# Experiment to Improve Air-Quality Forecasts with NASA Satellite Observations

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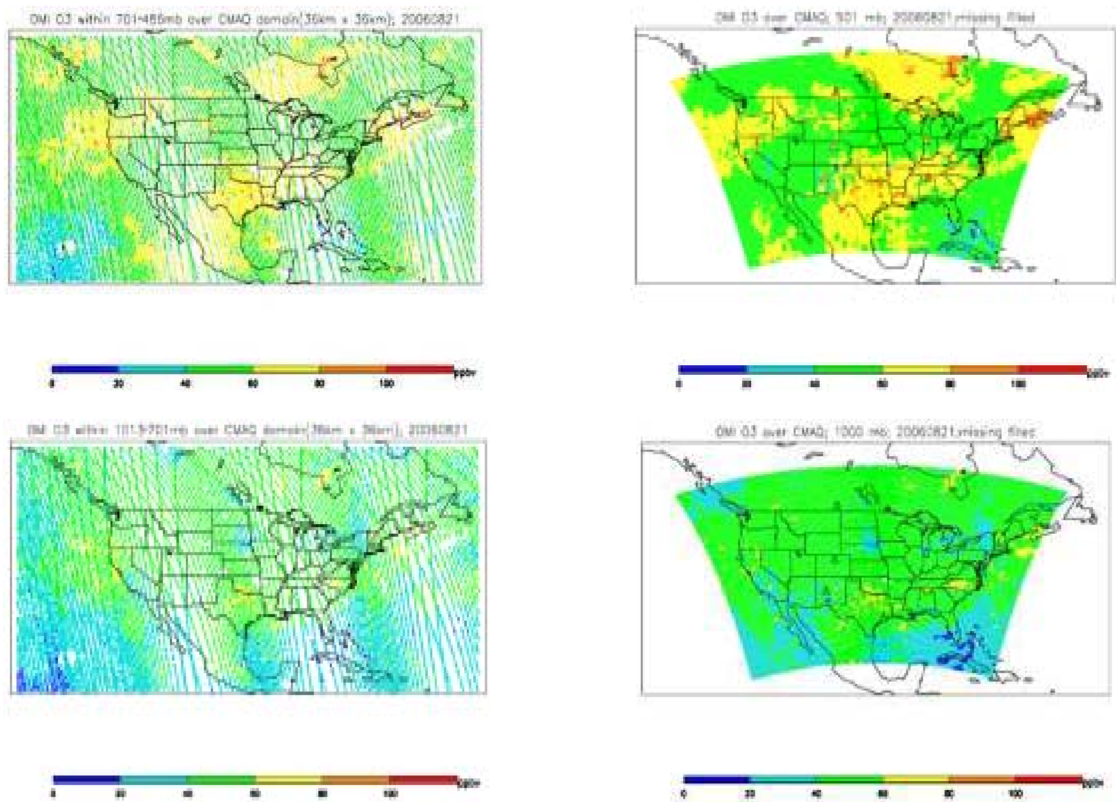
# PART I: Assimilation of Satellite Trace gases

## (1) Aura/OMI $O_3$ retrieval & IONS06 Network



Aura/OMI Level 2 O3 profiles (24 layers; credit: Xiong Liu) are mapped to CMAQ horizontal domain (36km x 36km) using a “drop-in-the-box” method; The daily-mean profiles are then interpolated to CMAQ 39 vertical layers (altitude-based).

Left: OMI O3 plotted with fixed pixel size (not real size)

Right: OMI O3 mapped to CMAQ 3-D domain (36kmx36km, 39 layers)

424 ozonesondes were launched from 23 North American sites during August 2006, providing the best set of free tropospheric ozone measurements ever gathered across the continent in a single season.

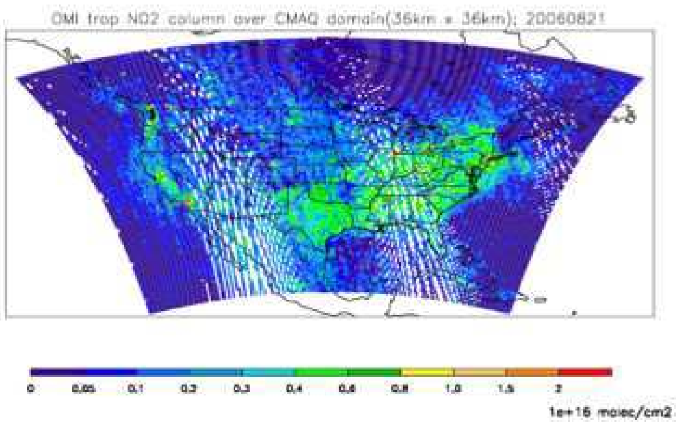
(http://croc.gsfc.nasa.gov/intexb/ions06.html)

This ozonesonde network was specifically designed to quantify: 1) the background ozone that flows into western and southern North America, 2) the ozone exported from North America in polluted air masses, and 3) the enhanced ozone mixing ratios in the upper tropospheric anticyclone above the southern USA. (Cooper et al., 2007)

**(Credit to: ANNE M. THOMPSON; Jacquelyn C. Witte)**

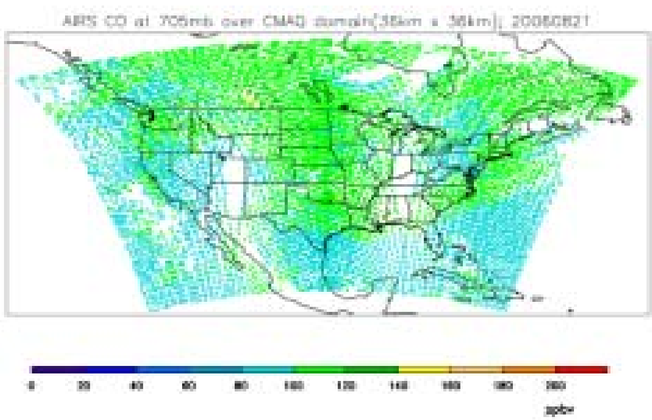
# PART I:
# (2) Other satellite trace gases (NO2/HCHO/CO) (8/21/2006)

**OMI Trop. NO2 column**

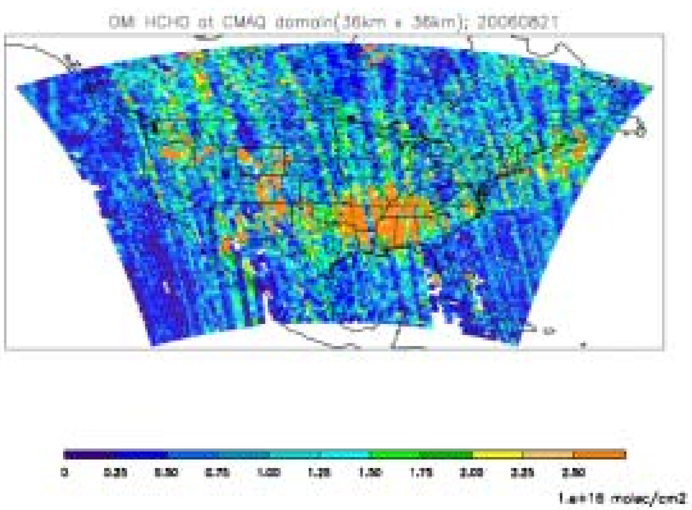



(Credit to: Thomas P. Kurosu,
Kelly Chance,
Wallace McMillian)

