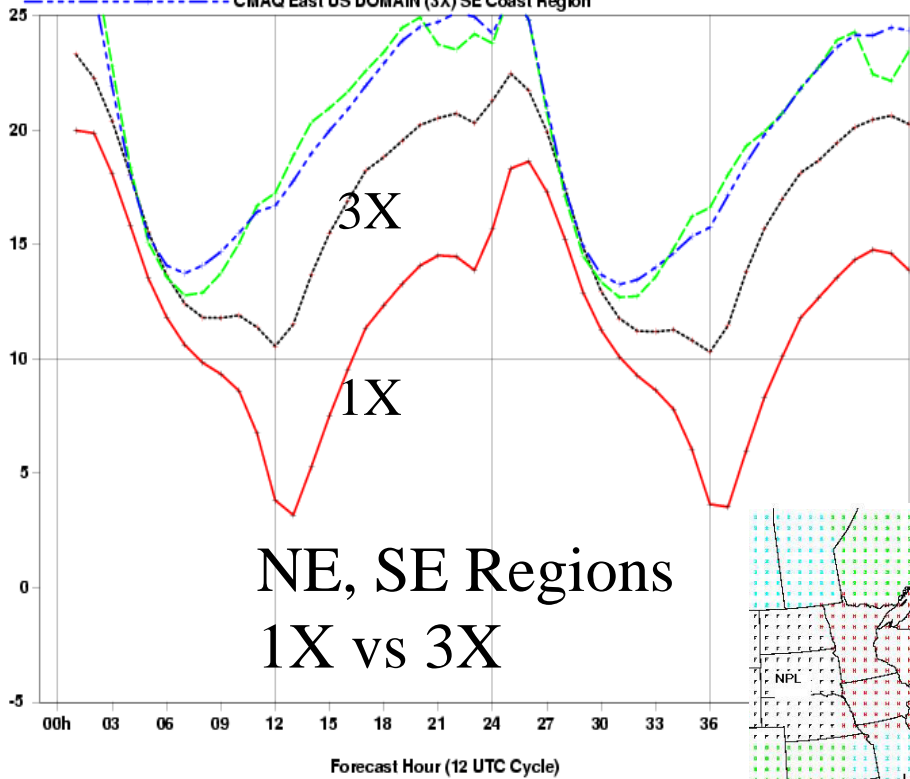


Summer 2005 Performance

Sub-Region Bias

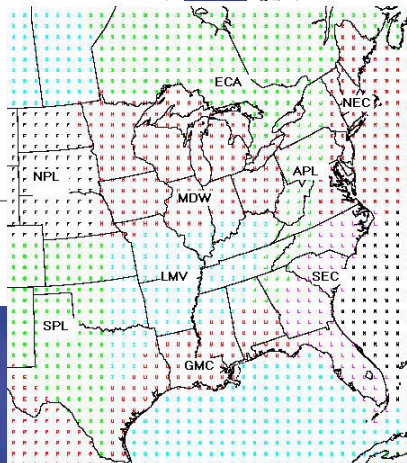
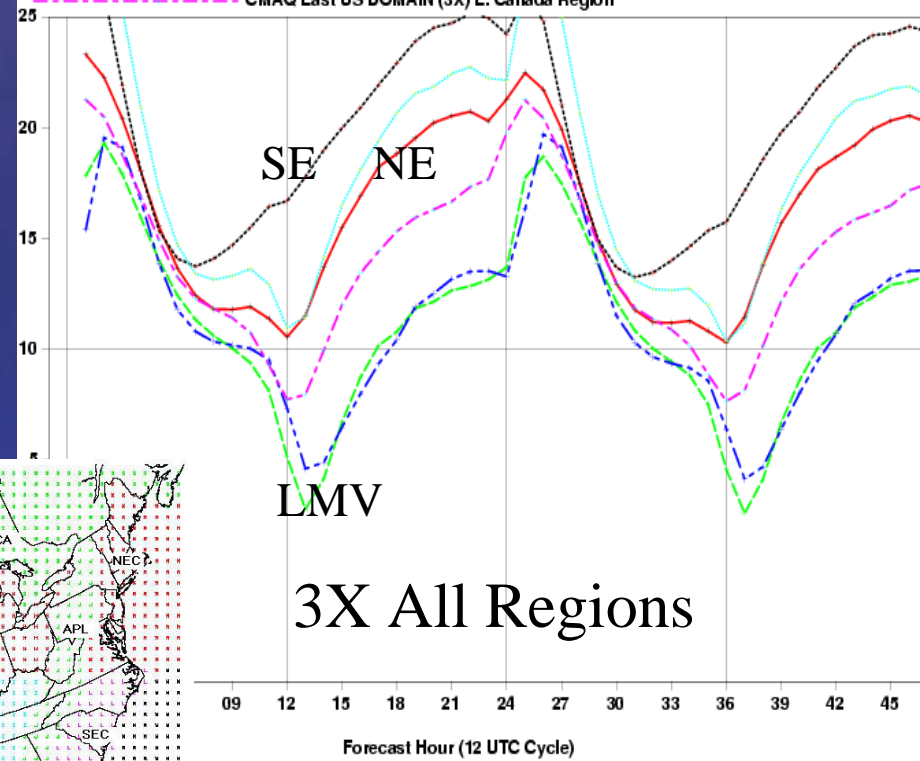
bias CMAQ Ozone Error(ppb)averaged by forecast hour for all fcsts thru 200509052359

- CMAQ NE US DOMAIN (1X) NE Coast Region
- - - CMAQ EAST US DOMAIN (3X) NE Coast Region
- . - CMAQ NE US DOMAIN (1X) SE Coast Region
- - - CMAQ East US DOMAIN (3X) SE Coast Region



bias CMAQ Ozone Error(ppb)averaged by forecast hour for all fcsts thru 200509052359

- CMAQ East US DOMAIN (3X) NE Coast Region
- - - CMAQ East US DOMAIN (3X) SE Coast Region
- . - CMAQ East US DOMAIN (3X) Mid West Region
- - - CMAQ East US DOMAIN (3X) Lower Miss. Valley Region
- . - CMAQ East US DOMAIN (3X) Appalachians Region
- - - CMAQ East US DOMAIN (3X) E. Canada Region

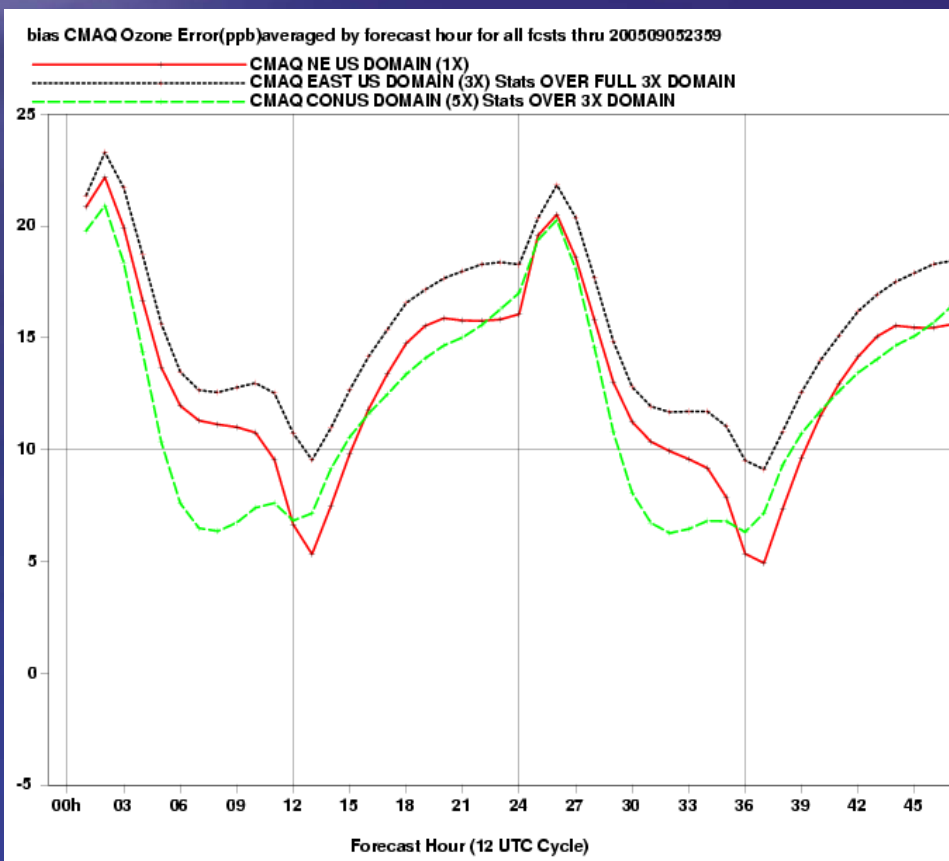
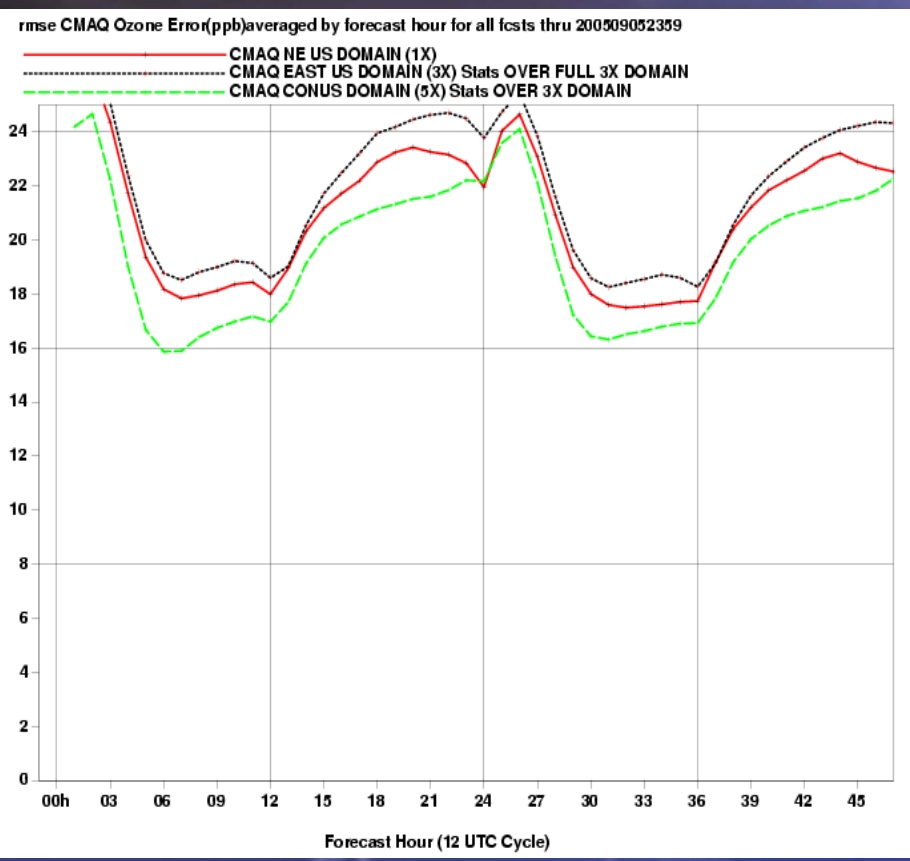