**AIRS CO at 700mb**



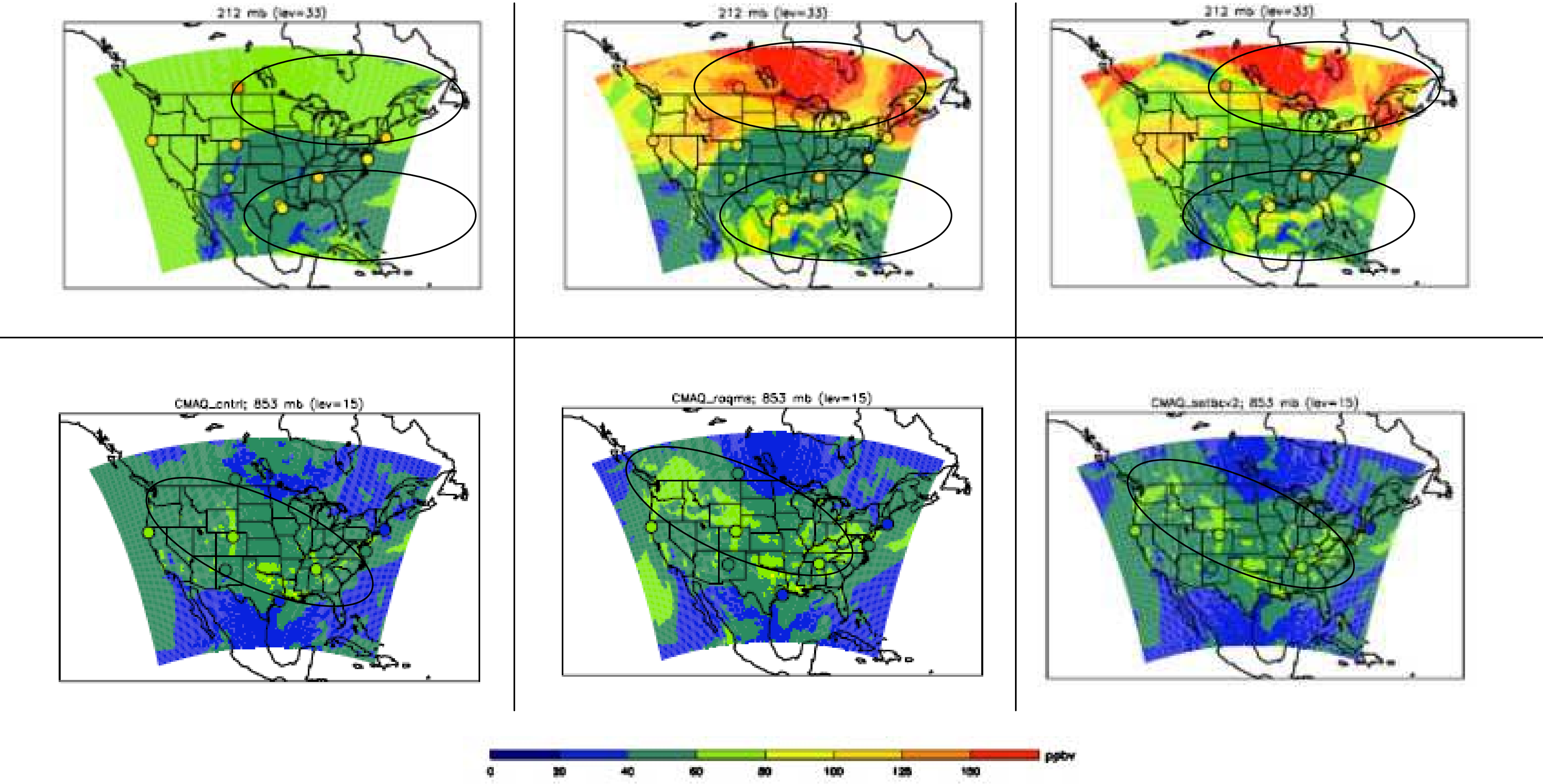

**OMI HCHO column**



# PART I

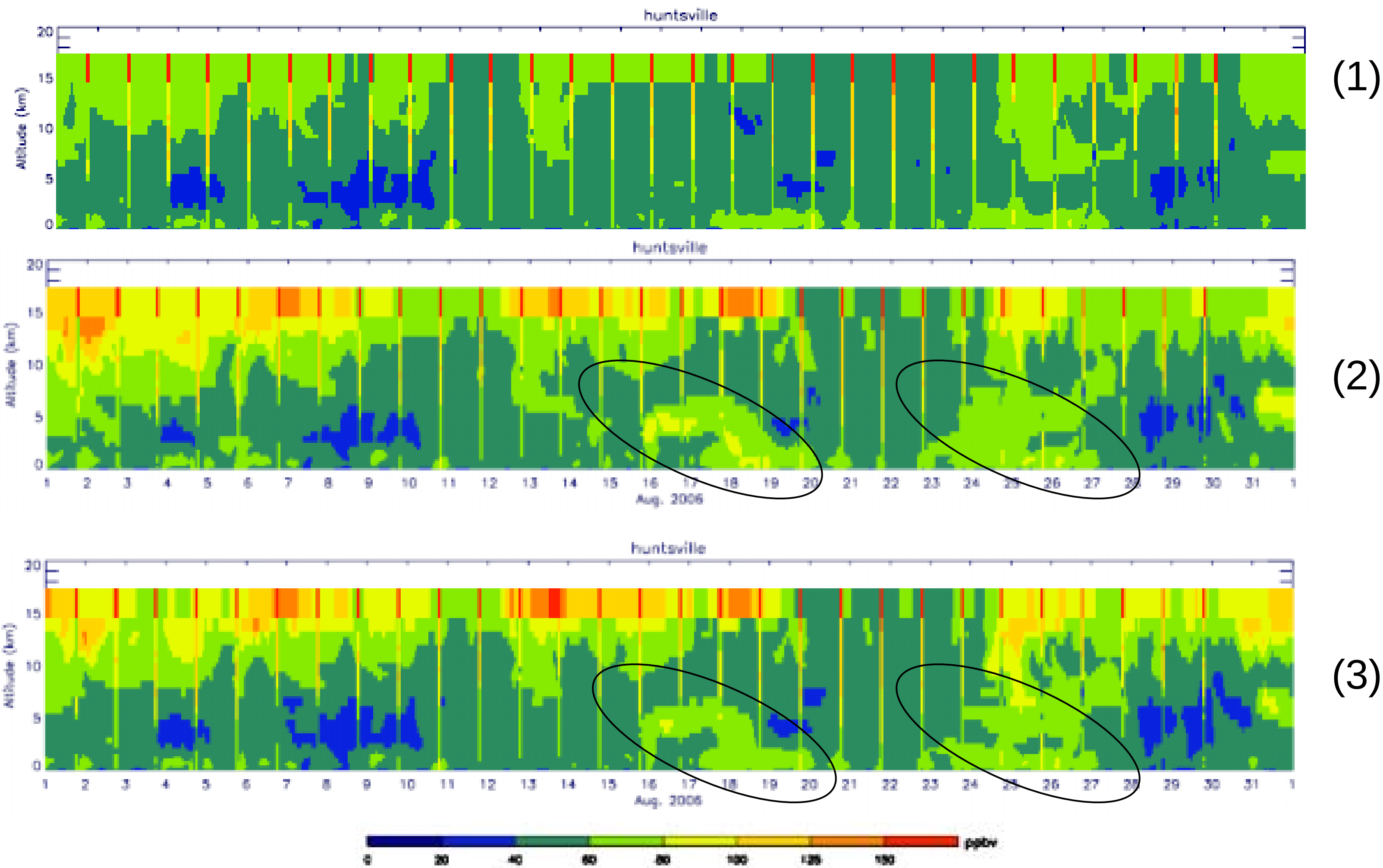
O3 (ppbv) 1900 UTC, 8/21/2006 simulated by 3 CMAQ runs; over plotted with 9 ozonesondes found within 1500~2300 UTC

cntrl | raqms_bc | sat_bc



# PART I

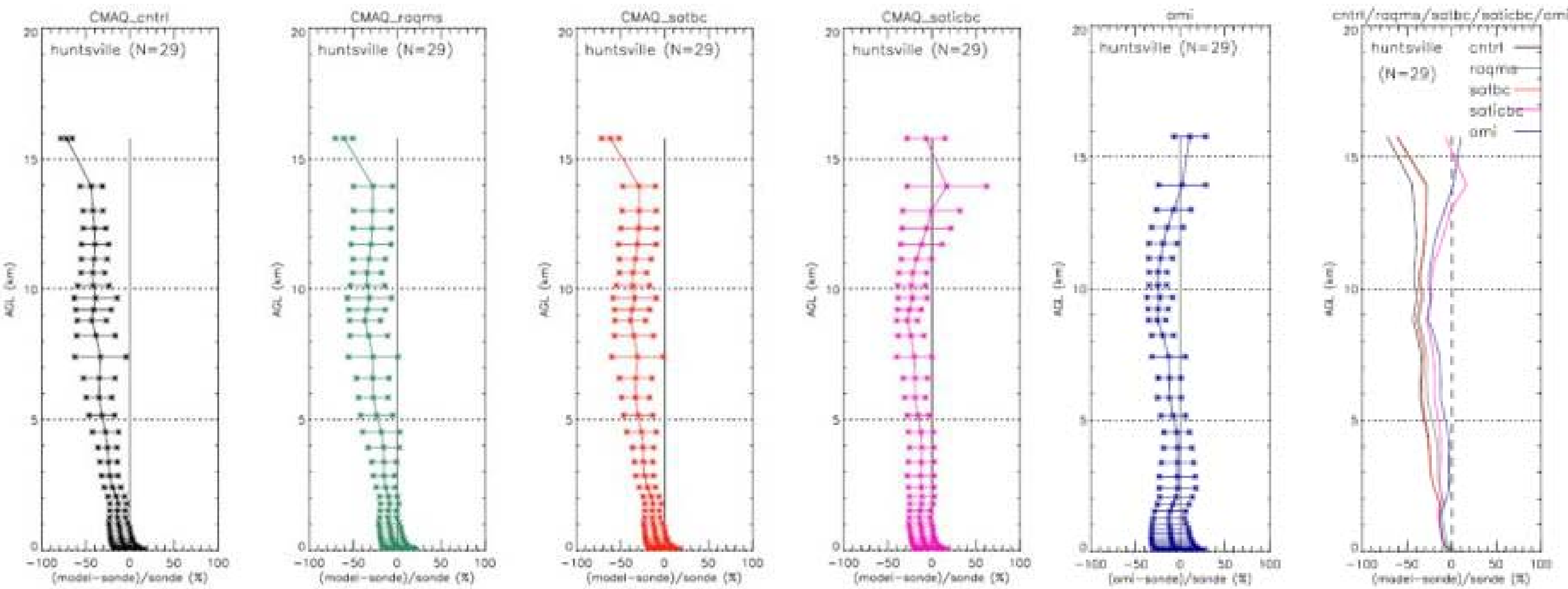
## Huntsville ozonesondes compared with 3 CMAQ runs ((1) cntrl (2) raqms_bc (3) sat_bc)



**PART I**

# Evaluation OMI O3 and CMAQ results with ozonesondes (Aug. 2006)
## (1) Huntsville, AL

cntrl raqms_bc sat_bc sat_icbc omi



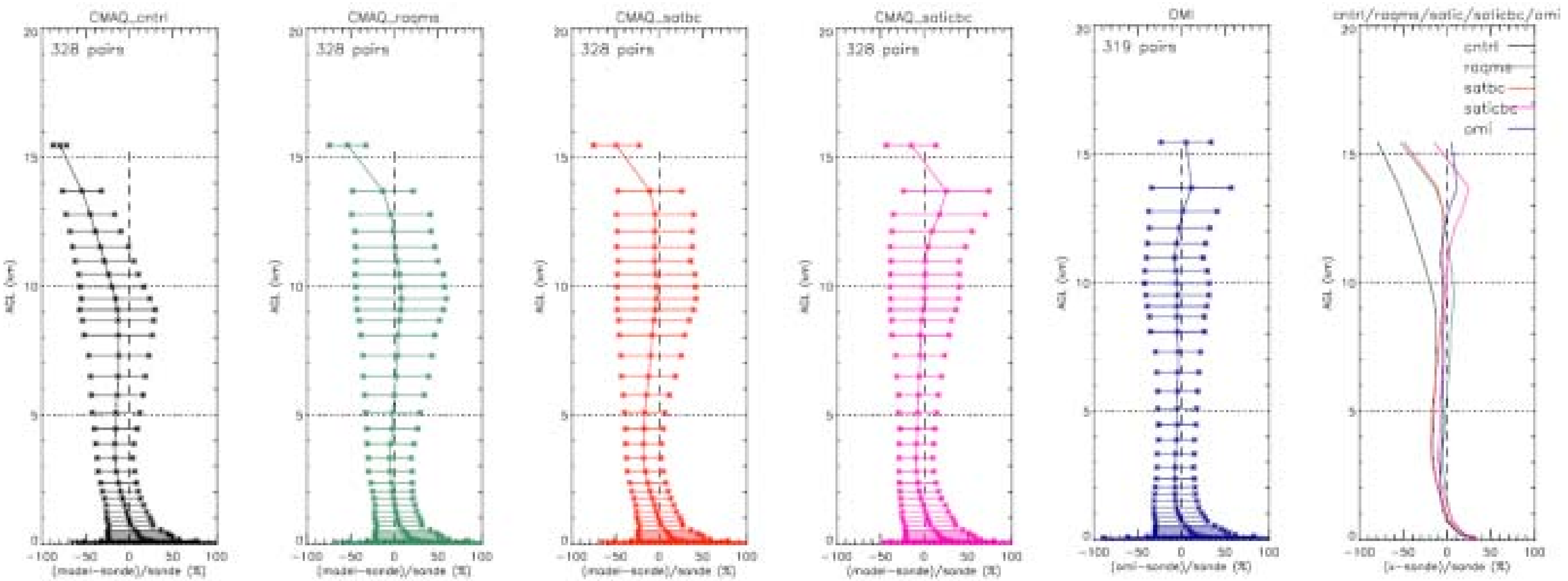

Mean and standard deviation of percent differences ((x-sonde)/sonde (%)) are plotted above, where x represents O3 simulated from 4 CMAQ runs or OMI/O3, respectively.

## PART I

## Evaluation OMI O3 and CMAQ results with ozonesondes (Aug. 2006)

## (2) 17 stations together (total 328 ozonesondes)

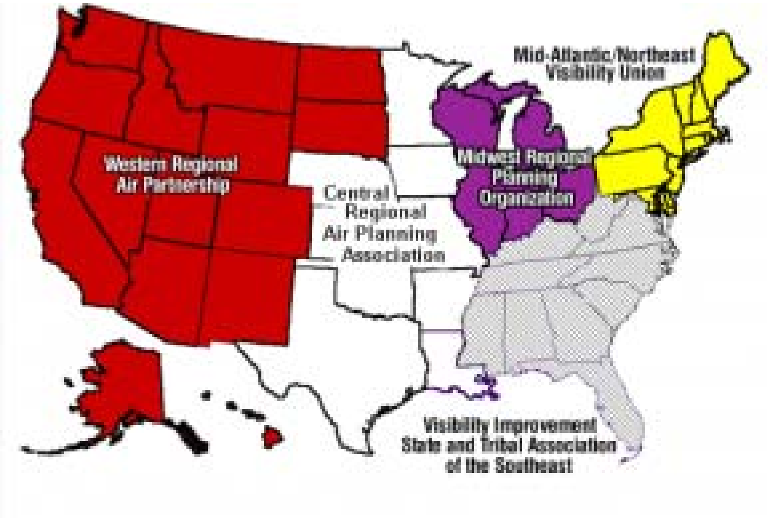
cntrl raqms_bc sat_bc sat_icbc omi

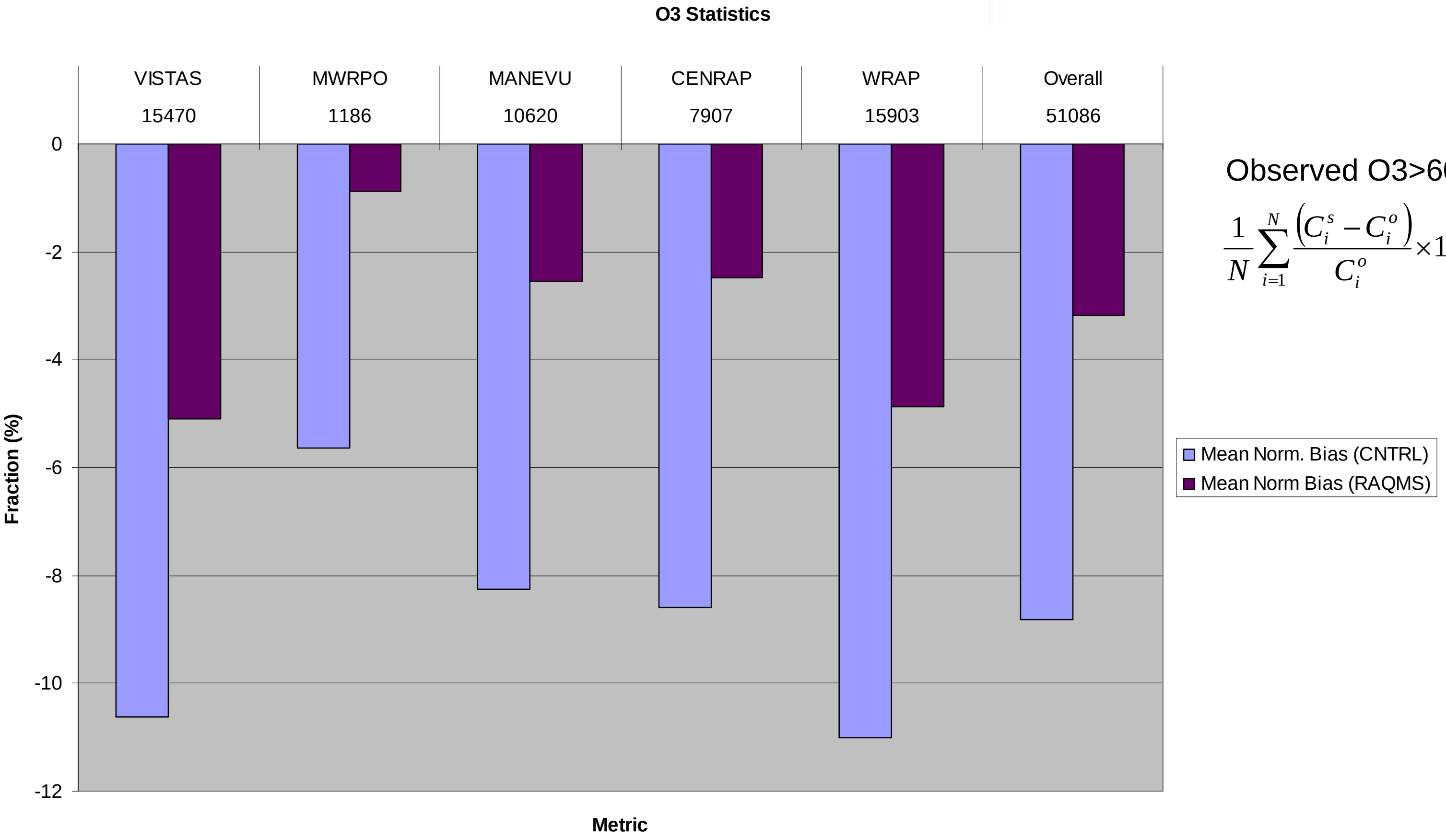



Mean and standard deviation of percent differences (x-sonde)/sonde (%) are plotted above, where x represents O3 simulated from 4 CMAQ runs or OMI/O3, respectively.