FVS O3 1h Aver. Aug 2005



1x - 3x - 5x over 3x domain



RMSE by Forecast Hour

BIAS

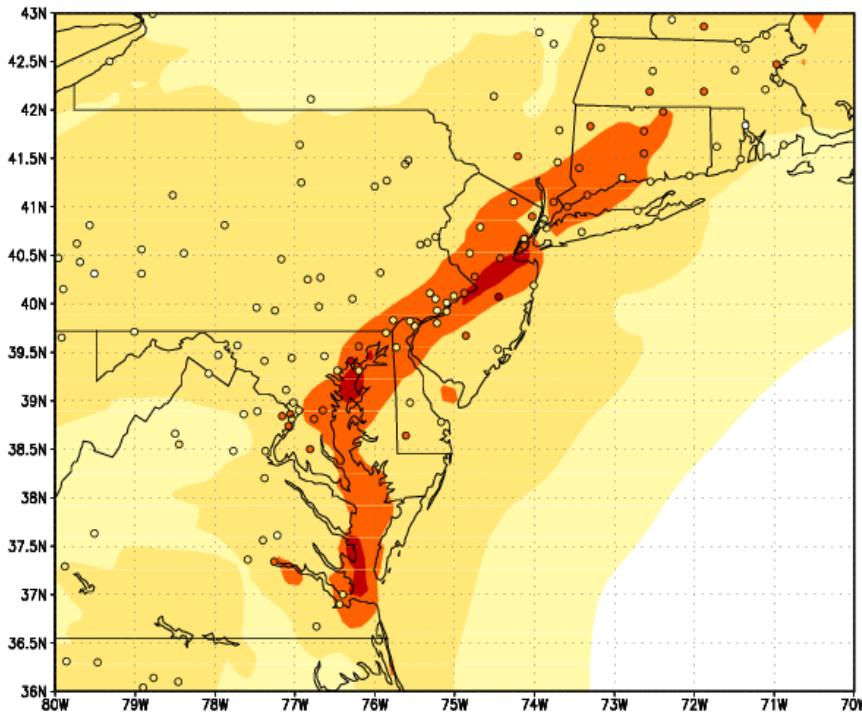


Objective Verification

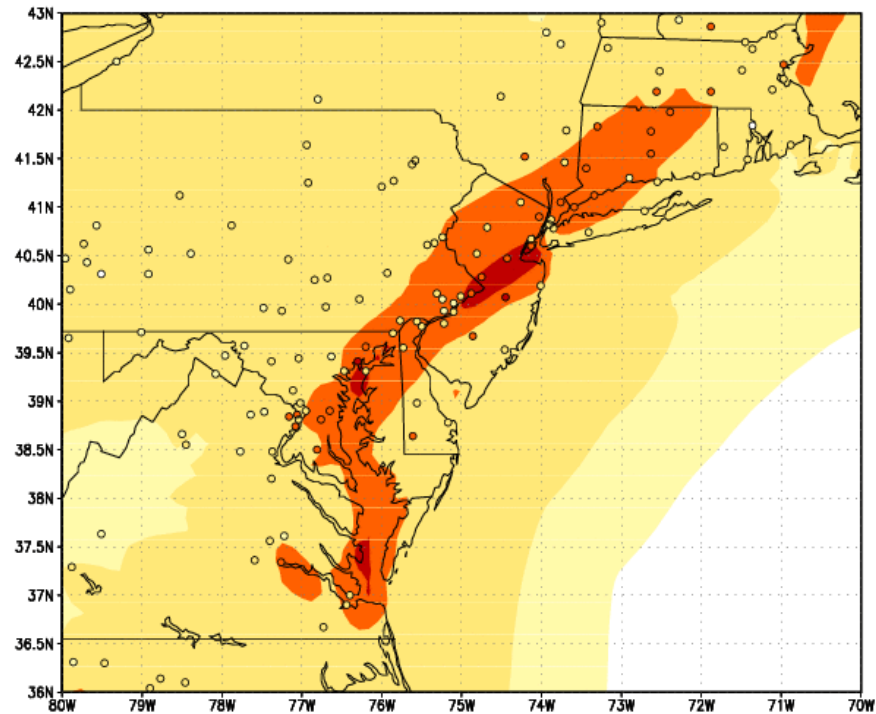
July 26, 2005 Case



1x 8-hr max 26JUL2005



3x 8-hr max 26JUL2005

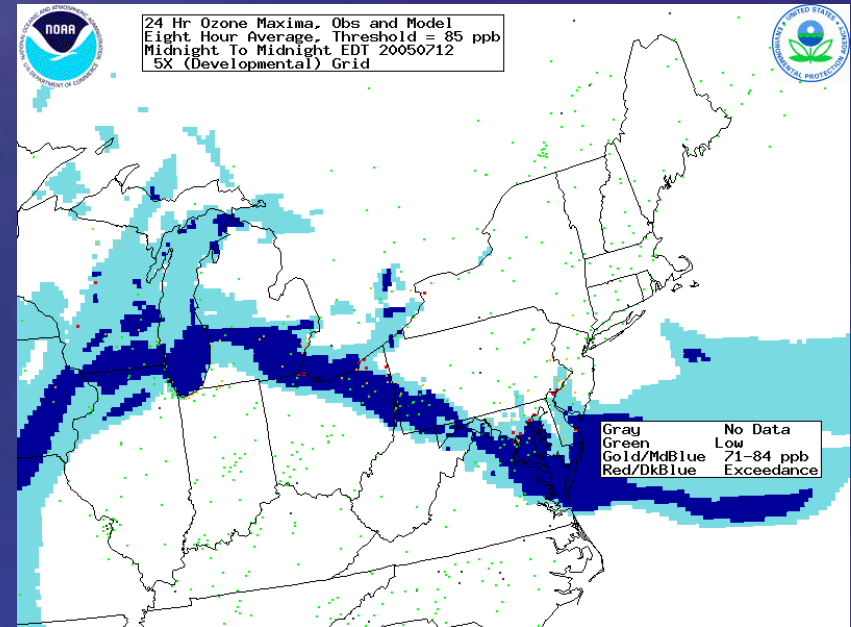
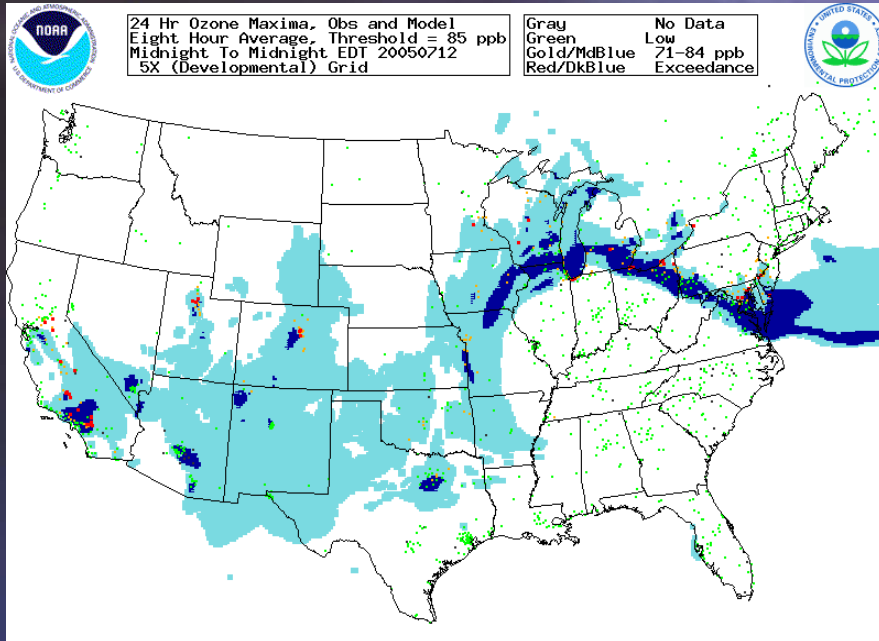