(Note: large variances at surface are mainly from Narragansett, Beltsville, and Houston.)

# USING RAQMS TO PROVIDE LATERAL BC FOR CMAQ IMPROVED SURFACE O3 PREDICTIONS




Observed O3>60 ppb

$$\frac{1}{N}\sum_{i=1}^{N}\frac{\left(C_i^s - C_i^o\right)}{C_i^o}\times 100\%$$

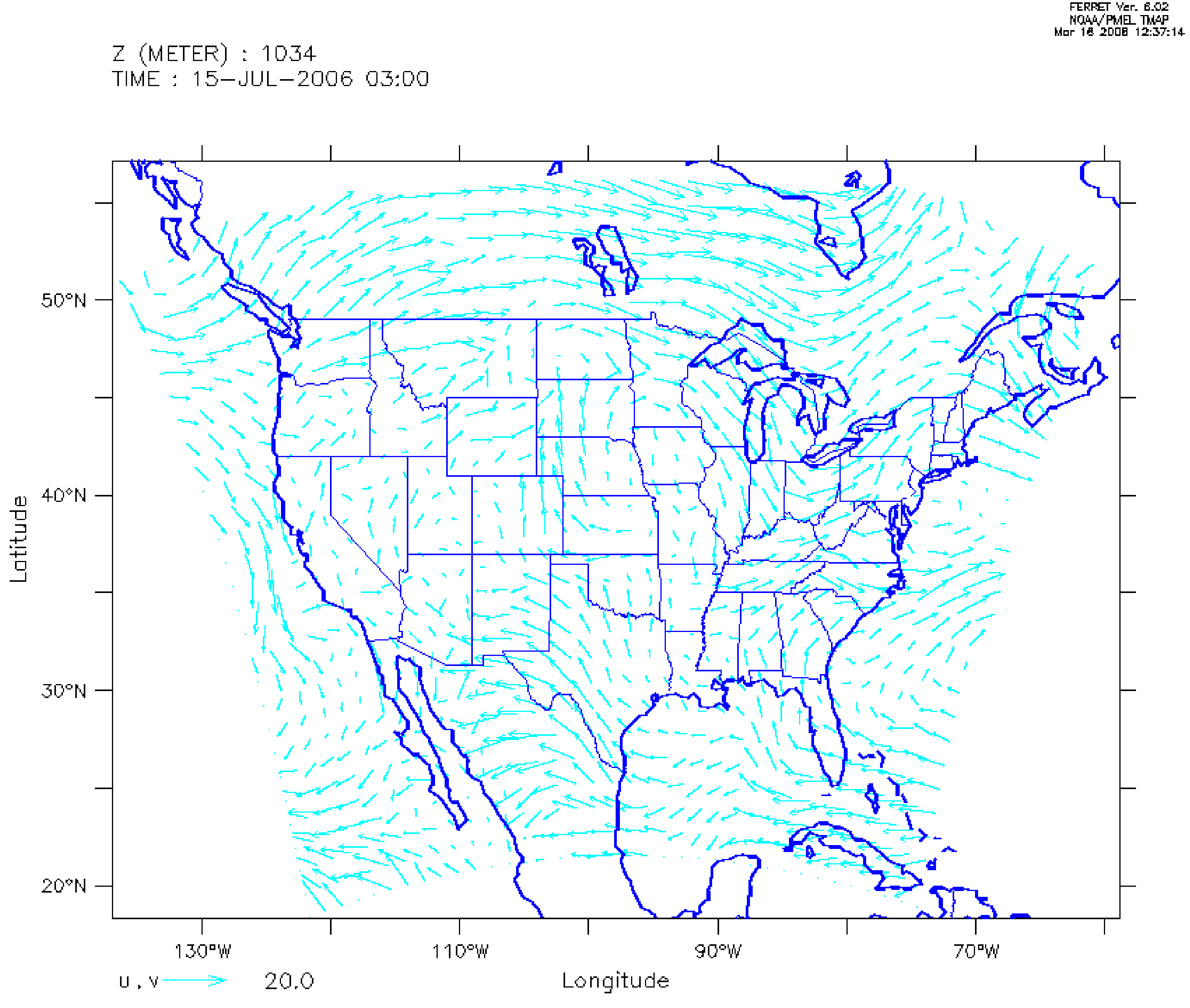
OZONE DIFFERENCE PLOTS @ 1-km

SATBC – CNTRL

SATBC: Simulation with OMI BC

CNTRL: Simulation With Standard CMAQ BC

ANIMATION FROM July 15 - September 6, 2006




Ozone Diff (SATBC−CNTRL) (ppb)

OZONE DIFFERENCE PLOTS

ZONAL CROSS SECTION

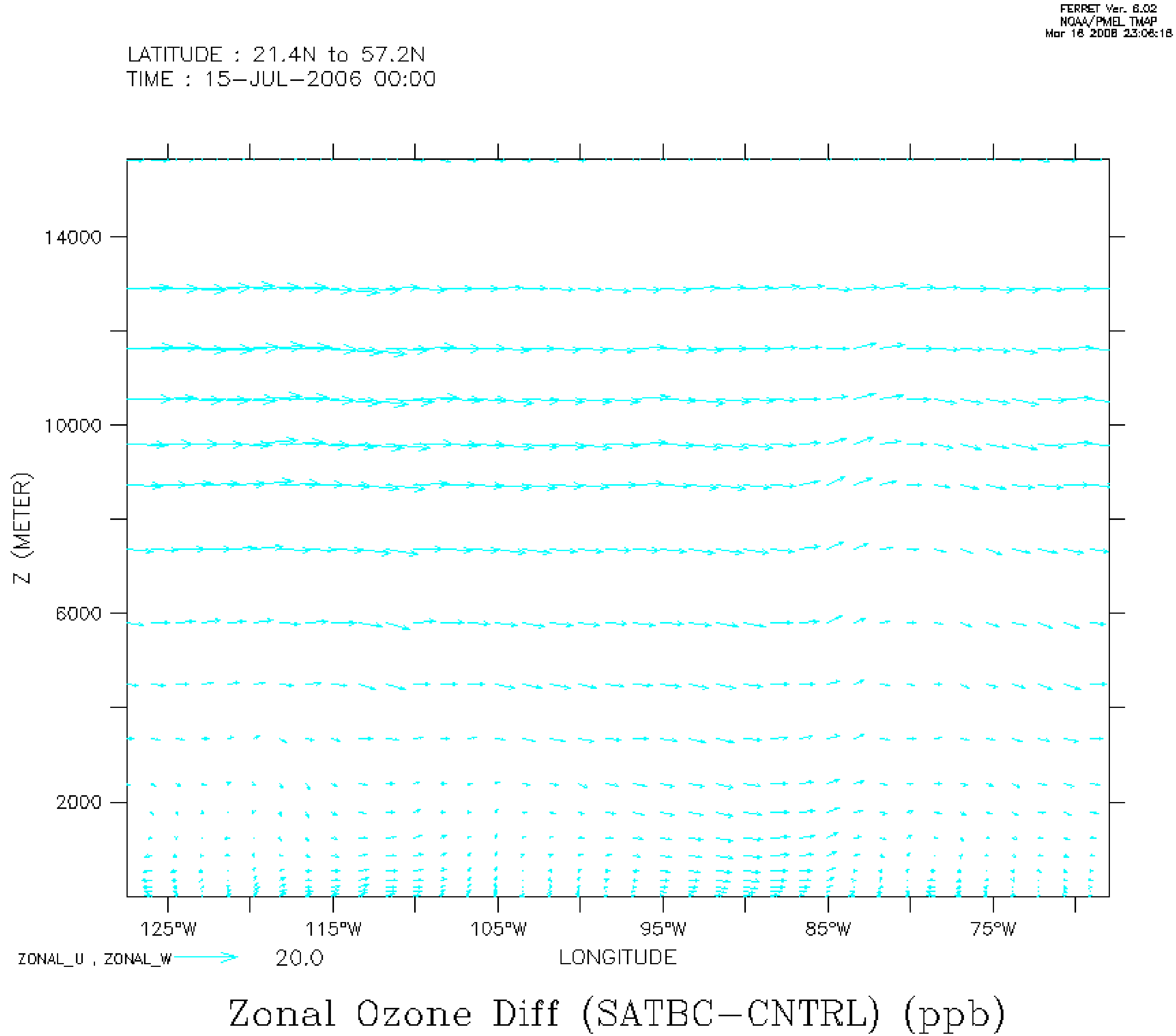
21N-57N averaged

SATBC – CNTRL

SATBC: Simulation with OMI BC

CNTRL: Simulation With Standard CMAQ BC

ANIMATION FROM July 15-September 6, 2006

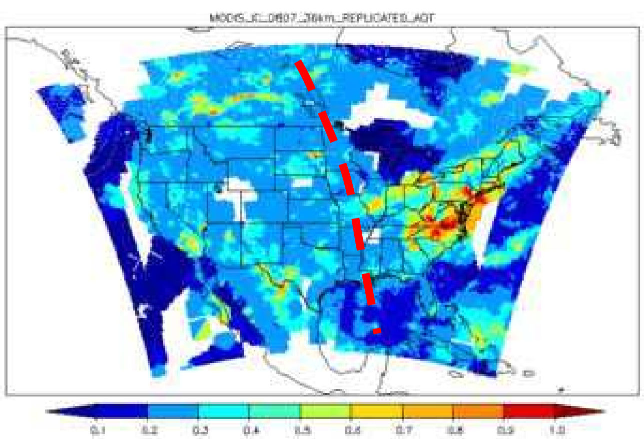


FERRET Ver. 6.02
NOAA/PMEL TMAP
Mar 18 2008 23:06:18
LATITUDE : 21.4N to 57.2N
TIME : 15-JUL-2006 00:00
14000
10000
6000
2000
Z (METER)
125°W
115°W
105°W
95°W
85°W
75°W
LONGITUDE
ZONAL_U , ZONAL_W
20.0
Zonal Ozone Diff (SATBC-CNTRL) (ppb)

# PART II: Assimilation of MODIS & CALIPSO Aerosol Products

- MODIS L2 from Terra(10:30) and Aqua(13:30) are combined and mapped to CMAQ 36-km grid spacing
- Data coverage is increased by replacing missing pixels by the average of surrounding pixels
- MODIS fine fraction is used to partition fine & coarse mode aerosols
- CMAQ AOD is based on IMPROVE equation

- For **fine mode**, CMAQ aerosol profiles are scaled as $C(z) = C_{CMAQ}(z) \times \frac{\tau_{MODIS}}{\tau_{CMAQ}}$




$$C(z) = C_{CMAQ}(z) \times \frac{\tau_{MODIS}}{\tau_{CMAQ}}$$

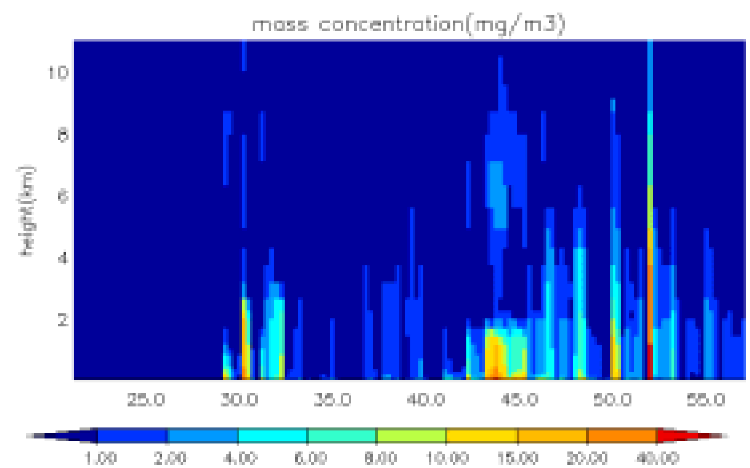
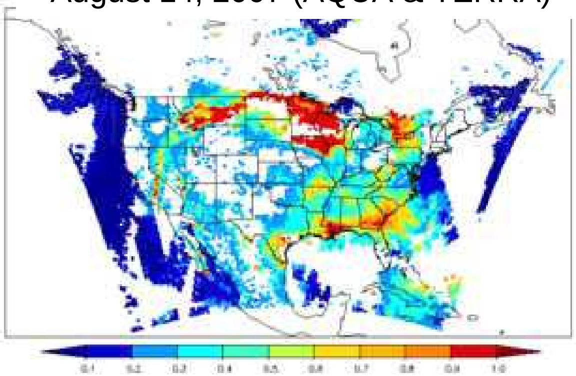



Fig. Along the track mass concentration from MODIS and CMAQ.

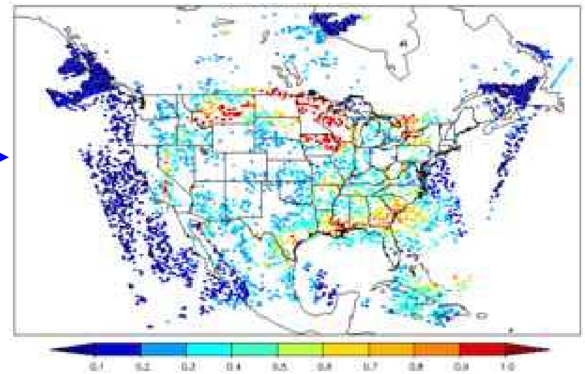
# INCREASING DATA COVERAGE

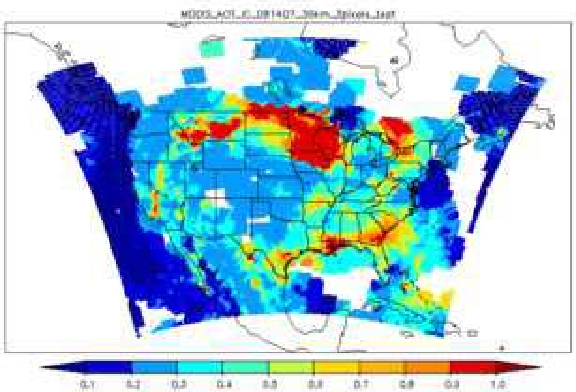
Original MODIS AOD Map for

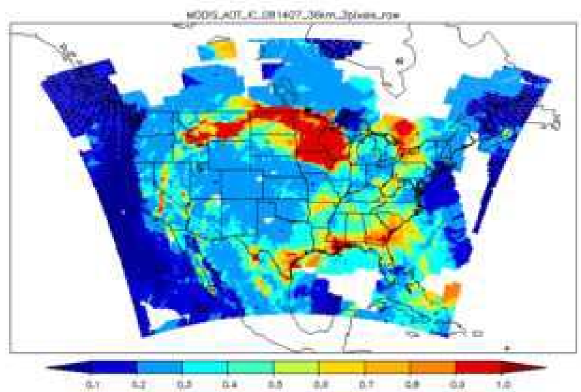
August 14, 2007 (AQUA & TERRA)



50% of pixels were removed randomly



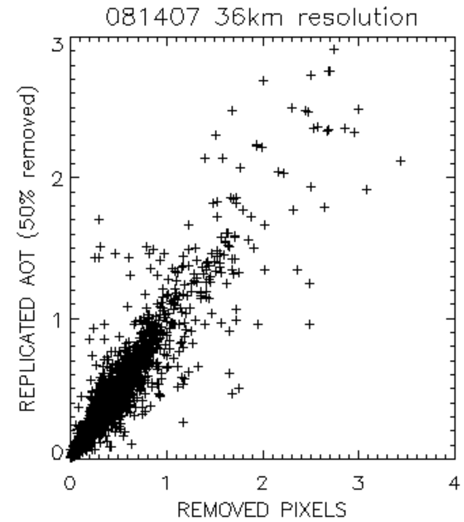




MODIS AOD from AQUA & TERRA were combined

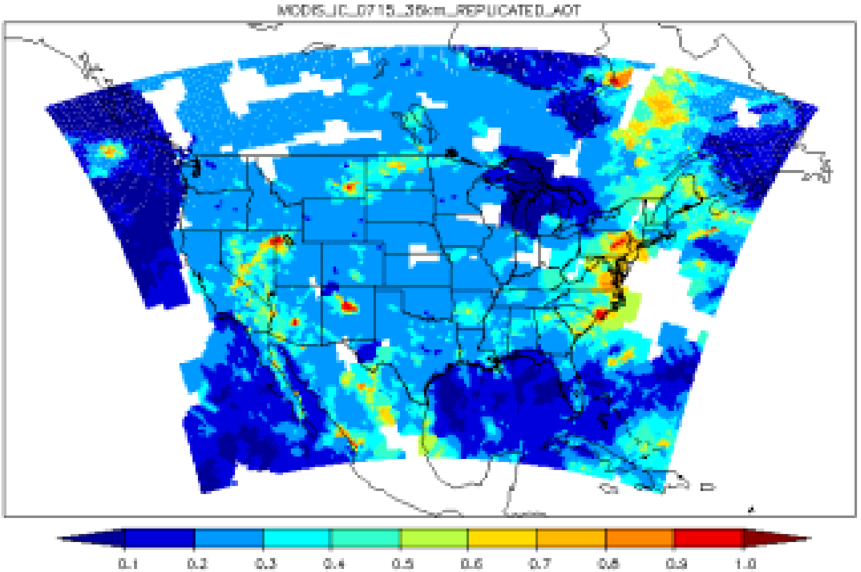
- 50% of pixels were removed randomly
- Data coverage were increased by replacing each missing pixel with the average of surrounding pixels
- Final product was well correlated with the original data