- Operational Run : NE US
- 8 hr daily max

- Experimental Run: Eastern 2/3 US
- 8 hr daily max

CONUS Domain Performance

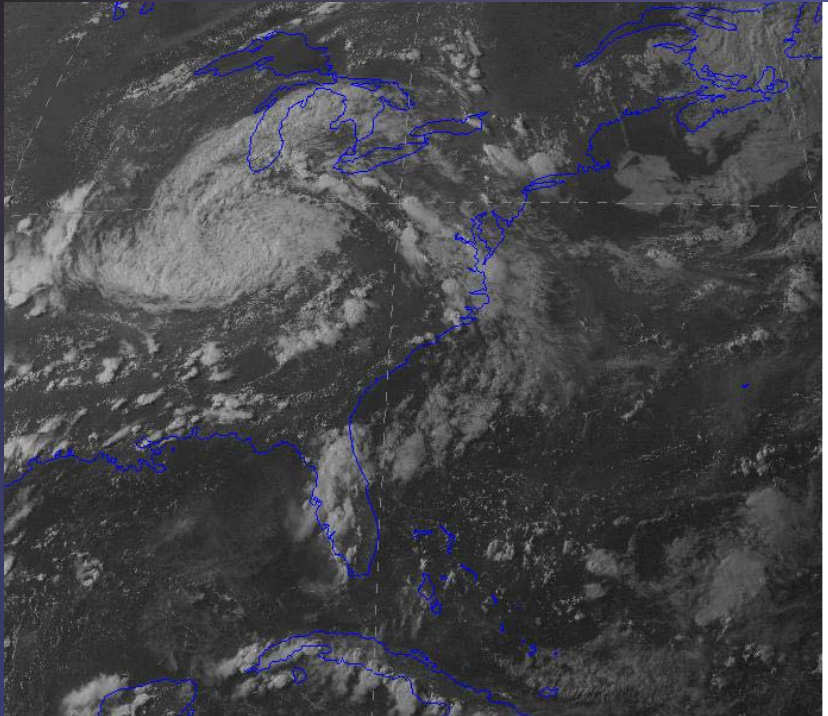
July 12, 2005 Case



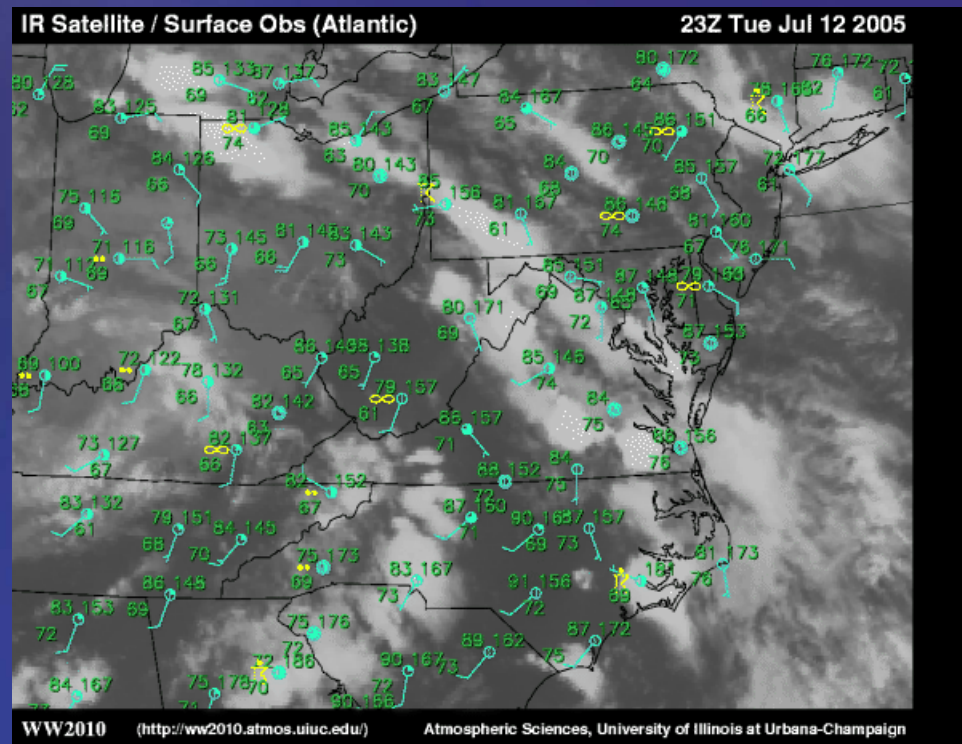
- 8h daily max obs vs predicted

CONUS Domain Performance

July 12, 2005 Case



Hurricane Dennis



WW2010

(<http://ww2010.atmos.uiuc.edu/>)

Atmospheric Sciences, University of Illinois at Urbana-Champaign



Summary



Mean daytime bias reduced from ~17 to 5 ppb

- Mean daytime rmse reduced from 22.8 to 14.5 ppb
- However, still general overprediction in day, poorer performance at night
- Temporary Fix of over-mixing from downward entrainment of strat (GFS) ozone
- Improved real-time verification (ozone, pbl hgt, cloud cover)
- Conus run errors comparable to 3x and 1x runs.
 - *Reduced impact of the boundaries*
 - *However, under-predictions in California*

FY06

- Complete WRF-CMAQ tight Coupling
- Test North American Run (CONUS, Canada, Alaska, Hawaii)
 - *Additional vertical levels, improved convective mixing (RAS ?), NAM radiative coupling*
- Continue Aerosol Run evaluation extend to CONUS .
- Improve boundary conditions from GFS chemistry
 - *Global aerosol forecasting using NASA-GOCART model*
- Ozonesonde evaluations with Howard U., NASA
 - *Beltsville, Huntsville, Boulder, Wallops*
- Complete In-line WRF/NMM-Chem development



BACKUPS





FY06 Developmental Testing

WRF-CMAQ



- **WRF/NMM tests**
 - *Test common vertical Sigma coordinate*
 - *Test common horizontal rotated E grid coordinate*
- **Improved Radiation Coupling for Photolysis**
 - *Sfc and 3d radiative fluxes*
- **Improved Cloud Coupling for cloud mixing & aqueous chemistry**
- **Improved PBL coupling for mixing**
- **Improved Emissions**
- **Improved LBCs**
 - *Improved vertical resolution near tropopause*
 - *Raised CMAQ model top*
- **Full bundle tests**



Data Assimilation/Global System Tasks



- **CMAQ data assimilation:**
 - *Plan for surface ozone assimilation*
 - *Correlate sfc ozone w/ precursors (Nox VOCs)*
- **GFS: Improved chemistry for regional LBCs**
 - **Ozone:**
 - Include tropospheric product/loss rate terms
 - Test reduced ozone chemistry (U.Wisc-RAQMS)
 - Begin testing assimilation of AURA/OMI
 - CMAQ LBC impact studies
 - **Aerosols:**
 - Include NASA-GOCART reduced biomass burning/dust and emission processes
 - Begin testing assimilation of MODIS & AURA/TESS
 - CMAQ LBC impact studies



Potential short-term collaboration projects

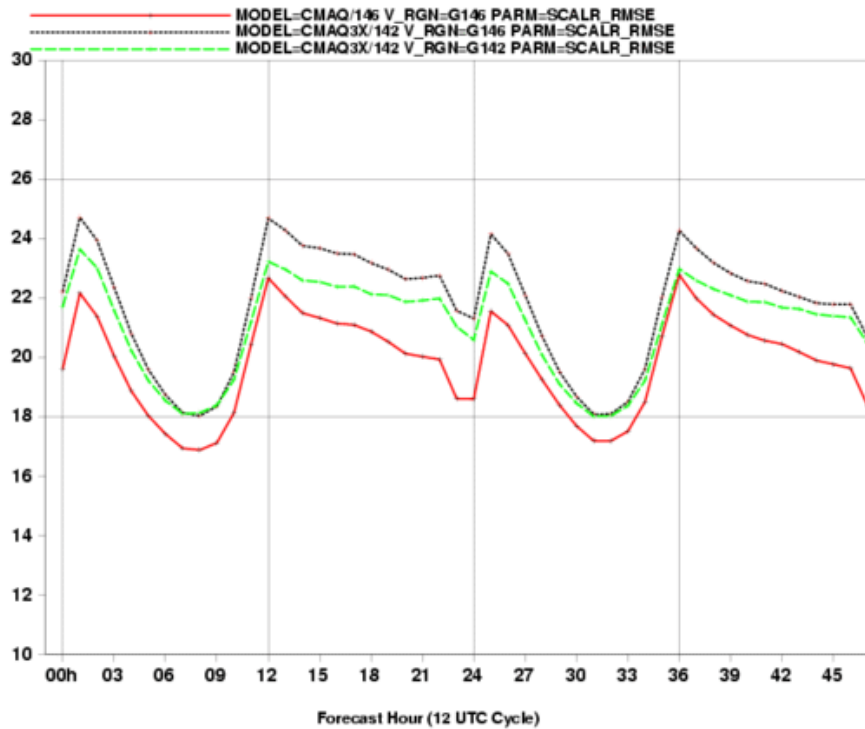
- Evaluation of NCEP WRF-CMAQ ozone & aerosol simulations
 - *Experimental & rural obs networks (eg: ETOS, AERONET, REALM lidar network)*
 - *GOES/MODIS satellite evaluation*
- Assimilation of AIRNOW ozone data into CMAQ initial conditions
- Improved cloud mixing, aqueous chemistry PBL coupling with WRF-CMAQ
- Testing of WRF-Chem on-line system to offline WRF-CMAQ forecasts



Real-Time Verification

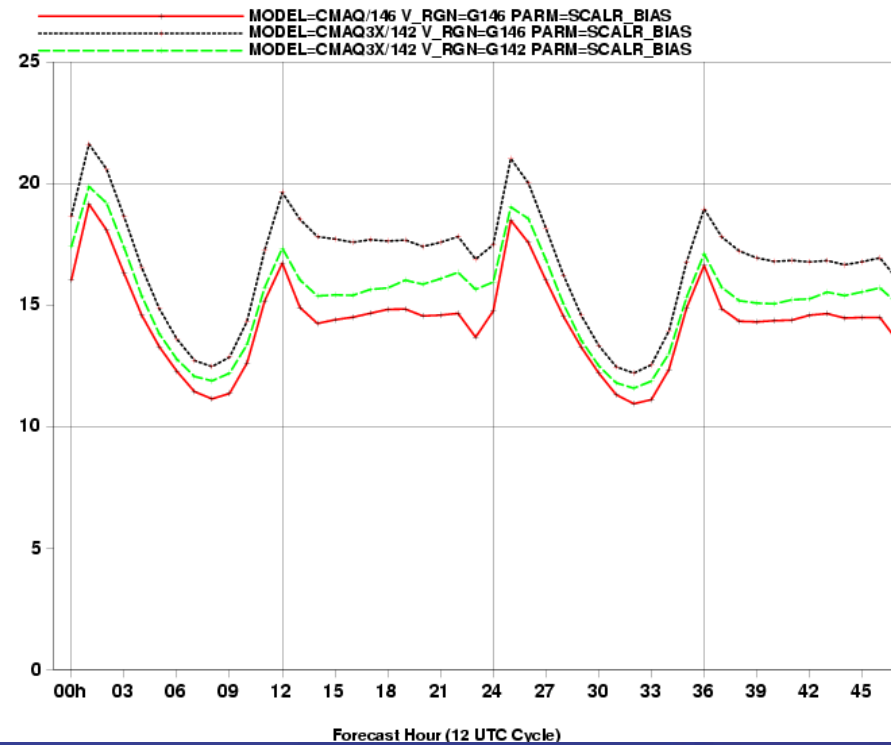
EMC FVS time-series binned by FHR

rms CMAQ Ozone Error(ppb)averaged by forecast hour for all fcsts thru 20040915



RMSE

bias CMAQ Ozone Error(ppb)averaged by forecast hour for all fcsts thru 20040915



Bias



Retrospective Tests

Eta-CMAQ (East U.S)



- Upgraded Eta Met. Driver tests (S0)
 - *1 km NOAA Landuse, soils*
 - *Improved cloud-radiation effects*
 - *2 mb top, improved precip assimilation*
- Improved Radiation Coupling for Photolysis (S2)
 - *Sfc radiation flux scaling*
- Improved Cloud Coupling for cloud mixing *and aqueous chemistry?*
 - *Use graupal, ice fields for aqueous*
 - *Use convective cloud base/top for mixing*
- Improved PBL coupling for mixing
 - *Use 3-D TKE Kh fields*
- Improved Emissions
- Improved LBCs
- Full bundle tests
- Begin Real-time Parallels



Operational Requirements



Driven by NCEP Operational Meteorological Model (Eta-12 and WRF/NMM)

- **I/O Formats:**
 - *Only machine binary, GRIB and BUFR, disk space limitations*
- **Time Requirement:**
 - *12 Z 48 hour forecast available by 17:25 Z (1:25 pm EDT)*
 - *06 Z 48 hour forecast available by 13:00 Z (9 am EDT)*
 - *65 IBM Power 4 procs available*
 - *12 Z start after Eta is complete (14:30 Z)*
- **Robustness:**
 - *Thoroughly tested & evaluated with retrospective and real-time experimental runs*
 - *Available to NWS Gateway, NDGD: 99% reliability, 24x7 NCEP support*
 - *Accuracy: 90% exceedence hit rate*



Summer 05 Planned NCEP Runs



Run	To EMC	To NCO	Real-time runs
Operational (3x East U.S.)	2/1/05	3/15/05	5/1/05
Experimental (CONUS U.S.)	3/15/05	5/1/05	6/1/05
Developmental (CONUS-WRF)	6/1/05 <i>If WRF/NMM is running realtime</i>	7/15/05	9/15/05
Research (Aerosols)	Real-time: Winter 05 Retrospect: Summer 05		
Fire Smoke (Hysplit-I)	12/31/04	2/1/05	3/1/05
Bluesky-hysplit-II	3/1/05	5/15/05	7/1/05

Air Quality Forecasting 2004 Verification (1x and 3x)

✓ NCEP EMC FVS System :

- ✓ 1 and 8 hour O3 averages
- ✓ **RMSE, Bias, STD, correlation coefficients Time series by fhr and day, subregion**
 - ✓ *using EPA AIRNOW O3 network began 7/12/04*
- ✓ FHO contingency exceedence stats (POD, FAR, threat scores)
 - ✓ *Began 8/1/04*

✓ NWS/MDL

- ✓ Daily Spatial obs vs predicted exceedence maps
- ✓ Contingency exceedence stats since June 1

✓ NOAA/OAR/EPA

- ✓ Retrospective evaluations (8/12-19, 2003)
- ✓ RT: Similar Stats except stations averaged over CMAQ grid points

✓ ICARRT web page: sfc & UL ozone timeseries vs observations

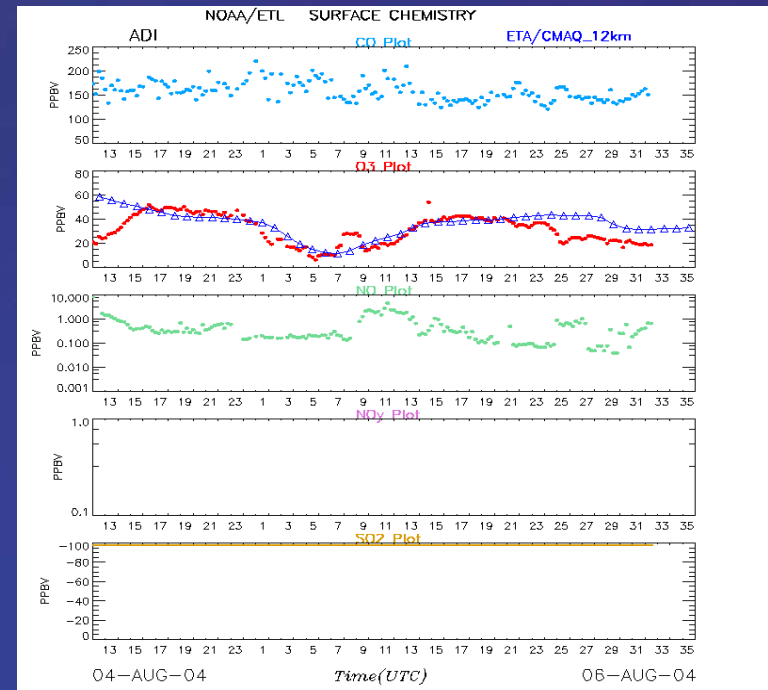
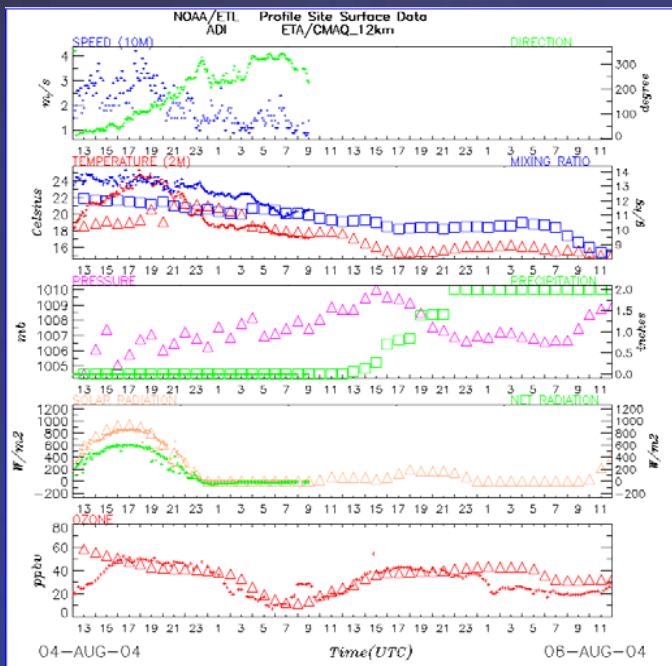
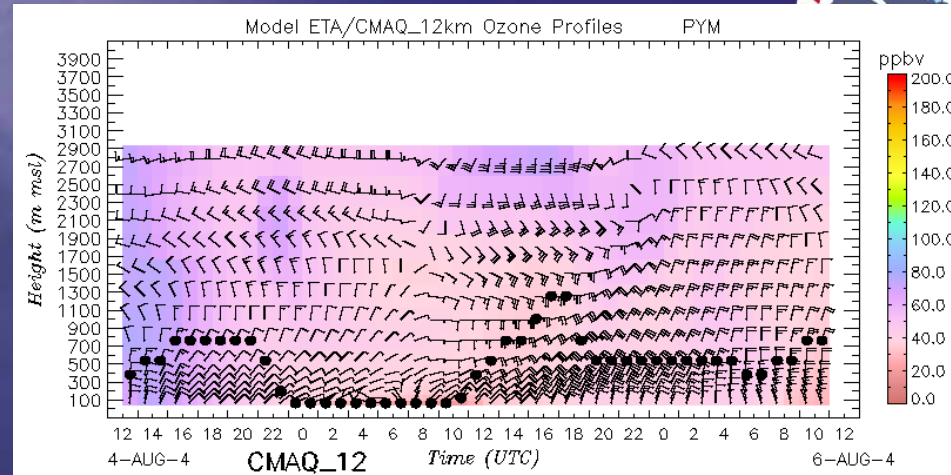
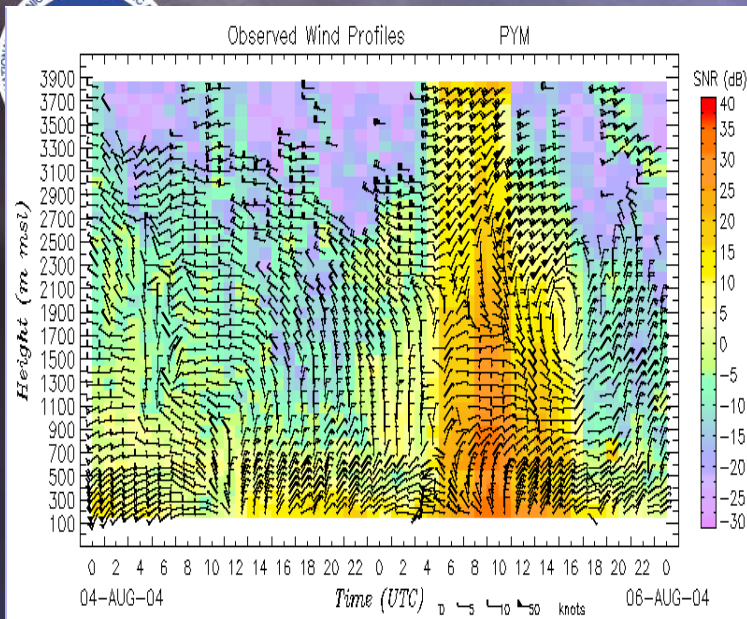
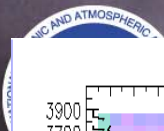