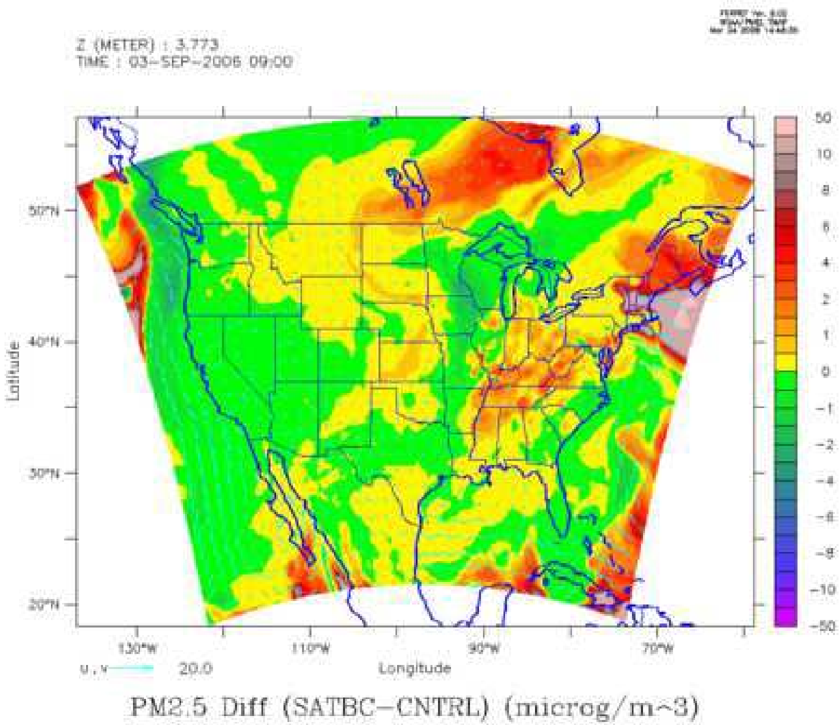
R = .97



## FINE Mode Assimilation of MODIS Aerosol Products

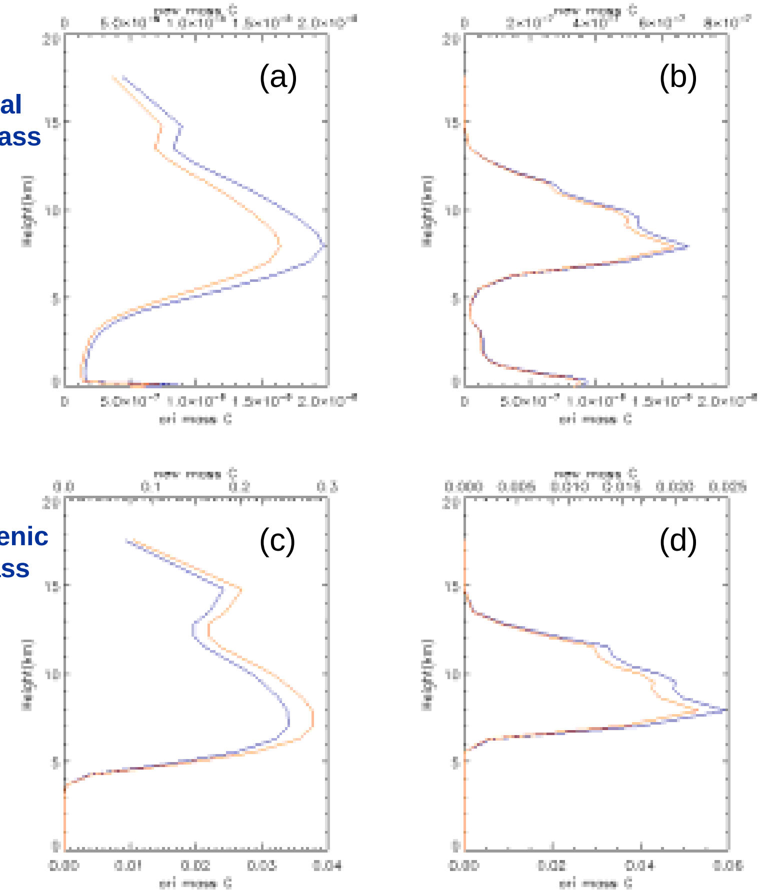
- Scaled CMAQ fine aerosol profiles
- CMAQ : 36km grid spacing
- MODIS L2 from Terra(10:30) and Aqua(13:30) was used



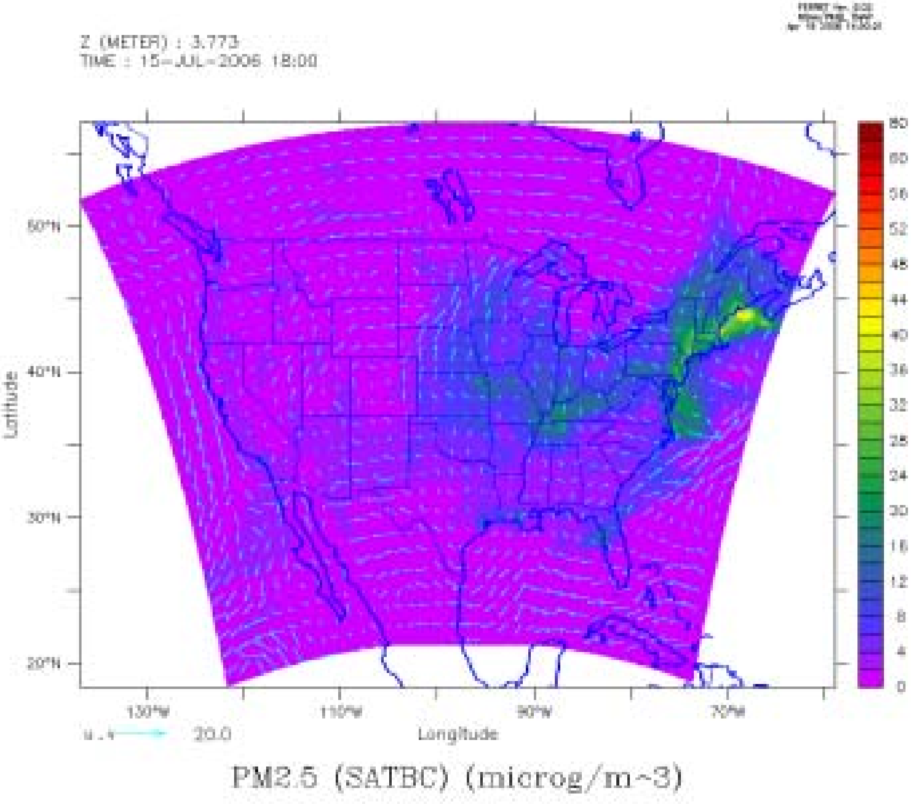

**Elemental carbon mass**

**Anthropogenic organic mass**




Elemental carbon mass ((a),(b)) and Anthropogenic organic mass ((c),(d)) ( [red line : scaled mass, blue line : original mass]