Implementation Tasks



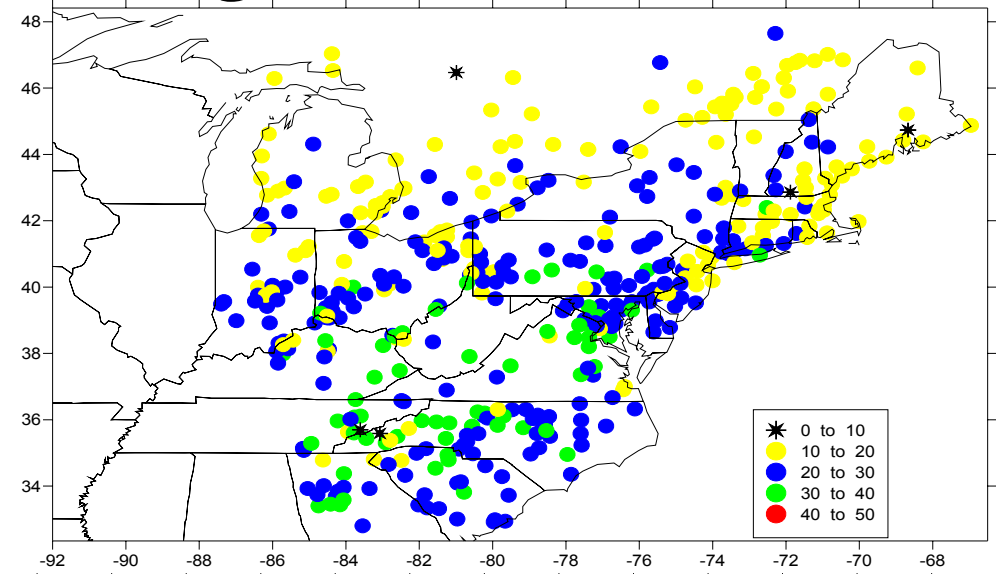
- **Transfer parallel experimental system to Operations:**
 - **Complete agreed upon Charter w/ NCO**
 - **Provide additional Eta/WRF fields from Postprocessors**
 - *** Transfer upgraded CMAQ to EMC**
 - **Add internal documentation, refine scripts, adjust IO & dataset names**
 - **Support GRIB2 hrly gridded outputs**
 - **Perform 2002/2004 retrospective tests w/ upgraded Eta or WRF**
 - **Perform real-time parallels w/ updated emissions files**
 - **System evaluation against AIRNOW w NCEP FVS**
 - **Prepare estimates of cpu/disk resources for NCO**
 - **Prepare Job Implementation Form (JIFs) requests to NCO:**
 - **Send out Change Notices, update web page change logs**
- **Maintain/improve operational graphics, verification plot web pages**
 - **May require additional output to GRIB files**

ICARRT Evaluation

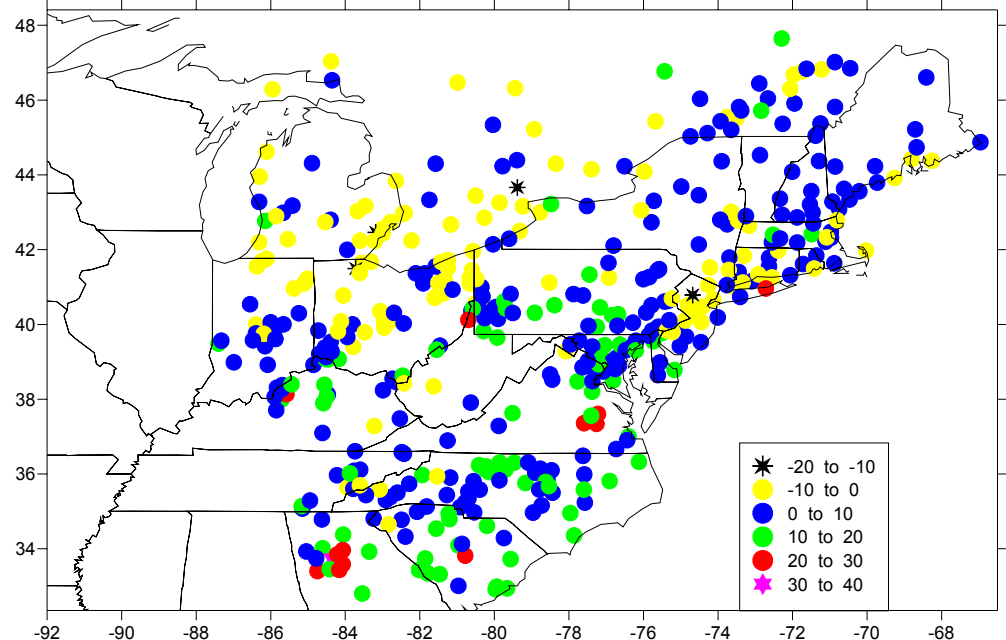


NE DOMAIN Retros. Evaluation

1 Hr Avg ozone Errors (8/12-19, 2003)



RMSE



Mean Bias



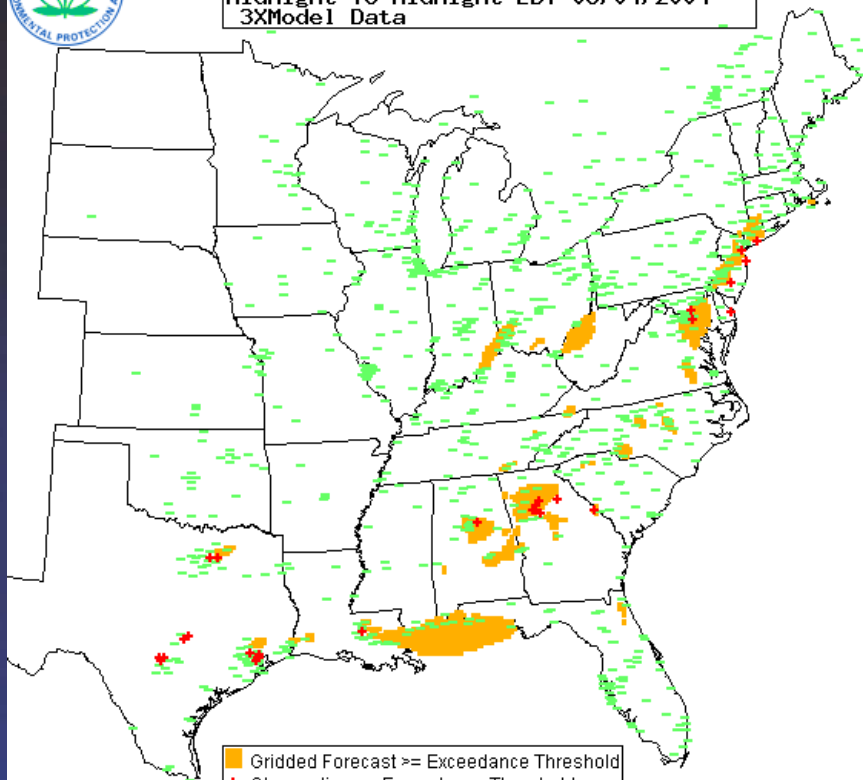
Real-Time Verification

NWS MDL Evaluation

Predicted vs Obs Exceedence

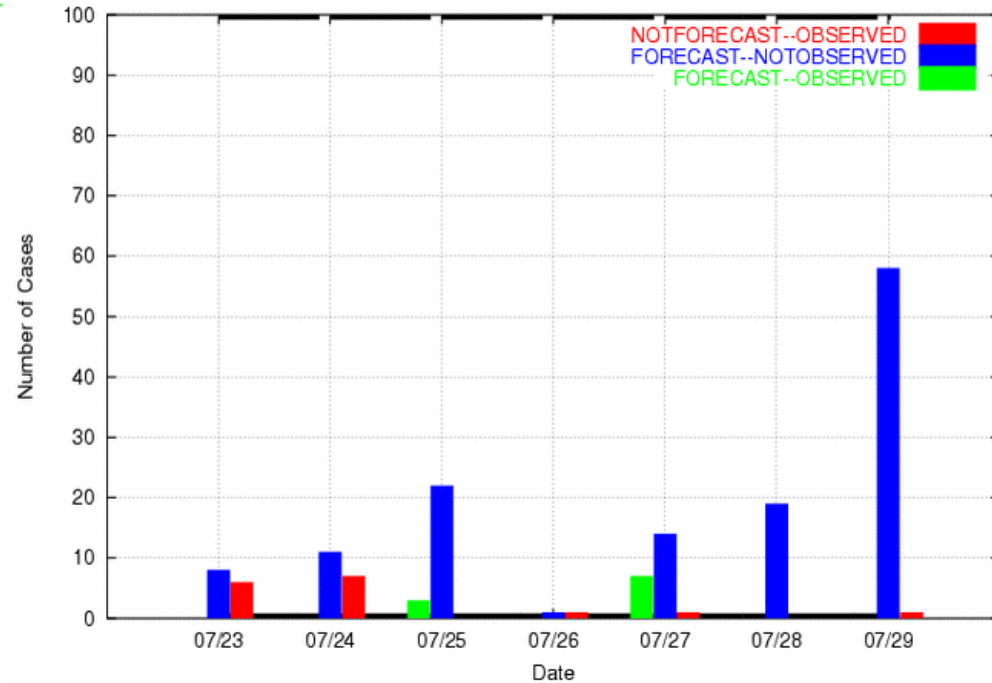


Ozone Exceedences
Eight Hour Average, Threshold = 85 ppb
Midnight To Midnight EDT 08/04/2004
3XModel Data



■ Gridded Forecast \geq Exceedence Threshold
+ Observation \geq Exceedence Threshold
● Observation $<$ Exceedence Threshold

Number of 8-hr Avg Exceedences Forecast and/or Observed
07/23/2004 to 07/29/2004
3XModel Data



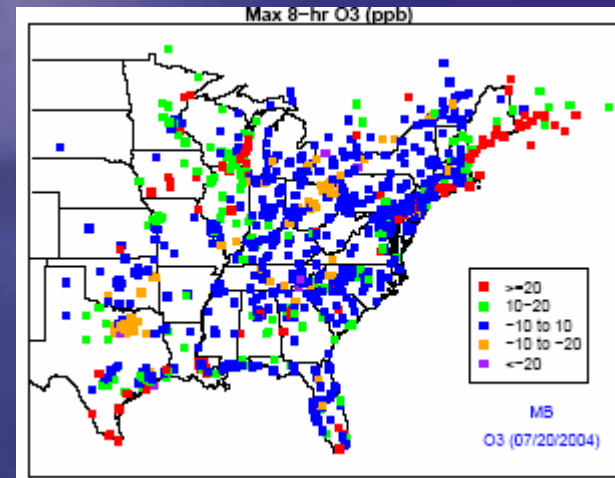
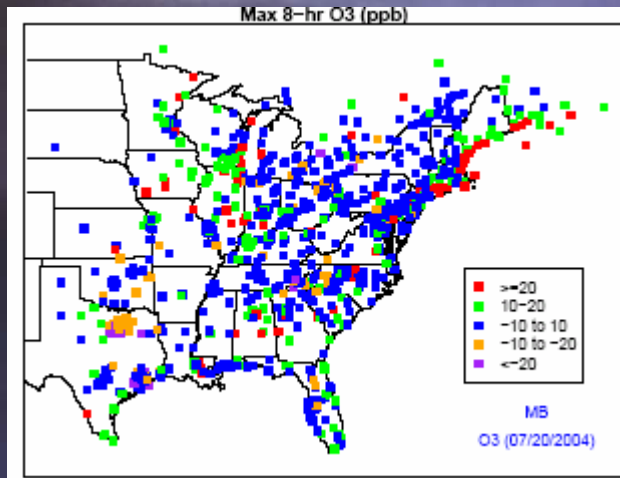


Max 8-hr O₃ Mean Bias Spatial Distribution: July 21, 2004



2004 Base

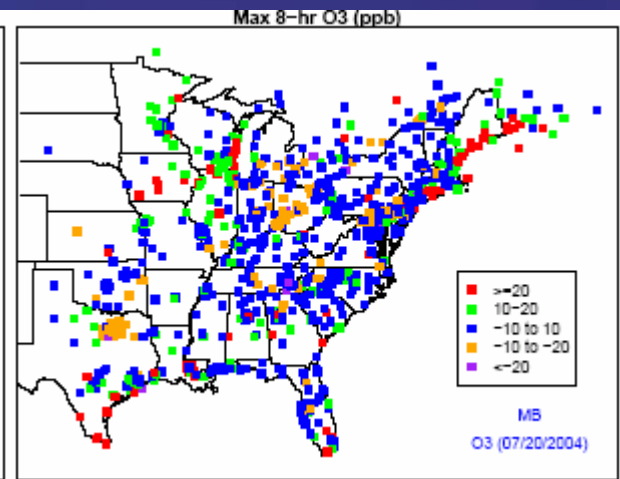
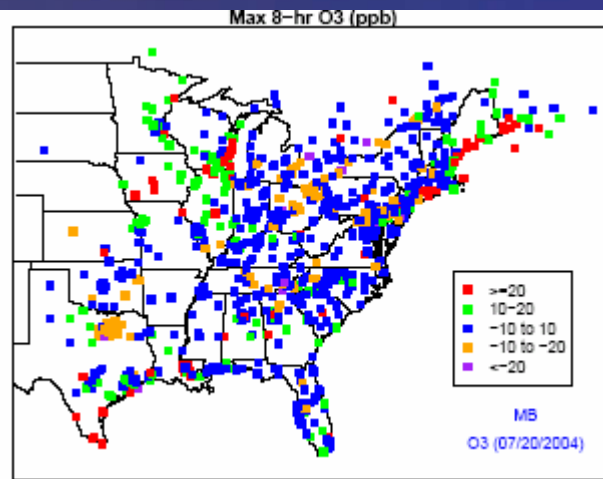
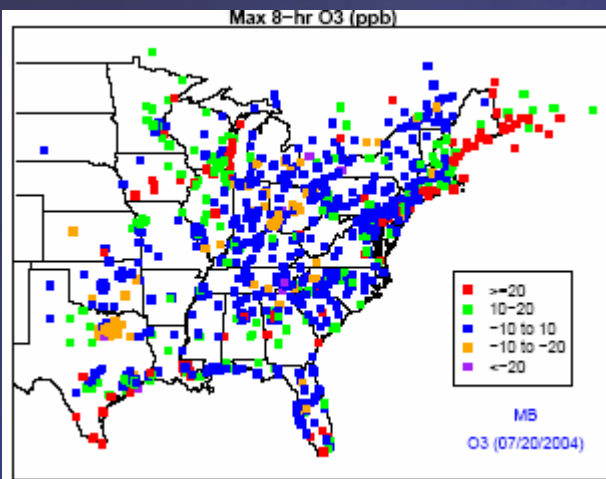
S0