# Aerosol prediction

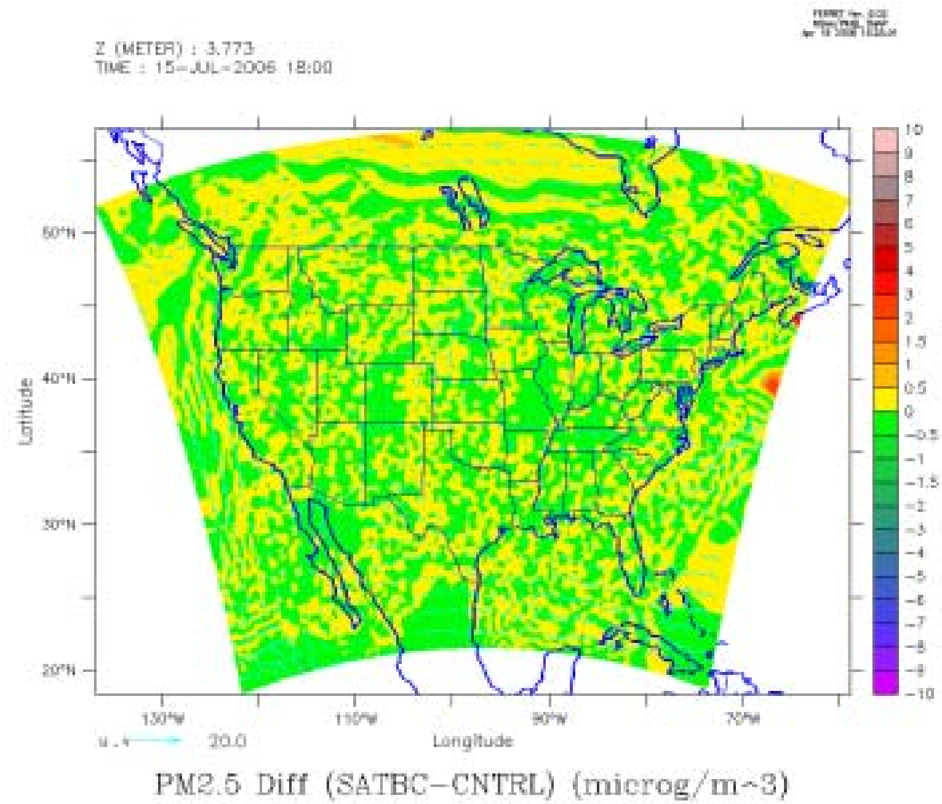



**PM2.5 Animations**

**(BC adjusted for satellite observed AOD)**

**Animations of PM2.5 difference**

**(sat_bc – control)**



# PART III: LIGHTNING INFLUENCE ON TROPOSPHERIC NOx and OZONE

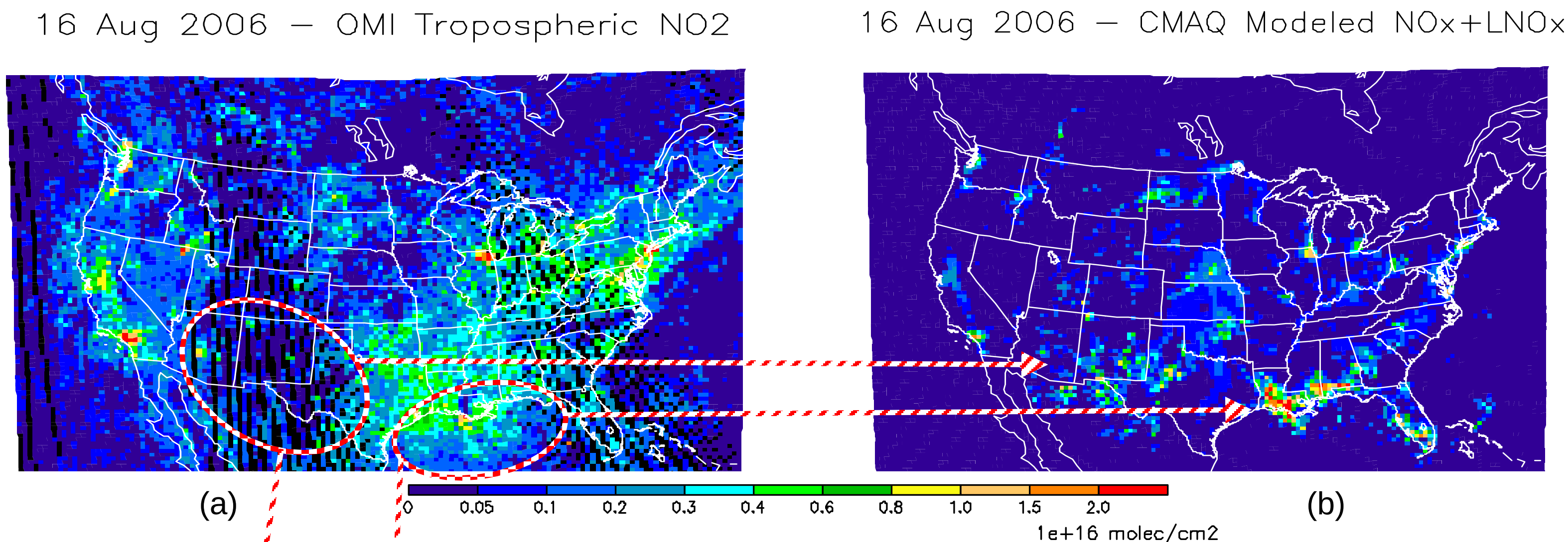



Fig 1. (a) OMI NO2 columns resampled to CMAQ grids (36km x 36km) and interpolated to minimize no-data (credit: L. Wang). (b) CMAQ modeled NO+NO2 (credit: A. Biazar) with lightning NOx. LNOx scenario variables: IC/CG=1 [Ott, et al., 2007], NOx=500 moles/stroke [Hudman et al., 2007 and references therein], IC altitude= upper troposphere only

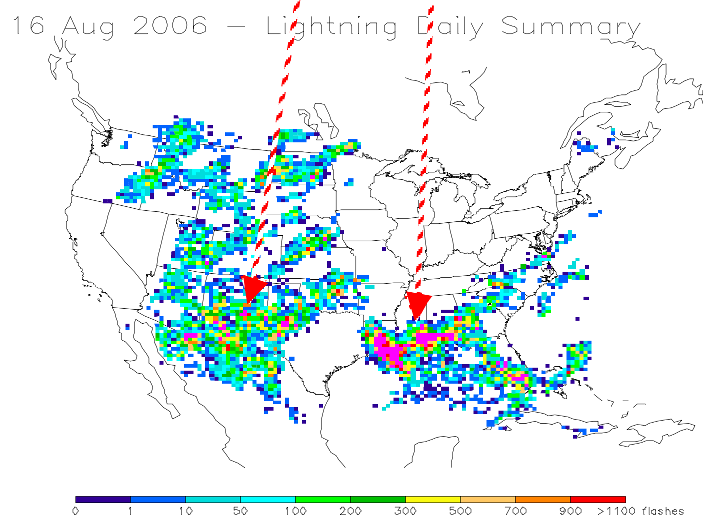



Fig 2. Daily total of CG initial and subsequent strokes recorded by U.S. National Lightning Detection Network sampled by CMAQ grids.

- Anthropogenic emissions from lightning are dominant source of mid- and upper-tropospheric NOx and ozone [Hudman et al., 2007; Singh et al., 2007; Cooper et al., 2006; Li et al., 2005, Biazar and McNider, 1995].
- OMI NO2 column retrievals, Fig 1a, suggest some correspondence with lightning data (Fig 2).
- Lightning NOx calculations, adjusted for IC/CG, molar fractions and altitude, become CMAQ model emission input (Fig 1b)
- Using OMI NO2 as CMAQ IC/BC and lightning NOx as anthropogenic emission source should help improve NOx and ozone forecasts (red and white arrows).

# LIGHTNING INFLUENCE ON TROPOSPHERIC NOx and OZONE

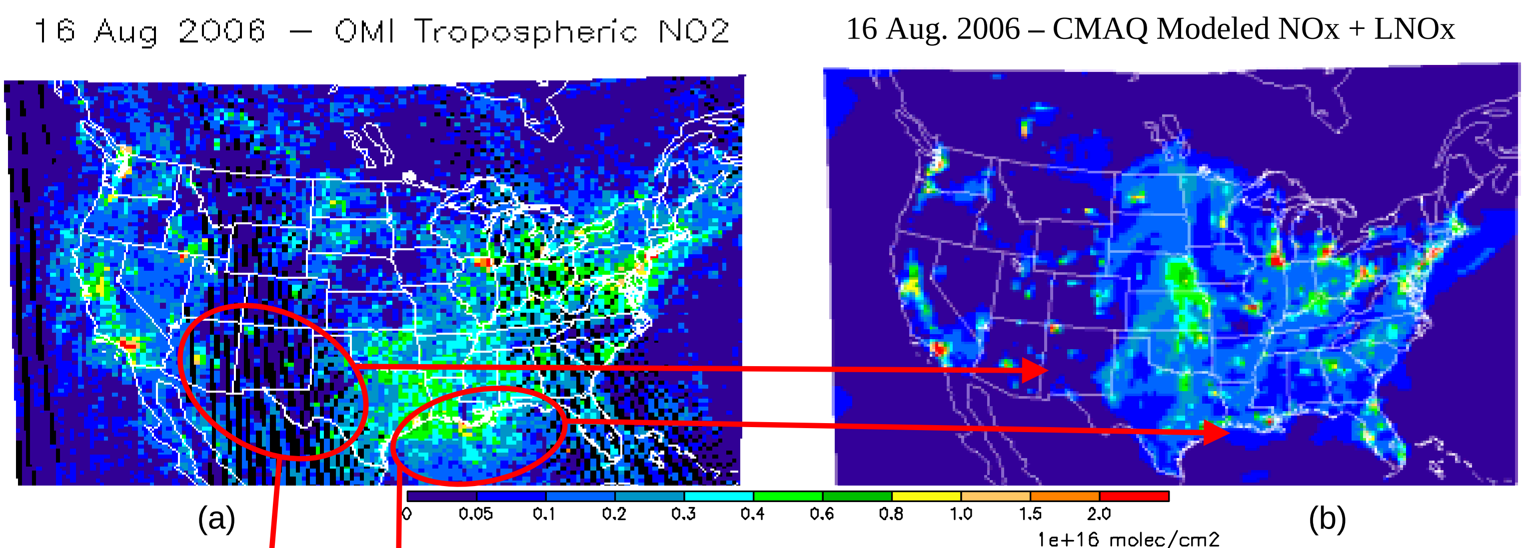



Fig 1. (a) OMI NO2 columns resampled to CMAQ grids (36km x 36km) and interpolated to minimize no-data (credit: L. Wang). (b) CMAQ modeled NO+NO2 (credit: M. Khan and A. Biazar) with lightning NOx. LNOx scenario variables: IC/CG=1 [Ott, et al., 2007], NOx=500 moles/stroke [Hudman et al., 2007 and references therein], IC altitude= upper troposphere only

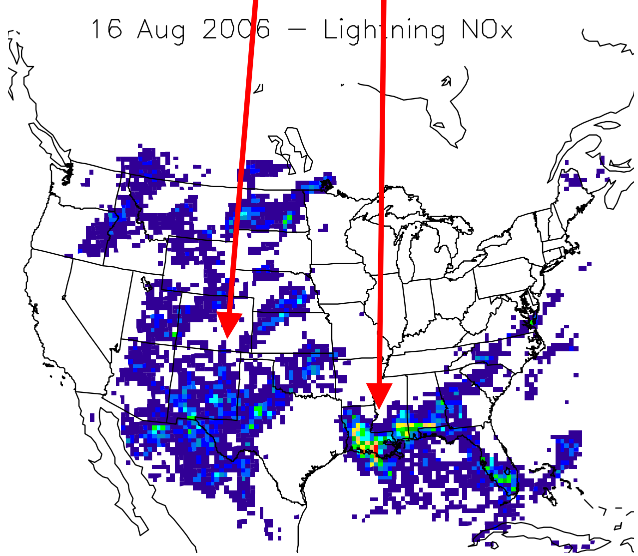
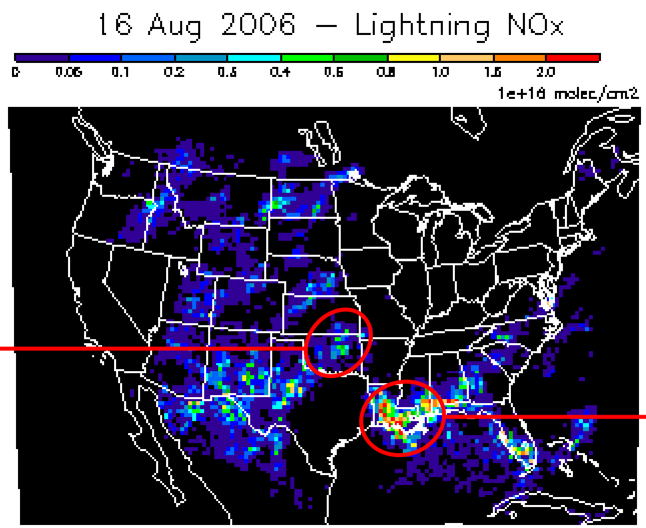
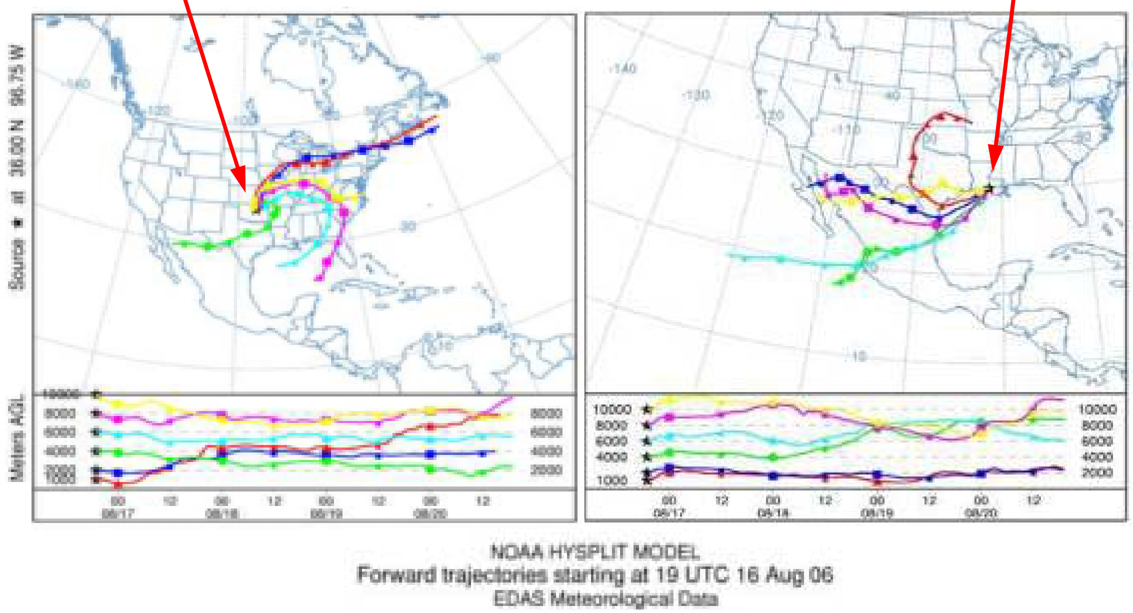



Fig 2. Lightning NOx calculated from daily total lightning recorded by U.S. National Lightning Detection Network sampled by CMAQ grids.

- Anthropogenic emissions from lightning are dominant source of mid- and upper-tropospheric NOx and ozone [Hudman et al., 2007; Singh et al., 2007; Cooper et al., 2006; Li et al., 2005, Biazar and McNider, 1995].
- OMI NO2 column retrievals, Fig 1a, suggest some correspondence with lightning data (Fig 2).
- Lightning NOx calculations, Fig 2, adjusted for IC/CG, molar fractions and altitude
- Using OMI NO2 as CMAQ IC/BC and lightning NOx as anthropogenic emission source should help improve NOx and ozone forecasts (red and white arrows).

# QUANTIFICATION OF LIGHTNING GENERATED NOX: SOUTHEASTERN U.S. TROPOSPHERIC NOX AND OZONE ENHANCEMENT DURING IONS06




- Significance of vertical lightning emission profile
- Forward particle trajectories (PT) from lightning [Cooper, 2007], backward PT from ozonesonde measurements, intersection of PT is lightning signature probability distribution.
- Adjust for STE [Cooper, 2006] and trajectory intersection with convective systems
- Compare results with CMAQ chemistry, OMI retrievals, North American Lightning Climatology, and published laboratory experiments for stroke signal strength and LNOx emission
- Case Studies:
  - Recurring Summertime Stagnant Southeastern Anticyclonic Circulation – pollution aging [Cooper (2006); Owen (2006)], horizontal and downward transport
  - North Alabama Lightning Mapper Array – vertical emission profile, CG/IC ratios, compare to current parameterizations

# Conclusions

- **Satellite $O_3$ boundary conditions (directly or through RAQMS) improve surface and middle to upper tropospheric $O_3$ predictions; Continuity of $O_3$ across the edge of model domain is improved.**

- **Satellite aerosol boundary condition improves the continuity of aerosol across the edge of model domain.**

- **Preliminary evidence shows influences of lightning-produced $NO_x$ on atmospheric $O_3/NO_x$.**

- **Potential improvement: satellite initial condition assimilation of $NO_2$, HCHO, $O_3$, aerosols to improve PBL calculations.**

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Thompson, A. M., et al. (2007), Intercontinental Chemical Transport Experiment Ozonesonde Network Study (IONS) 2004: 2. Tropospheric ozone budgets and variability over northeastern North America, J. Geophys. Res., 11 2 , D12S13, doi:10.1029/2006JD007670.