S1

S3

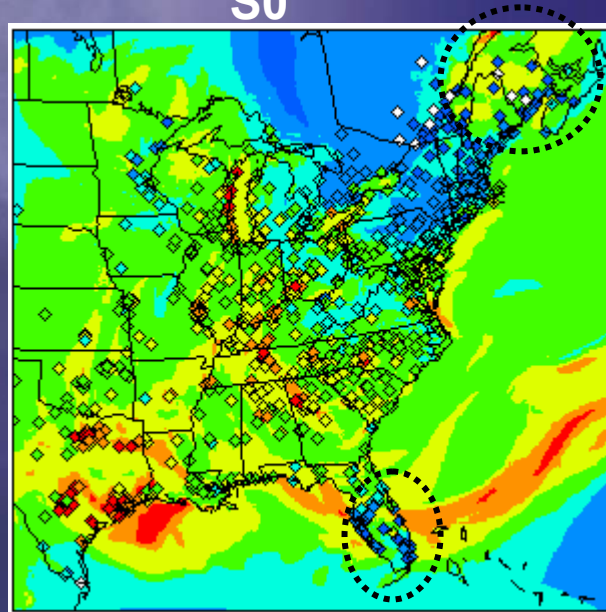
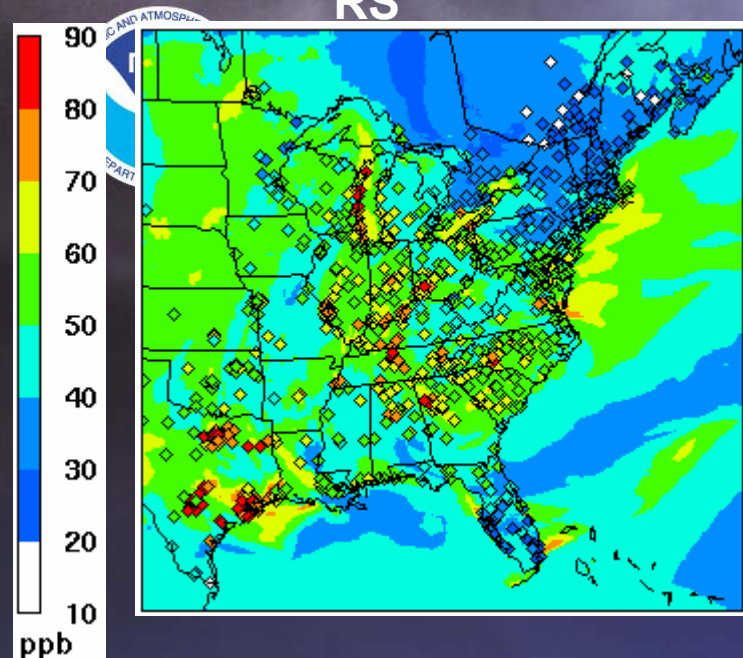
S5





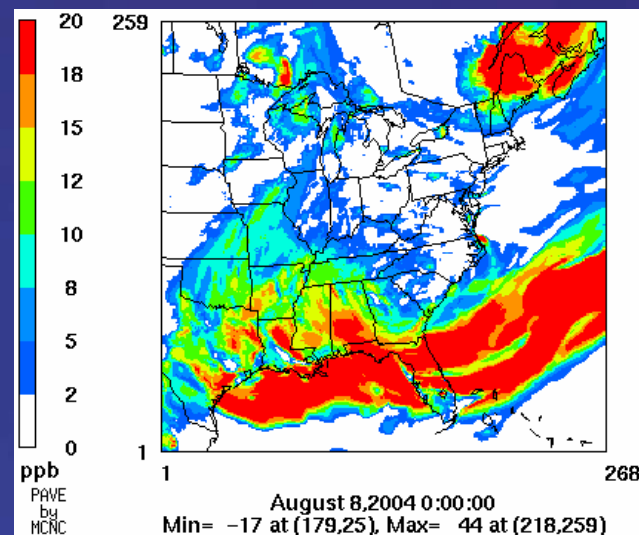
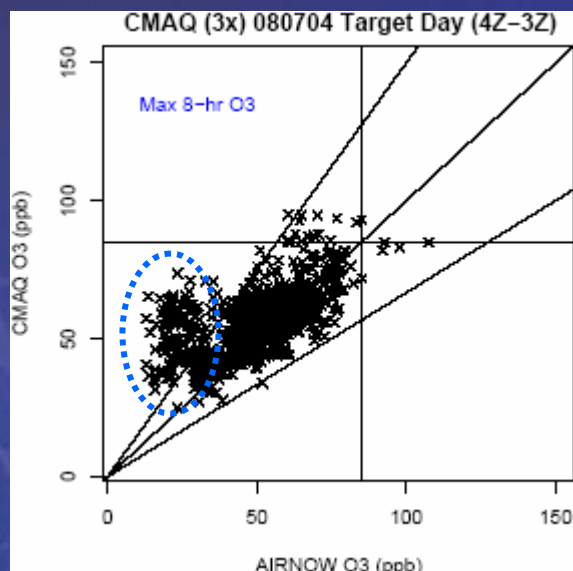
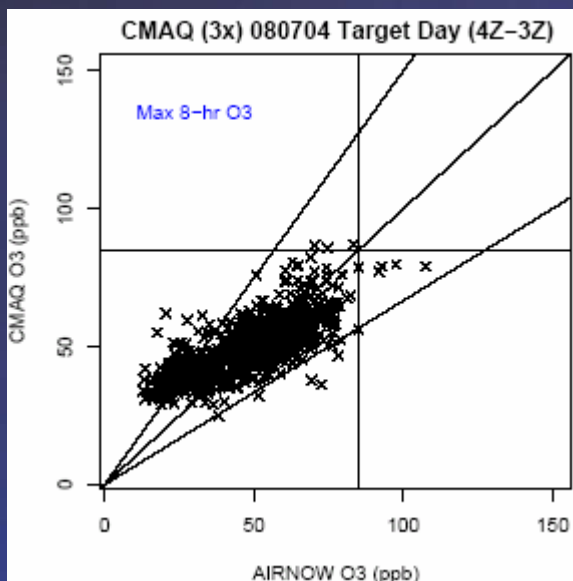
RS

S0



Max. 8-Hr. O₃
August 8, 2004

S0-RS



Slight tendency to under-predict

O3 increased regionally,
Over-predict at low range

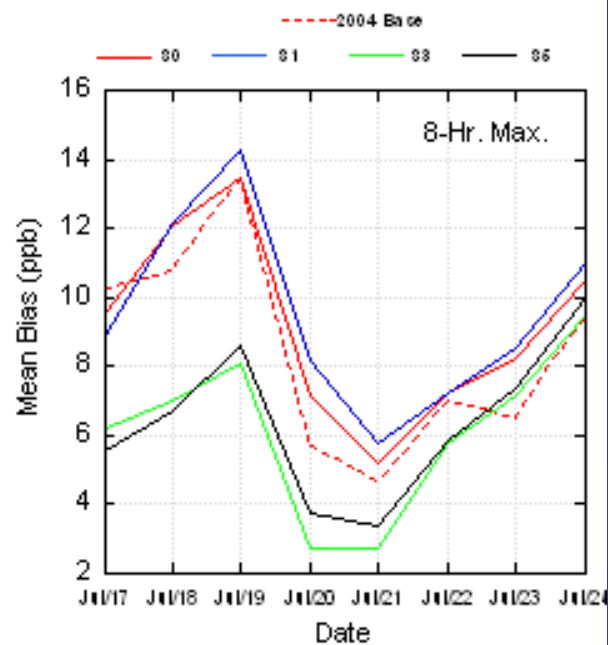
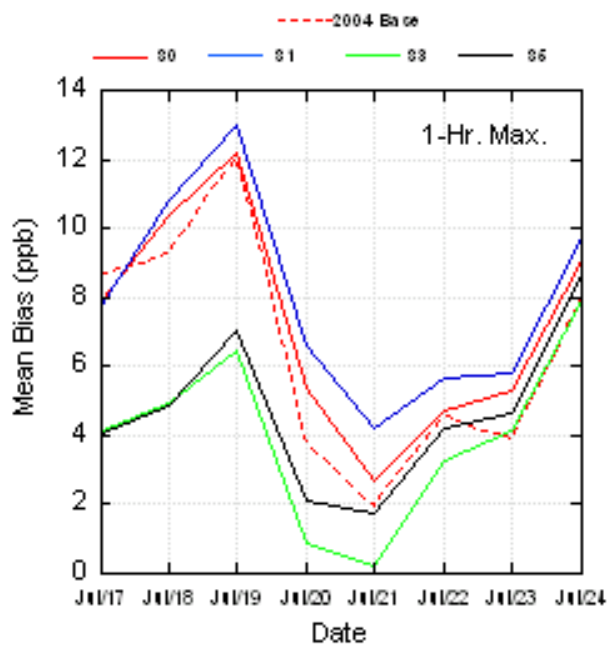
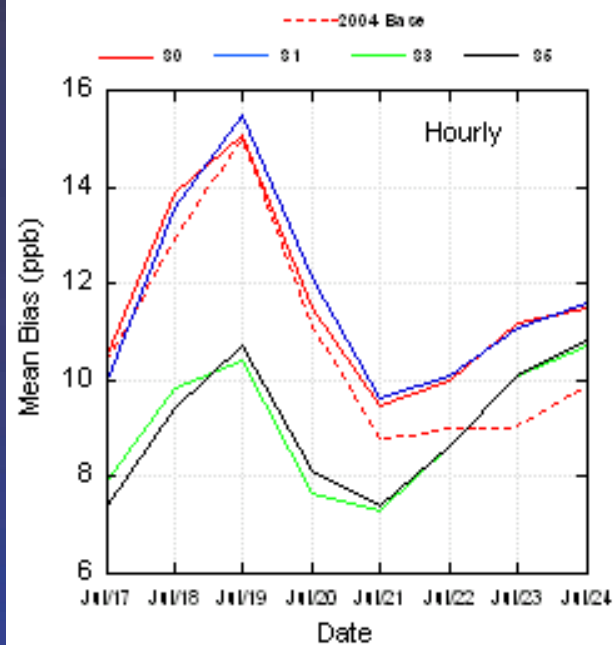
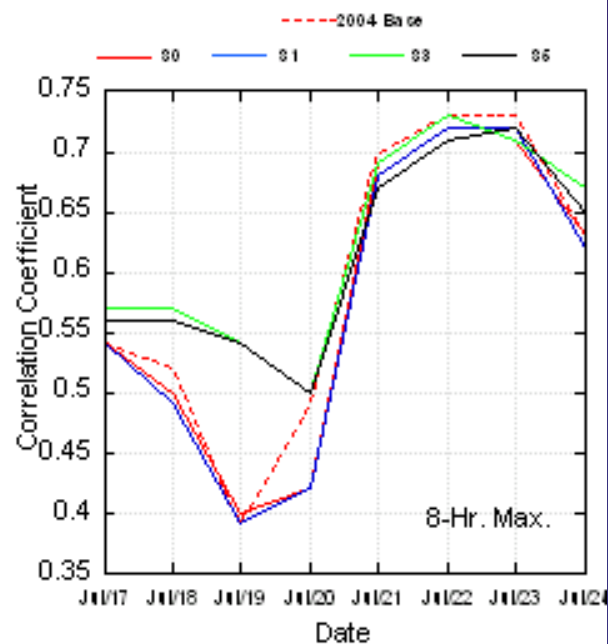
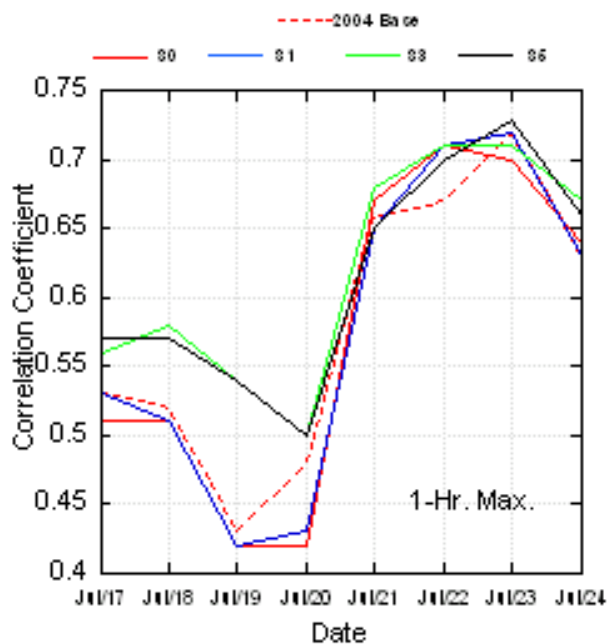
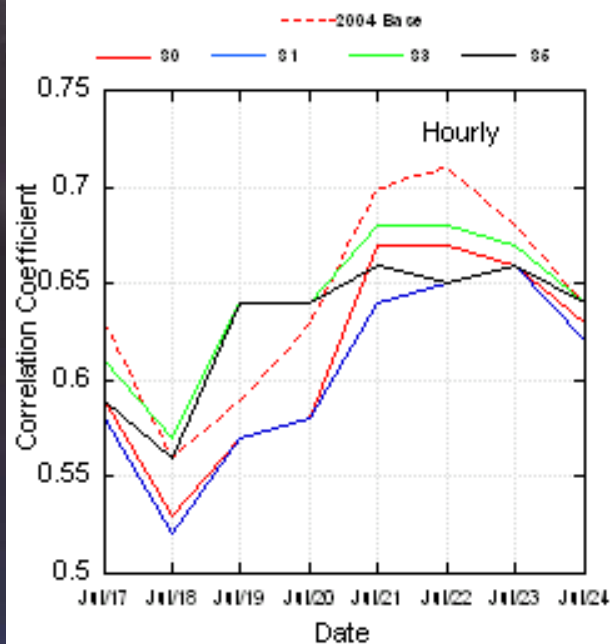


Developmental Runs Coupling



Run	NAM-CMAQ (3x, Conus)	WRF-CMAQ (Planned)
Domain	Interp to CMAQ C grid	<i>Common Rotated E grid</i>
Vertical Coordinate	Interpolate to CMAQ σ	<i>Common WRF/NMM σ-P</i>
Photolysis	<i>Surface Eta Radiative Scaling</i>	<i>3-D Radiative fluxes</i>
PBL	Eta PBL height into P-X	<i>NAM TKE/Kh to drive mixing</i>
Clouds Aqueous Mixing	NAM cloud water <i>Axisymmetric Convective Model (ACM) mixing extended for conv</i>	<i>NAM cloud water, graupel & ice NAM convective cloud base/top.</i>
LBCs	<i>GFS at model top Static below</i>	<i>GFS in strat, static below Higher top, improved vertical resolution near tropopause</i>

July Case

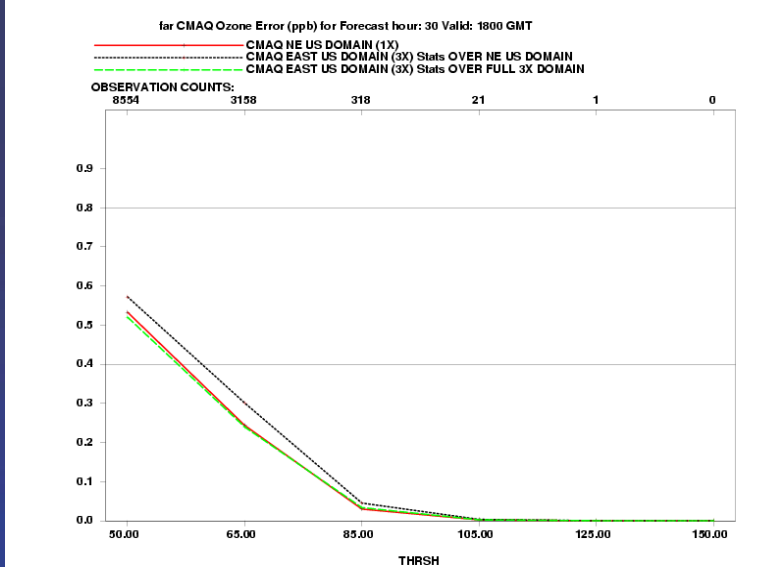
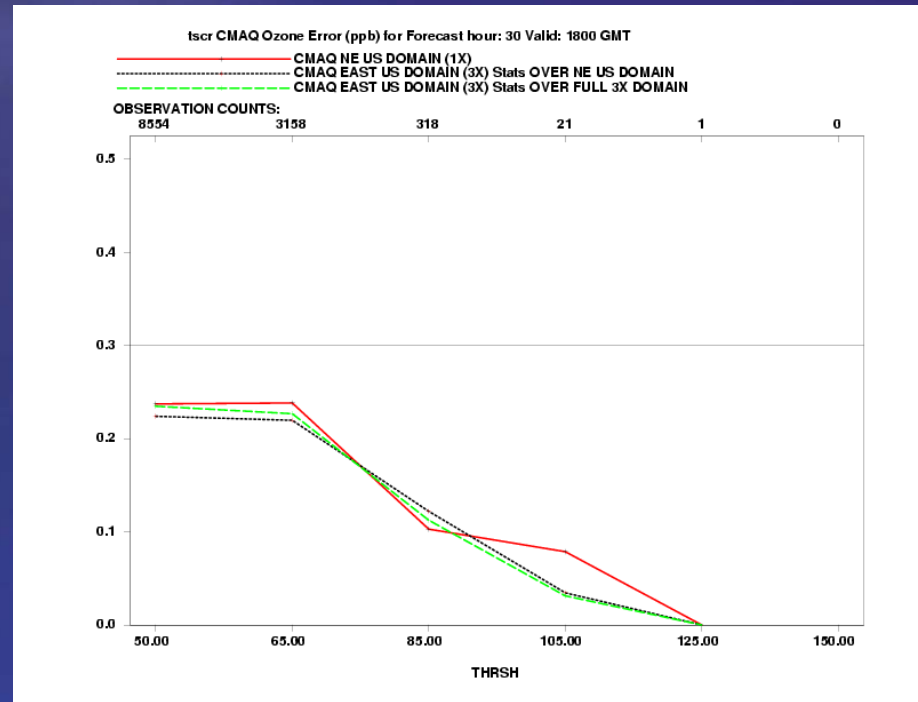
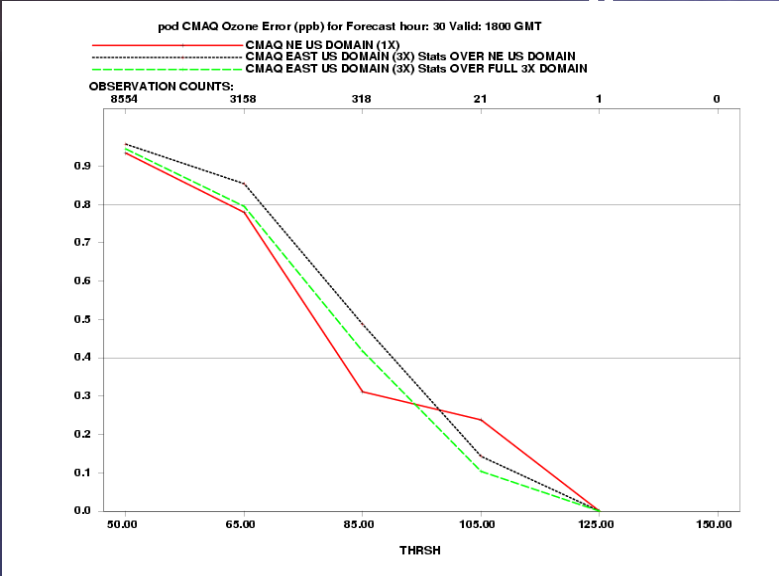




Objective Verification



Overall Performance - Summer 2005



- 1hr Equitable Threat Scores